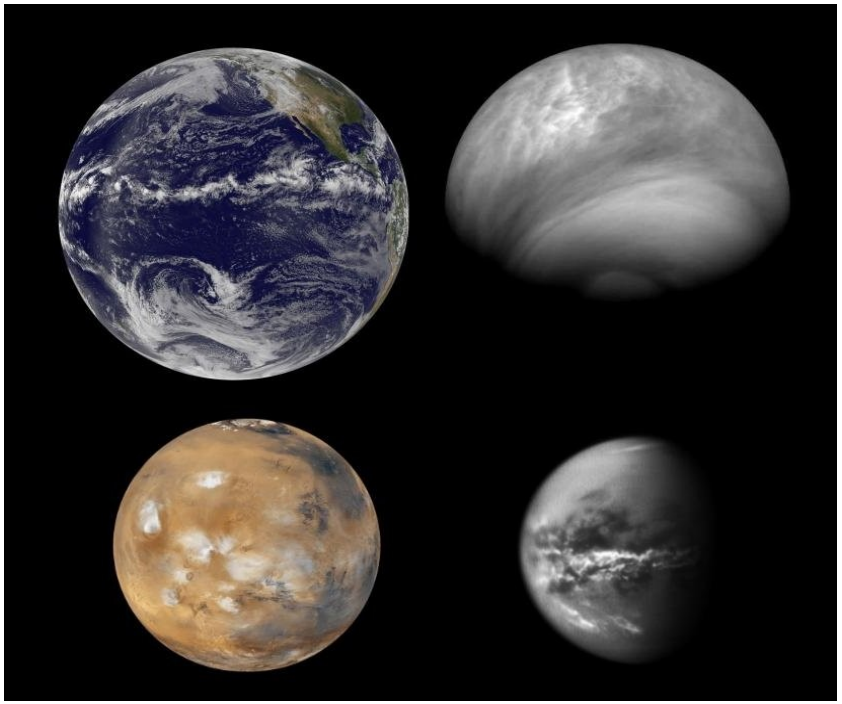
PLANETARY ATMOSPHERES



Sébastien LEBONNOIS
CNRS Researcher
Laboratoire de Météorologie Dynamique, Paris

PLANETARY ATMOSPHERES

Overview of planetary atmospheres in the Solar System

- Our Solar System : a large diversity of objects
- Different types of atmospheres
- Description of atmospheric structures
- Current exploration of planetary atmospheres
- Planets in other stellar systems

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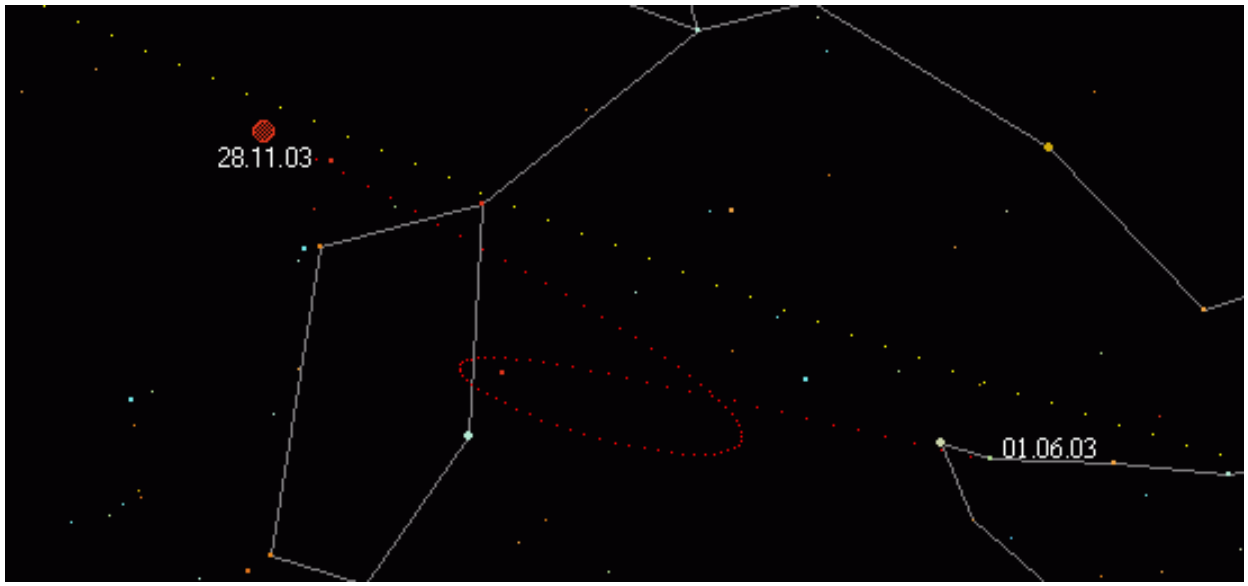
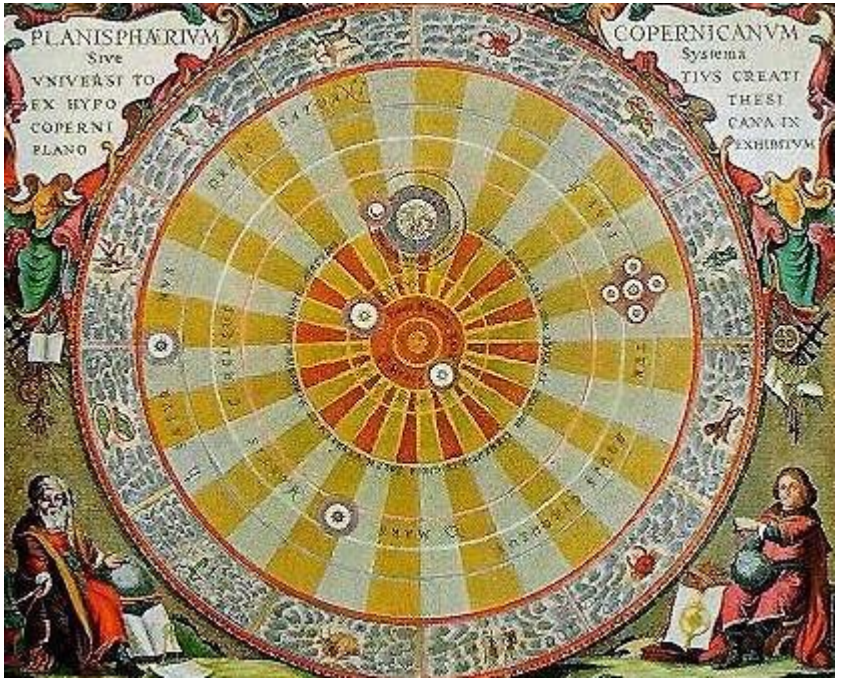
Planets in the sky

