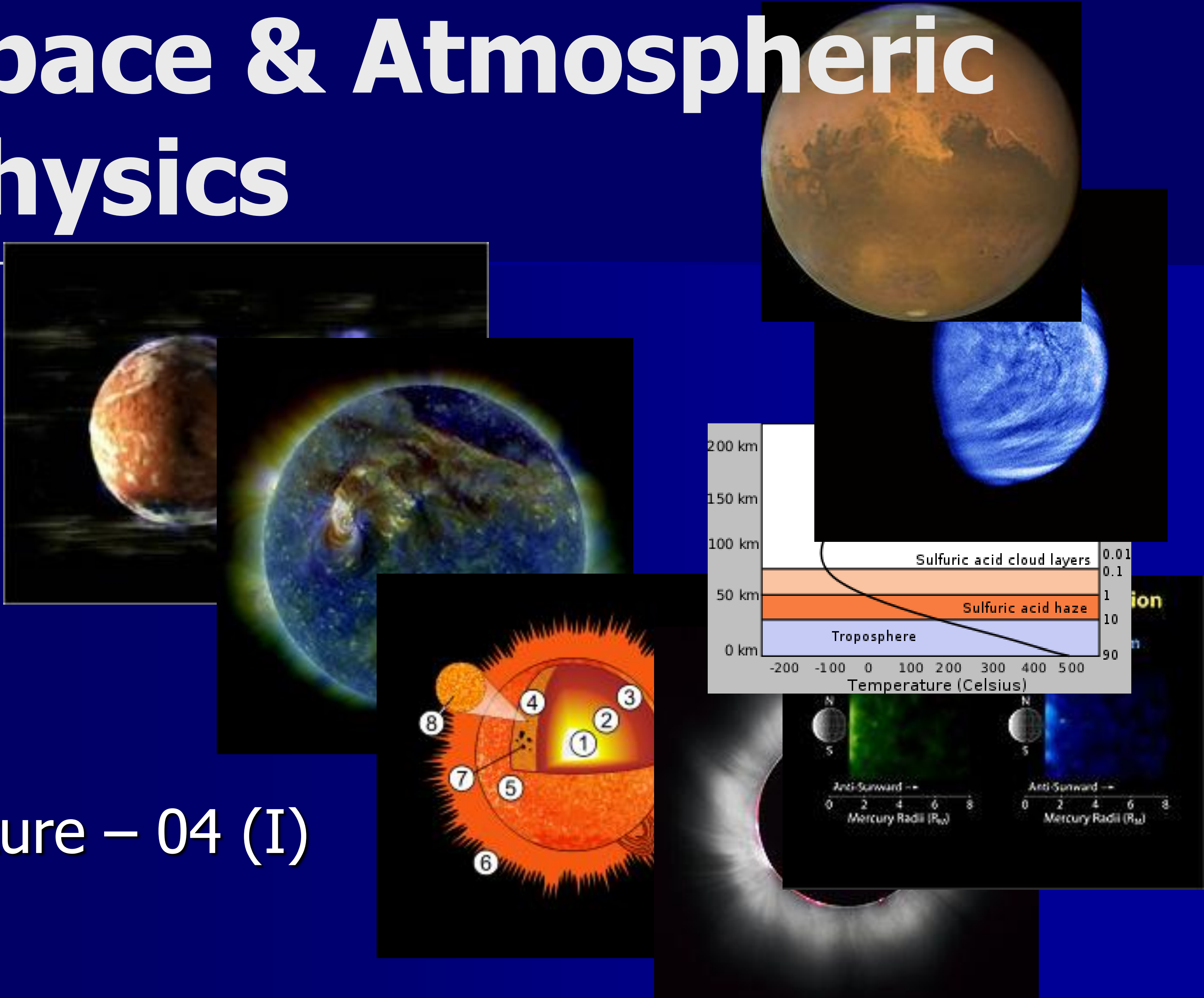
Space & Atmospheric Physics

Space & Atmospheric Physics



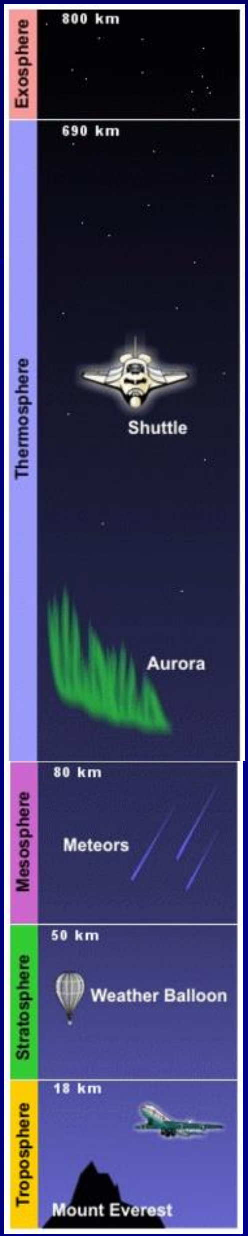
Lecture – 04 (I)

Planetary Atmospheres

Planetary Atmospheres

Formation and Evolution of Planetary Atmospheres
The Structure of the Terrestrial Atmosphere
The Temperature of the Neutral Atmosphere
The Escape of the Atmospheric Gases
The Atmospheres of the Planets

Atmosphere of Earth



Atmosphere of Earth

Biological significance

The Earth's atmosphere plays a vital role in sustaining life on this planet. **Oxygen is needed for respiration by animals, plants, and some bacteria.** Nitrogen is an inert gas that reduces the amount of oxygen available for the oxidation of natural materials, thus restricting spontaneous combustion (burning) of flammable materials and the corrosion of metals. Nitrogen is also used by "nitrogen-fixing" bacteria to produce compounds that are useful for plant growth.

Plants that perform photosynthesis take up carbon dioxide from the air and release oxygen. **Carbon dioxide and water vapor act as "greenhouse gases" that keep the Earth sufficiently warm to maintain life.** Water vapor in the air is part of the water cycle that produces precipitation (such as rain and snow) that replenishes moisture in the soil. In addition, water vapor prevents exposed living tissue from drying up.

Atmosphere of Earth

Air pollution

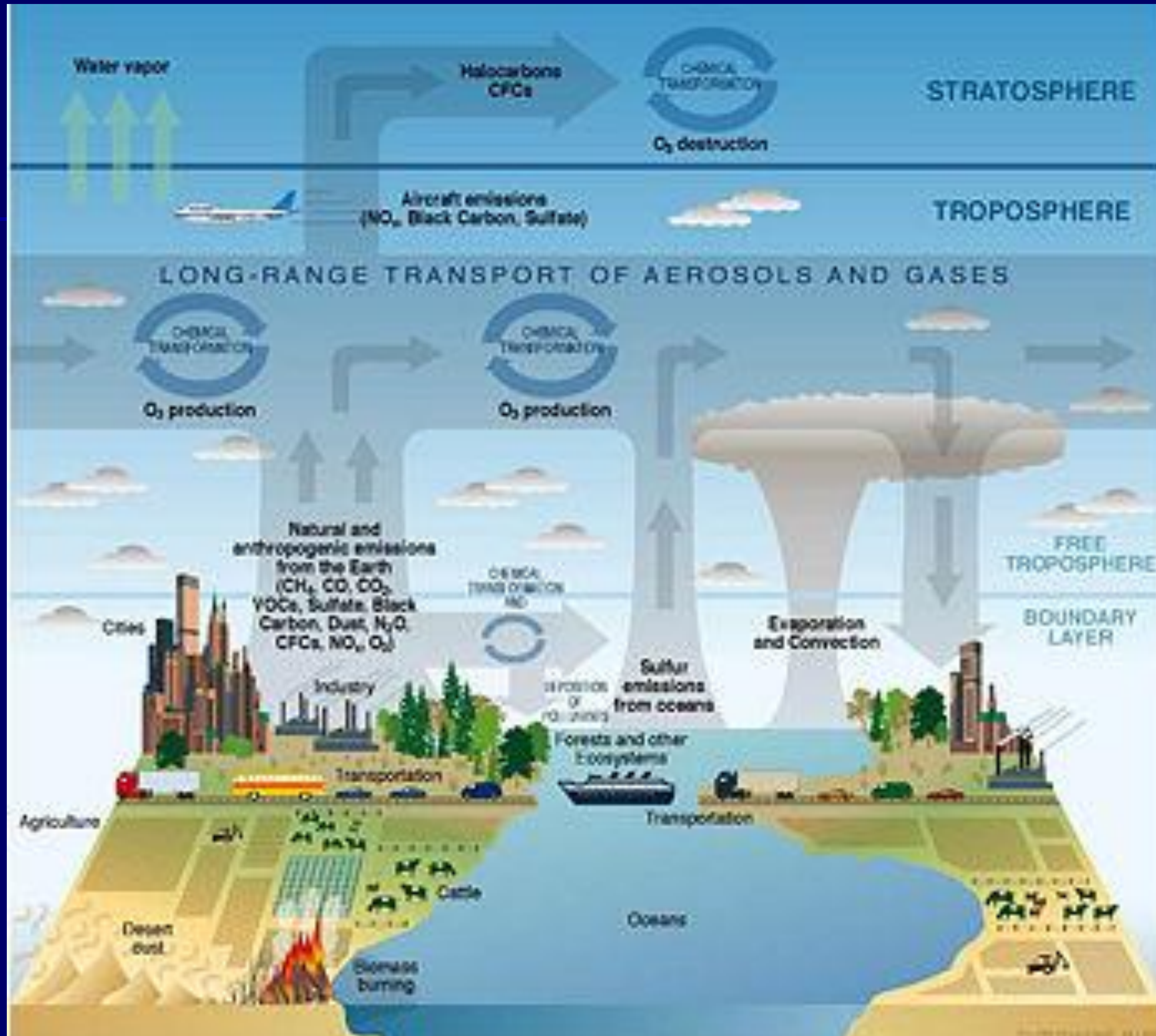


Diagram of chemical and transport processes related to atmospheric composition.

Atmosphere of Earth

Air pollution

Although technological advances have benefited humankind in numerous ways, they have been accompanied by adverse effects on the environment, including pollution of the air.

