

Exoplanets -- A new Frontier in Earth and Planetary System Science



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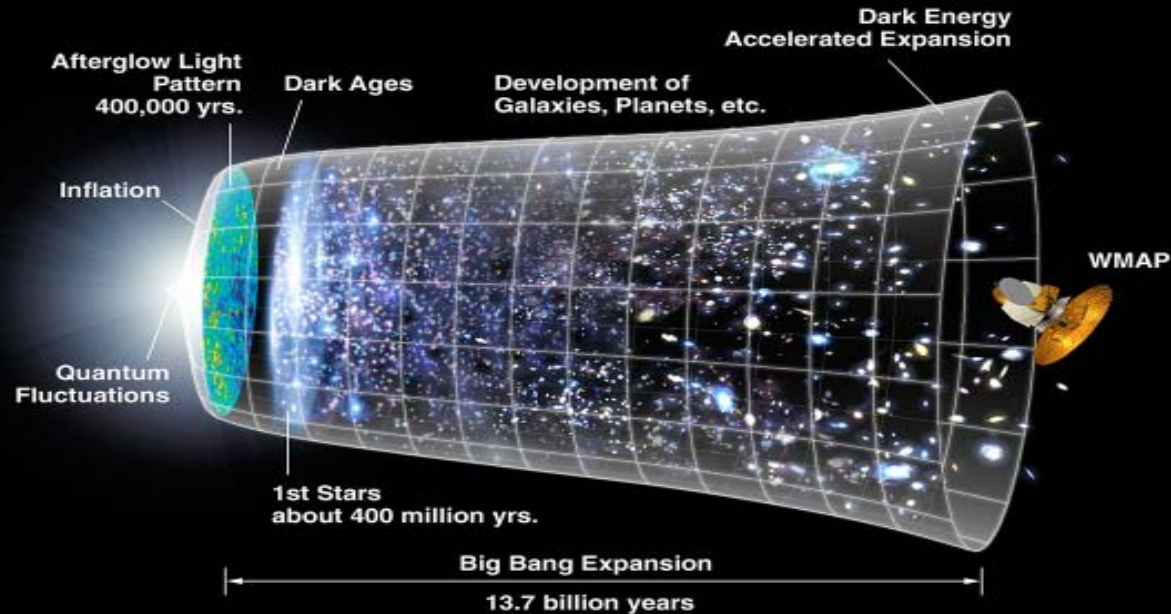
Topics Today

- 背景
- 太阳系的主要行星类型
- 地球、火星和金星的演化历史
- 系外行星
- 可居住行星

银河系

- 150亿年以前宇宙形成
- 宇宙中有约1000-5000亿个像银河系这样的星系
- 银河系中大约有1000-4000亿颗恒星
- 太阳是银河系恒星中的一个成员
- 我们生活在太阳系中的地球上
- 地球在46亿年前形成，50亿年之后毁灭
- 地球就像浩瀚宇宙中的一粒尘埃

Birth and Growth of the Universe



NASA/WMAP Science Team

Higgs
Boson
"God
particle"

10^{-9} seconds
 10^{15} K
Quark

10^3 seconds
 10^{14} K
Proton and
neutron

3 minutes
 10^{10} K
Nuclear

0.3 million
years
3000 K
H atom

H cloud;
H to He
Star formed

C, O, N, S,
Mg, Si ...
formed;
Fe formed;
Supernova

Nebula;
Secondary
stars

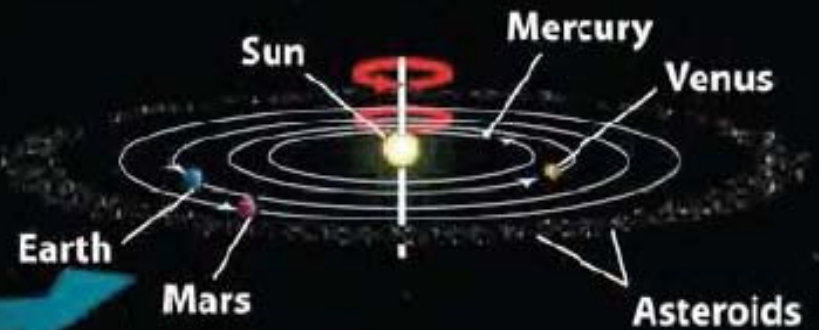
Solar System Formation

1 Cloud of matter (nebula) begins to contract gravitationally. Process may have been initiated or accelerated by shock waves from supernova explosion (not shown).

2 As gas cloud contracts, it spins faster and faster, forming a central bulge and a wide disk.

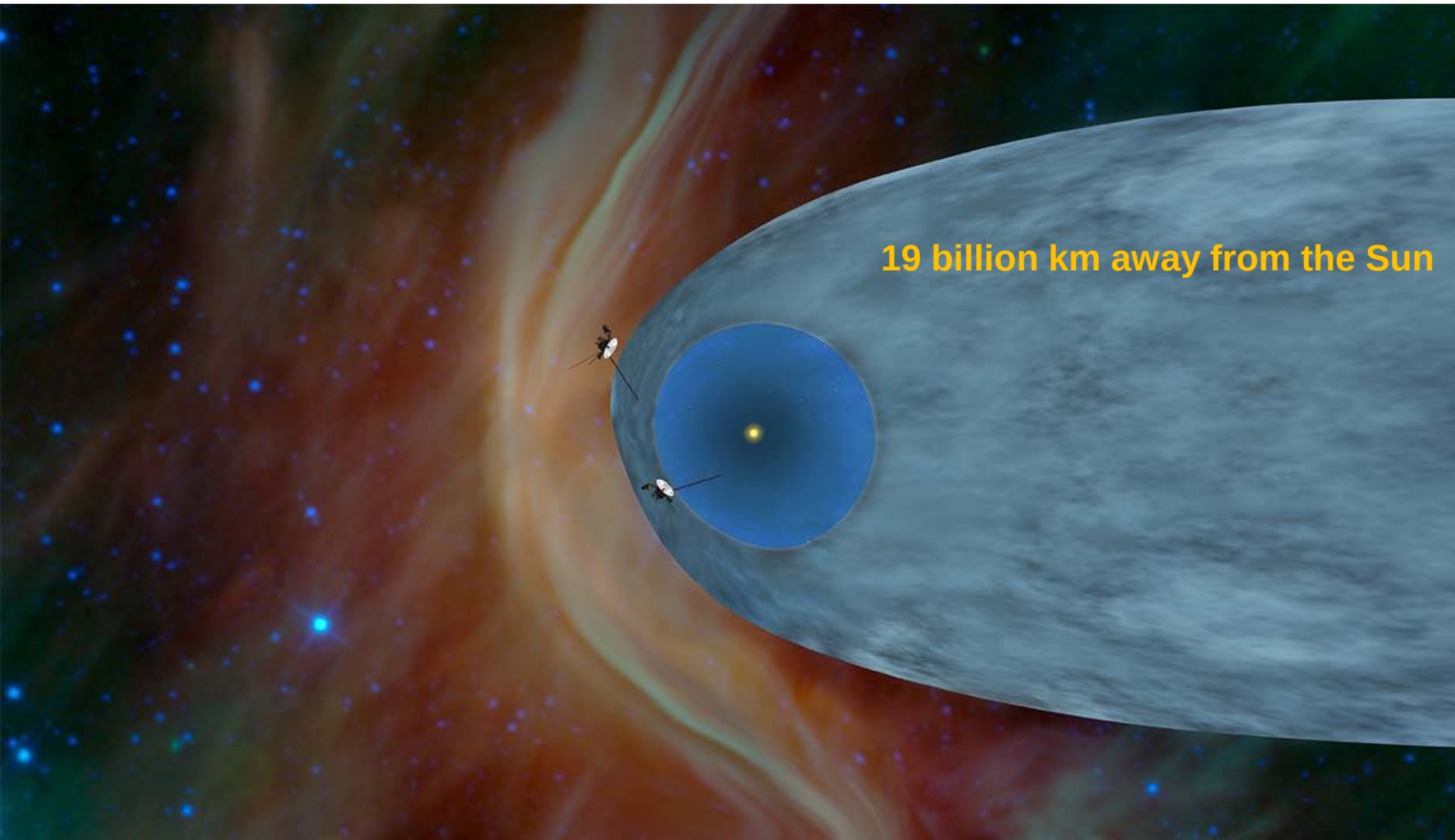
3 Contraction raises temperature; process of nuclear fusion begins in central bulge—Sun begins to shine. Outer disk cools—now contains wide swath of rocky debris. Larger chunks of debris begin to attract smaller chunks by gravity, thereby growing larger (accretion).

4 Within a few tens of millions of years, almost all the debris has accreted into today's planets.

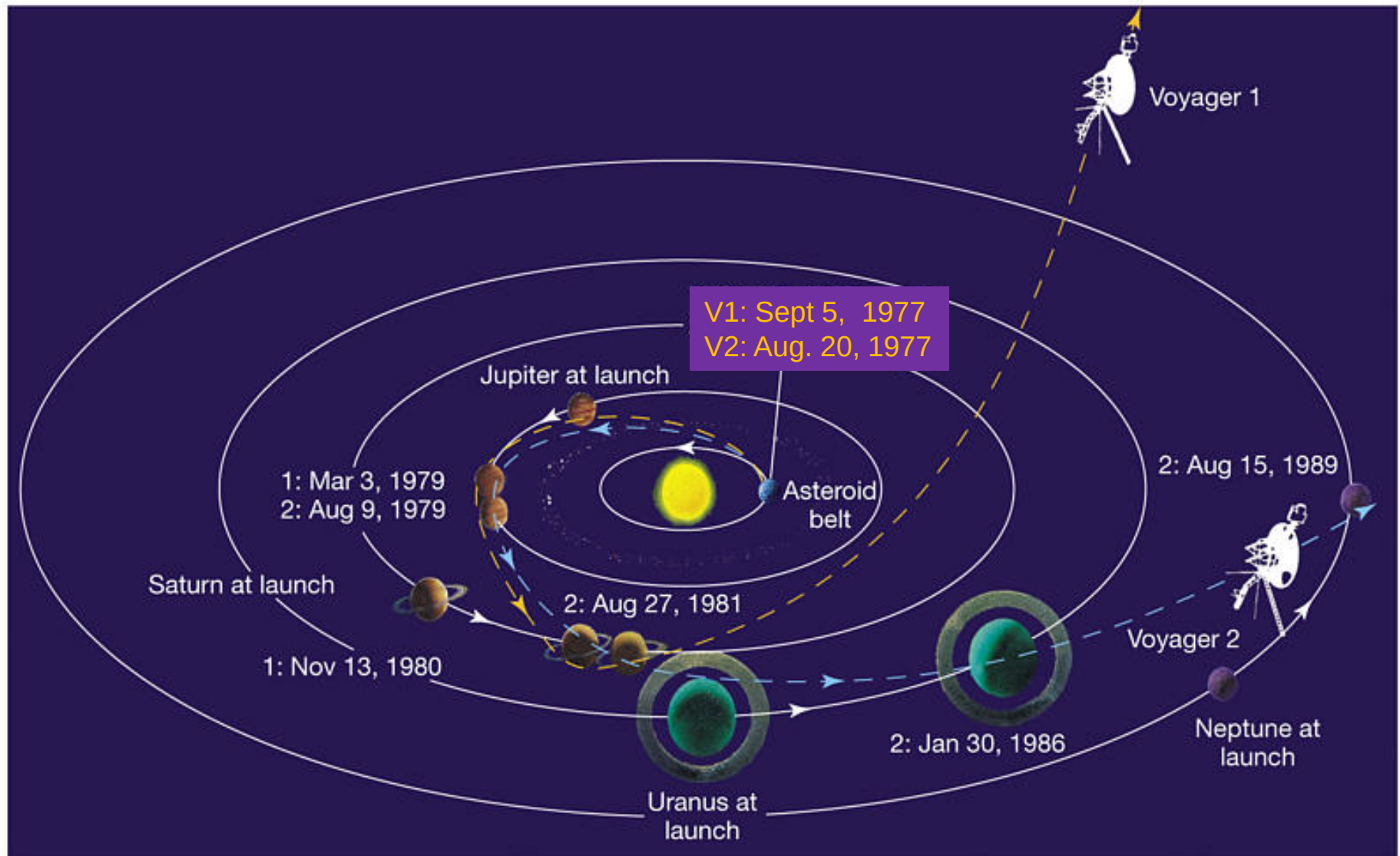


I. Tour of the Solar System

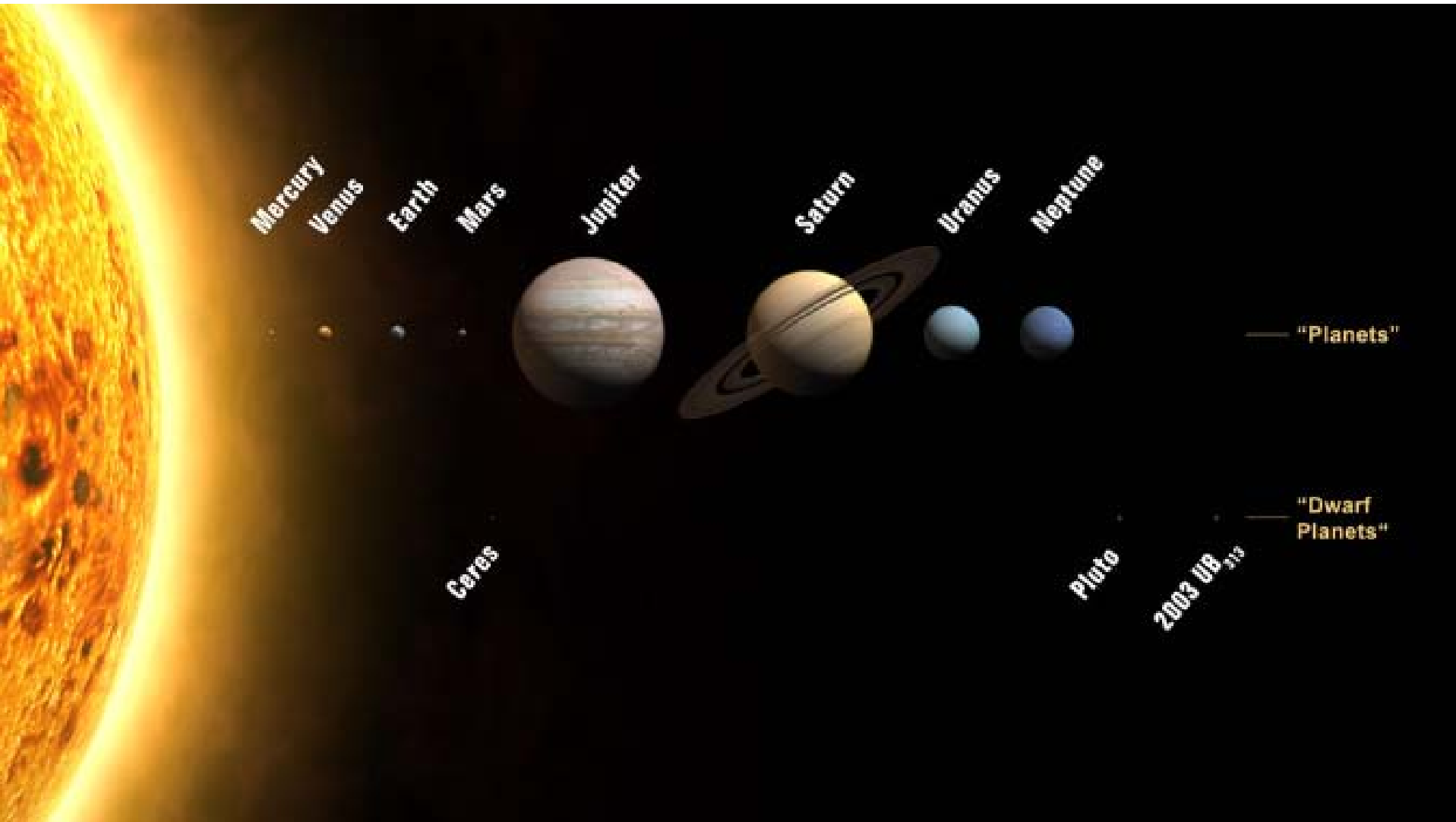
Sept. 12th, 2013: Voyager enters interstellar space – first manmade object to do so.