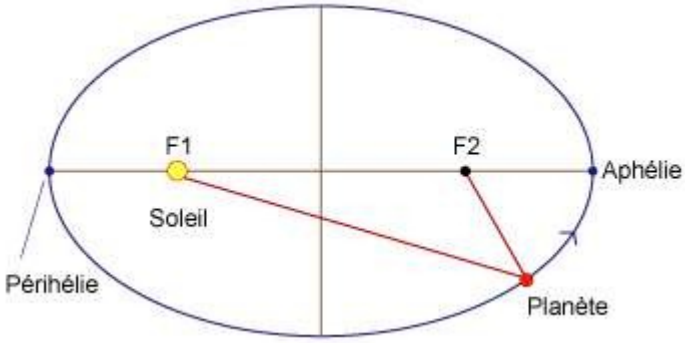


Building our Solar System

Aristarchos of Samos, ~ 310-230 BC

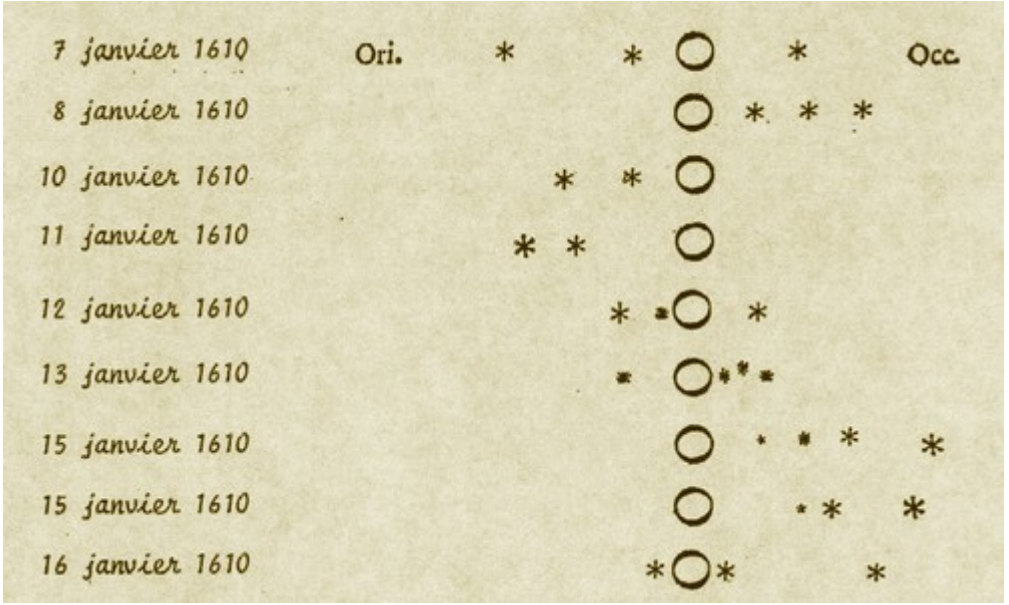


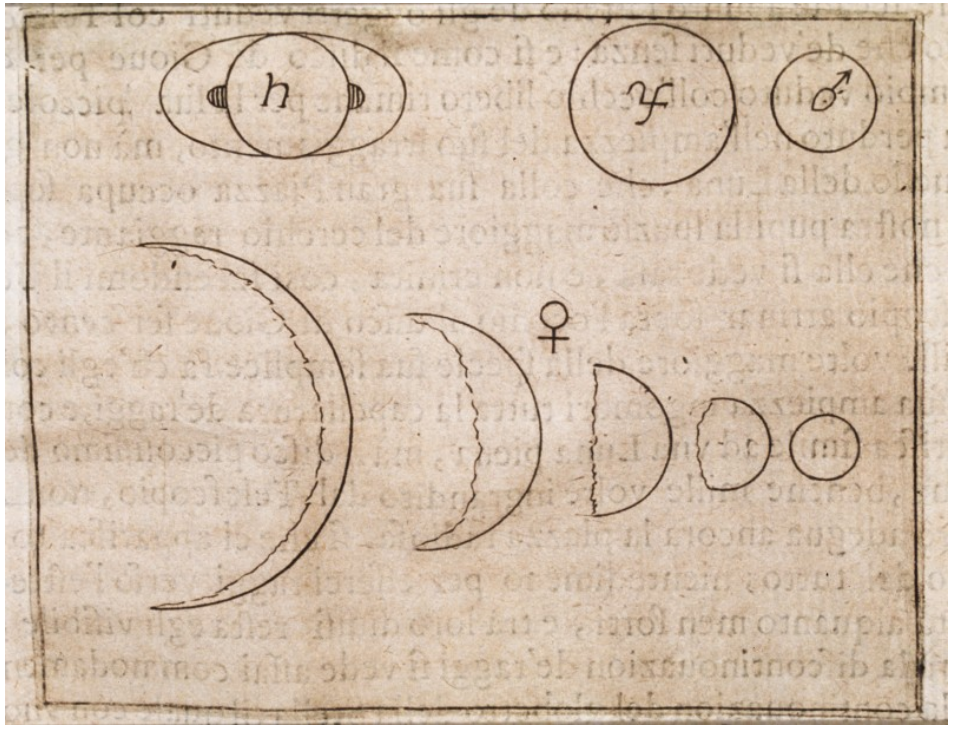
Nicolaus Copernicus, 1473-1543



Johannes Kepler, 1571-1630

Galileo Galilei

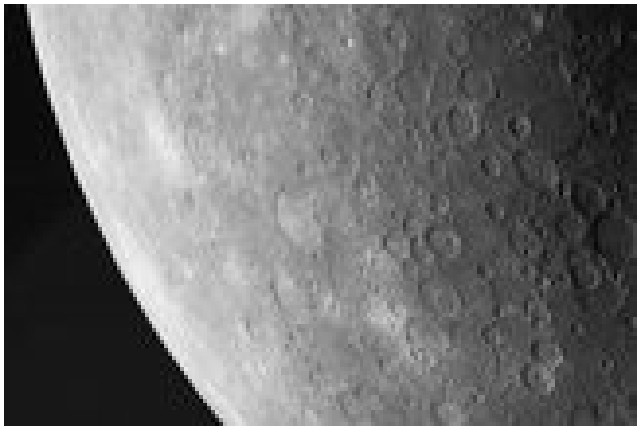





ASTEROID BELT

Space age : revealing many faces

Mercury



Mariner 10, 1974

Venus

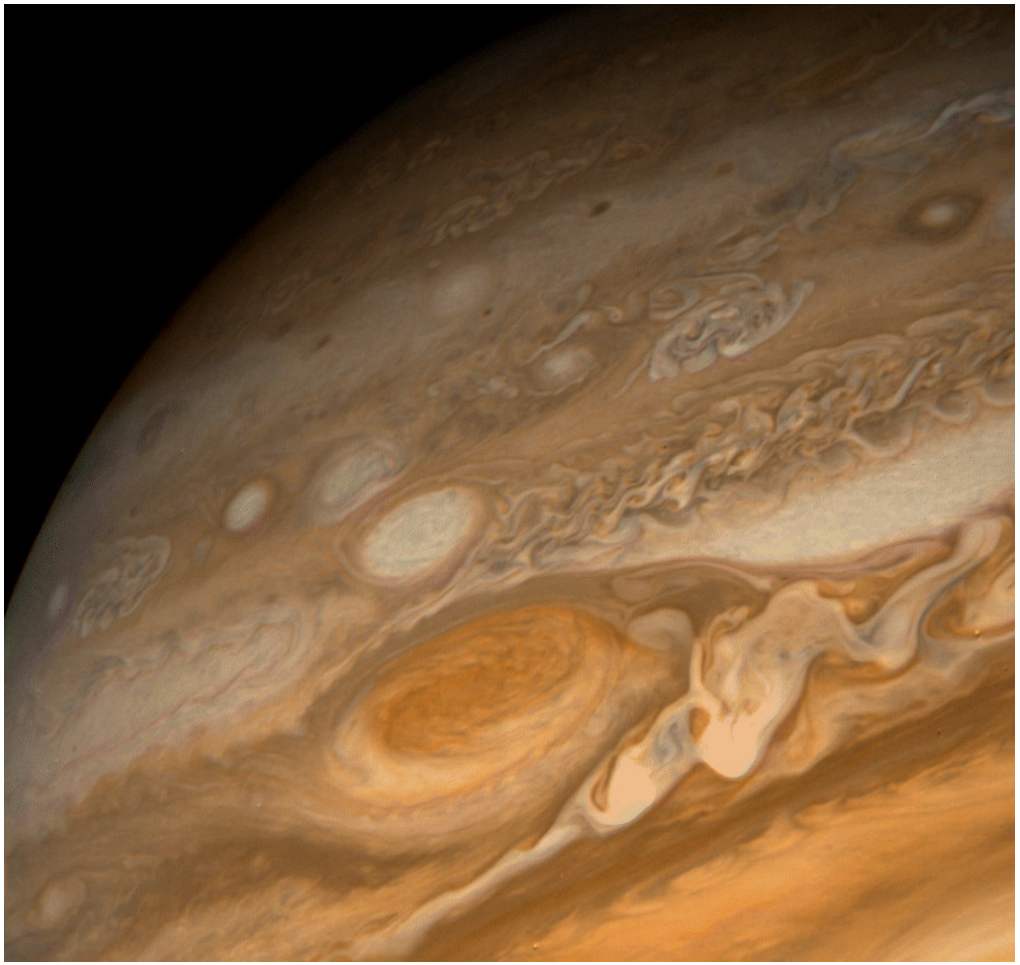
Earth

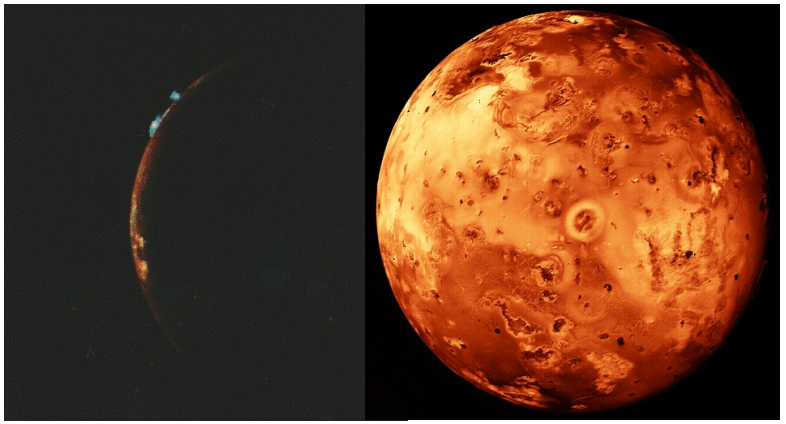
Gemini XI, 1966

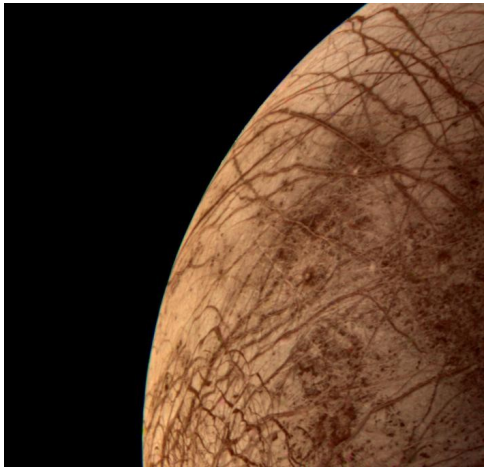
Mars

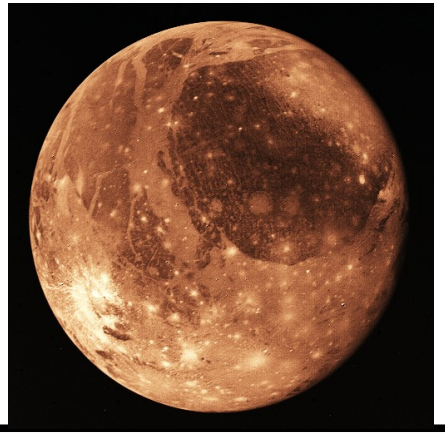
Viking 1, 1976

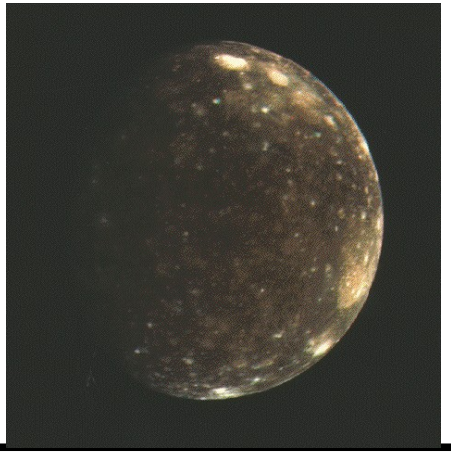
Space age : revealing many faces
Voyager 1+2





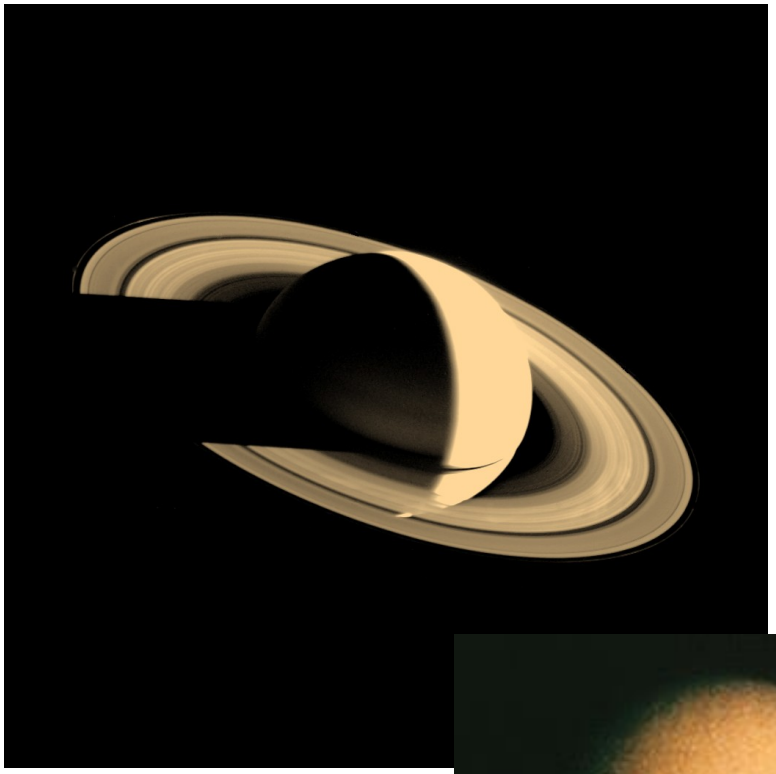


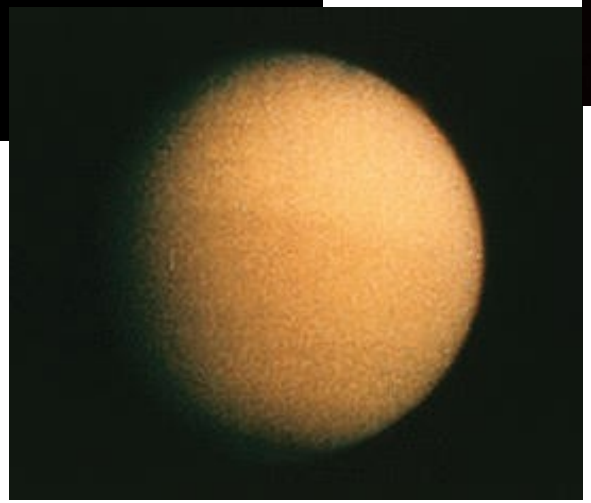




Jupiter's system

Space age : revealing many faces
Voyager 1+2





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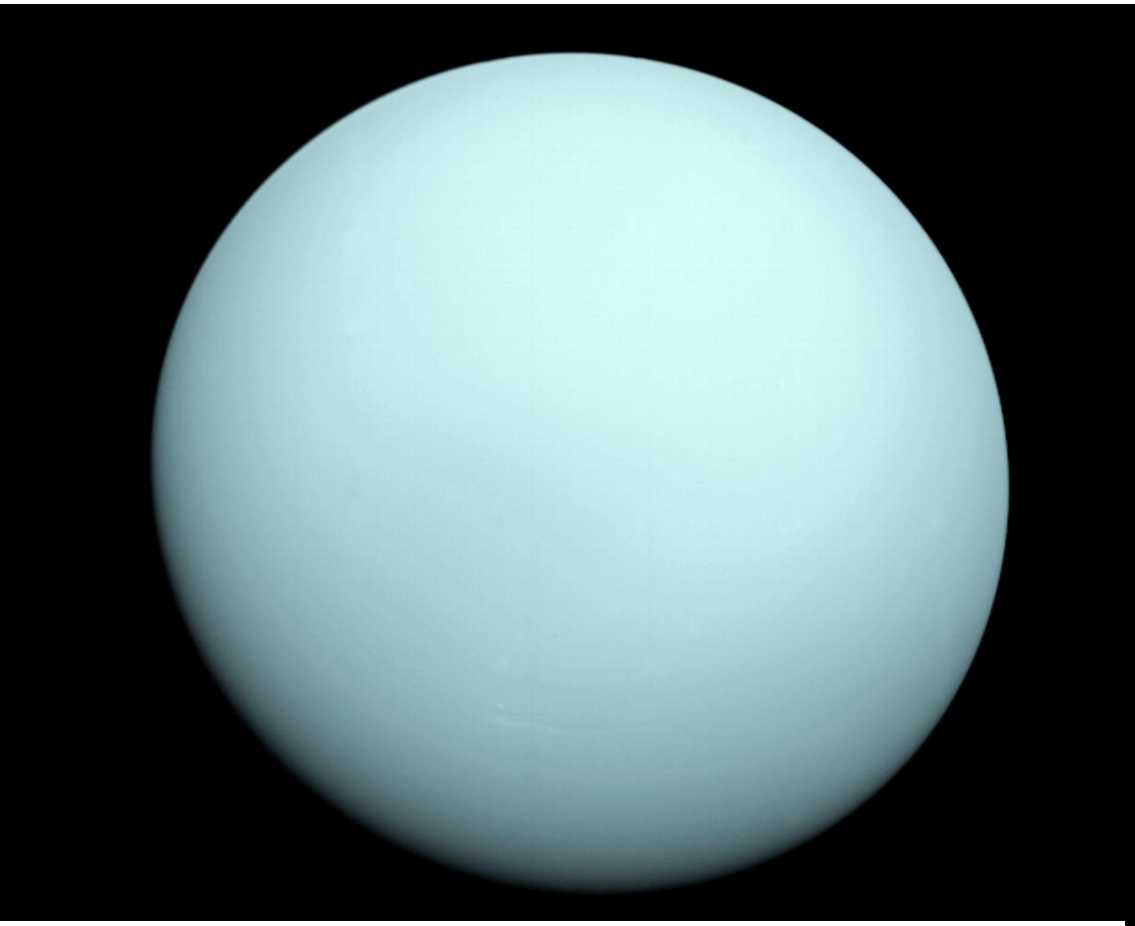