Common air pollutants include carbon monoxide (**CO**), nitrogen oxides (NOx), sulfur oxides (SOx), ozone, and particulate matter (PM). They are generally produced by such activities as

(a) combustion (burning) of fuels for transportation and the generation of heat and electricity, and

(b) industrial processes, including petroleum refining, cement manufacturing, and metal processing.

To reduce such pollutants, the governments of various nations have mandated measures such as the use of reformulated gasoline, catalytic converters in motor vehicle exhaust systems, and effluent traps for industrial wastes.

In addition to the problem of pollution, there is concern that global temperatures are rising as a result of increasing levels of greenhouse gases such as carbon dioxide and methane in the atmosphere.

Atmosphere of Moon

Atmosphere of Moon

For most practical purposes, the Moon is considered to be surrounded by vacuum. The elevated presence of atomic and molecular particles in its vicinity (compared to interplanetary medium), referred to as 'lunar atmosphere' for scientific objectives is negligible in comparison with gaseous envelope surrounding Earth and most planets of the solar system - less than one hundred trillionth of Earth's atmospheric density at sea level.

One source of the lunar atmosphere is out gassing: the release of gases such as radon and helium that originate from radioactive decay within the crust and mantle. Another important source is the bombardment of the lunar surface by micrometeorites, the solar wind, and sunlight, in a process known as sputtering.

Gases that are released by sputtering can either:

- be re-implanted into the regolith as a result of the Moon's gravity;
- be lost to space either by solar radiation pressure or, if the gases are ionized, by being swept away in the solar wind's magnetic field.

Atmosphere of Moon

The elements sodium and potassium have been detected in the Moon's atmosphere using Earth-based spectroscopic methods, whereas the isotopes radon-222 and polonium-210 have been inferred from data obtained by the Lunar Prospector alpha particle spectrometer. Argon-40, helium-4, oxygen and/or methane (CH4), nitrogen (N2) and/or carbon monoxide (CO), and carbon monoxide (CO2)) were detected by in-situ detectors placed by the Apollo astronauts.

The average daytime abundances of the elements known to be present in the lunar atmosphere, in atoms per cubic centi-meter, are as follows:

- Argon: 40,000
- Helium: 2,000-40,000
- Sodium: 70
- Potassium: 17
- Hydrogen: fewer than 17

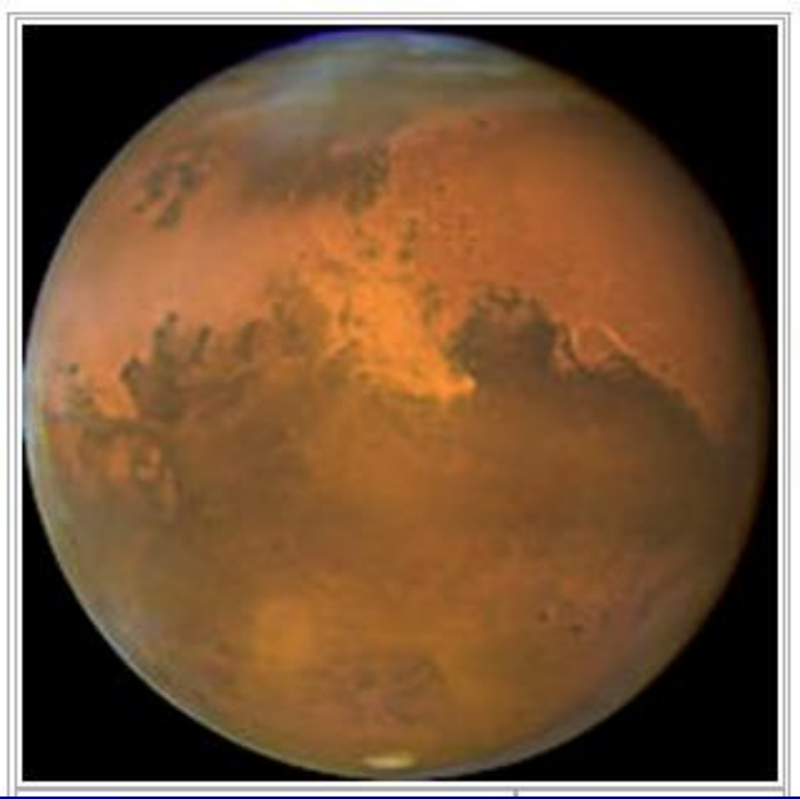
The **Moon is often considered to not have an atmosphere**, as it cannot absorb measurable quantities of radiation and does not appear layered or self-circulating.

Atmosphere of Moon

Moon's Strange Atmosphere: NASA to Probe Lunar Dust | Video

Atmosphere of Mars

Atmosphere of Mars



Carbon dioxide	95.32%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon monoxide	0.07%
Water vapor	0.03%
Nitric oxide	0.013%
Neon	2.5 ppm
Krypton	300 ppb
Formaldehyde	130 ppb
Xenon	80 ppb
Ozone	30 ppb
Methane	10.5 ppb

Atmosphere of Mars

History

Mars' atmosphere is believed to have changed over the course of the planet's lifetime, with evidence suggesting the possibility that Mars had large oceans a few billion years ago.

As stated in the **Mars Ocean Hypothesis**, atmospheric pressure on the present day Martian surface only exceeds that of the triple point of water (6.11 hectopascals in the lowest elevations; at higher elevations water can exist only in solid or vapor form)

Annual mean temperatures at the surface are currently less than 210 K (−63 °C), significantly less than what is needed to sustain liquid water. However, early in its history Mars may have had conditions more conducive to retaining liquid water at the surface.

Atmosphere of Mars

Structure

Mars' atmosphere is composed of the following major layers:

Lower atmosphere: This is a warm region affected by heat from airborne dust and from the ground.

Middle atmosphere: Mars has a Jetstream, which flows in this region.

Upper atmosphere, or thermosphere: This region has very high temperatures, caused by heating from the Sun. Atmospheric gases start to separate from each other at these altitudes, rather than forming the even mix found in the lower atmospheric layers.

Exosphere: Typically stated to start at 200 kilometers and higher, this region is where the last wisps of atmosphere merge into the vacuum of space. There is no distinct boundary where the atmosphere ends; it just tapers away.

Atmosphere of Mars

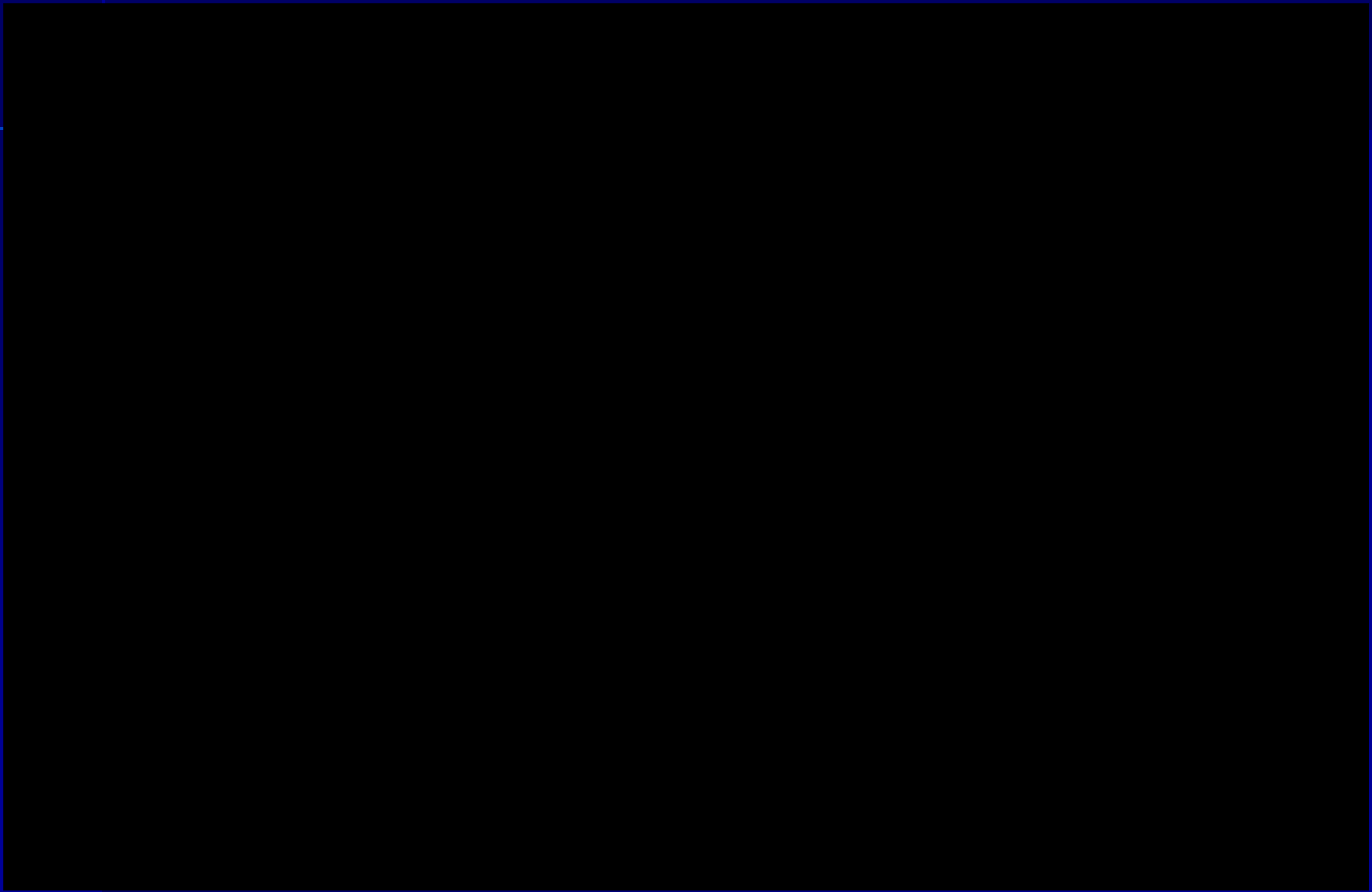
Composition…

Potential for use by humans

The atmosphere of Mars is a resource of known composition available at any landing site on Mars. It has therefore been proposed that human exploration of Mars could use carbon dioxide from Martian atmosphere as feedstock to make rocket fuel for the return mission.

