ATMÓSFERAS PLANETARIAS

MATERIAL COMPLEMENTARIO DEL CURSO DE PLANETOLOGIA 2014

(no sustituye al curso teórico)

http://www.astronomia.edu.uy/depto/planetologia/planet.html

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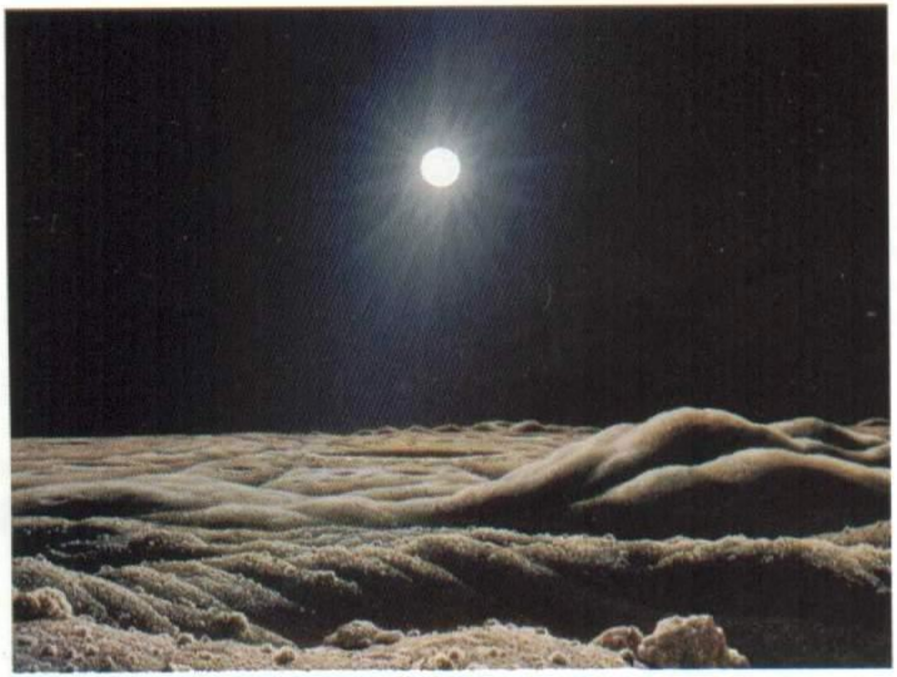
Las atmósferas son conglomerados de partículas en procura del equilibrio.

Clasificación:

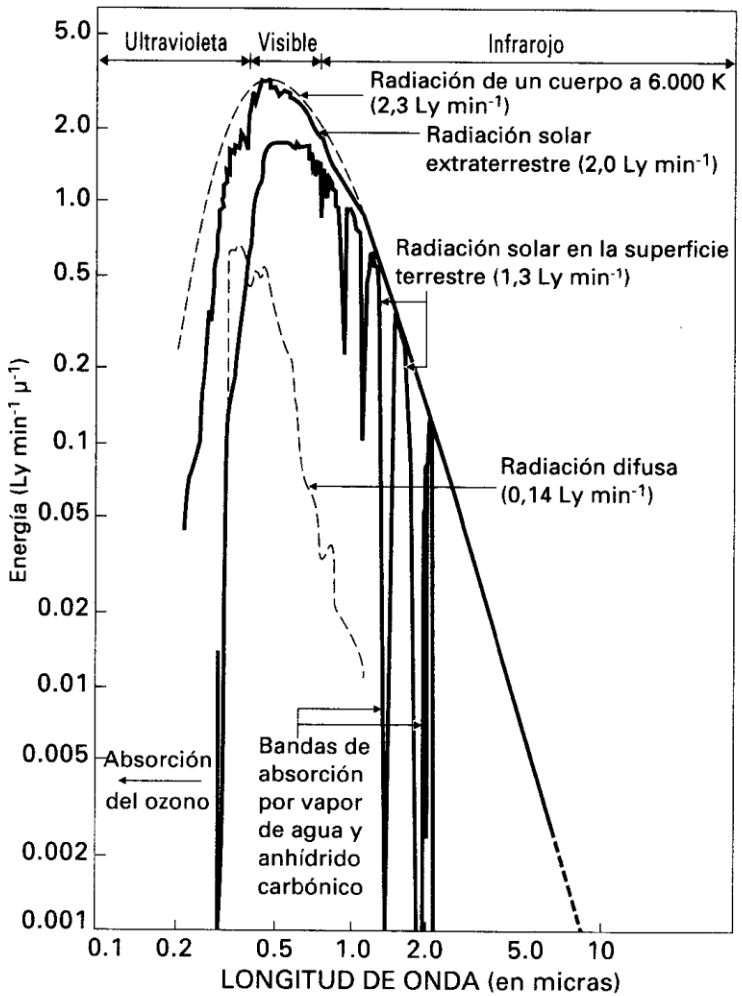
- “Planetas” terrestres: Venus, Tierra, Marte, Titan
- Atmosferas tenues: Mercurio, Luna, Io, Triton, Pluton
- Planetas jovianos

1. PLANETAS TERRESTRES

- Atmósferas secundarias, las originales fueron barridas por el viento solar TTauri



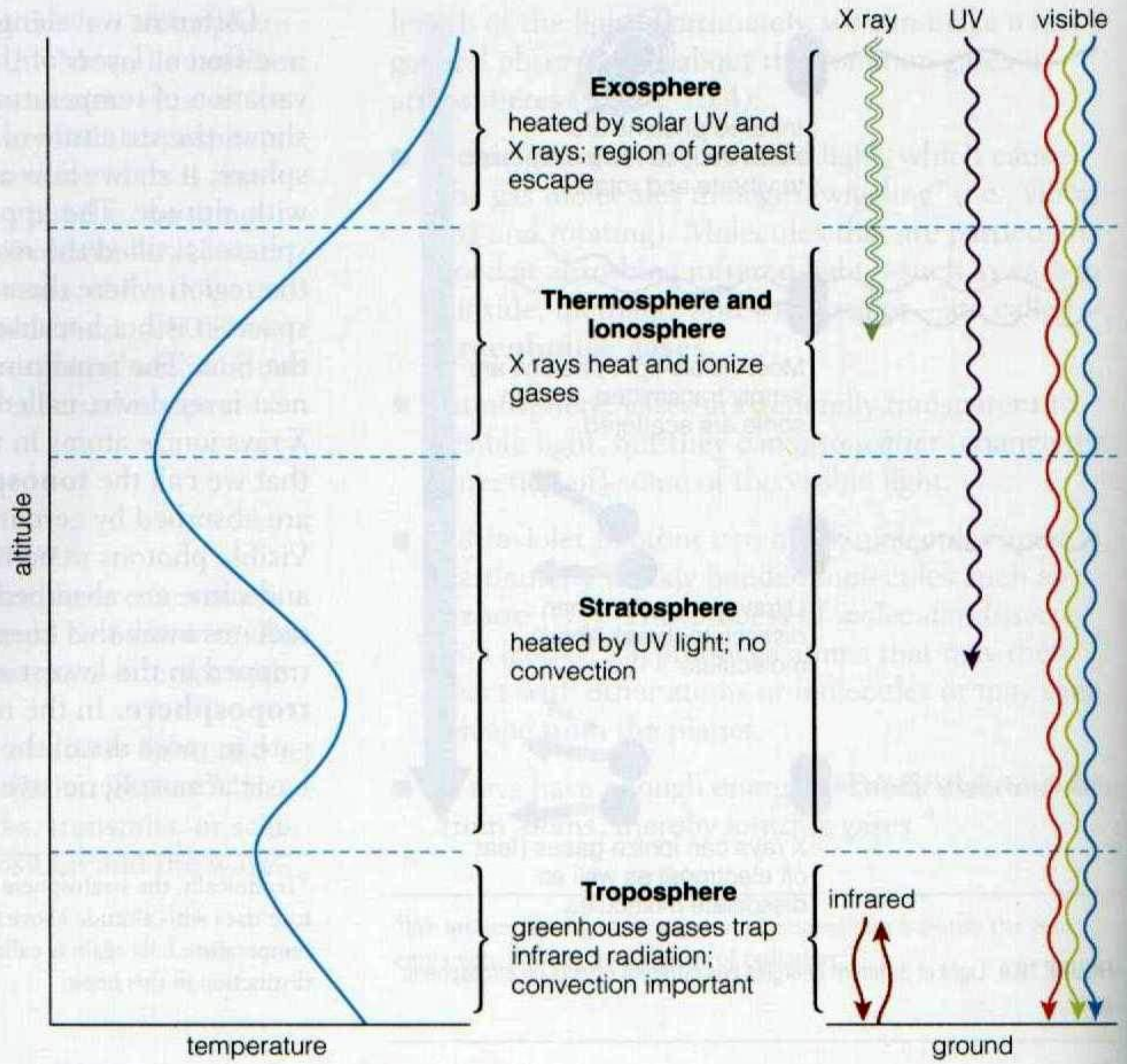

RADIACION SOLAR RECIBIDA EN EL TOPE DE LA ATMOSFERA Y EN LA SUPERFICIE TERRESTRE



ıra 3. Distribución espectral de la radiación solar, en escalas logarítmicas para ambas coordenadas (según Sellers, *et al.*).

ESTRUCTURA GENERICA

FIGURE 10.6 The structure of a generic planetary atmosphere: Solar X rays are absorbed in the thermosphere, ultraviolet light is absorbed in the stratosphere, and visible light reaches the ground. Planets that lack ultraviolet-absorbing molecules will lack a stratosphere, and planets with very little gas will have only an exosphere.



EXÓSFERA: no hay colisiones entre las moléculas

TERMÓSFERA: todos los gases absorben X

ESTRATÓSFERA: no hay convección, se requiere un buen absorbente de UV

TROPÓSFERA: moléculas con mas de 2 átomos son buenas absorbentes de IR

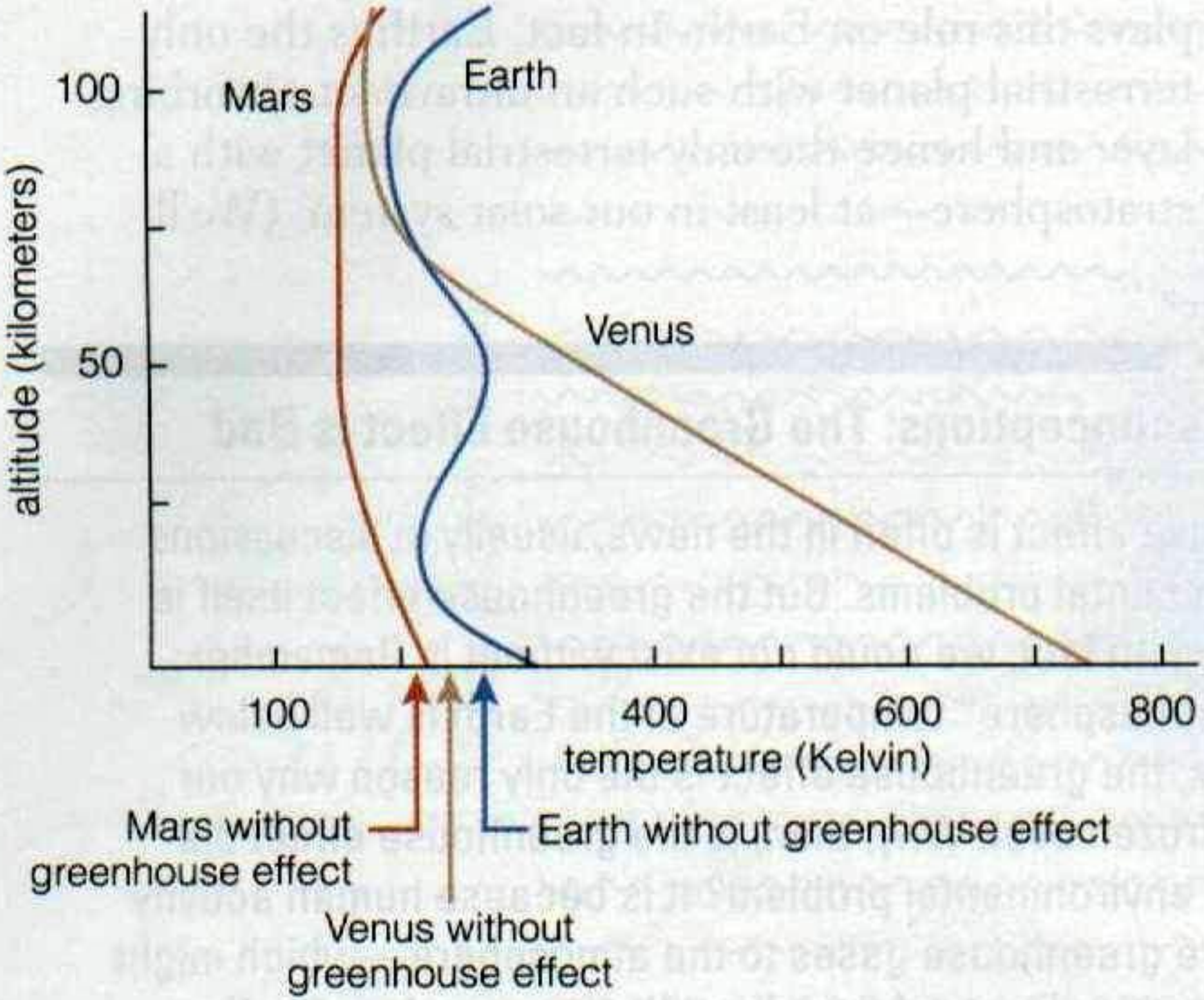


FIGURE 10.9 Temperature profiles for Venus, Earth, and Mars. Note that Venus and Earth are considerably warmer than they would be without the greenhouse effect. (The thermospheres and exospheres, not shown, are qualitatively alike.)

Pérdida selectiva de gases

$$V_{Escape} = \sqrt{\frac{2GM_P}{R_P}}$$

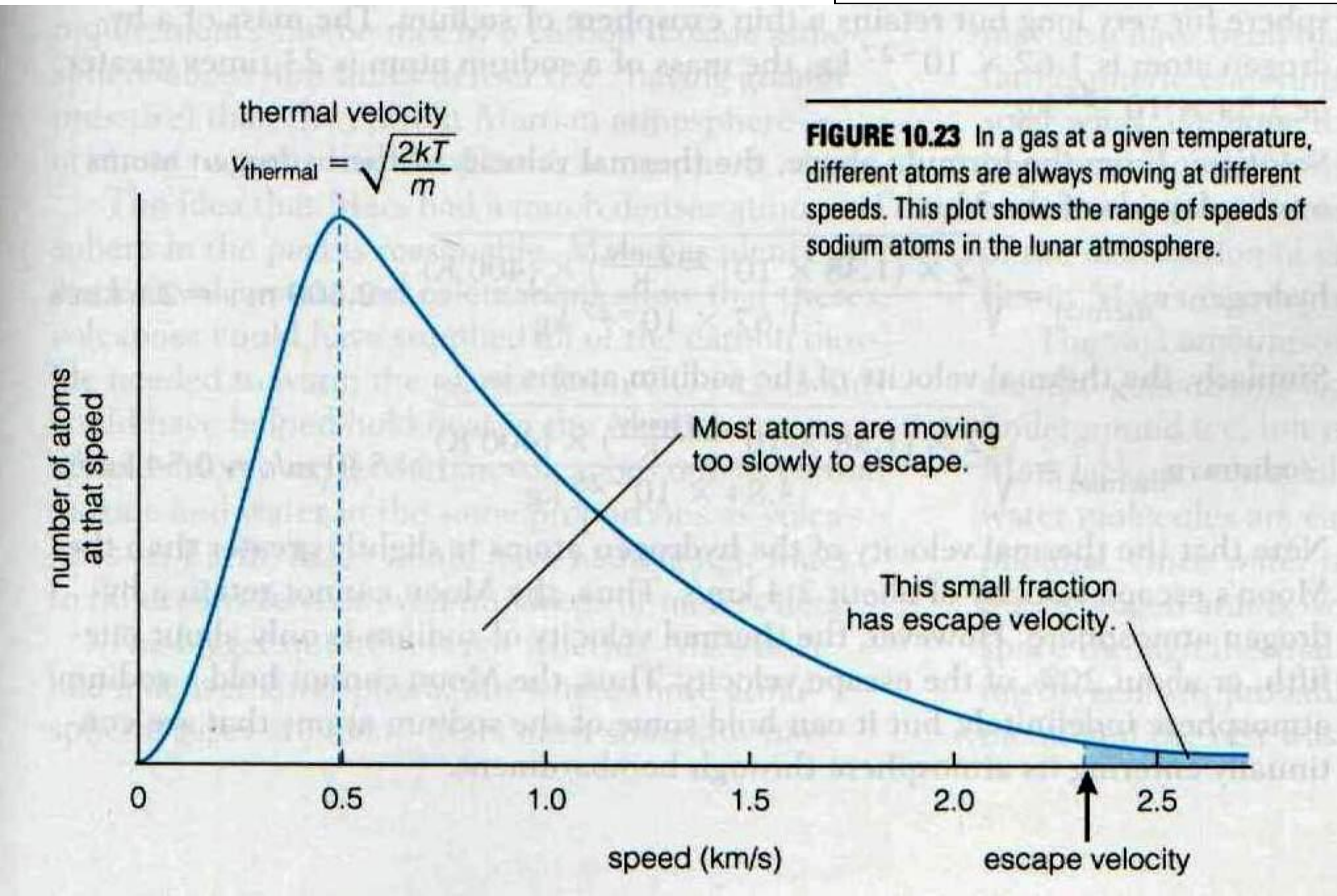


FIGURE 10.23 In a gas at a given temperature, different atoms are always moving at different speeds. This plot shows the range of speeds of sodium atoms in the lunar atmosphere.

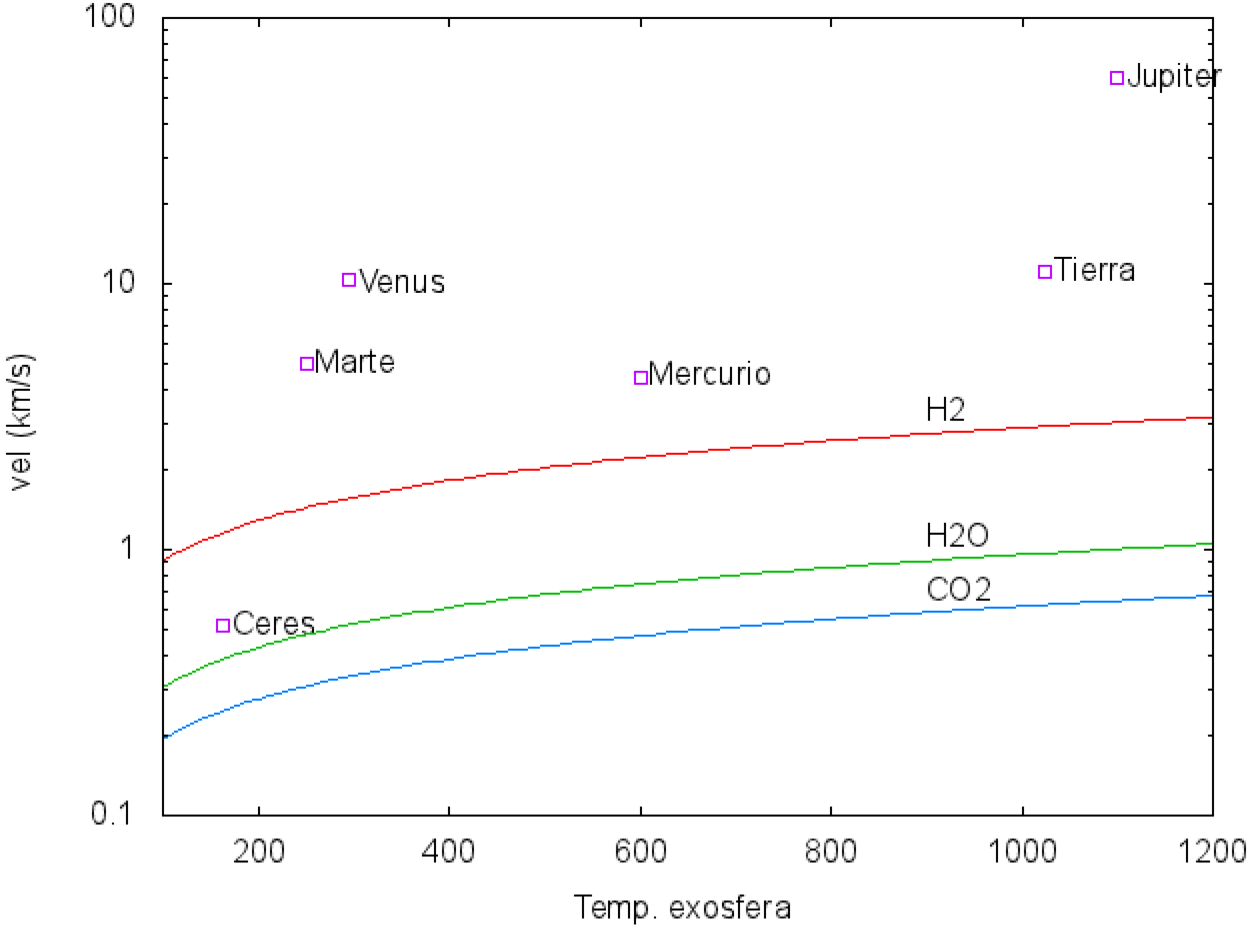
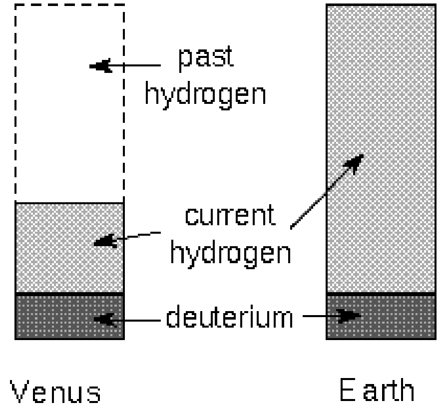

100
10
1
0.1
vel (km/s)
200
400
600
800
1000
1200
Temp. exosfera
Jupiter
Tierra
Venus
Marte
Mercurio
Ceres
H2
H2O
CO2

Table E.12 **Atmospheric Composition of Earth, Venus, Mars and Titan**[a]

Constituent	Earth	Venus	Mars	Titan
N_2	0.7808	0.035	0.027	~0.95
O_2	0.2095	0–20 ppm	0.0013	
CO_2	345 ppm	0.965	0.953	10 ppb
CH_4	2 ppm		10–250 ppb	0.049
H_2O	<0.03	30 ppm	<100 ppm	0.4 ppb
Ar	0.009	70 ppm	0.016	28 ppm
CO	0.2 ppm	20 ppm	700 ppm	45 ppm
O_3	~10 ppm		0.01 ppm	
SO_2	<2 ppb	100 ppm		

[a] From Table 4.4 of de Pater and Lissauer (2010). References and details are given therein. All numbers are volume mixing ratios.
ppb, part per billion; ppm, part per million.



Proportions of hydrogen to deuterium on Venus and Earth are very different—ordinary hydrogen isotope was preferentially removed on Venus.

GENERACIÓN Y PÉRDIDA DE ATMÓSFERA

FIGURE 10.20 Three processes by which atmospheres gain gas.

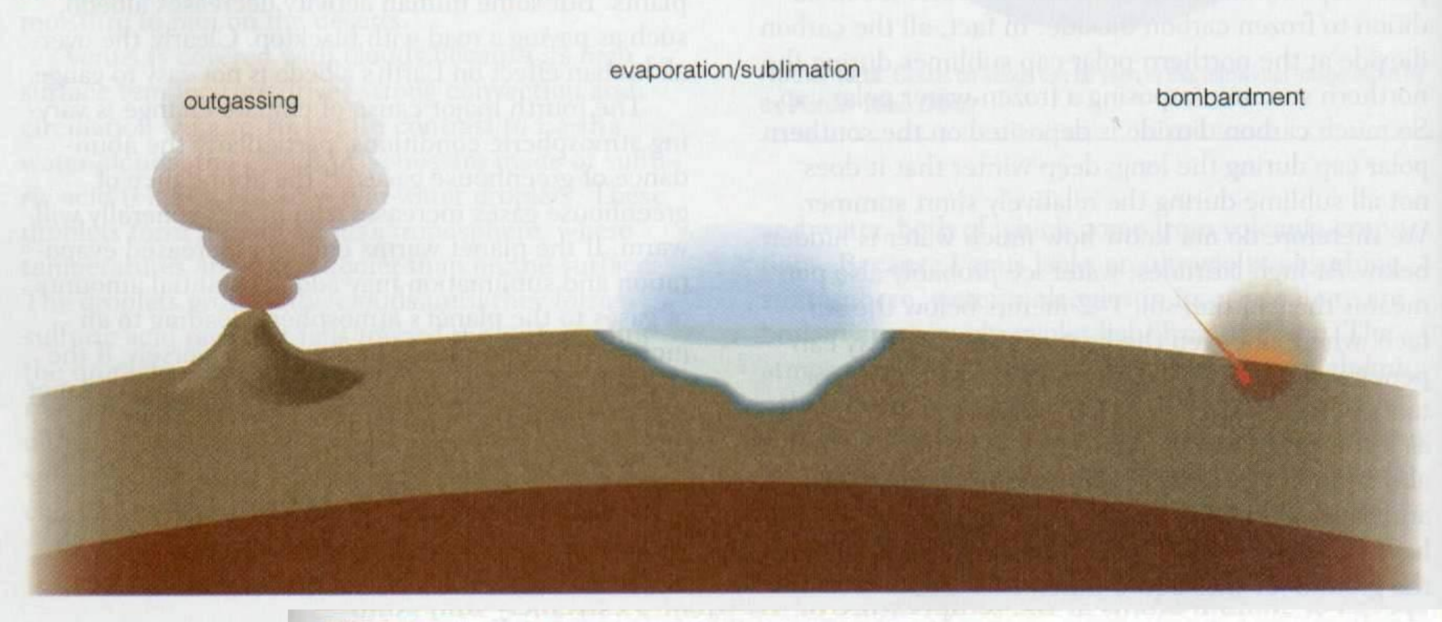
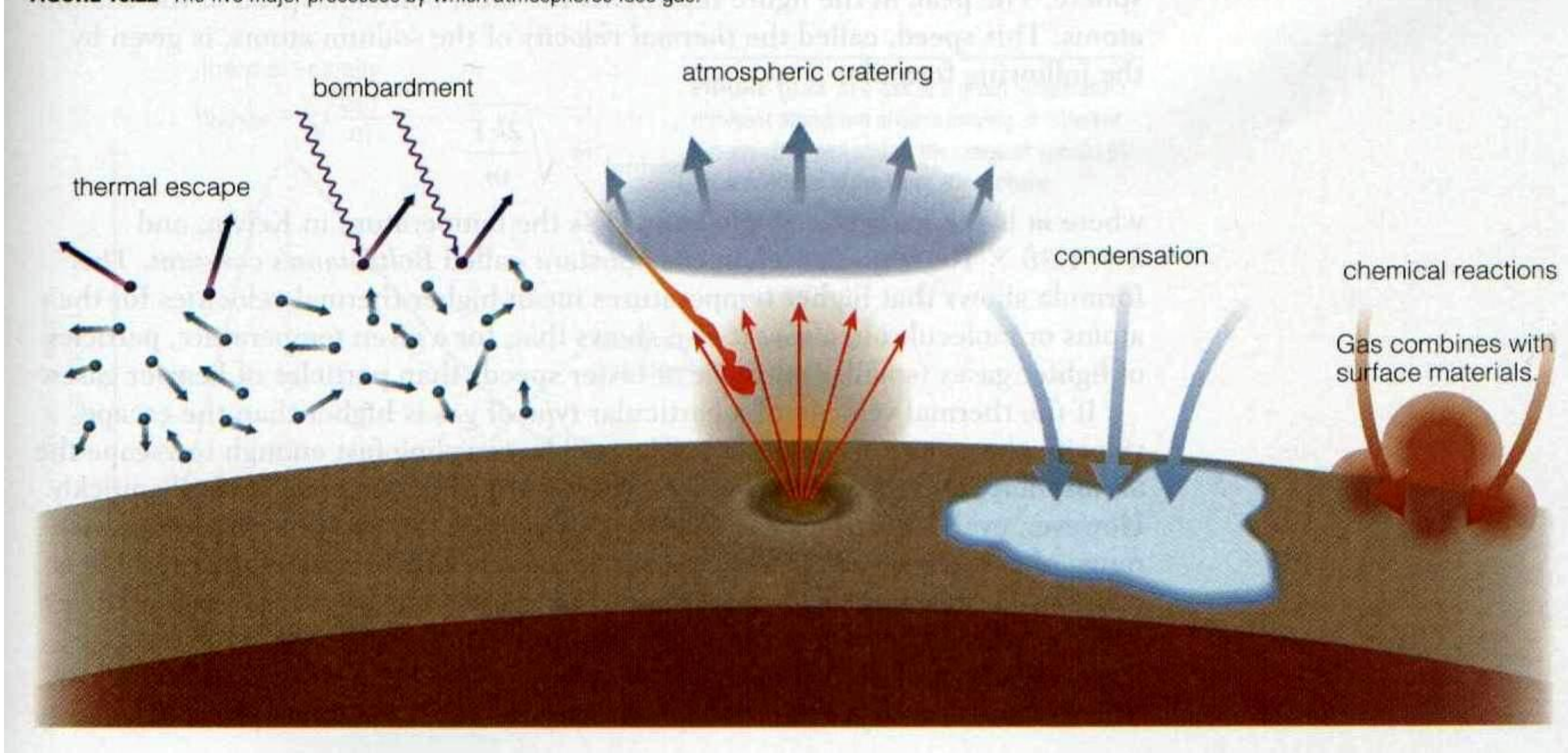


FIGURE 10.22 The five major processes by which atmospheres lose gas.