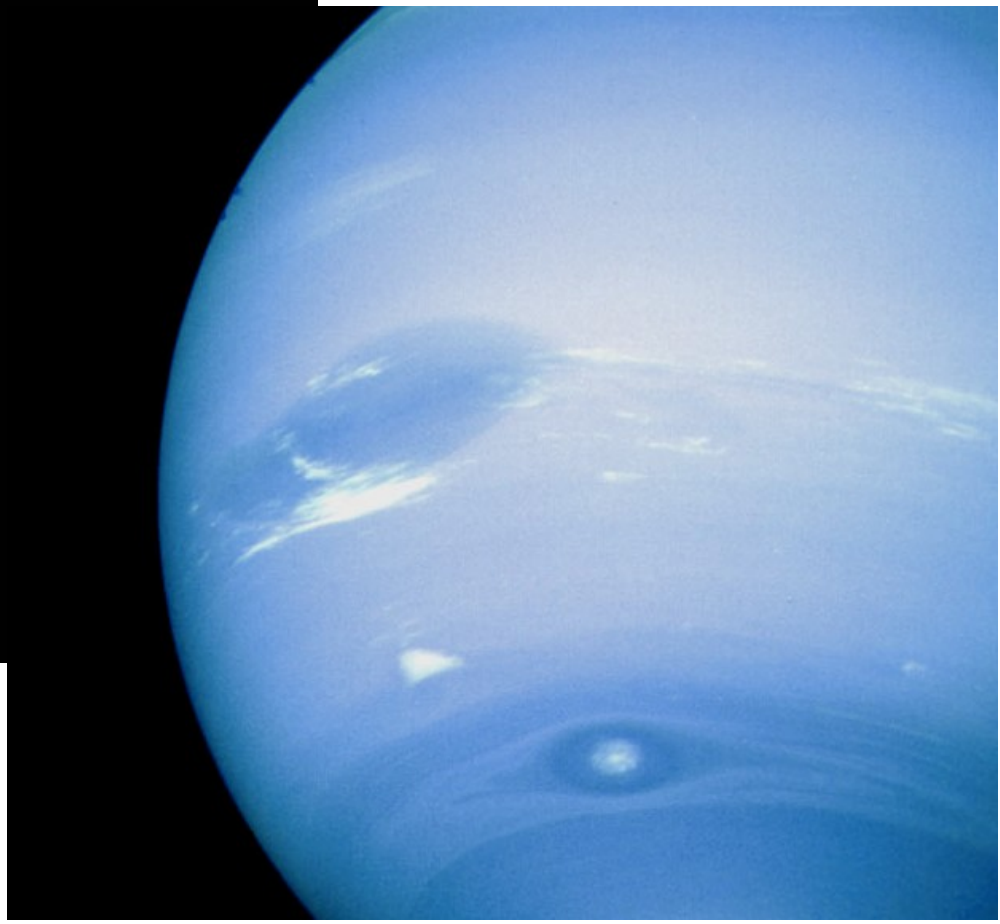

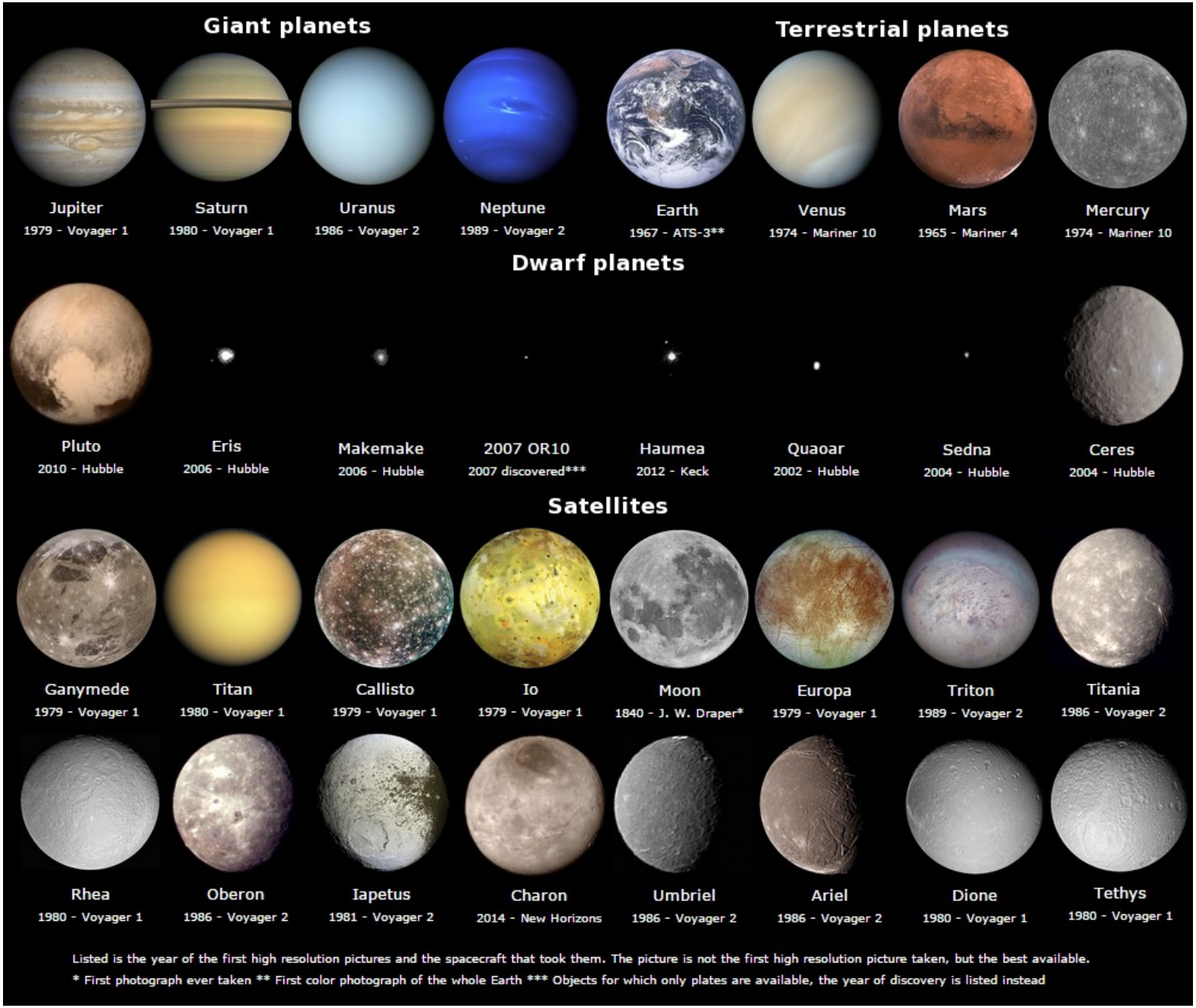
Giant planets
Terrestrial planets
Jupiter
1979 - Voyager 1
Saturn
1980 - Voyager 1
Uranus
1986 - Voyager 2
Neptune
1989 - Voyager 2
Earth
1967 - ATS-3**
Venus
1974 - Mariner 10
Mars
1965 - Mariner 4
Mercury
1974 - Mariner 10
Dwarf planets
Pluto
2010 - Hubble
Eris
2006 - Hubble
Makemake
2006 - Hubble
2007 OR10
2007 discovered***
Haumea
2012 - Keck
Quaoar
2002 - Hubble
Sedna
2004 - Hubble
Ceres
2004 - Hubble
Satellites
Ganymede
1979 - Voyager 1
Titan
1980 - Voyager 1
Callisto
1979 - Voyager 1
Io
1979 - Voyager 1
Moon
1840 - J. W. Draper*
Europa
1979 - Voyager 1
Triton
1989 - Voyager 2
Titania
1986 - Voyager 2
Rhea
1980 - Voyager 1
Oberon
1986 - Voyager 2
Iapetus
1981 - Voyager 2
Charon
2014 - New Horizons
Umbriel
1986 - Voyager 2
Ariel
1986 - Voyager 2
Dione
1980 - Voyager 1
Tethys
1980 - Voyager 1
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* First photograph ever taken ** First color photograph of the whole Earth *** Objects for which only plates are available, the year of discovery is listed instead

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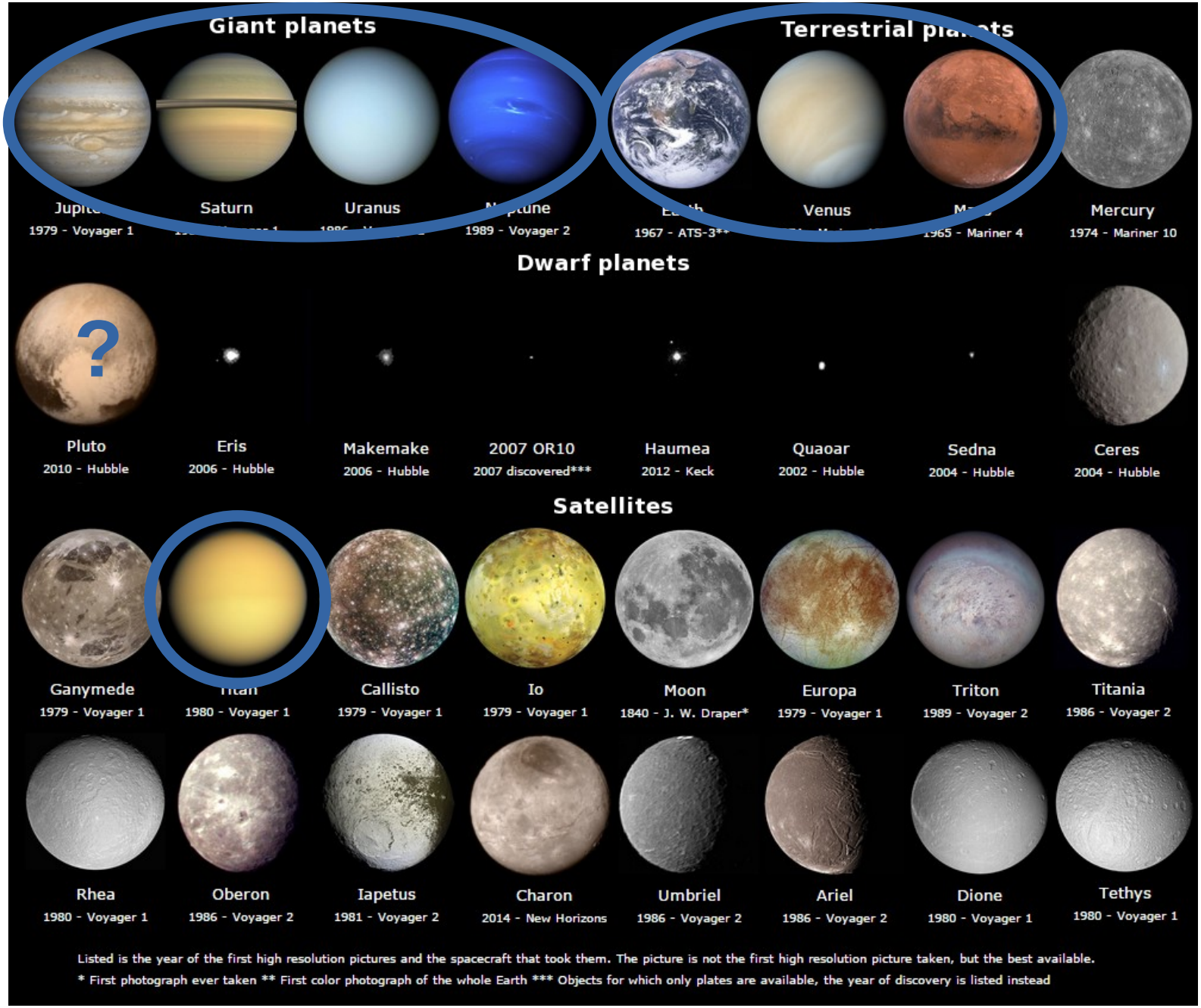
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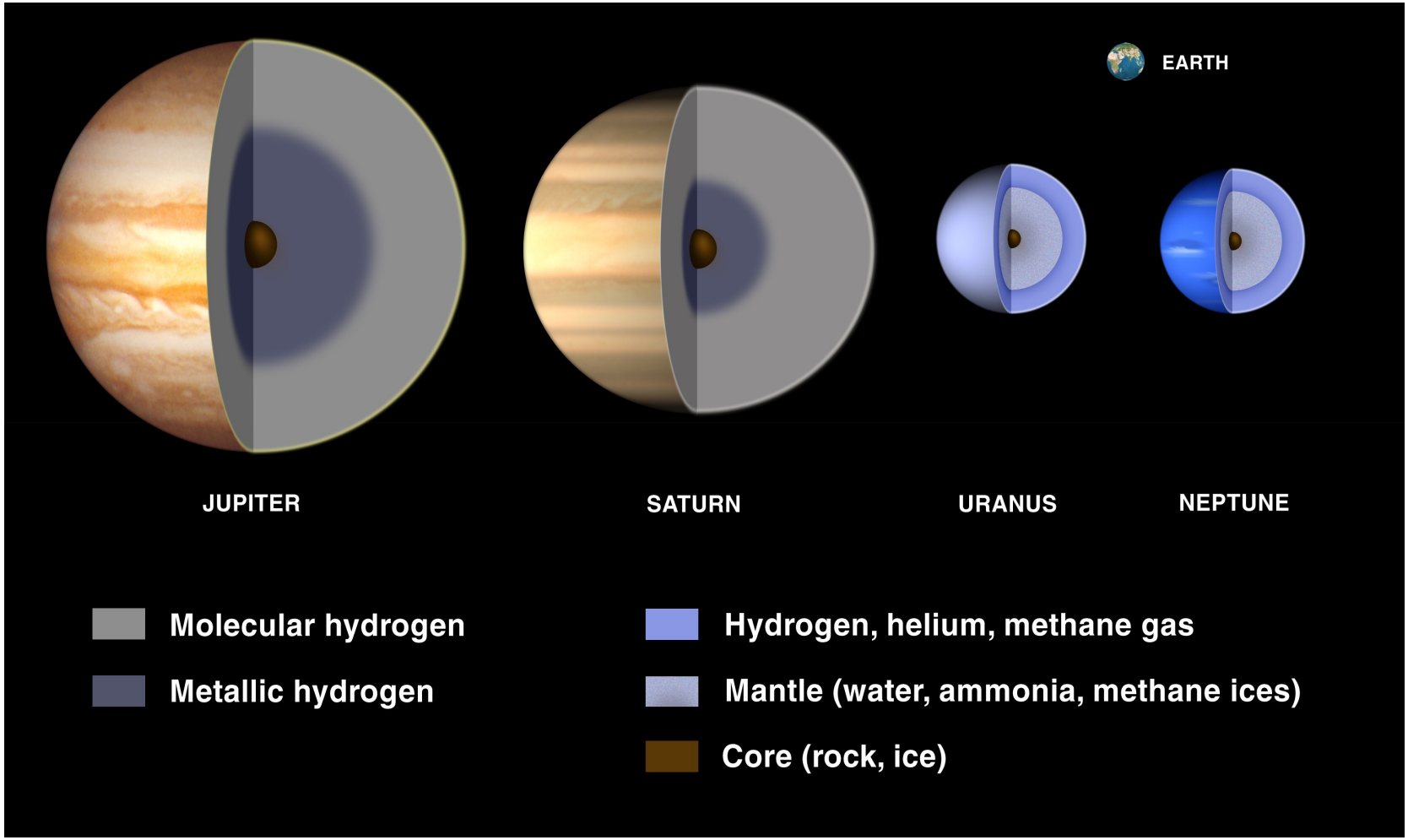
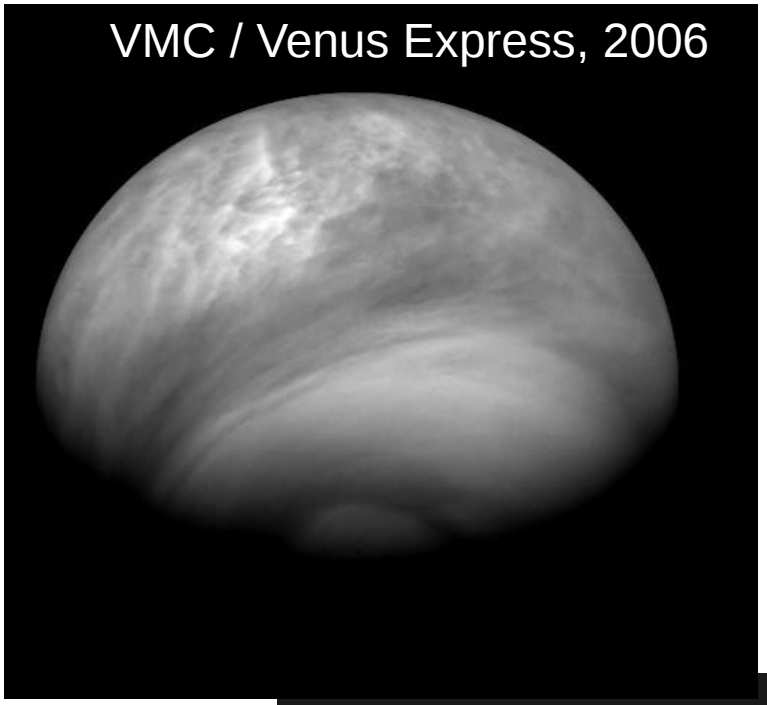
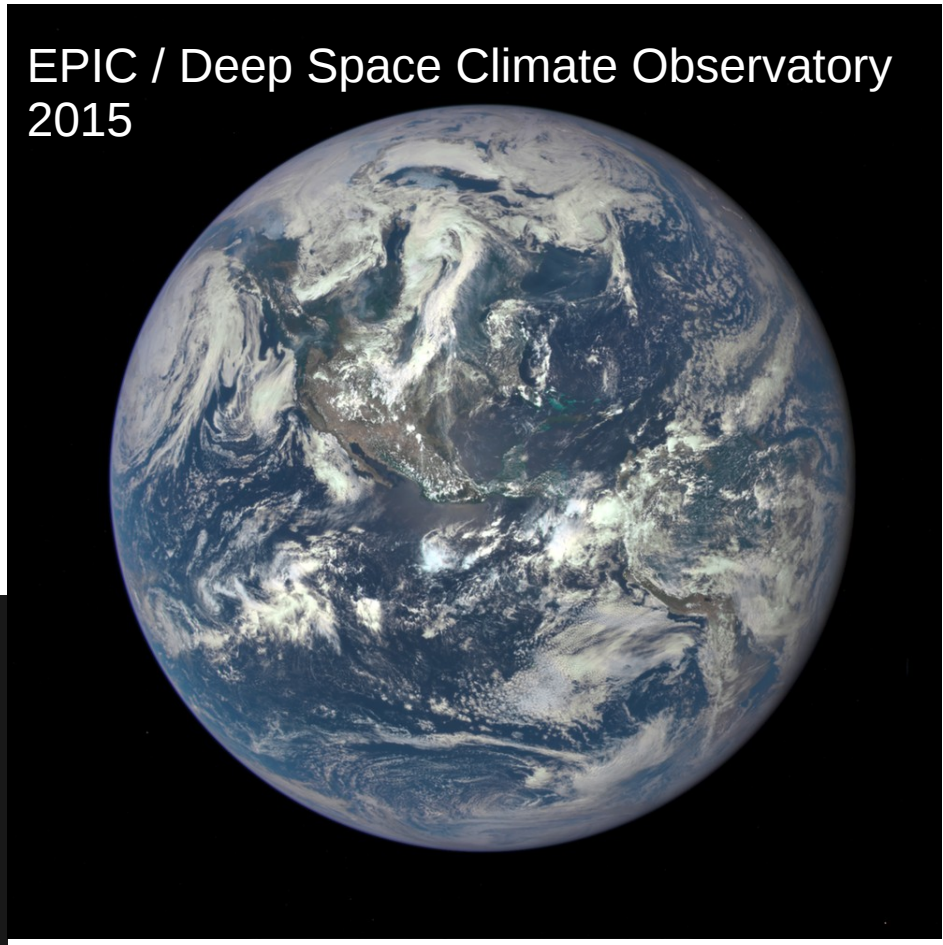