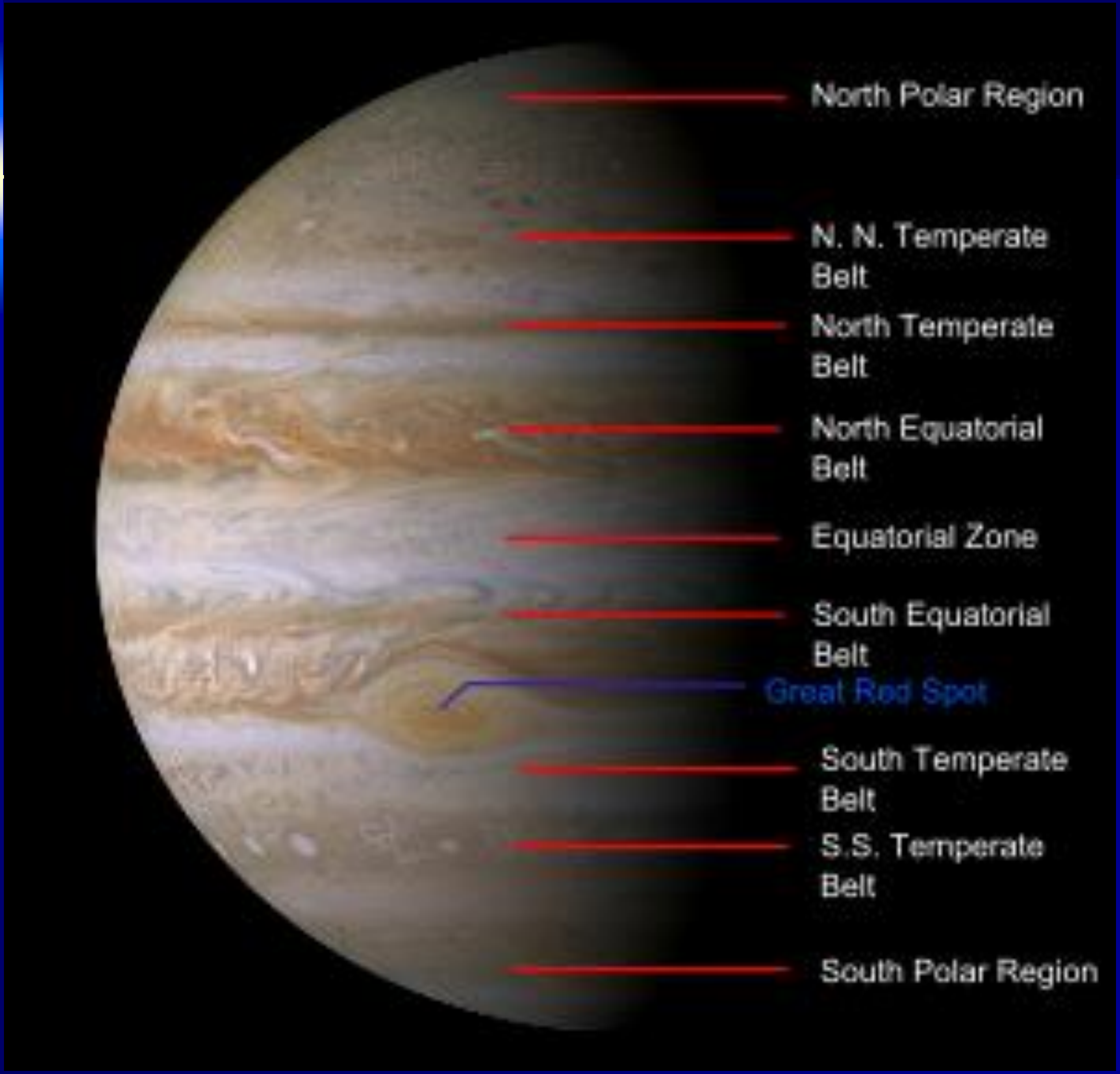
Atmosphere of Mars

The Mars Atmosphere



Atmosphere of Jupiter

Atmosphere of Jupiter



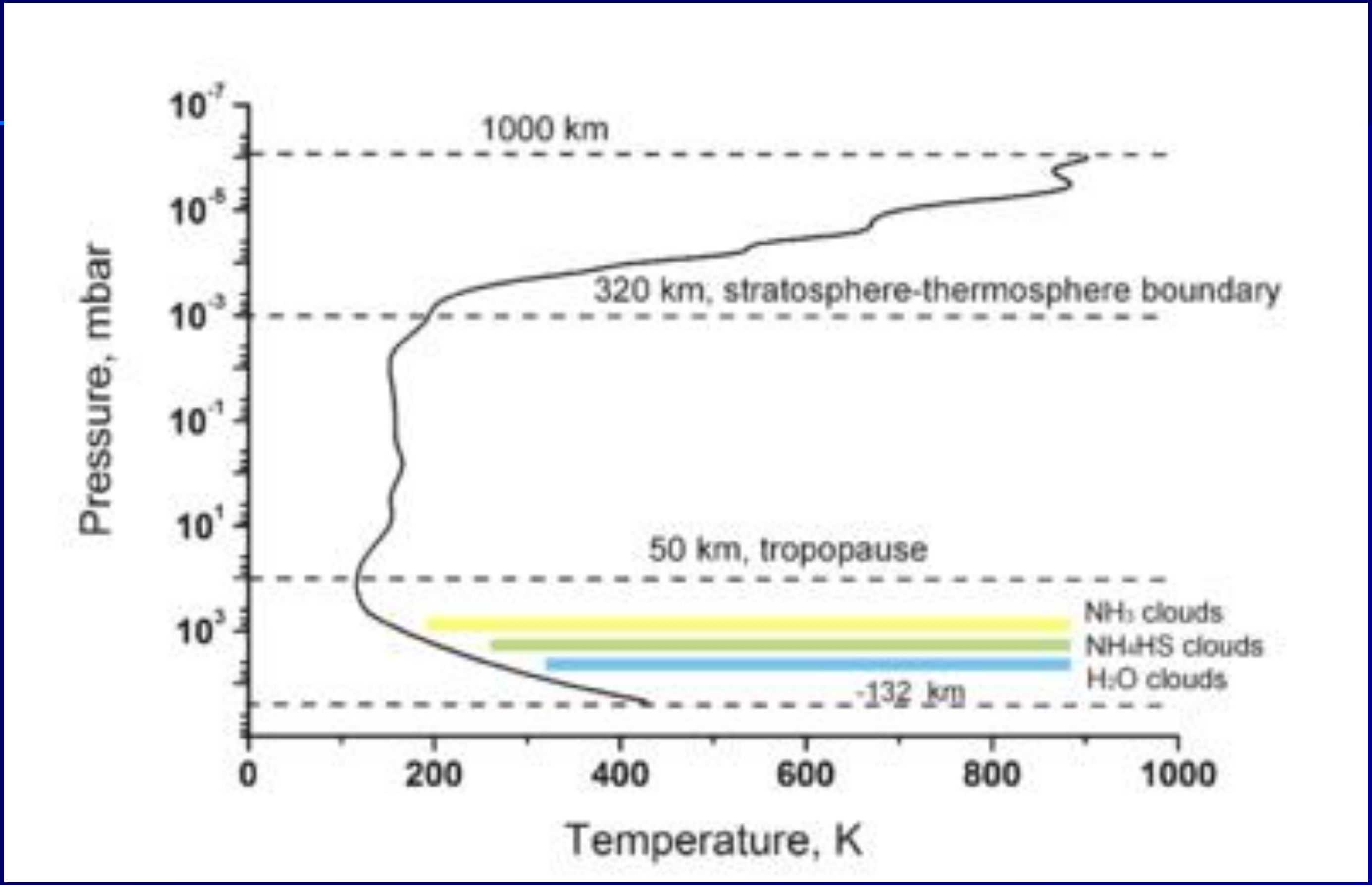
Cloud pattern on Jupiter in 2005

Atmosphere of Jupiter

Jupiter: Crash Course Astronomy #16

Atmosphere of Jupiter

Vertical structure



Vertical structure of the atmosphere of Jupiter. Note that the pressure drops together with altitude. The Galileo atmospheric probe stopped transmitting at a depth of 132 km below the 1 bar "surface" of Jupiter.

Atmosphere of Jupiter

Vertical structure…

The atmosphere of Jupiter is classified into four layers, by increasing altitude: the troposphere, stratosphere, thermosphere and exosphere. Unlike the Earth's atmosphere, Jupiter's lacks a mesosphere. Jupiter does not have a solid surface, and the lowest atmospheric layer, the troposphere, smoothly transitions into the planet's fluid interior.

The temperature of the troposphere decreases with height until it reaches a minimum at the tropopause, which is the boundary between the troposphere and stratosphere. On Jupiter, the tropopause is approximately 50 km above the visible clouds (or 1 bar level), where the pressure and temperature are about 0.1 bar and 110 K.

In the stratosphere, the temperatures rise to about 200 K at the transition into the thermosphere, at an altitude and pressure of around 320 km and 1 μbar. In the thermosphere, temperatures continue to rise, eventually reaching 1000 K at about 1000 km, where pressure is about 1 nbar.

Atmosphere of Jupiter

Vertical structure…

The high temperatures prevalent in the thermosphere (800–1000 K) have not been fully explained yet; existing models predict a temperature no higher than about 400 K. They may be caused by absorption of high-energy solar radiation (UV or X-ray), by heating from the charged particles precipitating from the Jovian magnetosphere, or by dissipation of upward-propagating gravity waves.

The thermosphere and exosphere at the poles and at low latitudes emit X-rays, which were first observed by the Einstein Observatory in 1983.

