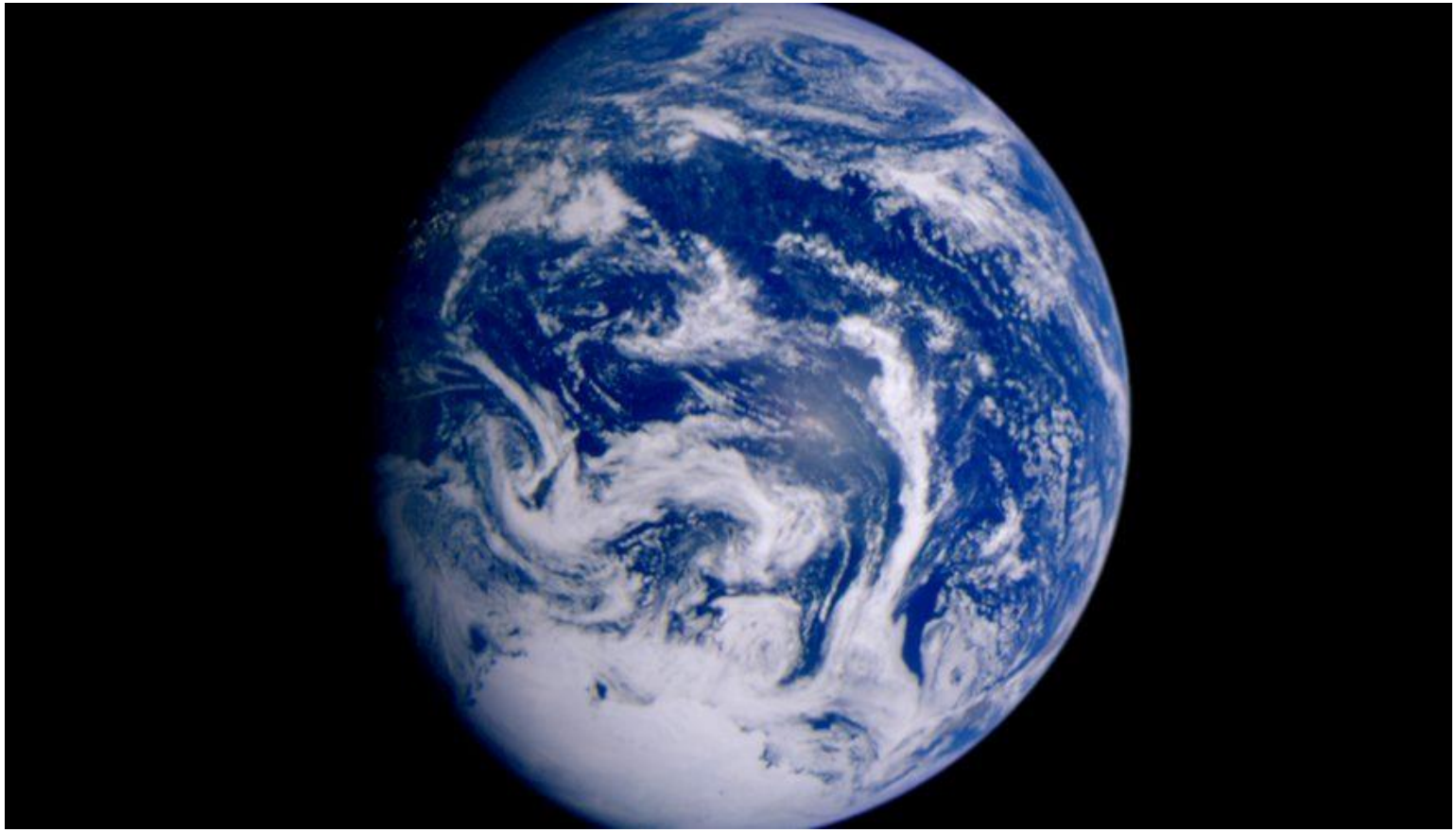
Composition of the Atmosphere

Atmosphere: envelope of air surrounding the earth and bound to the earth by the earth's gravitational attraction.

Extends from the surface into space with decreasing density with height. No real top.

The atmosphere is really very shallow compared to the size of the planet

- Just a thin veneer
- ¾ of the atmosphere by mass is in the lowest 33,000 ft, roughly 10 km



Atmospheric Constituents

- Gases

Non-Changing Gases

Gas	Symbol	Percent (by volume) Dry Air
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.92
Neon	Ne	0.0018
Helium	He	0.0005
Hydrogen	H_2	0.00006
Xenon	Xe	0.000009

Variable Gases

Water Vapor	H_2O	0 to 4
Carbon Dioxide	CO_2	0.037
Methane	CH_4	0.00017
Nitrous Oxide	N_2O	0.00003
Ozone	O_3	0.00000002
Sulfur Dioxide	SO_2	
Nitrogen Dioxide	NO_2	

CO2: a greenhouse gas (very effective absorber and emitter in the infrared).

O3: good in stratosphere (protects from UV), bad near the surface (corrosive to lungs and more)

SO2: emitted by volcanoes. Atmospheric particles and acid rain

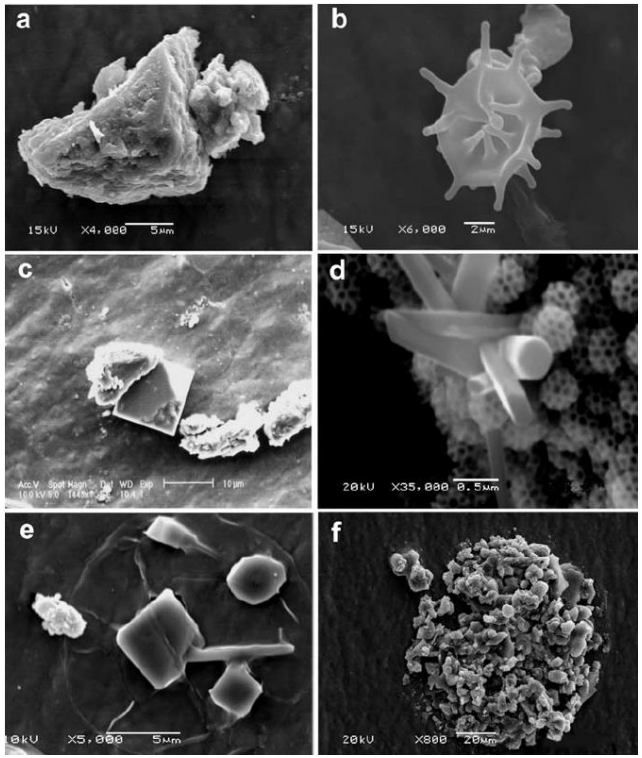
NO2: produced by combustion. Acid rain and smog.

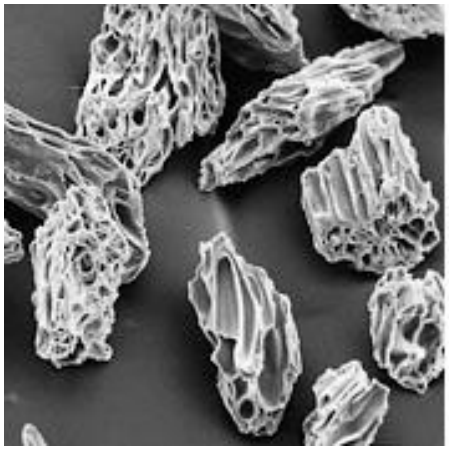
Variable gases

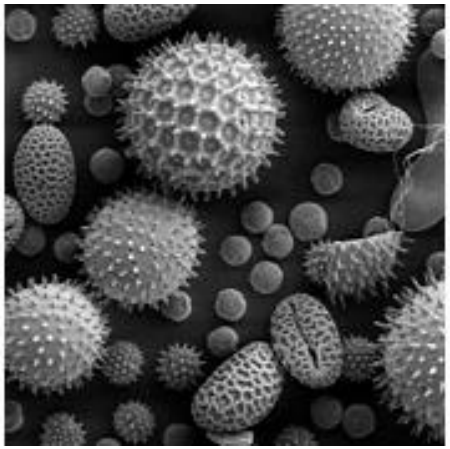
- Water vapor (~0 to 4%). Critically important!
  - Clouds and precipitation
  - Important way to move energy around
  - Major greenhouse gas!
- Methane (CH_4): major greenhouse gas

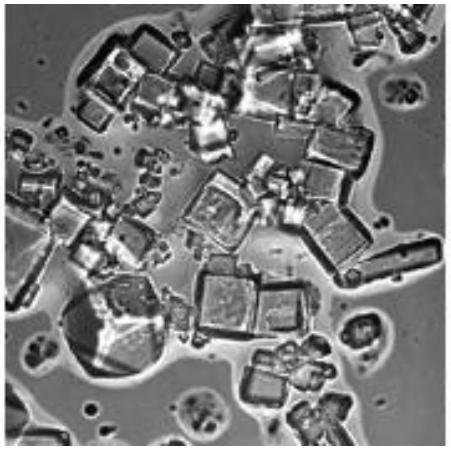
Non-Gas Constituents

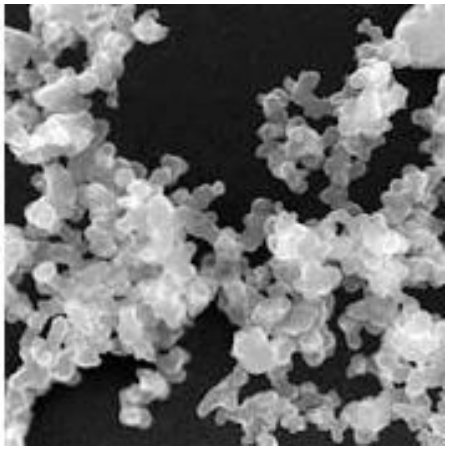
- Hydrometeors -rain clouds, hail
- Particulates and aerosols
  - Aerosol is a liquid or solid dispersed in a gas, usually air
- Particulates can be
  - Inorganic- soil, smoke, dirt, sea salt, volcanic dust, surface acid aerosol
  - Organic- seeds, spores, pollen, bacteria


a
15kU X4,000 5µm
b
15kU X6,000 2µm
c
10µm
d
20kU X35,000 0.5µm
e
X5,000 5µm
f
20kU X800 20µm







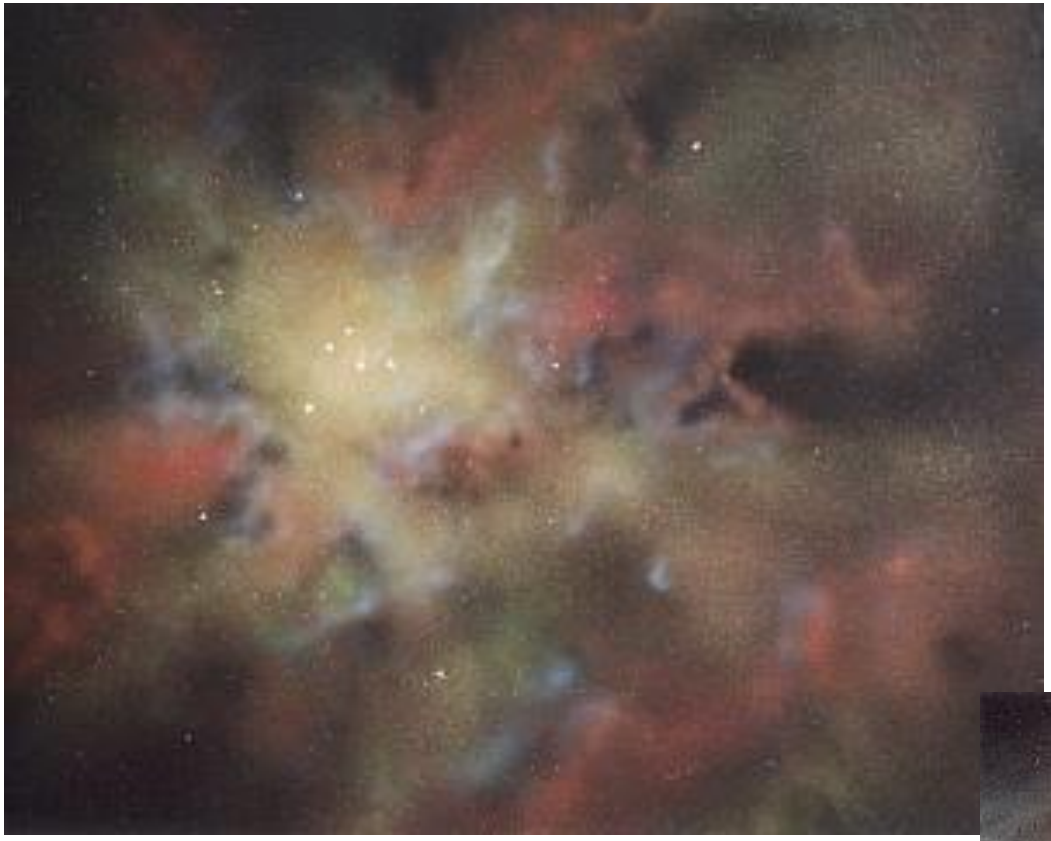


Why are particles in the air important?