The Voyagers are far from home...

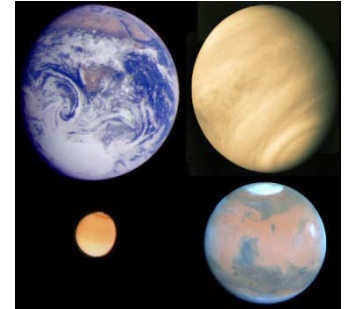


The Solar System Planets

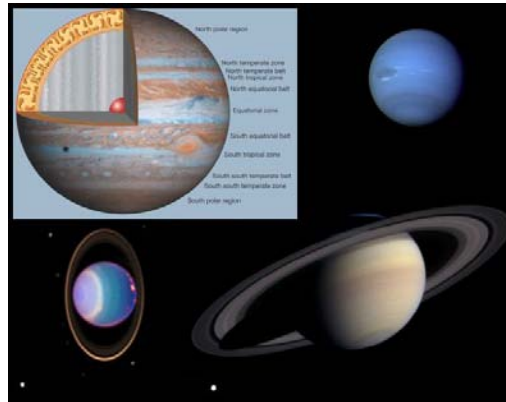


3 Classes of Solar System Objects

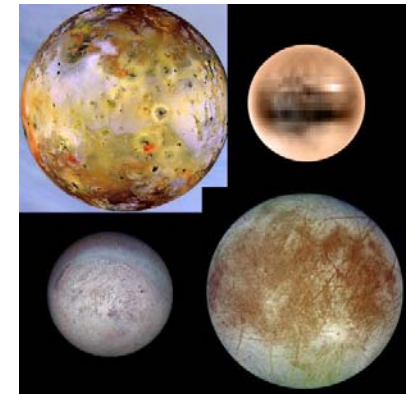
- Terrestrial planet (rocky surface + atmosphere)



- Gas bags

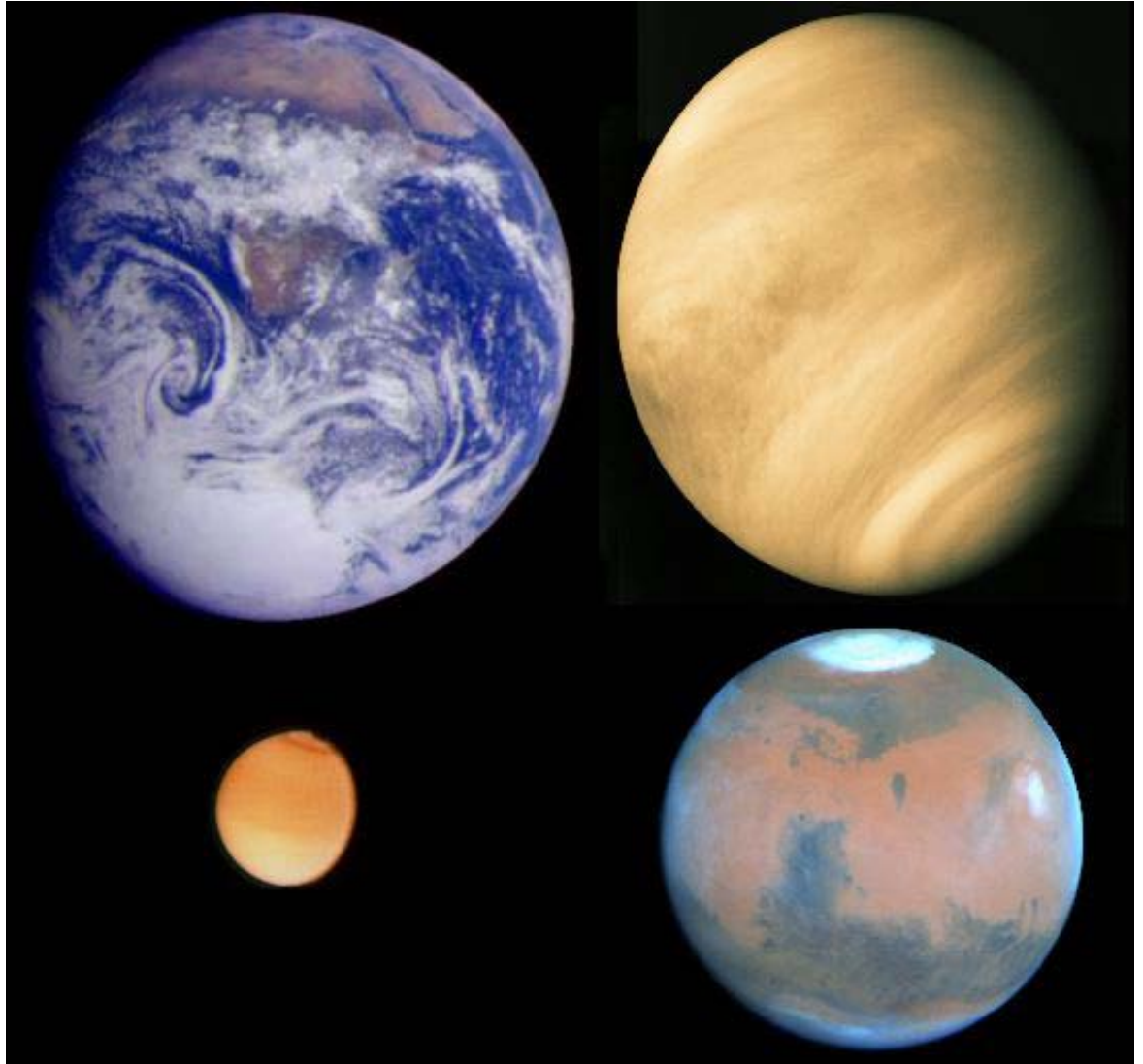


- Objects with No or tenuous atmosphere



Major Atmospheres

Mars, Earth, Titan, Venus

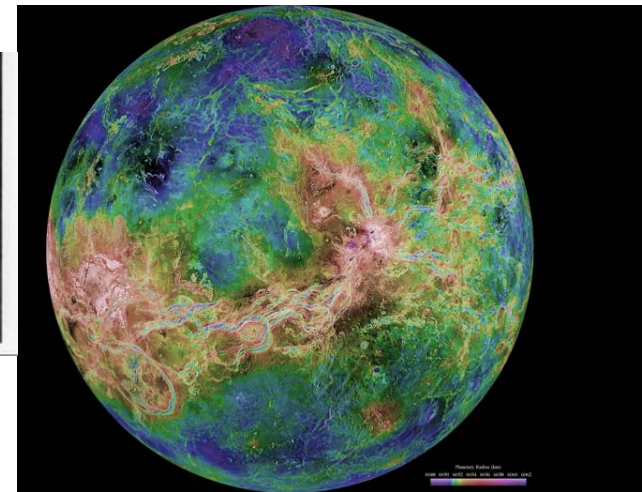
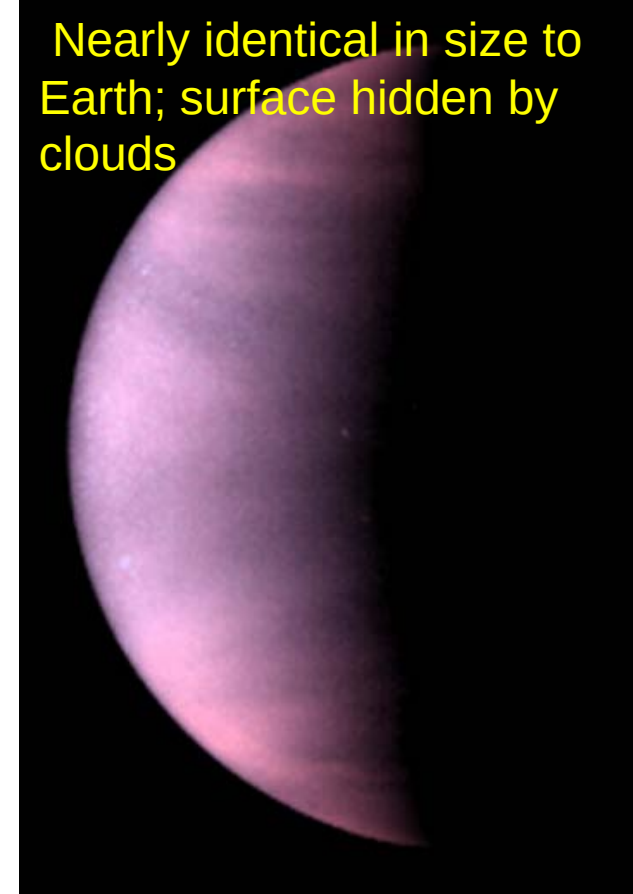


Venus:

- **Mass** = 4.865×10^{24} kg (= $0.815 \times M_{\text{Earth}}$)
- **Radius** = 6052 km (= $0.949 \times R_{\text{Earth}}$)
- **Distance from Sun:** 0.72 AU
- **Orbital Period:** 0.62 yr (224 days)
- **Rotation Period:** 243 days (retrograde)
- **Obliquity:** 178° (upside down)
- **Atmospheric Composition:** CO_2
- **Surface Pressure:** 90 atm
- **Surface Temperature:** 750 K
- **Magnetic Field:** No intrinsic
- **Satellites:** 0
- **Volcanoes:** Yes, in recent past
- **Plate Tectonics:** Yes
- **Water:** None on surface, tiny in atmosphere
- **Life:** Not likely at present



Nearly identical in size to Earth; surface hidden by clouds



- **Hellish conditions due to an extreme greenhouse effect:**
- Even hotter than Mercury: 470°C , day and night



Earth

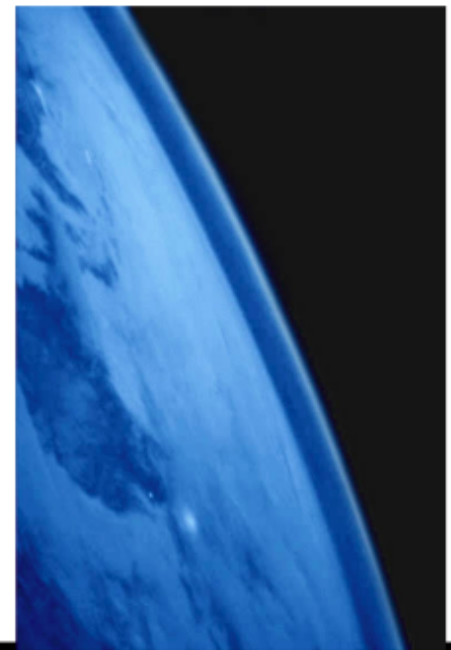


Earth and Moon
to scale

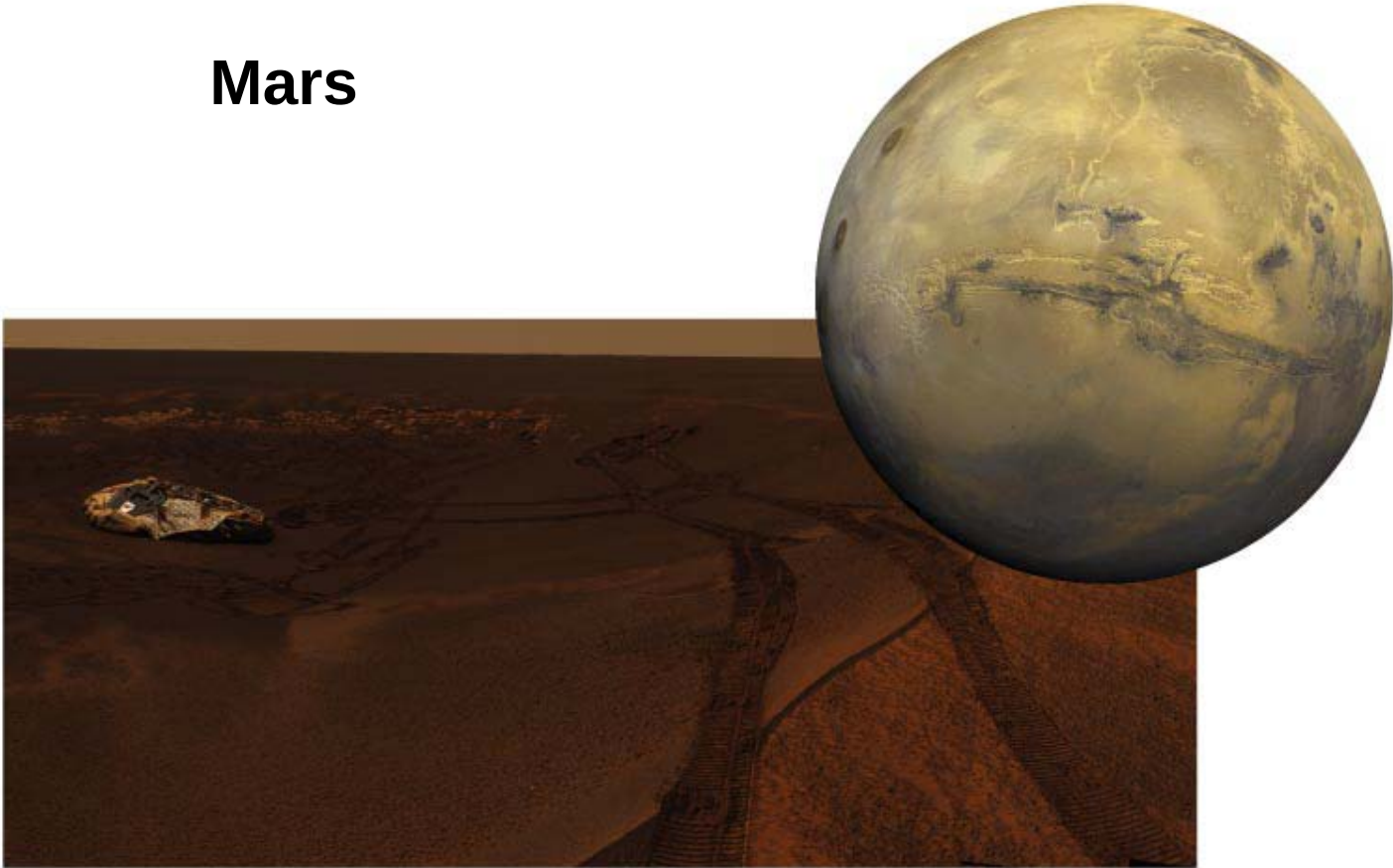
- An oasis of life
- The only surface liquid water in the solar system
- A surprisingly large moon

Earth:

- **Mass** = 6×10^{24} kg (= $1 \times M_{\text{Earth}}$)
- **Radius** = 6378 km (= $1 \times R_{\text{Earth}}$)
- **Distance from Sun:** 1 AU
- **Orbital Period:** 1 yr (365 days)
- **Rotation Period:** 24 hours
- **Obliquity:** 23.5°
- **Atmospheric Composition:** N_2 (78%), O_2 (21%)
- **Surface Pressure:** 1 atm
- **Surface Temperature:** 288 K
- **Magnetic Field:** Yes
- **Satellites:** 1 (The Moon)
- **Volcanoes:** Yes, active
- **Plate Tectonics:** Yes
- **Water:** Everywhere!
- **Life:** Everywhere!