Terrestrial planets

Venus

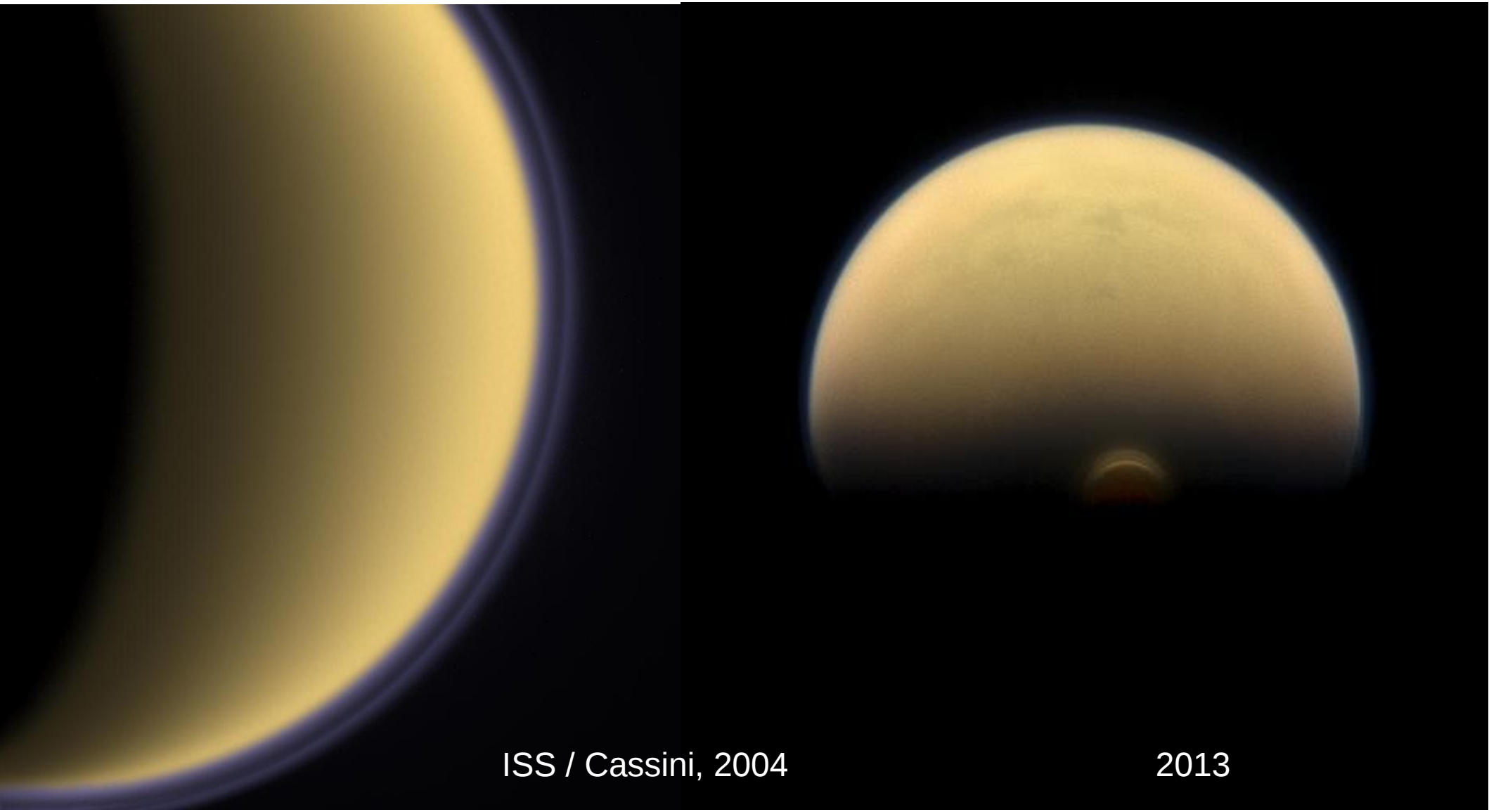


Earth



Mars

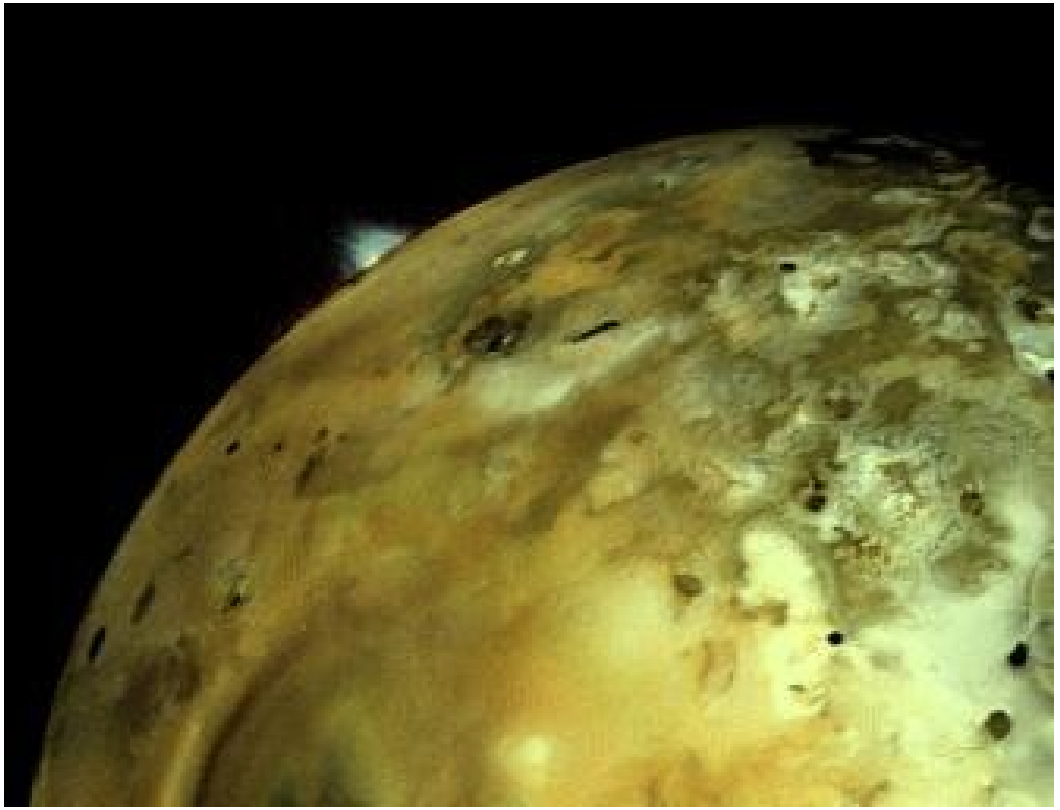
The case of Titan



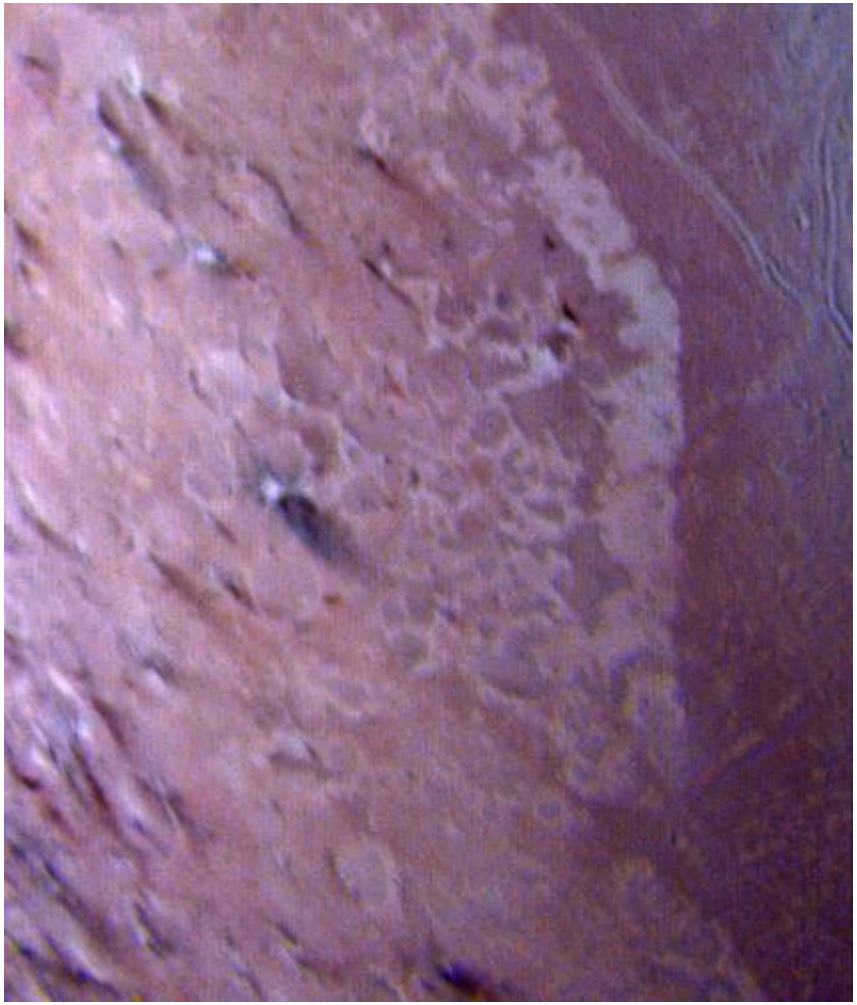
ISS / Cassini, 2004

2013

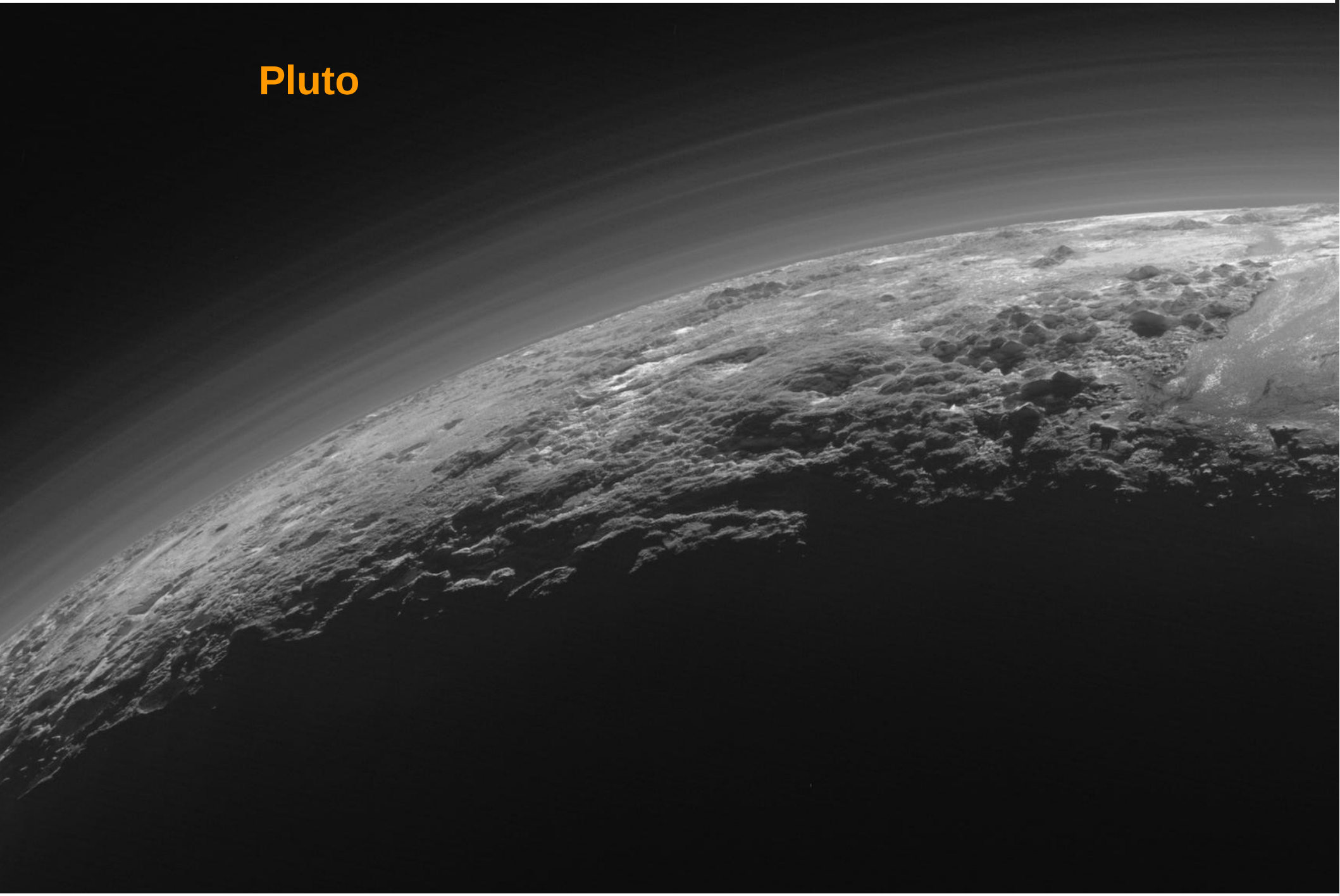
Tenous atmospheres



Io (Jupiter)



Triton (Neptune)

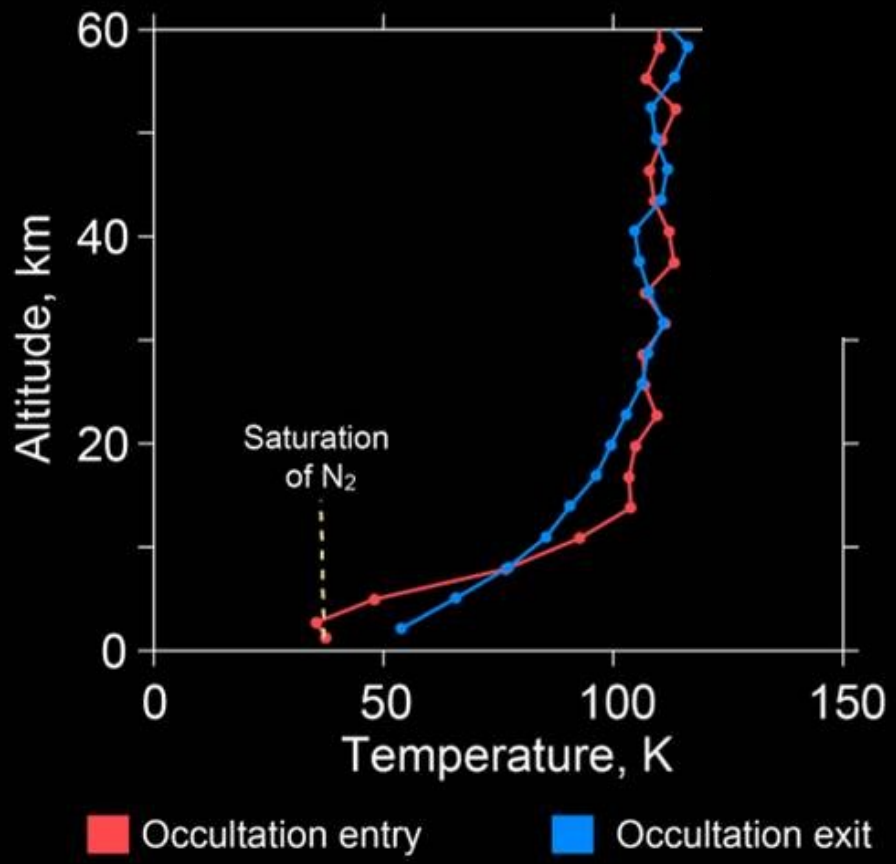

Pluto

Pluto Atmospheres:

- Surface pressure : ~1 Pa
- 99.5% N2, 0.5% CH4 0.05% CO

Scattering by organic hazes up to ~150 km

Temperatures (radio occulation)



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Giant planets

	Jupiter	Saturn	Uranus	Neptune
Mean distance to the Sun ($\times 10^8$ km)	7.78	14.27	28.69	44.96
Insolation (W/m^2)	50.6	15.1	3.72	1.52
Mass (in M_J=1.9×10^{27} kg)	1.	0.30	0.046	0.054
Radius ($\times 10^3$ km)	71.3	60.1	25.5	24.8
Gravity (m/s^2)	2288.	950.	869.	1100.
Obliquity (degrees)	3.08	26.7	97.9	28.8
Rotation period (h)	9.84	10.23	17.9	19.2
Orbital period (in Earth years)	11.86	29.5	84.01	164.8
Temperature at tropopause (K)	105.	82.	53.	52.
Pressure at tropopause (mbar)	100.	100.	100.	100.
Atmospheric composition (only majors, %)				
H_2	86.3	86.-90.	85.	85.
He	13.5	10.-14.	13.	12.
CH_4	0.2	0.4	2.4	3.5

Giant planets

	Jupiter	Saturn	Uranus	Neptune
Mean distance to the Sun ($\times 10^8$ km)	7.78	14.27	28.69	44.96
Insolation (W/m^2)	50.6	15.1	3.72	1.52
Mass (in M_J=1.9$\times 10^{27}$ kg)	1.	0.30	0.046	0.054
Radius ($\times 10^3$ km)	71.3	60.1	25.5	24.8
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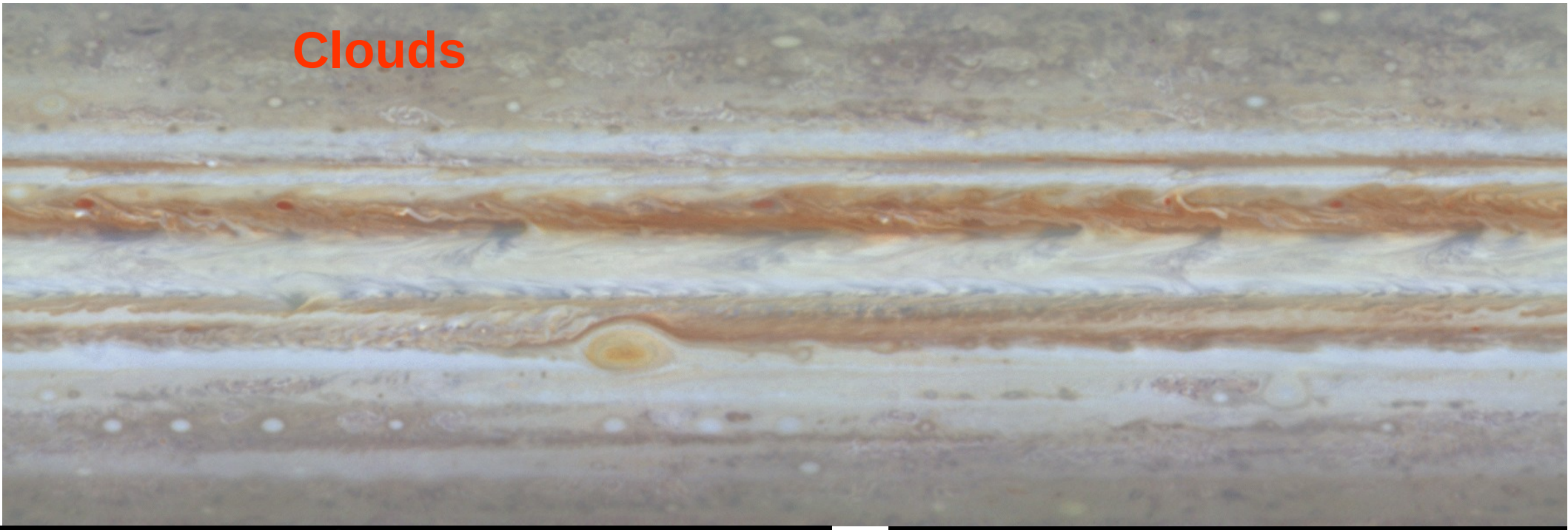
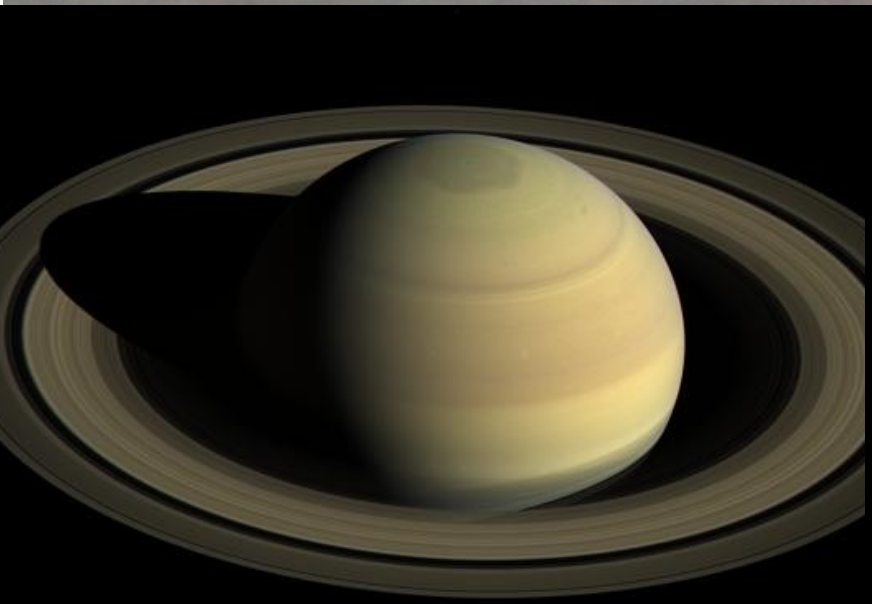
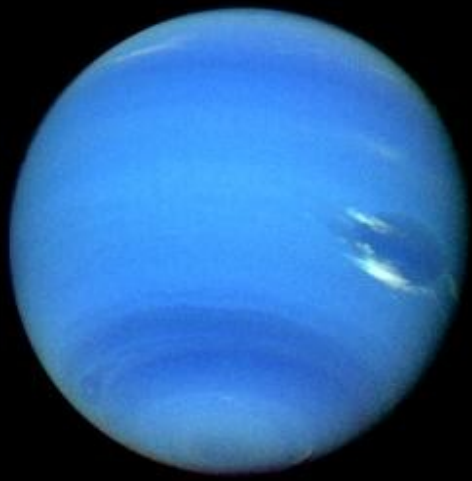
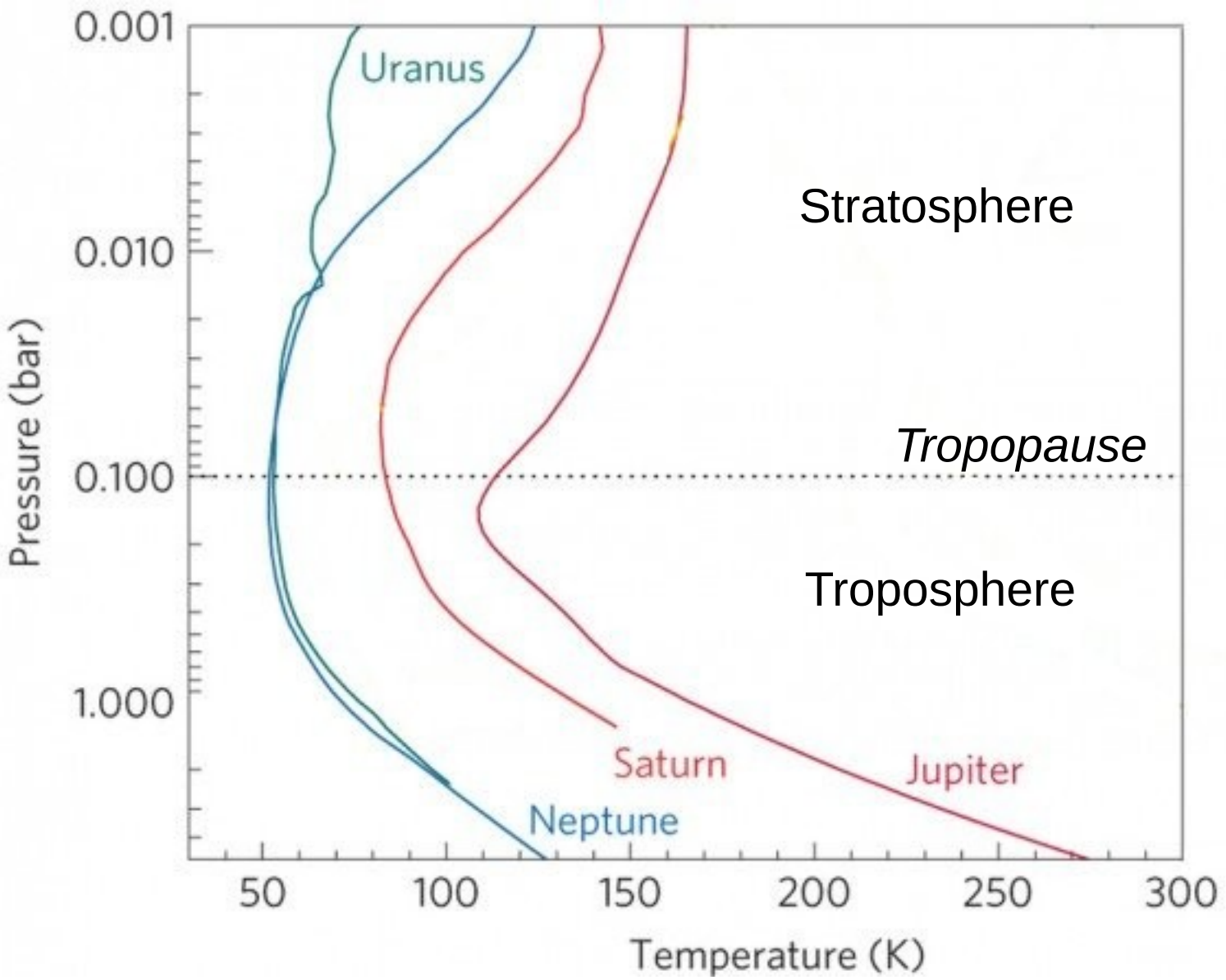

Clouds

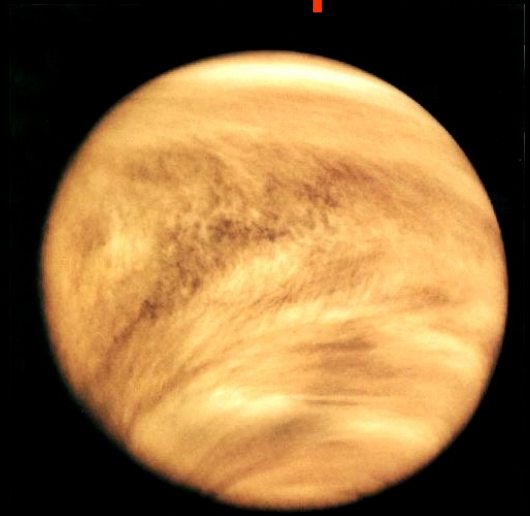


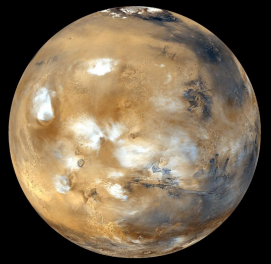


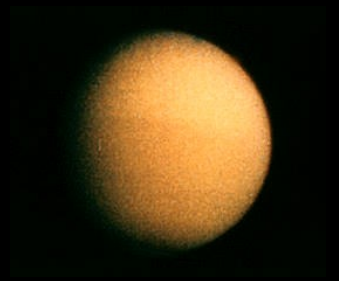
Temperature



Terrestrial planets (+ Titan)

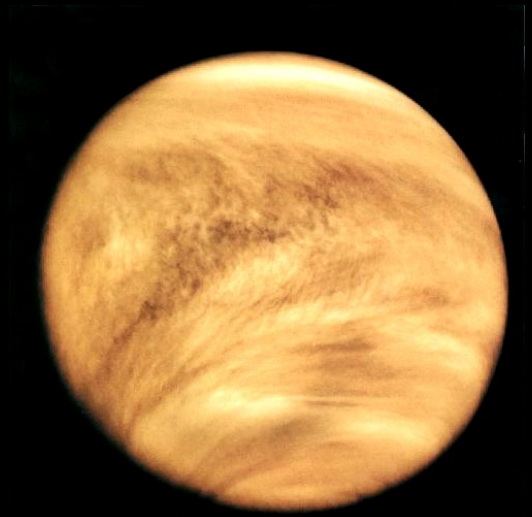


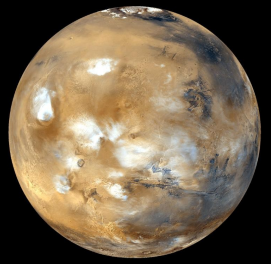


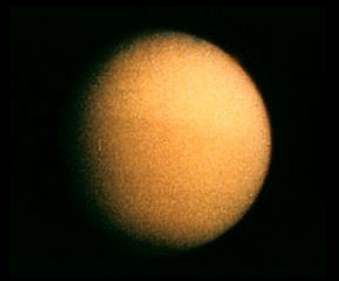


	VENUS	EARTH	MARS	TITAN
	<Ts> ~ 450 °C	<Ts> ~ 15 °C	<Ts> < -50 °C	<Ts> ~ 95 K
	CO_2~90bar	CO_2~0.0003 bar	CO_2 = 0.006 bar	CH_4 ~ 0.06 bar
	H_2O/CO_2<<1	O_2~0.2 bar	N_2 = 0.0002 bar	N_2 = 1.5 bar
	N_2~3bar	N_2~0.8 bar		
Sun distance	= 0.72 AU	1 AU	1.52 AU	9.5 AU
M	= 0.81 M_{Earth}	1	0.11 M_{Earth}	0.023 M_{Earth}
ρ	= 5.25	5.52	3.95	1.88
obliquity	= 177,4 °	23,5 °	25,2 °	26,7 °
rotation	= (-) 243 d	23 h 56 m	24 h 37 m	15.94 d
revolution	= 224,7 d	365,25 d	687 d	~30 years

Similarities / Differences







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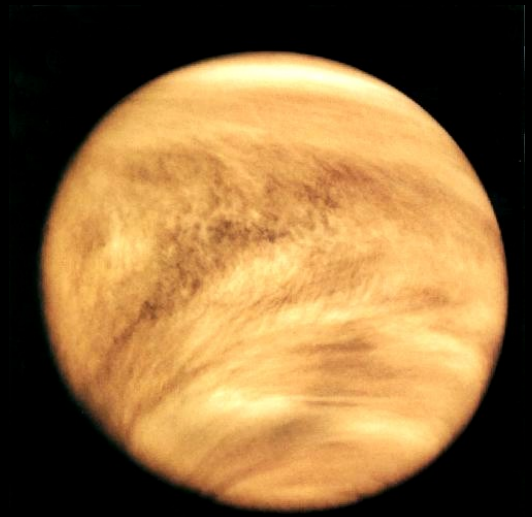