- Act as condensation and freezing nuclei!
  - Water likes to condense on or freeze on to particles
- Can absorb or scatter radiation
    - Reduce visibility
    - Can scatter solar radiation to space: cool planet
- Can impact human health.
  - Can irritate lungs, initiate asthma, heart disease

The Origin of the Earth's Atmosphere

Still Many Uncertainties ….

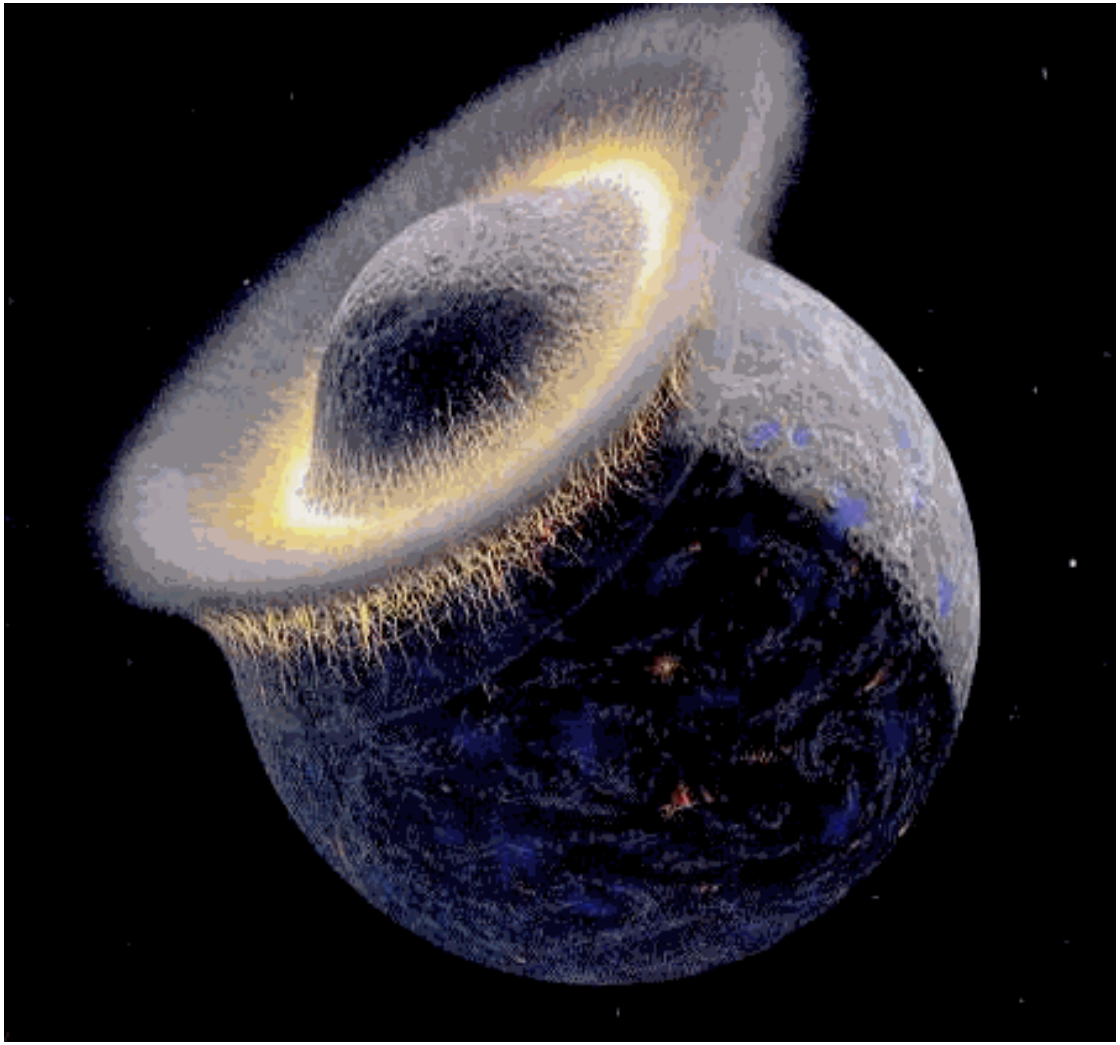


About 4.5 billion years ago, Earth formed out of nebula of gases and dust that were to become the solar system

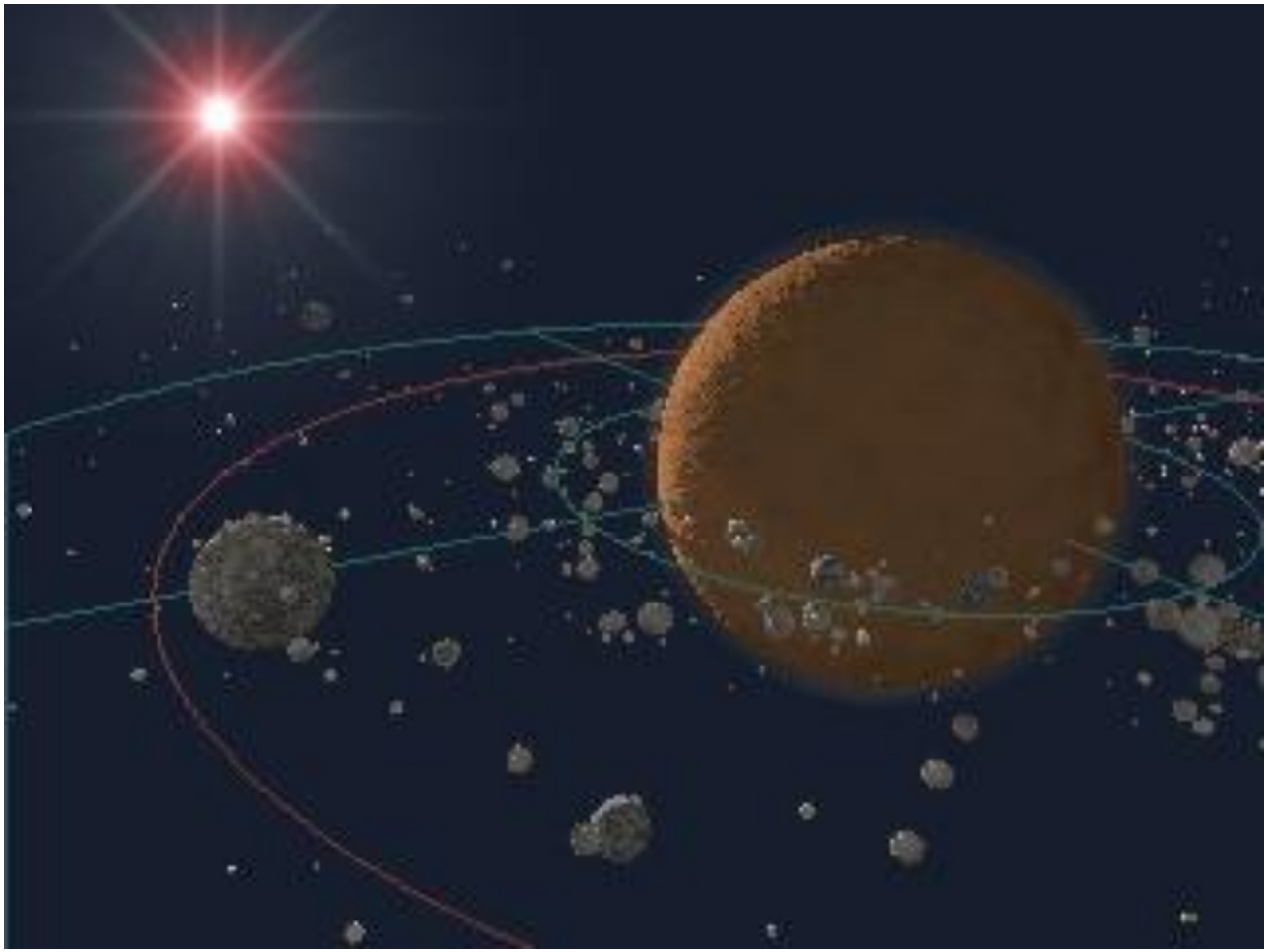
Small objects--called planetoids-- accreted or combined together to build larger objects…such as planets

The First Atmosphere

- The early atmosphere would have been similar to the Sun--mainly hydrogen and helium, but this atmosphere was lost quickly for at least two reasons:
  - (1) The gravity of the modest size earth was not strong enough to prevent such light gases from escaping to space. Particularly since the early earth was hot!
  - (2) It appears that around 30 million years after the earth's formation, it was struck by a large object…the size of Mars. The result: the origin of the moon and loss of earth's early H, He atmosphere.



Formation of Moon from the Debris of the Collision



Earth as Hell

- The surface of the earth during this period was extremely hot with numerous volcanoes
- The earth was under near constant bombardment by objects of varying sizes
- Slowly, the earth started to cool down and the second atmosphere began to form.

Earth's Second Atmosphere

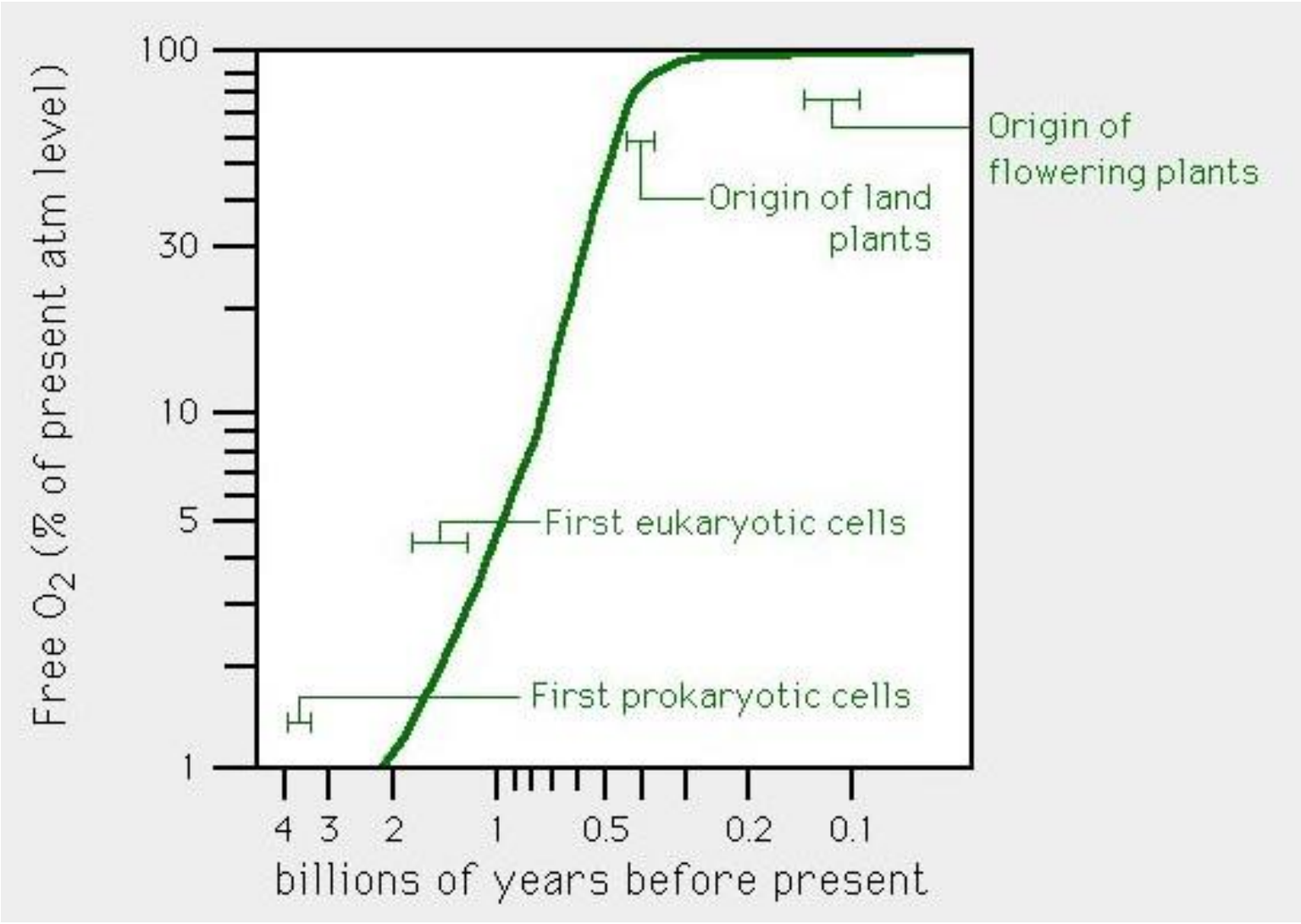
- A new atmosphere was established by the outgasing of volcanoes…the mixture of gases was probably similar to those of today's volcanoes:
- H_20 vapor (roughly 80%)
- CO_2 (roughly 10%)
- N_2 (few percent)
- Small amounts of CO, HCL, HS (Hydrogen Sulfide), SO_2, CH_4 (Methane), Ammonia (NH_3), and other trace gases.