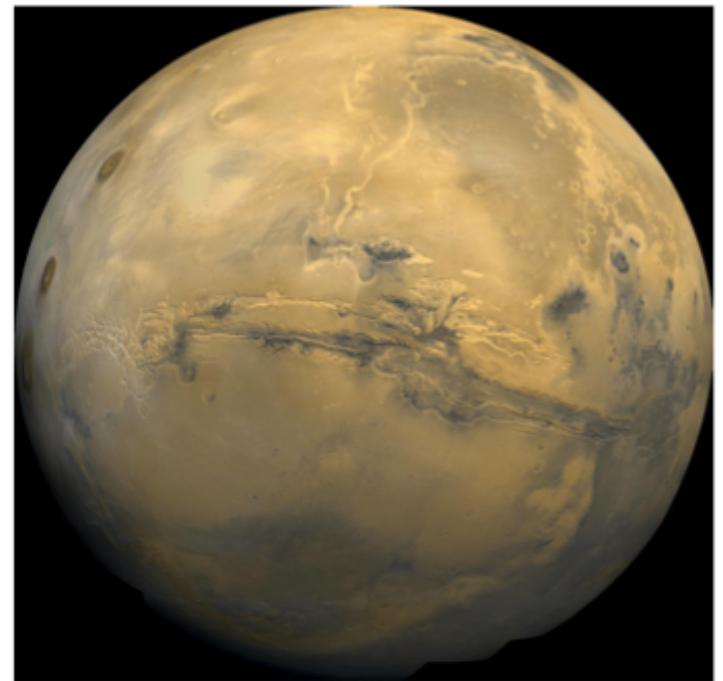
Mars



- Looks almost Earth-like, but don't go without a spacesuit!
- Giant volcanoes, a huge canyon, polar caps, more...
- Water flowed in the distant past; could there have been life?

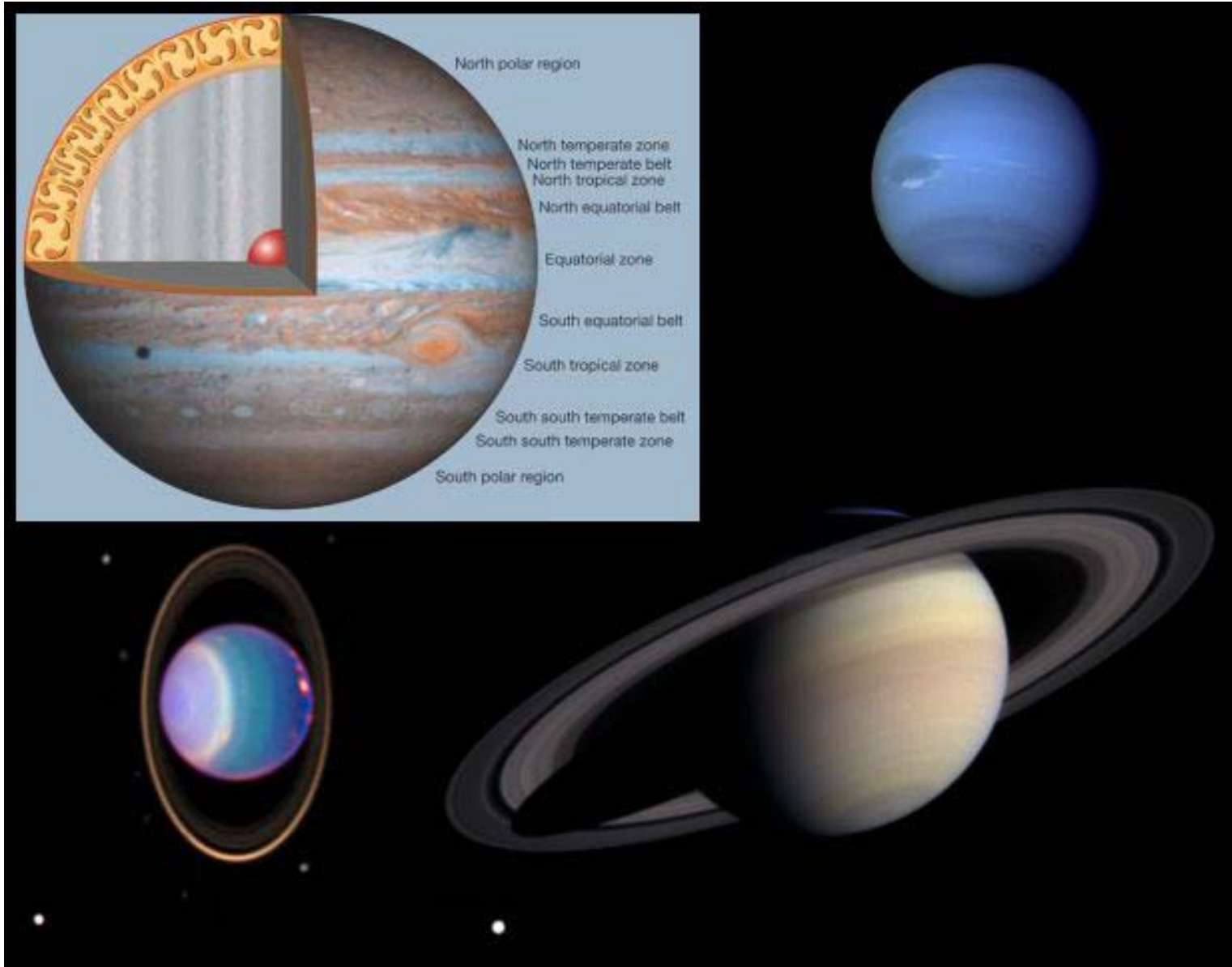
Mars:

- **Mass** = 6.4×10^{23} kg ($= 0.11 \times M_{\text{Earth}}$)
- **Radius** = 3396 km ($= 0.53 \times R_{\text{Earth}}$)
- **Distance from Sun:** 1.52 AU
- **Orbital Period:** 1.88 yr (687 days)
- **Rotation Period:** 24.6 hours
- **Obliquity:** 25.2°
- **Atmospheric Composition:** CO_2
- **Surface Pressure:** 0.007 atm
- **Surface Temperature:** 223 K
- **Magnetic Field:** Yes, but small
- **Satellites:** 2
- **Volcanoes:** Yes, in “recent” past
- **Plate Tectonics:** Maybe in past
- **Water:** currently frozen
- **Life:** Unlikely now, but maybe in past



Giant Planet Atmospheres

Jupiter, Saturn, Neptune, Uranus

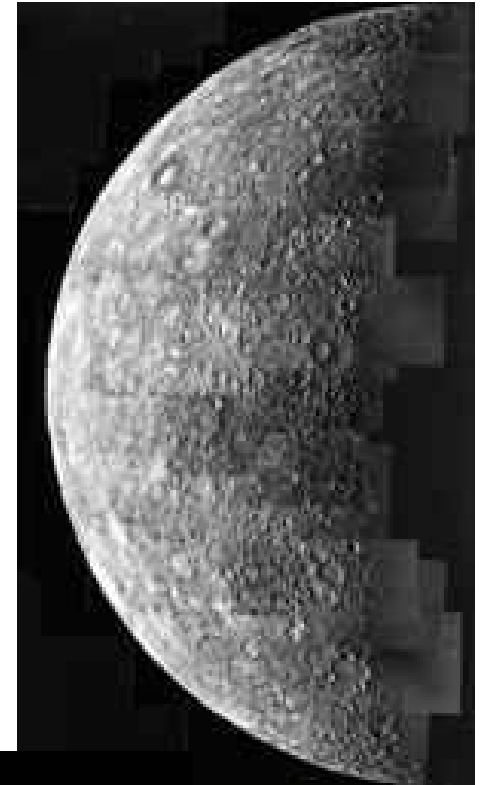


Almost No Atmospheres

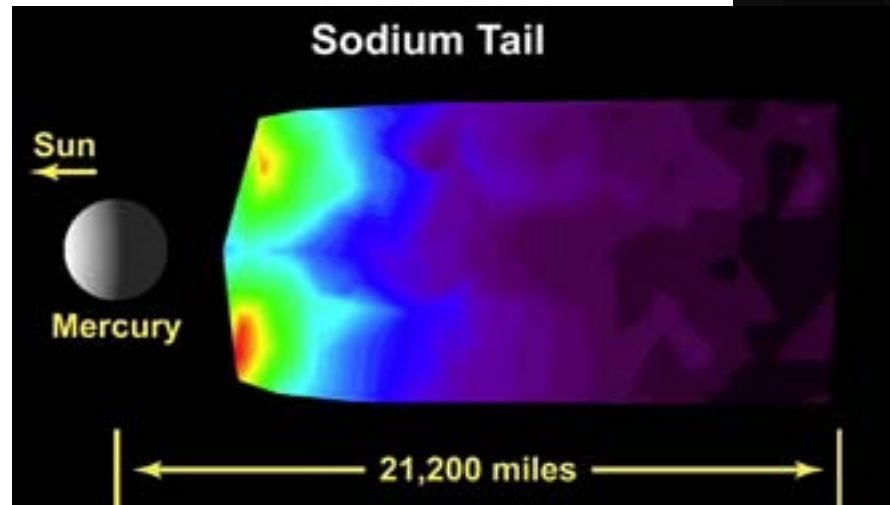
Moon, Mercury

1974 Mariner 10 image

Best ground-based image

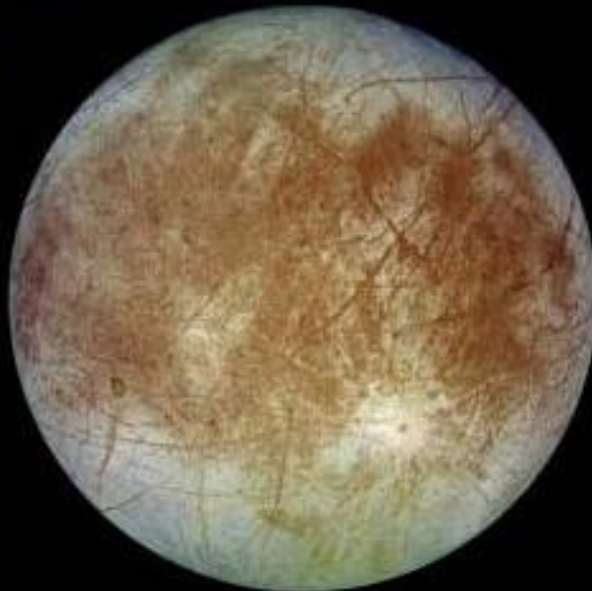
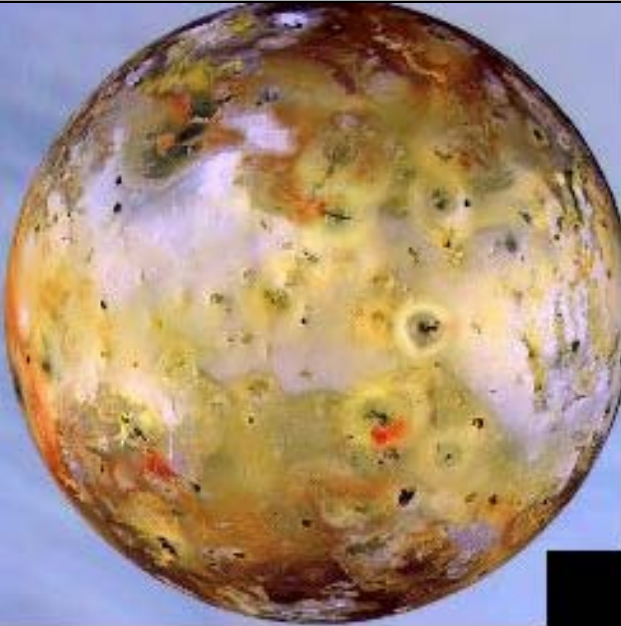