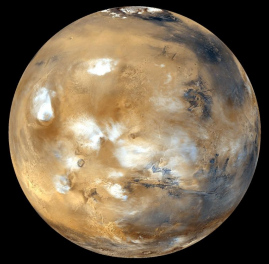

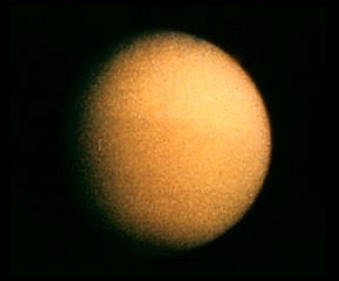

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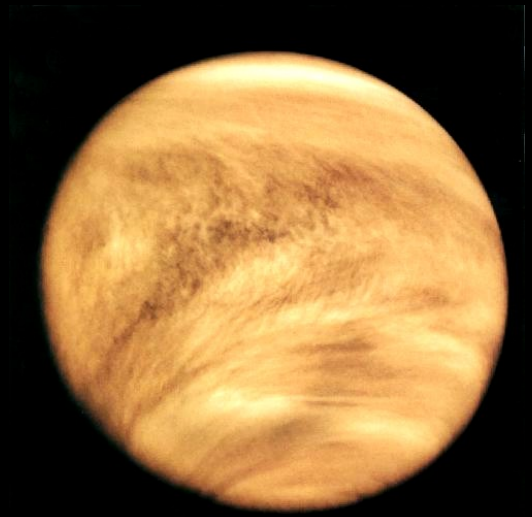
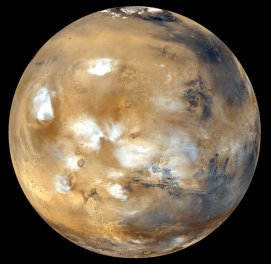
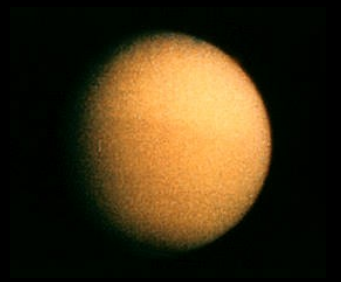
revolution	= 224,7 d	365,25 d	687 d	~30 years

Similarities / Differences

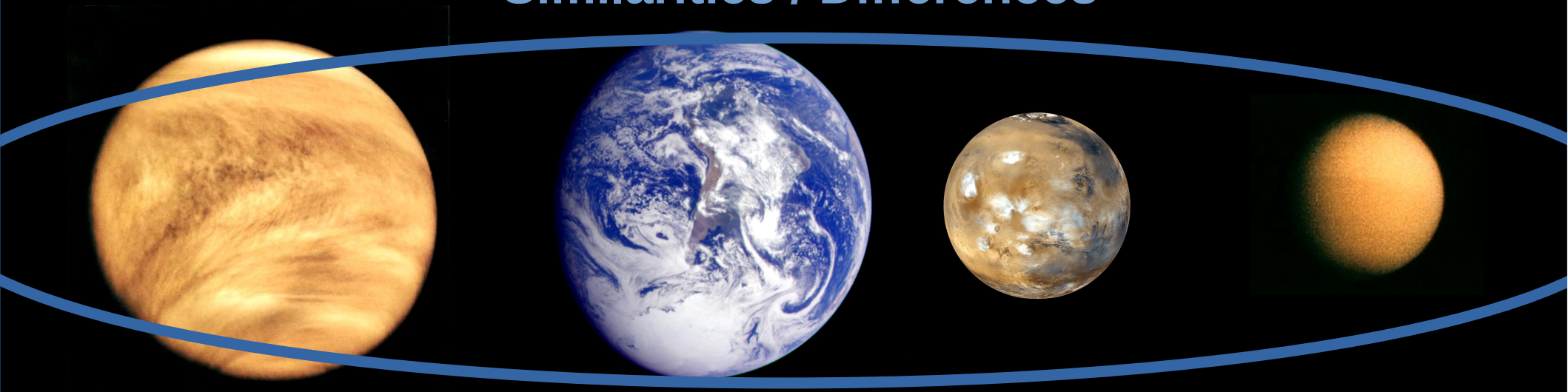






VENUS	EARTH	MARS	TITAN
<Ts> ~ 450 °C	<Ts> ~ 15 °C	<Ts> ~ -50 °C	<Ts> ~ 95 K
CO_2~90bar	CO_2~0.0003 bar	CO_2 = 0.006 bar	CH_4 ~ 0.06 bar
H_2O/CO_2<<1	O_2~0.2 bar	N_2 = 0.0002 bar	N_2 = 1.5 bar
N_2~3bar	N_2~0.8 bar		
Sun distance = 0.72 AU	1 AU	1.52 AU	9.5 AU
M = 0.81 M_{Earth}	1	0.11 M_{Earth}	0.023 M_{Earth}
ρ = 5.25	5.52	3.95	1.88
obliquity = 177,4°	23,5°	25,2°	26,7°
rotation = (-) 243 d	23 h 56 m	24 h 37 m	15.94 d
revolution = 224,7 d	365,25 d	687 d	~30 years

Similarities / Differences



VENUS	EARTH	MARS	TITAN
<Ts> ~ 450 °C	<Ts> ~ 15 °C	<Ts> < -50 °C	<Ts> ~ 95 K
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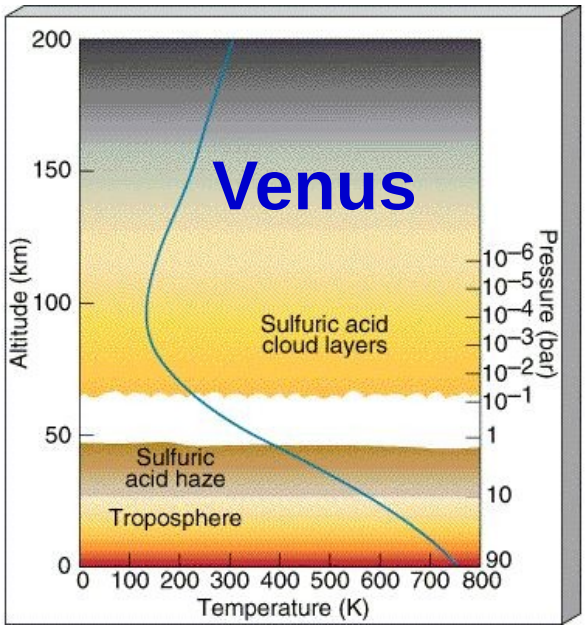
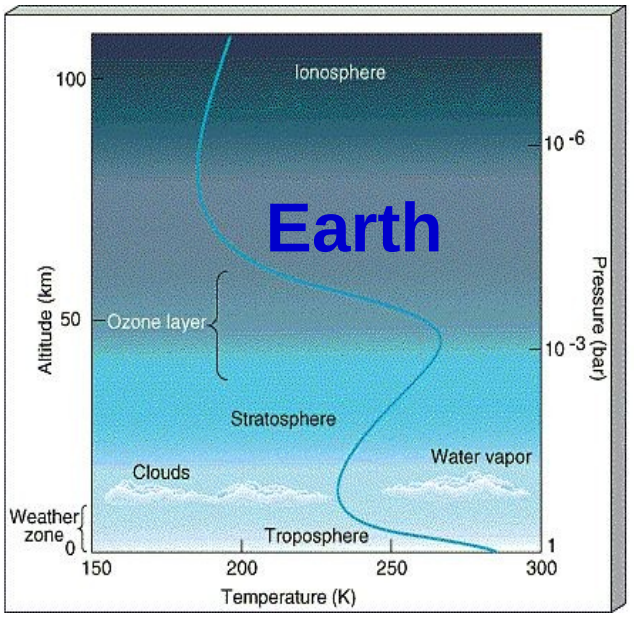
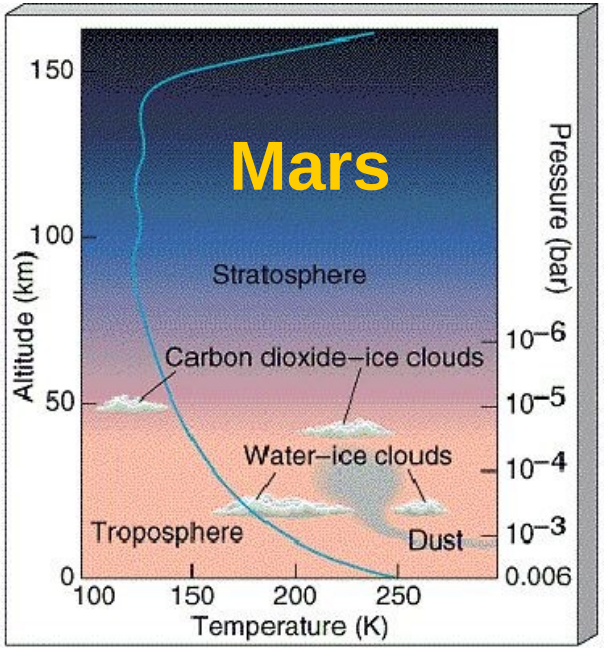
Similarities / Differences

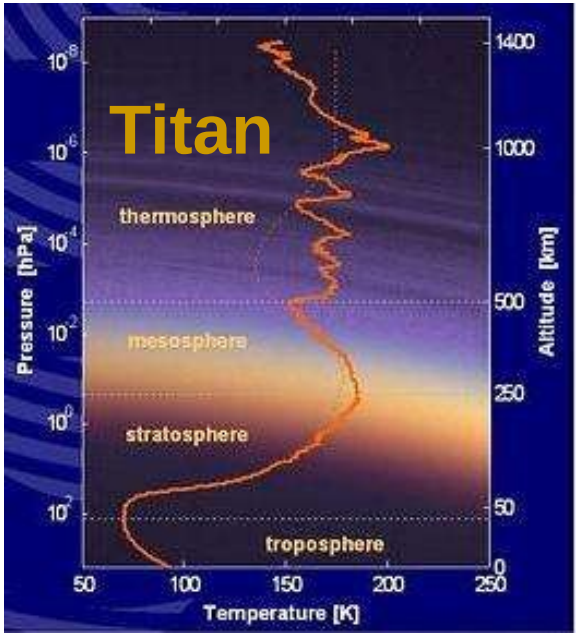
A particularity of Titan : thickness of its atmosphere

