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MARS THERMOPHYSICS

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by

W. P. McNutt  
Barbara Maye  
Nancy McHugh

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## ABSTRACT

This bibliography contains approximately 500 annotated citations on the planet Mars published from the latter part of the nineteenth century through early 1967. The selected references are concerned only with the thermophysics of Mars and, specifically, with the results of experiments and analyses in those regions of the electromagnetic spectrum which relate to thermophysics. References concerning the possibility of life on Mars and space vehicle design and performance have been excluded.

## FOREWORD

This bibliography, prepared for the Thermophysics Division, Space Sciences Laboratory of the George C. Marshall Space Flight Center, contains approximately 500 references on material published from the latter part of the nineteenth century to approximately April 1967. The primary sources searched to obtain these references were:

Astronomischer Jahresbericht

Defense Documentation Center holdings

Bibliographies from NASA magnetic tapes which contains information from Scientific & Technical Aerospace Reports and International Aerospace Abstracts

Science Abstracts

Geophysical Abstracts

JPL Space Program Summaries

RSIC document holdings

Titles and abstracts of many papers are changed when published in two or more journals, and duplication is difficult to locate; however, a careful screening was conducted to eliminate as much duplication as possible. Only those references which appeared to have made a significant contribution toward the determination of the thermophysics, thermophysical characteristics, or thermal conditions on Mars were selected for inclusion in this report.

Citations have been arranged alphabetically by author into eight subject sections. Since some authors discussed material applicable to more than one section, these citations were placed in the section which appeared to be most pertinent to the overall subject matter.

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## INTRODUCTION

This bibliography on Mars covers a particular region of the literature designated as thermophysics. Thermophysics includes that part of the physics of the planet which enters into a thermal energy balance at the planet surface, enters into the equation of radiative transfer, and concerns the thermal history of the planet.

Thus, the referenced literature concerns the results of experiments and analyses in those regions of the electromagnetic spectrum which relate to temperature; thermal radiation; light reflection, polarization, and scattering; thermal properties of materials; and those electromagnetic properties directly related to thermal properties.

Two major portions of the literature on the planet Mars which have little, if any, thermophysical connections are excluded from the bibliography; namely, (1) papers dealing with the possibility of life on Mars and related experiments, descriptions, and associated apparatus and (2) documents dealing with space vehicle design and performance. Specifically, excluded are references concerning the thermophysical characteristics of vehicles intended for use in the exploration of Mars.

Subject divisions then fall into natural categories. The Martian atmosphere (especially composition and scattering) forms a major category containing a large percentage of the total references. Another large group of references concerned with certain Martian characteristics are grouped in the electromagnetic spectral observations sections according to wavelength and are subdivided under light polarization, color, ultra-violet, visible and near infrared reflection, infrared emissions, radio (microwave) emission, radar reflections, and temperature. A general subject area is included which lists references containing comprehensive coverage of several subjects; such as books, other bibliographies, proceedings and general reviews. The Martian surface references were selected for their contributions to a better understanding of the thermal properties and are divided into composition, canals and polar caps. One section is devoted to photographic studies of Mars.

It is intended that this bibliography contain only material on the thermophysical characteristics of the planet itself in order to provide an efficient research tool for use in establishing the thermal environment of Mars and in planning scientific experiments in thermophysics.

## Section I. MARTIAN ATMOSPHERE

### A. CURRENTS

1. Bryan, C. H.,  
KINETIC THEORY OF PLANETARY ATMOSPHERES, Roy. Soc. Proc.,  
66, 9 June 1900, pp. 335-336.

The advance on work done in 1893 consists in the consideration of the effects of axial rotation of the planets, the surfaces of equal density then becoming of the form originally suggested by Roche. These cease to be closed surfaces when passing to the outside of the point on the equatorial plane, where the centrifugal force just balances planetary attraction. The author calls the surface through this point the "critical surface," and the ratio of density at planet's surface to the density at this critical surface, the "critical density ratio." He then calculates the logarithm of this quantity for particular gases at different temperatures on the various planets. Next the rate of flow outwards from this surface is determined, and instances cited of the values deduced for helium, hydrogen, and water-vapour, which would appear to indicate that helium cannot escape from the earth's atmosphere at existing temperatures, nor water-vapour from the atmosphere of Mars.

2. Geophysics Corporation of America, Bedford, Massachusetts,  
TIDES IN THE ATMOSPHERES OF EARTH AND MARS by R. A. Craig,  
September 1964, NASA CR-97, Contract No. NASw-704.

The theory of atmospheric tides, as developed for Earth's atmosphere is applied to the Martian atmosphere. For corresponding modes of oscillation, equivalent depths are less in the Martian atmosphere than in Earth's atmosphere. On the other hand, the eigenvalue corresponding to the presumed Martian temperature distribution in the troposphere and stratosphere is about 20 km, about twice the corresponding value on Earth. These differences arise mainly from the different radii and masses of the planets. Unless the temperature distribution at high levels on Mars has a rather special form so that a second eigenvalue appears, no resonance magnification is to be expected. Tides in the Martian atmosphere might arise from periodic temperature oscillations, induced either by surface heating, or by radiative heating through deep layers of the atmosphere.

3. Davies, T. V.,  
PLANETARY ATMOSPHERES AND CONVECTION IN ROTATING  
FLUIDS, Nature, 180, 28 December 1957, pp. 1455-1461,  
Observatory, 77, October 1957, pp. 172-186.

Report of a joint conference held by the Royal Meteorological Society and the Royal Astronomical Society at Burlington House, London, on 23 and 24 May 1957. Papers were presented on the indicated topics: Z. Kopal, The basic observational data on planetary atmospheres; P. A. Sheppard, The general circulation of the Earth's atmosphere; H. U. Sverdrup, The circulation of the oceans; E. Lorenz, The circulation of the atmospheres of the outer planets; R. Hide, Experiments on convection in rotating liquids; R. M. Goody, The thermal structure of Mars; H. C. Urey, The escape of planetary atmospheres; R. C. Sutcliffe, The influence of condensation on planetary atmospheres; J. S. Sawyer, Jet streams as a feature of the Earth's atmospheres; T. V. Davies, Theory of the experiments on convection in rotating liquids; J. G. Charney, Theory of the general circulation of the atmosphere; E. T. Eady, The physical parameters characterizing the dynamics of planetary atmospheres. Full reports of these papers will appear in the journals of the respective societies.

4. Rand Corporation, Santa Monica, California,  
SOME ASPECTS OF THE CIRCULATION OF MARS by C. Leovy, November 1965, presented at the Conference on Exploration of the Planets, Blacksburg, Va., 16-20 August 1965, NASA CR-68992, Contract No. NASr-21(07).

Estimates of the vertical temperature structure and heat balance of Mars are reviewed and compared with the corresponding quantities on the Earth. The probable resulting circulation is discussed and reasons for expecting a stronger solstice circulation on Mars than on the Earth are given. The problem of thermally driven tides is reviewed. The amplitude of such tides is likely to be small.

5. McLaughlin, D. B.,  
INTERPRETATION OF SOME MARTIAN FEATURES, Astronomical Society of the Pacific, San Francisco Publications, 66, No. 392, October 1954, pp. 161-170. FURTHER NOTES ON MARTIAN FEATURES, Ibid., pp. 221-229.

The Martian maria of the tropical girdle are interpreted as composed chiefly of dark volcanic ash drifted by the prevailing winds, which must be strongest during the summer of the southern hemisphere, when the winds cross the equator and become anti-trade winds. The vertices of the pointed bays are identified as active volcanoes, the sources of the ash. The curved flow pattern of the maria and intervening lighter strips are shown to be consistent with the expected deflection of the winds by the rotation of the planet. Canals that meet the maria in the

bays are interpreted as drifts of ash from the source volcanoes during the period of weaker reversed winds of the northern summer. In the second paper, the author covers the following topics: other explanations of canals, some anomalies of atmospheric circulation, possible height of Martian volcanoes, the color of the maria, the seasonal changes and the deserts.

6. McLaughlin, D. B.,  
CHANGES ON MARS, AS EVIDENCE OF WIND DEPOSITION AND VOLCANISM, Astronomical Journal, 60, No. 7, August 1955, pp. 261-270.

Evidence from moving clouds, summarized by De Vaucouleurs, supports the author's suggestion that extensive winds of monsoon type occur on Mars. The volcanic hypothesis, developed to explain the banded and oriented permanent maria and pointed "bays," accounts successfully for the greatest temporary changes observed on Mars. In several cases, a horn-shaped dark marking fanned out from a well-defined small source and showed curvature consistent with the Coriolis effect of the planet's rotation. Shifting boundaries of maria are interpreted as due to aeolian deposition of light-colored desert dust or of dark volcanic ash, accompanied by variable volcanic activity and changes of wind direction. In particular, the seasonal change of outline of Syrtis Major is explained by seasonal reversal of the winds. Distances of transport of ash on Mars are not excessive as compared with recorded cases on earth from Vesuvius, Mayon, etc. Amounts of ash required for any of the temporary markings are only a few cubic km, fairly comparable with ejecta of major terrestrial eruptions. Volcanism on Mars appears not to exceed greatly, if at all, that on earth at the present time.

7. Milankovitch, M.,  
VARIATION OF HEAT RADIATION IN ATMOSPHERE OF MARS, Ann. d. Physik, 44, No. 3, 26 May 1914, pp. 465-476.

A long analysis is given to obtain a value of the diminution of heat radiation through the Martian atmosphere, and the results are compared with the glasshouse or accumulative theory.

8. Miyamoto, S. and Matsui, M.,  
REPORT OF MARS OBSERVATIONS DURING THE 1958 OPPOSITION,  
Kyoto U. Inst. of Astrophys. and Kwasan Obs. Contrib., No. 87, 1958, pp. 191-215.

General description of the surface markings and cloud observations during the 1958 opposition were given. The pattern of general circulation of the Martian atmosphere in the equinoctial season was derived from these data, and compared with those obtained in 1956 for southern summer and with our terrestrial case. It was found close to our atmosphere and considerably different from the 1956 pattern, as was expected theoretically.

9. Miyamoto, S.,  
ON THE GENERAL CIRCULATION OF THE MARTIAN ATMOSPHERE,  
Kyoto U. Inst. of Astrophys. and Kwasan Obs. Contrib., No. 88, 1960,  
pp. 216-222.

General circulation in the Martian atmosphere is studied from the viewpoint of heat balance at each latitude. Theoretical insolation combined with the observed long wave radiation suggests that polar and middle latitudes have energy surplus, and the opposite hemisphere the deficit in the solstitial seasons, while the equatorial belt has energy surplus and both polar regions a deficit in the equinoctial seasons. This means that the lateral mixing is taking place between two poles in the solstitial seasons, and between the equatorial belt and poles in the equinoctial seasons. Such a circulatory pattern was discussed in relation to the observed migration of moisture from pole to pole, and to the predominance of easterlies over middle latitude in southern summer deduced from the drift of the great yellow cloud in 1958.

10. Miyamoto, S.,  
OBSERVATIONAL STUDY OF THE GENERAL CIRCULATION OF  
MARTIAN ATMOSPHERE - CLOUD OBSERVATIONS DURING THE  
1963 OPPOSITION, Life Sciences and Space Research II; International  
Space Science Symposium, 4th, Warsaw, Poland, 3-12 June 1963,  
sponsored by COSPAR, M. Florkin and A. Dollfus, ed., North-Holland  
Publishing Company, Amsterdam, Interscience Publishers, New York,  
1964, pp. 238-245.

Interpretation of observational data on the regime of general circulation of the Martian atmosphere. It is stated that the season on Mars at the time of the 1963 opposition was from Spring to Summer of the Martian Northern Hemisphere. Both for the surface markings and for cloud distributions, the progress of the seasons was quite regular. It is noted that, aside from the regular progress of meteorological phenomena, this opposition was characterized by an atmospheric disturbance of global scale, which was first discovered on the evening of 29 January 1963. The white cloud mass hanging over Noachis suddenly

burst into the Northern Hemisphere across the equator, and since then the disturbance propagated throughout the globe. It is stated that it is now clear that the regime of general circulation of the Martian atmosphere is quite different from that of the Earth. By construction of the radiation budget, it is predicted that the zonal winds are the easterlies in the solstice season of the Summer Hemisphere. According to Mintz, the circulation regime of the Martian atmosphere is symmetric, except in the Winter Hemisphere. The observational data seem to favor the symmetric regime, rather than the wave regime of the Earth.

11. Miyamoto, S.,  
OBSERVATIONAL STUDY ON THE GENERAL CIRCULATION OF  
MARS, Kyoto U. Inst. of Astrophys. and Kwasan Obs. Contrib., 1963,  
pp. 81-88.

In the Martian atmosphere, contrary to Earth, meridional circulation is more important than lateral mixing. Energy flows from pole to equator in summer. The prevailing winds over the middle latitude turns into easterlies during this season. An attempt is made to prove these particular circulation regimes with the observational data available. It is pointed out that local topographic circulations make important contributions to the general circulation. The topographical difference of northern and southern hemispheres should be taken into account in establishing the actual circulation pattern.

12. Miyamoto, S.,  
MARTIAN ATMOSPHERE AND CRUST, Icarus, 5, No. 4, July 1966,  
pp. 560-574.

The Martian atmosphere in its average condition is inactive and transparent to long-wave radiation. It is activated when moisture is supplied by the evaporation of the polar cap in spring time.

13. Neubauer, F. M.,  
THERMAL CONVECTION IN THE MARTIAN ATMOSPHERE, Journal  
of Geophysical Research, 71, 15 May 1966, pp. 2419-2426.

Formation of dust clouds observed in the Martian atmosphere can be explained by the action of dust devils larger than 100 meters in diameter. The condition for the onset of thermal convection is the existence of an unstable temperature profile. The daily variation of the atmospheric temperature profile shows that the Martian atmosphere is more favorable for the initiation of dust devils than the earth's atmosphere. The calculations indicate that dust devils on Mars produce wind velocities only slightly lower than those on earth.

14. Geophysics Corporation of America, Bedford, Massachusetts,  
THE METEOROLOGY OF MARS AND VENUS, Annual Technical Report  
by G. Ohring and O. Côté, January 1963, Contract No. NASw-286.

The meteorology of Mars and Venus is studied with primary emphasis on the thermal structure and circulation processes of these two planetary atmospheres.

15. Geophysics Corporation of America, Bedford, Massachusetts,  
PLANETARY METEOROLOGY by G. Ohring, Wen Tang, and Joseph Mariano, August 1965, NASA CR-280, Contract No. NASw-975.

Inferences concerning atmospheric circulation features on Mars are made from analysis and interpretation of some observed Martian cloud systems and from application of meteorological theory to the Martian atmosphere. The trajectories of several cloud systems and the use of two different theoretical criteria suggest the presence of a wave type circulation regime on Mars. Cloud observations also suggest the presence of subtropical high pressure centers and upper level meridional flow and frontal phenomena at equatorial latitudes. Radiative equilibrium temperatures are computed for the surface and atmosphere of Venus. In the model used for the computations, it is assumed that the atmosphere and cloud cover are both gray in the infrared. The effect on the computed surface temperature of different values of infrared emissivity, height, and thickness of the cloud layer, and infrared opacity of the gaseous absorbers, is evaluated. Equations are derived for the computation of the radiative equilibrium temperature profile in the nongray atmosphere above the Jovian cloud layer, and circulation phenomena in the Jovian atmosphere is examined.

16. Stoney, G. J.,  
ESCAPE OF GASES FROM PLANETARY ATMOSPHERES, Astrophys. Journ., 11, May 1900, pp. 257-258, June 1900, pp. 357-372.

The present paper is an answer to a criticism of the work of Stoney by S. R. Cook. Stoney draws attention to the statement that Maxwell's laws cannot be applied to gases under the conditions existing at the outer limits of a planet's atmosphere, but that the numbers determined by Cook will be useful as indicating the minimum rate of escape for the various gases.

The paper is divided into three parts, describing respectively:

- (1) Molecular movements in the lower strata of the atmosphere.
- (2) Molecular movements in the upper strata of the atmosphere.

(3) Behaviour of helium &c., in the earth's atmosphere. The conclusions from section (3) are as follows: (a) Argon is not able to escape from the earth. (b) Helium is escaping from the earth, and therefore (c) Water can probably escape from the planet Mars; thus the polar caps of that body may be due to solid carbon dioxide.

17. Geophysics Corporation of America, Bedford, Massachusetts,  
SOME ASPECTS OF THE ATMOSPHERIC CIRCULATION ON MARS,  
July 1965, NASA CR-262, Contract No. NASw-975.

Inferences concerning atmospheric circulation features on Mars are made from analysis and interpretation of some observed Martian cloud systems and from application of meteorological theory to the Martian atmosphere. The trajectories of several cloud systems and the use of two different theoretical criteria suggest the presence of a wave type circulation regime in the mean for the year on Mars. Cloud observations also suggest the presence of sub-tropical high pressure centers, upper level meridional flow at equatorial latitudes, and frontal cloud phenomena at equatorial latitudes. Theoretical estimates of the mean large scale zonal and meridional wind velocities yield values greater than on earth. Theoretical estimates of the maximum surface wind suggest a value greater than  $100 \text{ m-sec}^{-1}$ . Computations of the vertical velocity profile, based upon a simplified " $\omega$ " equation, indicate greater large scale vertical velocities than on earth, and a "dynamic" tropopause height of about 20 km.

18. Geophysics Corporation of America, Bedford, Massachusetts,  
A THEORETICAL ESTIMATE OF THE AVERAGE VERTICAL DISTRIBUTION OF TEMPERATURE IN THE MARTIAN ATMOSPHERE by  
G. Ohring, Icarus, 1, No. 4, January 1963, Contract No. NASw-704,  
pp. 328-333.

The average variation of temperature with height in the Martian atmosphere is probably controlled by radiative and convective processes. With the use of a simple theoretical formulation in which it is assumed that convection will extend to that height above which the radiative equilibrium lapse rate is just stable, the average temperature profile is computed. It is assumed that the average surface temperature is  $230^{\circ}\text{K}$ , that there is no absorption of solar radiation in the atmosphere, and that carbon dioxide in an amount equal to 2% by volume is the only important radiating gas. The radiation fluxes are computed with the aid of radiation tables; the radiative equilibrium temperatures are calculated using an iterative procedure. The computed temperature profile is characterized by an adiabatic troposphere

extending to about 9 km, above which the temperature continues to decrease with height to an average value of about 90°K for the topmost 5-mb layer.

19. Geophysics Corporation of America, Boston, Massachusetts,  
A STUDY OF THE METEOROLOGY OF MARS AND VENUS, Quarterly  
Progress Report No.1, 5 February 1963-5 April 1963, by G. Ohring,  
1963, Contract No. NASw-714.

Research on the effect of cloudiness on a greenhouse model of the Venus atmosphere has continued. Computations were performed for the case of 99% cloud cover, and for the case of 0.9 emissivity of the Venus surface. Techniques are being developed to allow machine computation of the greenhouse effect for any lapse rate of temperature. Research has started on the construction of a model Martian atmosphere for the purpose of computing the radiation budget of Mars.

20. Schilling, G. F.,  
LIMITING MODEL ATMOSPHERES OF MARS, August 1963, JPL Report,  
AD-635 806, Contract No. NAS7-100.

From factual observational knowledge, realistic upper and lower limits were calculated for the permissible ranges of temperature, pressure, and density of the Martian atmosphere. The results are presented in the form of two model atmospheres. Model I is in convective equilibrium throughout; model II, more realistically, assumed convective equilibrium to a tropopause level, then conductive equilibrium up to an altitude of 80 km. These two numerical models show that Martian atmospheric parameters still range widely in possible extreme values. Therefore, with certain speculative assumptions, the author tried to form a new, more coherent picture. The result is a conjectural model III, reaching to 200 km in altitude. It was based partly on the supposition that even a relatively small amount of oxygen would give rise to some ozone and, hence, to appreciable amounts of stratospheric heating. Though conjectural, this model atmosphere has some surprising and potentially important meteorological characteristics. A combination of these three models permits the prediction, with reasonable confidence, ranges of Martian atmospheric conditions for specific heights up to 180 km over middle and low latitudes. Regardless of season or time of day, the parameters of the Martian atmosphere are compared graphically, for practical use, with those of the earth's.

## B. COMPOSITION

21. Adamcik, J. A.,

THE WATER VAPOR CONTENT OF THE MARTIAN ATMOSPHERE AS A PROBLEM OF CHEMICAL EQUILIBRIUM, Planet Space Sci., 11, No. 4, April 1963, pp. 355-359.

Others have postulated, on observational grounds, the presence of ferric oxide hydrate on the Martian surface. In the present work the relevant thermodynamic quantities are utilized to calculate the partial pressure of water vapour in the Martian atmosphere which would be expected on the assumption that it is determined by the dissociation pressure of goethite, a hydrated iron oxide. The pressure so calculated agrees well with estimates of the atmospheric water content derived from data of other kinds, thus lending support to the hypothesis that ferric oxide hydrate forms a significant fraction of the Martian surface. The presence of such a hydrate would significantly extend the time scale for any evolution of the planet due to loss of water.

- 22.

Lockheed Missiles and Space Company, Palo Alto, California,  
A MODEL FOR THE LOWER ATMOSPHERE OF MARS BASED ON  
MARINER IV OCCULTATION DATA by A. D. Anderson, December 1965,  
LMSC 6 75 65 62.

The Mariner IV occultation has resulted in low values for the neutral properties (temperature, pressure, and density) and the dominance of CO<sub>2</sub> for the lower atmosphere of Mars. Guided by these new results and theoretical models of the Martian atmosphere, a neutral property model has been derived which takes into account surface air temperature variation. The neutral properties up to 50 km exhibit strong dependence on the surface temperature. An isopycnic (constant density) level is manifested in the model at 10 km where the density value is  $5.77 \times 10^{-6}$  gm cm<sup>-3</sup> for surface temperatures ranging from 175 to 325 °K. At 50 km, the density variation for this same surface temperature range is a factor of four. The height of the tropopause (boundary between convective and radiative equilibrium regimes), taken to vary linearly with the surface temperature, is one of the principal uncertainties since the computed properties are sensitive to it. The accuracy of the model appears to decrease with altitude, especially above 30 km where the effects of CO<sub>2</sub> photochemistry, doppler broadening, and departure from local thermodynamic equilibrium start to become important.

23. Arrhenius, S.,  
PLANETARY ATMOSPHERES, Publications de la Societe de Chim Phys.,  
Nature, 88, 28 December 1911, p. 292.

Starting with each planet as a separate portion of the supposed original solar nebula, the general method of evolution is traced, whereby the metals, hydrocarbons, &c., gradually become parts of the planet's surface. CO<sub>2</sub> could be the most resistant impurity of the atmosphere, and would be subsequently again produced by volcanic action.

24. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.  
EQUILIBRIUM THERMODYNAMIC PROPERTIES OF THREE ENGINEERING MODELS OF THE MARTIAN ATMOSPHERE by H. E. Bailey, 1965, NASA SP-3021.

Entropy, enthalpy, pressure, and sound speed of three carbon dioxide-nitrogen mixtures are presented graphically for wide ranges of temperature and density. The temperature range is 250°K ≤ T ≤ 25 000°K ( $\Delta T = 250^{\circ}\text{K}$ ). The density range is -7.0 ≤ log  $\rho/\rho_0$  ≤ +3.0 ( $\Delta \log \rho/\rho_0 = 0.2$ ). The chemical compositions of the three mixtures correspond to those selected as engineering models of the Mars atmosphere in NASA TN D-2525.

25. Barabashov, N. P.,  
INVESTIGATION OF VARIOUS PHENOMENA ON MARS,  
Astronomicheskii Zhurnal, 29, No. 5, September-October 1952,  
pp. 538-555.

Detailed tabular and descriptive analysis of observations of the brightness (spectral reflectivity) or albedo of various "seas," "gulfs," "lakes" and "continents" of Mars, made by the author with blue, green and red filters in 1931, 1935, 1939, 1941 and 1950. Other observations were made in 1920, 1924, 1926 and 1930. Conclusions drawn regarding the atmosphere, surface covering in equatorial and polar regions and along the edges when the sun rises or sets or changed noon angle. The "seas" have regions of varying albedo and colors ranging from green to yellow to blue to reddish, and on the continents the albedo and shading changes with time of day. The "seas" become more reddish when the noonday sun is lower and more bluish when it is higher. On the continents the albedo in red is as high as .448, yellow .190 and green .193.

26. Barabashov, N. P. and Garazha, V. I.,  
SOME CONSIDERATIONS ON THE DUST AND FOG FORMATIONS  
ON MARS, Astronomicheskii Zhurnal, 37, No. 3, May/June 1960,  
pp. 501-507.

On the basis of brightness distribution curves obtained during the opposition of 1956 and the indirect parts of indicatrices, some conclusions are made on the structure of the solid surface of Mars and properties of the yellow fog and mist, which often appear in the atmosphere of the planet.

27. Barabashov, N. P.,  
DUST FORMATIONS IN THE ATMOSPHERE AND THE COLOR OF THE  
SEAS OF MARS, Kharkov. Universitet. Astronomicheskaya  
Observatoriya, Tsirkulyar, No. 26, 1963, pp. 3-13, taken from  
Referativnyy Zhurnal. Astronomiya, No. 7, 1964, p. 7.5.446.

On the basis of analysis of photometric observational data of Mars in 1939, 1954, 1956, and 1958, the effect of the presence of yellow haze on the brightness distribution of the planetary disk and on the continent-sea contrast has been studied. In the presence of a yellow haze the distribution of brightness on the disk, characterized by the ratio of the values of the brightness factor in the center ( $\epsilon \approx 0^\circ$ ) and on the limb ( $\epsilon \approx 60^\circ$ ), changes spectrally considerably less than in the case of a transparent atmosphere. Examination of the variation of the brightness factor spectrally for individual sectors of the seas under different Martian atmospheric conditions has shown that it is possible to define three characteristic groups. To the first group belong seas which, with regard to spectral reflectivity, differ little from the continent adjacent. To the second group belong seas having a sharp break in the brightness factor line in the spectrum after which, in the shorter wavelength region, they are comparable in reflectivity to the neighboring continent. To the third group belong seas whose brightness factor after the break run somewhat higher than the corresponding curve for continents, gradually blending with it near 3600 Å.

28. American Meteorology Society, Boston, Massachusetts,  
PRELIMINARY RESULTS OF MARS by N. P. Barabashov, February  
1964, AFCRL, Bedford, Mass., AD-602 193, Contract No. AF 19 (628)-  
3880, translated from Vestn. Akad. Nauk SSSR, No. 5, 1957, p. 34-36.

Coordinated observations of Mars were conducted by various observatories throughout the U. S. S. R. for 5 months during the 1956 opposition. All observers noted that the Mars atmosphere was not

transparent but was filled with a fog, which interfered with the study of surface features. Considerable changes from past observations were noted, however, in the contrast between the seas and the continents, the appearance and brightness of the southern polar cap and the polar fringe, and the brightness variations of the same land areas with time. The observational data acquired are being processed more fully to get a more accurate picture of the physical conditions on Mars.

29. Belton, M. J. S. and Hunten, D. M.,  
THE ABUNDANCE AND TEMPERATURE OF CO<sub>2</sub> IN THE MARTIAN ATMOSPHERE, Astrophysical Journal, 145, August 1966, pp. 454-467.

Spectrophotometric observations of the R-branch of the weak  $\nu_1 + 2\nu_2 + 3\nu_3$  band of CO<sub>2</sub> at 1.05  $\mu$  in the spectrum of Mars yield an atmospheric abundance of  $68 \pm 26$  m-atm (STP). Taken together with the results of Gray's analysis of the strong bands of CO<sub>2</sub> at 2  $\mu$ , this abundance indicates a surface pressure in the range of 5-13 mb. Individual lines in the R-branch have been resolved up to J = 28, and their intensity distribution indicates a rotational temperature of 194°K. The head region alone yields a somewhat higher temperature of 210°K. The observations were also analyzed with the help of a polytropic model atmosphere. The most satisfactory fit to the data was found for a maximum air temperature at the surface of 270°K and a lapse rate of 5°K km<sup>-1</sup>. The paper is concluded with a brief discussion of the compatibility of the present observations with others that are available.

30. General Electric Company, Philadelphia. Missile and Space Division,  
USE OF A MASS SPECTROMETER TO DETERMINE THE COMPOSITION OF THE UNDISTURBED MARTIAN ATMOSPHERE FROM A HYPERSONIC ENTRY VEHICLE Final Report by M. H. Bortner,  
R. P. Fogaroli, H. L. Friedman, H. W. Goldstein, R. E. Simons et al, 25 October 1965, NASA CR-71307, Contract No. NAS5-9602.

The use of a mass spectrometer aboard a hypersonic entry vehicle, to determine the chemical composition of the Martian atmosphere, was studied by application to minimum and maximum engineering models of the atmospheric medium. First, the heating of the entry vehicle was calculated throughout the entry and the results were applied to find the corresponding thermal response of the graphite in mass losses and temperature changes. The quantity of the ablation products was then estimated and added to the chemical kinetic information to determine the gas flow composition that enters the mass spectrometer. Thus, the factors that influenced the accuracy of the analysis were established and related to the chemical composition of the atmosphere; final model

atmospheric compositions containing N<sub>2</sub>, N, CO<sub>2</sub>, CO, C<sub>2</sub>N<sub>2</sub>, CN, O<sub>2</sub>, O, C<sub>3</sub>, and C are shown in tables.

31. Briggs, M. H.,

PARTICULATE MATTER IN THE ATMOSPHERES OF THE TERRESTRIAL PLANETS, Societe Royale des Sciences de Liege, Memoires, Cinquieme Serie, 7, 1963, Physics of Planets Symposium Paper, Liege, Belgium 9-12 July 1962, pp. 251-260.

Discussion of the evidence for the composition of the hazes of each of the inner planets. The Earth possesses a wide variety of chemically different atmospheric particulate materials: water and ice, biogenic hydrocarbons, free metals, nitrogen dioxide, and the products of silicate weathering. On the whole, the hazes of Mercury are likely to be fluorescent-free radicals or volcanic sulphur. For Venus, however, it is possible to construct only a hypothetical model system because of the uncertain chemical composition of the two hazes present in the atmosphere. The hazes of the Mars atmosphere are of three types: one due to dust storms, another to ice crystals, while the third one (the so-called "blue haze" or "violet layer") has an undefined chemical composition.

32. Byutner, E. K.,

ON THE DISSIPATION OF HYDROGEN FROM PLANETARY ATMOSPHERES, Dokl. Akad. Nauk SSSR, 124, No. 1, 1959, pp. 53-56.

Photodissociation of water occurs mainly in a layer of the earth's atmosphere between 70 and 80 km and is due to radiation in the interval 1860-1760 Å; the associated probabilities are  $3 \times 10^{-9} \text{ sec}^{-1}$  at 70 km and  $4 \times 10^{-7} \text{ sec}^{-1}$  at 80 km. The speed of dissipation of terrestrial hydrogen is estimated at  $10^9 \text{ cm}^{-2} \text{ sec}^{-1}$ . The amount of oxygen in the atmosphere of Mars is found to be one thousandth of that in the earth's atmosphere, in agreement with the spectroscopic value.

33. IIT Research Institute, Chicago, Illinois,

A REVIEW OF RECENT DETERMINATIONS OF THE COMPOSITION AND SURFACE PRESSURE OF THE ATMOSPHERE OF MARS by M. W. P. Cann, W. E. Davies, J. A. Greenspan, and T. C. Owen, NASA CR-298, Contract No. NAS5-9037.

Recent determinations of the Martian surface pressure are reviewed. The polarimetric work of Dollfus is discussed and a new value of the surface pressure, 63 mb, is derived from his data making use of more recent photometric data and of a new treatment of the angular dependence

of the planetary surface brightness. A photometric argument by Musman is discussed and the general effects of aerosols and various mixtures of gases on the pressure estimates are investigated. It is shown that these lead to a range of pressures depending on the assumptions made, and that this method of pressure determination leads to indeterminate results. Several spectroscopic works are reviewed and a value of  $45 \pm 25$  m-atm for the Martian CO<sub>2</sub> abundance is derived, corresponding to a mean Martian atmospheric temperature of 200°K. Using this abundance, various methods for estimating the surface pressure are reviewed, leading to surface pressures ranging from 13 to 33 mb with relative errors on the order of  $\pm 90\%$ . The large uncertainty is due to the fact that the abundance determination rests on the measurement of three weak lines in a single spectrogram.

34. Chamberlain, J. W.,  
UPPER ATMOSPHERES OF THE PLANETS, Astrophys. J. USA, 136,  
No. 2, September 1962, pp. 582-593.

Most of our knowledge of the earth's upper atmosphere is obtained from experiments in situ or remote observations that offer fairly direct interpretations. For the other planets, neither approach is as yet possible; so indirect, theoretical procedures are required to construct models of their atmospheres. Herein the wide variety of basic physical processes governing the structure of a planetary high atmosphere are set forth, with a view toward obtaining "deductive models" - i. e., models derived theoretically when only the chemical composition and temperature of the lower atmosphere and the incident solar flux are specified (in addition to various physical and astronomical constants). The procedures are applied to Mars, whose lower and middle atmosphere is already partially understood from earlier work, notably that of Goody. The uncertainties involved at various stages in the construction of such a model are emphasized, as are the major differences in physical processes and atmospheric characteristics between Mars and the earth. The most significant result is that the CO that must be in the upper atmosphere of Mars should serve as an effective thermostat, keeping the temperature at the escape level (1500 km) from exceeding about 1100°K. This is cool enough for Mars to retain atomic oxygen. Were it not for CO cooling, the upper atmosphere of Mars would be so extensive and form such an effective thermal insulation between the upper ionosphere and the heat sink at the mesopause that the temperature would exceed 2000°K. The lifetime for the escape of oxygen is estimated as  $10^9$  years. The mesopause is determined by CO<sub>2</sub> radiation. Near the mesopause CO<sub>2</sub> should become dissociated and the free O atoms form a thin layer of O<sub>2</sub>; this effect has no analogy on earth. The

model ionosphere has considerably smaller densities of ionization than comparable regions in the earth's atmosphere. The E-region is split into two distinct portions, with X-rays forming the higher one ( $E_2$ ) and ultraviolet light ionizing  $O_2$  near the mesopause ( $E_1$ ). The Martian analogue to the terrestrial  $F_2$ -region may not develop a very high electron density, and the entire ionosphere should be depleted at night.

35. Chamberlain, J. W.  
UPPER ATMOSPHERE OF MARS, Mem. Soc. Roy. Sci. Liege, 7,  
1963, pp. 415-416, Physics of Planets Symposium Paper, Liege, 1962.

The possibility is discussed of providing "deductive models" of the Martian upper atmosphere i. e. models that are based solely on chemical composition, and temperature of the lower atmosphere, in addition to the incident solar flux.

36. Chamberlain, J. W. and Hunten, D. M.,  
PRESSURE AND  $CO_2$  CONTENT OF THE MARTIAN ATMOSPHERE--  
A CRITICAL DISCUSSION, Rev. Geophysics, 3, No. 2, 1965,  
pp. 299-317.

This article reviews the principal techniques that have been used to estimate the surface pressure on Mars. The basic physics behind each technique is outlined and illustrated with simplified examples. An attempt is made to evaluate the reliability of each technique and its use to date... The conclusions are principally (1) that the polarimetric and photometric techniques are not nearly so reliable as has been generally supposed, and (2) that, although the spectroscopic method should ultimately settle the problem, the data thus far available do not yield good accuracy in either the  $CO_2$  content or the total pressure.

37. Chamberlain, J. W. and McElroy, M. B.,  
MARTIAN ATMOSPHERE--THE MARINER OCCULTATION EXPERIMENT, Science, 152, No. 3718, 1966, pp. 21-25.

Mariner 4 observations of the Martian ionosphere have indicated that the upper atmosphere of that planet differs widely from earlier proposed models. A new model is computed, with 44 percent  $CO_2$  and 56 percent  $N_2$ , which fits the observations provided that  $CO_2$  is not strongly dissociated. A physical discussion of the radiative losses by  $CO_2$  shows that a normal thermosphere develops and that the exosphere (at the top of the thermosphere) is at least 400°K.

38. Chandra, S. and Srivastava, B. P.,  
ABSORPTION OF MICROWAVES IN PLANETARY ATMOSPHERES,  
Z. Astrophys., 47, No. 2, 1959, pp. 127-134.

The absorption of microwaves in various planetary absorbing gases was calculated. The integrated absorption due to oxygen present in the earth's atmosphere was found to be 0.16, 0.099 and 0.092 dB at  $\nu = 1$ , 0.33 and 0.1  $\text{cm}^{-1}$  respectively. The absorption due to nitrous oxide in Mars and Venus and the absorption due to ammonia in Mars, Venus and Jupiter has also been calculated. The absorption due to earth's ionosphere has been found to be negligible at these frequencies. Total absorption at  $\nu = 1$ , 0.33 and 0.1  $\text{cm}^{-1}$ : earth 0.16, 0.099, 0.092 dB; Mars 0.087, 0.019, 0.002 dB; Venus 0.17, 0.037, 0.003 dB; Jupiter 29.498, 6.374, 0.505 dB. It seems, therefore, that the atmospheres of most of the planets except Jupiter offer negligible attenuation to microwaves.

39. Space Sciences Laboratory, General Electric Company, Philadelphia, Pennsylvania,  
MOLECULAR OPTICAL THICKNESS OF THE ATMOSPHERES OF MARS  
AND VENUS by K. L. Coulson and M. Lotman, July 1962, R62SD71.

The volume scattering coefficient and optical thickness by molecular scattering of sunlight in several different models of the atmospheres of Mars and Venus are presented. The computations are based on Rayleigh's well-known scattering law. Data are given by eight different wavelengths from 2500A to 10,000A, as a function of altitude above the planetary surface. Fractional transmission of direct solar radiation is then computed for selected cases. Comparison of results with similar data for Earth's atmosphere shows the light-scattering techniques are applicable up to higher altitudes of the atmospheres of both Mars and Venus than in Earth's atmosphere.

40. Davies, W. O.,  
ELECTRICAL PROPERTIES OF SHOCK WAVES ON MARS, AIAA Journal, 1, February 1963, pp. 464-466.

Calculation of the electrical properties of the Martian atmosphere at temperatures and densities expected to occur in shock layers for probes circling the planet, and the reflection and attenuation by the shock layer of electromagnetic waves having radio and radar frequencies. The flight conditions considered are for a probe circling Mars at an altitude of  $2 \times 10^5$  ft, with constant velocities of 7,200, 10,000, and 15,000 fps. Kopal's model atmosphere for Mars is used in the calculations.

41. Davydov, V. D.,  
BEHAVIOR OF THE HYDROSPHERE UNDER MARTIAN CONDITIONS  
AND ITS OBSERVED MANIFESTATIONS, Probl. of Cosmogony, VII,  
Joint Publications Research Service, Washington, D. C., 25 May 1964,  
pp. 146-166.
- The propriety of comparing water resources on Earth to those on Mars is confirmed, even though the spectral method could not be used to detect water vapors in the Martian atmosphere. Oceanographic techniques are employed instead.
42. Dollfus, A.,  
STUDY OF THE WATER VAPOR OF THE ATMOSPHERE OF THE  
PLANET MARS, MADE ON A FREE BALLOON AT 7000 m ALTITUDE,  
Academie des Sciences, Paris, Comptes Rendus, 239, No. 16,  
18 October 1954, pp. 954-956.
- The Martian atmosphere resembles the earth atmosphere at 6500 m. The spectral band of water vapor for 8250 Å was measured at that altitude. The precipitable water was 0.25 mm.
43. Dollfus, A.,  
WATER VAPOR IN THE ATMOSPHERE OF THE PLANET MARS,  
Societe Royale des Sciences de Liege Memoires, Ser. 4, 18, 1957,  
pp. 165-168.
- The existence of water vapor on Mars is considered to have been demonstrated by observations of infrared diffusion spectra of polar caps similar to those of ice; by polarization of light reflected from the polar caps; and by polarization curves of Martian clouds indicating a fog of ice crystals. The water content in the Martian air is estimated much weaker than on Earth. The weak quantity of water in the Martian atmosphere circulates constantly. Water evaporates from one polar cap, scatters toward the equator, is drifted afterwards to the opposite polar regions where it freezes to the ground. Thereupon the mechanism is repeated in the opposite direction. The yearly evolution of clouds seems to accompany the transfer of water vapor.
44. Dollfus, A.,  
MEASUREMENT OF THE WATER-VAPOR CONTENT IN THE MARTIAN  
ATMOSPHERE, Academie des Sciences, Paris, Comptes Rendus, 256,  
No. 14, 1 April 1963, pp. 3009-3011.

Photometric comparison of the intensity of the  $1.4 \mu$  band for water vapor, from Mars, the Moon, and various stars, in order to determine the water-vapor content in the Martian atmosphere. The measurements were made in winter at high altitudes (from Jungfraujoch observatory) when the declination of Mars was  $+19^\circ$ . The vapor content is found to be  $0.02 \text{ gm/cm}^2$ .

45. Dollfus, A.,  
MEASUREMENT OF WATER VAPOR IN THE ATMOSPHERE OF MARS AND VENUS, Liege U. Infrared Spectra of Astron. Bodies, 1964, pp. 392-395.

Attempts to measure the water vapor on Mars and Venus using photometric equipment for the  $1.4\mu$  radiation of the  $\text{H}_2\text{O}$  molecule are described. The data presented were obtained using this equipment both in balloons and on high mountains. Comparisons of Mars and lunar observations gave a different signal that, when corrected for brightness inequalities and instrumental effects, indicate that water vapor exists in the Mars atmosphere at a concentration of  $2.6 \times 10^{-2} \text{ g/cm}^2$ . In the case of Venus, the water-vapor band was found to be juxtaposed with strong carbonic gas bands. Appropriate filtering out of the  $\text{CO}_2$  bands confirmed the estimate of water vapor in the upper layers of the Venus atmosphere as the value  $1.15 \times 10^{-2} \text{ g/cm}^2$ , assuming that the atmosphere is saturated to the level of the clouds.

46. Dollfus, A.,  
DETECTION OF WATER VAPOR IN THE ATMOSPHERES OF VENUS AND MARS, AFCRL Proc., 1964 AFCRL Sci. Balloon Symp., July 1965, pp. 409-417.

Balloon flights for the detection and measurement of water vapor in the atmosphere of Venus and Mars are discussed. A lightweight sealed cabin, and telescopic and spectroscopic devices used to record the measurements are described. Two lifting devices are mentioned. One type is composed of a cluster of 104 dilatable sounding balloons organized in 34 groups of three balloons, one above the other, along a vertical cable 1400 feet long. The second device uses a chaplet-like cluster of 23 neoprene Darex 7000-gram balloons capable of ascents to 80 000 feet. An observation was made from a high mountain site to determine for calibration purposes, the amount of water vapor contributed by the earth's atmosphere. Reduction of data, including minor corrections and recalibration, yielded the following water vapor values: for Venus,  $0.7 \times 10^{-2} \text{ g/cm}^2$ , and for Mars,  $1.5 \times 10^{-2} \text{ g/cm}^2$ .

47. Eksinger, D.,  
SOME PROPERTIES OF THE ATMOSPHERE OF MARS, Vasiona, 12,  
No. 1, 1964, pp. 4-6.

Brief discussion of some of the basic properties of the atmosphere of the planet Mars which distinguish it from the atmosphere of the Earth. In particular, circulation of air masses in the Martian atmosphere, water content in the inert air masses, and distribution of thermal flows are considered.

48. Eropkin, D.,  
QUANTITY OF OZONE IN PLANETARY ATMOSPHERES, Comptes  
Rendus de l'Acad. des Sciences, USSR, Leningrad, No. 5, 1933,  
pp. 64-69.

The author discusses the effect of distance from the sun on the amount of ozone in the upper atmospheres of planets; the increase in ozone with latitude on the earth is used to determine the rate of increase for more distant planets. A comparison of the faint ozone bands in the visible spectrum with the spectra of planets suggest a number of coincidences especially for Uranus and Neptune. The general oxygen reaction is briefly considered. The author does not support the view of a different chemical constitution of the atmospheres of the earth and the great planets.

49. Stanford University, California, Radioscience Laboratory,  
THE STANFORD STUDY OF THE MARINER IV OCCULTATION DATA  
Semiannual Report No. 3, 1 October 1965-31 March 1966 by  
V. R. Eshleman, June 1966, NASA CR-75816, Grant No. NGR-05-020-  
065.

The large difference in atmospheric surface pressure (actually more than 50%) between the occultation levels at Electris and Mare Acidalium is reported as the most interesting result derived from the analysis of the Mariner IV-Mars occultation experiment and the Martian atmosphere experimental models. Both the higher pressure and the smaller radius determined at Mare Acidalium suggest that this region is at a lower gravitational level than the bright Electris area. Analyzed data indicated that some of the haze and particle layers observed with earth-based telescopes and with the Mariner IV television camera may have been CO<sub>2</sub> particles.

50. Evans, D. C. and Wasko, P. E.,  
MODEL ATMOSPHERES FOR THE PLANET MARS, AIAA Aerospace  
Sciences Meeting, New York, N. Y., 20-22 January 1964, Preprint  
64-67, AD-424 644.

Presentation of model atmospheres of the planet Mars for the use of design, test, and reliability engineers. The four model atmospheres shown in detail in tables are: (1) Mars equator, the mean model; (2) Mars equator, the maximum model; (3) Mars South Pole, the minimum model; and (4) Mars South Pole, minimum-high molecular weight. Graphical illustrations of the model atmospheres are provided. It is noted that the models represent possible real conditions. They are internally consistent, rather than statistically synthetic or physically extreme. The best available data and information were used in their construction. Nevertheless, it is emphasized that the models must be used with discretion, as they may be changed with the advent of new information. Serious performance problems have arisen in the past because designs were based on a single mean-model atmosphere. The development of the model atmospheres presented is the culmination of a detailed survey of the literature on the planet Mars.

51. Firsoff, V. A.,  
DOES WATER VAPOUR ESCAPE FROM MARS?, British Astronomical Association, London, Journal, 66, No. 2, January 1956, pp. 53-59.

Atmospheric conditions on Mars are set out -- composition, temperature, lapse rate, surface pressure (83 mb). The mean altitude of the Martian tropopause is estimated as 30 km and all water vapor is frozen out below this level. The height of the ozone layer is estimated as 75 km; at night ozone may condense and break up into monatomic oxygen. No mechanism for the escape of oxygen and water vapor from Mars yet considered is confirmed.

52. Stanford University, California, Radioscience Laboratory,  
THE ATMOSPHERE OF MARS: A COMPARISON OF DIFFERENT  
MODEL STUDIES BASED ON MARINER IV OCCULTATION DATA  
Scientific Reports 16 and 3 by G. Fjeldbo, W. C. Fjeldbo, and  
Von R. Eshleman, June 1966, NASA CR-78134, Contract No.  
NgR-05-020-065, Grant No. NsG-377.

Three models for the atmosphere of Mars are compared. In the  $F_2$  models,  $CO_2$  is dissociated by solar ultraviolet radiation at 70 km altitude, and atomic oxygen predominates above 80 km. The principal ion in the daytime ionospheric layer would be  $O^+$ , and the topside of the

layer would be isothermal at 90°K. The mesopause temperature minimum would be at or below the freezing point of CO<sub>2</sub>, and dry ice particles would form. In the F<sub>1</sub> models, molecular constituents predominate in the upper atmosphere to 225 km, and molecular ions formed by solar ultraviolet radiation and various chemical reactions would make up the ionospheric layers. The temperature in the isothermal height region would be between 150° and 250°K. In the E model the main ionization layer is formed by solar X-rays in a mixed upper atmosphere. The mass density in the upper atmosphere for the E model would be more than two orders of magnitude larger than for the F<sub>1</sub> models, and about 10<sup>4</sup> times the mass density at the same altitudes in the F<sub>2</sub> models. The F<sub>2</sub> models fit theory and observation best, and identify the reaction which is critical in defining a particular F<sub>2</sub> model. However, an F<sub>1</sub> model might result if photodissociation and diffusive separation are markedly less than would be expected by analogy with the earth's upper atmosphere.

53. Stanford University, California, Radioscience Laboratory,  
MODELS FOR THE ATMOSPHERE OF MARS BASED ON THE  
MARINER IV OCCULTATION EXPERIMENT Scientific Reports 2 and  
15 by G. Fjeldbo, W. C. Fjeldbo, and Von R. Eshleman, January 1966,  
NASA CR-74152, Contract No. NgR-05-020-065, Grant No. NsG-377.

Several possible atmospheric models are investigated based on data from the radio occultation experiment, and one is shown to be more likely than the others. Profiles in height of the constituent number densities, electron number density, temperature, pressure, and mass density are derived. The analysis indicates that Mars has a tenuous carbon dioxide lower atmosphere with a temperature of about 180°K near the surface, and an atomic oxygen upper atmosphere with a temperature of only about 80°K. Frozen carbon dioxide particles may be an almost permanent feature of the atmosphere at intermediate altitudes. The main daytime ionospheric layer has its peak density at 120 km, and is most likely a Bradbury (F2) layer with the principal ion (O<sup>+</sup>) being lost through O<sup>+</sup> + CO<sub>2</sub> → O<sub>2</sub><sup>+</sup> + CO. The atmospheric mass density decreases nearly ten orders of magnitude from the surface to the base of the exosphere at 140 km, thus remaining several orders of magnitude below the density of the earth's atmosphere at corresponding altitudes despite the lower gravity.

54. Fjeldbo, G., Fjeldbo, W. C., and Eshleman, Von R.,  
MODELS FOR THE ATMOSPHERE OF MARS BASED ON THE  
MARINER 4 OCCULTATION EXPERIMENT, Jour. Geophys. Research,  
71, No. 9, 1966, pp. 2307-2316.

It is found that one of the several possible models of the Martian atmosphere, based on data from the radiooccultation experiment, is more likely than the others. In this model Mars has a tenuous CO<sub>2</sub> lower atmosphere with a temperature of only about 180°K near the surface, and an atomic oxygen upper atmosphere with a temperature of only about 80°K. Frozen CO<sub>2</sub> particles may be an almost permanent feature of the atmosphere at intermediate altitudes. The main daytime ionospheric layer has its peak density at 120 km, and is most likely an F2 layer. The atmospheric mass density decreases nearly 10 orders of magnitude from the surface to the base of the exosphere at 140 km, thus remaining several orders of magnitude below that of the Earth's atmosphere at corresponding altitudes despite the lower gravity.

55. Melpar, Inc., Falls Church, Virginia,  
A DESIGN STUDY PROGRAM OF A POLAROGRAPHIC OXYGEN  
ANALYZER FOR OBTAINING DATA ON THE ATMOSPHERIC COMPOSI-  
TION OF MARS Final Report, 16, May-15 September 1962, by  
R. T. Foley and G. Halpert, 1962, NASA CR-57085, Contract Nos.  
NAS7-100, JPL-950284.

A laboratory model gas phase polarographic cell was constructed with an 0.5-mil Teflon membrane, a platinum polarized electrode, a silver-silver chloride reference (reversible) electrode, and an aqueous methanol-potassium chloride electrolyte which was designed principally to conduct effectively at lower temperatures. A single compartment cell was constructed to provide a configuration which could be packaged into a compact unit. The cell operated without difficulty when subjected to the atmospheric conditions expected to be encountered during a Mars descent. A breadboard model was designed and constructed including the polarographic cell; the electrolyte injector and the accumulator, which allows the cell to be activated upon arrival at the planet; and the amplifier, which converts current output to a voltage for transmittance

56. Geophysics Corporation of America, Bedford, Massachusetts,  
A STUDY OF THE METEOROLOGY OF MARS AND VENUS Quarterly  
Progress Report No. 3, 6 July-5 October, 1963, NASA CR-55165,  
Contract No. NASw-704.

Several topics of importance to the meteorology of Mars and Venus were investigated. Atmospheric tides in the Martian atmosphere were discussed. Techniques for constructing thermodynamic diagrams for the Martian atmosphere were developed, and actual diagrams are under construction. Meteorological studies of Venus focused on two

problems, both of which are related to planetary and atmospheric temperatures. The first problem was an estimate of the amount of solar radiation absorbed by carbon dioxide in the atmosphere of Venus. The second problem concerned the temperature variation with altitude in the atmospheric layer between the planet's surface and the base of the cloud layer. Techniques for computing the radiative equilibrium distribution of temperature in this layer were developed.

57. Ghosh, S. N. and Malaviya, V.,  
MICROWAVE ABSORPTION IN THE MARTIAN ATMOSPHERE,  
Zeitschrift fur Astrophysik, 60, No. 2, 1964, pp. 87-93.

Calculation of the microwave absorption  $\gamma$  for the Martian atmosphere. The peak absorption at the resonance frequency and the line-widths of the absorption lines are calculated using the temperature variation and the distribution of constituent gases of the Martian atmosphere as given by Urey, and Ghosh and Sharma. It is shown that  $\gamma_0$  has a very large value in the Martian atmosphere. For example, at 90 km its value is 2.5 times the corresponding value in the terrestrial atmosphere. This large value of  $\gamma_0$  is attributed to the low temperature ( $130^{\circ}\text{K}$ ) at 90 km. Furthermore, because of the low gravity of Mars, the rate at which the density decreases with altitude is much less, and hence the values of  $\Delta\nu$  for different gases are larger than those in the Earth's atmosphere. The total absorption for the frequency range 55-65 Gc is plotted, and it is shown that the effective frequency range for absorption is smaller than that for the terrestrial atmosphere.

58. Goody, R. M.,  
THE ATMOSPHERE OF MARS, Weather, 12, No. 1, January 1957,  
pp. 3-15.

This general article usefully summarizes recent work. The albedo of Mars is 0.148 (earth 0.39), equilibrium temperature  $217^{\circ}\text{K}$  ( $245^{\circ}\text{K}$ ), general level of atmospheric temperature  $30^{\circ}\text{K}$  lower than earth. The year is nearly twice as long but the seasonal cycle is similar. The surface resembles a desert, with darker greenish areas. The seasonal polar caps are due to a few cm of ice-frost forming in spring from winter ice-mist. The albedo of clouds is 0.4, possibly due to a cold form of ice ( $210^{\circ}\text{K}$ ). The "violet layer" is possibly dust haze, yellow clouds are dust, blue and white clouds--ice. Surface isotherms at local noon, northern winter, are plotted. Winds at 10 km are 30-110 km/hr. Atmosphere is 0.2-0.25 as massive as earth's ground pressure about 85 mb. It is mainly nitrogen; there is little oxygen and water vapor, but about 15 times as much  $\text{CO}_2$  as earth's.

Vertical structure is shown compared with earth, but the position of the tropopause is uncertain.

59. Goody, R. M.,  
THE ATMOSPHERE OF MARS, The Origin and Evolution of Atmospheres and Oceans, Proceedings of a Conference, NASA, Goddard Space Flight Center, Goddard Institute for Space Studies, New York, N. Y., April 8, 9, 1963, P. J. Brancazio and A. G. W. Cameron, ed., John Wiley and Sons, Inc., 1964, pp. 289-296.

Discussion of information on the composition of the Martian atmosphere, including data available at the time of the Goddard Institute Conference. Polarimetric observations are described, and indications of the relative abundance of CO<sub>2</sub> were obtained by comparing spectra of Mars and the moon. The contributions made by Dollfus, Kaiper, de Vaucouleurs, and others to the field of Martian atmospheric investigation are considered.

