Exoplanetas

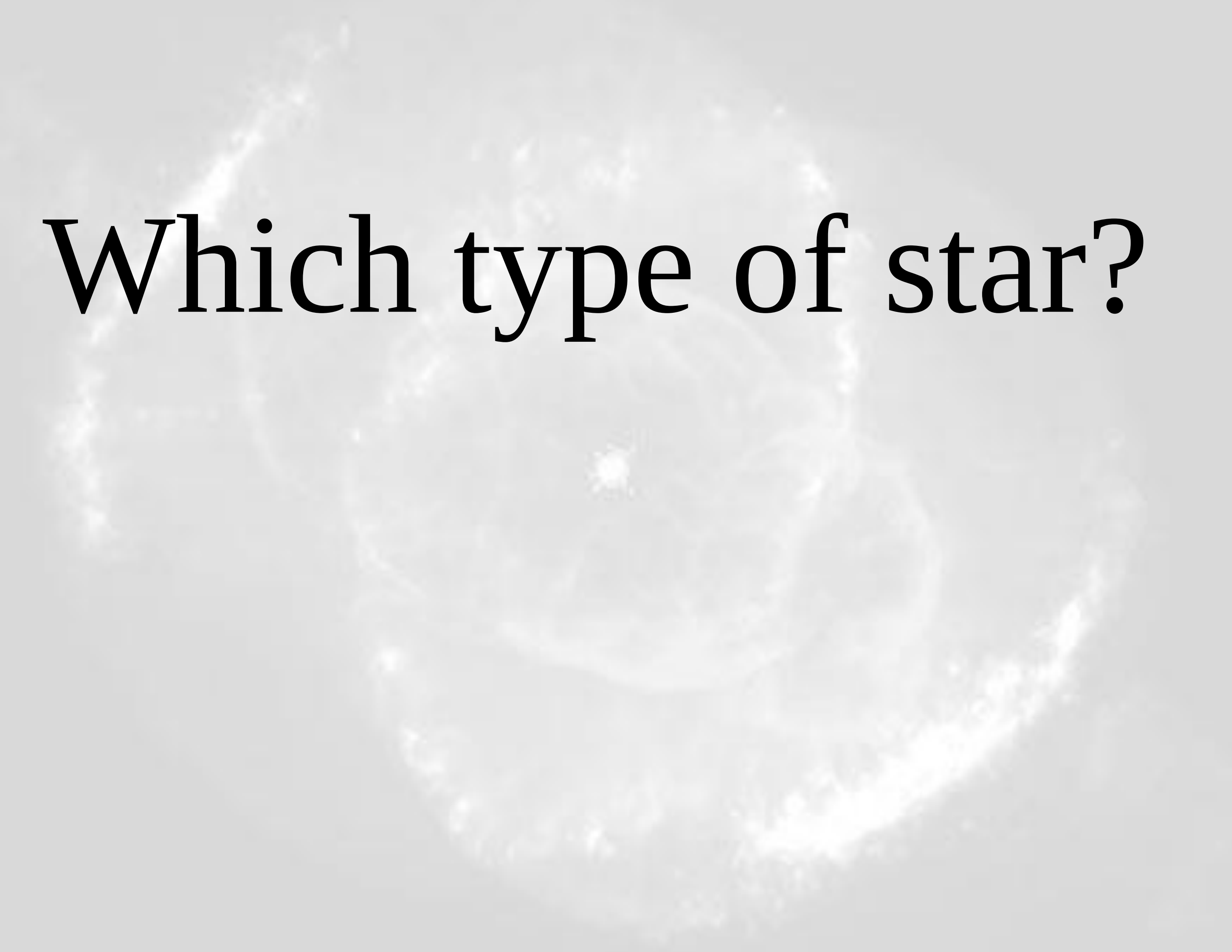
Extrasolar planets

- Extrasolar planets=Exoplanets= planets around stars other then the Sun
- Planets are the environments for the origin and evolution of life.
- Giordano Bruno: “There are countless suns and earths all rotating around their suns in exactly the same way as the seven planets of our system..” (1584)
- First exoplanets (around a pulsar)
  - PSR1257 + 12 B, C (Wolszczan & Frail 1992)
- First confirmed planet around MS star
  - 51 Pegasi on October 1995 (Mayor & Queloz 1995)