Temperature

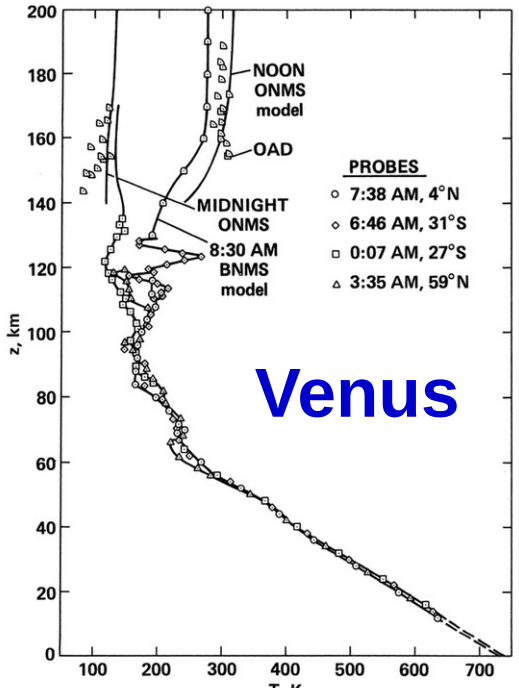


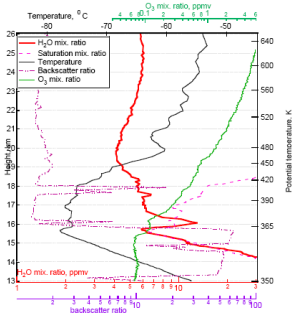


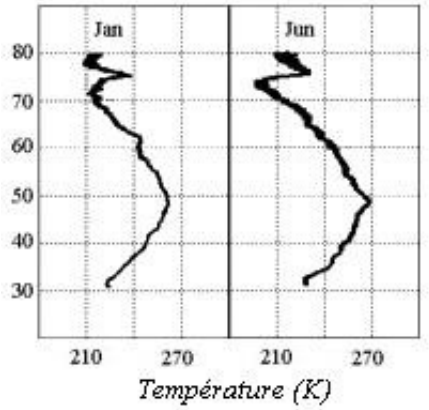




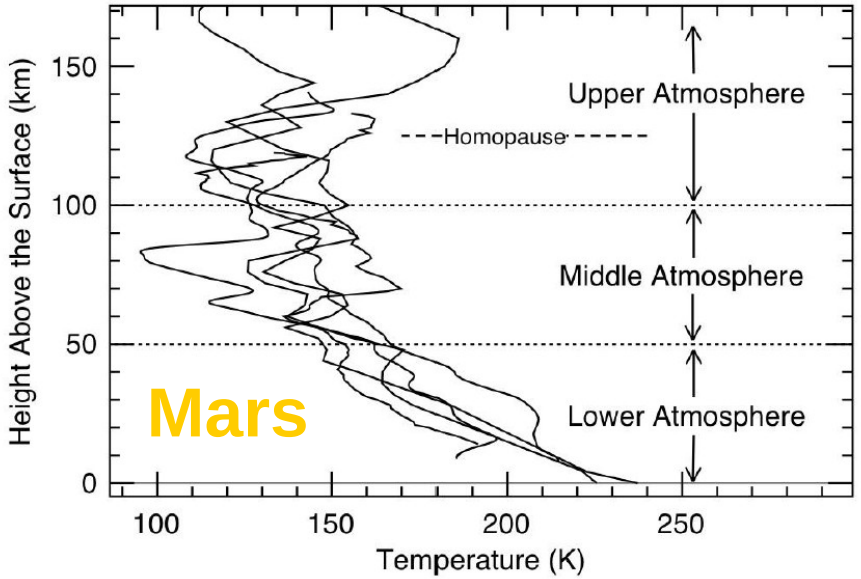
Temperature

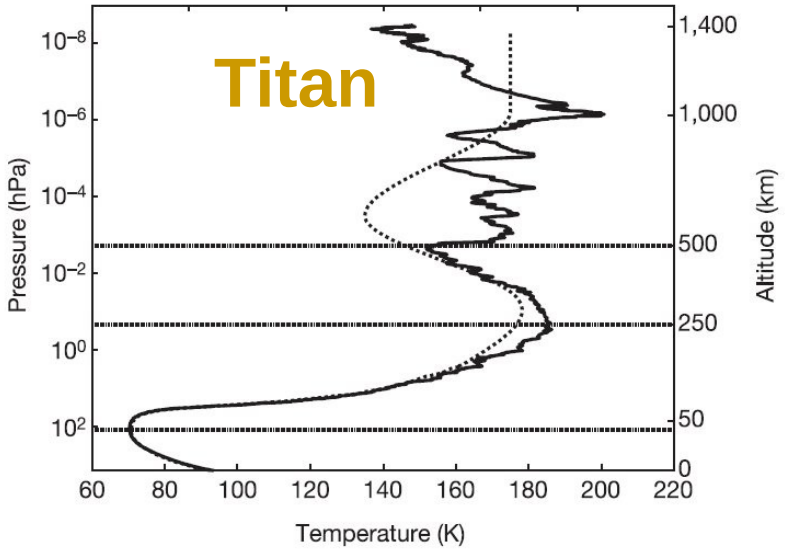






Earth





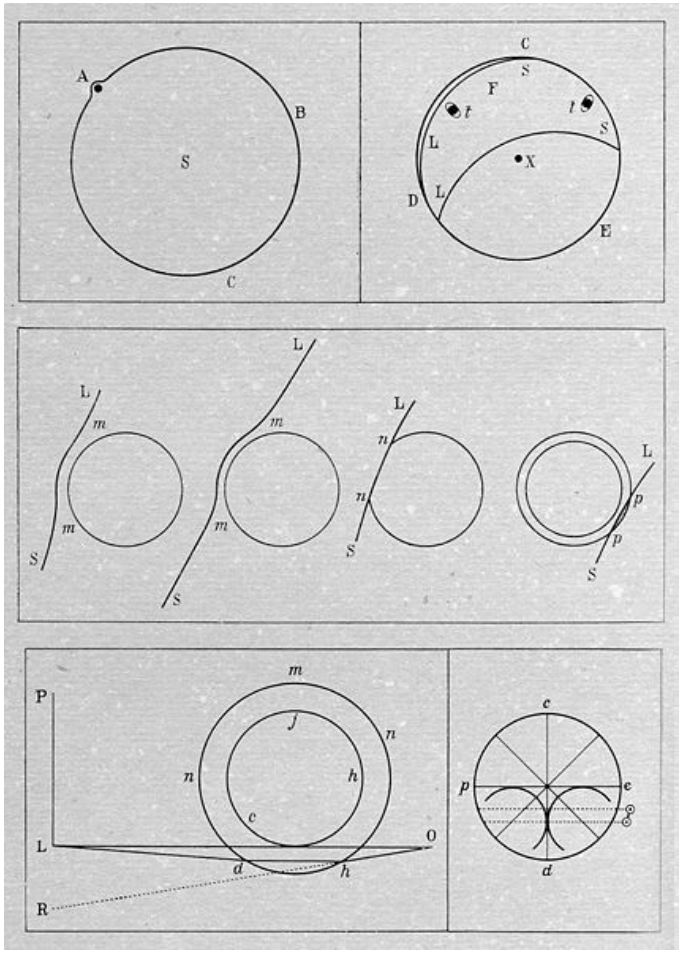
PLANETARY ATMOSPHERES

Overview of planetary atmospheres in the Solar System

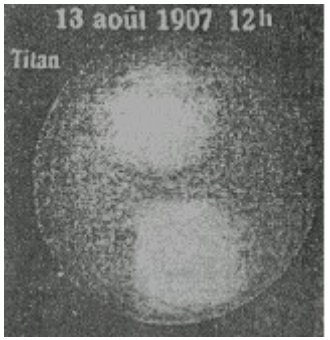
- Our Solar System : a large diversity of objects
- Different types of atmospheres
- Description of atmospheric structures
- Current exploration of planetary atmospheres
- Planets in other stellar systems

Historical observations

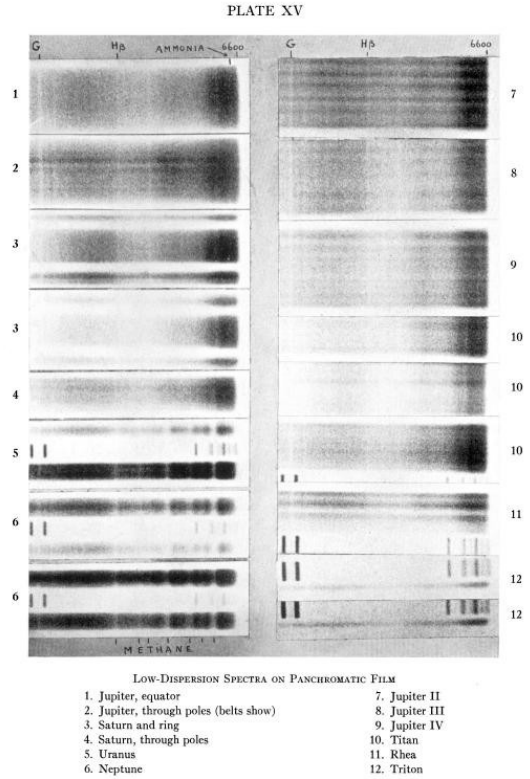
1761 : Lomonosov, Venus transit



1907 : Comas Sola, Titan



1944 : G. Kuiper, methane on Titar

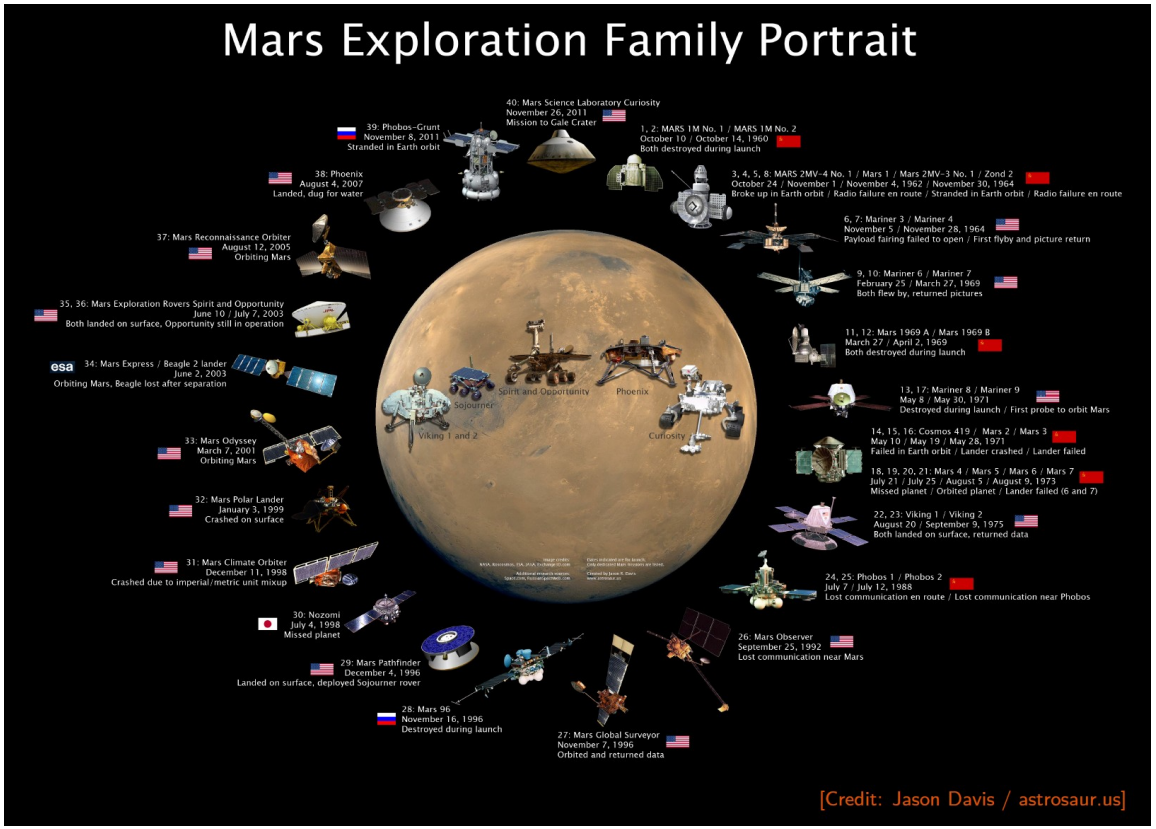


LOW-DISPERSION SPECTRA ON PANCHROMATIC FILM

1. Jupiter, equator
2. Jupiter, through poles (belts show)
3. Saturn and ring
4. Saturn, through poles
5. Uranus
6. Neptune
7. Jupiter II
8. Jupiter III
9. Jupiter IV
10. Titan
11. Rhea
12. Triton

Space probes : half a century of exploration

Mars



Venus

- Mariner 10 (1973)
- Venera 4 (1967) to 16 (1983)
- Pioneer Venus 1, 2 (1978-1992)
- Vega 1, 2 (1984)
- Magellan (1990-1994)
- Venus-Express (2006-2014)
- Akatsuki (2015-)

Outer solar system

- Pioneer 10 (1972), Pioneer 11 (1973)
- Voyager 1, Voyager 2 (1977)
- Galileo (1995-2003)
- Cassini-Huygens (2004-2017)
- New Horizons (2015)

Current missions

Mars

Mars Express (2003, Europe)
Mars Reconnaissance Orbiter (2006, USA)
Mangalayan (2014, India)
Maven (2014, USA)
ExoMars Trace Gas Orbiter (2016, Europe-Russia)

Opportunity (2004, USA)
Curiosity (2012, USA)

Insight (2018, USA)
ExoMars rover (2020, Europe-Russia)

Venus

Akatsuki (2015, Japan)

Jupiter

Juno (2016, USA)
Juice (2022 ? Europe)

