“EL CLIMA” DEL SISTEMA SOLAR

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1. **El Sistema Solar:**
   Planetas Terrestres.
   Satélites principales.

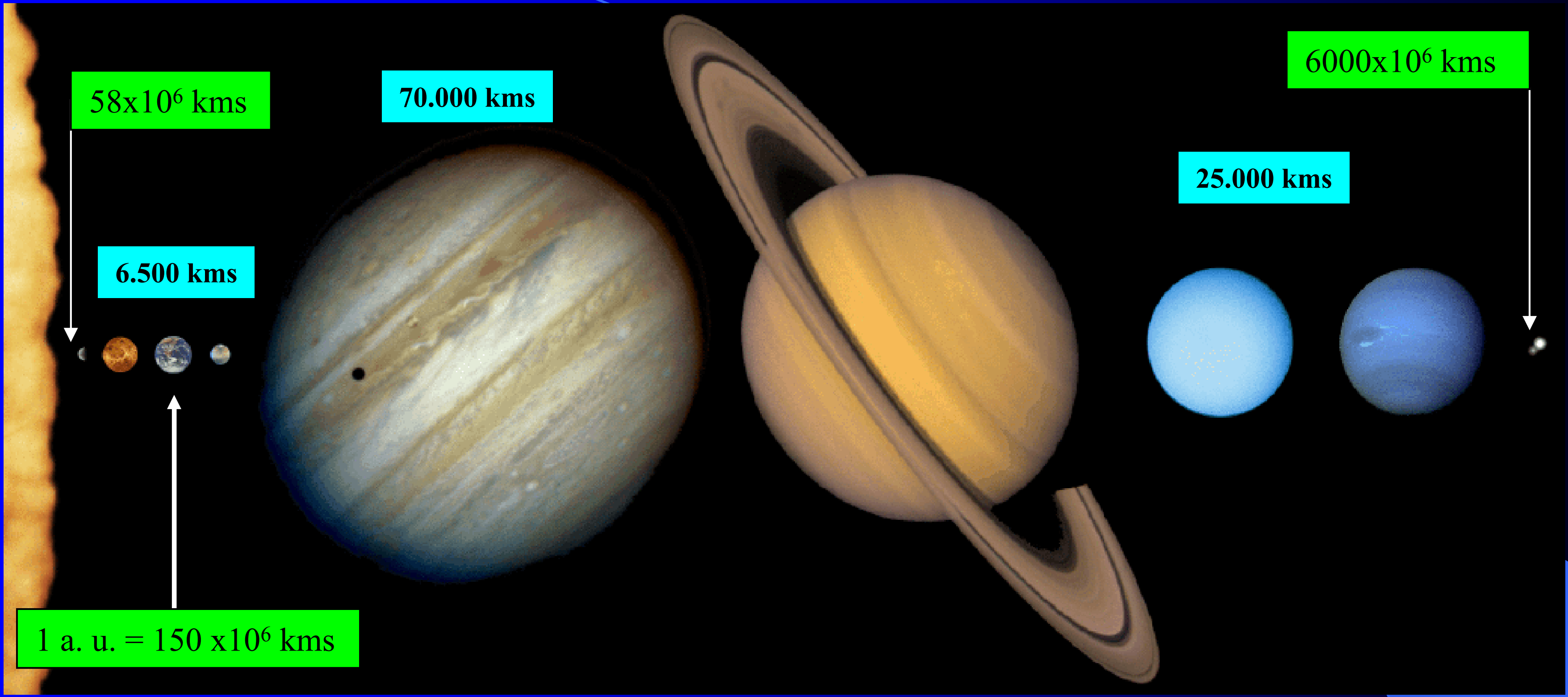
2. **El Sistema Solar: Planetas Gigantes.**
   Planetas Extrasolares.
   Vida en el Universo.
   Futuro Exploración Sistema Solar.

Parte – 1

EL SISTEMA SOLAR

Planetas Terrestres
y Satélites Principales.

Los Planetas del Sistema Solar



$\rho \sim 5 \rightarrow 3.5$ gr/cm ^{3}

$\rho \sim 1$ gr/cm^3

Rocosos-Metálicos

H_2-He + Hielos + Rocas?

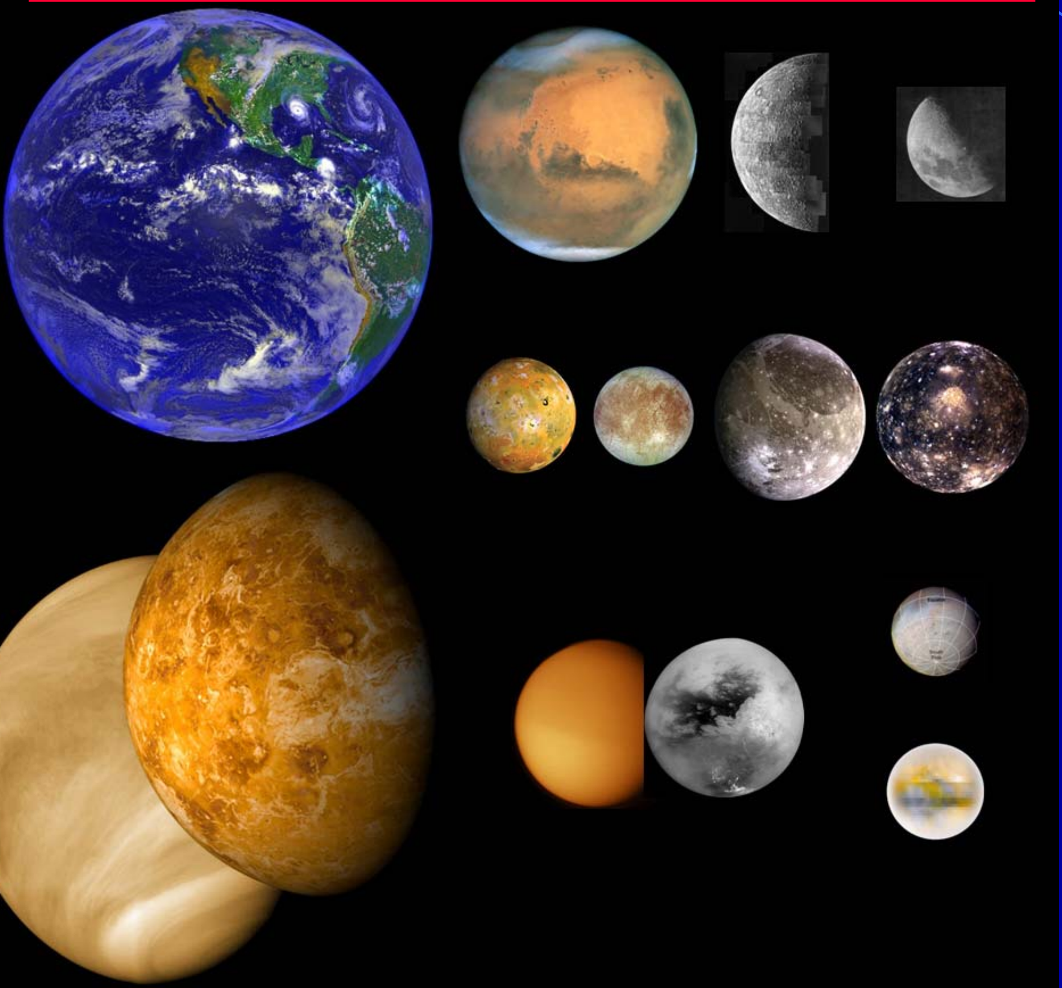
58-243 días

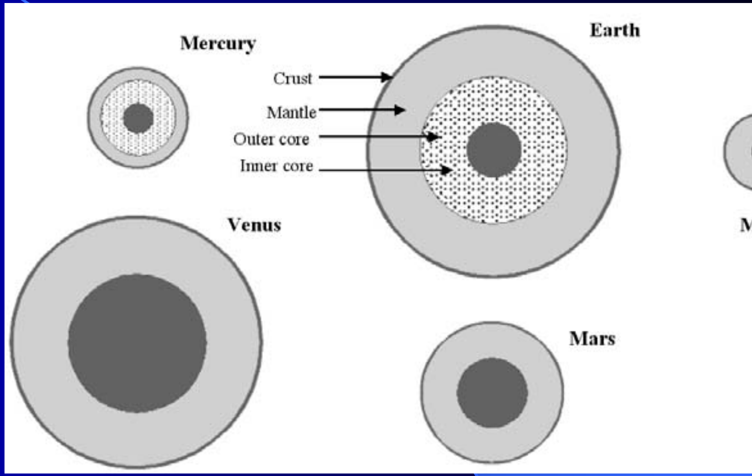
24 hr – 10 hr – 16 hr

1) **Diversidad Planetaria: Composición, Energía Interna, Rotación, Tamaño, Entorno magnético**
2) **En común:**
   a) Excentricidad orbital ~ 0 (órbitas circulares)
   b) Inclinación planos orbitales ~ 0 (órbitas en el plano ecuatorial del Sol)

Planetas Terrestres y Satélites Mayores

Densidad media Terrestres: $\rho = 5.5 \rightarrow 5 \rightarrow 3.5$ g cm^{-3}



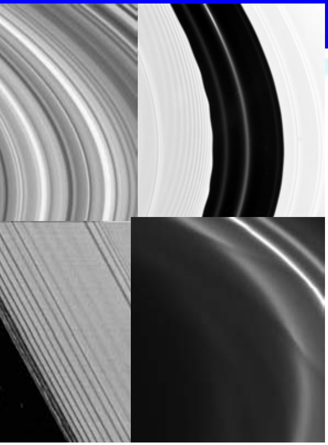


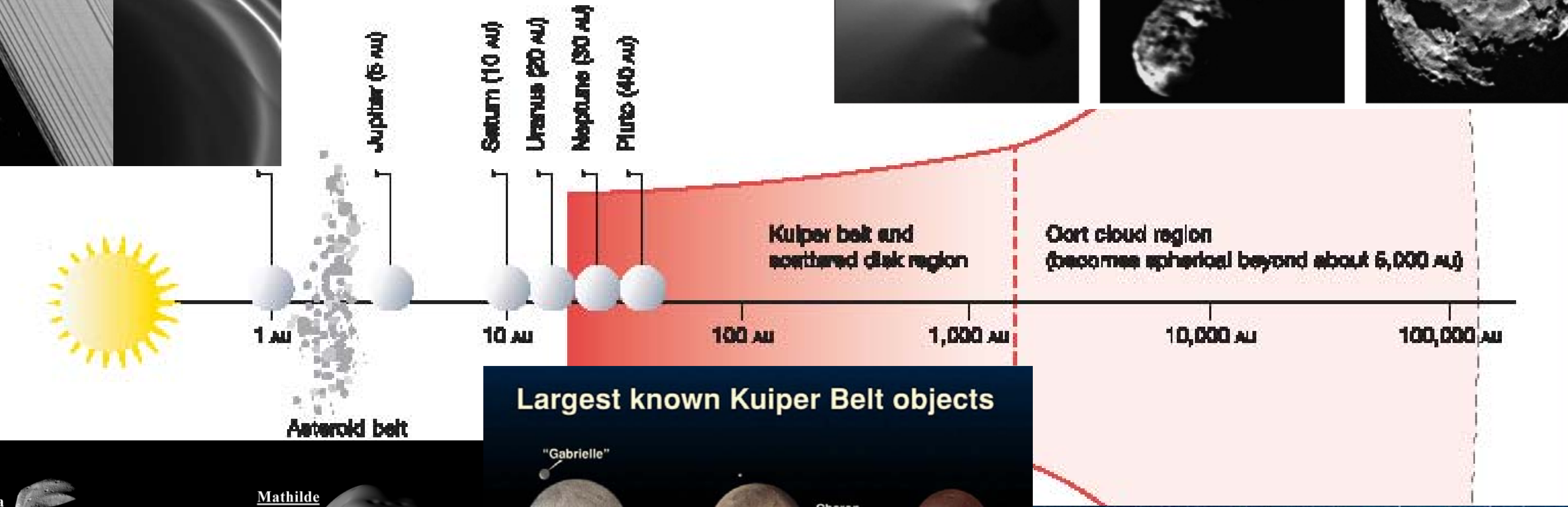
(1) Interiores "diferenciados":
Corteza-Manto-Núcleo.
a) Planetas terrestres:
Manto (SiO_2, MgO) – Núcleo (Fe-Ni).
b) Satélites exteriores:
Mezcla de Hielos y Rocas (80/20%).

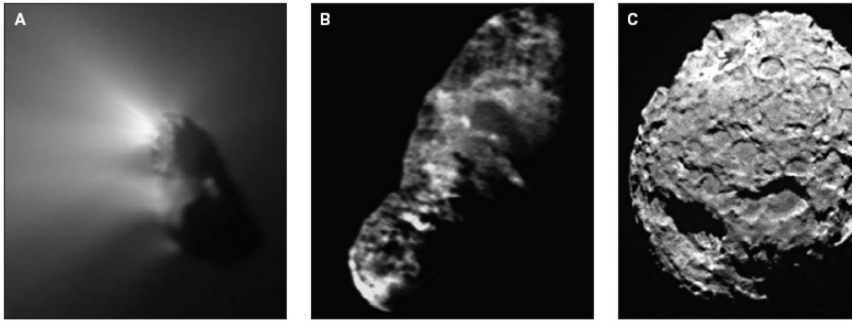
(2) Energía Interna (y estelar):
Radioactividad (K, Th, U)
Mareas gravitatorias.
(3) Composición química
(4) Masa

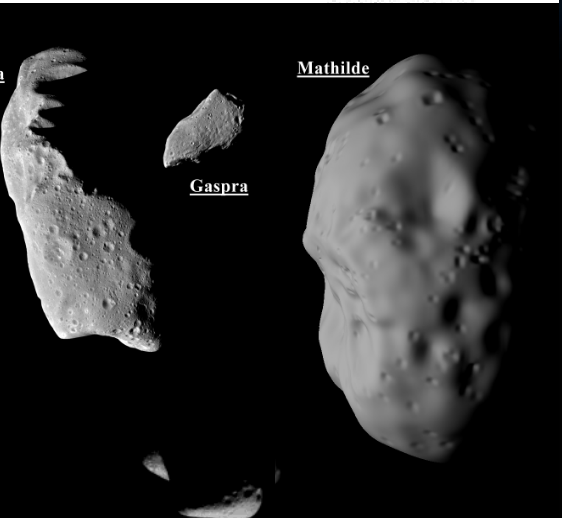
Densidad media Satélites de hielo: $\rho = 3.5 \rightarrow 1.5$ g cm^{-3}

El Sistema Solar: Cuerpos Menores

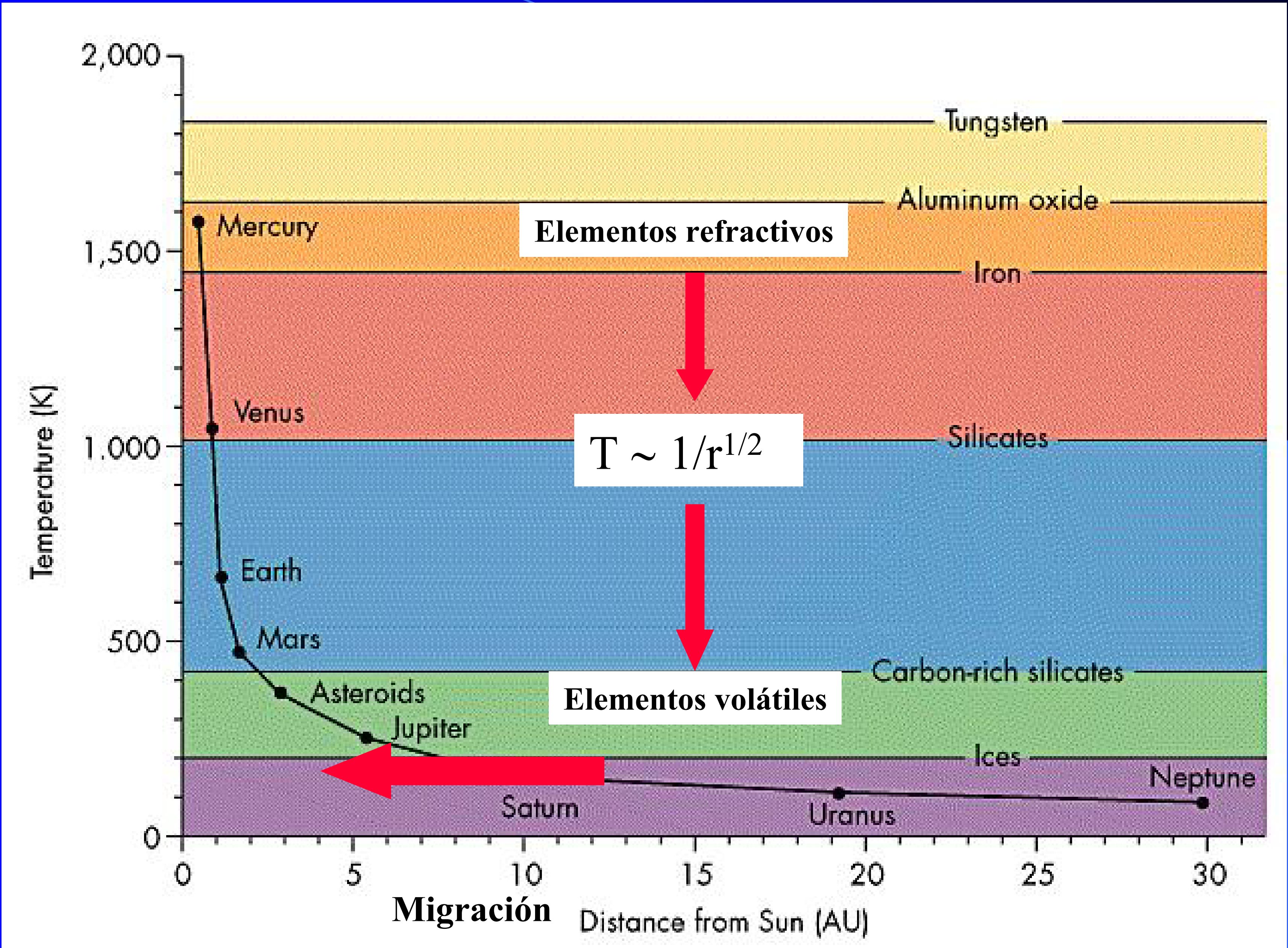








Basic Composition (Distance → Temperature)



Atmospheres: Gases & Aerosols

* Mass ($P_S = Mg/S$)

(1) Thin Atmospheres (Exospheres) [boundary surfaces, PS < 10^{-5} bar]: Mercury, Galilean satellites (Io, Europa, Ganimedes, Callixto), Triton, Pluto.

(2) Intermediate Atmospheres [boundary surfaces, $P_S = 7\times10^{-3}$ - 90 bar]: Venus, Earth, Mars, Titan.

(3) Massive and Deep Atmospheres [P > Kbar-Mbar]: Jupiter, Saturn, Uranus, Neptune.

* Chemical composition → Radiative (active) gases
→ Condensables (clouds and hazes) → Latent heat release

* Energy sources:

(1) Mechanical (kinetic) → rotation ~ $\Omega^2 R_p$, Ω v

(2) Thermal → pressure gradients

(a) External (insolation):

$$F_{abs} = \frac{(1-A_B)}{4}\frac{L_S}{4\pi a^2}$$

$$T_{eq} = \left(\frac{F_{abs}}{\sigma}\right)^{1/4}$$

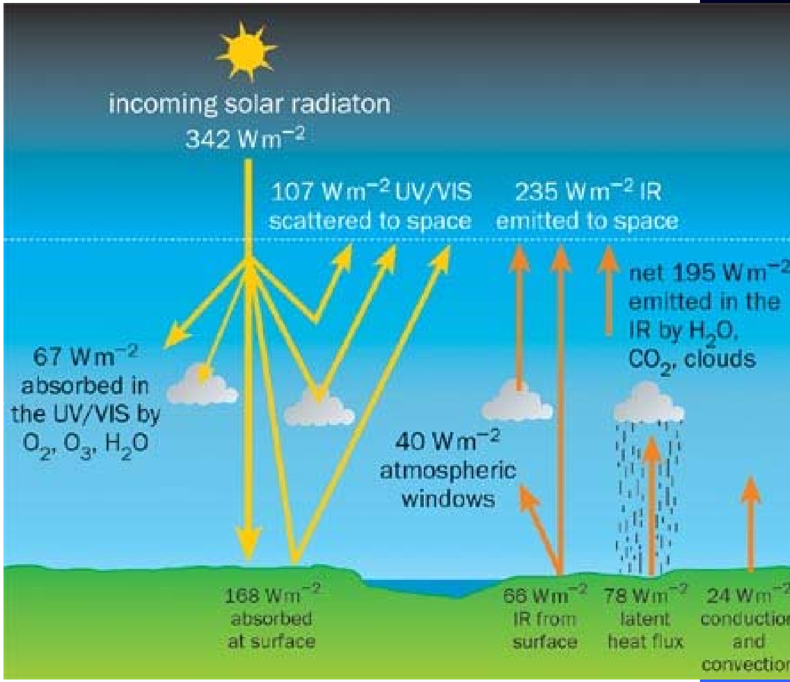
(b) Internal:

$$F_{\text{int}} = \frac{L_{\text{int}}(t)}{4\pi R_p^2}$$

$$T_{eff} = \left(\frac{F_{abs}+F_{\text{int}}}{\sigma}\right)^{1/4}$$

Heat balance →

$$E = \left(\frac{T_{eff}}{T_{eq}}\right)^4$$



(3) Friction (dissipation): internal & surface

Origin and evolution

(1) Thin atmospheres:

(a) Escape and strong surface interaction (sputtering by particles)

(2) Terrestrial (Secondary, evolved atmospheres):

(a) Accretion of planetesimals (comets, asteroids) → Volatiles (outgassing) due to temperature.

(b) Vulcanism.

(c) Evolution → Escape processes (thermal or Jeans, impact or catastrophic, solar wind and EUV fluxes)

→ Surface interaction (interior-tectonic).

→ Biology (Earth only!)

→ Photochemistry (solar irradiation) modification

(3) Giant (Primary, nearly primordial origin)

(a) Direct accretion from proto-planetary nebula.

Thermodynamic equilibrium (molecules with C, H, O, N):

$$CH_4 + H_2O \leftrightarrow CO + H_2 \quad \& \quad CO + H_2O \leftrightarrow CO_2 + H_2$$

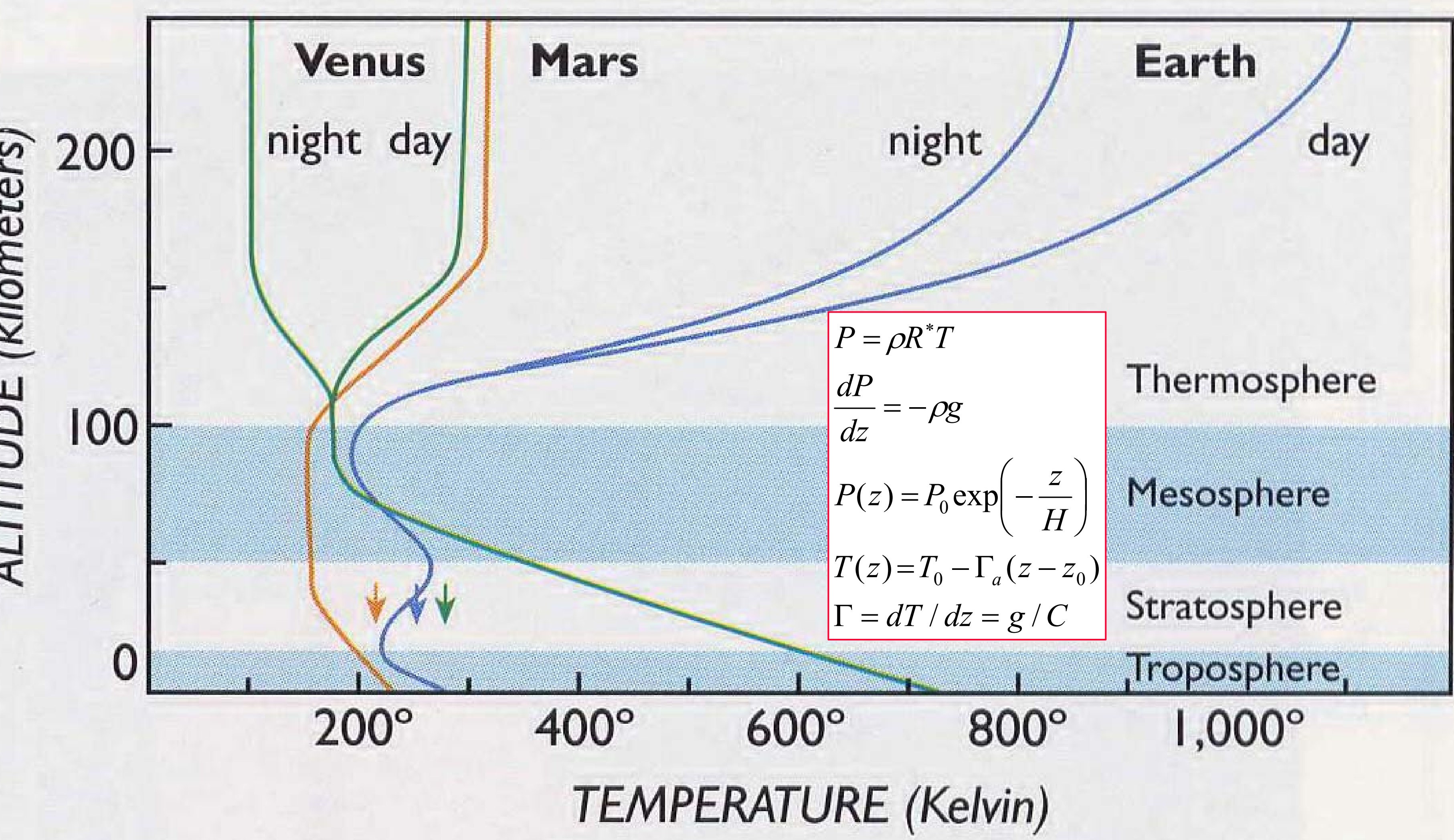
$$2NH_3 \leftrightarrow N_2 + 3H_2$$

[T low, P high ← → T high, P low]

Present "Terrestrial" (Thin & Thick) Atmospheric Properties

Planet/ Satellite	Composition (%)	P_s (bar) T_s (K)	τ_{rad} (years)	Clouds	Optical depth
Mercury	He(42), Na (42) O (15), H, K	10^{-12}, 700 (S), 93 (no S)	-	(Exosphere)	-
*** Venus**	CO_2 (96), N_2 (3)	90, 730 *	10.8	SO_4H_2 (100% coverage)	5-12
*** Earth**	N_2 (77), O_2 (21) H_2O (100 ppm)	1, <288>*	0.08	H_2O + aerosols (50% coverage)	5-10 (100)
Moon	NA, K		-	(Exosphere)	-
*** Mars**	CO_2 (95), N_2 (3), Ar (2)	0.007, <218>*	0.002	H_20, CO_2, dust (10-100% cov.)	0.3 - 6
Io (J)	SO_2 (O_2, SO) (Na, K, S^+, …)	10^{-7}, 120	-	Volcanic dust	0.1
Europa (J) Ganimedes(J) Callixto (J)	O_2, (Na)	10^{-11}, ~ 100	-	(Exospheres)	-
*** Titan (S)**	N_2 (90), Ar, CH_4	1.6, 92	7.9	CH_4 + C_nH_m	10
Triton (N)	N_2	10^{-5}, 38	-	N_2 (?) - CH_4	0.1-0.3
Pluto	CH_4, N_2	10^{-4}, 40	$5x10^{-4}$	CH_4	> 0.15

Temperature – Pressure (Layers): Venus, Earth, Mars



$$P = \rho R^* T$$

$$\frac{dP}{dz} = -\rho g$$

$$P(z) = P_0 \exp\left(-\frac{z}{H}\right)$$

$$T(z) = T_0 - \Gamma_a (z - z_0)$$

$$\Gamma = dT / dz = g / C$$

Balances: Horizontal Motions

(1) Zonal motions (East-West)