60. Grandjean, J. and Goody, R. M.,  
THE CONCENTRATION OF CARBON DIOXIDE IN THE ATMOSPHERE OF MARS, Astrophysical Journal, Chicago, 121, No. 2, March 1955, pp. 548-552.

From observations of carbon dioxide bands in the spectrum of Mars made by G. P. Kuiper, we have redetermined the fraction by volume of this gas in the planet's atmosphere, taking into account the fine structure of the band and the shape of the rotation lines. If the ground-level pressure on Mars is 100 mb, we find that the fraction by volume of carbon dioxide is 50 times greater than in the earth's atmosphere.

61. Gray, L. D.,  
TRANSMISSION OF THE ATMOSPHERE OF MARS IN THE REGION OF 2  $\mu$ , Icarus, 5, July 1966, pp. 390-398.

The random Elsasser band model is used to compute the transmission of the atmospheres of earth and Mars for the 2- $\mu$  bands of carbon dioxide. This band model is shown to give good agreement with measurements of spectral transmission for homogeneous paths of CO<sub>2</sub> and also for nonhomogeneous paths through the earth's atmosphere when the Curtis-Godson approximation is used. The 2- $\mu$  bands of CO<sub>2</sub> are strong in the atmosphere of both earth and Mars and, at a given temperature, their absorption is a function only of the product mp. Comparison of calculated values for transmission of sunlight through

both atmospheres indicates that  $mp_{CO_2} = 500 \pm 100$  mr-atm-mb where m is the amount of  $CO_2$  in one air mass and  $p_{CO_2}$  is the "effective" surface pressure. For  $m_{CO_2} = 60$  to 85 mr-atm, the above value of  $mp_{CO_2}$  leads to  $p_{SO_2} = 7.1 \pm 2.2$  mb for the surface pressure of the Martian atmosphere.

62. Gross, S. H., McGovern, W. E., and Rasool, S. I.,  
MARS -- UPPER ATMOSPHERE, Science, 151, No. 3715, 1966,  
pp. 1216, 1221.

The thermal structure of the upper atmosphere of Mars has been theoretically investigated. The exospheric temperature, for a pure  $CO_2$  model atmosphere, lies between 400°K and 700°K. The result has some implications regarding the origin of the observed  $CO_2$  on Mars. The present atmosphere could be a remnant of a heavier primitive atmosphere which once had a composition similar to that observed today on Jupiter, in which case there should be some Ne and N<sub>2</sub> present. An alternative hypothesis, that the present Martian atmosphere is the result of outgassing from the interior, implies that atmospheric pressure was never greater than the present value and that there must be large quantities of frozen water under the surface. These conjectures can be tested only by future fly bys or lands.

63. Hanst, P. L. and Swan, P. R.,  
THE ABSORPTION INTENSITY OF THE  $5\nu_3$  BAND OF CARBON  
DIOXIDE, AND THE MARTIAN  $CO_2$  ABUNDANCE AND ATMOSPHERIC  
PRESSURE, Icarus, 4, No. 4, September 1965, pp. 353-361.

The surface pressure of the Martian atmosphere strongly affects the design and payload capabilities of Mars entry vehicles. The current most widely accepted value of this surface pressure is 25 millibars. This value was determined by Kaplan, Munch, and Spinrad based on their observations of  $CO_2$  absorption lines near 8700 Å and on Sinton's and Kuiper's  $CO_2$  observations at 2.05 microns. It is noteworthy that their estimated value of 25 millibars is a factor of 3 or 4 below estimates determined both by photometric and by polarimetric techniques. A laboratory redetermination of the integrated absorption intensity of the  $5\nu_3$  band of  $CO_2$  near 8700 Å has been made with a long-path technique and photomultiplier detection. This has resulted in a revision of the calibration used by Kaplan, Munch, and Spinrand. In view of the importance of the surface pressure to current studies of Mars probes, a recalculation of the pressure utilizing the new laboratory measurements is carried out in this paper. The results of the present analysis give a revised value of (31 ± 13) m-atm for the Martian  $CO_2$  abundance

under the assumption of an effective temperature for the Martian atmosphere of 200°K. The surface pressure is now estimated, using this abundance value, to be (51 ±25) millibars.

64. Harrison, F. B. and Bernstein, W.,  
A DETECTOR FOR THE ARGON ABUNDANCE IN THE MARTIAN ATMOSPHERE, Planetary and Space Science, 12, July 1964,  
pp. 726-727.

Description of a simple instrument of low weight and small power consumption, suitable for inclusion in a "first generation" instrument package placed in the Mars atmosphere, for the determination of argon abundance, provided the total atmospheric density is independently measured. The instrument is a cylindrical ionization chamber 5-cm long and 10-cm in diam., which is open to the atmosphere; the ionization produced by a low-energy X-ray source is measured. The walls of the chamber are made of Z-material, such as beryllium or aquadag-coated magnesium to reduce the contribution of electrons generated by X-rays interactions with the walls to a negligible amount. It is stated that, since the mass absorption coefficient for 4- to 10-kev X-rays for argon is much greater than for the low-Z gases, the ionization current will depend sensitively on the argon concentration. On the other hand, the absorption coefficients for the high-Z gases such as Xe and Kr are not much greater than that for argon; thus, trace amounts of these gases will not distort significantly the argon determination. The currents calculated for a 30-Mc Fe<sup>55</sup> source for various total atmospheric densities and argon concentrations are shown.

65. Herzberg, G.,  
THE ATMOSPHERES OF THE PLANETS, J. Roy. Astron. Soc. Can.,  
45, May-June 1951, pp. 100-123.

Reviews the present status of spectroscopic investigations of planetary atmospheres, including that of the earth. In the case of the earth's atmosphere the recent discovery of OH in the spectrum of the night sky by Melnel is discussed and its importance for the phenomena in the upper atmosphere is pointed out. The spectroscopic detection of CO<sub>2</sub> in the atmospheres of Venus and Mars is described in some detail and laboratory investigations aiming at more accurate determinations of CO<sub>2</sub> content, pressure and temperature in these atmospheres are discussed. The observations of CH<sub>4</sub> absorption bands in the major planets and the satellite Titan are summarized and the possibility of detecting molecular hydrogen by means of the quadrupole rotation-vibration spectrum is outlined. It is probable that one of the unidentified

features in the spectrum of Uranus and Neptune is due to the 3-0 band of the pressure-induced rotation-vibration spectrum of H<sub>2</sub>.

66. Hess, S. L.,  
INVESTIGATION OF THE METEOROLOGY OF MARS, The Project for the Study of Planetary Atmospheres, Lowell Observatory Report No. 2, 1 July-31 December 1948, Contract No. Cwb-7896, pp. 1-23.

A detailed report on Martian meteorology covering: general description of Mars; vertical atmospheric structure and the blue clouds; polar caps; temperature distribution and atmospheric circulation. Future plans for observation of Jupiter and processing data for Mars are outlined briefly. The report contains many formulas, graphs, photos and figures.

67. Hess, S. L.,  
A METEOROLOGICAL APPROACH TO THE QUESTION OF WATER VAPOR ON MARS AND THE MASS OF THE MARTIAN ATMOSPHERE, Publ. Astr. Soc. Pacif., 60, October 1948, pp. 289-302.

The author discusses the apparent discrepancy between the observations of clouds on Mars, probably water, and the small amounts of H<sub>2</sub>O found by the spectroscope, < 0.5 mm of precipitable H<sub>2</sub>O in the atmosphere. There are two probable types of cloud: (a) low-lying fog-like, formed on the night side, for which it is shown 0.4 mm precipitable water would suffice; (b) high-level, convective cumulus, forming after noon, for which the author finds 0.6 mm precipitable water needed. The inconsistency is not great. The method used would give an estimate of the total atmospheric pressure if all the constants could be measured for one Martian cloud; available data lead to a surface pressure ~ 80 millibars (i. e., an amount of air  $\frac{1}{3}$  less than that above Mt. Everest).

68. Hess, S. L.,  
SOME ASPECTS OF THE METEOROLOGY OF MARS, Journal of Meteorology, 7, No. 1, February 1950, pp. 1-13.

A thorough treatment of the various observed phenomena on Mars and the derived meteorological conditions (pressure, density, convection, atmospheric circulation, temperature, atmospheric composition, clouds, dust storms, polar caps, water vapor and CO<sub>2</sub>). A model of the stratosphere is constructed, and isothermal and isobaric charts prepared for northern winter in Mars. An attempt is made to explain the yellow and blue clouds. Similarities and differences between the

general circulation on Mars and the Earth are discussed. A number of excellent photographs of Mars, showing the polar ice caps, the yellow clouds and the blue clouds, are reproduced. Work for this paper was done at Lowell Observatory. (Same item as 5-9, Met. Abs.) The review by Flohn mentions Hess's findings on pressure, division of the atmosphere into troposphere and stratosphere and particularly the horizontal distribution of temperature and wind regime.

69. Hess, S. L.,  
THE ATMOSPHERE OF THE PLANET MARS, New York Academy of Sciences, Transactions, Ser. 2, 19, No. 4, February 1957,  
pp. 352-357.
- Composition temperature (map shows distribution in N. Hemisphere for winter), clouds, haze, general circulation and other characteristics of the Martian atmosphere are discussed.
70. Hamilton Standard Division, United Aircraft Corporation, Broad Brook, Connecticut,  
MARTIAN ATMOSPHERIC COMPOSITIONAL ANALYSIS: ITS BIOLOGICAL SIGNIFICANCE, First Quarterly Progress Report,  
15 May-15 August 1965, by D. R. Hitchcock and J. E. Lovelock,  
Houston University, 1965, NASA CR-67354, Contract No. NASw-871.
- The potential biological significance of two types of atmospheric data is critically reviewed. These are the relationship between the atmosphere and surface material, as revealed by an experiment designed to detect a free energy gradient between the two; and observations of selected major and trace components of the atmosphere including isotopic abundances. Discussed are studies relating to life detection by detection of chemical free energy in surface matter; Martian atmospheric compositional analyses; and Martian biological atmospheric experiments.
71. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,  
EXPERIMENTAL STUDY OF RADIATIVE TRANSPORT FROM HOT GASES SIMULATING IN COMPOSITION THE ATMOSPHERES OF MARS AND VENUS by C. S. James, 1963, NASA RP-174, reprinted from AIAA J., 2, No. 3, March 1964, pp. 470-475, presented at AIAA Conf. on Phys. of Entry of Planetary Atmospheres, Cambridge, Mass., 26-28 Aug. 1963.

Measurements have been made of gross spectral quality and intensity of thermal radiation from the hot gas cap of small polyethylene models flying through mixtures of CO<sub>2</sub> and N<sub>2</sub>. Mixture proportions and ambient pressure were varied from pure N<sub>2</sub> to nearly pure CO<sub>2</sub> and from 0.004 to 0.08 atm, respectively. Model flight velocity varied from 5 to 8 km/sec. Strong radiation from CN, formed in the shock layer, is observed for a wide range of mixture proportions. Variation of the total intensity of gas-cap radiation with ambient pressure, flight velocity, and mixture proportions is defined. Radiation from the mixtures is compared with radiation from air. The total intensity of gas-cap radiation from the CO<sub>2</sub>-N<sub>2</sub> mixtures is found to be several times that from air at the same flight conditions, except when high CO<sub>2</sub> concentrations are combined with low velocities. Comparison of the measurements with available equilibrium calculations indicates agreement within factors of two or three over the test range.

72. National Aeronautics and Space Administration, Goddard Institute for Space Studies, New York, New York,  
RADIATIVE TRANSFER IN THE ATMOSPHERES OF VENUS AND MARS  
by R. Jastrow and S. I. Rasool, NASA-RP-251, 1962.

An approximate theory of radiative transfer in planetary atmospheres is developed and applied to atmospheres of Venus and Mars. The results for Venus indicate that the atmosphere of that planet must have an optical thickness of 60 in the infrared, corresponding to a transmission of 10<sup>-26</sup> to produce the observed surface temperature of 600°K. The surface temperature and tropopause height of Mars are also investigated.

73. Johnson, F. S.,  
ATMOSPHERE OF MARS, Science, USA, 150, 10 December 1965,  
pp. 1445-1448.

The Martian ionospheric observations made by Mariner IV are interpreted in terms of an atmospheric model. The ion peak is identified as an F2 peak, that is, as a maximum whose profile is controlled by ambipolar diffusion. The principal features of the resulting atmospheric model are that the atmosphere consists mainly of carbon dioxide, the temperature is very low, and there is no thermosphere. Surface temperature is 210°K. The tropopause occurs at an altitude of 14 kilometers and has a temperature of 140°K. Above the tropopause, the temperature decreases with altitude at the rate of 0.64 °C km<sup>-1</sup>, following the solid carbon dioxide vapor-pressure curve up to 100 km, where the temperature is 85°K; at higher altitudes the temperature is isothermal.

74. Jones, H. S.,  
ATMOSPHERES OF PLANETS, Nature, 142, 10 December 1938,  
pp. 1019-1022.

If velocity of escape is 5 times the mean  $H_2$  molecular velocity, the atmosphere of a cool planet should be immune from loss. The moon, however, has none and Mercury's is very tenuous. The earth should be immune, but is losing He, probably through the effect of the meta-stable state of  $O_2$  in the upper atmosphere;  $O_2$  is being replenished by vegetation. Mars'  $O_2$  is almost locked up in the iron rocks, but it has slight vegetation. The major planets have atmospheres of  $H_2$ , He and such, mixed with  $CH_4$ ,  $NH_3$  and  $H_2O$ , and little or no  $CO_2$  or free  $N_2$ . Jupiter's and Saturn's  $NH_3$  is in the form of droplets, and is frozen out of the atmospheres of more distant planets. Small planets have no atmospheres; middle-sized ones have moderate ones without  $H_2$  or its compounds; large ones have great atmospheres with  $H_2$  and its compounds, but with no  $O_2$  or its compounds.

75. Jones, H. S.,  
THE ATMOSPHERES OF THE PLANETS, Quart. J. Roy. Met. Soc.,  
68, April 1942, pp. 121-150.

The means by which planetary atmospheres can be investigated are outlined: theoretical methods concerning the escape of gases from the gravitational field and the estimation of surface temperatures complement observational data obtained both by direct photography in light of various wavelengths and by spectroscopy. A detailed review of our knowledge of the atmospheres, of the Moon, Mercury, Mars, Venus and the major planets, shows that the problem of their nature is now solved in its broad outlines: the atmospheres differ considerably from one another, but their extent and their composition are in general accordance with expectation.

76. Kellogg, W. W.,  
THE ATMOSPHERE OF MARS, Space Age Astronomy, Academic  
Press, Inc., 1962, pp. 425-429.

Summary of the known and deduced composition and characteristics of the atmosphere of Mars. The general circulation of the Martian atmosphere is briefly considered, as is the albedo of the planet.

77. Kiess, C. C., Corliss, C. H., and Kiess, H. K.,  
EVIDENCE FOR OXIDES OF NITROGEN IN THE ATMOSPHERE  
OF MARS, Science, 131, No. 3409, 29 April 1960, p. 1319.  
  
A short note reporting observational evidence for the existence of nitrogen oxides in the Martian atmosphere.
78. Kiess, C. C., Darrer, S., and Kiess, H. K.,  
A NEW INTERPRETATION OF MARTIAN PHENOMENA, Publ. Astron. Soc. Pacific, 72, August 1960, pp. 256-267.  
  
All the available spectroscopic features of the Martian atmosphere can be simply explained by assuming it contains oxides of nitrogen. It is shown how the presence of these compounds can also explain such features as the Martian polar caps and their colours, the seasonal colour changes in the dark areas and the various cloud and haze formations.
79. Jet Propulsion Laboratory, California Institute of Technology, Pasadena,  
DETERMINATION OF SOME PHYSICAL PROPERTIES OF THE ATMOSPHERE OF MARS FROM CHANGES IN THE DOPPLER SIGNAL OF A SPACECRAFT ON AN EARTH OCCULTATION TRAJECTORY by  
A. Kliore, D. L. Cain, and T. W. Hamilton, 15 October 1964,  
NASA CR-59161, Contract No. NAS7-100.  
  
The expressions describing the effects of refraction in the atmosphere are derived and used to compute expected doppler changes for several isothermal model atmospheres of Mars, using typical 1964 and 1966-1967 Earth-occulting Mars flyby trajectories. Based on these computed results, and on the expected data accuracy, it is estimated that the scale height and surface density of the atmosphere of Mars can be determined with an accuracy of better than 10% by means of the experiment. In addition, several limitations of the experiment are described, and their effects on the results are discussed.
80. Koval, I. K.,  
STUDY OF OPTICAL PROPERTIES OF THE ATMOSPHERE AND SURFACE OF MARS, Physics of the Moon and Planets, Naukova Dumka, Kiev, 1964, pp. 46-53.  
  
Study of the problem of brightness distribution along the visible radius of Mars. Results obtained by other authors for narrow regions of the spectrum over a range of 400 to 900 m  $\nu$  are discussed. It is concluded that, within this range of wavelengths, the Martian atmo-

sphere possesses mainly scattering properties. The darkening of the limb has its maximum at about 650 m  $\nu$ . A decrease in the limb darkening to the left of this wavelength is due to a scattering similar to that of the molecular type. To the right of this wavelength, this decrease is attributed to the scattering by large dust particles constantly present in larger or smaller quantities in the Martian atmosphere.

81. Kucherov, N. I.,  
OBSERVATIONS OF MARS IN 1950, Akademiiia Nauk Kasakhskoi SSR,  
Sektor Astrobolaniki, Trudy, 3, 1955, pp. 48-62.

Observations of Mars made at Alma-Ata, at the Kamenskow Plato mountain observatory near Alma Ata, and the Tashkent Astronomical Observatory are reported. The observations were made visually, using three different telescopes with red, yellow, green and blue filters. The principal objective of the observations was to study conditions of cloudiness on Mars, as well as transparency of the Martian atmosphere and visibility of surface features. The periods of observation were Feb. 14-June 1, 1950 (winter in the southern hemisphere of Mars), and April 10-May 31, 1952. Results are reported in the form of some 200 diary entries, each entry giving the date and time of observation, filter used, part of the planet observed and details of the observed phenomena. Out of 74 days of observation there were only 4 cloudless days on Mars. Blue bands of clouds oriented both meridionally and latitudinally, and patches of clouds were seen and are described in some detail. Atmospheric transparency showed considerable variability. In one instance such variable transparency is attributed to the presence of haze, possibly consisting of small ice crystals and perhaps acting on a mechanism of moisture transfer from one polar cap to the other. In 1952 the Martian atmosphere was more transparent and less cloudy than in 1950.

82. Kuiper, G. P.,  
PLANETARY AND SATELLITE ATMOSPHERES, Rep. Phys. Soc.  
Progr. Phys., 13, 1950, pp. 247-275.

A review of spectroscopic, visual and photographic observations of planetary atmospheres. For greater detail see the author's monograph.

83. Arizona University, Tucson, Lunar and Planetary Laboratory,  
COMMUNICATIONS OF THE LUNAR AND PLANETARY LABORATORY,  
VOLUME 2, NUMBERS 31-35: MARS ISSUE by G. P. Kuiper,  
T. C. Owen, D. P. Cruikshank, and J. V. Marshall, 1964, NASA CR-  
60264, Grant No. NSG-161.

Four papers on the atmosphere of Mars and one on laboratory spectra of various gases are presented. In the first paper, spectra of the planet Mars obtained from the 82-in. telescope of the McDonald Observatory are presented for the interval  $1\mu$  to  $2.5\mu$ , and the spectra are examined for the presence of constituents other than CO<sub>2</sub>. In the second paper, the Mars spectra reported in the first paper are calibrated with laboratory spectra of pure CO<sub>2</sub> and of mixtures of CO<sub>2</sub> with N<sub>2</sub> and Ar, and preliminary values are derived for the pressure of the Martian atmosphere and the total amount of gases other than CO<sub>2</sub>. The third paper presents two independent determinations of the CO<sub>2</sub> content of the Martian atmosphere, derived from the Mt. Wilson plate obtained in 1964 by Kaplan, Munch, and Spinrad. The fourth paper presents laboratory spectra of the region  $1\mu$  to  $2.5\mu$  for testing the presence of CH<sub>4</sub>, NH<sub>3</sub>, N<sub>2</sub>O, CO, and COS in planetary atmospheres. A new investigation of the reported presence of NO<sub>2</sub> in the Martian atmosphere is discussed in the fifth paper, and it is concluded that the upper limit on a vertical column of NO<sub>2</sub> on Mars is about 8 micron-atm.

84. Arizona University, Phoenix, Lunar and Planetary Laboratory,  
LABORATORY RESEARCH ON GASES OCCURRING IN PLANETARY  
ATMOSPHERES Final Report, June 1, 1963-May 31, 1964, by  
G. P. Kuiper, 1964, AD-608 352, Grant No. Nonr (G) -00014-64.

The major effort of the research was concerned with the atmospheres of Mars and Jupiter. A photographic spectrogram was calibrated using the 72-foot multiple-path absorption tube, and the abundance of CO<sub>2</sub> in the Martian atmosphere was derived. The result was  $46 \pm 20$  meter atm for an assumed Martian atmospheric temperature of 200°K. Studies on the determination of atmospheric pressure and of abundances of other gases are also reported. The analysis of the photographic spectrum of Jupiter was extended to longer and to shorter wavelengths. All of the planetary absorptions observed in the long wavelength region were due to either methane or ammonia. Upper limits were set on the abundances of a number of gases: acetylene, ethylene, ethane, methylamine, methyl deuteride, hydrocyanic acid, silane, and hydrogen deuteride. Low dispersion spectra of Saturn, Uranus, and Jupiter satellites to and Ganymede were also studied.

85. RAND Corporation, Santa Monica, California,  
RADIATIVE-CONVECTIVE EQUILIBRIUM CALCULATIONS FOR A  
TWO-LAYER MARS ATMOSPHERE by C. B. Leovy, May 1966,  
NASA CR-75633, Contract No. NASr-21(07).
- Preliminary to a numerical experiment in simulating the circulation of the Mars atmosphere, a computer model that simulates diurnal and seasonal variation in ground and atmospheric temperatures on Mars was constructed; it incorporates the effects of radiation, small-scale turbulent convection, and conduction into the ground. All calculations are based on an atmosphere having a surface pressure of 5 mb and composed entirely of CO<sub>2</sub>, as indicated by the Mariner 4 occultation experiment. Adjustable parameters in the model include: the thermometric conductivity of the ground, and the rate of turbulent heat exchange between ground and atmosphere. The model is calibrated by adjusting these constants so that observations of a portion of the diurnal variation in ground temperature are well simulated. An interesting result of the calculations is the prediction of an ice cap composed of solid CO<sub>2</sub> whose maximum extent corresponds with that of the observed Martian polar cap. Some possible implications of the computed temperature distributions are also considered, along with space probe experiments that could be made to verify, reject, or improve the model. A simplified model was devised to compute soil heat flux that depends on surface temperature variations rather than on ground temperatures.
86. Link, F.,  
ATMOSPHERIC EDGE OF MARS, Societe Royale des Sciences de Liege,  
Memoires, Cinquieme Serie, 7, 1963, Physics of Planets, Symposium  
Paper, Liege, Belgium 9-12 July 1962, pp. 417-424.
- Calculation of the brightness of the edge of Martian atmosphere when the planet is at opposition. Curves show the brightness of the atmospheric edge as a function of altitude. It is concluded that, if, the measurements of the brightness distribution on the disk seem to prove the existence of contaminated atmosphere on Mars, the enlargement of the optical edge does not necessarily require that this contamination be localized in the higher layers.
87. Maryland University, College Park, Department of Chemistry,  
THERMODYNAMIC EQUILIBRIA IN PLANETARY ATMOSPHERES  
by E. R. Lippincott, R. V. Eck, M. O. Dayhoff, and C. Sagan,  
Natl. Biomed. Res. Found. Invest. of Thermodyn. Mech. for the  
Production of Complex Compds. Essent. for the Origin of Life, 1966.

From present information on the composition, pressures, and temperatures of planetary atmospheres, we have calculated the expected thermodynamic equilibrium composition of the atmospheres of the Earth, Venus, Mars, and Jupiter. Departures from thermodynamics equilibrium must be attributed to special mechanisms, including, on the Earth, biological activity. The major constituents of the terrestrial atmosphere are found to be in approximate thermodynamic equilibrium; while many minor constituents have abundances exceeding their equilibrium values, there is a marked tendency for equilibrium to be restored. It appears that the atmosphere of Venus is in thermodynamic equilibrium, while that of Jupiter is not. The evidence for Mars is less conclusive, although not inconsistent with thermodynamic equilibrium. For none of these planets is there a molecular species with a large predicted equilibrium abundance and spectroscopically accessible absorption features which has not been already identified. The predicted equilibrium abundances of oxides of nitrogen are extremely low on all planets.

88. Lowell, P.,  
PRESENCE OF WATER VAPOUR IN THE ATMOSPHERE OF THE  
PLANET MARS, Comptes Rendus, 146, 16 March 1908, pp. 574-575,  
extract from a letter.

Early observers (Huggins, Janssen, Vogel) on recognising the bands of water vapour in the spectrum of Mars, admitted the presence of the vapour on the planet. But at a later date Keeler and Campbell remarked that the airless moon, when in the vicinity of Mars showed the same bands quite as intensely, and they therefore assigned a terrestrial origin to these bands. Researches on the subject at Flatstaff at first, with ordinary photographic plates, gave no definite results. But recently the author and Slipher have succeeded in preparing plates sensitive to the extreme red, and capable of giving with 2 or 3 hours' exposure the spectrum of Mars in the region of the  $\alpha$  band, which is much the most intense of the water-vapour bands. In Jan., 1908, they obtained spectra of Mars which show the  $\alpha$  band clearly, while the spectrum of the moon, photographed on the same plate, shows no trace of it. Yet on Jan. 15, to take an example, the altitude of Mars above the horizon was  $43^\circ$ , and that of the moon only  $30^\circ$ . The author infers that water vapour is certainly present in the atmosphere of Mars.

89. Lowell, P.,  
THE PRESENCE OF WATER VAPOUR IN THE ATMOSPHERE OF MARS,  
Nature, 77, 30 April 1908, p. 606.

In February and March, 1908, spectrograms of Mars were obtained at the Lowell Observatory showing the lines of water vapour in the "a" band stronger than comparison spectrograms of the moon at about the same altitude, and with exposures to give a like density. The presence of water vapour in the atmosphere of Mars was inferred therefrom. Repeated plates of the sort have been taken, and their consensus, it is stated, shows unmistakably the "a" band stronger in the spectra of the planet than in those of the moon. Plates specially prepared for the purpose by Slipher, the assistant in charge of the operations, were employed - 23 Seud, bathed in a mixture of pinacyanal, pinaverdol, dicyanin, water, and ammonia -- which enabled the spectrum to be photographed to somewhat beyond the "A" band. The author attributes the discordant conclusions reached by previous observers to the lack of instrumental means for observing the spectrum sufficiently far into red, either photographically or visually, for it is in this region that the greatest absorption of water vapour occurs. He accounts for his own successful results by the use of the above plates, and the great dryness of Arizona. Great dryness of climate, he remarks, is shown by the plates to be essential to the recording of a perceptible difference between the water vapour lines due to Mars plus the Earth, and those due to the Earth alone. "For examination of the oxygen bands, A, B, and  $\alpha$ , in the two spectra reveals no perceptible difference between them, and yet the presence of water vapour in the spectrum of Mars is strong presumptive evidence that free oxygen exists in its atmosphere as well, since it is the heavier of the two."

90. Meteorology Research, Inc., Altadena, California  
A MOISTURE ANALYZER FOR MARTIAN ATMOSPHERE Final Report  
by P. B. MacCready, Jr., 10 September 1962, NASA CR-56454,  
Contract NAS7-100.

A 4-month study and experimental program was undertaken to determine if the phosphorous pentoxide type of moisture meter could be used to measure the expected water vapor in the Martian atmosphere while being lowered to the surface in an instrument package ejected from a space vehicle near this planet. An operating breadboard model of the proposed system met or exceeded most of the criteria set forth for this project. For the system designed, temperature and sterilization requirements do not appear to impose any severe problems. The space and weight requirement of 1 lb and 500 cc were surpassed, the

model weighing approximately 11 ounces, with a volume of approximately 450 cc. The overall maximum power requirement of 500 mw can be met, but there would be some advantages if more power were available. The present moisture sensor and system is believed to be capable of operation down to levels of 0.5 ppm.

91. Geophysics Corporation of America, Bedford, Massachusetts,  
PHOTOCHEMICAL PROCESSES IN THE ATMOSPHERE OF MARS by  
F. F. Marmo and P. Warneck, Planetary Atmosphere Studies VIII,  
Final Report, December 1961, Contract No. NASw-124.

The atmosphere of Mars is analyzed by the adoption of a greatly simplified model atmosphere for the investigation of the atmospheric absorption of solar radiation and photochemical effects. This treatment can lead to the formulation of a number of specific problems of which a solution is required for further studies. The height of the 90% absorption level is presented for the spectral region 1100 to 3000 Å of an atmospheric model composed of nitrogen and carbon dioxide. Particle density distributions for CO<sub>2</sub>, O<sub>2</sub>, O<sub>3</sub>, and O are given for both two- and three-body photochemical mechanisms. A summation of the particle densities for the three-body mechanism reveals that the total count of photochemically produced molecular oxygen is 1 cm NTP, while the total amount of ozone present is about  $2 \times 10^{-9}$  cm NTP. At an altitude of 150 km, 100% of the CO<sub>2</sub> was dissociated in the three-body system while only 40% dissociation occurred in the two-body system.

92. Marmo, F. F., Shadananand, and Warneck, P.,  
OZONE DISTRIBUTION IN THE ATMOSPHERE OF MARS, Journal of  
Geophysical Research, 70, 1 May 1965, pp. 2270-2272.

Analytical attempt to reconcile the conflict between the results of Marmo and Warneck (1961), who found a monotonic increase in ozone concentration with decreasing altitude and those of Paetzold (1963), who suggested the existence of an ozone concentration peak at an altitude of about 40 km. There is agreement that the basic photochemical reactions involved in the atmosphere of Mars are: (1) O<sub>2</sub> + hν → O + O,  $\lambda \leq 2400$  Å; (2) O + O<sub>2</sub> + M → O<sub>3</sub> + M; (3) O + O<sub>3</sub> → O<sub>2</sub> + O<sub>2</sub>; (4) O<sub>3</sub> + hν → O<sub>2</sub> + O,  $\lambda \leq 3000$  Å; (5) O + O + M → O<sub>2</sub> + M; (6) CO<sub>2</sub> + hν → CO + O,  $\lambda \leq 1750$  Å; and (7) CO + O → CO<sub>2</sub>. The overriding discrepancy factor is seen to be that Marmo and Warneck included Eq. (5) which Paetzold ignored. It is concluded that the existence of an ozone layer in the atmosphere of Mars can be denied.

93. Kitt Peak National Observatory, Tucson, Arizona, Space Division,  
STRUCTURE OF THE MARTIAN UPPER ATMOSPHERE by  
M. B. McElroy, J. L'Ecuyer, and J. W. Chamberlain, 1963.
- We have computed a number of models of the Martian thermosphere with various constants and boundary values in the hydrostatic and heat-flux equations. The investigation is divided into two main parts. First, we have varied the basic parameters, one or two at a time, to find to what extent an uncertainty in one of these fundamental parameters affects the derived exospheric temperature and other characteristics of the upper atmosphere. These models are physically oversimplified, but mathematically serve their purpose. Second, with selected specific chemical compositions, we have integrated the equations with allowance for diffusive separation and absorption of sunlight in different spectral regions. A rather detailed and general discussion is included of the efficiency with which photon energy is converted into the kinetic energy of heat in the neutral atmosphere. The computed models are thought to be fairly representative of an actual atmosphere with the assumed compositions.
94. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,  
SOME EFFECTS OF UNCERTAINTIES IN ATMOSPHERE STRUCTURE AND CHEMICAL COMPOSITION ON ENTRY INTO MARS by  
R. L. McKenzie, January 1965, NASA TN D-2584.
- Provided are examples of the degree to which uncertainties in the structure and composition of the Martian atmosphere affect various aspects of entry. The discussion contains the effects on manned-vehicle entry corridors, aerodynamic heating, including shock-layer radiation for an unmanned probe-type entry, and vehicle design requirements for an unmanned probe soft landing. The results indicate that current uncertainties in atmosphere scale height are significant in that they greatly decrease the entry corridor heights for manned vehicles. Uncertainties in the atmosphere composition and scale height are shown to preclude accurate prediction of the heating rates for an unmanned probe entry. However, as expected, requirements for soft landings are the most restrictive. Already difficult to satisfy because of low surface pressure, these requirements become extremely limiting because of the uncertainty in atmosphere structure.

95. Menzel, D. H.,  
THE ATMOSPHERE OF MARS, Societe Royal Des Sciences de Liege,  
Memoires, Cinquieme Serie, 7, 1963, Physics of Planets, Symposium  
Paper, Liege, Belgium, 9-12 July 1962, pp. 411-414.

General conclusions on the lower atmosphere of Mars. The redness of Mars, its low albedo, and the visibility of surface markings in the red and yellow indicate that the total amount of atmosphere is small. The Martian atmosphere contains two layers of particulate matter; a thick layer of large dust particles near the surface, and a very thin layer of fine particles above the layer of dust. It is implied that the upper layer consists of fine ice crystals.

96. Geophysics Corporation of America, Bedford, Massachusetts,  
A STUDY OF THE METEOROLOGY OF MARS AND VENUS Quarterly  
Progress Report No. 2, 6 Apr. through 5 July 1963, by G. Ohring,  
1963, NASA CR-50918, Contract No. NASw-704.

Two improvements to the greenhouse model of the Venus atmosphere are reported. First, the greenhouse equation has been programmed for an IBM 1620 computer in such a way that any temperature lapse rate can be assumed, and the numerical integrations are being performed. Second, a two layer greenhouse model has been developed in which the temperature lapse rate is constant in the lower layer and equal to zero in the upper layer. The height at which the temperature starts to remain constant is predicted by this model which assumes that the upper layer is in radiative equilibrium. Results of computations with the two-layer model as applied to Mars, Earth, and Venus are tabulated. The computations for Mars indicate surface temperatures a few degrees lower than in the previous one-layer model computations. The computations for Earth indicate that, if all clouds were eliminated, the surface temperature would rise 6°K, whereas if the total cloud cover is increased to 90%, the Earth's temperature would decrease by 9°K. The computations for Venus indicate that a surface temperature of about 600°K requires an infrared opacity of about 3, and a surface temperature of about 700°K requires an infrared opacity of about 6 or 7.

97. Geophysics Corporation of America, Bedford, Massachusetts,  
THE METEOROLOGY OF MARS AND VENUS Final Report by  
G. Ohring, E. M. Brooks, and J. Mariano, March 1964, NASA CR--  
75315, Contract No. NASw-704.

A thermodynamic diagram for the Martian atmosphere is constructed, based upon a model atmosphere, consisting of 83% nitrogen,

11% carbon dioxide, and 6% argon, with a surface pressure of 25 mb. A theoretical study of tides in the Martian atmosphere indicates that tidal motions play no significant role in Martian meteorology. An estimate of the annual radiation budget reveals that below latitude 35° there is a surplus of radiational energy, and above 35° there is a deficit. Improved greenhouse models for the Venus atmosphere are developed and discussed. A two-layer greenhouse model, consisting of a troposphere with arbitrary but constant lapse-rate of temperature, and an isothermal stratosphere in gross radiative equilibrium, is applied to Venus, Mars, and Earth. For Venus, the computations indicate that the observed high surface temperatures can be the result of a strong greenhouse effect due to an infrared-opaque cloud high in the Venus atmosphere and carbon dioxide or other infrared absorbers in the atmosphere. Estimates of solar radiation absorbed by carbon dioxide in the Venus atmosphere indicate that about 12% of the solar radiation is absorbed by carbon dioxide near infrared bands.

98. Öpik, E. J.,  
THE ATMOSPHERE AND HAZE OF MARS, Journal of Geophysical Research, 65, No. 10, October 1960, pp. 3057-3063.
- The 'blue haze' is an absorbing smoke dark as soot in reflection, red in transmission. Its currently accepted explanation by pure scattering (omnidirectional or forward) is untenable, as it would either increase the surface brightness or fail to obscure the surface details. The limb darkening of Mars is mainly the result of absorption by the smoke. The opacity of the Martian atmosphere increases from the red toward the violet. The extinction by the Martian atmosphere is greater than that by the terrestrial at all wavelengths, but only about 20 per cent of the Martian extinction is due to scattering. Dollfus' polarimetric estimate, corrected for self-absorption, corresponds to a Martian atmospheric pressure of 87 mm Hg. The photochemical breakup of carbon dioxide and the escape of oxygen must lead to considerable concentrations of carbon monoxide in the Martian atmosphere.
99. Owen, T. C. and Kuiper, G. P.,  
A DETERMINATION OF THE COMPOSITION AND SURFACE PRESSURE OF THE MARTIAN ATMOSPHERE, Communications of the Lunar and Planetary Laboratory, 2, No. 31-35, University of Arizona Press, 1964, pp. 113-132, Grant No. NsG 61-161, NsG 223-61, Nonr (G)-0050-62, ONR-00014-64.

Calibration of 1 to 2.5  $\mu$  Martian spectra using laboratory spectra of pure CO<sub>2</sub> and mixtures containing CO<sub>2</sub>, N<sub>2</sub>, and Ar. Pathlengths up to 3.6 km are used and pressures down to 4 mm. With the aid of the total CO<sub>2</sub> content (based on the Mt. Wilson spectra) preliminary values are derived for the pressure in the Martian atmosphere and the total amount of gases other than CO<sub>2</sub>. The values obtained are 17  $\pm$  3 mb (13 mm Hg) and (N<sub>2</sub> + Ar)/CO<sub>2</sub> = 6. Arguments are given indicating that the Ar/N<sub>2</sub> ratio is probably similar to that for the Earth atmosphere ( $\approx 10^{-2}$ ) and that the O<sub>2</sub> content is probably less than 7 cm-atm.

100. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,  
THE MARTIAN ENVIRONMENT by R. B. Owen, 19 November 1964,  
NASA TM X-53167.

An intensive literature survey was made of the present consensus on the surface and atmospheric conditions of Mars. Knowledge of the gross features of the Martian surface appears to be fairly complete, but there is sharp disagreement on the atmospheric conditions. While estimates of the surface temperature are in fairly close agreement and estimates of the surface pressure range from 10 to 150 millibars, other phenomena such as the blue haze are inexplicable. Formal design criteria for entry vehicles cannot yet be finalized because of the wide range of the environmental parameter values.

101. Paetzold, H. K.,  
ON THE PROBLEMS OF A MARTIAN OZONOSPHERE, Mem. Soc. Roy. Sci. Liege, Belgium, 7, 1963, pp. 452-459, Physics of Planets Symposium Paper, Liege, 1962.

An extension of the photochemical theory of O<sub>3</sub> formation in the earth's atmosphere to include the condition of a very low O<sub>2</sub> concentration similar to that in the Martian atmosphere.

102. Petrie, R. M.,  
THE ATMOSPHERES OF THE PLANETS, Roy. Astron. Soc., Canada, J., 34, April 1940, pp. 137-145.

The author gives the evidence for and against planetary atmospheres by (a) surface appearances, (b) albedo, or reflecting power, (c) twilight and refraction effects, (d) spectroscopic effects, evidence from absorption bands, (e) gravitation effects. Venus, Jupiter, Uranus and Neptune have distinct atmospheres while Mercury and the moon show none, and Mars also fails to show conclusive spectroscopic evidence of atmosphere though its polar caps demonstrate water.

103. Prabhakara, C. and Hogan, J. S., Jr.,  
OZONE AND CARBON DIOXIDE HEATING IN THE MARTIAN ATMOSPHERE, Journal of the Atmospheric Sciences, 22, March 1965,  
pp. 97-109.

Examination of the radiative equilibrium temperature structure of the atmosphere of the planet Mars. The absorption of solar energy in the UV and visible by  $O_2$  and  $O_3$  and in the near IR by  $CO_2$  is included in the calculation of atmospheric heating. The transmission functions of  $CO_2$  are theoretically calculated making use of a "statistical" model for band absorption. These transmission functions are then used to evaluate the absorption of solar energy in the near IR and to investigate the radiative transfer in the far IR. The theoretical band parameters involving the line intensity and the mean ratio of line half-width to line spacing are derived using the transmittance tables of  $CO_2$  presented by Stull, Wyatt and Plass. The basic photochemical theory of  $O_3$  production is used to determine a vertical  $O_3$  distribution consistent with the radiative equilibrium temperature structure. The equation of radiative transfer is numerically integrated, avoiding the empirical relationships commonly involved in the pressure dependence of  $CO_2$  absorption. The IR flux transmittance is also calculated without any simplifying assumptions. Radiative equilibrium temperatures are calculated from the surface of the planet to the 100-km level. For surface temperatures ranging from  $230^\circ$  to  $270^\circ K$ , surface pressures from 10 to 50 mb, and  $CO_2$  amounts from 40 to 70 m atm, the "tropopause" is found at levels below 10 km. Within these limits of surface temperature and pressure and  $CO_2$  amounts, the temperature above the tropopause steadily decreases toward a value of  $\sim 155^\circ K$  in the upper layers. The results indicate that no temperature maximum is produced by the absorption of solar energy in the UV by  $O_3$  or in the near IR by  $CO_2$  in the Martian atmosphere. The maximum  $O_3$  number density is found at the surface of Mars with a gradual decrease upward. The total amount of  $O_3$  present is about one-tenth of the amount found in the Earth's atmosphere ( $\sim 0.3$  cm atm). The total UV energy absorbed in the Martian atmosphere by  $O_2$  and  $O_3$  is comparable to the near IR energy absorbed by  $CO_2$ . However, the vertical distribution of absorbed energy shows that, below  $\sim 30$  km,  $O_2$  and  $O_3$  absorption is comparable to  $CO_2$  absorption, while above this level  $CO_2$  absorption becomes considerably larger.

104. National Aeronautics and Space Administration, Goddard Institute for Space Studies, New York,  
THE ATMOSPHERES OF MARS, VENUS AND JUPITER by J. I. Rasool and R. Jastrow, 1963, presented at the Symp. on Extraterrestrial Biol. and Org. Chem. at 4th COSPAR Meeting, Warsaw, 3-12 June 1963.

Since composition, temperature, and pressure are the three parameters which determine the structure of a planetary atmosphere, these are discussed by considering the processes by which the planetary atmospheres evolved. The reliable physical data for the planet Mars are summarized. Considerably less is known about Venus.

Photoelectric measurements of mainly low galactic latitude stars studied in Sweden from 1956 to 1963 are presented. All data have been reduced to zenith and brought to a common system by means of standard stars observed every night. The lists include equatorial coordinates, the Bonner Durchmusterung number, the Henry Draper number, the Bayer designation or Flamsteed number, the visual magnitude and color as defined by Johnson, the number of measurements, and the colors in the instrumental system.

105. Rogovsky, E.,  
TEMPERATURE AND COMPOSITION OF PLANETARY ATMOSPHERES, Astrophys. Journ., 14, November 1901, pp. 234-260, translated from Transactions of the Russian Astronomical Society, Part 7, 1898, pp. 10-34, Part 8, 1899, pp. 32-45.

The paper contains an analysis of the results obtained by various methods involving different laws of radiation. Tables are given showing the probable relative temperatures and composition of the several planetary surroundings. The author concludes that the physical and chemical constitutions of the atmospheres of all the members of the solar system are in close relation, and that any variations in that of the central sun produce corresponding changes in the others, although a considerable interval may intervene between the two changes.

106. Rosen, B.,  
NOTES ON THE PART POSSIBLY PLAYED BY CARBONIC DUSTS IN PLANETARY ATMOSPHERES, Academie des Sciences, Paris, Comptes Rendus, 248, No. 14, 6 April 1959, pp. 2067-2070.

Carbonic dust and the molecule C<sub>3</sub> in the Martian atmosphere have been assumed for years as an explanation of the presence of a violet layer covering the entire surface of the planet. This hypothesis,

supported by Kozyrev's observations, is in accord with the theory of volcanic activity on the moon's surface. Admitting an analogous volcanic activity, the formation of C<sub>3</sub> and other products of hydrocarbons are also probable for Mars. The nature of the gas liberated from the interior, and forming the moon's atmosphere is, however, still unknown. The confirmation of the sphere observed by Kozyrev would support the escape of hydrocarbons.

107. Russel, H. N.,  
ATMOSPHERES OF PLANETS, Science, 81, 4 January 1935, pp. 1-9,  
Nature, 135, 9 January 1935, pp. 219-226.

Direct telescopic observations indicate the existence of atmospheres on some planets. Spectroscopy shows that water-vapour is present on Mars and CO<sub>2</sub> is abundant on Venus; and recently strong bands in the spectra of the major planets have been recognised as due to methane. Radiometric measurements prove the surface temperature of the large planets to be below -100°C., while the moon's exceeds 100°C. during every rotation. Observation has thus proved that the atmospheres of large planets contain H compounds, those of a size comparable with the earth contain O compounds, and small bodies like Mercury, the moons and asteroids have none. The lesser density of the major planets is now comprehensible, since they are large enough and cold enough to have retained the lighter gases; and although they doubtless have metallic and rocky cores like the earth, they must have very deep oceans of ice, and very extensive atmospheres of methane. The process of development from a gaseous condition in the different cases is described in detail. It is suggested that when the molten earth was solidifying it had an atmosphere largely composed of CO<sub>2</sub>, and that a vegetation developed which absorbed the C and set free the O, thus making animal life possible, though some of the O is slowly absorbed by the rocks; that a much later stage is seen in Mars, the ferric rocks giving its surface its red colour; that Venus, probably because of her higher temperature near the sun, has failed to develop life. The clouds on Jupiter are perhaps composed of frozen ammonia crystals, while in Uranus and Neptune the ammonia is completely frozen out, leaving the methane clear to a greater depth. The problem is now nearing solution, thanks to many workers in many branches of science.

108. Sagan, C., Hanst, P. L., and Young, A. T.,  
NITROGEN OXIDES ON MARS, Planet. Space Sci., 13, No. 1,  
January 1965, pp. 73-88.

In a series of recent papers, Kiess and collaborators have announced the identification of nitrogen peroxide on Mars and have attempted to interpret a wide range of Martian phenomena in term of nitrogen oxides. Analyses of observations at a variety of wavelengths in the present paper, and previously by Sinton, Spinrad and Moroz, place a firm upper limit on the Martian  $\text{NO}_2$  abundance of 1 mm-atm. Nitrogen dioxide is a highly photolabile gas and will be photodissociated by visible and ultraviolet radiation on Mars. The photochemical equilibria of nitrogen oxides on Mars have been computed from the observational upper limits on the NO and  $\text{O}_2$  abundances. The same procedure gives consistent results for the earth, at locales free from urban pollution. The corresponding theoretical upper limit to the abundance of  $\text{NO}_2$  on Mars is 1 mm-atm, when reactions with water are neglected. When reactions with water are considered, the  $\text{NO}_2$  abundance is further diminished. These low abundances are inadequate to account for the Martian observables discussed by Kiess et al. The one Martian phenomenon in which nitrogen peroxide may play a role is the blue haze, where 1 mm-atm may help to explain not only the general blue and violet opacity, but also the dependence of the opacity on time and position. The required abundance of NO must then be  $> 50$  cm-atm. Kiess et al. have expressed the opinion that the quantity of nitrogen peroxide on Mars is so large as to exclude indigenous life. It is of interest to note that a typical value for the abundance of  $\text{NO}_2$  over the city of Los Angeles exceeds the corresponding value for Mars.

109. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,  
**USE OF ENTRY VEHICLE RESPONSES TO DEFINE THE PROPERTIES OF THE MARS ATMOSPHERE** by A. Seiff and D. E. Reese, Jr., 1965, presented at the Am Astronautical Soc. Symp. on Unmanned Exploration of the Solar System, Denver, 8-10 February 1965, NASA TM X-56125.

Principles are developed by which the atmospheric properties of an unknown planetary atmosphere can be deduced from responses of a probe vehicle entering the atmosphere. Experiments to determine atmospheric density and pressure as functions of altitude, and to detect and determine quantities of selected gases in the atmosphere are examined in detail. Probe geometries are discussed and take lift, drag coefficient, Mach number, Reynolds number, gas composition, and angle of attack into consideration. The approach to the detection of atmospheric species is by spectrometry of selected wavelengths of emission from the hot atmospheric gases in the shock layer. Laboratory studies and theory show that very bright emission behind the bow wave in atmospheres of nitrogen and carbon dioxide is associated with

the cyanogen radical, and detection of the violet band system would constitute direct evidence for nitrogen in the atmosphere. Other radiometers to measure the nitric oxide and argon radiations are discussed.

110. Sieff, A. and Reese, D. E., Jr.,  
DEFINING MARS' ATMOSPHERE - A GOAL FOR THE EARLY  
MISSIONS, Astronautics and Aeronautics, 3, February 1965, pp. 16-21.

Technique for measuring the atmospheric properties of planets through the response of an entry vehicle to the atmosphere. This response can be sensed in many forms - in the deceleration, pitching oscillation, heating, and radiation exposure, among others - and it can be analyzed to define the properties of the atmosphere encountered. It is deemed necessary to define the profile of atmospheric density as a function of altitude in order to guide the design of payload-landing vehicles and to provide a firm base for long-range studies of manned entry systems. Integration of the density profile, once obtained, also permits the definition of static pressure profile and the RT product profile. These and atmospheric temperature serve to define the atmospheric structure. Atmospheric composition can also affect the aerodynamics of certain entry-vehicle configurations and the heating, especially the radiative heating. The primary experiment of this kind proposed for the Mars atmospheric probe involves measuring nitrogen, as yet only assumed to be a principal constituent of the Mars atmosphere, and its mole fraction. This can be done by measuring the intensity history of the prominent cyanogen violet bands. The possibility of detecting trace amounts of water vapor remains undemonstrated.

111. Schilling, G. F.,  
A NOTE ON THE ATMOSPHERE OF MARS, J. Geophys. Res., USA,  
67, No. 3, March 1962, pp. 1170-1172.

On the basis of the (sometimes widely) divergent available results, the author prepared a table of permissible ranges of astronomical and atmospheric (including atmospheric pressure, temperature and molecular mass) parameters, and calculates therefrom a table of possible extreme ranges of atmospheric conditions on Mars (temperature, pressure and density up to the altitude of 150 km).

112. RAND Corporation, Santa Monica, California,  
EXTREME MODEL ATMOSPHERE OF MARS by G. F. Schilling,  
June 1962, prepared for presentation at the 11th International Astro-  
physical Symposium, Liege, Belgium, 9-11 July 1962, AD 607 504,  
Contract No. NAS7-100.

Theoretical models of the atmosphere of Mars were computed on the basis of present factual knowledge with a minimum of assumptions. The resultant model atmosphere gives extreme upper and lower limits for pressure, temperature, and density in the Martian atmosphere up to 150 km altitude. While this rigorous method yielded reliable data needed for the engineering design of space probes, the spread of values is still extremely wide and indicative of the present scarcity of knowledge.

113. RAND Corporation, Santa Monica, California,  
PARAMETRIC LIMITS FOR THE UPPER ATMOSPHERE OF MARS  
by G. F. Schilling, November 1963, AD 423 922, Contract No.  
AF49 638 700.

Probable upper and lower limits are calculated for the distribution of atmospheric pressure and mass density in the upper atmosphere of Mars. The results extend an earlier engineering model atmosphere from an altitude of 150 km to one in excess of 2500 km above the planetary surface. They derive, in part, from a recent analysis by J. W. Chamberlain of the probable thermal regime in the upper atmosphere of planets, while taking into account our present uncertainties about the lower atmosphere of Mars.

114. Sharonov, V. V.,  
RESULTS OF OBSERVATIONS OF MARS DURING THE GREAT  
OPPOSITION OF 1956, Akademiiia Nauk Tadzhikskoi SSR, Stalinabad,  
Institute. Astrofiziki, Biulleten, No. 27, 1959, pp. 5-15.

In this thorough review of Martian studies in 1956 the author discusses the methods used and results obtained throughout the world during the planet's great opposition. The new techniques used included electronic photography, television devices, radioastronomy photoelectric and photometry. However, the most significant observations were not a result of advanced techniques used but rather of the unusual events taking place on the planet at the time, such as the appearance of large yellow clouds (attributed by most authors to dust particles) and the disappearance of the South Polar cap. Atmospheric pressure on Mars is now accepted as 85-90 mb, the temperature gradient as  $3.7^{\circ}\text{C}/\text{km}$ . Water vapor must be almost absent from the Martian atmosphere, but the formation of clouds similar to the noctilucent clouds observed on Earth is possible even with such a minute concentration; and such clouds have been observed on Mars. Several theories have been advanced concerning the violet scattering layer; the author believes that in order to explain this effect it is not necessary to assume the existence of some high-altitude layer or unusual absorption, but that all phenomena

observed on Mars can be fully accounted for by known processes of scattering by small and large atmospheric particles.

115. Shimizu, M.,  
VERTICAL DISTRIBUTION OF NEUTRAL GASES ON MARS, Rep. Ionosphere Space Res. Japan, 16, No. 4, December 1962, pp. 425-427.

The only detectable gas on Mars is CO<sub>2</sub> and it is probable that the bulk of the atmosphere is N<sub>2</sub>. Taking the concentration of CO<sub>2</sub> as 0.273% two models have been adopted for the atmosphere of Mars. Assuming the CO<sub>2</sub> concentration to be 1.9% a third model is adopted. The general feature of the results is quite similar to the case of Venus. The quantity of O<sub>2</sub> molecules due to photo-dissociation is about 1/4 that of Venus because of the corresponding reduction in the quantity of solar ultraviolet rays.

116. Shimizu, M.,  
THEORETICAL MODELS OF CY THEREAN AND MARTIAN UPPER ATMOSPHERES, I- DISSOCIATION LAYERS, Progress of Theoretical Physics, 31, June 1964, pp. 1153-1155.

Investigation of solar-planetary relationships, particularly upper atmosphere phenomena such as ionospheres and aurorae, on the basis of data from ground-based and space-probe observations. Tables show the following: (1) upper atmosphere models and heights of the dissociation layers of Venus and Mars, and (2) the amounts of CO on Venus. It is stated that the calculations have shown that the uncertainties of scale heights and temperatures do not cause serious changes to the results. The existence of small amounts of CO on Mars and of O<sub>2</sub> on both planets hardly affects them. On the other hand, the substitution of effective temperature for solar radiation from 4700 to 5000°K nearly doubles the quantities of CO and O. They also depend considerably on the values of the recombination rates. The effect of atmospheric density is only to change the heights of the dissociation layers.

117. Sinton, W. M.,  
AN UPPER LIMIT TO THE CONCENTRATION OF NO<sub>2</sub> AND N<sub>2</sub>O<sub>4</sub> IN THE MARTIAN ATMOSPHERE, Astronomical Society of the Pacific, San Francisco, Publications, 73, No. 431, April 1961, pp. 125-128.