Densidad

- La densidad de una atmósfera es el resultado del balance entre los procesos de GENERACIÓN y PÉRDIDA
- Marte cesó su actividad volcánica: atmósfera tenue
- Venus debe tener actividad volcánica reciente

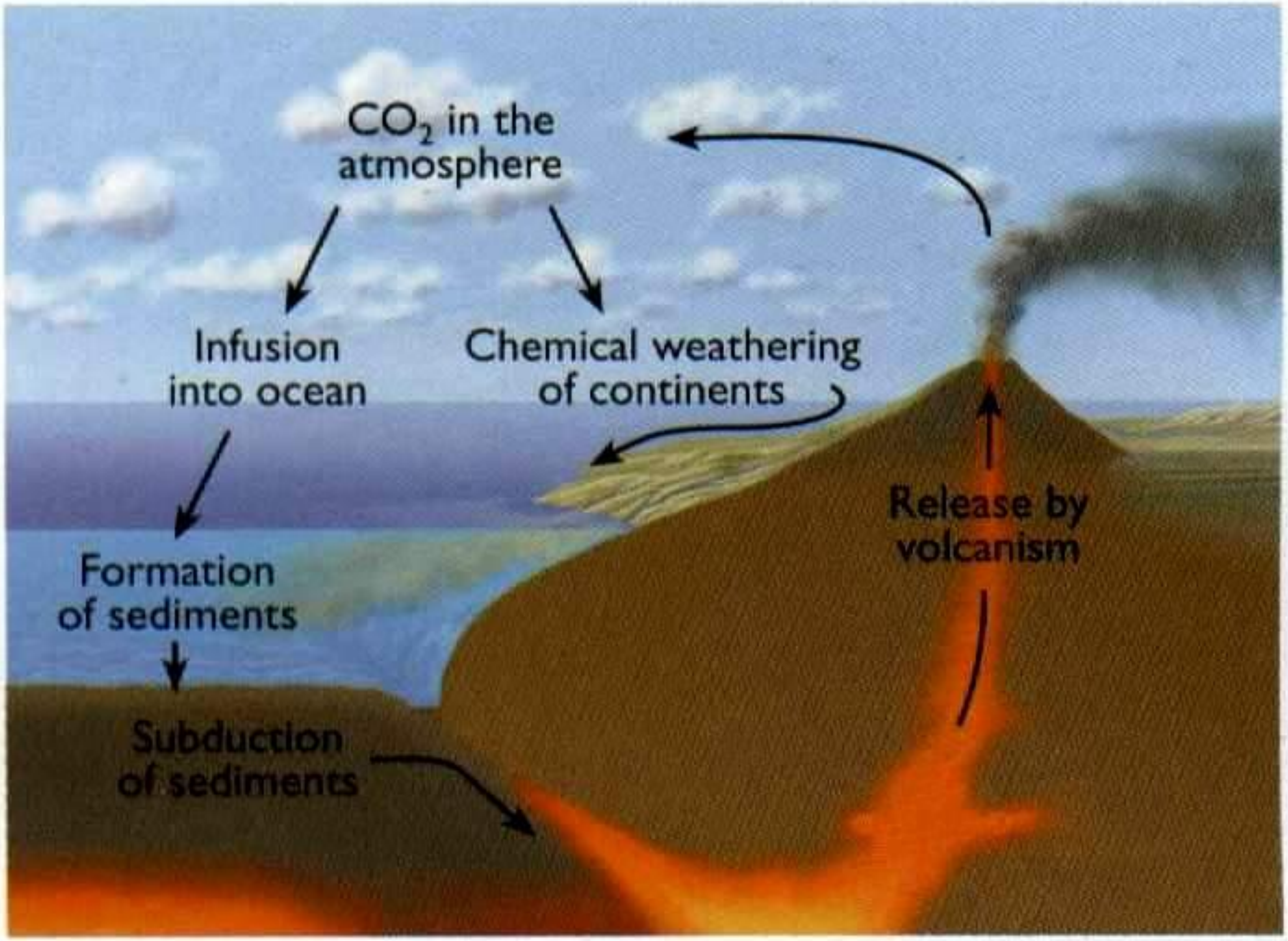


Figure 16. On Earth, carbon dioxide cycles between land and sky. Gaseous CO_2 is removed from the atmosphere to form sea-floor sediments; plate tectonism causes these sediments to be subducted into the upper mantle, and subduction-zone volcanism later releases the CO_2 back into the atmosphere. A balance thus exists between the loss of atmospheric CO_2 and its resupply, though the gas's actual abundance in the atmosphere may vary over time.

- La atmósfera de las primeras épocas de la historia de la Tierra estaría formada por vapor de agua, dióxido de carbono(CO_2) y nitrógeno, junto a muy pequeñas cantidades de hidrógeno (H_2), H_2S, SO_2 y monóxido de carbono pero con ausencia de oxígeno.
- Era una atmósfera ligeramente reductora hasta que la actividad fotosintética de los seres vivos introdujo oxígeno y ozono (a partir de hace unos 2000 millones de años) y hace unos 1000 millones de años la atmósfera llegó a tener una composición similar a la actual.

REACCIONES

$$CH_4 + H_2O \longleftrightarrow CO + 3H_2$$

$$2NH_3 \longleftrightarrow N_2 + 3H_2$$

$$H_2S + 2H_2O \longleftrightarrow SO_2 + 3H_2$$

$$8H_2S \longleftrightarrow S_8 + 8H_2$$

$$CO + H_2O \longleftrightarrow CO_2 + H_2$$

$$CH_4 \longleftrightarrow C + 2H_2$$

$$4PH_3 + 6H_2O \longleftrightarrow P_4O_6 + 12H_2.$$

CIRCULACIÓN

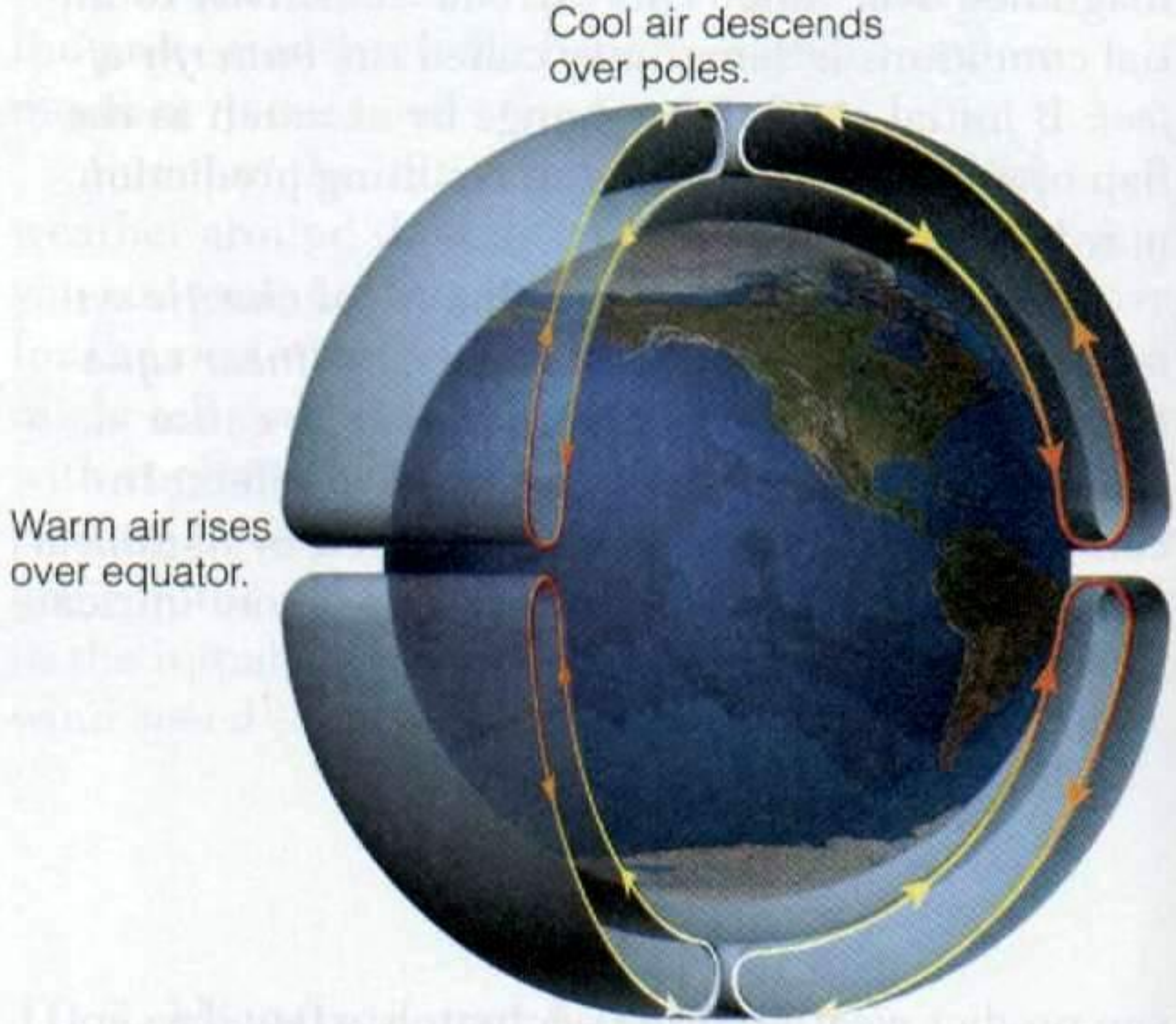
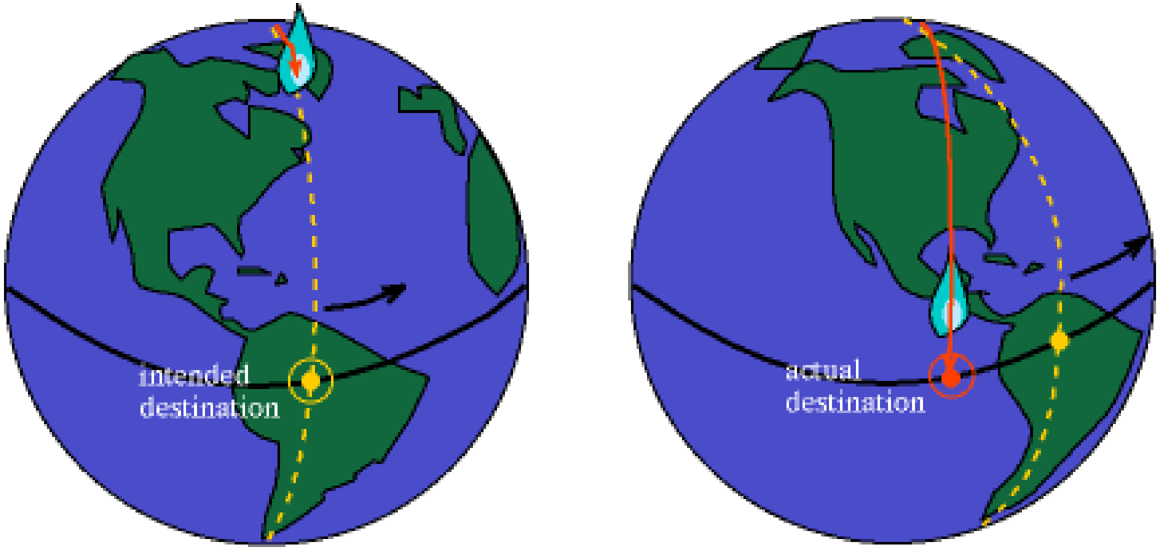
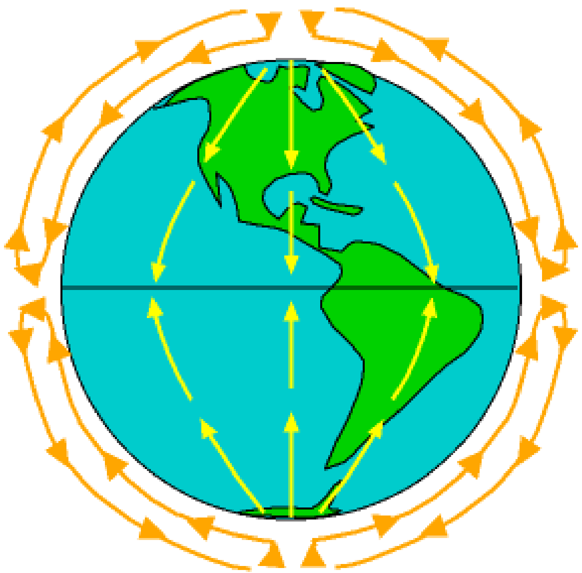


FIGURE 10.12 Circulation cells. Heat rises above the equator, setting up a flow of warm air toward the poles at high altitudes and a flow of cool air toward the equator near the surface. The planet's rotation is neglected for the moment.

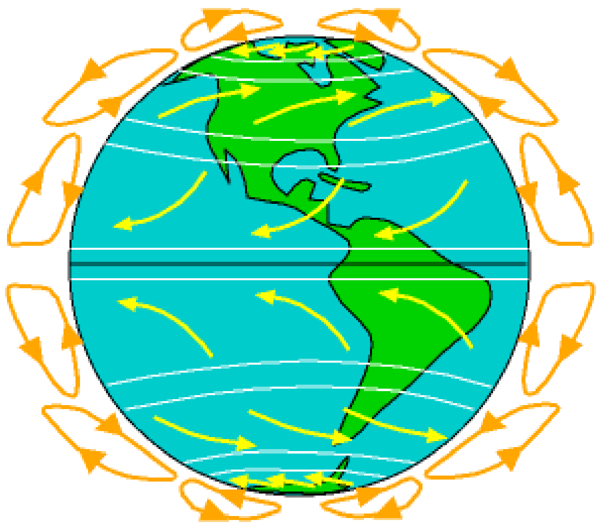


Coriolis effect: Original path of air is deflected westward by the rotation of the planet.

CORIOLIS



no rotation: no coriolis effect



rapid rotation: significant coriolis effect

On a planet with little or no rotation, the global air circulation pattern is very simple. On a planet with rapid rotation, the coriolis effect creates large-scale eddies with belts of wind and belts of calm.

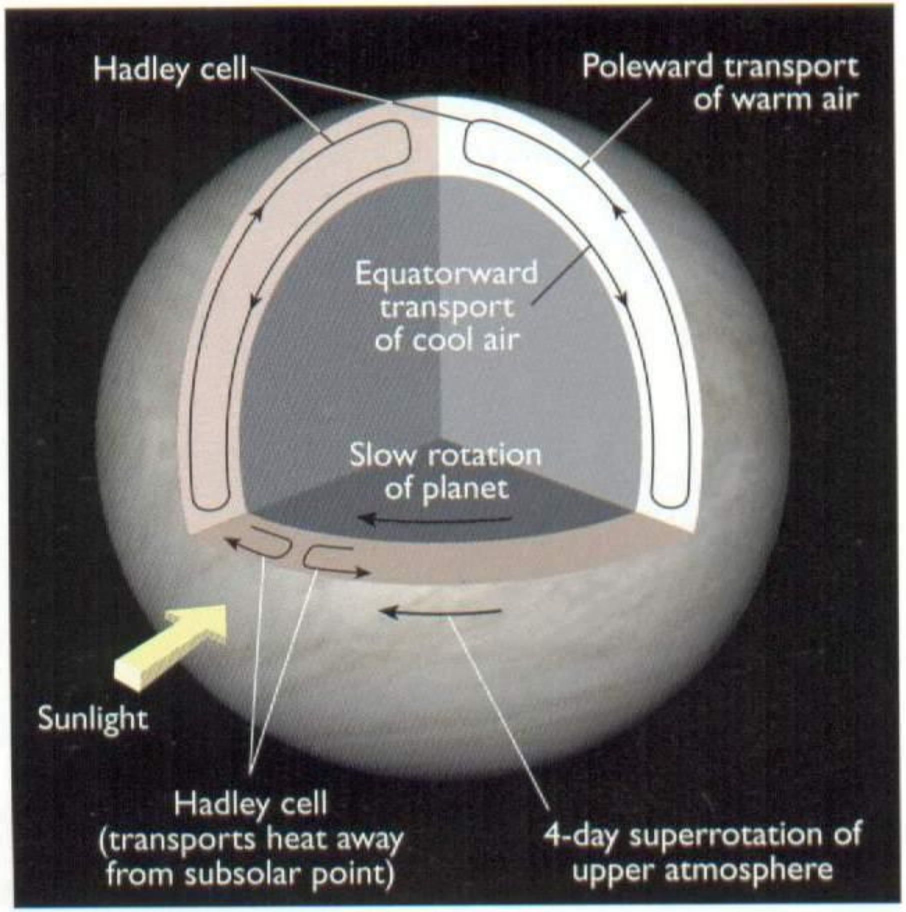


Figure 7. Rising motions occur wherever the strongest atmospheric heating occurs — near the subsolar latitude of Mars and Earth, and on the day side of Venus (as shown here). This movement is balanced by sinking parcels of air elsewhere, creating a net flow that keeps gases and heat from building up at any one location.

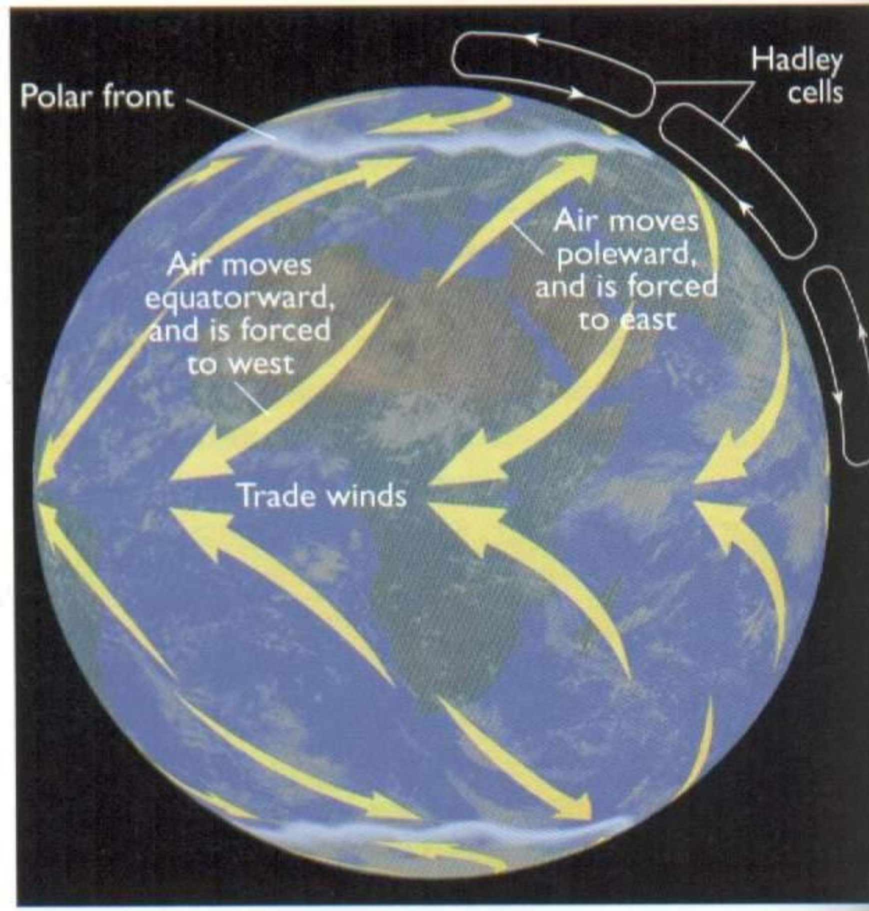


Figure 8. Zonal winds (along lines of constant latitude) result on Earth from the Coriolis force. Air is redirected eastward when it moves toward either pole and westward when it moves toward the equator. These east-west motions are analogous to the belts and zones in outer-planet atmospheres.

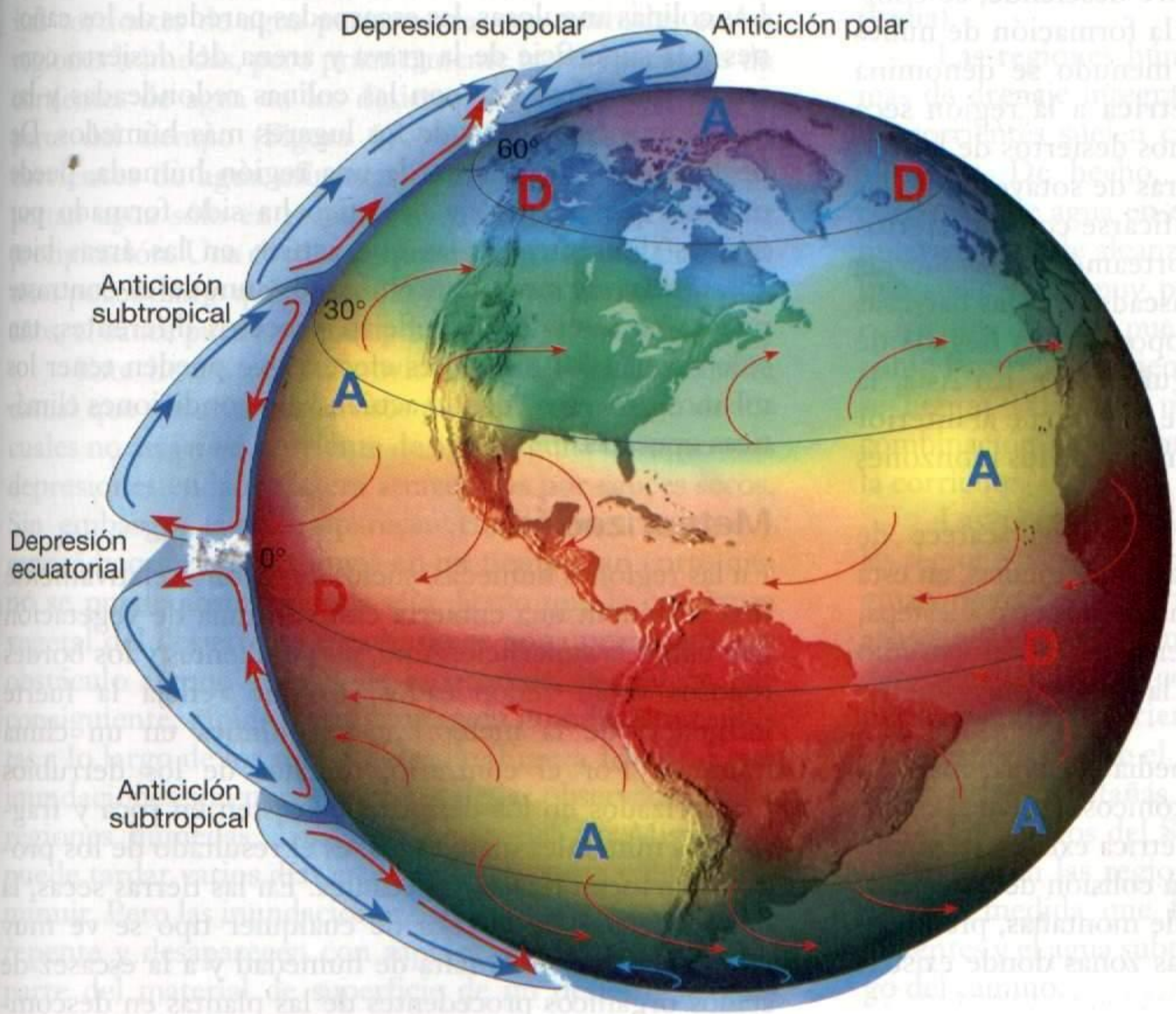
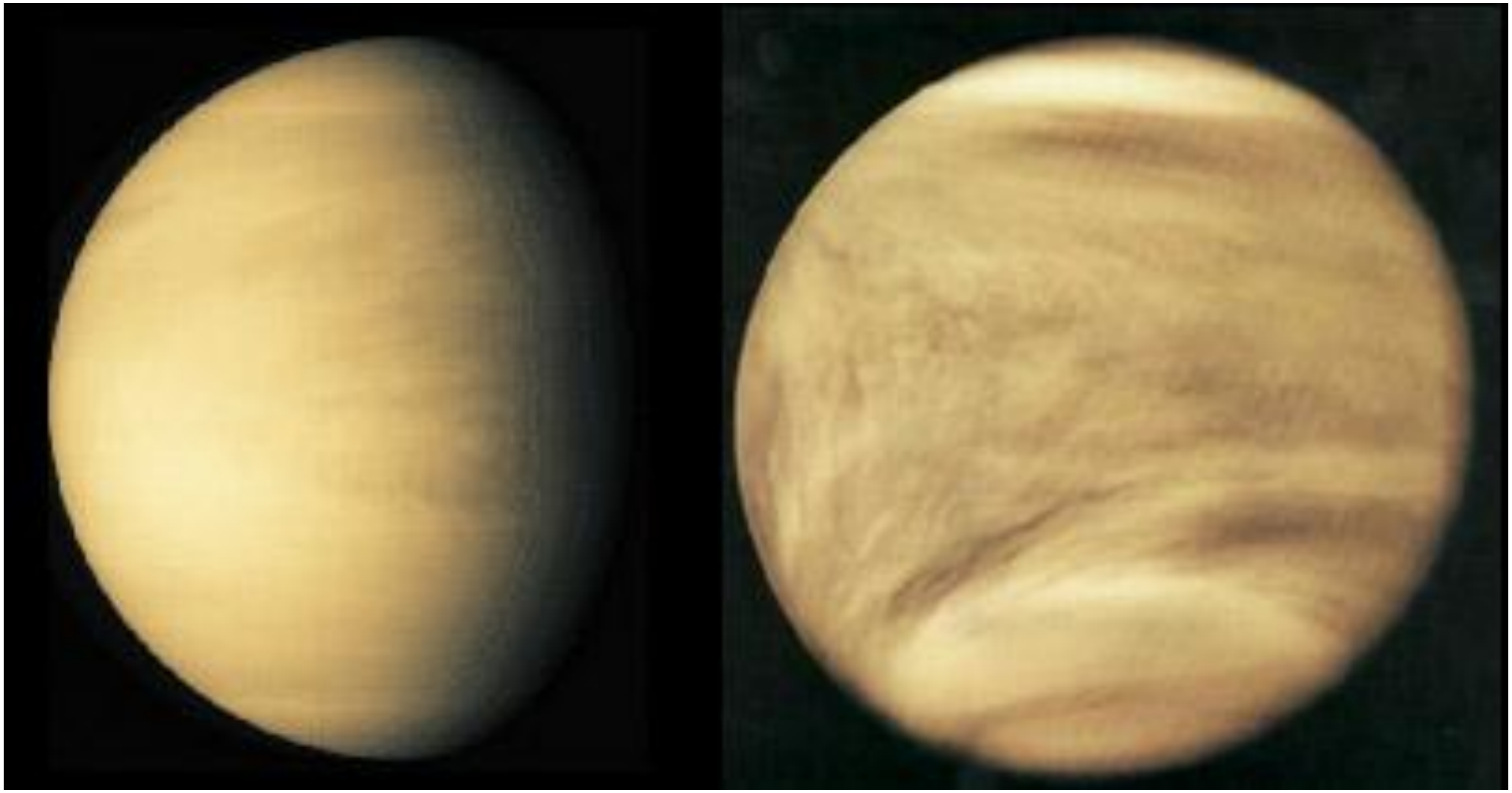


Figura 13.2 Diagrama idealizado de la circulación general atmosférica de la Tierra. Los desiertos y las estepas que están concentrados entre los 20° y los 30° de latitud norte y sur coinciden con los cinturones anticiclónicos subtropicales. Aquí, el descenso del aire seco inhibe la formación de nubes y la precipitación. Por el contrario, el cinturón de presiones conocido como depresión ecuatorial está asociado con áreas que se cuentan entre las más lluviosas de la Tierra.