Rossby number $Ro = \frac{u}{f\,L} \quad , f = 2\Omega \sin\varphi$

* **Ro < 1 Geostrophic balance (rapidly rotating)**
[Coriolis F. ≈ Pressure gradient]
(e.g.: Earth, Mars→ 24 hr)

$$\frac{\partial u}{\partial z} = -\frac{g}{f\,R_p T}\frac{\partial T}{\partial \varphi}$$

$$u_g \approx -\frac{g\,H}{f\,L}\frac{\Delta T}{T}$$

* **Ro > 1 Cyclostrophic balance (slowly rotating)**
[Centrifugal F. ≈ Pressure gradient]
(e.g.: Venus, Titan → 243 d, 16 d)

$$u_{cl} = \pm\sqrt{\frac{g\,D\Delta T}{T}}$$

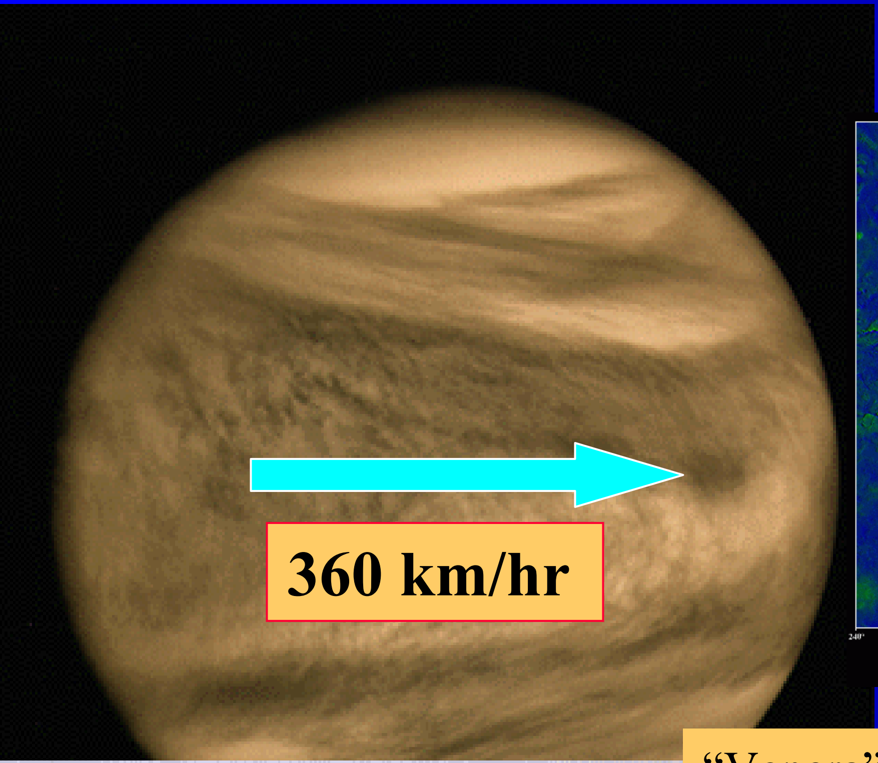
(2) Meridional Motions (North-South → Equator to Pole) → "Hadley-like" cells

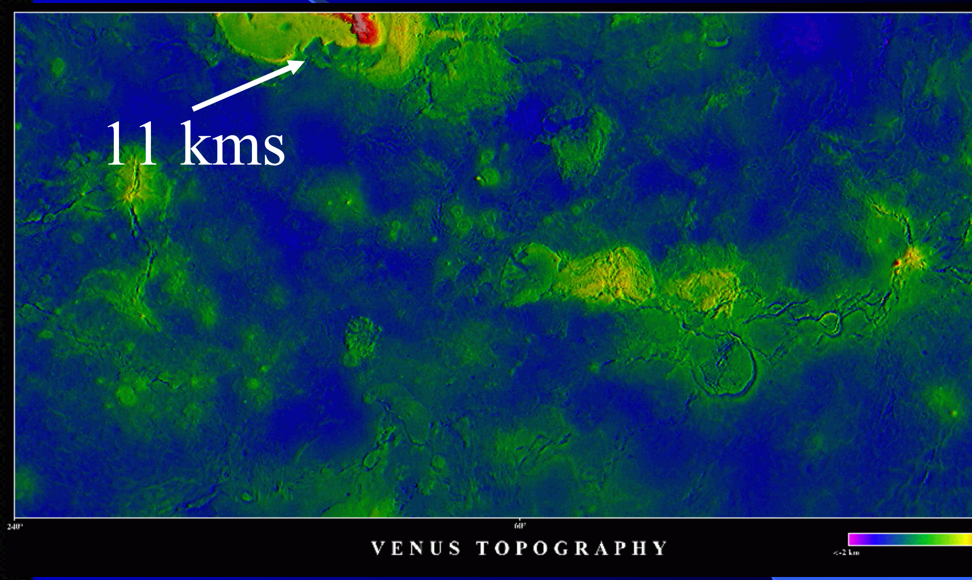
$$w \sim u\ (H/L)$$

$$v < u$$

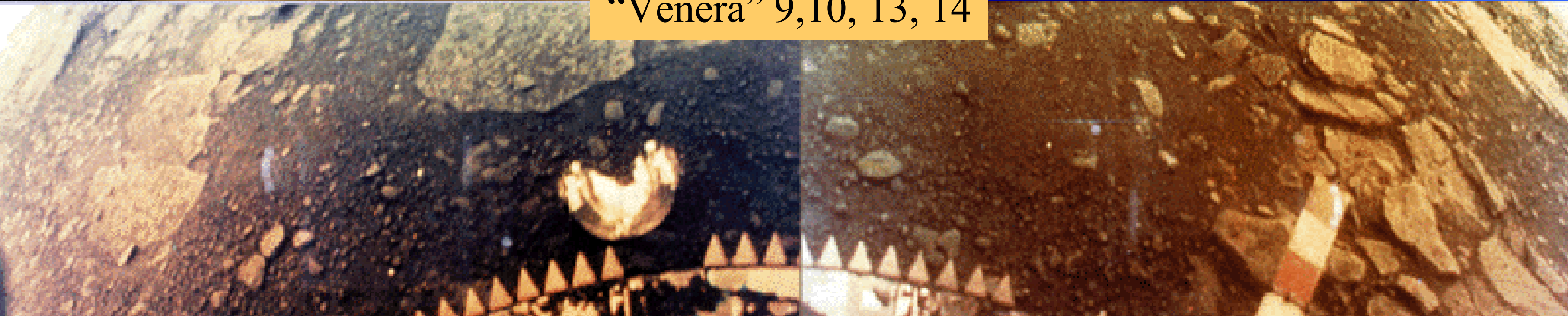
Venus torrido. Efecto invernadero desbocado

$X_p = CO_2$; Nubes: SO_4H_2; $P_{sup} = 90$ bar; $T_{sup} = 450^oC$





"Venera" 9,10, 13, 14



Venus Clouds: Vertical Structure

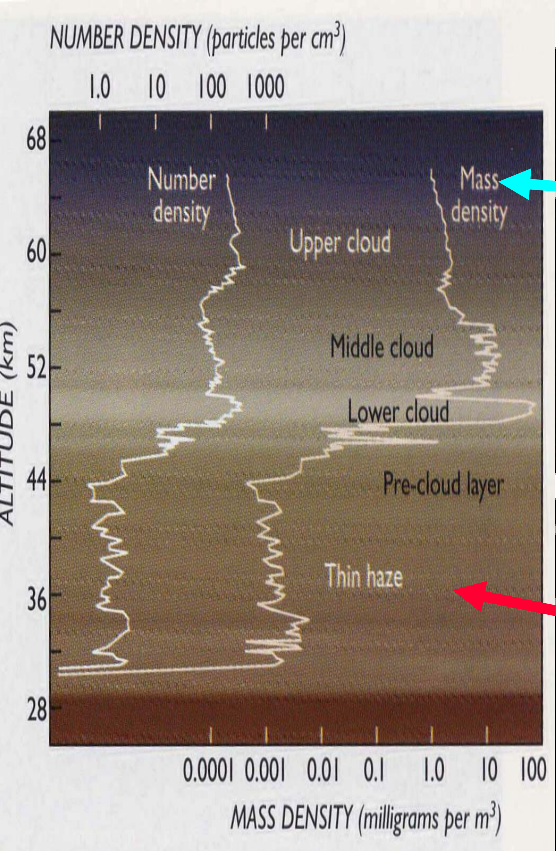
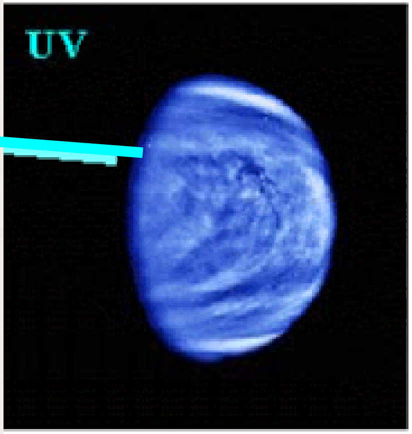
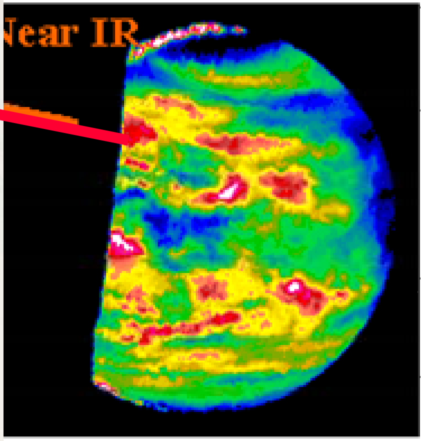


Figure 6. Clouds in the atmosphere of Venus form discrete layers that are fairly uniform from place to place. These are not condensations of water vapor, a gas that exists only in trace amounts on Venus. Instead, they consist almost entirely of droplets of sulfuric acid.





Basic facts

- Extinction coefficient < 4 km^{-1}
- Total optical depth 20 - 40
- Particle size < 20 μm
- Number density 10^2-10^3 cm^{-3}
- Composition: H_2SO_4 + ? (S_n, $AlCl_3$, H_3PO_4,...)

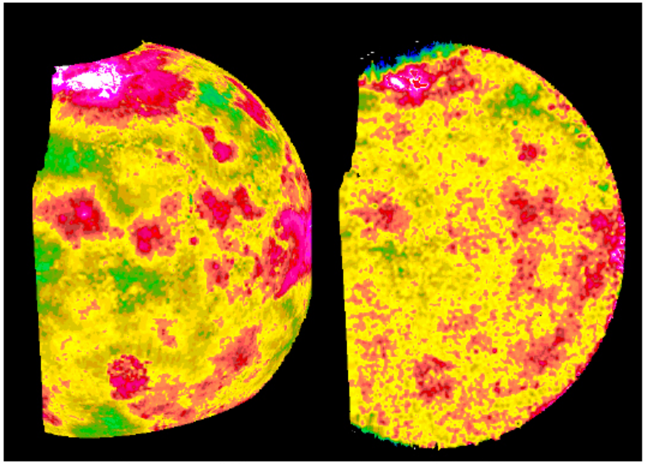
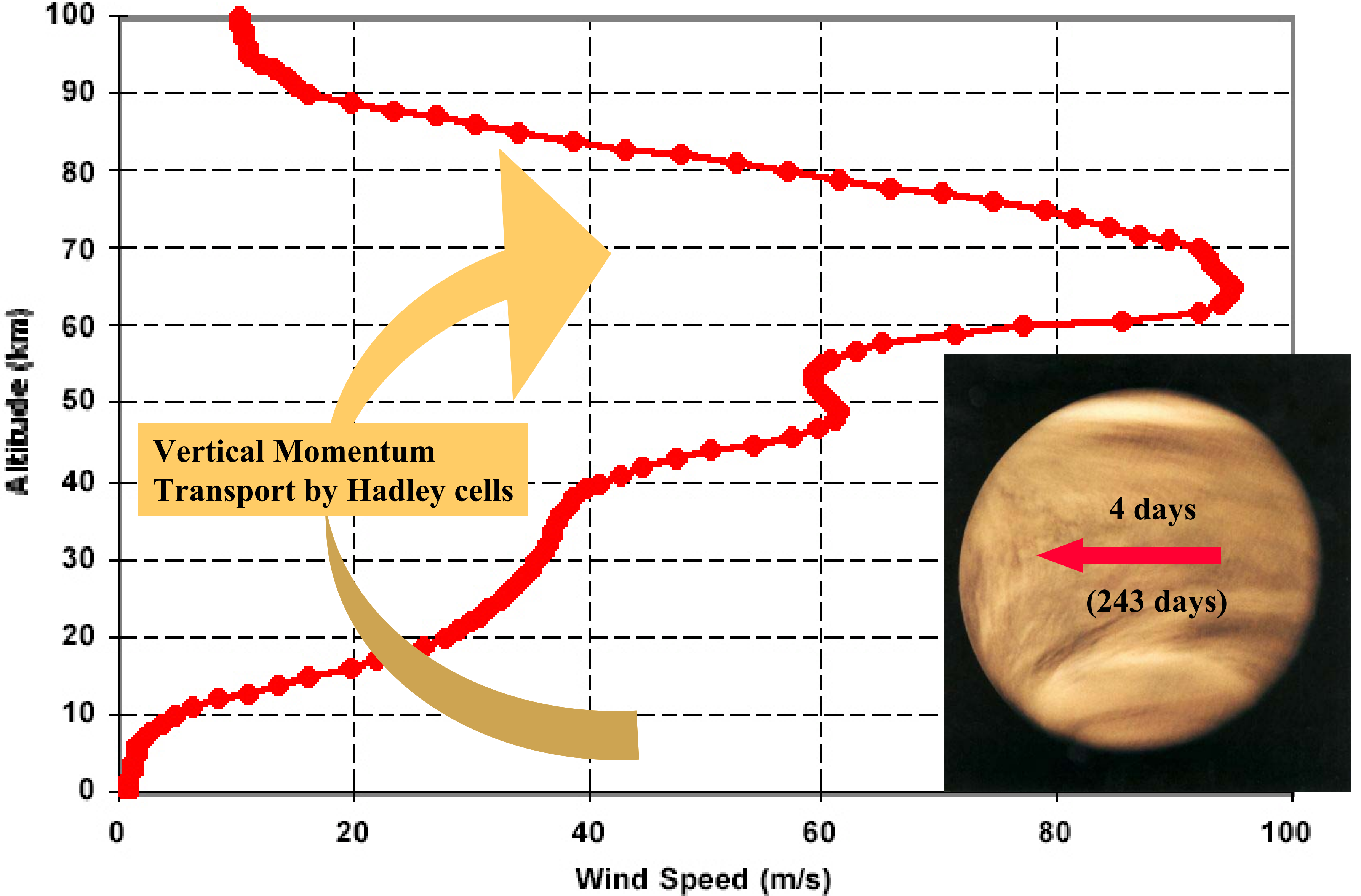


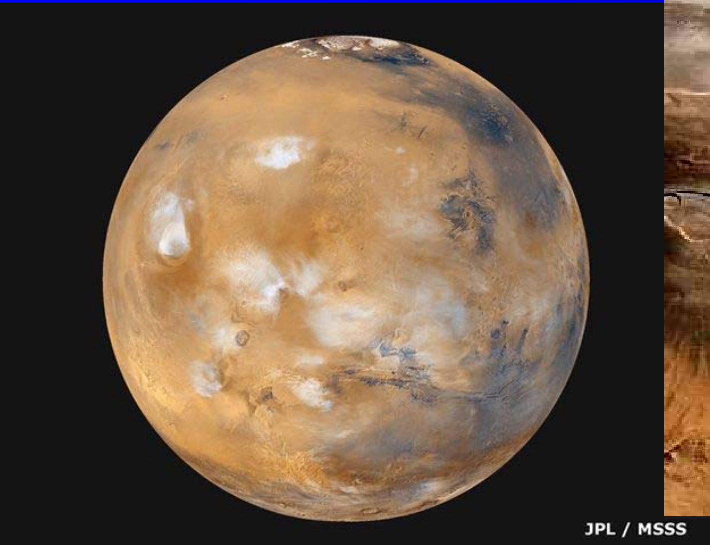
Figure 2.9 Venus altimetry as observed by Pioneer Venus (left), compared to 1.18μm Galileo/NIMS image (right). High altitude terrain (Ishtar Terra in the North, Aphrodite at right) correspond to lower thermal emission, due to the lower temperature of the surface. *(L. Kamp and the NIMS team JPL, priv. comm.)*

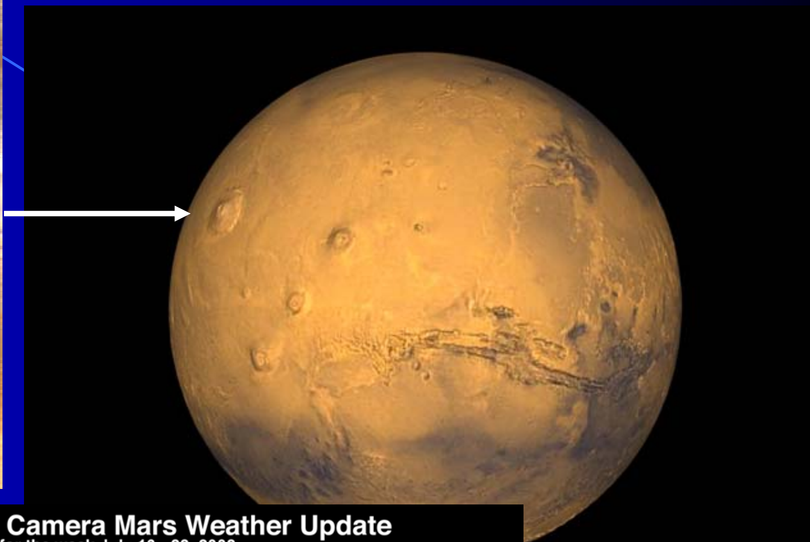
Venus Superrotation

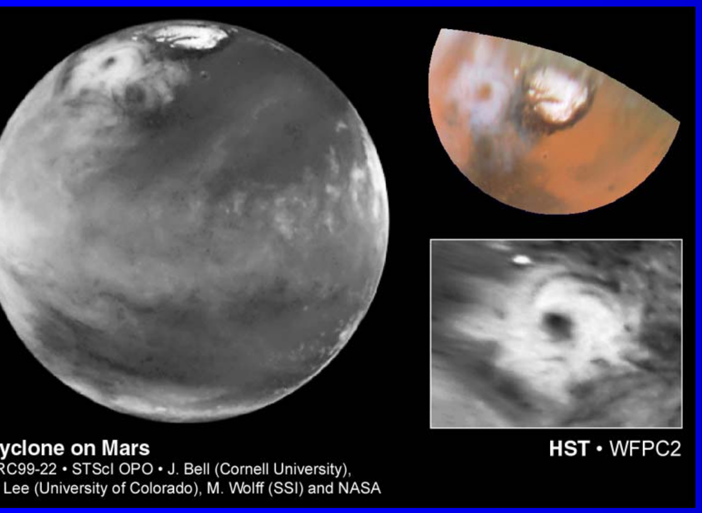


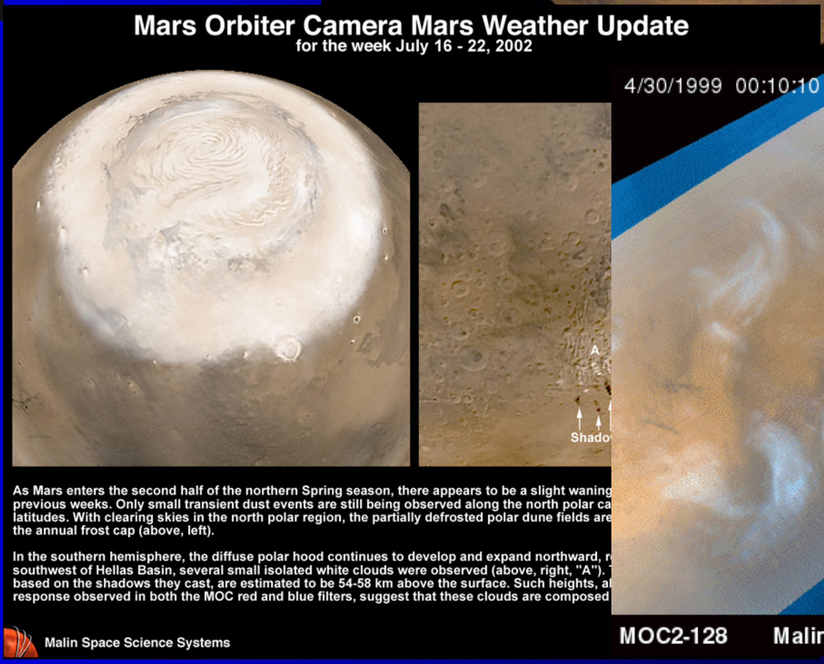
MARTE

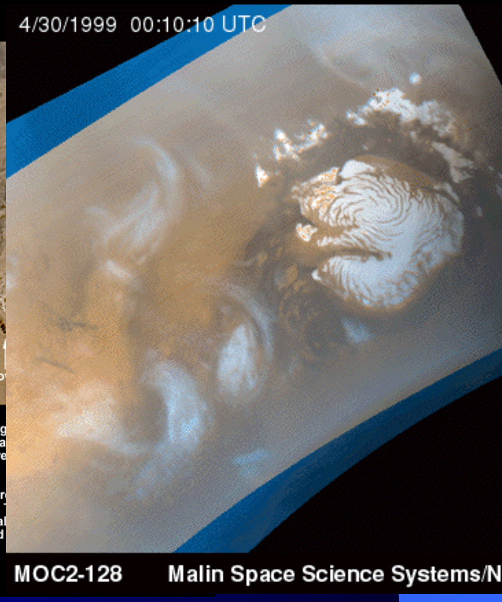
$X_p = CO_2$; Nubes: CO_2-H_2O; $P_{sup} = 7$ mbar; $<T_{sup}> = -50^0C$



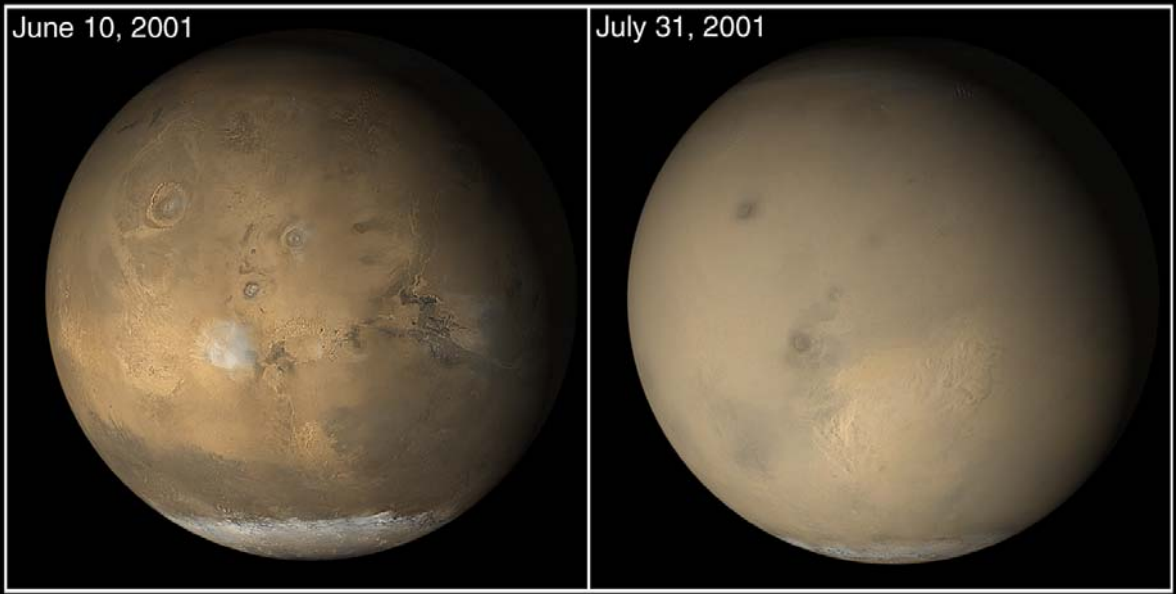




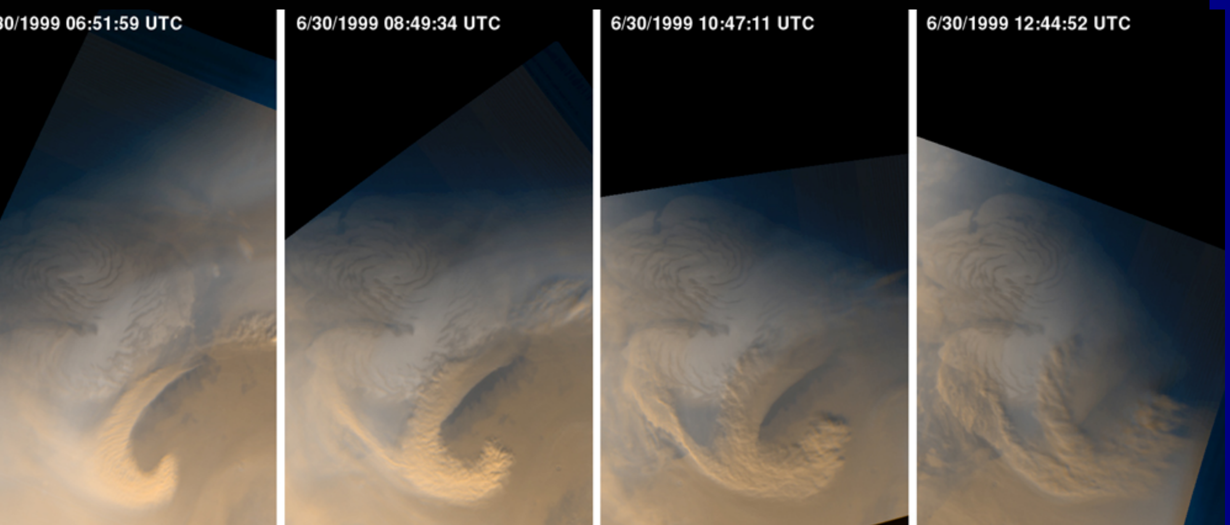


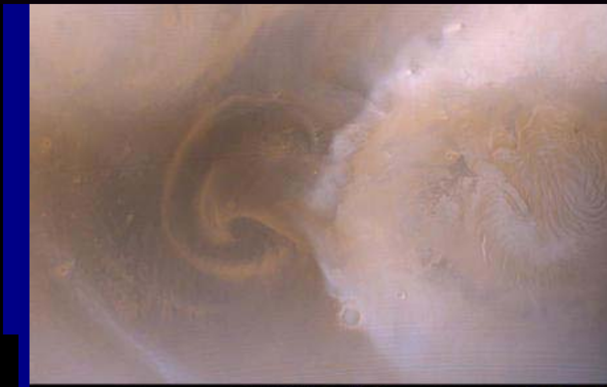


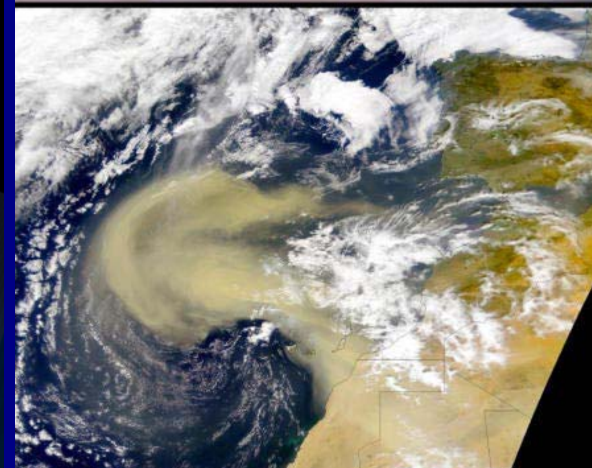
Tormentas de Polvo



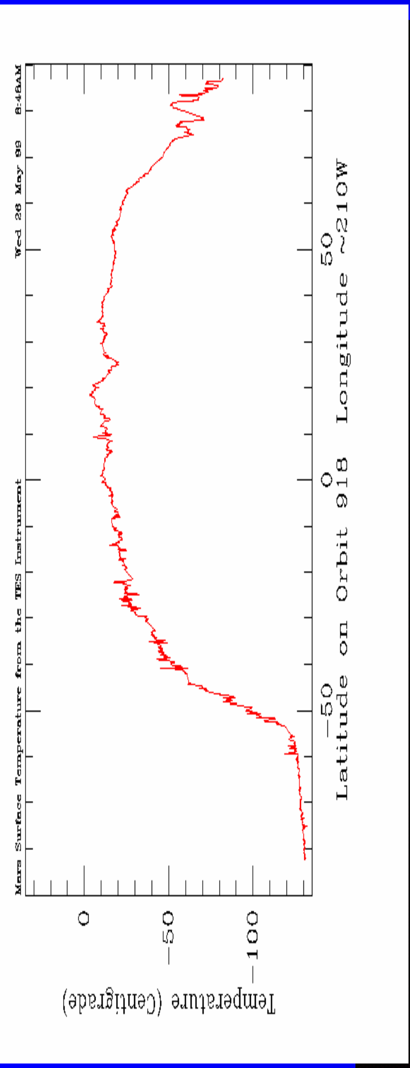
Polvo inyectado: z ~ 30 km cuando u ~50 m/s