The thermosphere was the first place outside the Earth where the trihydrogen cation (H+3) was discovered. This ion emits strongly in the mid-infrared part of the spectrum, at wavelengths between 3 and 5 μm; this is the main cooling mechanism of the thermosphere.

Atmosphere of Jupiter

Chemical composition

Elemental abundances relative to hydrogen in Jupiter and Sun		
Element	Sun	Jupiter/Sun
He/H	0.0975	0.807 ± 0.02
Ne/H	1.23×10^{-4}	0.10 ± 0.01
Ar/H	3.62×10^{-6}	2.5 ± 0.5
Kr/H	1.61×10^{-9}	2.7 ± 0.5
Xe/H	1.68×10^{-10}	2.6 ± 0.5
C/H	3.62×10^{-4}	2.9 ± 0.5
N/H	1.12×10^{-4}	3.6 ± 0.5 (8 bar) 3.2 ± 1.4 (9–12 bar)
O/H	8.51×10^{-4}	0.033 ± 0.015 (12 bar) 0.19–0.58 (19 bar)
P/H	3.73×10^{-7}	0.82
S/H	1.62×10^{-5}	2.5 ± 0.15

Isotopic ratios in Jupiter and Sun		
Ratio	Sun	Jupiter
$^{13}C/^{12}C$	0.011	0.0108 ± 0.0005
$^{15}N/^{14}N$	$<2.8 \times 10^{-3}$	$2.3 \pm 0.3 \times 10^{-3}$ (0.08–2.8 bar)
$^{36}Ar/^{38}Ar$	5.77 ± 0.08	5.6 ± 0.25
$^{20}Ne/^{22}Ne$	13.81 ± 0.08	13 ± 2
$^{3}He/^{4}He$	$1.5 \pm 0.3 \times 10^{-4}$	$1.66 \pm 0.05 \times 10^{-4}$
D/H	$3.0 \pm 0.17 \times 10^{-5}$	$2.25 \pm 0.35 \times 10^{-5}$

Atmosphere of Jupiter

Zones, belts and jets

The most detailed map of Jupiter ever produced; taken by Cassini.

The visible surface of Jupiter is divided in a number of bands parallel to the equator.

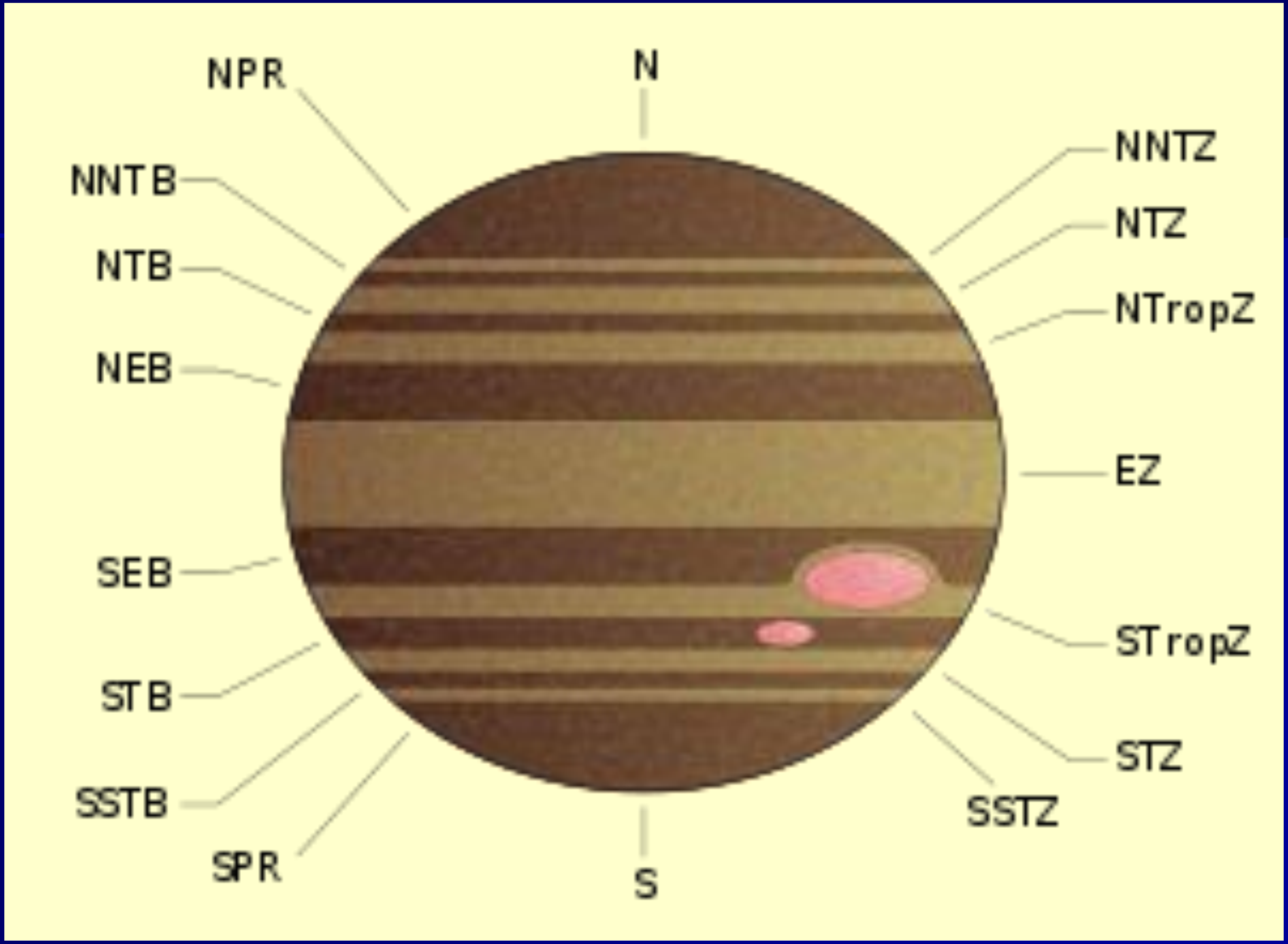
There are two types of bands:

lightly colored *zones* and **relatively dark *belts*.**

Farther from the equator lie the **North and South Tropical zones** (NtrZ and STrZ).

Atmosphere of Jupiter

Specific bands



Idealized illustration of Jupiter's cloud bands, labeled with their official abbreviations. Lighter zones are indicated to the right, darker belts to the left. The Great Red Spot and Oval BA are shown in the South Tropical Zone and South Temperate Belt, respectively.

Atmosphere of Jupiter

Dynamics

2009

2010

Circulation in Jupiter's atmosphere is markedly different from that in the atmosphere of Earth. The interior of Jupiter is fluid and lacks any solid surface. Therefore, convection may occur throughout the planet's outer molecular envelope.

Atmosphere of Jupiter

Internal heat

As has been known since 1966, Jupiter radiates much more heat than it receives from the Sun.

It is estimated that the ratio between the power emitted by the planet and that absorbed from the Sun is 1.67 ± 0.09.

The internal heat flux from Jupiter is 5.44 ± 0.43 W/m2, whereas the total emitted power is 335 ± 26 petawatts. The latter value is approximately equal to one billionth of the total power radiated by the Sun. This excess heat is mainly the primordial heat from the early phases of Jupiter's formation, but may result in part from the precipitation of helium into the core.

Discrete features - Vortices

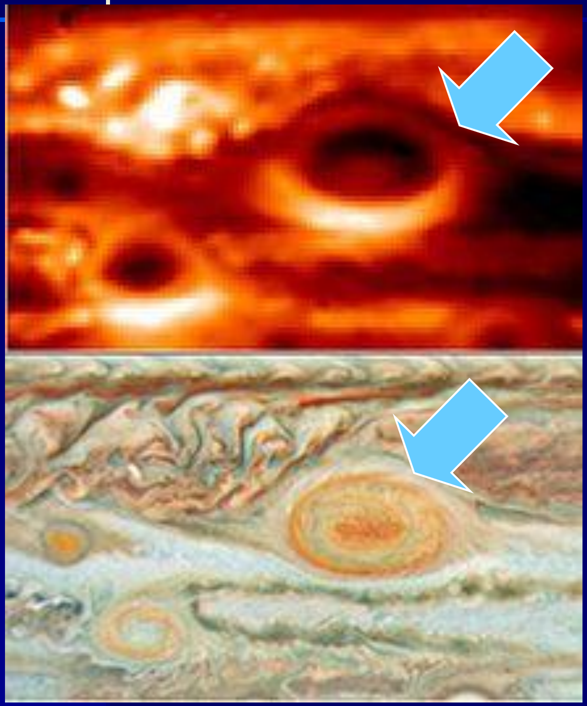
The atmosphere of Jupiter is home to hundreds of vortices circular rotating structures that, as in the Earth's atmosphere, can be divided into two classes:

cyclones and anti cyclones.

The former rotate in the direction similar to the rotation of the planet (counter-clock-wise in the northern hemisphere and clock-wise in the southern)

Atmosphere of Jupiter

Discrete features - Great Red Spot



An infrared image of GRS (top) showing its warm center, taken by the ground based Very Large Telescope. An image made by the Hubble Space Telescope (bottom) is shown for comparison.