Earth's Second Atmosphere

- Virtually no oxygen in that second atmosphere.
- Thus, no ozone layer, so ultraviolet radiation flooded the earth's surface.
- With a huge influx of water vapor and the cooling of the planet, clouds and earth's oceans formed.
- At that time the sun was about 30% weaker than today…why didn't the earth freeze over?
- The apparent reason: so much CO_2 so there was a very strong greenhouse effect.

The Rise of Oxygen and the Third Atmosphere

- In the first two billion years of the planet's evolution, the atmosphere acquired a small amount of oxygen, probably by the splitting of water (H20) molecules by solar radiation.
- The evidence of this oxygen is suggested by minor rust in some early rocks.
- The oxygen also led to the establishment of an ozone layer that reduced UV radiation at the surface.
- With the rise of photosynthetic bacteria (cyanobacteria) and early plants, oxygen levels began to rise rapidly as did indications of rust in rocks
- Between 2.5 billion years ago to about 500 bya, 0_2 rose to near current levels.


Free O_2 (% of present atm level)
100
30
10
5
1
4
3
2
1
0.5
0.2
0.1
billions of years before present
Origin of flowering plants
Origin of land plants
First eukaryotic cells
First prokaryotic cells

The Third Atmosphere

- While O_2 was increasing, CO_2 decreased due to several reasons:
- (1) In photosynthesis CO_2 is used to produce organic matter, some of which is lost to the system (e.g., drops to the bottom of the ocean or is buried)
- (2) chemical weathering, which removes CO_2

Chemical Weathering

- $H_20 + CO_2$ --> H_2CO_3 carbonic acid
- $CaSiO_3 + H_2CO_3$ --> $CaCO_3 + SiO_2 + H_20$

Silicate Rock Carbonate

- At first this happened without life, but the process was sped up tremendously by living organisms
- Marine organisms would incorporate carbonate into their shells, which would fall to the ocean bottom when they died---thus, removing them from the system for a long time.
- The bottom line…CO2 was being removed from the system.

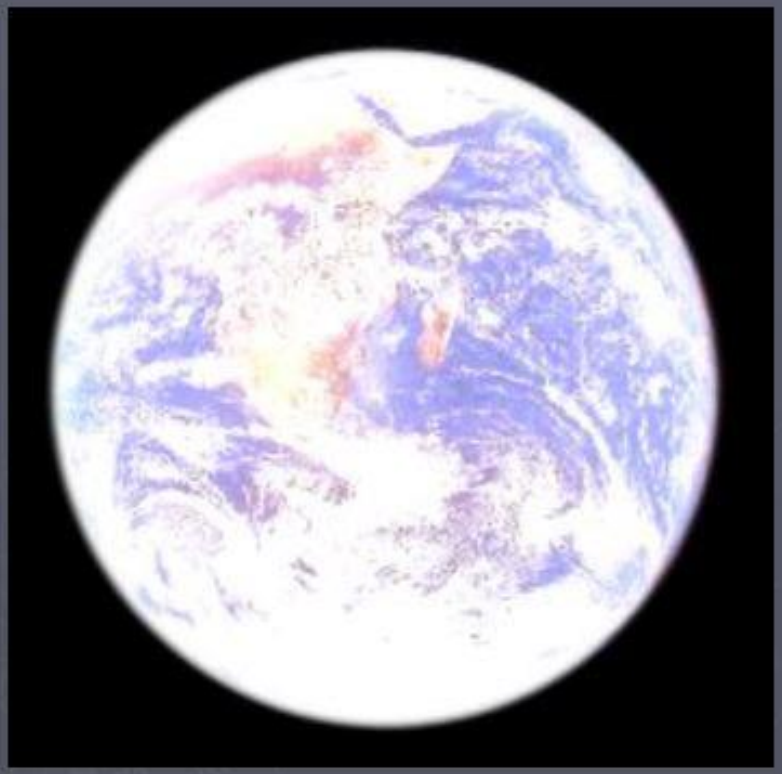
More Changes

- Sulfur compounds were taken out of the atmosphere as acid rain and were deposited on the ground as sulfates.
- N2 gas increased slowly but progressively since it was relatively inert.
- Current composition of the atmosphere was established approximately a billion years ago.

A Problem

- With lower CO2 levels the earth became more susceptable to ice ages when solar radiation decreases due to orbital variations,
- It appears that around 750-550 million years ago the earth cooled down and became nearly entirely glaciated.
- Note: one can get into a feedback with snow reflecting solar radiation, producing cooler temperatures and more snow, leading to less radiation, etc.

Snowball Earth?



How Did We Get UnFrozen?

- Volcanoes were still putting CO2 into the atmosphere
- Weathering was greatly reduced…since little liquid water.
- So CO2 increased until the greenhouse effect was so large the earth warmed up.
- Once warming started it would have happened very rapidly.

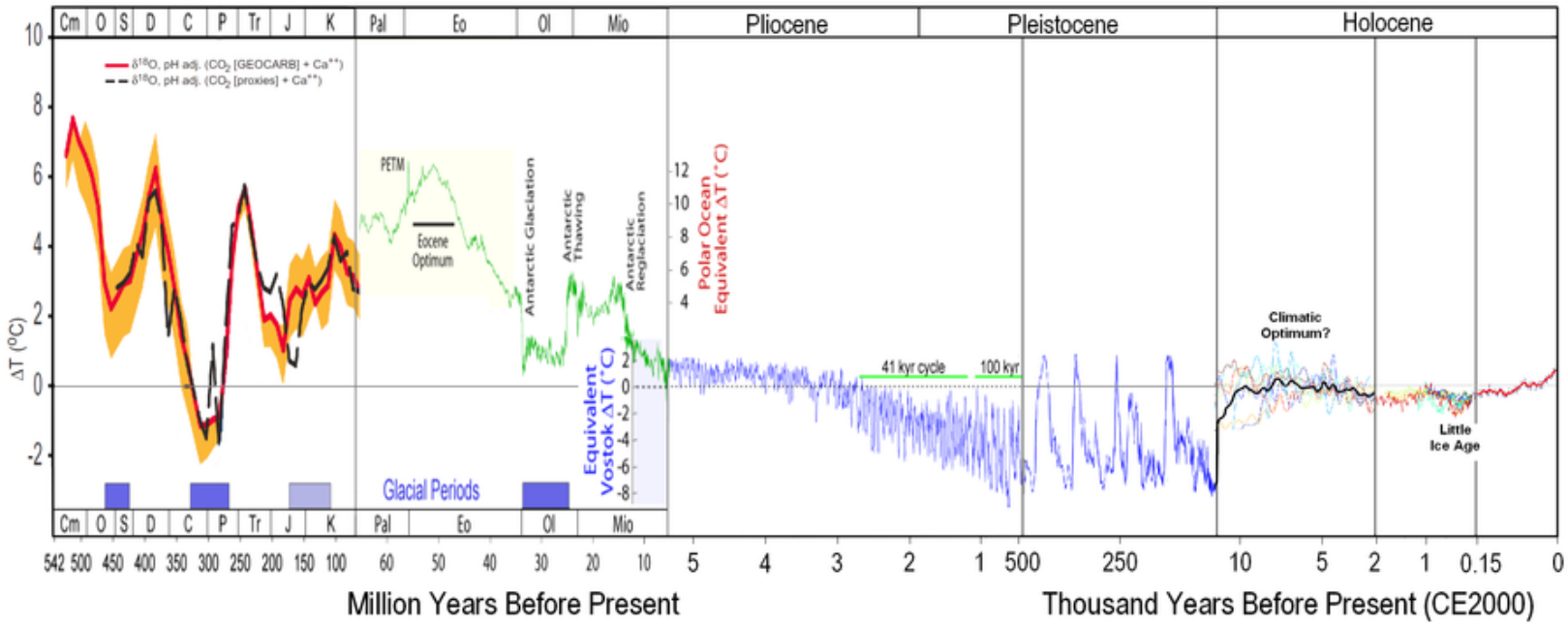
The Last 500 million Years

- The climate has not been constant, with warm periods interrupted by ice ages.
- Much of the variability forced by changing solar radiation due to periodic changes in the earth's orbital characteristics and tilt (Milankovitch cycles) and major volcanic eruptions (putting out massive CO2 that caused warming.

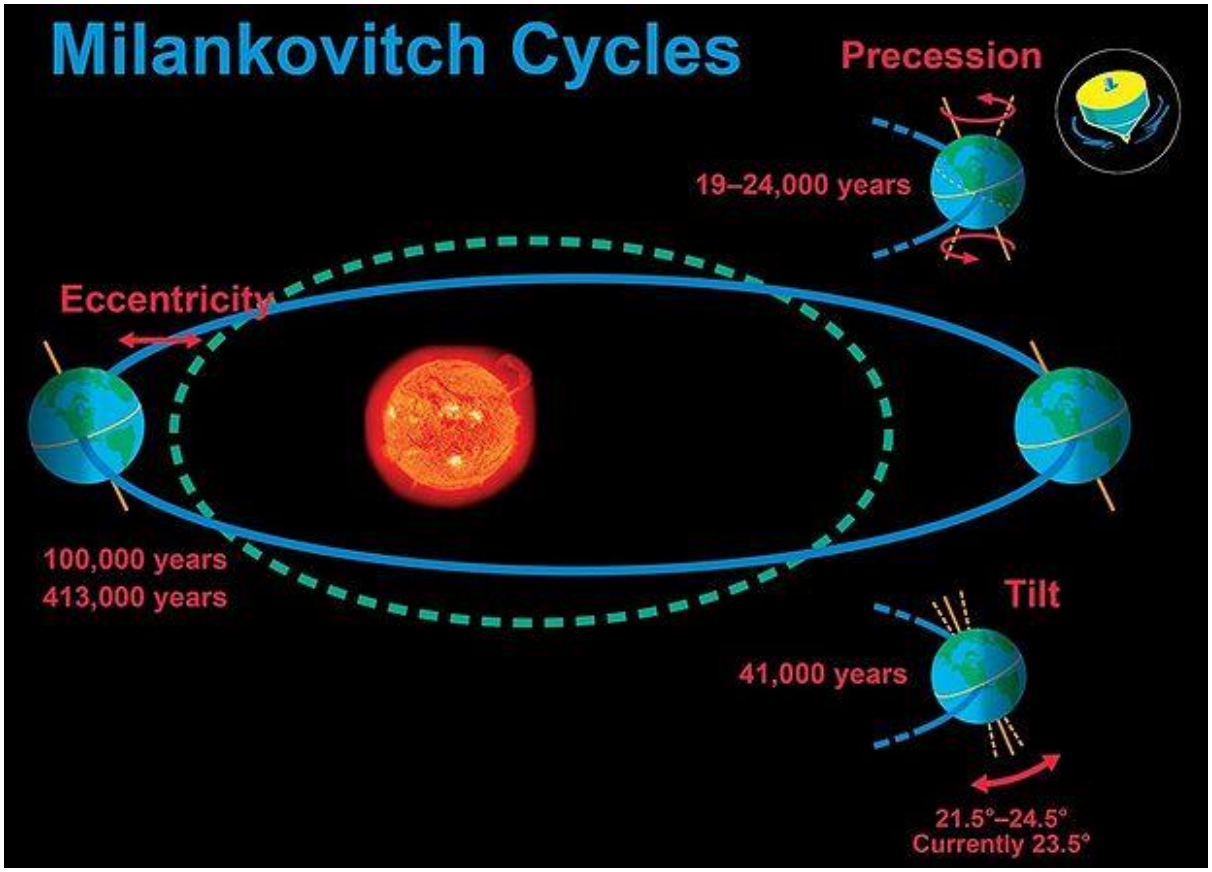
More Snowball Earths?