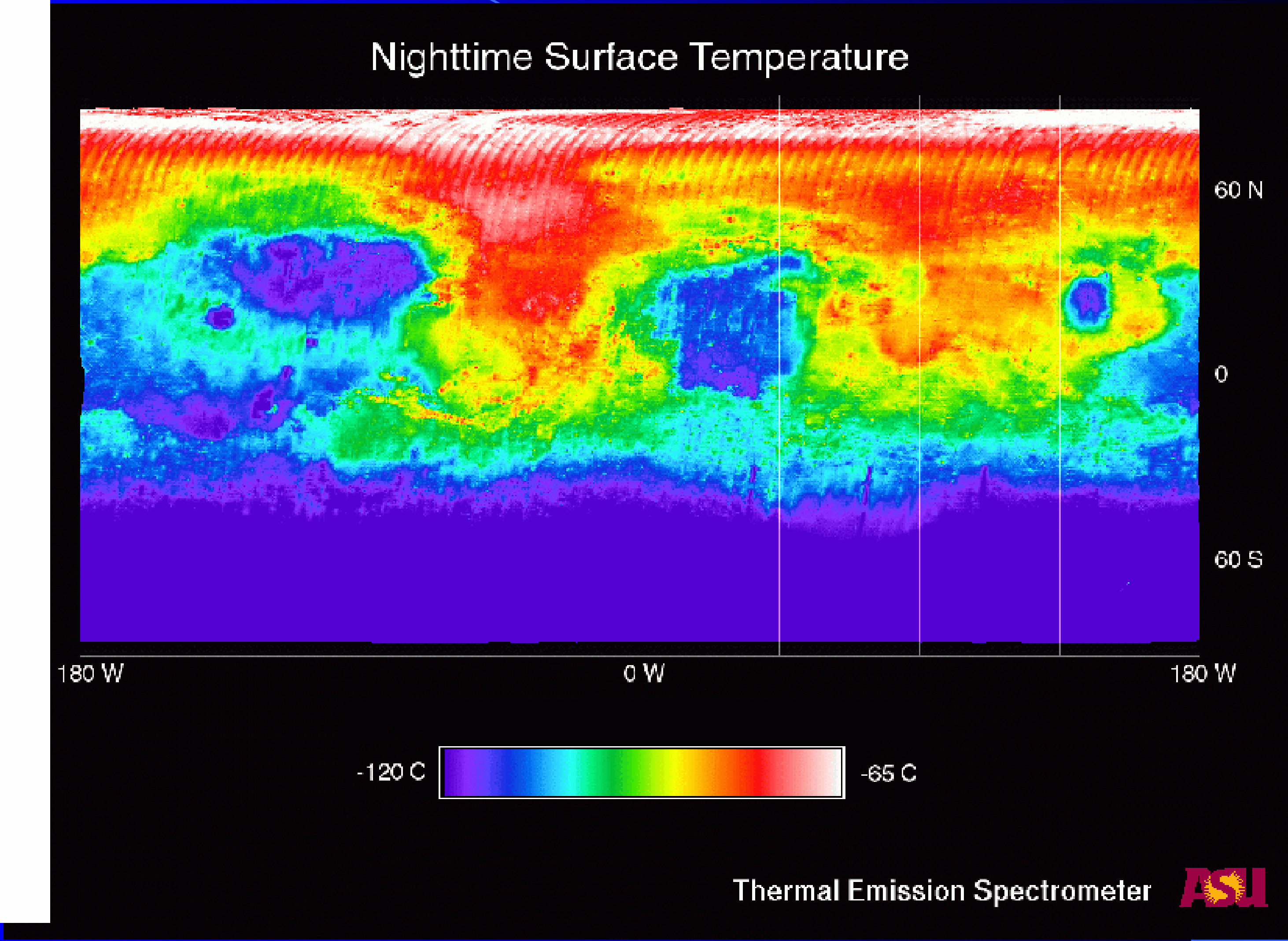






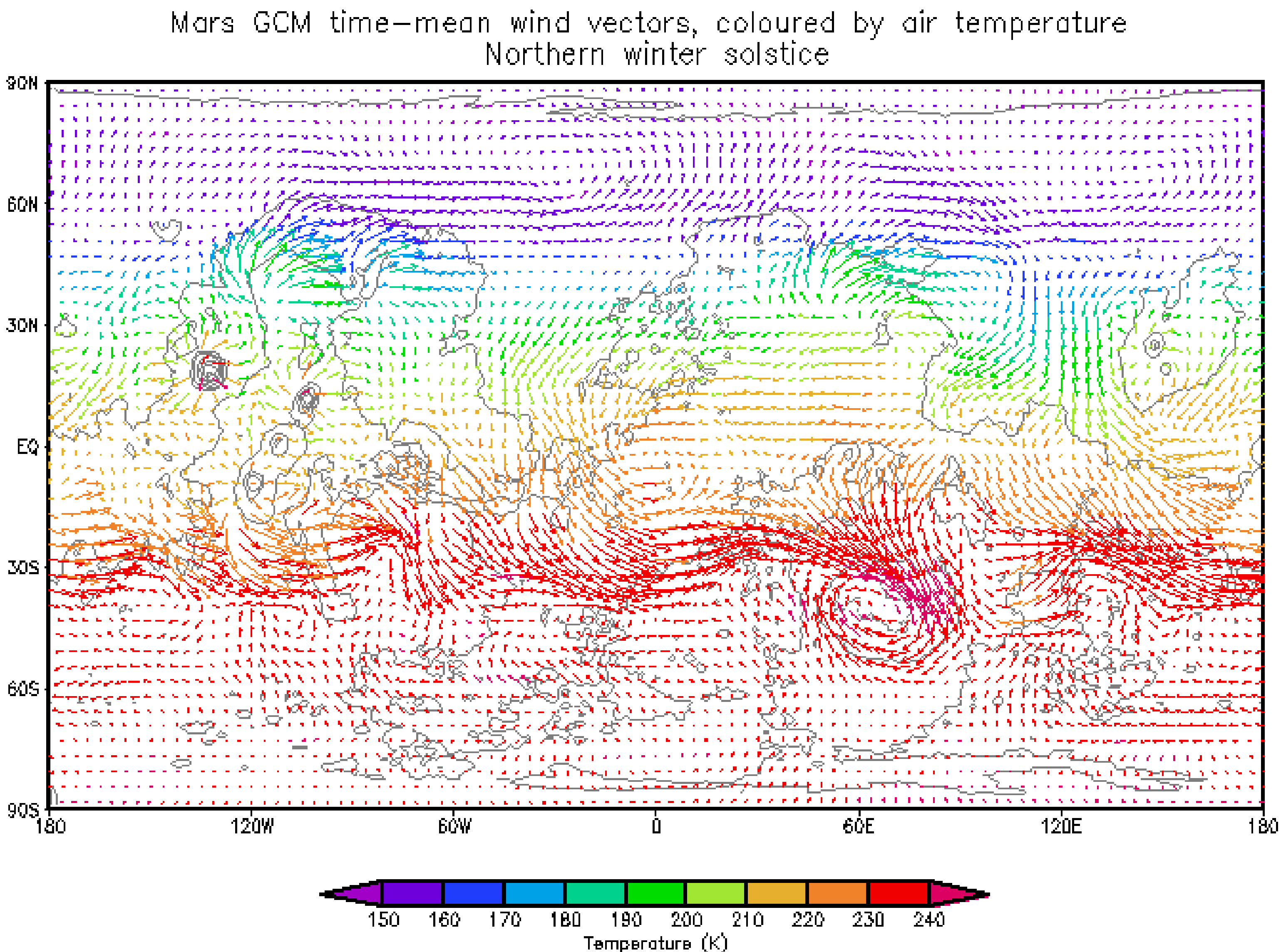
Martian Atmosphere: Global Temperature





Mars: Atmospheric Circulation

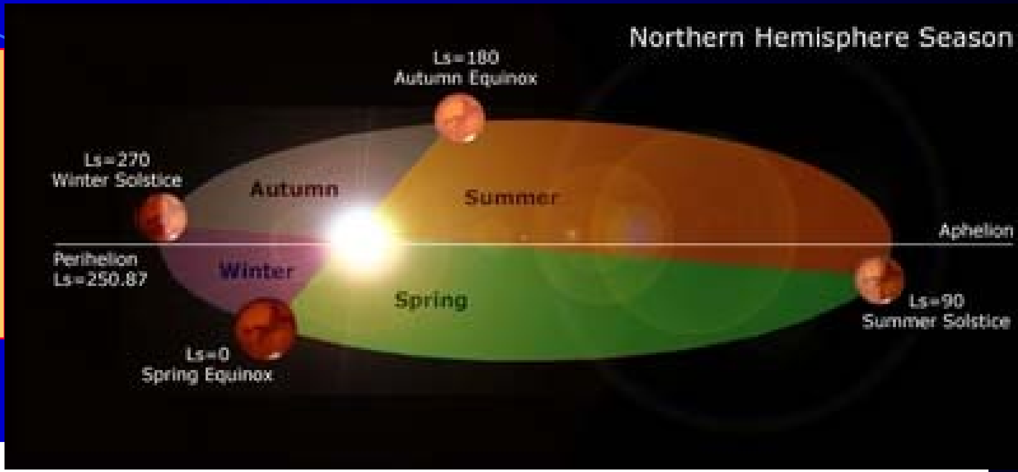
Geostropic (including orography) GMC model

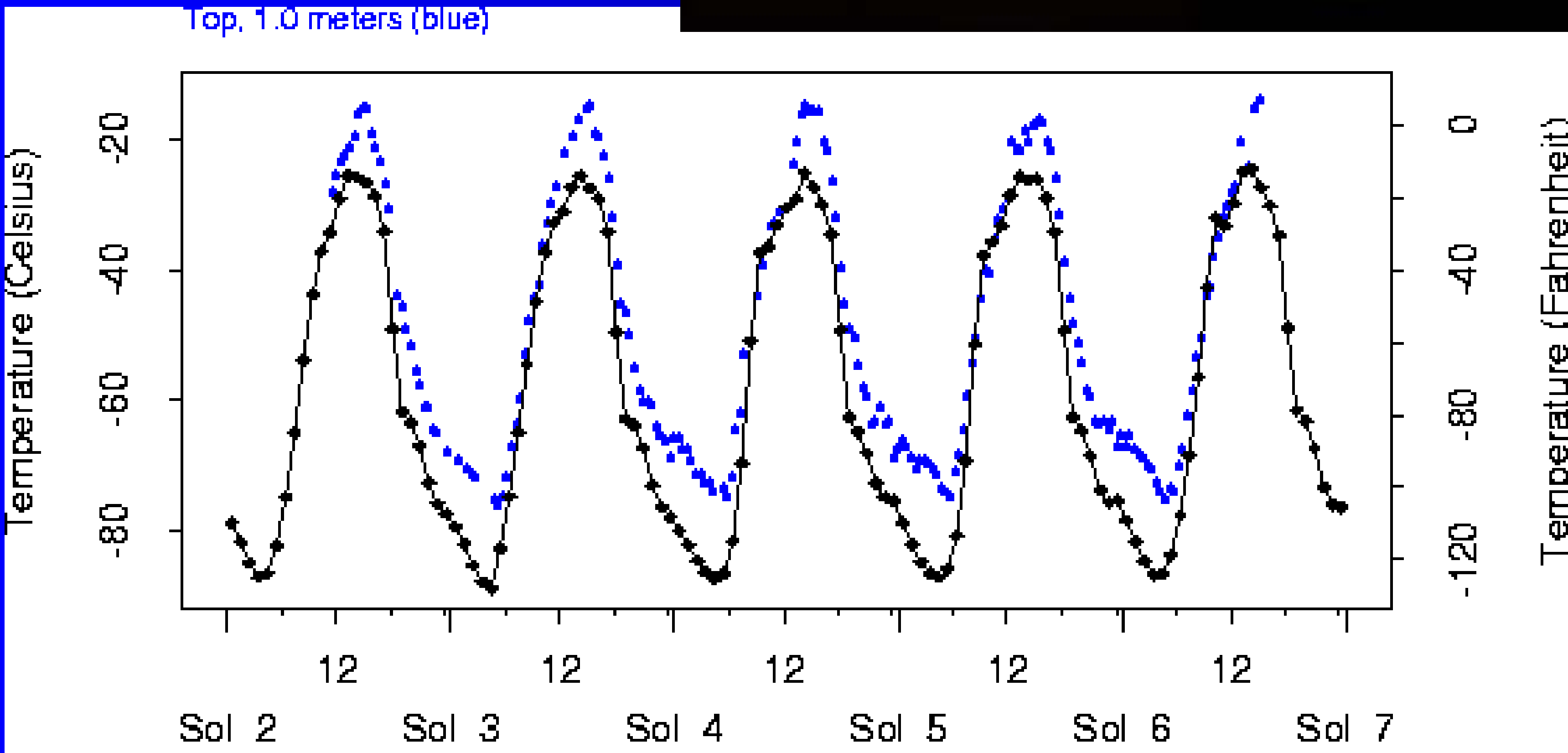


Mars's Atmospheric variability: Dayly and Seasonal

) **Seasonal effects (i=24^0 and orbital eccentricity)**
CO_2 condensation – sublimation cycle
Mean Pole to Pole flow

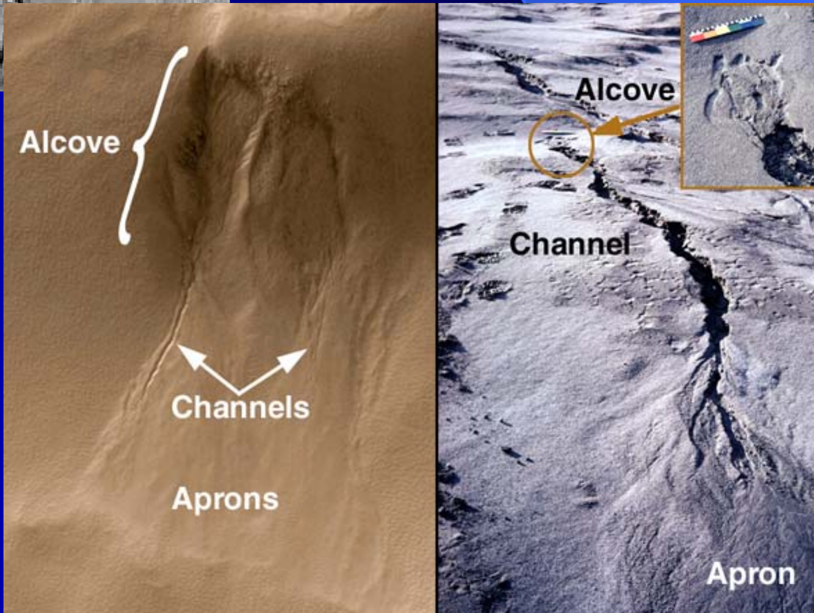
) **Daily: Fast radiative thermal response →**
$\Delta T \sim 60$ K



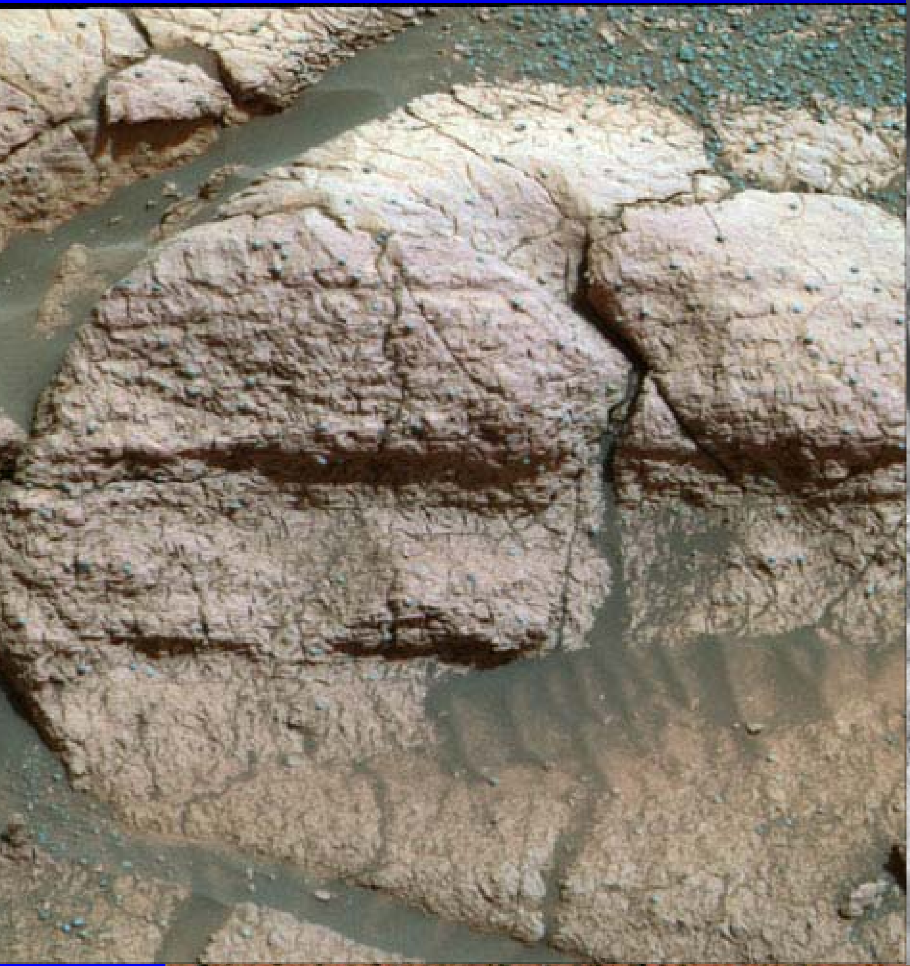


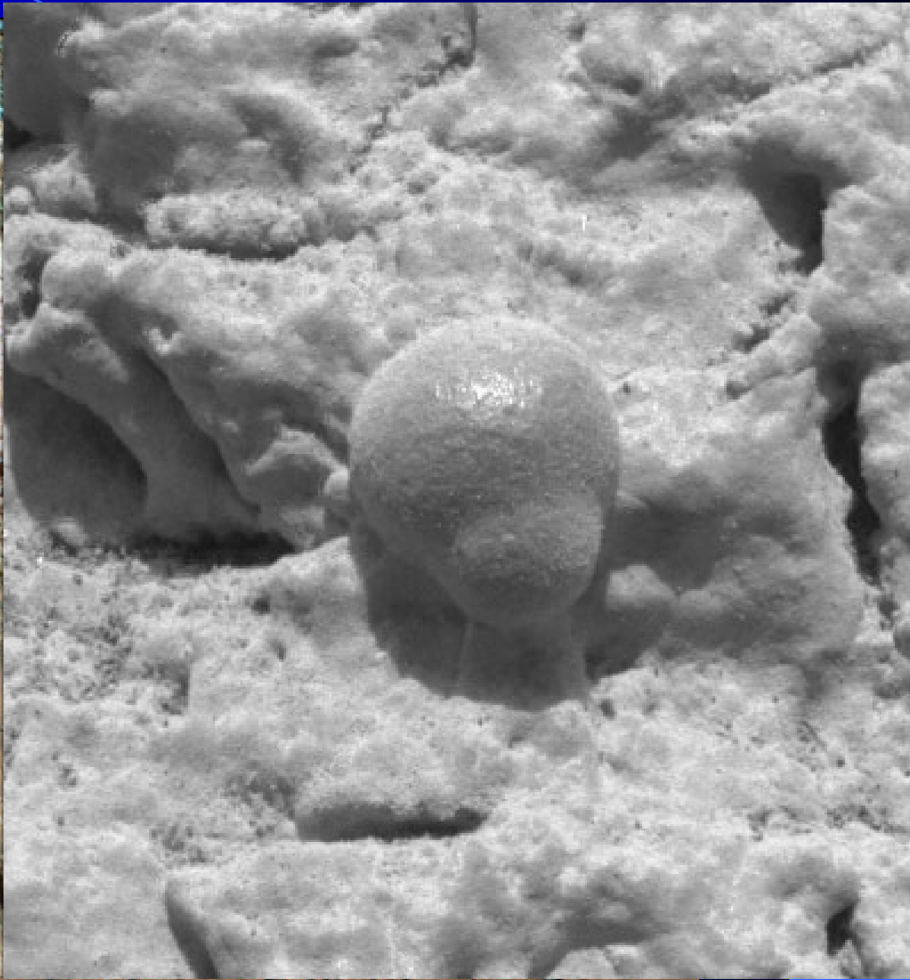
Agua hace 3.000 millones de años

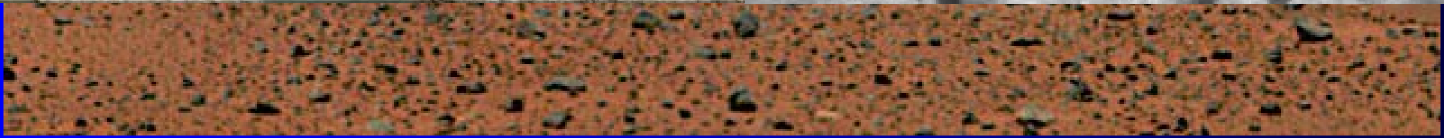
¿O solo 10 millones de años ?



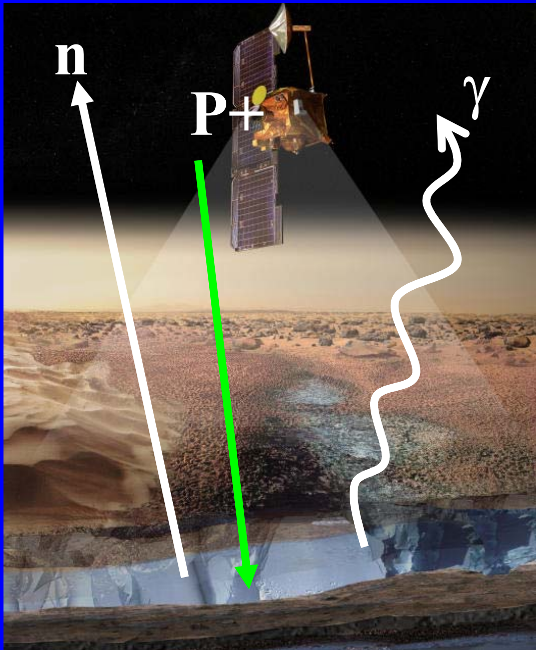
Spirit – Opportunity: Evidencia de depositos líquidos azufrados en el pasado