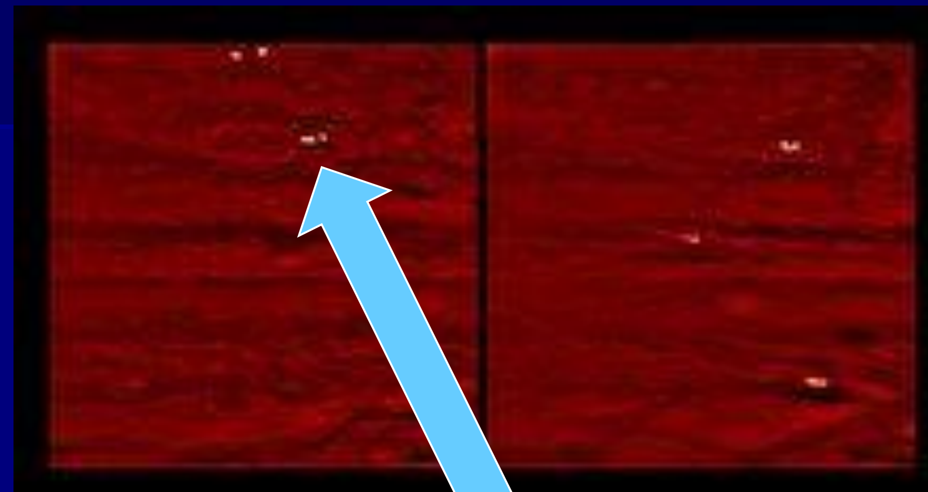
Approximate size comparison of Earth and the GRS

Atmosphere of Jupiter

Discrete features - **Oval BA**

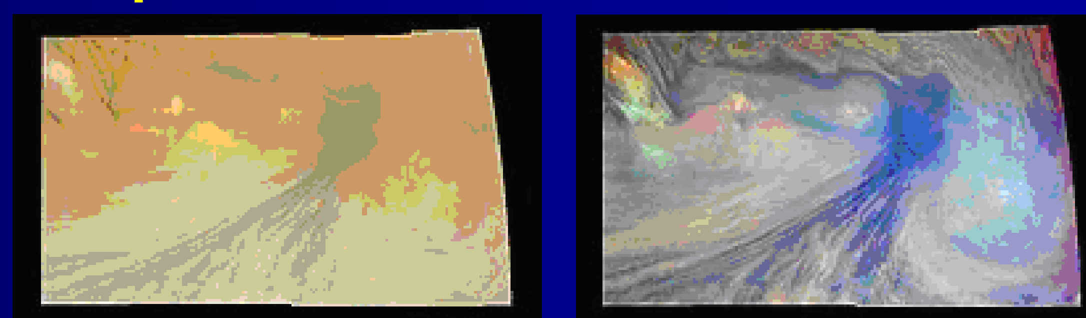
Oval BA (left)

- **Storms and lightning**



Lightning on Jupiter's night side, imaged by the Galileo orbiter in 1997

- **Hot spots**



False color image of an equatorial hot spot

Atmosphere of Jupiter

Jupiter's atmosphere

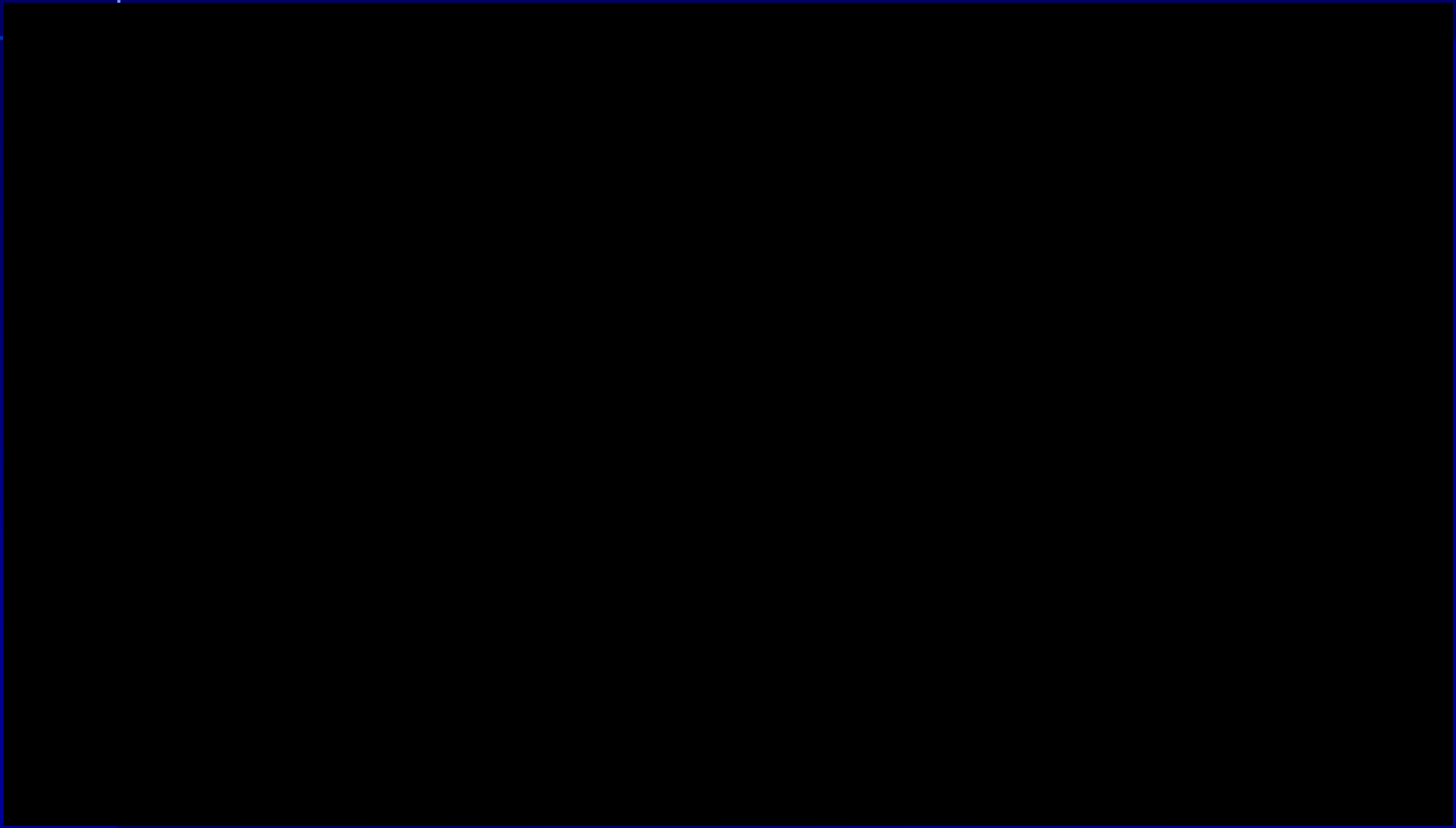
Atmosphere of Saturn

Atmosphere of Saturn

False-colored composite image of Saturn taken
By Voyager-1 that highlights features of Saturn's belts

Atmosphere of Saturn

Saturn- Our Solar System



Atmosphere of Saturn

Cloud layers

Saturn's atmosphere exhibits a banded pattern similar to Jupiter's, but Saturn's bands are much fainter and are also much wider near the equator. At depth, extending for 10 km and with a temperature of −23 °C, is a layer made up of water ice. Above this layer is probably a layer of ammonium hydrosulfide ice, which extends for another 50 km and is approximately −93 °C. Eighty kilometers above that layer are ammonia ice clouds, where the temperatures are roughly −153 °C. Near the top of the atmosphere, extending for some 200 km to 270 km above the visible ammonia clouds, are gaseous hydrogen and helium. Saturn's winds are among the Solar System's fastest. Voyager data indicate peak easterly winds of 500 m/s (1800 km/h).

Saturn's northern hemisphere, as seen by the Cassini-huygens space probe. (Note the planet's blue appearance through the ring.)

Atmosphere of Saturn

Cloud layers…

Saturn's usually bland atmosphere occasionally exhibits long-lived ovals and other features common on Jupiter. In 1990 the Hubble Space Telescope observed an enormous white cloud near Saturn's equator which was not present during the Voyager encounters and in 1994, another smaller storm was observed. The 1990 storm was an example of a Great White Spot, a unique but short-lived phenomenon which occurs once every Saturnian year, roughly every 30 Earth years, around the time of the northern hemisphere's summer solstice. Previous Great White Spots were observed in 1876, 1903, 1933 and 1960, with the 1933 storm being the most famous. If the periodicity is maintained, **another storm will occur in about 2020**.

In recent images from the Cassini spacecraft, Saturn's northern hemisphere appears a bright blue, similar to Uranus. This blue color cannot currently be observed from Earth, because Saturn's rings are currently blocking its northern hemisphere. The color is most likely caused by Rayleigh scattering.

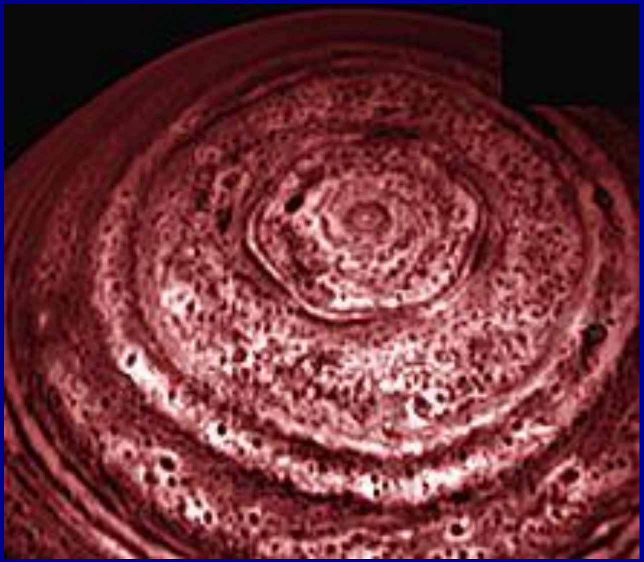
Atmosphere of Saturn

Cloud layers…

Infrared imaging has shown that Saturn's south pole has a warm polar vortex, the only example of such a phenomenon known to date in the Solar System.

Whereas temperatures on Saturn are normally −185 °C, temperatures on the vortex often reach as high as −122 °C, believed to be the warmest spot on Saturn.

North pole hexagonal cloud pattern



A persisting hexagonal wave pattern around the north polar
vortex in the atmosphere at about 78°N was first noted in the
Voyager images.

Discovered by Voyager-1 and confirmed in 2006 by Cassini.