Kiess et al. have proposed an explanation of Martian phenomena based on processes involving the presence of observable oxides of nitrogen in the Martian atmosphere. The author uses an absorption table for different wave lengths in comparison with observed Martin

spectra to show that the proposed theory is untenable.

118. Slipher, E. C.,  
WATER VAPOUR IN THE MARTIAN ATMOSPHERE, Lowell Observatory, Bull., No. 17 Nature, 72, 7 September 1905, p. 465.
- The author first describes a new spectroscopic method of determining the existence of water vapour in the atmosphere of a planet, depending chiefly on the displacement of lines from a body in motion. The earth's atmosphere is spectroscopically at rest with regard to a terrestrial observer, whilst the Martian atmosphere partakes of the planet's motion relative to the earth. This relative motion will be reflected in the solar spectrum obtained on a spectrogram of Mars, by a displacement of those lines which are due to the selective absorption common to both atmospheres. We know that in the terrestrial atmosphere water vapour accounts for a great deal of this absorption, so that if water vapour also exists in the atmosphere of Mars its lines should show a displacement, or possibly only a broadening of such lines as those in the  $\alpha$  band of the solar spectrum. For comparison the spectrum of the moon is photographed. In the same paper Slipher discusses the results obtained from a practical trial of the above method. Several spectrograms were obtained of the moon and Mars, the exposures being made when these objects were at the same altitude. An examination of the  $\alpha$  band and the water-vapour lines near D indicated a slight displacement, but the measurement was uncertain. Similar experiments on the spectrum of Venus were equally inconclusive.
119. Jet Propulsion Laboratory, California Institute of Technology, Pasadena,  
HIGH DISPERSION SPECTRA OF THE OUTER PLANETS. II. A NEW  
UPPER LIMIT FOR THE WATER VAPOR CONTENT OF THE MAR-  
TIAN ATMOSPHERE by H. Spinrad and E. H. Richardson, NASA CR-  
53004, Contract No. NAS7-100, repr. from Icarus, 2, June 1963,  
pp. 49-53.

A very high dispersion spectrogram of Mars has been searched unsuccessfully for Martian  $H_2O$  lines near  $\lambda$  7200. The plate was taken on a very dry night when the Doppler shift was sufficient to displace any Mars  $H_2O$  lines 0.29 Å from their telluric counterparts. From this data, an upper limit has been derived for the integrated Martian water vapor abundance of approximately  $3.5 \times 10^{-3}$  gm/cm<sup>2</sup> ( $35\mu$ ). The practical limits for detection of Martian water vapor by Earth-bound, balloon, and space probe techniques indicate that spectroscopic observations from the Earth can be refined to a point where they are at least as sensitive as present infrared space experiments.

120. Spinrad, H.,  
THE NO<sub>2</sub> CONTENT OF THE MARTIAN ATMOSPHERE, Publ. Astron. Soc. Pacific, USA, 75, April 1963, pp. 190-191.

High-dispersion spectra (3 Å/mm) of Mars and the sky in the visual, red, and ultraviolet were obtained in 1962. Using these plates, the author has been able to determine a new upper limit to the amount of NO<sub>2</sub> in the Martian atmosphere. A search for NO<sub>2</sub> bands in the Martian spectrum proved negative, yielding an upper limit for the NO<sub>2</sub> abundance of 0.1 cm-atm.

121. Spinrad, H.,  
THE ATMOSPHERE AND SURFACE FEATURES OF MARS, Va. Polytech. Inst. Conf. on Artificial Satellites, Pt. B., August 1964.

A review is presented of earthbound observations of Mars. An up-to-date description of the Martian surface is included, and it covers discussions of polar caps, dark areas, vibration absorptions in the infrared spectrum, color, mountain areas, canals, wave of darkening, propagation velocity, surface temperature, and the equatorial temperature. The molecular atmosphere of Mars reveals only two positively identified gases--carbon dioxide and water vapor. A study of the estimates of these gases is presented. The cloud and blue haze patterns are discussed in terms of absorption with photometric evidence.

122. Stoney, G. J.,  
PLANETARY ATMOSPHERES, Ast. Phys. Journ., 7, 1898, pp. 25-55.

This paper is a reprint from vol. vi. p. 305 of the Transactions of the Royal Dublin Society, and extends that application of the Kinetic Theory of Gas to the investigation of the phenomena of atmospheres which the author had employed in a paper on the "Physical Constitution of the Sun and Stars," published in the Proceedings of the Royal Society for 1868.

In the earlier paper the conditions which limit the height of an atmosphere were investigated, and it was shown that when an atmosphere consists of a mixture of gases, the elevations to which the constituents will range stand in the order of their densities; from which it follows that Dalton's law of the equal diffusion of gases does not extend to the upper regions of an atmosphere.

The conditions which prevail upon Mars are specially discussed.

123. Aerospace Medical Division, Brooks AFB, Texas, School of Aerospace Medicine,  
THE ECOLOGICAL PROFILE OF MARS: BIOASTRONAUTICAL ASPECT by H. Strughold, February 1963, Lectures in Aerospace Med., 4-8, pp. 431-448.
- The ecological profile of Mars shows: (1) atmosphere composition to be 93.8% nitrogen, 4% argon, 2.2% carbon dioxide, and traces of water vapor and oxygen, (2) a barometric pressure at ground level of about 65 mm. Hg, (3) the shield of the Martian atmosphere should after adequate protection from meteorites and cosmic rays, (4) gravity on the Martian surface is about 38% of that on Earth, and (5) there is no liquid hydrosphere on the Martian surface.
124. Sytinskaya, N. N.,  
CURRENT KNOWLEDGE ON THE NATURE OF MARS, Akademiia Nauk Kazakhskoi SSR. Sektor Astrobiologii, Trudy, 4, 1955, pp. 44-54.
- An attempt is made to compare the different interpretations of Martian observations and to indicate the relative reliabilities of the various findings. Considered in particular are observations and hypotheses concerning the atmospheric structure and composition, temperature, polar caps, continents and maria. The author believes that the structure of the Martian atmosphere as derived from Wright's red and violet photographs is erroneous. The Wright effect has been shown by Barabashov and Sharonov to be unreal and due to the so-called photographic irradiation, i. e. an apparent enlargement of the picture, different for the various spectral regions.
- In the absence of water, it is suggested that nitrogen, argon, and carbon dioxide are the most probable constituents of its atmosphere. The most condensable of these is carbon dioxide, and to it are referred the snow-caps which are formed alternately on the north and south poles of Mars. Carbon dioxide would be the heaviest constituent of such an atmosphere, and would behave differently to water in the earth's atmosphere, of which the vapour of water is its lightest constituent. It is inferred that the vapour upon Mars cannot produce clouds floating at a distance above the solid surface of the planet, as water does in the earth's atmosphere; but only low-lying fogs with frost and snow. To these and to the vapour being distilled towards the two poles alternately, are referred the varying but frequently recurring appearances which observers have recorded upon that planet.

125. Sytinskaya, N. N.,  
RECENT INVESTIGATIONS OF THE ATMOSPHERE AND SURFACE  
OF MARS, translated into English by JPRS, U. S. Army Missile  
Command, Huntsville, Alabama, Redstone Arsenal, Alabama, RSIC-44,  
5 August 1963 (Priroda, Moscow, 45, No. 6, 1956, pp. 33-41).

Investigations of the atmosphere and surface of Mars are reviewed.  
The review covers: (1) physical and chemical composition of the  
atmosphere, (2) clouds and fog, (3) temperature of the surface,  
(4) polar caps, and (5) nature of the surface.

126. Thomas, G. M. and Menard, W. A.,  
EXPERIMENTAL MEASUREMENTS OF NONEQUILIBRIUM AND  
EQUILIBRIUM RADIATION FROM PLANETARY ATMOSPHERES,  
AIAA Entry Technology Conference, Williamsburg and Hampton, Va.,  
October 12-14, 1964, Technical Papers, AIAA CP-9, 1964, pp. 170-185.

Investigation of the effect of composition upon the radiation from the shock-heated mixtures: 9% CO<sub>2</sub>/90% N<sub>2</sub>/1% Ar, 30% CO<sub>2</sub>/70% N<sub>2</sub>, and 100% CO<sub>2</sub>. An electric arc-driven shock tube was used. The mixtures simulate the atmospheres of Mars and Venus. Measurements of the shock-layer radiance at the stagnation point of a flat-faced cylinder in the 0.3- to 2.7- $\mu$  region, using a carbon-coated thin-film gage for flight velocities from 20,000 to 46,000 ft/sec and initial pressures from 0.25 to 2.0 mm Hg are described. Shock stand-off distances are measured by photographic techniques, the intensity behind the incident shock in the 0.3- to 1.0- $\mu$  region is measured by photometric techniques, and the nonequilibrium intensity in the far UV region is measured with a tungsten photoelectric gage. Shock-front-integrated nonequilibrium and equilibrium intensities, nonequilibrium relaxation distances, and time-to-peak intensity are determined. The stagnation-point radiance results are found to be higher than some current estimates, indirectly giving support to the CN radical heat of formation values obtained by Knight and Rink. The integrated nonequilibrium intensity for 9% CO<sub>2</sub> mixtures obtained is 55 w/cm<sup>2</sup>-2  $\pi$  ster at 25,000 ft/sec. The major radiating species are found to be the CN radical for CO<sub>2</sub>-N<sub>2</sub> mixtures and the CO<sup>+</sup> ion for 100% CO<sub>2</sub>. Oscillator strengths for the CN red and violet systems are deduced from the measurements.

127. Veronnet, A.,  
ABSORPTION OF WATER ON MOON AND PLANETS, Comptes Rendus,  
165, 5 November 1917, pp. 629-632.

Taking account of the determinations of occluded moisture in terrestrial granite as indicating the amount that may be absorbed from superficial or atmospheric sources at the time of congealing, after fusion, estimates are made of the probable extents of the aqueous portions of the initial atmospheres of the moon and planets. In the case of mercury it is thought the results indicate that the water is still all in the form of vapour, no condensation being yet possible owing to the high surface temperature.

128. Very, F. W.,  
WATER-VAPOUR IN ATMOSPHERE OF MARS, Science, 29,  
29 January 1909, pp. 191-193, Nature, 79, 25 February 1909, p. 499,  
Lowell Observatory, Bull., No. 36.

The first observations of the intensification of water-vapour bands in the spectrum of Mars were made by Huggins in 1867, and were confirmed by Vogel in 1873. Later the Lick observers questioned the reality of the phenomenon, but the recent photographic confirmation by V. M. Slipher at the Lowell Observatory has put the matter on a much more certain basis. From information supplied by Lowell the present author has been enabled to estimate the quantitative degree of intensification of the  $\alpha$  band on which the determination is based. The instrument used is called the spectral-band comparator, and compared with the moon as unity the  $\alpha$  band in Mars has an intensity of 1.224, but this requires standardisation for the readings of the comparator before absolute units can be stated. When this is allowed for, it is found that the  $\alpha$  water-vapour band in the spectrum of Mars during Jan., at Flagstaff, with the dew-point at 20°F., was 4.5 times as intense as in the lunar spectrum at the same altitude. This would correspond to about 5.0 gm. of water-vapour per m.<sup>3</sup> if, we assume terrestrial conditions. Owing, however, to the comparatively rare atmosphere of Mars, to the low boiling-point of water there, and to the prevailing desert conditions, the dew-point at the surface will remain low, probably seldom rising much above the freezing-point, and the prevailing conditions on Mars are probably those of a mild but desert climate.

129. Very, F. W.,  
OXYGEN IN THE ATMOSPHERE OF MARS, Lowell Observatory Bull.  
No. 41, Nature, 81, 28 October 1909, p. 529.

By employing his spectral band comparator the author finds a decided increase in intensity of the  $\beta$  oxygen-band in passing from the lunar to the Martian spectrum. The increase is given as more than eight times the probable error of the measurements.

130. Very, F. W.,  
WATER-VAPOUR IN ATMOSPHERE OF MARS, Lowell Observatory  
Bull., No. 65, Nature, 94, 7 January 1915, p. 518.

A discussion is given of certain spectrograms of Mars and the moon taken by V. M. Slipher at the Lowell Observatory, Arizona, on Feb. 6, 1914. The bands at C, B and  $\alpha$  were measured with a spectral-band comparator. It is concluded that the equatorial regions of the planet are excessively dry, and that the amount of oxygen in the Martian atmosphere is probably about half as great as in that of the earth.

131. de Vaucouleurs, G.,  
PRESSURE AND COMPOSITION OF THE ATMOSPHERE OF MARS,  
Societe Royale des Sciences de Liege, Memoires, Ser. 4, No. 18,  
1957, pp. 161-164.

Various data on Martian atmospheric pressure and composition from the latest photometric and polarimetric observations are reported. The atmospheric pressure on Martian ground level is estimated to be 70 to 100 mb which corresponds to the terrestrial atmospheric pressure at an altitude of  $18 \pm 2$  km. The most likely chemical composition of Martian atmosphere is 98.5% nitrogen, less than 0.1% oxygen and small amounts (1.2 to 0.25%) of argon and carbon dioxide.

132. de Vaucouleurs, G.,  
OPTICAL STUDIES OF THE SURFACE AND ATMOSPHERE OF MARS,  
Exploration of Mars, Proceedings of the American Astronautical Society Symposium on the Exploration of Mars, Denver, Colo., 6-7 June 1963, Advances in the Astronautical Sciences, 15, G. W. Morgenthaler, ed., Western Periodicals Co., North Hollywood, 1963, pp. 519-532.

Discussion of telescopic studies of Mars during the past 20 yr., which have confirmed and slowly added to our general knowledge of the planet. The fine structure of the surface, the so-called "canals," and the seasonal and irregular variations are described. The latest data on atmospheric composition and pressure are reviewed.

133. de Vaucouleurs, G.,  
THE ATMOSPHERIC ENVIRONMENTS OF MARS AND VENUS, Southwest Res. Inst. Bioastronautics and the Exploration of Space, December 1965.

Current knowledge of the Mars and Venus atmospheres is summarized. This incorporates discussions of the atmospheric pressure, violet layer, structure and temperature, and clouds and winds.

134. Geophysics Corporation of America, Bedford, Massachusetts,  
PLANETARY AERONOMY II: NO<sub>2</sub> IN THE MARTIAN ATMOSPHERE  
by P. Warneck and F. F. Marmo, May 1962, GCA-TR-62-5-N,  
Contract No. NASw-395.

The transmission curve of the Martian atmosphere derived by Opik is compared with transmission curves of an atmosphere containing various amounts of nitrogen dioxide. It is found that the amount of  $6 \times 10^{18} \text{ cm}^2$  column NO<sub>2</sub> (or even less) given by Sinton as an upper limit for the Martian NO<sub>2</sub> content could adequately explain the phenomenon of the blue haze. This finding made it worthwhile to investigate the effect of the temperature and pressure sensitive equilibrium  $2 \text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4$  upon the total NO<sub>2</sub> and the altitude-number density distributions of NO<sub>2</sub> and N<sub>2</sub>O<sub>4</sub>. Computations were carried out for surface temperatures of 273 °K, 243 °K, 213 °K and 183 °K and for three different temperature distributions. The discussion of the results leads to the suggestion of several important new experiments.

135. Warneck, P. and Marmo, F. F.,  
NO<sub>2</sub> IN THE MARTIAN ATMOSPHERE, J. Atmos. Sci., USA, 20,  
No 3, May 1963, pp. 236-240.

The martian atmosphere becomes increasingly optically dense in going from the red to the blue portion of the visible spectrum. The extent to which this occurs cannot be ascribed solely to Rayleigh scattering. It appears that the observations can be better explained in terms of some absorption process in addition to the effect of Rayleigh scattering. The authors show that as little as  $3 \times 10^{18} \text{ cm}^2$ -column NO<sub>2</sub> can account for the Martian blue haze. The effect of the chemical equilibrium  $2\text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4$  upon the total NO<sub>2</sub> content is discussed. It is suggested that the blue clearings may be associated with NO<sub>2</sub> depletion due to temperature decrease on Mars. The authors also suggest various experiments to test this hypothesis.

136. Boeing Company, Seattle, Washington,  
FLIGHT REGIMES IN THE ATMOSPHERES OF VENUS AND MARS  
by P. P. Wegener, July 1963, MEMO. RM3388PR, AD 411 951,  
Contract No. AF 49 638 700.

Preliminary estimates of the flight parameters to be encountered on Mars and Venus are desirable. Limiting models of the two atmospheres have been constructed, and from these models it has been possible to estimate the approximate extremes of aerodynamic parameters likely to be encountered. It is seen that the uncertainties in aerodynamic flight conditions encompass orders of magnitude, particularly at high altitudes.

137. Weldt, R.,

OZONE AND OXYGEN IN PLANETARY ATMOSPHERES, Gottingen Nachrichten 1.1 Fachgruppe 2, 1934, pp. 1-9.

The absence of oxygen from the observed spectrum of Venus and the small proportion of Mars also suggest that the atmospheres of the different planets present great differences. Most of the terrestrial oxygen may be due to assimilation of CO<sub>2</sub> by vegetable life; the author suggests that a high surface temperature on Venus has prevented this process, leading to an atmosphere of volcanic CO<sub>2</sub> and lack of free oxygen. For Mars the free oxygen has largely entered into mineral oxides, such as Fe<sub>2</sub>O<sub>3</sub>, producing the red coloration; the ozone layer is possibly close to the surface, and would then play a very different part from that of the earth's ozone.

138. Weldt, R.,

THE GEOCHEMISTRY OF THE ATMOSPHERE AND THE CONSTITUTION OF THE TERRESTRIAL PLANETS, Rev. Mod. Phys., 14, April-July 1942, pp. 151-159.

Spectroscopic evidence reg. the composition of the planetary atmospheres is reviewed. The dissimilarities in superficial constitution among the terrestrial planets are attributed to differences in gravitation and surface temperatures, in the rel. sizes of the iron cores, and in the deg. of reduction of the whole system. The period of fractional crystallization of the silicate phase is followed in some detail for the Earth, and the roles played by free and "fossil" oxygen in the Earth, Mars and Venus are discussed. The replacement of thermochemical by photochemical equilibrium, as the planetary temperature dropped, greatly complicates the atmospheric reactions.

139. Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson AFB, Ohio,

FLIGHT ENVIRONMENT DESIGN PARAMETERS FOR MARS AND VENUS by R. H. Zimmerman and C. D. Jones, September 1962, AD-288 538, ASD TDR62 805.

The physical characteristics of the planets Mars and Venus are assessed and probable quantitative limits are defined as minimum, representative and maximum probable values for application to environmental studies and equipment design. These data are applied to Chapman's generalized analysis for bodies entering planetary atmospheres to produce probable minimum, representative and maximum flight environment design parameters. These planetary parameters are applied with body and trajectory parameters, using Chapman's analysis, to selected direct, multipass and graze entries.

## C. DENSITY

140. General Electric Company, Space Sciences Laboratory, Philadelphia,  
NORMAL SHOCK PARAMETERS FOR THE MARTIAN ATMOSPHERE  
by F. Bosworth, C. Cook, L. Gilbers, and S. Scala, 30 January 1963.

Normal shock wave and stagnation point solutions are presented for two limiting models of the Martian atmosphere, covering a range of flight speeds from 6,000 to 25,000 feet per second, and a range of altitudes from zero to 500,000 feet. Curves of dimensionless pressure, temperature, and density of the shocked gas are presented as functions of flight speed for constant altitudes.

141. RAND Corporation, Santa Monica, California,  
STUDIES OF THE PHYSICAL PROPERTIES OF THE MOON AND  
PLANETS Quarterly Technical Progress Report (2) by M. H. Davis,  
3 December 1960, NASA CR-50576, Contract No. NASW-6, JPL  
Contract N-33561.

Among the subjects discussed in this progress report are: the ultraviolet spectrometer for the Mariner A, general circulation of the planetary atmospheres, the interpretation of radiometric measurements of Venus, atmospheric reentry (Mars vs. Venus), density of the very high atmosphere, and orbit determinations from terminator observations.

142. RAND Corporation, Santa Monica, California,  
STUDIES OF THE PHYSICAL PROPERTIES OF THE MOON AND  
PLANETS Quarterly Technical Progress Report (6) by M. H. Davis,  
December 1961, Contract N-33561, NASW-6.

Company research is proceeding in the following fields: (1) Light scattering and radiative transfer. The Chandrasekhar X and Y functions are being computed for optical thicknesses greater than unity in order to provide results for dense or extensive atmospheres; a mathematical investigation of the radiative-transfer problem has shown that certain properties which had formerly been assumed for the X and Y functions do not, in fact, hold. Elsasser-band models have been found that fit laboratory measurements of the infrared-absorption spectrum of carbon dioxide to within about 10 percent. (2) Planetary atmospheres. A paper has been completed which summarizes variations of pressure, temperature, and density with altitude for the Martian atmosphere;

also, theoretical analysis of the seasonal atmospheric circulation of Mars has been completed. (3) Planetary experiments. An entirely different concept is being considered for moving the exploring instruments about the surface of the planets in unmanned planetary explorations: it is believed that a balloon could be used for measurements of planetary atmospheres or for transporting suitable instruments from the landing point to other areas. (4) Lunar and planetary geology and magnetism. Papers completed and in progress discuss the optical ellipticity and internal structure of Mars, the age of the Earth-Moon system, and the magnetic fields of Mars and Venus. A harmonic analysis of lunar typography is under way.

143. Dollfus, A.,  
DETERMINATION OF THE ATMOSPHERIC PRESSURE ON THE  
PLANET MARS, C. R. Acad. Sci., Paris, 232, 12 March 1951,  
pp. 1066-1068.

Polarimetric measurements on the disk in various spectral regions at various phases indicate an atmosphere of pressure 83 millibars.

144. Donahue, T. M.,  
UPPER ATMOSPHERE AND IONOSPHERE OF MARS, Science, 152,  
No. 3723, 1966, pp. 763-764.

It is argued that the single-layer ionosphere at 125 km discovered in the Mariner IV occultation experiment is an F1 region coinciding with the ultraviolet photoionization peak. The CO<sub>2</sub> density there must be of the order of 10<sup>11</sup> molecules per cm<sup>3</sup>. Such a density is consistent with the properties of the lower atmosphere by Mariner IV and the temperature model of Chamberlain and McElroy if the atmosphere is mainly CO<sub>2</sub> below 70 km. The absence of an F2 region can be explained even if the density ratio of O to CO<sub>2</sub> is 100 at 230 km on the basis of the rapid conversion of O + to O<sub>2</sub> by CO<sub>2</sub>. Thus a model with an exospheric temperature of 400°K, a modest degree of CO<sub>2</sub> dissociation, and diffusive separation above 70 km is possible.

145. Eddington, A. S. and Nicholson, J. W.,  
DIFFRACTION EFFECTS IN OCCULTATIONS BY PLANETS, Roy. Astron. Soc., M. N. 79, March 1919, pp. 359-360.

This deals with the validity of the usual assumption that gradual extinction of the light of a star by occultation is really an indication of an atmosphere round the occulting planet, having regard to the effect of refraction bands fringing the planet's shadow. As an example Mars

is taken on 1918, April 11, when an occultation by it was observed in Australia, and the result points to a fading of the light from diffraction when the ray passes 200 metres above the surface, with a loss of nearly two magnitudes by the time it grazes. The conclusion is that this might be observable under very fortunate conditions in the case of a close graze, but normally it would be just below the limit of perception, while the effect of atmospheric absorption might be just above that limit.

146. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,  
MARTIAN AIRGLOW by C. Y. Edward, NASA RP-250, repr.  
J. Atmospheric Sci., 21, No. 2, March 1964, pp. 220-221.

A mechanism of blue Martian airglow, which can be expected to occur on Mars as well as on Venus, is discussed. It is assumed that the Martian atmosphere is composed of 2% CO<sub>2</sub> and the remainder is N<sub>2</sub>, the surface pressure being about 100 mb. The density distribution of these constituents, with altitude, should be somewhat similar to that of the Earth. Thus, at some altitude corresponding to unit optical depth for solar radiation short of 1700A where CO<sub>2</sub> absorbs, the following photodissociation process can be expected: CO<sub>2</sub> + hv → CO + O. If it is assumed that some sort of photochemical equilibrium exists at these altitudes, then one of the important reactions that follows the photodissociation is CO + O + M → CO<sub>2</sub> + M, where M refers to any other atom or molecule, principally, however to N<sub>2</sub>. This is in essence a chemiluminescent recombination reaction with a characteristic complex banded spectrum due to CO<sub>2</sub> between about 5,000A to 3,000A, the maximum intensity being at about 4,000A. Although there appears to be some question as to the kinetics and mechanism of this recombination, it is clear that the emission is due to electronically excited CO<sub>2</sub>.

147. Fjeldbo, G., Fjeldbo, W. C., and Eshleman, Von R.,  
ATMOSPHERE OF MARS - MARINER IV MODELS COMPARED,  
Science, 153, 23 September 1966, pp. 1518-1523.

Discussion of three classes of models for the atmosphere of Mars which differ in identifying the main ionospheric layer measured by Mariner 4 as being analogous to a terrestrial F<sub>2</sub>, F<sub>1</sub>, or E layer. At an altitude of several hundred kilometers, the relative atmospheric mass densities for these models are approximately 1, 10<sup>2</sup>, and 10<sup>4</sup>, respectively, and the temperatures are roughly 100, 200, and 400°K. Theory and observation are in best agreement for an F<sub>2</sub> model, for which photodissociation of CO<sub>2</sub> and diffusive separation result in an

atomic-oxygen upper atmosphere, with O<sup>+</sup> being the principal ion in the isothermal topside of the ionosphere. However, an F<sub>1</sub> model, with molecular ions in a mixed and warmer upper atmosphere, might result if photodissociation and diffusive separation are markedly less than would be expected from analogy with the earth's upper atmosphere.

148. General Electric Company, Missiles and Space Division, Philadelphia, MOLECULAR OPTICAL THICKNESS OF LOW-DENSITY MODELS OF THE ATMOSPHERE OF MARS by E. L. Gray and K. L. Coulson, March 1964, AD-437 226.

Values of volume scattering coefficient and normal optical thickness for the revised estimates of the Martian atmosphere are given, as a function of altitude above the planetary surface, for eight selected wavelengths from 2500 to 10,000 Å. Four models of the Martian atmosphere, as given by the Jet Propulsion Laboratory, are used, the surface pressure for the models being 11 mb (2 models), 15 mb, and 30 mb. Comparisons with the previous higher-density atmospheric models for Mars, and with the U. S. Standard Atmosphere, are shown, and the values of optical thickness are used to compute the energy directed outward from the top of a Rayleigh atmosphere on Mars. The computations show that the normal optical thickness is lower for the new models than for the previous models by approximately the ratio of the surface pressures.

149. Tohoku University, Sendai Geophysical Institute, HEIGHT PROFILES OF DENSITY, COMPOSITION, AND IONIZATION IN THE MARTIAN ATMOSPHERE by H. Kamiyama, February 1965, Sci. Rept. of the Tohoku Univ.

With a particular assumption for the vertical temperature distribution and the chemical composition of the lower atmosphere, a possible model of the Martian atmosphere is deduced on the terrestrial analogy. On the assumption that, at the surface, the pressure is 85 mb and the air is composed of 2.2% CO<sub>2</sub> and 97.8% N<sub>2</sub>, the photodissociation of CO<sub>2</sub> takes place in the region above 128 km, and peaks of the concentration occur at 137 km for O and at 132 km for CO and O<sub>2</sub>. Diffusion is considered to be important above 150 km. Two ionospheric layers are formed by the ionization of N<sub>2</sub>, O, and O<sub>2</sub>, the lower layer being located at about 135 km and the upper at a level between 600 km and 900 km. The maximum electron concentration is about  $4 \times 10^4 \text{ cm}^{-3}$  in the lower layer and between  $9 \times 10^4$  and  $1.8 \times 10^5 \text{ cm}^{-3}$  in the upper layer. The height variation of the ion composition is also described.

150. Kliore, A. Cain, D. L., Levy, G. S., Eshleman, Von R., Fjeldbo, G., and Drake, F. D.,

OCCULTATION EXPERIMENT--RESULTS OF THE FIRST DIRECT MEASUREMENT OF MARS' ATMOSPHERE AND IONOSPHERE,  
Science, 149, No. 3689, 1965, pp. 1243-1248.

Changes in the frequency, phase, and amplitude of the Mariner IV radio signal, caused by passage through the atmosphere and ionosphere of Mars, were observed immediately before and after occultation by the planet. Preliminary analysis of these effects has yielded estimates of refractivity and density of the atmosphere near the surface, the scale height in the atmosphere, and the electron density profile of the Martian ionosphere. The atmospheric density, temperature, and scale height are lower than previously predicted as are the maximum density, temperature, scale height, and altitude of the ionosphere.

151. Lohmann, W.,

RECENT INVESTIGATIONS OF MARS, Naturwissenschaftliche Rundschau, 3, No. 4, April 1950, pp. 156-161.

The author summarizes information on the climate and atmosphere of Mars, obtained with the aid of modern astrophysical methods. The density and constitution of the atmosphere--the presence of water vapor, carbon dioxide, oxygen and ozone--and the possibility of the existence of plant life under the atmospheric conditions of Mars are discussed.

152. Rakos, K. D.,

THE ATMOSPHERIC PRESSURE AT THE SURFACE OF MARS,  
Lowell Observatory Bull. No. 131, VI, No. 12, 1965, Grant NGR-03-003-003.

Photometric observations of eclipses of Phobos by Mars were carried out by a new photoelectric scanning technique for the purpose of estimating Martian atmospheric pressure on the surface of the planet. An upper limit of 30 mb for the pressure at a mean temperature of 200°K was obtained. The observations show strong evidence of particle absorption at high levels in the atmosphere. The data suggest that the absorption level which causes the so-called "blue haze" is not higher than 10 km above the surface of the planet. The question as to what value should be adopted for the surface pressure on Mars can be solved by first answering the question as to what distribution of solid particles in the atmosphere is the most probable.

153. RAND Corporation, Santa Monica, California,  
ENGINEERING MODEL ATMOSPHERE OF MARS by G. F. Schilling,  
September 1962, presented at AFOSR-GE Symp. on Dyn. of Manned  
Lifting Planetary Entry, Philadelphia, 29-31 October 1962,  
Contract No. AF 49 (638)-700.

A theoretical model of the Martian atmosphere is given. This model atmosphere gives extreme upper and lower probable limits of pressure, temperature, and density up to 150-km altitude over middle and low latitudes, independent of time of day or season. In addition, a number of parameters are tabulated which are of concern for the engineering design of entry probes. The mathematical method was based on our present factual knowledge with a minimum of assumptions and has therefore yielded results on a rather high confidence level. This has been achieved in part through an extremely wide spread of values. Nevertheless, a combination of circumstances makes it apparent that the engineering task of atmospheric entry will be easier for the Martian atmosphere than for the atmosphere of any other planet in our solar system. It can safely be concluded that Mars will be the first planet inviting manned exploration from an engineering as well as scientific point of view.

154. Schilling, G. F.,  
A NOTE ON THE UPPER ATMOSPHERE OF MARS, Journal of Geophysical Research, 68, 15 August 1963, pp. 4875-4876, Contract No. AF 49 (638)-700.

Results are presented of an extension of previously developed model atmospheres of Mars, which led to the derivation of upper and lower probable limits for the variation in temperature, pressure, and density. Parametric limits are now extended to altitudes in excess of 2,000 km. Two model atmospheres are presented, a tentative maximum and a tentative minimum. A table summarizes representative values for the permissible extreme ranges of both pressure and density.

155. RAND Corporation, Santa Monica, California,  
PARAMETRIC LIMITS FOR THE UPPER ATMOSPHERE OF MARS,  
by G. F. Schilling, November 1963, AD-423 922, Contract No.  
AF 49 (638)-700, Proj. RAND.

Probable upper and lower limits are calculated for the distribution of atmospheric pressure and mass density in the upper atmosphere of Mars. The three self-consistent model atmospheres (Tentative

Maximum, Tentative Minimum, and Tentative Standard) should bracket actual conditions in the Martian atmosphere up to 500-km altitude and, above that, plausibly represent the extreme range of probable conditions. At any specific altitude level, the true daily mean values prevailing during any season over middle and low latitudes should fall between these limits. If no specific season, time of day, or latitude is specified, the Tentative Standard Atmosphere will estimate, in orders of magnitude for the whole altitude range, those pressures and densities that will probably occur more often than not.

156. Geophysics Corporation of America, Bedford, Massachusetts,  
PLANETARY AERONOMY VII: THE SOLAR FLUX INCIDENT AT THE  
TOP OF THE ATMOSPHERES OF EARTH AND NEIGHBORING PLANETS  
FOR THE SPECTRAL REGION 50 Å TO 3000 Å by E. D. Schultz and  
A. C. Holland, November 1962, NASA CR-11, Contract No. NASw-395.

The solar flux incident at the top of the Earth's atmosphere has been compiled for the spectral region 50 Å to 3000 Å. Between 50 Å and 1850 Å, the major emission lines were distinguished from the continuum and are presented separately. The continuum and weak lines are lumped together. The pure experimental data are plotted in two clear and unambiguous presentations of the tabulation to provide a convenient comparison of the contribution of major emission lines with the contribution of the continuum and weak lines. To obtain the flux values at the top of the atmospheres of neighboring planets, intensity dilution factors are easily determined using an inverse square relation based on mean radius vector magnitudes. The tabulated data for Earth were used as a base to generate the entire model of the solar photon flux from 50 Å to 3000 Å for the top of the atmosphere of Venus and Mars.

157. Shane, E. D.,  
EQUILIBRIUM ELECTRON DENSITY ON MARS, AIAA Journal, 2,  
August 1964, pp. 1497-1499.

Presentation of thermochemical equilibrium values of electron concentration as a function of temperature and density corresponding to five models of the Martian atmosphere. The models consist of different percentages of carbon dioxide, argon, and nitrogen. It is shown that at a given temperature and density the electron concentration on Mars will be less than that on Earth and that this is most evident at low temperatures and high densities.

158. General Electric Company, Space Sciences Laboratory, Philadelphia,  
THE DENSITY STRUCTURE OF THE UPPER ATMOSPHERE OF MARS  
by D. N. Vachon, May 1962, AD-276 491.

A model atmosphere has been developed for the planet Mars which is more realistic than the presently available isothermal model at high altitudes. Results of the parametric study conducted in the evaluation of the effect of various layers on the upper level density structure are included.

159. General Electric Company, Space Sciences Laboratory, Philadelphia,  
EFFECT OF A THERMOSPHERE ON THE MARTIAN ATMOSPHERIC  
DENSITY AT HIGH ALTITUDES by D. N. Vachon, presented at  
AFOSR-GE Symp. on Dyn. of Manned Lifting Planetary Entry,  
Philadelphia, 29-31 October 1962, Dynamics of Manned Lifting Planetary Entry, John Wiley and Sons, Inc., New York, 1963, pp. 130-141.

Discussion of the effect of a possible region of increasing temperature with altitude, on the Martian atmospheric density; this effect is compared with the influence of the lower troposphere. The results are compared qualitatively to the Earth's atmosphere, and lead to the conclusion that isothermal model approximations will grossly underestimate the mass density at high altitudes.

160. de Vaucouleurs, G.,  
DETERMINATION OF ATMOSPHERIC PRESSURE ON MARS BY  
VISUAL PHOTOMETRY, Academie des Sciences, Paris, Comptes Rendus, 220, No. 23-26, 25 June 1945, pp. 903-904.

In this note a new value of the Martian atmospheric pressure is considered. It has been obtained by visual observations during the opposition of 1939, and based on the intensity of great patches of the planet's atmosphere.

161. Very, F. W.,  
WATER-VAPOUR ON MARS, Nature, 84, 20 October 1910, p. 495.

In questioning a statement attributed to W. W. Campbell that the nights of Sept., 1909, on which spectrograms of Mars were obtained on Mount Whitney, were perfect for the purpose, Very suggests that although the sky may have been clear, and the surface humidity low, this does not of itself prove that the aqueous vapour in the upper air was small in amount. The bolometric investigations of Fowle have shown that the absorption by water-vapour in north temperate latitudes

is decidedly at maximum in Sept., and minimum in Feb. Measurements of the absolute density of the  $\alpha$  water-vapour band on spectrograms of Mars taken at Flagstaff during Jan. and Feb., 1908, showed conclusively that it was stronger in the spectrum of Mars than in that of the moon.

162. Vorob'ev, A. G.,  
NEW INFORMATION ON ATMOSPHERIC PRESSURE ON MARS, Priroda,  
Moscow, No. 6, June 1953, pp. 84-85.

With reference to newest information contained in the latest articles by A. Dollfus, de Vaucouleurs and Kuiper treating the question of the intensity of atmospheric pressure on the planet Mars, the author discusses the correctness of their determinations, compares them with results obtained earlier and comes to the conclusion that the most trustworthy value of its intensity must be between 85 and 95 mb with a fluctuation of about 9 mb at different points of its surface. Taking into consideration that the weight of bodies is three times lighter on Mars than on the earth the author claims that airplane flights there from the earth are perfectly feasible.

163. RAND Corporation, Santa Monica, California,  
FLIGHT REGIMES IN THE ATMOSPHERES OF VENUS AND MARS  
by P. P. Wenener, July 1963, RM-3388-PR, Contract No. AF 49  
(639)-700, Proj. RAND.

Preliminary estimates of the flight parameters to be encountered on Mars and Venus are desirable. Although considerable qualitative information on the two planets is available, there are few quantitative data that contribute to an understanding of their atmospheres. From the available quantitative data, limiting models of the two atmospheres have been constructed, and from these models it has been possible to estimate the approximate extremes of aerodynamic parameters likely to be encountered. It is seen that the uncertainties in aerodynamic flight conditions encompass orders of magnitude, particularly at high altitudes.

## D. SCATTERING

164. Blackadar, A. K.,  
SCATTERING OF BLUE LIGHT IN THE MARTIAN ATMOSPHERE,  
The Project for the Study of Planetary Atmospheres, Lowell Observatory Report No. 1, 1 August-31 October 1949, Contract No. AF 19 (122)-162.
- The theory of isotropic scattering in a plane atmosphere of finite optical depth, developed by Chandrasekhar and Van de Hulst is reviewed and is applied to measurements of the brightness of Mars made on blue photographs. The optical depth of the blue haze was found to be between 0.10 and 0.15 at an estimated effective wave length of 4350 Å. Almost half or more, depending upon the angles of view and illumination of blue light from Mars, was reflected by the atmosphere. A procedure for determining optical depth by photographing a model of Mars of appropriate contrast and albedo through various scattering media is described.
165. Coulson, K. L. and Lotman, M.,  
MOLECULAR SCATTERING OF SOLAR RADIATION IN THE ATMOSPHERE OF MARS, J. Geophys. Res., USA, 68, No. 20, 15 October 1963, pp. 5681-5688.
- The exact theory of radiative transfer in a Rayleigh atmosphere is used for computing the molecular optical thickness of the Martian atmosphere, as a function of altitude above the planetary surface, for sixteen different wavelengths in five atmospheric models. Surface values vary by a factor of about 3 among the different models, and by a factor of approximately 300 between wavelengths of 2500 Å and 10 000 Å for a given model. Although the optical thickness of the total Martian atmosphere is up to nearly an order of magnitude less than that of the earth's atmosphere, the less rapid decrease of optical thickness with height for Mars results in a generally greater optical thickness above 10-20 km for Mars than for the earth. By establishing reasonable criteria for the applicability of light-scattering techniques for atmospheric measurements, it is shown that such techniques would be useful from the surface to altitudes of 50 to 130 km in the various models at a wavelength of 2500 Å, and up to 10 to 20 km at 10 000 Å. The corresponding altitudes for the earth's atmosphere are 57 and 15 km, respectively.

166. Dollfus, A. and Focas, J.,  
ON THE PURITY OF THE ATMOSPHERE OF THE PLANET MARS,  
C. R. Acad. Sci. B., France, 262, No. 15, 13 April 1966,  
pp. 1024-1027.

Measurements by polarimetry give for the scattering coefficients of the Martian atmosphere at the centre of the disc, in blue light  $0.47 \mu$ , the value  $15 \times 10^{-4}$  stilb/phot. This coefficient varies as  $\lambda^{-4}$ ; the pure atmosphere is free from residual aerosols except perhaps for very small particles which might cause an overestimation of the pressure, 30 mbars, deduced from the measurements. The glare of the atmosphere is insufficient to mask ground markings in blue light.

167. Kuiper, G. P., ed.,  
THE ATMOSPHERES OF THE EARTH AND PLANETS, University  
of Chicago Press, Cambridge University Press, W. J. Gage and Co.,  
Toronto 1949.

A symposium of papers by 18 authors on the circulation of the lower atmosphere, scattering in planetary atmospheres, rocket research programmes, seasonal variations in the upper atmosphere, spectra of night sky and aurorae, the atmosphere above 300 km, the evolution of earth's atmosphere, i. e. spectroscopy, spectroscopic observations of the planets, a survey of planetary atmospheres, long-path laboratory spectra, and the possibility of photosynthesis on Mars.

168. Kurachakov, A. V.,  
OPTICAL PROPERTIES OF THE ATMOSPHERE AND SURFACE  
OF MARS, Leningrad, Universitet, Vestnik, 15, No. 7, 1960,  
pp. 154-163.

Contradictory interpretations of Martian observations have been advanced due to the fact that some authors assumed the Martian atmosphere to be essentially a scattering medium, while others considered it an absorbing medium. Attempting to end this controversy, Sharonov evaluated the true absorption in the Martian atmosphere and found that brightness distribution over the Martian disk can be fully explained by the scattering properties of the Martian atmosphere. Sharonov, however, considered only primary scattering which made his findings inconclusive. The author of the present article undertakes to study the optical properties of the atmosphere of Mars, considering higher-order scattering. On the basis of Ambartsumian's theory he derives the relationships of the four optical parameters optical thickness, index of scattering, coefficient of scattering and coefficient of

absorption. By comparing these relationships with observed brightness distribution on Mars at several wave lengths, he calculates actual values of the above parameters. The conclusion is reached that Mars has essentially a scattering atmosphere and true absorption in it appears to be insignificant.

169. Menzel, D. H.,  
THE ATMOSPHERE OF MARS, Astrophys. J., 63, January 1926,  
pp. 48-59.

The appearance of a planet depends on the selective absorption and scattering of its atmosphere. Using the known values of the visual and photographic albedos, it is possible to evaluate the maximum quantity of atmosphere which Mars possesses. The amount per unit surface is not greater than one-fifth that above the earth. Under the lesser gravity, the corresponding pressure will be less than 5 cm. of mercury--equivalent to the pressure in the terrestrial atmosphere at a height of 18 km. The foregoing amount of atmosphere is insufficient to account for the appearance of Wright's photographs (Astron. Soc. Pacific Publ. 36. 234, 1924), which showed no detail in the ultra-violet, but strong contrast in the red. This is probably a characteristic of the material which composes the planet. The Martian polar caps are not an atmospheric but a surface phenomenon. Their relative prominence in the two pictures is due mainly to the difference in visual and photographic albedos. The greenish colour of Uranus and Neptune are due to the absorption by their atmospheres of the red end of their spectra.

170. Morozhenko, A. V. and Ianovitskii, E. G.,  
METHOD AND RESULTS OF DETERMINATION OF OPTICAL PARAMETERS OF THE MARTIAN ATMOSPHERE AND SURFACE, Physics of the Moon and Planets, E. K. Koval, ed., Naukova Dumka, Kiev, 1964, pp. 81-91

Presentation of a method for determining the optical parameters of the atmosphere and surface of Mars, based on data from absolute photometry. In particular, the method is shown to make possible a rapid and reliable determination of both the optical thickness and the absorbing power of the atmosphere. On the basis of the results obtained, it is concluded that, in the range of wavelengths from 450 to 840  $\mu\text{v}$ , the Martian atmosphere is purely diffusive. Beginning with  $\tilde{\lambda} \sim 450 \mu\text{v}$  the true absorption increases with a decrease in wavelength. In the range of wavelengths from 360 to 450  $\mu\text{v}$  the optical thickness of the Martian atmosphere can vary within very broad limits, frequently exceeding unity. In the infrared and ultra-violet regions of

the spectrum, the albedo of the Martian surface varies much more slowly with wavelength than in the visible region.

171. Musman, S.,  
AN UPPER LIMIT TO A RAYLEIGH SCATTERING ATMOSPHERE  
ON MARS, Planetary and Space Science, 12, August 1964, pp. 799-800.

Report of the use of Bellman's computations of the amount of light scattered from the top of a plane parallel layer of Rayleigh scatterers to construct models of spherical planets with completely absorbing surfaces and Rayleigh-scattering atmospheres. The model with optical depth of 0.058 is said to match Mars' dimensionless reflectivity of  $\rho\phi(21^\circ) = 0.032$ . This value of the optical depth is said to represent a rather high upper limit to the optical thickness of the atmosphere at 3300 Å. The Martian surface pressure for a nitrogen atmosphere is computed to be 27 mb, which is thought to be consistent with the  $25 \pm 15$ -mb pressure obtained by Kaplan, Münch, and Spinrad. The effects of non-Rayleigh scatterers are discussed and Dollfus' use of the polarization properties of Rayleigh scattering are commented on.

172. Öpik, E. J.,  
THE ATMOSPHERE AND HAZE OF MARS, J. Geophys. Res., USA,  
65, No. 10, October 1960, pp. 3057-3064.

The "blue haze" is an absorbing smoke, dark as soot in reflection, red in transmission. Its currently accepted explanation by pure scattering (omnidirectional or forward) is untenable, as it would either increase the surface brightness or fail to obscure the surface details. The limb darkening of Mars is mainly the result of absorption by the smoke. The opacity of the Martian atmosphere increases from the red toward the violet. The extinction by the Martian atmosphere is greater than that by the terrestrial at all wavelengths, but only about 20% of the Martian extinction is due to scattering. Dollfus, polarimetric estimate [Publ. Astron. Soc. Pacific (USA), Vol. 70, 56-64 (1958)], corrected for self-absorption, corresponds to a Martian atmospheric pressure of 87 mm Hg. The photochemical breakup of carbon dioxide and the escape of oxygen must lead to considerable concentrations of carbon monoxide in the Martian atmosphere.

173. Rosen, B.,  
A POSSIBLE ORIGIN OF THE VIOLET LAYER IN THE MARTIAN  
ATMOSPHERE, Ann. Astrophys., 16, No. 4, 1953, pp. 288-289.

Alternative explanations of the violet "haze-layer" in the Martian atmosphere postulate either ice, or solid CO<sub>2</sub> crystals as the scattering medium. The suggestion is made that a new interpretation is probable, namely, that the observed light-scatter is caused by carbon-smoke particles.

174. Schätzman, E.,  
ON SCATTERING PARTICLES IN THE ATMOSPHERE OF MARS,  
C. R. Acad. Sci., Paris, 232, 19 February 1951, pp. 692-693.

Agreement between the theoretical and observed variation of extinction coefficient with wavelength is obtained for particles (assumed spherical, of refractive index 1.33) of diameter about 0.15 microns.

175. Sobouti, Y.,  
FLUORESCENT SCATTERING IN PLANETARY ATMOSPHERES.  
III. FORMATION OF LYMAN-BIRGE-HOPFIELD BANDS OF N<sub>2</sub> IN THE MARTIAN ATMOSPHERE, Astrophys. J., USA, 138, No. 3, October 1963, pp. 720-747.

Formation of the Lyman-Birge-Hopfield bands of N<sub>2</sub> in a planetary atmosphere illuminated by the sun is investigated. This band system is expected to appear in the daytime ultraviolet spectrum of a planet observed from above. The band intensities are calculated for two model atmospheres of Mars: (1) a pure nitrogen atmosphere and (2) a nitrogen atmosphere with 1 per cent O<sub>2</sub> concentration. In the far ultraviolet the contribution of Rayleigh scattering to the continuum of the reflected spectrum is found to be much lower than the band intensities.

## E. IONOSPHERE

176. Committee on Space Research (COSPAR), The Hague, Netherlands,  
MODEL OF VENUS AND MARS IONOSPHERES by A. D. Danilov,  
1962, presented at Third International Space Science Symposium and  
Fifth COSPAR Plenary Meeting, Washington, 30 April to 9 May 1962.

Models of the Venus and Mars ionospheres were constructed, based on an analysis of photochemical reactions of the Earth's atmosphere. The Venus ionosphere was adopted to be composed mainly of carbon dioxide; and the Mars ionosphere, of molecular nitrogen. The CO<sub>2</sub>, CO<sup>+</sup>, and O<sup>+</sup> ions are found in the Venus ionosphere, with maximum electron concentration of the order of 10<sup>4</sup> electrons/cm<sup>3</sup> situated at an altitude of about 100 km. The N<sub>2</sub><sup>+</sup> and N<sup>+</sup> ions are found in the Mars ionosphere, with maximum electron concentration of the order of 10<sup>3</sup> electrons/cm<sup>3</sup> at an altitude of about 300 km.

177. Norton, R. B.,  
A THEORETICAL STUDY OF THE MARTIAN IONOSPHERE,  
Exploration of Mars, Proceedings of the American Astronautical Society Symposium on the Exploration of Mars, Denver, Colo., 6, 7 June 1963 (Advances in the Astronautical Sciences, 15), Western Periodicals Co., North Hollywood, 1963, pp. 533-542.

Presentation of a theoretical study, based on a neutral atmosphere composed of 2% carbon dioxide and 98% molecular nitrogen, which indicates that the Martian ionosphere would occur at a greater height above the planet's surface than does the terrestrial ionosphere, but at about the same total pressure. The maximum electron density for overhead Sun is about 2 x 10<sup>5</sup>/cm<sup>3</sup>, as compared to about 10<sup>6</sup>/cm<sup>3</sup> on Earth. On Mars there may be layers that absorb radio waves more strongly than the normal terrestrial D region.

178. National Bureau of Standards, Washington D. C.,  
A THEORETICAL STUDY OF THE MARTIAN AND CY THEREAN IONOSPHERES by R. B. Norton, July 1964, NASA Order R-65.

The approach to the theory of planetary ionospheres is made by reviewing the theory of the terrestrial ionosphere regions and applying this theory, with necessary modifications, to the planets Venus and Mars. Among the important procedures considered are the production of electrons, the exchange and recombination reactions, and finally, the diffusion of an electron-ion gas through the neutral gas.

## Section II. COMBINED GENERAL REFERENCES

### A. BIBLIOGRAPHIES, PROCEEDINGS, AND REVIEWS

179. Barabashov, N. P., ed.,

RESULTS OF OBSERVATIONS OF MARS MADE DURING THE GREAT OPPOSITION OF 1956 IN THE USSR, Moskva, Izd-vo AN SSSR, Komissiya po fizike planet, 1959.

This collection of articles describes observations made of Mars during the opposition of 1956. The following articles are included:

- 1) Observations of Mars made in the USSR in 1956
- 2) Tikhov, G. A.: Brief results of observations of Mars made in the Sector of Astrobotonics during the great opposition of 1956
- 3) Barabashov, N. P., and I. K. Koval': Photographic photometry of Mars with light filters
- 4) Sytinskaya, N. N.: On the Photometric investigations of the optical properties of the Martian atmosphere
- 5) Sharonov, V. V.: Surface and atmosphere of Mars based on photographic, photometric, and colorimetric observations made in 1956 in Tashkent
- 6) Sharonov, V. V.: Experience in determining the contrasts on the Martian disk through visibility measurements
- 7) Sytinskaya, N. N.: Some ideas on the state of the Martian atmosphere
- 8) Bronshten, V. A.: Visual observations of Mars during the great opposition of 1956
- 9) Bronshten, V. A., and O. B. Dluzhnevskaya: Photographic photometry of the bright region of Argyre on Mars in the end of August 1956.

180. General Electric Company, Missile and Space Division, Philadelphia,  
PLANETARY ATMOSPHERES AND RELATED INFORMATION: A  
BIBLIOGRAPHY by E. Colabrese, AD-266 458.

Although the composition of the planetary atmospheres is the prime concern of this bibliography, articles and reports on other aspects of the planets, such as surface features, temperature properties and radiation measurements were included. Section I contains 169 references on the planetary system in general; Section II 159 references on Mars; Section III 90 references on Venus; Section IV 49 references on Jupiter; Section V 15 references on Saturn; and Section VI 23 references on interplanetary space and exploration. Approximately one fourth of the references are abstracted. Abstracts were obtained from the sources consulted in compiling the bibliography. Within each of the six sections, references are arranged alphabetically by author.

181. Hess, S. L.,  
REMARKS ON THE METEOROLOGY OF MARS, Exploration of Mars,  
Proceedings of the American Astronautical Society Symposium on the  
Exploration of Mars, Denver, Colo., 6, 7 June 1963 (Advances in the  
Astronautical Sciences, 15), Western Periodicals Co., North Holly-  
wood, pp. 596-598.

Discussion of Mars circulation problems. It is stated that theory, suggests that, in the summer hemisphere, the north-south temperature gradient on Mars is sufficiently weak that we would have a kind of symmetrical circulation in a meridional plane similar to that in the vicinity of our tropics on Earth. On the other hand, the winter hemisphere has such a strong north-south temperature gradient that the prevailing westerly winds, which certainly exist there, must be unstable in the same sense that middle latitude flow is unstable on Earth.

182. General Electric Company, Space Sciences Laboratory, Philadelphia,  
AN ANNOTATED BIBLIOGRAPHY OF ARTICLES ON THE ATMO-  
SPHERES OF VENUS AND MARS by L. Hobbs, November 1961,  
Contract No. AF 04 (647)-476.
183. Library of Congress, Aerospace Technology Division, Washington, D. C.,  
SURFACE CHARACTERISTICS OF THE MOON, MARS AND VENUS  
Annotated Bibliography, 1963-1966, by J. Javis and D. W. Michaels,  
16 May 1966.

This annotated bibliography was compiled from Soviet bloc open sources published 1963-1966 on the surface characteristics of Mars, Venus, and the Moon with reference to light polarization and albedo measurement techniques and to radioastronomical investigations. The 110 bibliographic entries are listed alphabetically by author in sections on The Moon, Mars, Venus, and General; and an author index is included. Other information deals with photography of celestial bodies, photogrammetry, and photointerpretation in space investigations; unusual formation on Venus; radar observations of Venus; Martian canals; Mars satellites; volcanic activity on Mars; colorimetric comparison of asteroids and terrestrial rocks.

184. Space Science Board, National Academy of Sciences, Washington, D. C.  
THE ATMOSPHERES OF MARS AND VENUS, A Report by the Ad Hoc Panel of Planetary Atmospheres, by W. W. Kellogg and C. Sagan, 1961, NAS NRC-944.