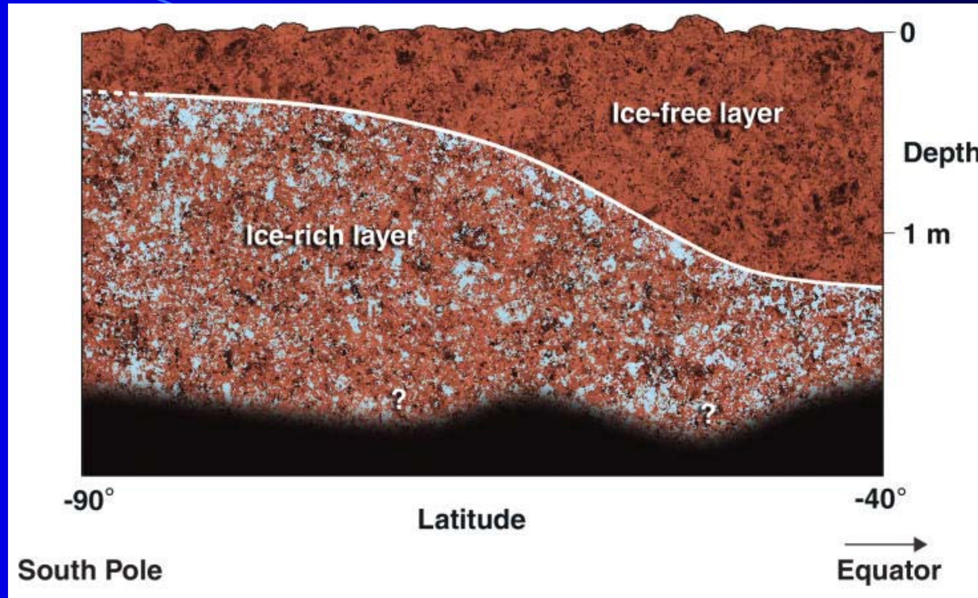


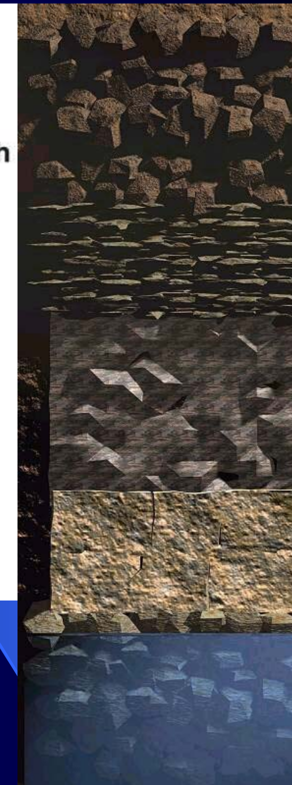


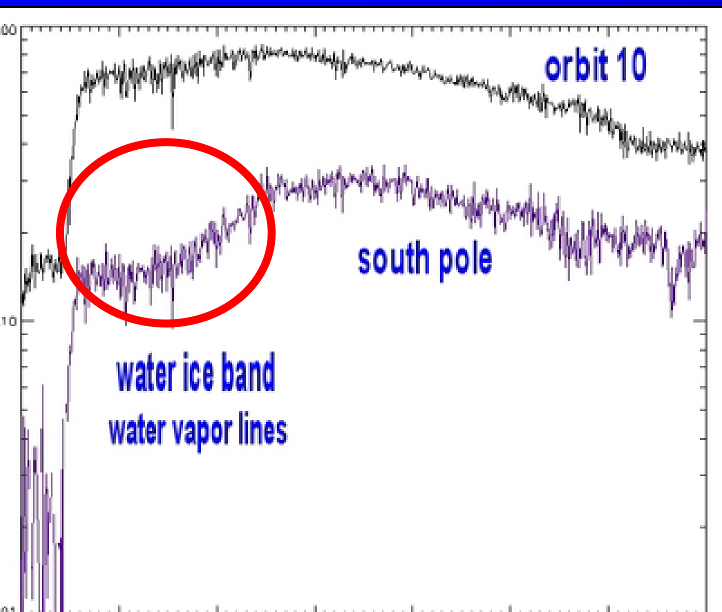


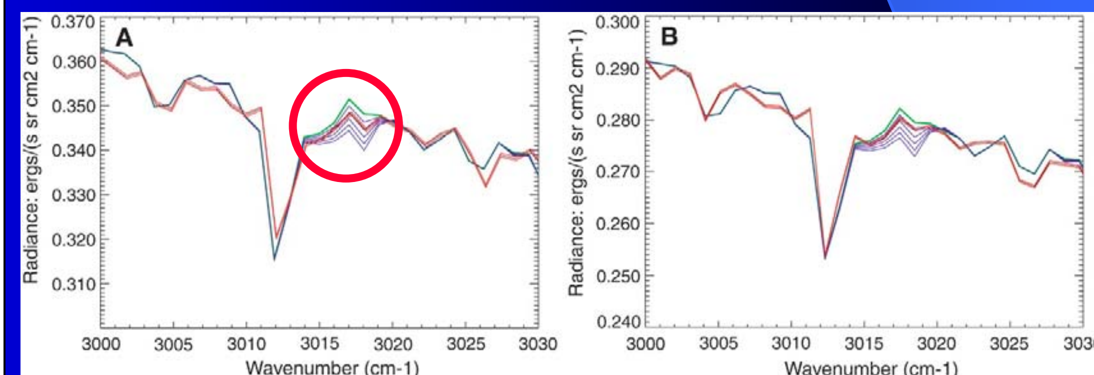
Presente: agua helada y metano





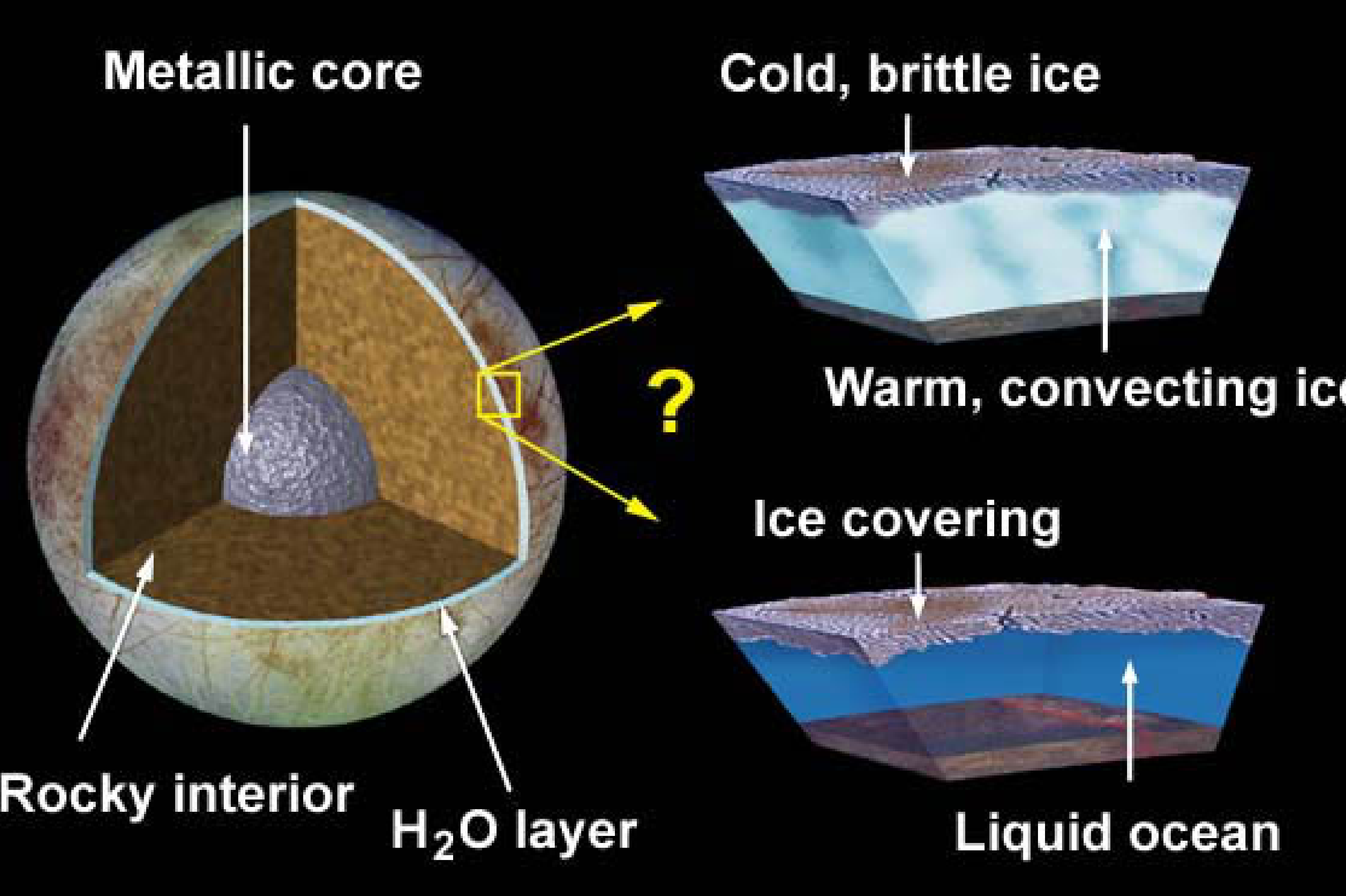




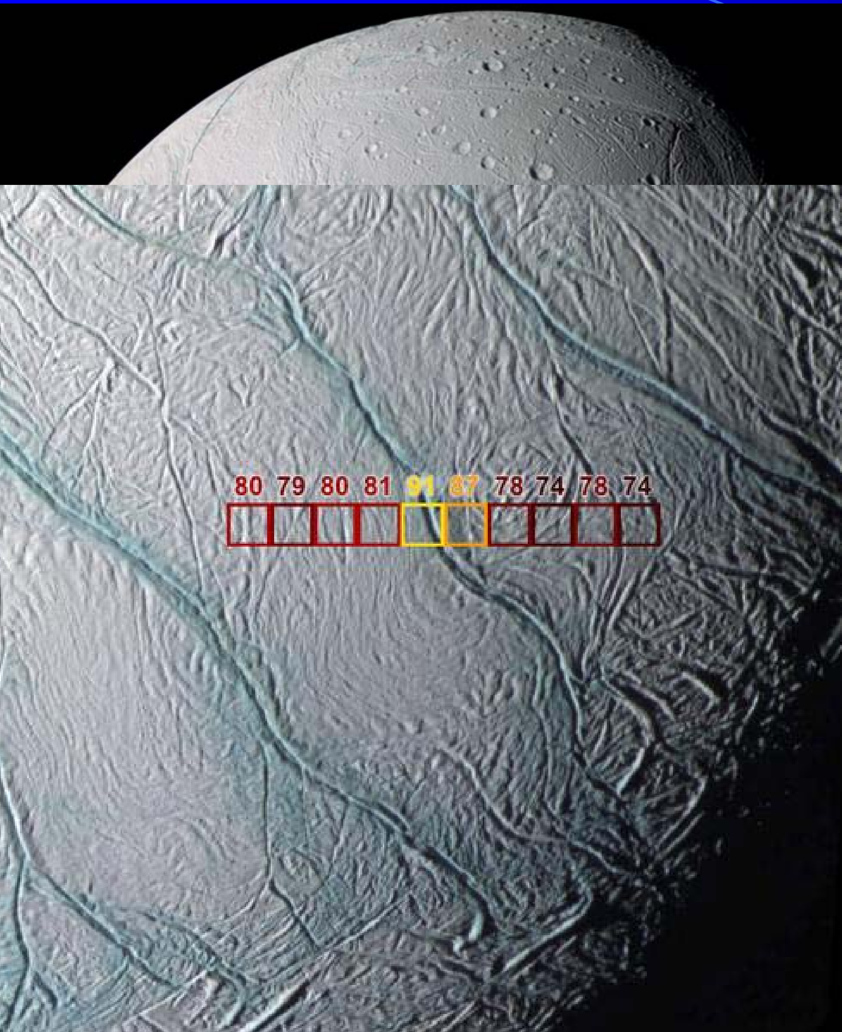


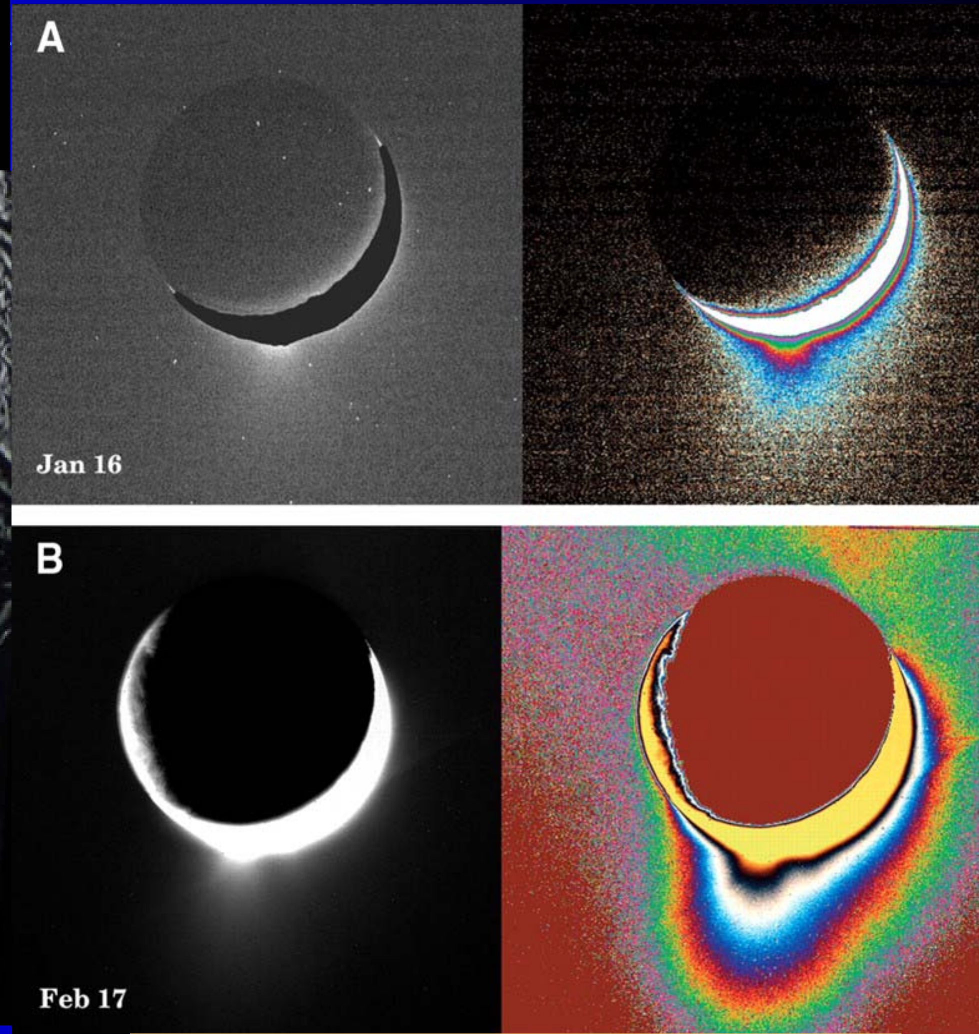
Europa: agrietado y oculto bajo el hielo...

¿Un océano subsuperficial?



Encelado (Saturno): Geíseres - Atmósfera



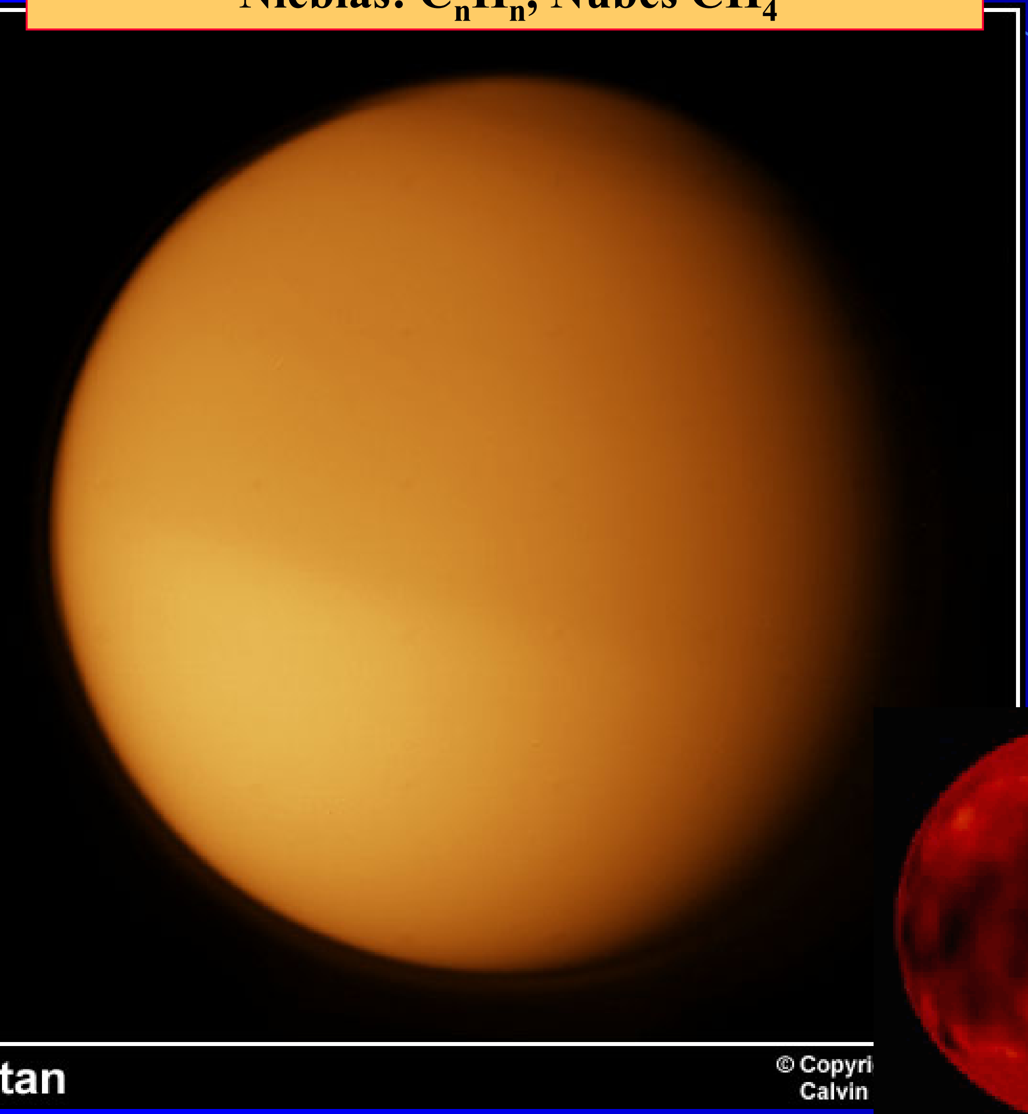


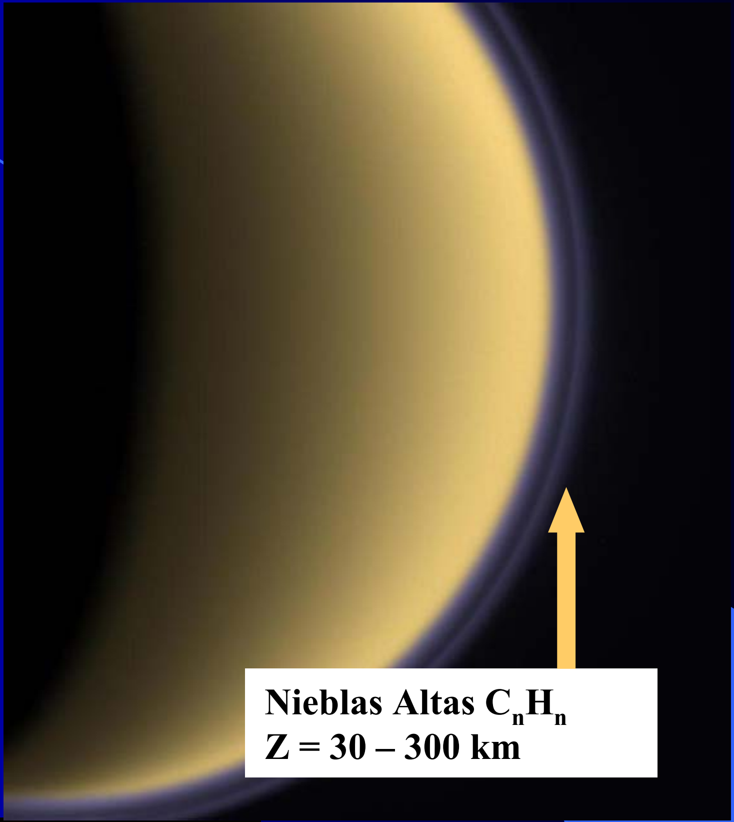
D = 500 kms
L = 130 kms, d = 40 kms
$\Delta T = 12^o$ C
Edad superficie ~ 10 años

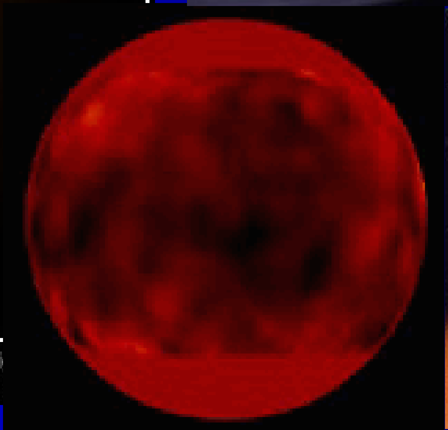
Gases: 65% H_2O, 20% N_2, CO_2, CO, CH_4.

Titán: brumoso y misterioso

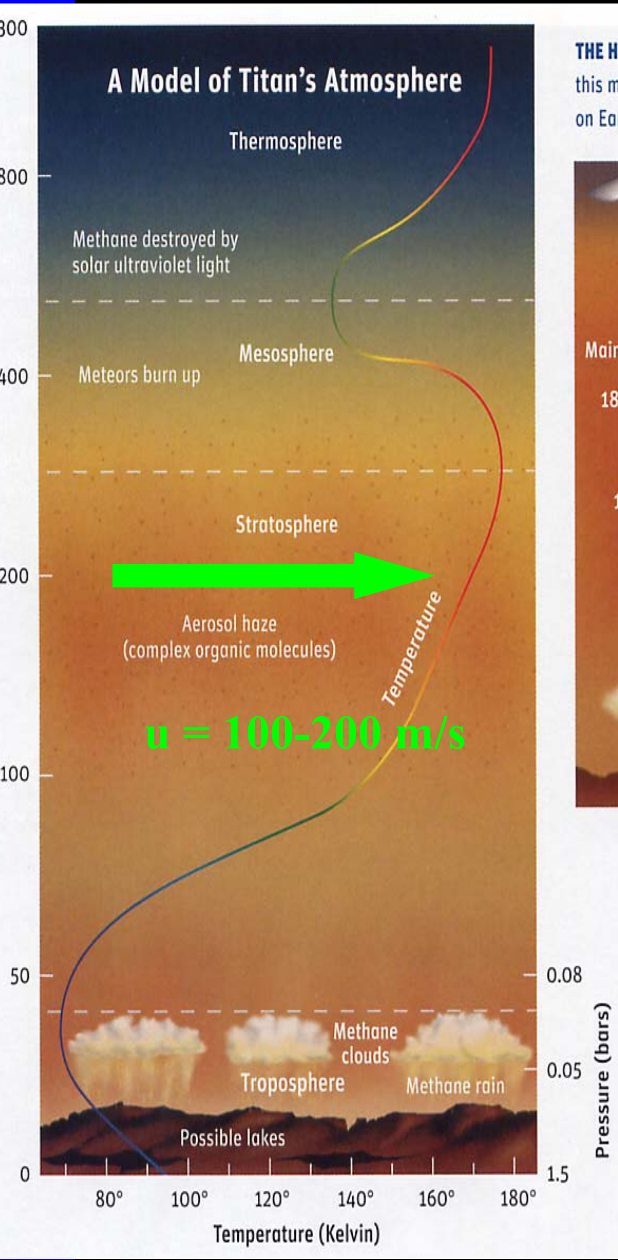
R = 2500 km, X = N_2, P = 1.6 bar, T = -180^{0}C
Nieblas: C_nH_n, Nubes CH_4





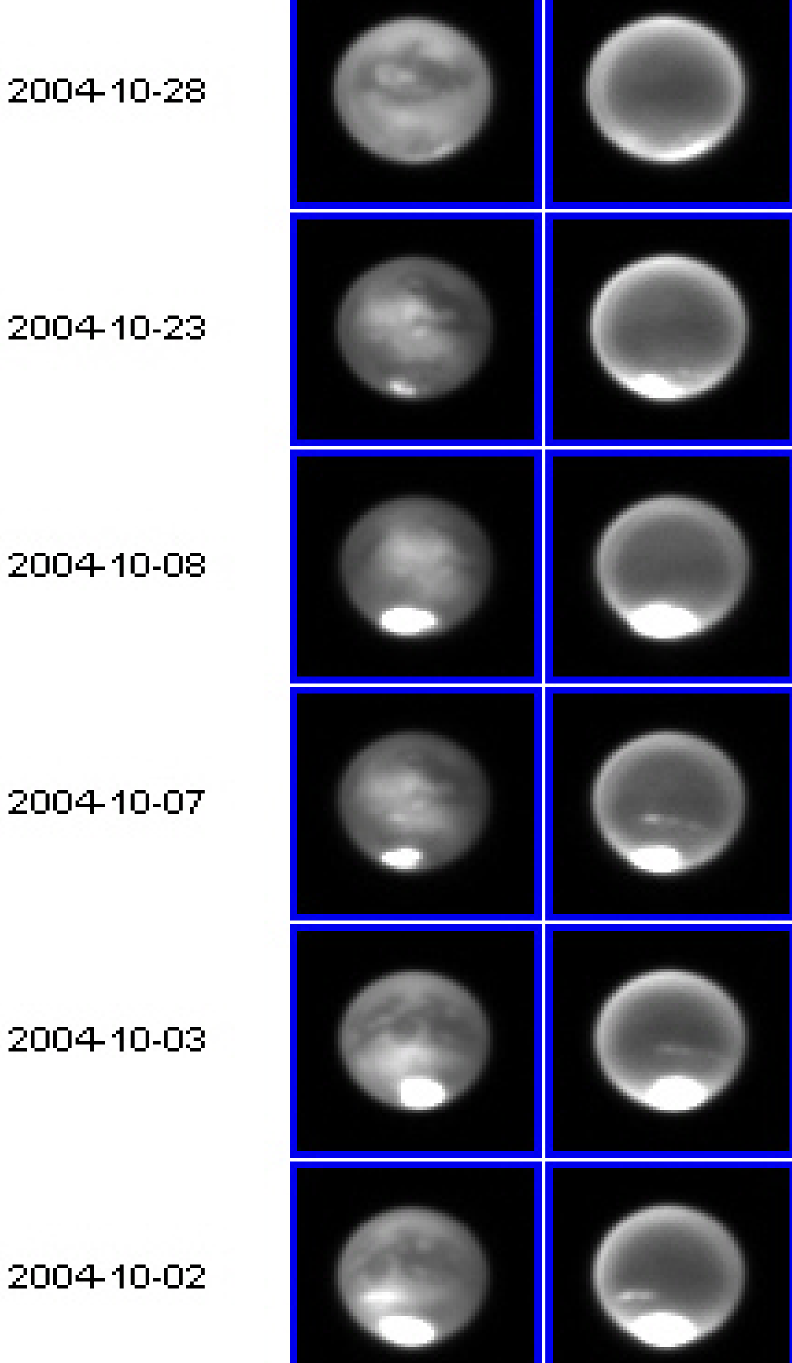


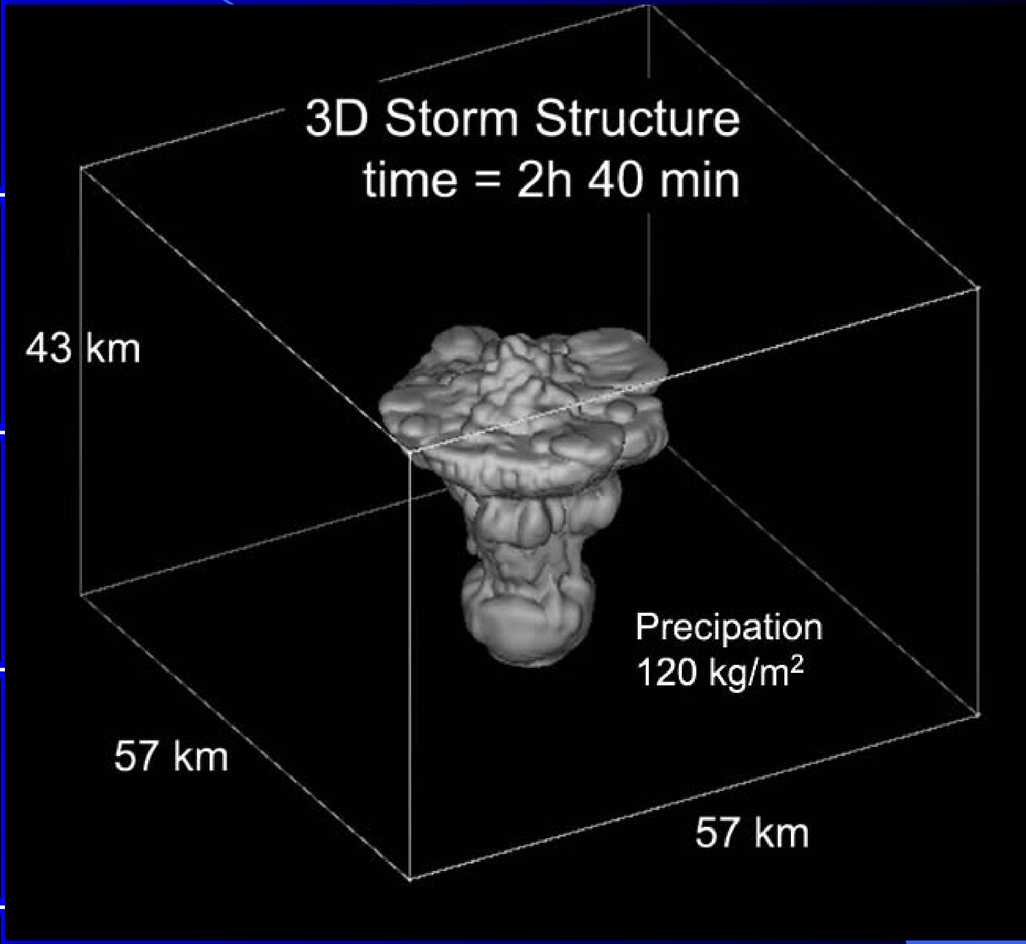
Cassini: Primeras Observaciones de Titan



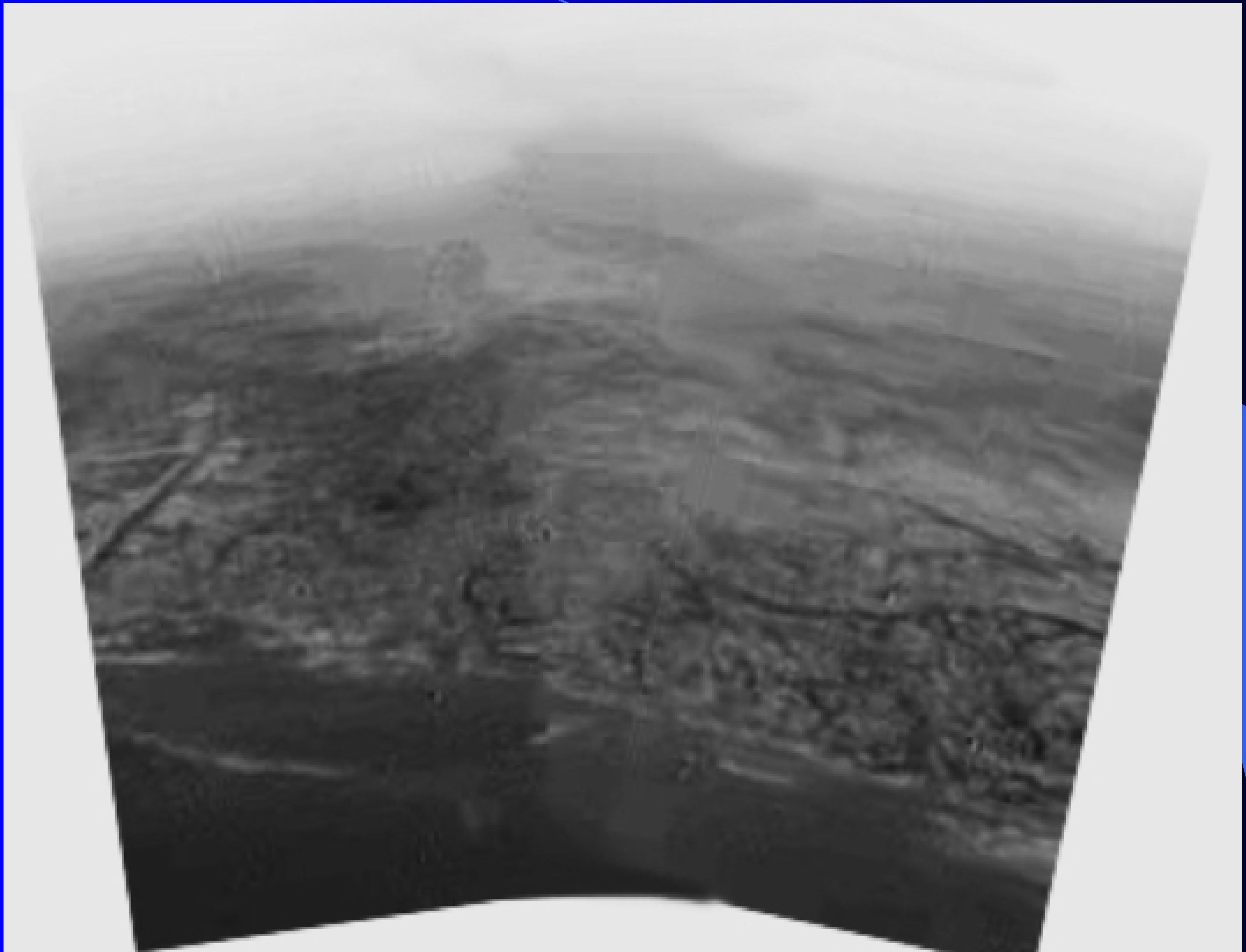
Nubes de hielo de Metano en el (verano) del Polo Sur

Titán
¿Luvias torrenciales?