Atmosphere of Saturn

Magnetosphere

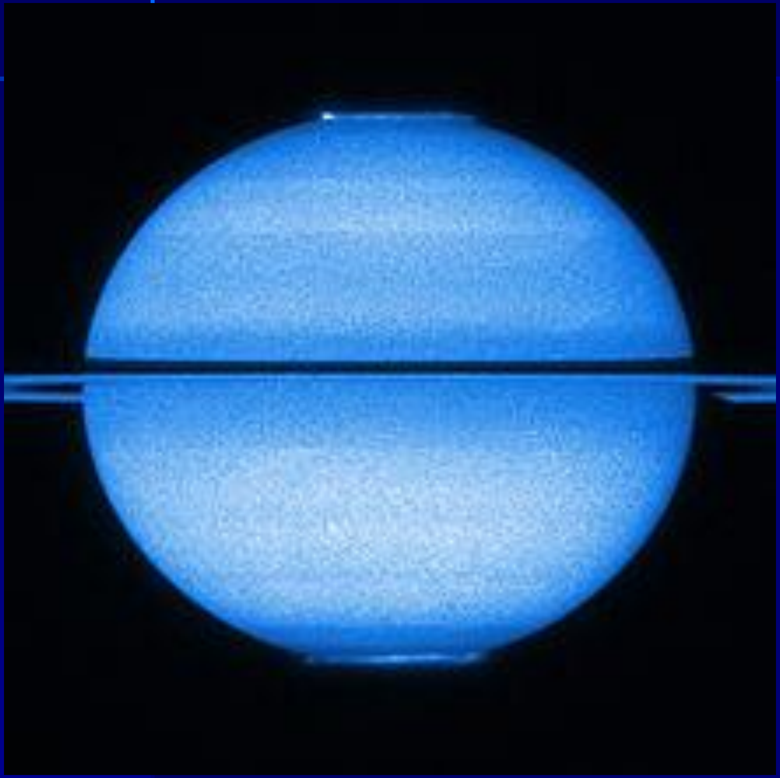


Photo of Saturn by Hubble showing both polar aurorae

Saturn has an intrinsic magnetic field that has a simple, symmetric shape a magnetic dipole. Its strength at the equator 0.2 Gauss (20 µT) is approximately one twentieth than that of the field around Jupiter and slightly weaker than Earth's magnetic field.

Most probably, the magnetic field is generated similarly to that of Jupiter by currents in the metallic-hydrogen layer, which is called a metallic-hydrogen dynamo. Similarly to those of other planets, this magnetosphere is efficient at deflecting the solar wind particles from the Sun.

Atmosphere of Uranus

Atmosphere of Uranus

Face of Uranus, by Voyager-2

Atmosphere of Uranus

Uranus 101 | National Geographic

Atmosphere of Uranus

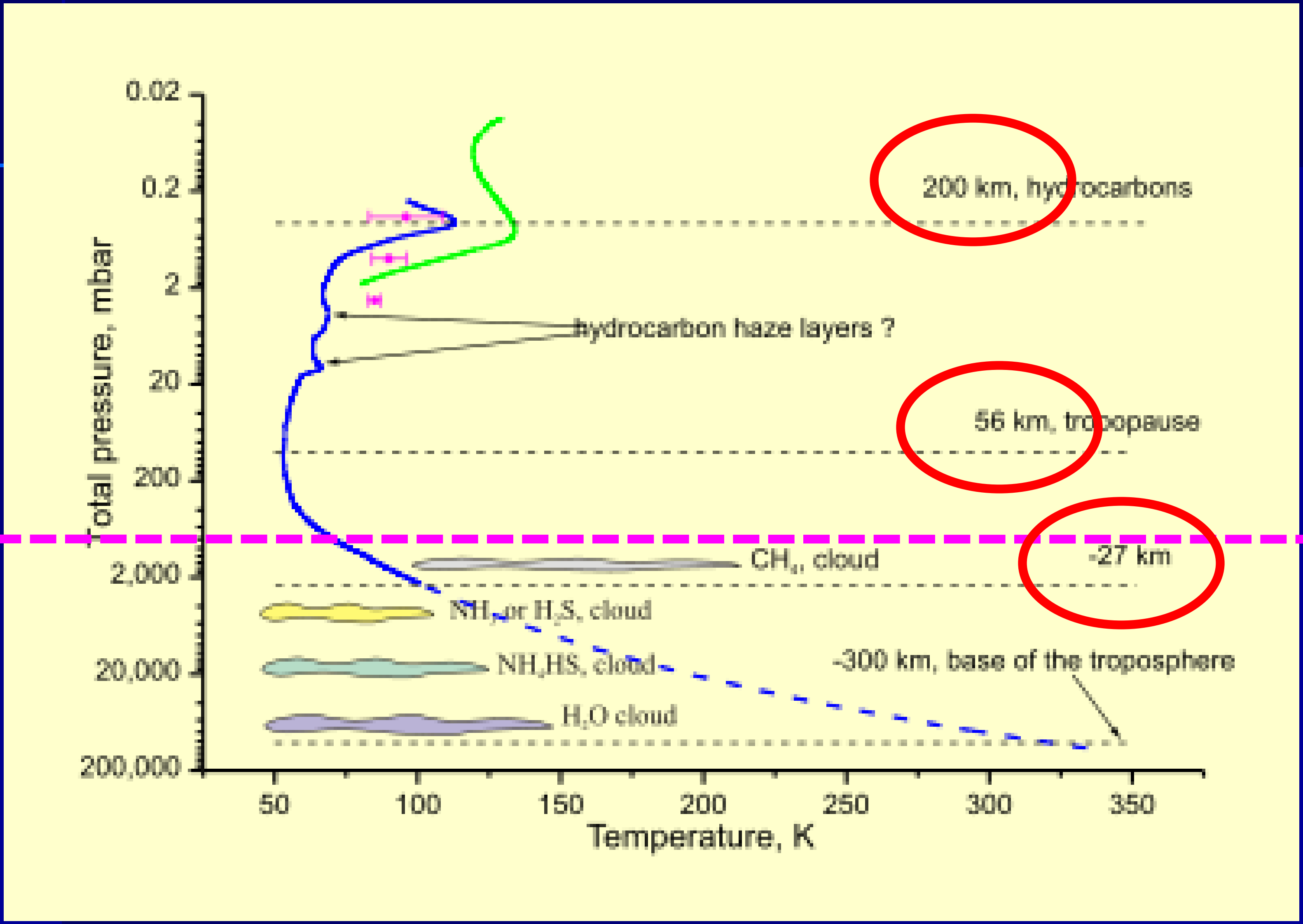
Observation and exploration

Although there is no well-defined solid surface within Uranus' interior, the outermost part of Uranus' gaseous envelope that is accessible to remote sensing, is called its atmosphere. Remote sensing capability extends down to roughly 300 km below the 1 bar level, with a corresponding pressure around 100 bar and temperature of 320 K.

The observational history of the Uranian atmosphere is long and full of errors and frustrations.

Atmosphere of Uranus

Composition



Temperature profile of the Uranian troposphere and lower stratosphere. Cloud and haze layers are also indicated

Atmosphere of Uranus

Composition…

The composition of the Uranian atmosphere is different from the composition of Uranus as a whole, consisting mainly of molecular hydrogen and helium. The helium molar fraction, i.e. the number of helium atoms per molecule of hydrogen/helium, was determined from the analysis of Voyeger-2 far infrared and radio occultation observations.

The fourth most abundant constituent of the Uranian atmosphere is methane (CH_4), the presence of which has been known for some time as a result of the ground-based spectroscopic observations.

The concentration of less volatile compounds such as ammonia, water and hydrogen sulfide in the deep atmosphere is poorly known.

Atmosphere of Uranus

Composition…

Infrared spectroscopy, including measurements with Spitzer Space Telescope (SST), and UV occultation observations, found trace amounts of various hydrocarbons in the stratosphere of Uranus, which are thought to be produced from methane by photolysis induced by the solar UV radiation.

They include ethane (C2H6), acetylene (C2H2), methyl acetylene (CH3C2H), diacetylene (C2HC2H). Infrared spectroscopy also uncovered traces of water vapour, carbon monoxide and carbon dioxide in the stratosphere, which can only originate from an external source such as infalling dust and comets.

Atmosphere of Uranus

Structure

The Uranian atmosphere can be divided into three layers: of

the troposphere, between altitudes of −300 and 50 km and pressures from 100 to 0.1 bar;

the stratosphere, spanning altitudes between 50 and 4000 km and pressures of between 0.1 and 10^(-10) bar; and

the thermosphere / exosphere extending from 4000 km to as high as a few Uranus radii from the surface. There is no mesosphere.

Atmosphere of Uranus

Structure… **Troposphere**

The troposphere is the lowest and densest part of the atmosphere and is characterized by a decrease in temperature with altitude. The temperature falls from about 320 K at the base of troposphere at −300 km to 53 K at 50 km.

The temperature at the cold upper boundary of the troposphere (the tropopause) actually varies in the range between 49 and 57 K depending on planetary latitude, with the lowest temperature reached near 25° southern latitude.

Atmosphere of Uranus

Structure… **Stratosphere**

The middle layer of the Uranian atmosphere is the stratosphere, where temperature generally increases with altitude from 53 K in the tropopause to between 800 and 850 K at in the thermosphere.

The heating of the stratosphere is caused by the downward heat conduction from the hot thermosphere as well as by absorption of solar UV and IR radiation by methane and complex hydrocarbons that form in this part of the atmosphere as a result of methane photolysis.

Atmosphere of Uranus

Structure… **Thermosphere and ionosphere**

The outmost layer of the Uranian atmosphere extending for thousands kilometers is thermosphere, which has a uniform temperature around 800 to 850 K. This is much higher than, for instance, the 420 K in the thermosphere of Saturn. The heat sources necessary to sustain such a high value are not understood, since neither solar FUV/EUV radiation nor auroral activity can provide the necessary energy.

The thermosphere as well as the upper part of the stratosphere contain a large concentration of ions and electrons forming the ionosphere of Uranus.

The electron density in the Uranian ionosphere is on average 10^4 cm−3, reaching to as high as 10^5 cm−3 in the narrow layers in the lower ionosphere. This fact may be related to the low concentration of hydrocarbons in the stratosphere. The ionosphere is mainly sustained by solar UV radiation and its density depends on the solar activity. The auroral activity on Uranus is not as powerful as at Jupiter and Saturn and contributes little to the ionization.

