the plages. The overriding impression from the photographs is that the x-ray emitting regions resemble the Hα regions at the base of the corona, but that at higher levels the x-ray emitting regions are rich in looplike structures which interconnect Hα active regions and are largely determined by the magnetic field. This interpretation strengthens theories that attribute the extra heating in upper layers of active regions to the presence of an enhanced magnetic field. We interpret the similar size of the x-ray emitting regions in the 44 to 60 Å and 3.5 to 14 Å wavelength intervals, both at the limb and on the disc, as evidence that the x-ray active regions as a whole do not show large-scale temperature structure. On the other hand, temperature structure may be present on a scale small with respect to the size of the regions, perhaps in a multilayer ropelike volume with strong magnetic field confinement.

With regard to the general corona, the following considerations apply. By comparing the x-ray with the Hα image we associate the weakly emitting regions with the brightest portions of the chromospheric magnetic network. It has been suggested that, in the heating mechanism of the corona, the magnetic field of the network plays an important role (*15*). We believe that the general x-ray corona at the limb is related to the weakly emitting regions on the disc associated with the brightest features of the network. The softness of the spectra from both regions is also consistent with our opinion that these are two views of the same type of activity.

Several flare events must be studied before we can determine whether the features we observe are a common characteristic of all flares. Our overriding impression from the analysis of these photographs is that more detailed understanding of solar phenomena can be achieved by modest improvement of spatial resolution in the x-ray region of the spectrum. The dominant role played by magnetic fields in the storage and release of energy in the solar atmosphere can be perceived from the correlation between Hα and x-ray structures, the existence of loops interconnecting active regions, and the development of the x-ray flare along a neutral magnetic field line.

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8. This effort is being conducted under the sponsorship of the Solar Physics Branch of NASA Headquarters. The payload used in this experiment is a scaled-down version of a more sophisticated experiment we are preparing for flight in a manned solar mission (Apollo Telescope Mount) carried out by NASA's Marshall Space Flight Center.
9. The spectrograph was suggested by H. Gursky and T. Zehnpfennig, *Appl. Opt.* **5**, 875 (1966), and developed by T. Zehnpfennig, *ibid.*, p. 1855.
10. Papers on the performance of, and on the preliminary result from, the three instruments have been presented at the American Astronomical Society Special Meeting on Solar Astronomy, Tucson, Arizona (1 to 3 February 1968) by H. Friedman *et al.*; J. L. Culhane *et al.*; and F. R. Paolini *et al.*; and at the Midwest Cosmic Ray Conference, Iowa City, Iowa (1 and 2 March 1968) by F. R. Paolini *et al.* and G. S. Vaiana *et al.*
11. P. S. McIntosh, personal communication; a magnetogram taken 9 June 1968 by R. Howard (Mount Wilson and Palomar Observatories) confirms the statements on the neutral line.
12. The 10^3 dynamic range of the negatives is larger than that of the printing paper, and we have had to compress the original density of the negatives in order to show both the brightest and faintest features; this has resulted in a considerable loss of contrast in the print. The faint halo visible around very intense features is an instrumental effect due to the wings of the telescope response to a point source. The dark rays in the halo are shadows of the ribs in the telescope aperture plates.
13. Such fine details can only be observed near the optical axis where the best resolution is obtained; there are, however, active regions that are as close to the optical axis as the flare and do not show the same type of fine features.
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16. We thank the staffs of ESSA, Sacramento Peak, McMath, Lockheed, and Sagamore Hill Observatories for providing flare alarm and ground measurements, in particular, D. Bucknam and R. Decker (ESSA) for coordinating the alarm network. We are indebted to R. Howard and H. Zirin (Mount Wilson and Palomar Observatories); W. Livingston and N. Sheely (Kitt Peak Observatory); W. Curtis (High Altitude Observatory) for additional ground measurements; also P. S. McIntosh for help in interpreting the Hα features discussed. We thank the personnel both of the Sounding Rocket Branch of Goddard Space Flight Center and of the White Sands Missile Range who supported us while we waited for the flare; we thank A. De Caprio, R. Haggerty, H. Manko, and D. Yansen (AS&E) for technical support. Supported by contracts NASW-1555, NASW-1700, and NAS 5-9041.