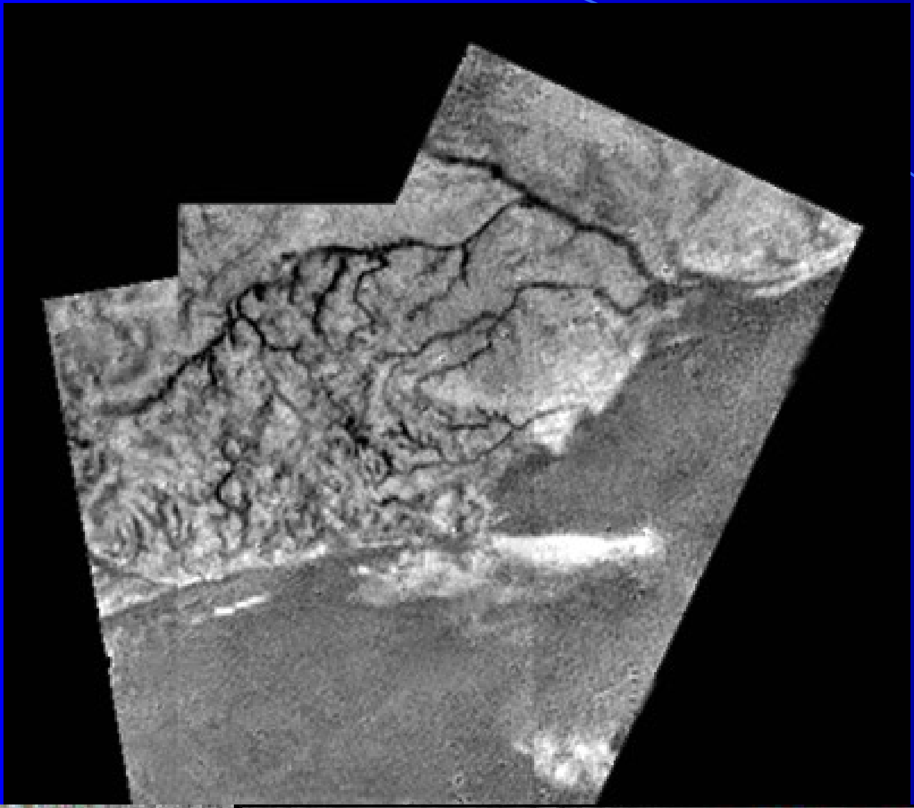




Descenso Huygens en Titán: 14 Enero 2005



Huygens en Titán (14 Enero 2005)



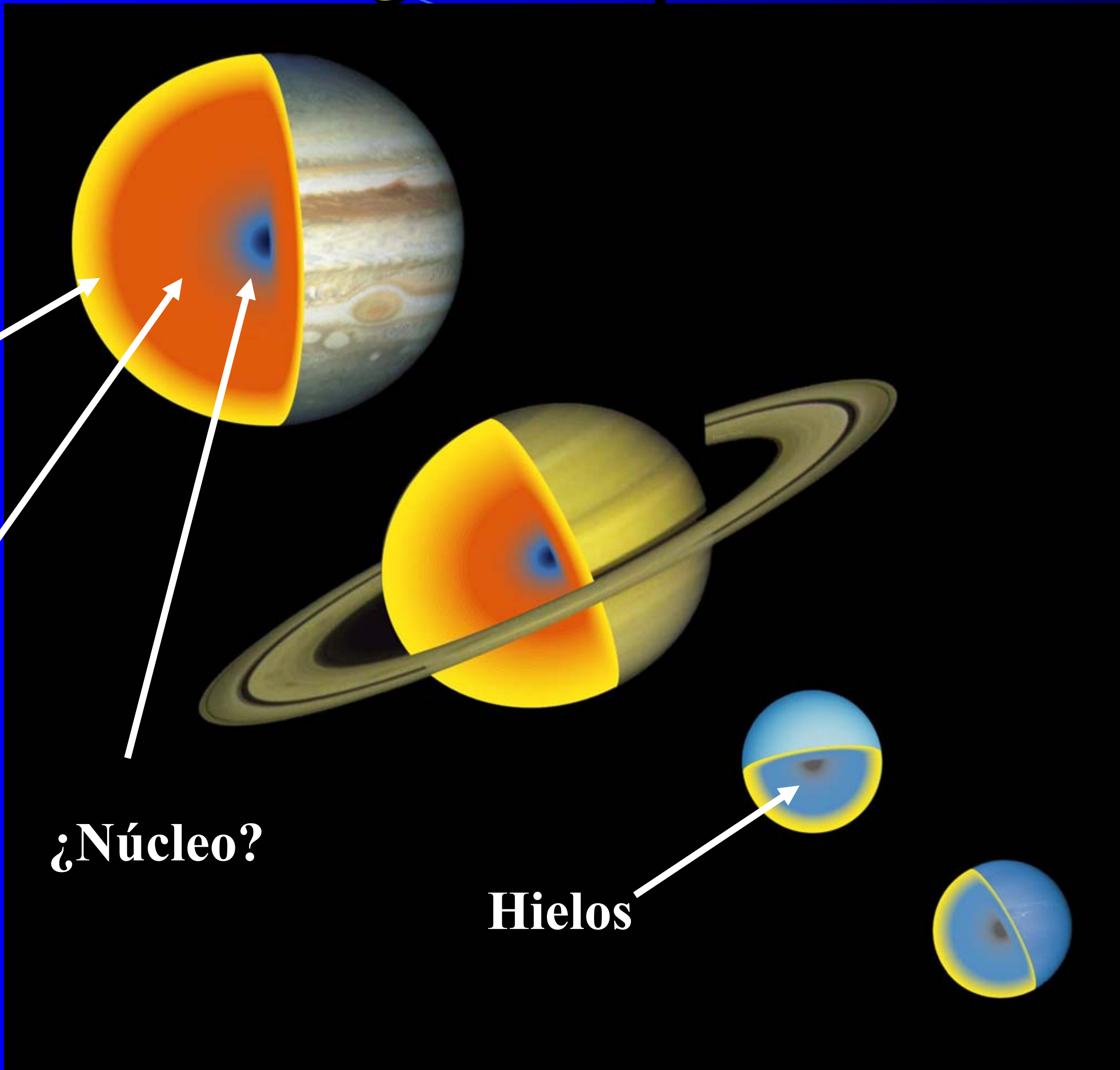
Parte – 2

PLANETAS GIGANTES Y PLANETAS EXTRASOLARES

LA VIDA EN EL UNIVERSO

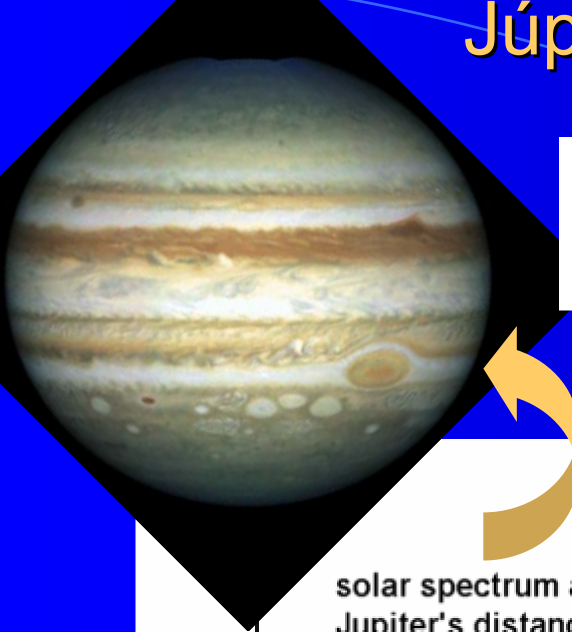
FUTURO EXPLORACION ESPACIAL

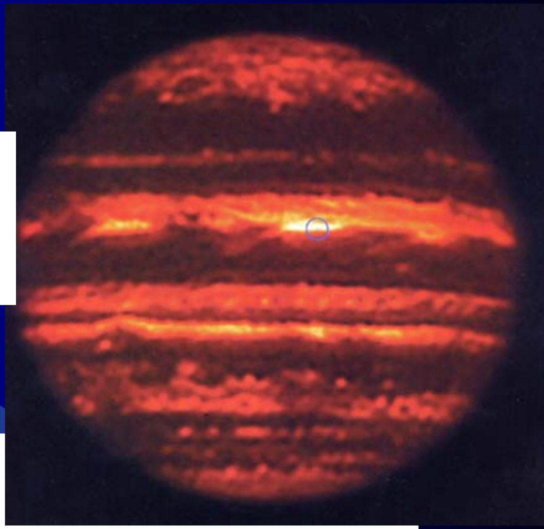
El hidrógeno: ¡ un metal!

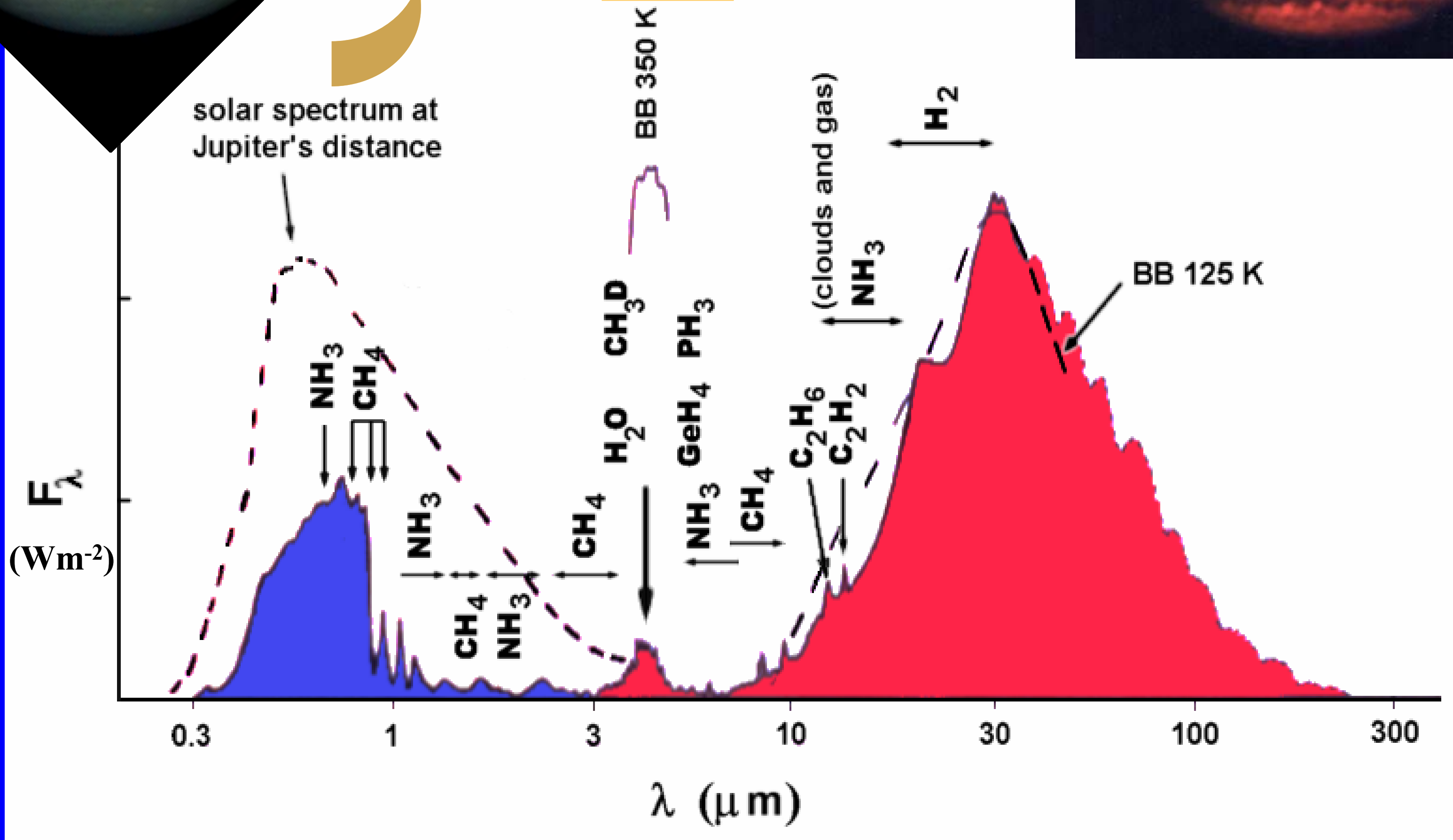


Júpiter: Energía Interna

Fuente de energía inetrna:
(1) Calor de formación
(2) Lenta contracción (1cm /100 años)







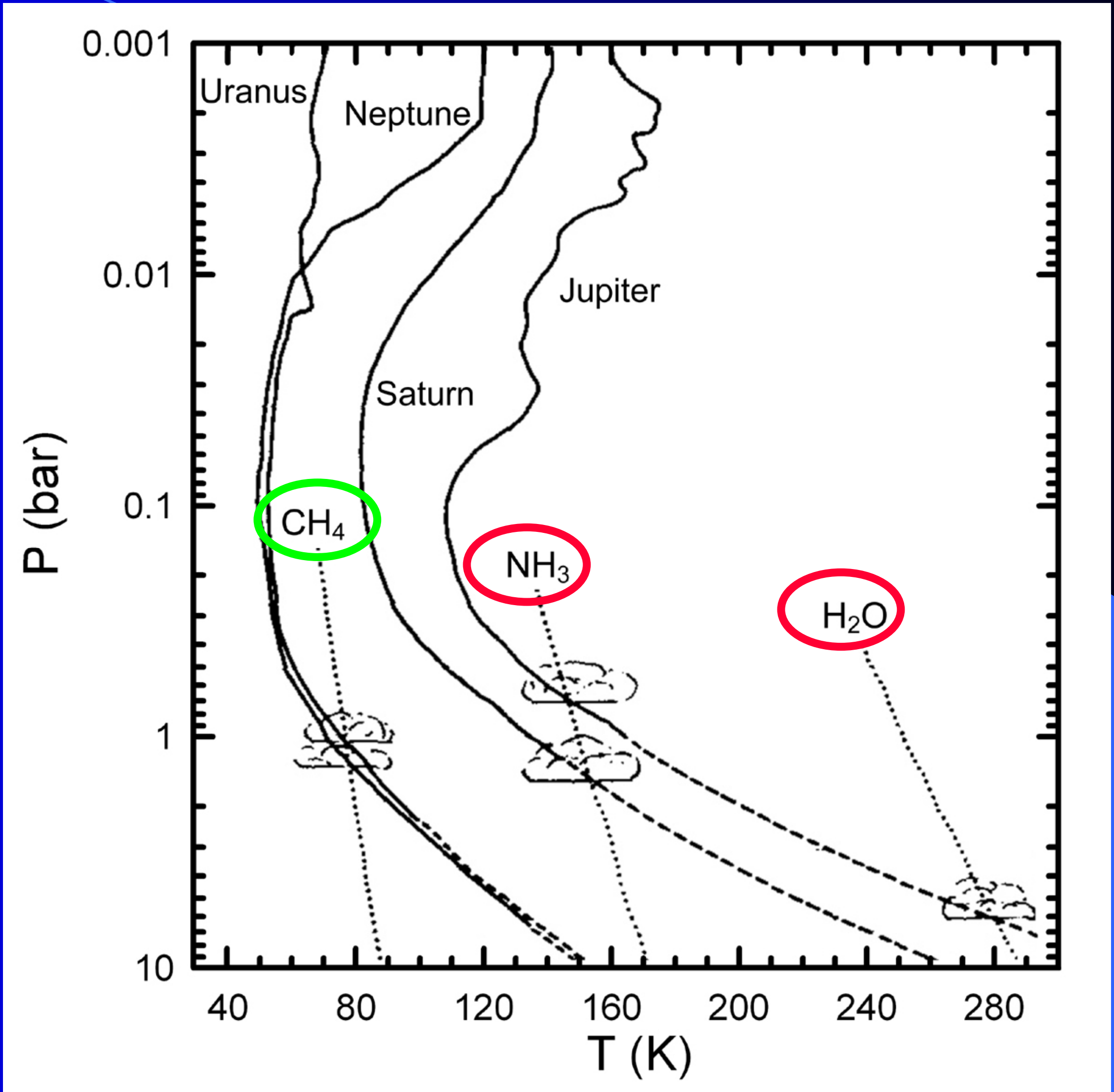
T(P) & Upper cloud layering

$$P_p = X_C P(T) \geq P_V(T)$$

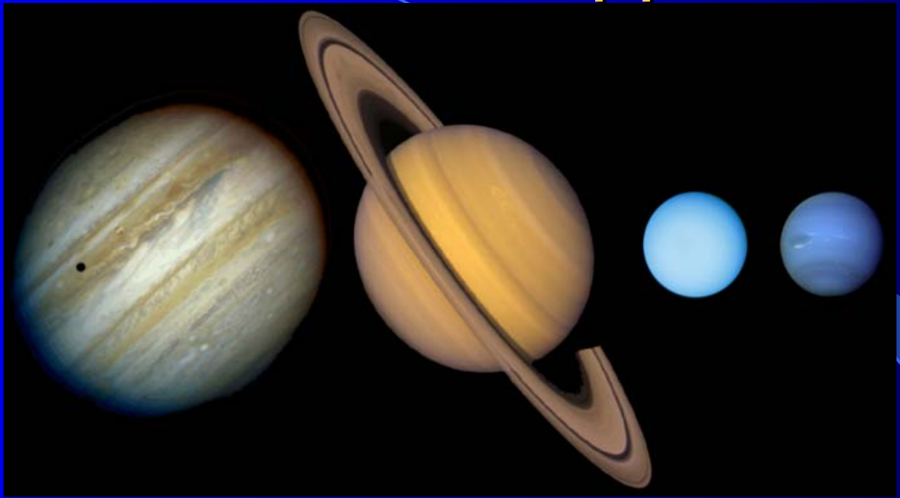
hermodynamic Equilibrium→

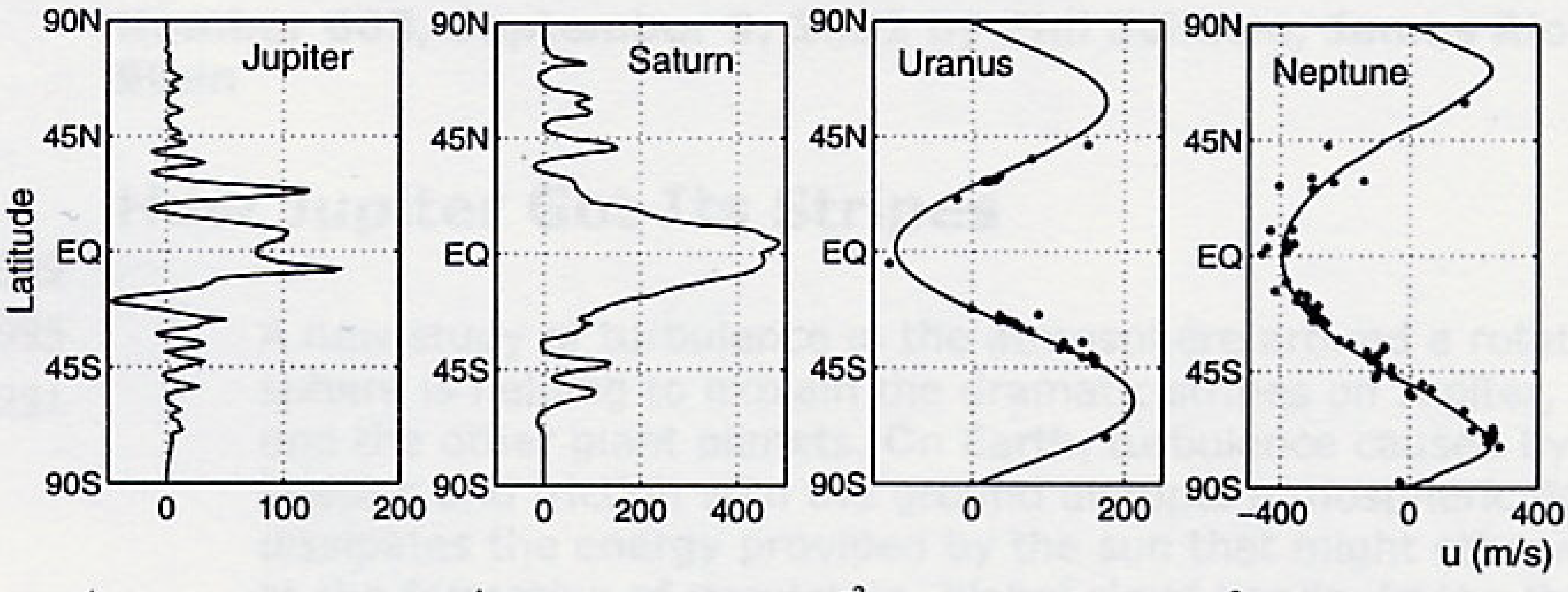
artial pressure P_p of the vapor
xceeds the saturation vapor
ressure $P_V\ (T)$
Clausius – Clapeyron eq.]→

upersaturation
Humidity > 100%)
cloud forms

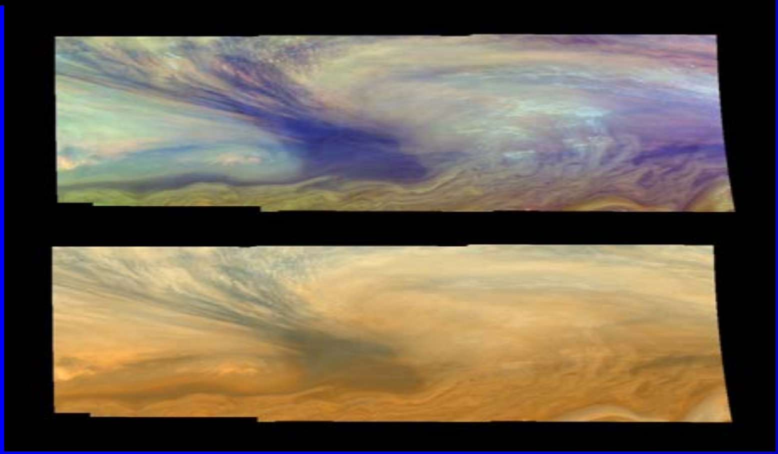


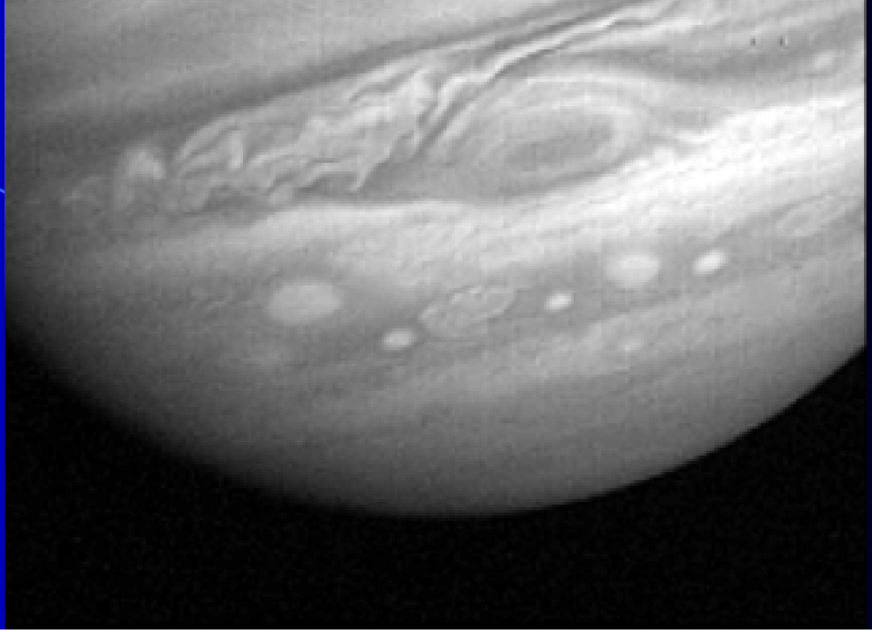
Atmospheric General Circulation
(P ~ 0.3 – 2 bar, upper clouds)

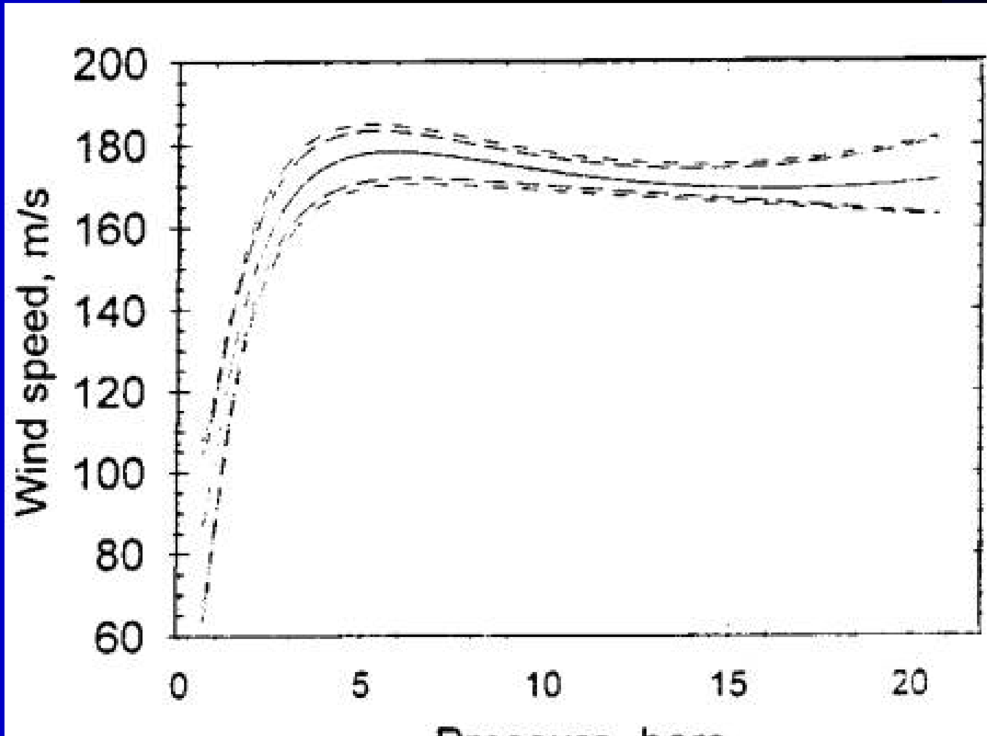




Jupiter

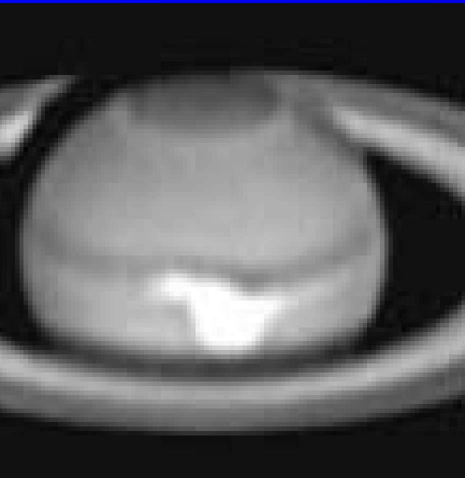


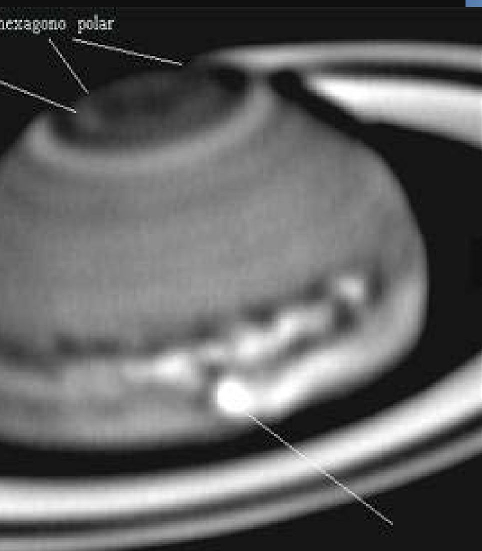


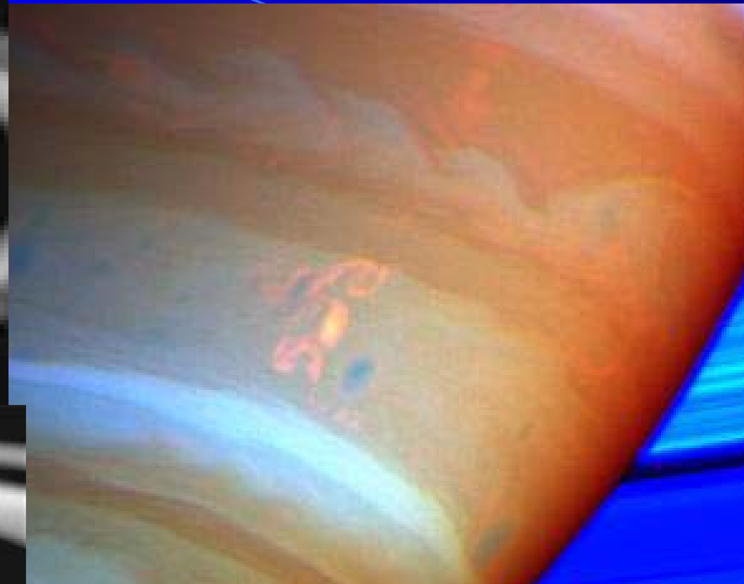


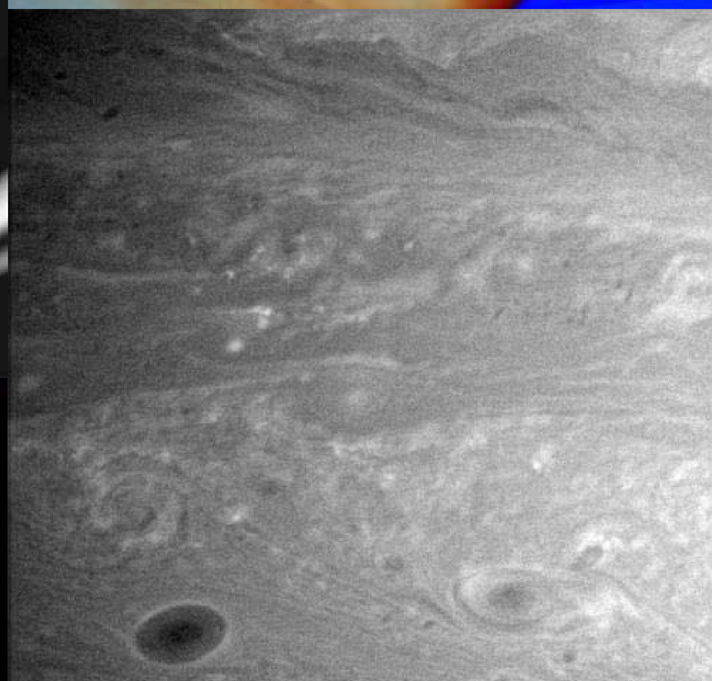
"Hot Spots":
- Peculiar meteorology
- Wave (?)