Atmosphere of Uranus

Structure… **Hydrogen corona**

The upper part of the thermosphere, where the mean free path of the molecules exceeds the scale height, is called exosphere.

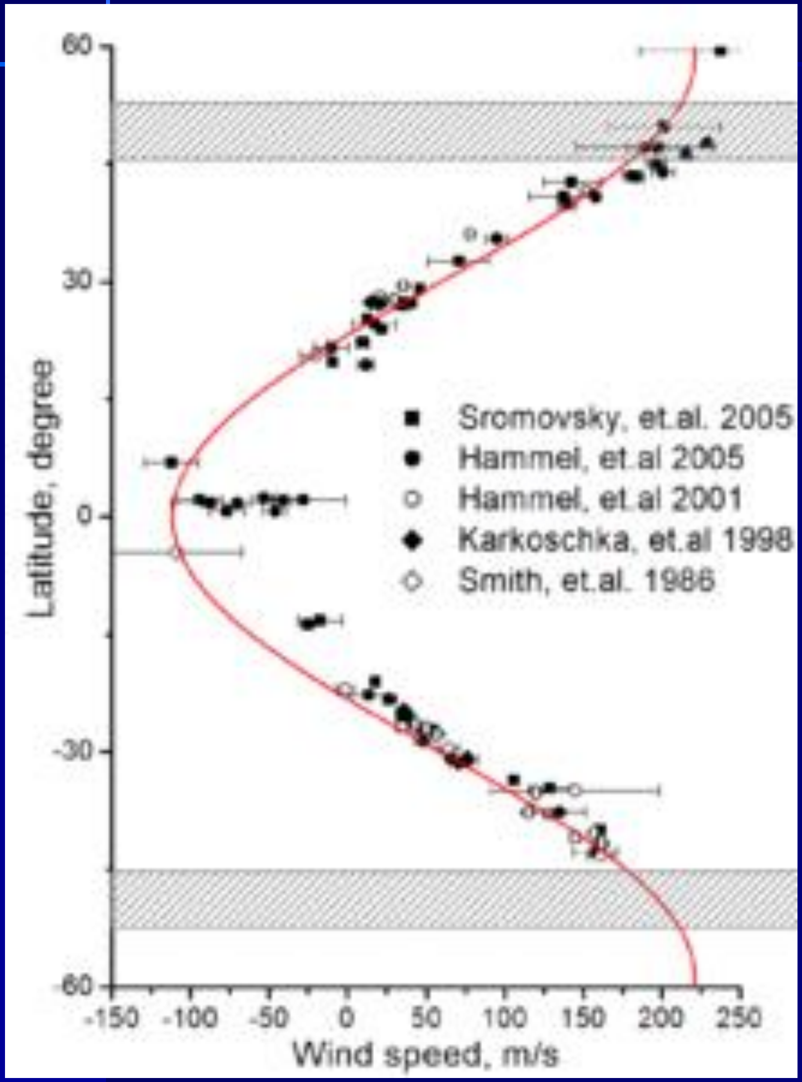
The lower boundary of the Uranian exosphere the exobase is located at the height of about 6,500 km or 1/4 of the planetary radius over the surface.

The exosphere is unusually extended reaching as far as several Uranian radii from the planet. It is made mainly of hydrogen atoms including a substantial non-thermal population and is often called the hydrogen corona of Uranus.

The effects of this bloated exosphere include a drag on small particles orbiting Uranus, causing a general depletion of dust in the Uranian rings, which may contaminate the upper atmosphere of the planet.

Atmosphere of Uranus

Dynamics



Zonal **wind speeds on Uranus**. Shaded areas show the southern collar and its future northern counterpart. The red curve is a symmetrical fit to the data.

Atmosphere of Uranus

Dynamics…

Uranus, being generally cyan in color, has a bland appearance lacking broad colorful bands and large clouds prevalent on Jupiter and Saturn.

In 1986 the most conspicuous features on Uranus observed by Voyager 2 were the dark low latitude region between −40° and −20° and bright southern polar cap.

The southern polar cap, which existed near the solstice in 1986, faded away in 1990s.

The atmosphere of Uranus is relatively calm as compared to those of other giant planets. Only a limited number of small bright clouds at middle latitudes in both hemispheres and one **Uranus Dark Spot** have been observed since 1986. One of those bright cloud features located at –34° of latitude probably existed continuously since at least 1986.

The wind speeds are from −50 to −100 m/s at the equator increasing to 240 m/s near 50° latitude in the northern hemisphere.

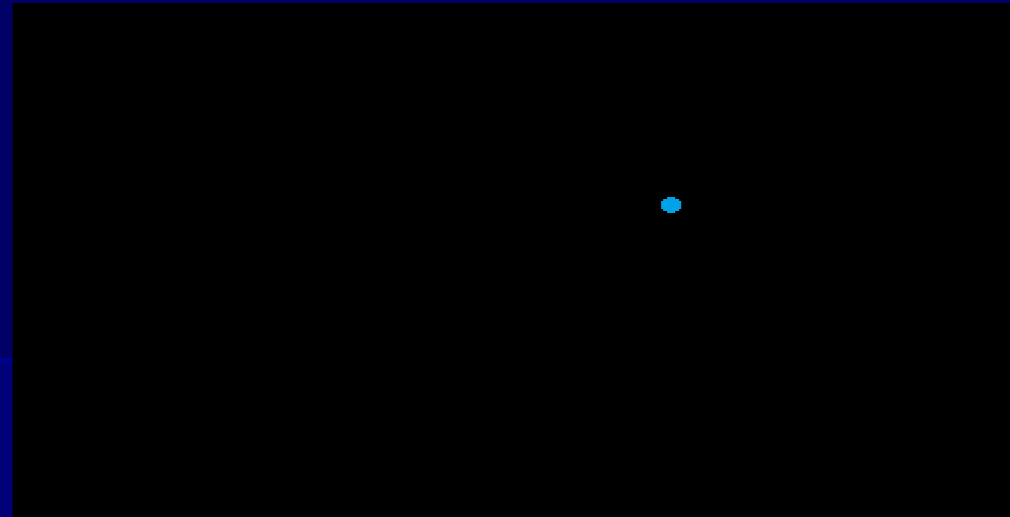
Atmosphere of Neptune

Atmosphere of Neptune

Combined color and near-infrared image of Neptune, showing bands of methane in its atmosphere, and its four moons, Proteus, Larissa, Galatea, and Despina.

Atmosphere of Neptune

What Would You See If You Fell Into Neptune?



- **Observation**
- Neptune is never visible to the naked eye, having a brightness between magnitudes +7.7 and +8.0.
- A telescope or strong binoculars will resolve Neptune as a small blue disk, similar in appearance to Uranus.
- Because of the distance of Neptune from the Earth, the angular diameter of the planet only ranges from 2.2 to 2.4 arcseconds, the smallest of the Solar System planets. Its small apparent size has made it challenging to study visually.

Atmosphere of Neptune

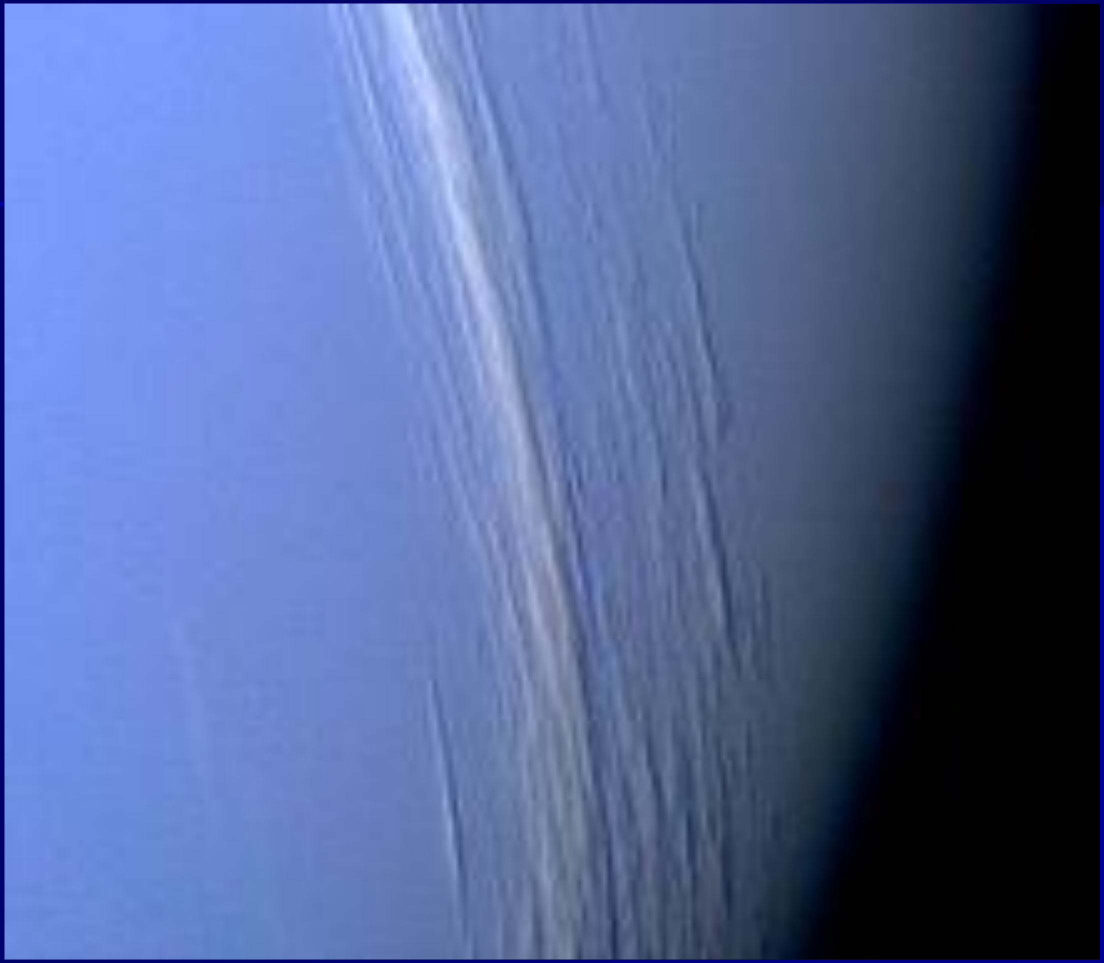
At high altitudes, Neptune's atmosphere is **80% hydrogen and 19% helium**. A trace amount of methane is also present. Prominent absorption bands of methane occur at wavelengths above 600 nm, in the red and infrared portion of the spectrum.