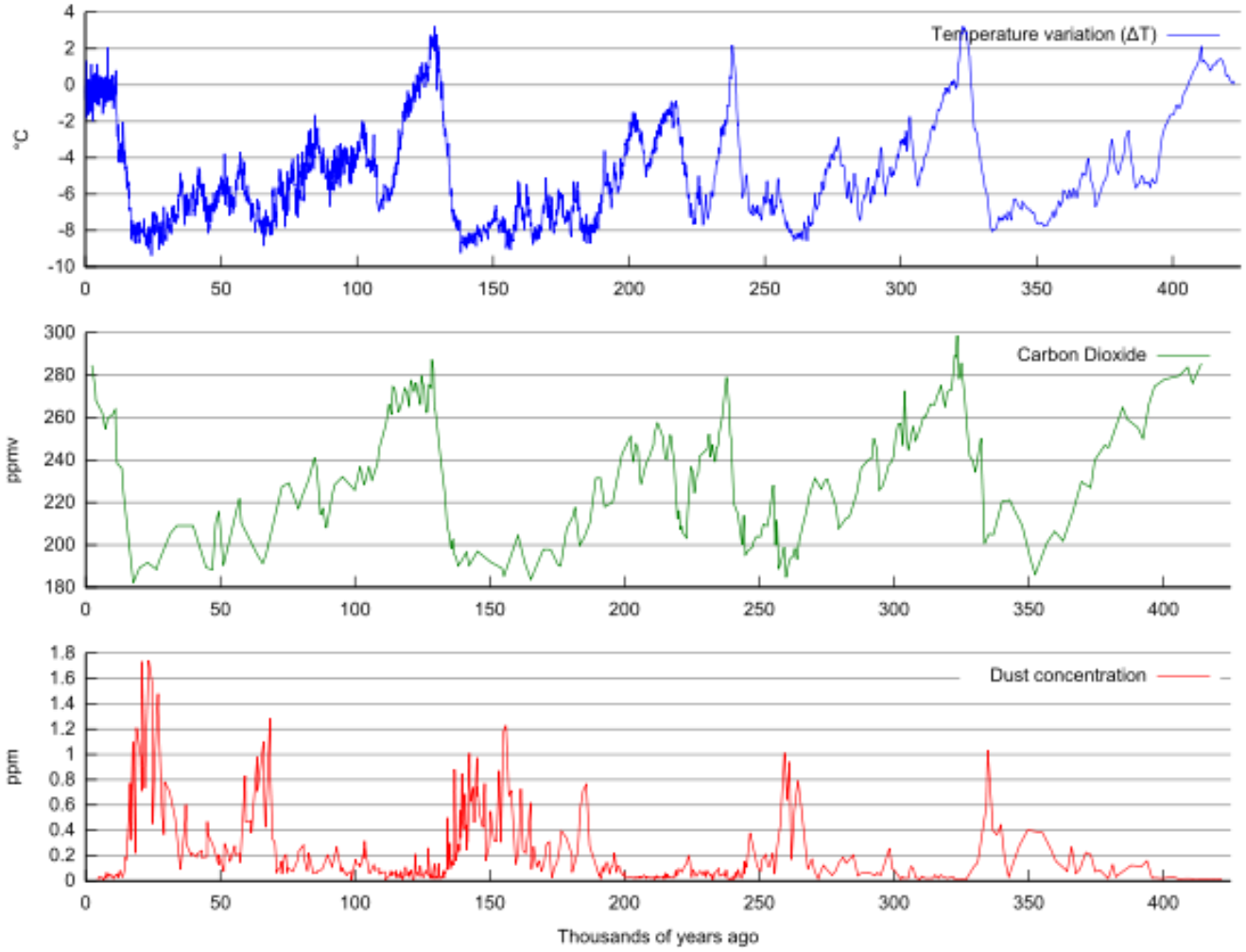
- Less chance now
- Sun is getting progressively stronger
- Human's can now stop it (increasing greenhouse gases)

Temperature of Planet Earth



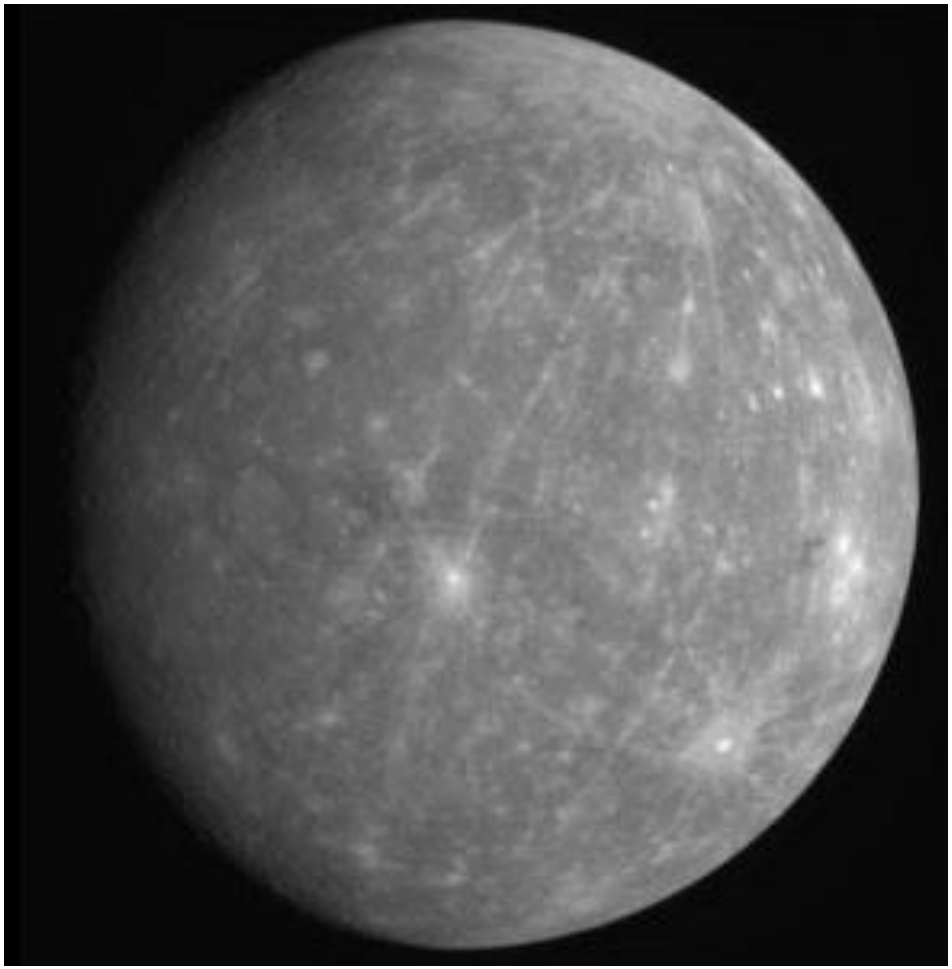
The Earth has had regular glaciations and melt backs…Why?



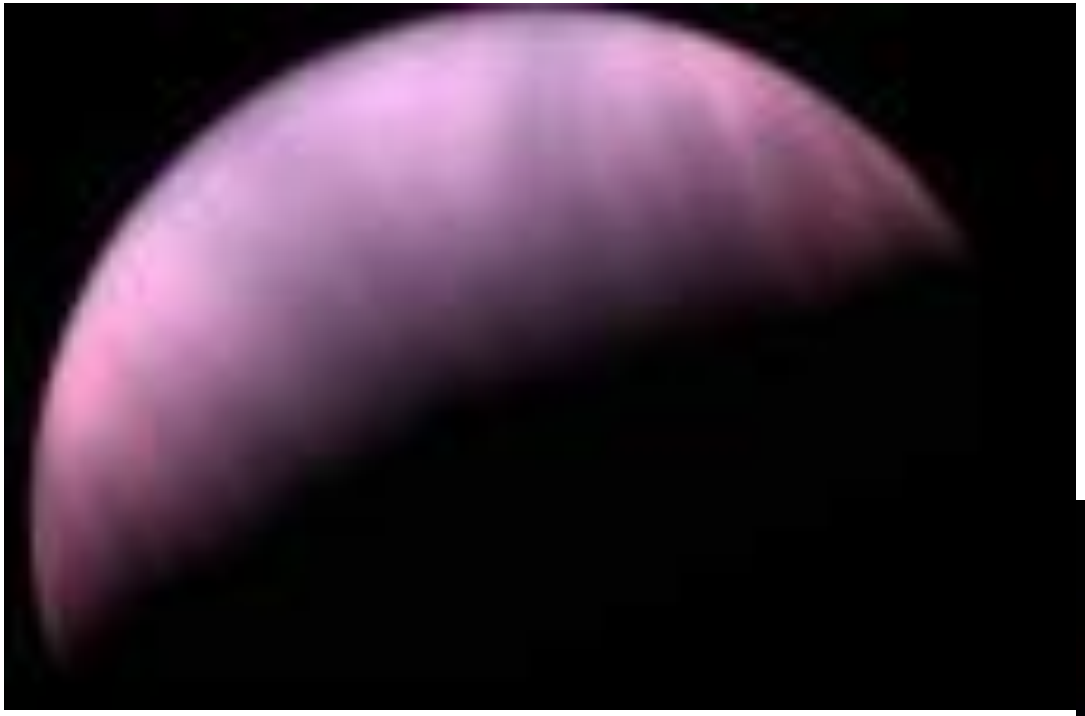

Temperature variation (ΔT)
°C
4
2
0
-2
-4
-6
-8
-10
0
50
100
150
200
250
300
350
400
Carbon Dioxide
ppmv
300
280
260
240
220
200
180
Dust concentration
ppm
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Thousands of years ago

Atmospheres of Other Planets

Mercury



No Atmosphere

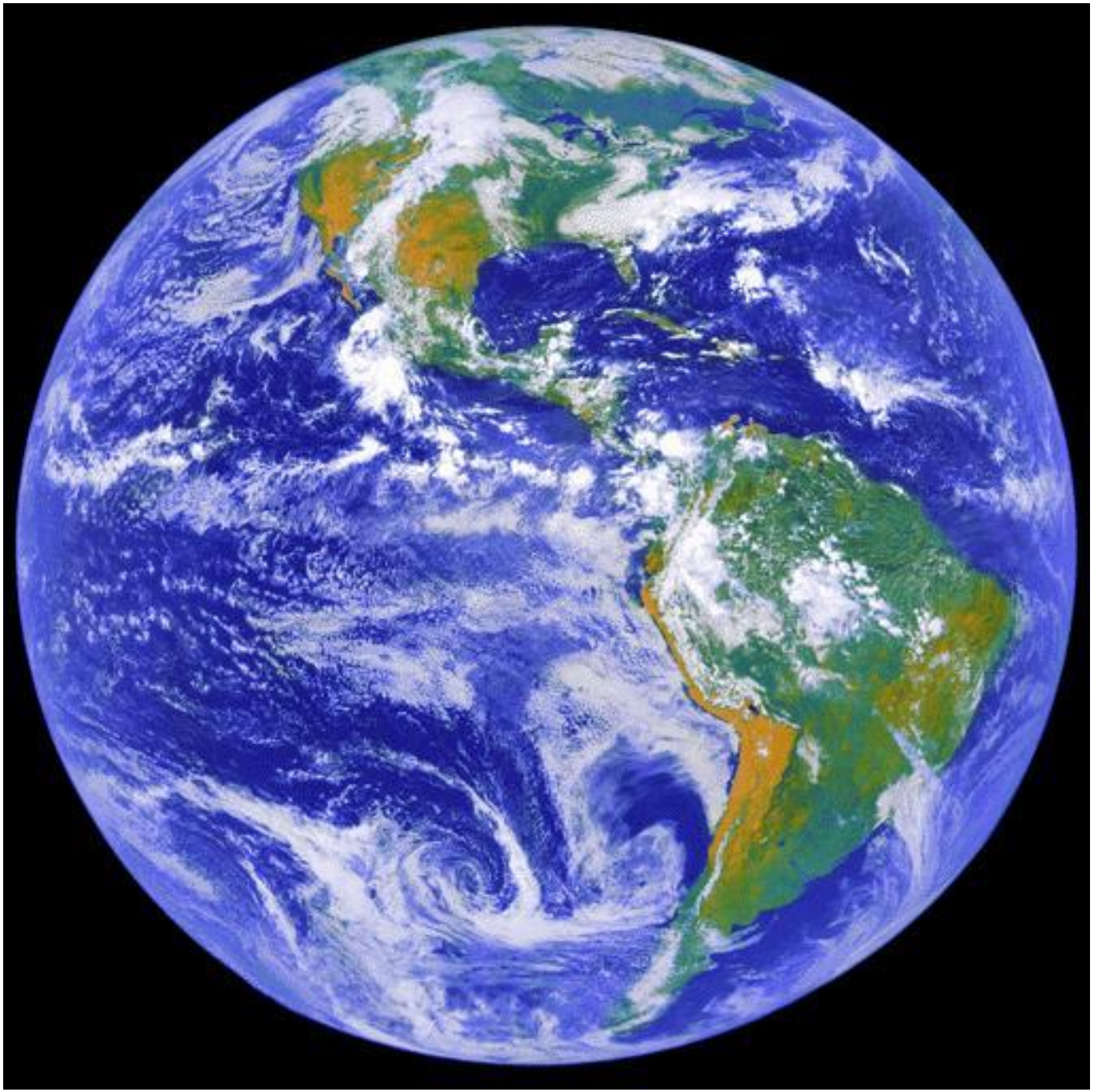


96% CO_2
Sulfuric acid clouds
Surface temp: 900F (470 C)
Surface pressure:
90 times greater than earty