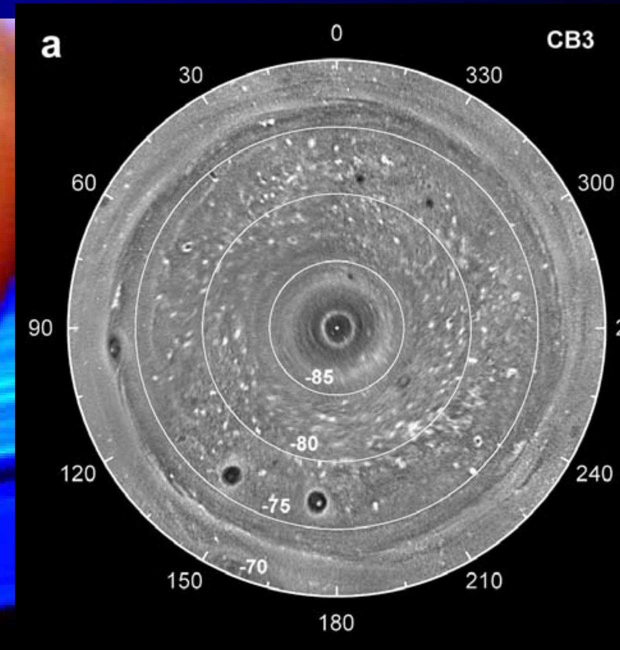
Meteorología Saturno

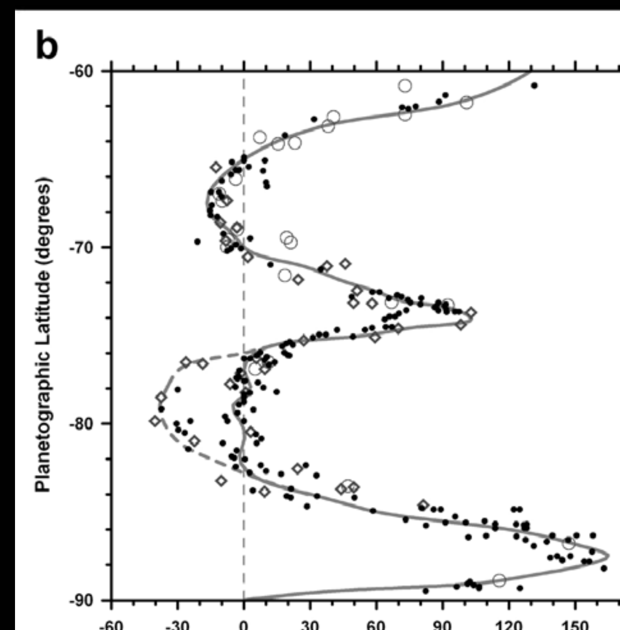






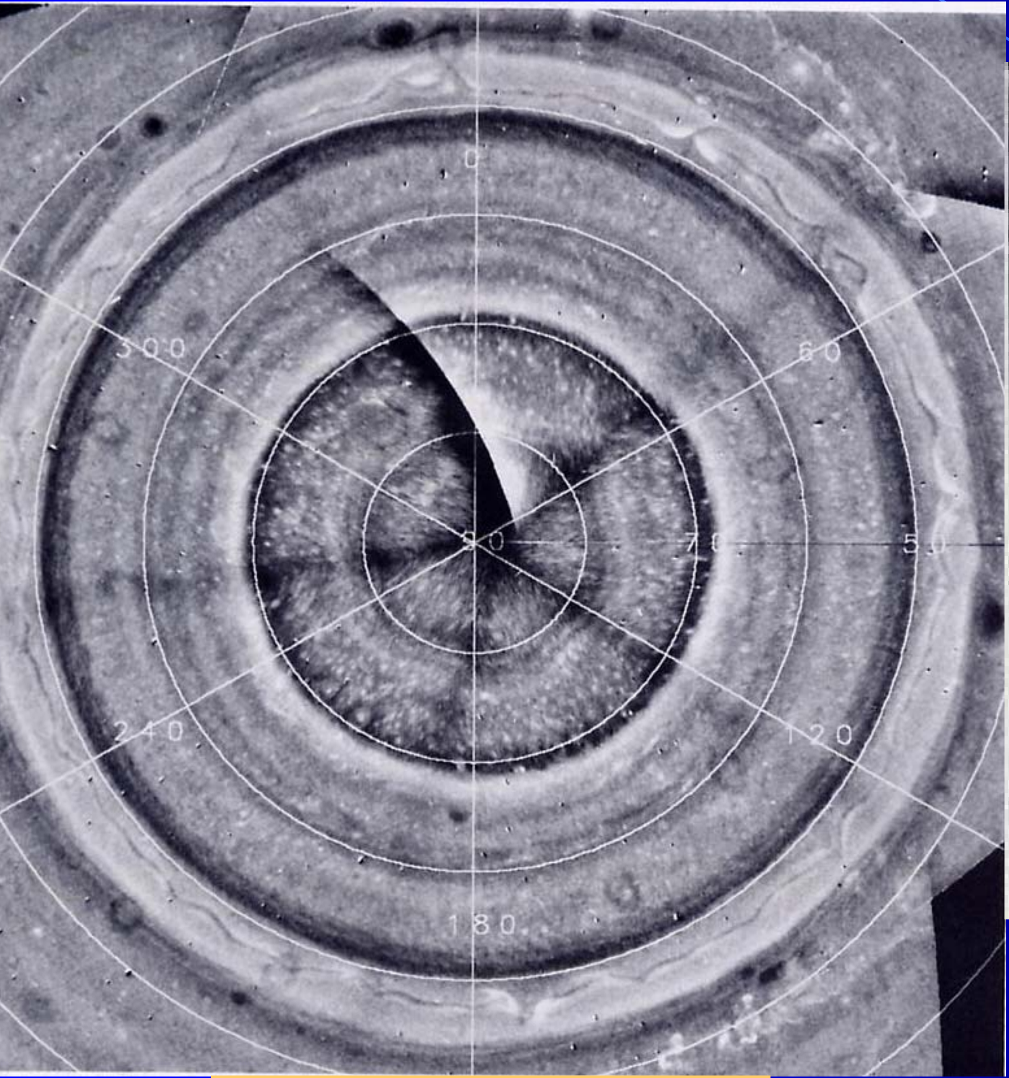


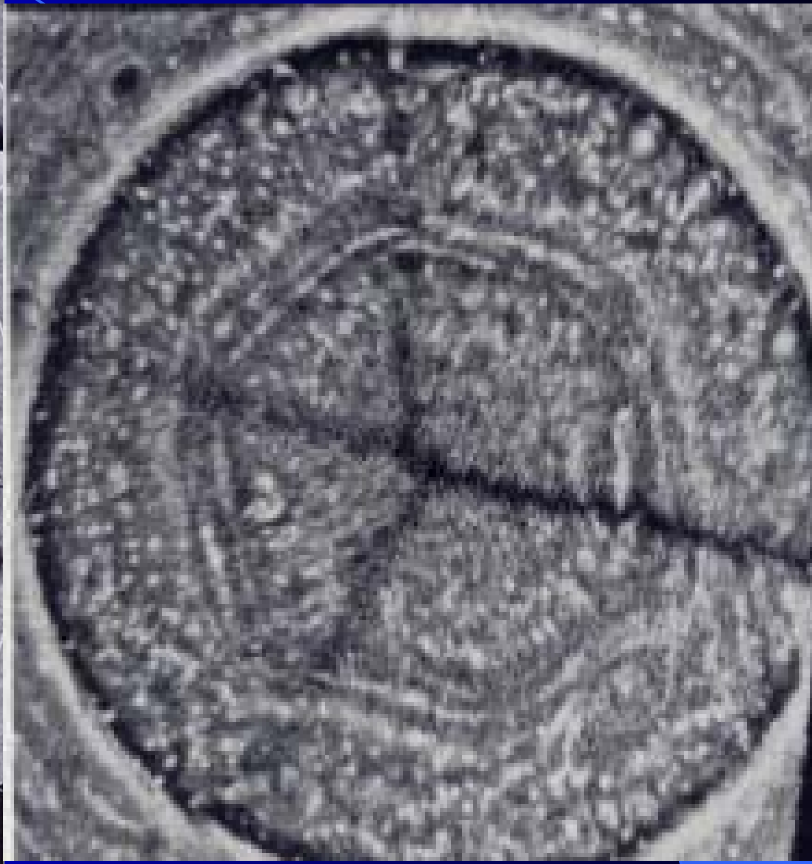




Nubes de amoníaco
Cubiertas de nieblas

Ondas en el Hemisferio Norte
"Serpentina" y "Hexágono"



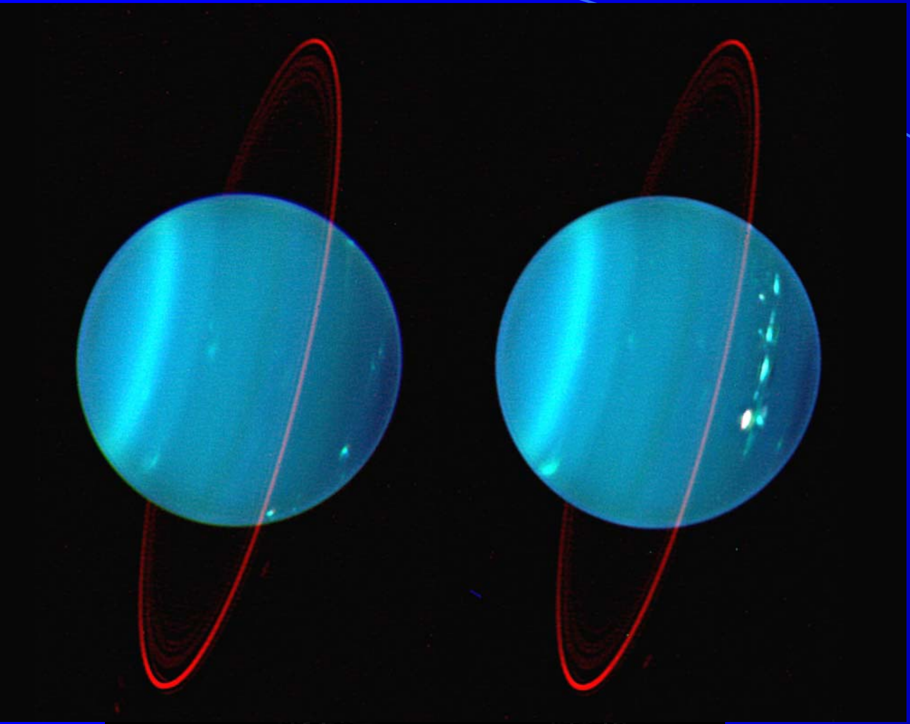


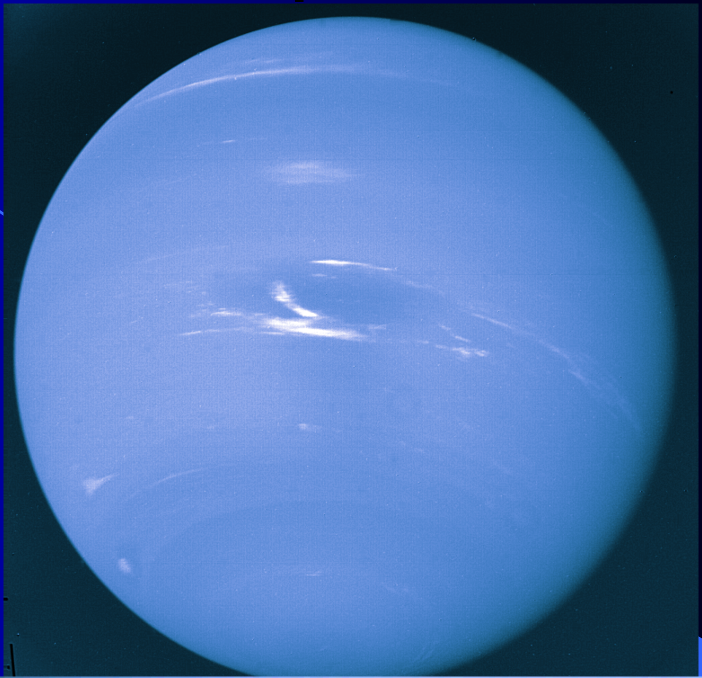
Latitud +78^0
Velocidad = 0.1 ms^{-1}
Corriente en chorro de 100 m/s

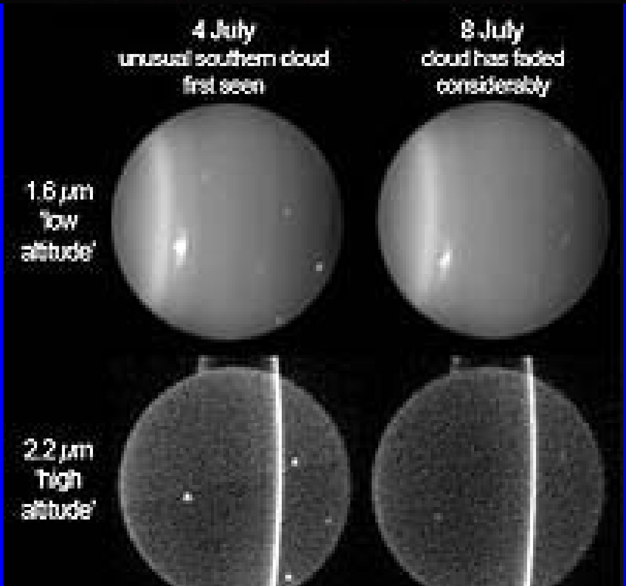
Latitud +48^0
Velocidad = 145 ms^{-1}

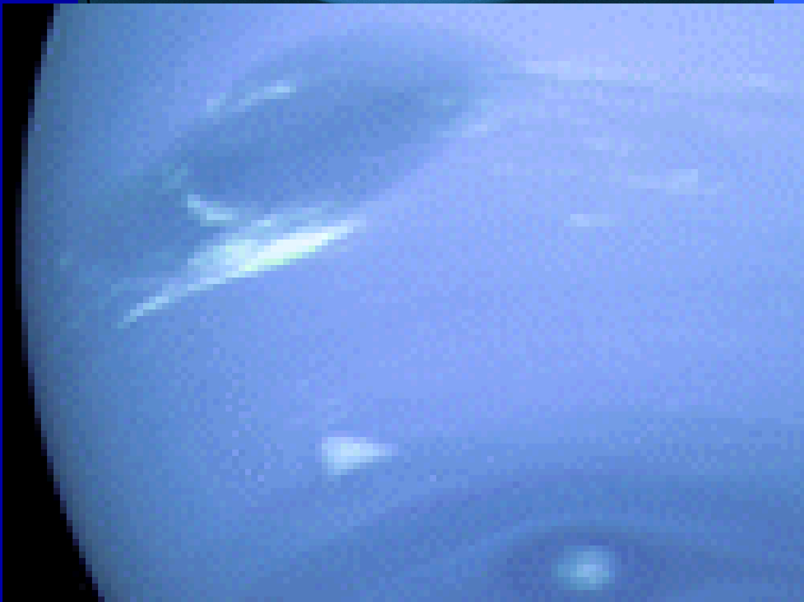
Urano

Neptuno

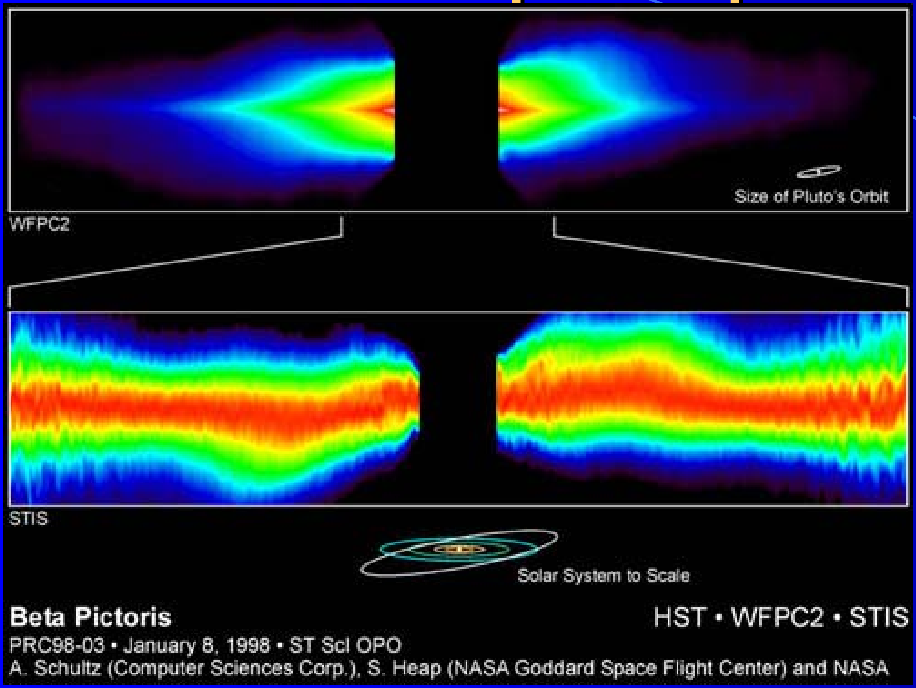


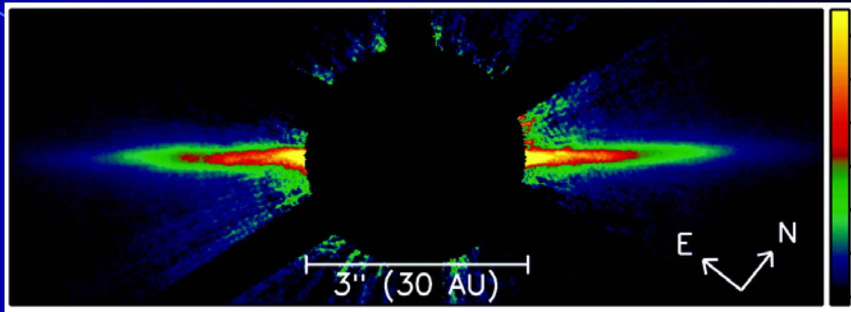




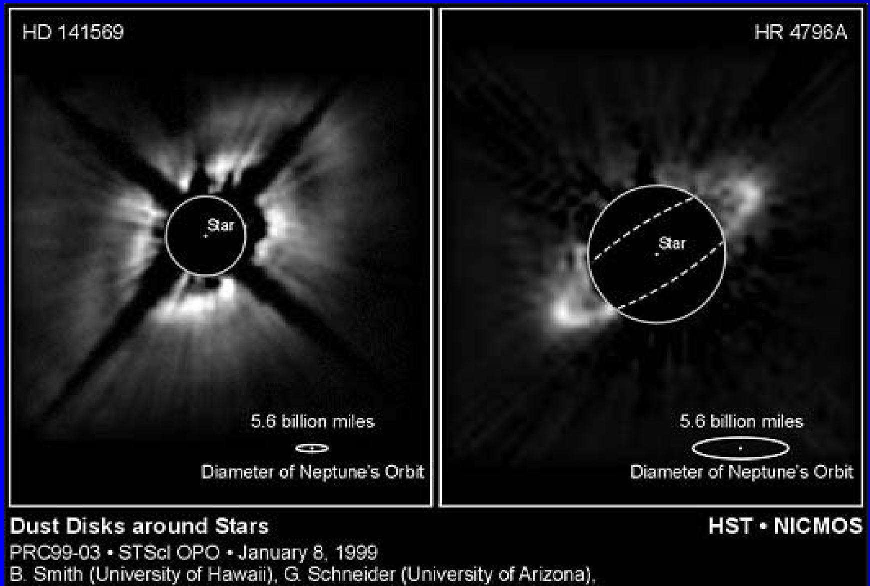


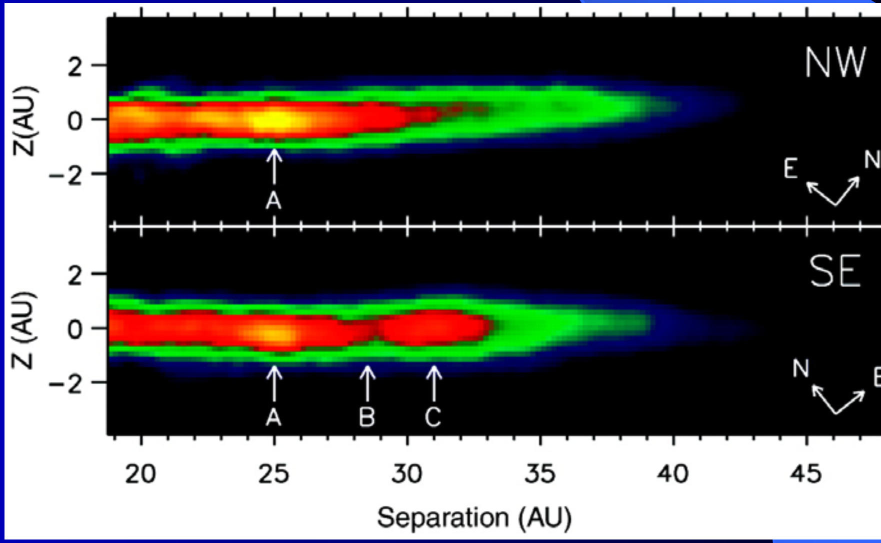
Discos protoplanetarios por doquier





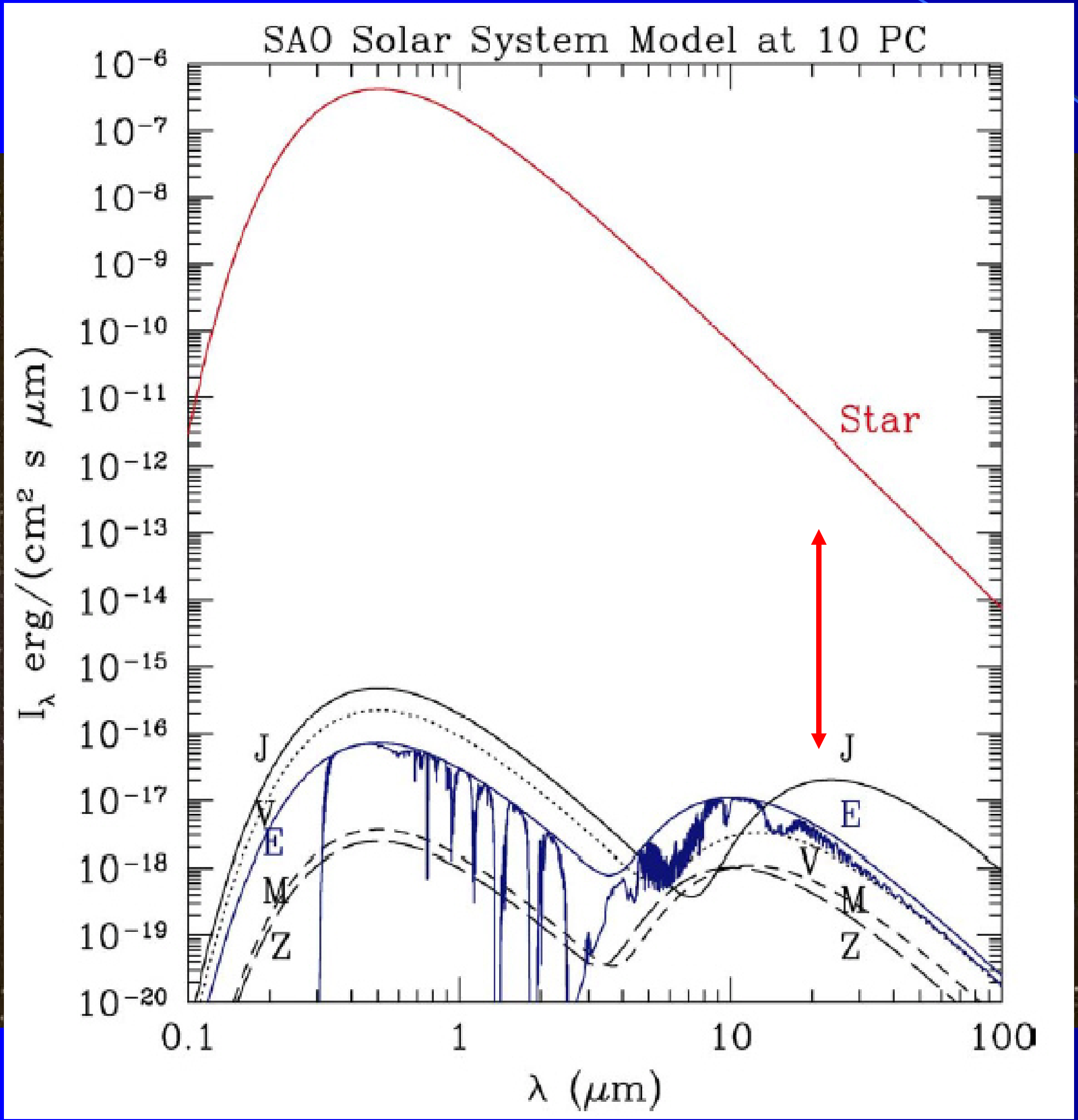
Au Microscopi:
¿Planetas gigantes en Formación?