- 1) DIRECT PHOTOGRAPHY IN THE EXPLORATION OF PLANETARY ATMOSPHERES, A. G. Wilson (Rand Corp.) p. 61-71.
- 2) VISUAL AND PHOTOGRAPHIC OBSERVATIONS OF VENUS AND MARS, Clyde W. Tombaugh (N. Mex. State U.), p. 72-75.
- 3) RADIO FREQUENCY RADIOMETRY OF THE PLANETS, Bernard K. Burke (Carnegie Institution of Wash., D. C.) p. 76-79.
- 4) POTENTIALITIES OF RADAR FOR THE STUDY OF PLANETARY ATMOSPHERES, Van R. Eshleman (Stanford U.) p. 80-84.
- 5) OBSERVATIONS WITH SATELLITE-SUBSTITUTE VEHICLES, John Strong (Johns Hopkins U.), p. 85-99, 7 refs.
- 6) SPACECRAFT EXPERIMENTS ON PLANETARY ATMOSPHERES, Richard W. Davies, A. R. Hibbs, Gary Neugebauer, and Ray L. Newburn (Jet Propulsion Lab.) p. 100-104.
- 7) INTERPRETATION OF PLANETARY PROBE MEASUREMENTS, Lewis D. Kaplan (Mass. Inst. of Tech.) p. 105-106, 5 refs.
- 8) THE GENERAL CIRCULATION OF PLANETARY ATMOSPHERES, Yale Mintz (U. of Calif.), p. 107-146, 18 refs.
- 9) THE INTERPRETATION OF ULTRAVIOLET SPECTRA OF PLANETARY ATMOSPHERES AND THE NEAR-INFRARED CO<sub>2</sub> BANDS OF VENUS, Joseph W. Chamberlain (Yerkes Obs.), p. 147-151, 6 refs. (NASA Grant NSG 118-61).

185. Koval, I. K.,  
DISTRIBUTION OF BRIGHTNESS IN THE EDGE ZONE OF MARS,  
Life Sciences and Space Research II; International Space Science  
Symposium, 4th Warsaw, Poland, June 2-12, 1963, sponsored by the  
Committee on Space Research (COSPAR), M. Florkin and A. Dollfus,  
ed., North-Holland Publishing Co., Amsterdam, Interscience  
Publishers, New York, 1964, pp. 246-249.
- Presentation of data on brightness distribution along the visible radius of Mars. During the 1963 opposition, photoelectric observations were made using a 28-in. reflector (20-m Cassegrain). The method used was that of drift curves in 10 spectral bands in the interval 355-900  $\mu\text{m}$ . Mars was moving over the diaphragm ( $d = 0.35$  in.) because of the diurnal motion. For each filter, 40-50 drift curves were obtained. While processing the observations, the diameter of the diaphragm was taken into account, together with the vibration of the image. Average distributions of brightness along the visible diameter of Mars up to  $0.95 R^\circ$  were obtained. It is shown that the steepness of the brightness curves increases from 420 to 600  $\mu\text{m}$  and remains almost constant for greater wavelengths. For 355  $\mu\text{m}$ , the steepness is the same as for 600  $\mu\text{m}$ .
186. Library of Congress, Aerospace Technology Division, Washington, D. C.  
SURFACE CHARACTERISTICS OF THE MOON, MARS, AND VENUS  
Annotated Bibliography, 1 March 1965, AD-458 260.
- An annotated bibliography of the surface characteristics of Mars, Venus, and the Moon is presented with emphasis on light polarization and albedo measurement techniques as well as radio-astronomical studies. Information on tektites is also presented. The report covers 125 research studies from the years 1960 to mid-1963. More recent findings from about mid-1963 through mid-1964 are included in appendixes A to C.
187. Liege University, Inst. d'Astrophysique, Belgium,  
PHYSICS OF PLANETS. PROCEEDINGS OF THE ELEVENTH  
INTERNATIONAL ASTROPHYSICAL SYMPOSIUM, LIEGE, JULY 9-12,  
1962, 1963, Contract No. AF 61 (052) -586.
- Papers presented at the Eleventh International Astrophysical Symposium and published in this volume cover the following: internal construction of the planets, planetary surfaces and atmospheres, and special papers on the successive planets. Mercury, Venus, Mars, Jupiter, and Saturn are discussed.

188. National Aeronautics and Space Administration, Washington, D. C.,  
PLANETARY ATMOSPHERES A Continuing Bibliography, Jan. 1962-  
Feb. 1965, NASA SP-7017, June 1965.

A selection of annotated references to unclassified reports and journal articles on planetary atmospheres announced in Technical Publications Announcements (TPA), Scientific and Technical Aerospace Reports (STAR), and in International Aerospace Abstracts (IAA) is presented. Each entry in the bibliography consists of a citation and abstract. The majority of the references pertain to studies, measurements and discussions concerning the atmospheres of Mars, Venus and Jupiter, but a limited number of references to the atmospheres of Mercury and Saturn are also included. The scope of coverage was defined to permit inclusion of references to such specific topics as the theory of planetary origins, extraterrestrial environment, planetary exploration and spacecraft reentry, and the physical properties of the planets. All reports and articles cited were introduced into the NASA Information System during the period January, 1962 to February, 1965.

189. National Aeronautics and Space Administration, Washington, D. C.,  
PLANETARY ATMOSPHERES--A CONTINUING BIBLIOGRAPHY,  
FEBRUARY--MAY 1966, NASA SP-7017, August 1966.

A continuing annotated bibliography, together with personal author and subject indices, on planetary atmospheres is presented. Most of the entries pertain to investigations of Mars and Venus, many of which are the result of the successful probes of the atmospheres of Venus by Mariner II and Mars by Mariner IV. A limited number of references to the atmospheres of Jupiter, Mercury, and Saturn is also included. References to such specific topics as the theory of planetary origins, extraterrestrial environment, planetary exploration and spacecraft entry, and the physical properties of the planets are provided. Pertinent references to the techniques of planetary observation and measurement, e. g., those involving photography, photometry, spectroscopy, astronomy, and meteorology, are also given.

190. Air Force Cambridge Research Laboratories, Geophysics Research Directorate, Bedford, Massachusetts,  
SPACE AND PLANETARY ENVIRONMENTS by Shea L. Valley, ed.,  
January 1962 (Air Force Surveys in Geophysics-139; AFCRL-62-270).

- 1) INTERPLANETARY GAS AND MAGNETIC FIELDS. Marvin L. White and A. A. Wyller. Aug. 1961.
- 2) THE TERRESTRIAL MAGNETIC FIELD. Paul Fougere. June 1961.
- 3) THE EXTERNAL TERRESTRIAL GRAVITY FIELD. Bela Szabo. June 1961.
- 4) CORPUSCULAR RADIATION IN THE VICINITY OF EARTH. Shea L. Valley. Oct. 1961.
- 5) SOLAR ELECTROMAGNETIC RADIATION. H. E. Hinteregger. June 1961.
- 6) THE LUNAR ENVIRONMENT. John W. Salisbury. July 1961.
- 7) PLANETARY ENVIRONMENTS. John W. Salisbury. July 1961.
- 8) SPACE ENVIRONMENT OF THE SOLAR SYSTEM. Gordon W. Wares. Nov. 1961.

191. de Vaucouleurs, G.,

REMARKS ON MARS AND VENUS, J. Geophys. Res., 64, No. 11, November 1959, pp. 1739-1744, Exploration of Space Symposium, Washington, 1959.

The significant astronomical and astrophysical facts, together with the rather fragmentary geophysical data for the two planets, are reviewed. These include tabulated information on (1) orbital elements; (2) physical elements; (3) atmospheric composition; (4) planetary temperatures (black-body, grey-body and radiometric) and densities. Recent researches on the Venusian clouds, and the new infrared absorption bands in the Martian atmosphere (Sinton, 1958) are discussed.

192. VIRGINIA POLYTECHNIC INSTITUTE, CONFERENCE ON THE EXPLORATION OF MARS AND VENUS, VIRGINIA POLYTECHNIC INSTITUTE, BLACKSBURG, VA., AUGUST 23-27, 1965, PROCEEDINGS, Conference supported by NASA and AFCRL, Blacksburg, Va., Virginia Polytechnic Institute, 1965.

- 1) THE ORBITS AND THE GRAVITATIONAL FIELDS OF MARS AND VENUS. Dirk Brouwer (Yale University, New Haven, Conn.),
- 2) BALLOON-TELESCOPE OBSERVATION OF THE PLANETS. John D. Strong (Johns Hopkins University, Baltimore, Md.),
- 3) SOME ASPECTS OF THE CIRCULATION OF MARS. Conway Leory (RAND Corp., Santa Monica, Calif.),
- 4) THE INTERIORS OF MARS AND VENUS. S. K. Runcorn (Newcastle-upon-Tyne, University, Newcastle-upon-Tyne, England),

- 5) THE SYSTEMATIC INVESTIGATION OF THE METEOROLOGY OF MARS. Morris Tepper (NASA, Office of Space Science and Applications, Washington, D. C.),
- 6) THE POSSIBILITIES OF LIFE ON MARS. Frank B. Salisbury. (Colorado State University, Fort Collins, Colo.),
- 7) CHEMICAL STUDIES ON THE ORIGIN OF LIFE. Cyril Ponnamperuma (NASA, Ames Research Center, Calif.),
- 8) SPECIAL ORBITS FOR THE EXPLORATION OF MARS AND VENUS. Victor G. Szebehely (Yale University, New Haven, Conn.),
- 9) SCIENTIFIC RESULTS OF MARINER MISSIONS TO MARS AND VENUS. Richard K. Sloan (California Institute of Technology, Pasadena, Calif.).
- 10) PROBLEMS AND POSSIBILITIES OF EXPLORATION OF MARS SURFACE BY MANNED LANDINGS. Rudolf Festa (NASA, Marshall Space Flight Center, Ala.).

193. Wattenberg, D.,  
 MARS THE RED PLANET, Urania-Verlag, Leipzig, 1956.

An attempt has been made in this semitechnical work to bring together the voluminous literature of the planet Mars, and enable the reader to review the contemporary level of research in this field. Mythical aspects of the planet in the past and present, planetary disciplines and Mars, phenomena observed, atmosphere, question of habitation, satellites of Mars, and bridges between Mars and earth are discussed. As far as the atmosphere of this planet is concerned, it was D. Cassini, in 1672, who made the first reference to the existence of atmosphere on Mars with the introduction of Mars photography, violet light photos showed a larger disk, including the atmosphere, than the red light ones. The height of the Martian atmosphere (190 km) has been calculated from the difference of the two characters. Colored photos in 1945 revealed the Martian atmosphere to be extremely transparent. Research of the composition of the atmosphere with spectra found carbon dioxide ( $\text{CO}_2$ ) the only component whose occurrence will be accepted as proven (G. P. Kuiper, 1948). Observations based on the Doppler effect lead to the assumption of the existence of 6% oxygen and 16% water vapor. Theories to explain the comparatively large percentage of carbon dioxide are presented. Other gaseous materials such as: ozone, carbon-monoxide, nitrogen oxide and nitrogen didn't show up in the spectra. The structure of the atmosphere; height of clouds, lapse rate of temperature, and pressure are discussed. Weather conditions on Mars are more stable than on Earth. V. G. Fesenkov compares the climate of this planet to a desert plane of the earth, situated at 18-20 km altitude, where the temperature is 30 to 40 °C lower.

194. Yagoda, Y.,  
INTERACTION OF COSMIC AND SOLAR FLARE RADIATIONS WITH  
THE MARTIAN ATMOSPHERE AND THEIR BIOLOGICAL IMPLICA-  
TIONS, Life Sciences and Space Research II; International Space Science  
Symposium, 4th, Warsaw, Poland, June 3-12, 1963, sponsored by the  
Committee on Space Research (COSPAR), M. Florkin and A. Dollfus,  
ed., North-Holland Publishing Co., Amsterdam, Interscience  
Publishers, New York, 1964.

195. Slipher, E. C.,  
PLANETS FROM OBSERVATIONS AT LOWELL OBSERVATORY,  
Am. Phil. Soc., Proc., 79, No. 3, 1938, pp. 441-473.

This observatory has emphasised the study of the planets since 1894, and the present paper briefly discusses the observations of Mercury, Venus, Mars, Jupiter, and Saturn, and their atmospheres. Mars is analogous to the earth, and its surface is marked by polar snow-caps and blue-green areas which change with its seasons, has a moderate surface temperature, and displays an atmosphere of considerable extent which supports clouds at relatively great heights and scatters light to an amazing degree, but is very changeable in the latter respect.

196. de Vaucouleurs, G.,  
MARS, Scientific American, 188, No. 5, May 1953, pp. 65-73.

After describing the well-established facts about the planet (characteristics of orbit and globe; seasonal changes of polar ice caps; extent of desert areas), the author discusses probable atmospheric composition of Mars, the possible plant life and the controversial problem of canals. Photographs showing various sizes of ice caps are presented.

## B. BOOKS

197. Antoniadi, E. M.,  
THE PLANET MARS 1659-1929. A STUDY BASED ON RESULTS  
OBTAINED BY MEANS OF THE GREAT TELESCOPE OF THE MEUDON  
OBSERVATORY, Herman, Paris, 1930.

The study gives an account of the observations of the planet Mars, carried out from the beginning of the century at the observatory of Meudon, and at the same time presents an analytical evaluation of important works of the author's predecessors, in order to obtain a satisfactory conception of the topography, meteorology and of the physical conditions on the surface of Mars. In Pt. 1, the generalia are discussed, such as: historical summary of ancient times; instruments and observation stations; astronomical and physical elements; the spots of the surface; the illusion of canals; the polar snow caps; the atmosphere; clouds and winds; the physical conditions and habitability, and the two satellites of Mars. The snow-covered poles of Mars, the effects caused by variations in the solar radiation on the diminution of the Martian snow, and the dark belts surrounding the polar caps are treated in Ch. VI; the observations in connection with the atmospheric cover, the clouds in various color, the dominant role of the sun on the Martian winds, their velocity, the different kinds of winds, and the protuberances of snow on the terminator are discussed in Ch. VII. Pt. 2 of the study presents an exhaustive and thorough picture of the contemporary topography of the planet with an evaluation of related works since Huyghens.

198. Barabashov, N. P.,  
RECENT STUDIES OF MARS, Priroda, Moscow, No. 6, June 1959,  
pp. 13-18.

The author gives a detailed account of the results of recent astronomic studies of Mars during the last great opposition of the planet in 1956 as obtained by the Soviet observatories of Kharkov, Tashkent, Abastumani, Crimea and Kazakh, by means of photographic, spectroscopic, astrographic and telescopic observations. It has been found that appreciable changes take place sometimes both in the atmosphere and on the surface of the planet.

199. National Aeronautics and Space Administration, Washington, D. C.,  
PHYSICAL CONDITIONS ON MARS by N. P. Barabashov, NASA TT-F-105, August 1963, translated from Vestnik Akad. Nauk SSSR, No. 10, 1962.

A discussion is presented in an effort to clarify what is reliably known about Mars, what is in the realm of more or less probable conjecture, and finally what is still completely unexplainable. Significant areas for future research toward determining the physical aspects of planets are indicated.

200. Douglas Aircraft Company, Inc., Santa Monica, California,  
PHYSICAL PROPERTIES OF THE PLANET MARS by V. Carter, August 1963, AD-421 569.

This summary was prepared by Miss Virginia Carter from material assembled by Mr. Claude Michaux, both members of the Atmospheric Sciences Branch. It will serve as a companion piece to the very popular report on Venus published in July, 1962. As in the case of the latter report, its purpose is to aid those who need factual data now on the physical properties of this planet for scientific or engineering purposes.

201. Ley, W. and von Braun, W.,  
EXPLORATION OF MARS, Viking Press, New York, 1956.

A general survey of knowledge concerning the planet Mars is presented in this easily readable book. The history of observations, the motion of Mars, its satellites, the ice caps, the Martian canals, atmospheric conditions, etc., with opinions, hypotheses and theories, are discussed. As far as the authors are concerned, they assume that man will set foot on Mars within a matter of decades. Chs. 5-8 are a treatment of an imaginary expedition to Mars with excellent colored illustrations. A useful bibliography of books and important papers on Mars and related subjects, principally life on other worlds, is appended.

202. Lowell, P.,  
MARS AS THE ABODE OF LIFE, Macmillan Co., New York, 1908.

The book presents eight lectures delivered by the author and of which his studies of Mars form but a part. From the data collected at the Observatory at Flagstaff, light has been thrown upon the evolution on the planets as worlds, resulting in a thesis of which this book is a presentation. The book is written for professionals, as well as

for nonprofessionals. In Pt. 1 the genesis of a world, the evolution of life, the dominant role of Sun, Mars and the future of the Earth, the canals and oases of Mars and the proofs of life on Mars are discussed. In Pt. 2, the validity of each step in the argument is demonstrated with references to the corresponding phases in the text. The density of the atmosphere on Mars, determined from the albedo, is about  $\frac{7}{9}$  of the Earth's, over similar square unit of surface. The barometric pressure is 64 mm, the mean temperature  $8.7^{\circ}\text{C}$  or  $47.7^{\circ}\text{F}$ .

203. Maggini, M.,  
THE PLANET MARS, Ulrico Hoepli, Milan, 1939.

The treatment covers the various aspects of the planet; the movement, opposition period, its satellites, duration of days, month and seasons, the topographic characteristics such as canals, polar caps, etc. In the discussion, the prominent persons who contributed to our present knowledge about Mars, including the Italian astronomers: Galileo, Cassini, Schiaparelli, Cerulli, Antoniadi, etc. are noted. In the last part of the study the Martian atmosphere and climate are considered. The observation of the yellow and white clouds and the bright protuberances support the existence of an atmosphere, the altitude of which, according to Wright, should be about 100 km. Infrared and ultraviolet photography lead to decisive observations. Atmospheric conditions, the existence of oxygen and water vapor, and spectroscopic observations of chlorophyll bands are evidence of vegetative life. The mean temperature on the surface of the planet was found around  $20^{\circ}\text{C}$ .

204. Moore, P.,  
GUIDE TO MARS, 2nd edition, Frederick Muller, London, 1965.

The original, 1956, edition of this book has been completely revised to include new information obtained in modern space science research. The book is intended as a general, nontechnical introduction to the study of Mars for relative beginners as basic material to use in study of more technical papers in astronomy.

The eleven chapters are: the red world, telescopic observation of Mars, the polar caps of Mars, dark areas of Mars, "Deserts" of Mars, Martian atmosphere, surface conditions, canals of Mars, life on Mars, satellites of Mars, and rockets to Mars. Five appendices include instructions on telescopic observation of Mars, numerical data, observational societies and programs, old and new nomenclature of Martian features, and description of the surface. Coordinates of Martian features are listed at the end.

205. Sharonov, V. V.,  
MARS, Izdatel'stvo Akademii Nauk SSSR, Moscow, 1947.

A popular book by one of the most quoted Russian authors on Martian studies. The book is divided into five chapters dealing with the problems of life on Mars, celestial mechanics of the planet, its landscape, atmosphere and canals respectively. In the chapter on the Martian atmosphere (p. 111-151) the various techniques of observation (occultation of stars, diffusion of light into dark area, blurring of detail around the edge of the disk, presence of clouds, etc.) are described. The Wright effect and its refutation by Russian scientists as being an apparent effect due to "photographic irradiation" are treated at length. The theory of determining atmospheric density from photometric observations is briefly explained and preliminary attempts made in this field are mentioned. Knowledge on clouds and winds on the chemical composition of the Martian atmosphere is reviewed. Finally climatic conditions on Mars and especially thermal conditions as affected by solar radiation, albedo, cloudiness, atmospheric circulation, "hothouse effect," etc. are treated. The use of balloon-borne radiometers is described and illustrated. By excluding all mathematics but describing physical details with considerable clarity the author succeeds in giving considerable insight into the problems of Martian investigations without making any demand on the reader.

206. Sinton, W. M.,  
NEW FINDINGS ABOUT MARS, Sky and Telescope, 14, No. 9, July 1955.

A summary of world-wide observations of Mars in 1954 is presented. Cooperating observatories are listed; some excellent photos are included to illustrate the text. The author discusses some of the planetary features observed, some atmospheric phenomena apparent in the photos, and temperature conditions on Mars as found in the author's investigations. Equipment and film used are also discussed.

207. Slipher, E. C.,  
THE PHOTOGRAPHIC STORY OF MARS, Sky Publishing Corp.  
Cambridge, Mass., Northland Press, Flagstaff, Ariz., 1962.

Includes Mars, key map.

208. National Aeronautics and Space Administration, Washington, D. C.,  
 RESULTS OF OBSERVATIONS OF MARS IN THE USSR DURING THE  
 GREAT OPPOSITION OF 1956 by G. A. Tikhov et al, NASA-TT-F-93,  
 December 1962, translated from USSR Acad. of Sci. Pub. House,  
 Moscow, 1959.
- 1) OBSERVATIONS OF MARS IN THE USSR IN 1956 p 1-3
  - 2) SUMMARY RESULTS OF THE OBSERVATION OF MARS BY  
 THE SECTOR OF ASTROBOTANY DURING THE PERIOD OF  
 THE GREAT OPPOSITION IN 1956 G. A. Tikhov
  - 3) PHOTOGRAPHIC PHOTOMETRY OF MARS WITH FILTERS  
 N. P. Barabashov and I. K. Koval
  - 4) PHOTOMETRIC STUDIES OF OPTICAL PROPERTIES OF THE  
 ATMOSPHERE OF THE PLANET MARS N. N. Sytinskaya
  - 5) THE SURFACE AND ATMOSPHERE OF MARS ACCORDING  
 TO PHOTOGRAPHIC, PHOTOMETRIC, AND COLORIMETRIC  
 OBSERVATIONS CONDUCTED IN 1956 AT TASHKENT  
 V. V. Sharanov
  - 6) AN EXPERIMENT TO DETERMINE CONTRASTS ON THE DISC  
 OF MARS BY THE METHOD OF VISIBILITY V. V. Sharanov
  - 7) SOME THOUGHTS ON THE STATE OF THE ATMOSPHERE  
 OF MARS N. N. Sytinskaya
  - 8) VISUAL OBSERVATIONS OF MARS DURING THE GREAT  
 OPPOSITION IN 1956 V. A. Bronshten
  - 9) PHOTOGRAPHIC PHOTOMETRY OF THE LIGHT REGION  
 OF ARGYRE ON MARS LATE IN AUGUST 1956 V. A. Bronshten  
 V. A. Bronshten and O. V. Dluzhnevskaya

209. de Vaucouleurs, G.,  
 PHYSICS OF THE PLANET MARS: INTRODUCTION TO AEROPHYSICS,  
 Albin Michel, Paris, 1951.

This book gives a surprising amount of information. The Martian atmosphere includes 3 cloud layers: 1) bluish-white clouds at  $10^{-6}$  km (probably droplets or crystals of CO<sub>2</sub> due to intense afternoon convection); 2) a violet layer at 10-15 km (finely divided matter of unknown origin); and 3) a yellow layer at 3-5 km, probably dust. Wind circulation is deduced from cloud drift; a chart for northern winter, with fronts and isobars, rather resembles earth in Jan. Atmospheric pressure at ground 87 ±8 mb, variation with height Z (km) given by log P<sub>1</sub> = 1.94 - 0.025z. S. L. Hess finds a tropopause (about -160 °C) at 40-50 km. At very high levels there may be an ionosphere and auroras. Air composition: N<sub>2</sub> 98.5%; Argon, 1.2; CO<sub>2</sub>, 0.25; O<sub>2</sub>, probably under 0.1%; O<sub>2</sub> still less. "Martian climatology" gives

calculated distribution of radiation, and surface and air temperatures derived by various methods. Soil temperature averages -23°C for whole disc, -10 at equator to -60 at poles, annual range 120° at S pole, 30° in tropics; diurnal range in tropics; diurnal range in tropics 50°C. Dark regions hottest. Air temperature near ground 30° lower than ground. Pt. 3 deals with polar caps, of ice, snow and rime only a few cm thick. A dark fringe in spring is probably liquid water. Deserts are intensely dry; dark areas have more water vapor, but no chlorophyll plants.

210. de Vaucouleurs, G.,  
THE PLANET MARS, Attaché de Recherches a l'Institut Astrophysique de Paris, translated from the French by P. A. Moore, Faber and Faber, Ltd., London.

CONTENTS:

- 1) THE POLAR CAPS
- 2) THE BRIGHT REGIONS OF MARS
- 3) THE ATMOSPHERE
- 4) CLIMATES
- 5) THE DARK REGIONS OF MARS
- 6) THE CANALS

211. Virginia Polytechnic Institute,  
VIRGINIA POLYTECHNIC INSTITUTE, CONFERENCE ON THE EXPLORATION OF MARS AND VENUS, VIRGINIA POLYTECHNIC INSTITUTE, BLACKSBURG, VA., AUGUST 23-27, 1965, PROCEEDINGS, Blacksburg, Va., Virginia Polytechnic Institute.

1 v. (various pagings) illus. (Virginia Polytechnic Institute Blacksburg Engineering extension series, circular no. 5)

Supported by grants from the National Aeronautics and Space Administration and the Air Force Cambridge Research Laboratories.

1. Mars (Planet) 2. Venus (Planet) I. The Exploration of Mars and Venus. II. U. S. National Aeronautics and Space Administration.

212. Wattenberg, D.,  
MARS: THE RED PLANET, Urania-Verlag, Leipzig/Jena, 1962.

A popularized account of all aspects of Mars research, reviewing both Soviet and Western contributions.

### Section III. MARTIAN SURFACE

#### A. COMPOSITION

213. Berlage, H. P.,  
ON THE COMPOSITION OF THE BODIES OF THE SOLAR SYSTEM,  
Proc. K. Ned. Akad. Wetensch. B, 56, No. 1, 1953, pp. 45-55.

An attempt is made to arrange current aspects of the internal constitution of the bodies of the solar system into one coherent picture.

214. Bondi, H. and Marder, L.,  
THE INTEGRATION OF THE EQUATIONS OF PLANETARY CONSTITUTION, Geophysical Journal, 10, September 1965, pp. 69-79.

The observed linear relation between bulk modulus and pressure in the earth is used to simplify the equations of hydrostatic equilibrium through the introduction of homology invariant variables. These variables, introduced previously for the discussion of simple stellar models, reduce the integrations to the fitting of curves belonging to a one-parameter family and so enable many models to be examined with comparative ease. Examples of the use of the method are given, particularly in relation to the structure of Mars and Venus.

215. Brown, H.,  
ON THE COMPOSITIONS AND STRUCTURES OF THE PLANETS,  
Astrophys. J., 111, May 1950, pp. 641-653.

The observed physical and chemical characteristics of the planets can be explained in a reasonably satisfactory manner by assuming that they condensed from a medium possessing varying temperatures and densities but fairly uniform composition. The conclusion is drawn that the inner planets possess nearly identical composition, the differences in density being largely the result of compression effects. Approximate models are derived for the major planets. It is found that Uranus, Neptune, Saturn and Jupiter possess, respectively, 3.1, 3.7, 6.4 and 9.1 earthlike cores and that nearly 70% of the mass of Saturn and 90% of the mass of Jupiter is composed of helium-hydrogen.

216. Bullen, K. E.,  
ON THE CONSTITUTION OF MARS, Royal Astron. Soc., Monthly Notices, 109, No. 6, 1949, pp. 688-692.

An earth model based on a compressibility-pressure hypothesis fits theories that the density change at the boundary of the earth's central core is purely a pressure phenomenon and that the earth and Mars are of the same primitive composition. The best fit is found if Mars is assumed to have an inner core in the same proportion by mass as in the earth and if the material in the inner core of the earth is chemically distinct from the material below the crust. The moment of inertia and ellipticity of Mars lend some support to these suggestions.

217. Bullen, K. E.,  
CORES OF TERRESTRIAL PLANETS, Nature, London, 170, 30 August 1952, pp. 363-364.

The relative merits of the models for the earth's structure of an iron core (Urey, 1951), a core due entirely to pressure modification (Ramsey, 1949) and a core partly of nickel-iron and partly of modified ultra-basic rock (Bullen, 1949) are examined in the light of observational data on Venus, Mars and Mercury.

218. Cameron, A. G. W.,  
PHYSICS OF THE PLANETS, Space Physics, D. P. Le Galley and A. Rosen, ed., John Wiley and Sons, Inc., New York, 1964, pp. 127-165.

Attempt at the construction of a general framework of physical interpretations of the properties of the planets and presentation of pertinent observational evidence. The subjects considered are the origin of the planetary atmospheres, the atmospheres of the Earth, Mercury, Venus and Mars, the atmospheres of the giant planets, the surface of the Moon, and planetary interiors. It is shown that many crucial observations are needed before such a framework of physical interpretations of planetary properties can become sufficiently concrete to allow many predictions to be made about such properties.

219. Texas University Austin Labs for Electronics and Related Science Research,  
THE USE OF ELECTROMAGNETIC RADIATION IN THE STUDY OF PLANETARY ATMOSPHERES AND SURFACES by H. D. Cubley and A. H. Lagrone, August 1965, AD-489 327, Contract No. AF-AFOSR-766-65.

Various techniques employing electromagnetic radiation are presently being used in the study of planetary atmospheres and surfaces. These techniques generally make use of either thermal radiation from the planet itself or solar radiation that is reflected and scattered from the surface and atmosphere of the planet. Such measurements are made from earth-based observation points. Radio astronomy used radio techniques to measure such quantities as the surface temperature of the planet and the polarization of any nonthermal radiation from the planet. Radar astronomy uses both pulsed and continuous wave radar. These radars can be used to study the surface roughness of a planet, its rotation rate, and the density of its ionosphere. Infrared astronomy is used in the study of the emission and absorption bands in a planetary atmosphere. Visual astronomy enables the observation of surface features such as clouds and haze. Close-up observations are possible when a spaceprobe such as Mariner 4 is occulted by a planet and its atmosphere. The expected diffraction pattern or signals from the space-craft can be computed. Such was done for Mariner 4 for the upper and lower probable limits of the Martian atmosphere.

220. Davidov, V.,  
IS MARS COVERED WITH ICE?, Weltraumfahrt, 12, No. 1,  
February 1961, pp. 14-15.

In regard to the various theories which reject canals on Mars as contrary to evidence indicating a yearly temperature below the freezing point. A. I. Lebedinskii's suggestion of 1956 is discussed concerning the existence of ice below its surface, the impossibility of the presence of water vapor in its atmosphere notwithstanding. The author tried to determine the volume of water by comparison with the processes responsible for Mars' and Earth's hydrosphere. A theory is developed on the existence of ice oceans below the products of decaying rocks, and on the Mars-canals representing cleavages in these ice-oceans.

221. RAND Corporation, Santa Monica, California,  
STUDIES OF THE PHYSICAL PROPERTIES OF THE MOON AND  
PLANETS Quarterly Technical Progress Report (3) by M. H. Davis,  
28 April 1961, Contract No. JPL Contract N-3356, NASw-6.

The following basic studies are included in a summary reporting research conducted on the properties of the moon and planets:

- (1) Some of the methods of modern abstract operator theory have been applied (Mullikin) to the theory of radiation transfer, and important simplifications have been made in the theoretical development.
- (2) Discrepancies between optical and dynamical analyses of the shapes of the earth, moon and Mars may be accounted for by a theory proposing

that phase changes in the minerals of the rock mantle cause density variations which possibly contribute to gravitational fields of the planets while permitting isostatic equilibrium. (3) Owing to the greater resolution or radiation measurements from planetary probes, infrared measurements from the Mars capsule should make it possible to determine whether the Sinton bands are due to gaseous absorption or to the surface's reflective properties. The CO<sub>2</sub> concentration in the Venus atmosphere can be determined with precision from measurements of scattered solar radiation in the ultraviolet. (4) Preliminary estimates of air densities in the earth's exosphere have been based on the orbit of Echo I. A new method of analysis is presented which includes the effects of radiation pressure. (5) In evaluating the future role of surface, balloon, and satellite observatories, and planetary probes, it is shown that much would be gained by an intensive coordinated program of observation from ground observatories, from platforms outside earth's atmosphere, and from probe vehicles. (6) Strong evidence is presented (Kaplan) against a recently published interpretation (Kiess, Karrer, and Kiess) that certain spectra indicate the presence of nitrogen oxides in the Mars atmosphere. It is shown in contradiction to this interpretation that no more than trace amounts of nitrogen peroxide can exist on Mars or Venus. (7) A method has been suggested by which the mean molecular weight of the gases in the Mars atmosphere might be determined from measurements of pressure and velocity made on the Mariner B capsule during its free-fall descent. It has been speculated that the Mars atmosphere may be like the atmosphere of Earth above the 10-km level. Also, on the basis of a thorough analysis, it has been concluded that the mean temperature of the air near the Mars surface is somewhat lower than had been generally suspected, being about -25°C day and night at 1 km above the Mars equatorial surface. (8) The published values of the surface gravity on Mars are discussed, and words of caution are given on how they should be used. (9) Despite the consistency of investigation results on the surface pressure of Mars, the likelihood of systematic errors could lead to a 50 percent error in reported values.

222. Dollfus, A.,  
MEASUREMENT OF THE GLOBAL DIMENSIONS OF THE PLANET  
MARS, C. R. Acad. Sci., France, 255, No. 18, 29 October 1962,  
pp. 2229-2231.

A new series of refined observations at 5 different wave-lengths made at the favourable Martian oppositions of 1954, 1956 and 1958 with the birefringent micrometer gave the following revised dimensions: polar diameter, 6710 km; equatorial diameter, 6790 km, with an error

of +30 km due to atmospheric scatter. The observed ellipticity was thus 0.117, and the global volume,  $1.62 \times 10^{26} \text{ cm}^3 \pm 1\%$ . Taking the probable mass as  $6.06 \times 10^{26} \text{ gm}$ , the density is 4.09. No dependence of planetary diameter on wavelength (as suggested by Wright) could be detected from measurements made at 4700 and 6300 Å.

223. Texas Technological College, Lubbock, Department of Chemistry,  
SPECTRAL STUDIES OF MATERIALS POSSIBLY PRESENT ON THE  
MARTIAN SURFACE Final Report, 1 Feb. 1965-31 Jan. 1966, by  
A. L. Draper and J. A. Adamcik, 1 April 1966, AD-630 806,  
Contract No. Nonr (G)-00035-65.

Comparisons of the reflectance spectra of synthetic mixtures have been made with the observed spectrum of Mars in an effort to develop a mixture congruous with the Martian soil. Mixtures containing various amounts of the iron oxides goethite and hematite as the coloring material show the features of the Martian spectrum, particularly when the goethite and hematite are precipitated on finely ground quartz and kaolin. However, such mixtures are much more reflective than the planet. To date, two promising mixtures have been made, one prepared by the addition of the dark material magnetite, blende. The spectra of these two mixtures closely match the spectrum of Mars in the visible region and bracket it in the infrared.

224. Jeffreys, H.,  
DENSITY DISTRIBUTIONS IN THE INNER PLANETS, Roy. Astron. Soc., M. N. Geophys. Supplement, 4, January 1937, pp. 62-71.

The results obtained for the earth have been applied to some of the inner planets mainly to test Bernal's hypothesis that a change of density about 470 km. deep in the earth represents a transition of olivine to a denser form under higher pressure. The hypothesis agrees well with data for the moon but the hypothesis that the transition is to a new material denser at all pressures fails. For Mars the density itself is not explained but agreement is obtained on assuming a small central core similar to that of the earth. The hypothesis of a new material for Mars fits the data but the amount required is too large. The former hypothesis gives, on the assumption of hydrostatic equilibrium, an ellipticity of Mars rather greater than the observed value, the second one rather less, but the differences are no more than those expected from the loads known to be supported by the strengths of the earth and moon.

225. Kothari, D. S.,  
INTERNAL CONSTITUTION OF THE PLANETS, Roy. Astron. Soc.,  
M. N., 96, October 1936, pp. 833-843.

The paper consists of three parts. (1) The present theory of white dwarf stars is summarised. The relation between the mass  $M$  and the radius  $R$  of agglomerations of degenerate ionised matter is shown to be in accordance with observations of white dwarfs. The theory fails, however, with the planets, the theoretical radii being 100 times too small. The failure is shown to be due to the assumption that the degree of pressure-ionisation is independent of the mass of the agglomeration. (2) A more general theory is evolved without this restriction. This theory gives the ordinary mass-radius relation and predicts, not merely assumes, complete ionisation of the matter in white dwarfs. (3) Numerical results are given for chemical compositions of Fe and of H, and a theoretical ( $M$ ,  $R$ ) diagram is constructed for both assumptions. With one exception, all the observed white dwarfs and all the planets fall in the region between the Fe and H curves. The implication is that planets may be regarded as "black dwarfs."

226. Lamar, D. L.,  
OPTICAL ELLIPTICITY AND INTERNAL STRUCTURE OF MARS,  
Icarus, 1, No. 3, 1962, pp. 258-265.

The optically determined values for the ellipticity of Mars are more than double the values determined from the motion of its satellites. It is assumed that the optical ellipticity represents the physical shape of the planet's surface and that the topographically high equatorial region is isostatically compensated by variations in crustal thickness. Consideration of the effect of this equatorial bulge on the gravity field, as determined by the motion of the satellites, leads to the conclusion that (1) the depth of compensation cannot be more than 225 km; (2) Mars may not have a more homogeneous distribution of material than Earth; and (3) Mars may have a core. In order for the bulge to be isostatically compensated, the percentage of crustal rock in Mars must be at least an order of magnitude greater than that in Earth; this can best be explained by assuming that the base of the Martian crust represents a phase change from basalt to eclogite rather than a change in chemical composition.

227. Jet Propulsion Laboratory, California Institute of Technology, Pasadena,  
SOME GEOLOGIC PROBLEMS OF MARS by A. A. Loomis, 4 March  
1963, Contract No. NAS7-100.

Geological and geophysical knowledge and uncertainties concerning the surface and body of Mars are briefly discussed and evaluated. The large number of uncertainties in present data precludes an adequate model of Mars; reliable data are needed. Some geological inferences which can be drawn from available photographic and photometric data concerning topography, areas of water accumulation, and biological activity are discussed. The priority of scientific geologic experiments is presented, and some present instrumentation capabilities and deficiencies are listed.

228. Loomis, A. A.,  
SOME GEOLOGIC PROBLEMS OF MARS, Geol. Soc. America Bull.,  
76, No. 10, 1965, pp. 1083-1104.

Data on the body of Mars are as yet insufficient to allow computation of meaningful models of the internal structure or density stratification within the planet. The flattening of the solid surface appears to be greater than the flattening of the equipotential surface by about a factor of two. The resultant possibility that the equatorial regions are high compared to the polar areas has many geological and biological implications. More data on the surface topography are required in order to make geological interpretations which are not largely subjective. Liquid water cannot exist on the surface of Mars, and aqueous erosion features, if they once existed, have become subdued by aeolian activity. Many craters with original depths of less than about 8,000 10,000 feet have become obliterated on Mars by windblown dust.

229. Lyttleton, R. A.,  
NOTE ON THE STRUCTURE OF MARS, Royal Astron. Soc. Monthly Notices, 130, No. 1, 1965, pp. 95-96.

A correction is given concerning previous computations (1965) of the internal structure of Mars. The linear law for the bulk modulus is capable of giving much closer agreement with observations, as concluded before, though the quadratic law in its corrected form cannot be ruled out altogether. The theory predicted the absence of mountains of folded and thrusted terrestrial types; the results of the Mars space flight, launched since submission of the earlier paper, are eagerly awaited.

230. MacDonald, G. J. F.,  
ON THE INTERNAL CONSTITUTION OF THE INNER PLANETS,  
J. Geophys. Res., 67, No. 7, July 1962, pp. 2945-2974.

The internal structures of the moon, Mars, Venus, and Mercury are examined in the light of what is known about the constitution of the earth. A review of the seismic determination of the elastic constitution of the earth's mantle, using new results on the stability of silicates at high pressures, leads to the following interpretation: The rapid increase of velocity beginning at 200 km depends on the olivine-spinel transition and the breakdown of silicates to oxides. Preliminary calculations of the stability field of periclase ( $MgO$ ) and stishovite (high-density  $SiO_2$ ) relative to olivine ( $MgSiO_4$ ) indicate that the oxides are stable at pressures greater than  $1.0-1.5 \times 10^5$  bars. The oxide transition produces a change in volume of about 20%. The gravitational figure of the earth, as obtained from satellite orbits, is used to estimate the possible deviations from hydrostatic equilibrium on other planets. The near coincidence of the present rate of heat production of a chondritic earth and the present surface heat flow is discussed as a limiting condition of the internal thermal structure of the earth. Observations of the orbital and rotational motion of the moon give its gravitational figure. Calculations of its thermal structure show that a model moon with uniform radioactivity and chondritic composition is inconsistent with the present figure. The inferred strength of the moon requires either that the radioactivity is substantially less than that of chondrites or that the heat sources are concentrated in the outer layers. The problem of differentiation without melting is noted. The average lunar material has a radioactivity perhaps one-half, or less, that of chondritic materials. The astronomical data on the mean density and gravitational figure of Mars receive critical examination. If the mean radius of Mars is taken to be 3310 km, the planet must have a surface density of about 3.8-3.9 and must be nearly homogeneous. If Mars were homogeneous and had a radioactivity equal to that of chondrites, the interior would be molten and large-scale gravitational differentiation would be expected. Since this differentiation is not apparent in the gravitational data, it is concluded that the radioactive composition of Mars differs from that of chondrites. The internal structures of Mercury and Venus are examined briefly in terms of their inferred rotational history. In conclusion, the inner planets differ both in the abundances of the heavy elements and in the abundances of potassium, uranium, and thorium. Chondrites may provide a satisfactory chemical model for the earth but not for the other inner planets; Venus is a possible exception, only on the grounds of our ignorance of its internal constitution.

231. MacDonald, G. J. F.,  
THE INTERIORS OF THE PLANETS, Origin of the Solar System,  
Academic Press, New York and London, 1963, pp. 155-169.

The composition of the Earth's core and mantle is discussed with reference to the propagation of seismic waves, the departure of the Earth's figure from the equilibrium configuration, and thermal flow from the surface. The ideas developed are used in a discussion of the composition of the moon and of Mars.

232. McLaughlin, D. B.,  
NEW INTERPRETATION OF THE SURFACE OF MARS, Scientific Monthly, 83, No. 4, October 1956, pp. 176-188.

The author believes that wind action plays an exceedingly important role in the geomorphology of Mars, and that water, snow, wave, glacier or artificial modifications of the terrain are nonexistent or at least unimportant. Bands and streaks appear oriented in directions of presumed prevailing winds and curve in conformity with Coriolis force. Volcanic ash carried by winds is also a prominent feature. Seasons vary more than on earth, though its inclination of  $24.8^{\circ}$  is about the same, its orbit is more eccentric so that vertical incidence insolation is 45% more in summer in the S. Hemisphere than in the N., but summers are much shorter. The atmosphere is rich in CO<sub>2</sub> and argon, but has very little water vapor, some cirrus clouds and many dust storms, a surface pressure of 83 mb and a temperature that occasionally goes above 0°C but often down to -70°C or lower. Eye observation is far superior to photography because of the long exposures (and distortion by surface turbulence) needed to make good large plates. The so-called canals have never been seen with high magnification or on a photograph but only with low magnification telescopes, so seem to disappear when more detail is obtained. Vegetation may exist in its lower forms but cannot be proven to exist. Wind patterns show much stronger monsoon features than on earth, because there is no tempering ocean area to modify them. Winds are strongest in the southern summer because of the greater heating and darker color of the S. Hemisphere. Canals may be vanees of dark volcanic dust or ash that follow prevailing winds but are not permanent. Clouds of condensed vapor may be seen during supposed volcanic eruptions.

233. Öpik, E. J.,  
ATMOSPHERE AND SURFACE PROPERTIES OF MARS AND VENUS,  
Progress in the Astronautical Sciences, Vol. I, North-Holland  
Publishing Co., Amsterdam, 1962, pp. 261-342, Grant No. NsG 58-60.

Critical review of some partly controversial general properties of the surface and atmosphere of Mars and Venus. Two major types of permanent or semipermanent surface formations on Mars are observed: the bright orange-red continents, and the dark grayish maria whose average coloration on an absolute scale is slightly brown or yellow, but by contrast may sometimes give the impression of green or blue. The bright polar caps, regularly varying with the season, are undoubtedly composed of a thin layer of water, hoarfrost or snow. The darkness and coloration of the maria also show regular seasonal variation, in addition to sporadic changes of a more persistent, nonseasonal character. The maria are commonly interpreted as vegetation consisting of primitive plants not containing chlorophyll. The failure to observe topographic irregularities near the Martian terminator is interpreted as indicating the absence of mountain chains or peaks; the upper limit of altitude is set for mountains at 2-3 km (Lowell) and for mountain ranges at 0.8 km (Russell). The Martian atmosphere is much thinner than the terrestrial, with carbon dioxide the only constituent which has been definitely observed spectroscopically. The bulk of the atmosphere may consist of nitrogen and argon. Oxygen is practically absent. The presence of water vapor is indirectly inferred from the polar caps, but its amount is small. Liquid water surfaces are definitely absent, except perhaps temporarily near the poles. The optical properties of the surface of Venus are consistent with a relatively thin-scattering gaseous atmosphere, overlying a continuous layer of clouds. The effective thickness of the gaseous layer appears to decrease with decreasing wavelength. The reflectivity of the clouds rapidly decreases toward the violet. The yellow color of the clouds is their intrinsic property, and is not caused by absorption in the atmosphere. The observed amount of water vapor is too small to be condensable. Water in liquid or solid form cannot exist on Venus. The clouds of Venus cannot consist of water; most probably they represent solid dust, possibly containing carbonates, blown up from the surface. Circumstantial evidence points to 10-13 days as the probable period of rotation of Venus. Kuiper's explanation of the bands in the upper haze level as corresponding to climatic zones, as well as their visibility in the ultra-violet and invisibility in longer wavelengths, is in excellent agreement with the general optical properties of the planet. Hydrocarbons cannot be present on Venus in large quantities, as indicated by the nonobservability of the spectral bands of the lighter compounds. A model of the

vertical distribution of temperature and structure of the atmosphere of Venus is proposed.

234. Öpik, E. J.,

THE MARTIAN SURFACE, Science, 153, 15 July 1966, pp. 255-265,  
Grant No. NsG-58-60.

Attempt to interpret the limited factual data available so as to derive a logical concept of the Martian surface and its origin. It is considered that craters larger than 20 km in diameter could have survived aeolian erosion since the formation of the planet. Because of the long survival of these craters, Mars could not have possessed a dense atmosphere for any length of time. The tenuous atmosphere may have originated entirely from outgassing of surface rocks due to asteroidal impacts. The large temperature range indicates that the Martian upper soil is of a porous unconsolidated structure, with a thermal conductivity as low as that of atmospheric air. Extensive comment is made on the possibilities of vegetation, the causes of observed changes in surface markings, and the characteristics of aerosols and yellow dust clouds.

235. Ramsey, W. H.,

ON THE CONSTITUTION OF THE TERRESTRIAL PLANETS, Mon. Not. Roy. Astr. Soc., 108, No. 5, 1948, pp. 406-413.

It is suggested that the density jump at the boundary of the earth's core is due to a pressure transition from the molecular to a metallic phase, rather than to the appearance of a new material such as an alloy of iron and nickel. The pressure at the boundary of the core will then be characteristic of the chemical composition of the material, and so may be assumed to be the same for all the terrestrial planets. The mean densities of the terrestrial planets calculated on the basis of this assumption are in good, but not perfect agreement with the empirical values. The calculated ellipticity of Mars is also satisfactory. If allowance is made for the tendency of the heavier elements to gravitate towards the centre of the earth, the small discrepancies in the calculated mean densities can be removed.

236. Rea, D. G.,

SOME COMMENTS ON "THE COMPOSITION OF THE MARTIAN SURFACE," Icarus, 4, No. 1, April 1965, pp. 108-109.

Van Tassel and Salisbury (1964) have recently addressed themselves to the composition of the surface of Mars. They state that "...the most common constituent of the present surface layer should

be that mineral (or those minerals) which is at the same time both abundant and resistant to abrasion." Since limonite is soft relative to other common minerals, and since its abundance on Mars is probably less than some of these, it should not be the predominant ground cover of the planet as has been suggested by photometric and polarimetric observations. The dilemma is resolved by proposing "a surface composed of either fine or coarse-grained silicates coated with finely divided limonite."

237. California University, Berkeley, Space Sciences Laboratory,  
THE ATMOSPHERE AND SURFACE OF MARS A Selective Review by  
D. G. Rea, 1965, presented at the Lunar and Planetary Seminar,  
Calif. Inst. of Tech., Pasadena, 17 September 1965, NASA-CR-68136,  
Contract No. NASr-220, Grant NsG-101.

Recent significant developments in our knowledge and understanding of the Martian atmosphere and surface are reviewed. The surface pressure estimates using different techniques are roughly as follows: near infrared spectroscopy, 3 to 90 mb; ultraviolet albedo and spectrum, 3 to 30 mb. The atmospheric abundances are: CO<sub>2</sub>, 45 m atm; H<sub>2</sub>O, 14 $\mu$  precipitable H<sub>2</sub>O, variable in time and space; no others detected. Of the latter two of the most important are O<sub>2</sub> and O<sub>3</sub>, whose upper limits are 2 cm atm and 4 $\mu$  atm respectively. The atmosphere probably contains a semi-permanent load of submicron particles (CO<sub>2</sub> or H<sub>2</sub>O crystals, or dust giving the "blue haze". The blue and white clouds are attributed to ice or CO<sub>2</sub> particles. The surface is characterized by bright and dark areas. The former are covered with dust which is evidently a weathering product of the dark areas. The color is attributed to the ferric ion, but its concentration relative to silicon need not be higher than the relative solar abundance. Dust storms originate in the bright areas, indicating that the local winds at an altitude of 1 meter are higher than 145 km hr<sup>-1</sup>, and may be as high as 300 km hr<sup>-1</sup> or higher. The dark areas consist of maria, oases, and canals. It is suggested that the maria are extensive deposits of volcanic ash, the oases impact craters of small asteroids, and the canals loci of small volcanoes oriented along crustal cracks connecting the oases with themselves and with the volcanoes.

238. See, T. J. J.,  
PHYSICAL CONDITIONS OF PLANETS, Nature, 71, 2 March 1905,  
p. 424, 13 April 1905, p. 559.

The author gives a detailed account of a lengthy series of investigations on the internal densities, pressures, and moments of inertia of the more important members of the solar system.

239. Sen, P.,  
INTERNAL CONSTITUTION OF PLANETS, Zeits. f. Astrophysik,  
16, No. 5, 1938, pp. 297-303.
- The theory of pressure ionisation, as has been shown by Kothari nad Majumdar when combined with the usual theory of the white dwarf stars predicts a maximum radius for a cold body and explains the broad features of the constitution of planets. Kothari has discussed two extreme cases when the material composing the planets is all H or Fe. In the present paper the mass-radius relation is calculated for the case of CH<sub>4</sub>, NH<sub>3</sub> and H<sub>2</sub>O. The method is indeed very rough but it serves to show how the theoretical (M, R) relation is modified when the chemical composition is changed. The theory suggests that the outer planets are probably composed of CH<sub>4</sub> and NH<sub>3</sub> with a proportion of H<sub>2</sub> and the terrestrial planets have cores of heavier elements.
240. Schiaparelli, G. V.,  
TOPOGRAPHY AND CONSTITUTION OF THE PLANET MARS,  
Accad. Lincei, Mem, 8, No. 2, 1910, pp. 101-156.
- A lengthy monograph dealing with the observations made at Milan during the opposition of 1890, illustrated with maps and photographic reproductions of the original drawings.
241. Sharonov, V. V.,  
A LITHOLOGICAL INTERPRETATION OF THE PHOTOMETRIC  
AND COLORIMETRIC STUDIES OF MARS, Astronomicheskii Zhurnal,  
Moscow, 38, No. 2, March/April 1961, pp. 267-272, Soviet Astronomy-AJ, USA, March/April 1961.
- The results of photometric and colorimetric observations of the surface of Mars, made during 1956 and 1958, are compared with data of the analogical study of a large number of samples of earth rocks. It is found that, according to the mean value of the albedo r and the color excess D, sand and other layers of deserts on the earth, the red colored rocks of the Permian formation and the dense varieties of limonite are not similar to the continents of Mars, as the red color of the latter is more saturated. Only ochre, i. e., a variety of limonite, is approximately similar to the color of the disk of Mars. Therefore a hypothesis is proposed that Mars is covered by dust or silt, consisting of small particles of limonite.

242. Sezawa, K. and Kanai, K.,  
PLASTIC STATE OF PLANETS, Tokyo Univ. Earthquake Research Inst., Bull., 16, March 1938, pp. 7-20.

The moon and Mercury are perfectly elastic provided their internal temperatures do not greatly exceed that of the earth. In every planet investigated the horizontal compression within the crust is larger than the vertical, regardless of whether the condition of the crust is elastic or plastic.

243. Urey, H. C.,  
THE COSMIC ABUNDANCES OF POTASSIUM, URANIUM AND THORIUM AND THE HEAT BALANCES OF THE EARTH, THE MOON AND MARS, Proc. Nat. Acad. Sci. U. S. A., 41, No. 3, March 1955, pp. 127-144.

Abundances of radioactive K, U and Th in representative chondritic meteorites appear to be higher by a factor of about 3.19 than in planetary bodies. Since the known thermal properties of the earth's mantle; the permanent anomaly in the shape of the moon; and the absence of a Martian core can all be accounted for on the basis of a decreased abundance for the above three elements, it is difficult to account for the present heat-balance of the earth without rejecting the hypothesis of radioactive heating in the initial stages of the melting of meteoritic matter. On the basis of the terrestrial abundances, the amount of heat available would be insufficient; but Al<sup>26</sup> may have provided the additional thermal energy. Alternatively, a depletion of these radioactive nucleides in the planetary bodies considered could account for the required lower abundance values, if this occurred during their formation.

244. Van Tassel, R. A. and Salisbury, J. W.,  
THE COMPOSITION OF THE MARTIAN SURFACE, Icarus, 3, September 1964, pp. 264-269.

Presentation of evidence contradicting the widely held assumption that the desert areas of Mars are composed of limonite. The limonite model is shown to be based on ambiguous polarimetric, spectrometric, color, and albedo measurements and to be inconsistent with sound geologic theory. Laboratory experiments demonstrate that the lack of the characteristic infrared emission spectra of minerals can be a result of small grain size. Finely powdered minerals have infrared emission characteristics of a gray body, and yield very little spectral information. Thus, the Martian surface materials could be composed primarily of fine-grained silicates, or of coarse-grained silicates

coated with finely divided limonite, without their presence being revealed spectrometrically.

245. Weldt, R.,  
STATE OF MATTER IN THE INTERIOR OF THE PLANETS, Astrophys. J., 87, June 1938, pp. 508-516.

The bulk of mass in the interior of the planets is in the ordinary condensed state. Only in the central parts of Jupiter and Saturn may there be matter in a state approaching the degenerate one. This is concluded from the central pressures of the terrestrial planets, as evaluated by Jeffreys, and from the internal pressures of the giant planets, which are computed here for a model consisting of a core similar in structure to the terrestrial planets, covered by a layer of ice and a layer of solid hydrogen on top of it. In this hydrogen layer the conditions are realised under which hydrogen should change to a metallic modification predicted by theory. The condensation of ice VII from the primeval atmosphere must have started long before the temperature had dropped to the critical one, and probably was finished before the critical point was reached, which would imply that there never was on the giant planets an ocean of a depth comparable to the total mass of H<sub>2</sub>O present.

246. Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson AFB, Ohio,  
FLIGHT ENVIRONMENT DESIGN PARAMETERS FOR MARS AND VENUS by R. H. Zimmerman and C. D. Jones, September 1962, ASD TDR 62 805, AD-288 538, Contract No. AF33 616 5914.