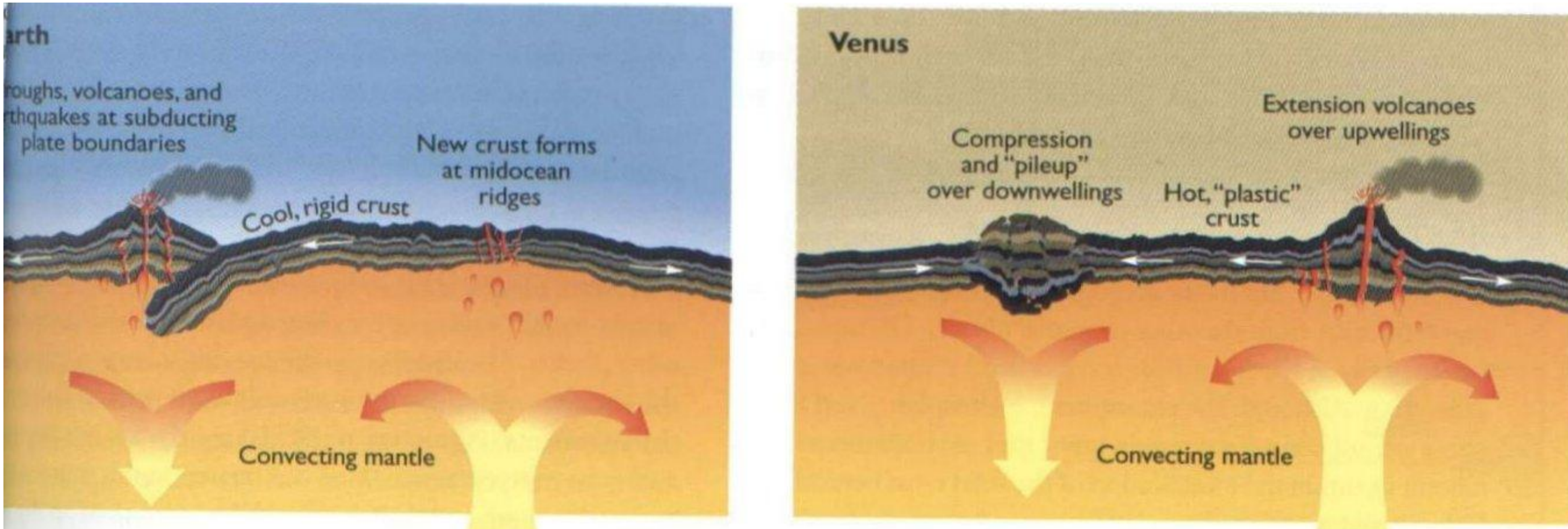
CIRCULACIÓN: generada por la INSOLACIÓN y la ROTACIÓN (Coriolis)



La alta atmosfera de Venus circula con un período de 4 dias provocada por la diferencia de temperatura entre el dia y la noche. Esta rotación frena al planeta pudiendo ser la causa de la escasa velocidad de rotación.

Generación de nubes:

- La temperatura superficial genera convección
- La convección es la responsable de la formación de nubes (líquido o cristales)
- Venus está cubierto de nubes de $H2SO4$ debido a sus altas temperaturas que generan una fuerte convección
- No posee estratósfera que absoba UV por lo tanto pierde $H2O$. A su vez el $SO2$ se combina en el suelo.
- Debe tener actividad volcánica
- Otra forma de generar nubes: viento sobre montañas como en Marte



[redacted]

Figure 16. In contrast to plate tectonism on Earth (left panel) Venus may pile up old crust over convective downwellings in the mantle and produce new crust over upwellings (right). At present Venus is a one-plate planet whose internal heat escapes to space largely by conduction.

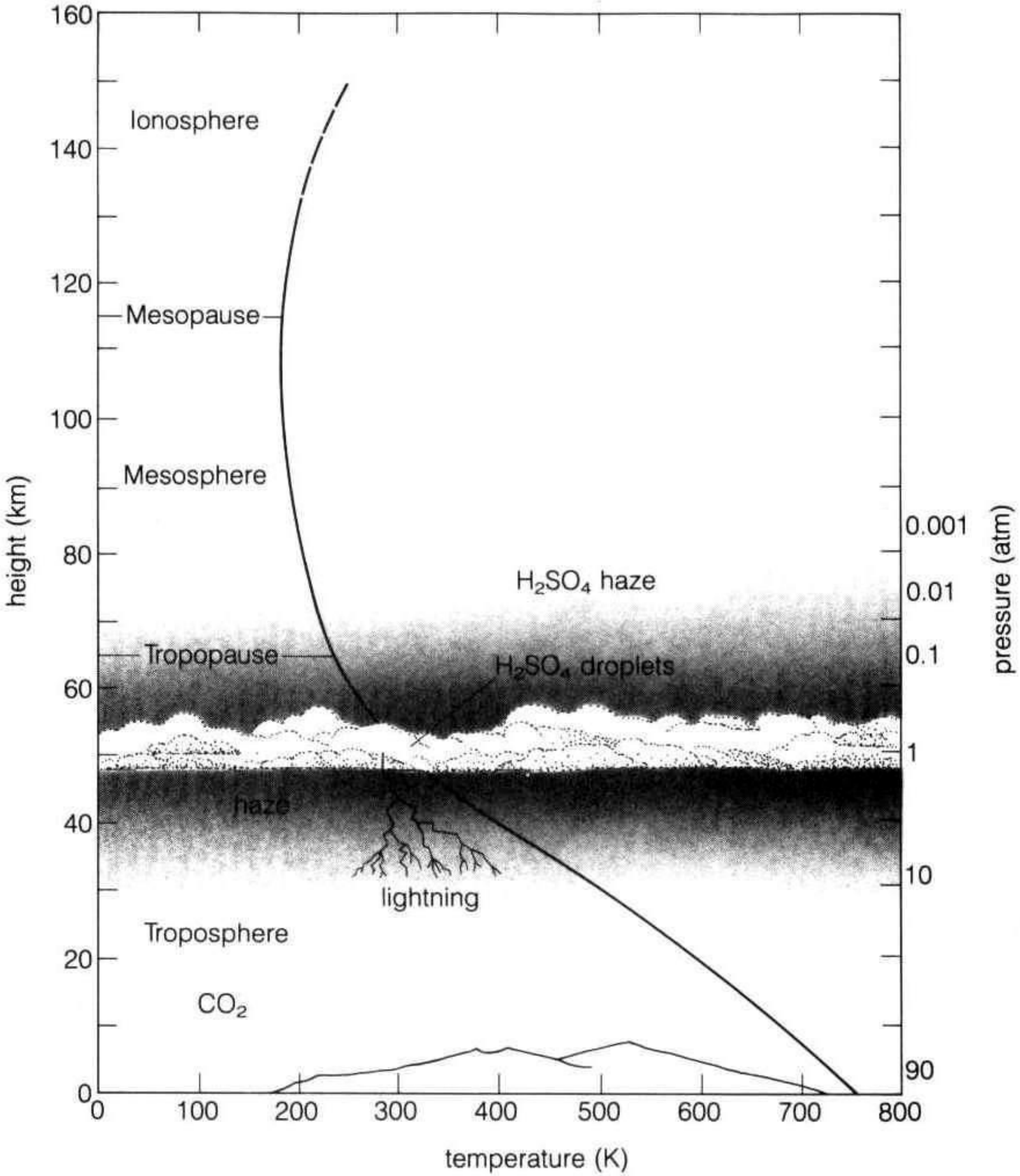


Figure 12–17. Structure and features of Venus' atmosphere, based on Pioneer and other measures.

Venus

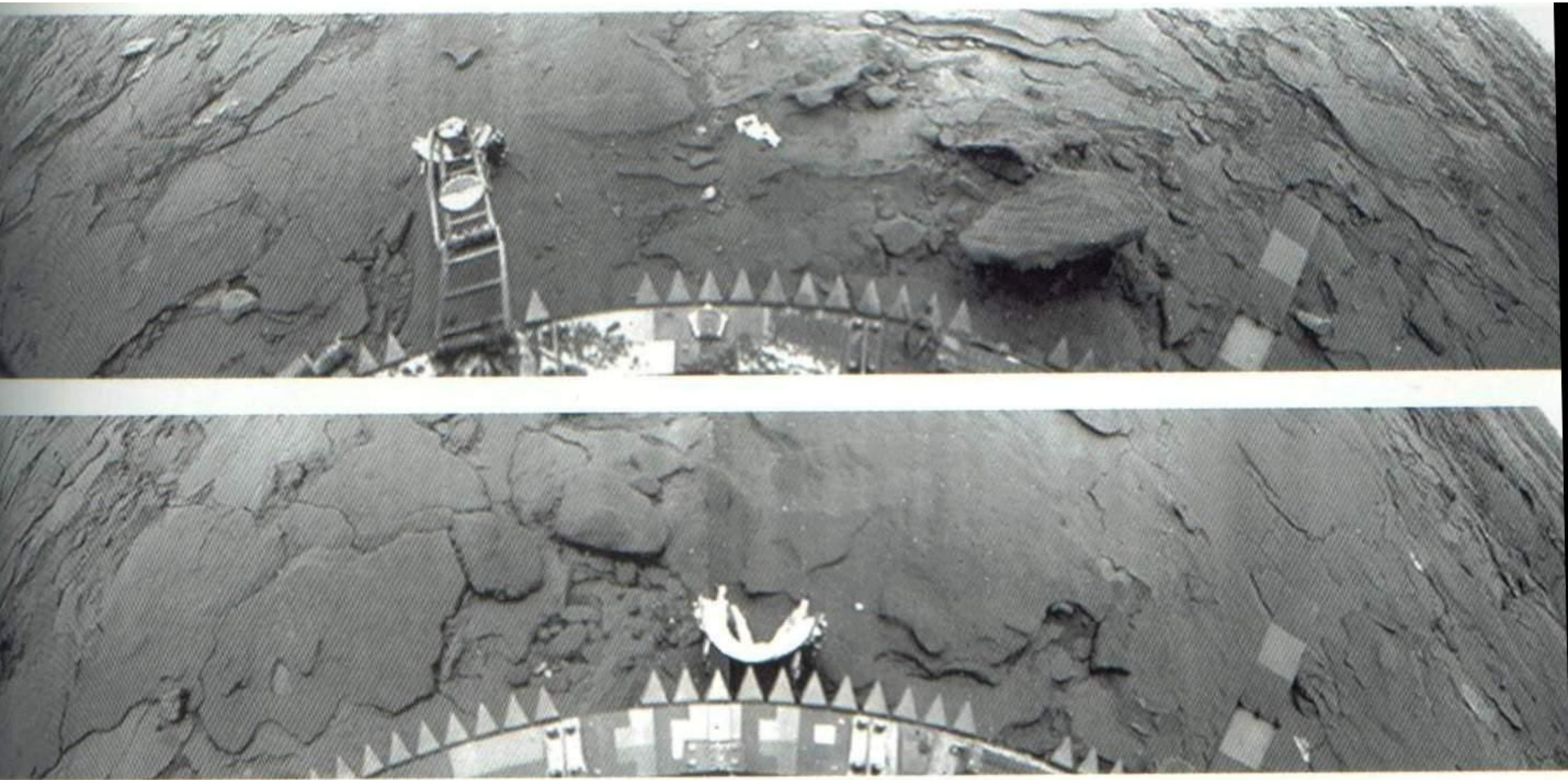


Figure 8. On 5 March 1982 the Venera 14 lander touched down on Venus at 13° south latitude and 310° east longitude, where it survived for 60 minutes before succumbing to the planet's heat. In that time it radioed to Earth these images of the Venusian surface, which include parts of the lander at bottom (a mechanical arm can be seen in the upper image, a lens cover in the lower one). The landscape appears distorted because Venera 14's wide-angle camera scanned in a tilted, sweeping arc. The horizon appears in the upper left and right corners of each scene, and the views are remarkably free of atmospheric haze. Note the dominance of slabby or platy rocks, separated by minor amounts of soil. The composition and texture of these rocks is similar to terrestrial basalts.

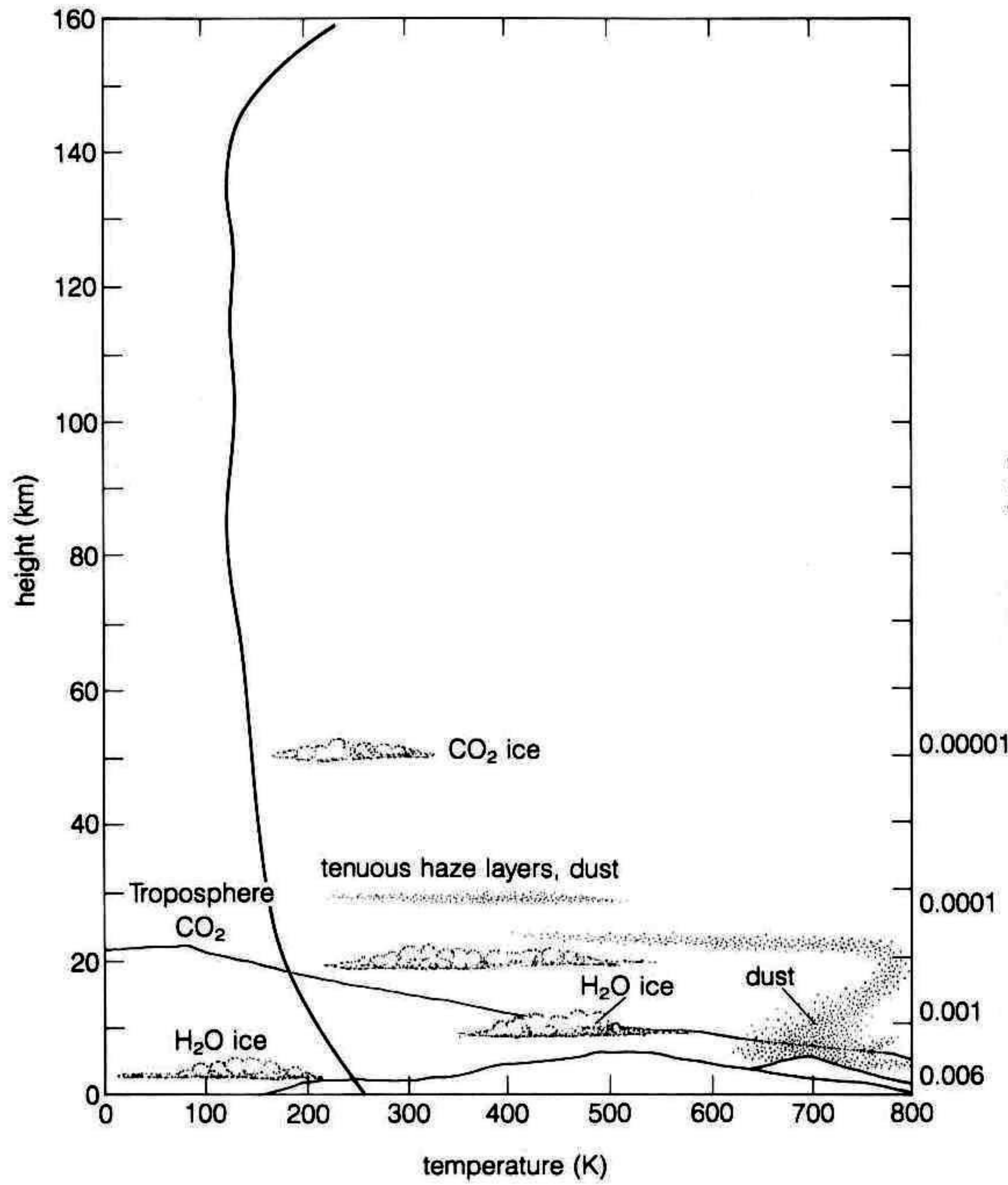
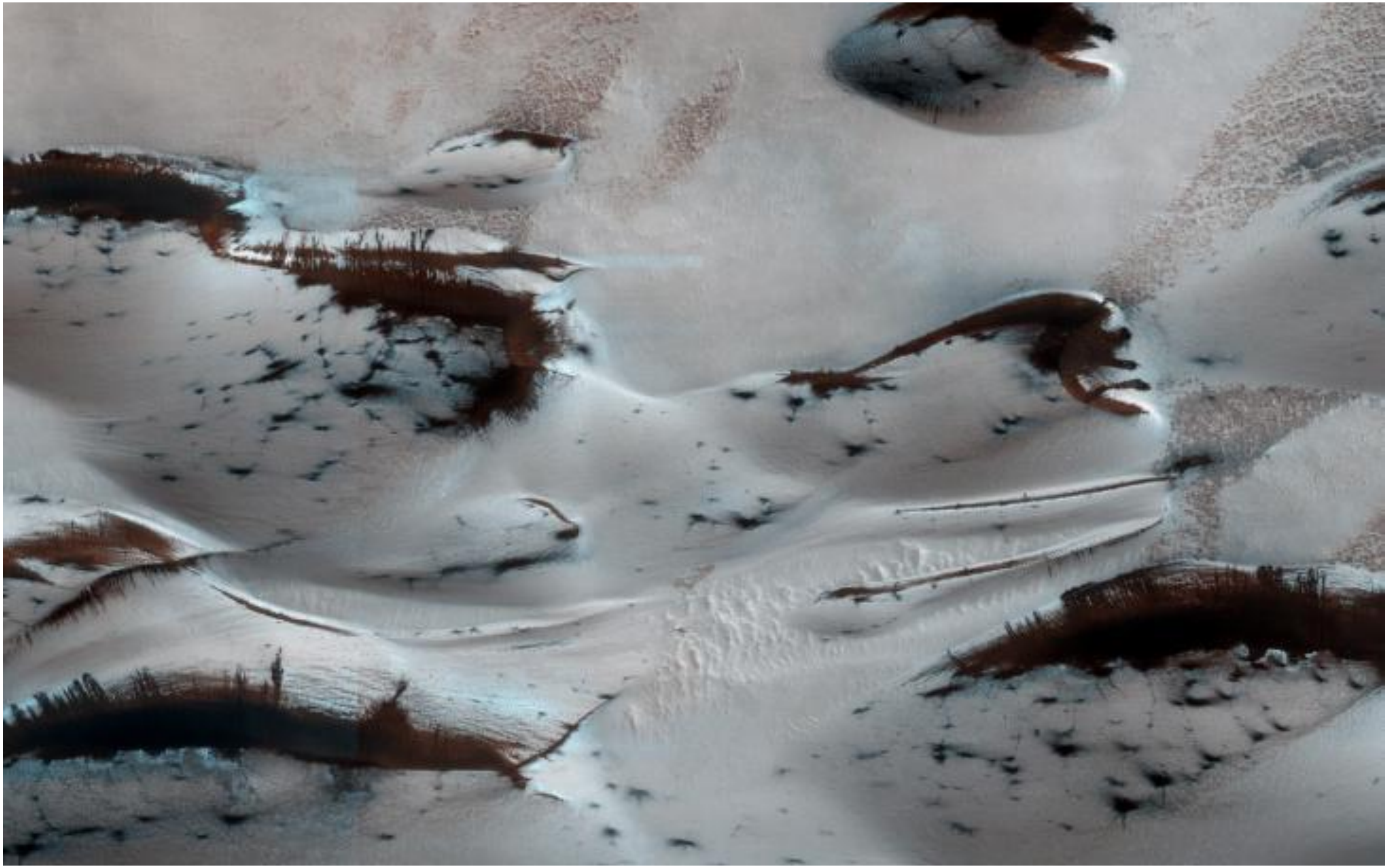


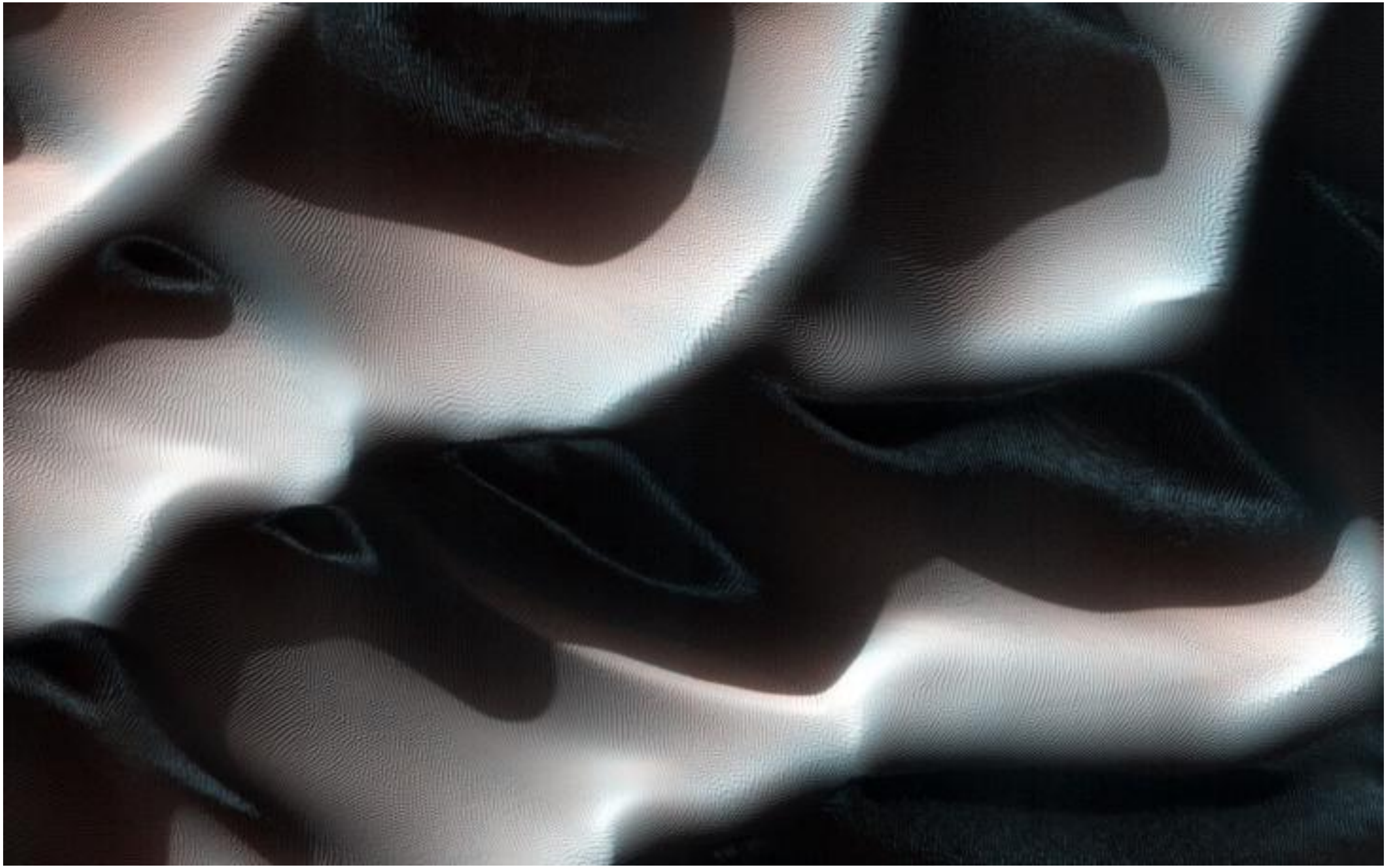
Figure 12–21. Structure and features of Mars' atmosphere, based on Viking and other measures.

Marte

- Mars' northern-most sand dunes are beginning to emerge from their winter cover of seasonal carbon dioxide (dry) ice. Dark, bare south-facing slopes are soaking up the warmth of the sun.



- This Southern autumn image captures a view of frosty dunes. The sunlight is shining on the dunes from the upper right.