MESSENGER 2008

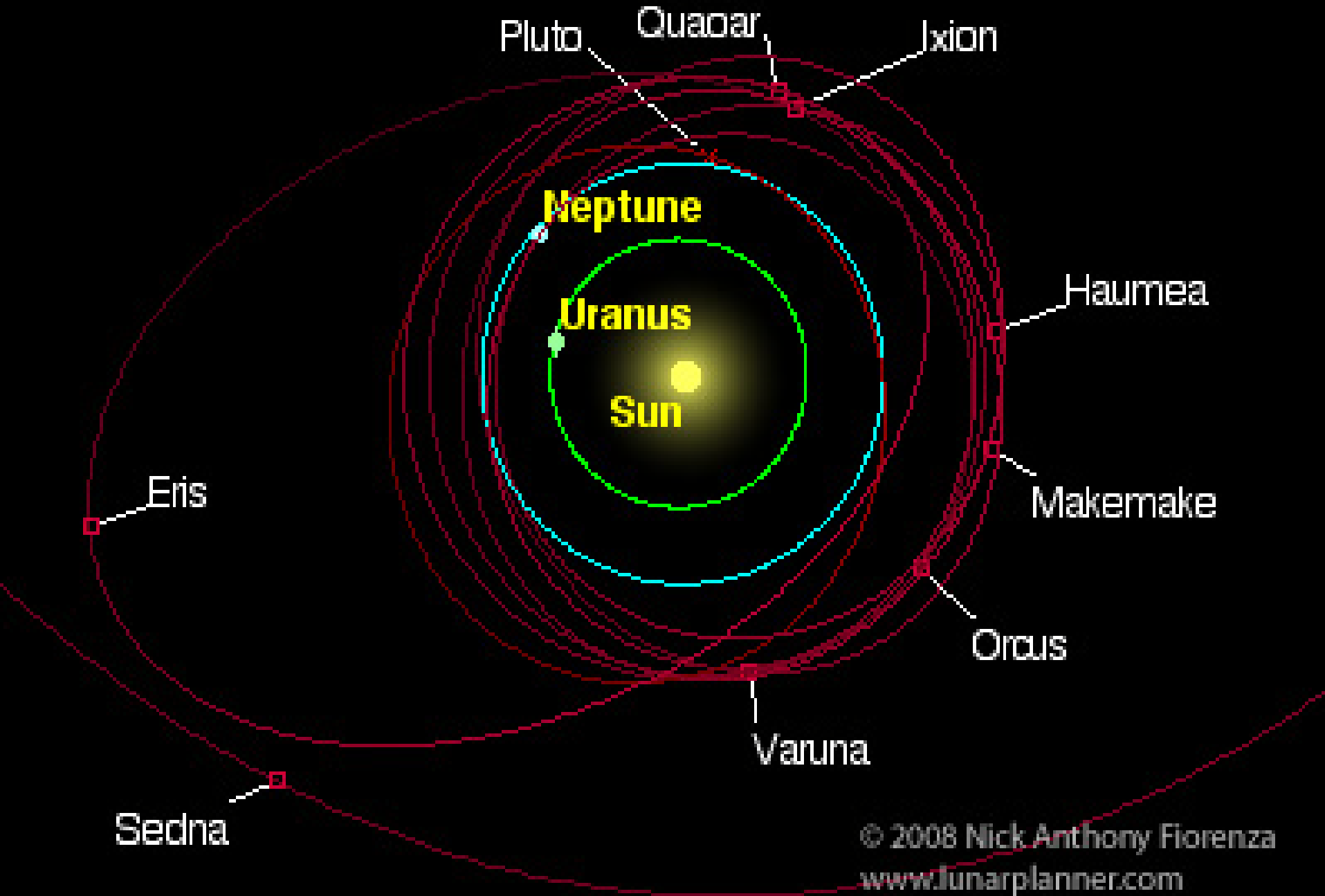


Tenuous Atmospheres

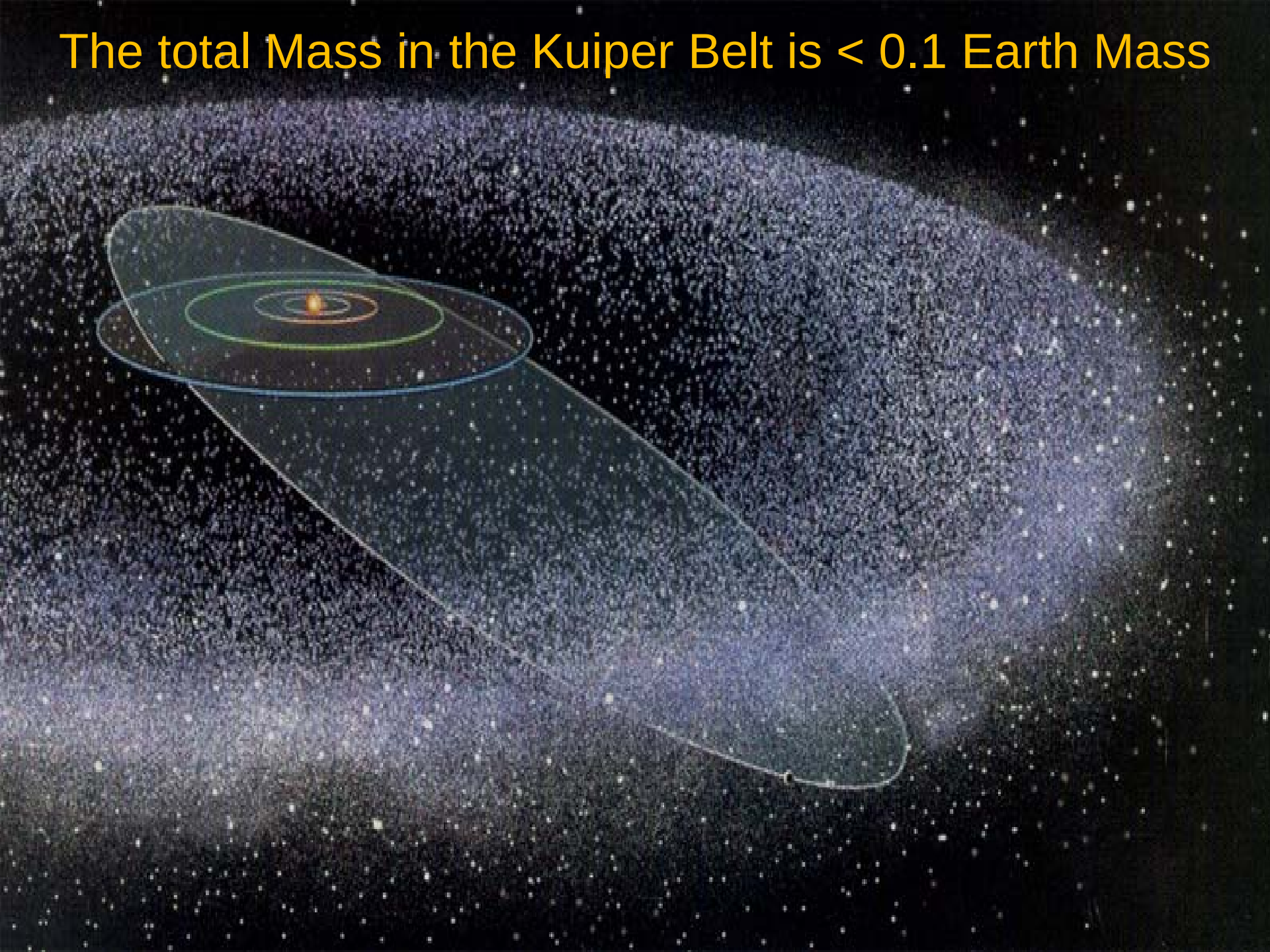
Io, Triton, Europa, Pluto, Ganymede, Callisto, Enceladus



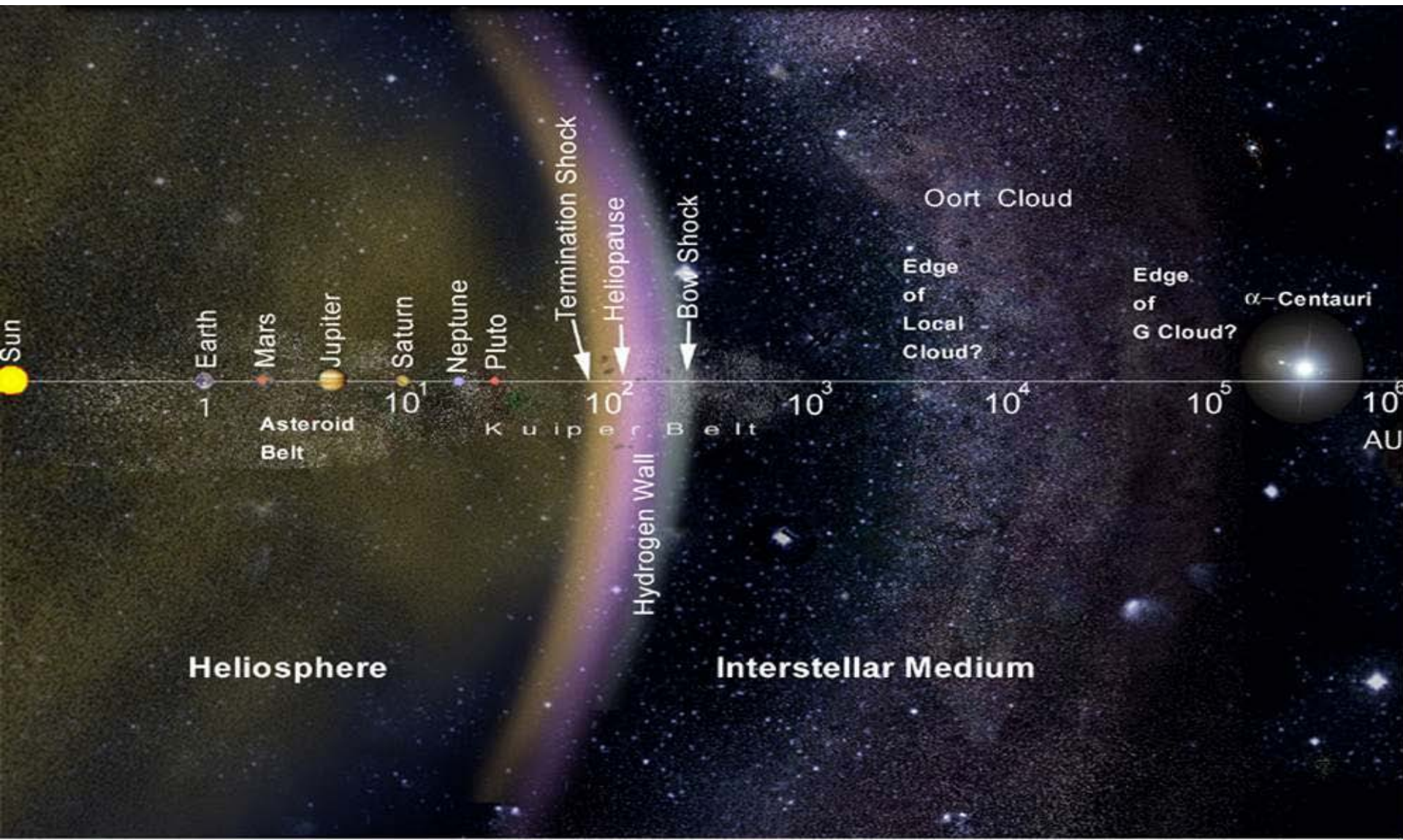
KBOs: the Dwarf Planets



The total Mass in the Kuiper Belt is < 0.1 Earth Mass



But the solar system does not end there...





This diagram shows the Oort Cloud as a large, spherical cloud of small white dots representing comets. A blue line points from the text box to the cloud. The cloud is centered on the Sun, which is at the center of the entire image.

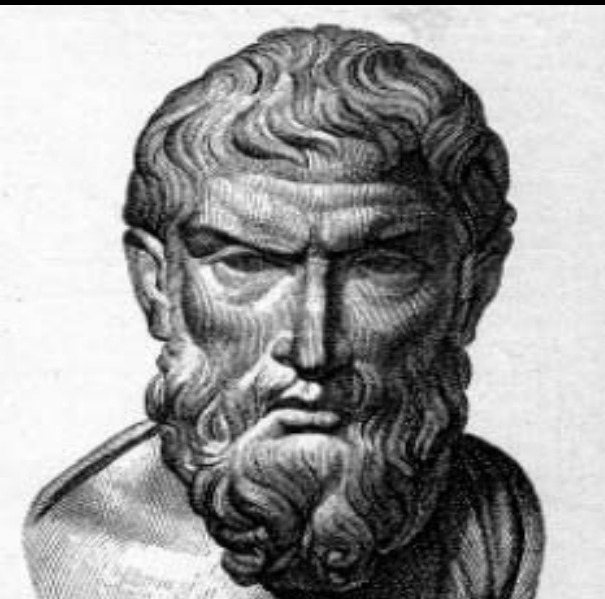
The Oort Cloud
(comprising many
billions of comets)

Photo	Planet	Relative Size	Average Distance from Sun (AU)	Average Equatorial Radius (km)	Mass (Earth = 1)	Average Density (g/cm ³)	Orbital Period	Rotation Period	Axis Tilt	Average Surface (or Cloud Tops) Temperature	Composition	Known Moons (2004)	Rings?
	Mercury		0.387	2,440	0.055	5.43	87.9 days	58.6 days	0.0°	700 K (day) 100 K (night)	Rocks, metals	0	No
	Venus		0.723	6,051	0.82	5.24	225 days	243 days	177.3°	740 K	Rocks, metals	0	No
	Earth		1.00	6,378	1.00	5.52	1.00 year	23.93 hours	23.5°	290 K	Rocks, metals	1	No
	Mars		1.52	3,397	0.11	3.93	1.88 years	24.6 hours	25.2°	240 K	Rocks, metals	2	No
	Jupiter		5.20	71,492	318	1.33	11.9 years	9.93 hours	3.1°	125 K	H, He, hydrogen compounds ^{\$}	63	Yes
	Saturn		9.54	60,268	95.2	0.70	29.4 years	10.6 hours	26.7°	95 K	H, He, hydrogen compounds ^{\$}	31	Yes
	Uranus		19.2	25,559	14.5	1.32	83.8 years	17.2 hours	97.9°	60 K	H, He, hydrogen compounds ^{\$}	24	Yes
	Neptune		30.1	24,764	17.1	1.64	165 years	16.1 hours	29.6°	60 K	H, He, hydrogen compounds ^{\$}	13	Yes
	Pluto		39.5	1,160	0.0022	2.0	248 years	6.39 days	112.5°	40 K	Ices, rock	1	No

II. Discoveries of Planets

There are infinite worlds both like and unlike this world of ours. We must believe that in all worlds there are living creatures and planets and other things we see in this world.

Epicurius, c.300 B.C.



There are countless suns and countless earths all rotating around their suns in exactly the same way as the seven planets of our system... The countless worlds in the universe are no worse and no less inhabited than our Earth.

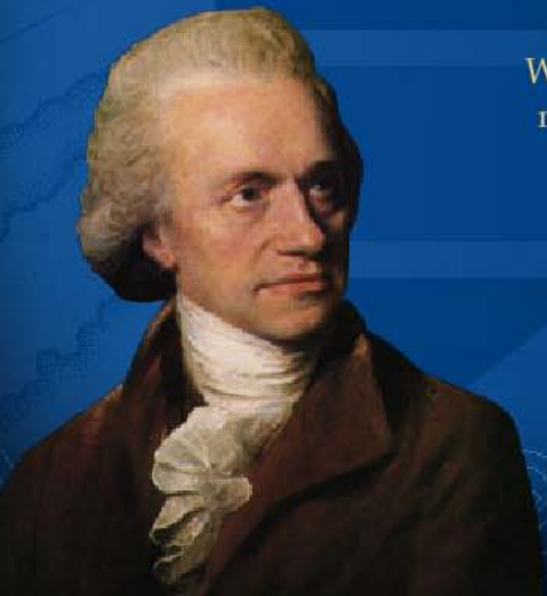
- Giordano Bruno, 1584

I have looked further into space than any human being did before me.

- William Herschel

1781

William Herschel discovers Uranus, the first new planet discovered since ancient times.



1781

There is, then, some positive evidence in favour of the existence of a planetary body in connexion with this system.

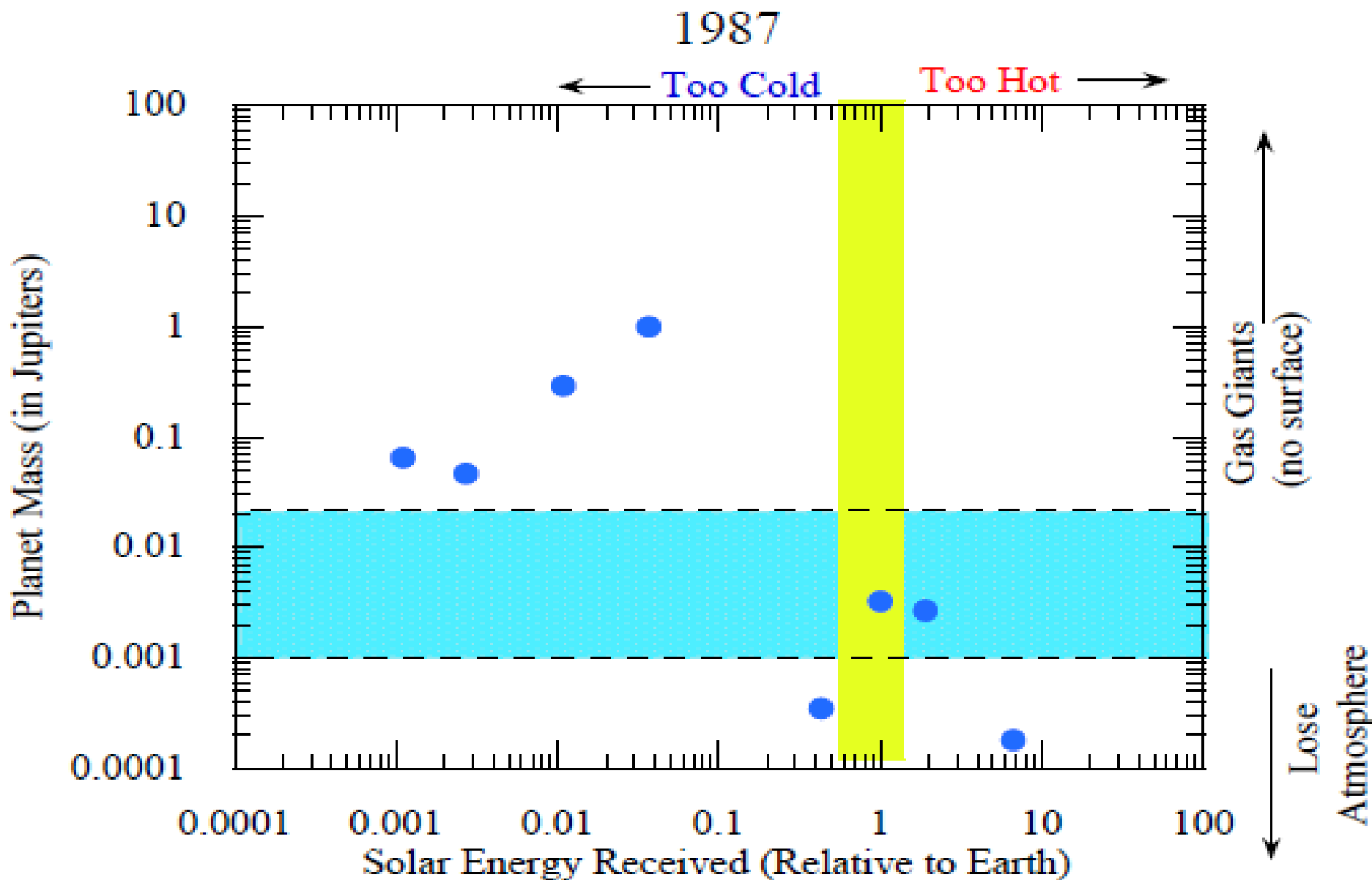
- Capt. W. S. Jacob, 1855

1855

Capt. W. S. Jacob of the East India Observatory in Madras, India, finds orbital anomalies in the binary star 70 Ophiuchi that he claims are evidence of an extrasolar planet - the first exoplanet false alarm. The "discovery" begins a 140-year period of other exoplanet discovery false alarms, but no actual planets are discovered.