The physical characteristics of the planets Mars and Venus are assessed and probable quantitative limits are defined as minimum, representative and maximum probable values for application to environmental studies and equipment design. These data are applied to Chapman's generalized analysis for bodies entering planetary atmospheres to produce probable minimum, representative and maximum flight environment design parameters. These planetary parameters are applied with body and trajectory parameters, using Chapman's analysis, to selected direct, multipass and graze entries.

## B. CANALS

247. Antoniadi, E. M.,  
OBSERVATIONS OF MARS MADE AT MEUDON, Comptes Rendus,  
149, 15 November 1909, pp. 836-838.

The planet was studied with the 0·83 m. telescope, with magnifications 320, 470, and 800 diams., on thirteen nights from Sept. 20 to Nov. 9. The results are combined in a chart attached to the paper, which shows much detail and many canals. Among the most remarkable changes noticed since the opposition of 1907 were, the return of Syrtis Major to its form of 1864 and 1877, the reappearance of Lac Moeris, and the formation of a multiple "island" in the eastern region of the Mare Cimmerium. At the same time the planet was partly veiled by mists or light cirrus, which lightened the indigo-grey tone of the "seas" and gave a yellowish hue to the "continents." The tint of these mists or cirrus varied, according to their intensity, from golden-yellow to dull white. Their effect sometimes in almost obliterating spots which had appeared black a few days earlier was very remarkable. Some 50 "canals" were observed. The author, adopting Schiaparelli's definition of a canal, as a greyish band or line in the regions called "continental," assuming all kinds of forms, and longer than the more or less elliptic spots called "lakes," proceeds to divide the canals into eight classes. The list does not include the fugitive straight lines, often also called canals, which are only visible a fraction of a second, and may be illusory. The observations here dealt with do not confirm the existence of a geometric network of straight lines crossing in all directions. Indeed, sometimes with very steady images, glimpses, not fugitive, but lasting several seconds, were obtained of a structure of an entirely different character in the continental regions. These regions appeared covered with a great number of greyish marblings, irregular and complex, which no artist could reproduce.

248. Arrhenius, S.,  
PHYSICAL CONDITIONS ON MARS, Journ. de Physique, 2, Ser. 5,  
February 1912, pp. 81-97.

The physical features of the surface of Mars are discussed from the standpoint of finding terrestrial analogies to their peculiar forms. Illustrations are given of various structures on the earth which closely resemble the Martian "canals," notably the network of geotectonic lines occurring in Calabria and Sicily. A comparison is also given of the recent investigations of the probable temperature of the planet.

249. von Bülow, K.,  
FUNDAMENTAL PLANETARY STRUCTURES DISPLAYED ON THE  
MOON, EARTH, AND MARS, Internat. Geol. Cong., 21st, Copenhagen  
1960, Proc., pt. 21, 1960, pp 7-14.

Parallels are pointed out between the Earth and Moon with regard to the general structure of the crust (concentric), tangential movements, subcrustal currents, morphologic elements, major lineaments (fracture zones) and their governing principles, and genuine volcanic forms. A volcanic origin for the lunar craters is accepted.

The tectonic picture of Mars is not clear enough for detailed interpretation. "Deserts," "seas," and "canals," are visible.

250. Gifford, F. A., Jr.,  
THE MARTIAN CANALS ACCORDING TO A PURELY AEOLIAN  
HYPOTHESIS, Icarus, 3, No. 2, 1964, pp. 130-135.

It is suggested that the Martian canals are chains of desert sand dunes. The main physical factors involved are discussed, and it is shown that necessary conditions for dune formation probably exist on Mars. The chief physical factor is the low density of air near Mars' surface, which implies a higher threshold speed (seven times) than that on Earth and results in longer dune chains on Mars. The Mars' canals are not unique in nature as is demonstrated by satellite photographs over the western Sahara desert where sand dune chains form long, narrow, straight, parallel, geometrically regular configurations. Furthermore, the parallel dunes of the Southern Arabian desert could explain the double canals of Mars.

251. Hamilton, G. H.,  
PHOTOGRAPHIC MEASUREMENT OF CANALS OF MARS,  
Observatory, No. 504, September 1916, pp. 363-367.

A drawing is given showing details measured on a photograph of Mars taken by Lowell on 1916 March 15. Many canals, some double, are certified to be distinctly seen, and equations are provided for reducing the rectangular coordinates of the measures to latitude and longitude on the planet.

252. Jarry-Desloges, R.,  
OBSERVATIONS OF MARS, Soc. Astronomique de France, Bull.,  
August 1907, p. 370, Abstract in Nature, 76, 29 August 1907, p. 451.

Observations made during July, 1907, at a temporary observatory on the summit of the Revard, at an altitude of 1,550 m. The doubling of the Solis Lacus is confirmed, and special mention made of the cloudy appearance of the Martian landscape in the northern hemisphere as compared with the clearly cut features of the southern hemisphere. The canal Ganges was seen very broad, and appeared double. On July 19 the region north of Lacus Niliacus was clear, but twenty hours later, on July 20, white spots were visible, suggesting the disappearance of clouds.

253. Jarry-Desloges, R.,  
OBSERVATIONS OF THE SURFACE OF THE PLANET MARS JUNE 4  
TO OCTOBER, 1909, Comptes Rendus, 149, 11 October 1909,  
pp. 587-590, 26 October 1909, pp. 664-667.

The planet was studied at two high-altitude observatories founded for mutual control, one on the Revard plateau (1,550 m.), the other near Massegros (900 m.). The Revard equatorial, with an objective of 0.37 m. aperture, is probably the most powerful refractor at such a high altitude in Europe. The Massegros objective is of 0.29 m. aperture. The earlier observations showed all the dark regions of the planet extremely pale, and very unlike what they appeared in 1907 at a similar Martian epoch. They darkened during Aug., and by Sept. had resumed their habitual tone of grey. Frequent measures were made of the diminishing polar cap. The diminution was particularly rapid about Aug. 15. Within the cap numerous dark rifts were seen, and also spots both grey and light. Important variations of form and extent, as well as tint, were noticed, especially in Mare Sirenum and Mare Cimmerium, which were at first pale and diffused, and later dark and well defined. Hellas altered from a large light region to a small and dark-ruddy one. The "canals," generally speaking, were invisible in June and July, becoming perceptible in Aug. and Sept. In Sept., at exceptionally clear moments, a multitude of fine details were perceived in certain greyish areas on Mars. The appearance of the surface on drawings of Sept. 16 and 18 but little resembles that on a planisphere given for June-July; the former showing numerous details and a wide range of gradation of tone, the latter only dim general features. The second paper deals with the canals, and contains two planispheres for July 20-Aug. 13, and Aug. 16-Sept. 23, that is for Martian late spring and early summer in the S. hemisphere,

respectively. The canals are decidedly more numerous and conspicuous on the later map, which shows about 70 of them. The author classifies the canals under three groups: (1) Broad light grey bands; (2) narrow linear markings, fairly dark, and well defined; (3) fine lines, generally at the limit of visibility. The canals which were most conspicuous when they first began to appear were, of the 1st class, Ganges and Araxes; of the 2nd, Coprates, Nilosyrtis; and of the 3rd, Orontes, Typhonius. The author himself never saw with certainty any canal double, but some were seen double by his assistants G. and V. Fournier. Araxes, they saw first single, then double, and finally triple. Notable changes were witnessed in the visibility of certain canals, some becoming darker and more visible, others less so, as time went on. A remarkable fact was the disappearance of the broad dark band Achelous which was conspicuous in 1907 at the same Martian epoch. In summing up, the author states that certain bands of the first and second groups are seen at times with certainty, and all those mentioned in the article were seen by three observers. Some bands of the 1st class, when images are best, appear to resolve into elemental parts. He also finds it difficult to doubt the reality of the linear appearances of the 3rd class, numbers of them having been seen simultaneously by him and his two assistants at the Revard and Massegros. Though the author himself has not seen nearly so many as his two collaborators, he has yet seen a considerable number and at different reappearances, both in 1907 and 1909, about which he thinks there can be no mistake. A fact in favour of the existence of these canals of the 3rd class is that most (but not all) take their rise in little "gulfs" of the dark areas, just as the larger canals do in larger "gulfs."

254. Jarry-Desloges, R.,  
CHANGES ON THE SURFACE OF MARS, Comptes Rendus, 183,  
29 November 1926, pp. 1025-1026.

A record of the changes in the surface appearance of Mars noted during the opposition of 1926. More changes took place during this opposition than have been observed previously.

255. Katterfel'd, G. N.,  
TECTONIC ORIGIN OF THE LINEAR FORMATIONS ON MARS,  
Vsesoiuznoe Geograficheskoe Obschestvo, Leningrad, Izvestiia,  
91, No. 3, May/June 1959, pp. 272-283.

An analysis of the statistics of the Martian "canals" and their azimuthal distribution reveals that they are more numerous in the

southern than in the Northern Hemisphere. This corresponds to the greater number of "oases" in the Southern Hemisphere and to the greater area of the marine submergence of the southern half of Mars. Hence the canals appear to be associated with the cases not only locally but also genetically. In the Northern Hemisphere a north-east concentration of the canals predominate while in the Southern Hemisphere a south-east one predominates. In both hemispheres the canals inclining to the east are more than  $1\frac{1}{2}$  times more numerous than those inclining to the west. An examination of the fractures and fissures on the surface of the moon indicates that in both hemispheres meridional fractures predominate over latitudinal ones and in the diagonal system of the Northern Hemisphere north-east directions are more frequent while in the Southern Hemisphere the south-east direction prevails over the south-west. The lunar fractures indicate the presence of a mobile and plastic subcone layer deforming the solid outer envelope as a result of tidal and rotational action; and the process of fracturing is associated with mountain formation. The Martian "canals" resemble the African rift valley. The arid nature of the Martian surface and the probable absence of extensive sedimentary deposits favor more plastic rocks on the surface of the planet absence of extensive sedimentary deposits favor more plastic rocks on the surface of the planet and hence a straight line axial extension of fractures in contrast to crustal deformation characteristics of the earth. The prevailing direction of linear structure of Mars corresponds to the figure and the position of the axis of rotation of the planet. This also indicates the endogenous origin of the "canals." The "canals" are zones of tectonic rifts nourishing plant zones and "oases" with tectogenic deep waters. On the basis of an analysis analogous to the origin of tectonic fractures on the surface of the earth, of the azimuthal statistics of "canals" of Mars and of the roses of the fractures of Mars and of the moon it is concluded that the tectonic origin of the "canals" of Mars is associated with the variable total compression and is determined by the uneven rotation of the planet and the lines and oases can be regarded as centers of tectonic deformation. The distribution of the centers of deformation on the surface of Mars is determined by pulsations of the form of the planet accompanied by its uneven rotation. The "oceanicity" of the Southern Hemisphere and the contraction of the Martian "seas" from north to south is homologous to the oceanicity of the southern hemisphere and contraction of the continents of the Earth of the south and have the same general cause--the asymmetric figure of the planet relative to the plane of the equator. The tectonic character of the planet is associates with its unequal gravitational compression and rotation.

256. Lowell, P.,  
CANALS OF MARS, Science, 21, 17 March 1905, pp. 416-417.

By tabulating comparisons of the observations of Schiaparelli in 1888, and Lowell in 1903, the author shows the probable truth of the measures by the three points: (1) The fact of similar formations showing double to both observers; (2) the agreement in relative widths of the double canals; (3) the agreement as to their absolute widths.

257. Lowell, P.,  
FIRST PHOTOGRAPHS OF THE CANALS OF MARS, Roy. Soc., Proc. Ser. A., 77, 8 February 1906, pp. 132-135.

After many attempts the author has succeeded in obtaining very beautiful photographs of the planet Mars, showing most distinctly the canals which have given so much occasion for controversy. They were secured with the 24-in. refractor at the Flagstaff Observatory, Arizona, and are much superior to those obtained last year. The improvement has been made possible by a very close study of the necessary atmospheric conditions for perfect definition. It has been found that much depends on the wave-length of the air disturbance compared with the diam. of the objective; if this length is double the diam. of the glass there will be a bodily oscillation of the whole image in the field of view; but if the wave-length is shorter than this, partitive motion occurs, while the bodily motion is reduced, and though we may get a steady image, a blurring and finally a complete obliteration of the delicate detail ensues. In many cases quite surprising improvement was secured by diaphragming down the objective to the proper degree suitable for the particular wave currents traveling at the moment. Another important feature which is through to have greatly conduced to success was the introduction of a colour screen specially suited to the colour-curve of the objective. For the photographs Cramer isochromatic plates were employed, and the camera was so arranged with a repeating back that numerous pictures of the planet could be obtained on the same plate, so as to increase the chances of catching the intermittent periods of best definition. In this way some 700 images of the planet were photographed during the time that it was favourably placed for observation at the last opposition. The time available was only while the planet subtended an arc of about 15 seconds, and most of the plates show the canals. The photographs show that, within the limits imposed by the silver grains of the plates, the canals are lines, narrow and direct, following either arcs of great circles or curving (like the Djihoun) in a systematic manner, thus proving, to the extent of their ability, the conclusions previously reached at Flagstaff from eye observations. The author does not wish to assert positively at present, but he thinks he

has evidence that both a double canal and a double oasis have been photographed. In the reproductions given in the paper there are drawings shown which were made at the same time but quite independently, and there is a very marked agreement in most of the features.

258. Lowell, P.,

THE CANALS OF MARS, OPTICALLY AND PSYCHOLOGICALLY  
CONSIDERED, Astrophys. Journ., 26, October 1907, pp. 131-142.

Lowell says that Newcomb, in discussing the diffuse border to the image of a point or line produced by telescopic aberration, has overlooked the two following facts: Firstly, that the brightness of an out-of-focus image is in inverse proportion to its area; secondly, that the eye is not equally sensitive to all colours. The effect of these two factors, according to Lowell, is to produce a curve of intensity not unlike that of the diffraction pattern for a circular aperture. He then cites as an argument against Newcomb's conclusions the sharpness of edge of the spurious disc of a star and of the surrounding rings. He also quotes some of Dennis Taylor's experiments on star discs [Roy. Astronom. Soc., Monthly Notices, 54. pp. 67-84, 1893] as giving results in contradiction to Newcomb's. He mentions that, in the clear air of Flagstaff, the shadows of Jupiter's satellites appear in the telescope so sharply edged as to look like black spots in the focal plane. Ink lines on paper viewed through the telescope at great distances appear as sharp as when seen close with the naked eye. On the other hand, faint shadings are seen on Venus and Jupiter totally differing in appearance from the "canals" of Mars. Referring to alleged discrepancies in the Flagstaff drawings, Lowell explains that none such are found between independent observers working consecutively. Such discrepancies as exist are mainly due either to change in atmospheric conditions or to seasonal change in the planet itself. He says Newcomb placed the disc used in his sketching experiments at such a distance as to subtend less than a third of the diameter of Mars as seen at Flagstaff during this opposition. For the copy of this disc reproduced in Newcomb's article the proper distance for viewing is only 2.7 m. (8.7 ft.), and the discontinuities in the lines are then easily seen. Even at the distance 30.3 ft., corresponding to that at which the original was sketched, the greater part of the lines reveal their composite character. Further, in the original experiment the disc was viewed by transmitted light, whereas in practice Mars is seen by reflected light. Experiments on the detection of irregularities or breaks in lines were made at Flagstaff through a 4-in. telescope upon ink lines ruled on paper set up at a distance of 585 ft. It was found possible to perceive: (1) A difference in thickness corresponding to 3 miles on Mars; (2) a break corresponding

to over 18 miles (29 km.) on Mars; (3) a line of width less than 2 miles (3 km.) on Mars. Note on the preceeding paper. S. Newcomb. Newcomb, replying, cannot concede that either of the two factors mentioned above has been omitted by him in such a way as to change the character of his results. These results are based on light between  $\lambda$  5614 and  $\lambda$  5894--a region in which the intensity is nearly uniform. He remarks that Lowell seems to overlook the difference between the shading off of dispersed light around the sharpest image of a luminous point, and the diffusion by aberration of the image of a black point on a bright background. He asserts that Lowell's useful telescopic observations of artificial dark lines, and the citations from Dennis Taylor, afford excellent illustrations of the process of visual inference mentioned in his paper. To correct misapprehension, he adds that his argument is not directed to prove that the canals of Mars are not fine dark lines, but only to show that there are a number of other features which an observer may train himself into interpreting as fine dark lines, and that the actuality on Mars may therefore differ from the observer's inferences. P. Lowell. Lowell (in reply to Newcomb's note) remains unconvinced, and remarks that it is precisely to light between  $\lambda$  5614 and  $\lambda$  5894 that Taylor's experiments referred. He responds to a challenge to revise Newcomb's computation of the area of the image of the canal system on the retina. The breadth of the canals is too small to be sensible and can only be got by comparison of intensity with the micrometer thread and by other experiments, giving 15 miles as the average maximum width. From the zonal numbers and breadth he calculates that the actual area on the planet is one-tenth of the surface. The probable retinal area he estimates as twice this value, assuming that when a single cone is struck it responds in toto to the stimulus, gauging size solely by intensity. If the cone does not respond in toto the area diminishes to the first-named value as its limit.

259. Lowell, P.,  
MARS. DUPLICATION OF SOLIS LOCUS, Lowell Observatory, Bull.,  
No. 28, Nature, 76, 11 July 1907, p. 258.

Lowell records that the Solis Locus showed double on May 18, being the first time it has appeared divided since the summer of 1894. It is not a case of gemination, as the two portions are not alike either in shape or size, nor were they in 1894. Along the canals which emerge from the eastern part, a new one was detected for the first time on May 18, and has received the name Ichor. The south polar cap has retreated southward, leaving dark ground behind it, and it is noticed that the canals connecting the Solis Locus on the south are darker and more easily visible than those proceeding from it on the

north, although the tilt of the planet's axis should render the former more difficult of detection. From the appearance of the dark ground Lowell argues that water, and not carbon dioxide, is concerned. It would follow from this that the temperature in this region, latitude  $42^{\circ}$ - $52^{\circ}$ , was already higher than  $0^{\circ}\text{C}$ . on May 18.

260. Lowell, P.,  
MARTIAN FEATURES, Lowell Observatory, Bull., No. 34, Nature, 79, 28 January 1909, p. 378.

The Bulletin describes, and gives positions of, eight white spots observed in the arctic and sub-arctic zones of Mars by Flagstaff observers, and which appear year after year in the same places. The chief spot appears in long.  $206^{\circ}$ , lat.  $83^{\circ}$  N., and was first observed by Schiaparelli in 1884; in 1903 at Flagstaff it was observed from June 21 to Aug. 10, Martian dates, being seen at every one of the six presentations.

261. Lowell, P.,  
ORIGINAL CANALS OF MARTIAN DOUBLES, Lowell Observatory Bulletin, No. 37, Nature, 80, 29 April 1909, p. 260.

Occasionally one of the component lines of a double canal on Mars becomes more conspicuous than the other, and continued observations indicate that it is always the same component which is so affected. A table is given showing eighteen of these peculiar canals, out of a total of twenty-two observed during 1907.

262. Lowell, P.,  
MARKINGS ON MARS, Nature, 82, 3 February 1910, pp. 397-398.

In regard to the recently expressed opinion that certain telescopes are too powerful to show the minute detail on Mars, the author replies that in certain cases large telescopes are liable to less accurate definition. The spurious disc and rings made of a star by a telescope is a real image, due to the interference of the light-waves. If atmosphere and glass be perfect, this image consists of a round disc, encircled by concentric and continuous rings of light. The only difference in the image with different apertures is that the larger the aperture the smaller the disc, and the closer and thinner the rings. If this image assume any other form, it is either because the objective is poor, or because the seeing is defective. In proportion as the seeing is bad, the rings begin to waver, then break up into fragments, and finally end in an indiscriminate assemblage of points. With a certain

amount of this unsteadiness it is found that by stopping down the aperture of the objective a point is reached where the definition is best. This same criterion will also apply to the delineation of fine detail on a planetary disc, and a series of linear markings would, under such conditions, break up into a mosaic, contrary to their true form of continuous linearity.

263.

Lowell, P.,

NEW CANALS ON MARS, Nature, 82, 24 February 1910, pp. 489-491.

On Sept. 30, 1909, when the region of the Syrtis Major came into view, two striking canals were at once evident to the east of the Syrtis, in places where no canals had previously been seen. One ran from the bottom of the Syrtis (lat. 20°N., long. 285°), the other from a point part of the way up its eastern side (lat. 17°N., long. 284°). Curving slightly to the left as they proceeded south, they converged to an oasis, itself new, on the Cocytus (lat. 5°N., long. 265°), about two-thirds of the distance to where that canal meets the Amenthes. With the two main canals were associated several small ones. These details were noted by E. C. Slipher and the author, and were subsequently photographed by Lampland. Thirty images were taken on each plate, and practically all show the new canals. Similar photographs taken in 1907 show no such features in this region. Reference to previous drawings made of the same region during Aug., July, June, and May failed to show any trace of their having been observed; the same remark applies to the recorded observations of previous years since 1894. The epochs at which similar seasonal presentations of the region have been observed were specially noted, but no record of these two canals was found. Additional evidence is given by a peculiarity of canal formation, in that while the great majority of the canals are quickened into conspicuousness alternately every six Martian months, first from the south and then from the north polar cap, there are some which respond only to one or the other cap. No canals in the position of these two new ones could be traced in the records. It would thus appear that they are actually new objects to Mars. The possibility of their being of artificial formation is then discussed.

264.

Milochau, G.,

OBSERVATIONS OF MARS AT MEUDON, Comptes Rendus, 137, 27 October 1903, pp. 636-639.

Several drawings of the planet are given showing the details observed with the great equatorial at Meudon during the spring months of 1901 and 1903. Special attention is drawn to the observations of the

fine elongated markings, which, seen as long threads in smaller instruments, are resolved into discontinuous shadings with the large refractor.

265. Newcomb, S.,  
INTERPRETATION OF THE SO-CALLED CANALS OF MARS,  
Astrophys. Journ., 26, July 1907, pp. 1-17.

The author begins by summarising data and formulae relating to telescopic aberration, with special application to the subject under discussion. He deduces that even with the best refracting telescope we cannot expect in practice to bring more than one-fourth the light of a star within a circle of radius 0.10 in. In the image of a star the dispersed light diminishes rapidly as we go out from the centre; but in the image of a bright line the diminution will evidently be much less rapid, since a point near the line will receive dispersed light from many points in the line. In the case of a black line or band observed against a bright background, the band will be partly illuminated by spreading of light from the bright edges which will be correspondingly dimmed. The effect will be to greatly widen the dark band at the cost of its blackness, and to render its borders indefinite. In discussing the psychological side of the question, it is to be noted that the eye does not perceive what is actually pictured on the retina, but unconsciously introduces a correction based on general experience. We have here a possible source of error, inasmuch as experience may prompt us to apply such correction to cases where the conclusion would be illusory. The process of visual inference plays a more important part as the object approaches the limit of visibility. The author has made experiments on the visual interpretation of dark lines on a white background, his method being to observe broken lines, drawn in ink, on paper placed against a window. At a certain distance the broken lines appeared uniform and continuous. Seen somewhat nearer the lines presented a blotched appearance. Drawings by Barnard, W. H. Pickering, and Bailey, the results of similar experiments made at the author's request, are reproduced; and it is suggested that experiments by other skilled observers, to test their own eyes, would be valuable. In one case the author saw lines on a paper he knew to be blank, the illusion being due to small irregularities of shade in the tissue. The article concludes with an attempt to calculate the area of Mars which would be covered by Lowell's canal system. Taking into account the facts that the canals are probably not black, and that the planet's surface is not uniform, he finds for the breadth of the narrowest visible canal 10 to 20 miles. To this must be added a border of 20 miles on each side, produced by aberration, diffraction, and atmospheric softening. Assuming 400

canals of mean length 1,500 miles, and mean breadth 55 miles, we have 33,000,000 square miles for the apparent area of the system as depicted on the retina. The total surface of Mars is about 55,000,000 square miles.

266. Pickering, W. H.,  
ATMOSPHERE OF MARS, Monthly Weather Rev., 42, August 1914,  
pp. 501-503.

Abstracts are made from a series of popular articles giving the main arguments for accepting the reality of the canals on the surface of the planet Mars. Attention is drawn to the presence of similar markings on the surface of the moon, when it is seen under a similar angle of view to that used for Mars with a telescopic power of about 500. Several well-known hypotheses concerning the possible nature of the Martian canals are noted, but the decision is left open as to whether there is any evidence for the existence of intelligent animal life on the planet.

267. Webb, W. A.,  
ON THE REJECTION OF THE MARTIAN CANAL HYPOTHESIS,  
Scientific Monthly, 85, No. 1, July 1957, pp. 23-28.

The author reviews briefly the controversy on the reality of the Martian canals and examines the question whether the rejection of the Martian canal hypothesis in accordance with the 1909 arguments of Hale and his associates agrees with current scientific evidence. An outline is presented of communication network theory which proves statistically that civilized continents of the earth are covered with lines that resemble in their disposition the Martian canals. Network patterns where a preponderance of the rays issue from four or more points are associated with human intelligent action; the Martian canals have a similar pattern. Suggestions for objective reliable observations of the Martian canals are suggested.

268. Worthington, J. H.,  
MARKINGS ON MARS, Nature, 85, 10 November 1910, p. 40.

During the 1909 opposition the writer was able to make numerous observations of the Martian features with the 24-in. refractor at the Lowell Observatory, Flagstaff, Arizona. An iris diaphragm was used over the objective, the best aperture being found to be about 18 in. Specially good views of the canals were obtained on Oct. 25, when the oases were also clearly defined.

## C. POLAR CAPS

269. Antoniadi, E. M. and Jonckheere, M.,  
PHYSICAL FEATURES OF MARS, Astronom Nachr., Nos. 4358,  
4363, and 4376, Nature, 82, 23 December 1909, pp. 227-228.

Discussion of the reality or otherwise of a dark band which has been described as surrounding the polar cap. If real, it should appear broader at the two extremities of the elliptical band; but the drawings show it as being about the same width throughout its extent.

270. Antoniadi, E. M.,  
DARK BAND SURROUNDING POLAR CAPS OF MARS, Roy. Astronom.  
Soc., M. N., 71, December 1910, pp. 144-145.

The writer briefly reviews the photographic evidence bearing on the relative brightness of the Martian polar caps and the general continental areas, showing that even on the best images taken at Mount Wilson there is no trace of the dark band which has been described by many observers from visual results only.

271. Antoniadi, E. M.,  
SOLAR RADIATION AND MELTING OF POLAR CAPS OF MARS,  
Roy. Astron. Soc., M. N., 76, June 1916, pp. 643-645.

Examination of the records of the melting of the polar caps of Mars from 1862 to 1914, furnishes satisfactory evidence of a relation between the phenomenon and the changes in the solar activity. Details of the principal cases are given. With a few exceptions, due to local causes on the planet, the melting of the polar caps is accelerated when sun-spots are numerous and retarded when they are few. A diagram is given showing the close relationship between the two phenomena.

272. Barabashov, N. P. and Koval', I. K.,  
CONTRIBUTION TO THE STUDY OF THE STRUCTURE OF THE SOUTH  
POLAR ICE CAP OF MARS DURING 1956, Astronomicheskii Zhurnal,  
Moscow, 35, No. 2, March/April 1958, pp. 261-264, Soviet Astronomy-AJ, New York, 2, No. 2, March/April 1958, pp. 234-238.

On the basis of the data of observations of Mars in 1956, made in visual light at various observatories of the world, and also observations in the ultraviolet made at the Kharkov Astronomical Observatory, one

of the possible interpretations of the structure of the ice caps of Mars is considered. The simultaneous disappearance of the southern polar cap around Sept. 1, 1956 in red and ultraviolet light makes probable the assumption that at that time the caps lay wholly on the solid surface of the planet (according to Wright, 1924). The contrast in brightness between the cap and the rest of the planet's surface observed in various parts of the spectrum is explained by the absorbing (besides the scattering) properties of the Martian atmosphere. An approximate estimation of the optical density of the planet's atmosphere in the ultraviolet ( $\tau \approx 0.3$ ) has been made.

273. Barnard, E. E.,  
SOUTH POLAR CAP OF MARS, Astrophys. Journ., 17, May 1903,  
pp. 249-257.

Observations taken at Lick Observatory with the 12- and 36-in. refractors during 1892 and 1894 respectively. The series of measurements show that the diameter of the S. polar cap underwent identical changes in the two corresponding periods leading up to the summer solstice, and the results are plotted in two curves. The cap, presumed to be of snow, continues to diminish after the summer solstice. The presence of an atmosphere is indicated. A yearly recurrence of a projection at the edge of the cap is attributed to a range of mountains.

274. Fessenkoff, V. G.,  
ON THE EXISTENCE OF OPEN BODIES OF WATER ON MARS, Astr. J., USSR, 26, No. 5, 1949, p. 273.

The white spots covering the polar regions of Mars are undoubtedly masses of ice, whose thickness must be small because of their rapid recession during the Martian summer. The author believes, however, that there are no open bodies of water, even of moderate size, because we fail to observe the reflection of the sun from water surfaces. Assuming a quiescent water surface of unlimited size, having the same surface curvature as Mars, he computes that the apparent magnitude of the reflected sun as seen from the earth would be +1.5. The size of the water surface plays no role if 2 lines of sight to the opposite edges of the area, after reflection by the water, diverge at an angle greater than that of the sun. In this manner he finds  $R_{\min} = 7.4$  km. Next,

he uses data by Hecht on the visibility of point sources on an illuminated background. This leads for a 20 in. telescope to a limiting magnitude of 9.0, which should still be detectable as a bright spot on the surface of Mars. Therefore, the author concludes that a body of water covering an area with a diameter of 300 m should still be detectable. He suggests

that there may be no free water at all and that this may have a bearing upon the question of the existence of plant life on Mars.

275. Focas, J. H.,  
POLARIMETRIC AND PHOTOMETRIC STUDY OF THE POLAR CAPS  
AND OF THE DARK REGIONS OF THE PLANET MARS, Academie  
des Science, Paris, Comptes Rendus, 246, No. 11, 17 March 1958,  
pp. 1665-1667.

The polarization of light at different regions of the planet Mars were measured from Pic-du-Midi in 1954 and 1956 as well as from the Observatory of Athens. The contract of circumpolar and temperate Martian spots showed stronger seasonal variations than those of the equatorial regions and of those propagating from the poles toward the equator at the end of spring at a velocity of 36 km per hour, as determined at Meudon Observatory. The glare of polar crust is 1.3 times that of the clouds covering it in winter. The analysis is described for the southern polar cap, the dark regions, the northern and southern regions, the equatorial regions and some special areas. The variation of the glare of the southern polar cap and the curve of polarization are illustrated. Maximum and minimum values of polarization between -65° and +45° latitude are presented in a table.

276. Focas, J. H.,  
SEASONAL EVOLUTION OF THE FINE STRUCTURE OF THE DARK  
AREAS OF MARS, Planet. Space Sci., GB, 9, July 1962, pp. 371-381.

The seasonal darkening of the dusky areas of Mars starts with maximum thickness of the winter polar clouds. The regional brightness of the polar caps is connected with the profile of the relief. The average intensity of the dark areas increases from the poles towards the equator; the amplitude of the darkening waves decreases from the poles towards the equator. The combined action of the two darkening waves shows that the action of the darkening generating element is constant for all areographic latitudes during the Martian year. The distribution of the total intensity of the dark areas, the sizes and frequency in areographic latitude of dark blocks or nuclei composing the dark areas of the planet, depend on the duration of the action of the darkening generating element.

277. Fournier, G.,  
MARS, 1935: SEASONAL PHENOMENA, Comptes Rendes, 202,  
6 April 1936, 11. 1262-1264.

Reports results of observations from 26th March to 12th June, at M. Jarry-Desloges' Observatory. Polar cap phenomena were perhaps two months in advance of 1920 and one month in advance of 1918 (comparable oppositions). Bright areas were observed in similar positions adjoining the cap; extensive atmospheric obscuration was also recorded. The dark material formed round the cap was irregularly distributed; L. Hyperboreus was the principal "reservoir" and the seasonal development of streaks leading to lower latitudes was confirmed. The N. part of Syrtis Major was exceptionally intense and well defined.

278. Hamilton, G. H.,  
MARS IN 1918, Lowell Observat. Bull., No. 82, Nature, 106,  
3 February 1921, p. 743.

Observations and drawings closely corroborate those of Lowell. Dark band round polar cap only when melting, edges indistinct when forming. The inference is that the band is not an optical effect. The author claims to have seen surface water flowing from the melting polar cap to join the Lacus Hyperboreas. He also noted seasonal development of "canals" towards equator, as described by Lowell. The "seeing" varied in patches according to local Martian atmospheric conditions.

279. Hess, S. L.,  
METEOROLOGICAL APPROACH TO THE QUESTION OF WATER  
VAPOR ON MARS AND THE MASS OF THE MARTIAN ATMOSPHERE,  
The Project for the Study of Planetary Atmospheres, Lowell Observatory, Report No. 1, 1 January-1 July 1948, Contract No. Cwb-7896, also in Astronomical Society of the Pacific, San Francisco, Publications, 60, No. 356, October 1948, pp. 289-302.

This paper is intended as an attempt to reconcile the contradictory evidence provided by visual and radiometric techniques on the one hand, and spectroscopic techniques on the other, by examination and computation in the light of meteorological knowledge and techniques. The author covers: water vapor vs. CO<sub>2</sub> as the element forming Martian "polar caps"; possible types of clouds; consequences of the existence of low-level water clouds and high-level convective clouds and, finally computation of the surface vapor pressure and surface atmospheric pressure.

280. Jonckheere, R.,  
STUDIES OF THE PLANET MARS, Comptes Rendus, 149,  
29 November 1909, pp. 969-971.

The observations were made at the observatory of Hem with a refractor of 0.35 m. aperture, and 6.5 m. focus. A list is given of measures of the south polar cap from July 16 to Nov. 18. The greatest value is  $4\cdot33''$  or  $32^\circ$  (aerocentric arc) on July 16, and the least  $1\cdot28''$  or  $9\cdot5^\circ$  on Nov. 14. The widths are influenced by the longitude, and by the presence of lands covered with snow in the vicinity. An island, identified as Novissima Thyle, emerged from the polar snows on Aug. 11, Argyre II. was seen on Sept. 2, and the same night a new land ( $120^\circ$ ,  $-84^\circ$ ) was discovered in the polar snows, and named Stella from its brightness. All these were measured for position. The canals began to appear Sept. 1, and 23 new ones were observed. Another new land ( $100^\circ$ ,  $-43^\circ$ ) was found Oct. 5, and named Thaumas. From measures of the diam. of Mars on Sept. 21, 23, 24, 27, the value  $24\cdot325''$  was deduced for the mean diam. This gives for unit distance the value  $9.533''$ , corresponding to a radius 3444 km. The polar flattening was measured as 1:270.8.

281. Jarry-Desloges, R.,  
GRADUAL SHRINKING OF SOUTH POLAR CAP OF MARS DURING  
OPPOSITION OF 1909, Comptes Rendus, 149, 27 December 1909,  
pp. 1346-1349.

The South Polar Cap was observed from the beginning of June until the date of writing, when it was so small, and dull of hue, as to be barely perceptible. A series of 16 drawings shows the principal details observed, cracks, grey or dark regions, bright spots, &c. while the process of shrinking can be traced by help of a diagram constructed from micrometric measures by G. Fournier. The summer solstice for the south hemisphere occurred on Sept. 14. The lightest regions were situated, as a rule, approximately in the position of the so-called "islands," such as Novissima Thyle. The extra whiteness may be due either to more recent precipitation or to reflection of the solar rays from inclined planes. The general deduction from the observations is that the surface underlying the Polar Cap is of very varied relief, and it is suggested that careful future study of the phenomena accompanying the shrinking of the cap may furnish data concerning the contour of the ground and nature of the watersheds.

282. Jarry-Desloges, R.,  
PHYSICAL OBSERVATIONS OF MARS, Comptes Rendus, 152,  
1 May 1911, pp. 1142-1144.

Summing up the general results from observations made at the three stations of Revard, Massegros, and Toury it is remarked that

one of the chief points noticed was the regularity with which the south polar cap diminished and disappeared. On the contrary the changes noted in the form of the dark markings did not exhibit any definite regularity. The various discolourations which have been seen from time to time are at present inexplicable. A few remarks are given describing the interference of terrestrial air-currents on the definition of celestial objects seen through the disturbed air strata.

283. Jarry-Desloges, R.,  
BRIGHT AREAS ON MARS, Comptes Rendus, 172, 3 June 1921,  
pp. 1473-1474.

The north polar cap of Mars, from observations in Algiers, appears to be very eccentric with reference to the axis of the planet. Various positions are given in a diagram, with dates, and it is to be noted that on April 25, 1920, the actual pole was outside the polar cap. Nix Olympica [see Abs. 1562 (1920)], or at any rate the white patch in which it is situated, seems to have occupied the same position in 1916 as in 1918 and 1920, according to the records of the Setif Observatory.

284. Jarry-Desloges, R.,  
PHENOMENA ACCOMPANYING THE SOUTHERN POLAR CAP  
REGRESSION ON MARS, Comptes Rendus, 209, 7 August 1939,  
pp. 344-346.

At the author's observatory at Setif, Fournier and Hudelot observed at the opposition of Mars in 1924 the epoch and positions of the principal fissures, which seemed to issue from a central sinus; they extended along  $80^{\circ}$  parallel, between  $150^{\circ}$  to  $330^{\circ}$  meridians, but were not all necessarily coexistent. They find that the climatic conditions in southern Mars are very stable. Novissima Thyle broke off at the same epoch as an island, in 1909 and 1924 (within 2 days). Yellow colours are characteristic of the early southern spring, the yellowness being due to vapours, and indicate a very transparent atmosphere, at this time of year. The polar cap "dark" border is real, and not due to contrast. Several of the troughs correspond exactly to the positions of fissures (already disappeared), and are comparable in size with these.

285. Aerospace Information Division, Washington, D. C.,  
WATER ON MARS, 1 October 1962, review of ON THE QUANTITY  
OF FREE WATER ON MARS by A. I. Lebedinskiy and G. I. Salova,  
Astron. Zhur. Akad. Nauk SSSR, 39, No. 3, May-June 1962,  
pp. 494-505.

The possibility of the existence of free water on Mars in the form of a thin snow layer or as fog is discussed. The quantity of such water is determined by two methods, both involving the change of the Martian seasons. The first method relates the formation of the polar icecaps to ice crystals carried from place to place by Martian winds. Part of these crystals thaw on the day side, freeze at night, and either fall to the surface or remain in the atmosphere. The size of the ice crystals and their time of formation is computed, and the results show that crystals with radii  $< 10\mu$  could remain suspended, but that those with radii =  $10\mu$  would quickly fall to the surface. The quantity of solid water in the polar icecaps is computed by the second method which relates the mean quantity of ice crystals per unit area of the icecap to the heats of fusion and evaporation of these crystals for various temperatures. Thickness of the snow layer is then computed for the various seasonal changes noted in the polar icecap. The quantity of crystals and the evaporation energy are found to diminish as the time required for thawing decreases. The probable average thickness of the Martian snow layer is  $0.01 \text{ g/cm}^2$ , and the total amount of water in a winter polar cap is about  $2 \times 10^{15} \text{ g}$ .

286. Leighton, R. B. and Murray, B. C.,  
BEHAVIOR OF CARBON DIOXIDE AND OTHER VOLATILES ON MARS,  
Science, 158, 8 July 1966, pp. 136-144, Grant No. NsG-426, Nsg-56-60.

Outline of a thermal model of the Martian surface which suggests that the polar caps of Mars are solid carbon dioxide. The expected diurnal and annual temperature variations at various latitudes are investigated. Calculations which permit the condensation of CO<sub>2</sub> are made; these are made progressively more complete and realistic until ultimately even the effects of orbital eccentricity and depletion of CO<sub>2</sub> by freezing are included.

287. Lowell, P.,  
SOUTH POLAR CAP OF MARS, Nature, 76, 13 June 1907, p. 161,  
from Lowell Observatory Bull., No. 26.

Observations of the south polar cap during the favourable opposition of 1905. The paper gives the latitudes of the edge of the cap in successive longitudes, as seen during the period May 10 to Aug. 14. They indicate that during the beginning of the opposition cloud or mist enveloped the polar cap, as the edge was not definitely recognised until May 15.

288. Lowell, P.,

MARS IN 1907. OBSERVATIONS AT THE LOWELL OBSERVATORY,  
Nature, 76, 29 August 1907, p. 446.

The results exceed expectation, in view of the unfavourable southern declination of the planet. Work was begun in March,  $3\frac{1}{2}$  months before opposition, so that the polar caps could be observed at the interesting phase when the southern one had its maximum, the northern its minimum, extent. In one respect the occasion was exceptionally propitious, for the planet was "upon an even keel" as regards the earth, the equator lying nearly in the plane of sight. The southern cap at first stretched across  $95^{\circ}$  of latitude, the northern only over  $8^{\circ}$ . Subsequent observations bore out the testimony of the two previous oppositions as to the curious manner in which the northern cap is formed [see Lowell Observatory Bulletin 30]. In addition to noting changes in both polar caps, the observers watched the development of the canal system in the antarctic and south temperate zones. After the melting of the south polar cap had got well under way, canals began to make their appearance about it, running thence down the disc. These canals left the cap at its edge and joined the rest of the system in lower latitudes. In connection with these polar phenomena, the light region, Thaumasia, lying around the Solis Lacus, first showed symptoms of awaking activity. The Solis Lacus appeared composed to two portions, a large oval patch on the east and a smaller round one on the west. Of the canals joining it to the dark areas, those on the south were now darker and more pronounced than those running north. Meanwhile the equatorial canals were steadily fading out. The process of evolution was similar to that observed during the northern presentation in 1903. Photographs show more detail than at the last opposition owing to the increased size of the disc. Fifty-six canals have been counted on various plates, the twin Gihon has been photographed double, and such delicate markings as Fons Juventae and the little canals leading to it appear unmistakably in the prints. Such larger matters as the dwindling of the southern snow-cap show well, and it seems as though the scheme of settling points of Martian topography by measures of photographs was in process of realisation. The paper is illustrated by three reproductions of photographs of the disc, with Solis Lacus near the central meridian. Some 8 canals radiating from Solis Lacus, together with a few others in its near neighborhood, are shown sharply and distinctly; two or three long, faint ill-defined bands can also be traced crossing the body of the planet further north.

289. Lowell, P.,  
HABITABILITY OF MARS, Nature, 77, 19 March 1908, p. 461.

This is a reply to the opinions expressed by Wallace in his book. He shows that as the south snow cap comes down to 36.5° latitude on the average, this will provide an area of 11,330,000 sq. miles of snow. The canal system covers some 4,750,000 sq. miles, so that when the snow melts we may have a depth of quite 2½ ft. The argument for temperature is equally erroneous, as the effect of blanketing has been taken into account. The theory of Wallace as to Mars having completely lost all internal heat is considered invalid, for it can be shown that Mars could not have captured any meteoric swarms not traveling in its own orbit when it coalesced into a planetary mass. G. Johnstone Stoney (*Ibid.* pp. 461-462) contributes a few remarks concerning the evidence for thinking that certain gases can effect their escape from planetary atmospheres, and of the weight such evidence has on the theory of constitution of the atmosphere of Mars. Mention is made of the failure of various observers to detect water vapour on Mars, suggesting that its visibility is variable.

290. Miyamoto, S.,  
METEOROLOGICAL OBSERVATIONS OF MARS DURING THE 1962-63  
OPPOSITION, Kyoto U. Inst. of Astrophys. and Kwasan Obs., 1963.

In Martian spring, the Propontis-Cerberus and Nilokeras-Lacus vapor courses were well developed and very dark, whereas the Utopic-Nodus Laocoontis course was somewhat fainter than in the 1960 opposition. Compared with the 1960 opposition, the polar cap in 1963 was larger, and in late spring, the retreat of the cap stopped and even increased its dimension for a while. The Casius-Neith yellow cloud appeared at the same season as in the last opposition, and in summer, an outburst of the Noachis white cloud was observed across the equator. The doldrum was conspicuous in spring. It followed the subsolar point and faded in summer.

291. Otterman, J. and Bronner, F. E.,  
MARTIAN WAVE OF DARKENING--A FROST PHENOMENON?,  
Science, 153, No. 3731, 1966, pp. 56-60.

A new hypothesis attributes the Martian "wave of darkening" to soil frost phenomena. Diurnal thawing and freezing of the ground, which uses moisture transported by the atmosphere from the melting polar cap, can produce various minute, frost-heaved, soil surface features. These microrelief features result in a complex porous

surface structure, which causes optical darkening. The boundary at which the wave of darkening terminates on the winter hemisphere correlates with the latitude at which the diurnal peak surface temperature drops below 0°C. The hypothesis is examined in terms of known properties of the Martian atmosphere and surface and the availability of water.

292. Phillips, T. E. R.,  
OBSERVATIONS OF MARS IN 1924, Roy. Astron. Soc., M. N., 85,  
December 1924, pp. 179-184.

Between June 23 and November 30 twenty-five whole-disc drawings and sketches of particular features were made, some of which are here reproduced. Although the south polar cap diminished greatly, it never entirely disappeared, as in 1894, near sunspot maximum; thus the relation between the melting of Martian snows and the sunspot cycle, announced by Antoniadi and by Shajn of Pulkovo, is confirmed. Deformations of the terminator, suggesting the formation of cloud, were twice clearly seen.

#### Section IV. MARTIAN PHOTOGRAPHIC STUDIES

293. Antoniadi, E. M.,

SOME PHOTOGRAPHIC IMAGES OF MARS TAKEN IN 1907 BY  
LOWELL, Roy. Astronom. Soc., Monthly Notices, 69, December  
1908, pp. 110-114.

Notes on a print showing 40 images of Mars taken on July 11, 1907, when the longitude of the centre of the disc was about  $250^{\circ}$ . The 40 images differ widely in the amount of detail recorded, and also the same markings presents themselves under varying forms, owing probably to atmospheric tremors. The superior brightness of the limb, so striking a feature in visual observations, is non-existent on the photographs. Schiaparelli depicted the Maria as bordered by darker canals whenever the markings were seen to double, but no trace of such a structure is shown. In accordance with Schiaparelli's map, the part of the South hemisphere between the Maria and polar cap is dusky. The "islands" in this expanse is known to be ruddy. Seven "lakes" are shown, and 17 "canals" are more or less discernible, corresponding, with one exception, to canals of Schiaparelli. All these canals are diffuse. Comparison of the photographs with Schiaparelli's observations furnishes strong evidence of change in the form and intensity of the dusky areas. For instance, Syrtis Major had always the form of a regular V to Schiaparelli, but in the photographs it shows a distinct bulge to the north-east. A reproduction of a composite drawing made by the writer from the prints accompanies the paper.

294. Antoniadi, E. M.,

DRAWINGS FROM PHOTOGRAPHS OF MARS, Roy. Astronom. Soc.,  
M. N., 71, June 1911, pp. 714-716.

The drawings are made from several photographs of Mars made by Barnard in 1909 with the 40-in. Yerkes refractor, and by Hale with the 60-in. reflector at Mount Wilson. Many of the details thus recorded for the first time photographically had been seen by the author with the large refractor at Meudon, near Paris. The new photographs have been obtained with the aid of colour screens, and by this means it is now proved that the limb of the planet is not brighter than the central region. Also the general continental regions are seen to be varied in shading, and not uniformly yellow expanses as has been sometimes represented. Some of the markings appear to be identical with those portrayed as far back as 1877, thus indicating remarkable stability for certain of the natural surface features.

295. Barabascheff, N. and Semejkin, B.,  
COLOUR-FILTER PHOTOMETRY OF MARS, Zeits. f. Astrophyski,  
8, February 1934, pp. 44-45.

As part of a general study of planetary photometry at Kharkov observatory, photographs of Mars with red, yellow, and blue filters have been measured with the Koch microphotometer. Lambert's Law holds for the surface. Scattering follows Rayleigh's equation except for the blue filter, which gives wide divergence. Albedoes and transmission coefficients are given. The brightness of several regions in 20° longitude (Argyre, Oxia, etc.) agrees with that found by Gotz. Special albedoes for red radiation are: deserts, 0.153; seas, 0.133; polar regions 0.220.

296. Barabashov, N. P. and Koval', I. K.,  
PHOTOGRAPHIC PHOTOMETRY OF MARS WITH LIGHT FILTERS IN  
1956, Izd-vo Khar'kovskogo gosudarstvennogo universiteta, Kharkov,  
1959.

The methods and results of investigating Mars at the Kharkov Astronomical Observatory during the great opposition in 1956 are presented. All of the material on the absolute photometry of Mars as well as some of the results of visual observations of its surface are given.

297. Barabashov, N. P.,  
ON THE ATMOSPHERE AND SURFACE OF MARS, Akademiiia Nauk  
SSSR, Komissiia po Fizike Planet, Izvestiia, No. 2, 1960, pp. 3-23.

Data on the Martian disk obtained in 1939, 1954, and 1956 by means of photographic photometry are analyzed. Values of the optical parameters of the atmosphere of Mars are computed. These parameters indicate that the Martian atmosphere possesses diffusive properties and has a small optical thickness.

298. Barabashov, N. P., Koval', I. K., and Chekirda, A. T.,  
SOME RESULTS OF THE PHOTOMETRY OF CLOUD FORMATIONS  
ON MARS, Akademiiia Nauk SSSR, Komissiia po Fizike Planet,  
Izvestiia, No. 2, 1960, pp. 36-40.

Some results of photometric measurements of "blue clouds" on Mars made in 1958 through ultraviolet and blue light filters are presented. It is found that the brightness contrast between clouds located near the intensity equator on the limb or terminator, and those in adjacent regions of the disk, has an average value of 14%.

299. Barabashov, N. P., Koval', I. K., and Chekirda, A. T.,  
PHOTOMETRIC OBSERVATIONS OF MARS IN 1958, Akademiya  
Nauk SSSR, Komissiya po Fizike Planet, Izvestiya, No. 3, 1961,  
pp. 3-15.

Photometric observations of Mars were made from September through November 1958 on the 270-mm reflector of the Kharkov University Astronomical Observatory. No correlation was seen between the data for contrasts in red and blue light for points lying within the aerographic longitudes of 90-200°.

300. Becker, W.,  
VARIABILITY OF THE OUTER PLANETS AND CORRELATED  
PHENOMENA, Preuss. Akad. Wiss. Berlin, Ber. 28, 1933,  
pp. 839-859.

Photometric observations of Mars, Jupiter, Saturn, Uranus, and Neptune are reduced to Harvard scale and mean opposition, and tabulated. Published observations as well as the author's are used. The period covered is from 70 to 90 years. The curves of about  $\frac{1}{2}$  magnitude. Mars shows irregular pointed maxima, no period obtainable; Jupiter, a period of about  $11\frac{1}{2}$  years, similar to that obtained from belts, etc.; Saturn, great irregularity, and some correlation with white spots; Uranus, orbital period, with  $8\frac{1}{2}$  year period superimposed, and sudden changes in short period; Neptune, more doubtful period of 21 years. Albedo and colour index are discussed.

301. Binder, A. B.,  
MARINER IV - ANALYSIS OF PRELIMINARY PHOTOGRAPHS,  
Science, 152, 20 May 1966, pp. 1053-1055.

Comparison of the surface structure of the earth, the moon, and Mars, using photographs from Mariner 4. Comparison of the crater-diameter distributions for Mars and the moon indicates the surface of Mars is  $2.2$  to  $3 \times 10^9$  yr old, implying that large-scale subaerial erosion occurred during Mars' early history. The frequency (13% for Mars, 11.7% for the moon) of central peaks in craters of diameter  $>10$  km indicates that the peaks may be a direct result of an impact mechanism rather than of postimpact volcanism. The presence of a well defined system of lineaments on the Mariner photos indicates that Mars may have lost appreciable angular momentum during its history.

302. Bronshten, V. A.,  
ON THE QUESTION OF THE PHOTOGRAPHIC PHOTOMETRY OF MARS  
AT GREAT PHASE ANGLES, Akademiya Nauk SSSR, Vsesoyuznoye  
astronomo-geodezicheskoye obshchestvo, No. 32, 1962, pp. 15-22.

To determine the basic optical parameters of the Martian surface and atmosphere, viz., brightness  $r$ , smoothness factor  $q$ , and optical thickness of the atmosphere  $\tau$ , observations were made near opposition when the phase angle of the planet  $\vartheta \leq 9.5$ . Brightness  $r$  is a function of three parameters: the angle of incidence  $i$ , the angle of reflection  $\epsilon$ , and the azimuth of the reflected light  $a$ . Several methods are proposed to clarify the function  $r(i, \epsilon, a)$ . The form of the function for each value if  $i$  can be expressed by a geometric surface, an indicatrix of scattering. The Department for the Study of the Planets and the Moon, Moscow Branch of the All-Union Astronomical and Geodetic Society, is reported to be making model experiments to explain the dependence of  $r$  on angles  $i$  and  $\epsilon$  at different phase angles  $\vartheta$  and different degrees of surface roughness.

303. Bugaenko, L. A., Bugaenko, O. I., Koval', I. K., and Morozhenko, A. V.,  
BRIGHTNESS DISTRIBUTION IN THE MARGINAL ZONE OF MARS,  
Physics of the Moon and Planets, I. K. Koval, ed., Naukova Dumka,  
Kiev, 1964, pp. 54-57.

Presentation of the results of photoelectric observations of Mars by the method of cross sections. The brightness distribution along the visible radius of the planet was traced up to  $\tau = 0.97$  of the Mars radius. The results, averaged and corrected for turbulent vibration of the image and for the dimension of the diaphragm ( $D = 0''.35$ ), are tabulated. It is found that for  $\lambda < 390$  mu, the atmosphere of Mars possesses a considerable true absorption, while at large wavelengths the main role is attributed to scattering.

304. Bugaenko, L. A., Bugaenko, O. I., Koval', I. K., and Morozhenko, A. V.,  
THE BRIGHTNESS DISTRIBUTION IN THE MARGINAL ZONE OF MARS,  
Phys. of the Moon and the Planets, Israel Program for Scientific  
Translations, Ltd., Jerusalem, 1966.

Photoelectric cross sections of the planetary disk are used to measure the radial brightness distribution of Mars to obtain data on the brightness variation at the edge of the image and to increase accuracy of measurements. Observations, reported for the 1963 opposition of Mars, were made at the Cassegrain focus of a 70-cm reflector using light filters. Two photomultipliers served as radiation

pick-ups and the recordings were made on a loop oscillograph. Since errors in such observations are mainly due to turbulent vibrations of the image, only those observations made under the most favorable conditions were processed. At  $600 \text{ m}\mu$ , variation of brightness with angle of incidence is close to a Lambert-type variation. For  $355 \text{ m}\mu$ , the Martian atmosphere is considered to have considerable true absorption. It is concluded that the Martian atmosphere constantly carries scattering dust particles with radii of about one micron. For each wavelength from  $420 \text{ m}\mu$ , the values of the visual albedo at the center of the disk are used to find the limb for various values.