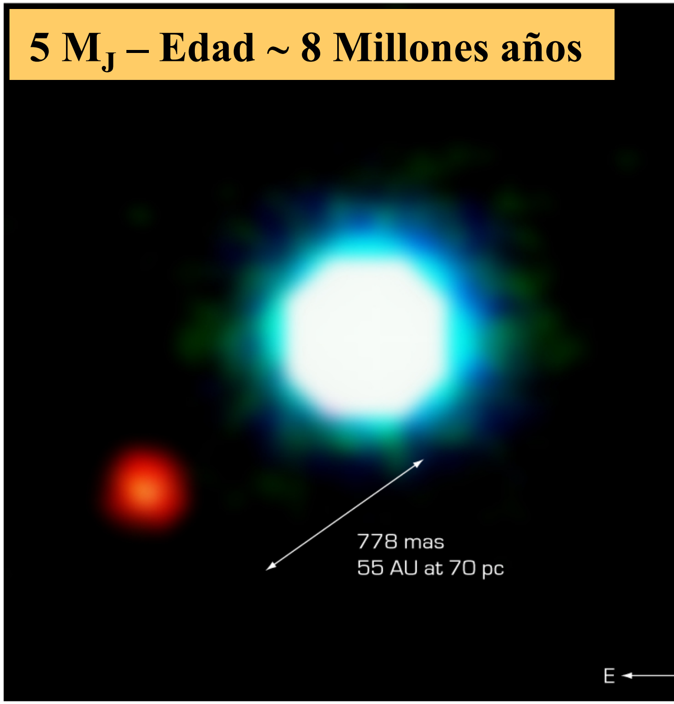
Planetas Extrasolares

Brillo (Estrella / Planeta) ~ 10^6-10^{10}



Brillo Planetas Jóvenes (My) ~ 10-10^3 Planetas Viejos (Gy)

5 M_J – Edad ~ 8 Millones años



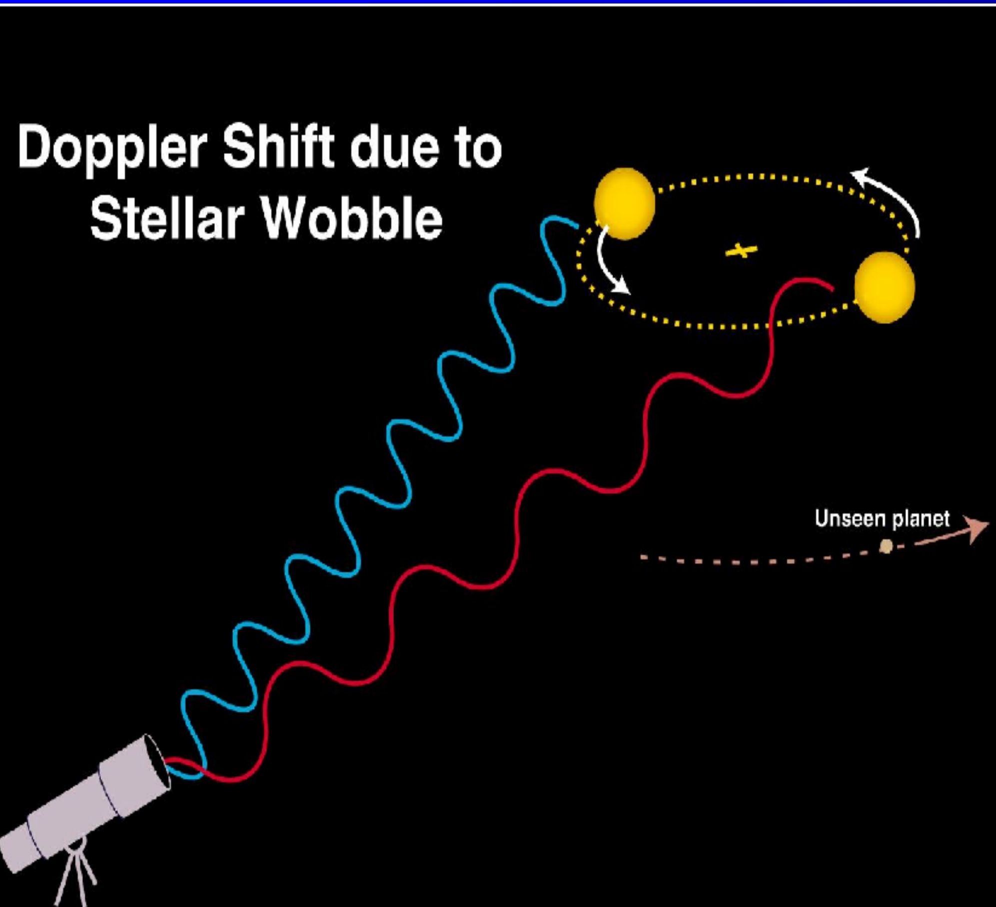
NACO Image of the Brown Dwarf Object 2M1207 and GP

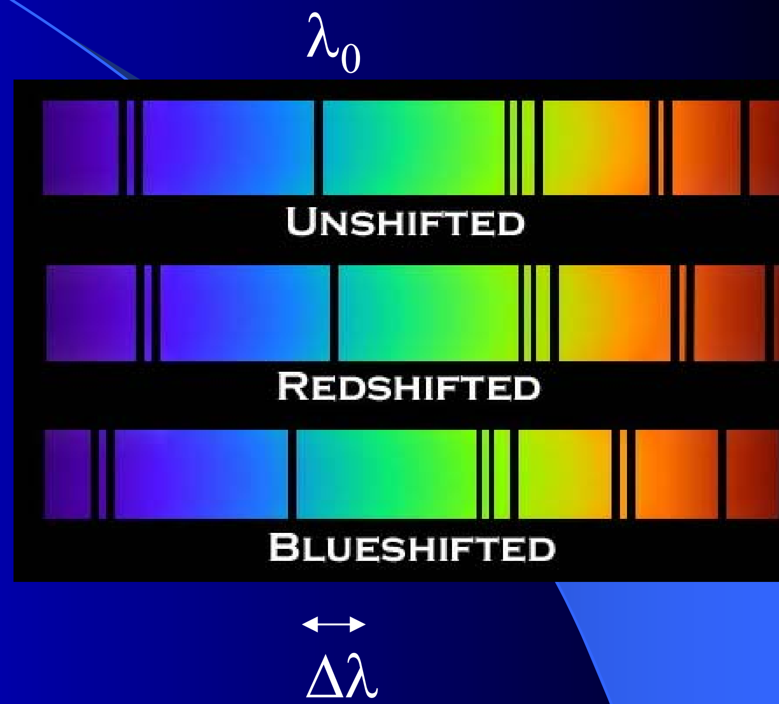
ESO PR Photo 26a/04 (10 September 2004)

"Planetas"

$M < 13\ M_J$ ($1\ M_J = 300\ M_{Earth}$)

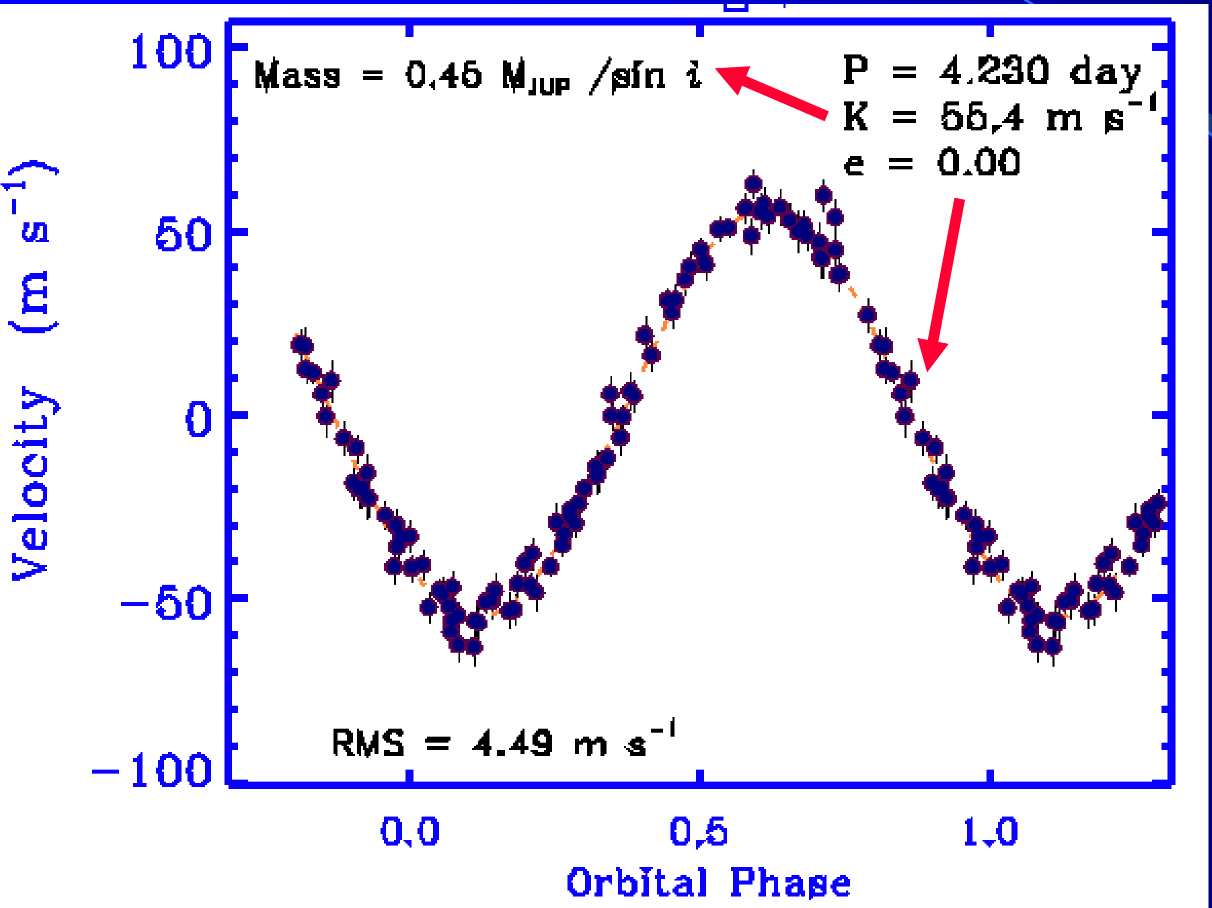
Efecto Doppler



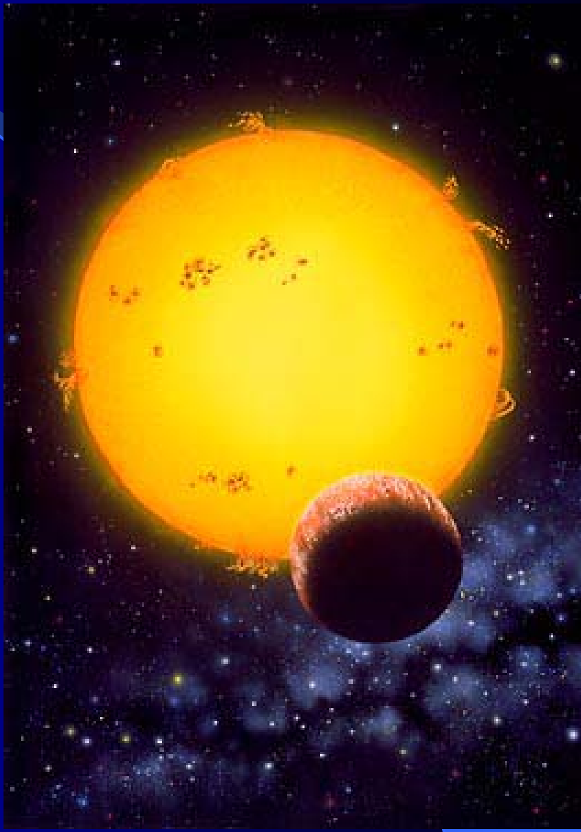


$$V_r = c\frac{\Delta\lambda}{\lambda_0} \approx \frac{M_p sen}{\sqrt{a}}$$

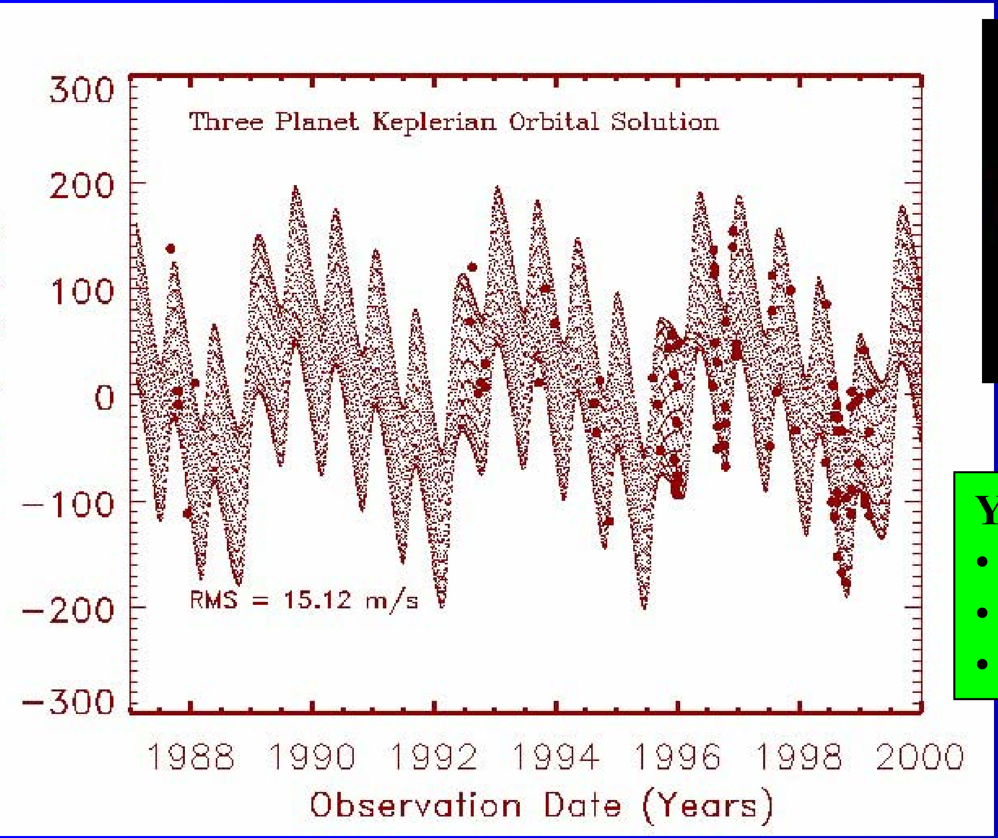
51 Pegaso b



Mass = 0.46 M_{JUP} /sin i
P = 4.230 day
K = 55.4 m s^{-1}
e = 0.00
RMS = 4.49 m s^{-1}
Velocity (m s^{-1})
100
50
0
−50
−100
0.0
0.5
1.0
Orbital Phase

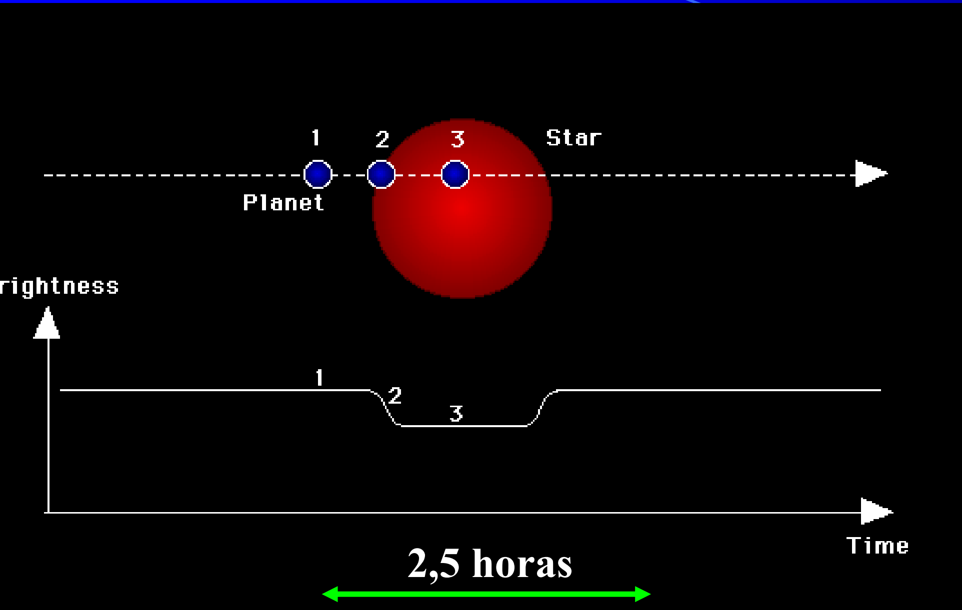


Upsilón Andrómeda:
Un sistema planetario triple



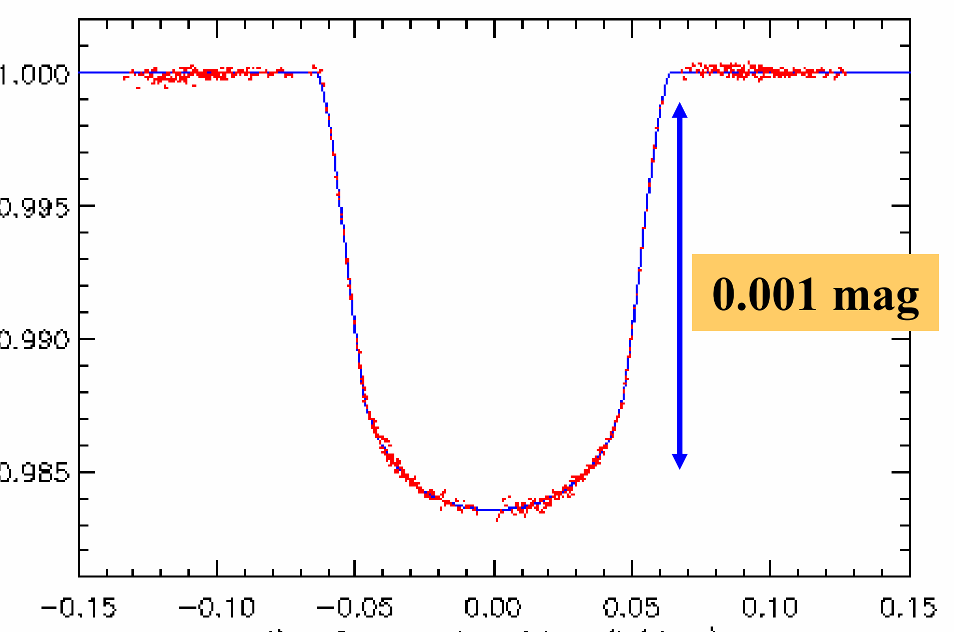
Y así (10 Junio 2006):
- **193 candidatos a planetas extrasolares**
- **157 sistemas planetarios**
- **20 múltiples**

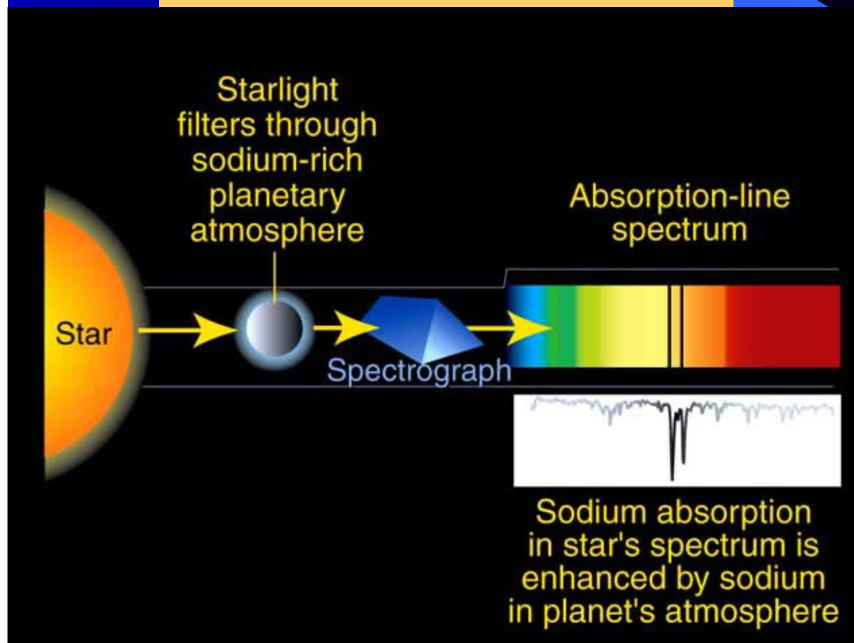
HD 209458 b: un planeta eclipsante



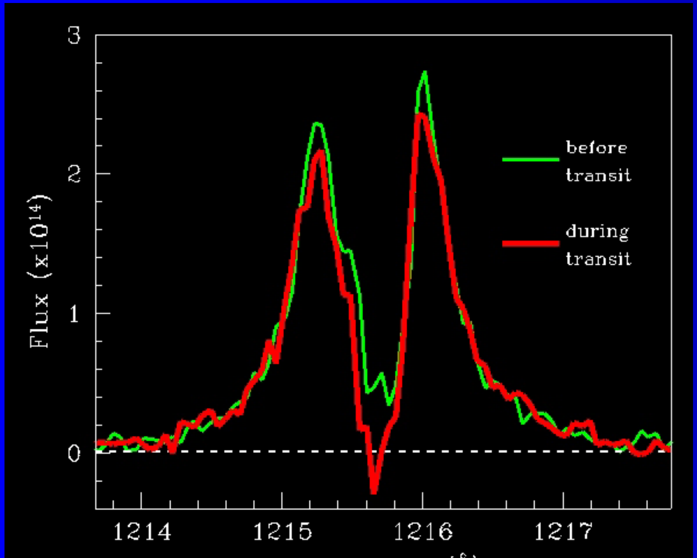
- **10 Planetas en tránsito:**
- **"Hot Jupiters"**
  (6-7 mill km)
  (P = 3-9 días)
- **"Very Hot Jupiters"**
  (3-4 mill km)
  [1/17 Mercurio]
  (P = 1-3 días)

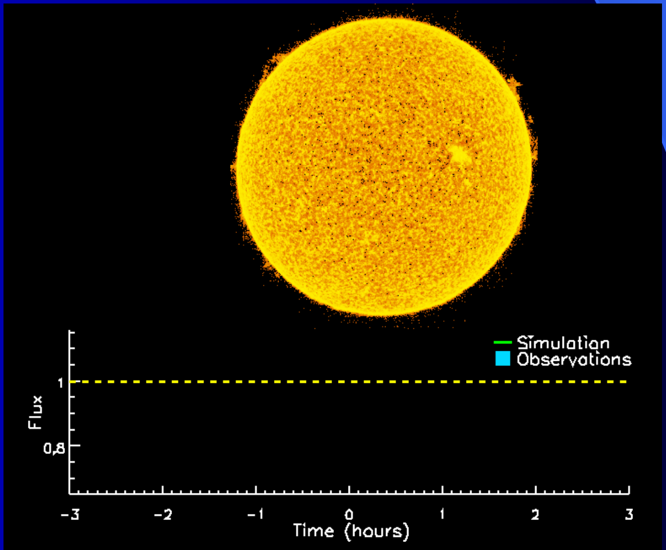
→ T ~ 1500 – 1800 K





HD 209458 b: La Atmósfera de hidrógeno se evapora

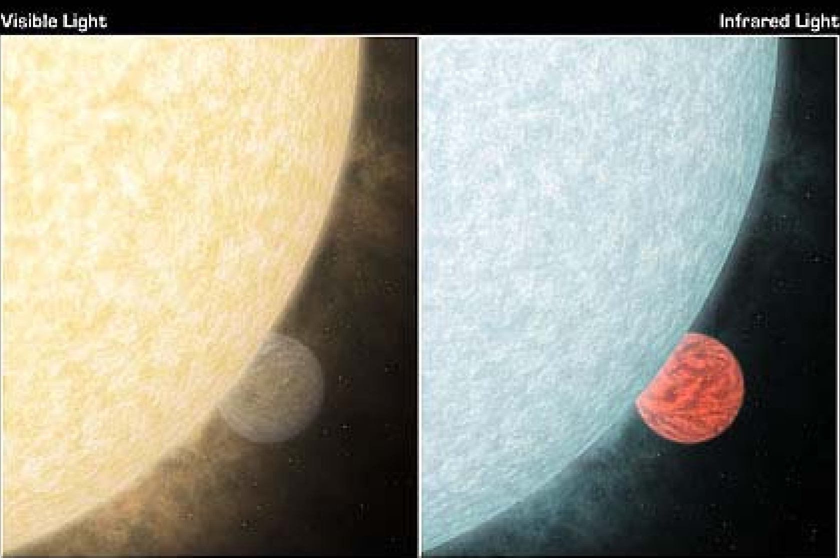




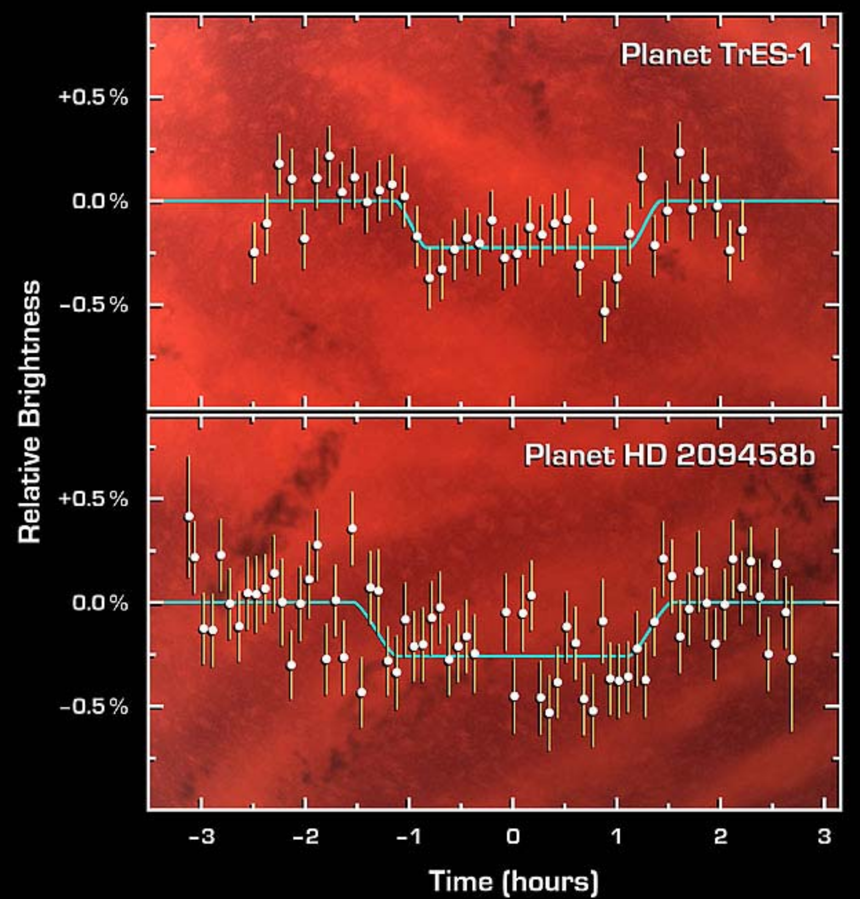
HD 209458b & TrES-1 Eclipse IR

Detección de eclipses: Emisión IR de ambos astros superpuesta decrece durante el eclipse del planeta.

Longitudes de onda IR: 3-20 μm (Spitzer, Telescopio IR en Tierra)



Extrasolar Planet Eclipse (artist's rendition) ssc2005-09b



Planetary Eclipses Spitzer Space Telescope • IRAC • MIPS

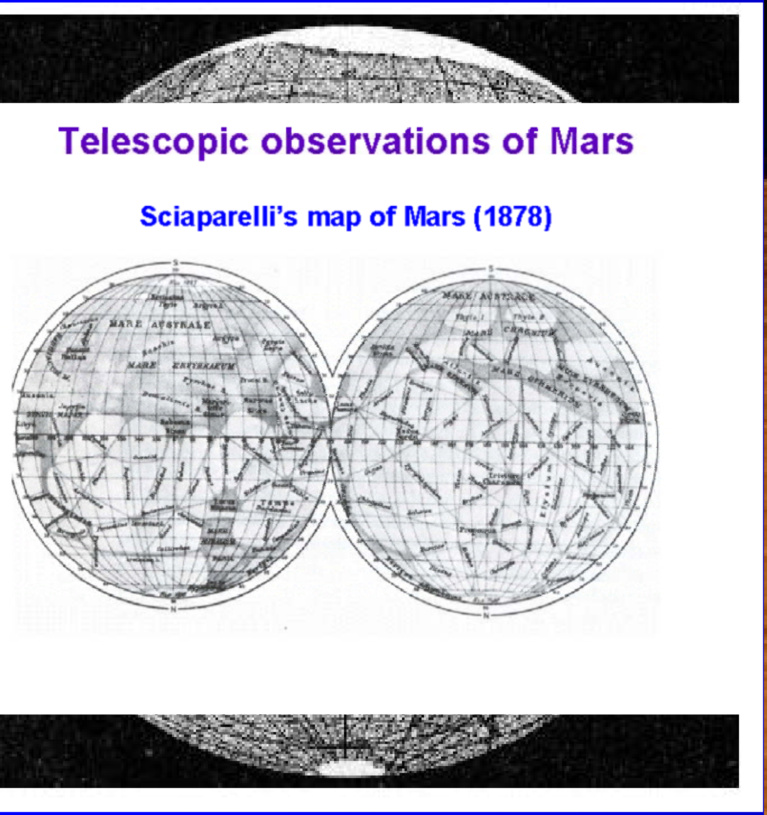
NASA / JPL-Caltech / D. Charbonneau (Harvard-Smithsonian CfA) ssc2005-09a
D. Deming (Goddard Space Flight Center)

En busca de la vida

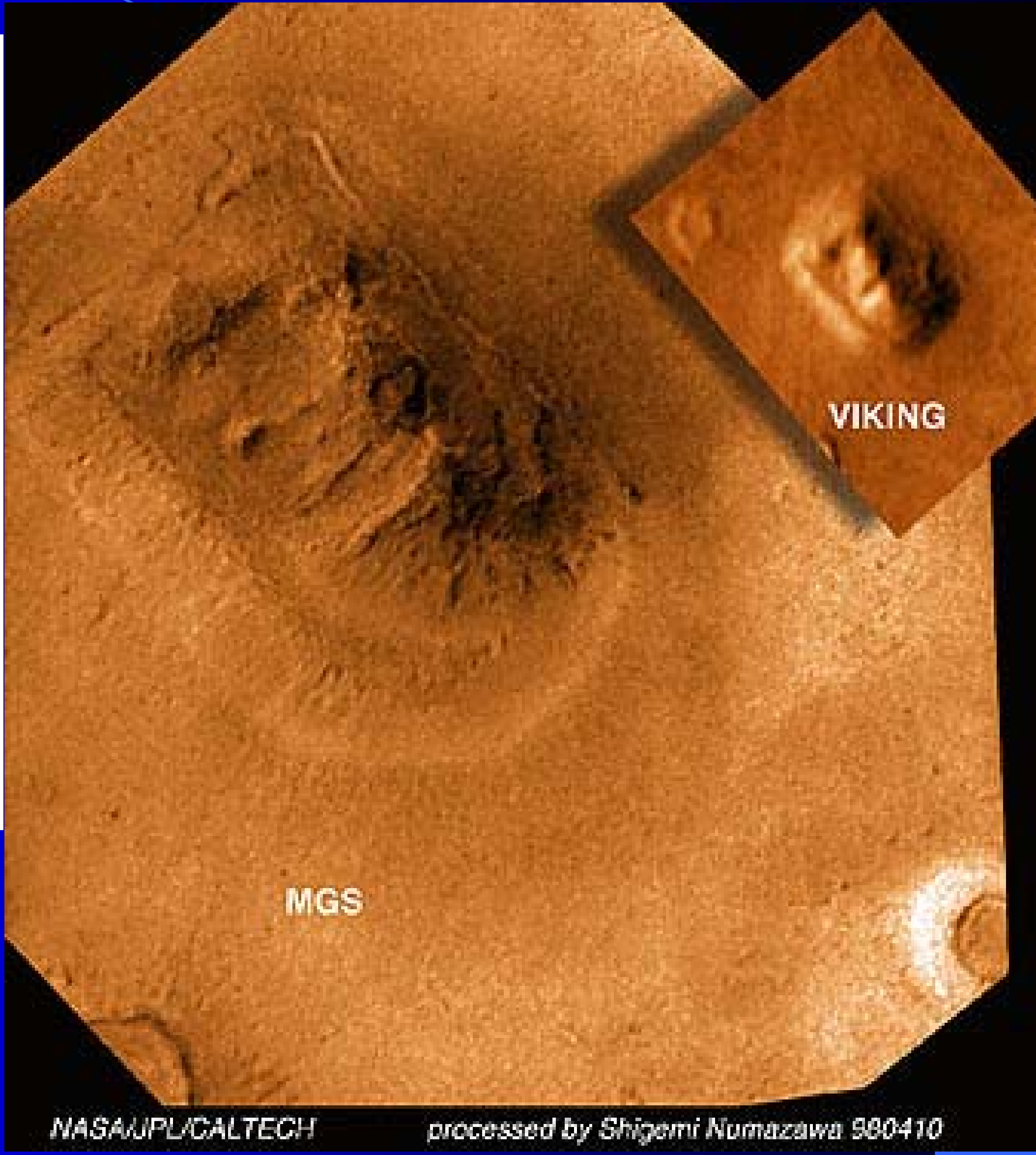
Fuente de energía + Agua líquida + Carbono (“condiciones apropiadas”) = ¿Vida?