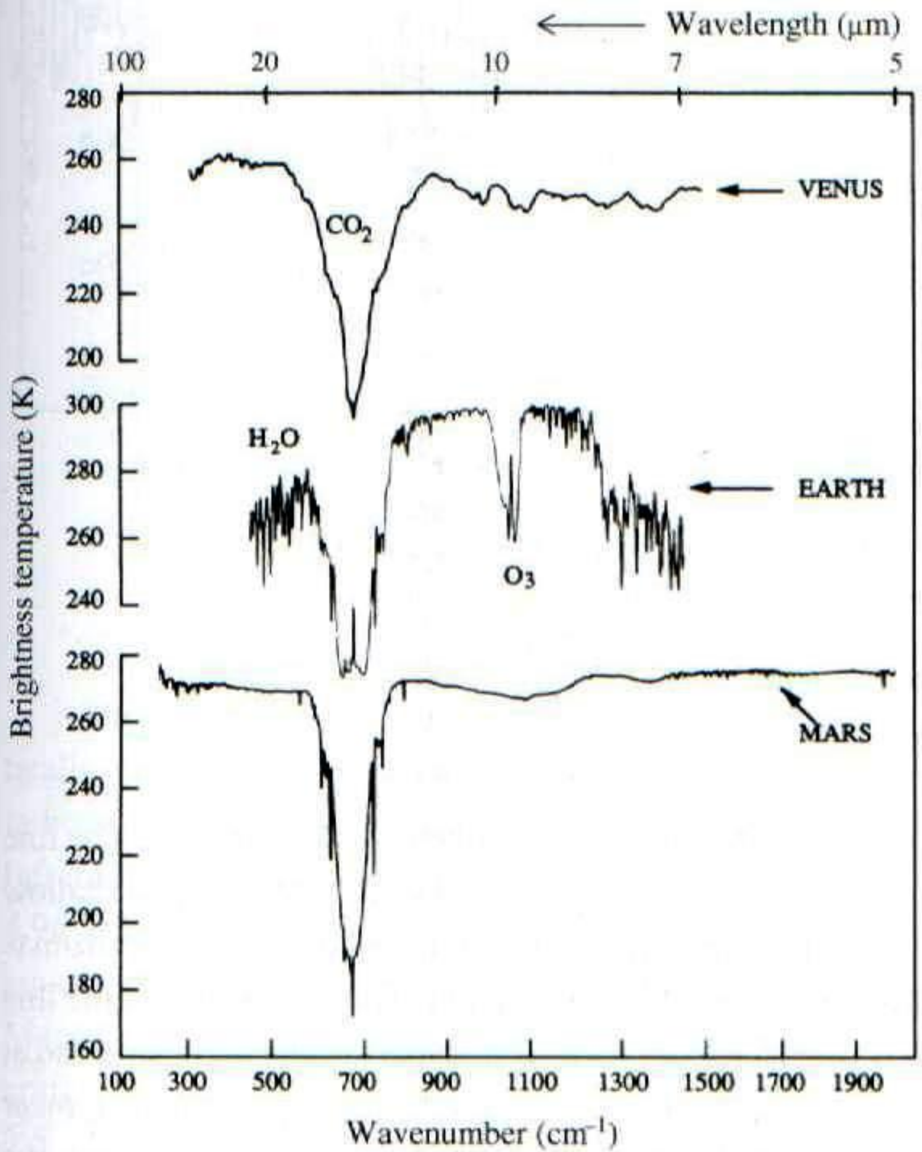


FIGURE 4.6 Thermal infrared emission spectra of Venus, Earth and Mars. The Venus spectrum was recorded by Venera 15, the spectrum of the Earth by Nimbus 4 and that of Mars by Mariner 9. (Adapted from Hanel *et al.* 1992)

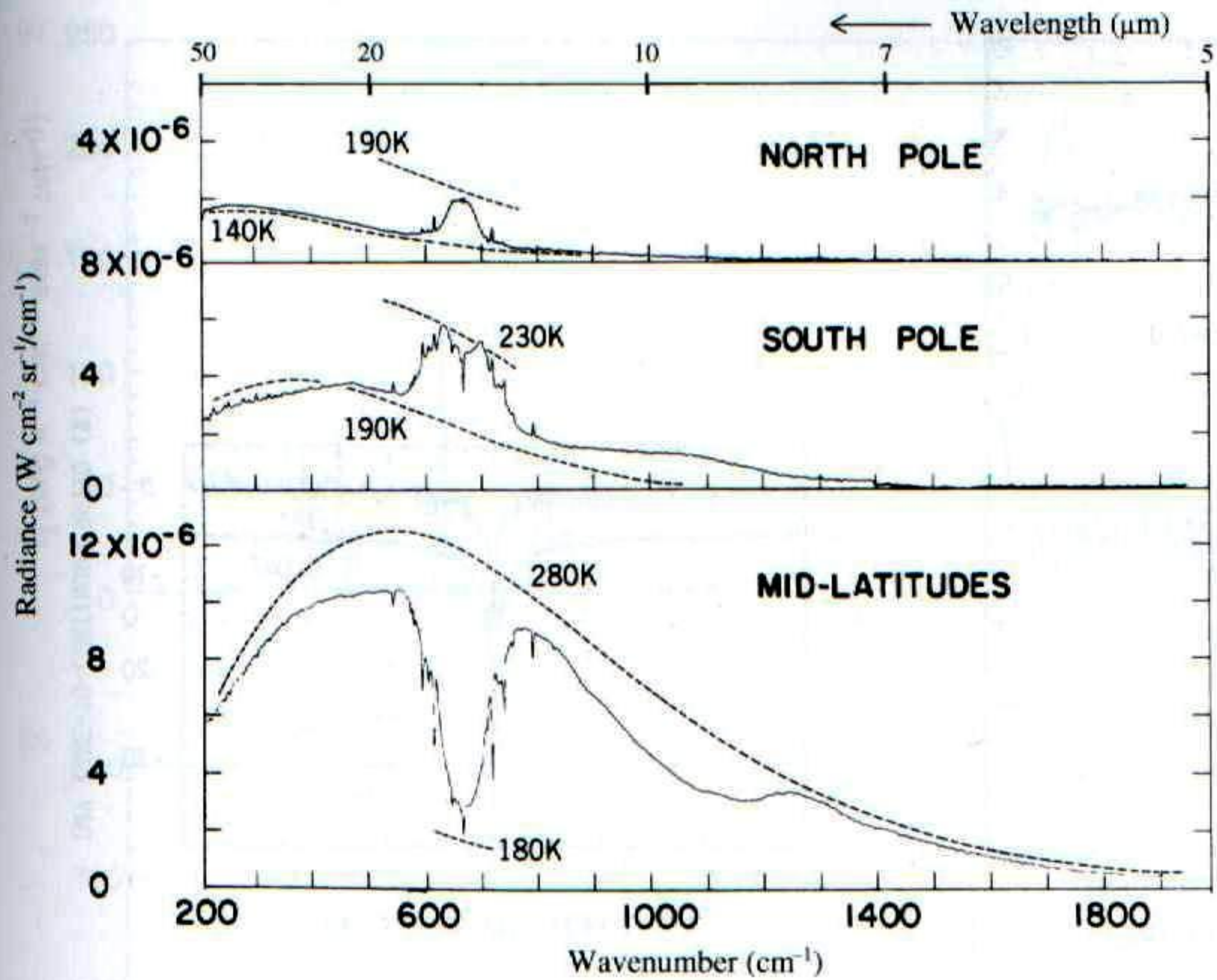


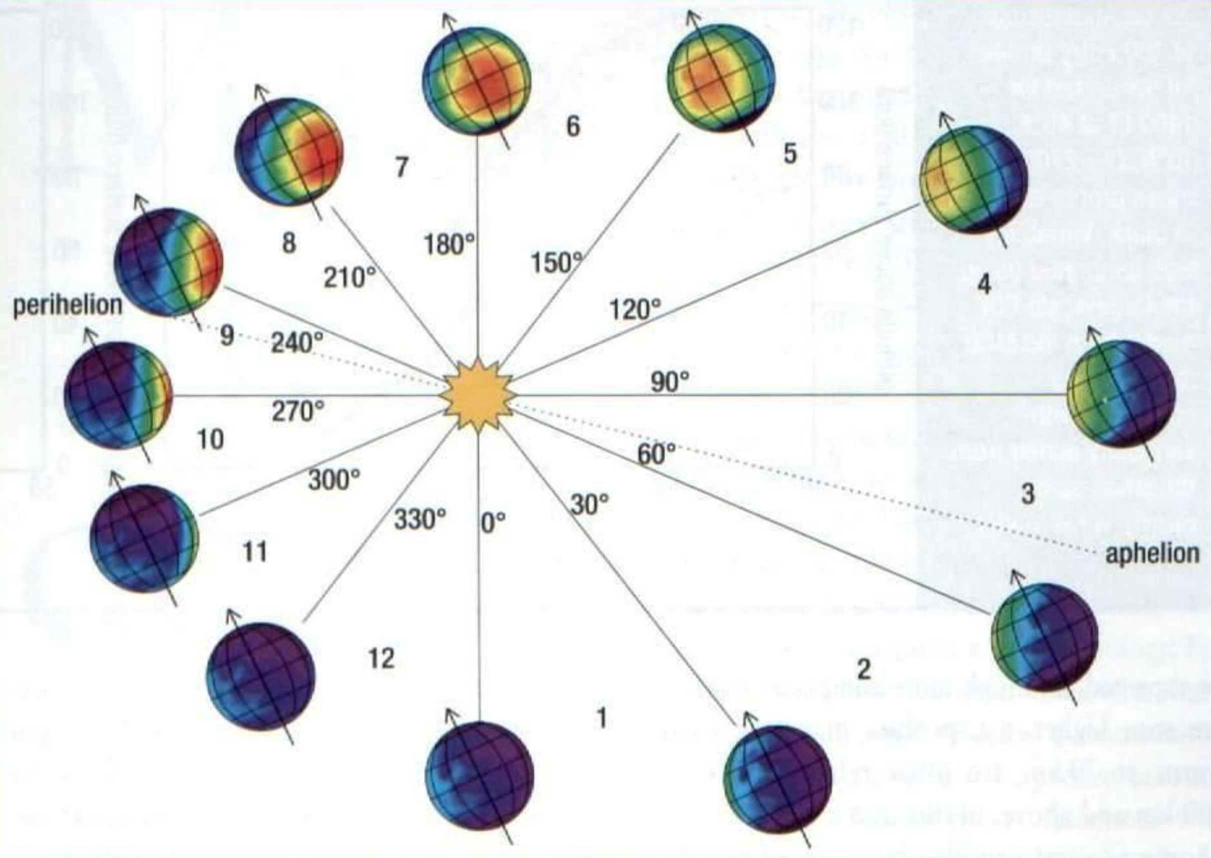
FIGURE 4.7 Thermal infrared spectra of the poles and mid-latitudes on Mars. The data were taken by the Mariner 9 spacecraft when it was late spring in the southern hemisphere. Blackbody curves at various temperatures are indicated for comparison. Note that the CO_2 feature is seen in emission in the polar spectra, while in absorption at mid-latitudes. (Adapted from Hanel *et al.* 1992)

Marte: gases CO2 y H2O sublimados en equilibrio con fase sólida.

PHILIP JAMES (UNIVERSITY OF TOLEDO) AND NASA

During local winter, a broad area surrounding the north pole of Mars is covered with a meter-thick layer of frozen carbon dioxide (left). But as spring arrives (middle and right), the seasonal blanket of dry ice returns to the atmosphere, revealing an underlying "permanent" polar cap consisting of water ice. These pole-on views were assembled from reprojected Hubble Space Telescope images.

8: A schematic diagram showing the orbit of Mars about the Sun. The orbital eccentricity (actually 0.093) has been exaggerated for clarity. The positions of aphelion and perihelion (at $L_S = 251°$) are shown by the dashed line. The 12 months used for the Mars climate database are numbered around the orbit, dividing the Martian year into equal segments of 30° areocentric longitude. Northern hemisphere spring equinox ($L_S = 0°$) is directly below the Sun as drawn, summer solstice ($L_S = 90°$) to the right, autumn equinox ($L_S = 180°$) above and winter solstice ($L_S = 270°$) to the right. The arrow indicates the rotation axis of the planet, at 25.19° obliquity. The colour shading shows the surface temperature on Mars, taken from the MCD at an approriate time of day for the position of the Sun in each case, with the colour scale varying from deep purple at 140 K to bright red at 315 K, the highest temperatures are only reached close to perihelion. The position of the polar CO_2 ice caps can be seen as a region of cold surface temperatures.



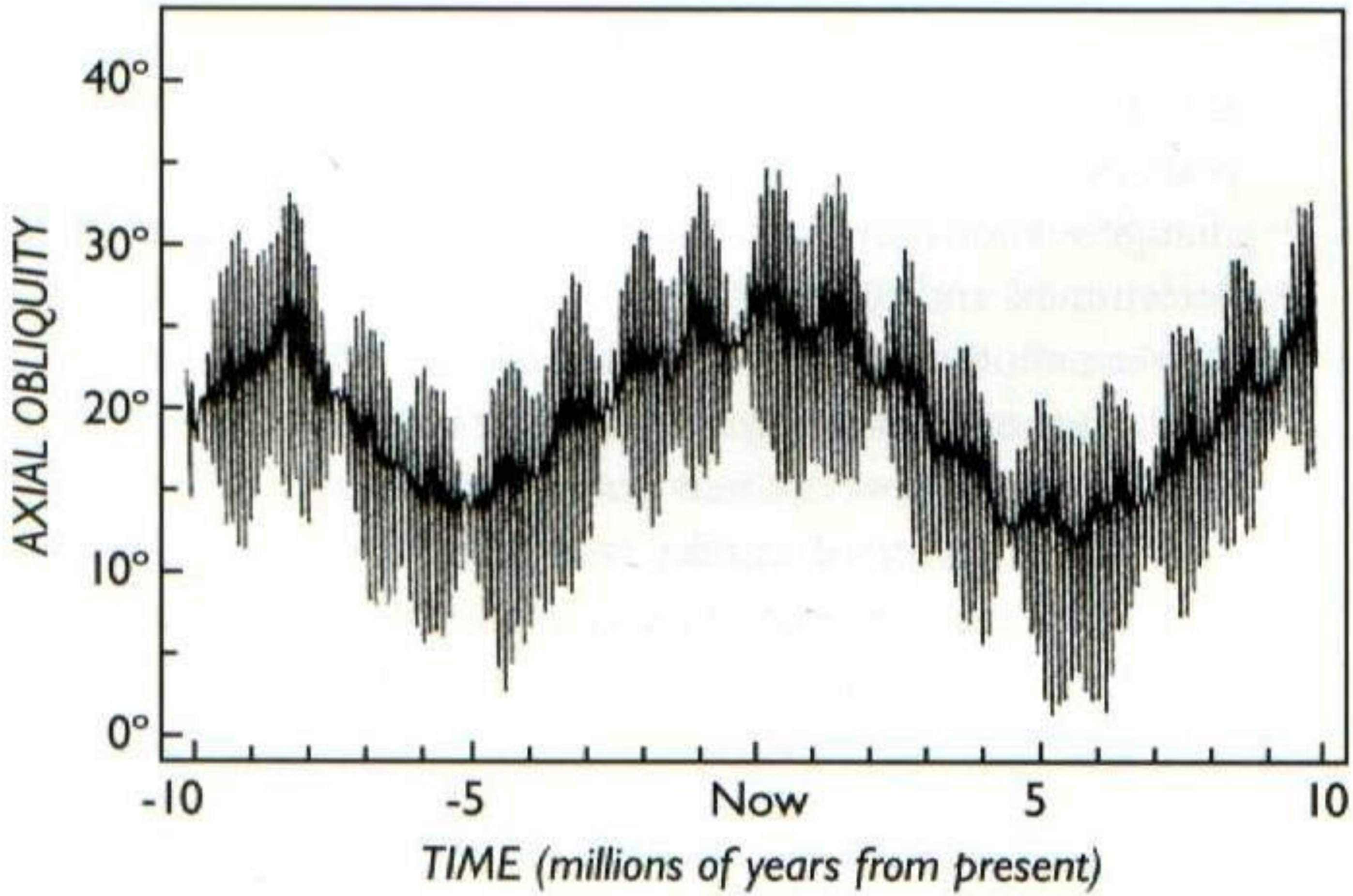
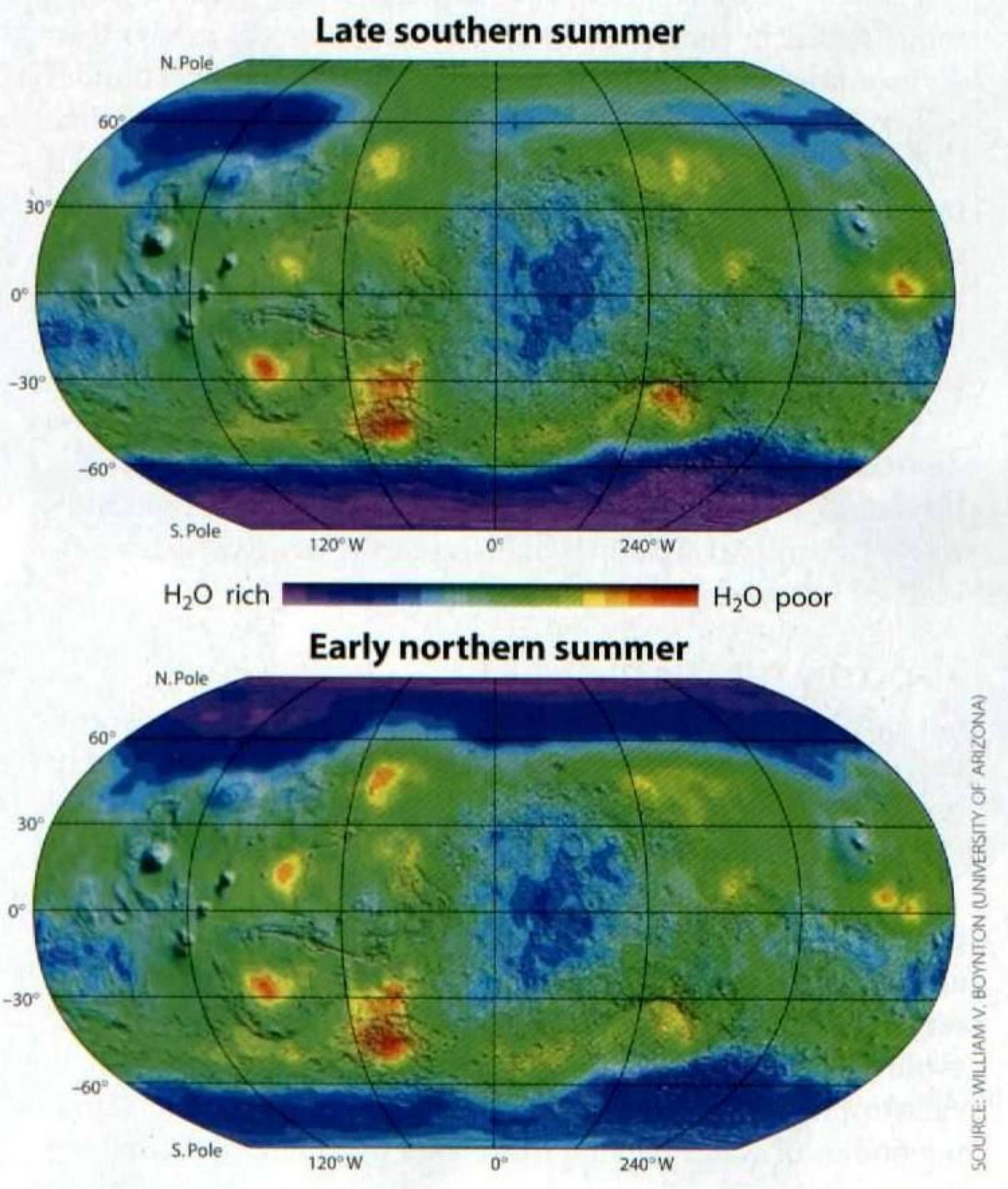


Figure 20. Calculations show that the axial obliquity of Mars oscillates with a period of about 100,000 years, with even wider excursions occurring every million years or so. These swings change the energy balance at the planet's poles, causing water and CO_2 to move into the polar regions and back out again.

VAPOR DE AGUA EN MARTE



Agua

- En Venus el efecto invernadero no permite condensar el H2O que es destruida por la radiacion UV, escapando el H2. El CO2 no se integra al suelo y permanece en la atmosfera.
- En la Tierra el vapor de agua de las erupciones volcánicas saturó la atmósfera provocando precipitaciones y los océanos. Ciclo de CO2.
- En Marte al cesar la actividad volcánica el CO2 no retorna, el agua no puede existir en estado liquido.

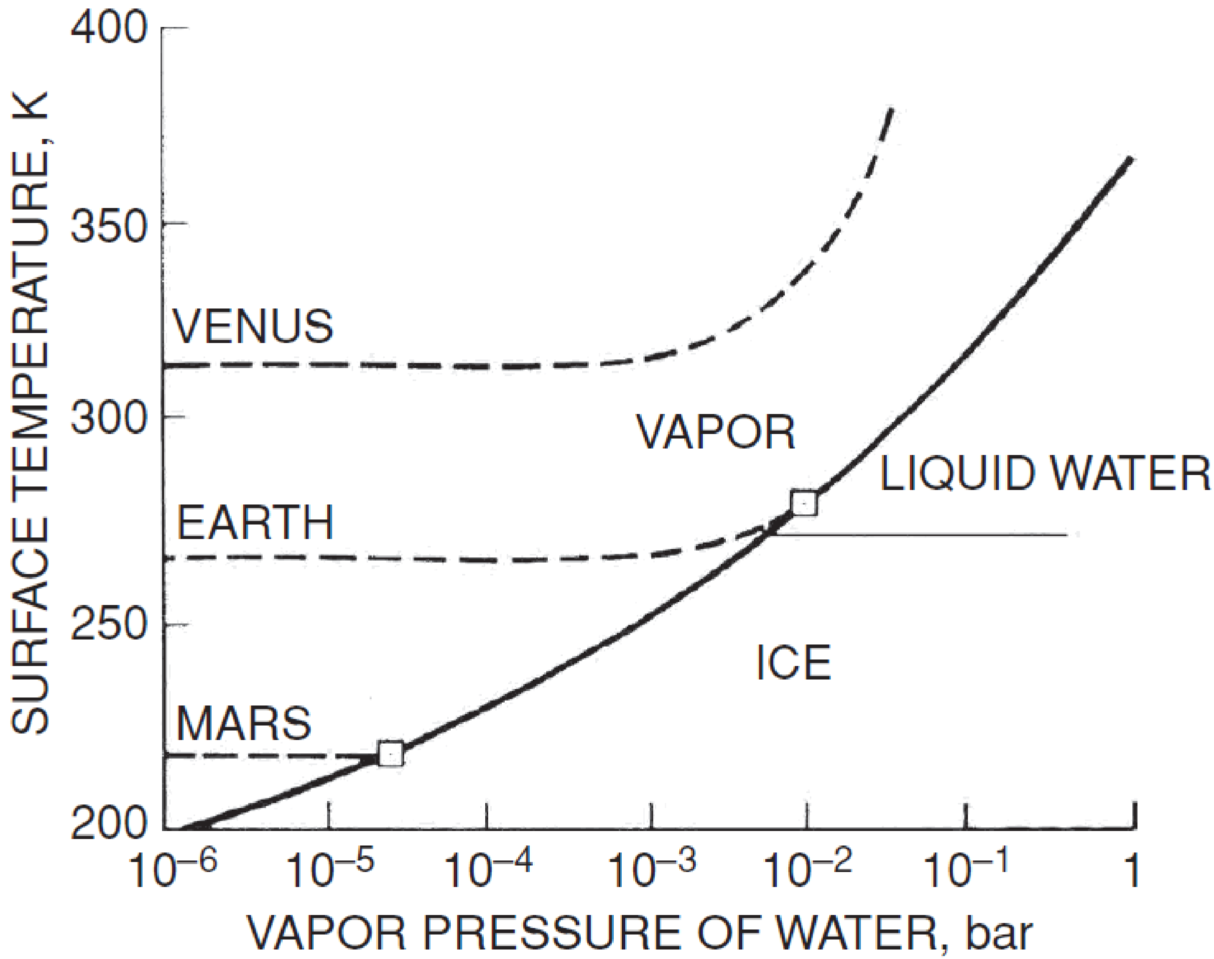
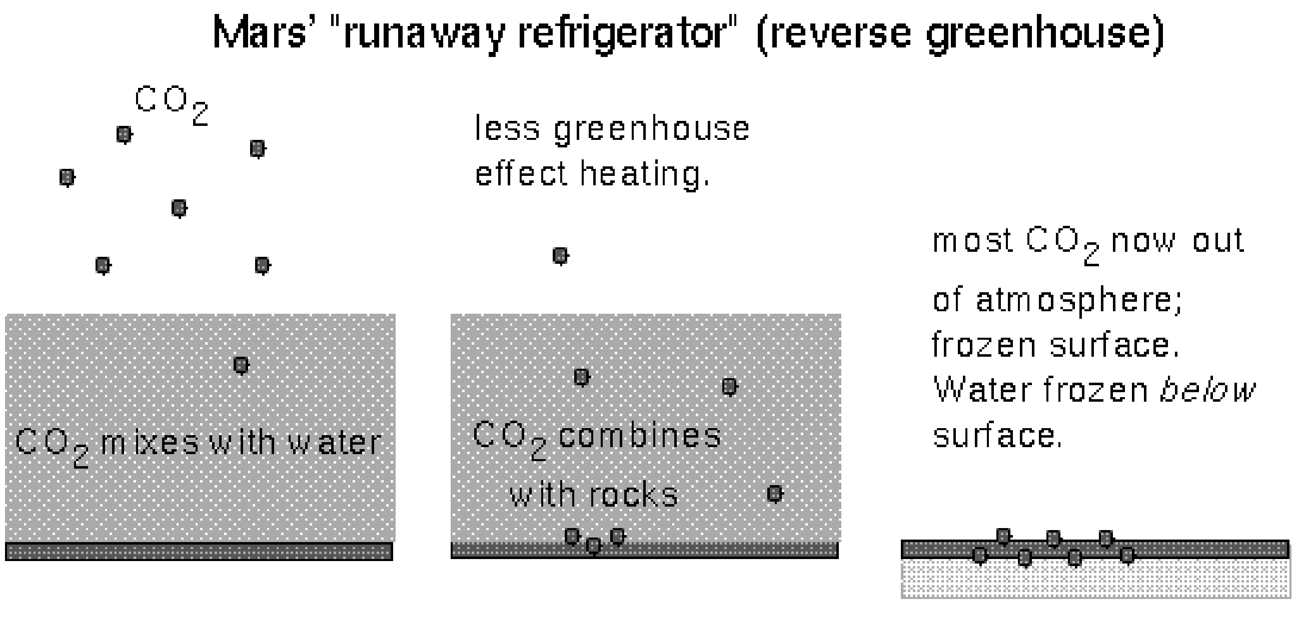
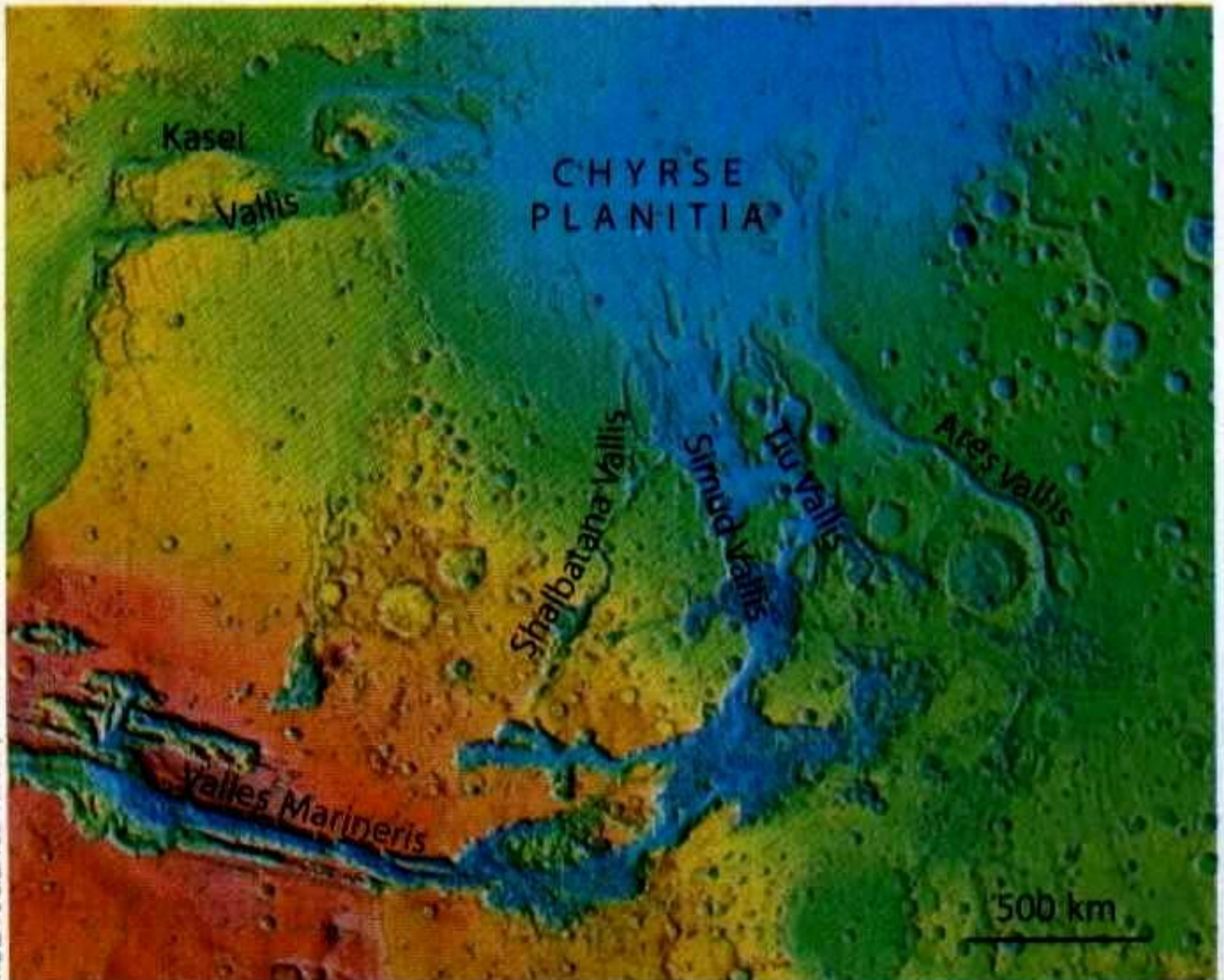