305. National Aeronautics and Space Administration, Washington, D. C., BRIGHTNESS DISTRIBUTION IN THE LIMB ZONE OF MARS by L. A. Bugayenko, O. I. Bugayenko, I. K. Koval", and A. V. Morozhenko, NASA TT-F-10018, March 1966, translated from Fiz. Luny i Planet, Kiev, 1964, pp. 54-57.

The results of photoelectric observations of Mars by the method of cross sections are presented. The observations were made in the Cassegrain focus of the 70 cm reflector at the Main Astronomical Observatory of the Academy of Sciences of the Ukrainian SSR. In the opposite of 1963, the brightness distribution along the apparent radius of the planet was traced up to  $r = 0.97R_\oplus$ . The data, averaged and corrected for turbulent scintillation of the image and for the finite size of the diaphragm ( $D = 0''.35$ ), are tabulated. It was found that for  $\lambda < 390 \text{ nm}$  the atmosphere of Mars possesses an appreciable true absorption, while for longer wavelengths scattering provides the main contribution.

306. Butslav, M. M., Kaliniak, A. A., and Kamionko, L. A., RESULTS OF THE PHOTOMETRIC REDUCTION OF PHOTOGRAPHS OF MARS OBTAINED IN THE NEAR INFRARED SPECTRAL REGION, Pulkovo, Glavnaya Astronomicheskaya Observatoriia, Izvestiia, 21, No. 3, 1958, pp. 63-71.

Some photometric results obtained during the opposition of Mars in 1956 are discussed. The absolute values of brightness of Mars expressed in units of solar brightness for the equivalent wavelengths of  $0.840$  and  $0.983\mu$  are found to be  $1.11 \cdot 10^{-6}$  and  $1.45 \cdot 10^{-6}$  respectively. The rate of change of brightness of Mars with wavelength, as well as of the Moon, is in good agreement with values determined earlier by G. P. Kuiper for the same spectral region. The brightness of scattered light due only to the hazy conditions in the atmosphere of Mars can be estimated as being as large as about 20% of the whole apparent brightness of the planet.

307. Camichel, H.,  
PHOTOGRAPHIC OBSERVATIONS OF MARS MADE AT PIC DU MIDI  
IN 1954, Bulletin Astronomique, Paris, 20, No. 2, 1956, pp. 131-139.

The observations of 1954 confirm the results of preceding oppositions. The position found for the pole is the same. The value for the radius is the same as that found in 1941, but differs from that found in 1943, 1946, 1948 and 1950. The same systematic errors have been found in the position of markings observed before and after the opposition.

308. Ebisawa, S.,  
PLANISPHERE OF MARS WITH THE LIST OF THE NAMES OF ITS  
SURFACE MARKINGS, Kyoto U. Inst. of Astrophys and Kwasan Obs.  
Contrib., No. 89, pp. 223-238.

The planisphere of Mars was constructed from many photographic and visual observations made in the United States of America, South Africa, Europe and Japan, from 1907 to 1956, including new dark markings and secular and temporal changes which took place since 1916. The list of surface markings include all of the names used by many observers.

309. Fielder, G.,  
PHOTOGRAPHS OF MARS TAKEN BY MARINER IV, Nature, 207,  
No. 5004, 1965, p. 1381.

Mariner IV photographs of Mars show craters analogous to the lunar craters, suggestive of volcanic terrain. The pictures are scored by ridge and depression lineaments similar to those on the Moon. A correlation is found between the trends of the lineaments and the directions of the previously mapped canals. It is tentatively suggested that the craters are not necessarily impact phenomena, and that the canals are not continuous markings as drawn on the older maps, but may be indicative of fractures or faults that dissect the solid surface.

310. Focas, J. H.,  
PHOTOMETRIC STUDY OF THE SEASONAL VARIATION OF THE  
BRILLIANCE OF THE REGIONS OF THE PLANET MARS, Academie  
des Sciences, Paris, Comptes Rendus, 248, No. 7, 16 February 1959,  
pp. 924-926.

The movement of the dark regions of the Martian surface takes place from the poles toward the equator in seasonal moves. The speed is calculated to be 35 km a day. The amplitude of the darkening diminishes and terminates toward  $22^{\circ}$  on the opposite hemisphere. A lag of 180 days has been observed between the beginning and the peak of darkening.

311. Glagolevskii, Iu. V. and Kozlova, K. I.,  
PHOTOMETRY OF AREAS OF THE MARTIAN SURFACE IN 1956  
WITH THE AFM-3 ELECTROPHOTOMETER, Akademiiia Nauk  
Kazakhskoi SSR, Sektor Astrobolaniki, Trudy, 6, 1958, pp. 197-207.

Results of photoelectric measurements of various portions of Mars during the 1956 opposition are reported. Data on brightness, color index and albedo are presented, and the optical thickness of the Martian atmosphere is derived (Oct. 8-9, 1956). There was found to be little contrast between maria and continents, due to the considerable dust content of the Martian atmosphere.

312. Guthnik, P.,  
PHOTOELECTRIC DETERMINATIONS OF STELLAR MAGNITUDE  
OF PLANETS, Astron. Nachr., No. 4976, Nature, 103, 20 March  
1919, p. 53.

The method is applied to Saturn and Mars, the probable error of a determination being one-hundredth of a magnitude. Saturn is compared with Pollux at four oppositions, to allow for the effect of the changing aspect of the ring, without which it appears that the planet's brightness is practically constant, and  $\frac{1}{3}$  mag. brighter than Pollux. It is further inferred from the cycle distribution of the dates that sunlight does not vary sensibly during the sunspot period. Mars is compared with many standard stars, and the stellar magnitude varies through  $2\frac{1}{6}$  mag., according to the longitude of the face of Mars presented to the earth, and varies also at different oppositions according to the tilt of the axis and the "snow" or cloud conditions.

313. Hall-Hamilton, G.,  
OBSERVATIONS OF MARS AT FLAGSTAFF (ARIZONA), Comptes Rendus, 162, 5 June 1916, pp. 871-872.

A drawing is given showing details measured from photographs taken at the Lowell Observatory, the author giving great praise to the quality of the observing conditions, and to the certainty of recognising details on the planet which have been consistently observed during the past 15 or 20 years.

314. de Idrac, M.,  
OBSERVATIONS OF MARS, VISUAL AND PHOTOGRAPHIC, Comptes Rendus, 149, 15 November 1909, pp. 834-835.

The large double telescope of Meudon Observatory was employed. The photographic exposures had to be limited to a fraction of a second, as, owing to the weakness of the mounting, the telescope is in continual vibration. In addition to the south polar cap and other large features, the plates show white patches on the borders of the disc, especially in the region of the equator. These patches, which were also seen visually, appear more intense and extensive on the side of sunrise. On the plates of Sept. 20 the canals Nilosyrtis, Protonilus, and perhaps Nepenthes, are visible. From Sept. 20 the plates also show a broad faint white patch near the north pole (the pole itself is hidden) which was not seen visually. On Sept. 25 this patch extends as far as lat.  $55^{\circ}$ . Attempts were made to take photographs with the visual telescope of the doublet, by using orthochromatic plates and a yellow screen. These, however, were unsuccessful, serving only to confirm Lowell's observation that the contrasts between the "seas" and "continents" are more marked with the red and yellow rays than with the violet.

315. Johnson, H. M. and Haas, W. H.,  
1939-1940 APPARITION OF MARS, J. Roy. Astr. Soc. Can., 35, May-June 1941, pp. 185-202.

A composite map is reproduced from individual observations by 3 observers in the U. S., using reflectors and refractors up to 12 in. aperture. Photographs taken on a 12 in. reflector are also discussed. The surface is described with special reference to the polar caps, limb and terminator projections, and surface colours.

316. Koval', I. K.,  
RESULTS OF PHOTOGRAPHIC OBSERVATIONS OF MARS AT THE KHARKOV ASTRONOMICAL OBSERVATORY DURING 1954,  
Astronomicheskii Zhurnal, Moscow, 34, No. 3, May/June 1957,  
pp. 412-418, Soviet Astronomy-AJ, New York, 1, No. 3, May/June 1957, pp. 404-410.

On the basis of results of observations of Mars, made in four spectral regions on the 20 cm refractor of the Kharkov Astronomical Observatory from June 1 to Sept. 10, 1954, the author comes to the conclusions: 1) For the reduction of observations of Mars the formula of V. V. Sobolev and the formulae of V. G. Fesenkov and E. Schonberg may be used with equal success. 2) The slope of the brightness

distribution curves in the spectral region 560-660 m $\mu$  decreases with increasing meridian altitude of the Sun. 3) Near the date of opposition, the color of the "maria" differs little from the color of the "continent." The "maria" at low southern latitudes change their color with variation of the meridian altitude of the Sun. 4) The reflection of light from the surface of "maria" of Mars does not follow Lambert's law. 5) The atmosphere above the Martian "maria" is more transparent than that over the "continent." 6) The south polar cap is reddish in comparison to a white screen.

317. Koval', I. K.,

ON THE DEGREE OF SMOOTHNESS OF THE CONTINENTS AND SEAS OF MARS, Akademiya Nauk SSSR, Komissiya po Fizike Planet, Izvestiya, No. 1, 1959, pp. 85-92.

Changes in the continent-sea contrast from the center to the limb of the Martian image were studied on the basis of photos obtained through the use of red and infrared light filters. The contract on the surface of Mars is seen to decrease towards the limb of the disk. The images of Mars obtained in 1954 are held to be most satisfactory in determining the light reflection from continents, while those obtained in 1956 are most suitable for studying the seas. The brightness distribution on the Martian seas differs from that on the continents.

318. Lebedeva, I. I.,

MEASUREMENT OF THE DIAMETER AND OBLATENESS OF MARS ON THE BASIS OF PHOTOS OBTAINED IN 1956, Akademiya Nauk SSSR, Komissiya po Fizike Planet, Izvestiya, No. 2, 1960, pp. 41-45.

On the basis of photos of Mars obtained during the opposition of 1956 it has been possible to determine the equatorial diameter and the oblateness in the photovisual and the photored systems. The final value of the Martian equatorial diameter, expressed in angular measurement reduced to a distance of one astronomical unit, is: photovisual system 9.13", photored system 8.97", difference 0.16". The values of the equatorial distance expressed in kilometers are photovisual system, 6618 km, and photored system, 6496 km. The final value obtained for the oblateness of Mars is  $0.0079 \pm 0.0022$ .

319. Leighton, R. B., Murray, B. C., Sharp, R. P., Allen, J. D., and Sloan, R. K.,

MARINER IV PHOTOGRAPHY OF MARS - INITIAL RESULTS, Science, 149, 6 August 1965, pp. 627-630.

Study of 22 photographs of Mars taken by Mariner IV and successfully received on earth. The Martian surface photographed is rather densely populated with impact craters whose sizes range up to at least 120 km in diameter. It is inferred that the visible Martian surface is extremely old and that neither a dense atmosphere nor oceans have been present on the planet since the cratered surface was formed.

320. Lowell, P.,  
PHOTOGRAPHS OF MARS, Roy. Astronom. Soc., M. N., 70, No. 9,  
1910, p. 652.

It has been stated by Antoniadi that the photographs of Mars taken at Flagstaff, Arizona, during the 1909 opposition do not show the polar cap to be brighter than the continental regions. With the present paper is included a plate showing a series of photographs of the planet, demonstrating that the opposite is in reality the case. Moreover, the irradiation from this brilliant cap masks the thin dark border which actually exists around the edge of the polar cap. This is clearly shown in spite of the fact that the photographs were taken in almost monochromatic light ( $\lambda 5400-5800$ ), which toned down the white caps relatively to the yellowish-tinted continental areas.

321. Lyot, B.,  
PLANETARY AND SOLAR OBSERVATIONS ON THE PIC DU MIDI IN  
1914, 1942, AND 1943, Astrophys. J., 101, March 1945, pp. 255-259.

The work summarized includes: coronagraph moving pictures through a polarizing monochromator isolating the red and green coronal lines; chromospheric films of prominences and flares in  $H\alpha$ ; direct films in integrated light of the solar granulation; photometric work on the corona; and both visual and photographic observations of Mars, Mercury, Jupiter's satellites, Saturn and the Moon.

322. Martz, E. P., Jr.,  
VARIATION IN ATMOSPHERIC TRANSPARENCY OF MARS IN 1939,  
Astronomical Society of the Pacific, San Francisco, Publications, 66,  
No. 389, April 1954, pp. 45-51.

The author discusses various theories covering the cause of Martian atmospheric transparency variations (e. g., vegetation, frozen  $CO_2$ ). The discussion then turns to analysis of photographic observations made by the author in 1939 in hopes that these may throw more light on the nature of Martian surface and atmospheric phenomena. Sixteen pairs of photos, one of the pair in red light and the other in

blue-violet light, are included as illustrations of the textual analysis. The article concludes with another discussion of possible causes of the transparency variations.

323. Miyamoto, S.,

MARTIAN ATMOSPHERE AND CRUST, Icarus, 5, July 1966,  
pp. 360-374.

Analysis of the atmosphere and crust of the planet Mars. A tentative picture of the circulation pattern in the planet's northern hemisphere is proposed, based on cloud data. Mariner-4 photographs are used to analyze the crust of Mars, including the so-called "canals."

324. Moroz, V. I. and Kharitonov, A. V.,

PHOTOELECTRIC PHOTOMETRY OF SECTIONS OF THE SURFACE OF MARS, Astronomicheskii Zhurnal, Moscow, 34, No. 6, November/December 1957, pp. 903-920, Soviet Astronomy-AJ, New York, 1, No. 6, November/December 1957, pp. 874-890.

In 1956, during the favorable opposition of Mars, measurements of the brightness of regions of the planet's surface were made with an electrophotometer and reflector,  $f = 11.26$  m,  $d = 50$  cm. As a result the international photovisual and photographic magnitudes of the brightness (the brightness of  $1 \text{ sec}^2$ , expressed in stellar magnitudes) and the color indices of different points of the planet's surface were derived. The stellar magnitude of the brightness of each measured point was used for determining the albedo. The data are given in the form of tables and maps. The contrast between the maria and continents is comparatively small. For  $\lambda = 5450 \text{ \AA}$  it does not as a rule exceed  $0^m 1$ , and usually equals only several hundredths. The contrast in blue light is less, but on the whole the color index of the maria differs little from that of the continents (the maria are a little "bluer"). Evidently the contrast between dark and light regions varies strongly with time, in particular from one opposition to another, in dependence on different factors. Of the regions measured, of special interest is that of the bright cloud which appeared at the end of Aug. The contrast between the cloud and the "undisturbed" surface  $0^m 07$  in photographic light. For one of the nights the radiometric luminous intensity from  $1 \text{ sec}^2$  of the planet's surface in three wavelengths was calculated.

325. de Mottoni, G.,

OBSERVATIONS OF THE PLANET MARS IN 1954, Osservatorio Astronomico di Milano-Merate, Publicazioni, n. s., Milan, No. 11, 1958, pp. 173-197.

This publication contains data gathered from 31 direct observations of Mars conducted in Genoa from May 9 to Sept. 5, 1954. Although the planet was relatively close to Earth during that period, both poles of Mars remained entirely or partially invisible. Only the last three observations furnished some data on the north polar cap. Unfavorable atmospheric conditions over Genoa added to the difficulties of observation. Aside from a simple enumeration of data under each observation, the publication contains short discussions of some particular phenomena observed in the following areas: polar regions, bright zones, surface formations in the northern temperate zone, equatorial and southern temperate zones. A page containing six photographs of Mars in full color is appended.

326. Pettit, E. and Richardson, R. S.,  
OBSERVATIONS OF MARS MADE AT MOUNT WILSON IN 1954,  
Astronomical Society of the Pacific, San Francisco, Publications, 67,  
No. 395, April 1955, pp. 62-73.

A somewhat extended analysis of photographic observations of Mars with tables, graphs and figures to illustrate the text. The method, instrument, and film used for observation are discussed. The analysis itself covers the canals, surface markings and the blue haze and clouds.

327. Pickering, W. H.,  
MARTIAN METEOROLOGY, Harvard College Observatory, Annals,  
Harvard University, 53, No. 8, 1893?, pp. 155-171.

A detailed analysis of photographs of Mars made in 1888 and 1890. The author interprets various markings on successive photographs as changing cloud patterns and snow caps. Tables, plates and figures illustrate the analysis.

328. Pluvinet, A. de la B. and Baldet, F.,  
PHOTOGRAPHY OF THE PLANET MARS, Comptes Rendus, 149,  
15 November 1909, pp. 838-841.

The photographs were obtained at the observing station on the Pic du Midi with a new double instrument comprising a reflector and a refractor (diams. 0.50 and 0.25 m., focus 6 m.) on a very steady mounting. The focal image of Mars being only 0.8 mm. diam., an enlarging lens was employed, giving discs of 3 to 5 mm. diam. During Sept. and Oct. 80 plates with 1350 images were obtained. At first Lumière violet and Guilleminot lactate of silver plates were used, but soon abandoned, as they rendered the ruddy surface of the planet

uniformly grey without any detail. They show the polar caps distinctly, however. The southern cap is much reduced, but very brilliant; at the north pole, on the contrary, a region of the cap is seen which is rather far from the pole and deficient in brightness. The eastern border of the planet is brighter than the rest of the disc. After the first trials a yellow screen was placed behind the magnifying lens, and plates sensitive only to the rays passing through it were employed, Lumière violet bathed in pinacyanol and others specially prepared. Under these conditions the Martian snows act feebly on the plate; the south cap is still fairly intense, but the north cap, and also the white border on the eastern limb, are invisible. On the other hand, the contrasts between the Martian lands and seas are very apparent, and a considerable amount of detail is shown. The canals of the first order are visible on the photographs, such as Indus, Ganges, Axarxes, &c. No trace appears of the geometric network of fine lines seen by certain observers, the existence of which is disputed.

329. Richardson, R. S.,  
PRELIMINARY REPORT ON OBSERVATIONS OF MARS MADE AT  
MT. WILSON IN 1956, Astronomical Society of the Pacific,  
San Francisco, Publications, 69, No. 406, February 1957, pp. 23-30.

After a brief reference to the types of observations made in 1956 program, the author discusses visual and photographic observations of the disk, the high dispersion spectra of Mars, and briefly, the role that photographs of Martian satellites will play in determining the nature of the interior of Mars. Four excellent photos illustrate the discussion.

330. Richardson, R. S.,  
OBSERVATIONS OF MARS AND VENUS, Lunar and Planetary  
Exploration Colloquium, Oct. 29, 1958, Proceedings, 1, No. 3, 1960,  
pp. 19-27.

An attempt is made to interpret some phenomena on Mars as shown on photographs, including the region Photh, a W-shaped cloud, the maria as probable vegetation, the canals as probably extensions of the maria, the Martian atmosphere and its clearing, the evidence of atmospheric oxygen and water vapor, the problem of plant life as approached by an experiment of photographs in deep red and infrared, the orientation of the axis of Venus, its rotation period, the problem of oxygen and water vapor in the atmosphere. The discussion dealt with some of the suggested theories on different problems.

331. Robinson, J. C.,  
PHOTOGRAPHIC OBSERVATIONS OF MARS AT NEW MEXICO STATE  
UNIVERSITY IN 1960-61, Icarus, 2, No. 5-6, 1063, pp. 403-410.

Routine three-color photography of Mars at the 1960-61 approach revealed the presence of a number of canals at this season, as well as the continued existence of the large dark area near the Thoth. Blue clearings were asymmetrically distributed about opposition, although the strongest degree of clearing apparently occurred at opposition. Blue cloud activity reached a maximum concurrently with the maximum extent of the polar haze caps in blue and ultraviolet shortly after Martian vernal equinox. A persistent blue cloud streak paralleling the Gigas canal was found to rotate with the surface.

332. New Mexico State University, University Park Observatory,  
GROUND-BASED PHOTOGRAPHY OF THE MARINER IV REGION  
OF MARS by J. C. Robinson, August 1965, NASA CR-64466,  
TN-701-66-10, Grant No. NsG-142-61.

Observable portions of the path of Mariner IV at central meridian longitudes from 90° to 240° were studies from 251 plates which included ultraviolet, blue, green, red, and near infrared regions. An atmospheric haze appears to have obscured some of the surface details of Mars, but the dark features recorded along the Mariner path are summarized. These include the positions of oases, canals, and a caret; three of the features were prominent enough for direct positional determination with a Mann measuring engine, but crude determinations were made for the other six features. The approximate areas and positions of regions of clouds or bright haze are also given.

333. Robinson, J. C.,  
GROUND-BASED PHOTOGRAPHY OF THE MARINER IV REGION  
OF MARS, Icarus, 5, May 1966, pp. 245-247, Grant No. NsG-142-61.

Discussion of data obtained from ground photography of Mars in five color regions yielding a total of 339 plates covering central meridian longitudes from 90 to 240°, thus including observable portions of the path of Mariner 4. The probe photographed the western limits of this region, where the haze tended to clear off by noon of each day, reforming in late afternoon. However, there were indications that this western zone may have completely cleared at the time of the Mariner encounter. Surface features in this region include a number of oases and canals. The large Propontis I oasis was found to be considerably further south than expected from positional determinations of other apparitions.

334. Ross, F. E.,  
PHOTOGRAPHS OF MARS, 1926, Astrophys. J., 64, November 1926,  
pp. 243-249.

Photographs of Mars were made at Mount Wilson with the 60-in. reflector, in light of five different colours. The surface markings are portrayed by the longer wave-lengths, while the atmospheric clouds and haze are well brought out in the shorter wave-lengths. A cloud formation of unusual brilliance was photographed. The atmospheric rim-light is a feature of the ultra-violet pictures. The excess of diameter of Mars in the ultra-violet over the diameter in the infra-red, discovered by Wright, is confirmed.

335. Russell, H. N.,  
ALBEDO OF THE PLANETS AND THEIR SATELLITES, Astrophys. J.,  
43, April 1916, pp. 173-196.

The various values available are discussed in detail and a table is given showing for the planets and satellites (1) stellar magnitude at mean opposition; (2) equivalent magnitude at full phase and unit distance from earth and sun; (3) assumed mean semi-diameter at unit distance; (4) a factor  $p$  defined as the ratio of the actual brightness of the planet at the full phase to that of a self-luminous body of the same size and position, which radiates as much light from each unit of its surface as the planet receives from the sun under normal illumination; (5) a quantity  $q$ , depending on the laws of diffuse reflection; (6) the determined albedo; the colour-index; (8) the photographic albedo.

336. Sagan, C.,  
THE MARINER IV MISSION TO MARS, Astronomical Society of the Pacific, Leaflet, July 1966.

Analysis and interpretation of the data obtained by Mariner 4 on the planet Mars. The significance of the lack of an appreciable magnetic field for this planet is discussed; it suggests that no migration of iron from the mantle toward the core occurred. It is shown that the highly diminished differentiation on Mars as compared with earth would lead to correspondingly low levels of outgassing. The analysis of the results of the radio occultation experiment to determine the temperature at the base of the Martian atmosphere is described - a temperature of about 100°K is indicated, with a surface pressure in the range from 6 to 10 mb. An analysis of the photographs indicates that there has been crater erosion. Thus the past presence of water on Mars is highly probable.

337. Salisbury, J. W.,  
THE LIGHT AND DARK AREAS OF MARS, Icarus, 5, May 1966,  
pp. 291-298.

Review of past work and critical examination of photographic information on the light and dark areas of Mars, together with new data from other sources. It is suggested that both organic and nonorganic hypotheses are consistent with the observations and that internal water might play an important role in the creation of dark areas, through either organic or inorganic means. Lacking conclusive evidence for any darkening mechanism, it appears that still more alternative hypotheses might usefully be sought.

338. Slipher, E. C.,  
PLANETARY PHOTOGRAPHY, Astron. Soc. Pacific Publ., June 1921,  
Nature, 107, 4 August 1921, p. 725.

Flagstaff photographs of Venus show no surface markings. Those of Mars number 100,000, many exposures being made on one plate in hope of catching moments of good definition. The author gives a long list of features he claims to have verified on the plates, but not all can be seen in the published reproductions. The very clear photographs of the polar cap suggest that this can be used for an independent determination of the position of the axis.

339. Slipher, V. M.,  
PLANETARY PHOTOGRAPHY, Nature, 133, 6 January 1934,  
pp. 10-13, Royal Inst., Proc., 27, No. 5, 1933, pp. 903-921.

A review of planetary observations, visual, photographic and spectral, at the Lowell Observatory since 1894. Mars; the waxing and waning of its polar caps harmonise with its calendar, indicating an atmosphere and its spectrum gives both oxygen and water; its temperature is about 48°F.; there is a reality underlying its canal phenomena, but there is difference of opinion about its interpretation. In the major planets (Jupiter to Neptune) ammonia and (possibly) methane gas have been identified, but are weakened progressively from Jupiter outwards with distance from the sun; on the other hand, absorption bands increase in intensity from Jupiter with the greater distance. The atmospheres of these four outer planets are more effective than the atmospheres of the earth-like group in utilising their "small energy gift from the sun," by conserving the energy of the longer heat waves. Photographs are reproduced of the planets, Mars, Jupiter and Saturn, and comparison spectra of the moon and four outer planets.

340. Sytinskaya, N. N.,  
THE APPLICATION OF PHOTOMETRY IN RESEARCHES ON THE  
NATURE OF MARS, Mem. Soc. Roy. Sci. Liege, Belgium, 7,  
Spec. No. 1963, pp. 394-401, Physics of Planets Symposium Paper,  
Liege, 1962.
- A review of photometric methods (including laboratory standardization) used for observing the albedo of Mars at the Tashkent and Kahrkov Observatories, USSR in 1939, 1954, and 1956. The parameter measured is the ratio,  $B/B_d$ , where  $B$  is the observed brightness of a given disk feature, and  $B_d$  that of a perfectly diffusing surface of known albedo presented normally to the direct rays of the sun, and at such a distance that the surface subtends a similar angle to that of the disk of Mars at the time of observation.
341. Thihoff, G. A.,  
PRELIMINARY NOTE ON PHOTOGRAPHING MARS WITH A 40-IN.  
REFRACTOR, Acad. Sci. St. Petersburg, Bull., 15, 1 November  
1909, pp. 1039-1042.
- The author has taken photographs of Mars with a 30-in. refracting telescope, the diam. of the image on the sensitive plate being about 1.5 mm. In order to intensify the contrast between the light and dark parts of the planet, red, green, and yellow light-filters were employed.
342. Tikhoff, G. A.,  
PHOTOGRAPHS OF MARS THROUGH COLOURED SCREENS, Mitt. der Nikolai-Hauptsternwarte zu Pulkowo, No. 42, Nature, 87, 19 October 1911, p. 529.
- Photographs of the planet Mars taken with the 30-in. refractor through differently coloured screens show differences in the intensity of the surface markings. With the red screens the continents show up very bright, while with the green screens the polar caps are the most distinctive features.
343. van de Kamp, P.,  
DETERMINATION OF THE DIAMETER OF MARS, Astron. J., 38, No. 894, 17 February 1928, pp. 61-71.
- The diameter of Mars at unit-distance, as derived from 123 photographic images taken through a yellow screen in the focus of the

26-in. refractor at the Leander McCormick Observatory, between July, 1924, and March, 1927, is found to be  $9''.48 \pm 0''.06$ . The author describes his methods, and points out ways in which errors may be avoided. Photographs in yellow light give clear-cut images, suitable for accurate measurement, chiefly because of the very limited range of wave-length employed.

344. de Vaucouleurs, G.,  
PHOTOGRAPHIC OBSERVATIONS IN 1956 OF THE BLUE CLEARING  
ON MARS, Astronomical Society of the Pacific, San Francisco,  
Publications, 69, No. 411, December 1957, pp. 530-532.

A short series of photographic observations of Mars in blue light was secured at Mount Stromlo, Australia with the 26-inch photographic refractor of the Yale-Columbia Southern Station, principally in July, Aug. and Sept., 1956. Because of the limited time available for this program, the observations were mainly intended to help fill the longitude gap in the photographic patrol of Mars in blue light and, especially, to watch for a possible renewal of the "blue clearing" of the atmosphere near opposition. The equipment and film used are described briefly, and the results obtained are discussed.

345. de Vaucouleurs, G.,  
OBSERVATIONS OF MARS IN 1958, Sky and Telescope, 18, No. 9,  
July 1959, pp. 484-489.

During recent years, the world has shown increasing interest in space problems. In this article some observations of Mars in 1958 are described. The observations show the dark area around longitude  $250^\circ$ , latitude  $+25^\circ$  still visible. The blank desert region between longitudes  $100^\circ$  and  $180^\circ$  was carefully scrutinized. The canal phenomenon is specifically a Martian phenomenon. Many photographs are included in the article.

346. de Vaucouleurs, G.,  
MULTICOLOR PHOTOMETRY OF MARS IN 1958, Planetary and Space  
Science, 2, No. 1, October 1959, pp. 26-32.

Photoelectric observations of Mars in Oct. and Nov. 1958 at the Lowell Observatory give values of the stellar magnitude and integral albedo at five wave lengths from  $\lambda 3300$  to  $\lambda 6900$ . In the near ultraviolet  $3000 < \lambda < 4000$  Mars is "grey" and very dark, with a nearly constant albedo  $A = 0.046$ . Earlier Mount Stromlo and Flagstaff data are also discussed.

## Section V. ELECTROMAGNETIC SPECTRAL OBSERVATIONS

### A. COLOR (VISIBLE)

347. Antoniadi, E. M.,  
OBJECTIVE CHANGES ON SURFACE OF MARS, Roy. Astron. Soc.,  
M. N., 76, March 1916, pp. 413-414.

Observers have from early days suspected the reality of changes in the markings of the surface of Mars, usually ascribed to the presence of clouds. The author considers he has been able to confirm this at Meudon, and mentions that the atmospheric veils which so frequently deformed the dark areas showed all tints from brilliant white to deep orange. Apart from this, however, from a study of all available drawings of the planet published since the beginning of the eighteenth century, he finds evidence of changes which may be secular, recurrent, or seasonal in character. Examples of these three types are given concerning the Hydaspes, Nepenthes-Thoth, and Syrtis Major.

348. Antoniadi, E. M.,  
RETARDED DIMINUTION OF THE CIRCUMPOLAR SNOWS OF MARS,  
Comptes Rendus, 179, 22 September 1924, pp. 557-559.

The author has studied the size of the circumpolar snows of Mars from all the data available, and has arrived at the average throughout the year for the period since 1856. A comparison of the areas observed this year with the mean value over the period since 1860 shows that the snows were much more extensive than normal from the beginning of June until the end of August, but resumed their normal size from the beginning of September. A similar retardation of the snow disappearance took place in 1913, and the author considers that these retardations are due to minima in the solar radiation.

349. Antoniadi, E. M.,  
CHANGES OBSERVED ON MARS, Comptes Rendus, 179, 13 October  
1924, pp. 668-671.

A record of certain changes in form and colour of some of the darker markings on Mars as seen with the 83-cm. refractor of the Meudon Observatory. The changes extend in some cases over distances of several thousand kilometres, while changes of shade from green to brown and from pure brown to "lilac-brown" are noted.

350. Barabashov, N. P. and Koval', I. K.,  
RESULTS OF STUDIES OF CONTRAST ON MARS, Astron. Zh., USSR, 37, No. 2, March-April 1960, pp. 301-305, Soviet Astron. - AJ, USA, 4, No. 2, September-October 1960, pp. 283-287.

An attempt at critical evaluation of the possibility of explaining contrast variations in terms of variations in the transparency of the Martian atmosphere is here based on a study of contrasts on Mars, in red, green, and blue light. The conclusion is that the observational data on contrasts on Mars in red, green, and blue light ( $\lambda > 420 \text{ m}\mu$ ) are primarily attributable to the energy distribution in the surface of the planet proper.

351. Barabashov, N. P. and Garazha, V. I.,  
SOME REMARKS ON THE DUST AND HAZE FORMATIONS ON MARS,  
Astron. Zh., USSR, 37, No. 3, May-June 1960, pp. 501-507, Soviet Astron.-AJ, USA, 4, No. 3, November-December 1960, pp. 473-479.

Inferences based on an examination of the brightness distribution curves during the 1956 opposition and the rearward portions of indicatrices are drawn as to the structure of the Martian solid surface, and as to the properties of the yellow clouds and mist which often appear in the Martian atmosphere.

352. American Meteorological Society, Boston, Massachusetts,  
INVESTIGATION OF VARIOUS FORMATIONS ON MARS by  
N. P. Barabashov, February 1964, AD-602 194, Contract No. AF 19 (628)-3880, translated from Astron. Zh., USSR, 29, No. 5, 1952, pp. 538-555.

Among the basic results of Martian observations discussed in this report are these: (1) The various regions of the Martian seas have different albedos. The seas contain greenish and bluish regions, as well as reddish and yellow ones. (2) Certain dark areas observed are moist regions of the Martian continent. Their color does not vary with the meridian altitude of the Sun. (3) The color changes, with the meridian altitude of the Sun, in a large number of areas in the seas, viz., the region becomes red with decreasing altitude and becomes blue with increasing altitude. (4) The increase in greenness and the color variations of the Martian continent and seas do not contradict the hypothesis that vegetation develops in these regions. (5) There are regions on the Martian continent whose albedo reaches 0.448 in red, 0.190 in yellow, and 0.193 in green. (6) The polar caps of Mars are reddish. The atmospheric portion of the polar cap is probably

identical with the bright areas of the eastern and western limbs of the disc of Mars, which gives the impression of four polar caps located at the ends of two mutually perpendicular diameters on the planetary disc. This indicates that there is very little moisture on Mars. (7) The atmosphere of Mars often becomes turbid, apparently because of fine ice crystals at great heights in the atmosphere.

353. Blum, R.,  
MAGNETOSPHERE AND THE MARTIAN BLUE CLEARING, Nature,  
GB, 207, 25 September 1965, pp. 1343-1344.

Observations are made in favour of the hypothesis that the obscuration of martian surface features in blue light is caused in some way by the magnetohydrodynamic wake arising from the interaction of the geomagnetic field with the solar wind.

354. Bohlin, K.,  
DRAWINGS AND COLOUR STUDIES OF MARS MADE WITH THE  
7-INCH EQUATORIAL AT STOCKHOLM, Astron. Iaktagelser  
Undersokning, Stockholm, 11, No. 6, 1929.

In 1924 and 1926 visual observations were made of the planet Mars; and drawings are here reproduced which confirm the main details drawn in 1911. Chief attention, however, was paid to colour, with the aid of Zeiss colour screens, gray, red, blue and yellow. The red screen gives the sharpest details. The yellow tint, which is usually seen round the limb and seems to mingle with the red as if superposed upon it, in a greater or less degree at different times, is probably to be ascribed to the atmosphere of the planet, while the red represents its surface. The notes are given in full, and their significance is discussed.

355. Dollfus, A.,  
PHOTOMETRIC STUDY OF THE DARK REGIONS ON THE SURFACE  
OF THE PLANET MARS, Academie des Sciences, Paris, Comptes  
Rendus, 244, No. 11, 11 March 1957, pp. 1458-1480.

The author has studied the dependence of the brightness of the so-called "seas" of Mars upon their distance from the margin of the planet's surface. A darkening of the margin decreasing with the wave length of light was noted. Martian air was found to contain fine particles since scattered light was greater than in a clear gaseous mixture. The brightness contrast between the bright "continents" and the dark "seas" diminishes from red towards violet. For the dark surfaces the

scattering coefficient drops from 0.12 to 0.056. The visually observed green and blue colors of the "seas" are not real. The seasonal variation on the brightness of these surfaces may be explained by the development of micro-organisms.

356. Dollfus, A.,  
DISCUSSION OF F. LINK'S PAPER, Mem. Soc. Roy. Sci. Liege,  
Belgium, 7, Spec. No., 1963, pp. 460-461, Physics of Planets  
Symposium Paper, Liege, 1962.

With reference to the measures of variation of the diameter of Mars in blue and red light, involving the "Wright Effect" (1924), the results of some recent precision measurements of equatorial and polar diameters of the planet in orange, and blue light are quoted. The observations extended over the period 1954-58, and gave mean values of 9".42, and 9".31 for equatorial and polar diameter in orange light, and 9".44 and 9".31 respectively in blue light. On reduction to 1 U. A. the corresponding linear diameters are: equatorial 6790 km; polar, 6710 km. The polar flattening amounts to 0.012.

357. French, H.,  
SOME NOTES ON THE ORIGIN OF THE COLOUR OF THE MARTIAN  
DESERTS, J. Brit. Astron. Assoc., 70, No. 3, March 1960,  
pp. 136-138.

It is suggested that red colour is due to ferric oxide and that the orange red is due to part of the oxide being changed into yellow hydroxide. Conditions on Mars are very suitable for this transition.

358. Gifford, F. A., Jr.,  
THE PROBLEM OF THE MARTIAN YELLOW CLOUDS, Monthly  
Weather Review, 91, October-December 1963, pp. 610-612.

Observations on the problem of the yellow clouds of Mars - the usually isolated and more or less clearly delimited obscurations of comparatively small areas of the Martian disk which can be detected visually or in photographs with yellow or red filters. It is noted that, in view of the known dryness of the Martian atmosphere, the desert location of most of the yellow clouds shown in a table, and their occurrence in regions of comparatively high surface temperature, certainly tend to confirm the hypothesis that they are dust clouds, probably initiated by thermal convection. Their generally equatorward drift seems to imply that they are low-level phenomena, possibly steered by the tropical portion of a symmetric circulation cell.

Considered as perturbations on some steady-state circulation regime, the dust storms appear to be damped out fairly rapidly. Moreover, they are fairly small, of the order of several hundred to 1,000 km in horizontal extent.

359. Graf, K.,  
VISUAL MEASURES OF PLANETARY COLOURS, Akad. Wiss. Wien,  
Ber., 140, 2a, No. 7, 1931. pp. 519-520.

The colour of the planets is due to sunlight and the selective absorption of each planetary atmosphere, and these colours have been determined photographically. In January and February, 1931, visual observations were made in Majorca with the new Vienna colorimeter [see preceding Abstract], and the colours were compared with stellar spectral types. Every type is represented from B to K. The colours of Mercury, Venus, Jupiter, and Saturn agree with the photographic colour-index, but Mars is visually much redder and Uranus very much bluer.

360. Gurtovenko, E. A. and Gordeladze, Sh. G.,  
THREE-COLOR COLORIMETRY OF THE INTEGRAL BRIGHTNESS  
OF MARS, BASED ON 1956 OBSERVATIONS, Astronomicheskii  
Zhurnal, Moscow, 3, No. 6, November/December 1957, pp. 959-961,  
Soviet Astronomy AJ, New York, 1, No. 6, November/December 1957,  
pp. 926-928.

The integral brightness of Mars in three different colors ( $\lambda_{\text{eff}} = 430, 546$  and  $622 \mu$ ) was studied from observations made from Sept. 1, 1956-Jan. 2, 1957. Vega was used as a standard. The white stars of the Pleiades, which were photographed on the same negatives as the planet, were used for the calibration curves. The results of the measurements are given in a table. The great brightness of the planet during opposition, the sharp decrease in brightness with increasing phase, and the considerable decrease of the color index of Mars during the period of observations should be specially noted.

361. Hamilton, G. H.,  
OBSERVATIONS OF MARS AT FLAGSTAFF, Lowell Observat., Bull.,  
No. 83, Nature, 108, 1 December 1921, p. 447.

Nine drawings made on dates between March 8 and May 26, 1920, are reproduced. An unusually large number of white markings appeared near E. and W. limb, but disappeared in the centre; they are attributed to cloud or mist, and not to ground frost, as they partially obscured

the "canals," even Syrtis Major. Similar drawings were made in 1903, so perhaps the phenomenon is a fixed seasonal one on Mars, only visible from the earth once in 15 years. The whitish areas have no dusky border, which tends to prove the reality of the dusky border seen around the polar cap. Some of the dusky regions seemed darker after being cloud-covered, suggesting growth of vegetation after rain. The inference is that weather on Mars instead of being quite insignificant is very marked, a conclusion reached many years ago by N. Lockyer.

362. Hess, S. L.,

MARS, The Project for the Study of Planetary Atmospheres, Lowell Observatory, Report No. 3, 1 January-30 June 1949, Contract No. Cwb-7896.

Franck has pointed out that if the blue-green areas of Mars are mainly plant life, then some mechanism must exist to protect these plants from ultra-violet radiation since this light will damage proteins and other large organic molecules necessary to life. The ozone layer, which performs this protective function on earth, is apparently absent on Mars due to a lack of oxygen. The possibility remains, however, that the blue haze in the Martian atmosphere serves as a partial substitute for ozone since it selectively scatters light of short wave length and so may sufficiently attenuate the UV before it reaches the surface. If the blue haze does indeed perform the function indicated, then, during occasional periods of clearing of the blue haze, the planet ought to suffer some damage (not necessarily fatal) and this damage may well be expected to manifest itself through slight changes in color of the dark markings. This color change may be observable and thus, if recorded, would verify, at least in part, the hypothesis on the function of the blue haze. The report concerns the testing of this hypothesis; procedure and results are outlined. Preliminary verification of the hypothesis resulted from this test.

363. Hess, S. L.,

COLOR CHANGES ON MARS, The Project for the Study of Planetary Atmospheres, Lowell Observatory, Report No. 2, 1 November 1949-31 January 1950, Contract No. AF 19 (122)-162.

The author discusses the hypothesis of plant life on Mars and attempts to verify it by investigating the relationship between changes in the opacity of the "blue haze," which absorbs UV radiation, and change in color of the dark surface markings. Color filter photographs which were taken during the oppositions of 1939 and 1941 and which were in the visible red of the spectrum were used to test the effect of

blue haziness upon color of markings and a confirmatory result was obtained in 1941 but not in 1939.

364. Hess, S. L.,

BLUE HAZE AND THE VERTICAL STRUCTURE OF THE MARTIAN ATMOSPHERE, Astrophysical Journal, Chicago, 127, No. 3, May 1958, pp. 743-750.

The atmospheric haze which usually obscures the surface of Mars in blue light is probably a condensate rather than a dust because it can clear away rapidly. Carbon dioxide and water vapor are both present in the atmosphere, and condensation of each into the solid phase has been suggested to explain the blue haze. Calculations are carried out by assuming a convective atmosphere with a surface temperature of  $+10^{\circ}\text{C}$  for the subsolar point and a lapse rate of  $3.7^{\circ}\text{C}/\text{km}$ . When the optical properties of clouds produced in such an atmosphere are determined with the aid of the Mic theory of scattering, it is found that (1) carbon dioxide ice clouds are far too opaque to be the cause of the blue haze; (2) water ice clouds can cause the modern attempts to detect water vapor spectroscopically in the Martian atmosphere, since the total precipitable water content corresponding to such a frost point is only  $2\mu$ . These results indicate that the author's earlier suggestion of carbon dioxide ice clouds should be rejected. Urey comments on S. L. Hess's article. He states that the blue haze cannot be due to scattering of blue light by fine ice crystals at an altitude of 30 km since no water bands have been reported in the blue haze, uniform conditions of temperature and temperature change over the whole of Mars are unlikely, and the blue haze cannot come down to the surface at the pole as Hess postulates, since the blue image is elongated (not flattened) at the poles, whereas the red image is flattened at the poles. Urey suggests fluorescing molecules produced by solar radiation as origin.

365. Jarry-Desloges, R.,

PHENOMENA OBSERVED ON MARS DURING THE PRESENT OPPOSITION, Comptes Rendus, 170, 21 June 1920, pp. 1486-1488.

At Setif important changes have been noted since the opposition of 1918. A large very dark patch in the region called Aeria, forming a sort of promontory connected with Syrtis Major, replaces the light grey "Astaborae Fons," on the maps, but whereas the "Fons" was faint, small, and uncertain, the new patch is dark, large, and conspicuous. Moreover, Schiaparelli's "Nix Olimpica," measured in 1879, has reappeared, and has been re-measured as well as the

whitish patch surrounding it, which extends principally to the south-east. After being unseen since 1879, the patch reappears, not in the Martian winter, as in 1879, but in the summer, when conditions of snow should be different. The author suggests an explanation by which cloud in summer replaces winter snow over a mountain range.

366. Jarry-Desloges, R.,  
PLANET OBSERVATIONS AT SÉTIF, Nature, 109, 23 March 1922,  
p. 386.

The observatory was established in Algiers specially for lunar and planetary observation, and the author has published a large illustrated volume of studies of these objects. Mercury by day was found as easy as Mars, and the rotation period comes out at 88 days in accord with the results of Schiaparelli and Lowell. In contrast with other observers, the author does find evidence of occasional cloud or mist veiling and modifying the appearance of markings. As the light and heat received from the sun in perihelion and aphelion are in the ratio of 9 to 4, the cloud and precipitation conditions will be greatly affected. The disc, generally of a rosy colour, shows broad, curved dusky streaks,  $60^\circ$  in length with a few larger spots. Uranus shows markings like those of Saturn, with a bright equatorial belt and bright belts in N. and S. temperate zones, but these are not strictly parallel to the equator. The markings are curved and inclined. Dark belts were seen on Neptune in 1914. Neptune's satellite Triton was generally an easier object than Mimas. Drawings of Saturn show notches in the outline of the Cassini division and in that of the crêpe ring. The rotation of Venus could not be determined.

367. Koval, I. K. and Morozhenko, A. V.,  
SOME PROPERTIES OF THE YELLOW HAZE OBSERVED ON MARS  
IN 1956, Astron. Zh., USSR, 39, No. 1, 1962, pp. 65-72, Soviet  
Astron.-AJ, USA, 6, No. 1, July-August 1962, pp. 45-50.

The approximate values of the optical thickness  $\tau_\lambda$  of the "dust cloud" in red and infrared light have been computed from the washing-out of contrasts between light and dark regions of Mars. Observational data given in the catalogue of Barabashev and Koval are used. The radius of particles composing the "dust cloud" is found ( $1.45\mu$ ), using the values of  $\tau_\lambda$  obtained from computations by Shuleikin. Approximate data, characterizing the time of descent of particles of the computed size from different heights and at a given density of the particles, are derived by applying the Stokes formula for the velocity of descent of such

particles in the atmosphere. It is found that the time of descent from a height of 1 km is not less than 40 days, if the density of a particle does not exceed 3.

368. Koval', I. K.,  
ON THE STUDY OF THE OPTICAL PROPERTIES OF THE ATMOSPHERE AND SURFACE OF MARS, Phys. of the Moon and the Planets, Israel Program for Scientific Translations, Ltd., Jerusalem, 1966.

Following a review of various findings dealing with the surface of the moon, it is concluded that the distribution of energy in the visible spectrum of Mars and its color depend mainly on surface energy distribution. The surface of Mars may be regarded as covered by a powdered limonite which is orange in color; and the visual albedo of Mars and the albedo of the true surface may differ slightly from each other. During clear periods, fluctuations of the visual albedo in the violet region may not be noticed. The true continent-mare contrast at  $\lambda = 400 \text{ m}\mu$  is usually entirely blurred by an atmospheric veil produced by light scattering in the Martian atmosphere. In the 400 to 650  $\text{m}\mu$  range, the light is scattered in the same sense as Rayleigh scattering, so that toward lower wavelengths the rate of limb darkening of the apparent disk is more gradual. At even greater wavelengths, coarse particles float in the Martian atmosphere and result in a decrease in the limb darkening to the infrared.

369. Kozlova, K. I. and Glagolevskii, Iu. V.,  
COLOR CHANGES ON MARS ACCORDING TO PHOTOELECTRIC OBSERVATIONS IN 1958, Astronomicheskii Tsirkuliar, Moscow, No. 201, 15 April 1959, pp. 4-6.

Observations of Mars were made in Alma-Ata in 1958 during a period of opposition with a telescope (AZT-7) and with an electro-photometer (AFM-3). The maximum diameter of the Martian image was only 0.925 mm. Observation and recording were made through blue and yellow filters and in comparison with the star ( $\alpha$  Aur). Mars and the star had the same zenith distances during the observations. The color excess ( $CE_M$ ) and color index ( $CI_M$ ) were determined with a given formula. The results obtained during 1956 and 1958 are tabulated for each day and discussed in the text.

370. Kuiper, G. P.,  
VISUAL OBSERVATIONS OF MARS, 1956, Astrophysical Journal, Chicago, 125, No. 2, March 1957, pp. 307-317.

Visual observations of Mars are recorded, made with the 82-inch telescope during one month of nearly continuous observations, centered on the time of closest approach in 1956 (Sept. 7). Emphasis was placed on obtaining dependable determinations of the colors of the Martian dark areas and on the general appearance of the planet, including fine detail. The colors, expected to be green at this season (Martian spring), were found neutral gray, with a mere touch of moss-green in some of the equatorial regions and a touch of brown in the dark border surrounding the South Polar Cap. A spectacular system of dust storms was observed to develop, eventually enveloping the entire observable planet except the polar zones. Between Sept. 6 and 9 a dense cloud cap formed over the South Pole, which had cleared away on Sept. 14 and had deposited a new polar cap that has remained largely intact since. It is remarkable that this event occurred shortly before the summer solstice. The bearing of the surface studies on the vegetation hypothesis is discussed.

371. American Meteorological Society, Boston, Massachusetts,  
RESULTS OF OBSERVATIONS OF MARS by Iu. N. Lipskii, 1957,  
AD-602 180, Contract No. AF 19 (628)-3880, translated from Priroda,  
Moscow, 46, No. 4, 1957, pp. 105-106.

Preliminary results of observations made during the opposition of Mars in September 1956 are discussed. Included in these observations are the following: (1) an investigation of the optical properties of the vegetation of the various climatic zones; (2) brightness; (3) the polar cap; (4) the seas; (5) a comparison between the color of the seas and that of the continents; (6) water in the atmosphere and on the surface; and (7) the polarization of light reflected by various portions of the surface.

372. Miyamoto, S. and Nakai, Y.,  
METEOROLOGICAL OBSERVATIONS OF MARS DURING THE 1960-61  
OPPOSITION, Kyoto U. Inst. of Astrophys. and Kwasan Obs. Contrib.,  
No. 12, 1961, pp. 84-161.

Meteorological phenomena of Martian atmosphere during the 1960-61 opposition secured by the visual and photographic observations at the Kwasan observatory are described. First two sections are concerned with the general appearance of the surface markings in this opposition. Three dark belts--namely, through Nodus Loacoontis-Sinus Gomer, Nilokeras and Lunae Lacus, and Cerberus and Propontis--connecting the northern and southern hemisphere were remarkably developed.

The remaining parts are concerned with the records and interpretations of the meteorological phenomena. On the blue filtered photographs, it was noticed that both polar regions were almost always covered with white haze, and that a faint white belt of haze extended along the equator. The Martian atmosphere was very cloudy in this season of the year. White clouds were observed almost every night. A yellow cloud of considerable dimension emerged on the Neith and Casius area and drifted eastward. The retreat of the north polar cap has been traced. Evening and morning hazes and a rapid change of the atmospheric transparency were often observed. A peculiar behavior of the stratum of white clouds over Dioscuria and Cydonia and a semipermanent low over Niliacus Lacus suggest the existence of mountain ranges along Dioscuria and Cydonia. Also the afternoon brightening of white clouds hanging over Hellas suggests that this desert may be a high land.

373. Moore, P.,  
A POSSIBLE CLOUD ON MARS? , British Astronomical Association, Journal, 75, June 1965, p. 217.

Observation of clouds on Mars. During the present apparition of Mars, conditions have been generally poor, but one or two possible clouds have been detected. The most interesting of these was seen on Feb. 27, 1965. A fairly well-defined white cloud was seen, placed approximately over the western end of the Deucalionis Regio. Unfortunately the weather conditions for the next few nights were quite hopeless, and when the area was next seen, there was no sign of the cloud. The only other cloud phenomenon was seen on Mar. 28-29 in the area of Thymiamata. However this was by no means so clear as that of Feb. 27. The observations were made with a  $12\frac{1}{2}$ -in. reflector at 460x.

374. Palm, A. and Basu, B.,  
THE BLUE HAZE OF MARS, Icarus, USA, 4, No. 2, May 1965,  
pp. 111-118.

The extend of blue clearings is investigated as a function of the number of the meteor showers intersection Mars' orbit, at  $10^{\circ}$  intervals of heliocentric longitude. A rank correlation method has been employed. The analysis indicates a small but statistically significant negative correlation between the extent of blue clearing and meteor shower activity. This result combined with the optical properties of the Martian atmosphere and the close resemblance between the characteristics of the blue haze and those of the terrestrial noctilucent clouds suggests that variable amounts of interplanetary dust are suspended in the Martian

atmosphere and that the occasional clearings of the blue haze are caused by diminishing influx of these dust particles.

375. Perevertun, M. P.,  
VISUAL OBSERVATIONS OF MARS IN 1958, Akademiya Nauk Kazakhskoy SSR, Sektor Astrobotaniki, Trudy, No. 8, 1960, pp. 117-120, taken from Referativnyy Zhurnal, Astronomiya i Geodeziya, No. 1, 1962, 1 A509.

Visual observations of Mars were made in Alma-Ata from 1 October through 5 December 1959 and on the AZT-7 reflector with red, yellow, green, light and dark blue, and color-contrast light filters (magnification 270 and 400 times). In all, 110 sketches of Mars were made; a detailed record was kept of the atmospheric and light phenomena noted. Visual estimates of the brightness of individual details were made using a 10-unit scale. In order to achieve evaluation of the green and blue shading of the individual seas and polar caps, a simple visual photometer was designed. The basic component was a Lummer-Brodhun cube. Filters were changed with a disk with automatic locator. It was concluded that Solis Lacus has a dark yellow color; the Mare Sirenum, violet; and the Mare Cimmerium, yellow. The brightness of the south polar cap is greatest through the green and yellow filters; it was not possible to detect it through the red. The color of the north polar cap without a filter is light blue; its brightness was greatest in green, yellow, and at times in the blue. A thick fog, covering both polar regions, appeared in the middle of November. The contrast of dark regions with the continents in the visual and particularly in the green is less than in the red. In the green the central part of the seas was darker than the periphery, while in the yellow the central part is brighter than the edge. It is noted that Syrtis Major and Solis Lacus have a mosaic structure. On the night of 8-9 November a light spot that exceeded in brightness the entire polar cap region was noted in the region of the north pole.

376. Pickering, W. H.,  
CLOUDS ON MARS, Popular Astronomy, 24, 1916, p. 639, Nature, 98, 18 January 1917, p. 397.

Observations made by members of an international organisation are summarised with special reference to clouds observed on the planet during the opposition of 1916. These were always seen over the so-called desert regions of the disc.

377. Rea, D. G.,  
THE DARKENING WAVE ON MARS, Nature, GB, 201, 7 March 1964,  
pp. 1014-1015.

Possible causes of the seasonal wave of darkening and associated changes in the (optical) polarization and related phenomena on Mars are discussed. It is thought that the wave may be caused by a decrease in transparency of the (optical) scattering surface particles due to a possible chemically induced increase in the extinction coeff. Transparency could also be reduced by particle removal by winds. Change of particle size through fractionation in altitude by winds as a possible cause of variations in brightness for all times and areas is considered. For the centre of the disc at exact opposition the brightness of bright areas with respect to a white Lambert reflector at the position of Mars is 0.27 at 6500 and 0.22 at 6100 A. N. A. West.