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The Effect of Mass on Frequency

Abstract. *Two experiments are described where an apparent decrease in frequency was detected when the optical path was in the vicinity of a mass. In the first experiment the 21-centimeter absorption line from Taurus A was observed near occultation by the sun. In the second experiment the frequency of a portable cesium clock was compared with the frequency of a similar clock which transmits its signals from Cape Fear, North Carolina. A decrease of frequency of the received signals as a function of the distance between the two clocks was apparent. Several relevant observations (the red shift of lines from the sun, the Mössbauer determination of the gravitational red shift, and the cosmological red shif) are discussed in view of the present results.*

Two known effects can change the frequency of a spectral line: the Doppler effect and the gravitational red shift. Because so much importance is attached to deviations of the frequencies of lines coming from stars and galaxies, we tried to devise and perform experiments that may disclose further influences on the frequency of a line. This report describes experiments aimed at finding an effect of mass on the frequency of light passing near the mass.

During the annual approach (every June) of the radio source Taurus A to the sun, one can measure whether the 21-cm absorption line from Taurus A changes its frequency. Such an experiment was performed by us (*1*) and the results indicated a decrease of the frequency when the optical path approaches the sun. This same experiment was repeated with better instrumentation this year and once again a decrease was detected. Figure 1 shows the observation of a decrease in frequency upon closest approach. Several controlled experiments were performed to avoid any instrumental or systematic error (*1*).

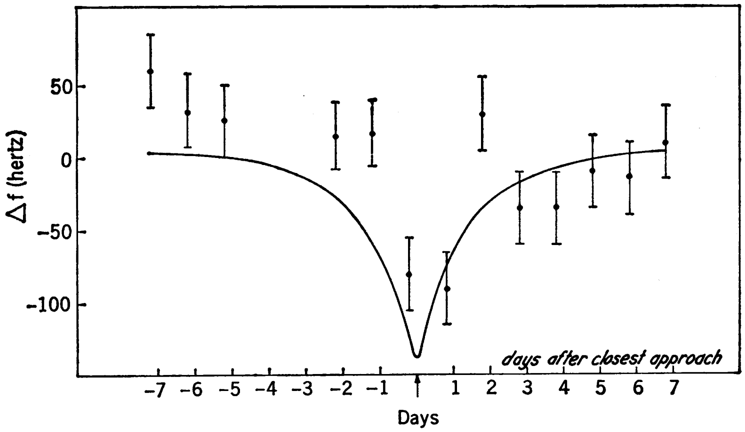
If the Taurus A experiment showed

a genuine change in frequency, and if this change is caused by the mass of the sun, such a decrease must manifest itself for an experiment on the surface of the earth. It is sound logic to assume that if a mass affects the frequency, the effect will be greater the longer the rays are under the influence of the mass. This means that if a well-defined frequency is sent from a station on earth, it is affected by the nearby masses (the earth, the moon, and the sun) as it travels to another station on earth. The receiving station, according to our assumption, will record a frequency $f_0 - \Delta f$, where Δf depends on the distance d from the first station. To check the dependence of Δf on d one can move the receiver and measure Δf at each of several locations.

For this experiment we used cesium beam oscillators. The original frequency of 9.192631770×10^9 hz is reduced to time ticks of one per second. As no two clocks have exactly the same frequency, an electronic comparison between them tells what their frequency difference is. The comparison is done by measuring the time interval between the 1-second ticks of the two clocks. A change with time of this time interval gives the difference in frequency of the clocks. The relative long-term precision of this comparison is one part in 10^{13}. By increasing the distance between the two clocks, and transmitting the pulses from one clock to the other, one can compare whether their frequency difference changes with distance. The transmitting and receiving system used is the Loran C system which transmits the time ticks on a 100-khz carrier where the 100 khz itself and its modulation is derived from the cesium clock. The pulses can be detected hundreds of miles from the transmitter, and provisions are made that only ground waves are detected, and no ionospheric reflections can occur (*2*).