Figure 5.18 Evolution of the surface temperatures of Venus, Earth and Mars for a pure water-vapor atmosphere. (Adopted from Goody and Walker 1972)

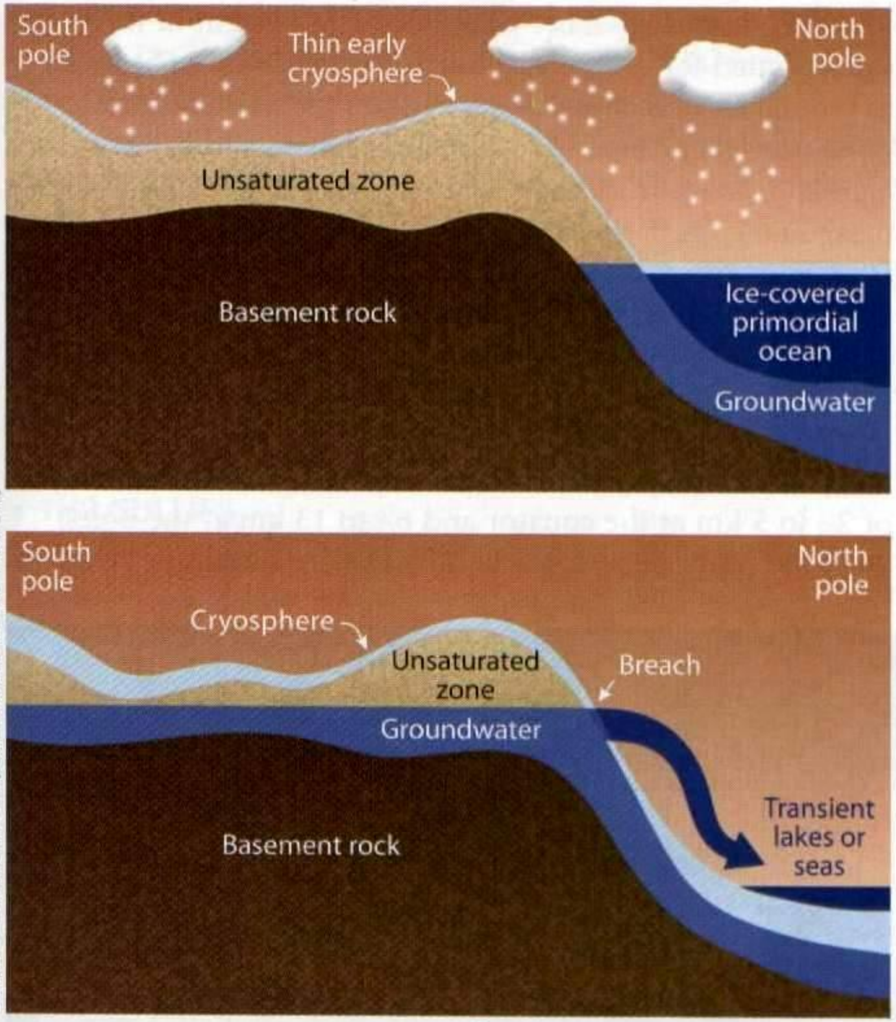
El agua en Marte





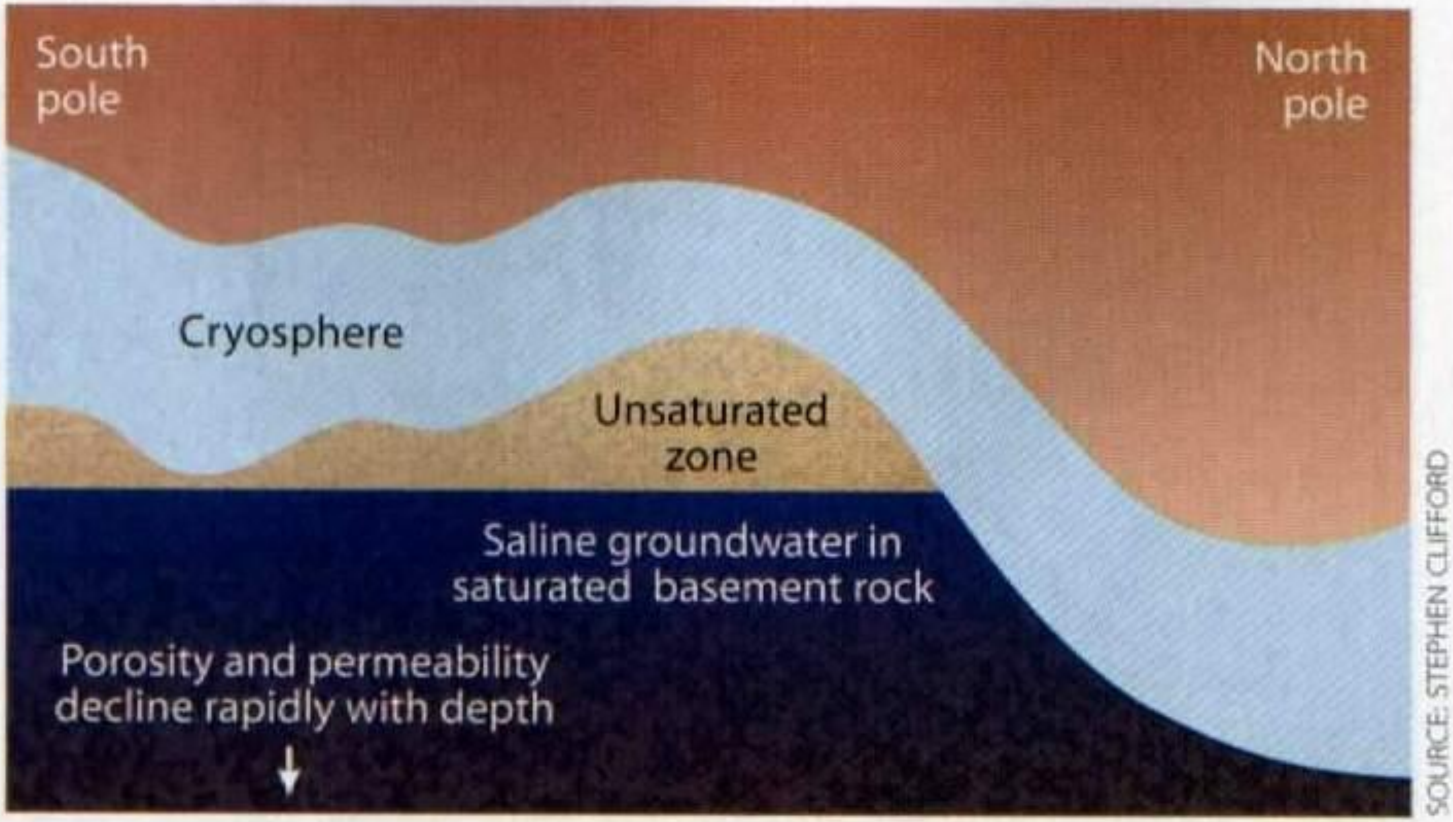
MOLA SCIENCE TEAM (NASA/GODDARD SPACE FLIGHT CENTER)

Throughout the middle of Martian geologic history, evidence suggests that catastrophic outflows repeatedly discharged huge floods onto Chryse Planitia ("Plain of Gold") from storage reservoirs in the planet's southern highlands. Similar events, elsewhere on the planet, may have occurred within the past billion years.

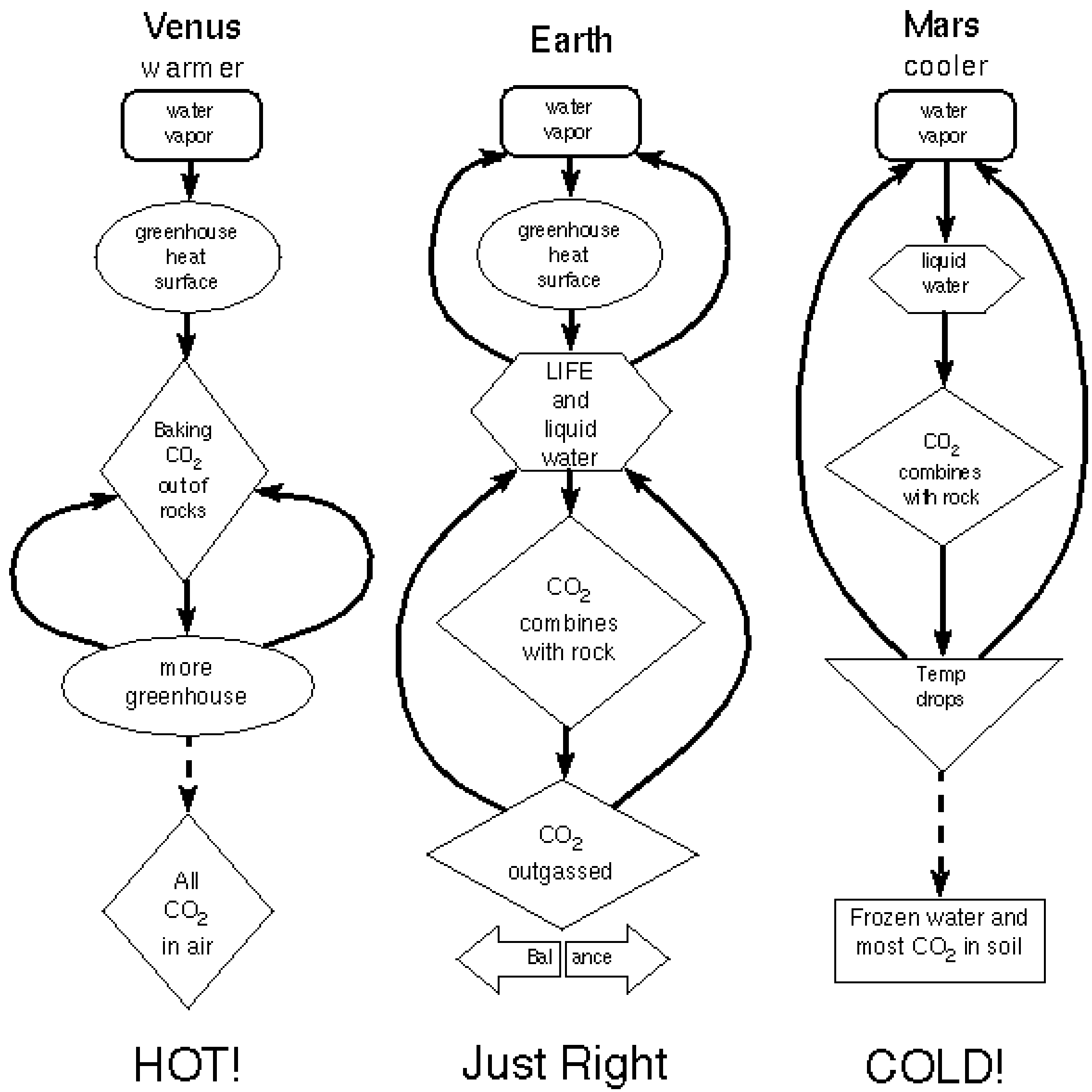


SOURCE: STEPHEN CLIFFORD (LUNAR AND PLANETARY INSTITUTE)

Top: Very early in Martian history, the planet's frozen outer crust, or cryosphere, was not yet deep enough to prevent the wholesale discharge of groundwater from the southern highlands onto the northern plains and other low-lying basins. _Above:_ Eventually the cryosphere thickened enough to trap the groundwater believed to have been introduced into the subsurface over time by melting at the ice cap's base. But huge reservoirs of fluid sporadically broke through, creating the gigantic outflow channels seen today.



Today the outer crust of Mars is frozen so solidly, and to such great depth, that any remaining liquid water should lie kilometers beneath the surface. Thus, researchers are puzzled by spacecraft views showing evidence of recent flows across the Martian landscape.



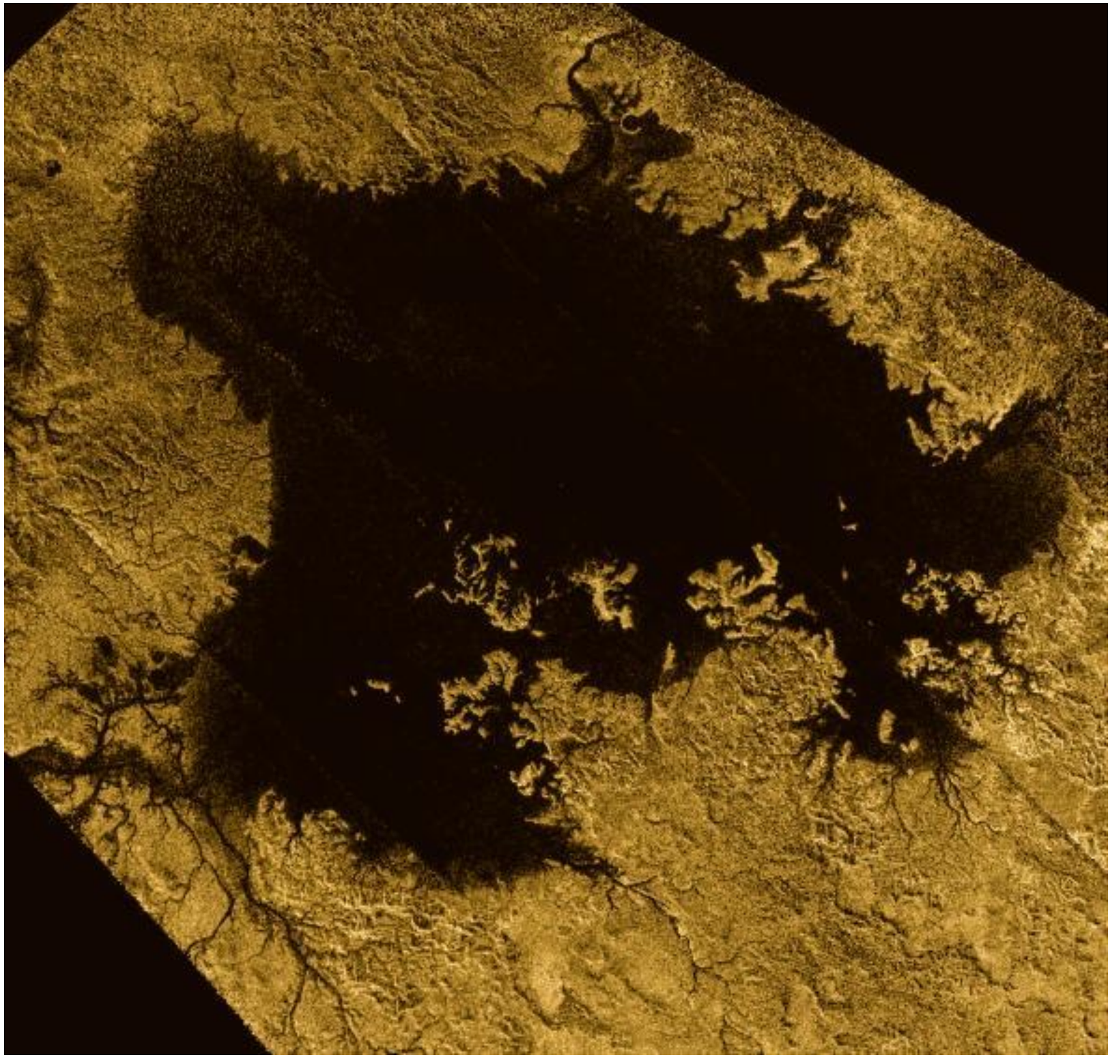
Venus has runaway greenhouse effect and no water left. Earth has life and liquid water keeping temperature balanced and most of its CO_2 in the rocks. Mars has runaway refrigerator with water frozen in permafrost layer and most of its CO_2 in the rocks or frozen on the surface.

Titán

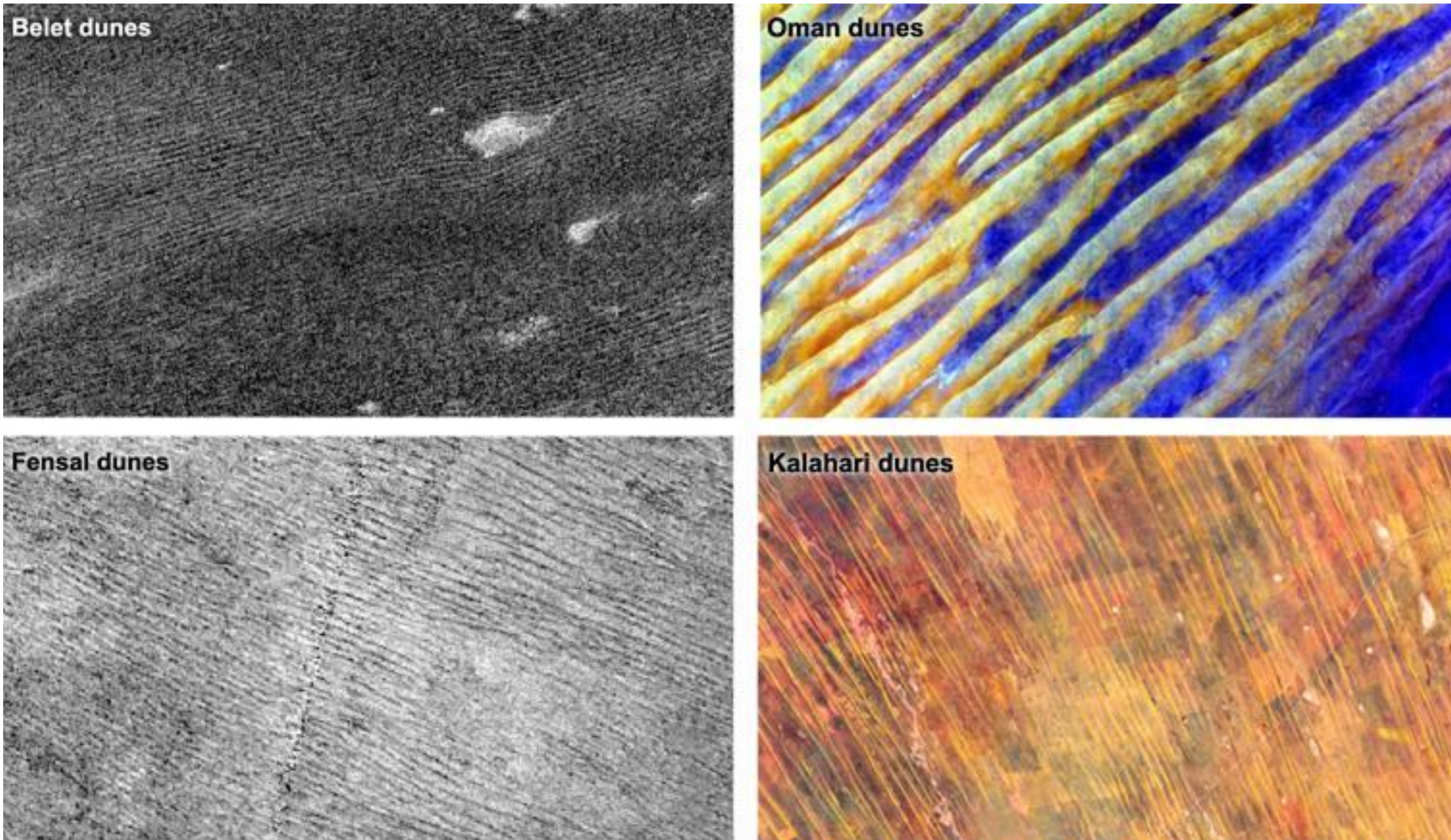
Titán

- Saturn's largest and second largest moons, Titan and Rhea, appear to be stacked on top of each other in this true-color scene from NASA's Cassini spacecraft.

Ligeia Mare, shown here in a false-color image from NASA's Cassini mission, is the second largest known body of liquid on Saturn's moon Titan. It is filled with liquid hydrocarbons, such as ethane and methane, and is one of the many seas and lakes that bejewel Titan's north polar region.



- Data from NASA's Cassini spacecraft show that the sizes and patterns of dunes on Saturn's moon Titan vary as a function of altitude and latitude.



2. ATMÓSFERAS TENUES

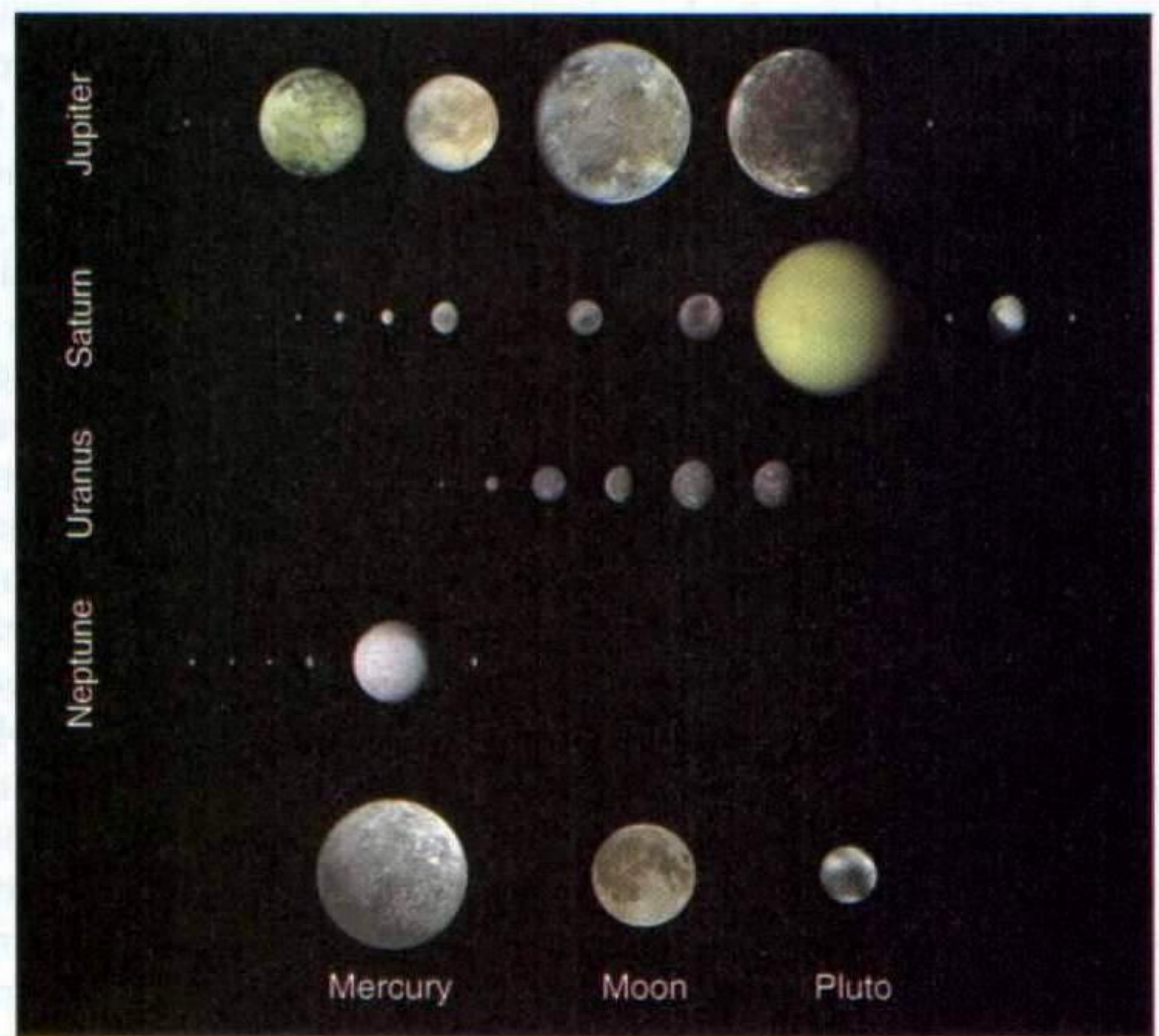
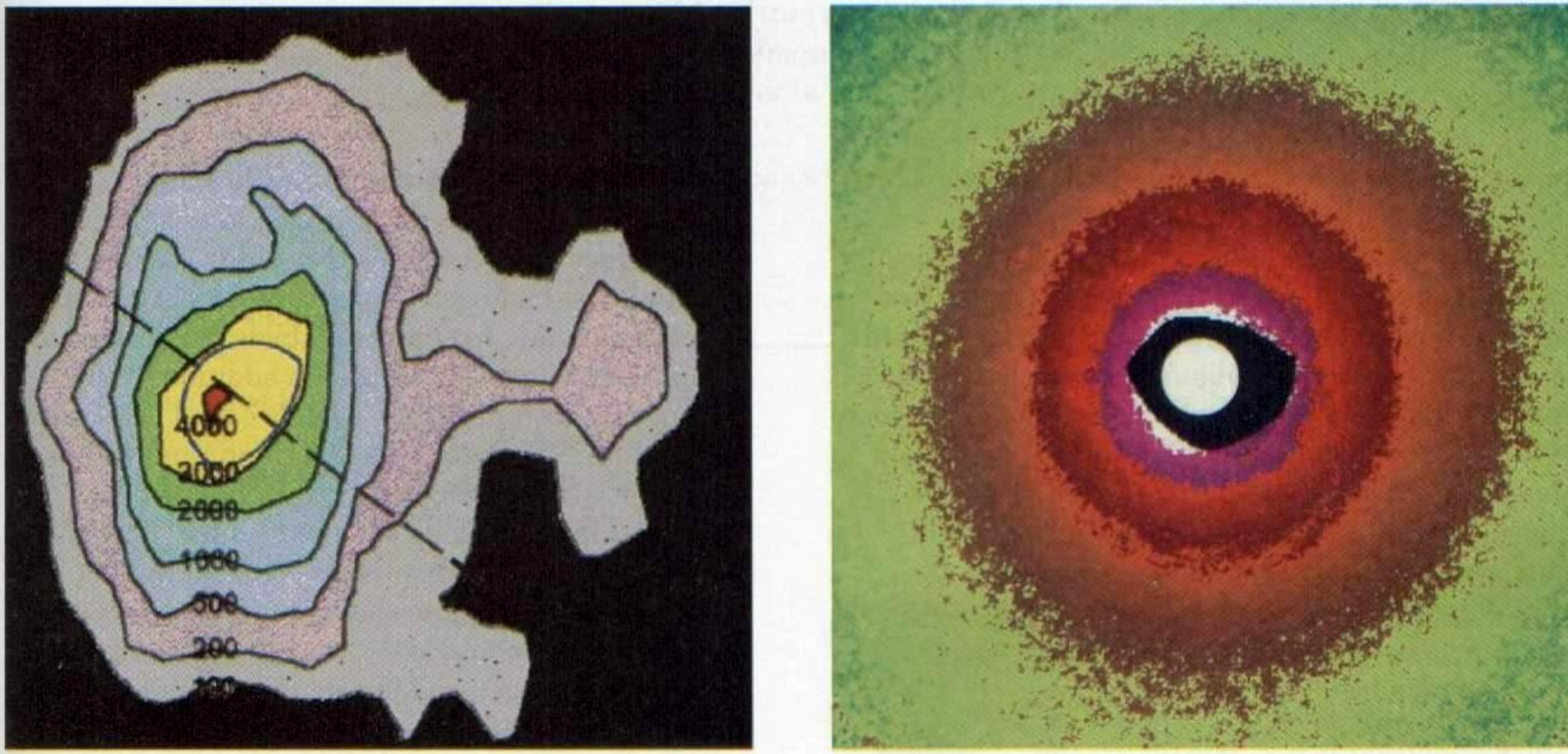


TABLE 4.4 Composition of Planets and Satellites with Tenuous Atmospheres[a].