378. Rosen, B.,  
POSSIBLE ORIGIN OF THE HAZE LAYER IN THE ATMOSPHERE  
OF MARS, Annales d'Astrophysique, Paris, 16, No. 4, July/August  
1953, pp. 288-289.

The haze layer (a layer absorbing blue and violet light) of the Martian atmosphere and its investigation by various authors are discussed. The author proposes a new hypothesis according to which the absorption phenomenon might be due to carbon dust (smoke) suspended in the outer layers of the planet's atmosphere.

379. Ryan, J. A.,  
NOTES ON THE MARTIAN YELLOW CLOUDS, Journal of Geophysical  
Research, 69, 15 September 1964, pp. 3759-3770.

Consideration of questions associated with the clouds. Those of interest are: (1) the surface winds required to initiate grain motion, (2) the particle grain size which may be primarily responsible for the surface obscuration, and (3) the effects such material movement may have on the surface. The Martian and terrestrial atmospheres are compared as to the ease with which particles can be maintained aloft. The conditions under which material may be transported into the Martian atmosphere is considered. Saltation, compatibility between calculated and observed wind velocities, and the material constituting the yellow clouds are discussed. Conclusions indicate that the Martian dust storm is more violent than terrestrial ones.

380. Sharonov, V. V.,  
EXISTENCE OF A CORRELATION BETWEEN COLOR AND PHASE  
FOR MARS, Astronomicheskii Tsirkuliar, Moscow, No. 208,  
30 January 1960, p. 11.

The results obtained at 1956 by different investigators on changes of color index of Mars with time and its phase are contradicting. The photographic method indicates that the color of Mars is changing to a blue shade, however the photoelectric measurements are indicating a change to a red shade. The author's visual-colorimetric observations indicate no changes in the color. The author's method of observation with simultaneous comparison with the moon's color under the same conditions is described in detail and data are tabulated.

381. Sharonov, V. V.,  
THE NATURE OF THE SURFACE AND ATMOSPHERE OF THE  
PLANET MARS ACCORDING TO PHOTOMETRIC AND COLORIMETRIC  
RESULTS, Mem. Soc. Roy. Sci. Liège, Belgium, 7, Spec. No., 1963,  
pp. 386-392, Physics of Planets Symposium Paper, 1962.

"Physics of Planets" Symposium, Liège, 1962 (see Abstr. 13862 of 1963). The characteristic features of three Mars models are described. Results are based on observational data collected at the University of Leningrad. Tabulations are included of albedo, and colour of various characteristic surface features of the earth, and Mars.

382. Sharonov, V. V.,  
DUST COVERS ON THE SURFACE OF PLANETS AND SATELLITES,  
Life Sciences and Space Research II; International Space Science  
Symposium, 4th Warsaw, Poland, June 3-12, 1963, sponsored by the  
Committee on Space Research (COSPAR), M. Florkin and A. Dollfus,  
ed., North-Holland Publishing Co., Amsterdam, Interscience Publishers,  
New York, 1964, pp. 171-177.

Consideration of the problem of the existence of extensive dust covers on the Moon, Mars, and other planets. It is stated that, as is generally known, photometric observations of the Moon give a reflectivity diagram that is sharply elongated towards the Sun. Since a powdery material cannot possess such a diagram, the existence of an extensive dust cover on the Moon is said to be unlikely. The hypothesis is expressed that the lunar surface throughout consists not of dust, but of a slag-like material, as recently confirmed the analysis of radio-astronomical observations. The surface of Mercury should resemble that of the Moon; therefore, there is no reason to suppose that there

are dust covers on it. As to Mars, it is noted that photometric data indicate that the reflectivity is nearly orthotropic. The orange or reddish dust mist or fog observed in the planet's atmosphere is said to warrant the supposition that the surface of the planet is mostly covered with dust which, on account of its color, consists in all probability of powdery limonite or ochre. That this material remains uncemented is said to be a result of the lack of moisture.

383. New Mexico State University, Research Center, University Park,  
BLUE CLEARING DURING THE 1960-61 MARS APPARITION by  
B. A. Smith, Grant No. NsG-142, reprinted from Pub. Astron. Soc.  
Pacific, 73, No. 435, December 1961, pp. 456-459.

During the 1960 to 1961 Mars apparition, the New Mexico State University Research Center conducted a photographic study of Mars in red, blue, and ultraviolet light. Blue clearing and an extensive network of fine and coarse lines on blue and ultraviolet plates were recorded. Blue plates of sufficiently good quality for determination of blue clearing were obtained. Opposition of Mars occurred on December 30, 1960, and a higher percentage of dates of blue clearing occurred following this date. This survey, at an effective wavelength of  $\lambda$  4500, recorded many blue images with complete obscuration, but found none that showed complete visibility of surface markings. The survey does indicate that partial weak clearings are probably more common than is generally supposed.

384. Teifel', V. G.,  
COLOR INDEX OF MARS DURING THE 1958 OPPOSITION,  
Astronomicheskii Tsirkuliar, Moscow, No. 202, 5 June 1959, p. 1,  
No. 204, 15 September 1959, pp. 10-11.

Spectrophotometric observations of Mars made with a telescope (AZT-7) and with a spectrograph (ASP-g) in comparison with spectrum of the star ( $\alpha$  Aur) at the same zenith distances are briefly described with tabulated data. The table contains the data, computed with given formula, for color index ( $C_{1g}$ ), phase angle ( $\alpha$ ), latitude of central meridian of Mars (L) and number of measured spectrograms (n).

385. American Meteorological Society, Boston, Massachusetts,  
CONCERNING N. A. KOZYREV'S ARTICLE "EXPLANATION OF THE COLOR OF MARS BY THE SPECTRAL PROPERTIES OF ITS ATMOSPHERE," by G. A. Tikhov, March 1964, AD-602-202, Contract No. AF 19 (628)-3880, translated from Izv. Krymsk. Astrofiz. Observ., Moscow, No. 16, 1956, pp. 159-161.

In this paper, the author substantiates his reasons for believing that Kozyrev's conclusion that the red color of Mars is determined solely by the properties of its atmosphere is incorrect.

386. Urey, H. C. and Brewer, A. W.,  
FLUORESCENCE IN PLANETARY ATMOSPHERES, Proc. Roy. Soc. A, 241, 23 July 1957, pp. 37-43.

It is pointed out that ions and free radicals will exist in the high atmospheres of the planets and that these ions will absorb and fluoresce in the visible and near ultraviolet radiations. Applications of this effect to the problem of the colour of Venus, the blue haze of Mars, the variation of brightness of Jupiter and the haze of Mercury are discussed. The presence of a tenuous atmosphere on Mercury is justified by its equilibrium with the local interplanetary gas.

387. Vladimirkii, B. M. and Liubarskii, K. A.  
PROBLEM OF THE NATURE OF THE SURFACE OF MARS,  
Akademiiia Nauk Kazakhskoi SSR, Sektro Astrobolaniki, Trudy, 6,  
1958, pp. 34-38.

This is a critical note on the book Life in the Universe by Oparin and Fesenkov. Fesenkov is criticized for adopting McLaughlin's hypothesis in which different colors on the surface of Mars are explained by the presence of volcanic material. The quiet surface of Mars contradicts this hypothesis. Another principal feature of McLaughlin's theory is the coincidence of Martian winds with contours of the maria. It is contended that this coincidence is purely fictitious and it was derived with considerable bias in the use of Martian circulation data. The authors present their own analysis of the directional distribution of canals with latitude and conclude that their nature cannot be explained by any simple hypothesis.

388. University College, London,  
AN ANALYSIS OF MARTIAN CLOUDS AND THEIR TOPOGRAPHICAL  
RELATIONSHIPS by R. A. Wells, Paris, ESRO, May 1966.

The frequency of cloud occurrences distributed against heliocentric longitude is displayed in histogram form for the two chief cloud groups, white and yellow. White clouds show two peaks of maximum occurrence, while yellow clouds appear to show three peaks. Aerographic latitude plots of white and yellow cloud positions against heliocentric longitude reveal that the darkening wave is due to the transport of both water vapor and dust from high latitudes towards the equator. An examination of certain white clouds implies that at least some of the dark

maria are elevations. Order of magnitude estimates of these mountain heights are calculated by a new method. The unusual 'W'-shaped cloud phenomena are explained by orographically-produced air disturbances which imply that mountain ridges may be present on the surface with their axes arranged in the general patterns of a 'W'.

389. Wells, R. A.,  
EVIDENCE THAT THE DARK AREAS ON MARS ARE ELEVATED  
MOUNTAIN RANGES, Nature, 207, 14 August 1965, pp. 735-736.

Discussion of evidence regarding the existence of elevated mountain ranges on Mars which appear as dark areas when observed by telescope. A statistical survey of the occurrence of localized white and yellow Martian clouds has indicated that many white clouds are observed to form over the bright desert regions along dark areas and to remain stationary for some time. Notable areas for such occurrences have been recorded by Focas and Dollfus for the "Edom" region to the north of Sabaeus Sinus. From polarization investigations Dollfus has interpreted the curves for white clouds to be identical with that observed for ice crystal clouds. Scorer's theory of the formation of standing waves to the lee side of mountain ridges is used to explain this phenomenon. A mathematical analysis of this theory is then given, corroborated by terrestrial observations on Alpine Föhn winds. The hypothesis is made that the observed Martian white cloud formations are physical evidence of the presence of mountain ranges on Mars, confirmed by telescopic observations of dark areas.

390. Wilson, A. G.,  
SPECTROGRAPHIC OBSERVATIONS OF THE BLUE HAZE IN THE  
ATMOSPHERE OF MARS, RAND Corp. Paper 1509, 6 October 1958.

The author discusses the nature and observation of Martian blue haze; presents formulas for singling out the blue haze phenomena from lunar reflectivity and extinction, solar spectrum and the earth's atmospheric extinction; and also presents the possibility of an "Earth blue haze" with a suggestion for detecting such a phenomenon.

391. Wilson, A. G.,  
THE PROBLEM OF THE MARTIAN BLUE HAZE, Lunar and Planetary  
Exploration Colloquim, Proceedings, 1, No. 4, 12 January 1959,  
pp. 33-37.

The problem is approached by assuming that similarities with the earth's atmosphere permit the application of terrestrial meteorological principles and that differences reveal the effects of extrapolated conditions of phenomena. Reviewing the observational data some advanced explanations and some objections are presented. The dominant constituent of the Martian atmosphere is N<sub>2</sub>; H<sub>2</sub>O and CO<sub>2</sub> of the polar ice caps can also be expected in the atmosphere as the most likely causes of the blue haze besides storms of meteoritic dust. But the rapid times of clearing and reforming of the haze preclude all types of dust. The need for rapid, planet-wide temperature changes remains a serious objective to the condensation hypotheses. The spectral study of the haze opens for consideration as its cause several substances besides H<sub>2</sub>O and CO<sub>2</sub>. The earth might possess a haze layer as that of Mars. Color changes noctilucent clouds, etc. are discussed.

## B. ULTRAVIOLET (0.036 to 0.4 $\mu$ )

392. Brandt, J. C.,  
HYDROGEN AND HELIUM RESONANCE RADIATION FROM THE  
PLANETS, Mem. Soc. Roy. Sci. Liège, Belgium, 7, Spec. No. 1963,  
pp. 137-142, Physics of Planets Symposium Paper, Liège, 1962.

Estimates are made of the probable amounts of solar Lyman- $\alpha$  (1215 Å) and He I (584 Å) resonance radiation scattered by the atmospheres of Venus, Mars, Jupiter, and Saturn. The likely intensities appear sufficiently high to be detectable by modern instrumentation. Much valuable information could be derived from such studies: in particular, observations of the He I line should be helpful in elucidating the nature of the surface crusts (and possibly the sub-surface layers also) of Mars and Venus.

393. Coblenz, W. W. and Lampland, C. O.,  
FURTHER RADIOMETRIC MEASUREMENTS OF MARS, 1926,  
Bureau of Standards, Sci. Papers, No. 553, 1927, pp. 237-276.

The measurement of radiation from the planet Mars at the opposition of 1926 was in continuation of the work carried on in 1922 and 1924 at the Lowell Observatory, Flagstaff, Arizona, using the Lowell 42-in. reflector and a series of thermocouples in vacuum cells. The planetary radiation was resolved into spectral components by means of a series of transmission screens of water, quartz, glass and fluorite. The measurements were reduced to temperatures by three independent methods of analysis, which gave concordant results; and these showed, as before, that bright areas on the planet are cooler than adjacent dark areas, that the summer hemisphere is warmer than the winter hemisphere, and that the forenoon side is cooler than the afternoon side, unless there happen to be sunset clouds. This year clouds were frequently observed on Mars. An important result is the demonstration that the surface temperature of the summer hemisphere rises considerably above the freezing point of water, which has for years been a disputed question. Noonday temperatures of from 10° to 20°C have been deduced from the observations.

394. Evans, D. C.,  
ULTRAVIOLET REFLECTIVITY OF MARS, Science, 149, 27 August  
1965, pp. 969-972.

Analysis of UV spectrograms of Mars (2400 to 3500 Å, ~50-Å resolution) obtained with an objective grating spectrograph on an Aerobee rocket. The data indicate a reflectivity of 0.04 to 0.08 in the UV, increasing toward shorter wavelength according to a Rayleigh law. The data can be represented by a model having an atmosphere of nitrogen, carbon dioxide, and argon, and a surface pressure of about 5 to 20 mbar. The photographic appearance of the planet in the blue is interpreted as a loss of surface contrast and reflectivity rather than an absorption in the atmosphere by the "blue haze." The model permits prediction of the general appearance of the planet in the photographic UV, blue, visible, and red. There are serious biological implications since the model suggests that UV radiation (2000 to 3000 Å) will reach the surface.

395. Consultants and Designers, Inc., Arlington, Virginia,  
OPTICAL PROPERTIES OF THE ATMOSPHERE OF PLANET MARS  
IN THE ULTRAVIOLET SPECTRUM REGION by V. I. Garazha and  
E. G. Yanovitskiy, NASA-TT-F-8994, 19 November 1964, Contract  
No. NAS5-3760, translated from Astron. Zh., USSR, 41, No. 5,  
1964, pp. 942-950.

It is shown that during the 1956 opposition, the optical thickness of the atmosphere of Mars in the spectral region  $\tilde{\lambda} = 360\text{m}\mu$  was considerably greater than the unity. It is assumed that the ultraviolet layer of the atmosphere of Mars consists of a mixture of gas with aerosol particles. It was found that at this mixture's single scattering, the albedo of particles is 0.50. Using the Rocard theory for the interpretation of atmosphere indicatrices, the scattering indicatrix was obtained in the indicated spectral region, and the mean radius of the aerosol particle was found to be  $0.9 \cdot 10^{-5}\text{cm}$ . It was found that aerosol particles have an albedo of single scattering equal to 0.38 and that the concentration of these particles in the ultraviolet layer is rather high.

396. Guerin, P.,  
CORRECTED REFLECTIVITY CURVE OF A BRIGHT REGION OF  
MARS AT THE CENTRE OF THE DISK IN OPPOSITION, Ann. Astrophys.,  
France, 25, No. 6, 1962, pp. 429-433.

New spectrophotometric observations were carried out to compare a non-luminescent region of the Moon and  $\eta$  Cas A. They showed that the wavelike variations present on the apparent reflectivity curve of Mars in the ultraviolet, brought into evidence by comparison of the spectra of Mars and this star, have their origin in the differences of spectral type between  $\eta$  Cas A and the Sun and are not real features

of Mars. The results corrected for this effect could give information about the nature of the Martian surface when used in the visible. In the ultraviolet they are an indication of atmospheric scattering by small particles.

397. Mecke, R.,

NEW ABSORPTION BANDS OF METHANE IN THE ULTRA-VIOLET,  
Zeits. f. Astrophysik, 6, No. 1-2, 18 January 1933, pp. 144-149.

The study of the absorption-spectrum of a layer of methane 20.3m. thick at a pressure of 5 atmospheres has revealed five new bands at wave-lengths 8900, 8600, 8400, 7840 and 7250 Å respectively. Comparison with the spectra of planets leads to the conclusion that hydrocarbons are probably present in their atmospheres.

### C. POLARIZATION (0.22 to 1.6 $\mu$ )

398. Barabashov, N. P.,  
PHYSICAL CONDITIONS OF MARS, Akademiya Nauk SSSR, Vestnik,  
No. 10, 1962, pp. 18-25.
- Photometric studies in the red and near infrared light show that the brightness distribution of the Martian disk from the center to the edge resembles that yielded by Lambert's light reflection law, which holds for ideally dull surfaces with irregularities smaller than 0.1 mm.<sup>1</sup> The Martian atmosphere is believed to posses chiefly scattering properties. The pressure has been estimated at 6-8 cm Hg. Spectral, photometric, and polarization characteristics suggest that the Martian surface is composed of rocks resembling terrestrial reddish fragmented volcanic tuffs as well as limonite, ochra, and reddish sandstone. It is thought that the Martian seas and continents may be composed of the same rock but in different stages of oxidation. Kozyrev, on the other hand, maintains that the reddish-color of Mars is the exclusive product of the atmosphere in which absorption predominates over scattering. The Astronomical Observatory of Kharkov University has ascertained that the surface of the Martian seas is more irregular and rougher than that of the continents. On the basis of pressure and density estimates, it is thought that a height of 28-km propeller-driven aircraft could operate in the Martian atmosphere, and that such craft would be able to climb to greater heights than on earth. It is believed that the polar caps are not solid but are interrupted by patches of the reddish surface. The caps consist of two components: the surface component of snow or frost and the atmospheric component of fog or light clouds.

399. Observatoire de Paris, Section d'Astrophysique,  
POLARIMETRIC STUDY OF THE PLANET MARS Final Scientific  
Report by A. Dollfus and J. H. Focas, 30 April 1966, AD-635 928,  
Contract No. AF 61 (052)-508.

Analysis was made of five thousand two hundred measures of the polarized light of Mars, collected during the last nine apparitions of this planet, since 1948. The polarization curves for the bright and the dark areas of the planet are reproduced for each one of the apparitions. The variation of the polarization for the spectral range 1.05 to 0.45 micron is examined. A polarimetric and photometric study of selected samples of minerals indicated the presence, in the

bright areas of the planet, of a fine powder of hydrated iron oxide of the limonite type. The seasonal variation of the polarizing properties of the dark areas of Mars follows closely the variation of their darkness at Martian spring; this suggests a seasonal modification of their microscopic texture. The luminance of the atmosphere of the planet amounts, for a wavelength of 0.61 micron, to  $K_a$  (0.61 Micron) = 0.0006 stilb/phot; this corresponds to a surface pressure of 30 millibars. The scattering coefficient of the atmosphere at 0.47 micron is  $K_a$  (0.47 micron) = 0.00151 stilb/phot. This value shows that the atmosphere of the planet is much too transparent in the blue to mask the markings of the soil.

400. Dollfus, A.,  
A STUDY OF THE POLARISATION OF THE SOLAR LIGHT REFLECTED FROM THE PLANET MARS, C. R. Acad. Sci., Paris, 227, 2 August 1948, pp. 331-333.

Gives results of observations made in early 1948 from the Pic du Midi with a 24 in telescope with polarimeter. Four effects contribute and each has been measured and a value derived.

401. Dollfus, A.,  
POLARIMETRIC STUDY OF THE LIGHT REFLECTED BY CLOUDS AND ATMOSPHERE OF THE PLANET MARS, Academie des Sciences Paris, Comptes Rendus, 227, No. 6, 19 August 1948, pp. 383-385.

A brief note of observations which led to the following conclusions: the white clouds of the planet consist of ice crystals; the structure of the blue clouds has an apparent resemblance to the mother-of-pearl clouds of the terrestrial atmosphere; there is a deviation in the plane of polarization; and, finally the brilliance of the Martian atmosphere in the center of the disk would be 0.06 that of the clear regions of ground which corresponds to an atmospheric pressure of 6 cm Hg.

402. Dollfus, A.,  
DETERMINATION OF ATMOSPHERIC PRESSURE ON MARS,  
Academie des Sciences, Paris, Comptes Rendus, 232, No. 11, 12 March 1951, pp. 1066-1068.

The atmospheric pressure on Mars has been studied by polarization measurements of the light from Mars. The methods are:  
1) difference between polarization at the center and at the edge of the disc; 2) the difference between these two areas for green and orange; 3) comparison of polarization curves for different areas of the

surface for green and red. It is estimated that the atmosphere on Mars has a pressure of 83 millibars at the ground surface.

403. Dollfus, A.,  
INTERPRETATION OF THE POLARIZATION OF LIGHT REFLECTED BY THE DIFFERENT REGIONS OF THE SURFACE OF THE PLANET MARS, C. R. Acad. Sci., Paris, 233, 6 August 1915, pp. 467-469.

Previous observations have been extended, and the results are compared with polarization produced under known conditions. The polarization of light from the bright regions is analogous to that produced by reflection from powdered limonite; light from the dark regions resembles that reflected from small opaque granules (mineral, or perhaps microscopic plants), and differs from light reflected by extended vegetation.

404. Fish, F. F., Jr.,  
THE STABILITY OF GOETHITE ON MARS, Jour. Geophys. Research 71, No. 12, 1966, pp. 3063-3068.

Polarization and visible and infrared studies of Mars and of various minerals and rocks have been interpreted as implying that a significant part of the Martian surface material is finely divided limonite--a mixture of iron oxides and hydroxides--but principally the monohydrate, goethite. In this paper, the thermodynamic stability of goethite under Martian surface conditions is examined using the available experimental data. It is concluded that hematite ( $Fe_2O_3$ ) rather than geothite ( $HFeO_2$ ) is the stable form on the Martian surface.

405. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, OBSERVATIONS OF MARS MADE IN 1961 AT THE PIC DU MIDI OBSERVATORY by J. H. Focas, 30 January 1962, JPL-TR-32-151, Contract No. NAS7-100, JPL Contract 1-109412/013550.

Results are presented of observations of Mars made in 1961 through the 24-in. refractor of the Pic du Midi Observatory. The following measurements were included in the observation program: polarimetric measurements of the proportion of polarized light coming from various regions of the planet; photometric measurements, using photographic negatives, of the contrast between selected areas; and photographic and visual observations of the upper atmosphere of Mars (in ultraviolet and blue light) and of the fine surface markings of the planet.

406. Lyot, B.,  
POLARISATION OF LIGHT FROM THE MOON, MARS AND MERCURY,  
Comptes Rendus, 178, 26 May 1924, pp. 1796-1798.

The degree of polarisation of the light diffused from these bodies is plotted against the angle of diffusion. The curves are very similar in form. If light polarised in the plane of diffusion be denoted positive, and at right angles to this plane negative, the curve is of the following form: At zero angle the polarisation is zero, falling to a minimum value of 0.012 at about  $10^\circ$ . It becomes zero again at  $24^\circ$ , rising to a maximum of 0.04 -- 0.09 at about  $100^\circ$ , and thence falling steeply. These results indicate that the three bodies are similarly constituted as regards atmosphere, and differ entirely from Venus, of which the polarisation behaves in another way.

407. Morozhenko, A. V.,  
RESULTS OF POLARIMETRIC OBSERVATIONS OF MARS IN 1962-1963,  
Phys. of the Moon and the Planets, Israel Program for Scientific  
Translations, Ltd., Jerusalem, 1966, pp. 43-60.

A literature survey is made relating to properties of light polarized via diffusion reflection from the Martian surface and scattering in its atmosphere, and results are reported for polarimetry studies conducted during the 1962-1963 opposition. The variation of polarization with phase angle for all Martian features is found to be close to that observed for the center of the disk. The spectral variation positive polarization for these features is less steep than for the center, however, in keeping with a difference in the spectral variation of apparent albedo. Polarization in the southern polar region is consistently less than in the northern region, apparently due to differences in structure. Degree of polarization is found to fluctuate widely from day to day.

408. Morozhenko, A. V.,  
POLARIMETRIC INVESTIGATIONS OF MARS AT THE MAIN  
ASTRONOMICAL OBSERVATORY OF THE UKRAINIAN ACADEMY  
OF SCIENCES, Life Sciences and Space Research II; International  
Space Science Symposium, 4th, Warsaw, Poland, June 3-12, 1963,  
sponsored by the Committee on Space Research (COSPAR), M. Florkin  
and A. Dollfus, ed., North-Holland publishing Co., Amsterdam,  
Interscience Publishers, New York, pp. 251-254.

Presentation of results of a polarimetric investigation, during the 1962-1963 opposition of Mars, of the relationship between polarization and phase angle for the entire disk, as well as for some parts of it in 8 spectral intervals (350-600  $\mu\text{m}$ ). The results are as follows:

(1) for the phase angle  $39^\circ$  the spectral polarization curve is:  
355  $\mu\text{-}9.10\%$ , 390  $\mu\text{-}4.80\%$ , 420  $\mu\text{-}3.10\%$ , 450  $\mu\text{-}2.70\%$ ,  
475  $\mu\text{-}2.40\%$ , 510  $\mu\text{-}2.00\%$ , 560  $\mu\text{-}1.60\%$ , 600  $\mu\text{-}1.40\%$ ;  
(2) during two months, a considerable variation of the degree of polarization was observed while the phase angle remained almost unchanged ( $37.40\text{-}39.20^\circ$ ). Two groups (each including two periods of observations) with different polarization may be distinguished. The ratio of upward polarization of the second group to the first is: 355  $\mu\text{-}1.01$ , 390  $\mu\text{-}1.14$ , 420  $\mu\text{-}1.32$ , 450  $\mu\text{-}1.31$ , 475  $\mu\text{-}1.37$ , 510  $\mu\text{-}1.50$ , 560  $\mu\text{-}1.71$ , 600  $\mu\text{-}2.32$ . It is noted that the possible explanation of this phenomenon is the variation of dust in the Martian atmosphere.

409. Rea, D. G. and O'Leary, B. T.,  
VISIBLE POLARIZATION DATA OF MARS, Nature, 206, 12 June 1965,  
pp. 1138-1140, Grant No. NsG 101-61.

Discussion of the discrepancy in values derived by different methods for the surface pressure of Mars. A value of 90 mbar for this pressure, based on visible photometric and polarimetric work, has generally been accepted. Recently, however, a value of 25 mbar has been derived by Kaplan, Munch, and Spinrad from a curve-of-growth analysis of pressure-broadened carbon-dioxide vibration-rotation lines in the near IR Martian spectra. It is suggested that this discrepancy can be accounted for by the presence of aerosol particles in the Martian atmosphere contributing an appreciable component to the observed brightness and polarization of Mars. Calculations are given indicating the feasibility of this explanation.

## D. REFLECTION (0.22 to 1.6 $\mu$ )

410. Adams, W. A. and Dunham, T., Jr.,  
B BAND OF OXYGEN IN THE SPECTRUM OF MARS, Mt. Wilson  
Observat. Contrib., No. 488, Astrophys. J., 79, April 1934,  
pp. 308-316.

Ten spectrograms of Mars covering the region of the B band of oxygen were obtained in the first order of the 9-foot grating spectrograph at the coudé focus of the 100-inch reflector during the autumn and winter of 1932-1933. During the interval covered by the observations, the radial velocity of the planet relative to the earth varied from -13.8 to +12.6 km./sec. The linear scale of the spectrograms was 5.6 Å/mm. Measures of the wave-lengths of about thirty oxygen lines on each of the ten spectrograms relative to lines of solar origin showed a mean displacement of but 0.0011 Å from the position of the telluric oxygen lines. The contours of the oxygen lines were also investigated with the microphotometer and compared with the theoretical contours on the assumption of a ratio of 1 : 1000 in the relative abundance of molecules of free oxygen in the atmospheres of Mars and the earth. The final conclusion is that the amount of oxygen in the atmosphere of Mars is probably less than 0.1% of that in the earth's atmosphere over equal areas of surface.

411. Jet Propulsion Laboratory, California Institute of Technology, Pasadena,  
PLANETARY SPECTRA BY FOURIER SPECTROSCOPY. I: MARS  
by P. Connes and J. Connes, 1 August 1966, NASA CR-77116,  
Contract No. NAS7-100.

Mars spectra, obtained during the spring 1965 apparition by interferometric spectroscopy, are presented. A brief discussion is included, together with a summary of the format used to characterize the individual spectral traces. Tables, covering the observing conditions at the time the spectra were taken are also included.

412. Connes, J., Connes, P., and Kaplan, L. D.,  
MARS - NEW ABSORPTION BANDS IN THE SPECTRUM, Science,  
153, 12 August 1966, pp. 739-740.

Note on the finding of new absorption bands in the near-IR spectrum of Mars by Fourier spectroscopy. They are tentatively identified in part as due to reduced gases in the Martian atmosphere. The Mars

spectra were obtained mainly to measure absorption by lines in the 1.6 1.6- $\mu$  CO<sub>2</sub> bands to make it possible to estimate the surface pressure more precisely.

413. Draper, A. L., Adamcik, J. A., and Gibson, E. K.,  
COMPARISON OF THE SPECTRA OF MARS AND A GOETHITE-  
HEMATITE MIXTURE IN THE 1 TO 2 MICRON REGION, Icarus, 3,  
May 1964, pp. 63-65.

Discussion of the reflectance spectrum of a mixture of goethite (hydrated iron oxide) and hematite. The spectrum generally agrees with the spectrum of the bright areas of Mars in the 1- to 2- $\mu$  region. The procedure of preparation of goethite is described in detail. Both components are physically mixed in proportions possibly close to the composition of the surface soil of the bright areas of Mars. An iron oxide composition appears to constitute a considerable portion of the Martian surface.

414. Guerin, P.,  
SPECTROPHOTOMETRIC STUDY OF THE REFLECTIVITY OF THE  
CENTRE OF THE MARTIAN DISK AT OPPOSITION, AND THE NATURE  
OF THE VIOLET LAYER, Planet. Space Sci., GB, 9, March 1962,  
pp. 81-87.

Spectra of the centre of the martian disk (Arabia region) were compared, wavelength by wavelength, with those of a GO V star. The martian reflectivity curve was obtained by taking account of the visible and ultraviolet gradients of this star relative to the sun. Mars is red from 6100 to 3850 Å, and "grey" on the average from 3850 to 3100 Å, but in this region of the spectrum, the reflectivity curve presents undulations which, if real, may perhaps be due to packets of absorption bands produced by some organic compound ejected by martian "vegetation".

415. Guerin, P.,  
CONTINUOUS SPECTROPHOTOMETRY (BETWEEN 3200 AND 6100 Å)  
OF A LIGHT REGION OF MARS AT OPPOSITION, AND THE NATURE  
OF THE VIOLET LAYER, Mem. Soc. Roy. Sci. Liège, Belgium, 7,  
Spec. No. 1963, pp. 402-410, Physics of Planets Symposium Paper,  
Liège, 1962.

On 4 nights in December 1960 the spectral distribution of light from a light region at the centre of the Martian disk ("Arabia") was compared with that of the G<sup>0</sup>V star, η Cas A, similar to the sun.

Spectrophotometric data were obtained from both spectra at more than 40 places between 3167 and 6113 Å. In the visual region, the intensity measures showed no significant contribution by planetary absorptions, or emissions to the Fraunhofer spectrum of sunlight. In the u.v. region also there was a total absence of diffuse absorption, or emission bands, such as have been postulated by previous investigators to account for the violet layer in the Martian atmosphere. It now appears that this particular feature can be explained in terms of classical scattering of sunlight by small particles, droplets, or crystals.

416. Ibragimov, N. B.,

PRELIMINARY RESULTS OF THE INTEGRAL SPECTROPHOTOMETRY OF MARS, Kharkov, Universitet, Astronomicheskaya Observatoriya, Tsirkulyar, No. 26, 1963, pp. 37-42, taken from Referativnyy Zhurnal, Astronomiya, No. 7, 1964.

As a result of spectrophotometric observations of Mars made with the ASP-9 spectrograph and AZT-7 telescope in the period September 1960 through May 1961, values of monochromatic stellar magnitudes of Mars for 20 wavelength values in the Greenwich monochromatic stellar magnitude system were determined. Examination of the phase coefficient variation along the spectrum has shown that, besides a general lessening with an increase of wavelength, a minimum occurs near  $\lambda$  5250. The dependence of the color index on the phase angle was also defined. It may be represented by the relationship

$$C\lambda_1\lambda_3 = 1^m .48 + 0.009\alpha,$$

where  $\lambda_1 = 4250 \text{ \AA}$  and  $\lambda_3 = 5550 \text{ \AA}$ .

417. Kozyrev, N. A.,

EXPLANATION OF THE COLOR OF MARS BY THE SPECTRAL PROPERTIES OF ITS ATMOSPHERE, Akademiiia Nauk SSSR, Krymskaja Astrofizicheskaja Observatoriia, Izvestiia, 15, 1955, pp. 147-152.

A photometric comparison of spectra of Martian surface details and of the solar spectrum was made from spectrograms of Mars obtained in 1954 with the 50 duim reflector of the Crimean Astrophysical Observatory. The curves obtained and presented in this paper show that the maria and continents on Mars have the same proper colorings. The observed difference in colors is completely accounted for by the properties of the Martian atmosphere. On the basis of this consideration the reflectivity of the atmosphere of Mars was determined for

various wave lengths. The values obtained are tabulated. Apparently the surface of Mars has a proper albedo of about 0.45, with no significant variations in the visible spectrum. It is only the considerable atmospheric dust content which makes such a neutral surface to look bright red. On this assumption the dependence of the optical thickness of the Martian atmosphere upon wave length is calculated and graphically represented. Tikhov takes exception of Kozyrev's statement and argues that the red coloring on Mars must be due to vegetation.

418. Kozyrev, N. A.,  
SPECTRAL INDICATIONS OF SNOW IN THE ATMOSPHERE OF MARS,  
COSPAR, Fourth International Space Science Symposium, Warsaw,  
Poland, 3-12 June 1963.

Comparative spectrophotometric investigations of Martian seas and continents support the contentions that the Martian atmosphere is opaque to short wavelengths (< 4200 Å) and that the polar caps are mainly an atmospheric phenomenon. The red color of Mars is also believed to be an atmospheric, rather than a surface characteristic. The polar caps are considered to be a concentration of the same scattering particles that cause Martian atmospheric haze. Since a similar band of scattering was detected in the spectrum of finely powdered dry snow sifted in front of the spectrograph slit, it is believed probable that there are ice needles in the Martian atmosphere similar to those observed in the terrestrial atmosphere when the temperature falls considerably below freezing.

419. American Meteorological Society, Boston, Massachusetts,  
SOME PROPERTIES OF THE MARTIAN ATMOSPHERE INDICATED  
BY SPECTROPHOTOMETRIC OBSERVATIONS OF 1956 by  
N. A. Kozyrev, March 1964, AD-602 183, Contract No. AF (628)-3880,  
translated from Izv. Krymsk. Astrofiz. Observ., Moscow, No. 18,  
1958, pp. 61-65.

In 1956, the contrast of the surface details of Mars decreased sharply, while the general color of the planet changed but little. It is concluded that the atmosphere became turbid only in the lowest layers, and that no essential changes took place in the general optical properties of the atmosphere itself. Spectrograms of the polar cap, made in the second half of September and early October, showed it to be an atmospheric formation resulting from the condensation of the particles that cause normal scattering in the upper layers of the Martian atmosphere.

420. National Aeronautics and Space Administration, Washington, D. C.,  
SPECTROPHOTOMETRIC COMPARISON OF MARTIAN CONTINENTS  
WITH RED-COLORED TERRESTRIAL CAPROCK by I. I. Lebedeva,  
NASA-TT-F-1008, April 1966, translated from Tr. Astron-Observ.,  
SFR, Mat., Leningrad, 22, No. 39, 1965, pp. 125-131.

Relative spectral curves of the integral Martian radiation in the visual region are plotted. The same curves are drawn for the brightness of continents in the center of the disk of the planet, taking into account the optical effect of Martian atmosphere. The curves are compared with the curves of spectral reflectance of red-colored terrestrial rocks. The latter are determined with the SF-2M spectrophotometer. Satisfactory coincidence of these curves may be considered as confirmation of the hypothesis according to which the specific color of the Martian surface is attributed to the presence of a limonite dust.

421. Lowell, P.,  
SPECTRA OF THE LARGER PLANETS PHOTOGRAPHED IN 1907  
AT FLAGSTAFF OBSERVATORY, Comptes Rendus, 147,  
21 September 1908, pp. 516-521.

In 1907 by means of special plates bathed in a mixture of pinacyanol, pinaverdol, and dicyanine, V. M. Slipher obtained at Flagstaff spectra of the moon, Mars, Jupiter, Saturn, Urnaus, and Neptune which extended unexpectedly far into the infra-red, showing the important region from C to beyond A. The results for Mars have already been published [see Abstract No. 1619 (1907)]. It may be remembered that the  $\alpha$  band was found to be decidedly stronger than on the moon.

422. National Aeronautics and Space Administration, Washington, D. C.  
PLANETARY SPECTRA, NASA-TT-F-888, May 1964, translated  
from Priroda, Moscow, No. 6, June 1961, pp. 39-45.

The analysis of data gathered from the earth by the spectral method of investigations is discussed briefly. It is pointed out that spectroscopic investigations of the planets have developed in three principal directions: study of planetary rotation on the basis of the Doppler shift of spectra lines, photometric study of the continuous spectrum of planets as well as the search for new lines and absorption bands, and study of already known lines and bands. Reports on the results of these investigations are presented on greater detail. A survey of research on the following topics is presented: auroras, and carbon dioxide and water vapor in the Venusian atmosphere; vegetation on Mars; hydrogen and its compounds in the atmospheres of the giant

planets; the meteoric nature of Saturn's rings; luminescence and lunar surface color; and the minor planets' spectra.

423. Sagan, C., Phaneuf, J. P., and Ihnat, M.,  
TOTAL REFLECTION SPECTROPHOTOMETRY AND THERMO-  
GRAVIMETRIC ANALYSIS OF SIMULATED MARTIAN SURFACE  
MATERIALS, Icarus, USA, 4, No. 1, April 1965, pp. 43-61.

The ultraviolet, visible, and near infrared reflection spectra of the Martian bright areas have been compared with the corresponding laboratory reflectivities, measured with an integrating sphere, of a variety of minerals containing ferric oxides and silicates, as solids and in pulverized form. Except in the ultraviolet, where the effects of the Martian blue haze are prominent, pulverized limonite, a ferric oxide polyhydrate matches the shape and amplitudes of the Martian Russell-Bond albedo within experimental and observational error. Further observational tests of this identification are outlined. If water-rich limonite is a primary constituent of the Martian bright areas, conditions in the earlier history of Mars were probably much more equable than contemporary conditions, and the origin and evolution of life on primitive Mars becomes easier to understand.

424. Sharonov, V. V.,  
SOME RESULTS OF OBSERVATIONS OF MARS DURING THE  
OPPOSITION OF 1958, Akademiiia Nauk SSSR, Komissiia po Fizike  
Planet., Izvestiia, No. 2, 1960, pp. 24-29.

The various methods of determining optical characteristics of the atmosphere and surface of Mars are briefly reviewed. It is found that in interpreting the data obtained by means of spectrophotometry of Mars, there is no need for resorting to the hypothesis of large optical thickness of the planet's atmosphere, at least not in the visible range of the spectrum.

425. Slipher, V. M.,  
SPECTRUM OF MARS, Astrophys. Journ., 28, December 1908,  
pp. 395-404.

All observations of the spectrum of the planet Mars previous to 1895 were made visually, and it is doubtless owing to the subsequent application of continually improved photographic investigation that the recent definite conclusions have been rendered possible. One of the chief difficulties with the visual determinations was the absence of a suitable comparison spectrum which could be examined simultaneously

with that of the planet. The photographs reproduced were taken at Flagstaff, Arizona, under ideal conditions. At the altitude of 7,250 ft. most of the water-vapour from the earth's atmosphere is avoided, and the observations were made in the winter months when the percentage of vapour was least. Special red-sensitive plates enabled the spectrum to be obtained as far as the A line, thus permitting the  $\alpha$  band of water-vapour to be used as standard. Close discussion of the relative intensity of this  $\alpha$  band when the moon's spectrum was photographed at the same altitude show most distinctly that it is relatively much stronger in the Mars spectrum. As this is undoubtedly associated with water-vapour, the conclusion is that water-vapour is present in the atmosphere of Mars. The results suggest the presence of snow-caps and a comparatively moderate temperature rather than hoar-frost caps and a low temperature.

426. Slipher, V. M.,  
SPECTROGRAPHIC STUDIES OF THE PLANETS, Roy. Astron. Soc.,  
M. N., 93, October 1933, pp. 657-668.

A general account is given of the methods of spectrographic study of the planets, especially as carried out at the Lowell Observatory. The planets fall into two main groups: those which show little or earth-like atmospheric bands and those which show strong selective absorptions. The first group contains Mercury, Venus, Mars, Pluto and the Earth; the latter, the four giant planets. The absorption of the atmospheres of the giant planets apparently persists deep into the heat spectrum. If the atmospheres of these planets obstruct the spectrum range which our atmosphere transmits and vice versa, the temperatures of the major planets will be far higher than radiometric measures suggest.

427. Teifel', V. G.,  
STUDIES OF THE MOON AND PLANETS IN KAZAKHSTAN, Akademiiia Nauk Kazakhskoi SSR, Vestnik, 20, August 1964, pp. 9-17.

Review of the physical studies of the planets and satellites of the solar system conducted since 1956 at the Astrophysical Institute and the Department of Astrobotany of the Academy of Sciences of the Kazakh SSR. The studies include spectrophotometric and spectrocolorimetric investigations of the lunar surface, photometric and spectral observations of Mars and Venus, spectral measurements of molecular light absorption in the atmospheres of Jupiter, Saturn, and Uranus, and the optical properties of the Red Spot, an elliptical configuration in the cloud layer of Jupiter. Future studies are outlined.

428. Yezerskaya, V. A. and Yeremenko, N. F.,  
SPECTROPHOTOMETRY OF MARS NEAR THE OPPOSITION OF 1956,  
Kharkov, Universitet Astronomicheskaya Observatoriay, Tsirkulyar,  
No. 19, 1964, pp. 27-28, taken from Referativnyy Zhurnal,  
Astronomiya i Geodeziya, No. 2, 1962 2 A467.

Spectrograms were obtained on 4 and 27 September 1956 by means of an objective prism with an angle of 12° on the Merz refractor ( $D = 110$  mm,  $F = 550$  mm, dispersion  $340 \text{ Å/mm}$  at  $H\gamma$ ). FP-4 plates were used;  $\alpha\text{Aql}$  was chosen as comparison star. The recordograms of the spectra were obtained on the MF-4 microphotometer. Corrections for atmospheric attenuation of the value  $\log J_{\text{Mars}}/J_{\text{Aql}}$  for  $322-588 \text{ m}\mu$  are given in tabular form. The relative distribution of intensity in the Martian spectrum is given in the graph. The color index, computed from the observations of 4 September, is +1.43, while for 27 September, +1.66.

## E. INFRARED (1 to $100\mu$ )

429. Adams, W. S. and St. John, C. E.,  
AN ATTEMPT TO DETECT WATER-VAPOUR AND OXYGEN LINES  
IN THE SPECTRUM OF MARS WITH THE REGISTERING MICRO-  
PHOTOMETER, Mt. Wilson Observat. Contrib., No. 307,  
Astrophys. J., 63, March 1926, pp. 133-137.

If water-vapour and oxygen are present in the atmosphere of Mars, the motion of the planet with reference to the earth should produce a relative displacement of the lines due to these gases in the two spectra. Spectrograms of Mars and the sky were made with a six-prism spectrograph, the scale being 1 mm. =  $7.3\text{ \AA}$ . at D, and graphs were drawn by a registering microphotometer on a scale of 1 mm. =  $0.12\text{ \AA}$ . The lines of water-vapour and oxygen in the graphs of the two spectra were superposed, and the relative displacements of the solar lines were then read directly from the curves. The water-vapour lines in the spectrum of Mars were displaced  $0.03 \pm 0.01\text{ \AA}$ ., and the oxygen lines  $0.09 \pm 0.03\text{ \AA}$ . to the red, with respect to their positions in the sky spectrum. On taking account of the Doppler displacement, the length of path in the two atmospheres and the amounts of water-vapour and oxygen above Mt. Wilson, the quantity of water-vapour in the atmosphere of Mars, area for area, was found to be approximately 3% of that over Pasadena, and the quantity of oxygen two-thirds of that above Mt. Everest.

430. Barabashov, N. P. and Koval', I. K.,  
DISTRIBUTION OF BRIGHTNESS IN MARTIAN "SEAS," Akademia Nauk URSR, Kiev, Dopovidyi, No. 2, 1959, pp. 153-155.

Measurements of the brightness of "seas" and "continents" of Mars and the contrast between the "seas" and "continents" during its last opposition, made in the infrared portion of the spectrum at various distances from the center of the planet's image, indicate different values of the smoothness factor, which is in disagreement with these advanced by V. G. Fresenkov.

431. Binder, A. B. and Cruikshank, D. P.,  
COMPARISON OF THE INFRARED SPECTRUM OF MARS WITH THE  
SPECTRA OF SELECTED TERRESTRIAL ROCKS AND MINERALS,  
Communications of the Lunar and Planetary Laboratory, Volume 2,  
No. 36-39, University of Arizona Press, Tucson, 1964, pp. 193-196,  
Grant No. NsG 161-61.

Comparison of Kuiper's low-dispersion IR spectrograms of Mars (obtained with the 82-in. telescope of the McDonald Observatory) with laboratory and solar spectra obtained by the authors with the same equipment and matching resolution. The detector was a 0.1-mm PbS cell, used with a rapid scan rate ( $1.3 \mu/\text{min}$ ), giving a resolution of about 60 at  $1.5 \mu$ . This resolution is sufficient to resolve the  $\text{CO}_2$  bands at  $2.01$  and  $2.06 \mu$ . The rock and mineral samples were observed using solar illumination in the laboratory at Tucson. The results indicate that if a Martian analogy can be drawn with terrestrial deserts, it may be assumed that the Martian surface is composed partly of stained outcrops, rock fragments and finer material.

432. Ludwig-Maximilians-Universitat, Meteorologisches Inst., Munich,  
MORE-RECENT RESULTS OF RESEARCH ON THE ATMOSPHERES  
OF THE PLANETS MARS AND VENUS. A LITERATURE REPORT  
by H. J. Bolle, 18 June 1962.

It appears that the Moon, Mars and Venus will be the only heavenly bodies that can be directly observed by space vehicles for some time to come. This report attempts to demonstrate how the knowledge of the atmospheres of these planets, obtained from earth observations, may be correlated with investigations made in the infrared spectral domain. Infrared methods have been applied in the study of Earth's atmosphere and have resulted in great advances. Infrared methods will also probably be applied successfully in investigations of other heavenly bodies.

433. Campbell, W. W.,  
SPECTRUM OF MARS, Science, 29, 26 March 1909, p. 500.

The author considers that Very's article may convey a wrong impression concerning the early observations of the spectrum of Mars. The pioneer observers believed they saw in the spectrum of Mars evidence of the modifying influences of oxygen and water-vapour in its atmosphere, but other work of similar nature led to doubt as to the spectroscopic evidence. In those days the spectrum could not be observed beyond  $\lambda 6900$ , and it is only by means of the newly discovered sensitizers for photographic plates that determinations of the  $\alpha$  water-vapour band at  $\lambda 7175$  have been possible. As Very's discussion was entirely based on the intensity of this band, the question of the correctness of the older observations is not involved. It is pointed out that Slipher's photographs show no traces of absorption of oxygen or water-vapour, in the region  $\lambda 5400-6900$ , and thus confirm Campbell's observations of 1894-5.

434. Campbell, W. W. and Albrecht, S.,  
SPECTRUM OF MARS, Science, 81, 24 June 1910, pp. 990-992.

Observations were made with a specially designed spectrograph having a 5-in. plane Michelson grating (15,000 lines to the inch), second order spectrum, used in conjunction with the 86-in. refractor. The plates secured on Jan. 26, 27, and Feb. 2, 1910, failed to show any traces of water-vapour lines. On Feb. 3 two plates were exposed to the " $\alpha$ " region near  $\lambda$ 6280, which includes several oxygen absorption lines. These last were observed displaced by amounts corresponding to velocities of 18.8 and 17.4 km. per sec., the computed velocity being 19.1, so that if any outstanding lines were present the conditions appeared to be excellent for their detection. Here again, however, the terrestrial oxygen lines were not accompanied by Martian lines. The conclusion given is that the quantity of water-vapour existing above unit area in the equatorial atmosphere of Mars was certainly less than one-fifth that existing above Mt. Hamilton under the excellent conditions on Feb. 3. The air temperature was 0°C., relative humidity 33 per cent., absolute humidity 1.9 gm. per m.<sup>3</sup>, and zenith distance 55°. Similarly the quantity of oxygen must be small in comparison with that in the earth's atmosphere.

435. Connes, J. and Connes, P.,  
NEAR-INFRARED PLANETARY SPECTRA BY FOURIER SPECTROSCOPY. I-INSTRUMENTS AND RESULTS, Optical Society of America, Journal, 56, July 1966, pp. 896-910, Contract No. AF 61 (052)-842.

A near-infrared, two-beam interferometer has been built for astronomical observations by Fourier transform spectroscopy. Various improvements, especially a highly accurate interferometrically controlled stepping drive, have resulted in the production of laboratory spectra with 0.1-cm<sup>-1</sup> resolution and unusually clean instrumental line shape, and spectra of Venus and Mars with about 1-cm<sup>-1</sup> resolution.

436. Danielson, R. E., Gaustad, J. E., Schwarzschild, M., Weaver, H. F., and Woolf, N. J.,  
MARS OBSERVATIONS FROM STRATOSCOPE II, Astron. J., USA, 69, No. 5, June 1964, pp. 344-352.

On 1 March 1963 Stratoscope II, a balloon-borne telescope was flown for the first time with the aim of investigating the infrared spectrum of Mars. A series of technical difficulties arose during the flight and severely restricted the number and quality of the spectrometer scans that were obtained. Nevertheless, the following results could be

deduced from these scans: (1) It is improbable that the water vapor content of Mars is greater than  $40\mu$ ; (2) If the total pressure at the surface of Mars is assumed to be 87 mbar, the amount of CO<sub>2</sub> in the atmosphere of Mars amounts to about 6000 cm-atm rather than 3000 cm-atm as previously estimated.

437. Gray, L. D.,  
TRANSMISSION OF THE ATMOSPHERE OF MARS IN THE REGION OF  
 $2\mu$ , Icarus, USA, 5, No. 4, July 1966, pp. 390-398.

The random Elsasser band model is used to compute the transmission of the atmospheres of Earth and Mars for the  $2-\mu$  bands of carbon dioxide. This band model is shown to give good agreement with measurements of spectral transmission for homogeneous paths of CO<sub>2</sub> and also for nonhomogeneous paths through the Earth's atmosphere when the Curtis-Godson approximation is used. The  $2-\mu$  bands of CO<sub>2</sub> are strong in the atmospheres of both Earth and Mars and, at a given temperature, their absorption is a function only of the product mp.

438. Guerin, P.,  
SPECTROPHOTOMETRIC STUDY OF THE REFLECTIVITY OF THE  
CENTRE OF THE MARTIAN DISK IN OPPOSITION, Ann. Astrophys.,  
France, 25, No. 1, 1962, pp. 42-48.

Spectra of the centre of the martian disk (bright area of Arabia), and of a star whose spectral type is nearly the same as that of the Sun, were obtained during the 1960 opposition by means of a small oscillating Chalonge spectrograph at the Cassegrain focus of the 32 in. reflecting telescope of the Haute-Provence Observatory, covering the spectral interval 6113-3176 Å. The spectrophotometric comparison of these spectra, wave-length by wave-length, gave the Arabian reflectivity curve. It is well known that the observed ultraviolet reflectivity is that of the martian atmospheric "blue haze". The reflectivity curve decreases with wavelength to 3800 Å and then remains constant with several undulations up to the terrestrial ozone absorption limit.

439. Center for Radiophysics and Space Research, Cornell University,  
Ithaca, New York,  
RADIOMETRIC OBSERVATIONS OF VENUS AND MARS AT 430 MC/S  
by H. E. Hardebeck, October 1965, AF-2838, AFOSR 66-1526,  
AD 639 267, Contract No. AF 49 (638)-1156, Astrophysical Journal,  
142, No. 4, 15 November 1965, p. 169.

Observation of Venus near inferior conjunction in 1964 and of Mars near the opposition of 1965 were made at the Arecibo Ionospheric Observatory at 430 Mc/sec. The average black-body temperature of Venus was found to be  $518^{\circ} \pm 40^{\circ}$ K. No radiation from Mars was detected in these observations. A recomputation of results previously reported for Jupiter indicate that its black-body disk temperature is  $28900^{\circ} \pm 2700^{\circ}$ K.

440. Georgetown University, Washington, D. C., College Observatory, SPECTROSCOPIC STUDY OF SOLAR AND PLANETARY ATMOSPHERES Semianual Status Report No. 6, Aug. 1, 1965-Feb. 1, 1966, by F. J. Heyden, 1966, NASA CR-76488, Grant No. NsG-362.

This report describes activities performed during this period on spectroscopic studies of solar and planetary atmospheres. Spectral observations made on Venus and Jupiter are discussed. An attempt is being made to prove the existence of nitrogen oxides in the Martian atmosphere by identifying spectral lines or bands in the planet's spectrum. The main problems in positively identifying these lines and procedures to circumvent these difficulties are outlined. Infrared spectral reflectance measurements made of the Martian atmosphere are described and the results discussed.

441. Hovis, W. A., Jr., INFRARED REFLECTIVITY OF  $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$  - INFLUENCE ON MARTIAN REFLECTION SPECTRA, Icarus, 4, April 1965, pp. 41-42.

Measurement of the IR reflectivity of limonite and  $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$  from 1 to  $5 \mu$ . A strong reflection minimum due to water of hydration is shown. The influence of the measured reflectivities on Martian spectra is discussed. It is considered possible that, by combining measurements of water vapor in the atmosphere made in other spectral regions with measurements in the 2 to  $4 \mu$  region an estimate of the degree of hydration of the Martian surface may be made.

442. Hunt, G. R., INFRARED SPECTRAL EMISSION AND ITS APPLICATION TO THE DETECTION OF ORGANIC MATTER ON MARS, J. Geophys. Res., USA, 70, No. 10, 15 May 1965, pp. 2351-2357.

Infrared spectral emission was obtained for various thicknesses of Teflon, Mylar, and Dupont film H at temperatures below  $100^{\circ}\text{C}$ . Characteristic data are apparent for samples which exceed the thickness limits imposed by Hovis (Abstr. 13021 of 1965). The use of an uncooled detector to obtain such characteristic spectral data as long

wavelengths (out to  $40\mu$ ) is demonstrated. Thus, it should be possible to obtain diagnostic spectral emission from the surface of the planet Mars by using proper instruments aboard a Mars probe.

443. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, AN ANALYSIS OF THE SPECTRUM OF MARS by L. D. Kaplan, G. Munch, and H. Spinrad, NASA-CR-53573, JPL-TR-32-554, Contract No. NAS7-100, repr. from Astrophys. J., 139, No. 1, 1 January 1964, pp. 1-15.