So here are the planets we grew up with ...



The dream for other planets continues.. On mass media!

The mission of this vessel is to seek out and contact alien life.

- Captain James T. Kirk

1966

Debut of television series "Star Trek." The show introduces exoplanets and alien life into pop culture, with numerous spin-offs, movies, and merchandise. Show creator Gene Roddenberry will later endorse 40 Eridani A - which may have an Earth-like planet - as the home solar system for Mr. Spock.



1966

The turning point

Many questions remain unanswered. How did a Jupiter-like planet form so close to its host star?

- Geoff Marcy and Paul Butler, 1995

1995

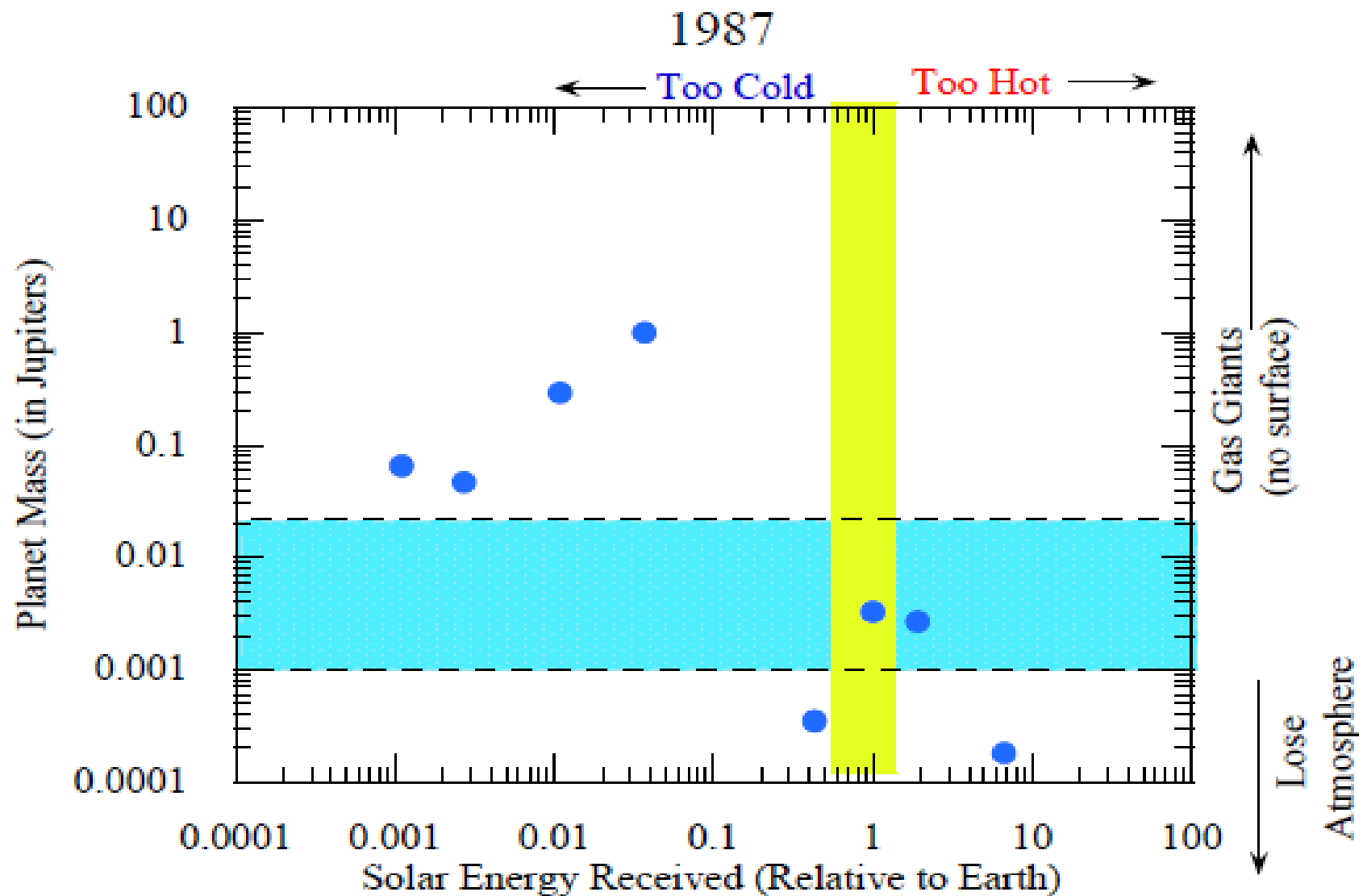
Michel Mayor and Didier Queloz find the first planet orbiting a main-sequence star, 51 Pegasi, a discovery that is confirmed a week later. The planet, which is half the size of Jupiter, orbits so close to 51 Peg that it practically grazes the surface, a revelation that baffles astronomers.

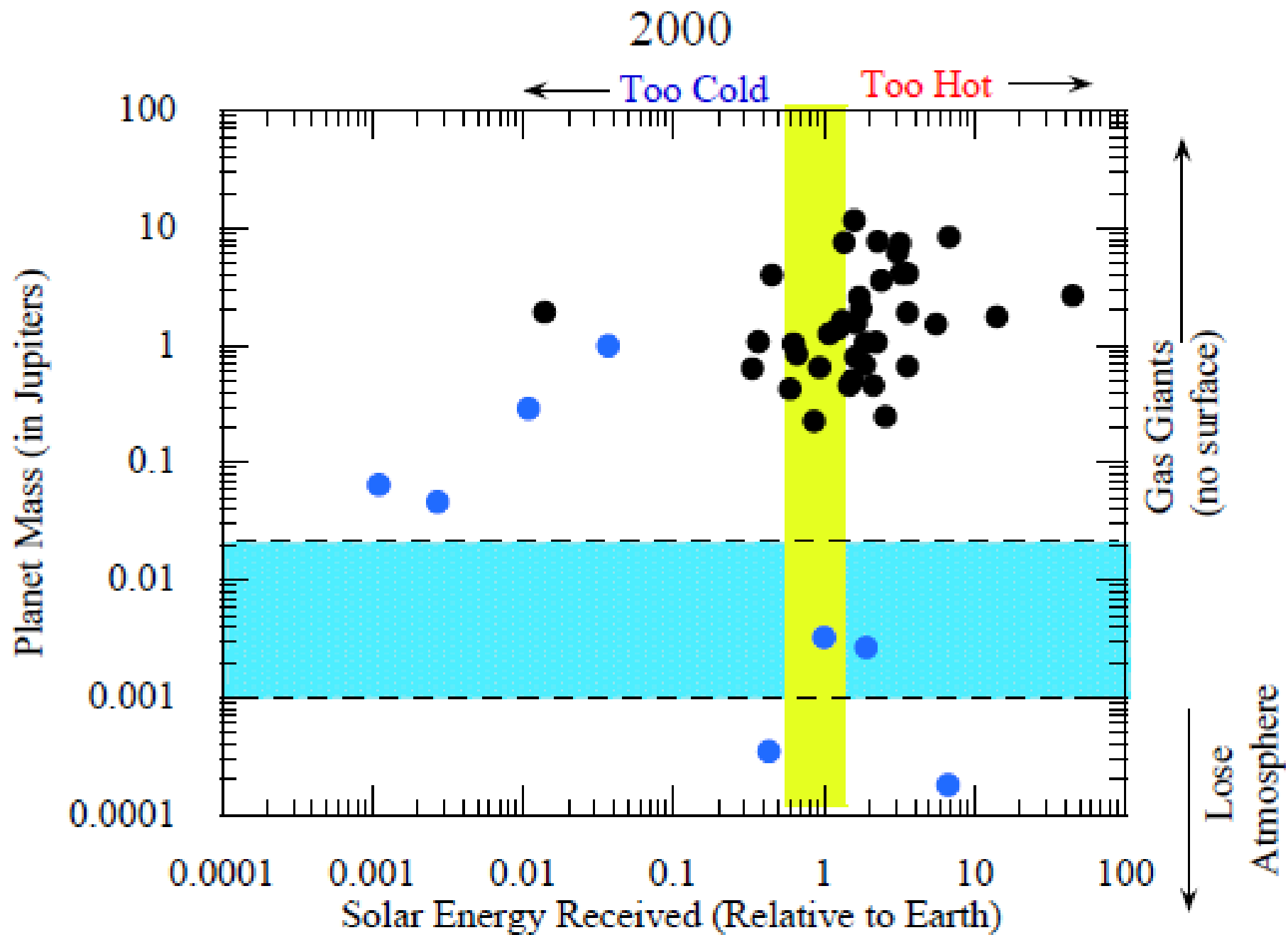


1995

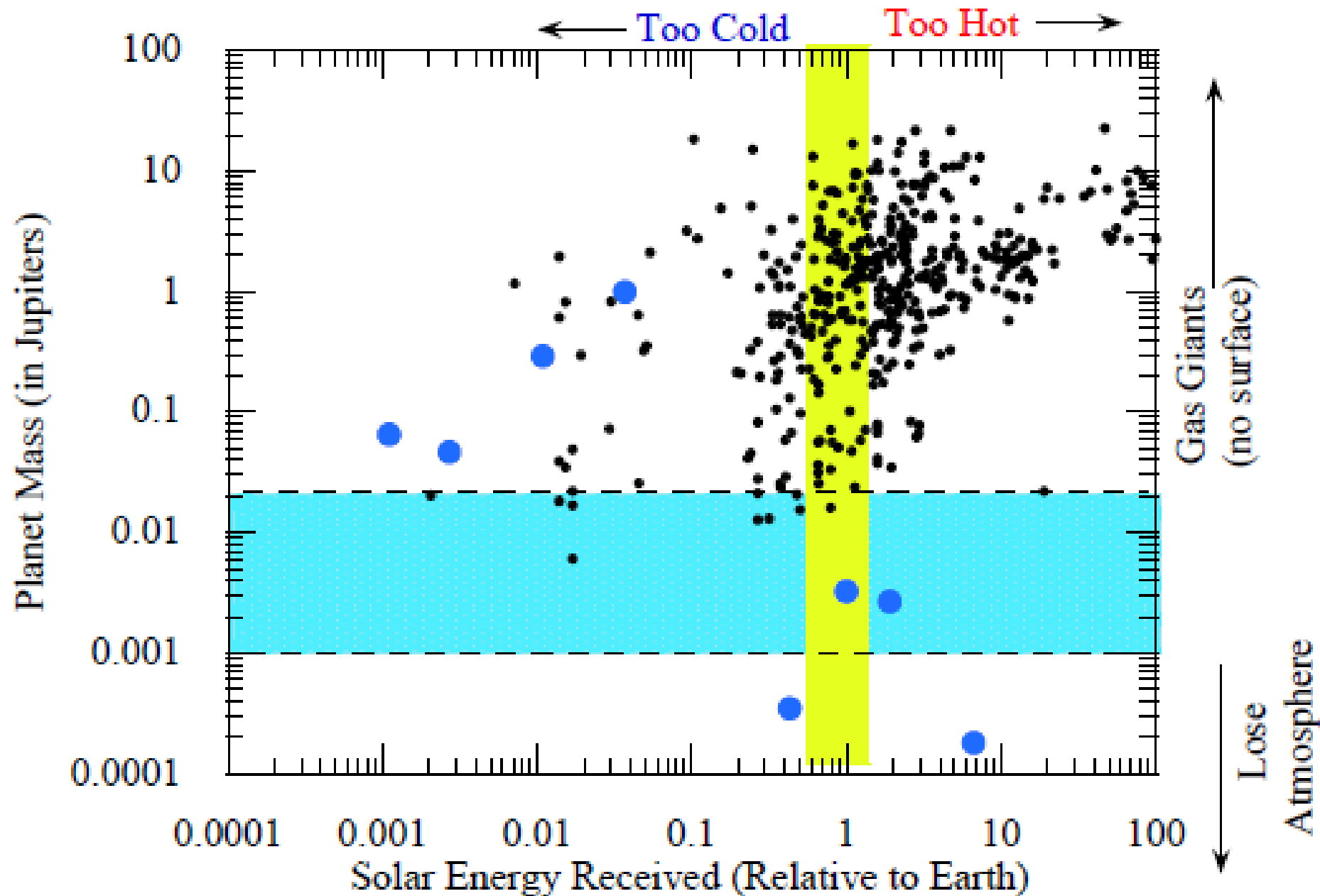


The planets we grew up with



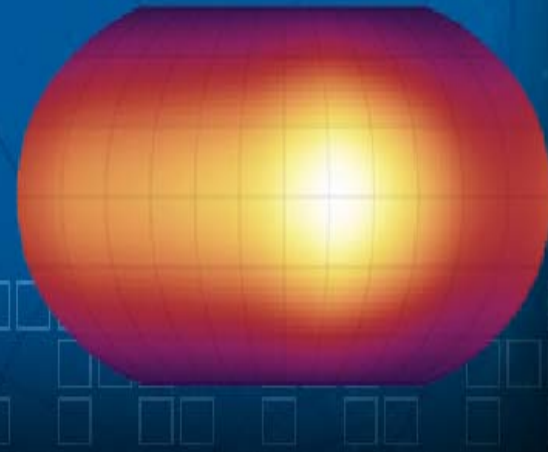


2011 (w/o Kepler)



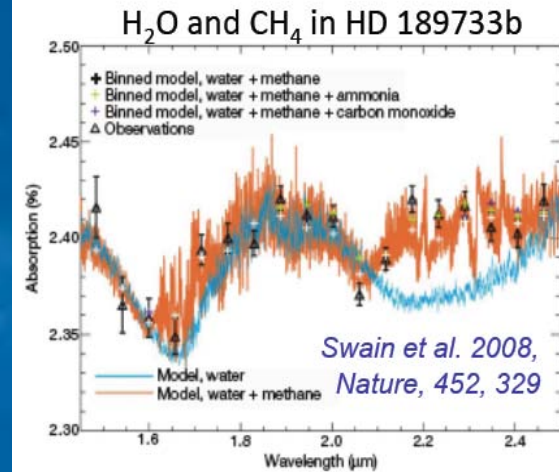
2007

NASA's Spitzer Space Telescope takes the first spectroscopic measurements of an exoplanet's atmosphere. Later, data from Spitzer is used to create the first temperature map of an exoplanet.



2008

Astronomers using the Hubble Space Telescope measure the first sign of an organic molecule on an exoplanet. The discovery is made by analyzing the spectrum from HD 189733 b.