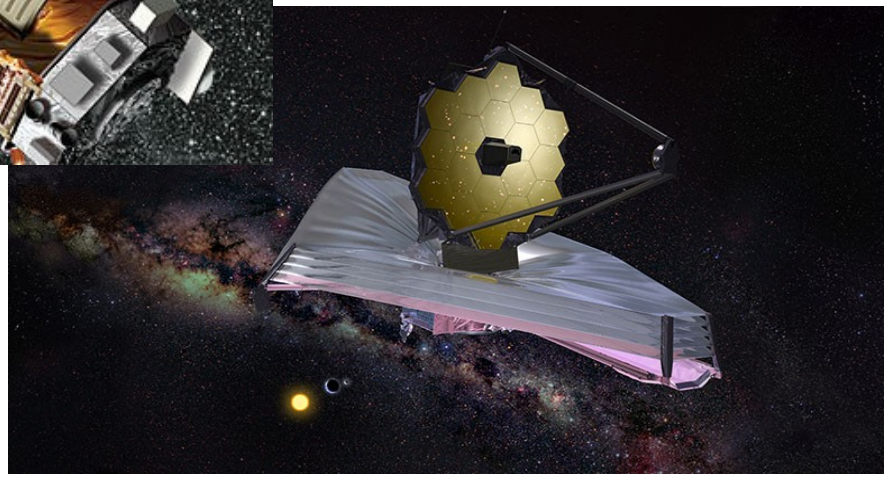
Ground based, space based telescopes

VLT

Mauna Kea

ALMA

Hubble, JWST
Corot, Kepler
IUE, ISO, Spitzer



A good complementarity

Spatial resolution

Duration of the observations

Instruments technology

Type of measurements

PLANETARY ATMOSPHERES

Overview of planetary atmospheres in the Solar System

- Our Solar System : a large diversity of objects
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- Description of atmospheric structures
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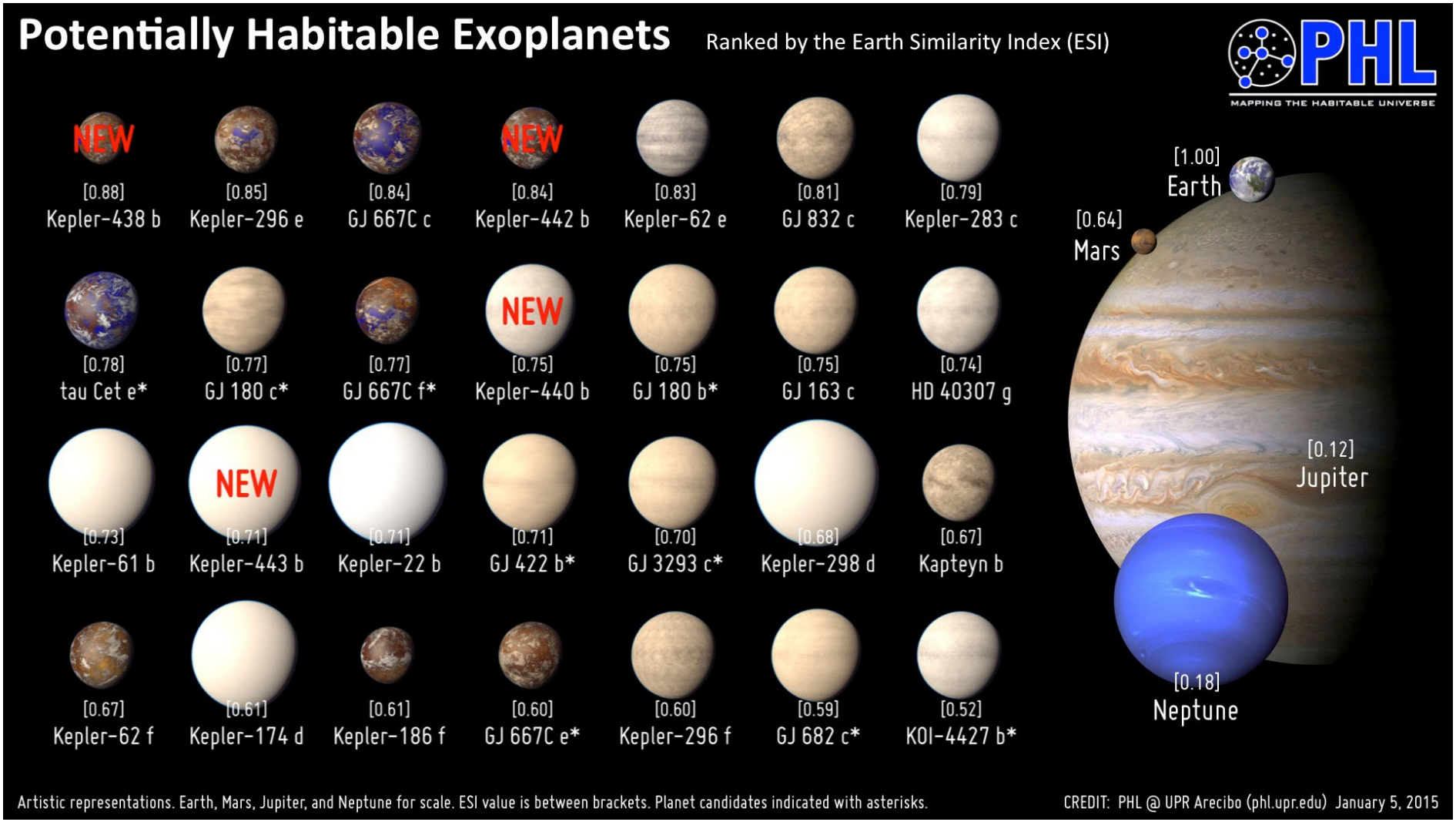
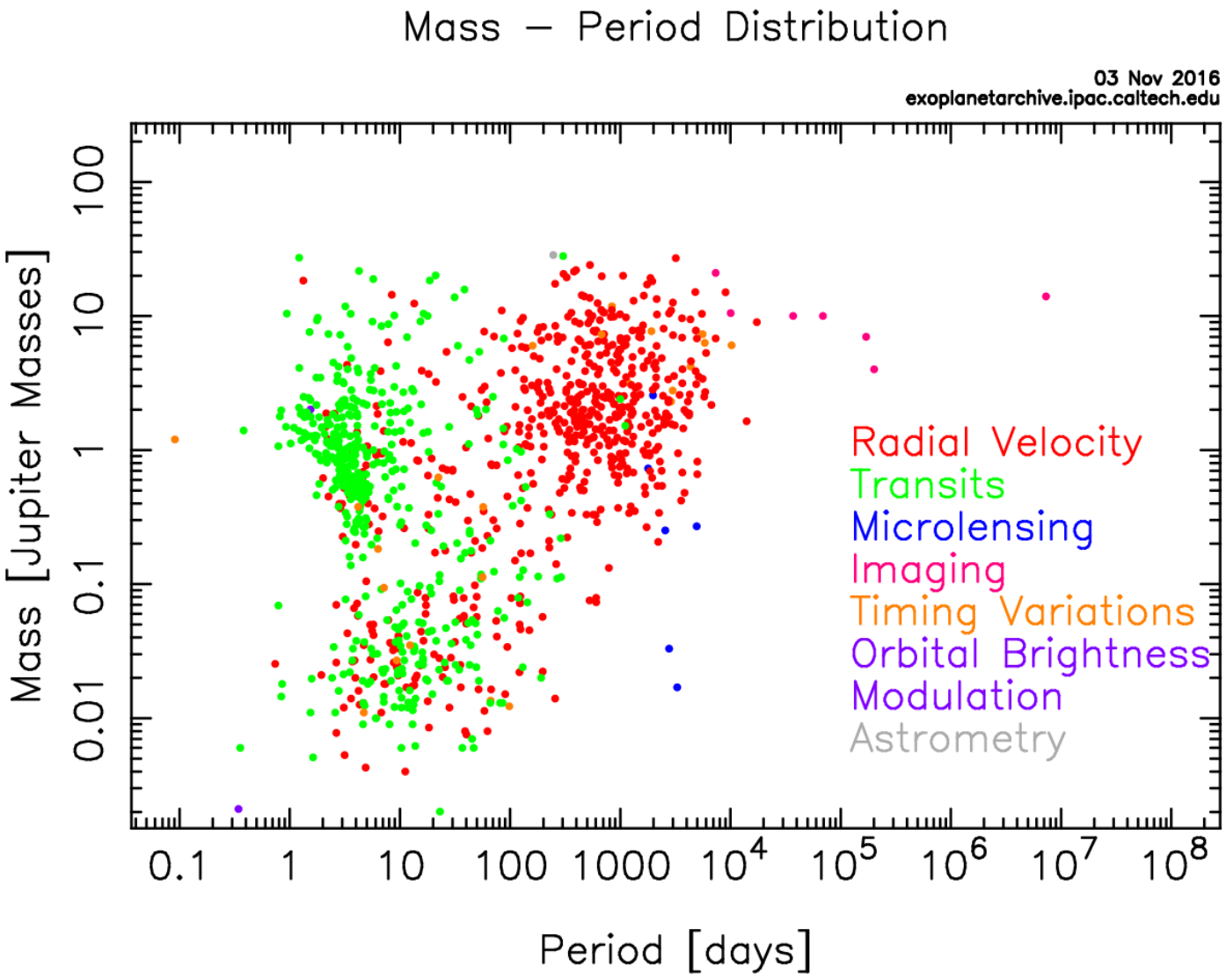
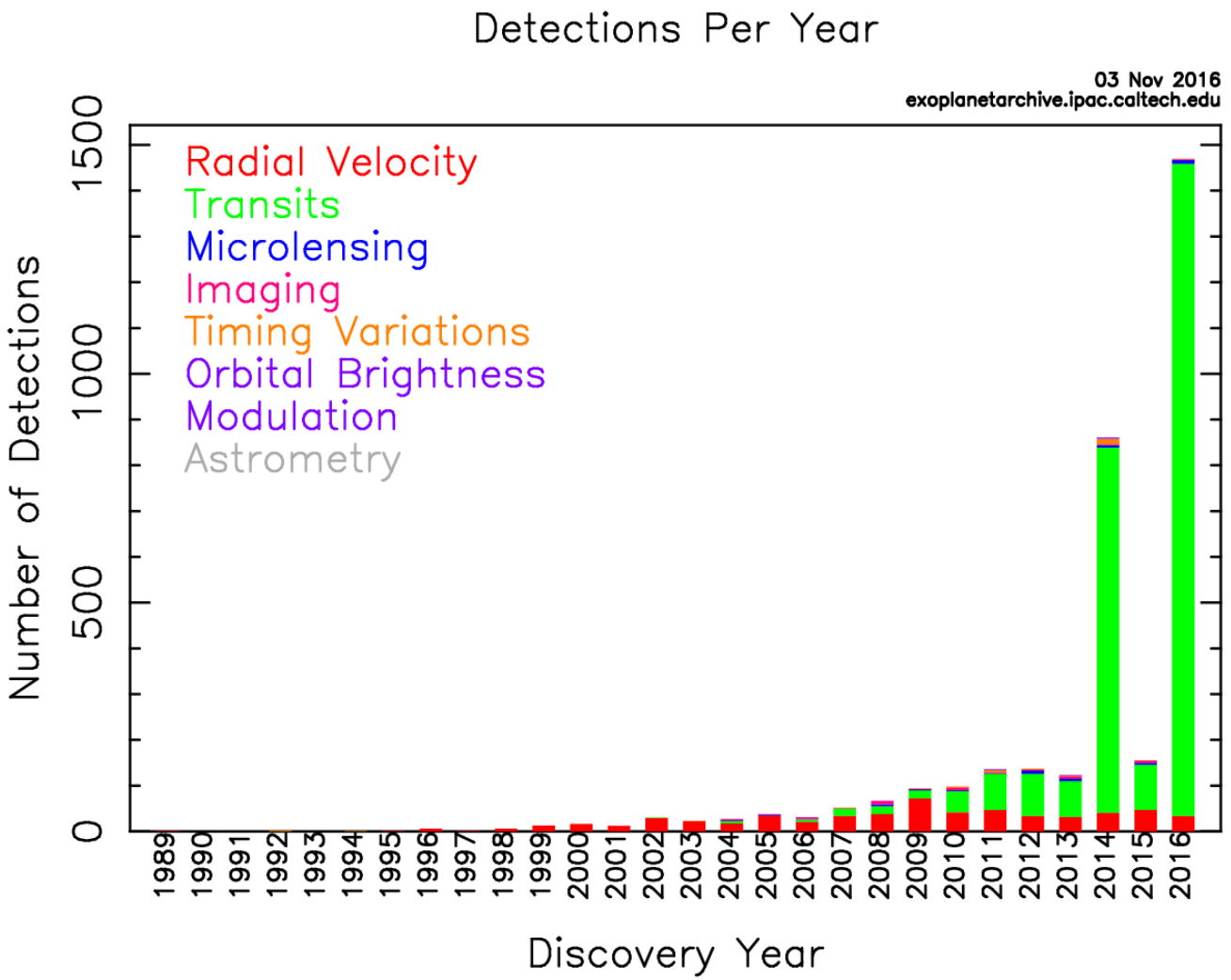
Exoplanets !


Potentially Habitable Exoplanets
Ranked by the Earth Similarity Index (ESI)
PHL
MAPPING THE HABITABLE UNIVERSE
NEW
[0.88] Kepler-438 b
[0.85] Kepler-296 e
[0.84] GJ 667C c
NEW
[0.84] Kepler-442 b
[0.83] Kepler-62 e
[0.81] GJ 832 c
[0.79] Kepler-283 c
[0.78] tau Cet e*
[0.77] GJ 180 c*
[0.77] GJ 667C f*
NEW
[0.75] Kepler-440 b
[0.75] GJ 180 b*
[0.75] GJ 163 c
[0.74] HD 40307 g
[0.73] Kepler-61 b
NEW
[0.71] Kepler-443 b
[0.71] Kepler-22 b
[0.71] GJ 422 b*
[0.70] GJ 3293 c*
[0.68] Kepler-298 d
[0.67] Kapteyn b
[0.67] Kepler-62 f
[0.61] Kepler-174 d
[0.61] Kepler-186 f
[0.60] GJ 667C e*
[0.60] Kepler-296 f
[0.59] GJ 682 c*
[0.52] KOI-4427 b*
[1.00] Earth
[0.64] Mars
[0.12] Jupiter
[0.18] Neptune
Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. ESI value is between brackets. Planet candidates indicated with asterisks.
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) January 5, 2015

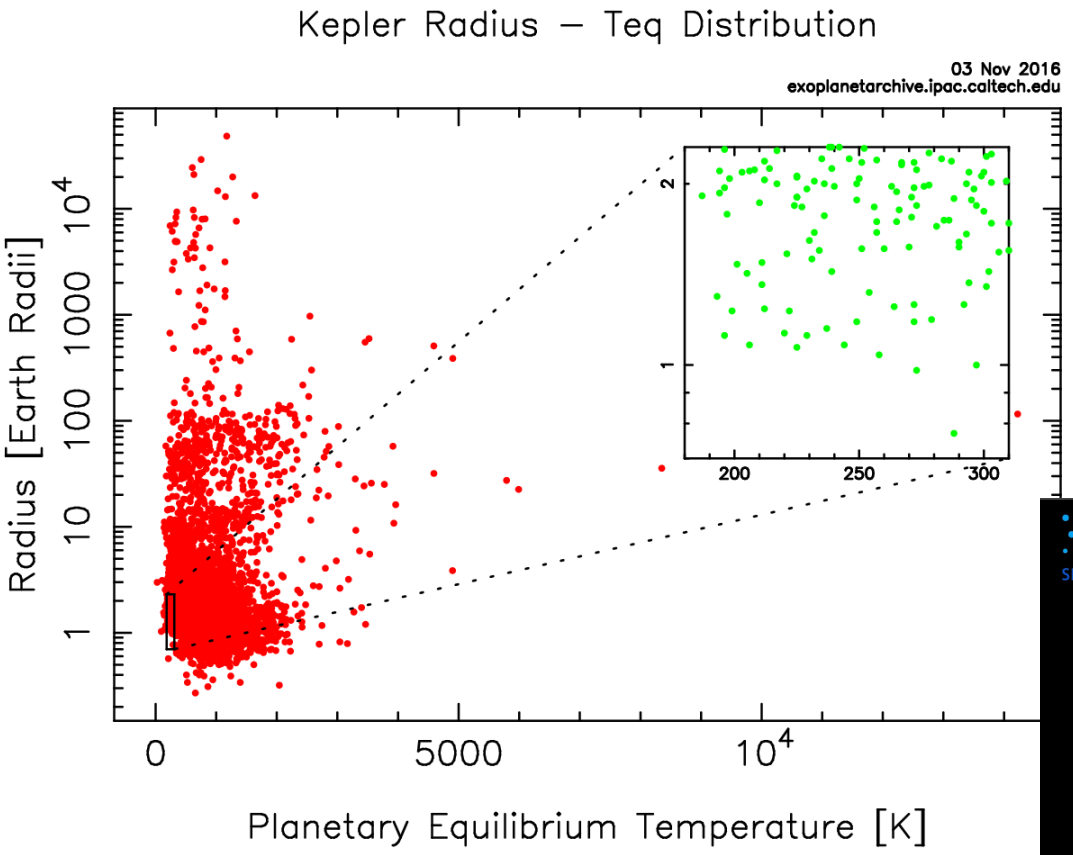
Techniques

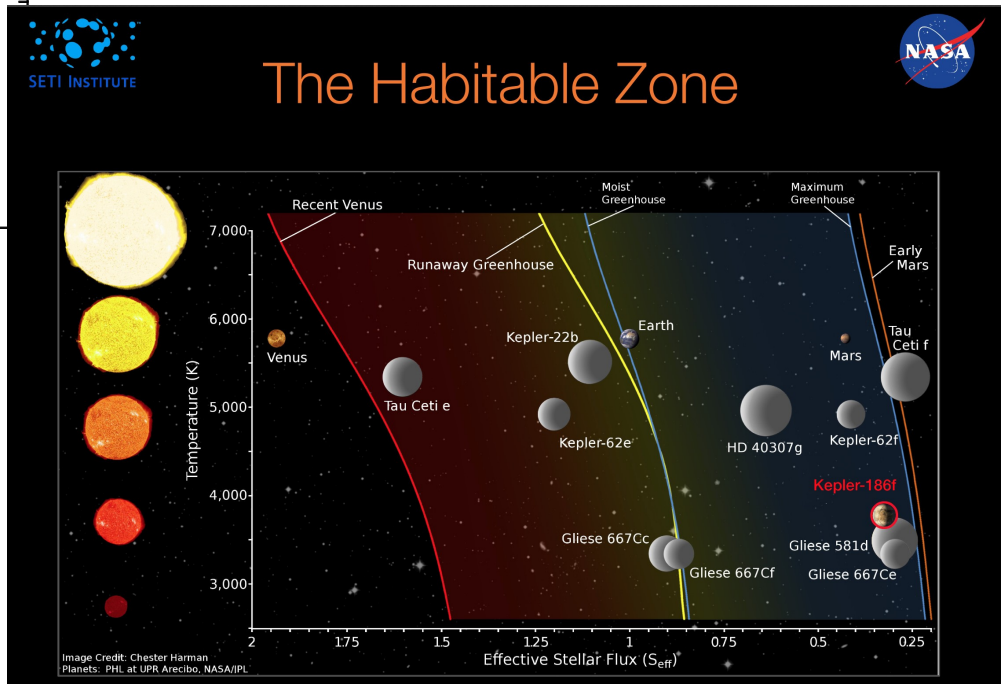

Mass – Period Distribution
03 Nov 2016
exoplanetarchive.ipac.caltech.edu
Mass [Jupiter Masses]
0.01
0.1
1
10
100
Period [days]
0.1
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness Modulation
Astrometry

Number is increasing

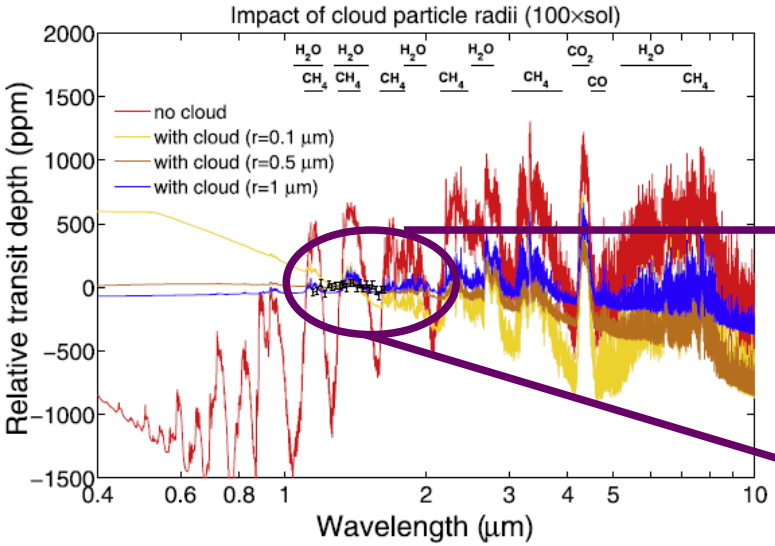


Types of planets





Atmospheric hints



GJ1214b : spectrum by HST