Venus

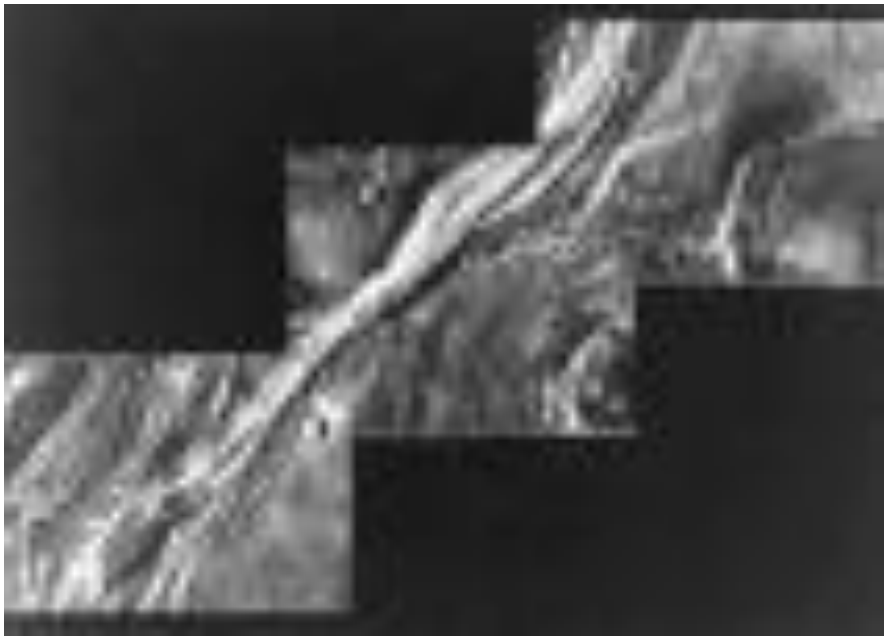
Venus Beneath The Clouds From Radar

Earth

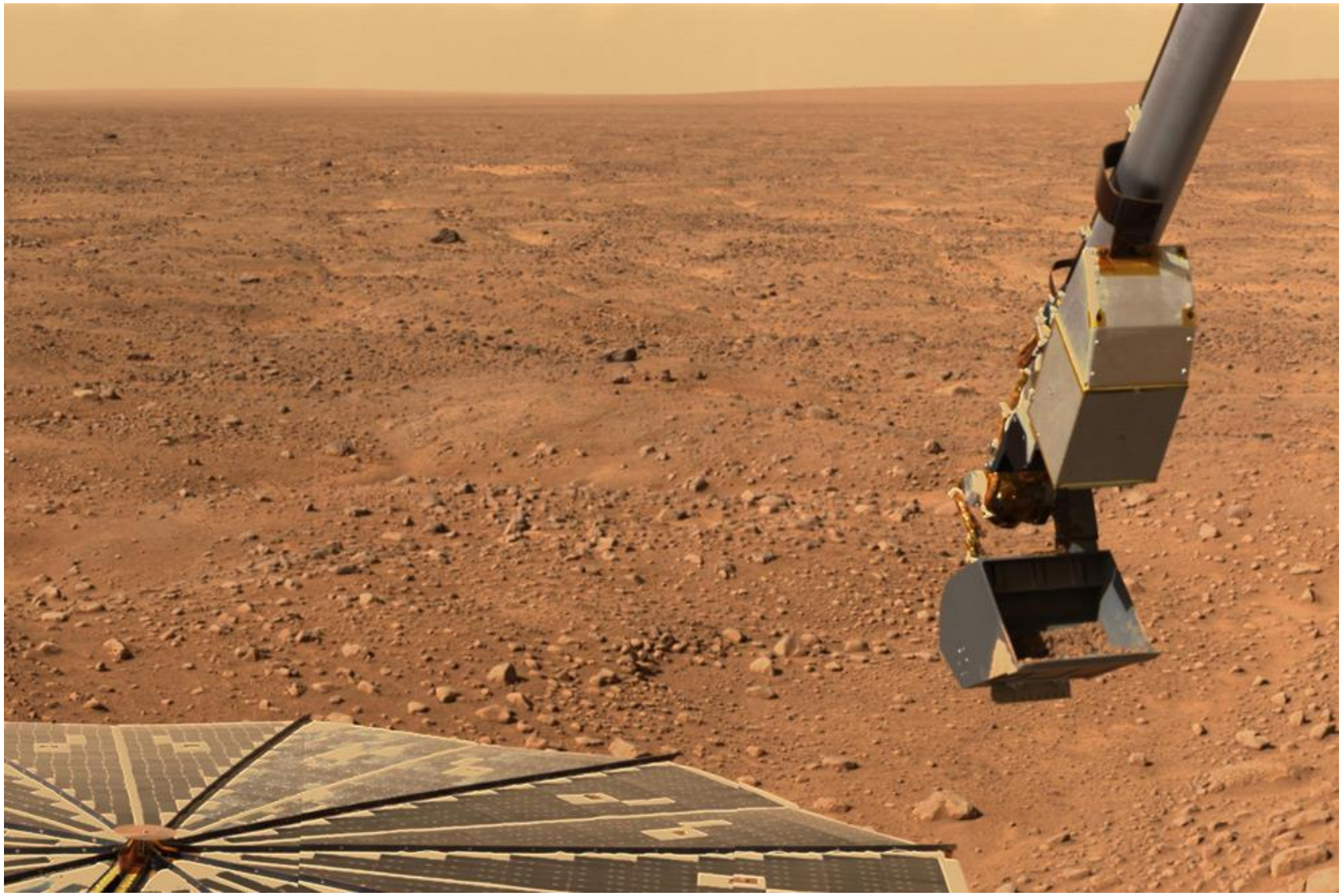


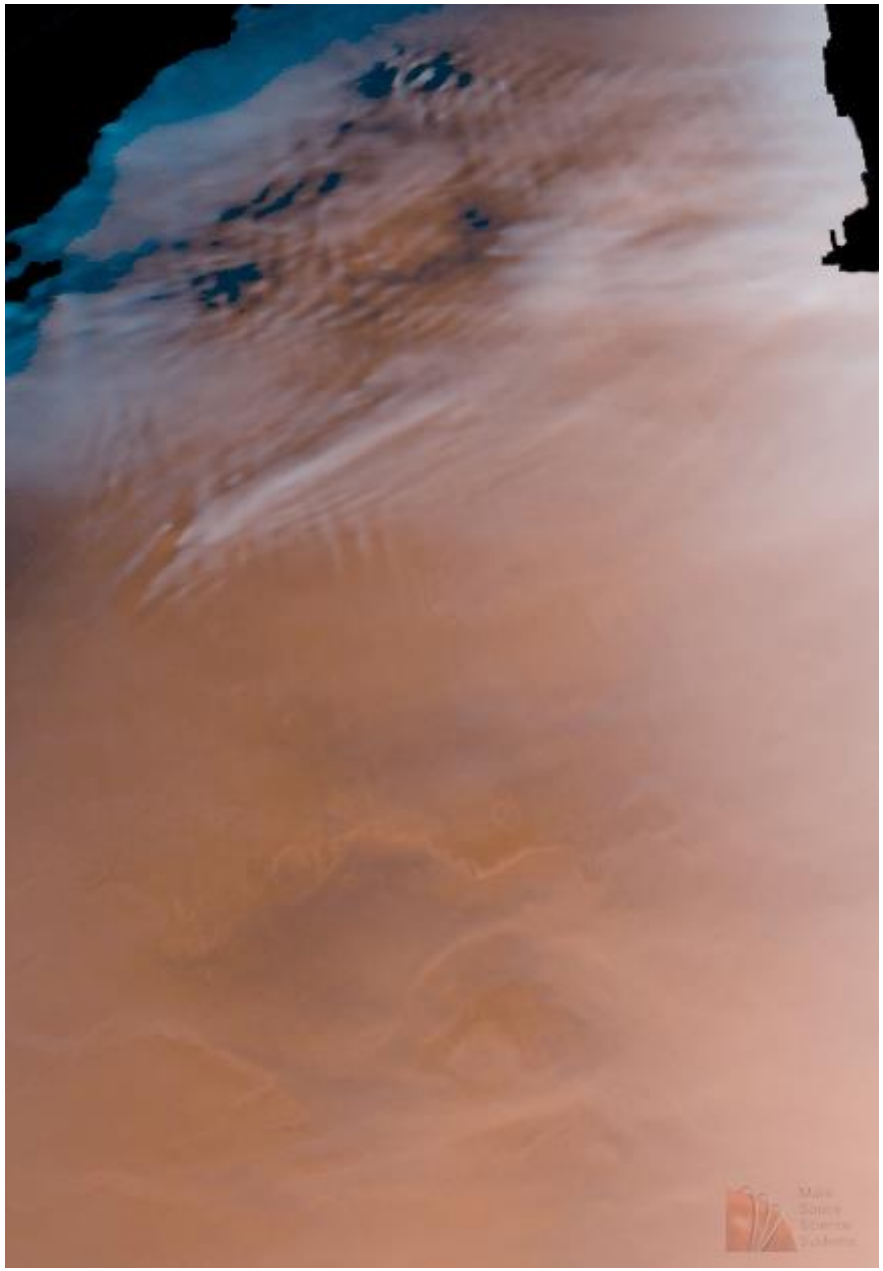
Surface Pressure: ~6 hPa
Mostly (~96%)CO_2, small amounts of H_2O vapor
CO_2 and H_2O polar ice
Lots of dust
Average T: -80F but warmer near equator in summer (70F)