On a high-dispersion spectrogram of Mars, rotational lines of  $H_2O$  near  $\lambda 8300$  and  $CO_2$  near  $\lambda 8700$  have been detected. Recent laboratory measurements of line strengths have been used to determine the amounts of  $H_2O$  and  $CO_2$  in the atmosphere of Mars:  $14 \pm 7\mu$  precipitable water and  $55 \pm 20$  m atm  $CO_2$ . From the absence of  $O_2$  in the Martian spectra, an upper limit of 70 cm atm for the  $O_2$  content has been set. By suitably combining the  $CO_2$  amount with observations by Kuiper and Sinton of the strongly saturated bands in the  $2\mu$  region, a surface pressure of  $25 \pm 15$  mb has been derived. The implications of the results on the composition of the Martian atmosphere are discussed

444. Kiess, C. C., Corliss, C. H., Kiess, H. K., and Corliss, E. L. R., HIGH-DISPERSION SPECTRA OF MARS, Astrophysical Journal, Chicago, 126, No. 3, November 1957, pp. 579-584.

In July 1956 a concave-grating spectrograph was set up at the Slope Observatory of the U. S. Weather Bureau near the summit of Mauna Loa, Hawaii, for the purpose of photographing spectra of Mars with high dispersion. Several sets of spectrograms with spectra of the moon and Mars in juxtaposition were obtained with dispersions of 5 and 2 A/mm. The shift of the spectrum of Mars, due to the Doppler-Fizeau effect, was sufficient to separate Martian lines of  $O_2$  and  $H_2O$  in the B and "a" bands from those of terrestrial origin. No such shifted lines were detected. After opposition, the spectrograph was set up again, at the Georgetown College Observatory, adjusted to cover the spectral range from 5,000 to 9,000 A. Again the results were negative. Observations at the National Bureau of Standards on the relative strengths of water-vapor bands are in agreement with their calculated relative transition probabilities and show that the bands sought thus far in the spectrum of Mars are not the ones to use for this purpose. It is suggested that future work be devoted to the bands of  $H_2O$  at  $1.13$  and  $1.38\mu$ .

445. Kuiper, G. P.,  
INFRARED SPECTRA OF STARS AND PLANETS. IV - THE SPEC-  
TRUM OF MARS, 1-2.5 MICRONS, AND THE STRUCTURE OF ITS  
ATMOSPHERE, Communications of the Lunar and Planetary Laboratory,  
Volume 2, No. 31-35, University of Arizona Press, Tucson, 1964,  
pp. 79-112, Grant No. NsG 161-61.

Presentation of 1 to 2.5  $\mu$  spectra of the planet Mars obtained with the 82-in. telescope of the McDonald Observatory, including lunar comparisons and a limited set of laboratory calibrations. The IR spectra are examined for the presence of constituents other than CO<sub>2</sub> (CO, CH<sub>4</sub>, NH<sub>3</sub>, H<sub>2</sub>S, NO, N<sub>2</sub>O, HCHO, and COS), and for the presence of isotopic bands of CO<sub>2</sub>. The O<sup>18</sup> isotopic band at  $\lambda$  2.15  $\mu$  is definitely present in the Martian spectra and allows a provisional determination of the O<sup>18</sup>/O<sup>16</sup> ratio relative to the Earth. The evidence is strong, though not yet conclusive, that this ratio is larger on Mars than on the Earth. The other gases listed are all below the threshold of detection, with the upper limits given in the text. The Martian spectral intensities are also expressed in terms of those derived for the Moon; the ratio spectra so obtained for Mars are summarized graphically. In the introductory parts of the paper a discussion is given of the types of atmospheric particles detected in the Martian atmosphere and the information that may be derived therefrom. A rough value of the atmospheric pressure (10 to 20 mb) is thus derived.

446. Lebedinskii, A.,  
PHYSICAL CONDITIONS OF MARS, Dokl. Akad. Nauk SSSR, 108,  
No. 5, 1956, pp. 795-798.

A discussion of the atmospheric conditions on Mars in terms of the infrared carbon dioxide absorption spectra.

447. Lebedinskii, A. I.,  
INFRARED MOLECULAR ABSORPTION IN THE ATMOSPHERE OF  
MARS AND THE PHYSICAL CONDITIONS ON ITS SURFACE, Societe  
Royale des Sciences de Liege, Memoires, Ser. 4, 18, 1957,  
pp. 174-180.

A formula for atmospheric temperature determination on Mars is worked out and, in so doing, the author indicates that Martian atmospheric processes are not similar to those on Earth. A discussion of water vapor and possible life on Mars in view of physical conditions there concludes the article.

448. Moroz, V. I.,  
RECENT OBSERVATIONS OF THE INFRARED SPECTRA OF MARS  
AND VENUS ( $1-4\mu$ ) IN CONNECTION WITH THE SPACE INVESTIGA-  
TIONS PROBLEM, COSPAR, Fourth International Space Science  
Symposium, Warsaw, Poland, 3-12 June 1963.
- A CO absorption band at  $2.35\mu$  and several unidentified absorption features have been found in the infrared spectrum of Venus during observations in 1963. A model of the Venusian atmosphere in the region of  $\text{CO}_2$  photodissociation was constructed and was determined to be in rough agreement with observed absorption. The Venusian albedo decreases from 2.5 to  $2.9\mu$ . Absorption at  $\lambda > 3\mu$  is believed to cause the greenhouse effect which heats the planetary surface; however, the constituent which produces this absorption is still unidentified. Infrared spectral investigations of Mars confirmed the "ice" origin of the polar caps and the presence of Sinton's "bands of life." New  $\text{CO}_2$  bands were also found. The equivalent widths of Martian  $\text{CO}_2$  bands were observed to be lower than those previously determined by Dr. Kuiper. In addition to the  $3.56\mu$  band identified by Sinton, a second band ( $3.53\mu$ ) was detected.
449. Moroz, V. I.,  
OBSERVATIONS OF THE INFRARED SPECTRUM OF MARS IN THE  
INTERVAL  $1.1-4.1$ , Astronomicheskiy Tsirkulyar, No. 262, 1963,  
pp. 4-5.
- Using the 125-cm reflector of the Shternberg State Astronomical Institute with a diffraction spectrometer, a spectrum of Mars was obtained with a resolution of 400 in the  $1.1-2.5\mu$  region, and with a prism spectrometer with a resolution of 40 in the  $2.9-4.1\mu$  region. A PbS photoresistor, cooled by dry ice and liquid nitrogen, served as the radiation receiver. In the  $1.1-2.5\mu$  region, 12  $\text{CO}\mu$  absorption bands, 7 of which were obtained for the first time, were detected. One of the new bands  $\lambda 2.10\mu$  is isotopic. Bands at  $\lambda 1.6\mu$  are less intensive than had been thought earlier, and, consequently, it was necessary to decrease the quantitative concentration of  $\text{CO}_2$  in the Martian atmosphere. The relative concentration of  $\text{CO}_2$  in the Martian atmosphere, computed from these observations, was equal to  $[\text{CO}_2] = 33/p^2$ , where  $p$  is the pressure in the Martian atmosphere in millibars. In the region  $2.9-4.1\mu$ , 4 unidentified bands,  $\lambda \approx 4.43, 3.53, 3.59$ , and  $3.69\mu$ , 3 of which approximately correspond to Silton's "life bands," were found. On the basis of the absence of bands of other compounds, the upper limits of content in the Martian atmosphere were computed. Thus,  $\text{CO} < 5$ ,  $\text{NO}_2 < 0.1$ ,  $\text{N}_2\text{O} < 5$ ,  $\text{NH}_3 < 1$ ,  $\text{CH}_4 < 0.3$ ,  $\text{C}_2\text{H}_2 < 0.1$ ,  $\text{C}_2\text{H}_4 < 0.1$ ,  $\text{C}_2\text{H}_6 < 0.05$ . Using the prism spectrometer

a polar cap spectrum in the  $1.1\text{--}2.5 \mu$  region was obtained with a resolution of 10. The author concludes that the polar caps consist of hoarfrost, snow, or ice clouds.

450. Morozhenko, A. V. and Yanovitskii, E. G.,  
DETERMINATION OF OPTICAL PARAMETERS OF THE ATMOSPHERE  
AND SURFACE OF MARS, Phys. of the Moon and the Planets, Israel  
Program for Scientific Translations, Ltd., Jerusalem, 1966, 11. 61-68.

The known brightness distribution of the Martian disk was used to determine the optical parameters of its atmosphere and surface from absolute photometric data. A computational procedure and related tables are given which enable the calculation of these optical parameters with relative ease and accuracy. It is assumed that the Martian highlands are orthotropically reflecting, that these parameters are constant for all scanned points of the highland from which the brightness distribution curve is plotted, and that the atmosphere of Mars does not absorb selectively in the entire range of wavelengths used in Martian photometry. In the 450 to  $850 \text{ m}\mu$  range, the Martian atmosphere is purely scattering; below this true absorption is felt which increases with decreasing wavelength. During dust storms, the optical thickness of the Martian atmosphere in the infrared decreases with increasing wavelength because of the presence of coarse dust particles.

451. Murray, B. C. and Westphal, J. A.,  
INFRARED ASTRONOMY, Scientific American, 213, August 1965,  
pp. 20-39.

General survey of IR astronomy, methods of detecting IR radiation, and an evaluation of the results obtained from observations of the moon and the planets. The earth's atmosphere is transparent to radiation in the range from 0.7 to  $5.2 \mu$ ; opaque from  $5.2$  to  $8 \mu$ , transparent again from 8 to  $14 \mu$ , opaque from  $14$  to  $17 \mu$ , and transparent again from  $17$  to  $22 \mu$  range. From  $22$  to  $1000 \mu$  the earth's atmosphere does not transmit because of the absorption bands caused by water vapor, which are broadened by the effect of atmospheric pressure. The development of IR detectors is described beginning with the primitive thermocouple, then followed by the Golay cell, the Low cryogenic bolometer, and terminating with the present-day sensitive semiconductors. Sinton's observations on the planet Mars are discussed, together with his work on Venus, Jupiter, and the moon.

452. Rea, D. G., O'Leary, B. T., and Sinton, W. M.,  
MARS - THE ORIGIN OF THE 3.58- AND 3.69-MICRON MINIMA IN  
THE INFRARED SPECTRA, Science, 147, 12 March 1965, pp. 1286-  
1288, Contract No. NASr 220.

Analysis of the 3- to 4- $\mu$  spectra of Mars recorded in 1958 with the 200-in. Hale telescope, in order to determine if the minima at 3.58 and 3.69  $\mu$  are due to terrestrial HDO molecules, rather than to substances on Mars as previously indicated. Solar spectra, together with water-vapor abundances derived from radiosonde flights, obtained during the observing period are studied. There appears to be a correlation between the intensities of the 3.58- and 3.69- $\mu$  features and the amount of terrestrial water vapor in the optical path. Thus, the data considered are no evidence for the presence on Mars of substances absorbing at these wavelengths.

453. Rea, D. G.,  
THE ROLE OF INFRARED SPECTROSCOPY IN THE BIOLOGICAL  
EXPLORATION OF MARS, International Symposium on Basic Environmental  
Problems of Man in Space, 2nd, Paris, France, June 14-18,  
1965, Preprint no. 9.

Symposium sponsored by the International Astronautical Federation, International Academy of Astronautics, UNESCO, International Atomic Energy Agency, Internal Telecommunication Union, World Health Organization, and World Meteorological Organization; Grant No. NsG 101-61; Contract No. NASr-220.

Discussion of the theory underlying infrared spectroscopy and summary of the remote infrared observations made of Mars. The emission and absorption characteristics of liquids, solids, and gases resulting from the electromagnetic dipole, rotational, and vibrational properties of their molecules are outlined. Infrared spectroscopy has provided information on the atmospheric composition, pressure, and other parameters which are vital in the designing of a lander to explore the surface of Mars for evidence of life. Infrared radiometry has been used to measure the surface temperatures for the entire disk during the various seasons. The possibilities afforded by spacecraft orbiting Mars and by a landed vehicle in the search for life on that planet are detailed.

454. Shaw, J. H., Burch, D. E., and Cummins, H. Z.,  
NEAR INFRARED SPECTRUM OF MARS, Ohio State Univ. Scientific  
Report, No. 8, November 1957, Research Foundation Contract AF 19  
(604)-1003.

Infrared spectra of Mars were obtained in the autumn of 1956. From the intensity of the CO<sub>2</sub> bands near 1.6 $\mu$  it has been estimated that the amount of CO<sub>2</sub> in the atmosphere of Mars is about four times greater than in the earth's atmosphere if the surface pressure is 100 mb and the atmosphere is mostly composed of nitrogen. This is compared with a Martian CO<sub>2</sub> abundance of 13 ±4 times that of the earth's atmosphere obtained by Grandjean and Goody from the data of Kuiper. No evidence of bands of CO<sub>2</sub> (2.35 $\mu$ ) or N<sub>2</sub>O (2.11, 2.26 and 3.94 $\mu$ ) was found, and upper limits of 50 atmo-cm have been placed on these gases. On one spectrum, indications of an absorption at 3.5 $\mu$  were obtained, in agreement with the results of Sinton. However, the detector failed before confirmatory spectra could be obtained.

455. Shirk, J. S., Haseltine, W. A., and Pimentel, G. C.,  
SINTON BANDS - EVIDENCE FOR DEUTERATED WATER ON MARS,  
Science, 147, 1 January 1965, pp. 48-49.

Analysis of IR spectra of the atmosphere of Mars in the region from 1 to 4.2  $\mu$ . The IR absorption bands observed by Sinton at 2710, 2793, and 2898 cm<sup>-1</sup> (3.69, 3.58, and 3.45 $\mu$  respectively), in the spectrum of Mars, may be due to gaseous D<sub>2</sub>O and HDO in the Martian atmosphere. The implication would be that the deuterium/hydrogen ratio exceeds that on Earth, presumably because of escape of the lighter gases from Mars, with accompanying gravitational fractionation of the hydrogen isotopes.

456. Sinton, W. M.,  
SPECTROSCOPIC EVIDENCE FOR VEGETATION ON MARS,  
Astrophysical Journal, Chicago, 126, No. 2, September 1957, pp. 231-  
239, Astronomical Society of the Pacific, San Francisco, Publications,  
70, No. 412, February 1958, pp. 50-56.

A new test for the presence of vegetation on Mars depends on the fact that all organic molecules have absorption bands in the vicinity of 3.4 $\mu$ . These bands have been studied in the reflection spectrum of terrestrial plants, and it is found that for most plants a doublet band appears which has a separation of about 0.1 $\mu$  and is centered about 3.46 $\mu$ . Spectra of Mars taken during the 1956 opposition indicate the probable presence of this band. This evidence and the well-known

seasonal changes of the dark areas make it extremely probable that vegetation in some form is present.

457. Laboratory of Astrophysics and Physical Meteorology, Johns Hopkins University, Baltimore,

RADIOMETRIC OBSERVATIONS OF MARS by W. M. Sinton and J. Strong, September 1959, AD-248 840.

Radiometric temperature measurements of Mars were made with the 200-inch reflector in 1954. The radiometry utilized filters that isolate bands of radiation within the 8-13 micron window. This broadband radiometry was augmented with spectra obtained with moderately good resolution with a grating spectrometer. The temperature of Mars at the center of the disk was found to be 15 degrees C. Scans across the planet providing good signal-to-noise ratios were made with an aperture as small as 1.5 seconds diameter. Several interesting phenomena were found and correlated with their appearance on photographs. The temperature of a yellow cloud, which appears on photographs taken by others, was -25 degrees C. Dark areas were a few degrees warmer than adjacent bright regions.

458. Sinton, W. M. and Strong, J.,

RADIOMETRIC OBSERVATIONS OF MARS, Astrophys. J., 131, No. 2, March 1960, pp. 459-469.

Radiometric temperature measurements of Mars were made with the 200 in. reflector in 1954. The radiometry utilized filters that isolate bands of radiation within the  $8-13 \mu$  "window". This broadband radiometry was augmented with spectra obtained with moderately good resolution with a grating spectrometer. The temperature of Mars at the centre of the disk was found to be  $15^{\circ}\text{C}$ . Scans across the planet providing good signal-to-noise ratios were made with an aperture as small as 1.5 seconds diameter. Several interesting phenomena were found and correlated with their appearance on photographs taken by others, was  $-25^{\circ}\text{C}$ . Dark areas were a few degrees warmer than adjacent bright regions. From several scans the diurnal temperature variation was determined, and this has been compared with that derived from the theory of surface heat conduction. It is found that no choice of the thermal constants will give agreement in both phase lag and amplitude simultaneously. The reason appears to be the presence of the Martian atmosphere, which is ignored in the theory. The bands of carbon dioxide at 9.4, 10.4, and  $12.6 \mu$  have been found in the Martian spectrum. From the spectrum it may be said that silicates are not present on the surface in large proportions.

459. Sinton, W. M.,  
RECENT INFRARED SPECTRA OF MARS AND VENUS, J. Quant Spectrosc. Radiative Transfer, GB, 3, No. 5, October-December 1963, pp. 551-558.
- Infrared spectra of Mars and Venus are discussed with regard to the composition of these two planets' atmospheres. The evidence for carbon monoxide in the Venus atmosphere is presented. The transparency of the Venus cloud level is found to be less than 0.1 per cent between 3 and 4  $\mu$ . Spectra of Mars are analysed for the CO<sub>2</sub> content of that planet's atmosphere. A new instrument, a birefringent interferometer that has just been put into operation, is described briefly.
460. Spinrad, H., Munch, G., and Kaplan, L. D.,  
THE DETECTION OF WATER VAPOR ON MARS, Astrophys. J., USA, 137, No. 4, May 1963, pp. 1319-1325.
- The authors found eleven weak lines of water vapour on a high-dispersion near-infrared spectrogram of Mars taken at the coude focus of the Mount Wilson 100-inch reflector on 12/13 April, 1963. The lines in the  $\lambda$  8200 water vapour band are displaced 0.42 Å longward of their telluric counterparts due to the relative velocities of Mars and Earth of 15 km/sec on that date. The data indicates an H<sub>2</sub>O abundance near 5-10  $\mu$  precipitable over the Martian poles. The authors also found the  $5\nu_3$  band of CO<sub>2</sub> at  $\lambda$  8689 in the Martian spectrum.
461. Wells, R. A.,  
A RE-EVALUATION OF W. H. WRIGHT'S PLATES OF THE 1924 AND 1926 OPPOSITIONS OF MARS, Planet. Space Sci., GB, 13, No. 3, March 1965, pp. 261-263.
- During the forty years since the announcement by Wright that Mars photographed on infrared plates has a smaller diameter than when photographed on ultraviolet plates, considerable disagreement has arisen among observers as to the magnitude of the difference. The purpose of the present programme was to re-examine the original plates of the 1924 opposition from which Wright made the discovery mentioned above. In addition a large number of plates from his 1926 series was analyzed. For 1924 the author found a difference of 3% between the infrared and violet diameters. This difference is the same as Wright originally found although the individual diameter measures are significantly larger.

462. Woolf, N. J.,  
INFRA-RED SPECTRA OF STARS, PLANETS AND THE MOON  
FROM STRATOSCOPE II, Ann. Astrophys. Suppl., France, 28,  
No. 1, 1965, pp. 218-224.

Two flights of the balloon borne telescope Stratoscope II have been made for infrared spectroscopic observations. The paper summarises the results of observing cool stars, Mars, Jupiter and the Moon.

463. Younkin, R. L.,  
A SEARCH FOR LIMONITE NEAR-INFRARED SPECTRAL FEATURES  
ON MARS, Astrophysical Journal, 144, May 1966, pp. 809-818.

Description of spectrophotometric measurements from 0.5 to  $1.1 \mu$  of the integral intensity of the disk of Mars and of a bright area and a dark area in a search for limonite near-infrared spectral features. Comparison of the intensities of the two areas gives no indication of any difference in limonite content. The integral intensity was reduced to relative reflectance by means of the energy distribution of  $\alpha$  Lyr, and independently it was compared directly to the intensity of the lunar crater Plato. An upper limit of 2% may be placed on the strength of the limonite spectral features in the reflectance of Mars.

## F. RADIO EMISSION (0.1 to 20 cm)

464. Barrett, A. H.,  
MICROWAVE SPECTRAL LINES AS PROBES OF PLANETARY  
ATMOSPHERES, Societe Royale des Sciences de Liège, Memoires,  
Cinguieme Serie, 7, 1963, Physics of Planets Symposium Paper  
Liège, Belgium, 9-12 July, 1962.

Discussion of the possibility of detecting atomic and molecular spectral lines by radio techniques in planetary atmospheres. Tables present the atoms and molecules that have been identified in planetary atmospheres, including the Earth's, together with other possible molecular constituents. The molecules are separated into those that do not have microwave spectra, and those that do, and only the latter group is considered. Discussed is the dependence of microwave properties on planetary environment and their importance in dictating equipment design, planning an observing program, or interpreting the observations. A microwave experiment is outlined for the determination of atmospheric properties.

465. Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge,  
PASSIVE RADIO OBSERVATIONS OF VENUS, SATURN, MERCURY,  
MARS, AND URANUS. SESSION III by A. H. Barrett, 1966, AD-633  
794, Contract No. DA-36-039-AMC-03200 (E), NSG-419.

The radio observations of Mercury, Venus, Mars, Saturn, and Uranus are reviewed and discussed in relation to knowledge of these planets acquired by other means. In the case of Mercury, it is shown that the radio observations imply a temperature of approximately 300K for the unilluminated hemisphere, a result which appears to be in sharp disagreement with infrared measurements of Mercury. Two detailed measurements of the Venus spectrum near 1-cm wavelength are presented and compared.

466. Aerospace Corporation, El Segundo, California, Laboratory Operations,  
OBSERVATIONS OF PLANETS AND QUASI-STELLAR RADIO SOURCES  
AT 3 MM by E. E. Epstein, September 1965, TDR-469 (5230-41)-4,  
AD-475 774, Contract No. AF04 (695) -496.

Depending upon the method used to derive the terrestrial atmospheric attenuation, Venus 3.3-mm brightness temperatures obtained

on 55 days in 1964 indicate either (1) no phase effect and a mean brightness temperature of 292°K, (2) an inverse phase effect, or (3) no phase effect for two weeks in June above a mean temperature of 285°K. The estimated total systematic errors for the mean temperatures are +40°, -30°K. There were not enough data for meaningful correlations with the 10.7-cm solar flux or sunspot index. The quasi-stellar radio source 3 C 279 has been observed at lambda equals 3.4 mm with the 15-ft antenna of the space radio systems facility. The fact that the measured flux value is well above the centimeter flux may infer that a nonthermal emission mechanism is operating at 3.4 mm. The measured 3.4 mm flux from the quasi-stellar source 3 C 273 in April and July 1965 are analyzed. The disk temperatures at 3.4 mm of Mercury and Mars were measured in April 1965. At that Mercury was near inferior conjunction: the average illuminated fraction was 0.10 during the observations. The average disk temperatures of Mercury and Mars were 220° + 05° - 35°K and 190° + or - 40°K, respectively. The seven individual daily values of Mercury showed no evidence of a phase effect.

467. Glordmaine, J. A.,  
CENTIMETER WAVELENGTH RADIO ASTRONOMY INCLUDING  
OBSERVATIONS USING THE MASER, Proc. Nat. Acad. Sci., USA,  
46, No. 3, March 1960, pp. 267-276.

Previous measurements made at centimetre wavelengths are summarized and the potentialities of new receiver devices such as travelling wave tubes, parametric amplifiers and masers are outlined. Observations were taken at 3 cm wavelength using a maser in conjunction with the 50 ft N. R. L. antenna. The temperature of Venus was found to be 575 ±58°K. Jupiter at this wavelength has a temperature of 177 ±22°K which can be interpreted entirely in terms of thermal emission from NH<sub>2</sub>. Mars is at 211 ±28°K. No emission was found from planetary nebulae greater than 0.1°K antenna temperature.

468. Kellermann, K. I.,  
RADIO OBSERVATIONS OF MARS, Nature, 206, 5 June 1965,  
pp. 1034-1035.

Observation of radio emission from Mars for eleven days near the opposition of Mar. 1965 at 6-cm, 11.3-cm, and 21.3-cm wavelengths using the CSIRO 210-ft radio telescope and low-noise receivers to investigate the apparently widely different temperatures found at centimeter and decimeter wavelengths. The observed Martian temperatures at the three wavelengths are summarized in a table. There

appears to be little difference in the measured temperature over the range from 3 to 20 cm, although the temperature appears to be somewhat lower than the mean daytime temperature of about 250°K determined from the infrared measurements.

469. Mayer, C. H., McCullough, T. P., and Sloanaker, R. M.,  
OBSERVATIONS OF MARS AND JUPITER AT A WAVE LENGTH OF  
3.15 cm, Astrophys. J., 127, No. 1, January 1958, pp. 11-16.

A number of observations of Mars were made with the Naval Research Laboratory 50 foot reflector at a 3.15 cm wavelength during September, 1956, when the planet was near opposition. Of these, 71 observations were selected for a quantitative reduction, which yielded a black-body temperature for Mars of  $218^\circ \pm 76^\circ\text{K}$  (m. e.). Twenty-nine observations of Jupiter were made with the same apparatus in May, 1956. A black-body temperature of  $140^\circ \pm 56^\circ\text{K}$  (m. e.) was found from these data. Further observations of improved accuracy were made in March, 1957, when Jupiter was near opposition. A quantitative reduction of the average of 45 of these observations gave a black-body temperature for Jupiter at the 3.15 cm wavelength of  $145^\circ \pm 26^\circ\text{K}$  (m. e.).

470. Mayer, C. H.,  
PLANETARY RADIATION AT CENTIMETER WAVE LENGTHS,  
Astron. J., 64, No. 2, March 1959, pp. 43-45.

The results of short wavelength observations of thermal radiation from the planets are summarized. Venus has an apparent black body temperature of about  $550^\circ\text{K}$  in the 3 to 10 cm range, falling to near the infrared radiometric value at 0.86 cm. Jupiter has a temperature of  $150^\circ\text{K}$  at 3 cm rising probably to  $600^\circ\text{K}$  at 10 cm. Mars and Saturn have also been detected.

471. Mayer, C. H.,  
THERMAL RADIO RADIATION FROM THE MOON AND PLANETS,  
IEEE Transactions on Military Electronics, MIL-8, July-October  
1964, pp. 236-247.

Discussion of the thermal radio radiation observed from the Moon, Mercury, Venus, Mars, Jupiter, and Saturn. Particularly emphasized among the results is the important discovery of a surface temperature of Venus, below the clouds, greater than  $600^\circ\text{K}$ . The thermal radio radiation from beneath the surface of the Moon is examined with respect to the information that it contains about the

temperature distribution and variation, which may be interpreted in terms of the physical characteristics of the subsurface material. This is seen to apply also to planets with thin atmospheres. No complicating nonthermal radiation has been found for most of the planets; however, the nonthermal synchrotron radiation from the Jupiter belts has confused the accurate specification of thermal-radiation intensity over the centimeter wavelength range, and there is some evidence for non-thermal radiation from Saturn.

472. RADIO SIGNALS FROM MARS, Science, Washington, D. C., 124, No. 3223, 5 October 1956, p. 620.

Navy announced detection of first radio waves from Mars, picked up with a 600 in. radio telescope at National Research Lab. in Wash., D. C. (where first radio signals from Venus were detected earlier in 1956). Emissions indicate an average temperature of Mars of slightly below 32°F. The 3 cm signals were picked up on 2 nights in early Sept. 1956.

473. Troitskii, V. S.,  
THE THEORY OF THE RADIO EMISSION OF VENUS AND MARS,  
Radiofizika, 7, No. 2, 1964, pp. 208-214.

Investigation of the phase variation of radio emissions from the surface of Mars and Venus, on the assumption that there exists a given periodic temperature regime on the surface of these planets. The rotation period of Venus is estimated at about 2 to 10 days in the case of opposite rotation, using data on the phase variation of radio emissions of this planet and radar probing data on the reflection coefficient.

## G. RADAR REFLECTION (12.5 to 125 cm)

474. Aleksandrov, Iu. N. and Rzhiga, O. N.,  
COMPARISON OF MARTIAN REFLECTION CHARACTERISTICS  
AT WAVELENGTHS OF 40 AND 125 CM, BASED ON RADAR  
OBSERVATIONS DURING THE OPPOSITION OF 1963, Astronomicheskii  
Zhurnal, 43, July-August 1966, pp. 813-816.

Proof, by radar observations at 40 and 125 cm, that signals returned to a radar from Mars are largely reflected from the planet's near-center disk sections. The mean reflection coefficient for wavelengths greater than 40 cm is roughly 0.07 and corresponds to a permittivity of 3.0. Radar observations give no indication of the presence of water on Mars.

475. Goldstein, R. M.,  
MARS: RADAR OBSERVATIONS, Science, USA, 150, 24 December  
1965, pp. 1715-1717.

Radar studies of Mars indicate that certain areas are quite smooth. Rough, strongly reflecting regions have also been found, as well as poorly reflecting ones. Mars as a whole is significantly smoother to radiation of 12.5-centimeter wavelength than Venus.

476. Kotel'nikov, V. A., Dubrovin, V. M., Dubinskiy, B. A., Kislik, M. D., Buznetsov, B. I., Petrov, G. M., Rabotyagov, A. P., Rzhiga, O. N., and Shakhovskoy, A. M.,  
RADAR OBSERVATIONS OF THE PLANET MARS IN THE SOVIET UNION, Akademiya Nauk SSSR, Doklady, 151, No. 4, 1963, pp. 811-814.

Radar observations of Mars' northern hemisphere from  $14^{\circ}30'$  to  $14^{\circ}$  latitude and from  $310$  to  $360^{\circ}$  and from  $0$  to  $140^{\circ}$  longitude were carried out in the Soviet Union on 6-10 February 1963 at a frequency of approximately 700 Mc.

477. Shachovskoi, A. M.,  
RADAR OBSERVATIONS OF THE PLANET MARS IN THE SOVIET UNION, Life Sciences and Space Research II; International Space Science Symposium, 4th Warsaw, Poland, June 3-12, 1963, sponsored by the Committee on Space Research (COSPAR), M. Florkin and A. Dollfus, ed., North Holland Publishing Co., Amsterdam, Interscience Publishers, New York, p. 964., pp. 255-257.

Presentation of results of radar observations of Mars during the opposition of Feb. 1963. The results of the signal's analysis by means of filters with a frequency band of 4 cps are shown. It is stated that the narrow-band spectrum received from the fast rotating planet indicates that the surface of Mars has plane areas not less than a few km<sup>2</sup>. The observed area corresponds to the Northern Hemisphere of Mars, its areographic latitude being 14 to 15°, and its areographic longitude 320 to 360° and 0 to 140°. It is noted that, according to the known astronomical maps of Mars shown, this area corresponds to the lighter parts of its surface, conventionally called continents. The results of the radar measurements are said to show that individual areas of the observed surface of the planet Mars have a higher coefficient of reflection than the surface of the Moon.

478. Conductron Corporation, Ann Arbor, Michigan,  
**POTENTIAL SURFACE MEASUREMENTS OF THE PLANET MARS**  
Quarterly Progress Report, Jan. 11-May 11, 1963, by K. M. Siegel  
and D. Galbraith, 31 May 1963, Contract No. NASw-490.

The advantages which are obtained from the use of nonconventional communication systems operating at wavelengths other than microwave, e. g., optical and millimeter, are weighed against the disadvantages. It is concluded that some small relative advantage can probably be gained in the millimeter range, but that this advantage is not significant; there is no foreseeable advantage in the optical range. Therefore, it appears that improvements in space communication techniques are most likely to be found within the microwave region. A set of experiments to determine the geometrical character and material composition of the Martian surface are described. These experiments depend upon both passive and active electromagnetic radiation measurements. Bistatic and monostatic, multiwavelength, high-resolution radar mapping experiments are strongly recommended.

## H. TEMPERATURE

479. Coblenz, W. W. and Lampland, C. O.

SOME MEASUREMENTS OF THE SPECTRAL COMPONENTS OF PLANETARY RADIATION AND PLANETARY TEMPERATURES,  
Frank. Inst., J., 199, June 1925, pp. 785-841, 200, July 1925,  
pp. 103-126.

By transmission screens of water, quartz, glass and fluorite planetary radiation was separated into spectral components and radiation intensities determined in the spectral regions of  $0\cdot 3 \mu$  to  $1\cdot 4 \mu$ ,  $1\cdot 4 \mu$  to  $4\cdot 1 \mu$ ,  $4\cdot 1 \mu$  to  $8 \mu$ ,  $8 \mu$  to  $12\cdot 5 \mu$  and  $12\cdot 5 \mu$  to  $15 \mu$ . Measurements were made on Venus, Mars, Jupiter, Saturn, Uranus, the Moon and on terrestrial sources. Radiation from Jupiter and Saturn transmitted by out atmosphere is very small; from Venus, Mars and the Moon relatively very intense. Measurements on Venus were made when the bright phase was a narrow crescent. Radiation from the dark part amounted per unit area to 10% of the total radiation from the bright crescent. The southern hemisphere was hotter than the northern. The bright regions on Mars are cooler than the dark; the sunrise side cooler than that exposed to the afternoon sun; the polar regions emit no planetary radiation. The temperature of the irradiated surface was estimated as follows: (1) By direct comparison of the spectral components of planetary radiation from Mars and the Moon temperatures were obtained ranging from  $5^{\circ}\text{C}$ . for the bright equatorial regions to  $20^{\circ}\text{C}$ . for the adjoining dark regions; (2) by comparison with similar data calculated from the laws of spectral radiation from a black body temperatures ranged from  $-15^{\circ}\text{C}$ . for the bright to  $12^{\circ}\text{C}$ . for the dark regions; (3) by calculation using the fourth-power law of total radiation the temperatures were  $-5^{\circ}\text{C}$ . for the bright to  $15^{\circ}\text{C}$ . for the dark regions. When there was no phase on Mars the temperature of the east limb was  $-45^{\circ}\text{C}$ . , of the west limb  $0^{\circ}\text{C}$ . ; that of the north polar region in winter  $-75^{\circ}\text{C}$ . , of the south polar region in early summer  $-60^{\circ}\text{C}$ . and in late summer  $+12^{\circ}\text{C}$ . The temperature estimates of the other planets are: Mercury,  $75$  to  $100^{\circ}\text{C}$ .; the upper limiting temperatures of the outer atmospheres of Venus, Jupiter, Saturn and Uranus,  $-60^{\circ}$ ,  $-75^{\circ}$ ,  $-65^{\circ}$  and  $-75^{\circ}\text{C}$ . respectively; the unilluminated face of the Moon,  $-75^{\circ}$  to  $-200^{\circ}\text{C}$ .

480. Coblenz, W. W.,

TEMPERATURE ESTIMATES OF THE PLANET MARS, Bureau of Standards, Sci. Papers, No. 512, 1925, pp. 371-397.

The present paper gives the results of an investigation of methods of estimating planetary temperatures, especially of Mars from measurements obtained by newly designed radiometric instruments adapted to these problems. These temperature estimates are based upon radiometric measurements at the Lowell Observatory, Flagstaff, Arizona, during 24 nights extending over a period of 10 weeks from July to September, 1924. By means of a series of transmission screens of water, quartz, glass, and of fluorite the planetary radiation emanating from the irradiated surface of Mars was resolved into spectral components. The bright areas along the apparent centre of the disc have a temperature of  $-10^{\circ}$  to  $+5^{\circ}\text{C}.$ , while the contiguous dark areas have a temperature of  $10^{\circ}$  to  $20^{\circ}\text{C}.$ . During the period covered by these observations the temperature of the north polar region, where winter prevailed, remained fairly constant at  $-70^{\circ}\text{C}.$ , while in the south polar region, where summer was advancing, the temperature increased to  $10^{\circ}\text{C}.$ , or perhaps even higher, at the Martian summer solstice.

481. Coblenz, W. W.,  
TEMPERATURE ESTIMATES OF THE PLANET MARS, 1924 and 1926,  
J. Res. Nat. Bur. Stand., Washington, 28, March 1942, pp. 297-309.

The various methods previously employed in deriving temperatures from radiometric measures on Mars are reviewed. Revisions due to the use of different atmospheric transmission curves are negligible where the reduction method employs the law of total radiation of a black body, but are serious where the fluorite-filter method involves the spectral distribution law. The discrepancy can be partly removed by assuming high selective emission at  $8-10\ \mu$  by silicates on the surface of Mars.

482. Gifford, F. A., Jr.,  
SURFACE-TEMPERATURE CLIMATE OF MARS, Astrophysical Journal, Chicago, 123, No. 1, January 1956, pp. 154-161.

The Lowell Observatory radiometric measurements of Martian surface temperatures are analyzed, and surface-temperature climatological properties of Mars are obtained. Annual and diurnal temperature variations and seasonal isotherm maps are displayed and discussed.

483. Hattori, A.,  
THE HEAT BALANCE ON THE SURFACE OF MARS, Kyoto U. Inst. of Astrophysics and Kwasan Obs. Contrib., No. 115, 1962, reprinted from Mem. Coll. Sci., Univ. Kyoto, Ser A, 30, No. 2, art. 2, 1962, pp. 125-135.

The insolations (for  $\tau = 0.0.1$ , 0.2, and 0.3) and the heat loss on the Martian surface for various seasons have been calculated. Then, the heat balance on the surface and the effect of Martian cloud have been discussed. It is shown that the theoretical results agree fairly well with observations.

484. Kachur, V.,

THERMOLOGICAL ASPECTS OF THE MARTIAN SURFACE ENVIRONMENT, Institute of Environmental Sciences, Annual Technical Meeting, San Diego, California, April 13-15, 1966, Proceedings, Mt. Prospect, Ill., Institute of Environmental Sciences, 1966, pp. 1-7.

Quantitative study of the thermal aspect of the Martian surface environment on the basis of Sinton and Strong's radiometric temperature measurements of July 1954. The blackbody surface temperatures given by these measurements are extended to both sunrise and sunset by Fourier series analysis. The sunrise temperatures are found to be in a 170 to 210°K range for the brightlands, dust storm locales, and darklands, the higher temperatures being those of the latter sites. The amplitudes of both daytime heating and nighttime cooling are derived. Midday temperatures are shown to depend greatly on insolation and are expected to range from 259 to 269°K at aphelion to 295 to 305°K at perihelion. The surface of Mars is concluded to have a thermally rigorous climate characterized by near-cryogenic temperatures at night and large, seasonally dependent temperature variations during the day.

485. Klotz, I. M.,

ON THE CALCULATION OF PLANET TEMPERATURES FROM THE COMPOSITION OF METEORIC MATTER, Science, 109, 11 March 1949, pp. 243-251.

486. Jet Propulsion Laboratory, California Institue of Technology, Pasadena, THERMAL HISTORY OF THE MOON AND OF THE TERRESTRIAL PLANETS, NUMERICAL RESULTS by Z. Kopal, TR32 225, January 1962, AD-275 019, Contract NAS7-100.

The equations governing the distribution of the internal temperature and thermal dilatation, deduced in the first report of this series, have been integrated for the cases of the Moon, Mercury, and Mars, on the assumptions that their sources of radiogenic heat (due to spontaneous disintegration of K-40, Th-232, U-235, and U-238) are distributed uniformly throughout their mass in the same concentration as exhibited by the chondritic meteorites, and that conduction represents

the principal mechanism of heat flow. The major part of this analysis consists of the numerical tabulations of the respective particular solutions for the temperature  $T(R, T)$  and thermal dilatation  $\psi(R, T)$  during a time-span of seven billion years constructed for four different values of the coefficient of thermal diffusivity; and the variation of these functions with the distance  $R$  from the center of the respective configuration and the time  $T$  since their origin is diagrammatically shown.

487. RAND Corporation, Santa Monica, California,  
NOTE ON THERMAL PROPERTIES OF MARS by C. Leovy, April 1963,  
NASA-CR-63278, Contract NASr-21(07).

As measured by Sinton and Strong, the variation of infrared emission from the surface of Mars with local time on Mars is here interpreted in terms of a simplified theory of diurnal temperature variations, in which the effect of the atmosphere is included. The results suggest a very low thermal conductivity for the upper few centimeters of the Martian ground. Such low conductivities appear to be possible only if the material composing these layers is very fine powder having a characteristic size of not more than a few microns. If a linear relationship is assumed between convective heat transfer and surface temperature, the appropriate constant of proportionality is on the order of  $10^{-4}$  cal per  $\text{cm}^2 \text{ deg}$ .

488. Lowell, P.,  
TEMPERATURE OF MARS, Amer. Acad., Proc. 42, No. 25,  
March 1907, pp. 651-667.

The chief obstacle to crediting Mars with the possibility of life has hitherto lain in accounting for sufficient heat on the surface of the planet. Determinations have been based only on consideration of distance from the sun, and apparently some investigators have calculated the temperature either by Dulong and Petit's law, which would give for the mean temperature  $-96^\circ\text{F.}$ , or by Newton's assumption that a body radiates heat in direct proportion to its temperature, which would give  $-236^\circ\text{F.}$ ; for they have believed that the polar caps may be composed of solid carbonic acid, which freezes only at  $-109^\circ\text{F.}$ . A better determination has recently been made by Moulton taking Stefan's law of radiation, that of the fourth power of the temperature, which gives  $-33^\circ\text{F.}$  The author, however, points out that distance is but one of several factors that must be taken into account, and proceeds to consider the proportion of radiant energy reflected, absorbed, and transmitted, both by the air and by the actual surface of the planet; the relation borne by the visible and invisible rays to the subject; the

blanketing effect of the atmosphere, &c. It might be supposed that owing to the thinness of the Martian air relatively to the earth's, a larger fraction of solar heat would be received by the planet's surface. But the very rarity of the air joined to the lesser gravity at the surface of Mars would lower the boiling-point of water to something like 110°F. The sublimation at lower temperatures would be correspondingly increased. Hence the amount of water vapour in the Martian air must on that score be relatively greater than our own. Further, the planet would part, caeleris paribus, with its lighter gases the quickest, and this gives reason to think that both water vapour and CO<sub>2</sub> are present in relatively greater quantity than in our air. The absorption due to their presence will lessen the heat received at the surface of Mars, but it is to be noted that what is thus lost in reception furthers retention. About 50 per cent. of the earth's surface is covered by cloud which only transmits 20 per cent. of heat received, while Mars is almost free from cloud. Taking this into consideration the author calculates the mean annual temperature of Mars from that of the earth by Stefan's law. A first result based on comparison of albedoes gives 72°F. or 22°C. as the mean annual temperature on Mars if heat were retained there as well as on earth, which is probably far from being the case. He also attempts to calculate the density of the Martian air from its albedo, taking the density as proportional to the brilliancy, on the ground that the brilliancy is largely due to dust, and the denser the air the more dust it will buoy up. The author's final results are as follows: Mean temperature, 48°F. or 9°C.; boiling-point of water, 111°F. or 44°C.; amount of air per unit surface, 177 mm. ( $\frac{2}{3}$  of earth's); density of air at surface, 63 mm. ( $\frac{1}{12}$  of earth's). Albedo of Venus. -- The author regards the high albedo of Venus, given by Müller as 0.92, as due to the presence of dust. The albedo of cloud being only 0.72 can hardly account for it. The planet's markings appear to him not obscured by cloud, but seen as through a veil. His observations confirm Schiaparelli's view that Venus keeps the same face to the sun, and this would cause convection currents and absence of moisture on the sunlit half. Dry winds blowing over a Sahara would be laden with dust, and Very's investigations find dust to be the chief cause of reflection in our own air.

489. Maeva, S. V.,  
SOME CALCULATIONS CONCERNING THE THERMAL HISTORY OF  
MARS AND THE MOON, Akademiiia Nauk SSSR, Doklady, 159,  
11 November 1964, pp. 294-297, translated in Soviet Physics-Doklady,  
9, May 1965, pp. 945-948.

Computations of the current and past temperature distributions and heat transfer rates through the bodies of the Moon and Mars from the known contents of thorium, uranium, and other radioactive elements in meteorites. The heat flux through the surface of Mars is calculated to lie between  $0.28$  and  $0.41 \times 10^{-6}$  cal/cm<sup>2</sup>-sec. The Moon is found to be solid down to a depth of 500 to 800 km and to possess a liquid core.

490. Menzel, D. H.,  
WATER-CELL TRANSMISSIONS AND PLANETARY TEMPERATURE,  
Astrophys. J., 58, September 1923, pp. 65-74.
- The theory of the method is outlined and the influence of the uncertain factors, the area of the planet exposed and the humidity of the atmosphere discussed. Results obtained at present indicate temperature of 50°C. for Venus -16°C. for Mars, 120°C. for the moon, and -110°C. for Jupiter and Saturn. These can all be satisfactorily explained by radiative equilibrium except in the case of the two major planets which show unmistakable evidences of internal heat. Mercury, Uranus, and possibly Neptune should be within the scope of the method. The effect of air mass and humidity in the atmosphere can be allowed for as the product of two factors. Further work on infra-red transmission of water-vapour and carbon dioxide is desirable.
491. Menzel, D. H., Coblenz, W. W., and Lampland, C. O.,  
PLANETARY TEMPERATURES DERIVED FROM WATER-CELL TRANSMISSIONS, Astrophys. J., 63, April 1926, pp. 177-187.

In this paper the measurements of the planetary radiation transmitted through a water cell as observed by Coblenz and Lampland at the Lowell Observatory during the summer of 1924 are reduced by Menzel by the method published by him in 1923. The results obtained seem to prove quite conclusively that the bright areas are at a lower temperature than the dark areas, and that the equatorial (black-body) surface temperature of Mars at perihelion rises above 0°C. The true temperature, corrected for emissivity, would be about 10° higher. The temperature of the south polar cap was -100°C. on August 14, gradually increasing to about -15°C., on October 22, indicating that the cap is probably composed of ice and snow. The low temperature of the east limb, which was down to -85°C., is definite proof of an enormous diurnal fluctuation. Various methods of combining the observations give concordant results. The temperature of the moon reached 120°C. under perpendicular insolation. The distribution of energy in its heat spectrum is not consistent with a radiating surface of quartz. The temperatures of Jupiter, Saturn and Uranus are low, the values

calculated from the water-cell transmission being -150°C., -150°C., and -170°C. respectively. There is little evidence of internal heat.

492. Geophysics Corporation of America, Bedford, Massachusetts, THEORETICAL ESTIMATES OF THE AVERAGE SURFACE AND ATMOSPHERIC TEMPERATURES ON MARS by G. Ohring, 1962, reprinted from Mem. Soc. Roy. Sci., Liège, ser. 5, 7, 1962, presented at the Intern. Colloq., Liège, 9-11 July 1962, pp. 425-447, Contract No. NASw-704.

From theoretical computations based upon radiative equilibrium considerations, the average surface temperature of the planet Mars is found to be in the range of 219° to 233°K. This is in reasonable agreement with the thermal emission observations which suggest a mean temperature of about 233°K. The computations also indicate that the maximum greenhouse effect on Mars is about 40% of the average greenhouse effect in the earth's atmosphere, and that carbon dioxide is the most important contributor to the Martian greenhouse. The major characteristics of the computed vertical distribution of temperature in the Martian atmosphere are an adiabatic troposphere extending to 9 km. and a stratosphere that is stable, but with temperature still decreasing with height. If ozone is present in the atmosphere, additional computations should be made to evaluate its effect on the temperature distribution.

493. Geophysics Corporation of America, Bedford, Massachusetts, THEORETICAL ESTIMATES OF THE AVERAGE SURFACE TEMPERATURE ON MARS by G. Ohring, W. Tang., and G. De Santo, GCA-TR-62-3-N, reprinted from J. Atmospheric Sci., 19, No. 6, November 1962, pp. 444-449, Contract No. NASw-704.

Estimates of the average surface temperature on Mars are derived from radiative equilibrium considerations. A minimum possible surface temperature is estimated by computing the radiative equilibrium temperature that the Martian surface would have if the planet had no atmosphere. An estimate of the maximum possible value of the average surface temperature is obtained by computing the surface temperature that would result from a maximum greenhouse model. The computations indicate that the average surface temperature is in the range 219° to 233°K. Comparisons of the theoretical computations with indications of surface temperature obtained from thermal emission observations are found to be in reasonable agreement.

494. Geophysics Corporation of America, Bedford, Massachusetts,  
A STUDY OF THE METEOROLOGY OF MARS AND VENUS Quarterly  
Progress Report No. 4, 6 Oct. 1963-5 Feb. 1964, by G. Ohring, 1964,  
NASA-CR-58285, Contract No. NASW-704.

Computations of the radiative equilibrium distribution of temperature between the cloud-base and the surface of Venus were completed, and the results are presented. To the extent that this region of the Venus atmosphere is in radiative equilibrium, and to the extent that the computed temperature distribution is thermally stable, the results provide estimates of the actual temperature versus altitude distribution below the clouds. Work has continued on the construction of a model radiation budget for the planet Mars. A preliminary version of the average annual radiation budget at the top of the Martian atmosphere is presented.

495. Poynting, J. H.,  
SURFACE TEMPERATURES OF THE PLANETS, Phil. Mag., 14,  
December 1907, pp. 749-760.

In criticising a previous article by Lowell [Phil. Mag. July, 1907, and Abstract No. 803 (1907)] dealing with the evaluation of planetary temperatures, the author thinks that more attention should be given to the conserving action of the atmosphere. This action is compared to that of the glass covering of a greenhouse, and a hypothetical case is treated analytically from this point of view. Taking the temperature of the earth as 17°C. (290° abs.), it would at the distance of Mars be about 235° abs., and so the temperature of Mars would be from -26° to -42°C. (247° to 231° abs.). This is much lower than the value obtained by Lowell, and his higher result may be based on a peculiar atmosphere practically opaque to radiations from the cold surfaces. This conserving effect will hold only in the case of steady conditions. When the phenomena of day and night are considered very different values are obtained, and the variation of temperature with altitude comes into play. The lower mean temperature of elevated parts of the earth's surface is well established, and if the atmosphere of Mars is comparable with our own at high levels, and if the effect is of the same general character in the two cases, it appears probable that the surface temperature of Mars is actually lower by many degrees than that which the surface of the earth would have at the same distance from the sun.

496. Schoenberg, E.,  
PLANETARY TEMPERATURES, Phys. Zeits., 26, 23 December 1925,  
pp. 870-898.

This is a summary of the attempts which have been made to estimate the surface temperatures of the planets. The difficulties of the problem are greatest with youthful planets, such as Jupiter and Saturn, which are still gaseous and radiating heat from their centres, as well as receiving it from the sun; they are less in the case of planets with a solid surface and an atmosphere, such as Mars and Venus; least with those which have no appreciable atmosphere, such as the minor planets and the moon. A review is given of the early work of Christiansen, Lowell, Poynting, Arrhenius, Very, etc., and of the comprehensive mathematical treatment of the problem by Milankowitsch. With the recent bolometrical observations in America the problem has centered a new stage, which is full of promise, although not all the results have yet been published. The methods are described and the results discussed. Those for Venus are doubtful, but the high temperatures deduced for Jupiter and Saturn are reliable and of great interest, and a more detailed study may throw much light on the constitution of the giant planets. It is now possible to estimate separately the temperatures of different portions of a planetary disc; and the results of Coblentz show that the dark regions on Mars are quite warm enough to be covered with vegetation during the Martian summer, even if it is only of a Polar type like that of our Siberian tundras. Finally, a new method has been suggested by the Russian astronomer Fessenkow of determining the temperature and the depth of atmosphere (if any) on the moon by measuring the brightness of her twilight zone, and this might perhaps be applied to Venus and Mars.

497. Schoenberg, E.,  
METEOROLOGY OF MARS' ATMOSPHERE, Sternenwelt, Munich, 3,  
No. 5/6, May/June 1951, pp. 82-86.

Radiometric temperature measurements of the surface of Mars and photographs of the planet served as a basis for these considerations regarding various properties of the Martian atmosphere. Discussed in particular are: 1) chemical composition of the air, 2) the polar caps (identified as condensed water vapor in the air above the poles), 3) the behavior of clouds and fog, 4) horizontal and vertical distribution of atmospheric temperature, pressure and density (with data presented in graphs), and 5) the atmospheric circulation (chart). The description of the probable atmospheric structure of Mars is based on a theory proposed by S. L. Hess.

498. Vercelli, F.,  
TEMPERATURE OF PLANETS, Accad. Sci. Torino, Att., 49, No. 5a,  
1913-1914, pp. 298-325.

Shows on general grounds that the age, temperature, and thermal gradient of planets, calculated by Fourier's method, must be considered as minimum values. Applying the method on a wider range to spheres, and using elliptic functions, the author deduces 187 million years as the minimum time since solidification began. The absolute temperature at the centre after the same period rapidly increases with the diameter of a planet, being  $0^{\circ}$  in the case of Eros,  $40^{\circ}$  in the case of June,  $2000^{\circ}$  for Vesta, and  $4000^{\circ}$  for all planets from the size of the moon upwards. This supposes that the physical structure of the planet is similar to that of the earth. The temperature gradient would thus be of the order of that of the earth for the larger planets, but would be very low for the planetoids.

499. Very, F. W.,  
GREENHOUSE THEORY OF PLANETARY TEMPERATURES, Phil.  
Mag., 16, September 1908, pp. 462-480.

Various attempts have been made to apply the phenomenon of heat conservation by enclosed glass structures to the theory of planetary atmospheric temperatures. In the ideal case, where all the solar radiation would be arrested and transformed into radiation of different wave-length, there would still be the time-factor to consider; where a layer of conducting material of indefinite thickness is to be heated, a day is too short a time to reach thermal equilibrium, but for a small thickness a second might be sufficient. The author considers the conserving action of an extended series of arresting screens, each of very small absorption, and moreover suggests that the true constitution of matter may really resemble such a collection of screens: the particles are really discontinuous, and the interspaces may act as a series of chambers through which thermal energy may be transferred from molecule to molecule by a process which involves a time-factor and discontinuous mechanism. Experimental readings under multiple glass screens showed that a temperature higher than that of boiling water could easily be attained, with the sun's altitude about  $50^{\circ}$  and the solar radiation about  $1 \cdot 30$  small calories per cm.<sup>2</sup> per min. From this it is computed that the sun can give at the earth's distance a temperature of  $468^{\circ}$  abs., which agrees with the value previously determined by the author for the moon's temperature at lunar midday ( $454^{\circ}$  abs.). Consideration is then given as to how much of the solar radiation is arrested by the upper water-vapour layers of the atmosphere; this must be considerable, and may account for the departure from the adiabatic rate found by recent observations by sounding balloons, indicating the existence of a high-level isothermal stratum. Following Lowell, the author then discusses the influence of albedo on a planet's temperature.

As about a third part of the sun's radiant energy is in the visible spectrum where selective scattering is most effective, the earth, with its greater albedo, will receive a smaller proportion of heat at its surface than the planet Mars. The effects due to diffraction and scattering reflection from dust particles are also considered. It is suggested that the major planets have atmospheres containing unknown and highly absorbent gases which produce bands in the visible spectrum, increasing in strength with the distances of the planets from the sun. These bands invade the red end of the spectrum, but diminish in width and blackness towards the shorter waves, and die out near the middle of the visible spectrum. This suggests that there may be present in the atmospheres of these planets substances having very numerous and intense absorption bands in the infra-red; if these bands are so strong that they give metallic reflection for surface radiation, even the small amount of energy in the solar radiation on Neptune could be so largely stored up that a high surface temperature might be maintained.

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