As with Uranus, this absorption of red light by the atmospheric methane is part of what gives Neptune its blue hue, although Neptune's vivid azure differs from Uranus's milder cyan.

Neptune's atmosphere is sub-divided into two main regions;

1. The **lower troposphere,** where temperature decreases with altitude, and the stratosphere, where temperature increases with altitude. The boundary between the two, the tropopause, occurs at a pressure of 0.1 bars (10 kPa).
2. The stratosphere then gives way to the thermosphere at a pressure lower than 10^{-5} to 10^{-4} microbars (1 to 10 Pa). The thermosphere gradually transitions to the exosphere.

Atmosphere of Neptune



Bands of high-altitude clouds cast shadows on Neptune's lower cloud deck

Atmosphere of Neptune

Models suggest that Neptune's troposphere is banded by clouds of varying compositions depending on altitude.

The upper-level clouds occur at pressures below one bar, where the temperature is suitable for methane to condense.

For pressures between one and five bars (100 and 500 kPa), clouds of ammonia and hydrogen sulfide are believed to form.

Deeper clouds of water ice should be found at pressures of about 50 bars (5.0 MPa), where the temperature reaches 0 °C. Underneath, clouds of ammonia and hydrogen sulfide may be found.

Atmosphere of Neptune

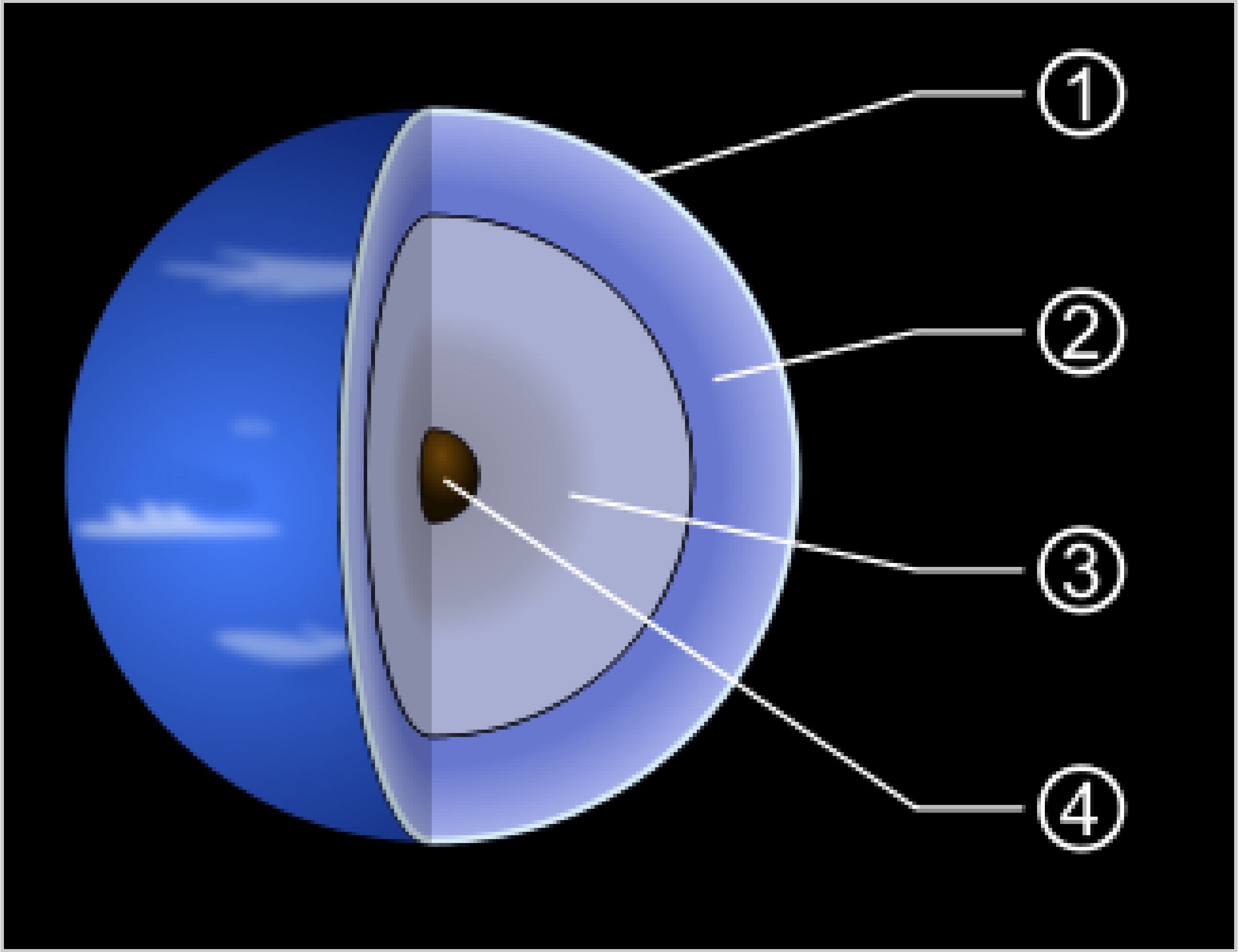
The stratosphere of Neptune is warmer than that of Uranus due to the elevated concentration of hydrocarbons.

For reasons that remain obscure, the planet's thermosphere is at an anomalously high temperature of about 750 K.

The planet is too far from the Sun for this heat to be generated by ultraviolet radiation.

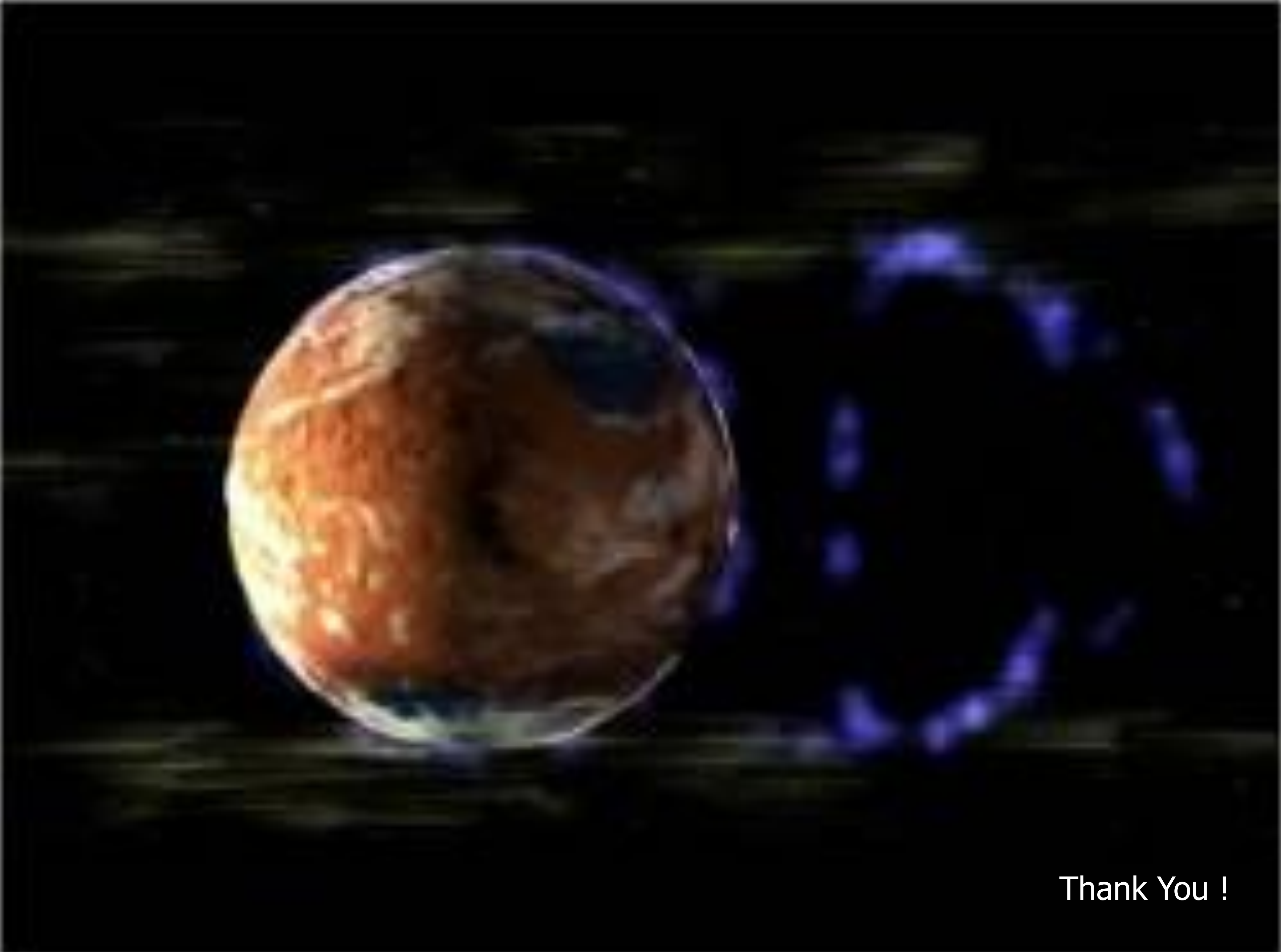
One candidate for a heating mechanism is atmospheric interaction with ions in the planet's magnetic field.

Other candidates are gravity waves from the interior that dissipate in the atmosphere.



The internal structure of Neptune:

1. Upper atmosphere, top clouds
2. Atmosphere consisting of hydrogen, helium and methane gas
3. Mantle consisting of water, ammonia and methane ices
4. Core consisting of rock (silicates and nickel-iron)



Thank You !