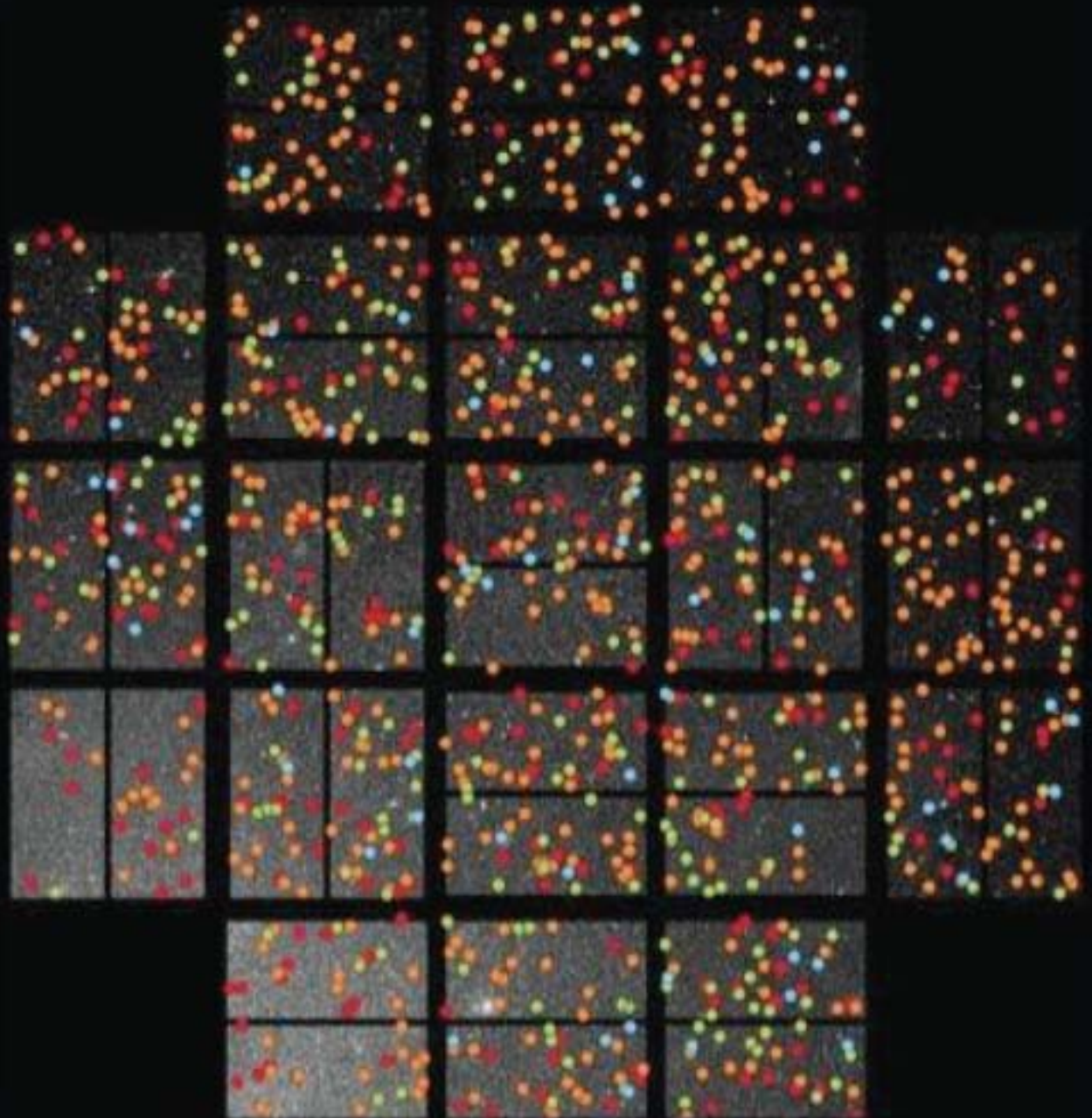
2009

NASA's Kepler mission launches in March. Kepler observes thousands of stars at once, looking for transiting Earth-like planets. The results will tell astronomers how plentiful planets like Earth are in the galaxy.

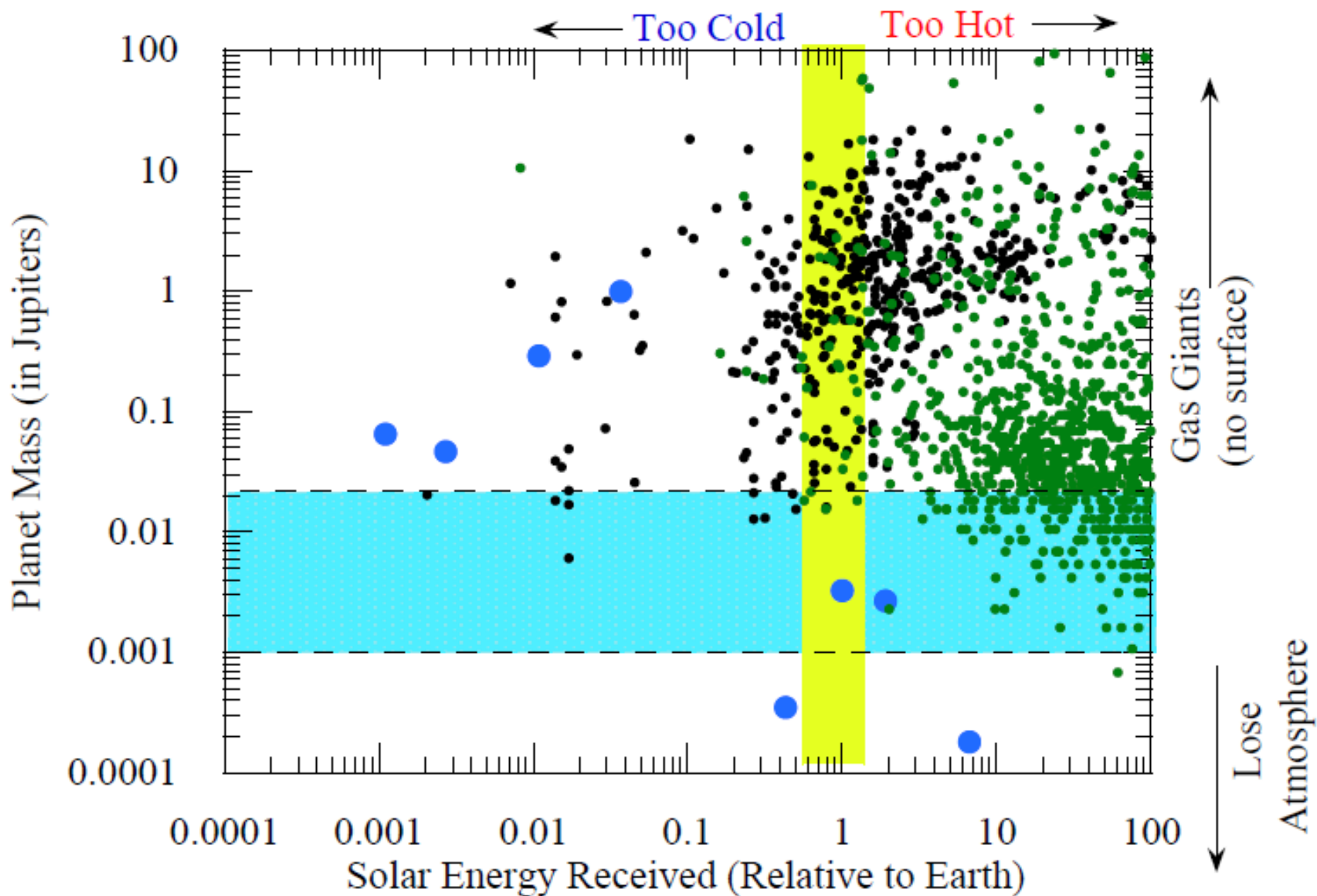


Locations of Kepler Planet Candidates

- Earth-size
- Super-Earth size
1.25 - 2.0 Earth-size
- Neptune-size
2.0 - 6.0 Earth-size
- Giant-planet size
6.0 - 22 Earth-size

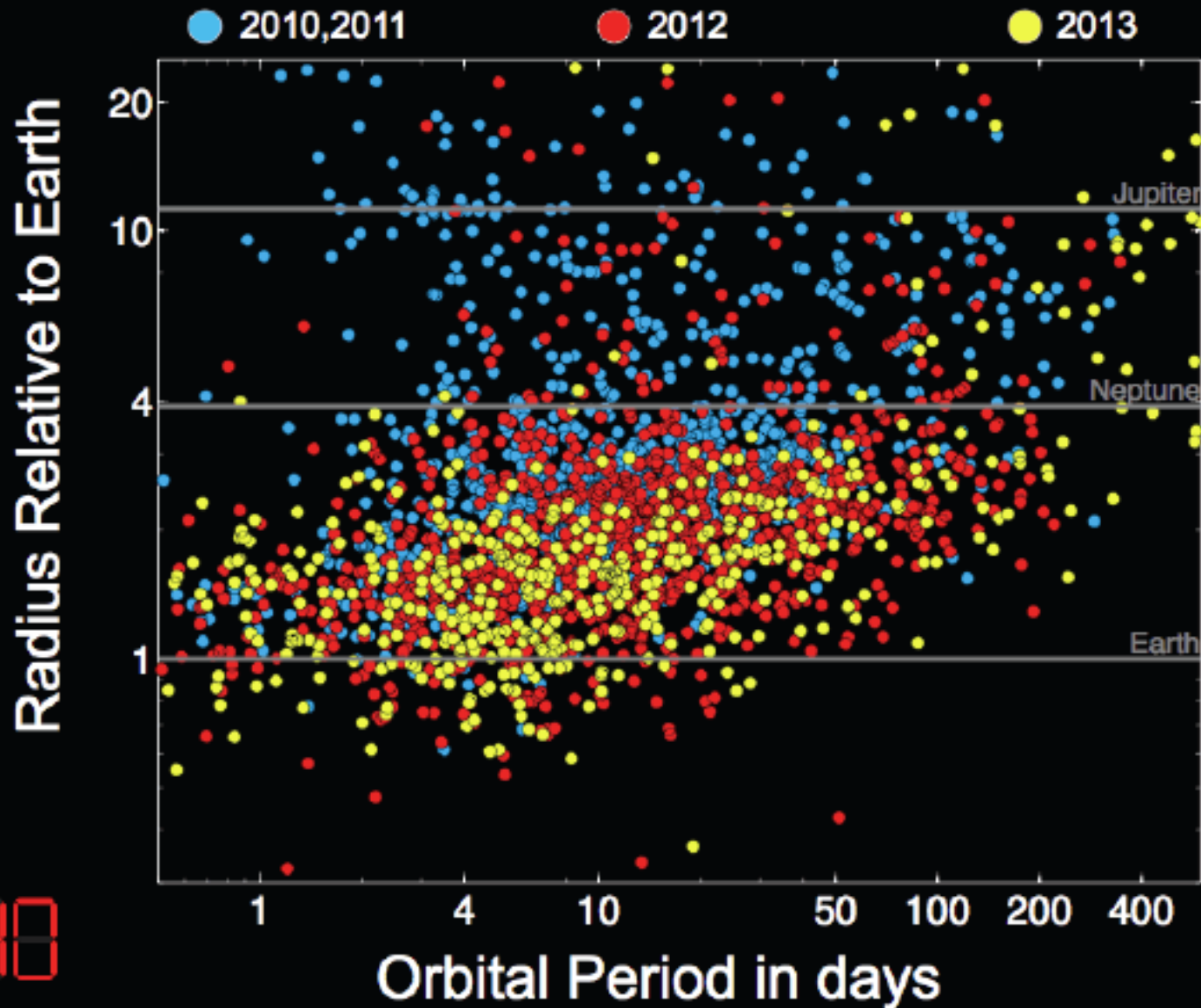


2011 (w/ Kepler Aug 2011 candidates)