The techniques are easily explained by describing the experimental procedure. The transmitter, whose time ticks are derived from a cesium clock, is situated at Cape Fear, North Carolina, and a second cesium clock moved on a truck can receive these time ticks and compare them with its own ticks. In the truck there are two additional cesium clocks which constantly monitor the first clock to check its stability. An additional clock is situated at Cape Fear and is monitoring the frequency of the transmitted ticks. At the beginning of the experiment the truck was parked 10 miles (16 km) north of Cape Fear. The received ticks were compared with the local clock for 7 days and we established that the received clock's frequency was higher than the local clock's frequency by $\Delta f/f = (1.5 \pm 0.1) \times 10^{-12}$. Then we went to Elizabeth City, North Carolina, which is 270 km from Cape Fear, and stayed a week. We found that now the received clock's frequency had decreased relative to the local clock and was now higher by only $(1.1 \pm 0.1) \times 10^{-12}$, although no change in the rate of the clocks was detected by the monitors. As we went farther and farther away from the transmitter its frequency (or the rate of its ticks) dropped lower and lower compared to our local clock. The last place, Yarmouth, Nova Scotia, was 1500 km away from Cape Fear, and there the received clock's ticks were lower in frequency than the local frequency by $(1.7 \pm 0.5) \times 10^{-12}$. From Nova Scotia the truck was driven back to the first position 10 miles north of Cape Fear. There we found the frequency difference returned to what it was at the beginning: $\Delta f/f = (1.5 \pm 0.1) \times 10^{-12}$. This proved that there was no change in the frequency of the clock during the trip. Further proof is that before and after the trip the clocks were compared with the U.S. master clock at the Naval Observatory and no change in frequency was detected. Figure 2 shows the results, and a decrease in frequency with distance is apparent. A decrease in the 100-khz frequency or the frequency of the time ticks (1 hz) will give the same result.

Neither the Doppler shift nor the gravitational red shift can explain this decrease in frequency. As there is no relative motion between the receiver and the transmitter, no Doppler effect can occur except for the transverse Doppler effect. As the earth rotates, a point at Cape Fear, North Carolina, has a higher velocity than a point at



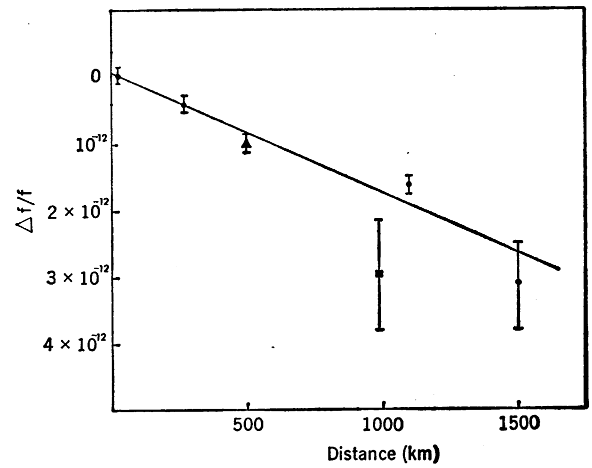


Fig. 1 (left). The points represent the experimentally determined residual frequency (measured minus calculated) of the 21-cm line during the days before and after the closest approach of Taurus A to the sun, averaging 2 years' measurements. The solid line is a $1/a$ dependence (to -30 hz) where a is the distance from the center of the sun to the line of sight at closest approach. The probability that random fluctuations gave the red shift shown on the 2 days near closest approach is only 1 percent. After and before the days plotted here the residuals were near the zero line. The error bars represent the actual spread of 1 day's measurement. Arrow indicates time of closest approach. Fig. 2 (right). The dots represent the experimentally determined difference in frequency between two cesium beam clocks as a function of distance between the two clocks. The four dots represent the results of an experiment started at Cape Fear, North Carolina, on 2 May 1968 and ended at Yarmouth, Nova Scotia, on 10 June 1968 (a northeast path). The triangle represents the result on a northwest path between Cape Fear and Washington, D.C. The square is the result on a south path from Cape Fear to Jacksonville, Florida. The error bars are determined from the actual scatter in the time intervals between the two clocks.

Yarmouth, Nova Scotia, 9° north of Cape Fear. The transverse Doppler effect is equal to v^2/c^2 and amounts in our case to 3×10^{-14}, which is much smaller than what was found. The gravitational red shift also predicts an effect much smaller than the one found. All five locations are at approximately the same gravitational potential; they are all at sea level and thus on the same geoid. [If one wants to use these clocks to measure the gravitational red shift, a transmitter at sea level and a receiver on top of a 10,000-foot (3048-m) mountain will give a shift of only $\Delta f/f = 4 \times 10^{-13}$.]

The frequency shift recorded in this experiment could not be caused by changes of temperature, humidity, or magnetic field. Tests showed that even larger environmental changes than those that actually occurred did not change the frequency by a measurable amount.