Planet	Constituent	Abundance (cm^{-3})	References
Mercury	O	4×10^4	1
	Na	3×10^4	
	He	6×10^3	
	K	500	
	H	23 (suprathermal)	
		230 (thermal)	
	Ca	~ 30	2
Moon	He	2×10^3 (day)–4×10^4 (night)	1, 3, 4
	Ar	1.6×10^3 (day)–4×10^4 (night)	
	Na	70	
	K	16	
Pluto	N_2		5
	CO	trace	
	CH_4	trace	
Triton	N_2		6
	CH_4	trace	
Io[b]	SO_2	10^{11}–10^{12}	7
	SO	trace	
	Na		8
	K		
	O		

Impactos Cometarios, Viento Solar, Fotones

Gas sublimado en equilibrio con fase sólida

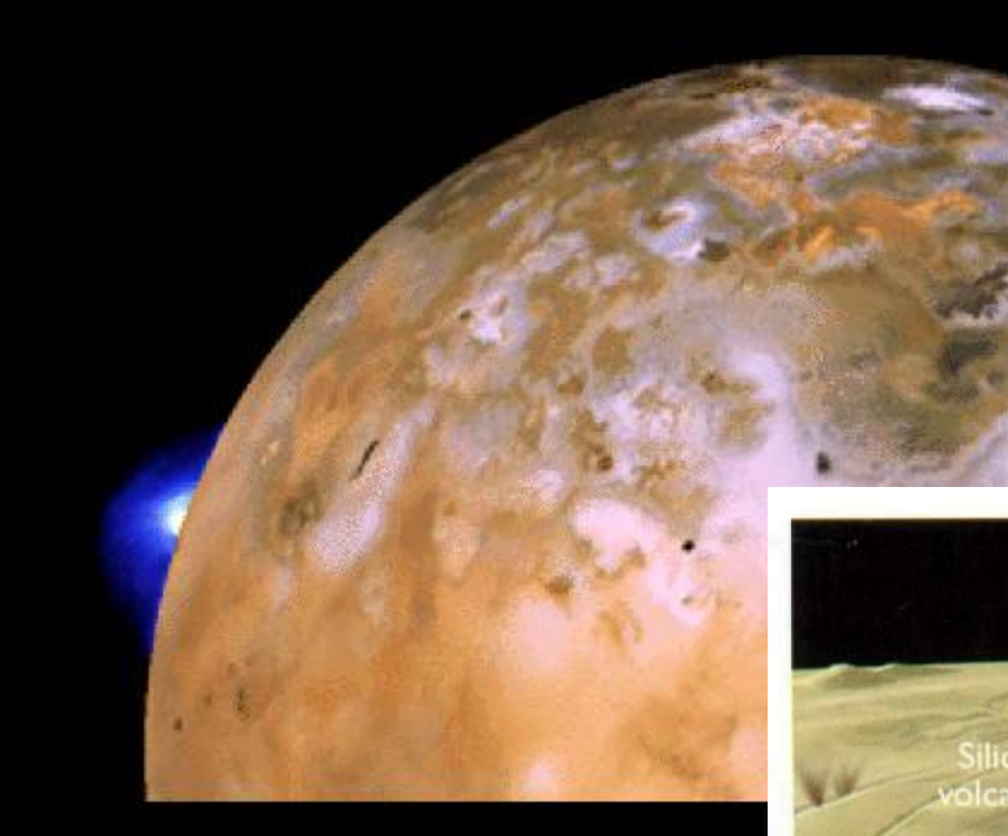


a Mercury's atmosphere. Color-coded contours represent the gas density from lowest (black) to highest (red). Mercury's partially illuminated disk is indicated as the gibbous-shaped blue contour near the center (just within the yellow region); the Sun lies to the left along the direction of the dashed line.

b The Moon's atmosphere. This composite image represents the gas density from lowest (green) to highest (red). The Moon itself was blocked to make this image, resulting in the central black area of no data. The Moon's size is shown schematically by the white circle.

FIGURE 10.24 The atmospheres of Mercury and the Moon—which are essentially exospheres only—viewed through instruments sensitive to emission lines from sodium atoms. Although these are extremely low-density atmospheres, they extend quite high.

Mercurio y Luna



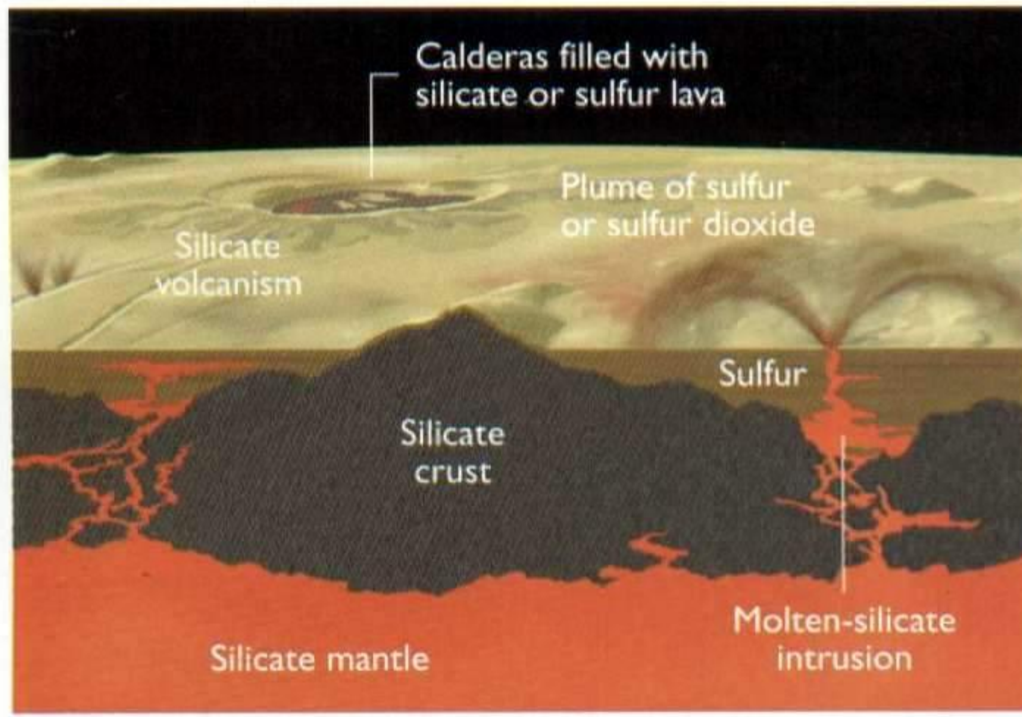
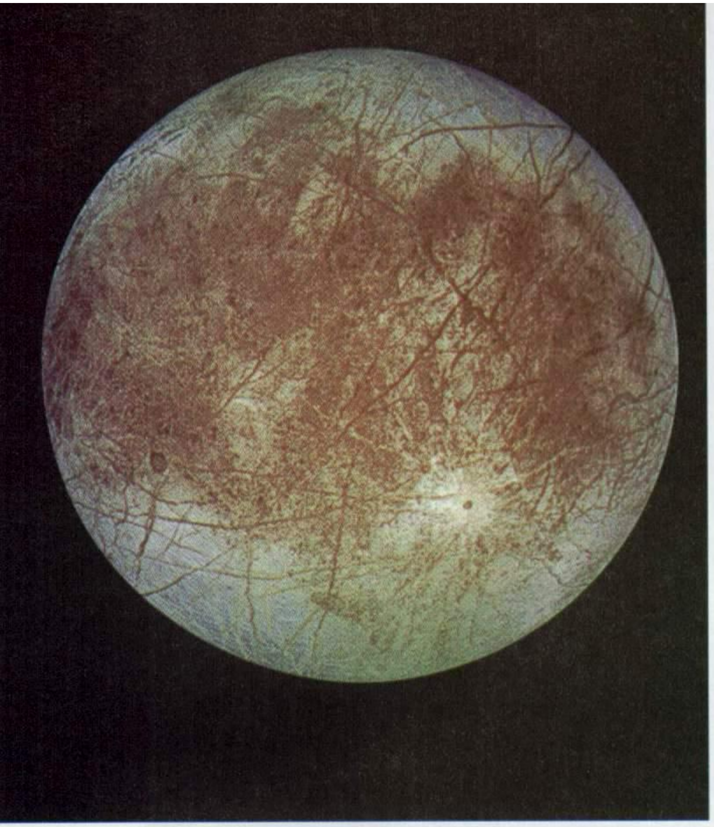


Figure 14. A schematic depiction (not to scale) of most of the major phenomena found on Io. As described in the text, at least three distinct types of active volcanism appear to be reworking the satellite's surface and outer layers of crust.

Io

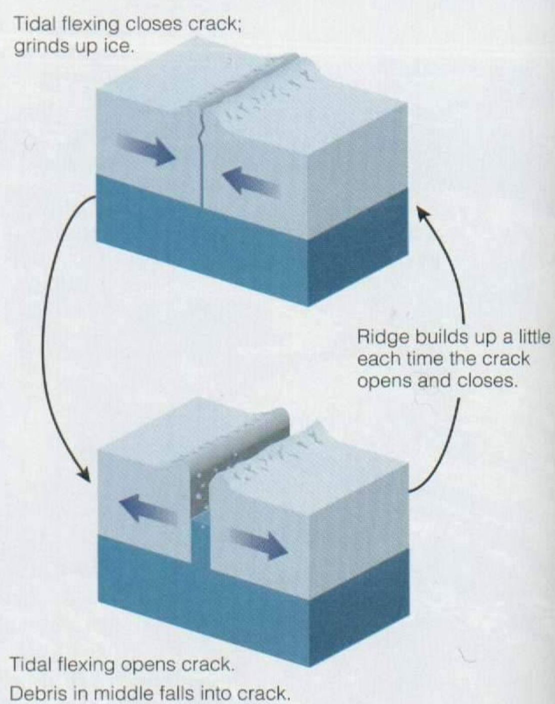
Europa



a Europa's icy crust is criss-crossed with cracks.

b Some regions show jumbled crust with icebergs, apparently frozen in slush.

c Close-up photos show that surface cracks have a double-ridged pattern.



d A possible mechanism for making the double-ridged surface cracks.

FIGURE 11.20 Europa is one of the most intriguing moons in the solar system.

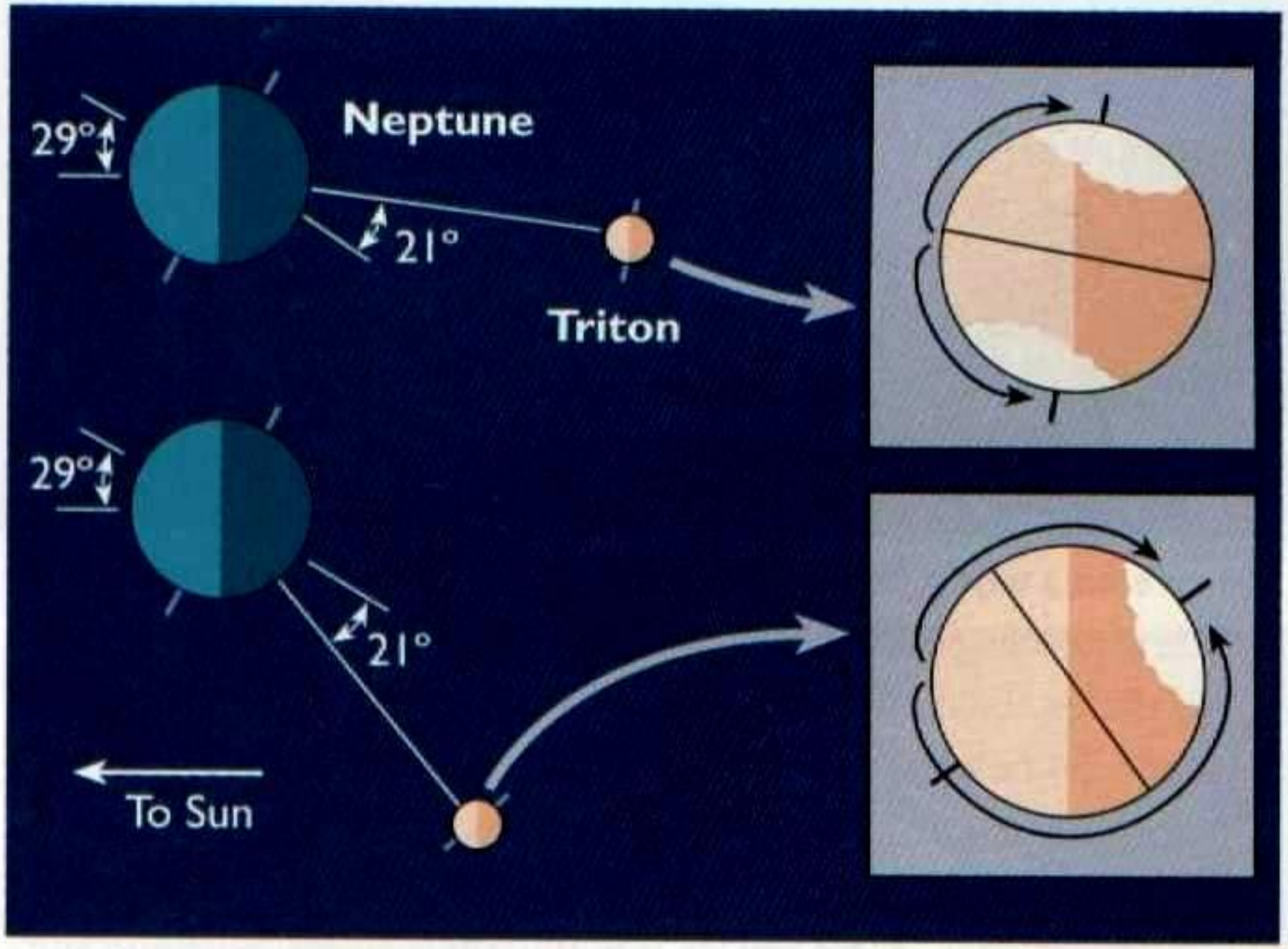
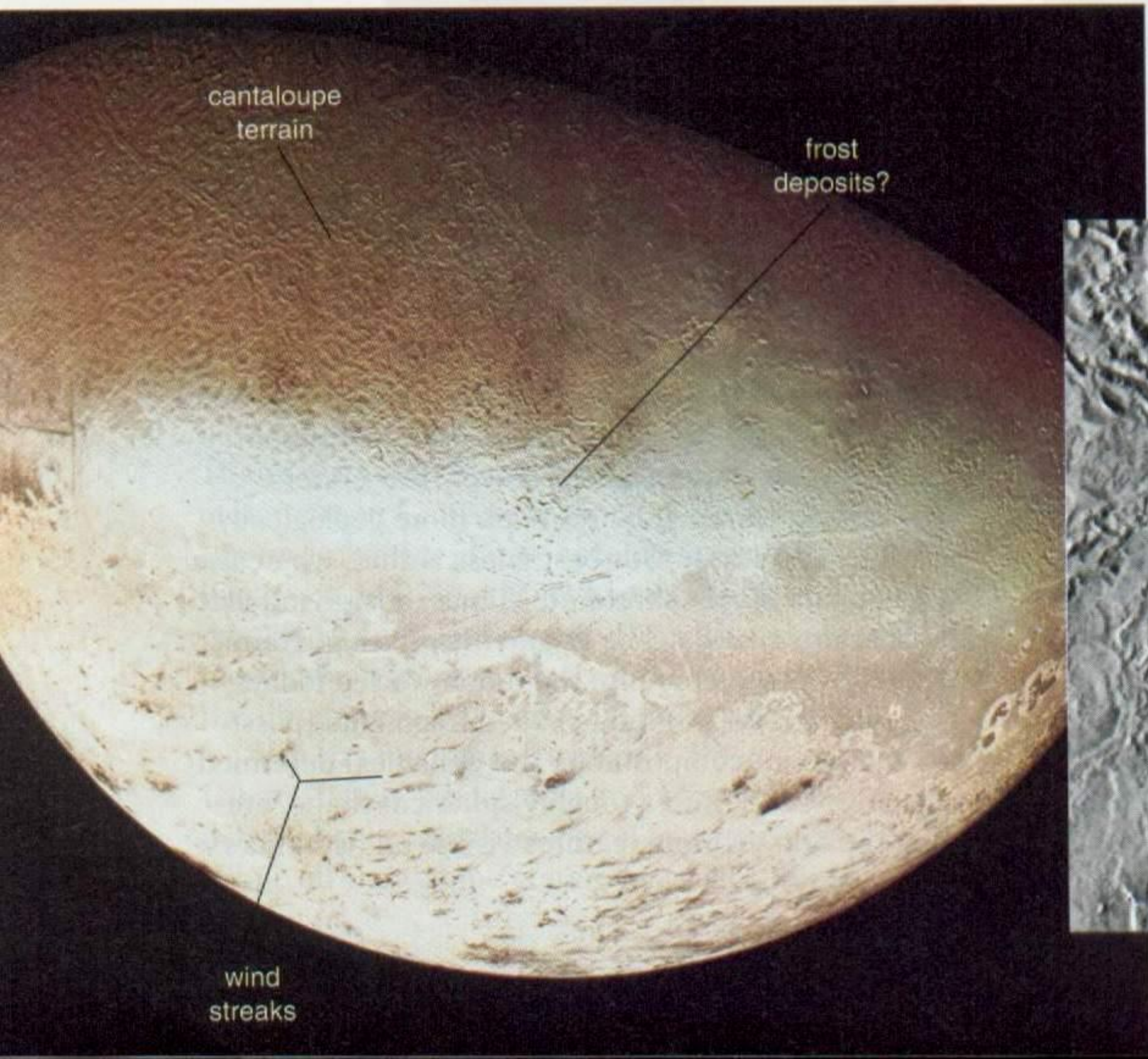


Figure 9. At certain times in Triton's 688-year climate cycle the Sun is almost directly over the equator (upper half), which causes atmospheric gases to migrate toward a pair of polar caps. But at the seasonal extremes (lower half) one cap basks in constant sunlight and disappears, while the other, in shadow, accumulates large deposits of ice condensing from the atmosphere.

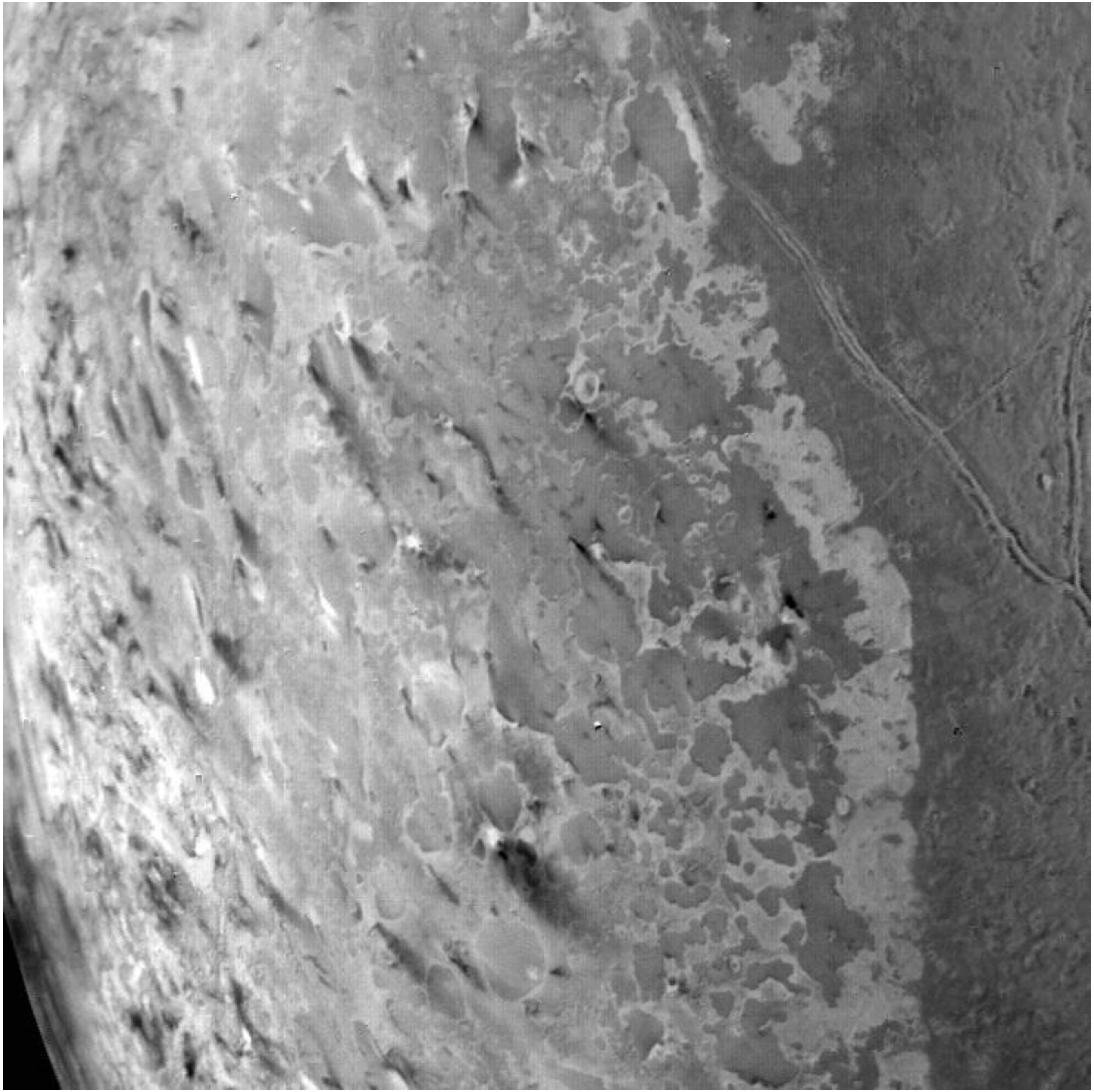
Tritón

FIGURE 11.26 Neptune's moon Triton.

a Triton's southern hemisphere as seen by *Voyager 2*.



b The flat regions in this close-up photo of Triton's surface may be lava-filled impact basins similar to the lunar maria.



Plutón y Caronte

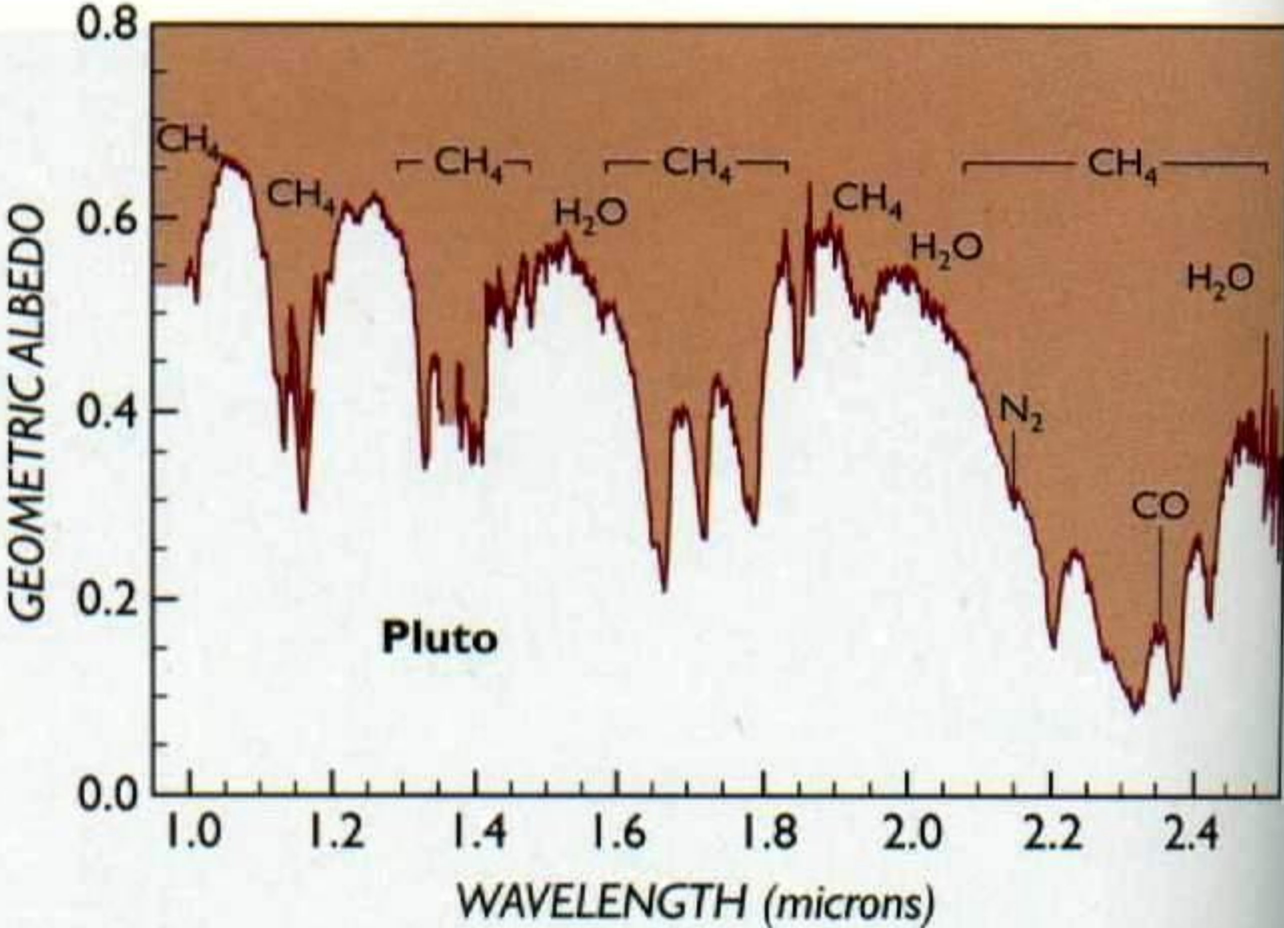


Figure 15. Pluto's surface is covered with a mixture of four different kinds of ice — the same ones Triton has, with the exception that carbon dioxide has not been found. Comparison of this spectrum with that of Triton (*Figure 6*) suggests that Pluto has about twice as much methane on its surface, and possibly less nitrogen ice, as Triton has.