Mars



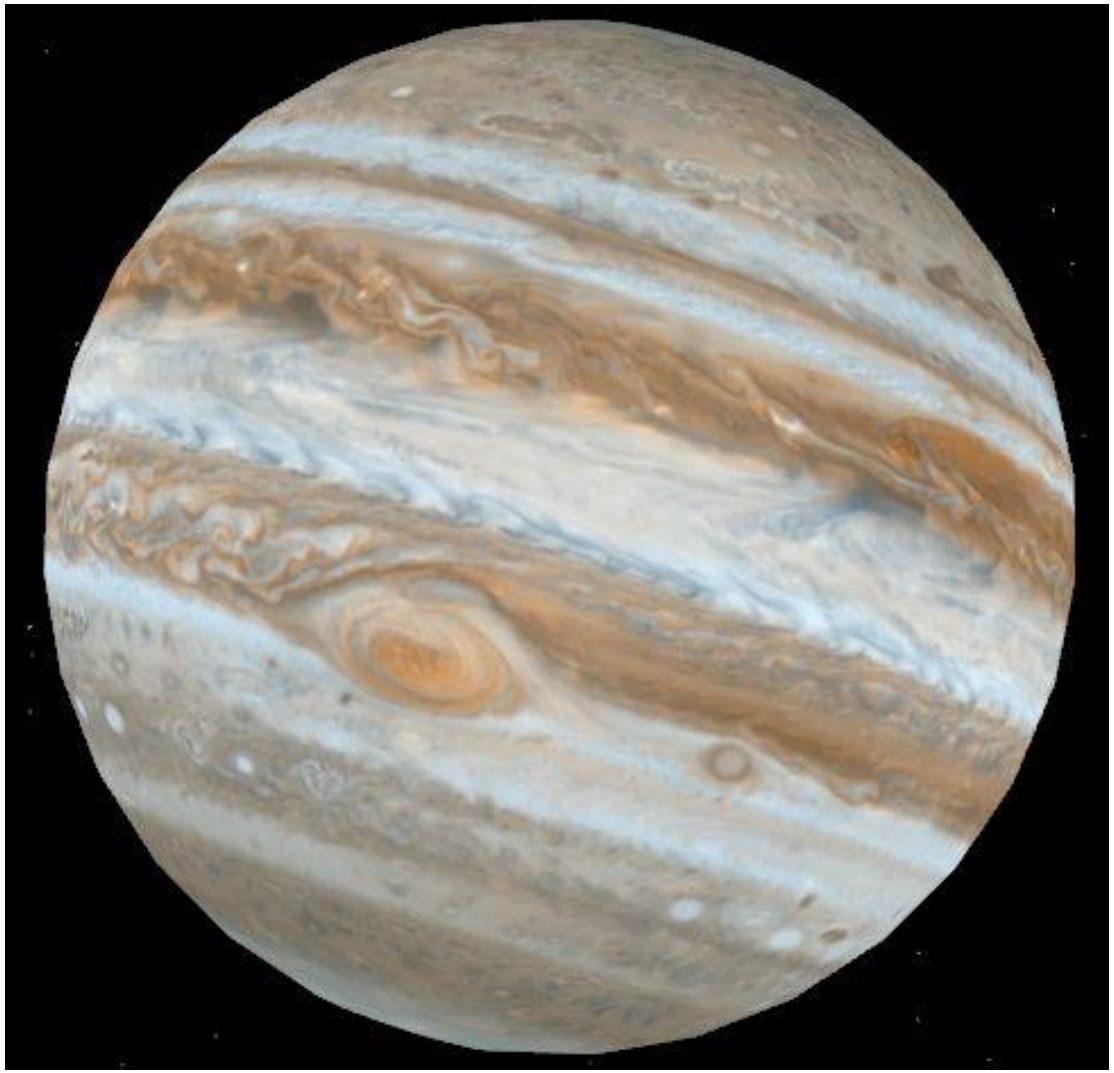
Water once flowed
on the surface





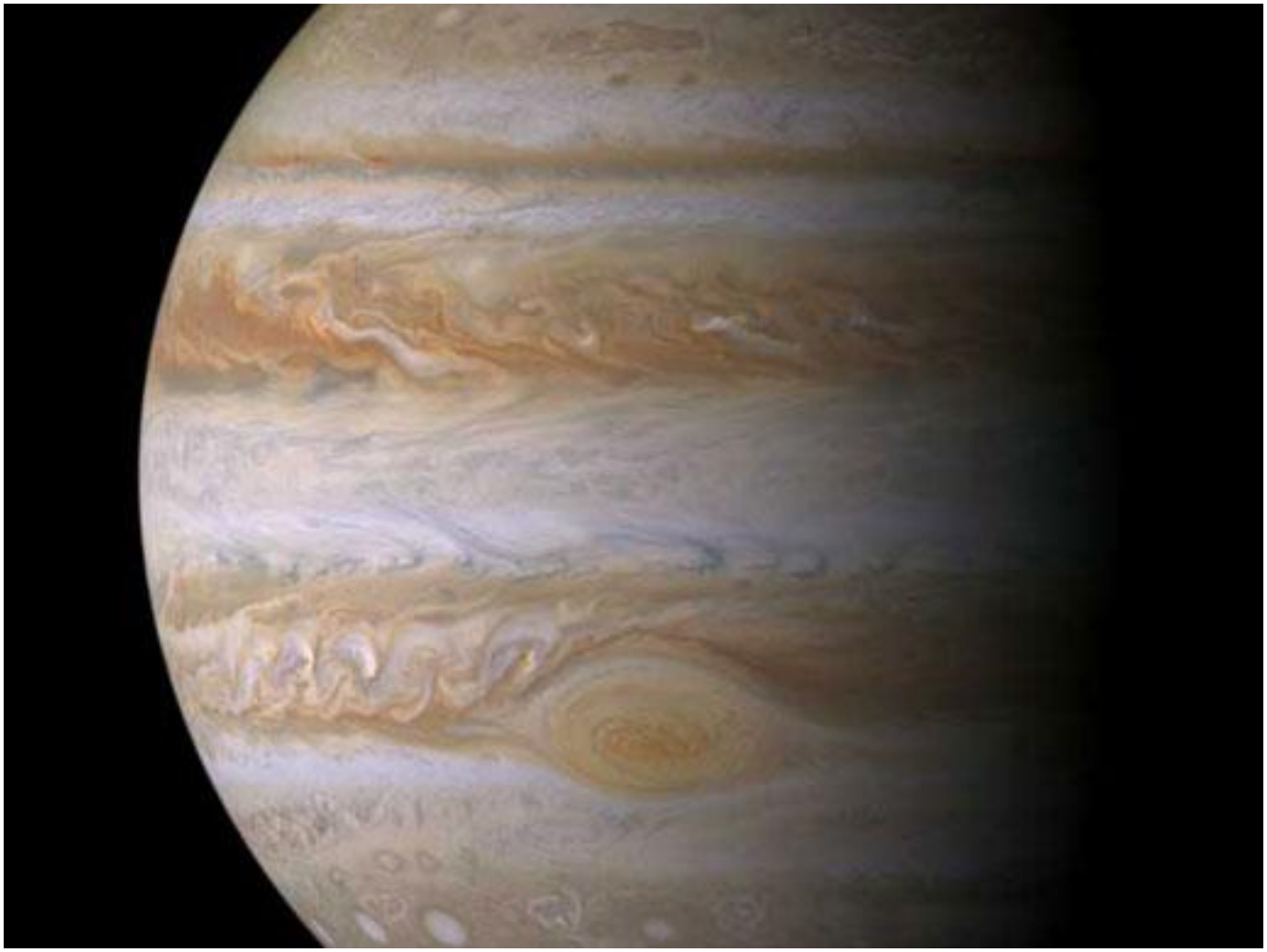
Martian
Clouds

Atmosphere
Mainly
hydrogen
(90%)
and helium



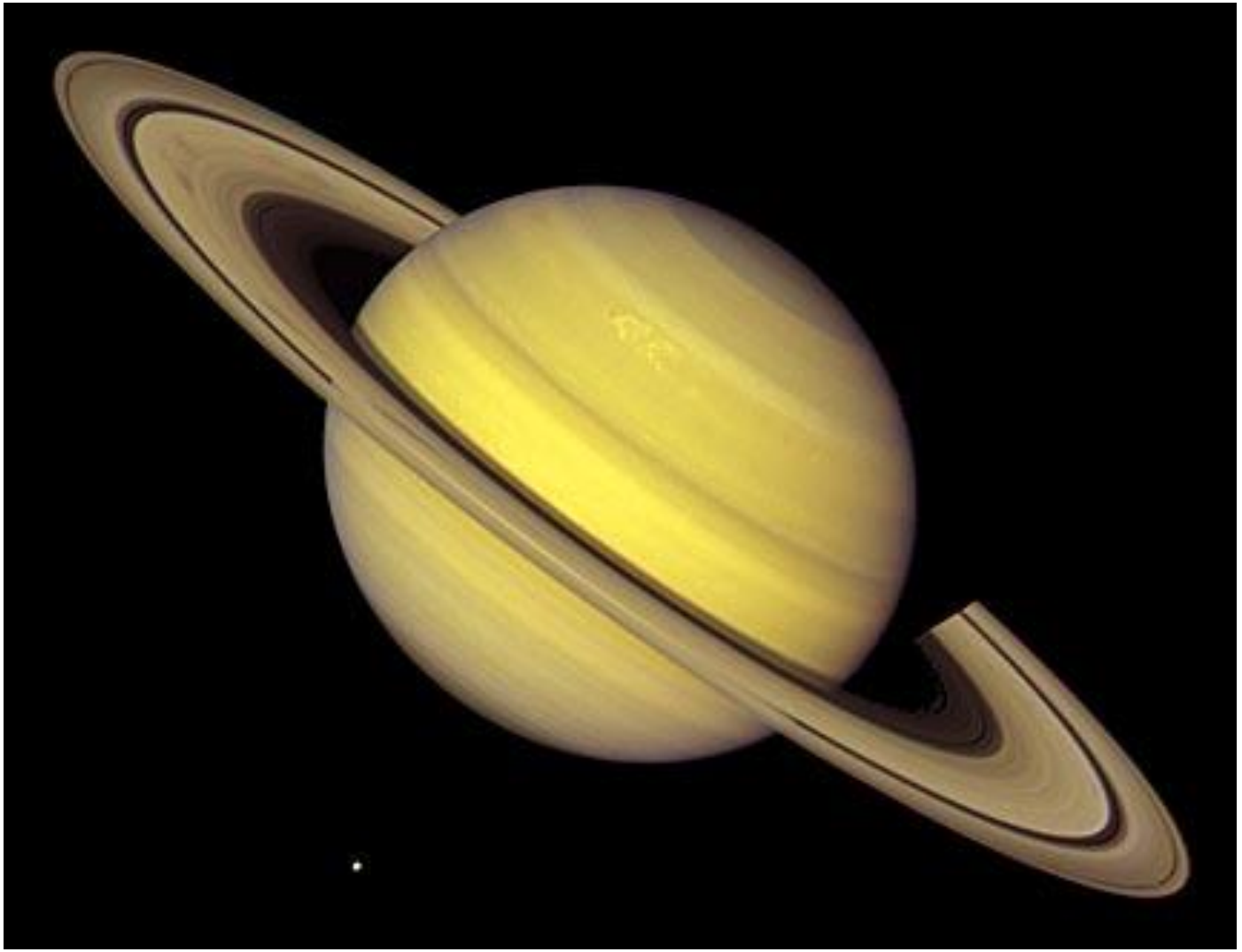
Jupiter

No solid surface

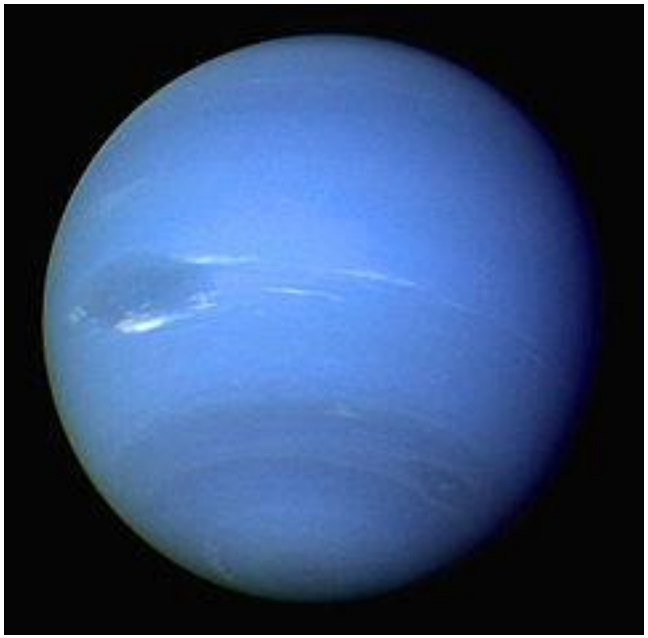


Jupiter’s atmosphere has jets and storms (e.g. red spot)

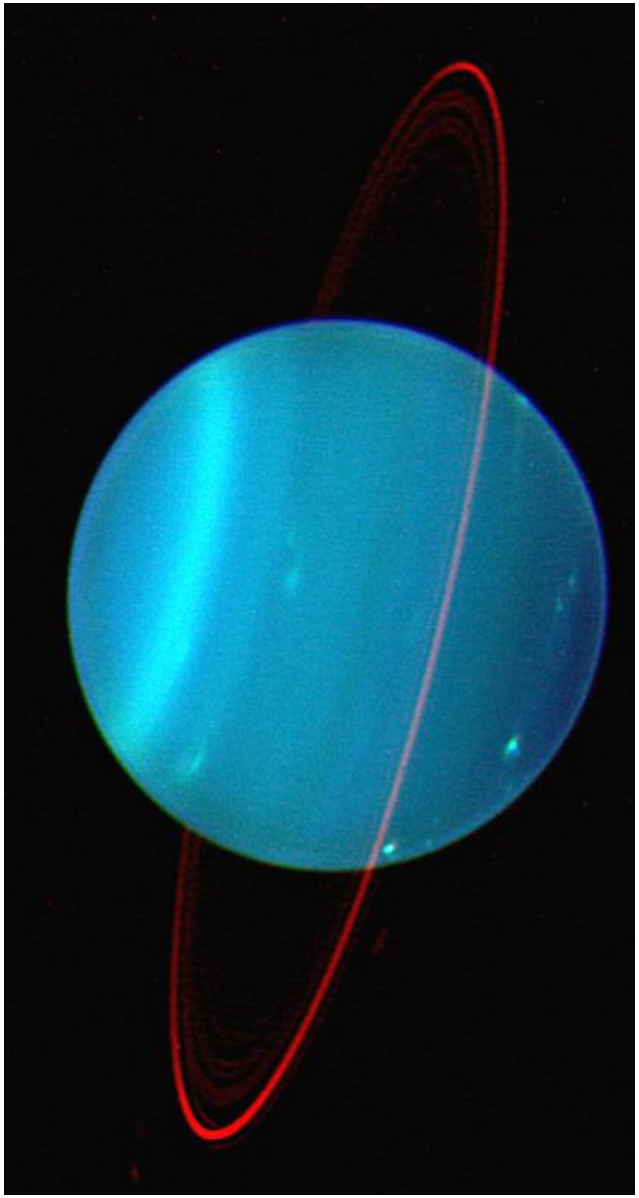
75 H2 and 25% HE



Saturn



Neptune



Uranus

Both Gas Giants (H2 and He)

Structure of the Atmosphere

Earth's Atmosphere Is a Thin Veneer

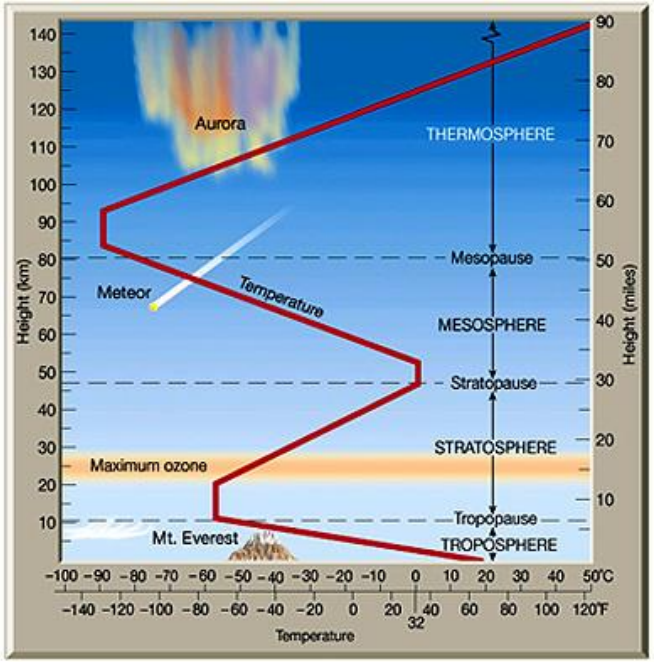
Earth's radius is about 6400 km (3840 miles)