As there still could be a systematic error in both experiments it is premature to propose any theory which can explain these results before further checks and new experiments are done. (One now in preparation is to measure the period of the pulsar CP0950 as it approaches the sun.) Nevertheless, it is important to see if the Taurus A and the cesium clock experiments could be explained by the same relationship between mass and frequency. If we assume that there is a decrease in frequency of a periodic event in the presence of a mass and we deliberately speculate that the decrease is proportional to the mass M, and inversely proportional to the square of the distance, then for each small path length dL

$$\Delta f/f = -K\,\frac{M dL}{r^2}$$

where K is a constant and the minus sign means the frequency always decreases.

For the entire path (a being the distance of closest approach)

$$\Delta f/f = -KM\int_{-\infty}^{\infty}\frac{dL}{r^2} = -KM\pi/a$$

The constant K (dimensions cm/g) can be determined from the Taurus A observation

$$-\frac{120}{1.4\times10^{9}} = \Delta f/f = -K\pi M_\odot/5R_\odot$$

whence

$$K = 4.8\times10^{-30}$$

If we calculate K from the cesium clock experiment where M_e and R_e are the mass and the radius of the earth

$$-2.7\times10^{-12} = \Delta f/f = KM_e\int_0^{1500\ \text{km}}\frac{dL}{R_e^2}$$

$$K = 1.23\times10^{-30}$$

The two determinations of K differ by only a factor of 3.9, which is not very much considering the large differences in M, R, and f. [The gravitational constant G divided by the square of the velocity of light has the same dimensions as K and equals 7.4×10^{-29}; thus we can replace K by $K_0(G/C^2)$ and now K_0 is dimensionless and equals 0.04 ± 0.026.]

Both the Taurus A and the cesium clock experiments are "one way" experiments in contrast to "round trip" experiments where the waves are reflected back (*3*). Thus, three "one way" experiments should be examined in view of the present suggested interpretation of the result. Lines emitted from the sun should be red-shifted due to the gravitational red shift by $\Delta f/f = 2 \times 10^{-6}$ and by additional $\Delta f/f = 8 \times 10^{-8}$ [for $K = (3 \pm 2) \times 10^{-30}$ or $K_0 = 0.04 \pm 0.026$] due to the present results. The observations (*4*) show that this additional effect is well within the experimental errors. The second experiment is the Pound-Rebka measurements using the Mössbauer effect (*5*). The predicted effect should be

$$\Delta f/f = \frac{gh}{C^2} = \frac{M_e Gh}{R_e^2 C^2}$$

and the additional increment due to the present results is

$$\Delta f/f = 0.04\frac{M_e Gh}{R_e^2 C^2}$$

where g is the acceleration due to gravity on the surface of the earth, $M_e R_e$ is the mass and radius of the earth, and h is the path length. Thus the present effect adds 4 ± 2.6 percent to the total effect, which is barely in the estimated error of 1 percent claimed by Pound and Snider (*5*). The third observation that should be considered is the cosmological red shift. If our simple rule is true, there should be a red shift for light coming from a distant galaxy as it passes near other galaxies. Let us calculate the amount of this red shift for a simple Euclidian, finite universe and compare it with the experimental cosmological red shift. A mass M, r cm away from the path (in any direction), will give rise, according to our assumption, to a frequency shift $\Delta f/f = -K\ (ML/r^2)$, where L is the path length. Integrating over all the masses of the universe

$$\Delta f/f = -KL\int_0^{\text{Ro}}\frac{dM}{r^2} =$$

$$-KL4\pi\rho\int_0^{\text{Ro}} dr = 4\pi KL\rho\text{Ro}$$

where Ro and ρ are the radius and the mass density of the universe, and we assume $M = 4\pi\,\rho\, r^3/3$.

For $\rho = 10^{-29}$ g/cm^3 and for Ro $= 10^{28}$ cm the red shift per megaparsec should be $\Delta f/f = 1.2 \times 10^{-5}$, compared with the observed red shift per megaparsec of 3.3×10^{-4} (100 km/sec per megaparsec). Thus, the present effect can only be responsible for less than 10 percent of the cosmological red shift. Only if one assumes that the radius of the universe is 10 times larger than the Hubble radius or that the density of matter increases towards the edge, can the present effect equal the cosmological red shift. As it stands now the effect does not disagree with "one way" observations. A "round trip" experiment (*3*) is clearly not in agreement with our suggested effect and if and when more experiments prove that there is an effect of a mass on frequency the theory should have to explain the difference between "one way" and "round trip" experiments. We are aware of the enormous theoretical difficulties implied by the apparent results and of the need to seek further confirmation.

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