Figure 8. **Ammonia-water eutectic melt, a probable outer solar system lava, is mobile even at 176° K and flows like cold honey (or basaltic magma).**

Cambios climáticos de largo plazo producidos por:

- Incremento de la luminosidad del Sol
- Variación de inclinación del eje de rotación
- Variaciones de albedo
- Abundancia de gases absorbentes de IR

3. PLANETAS JOVIANOS

- Atmósferas primordiales, gases capturados de la nebulosa solar

Table E.13 **Atmospheric Composition of the Sun and the Giant Planets**[a]

Gas	Element[b]	Protosolar	Jupiter	Saturn	Uranus	Neptune
H_2	H	0.835	0.864	0.88	$\sim$0.83	$\sim$0.82
He	He	0.162	0.136	0.119	$\sim$0.15	$\sim$0.15
H_2O	O	8.56×10^{-4}	$>4.2 \times 10^{-4}$			
CH_4	C	4.60×10^{-4}	2.0×10^{-3}	4.5×10^{-3}	0.023	0.03
NH_3	N	1.13×10^{-4}	7×10^{-4}	5×10^{-4}		
H_2S	S	2.59×10^{-5}	7.7×10^{-5}			

[a] From Table 4.5 of de Pater and Lissauer (2010). References and details are given therein. All numbers are volume mixing ratios (i.e., mole fractions).

[b] The elements O, C and N are in the form of H_2O, CH_4 and NH_3 on the giant planets, respectively.

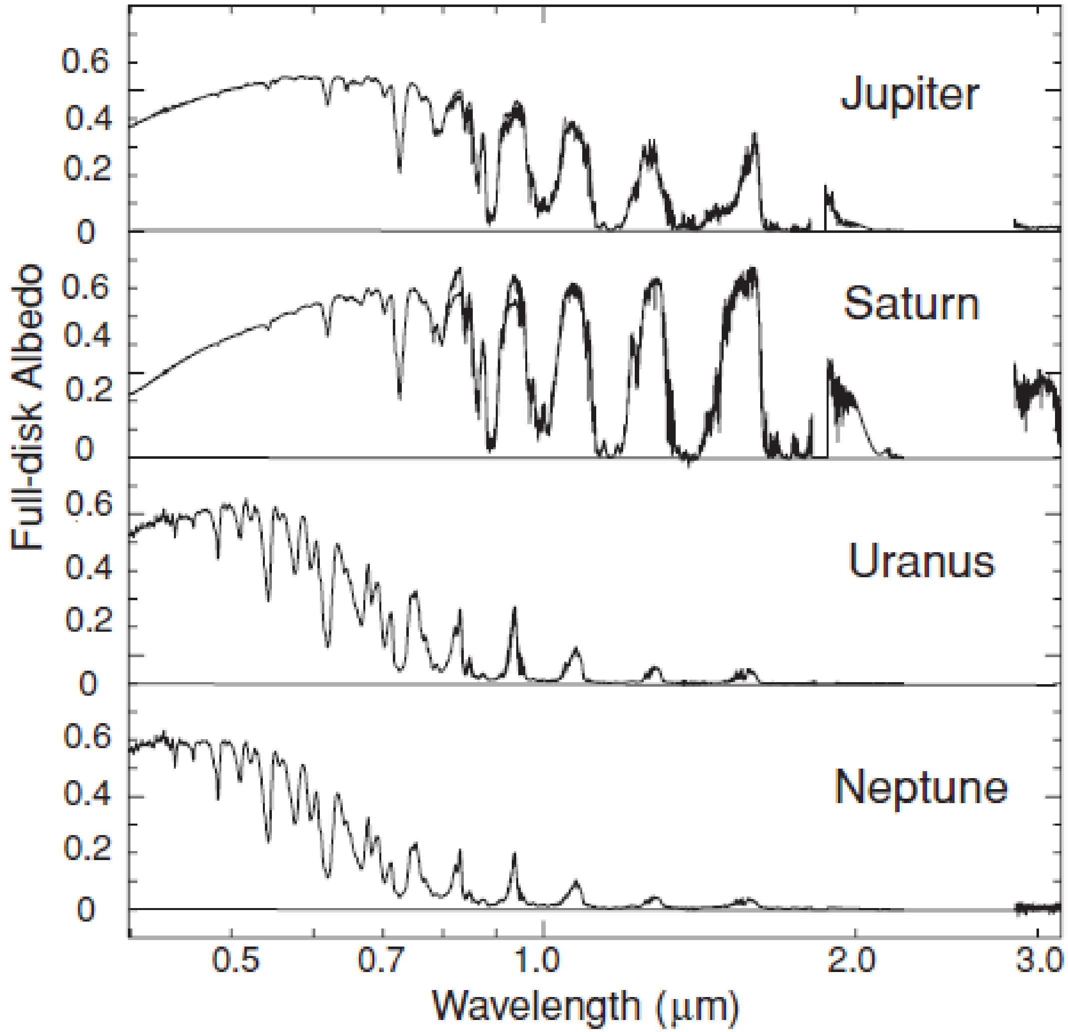
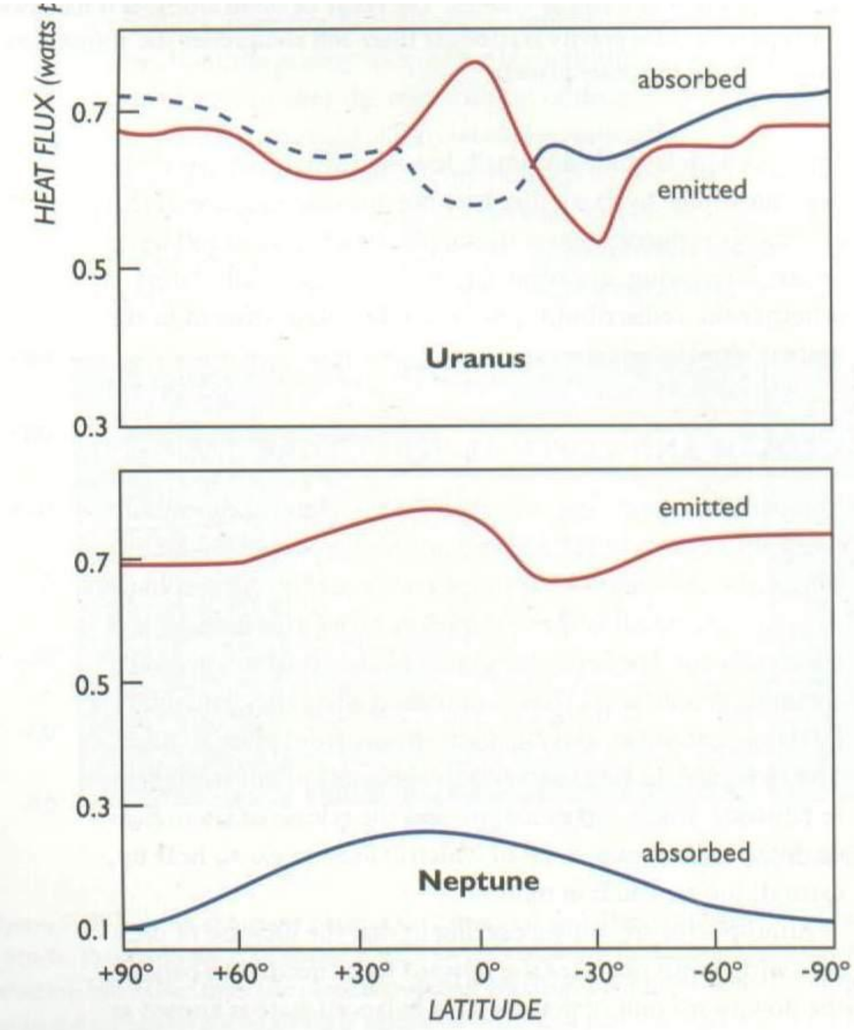


Figure 8.6 Full-disk albedo spectra of Jupiter, Saturn, Uranus and Neptune. All spectra show strong CH_4 absorption bands. (de Pater and Lissauer, 2010)

Balance de energía



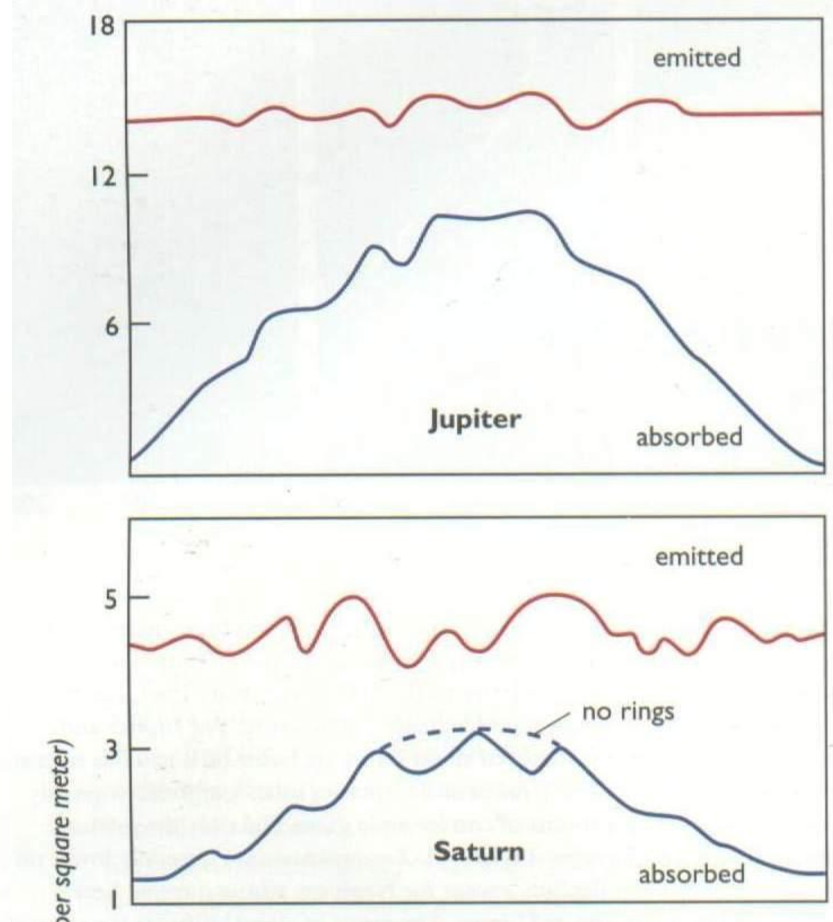
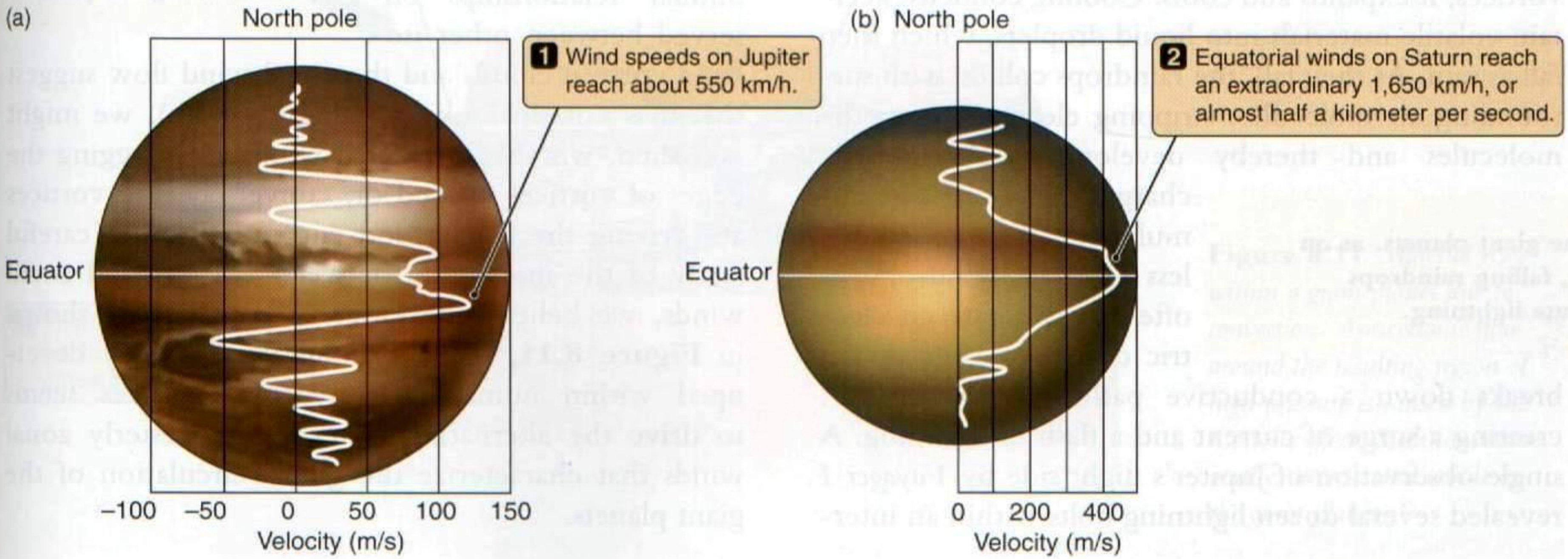


Figure 9. **A comparison of absorbed solar energy and emitted infrared radiation, averaged with respect to longitude, season, and time of day. Jupiter, Saturn, and Neptune each radiate away more energy than they absorb, implying an internal heat source. This radiation is also distributed more uniformly than the absorbed sunlight, which suggests heat transport across latitude circles at some depth within the planet. The dashed curve for Saturn shows how much sunlight it would absorb without the shadowing caused by its ring system. The dashed curve for Uranus is an extrapolation northward of Voyager's measurements, which assumes that planet's absorption of heat is symmetric with respect to latitude over the course of a Uranian year. Small bumps are due to temperature and brightness differences between adjacent latitude bands.**

Coriolis genera fuertes vientos

Figure 8.10 *Strong winds blow on Jupiter and Saturn, driven by powerful convection and the Coriolis effect on these rapidly rotating worlds.*



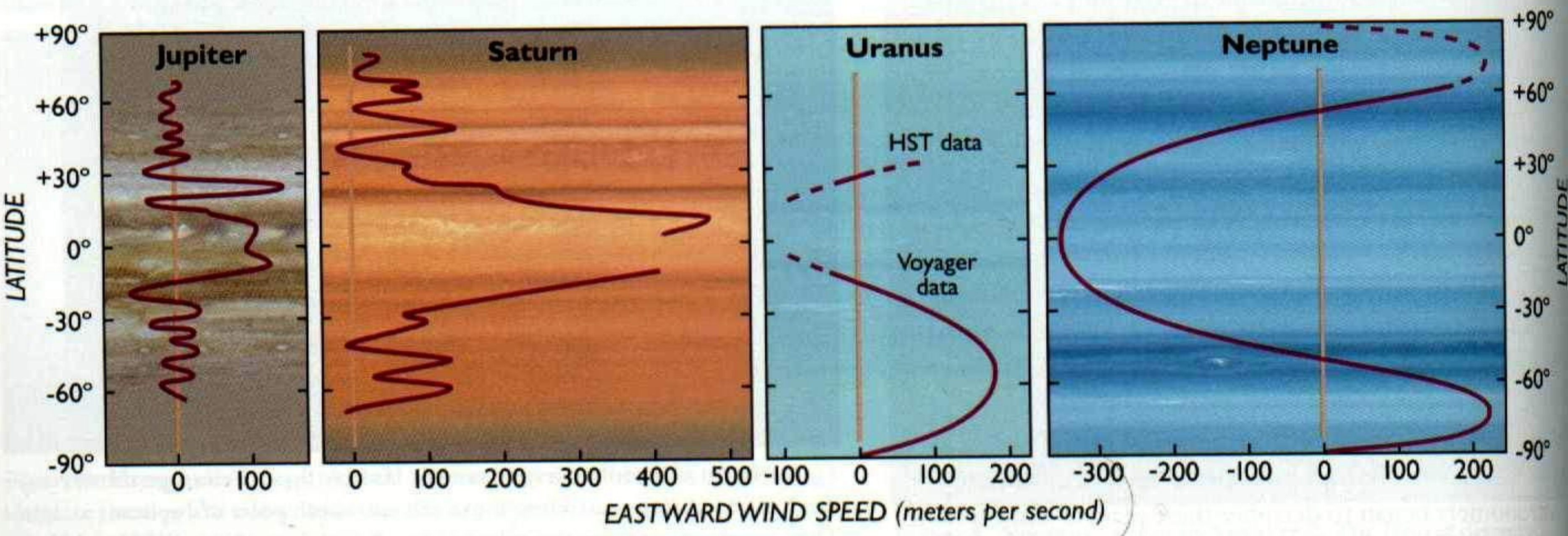


Figure 7. **Winds on the giant planets vary in speed and direction with latitude. Positive velocities correspond to winds blowing in the same direction but faster than the planets' internal rotation periods, which are based on observations of their magnetic fields and periodic radio emissions. Negative velocities therefore, are winds moving more slowly than these reference frames. The equatorial jets are slower than the planets' rotation on Uranus and Neptune, faster on Jupiter and Saturn. In fact, the winds are faster on Saturn than on any other planet.**

Urano y Neptuno tienen una circulación diferente

Zonas (blancas) y Cinturones

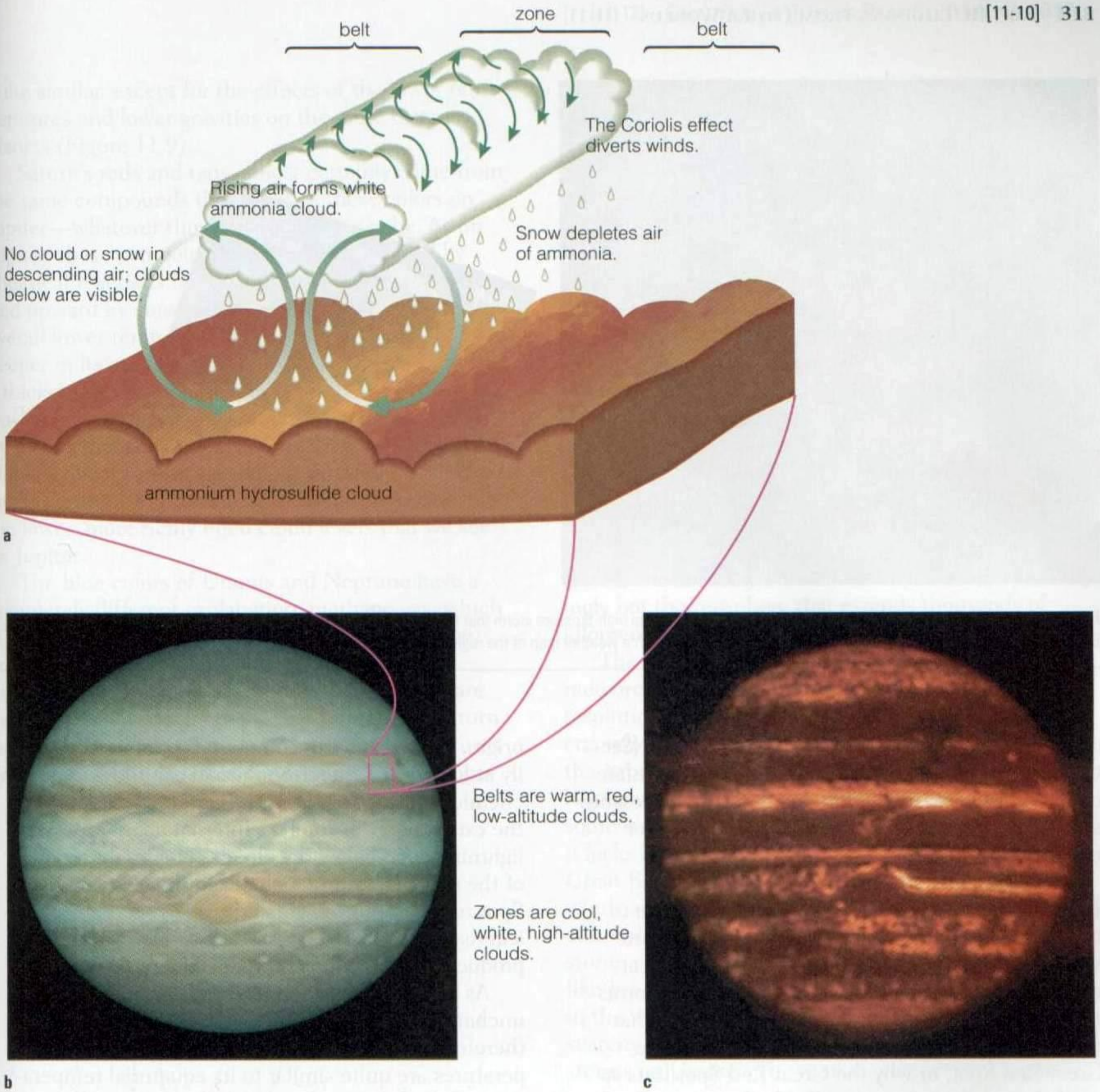


FIGURE 11.7 This figure explains the origin of Jupiter's banded appearance. (**a**) Belts and zones correspond to clouds of different composition at different altitudes. The Coriolis effect diverts motions in the circulation cells into strong easterly and westerly winds. (**b**) The color difference between belts and zones is evident in this Hubble Space Telescope image. (**c**) In this infrared image taken nearly simultaneously with (b), brightness indicates high temperatures.

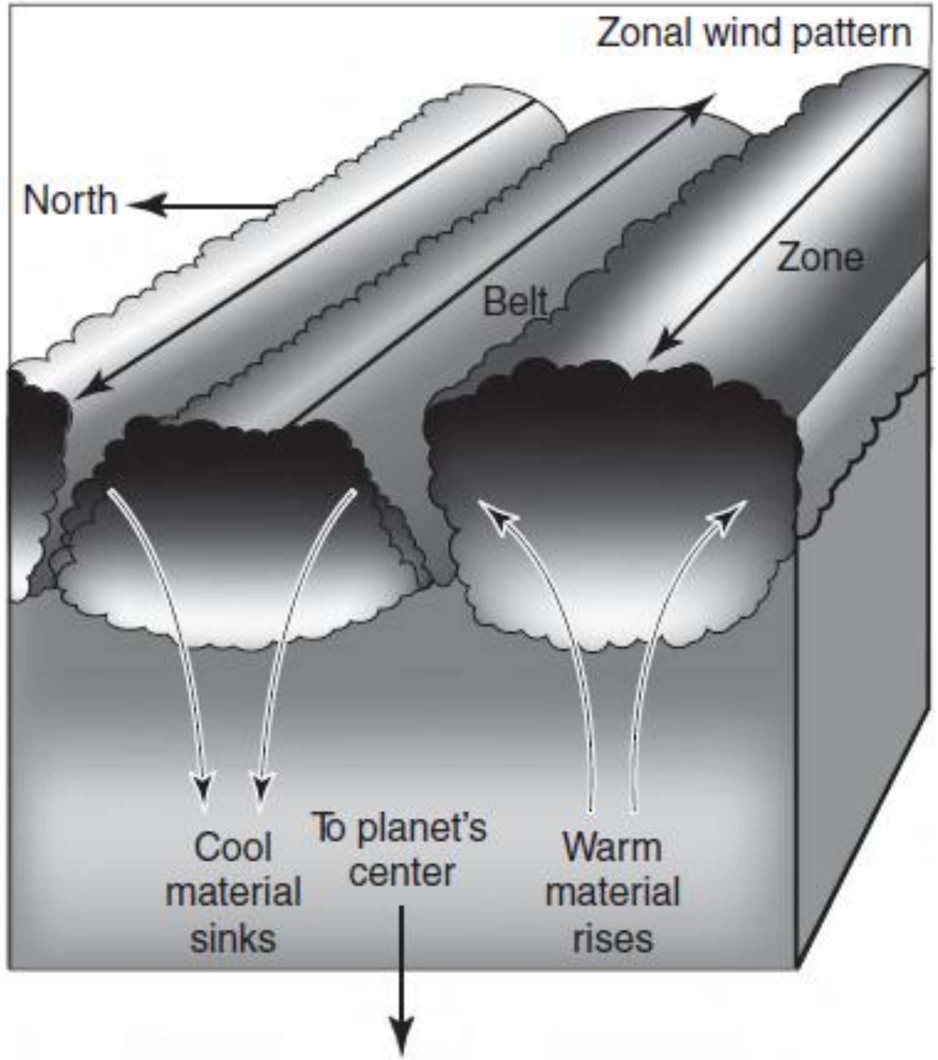
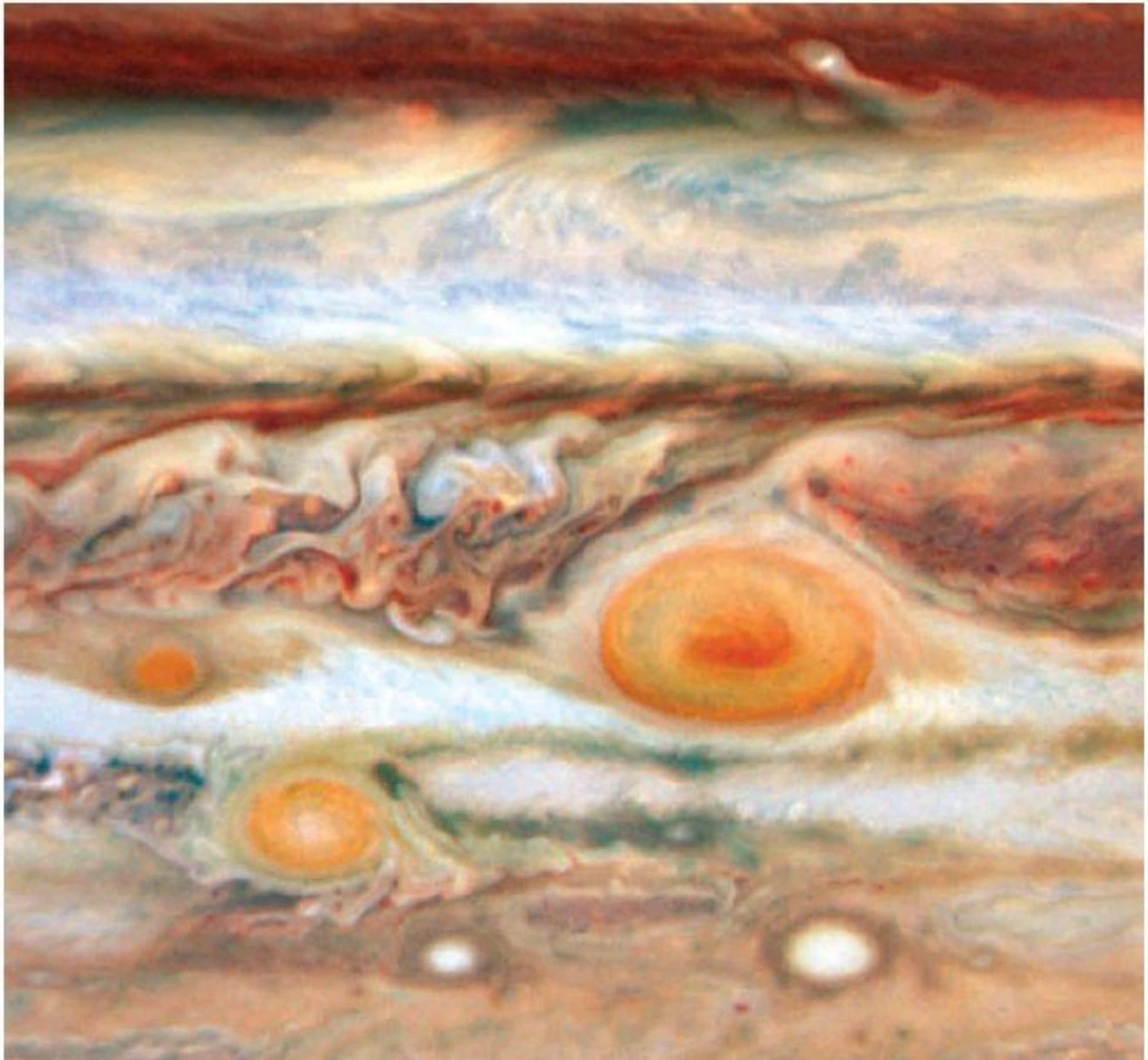
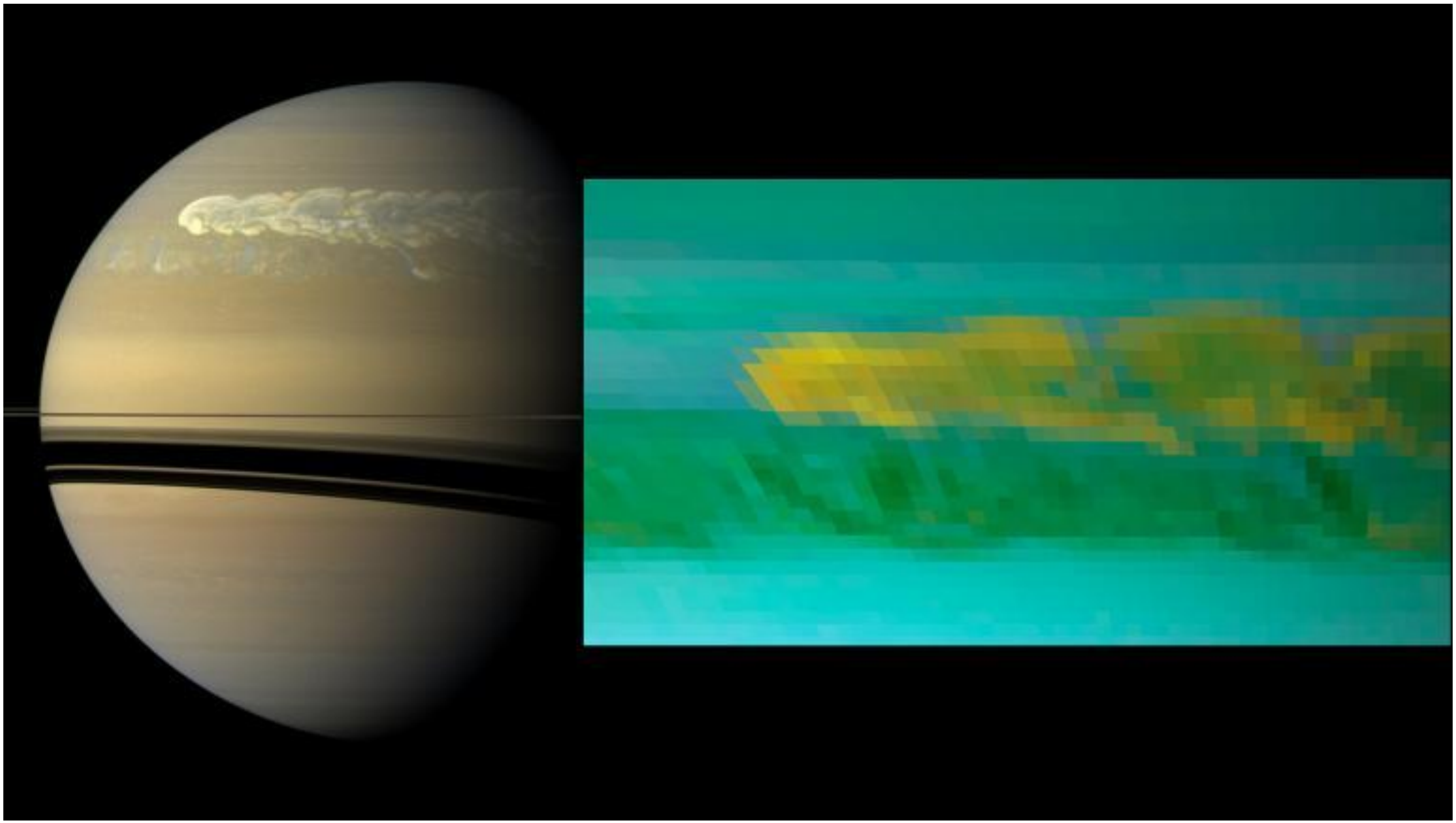