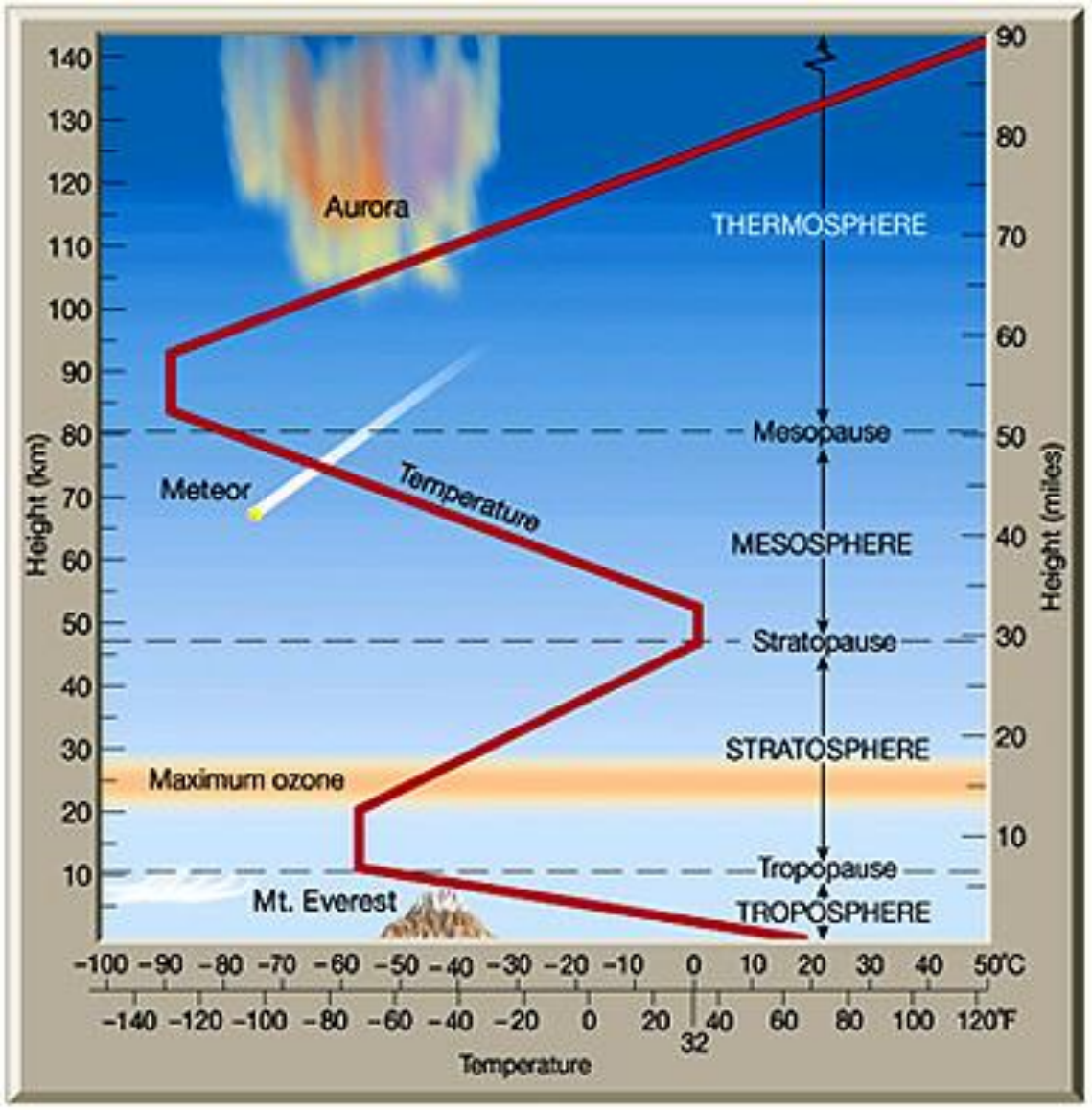
Nearly all of the atmosphere is contained in the layer from the surface to 100 km. Habitable atmosphere only the first 5 km.

So the habitable atmosphere is only 5/6400 km….00078 ….or 1/1280th of the distance to the earth's center. Much thinner than the peel on an orange.

The Vertical Structure of the Atmosphere

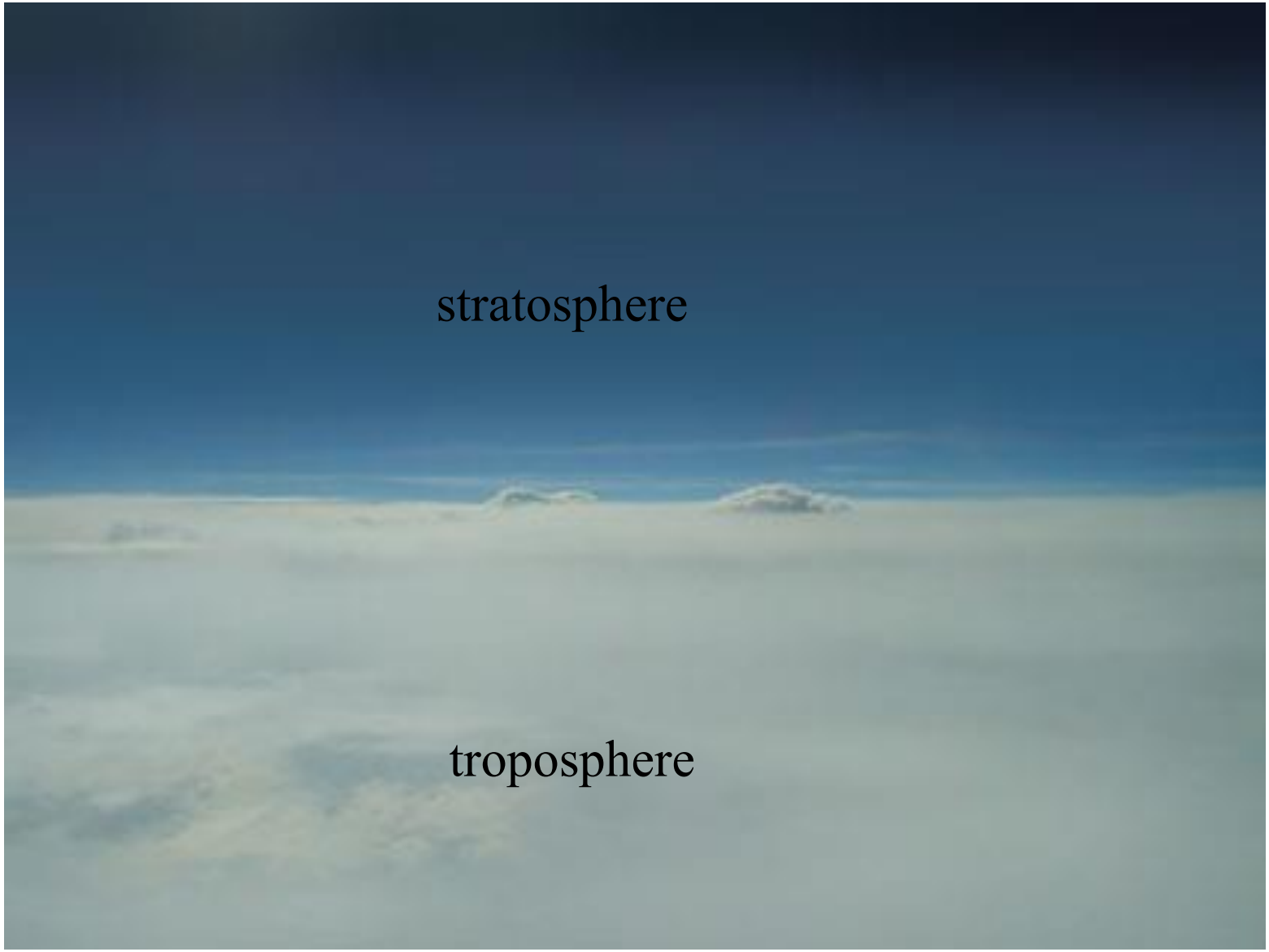
- The Earth's atmosphere is made of distinct layers
- Complex variation of temperature with height
- Main layers to know:
  - Troposphere
  - Stratosphere
  - Mesosphere
  - Thermosphere




Aurora
THERMOSPHERE
Mesopause
Meteor
Temperature
MESOSPHERE
Stratopause
STRATOSPHERE
Maximum ozone
Tropopause
Mt. Everest
TROPOSPHERE
Height (km)
Height (miles)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
90
80
70
60
50
40
30
20
10
−100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50°C
−140 −120 −100 −80 −60 −40 −20 0 20 32 40 60 80 100 120°F
Temperature

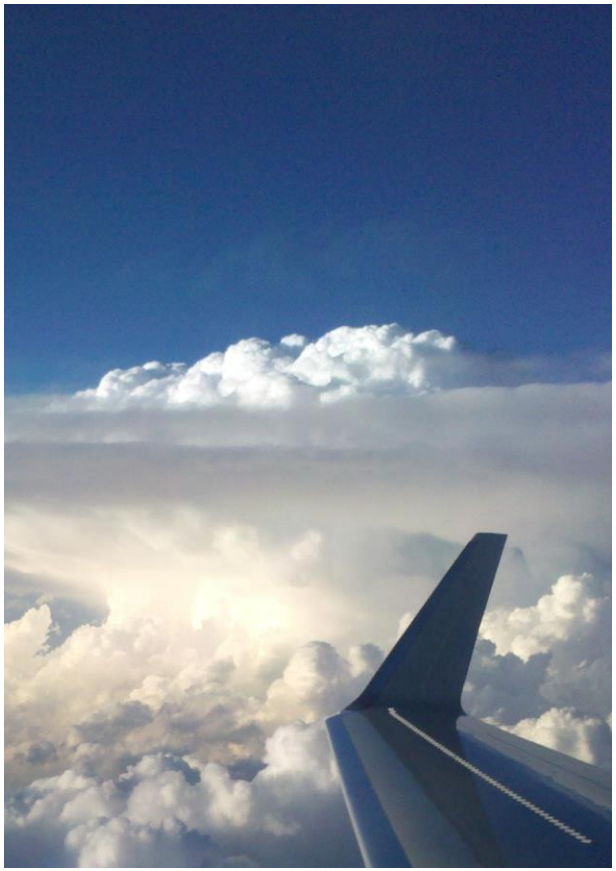
Troposphere

- Surface to roughly 10 km (~1000 hPa to ~ 250 hPa)
- ~3/4 of mass of atmosphere in this layer
- Most weather occurs in this layer
- Temperature generally decreases with height in this layer (by ~6.5C per km, 3.6 F per 1000 ft)
- The top of troposphere is called the *tropopause*. Midlatitude jet stream tends to be strongest near the tropopause.
- Above the tropopause is the stratosphere.