Kepler's Planet Candidates

22 Months: May 2009 - Mar 2011



III. Evolution History



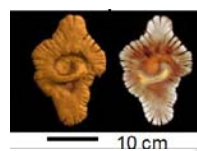
0.1 Ga

0.5 Ga
Diversification
of Life

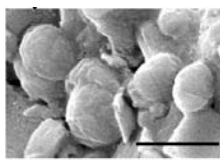


1.5 Ga
Origin of Multi-
Cellular Life?

2.5 Ga
Origin of
Eukaryotes?

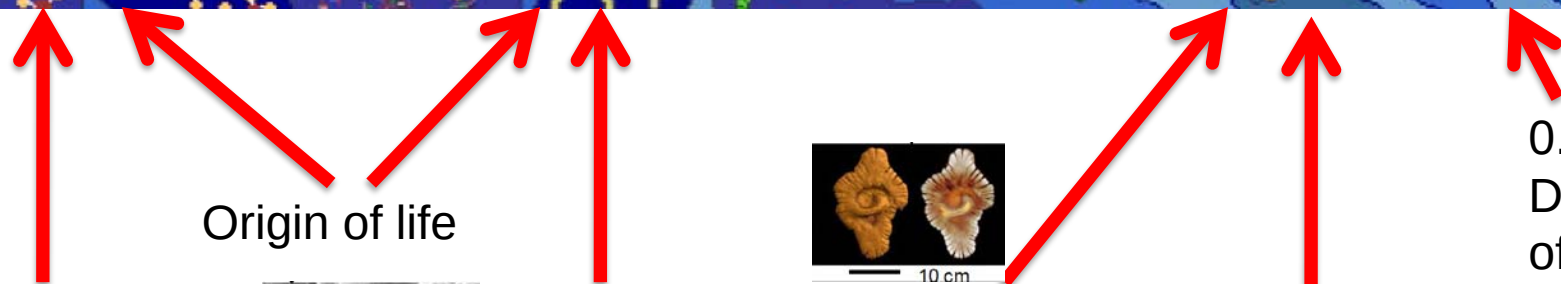


3.5 Ga
Oldest Evidence
of Life

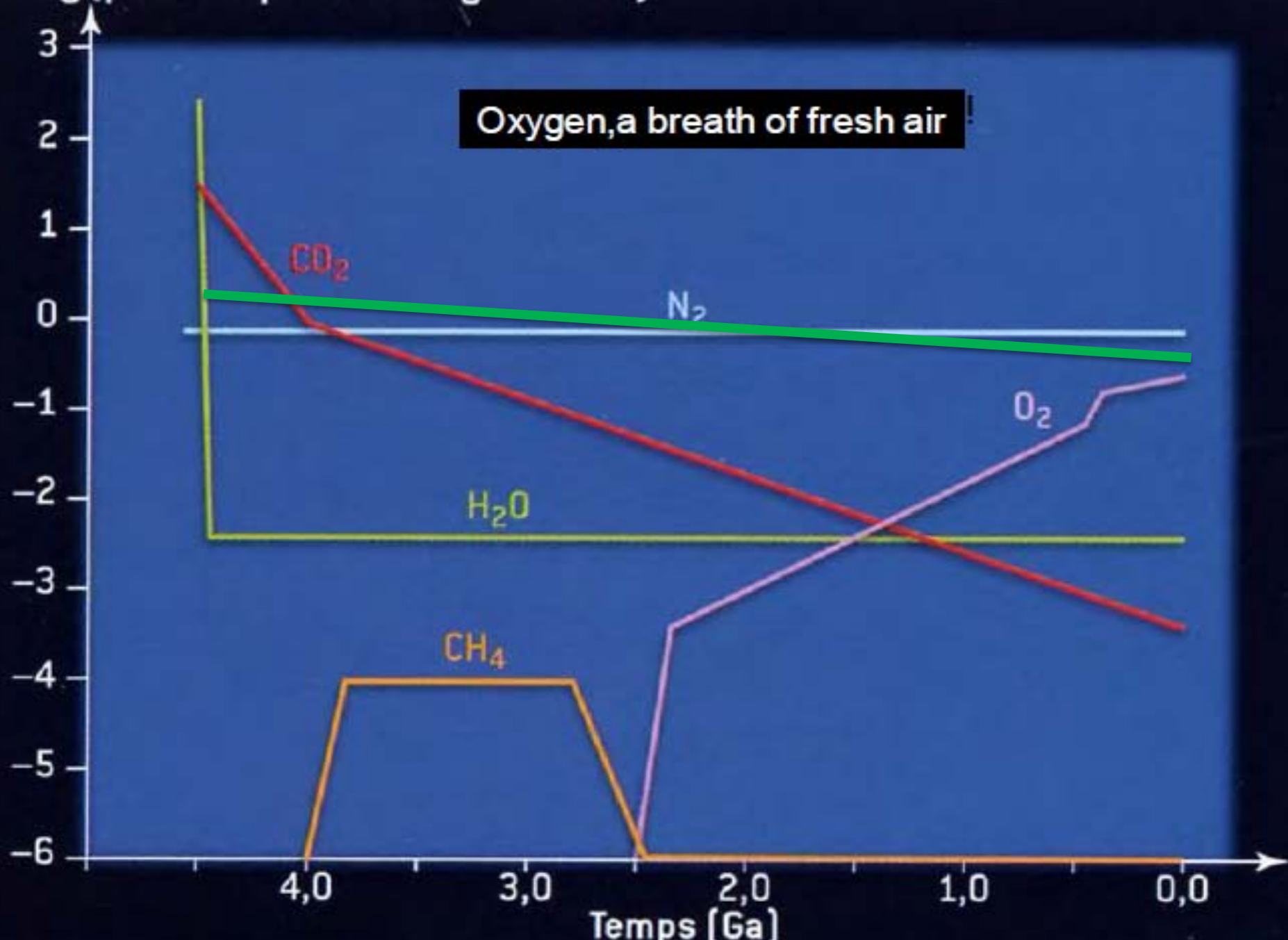


Origin of life

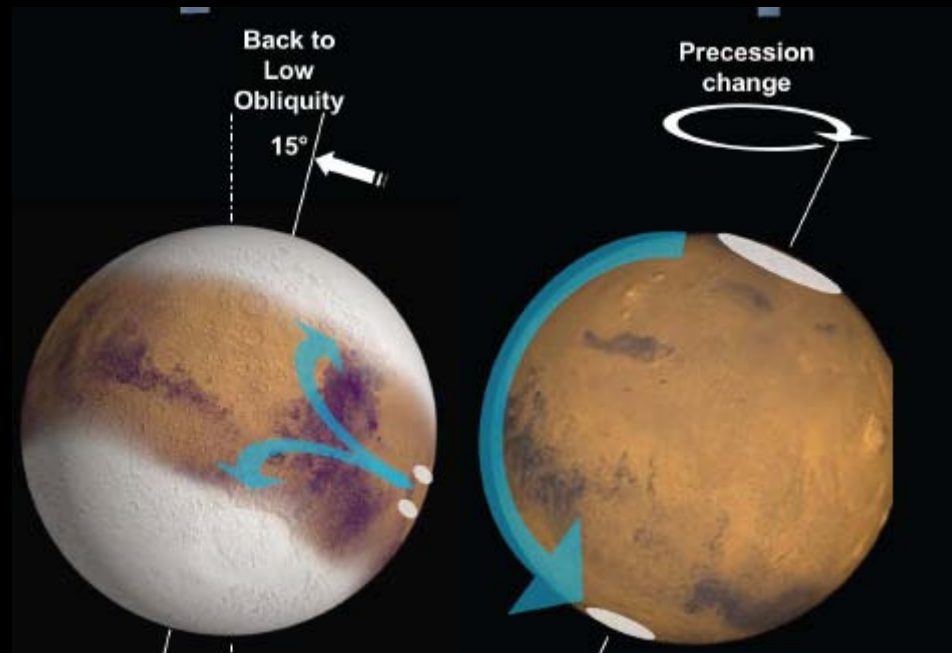
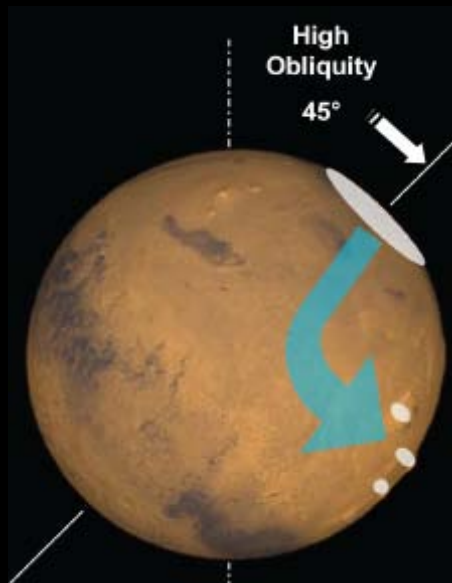
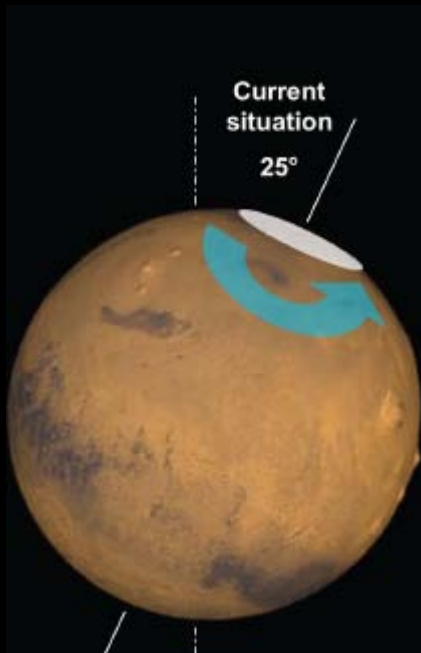
4.5 Ga
Prebiotic
Soup



Log (pression partielle de gaz en bar)

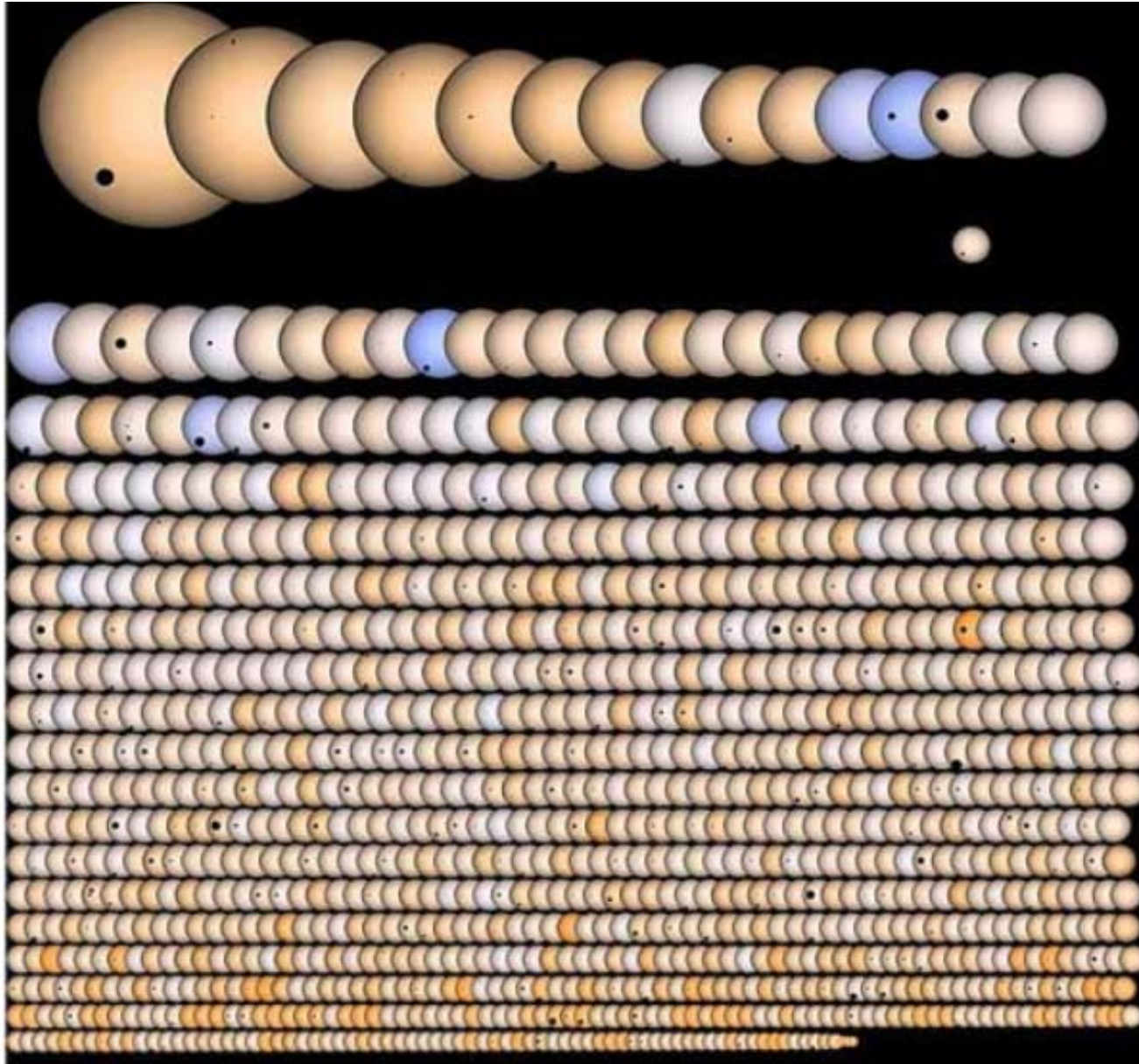


The Climate Change History of Mars



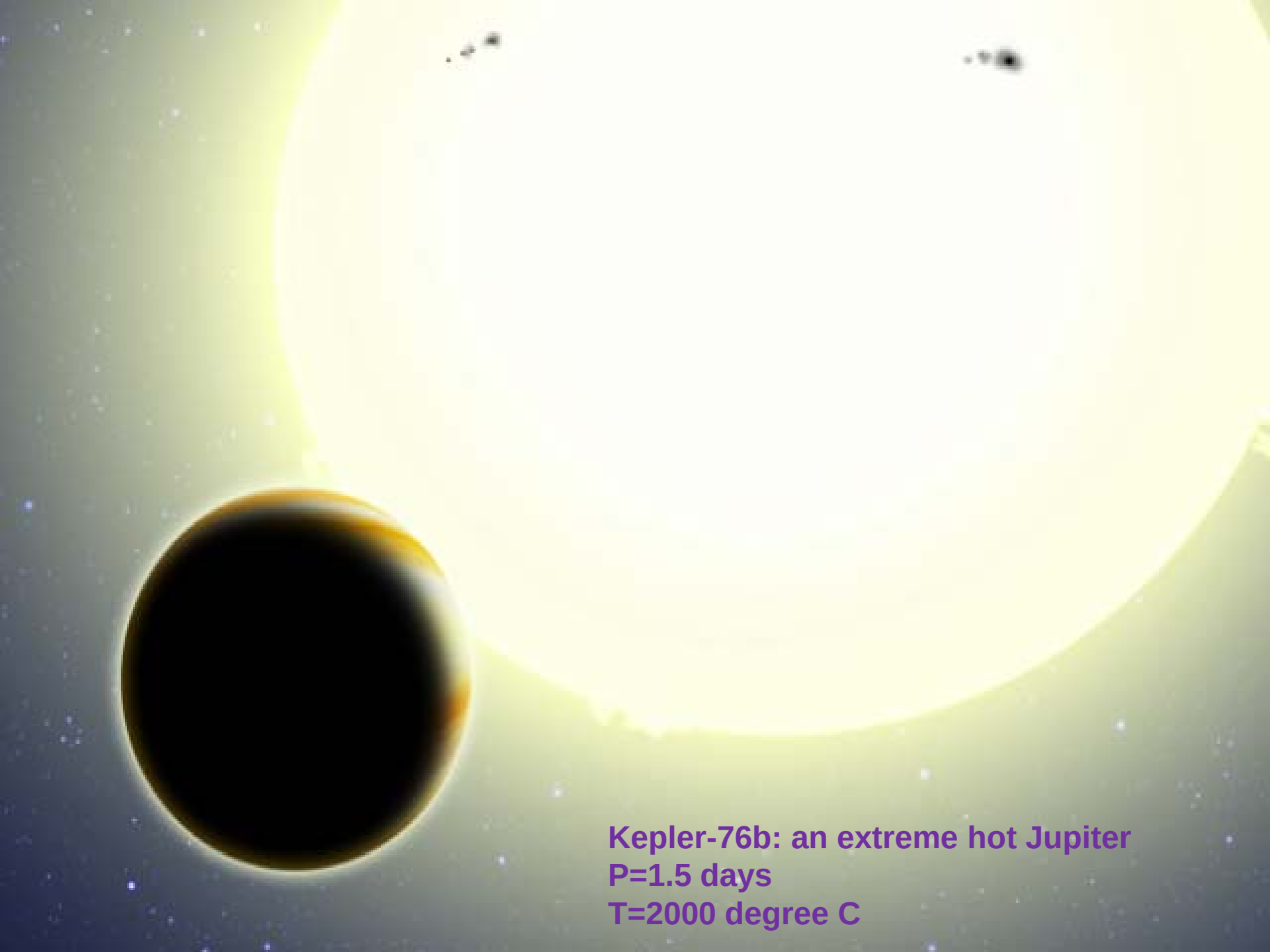
IV. Exoplanets

There are so many more exoplanets....



Kepler found more than 2000 planet candidates.

Here we show just a few extreme examples..