Figure 8.3 Sketch of the rising and sinking motions of the gas in Jupiter's zones and belts. The resulting zonal flow is also indicated.

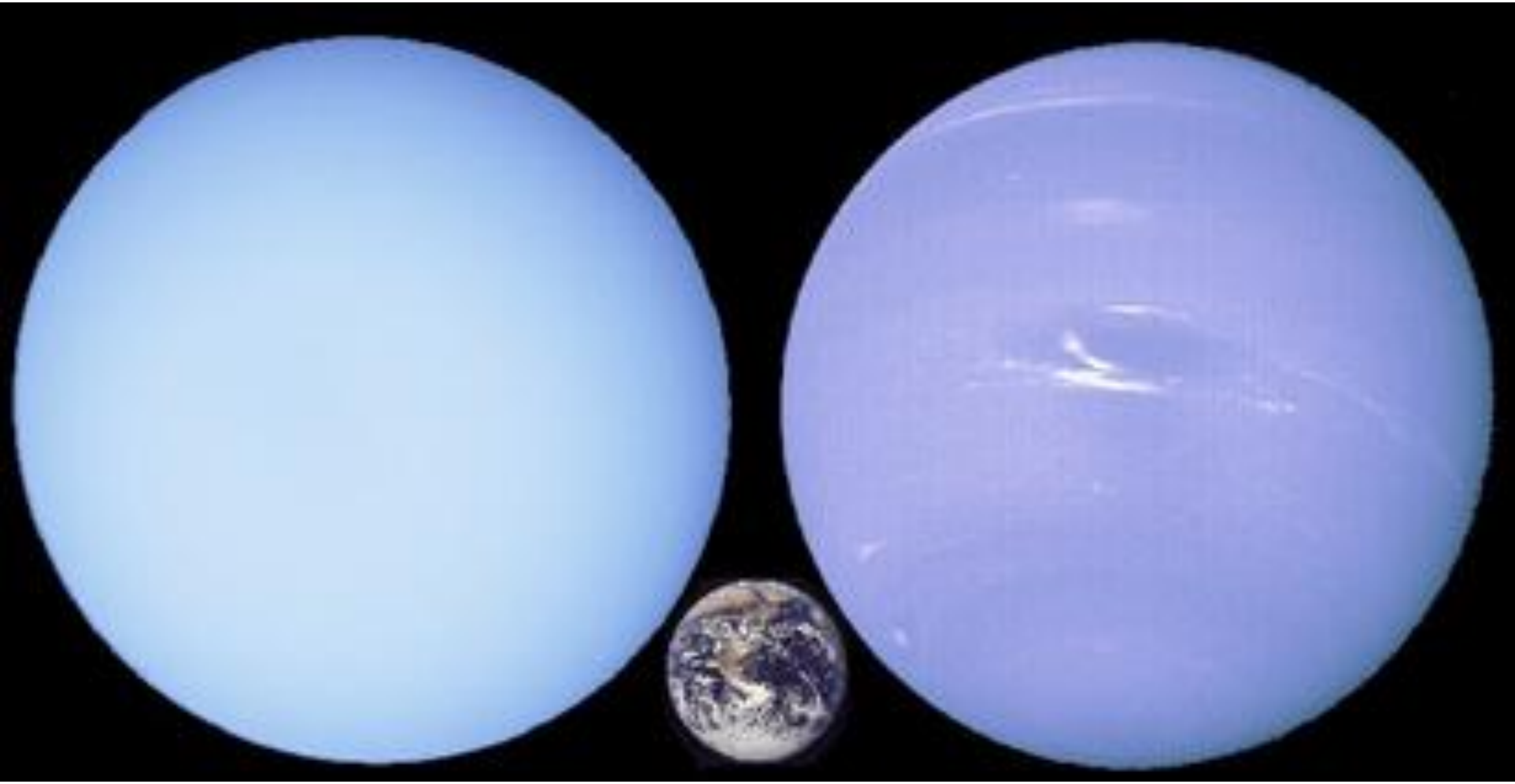
Figure 17. The possible large-scale flow within the giant planets' fluid interiors. Each cylinder has a unique rotation rate, and zonal winds may be the surface manifestation of these rotations. The tendency of fluids in a rotating body to align with the rotational axis was observed by Geoffrey Taylor during laboratory experiments in the 1920s, and was applied to Jupiter and Saturn by Friedrich H. Busse in the 1970s. Such behavior seems reasonable for Jupiter and Saturn if their interiors follow an adiabatic temperature gradient.

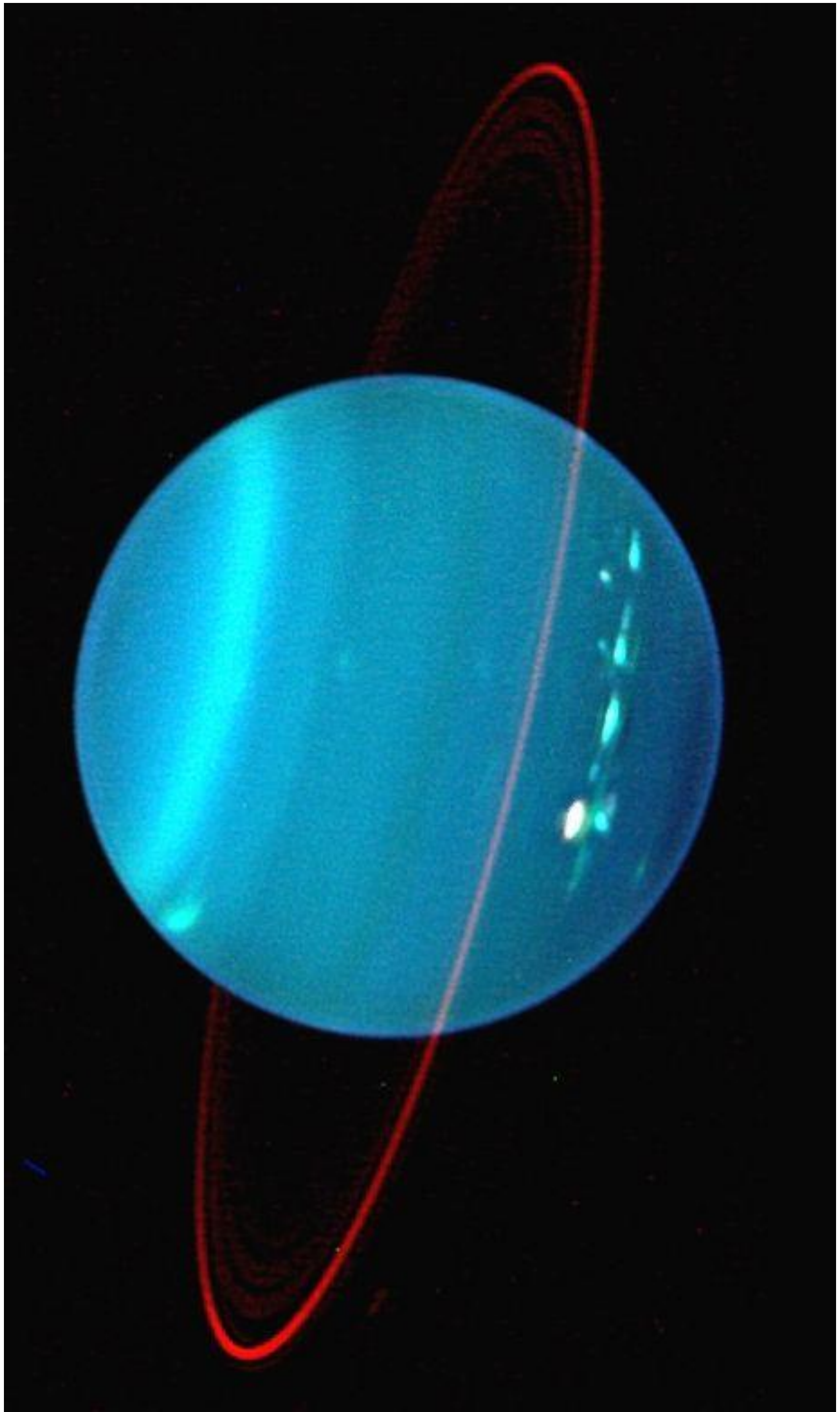
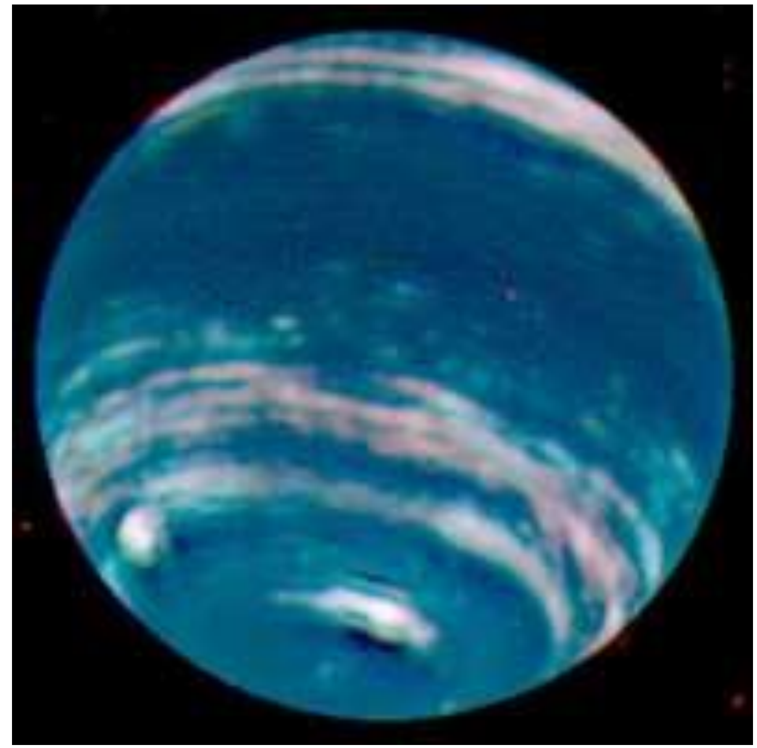


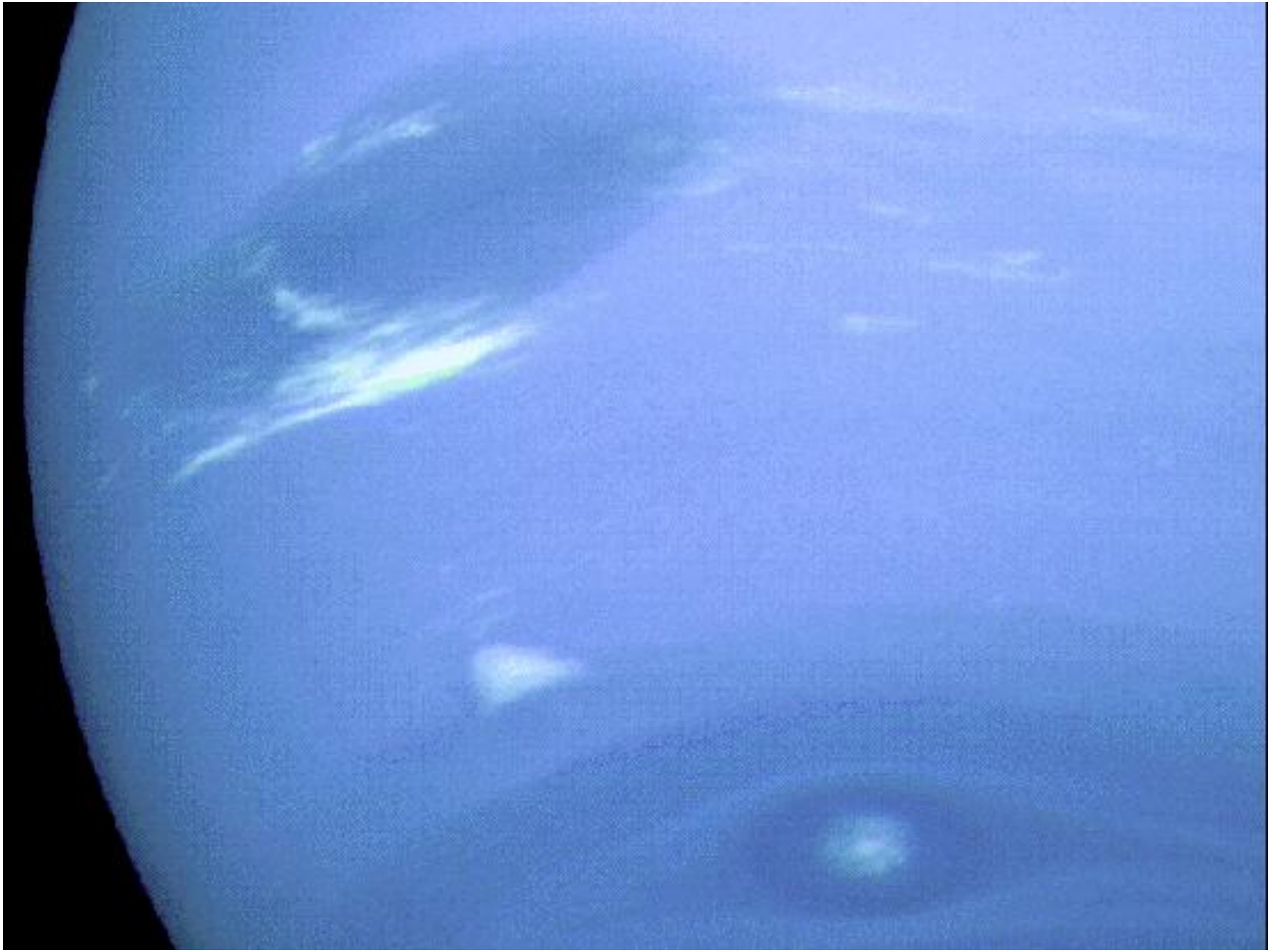
- This set of images from NASA's Cassini mission shows the turbulent power of a monster Saturn storm. The visible-light image in the back, obtained on Feb. 25, 2011, by Cassini's imaging camera, shows the turbulent clouds churning across the face of Saturn.



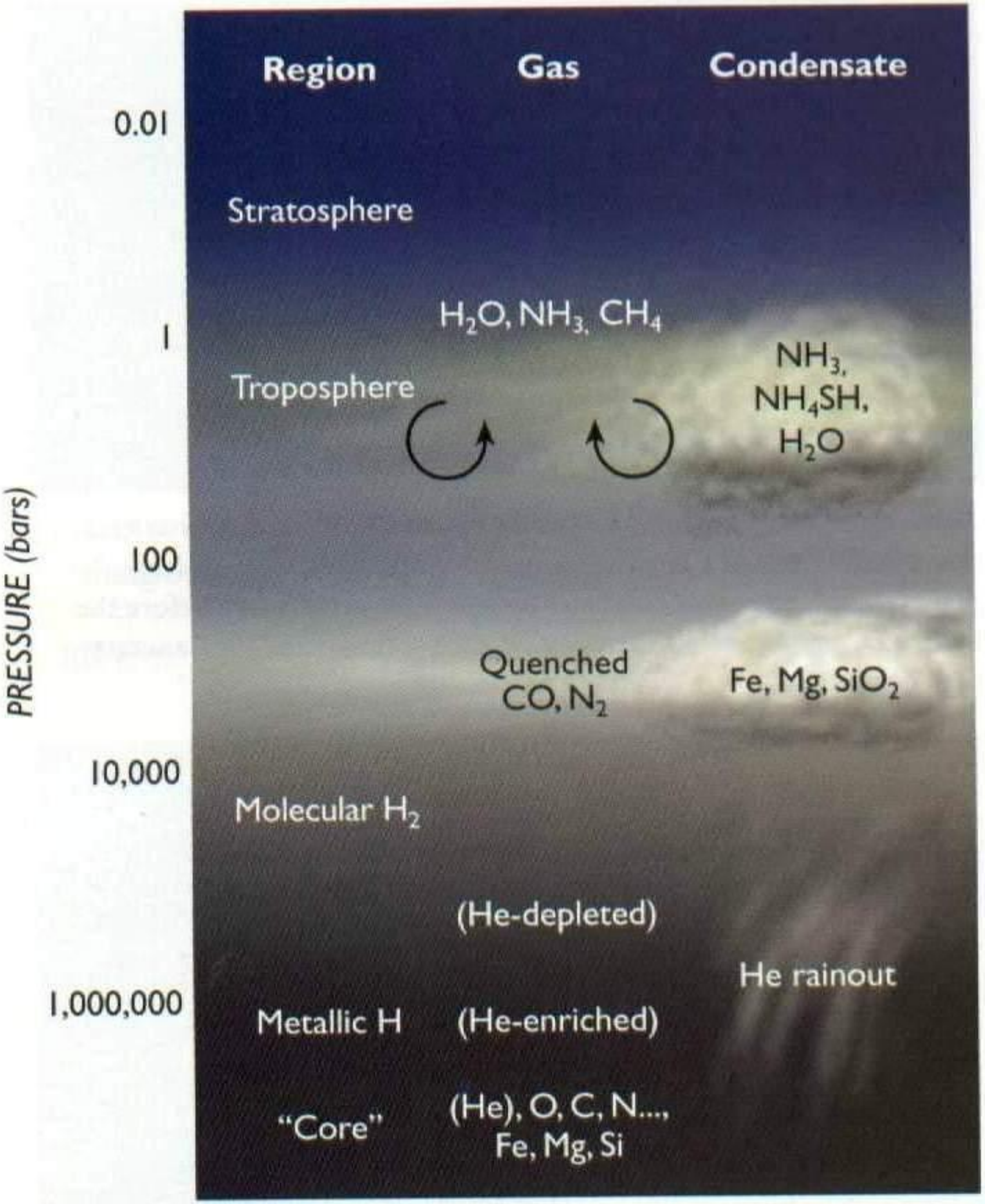
URANO y NEPTUNO





ESTRUCTURA GENÉRICA



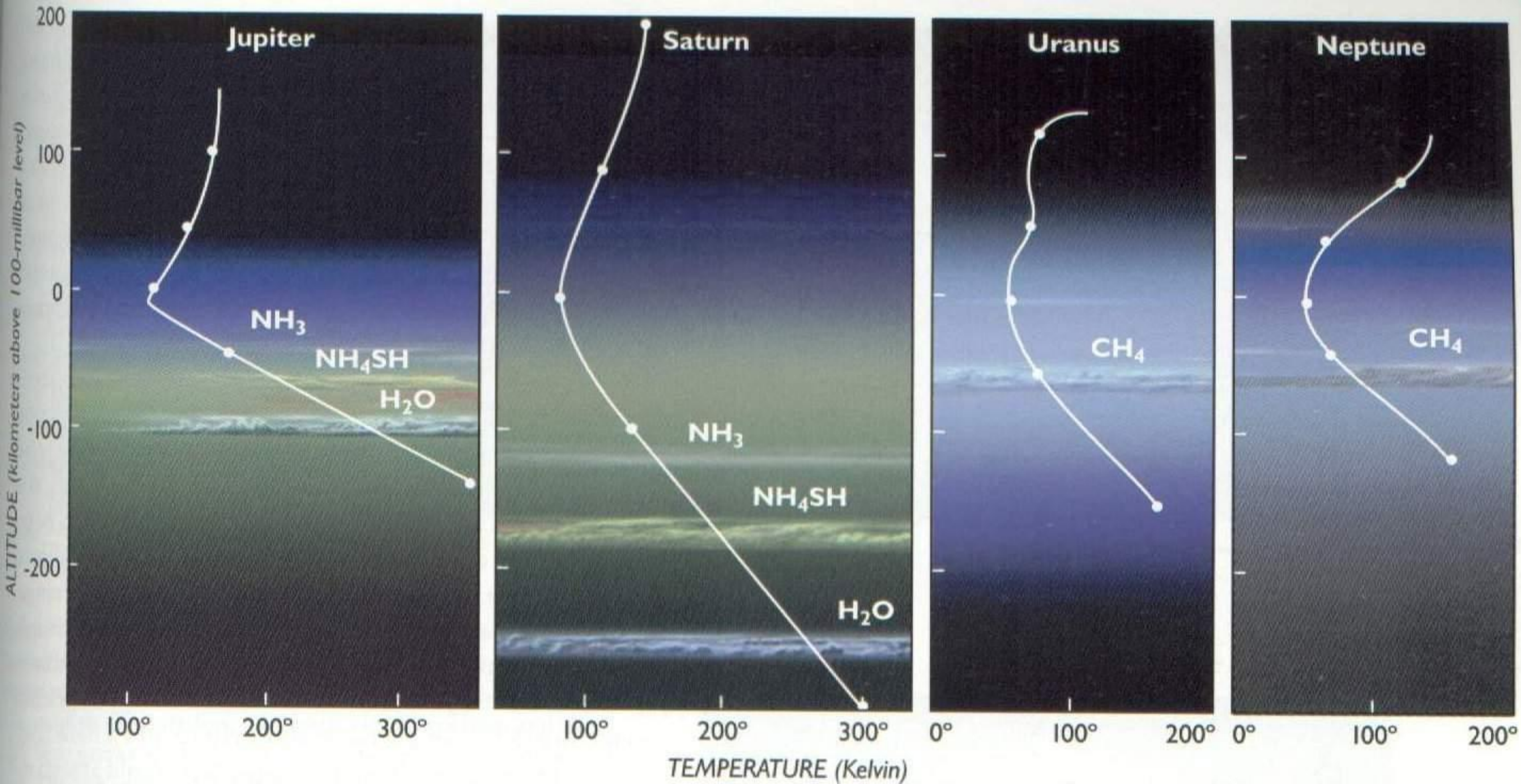


Figure 8. Pressure-temperature profiles for the upper atmospheres of the giant planets, as determined by Voyager measurements at radio and infrared wavelengths. Altitudes are relative to the 100-mb pressure level, and the dots are spaced to indicate tenfold changes in pressure. For Jupiter and Saturn the altitudes of predicted cloud layers are based on a gaseous mixture of solar composition. For Uranus and Neptune, solar composition grossly underestimates the amounts of condensable gases, and only the methane cloud detected by Voyager 2 is shown. Temperatures are generally lower on planets farther from the Sun, except for Neptune, whose internal heat source makes it as warm as Uranus. The range of cloud altitudes is narrower on Jupiter because gravity is stronger there and compresses the atmosphere more than on the other planets

Nubes de metano

Figure 5. The elongated nucleus of Halley's Comet, as seen in a composite of 60 images from the Giotto spacecraft. Resolution varies from 800 m at lower right to 80 m at the base of the jet at upper left. The Sun is toward the left, and material in the bright jets streams sunward. Measuring 16 by 8 km, Halley's nucleus is much larger than that of a typical comet.

Otras atmósferas…

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