stratosphere
troposphere

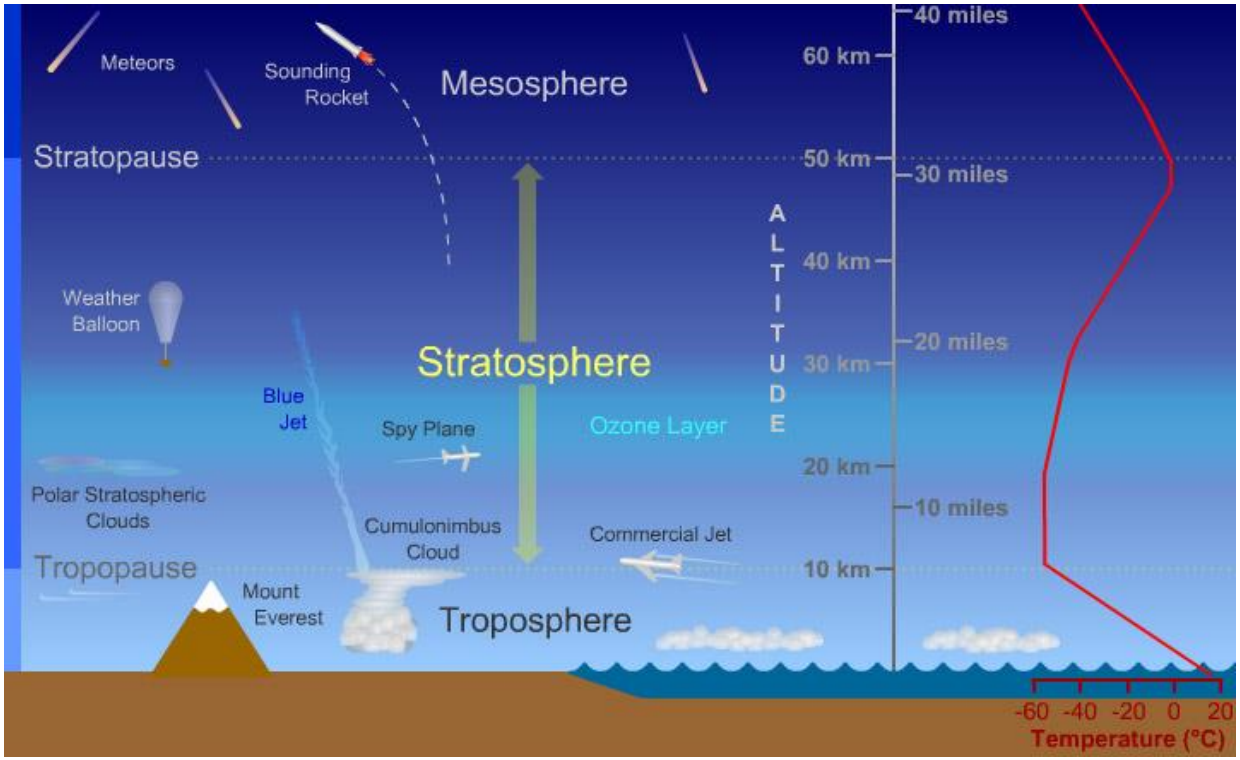
Stratosphere

- 10-50 km above the surface
- Temperature constant or INCREASING with height
- Stable (not a lot of vertical mixing) and dry
- Only occasionally get overshooting tops from convection pushing into this layer



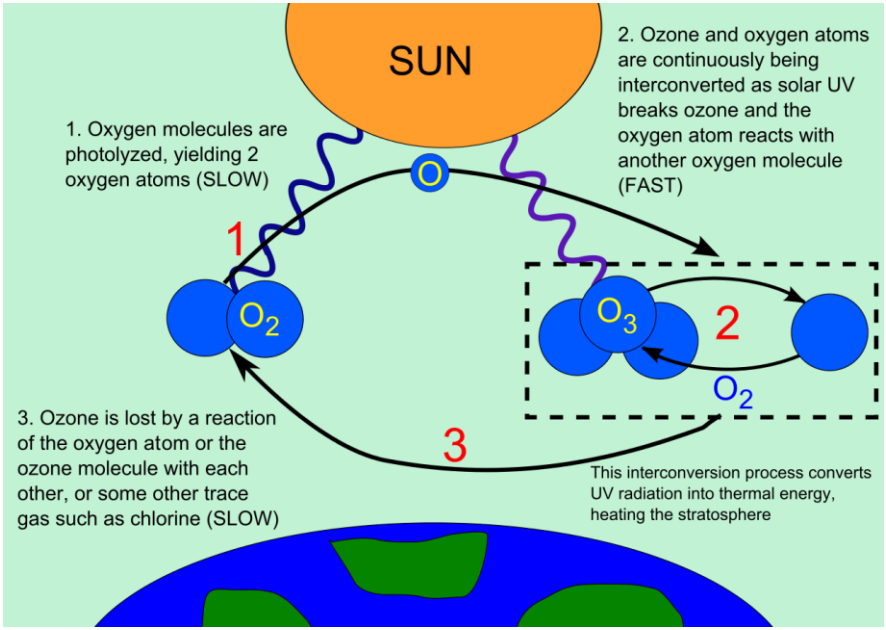
Why constant temperature and warm with height in stratosphere?

- Absorption of solar radiation by the stratospheric ozone layer



Stratospheric Ozone Layer

- Maximum ozone (O3) between 20 and 30 km.
- Protects the surface from harmful ultraviolet (UV) radiation
- Ozone is produced photochemically



A photochemical reaction is a chemical reaction in which radiation affects the chemical composition of a substance.

- Simplified photochemical reaction for ozone

$$UV + O_2 \longrightarrow O + O$$

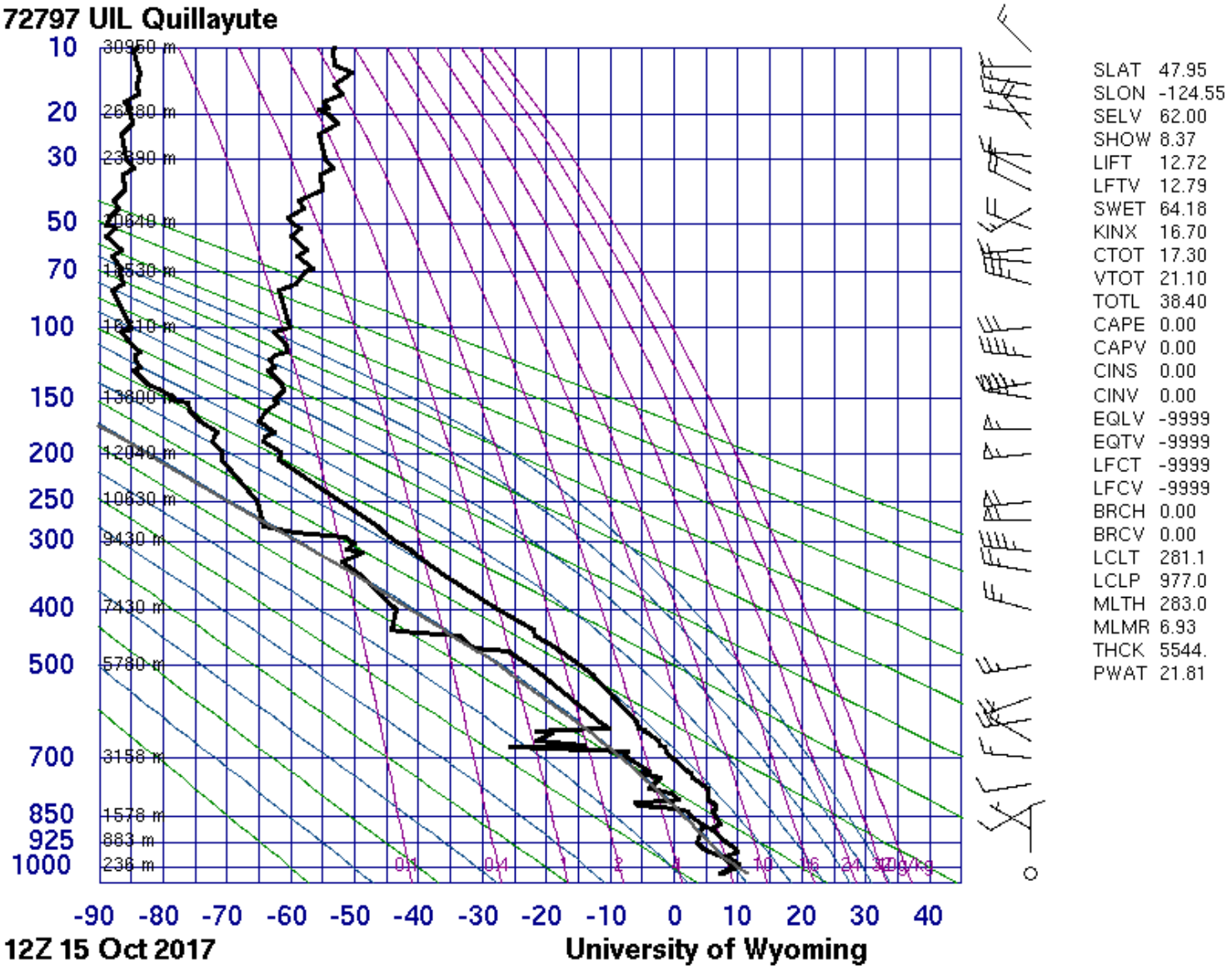
$$O_2 + O + M \longrightarrow O_3 + M$$

$$O_3 + UV \longrightarrow O_2 + O$$

- M is some catalyst molecule. This reaction produces heat at UV is absorbed . Warms stratosphere.

Ozone Destruction

- Later is the class we will talk about the destruction of the ozone layer
- Problems caused by chemicals such as chloroflurocarbons (e.g., Freon, refrigerants)
- Produced the ozone hole.
- Now being repaired by restrictions on chemical releases, but some new issues.

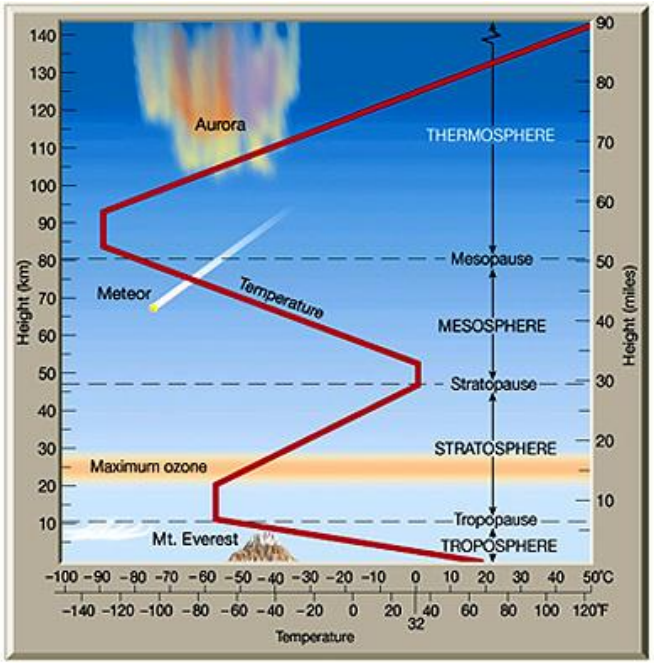

72797 UIL Quillayute
10
20
30
50
70
100
150
200
250
300
400
500
700
850
925
1000
30950 m
26480 m
23890 m
20640 m
18530 m
16810 m
13600 m
12040 m
10630 m
9430 m
7430 m
5780 m
3158 m
1578 m
883 m
236 m
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40
12Z 15 Oct 2017
University of Wyoming
SLAT 47.95
SLON -124.55
SELV 62.00
SHOW 8.37
LIFT 12.72
LFTV 12.79
SWET 64.18
KINX 16.70
CTOT 17.30
VTOT 21.10
TOTL 38.40
CAPE 0.00
CAPV 0.00
CINS 0.00
CINV 0.00
EQLV -9999
EQTV -9999
LFCT -9999
LFCV -9999
BRCH 0.00
BRCV 0.00
LCLT 281.1
LCLP 977.0
MLTH 283.0
MLMR 6.93
THCK 5544.
PWAT 21.81

Stratosphere

- Jet aircraft frequently enter the stratosphere, particularly during winter
- Air becomes drier and sometimes have ozone in cabin
- Can see the difference…getting above the clouds
- Stratosphere ends at the stratopause, ~ 1hPa, 50 km

Mesosphere (50-80 km)

- A second region of temperature decline with height
- Why? Getting away from ozone heating
- **Noctilucent Clouds**-ice coated meteor dust

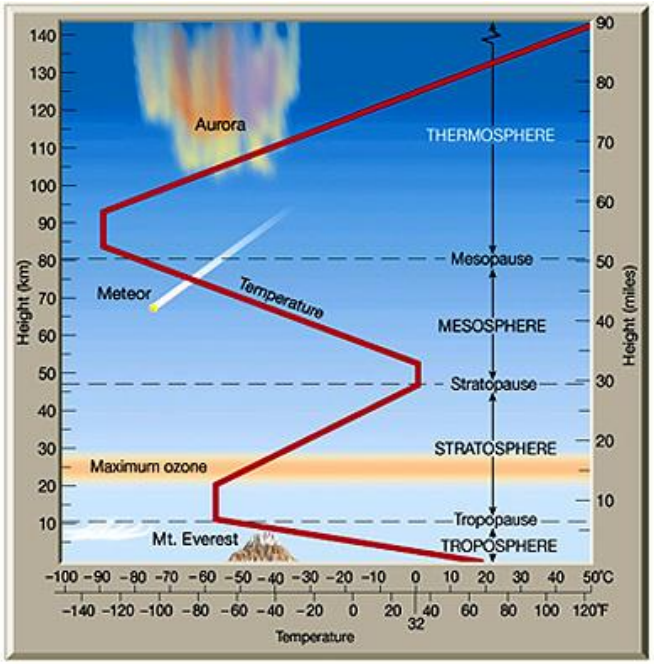


Noctilucent Clouds


Noctilucent clouds by P-M Hedin
2006-07-11

Mesosphere

- Ends at mesopause (~80 km ~.01 hPa), the coldest place in the atmosphere ~-90C)



Thermosphere

- 80-140km
- Region of warming with height
- Warming produced by absorption of shortest wavelength ultraviolet components in upper troposphere by 02,), N, N2
- Aurora in this layer