Kepler-76b: an extreme hot Jupiter
P=1.5 days
T=2000 degree C

Glass Raining Hot Jupiter

T= 800 degree C

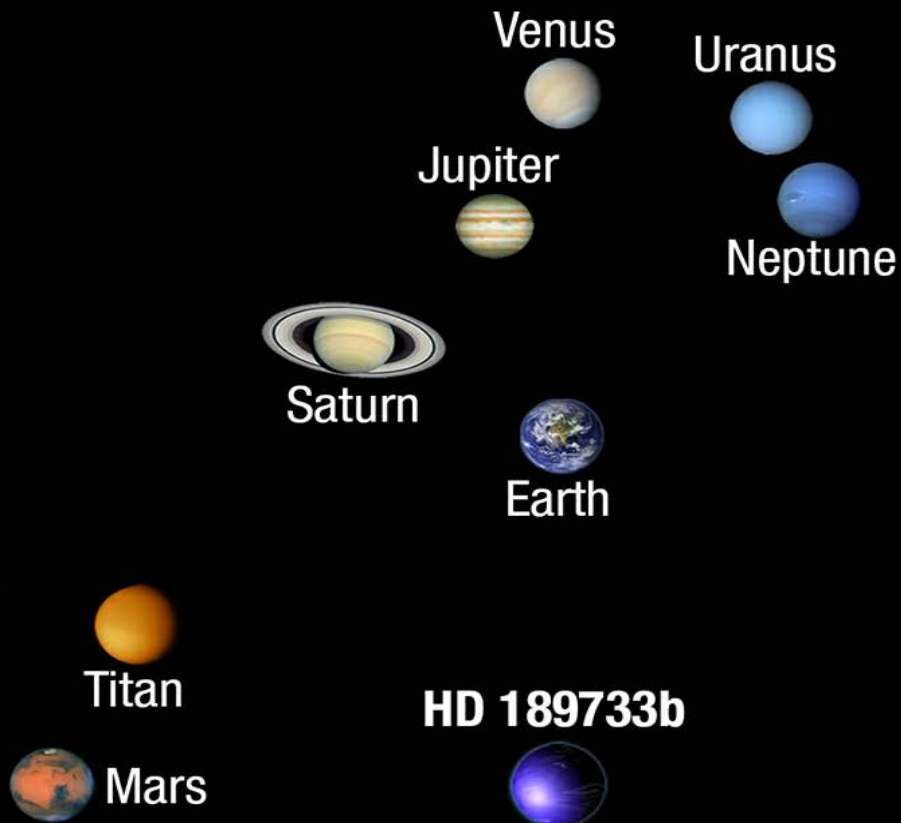


Artist's View of Extrasolar Planet HD 189733b

NASA, ESA, and G. Bacon (STScI) ■ STScI-PRC13-26a

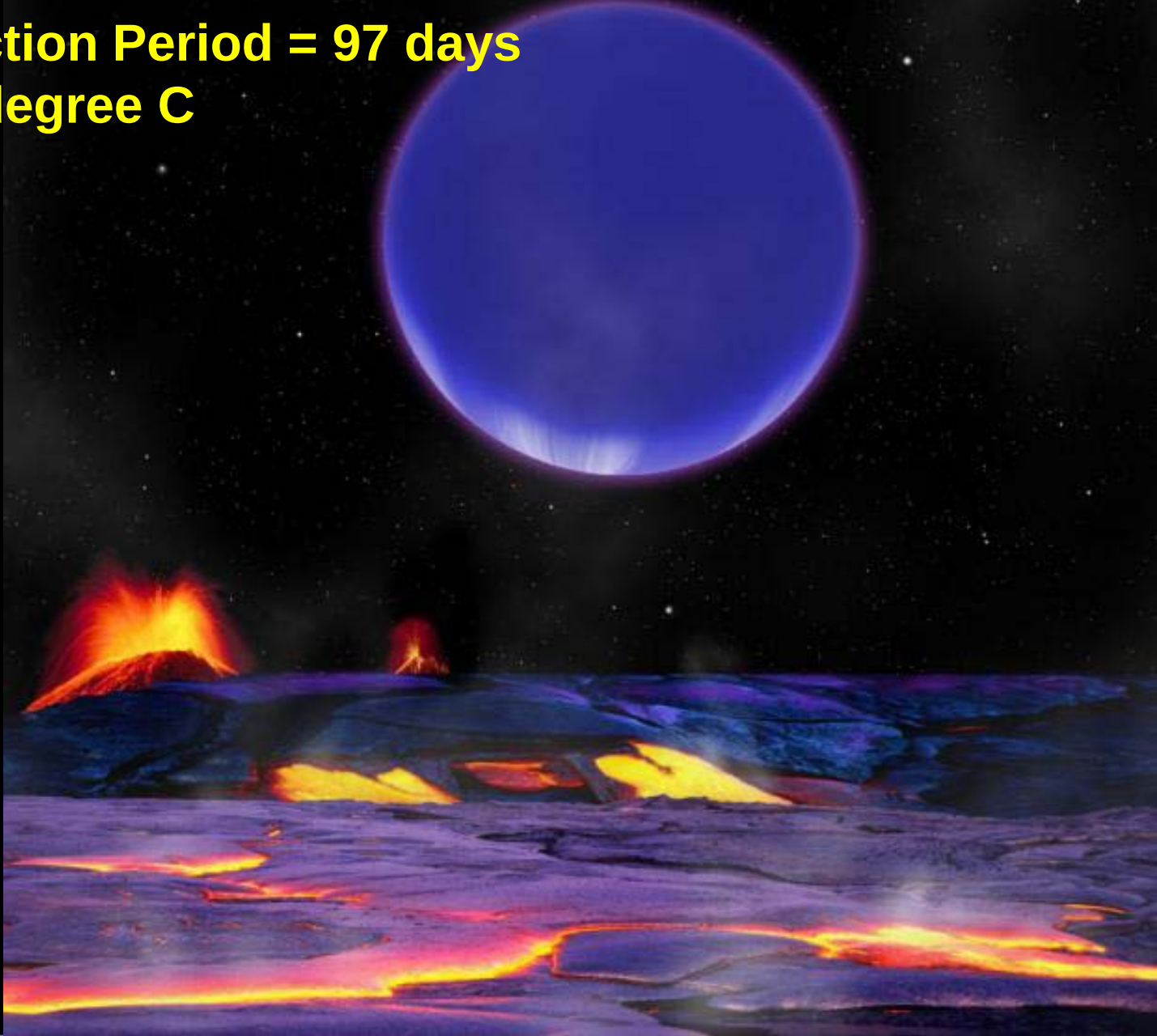
Visible-light Colors of Planets

Reflection of Green Light



Reflection of Blue Light

Kepler 36b: Bad Big Brother Comes Back!
Minimum Distance = 5x Earth-Moon distance
Conjunction Period = 97 days
T= 700 degree C



And many... (2013)

Kepler-62: A Five-Planet System with Planets of 1.4 and 1.6 Earth Radii in the Habitable Zone

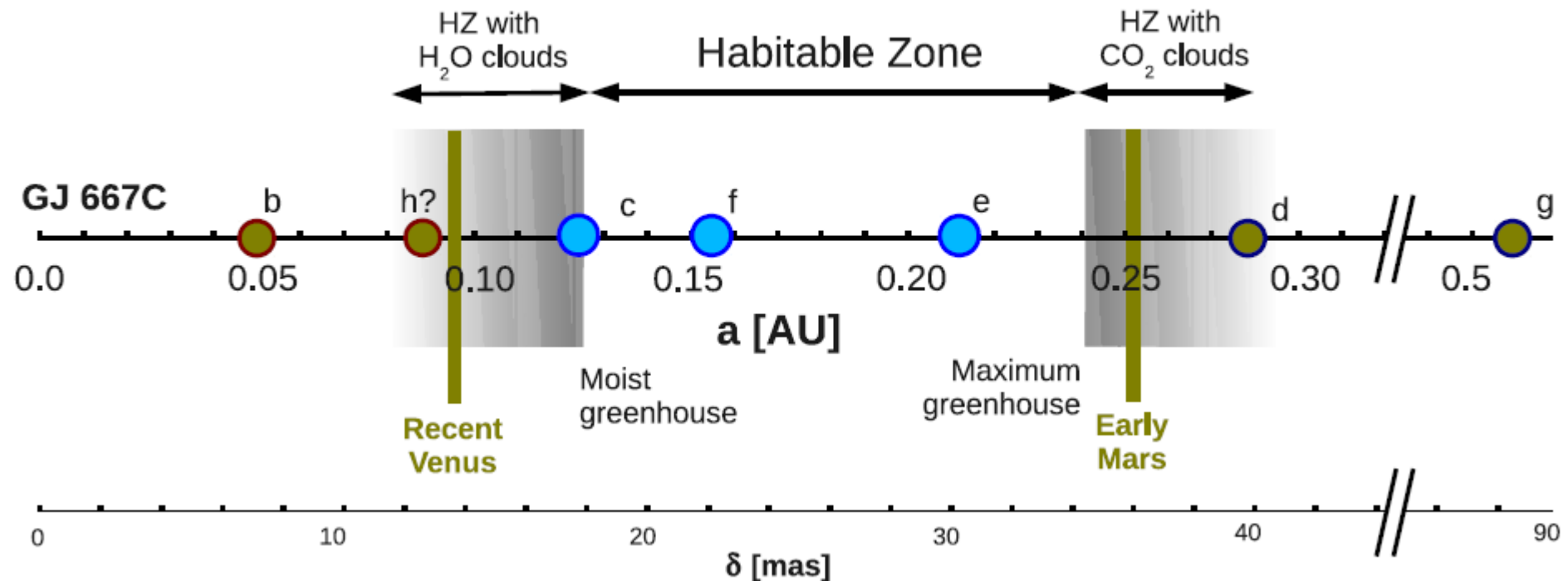
dates KOI-701.01, 701.02, and 701.03 in the Kepler 2011 catalog (7) and the Kepler 2012 catalog (8). KOI-701.04 and 701.05 were subsequently identified using a larger data sample (9).

Analysis of high-resolution spectra indicates that Kepler-62 is a K2V spectral type with an estimated mass and radius (in solar units) of



Or maybe interplanetary trade is not just a fantasy?

Guillem Anglada-Escudé et al.: Three HZ super-Earths in a seven-planet system



Now there are ~10 potentially habitable planets.

Current Potential Habitable Exoplanets



Earth



Mars



Kepler-62 e

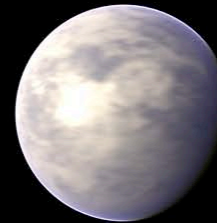


Gliese 581 g*

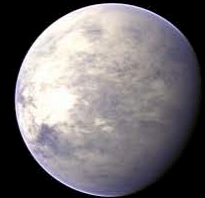


Gliese 667C c

and f, e



Kepler-22 b



Tau Ceti e*



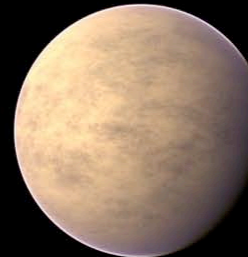
Kepler-61 b



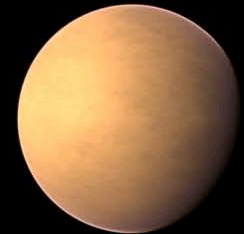
Kepler-62 f



Gliese 163 c

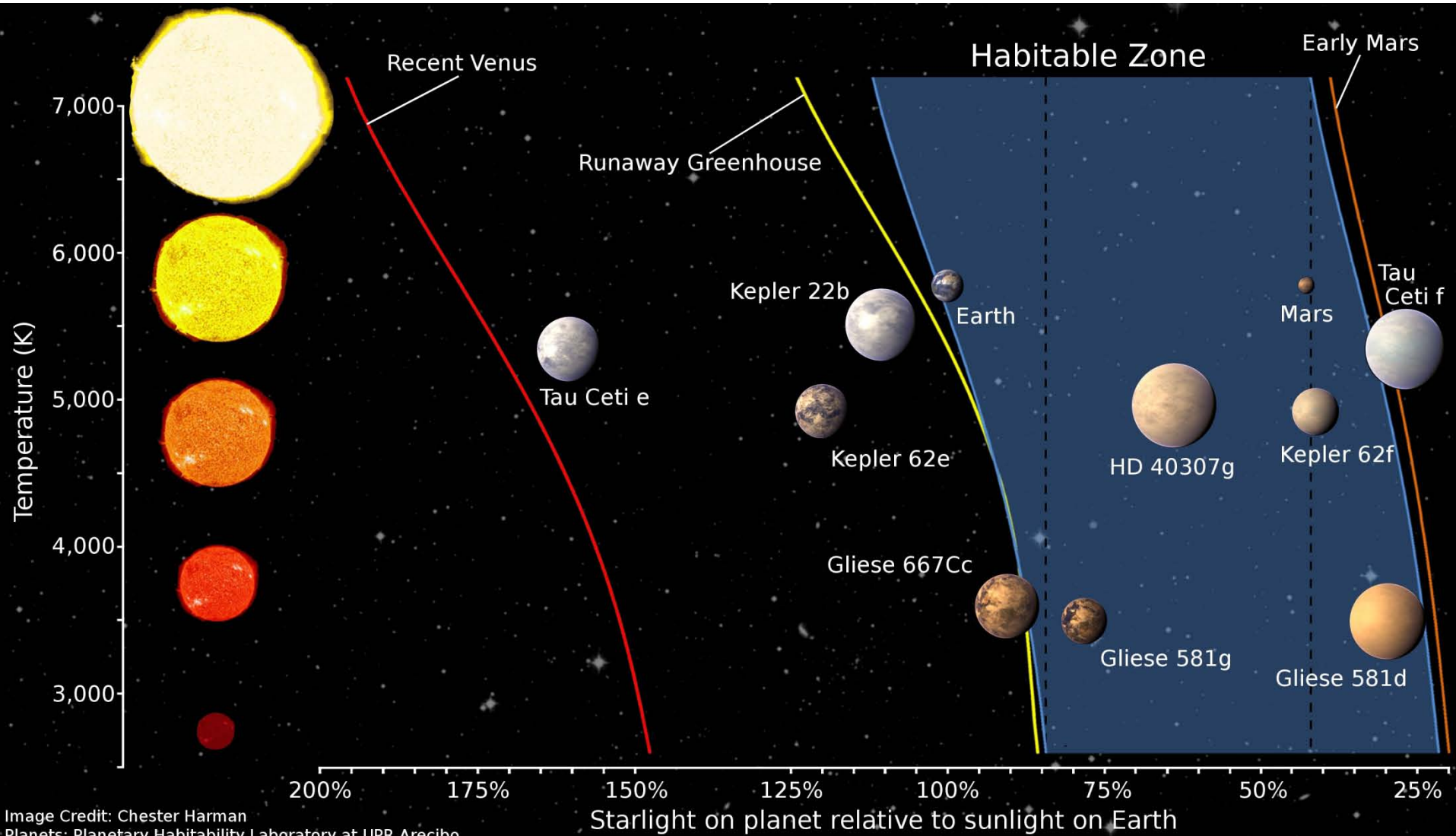


HD 40307 g*



Gliese 581 d

Where are they?

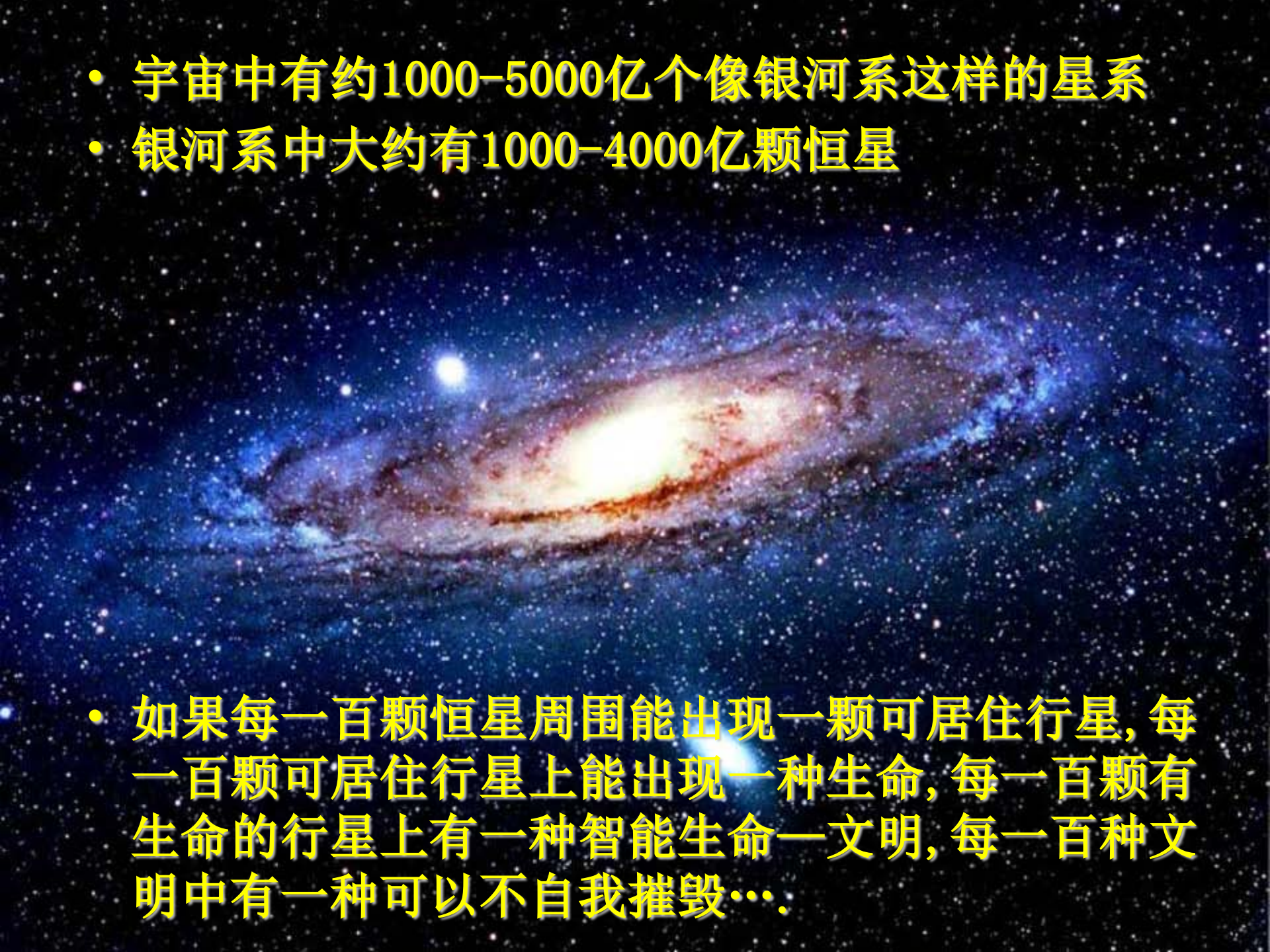




Dim, Small Red Stars



- 宇宙中有约1000-5000亿个像银河系这样的星系
- 银河系中大约有1000-4000亿颗恒星



- 如果每一百颗恒星周围能出现一颗可居住行星, 每一百颗可居住行星上能出现一种生命, 每一百颗有生命的行星上有一种智能生命—文明, 每一百种文明中有一种可以不自我摧毁….



There could be hundreds to thousands of civilizations out there....

Go Explore!

But please also remember to take good care of our own home planet 😊