Macromolécula orgánicas → célula

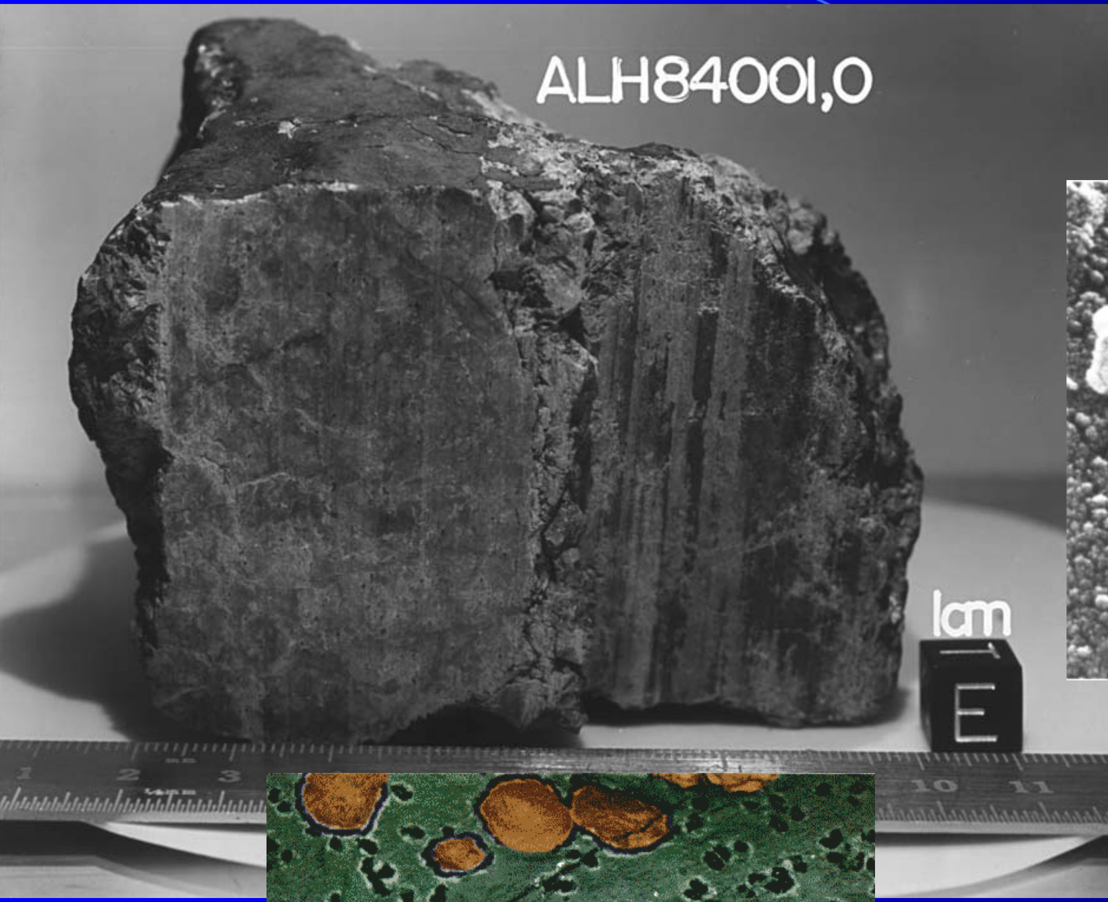
¿Extraterrestres o fraude? La “cara de Marte” y la caradura de muchos ...



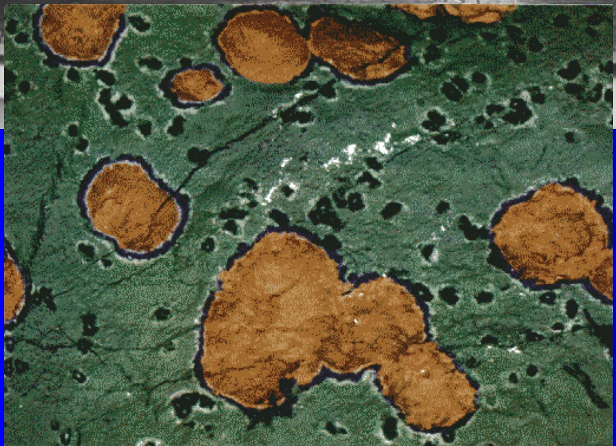
Los “Canales” de Marte según G. V. Schiaparelli y P. Lowell

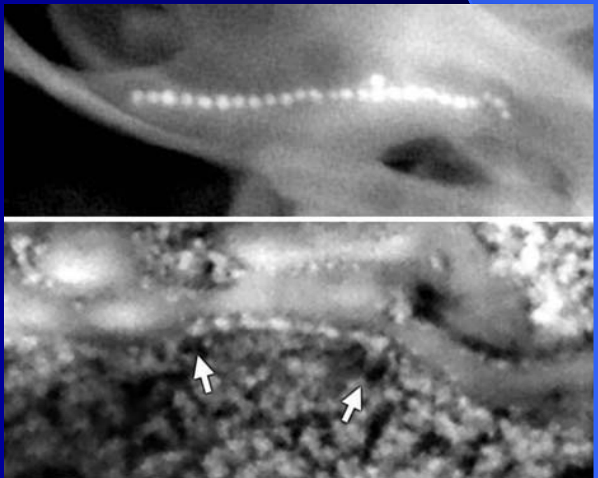


¿Microbios marcianos?

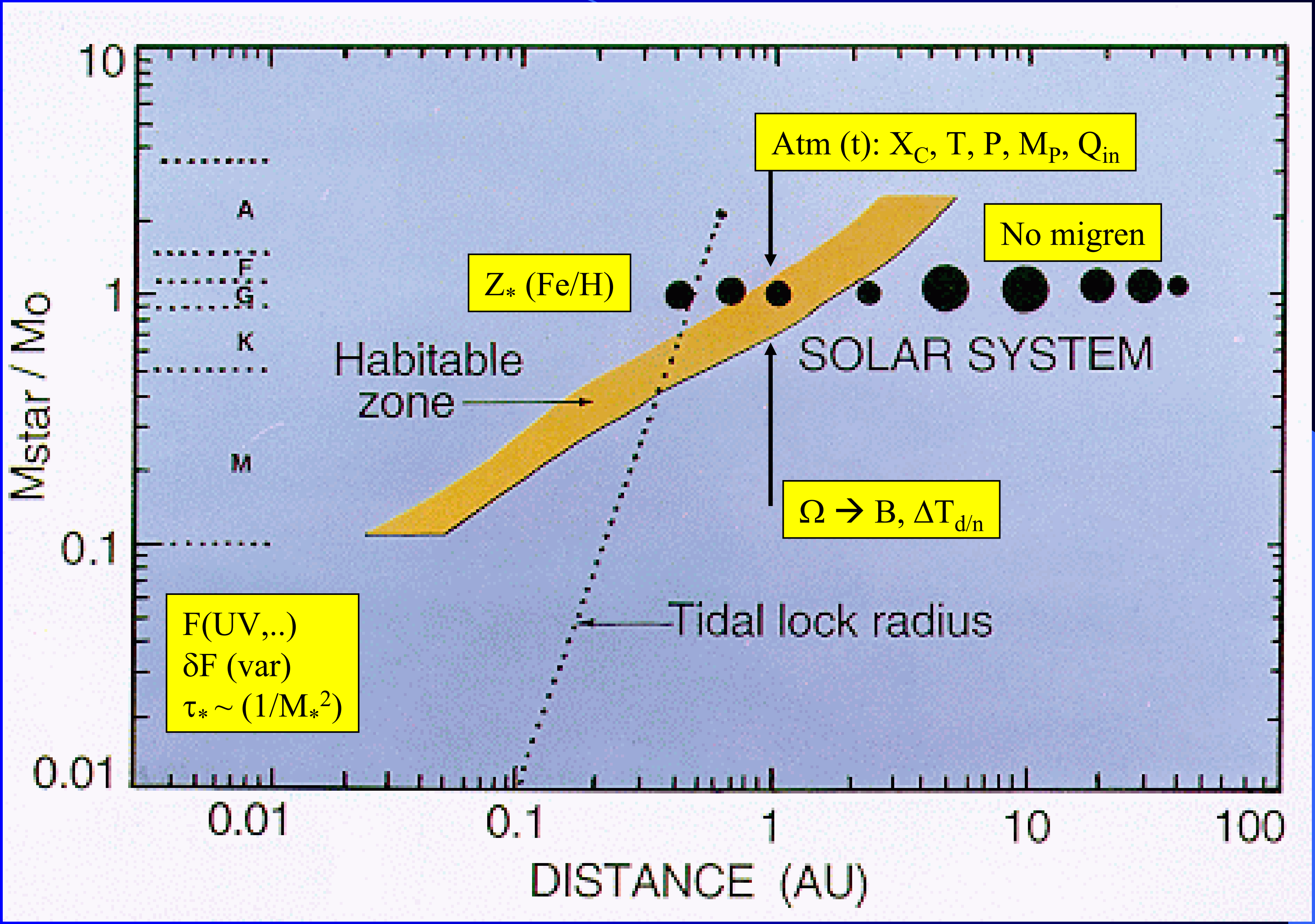


PAH

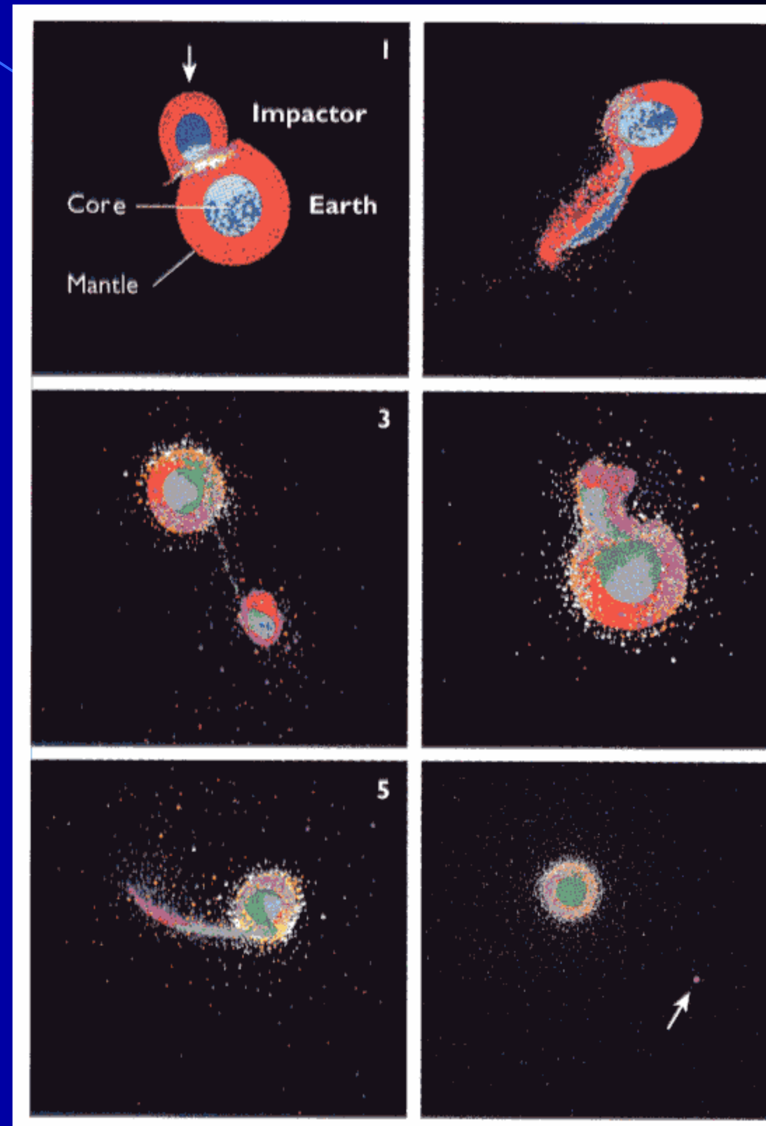




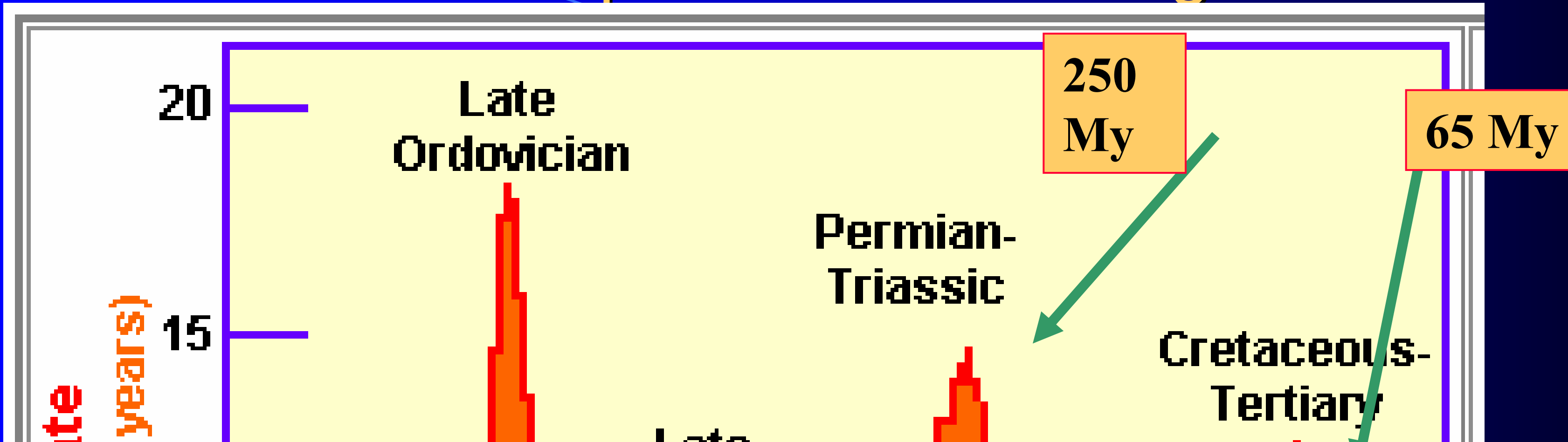
Zona de habitabilidad planetaria



Pero hacen falta muchos más requisitos, algunos afortunados ...



Impacts → Life Changes



Impactos Recientes

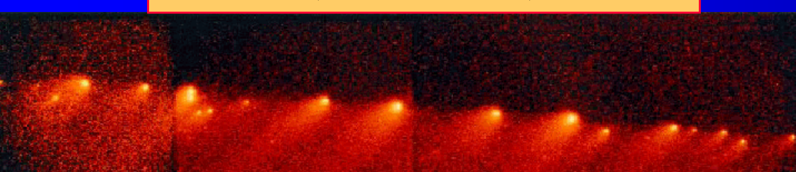
Crater Barringer
(Arizona, USA) 49.000 años

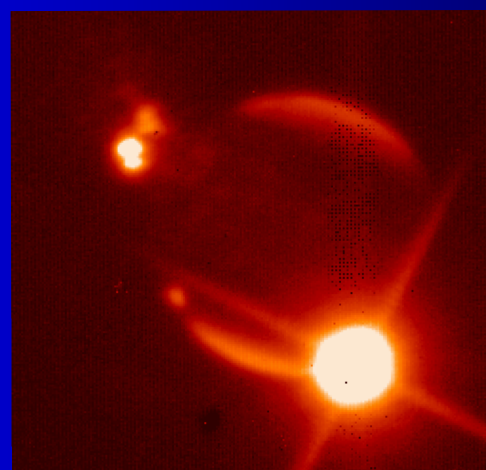
Energía cinética (v ~ 60 kms^{-1}) → Calor, luz, onda choque

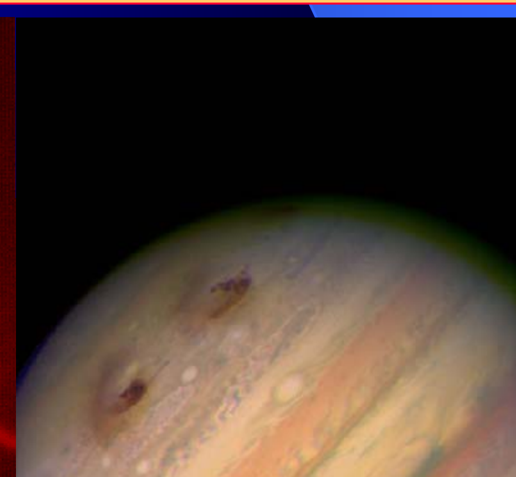
Tunguska (Siberia) Lat. 61º
30 June 1908

D = 50 m, H = 8-10 km; E = 10-15 MTn (500 x Hiroshima), 2150 km^2 afectados

Impacto SL9 con Júpiter
(Julio 1994)

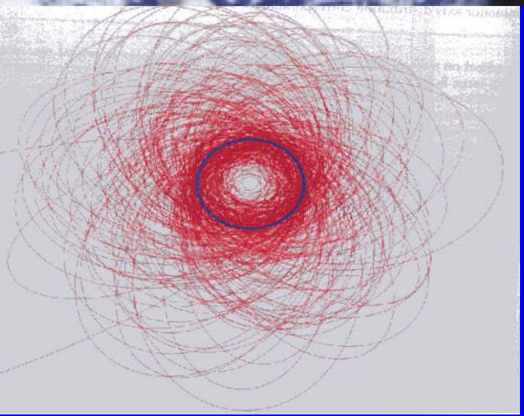






NEOs - NEAs

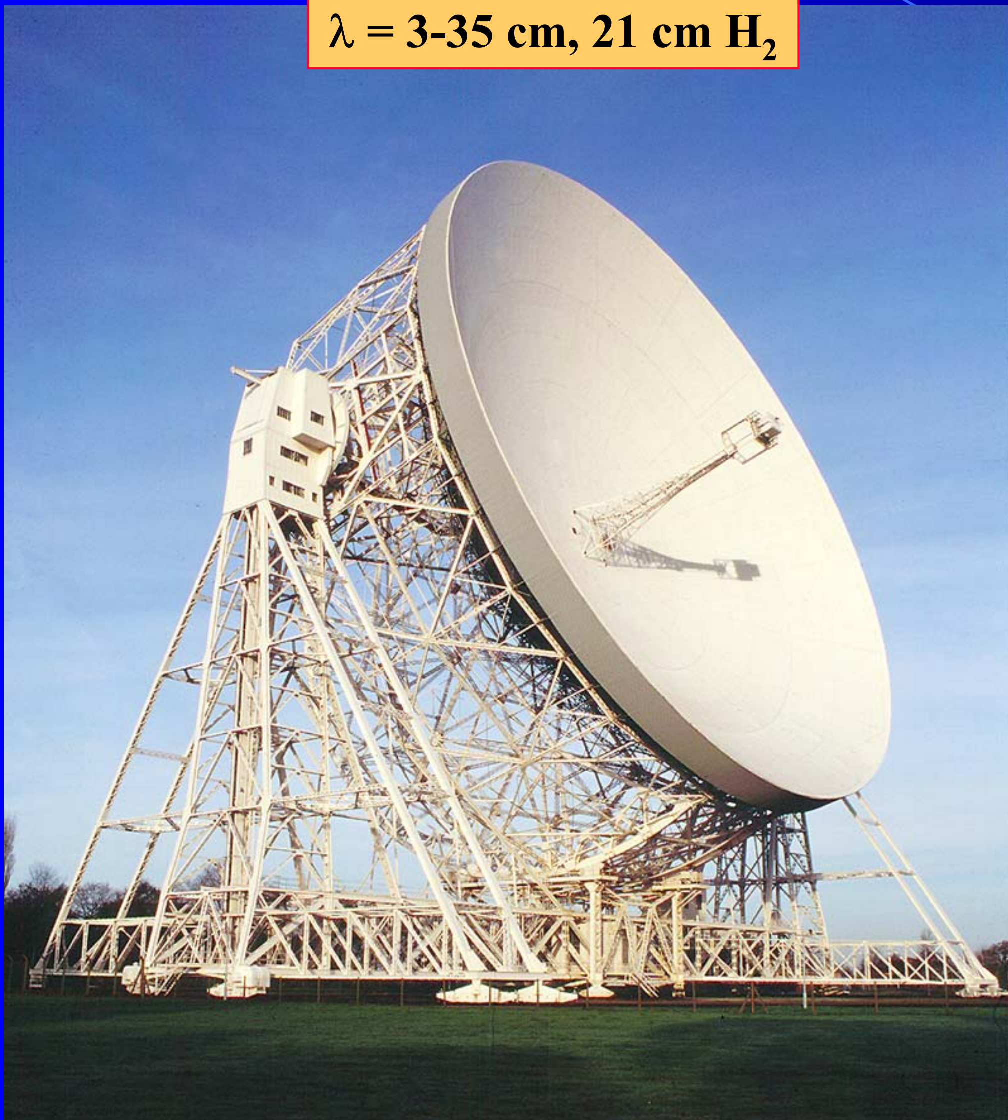
NEA –NEOS
N =1000 (size > 1 km)



Example: 2004 FH
D = 42.700 km
Size = 30 m
Impact frequency (Size):
Sizes > 220 m →
Impact rate = 1/170.000 years

¿Hay alguien ahí?

λ = 3-35 cm, 21 cm H_2

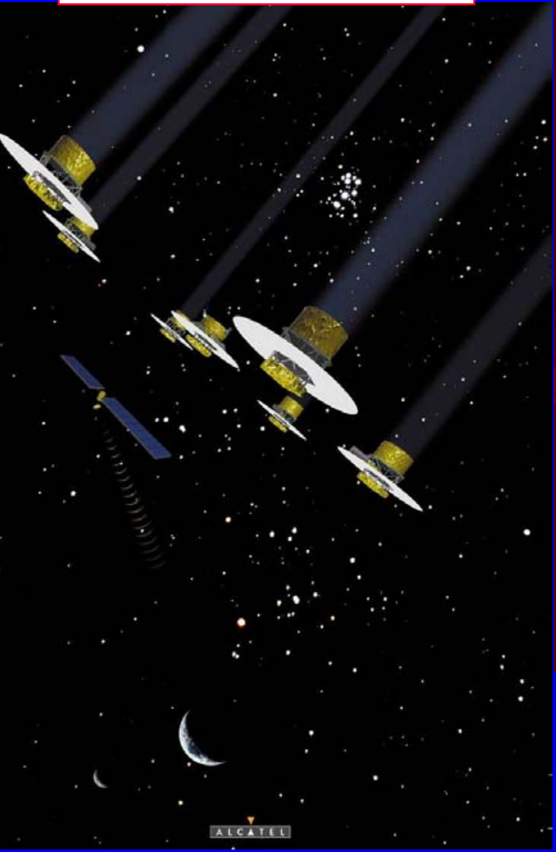


SETI

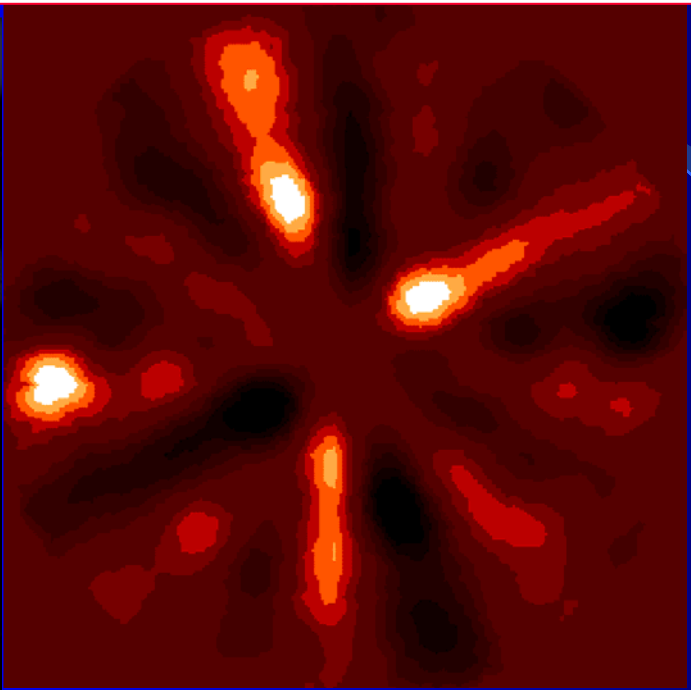
This 34-meter (about 98-foot)-wide telescope near Buenos Aires scans the southern hemisphere.
Photo: Argentine Institute of Radio Astronomy .

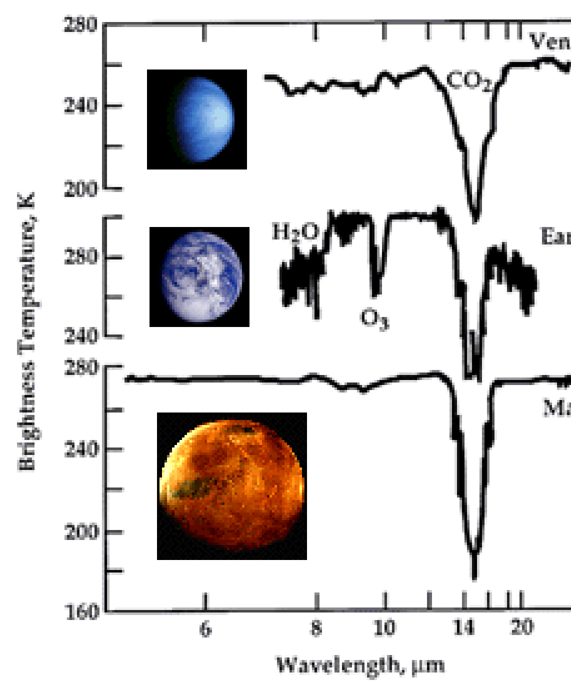
El futuro: telescopios interferométricos

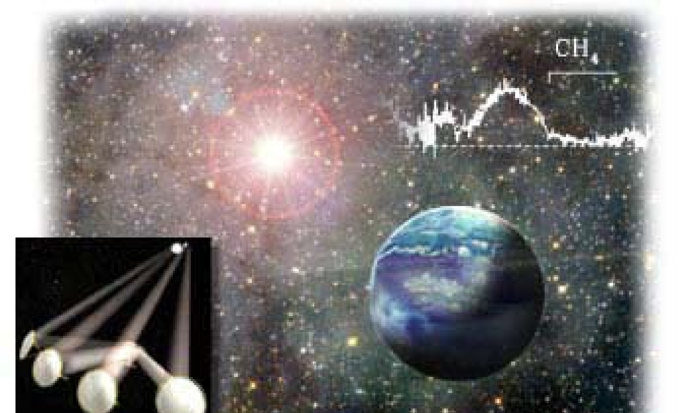
Darwin (ESA)



El Sistema Solar desde 10 pc







Future Exploration of the Solar System

Mercury → Messenger , Beppi-Colombo
Venus → Venus Express, ….
Moon → Manned visits ? (USA, China, India?)
Mars → MRO-Mars Laboratory, Exomars, …
Asteroids → Dawn (Vesta-Ceres)-Sample return
Jupiter → Juno, Europa-Jupiter (?), …
Saturn → Cassini-Huygens (+ 4 years)
Pluto → New Horizons
Comets → Stardust, Rosetta

Más las del Sol y del Medio Interplanetario

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- Physics of the Solar System, B. Bertotti, P. Farinella, D. Vokrouhlicky, Astrophysics and Space Science Library, Vol. 293 (2003).

* Series books on each planet by Arizona University Press, and Jupiter, from Cambridge University Press.

* Encyclopedia of Planetary Sciences, Elsevier.