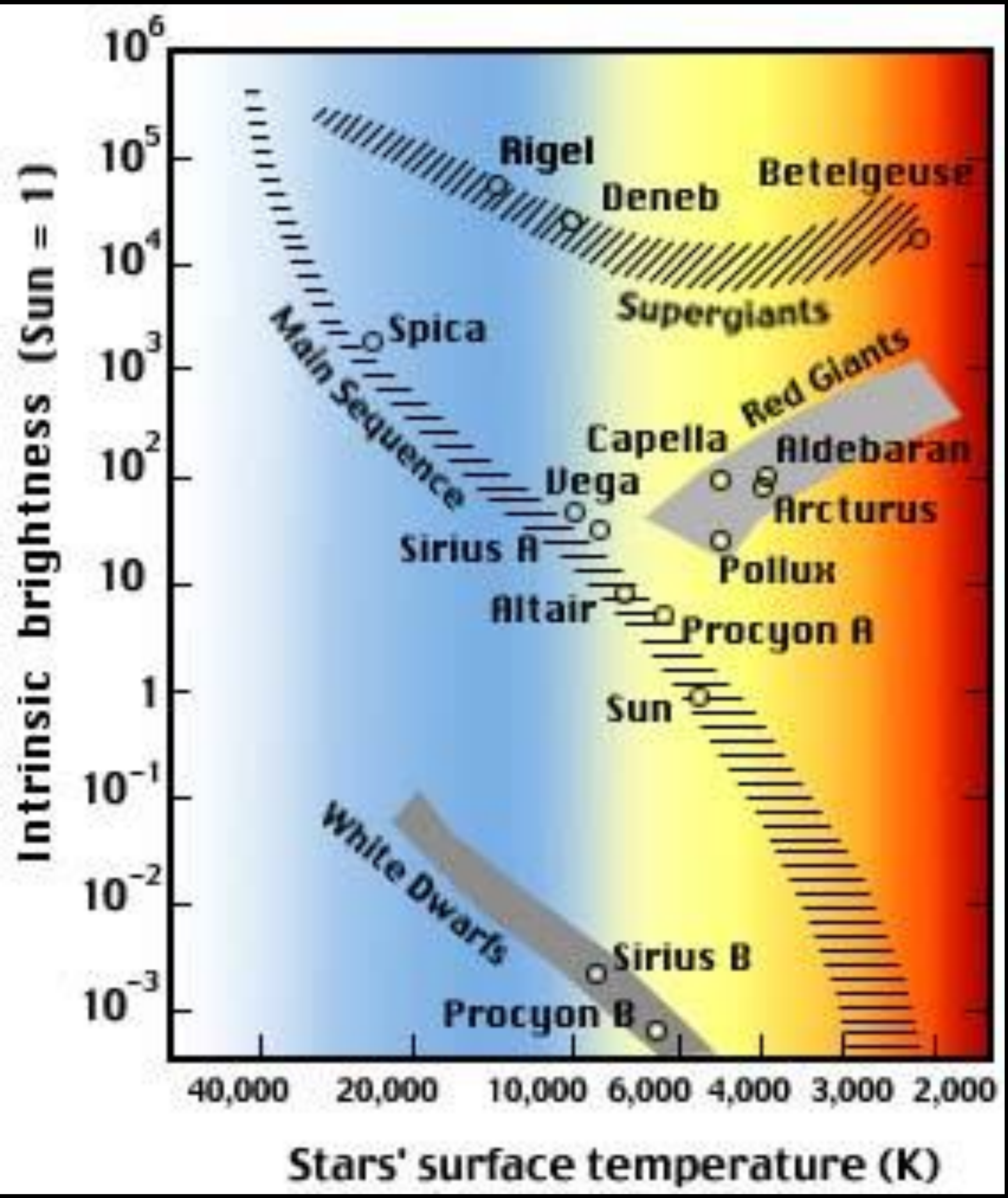
Exoplanetas

(11/06/2024: 5905 CONFIRMADOS)

Which type of star?



Main Sequence stars!



Hertzsprung-Russell (HR) Diagram

Why Main Sequence Stars?

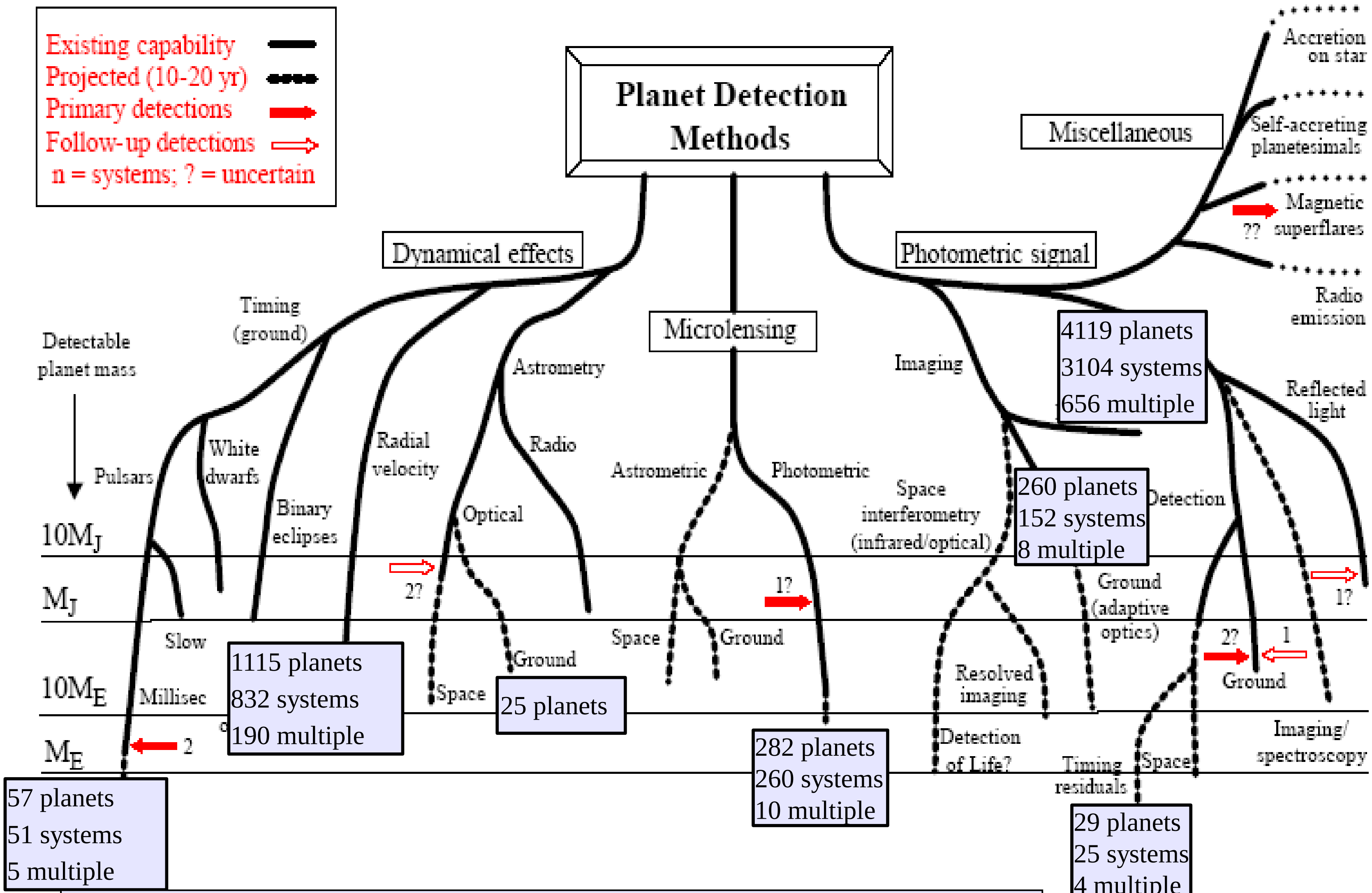
The survey for Exoplanets focus on Main Sequence (MS) stars because MS stars (like the Sun) represent the more stable, longest stage in the evolution of a star, during which the star is burning hydrogen into Helium in its core. During the MS stage, the condition around the star are constant enough to allow the existence of planets. By contrast, the late stages of stellar evolution (for instance, the red giant stage) are so rapidly evolving and violent that lead to the devastation of planets around the star.

http://observe.arc.nasa.gov/nasa/space/stellardeath/stellardeath_1ai.html

Planet Detection Methods

Michael Perryman, Rep. Prog. Phys., 2000, 63, 1209 (updated September 2003)

5905 planets
4337 planetary systems
945 systems with multiple planets



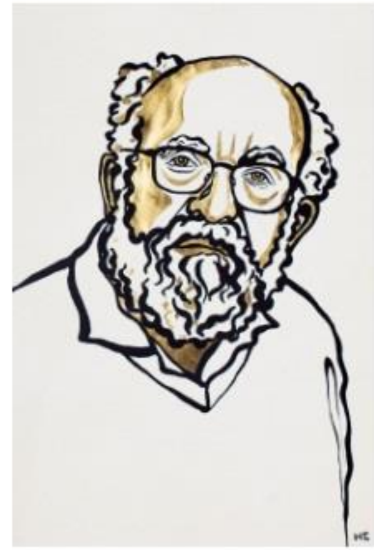
Extra-Solar Planets Catalog (https://exoplanet.eu/catalog/). Retrieved: 2024/05/28

The Nobel Prize in Physics 2019

Ill. Niklas Elmehed. © Nobel Media.

James Peebles

Prize share: 1/2



Ill. Niklas Elmehed. © Nobel Media.

Michel Mayor

Prize share: 1/4

Ill. Niklas Elmehed. © Nobel Media.

Didier Queloz

Prize share: 1/4

The Nobel Prize in Physics 2019 was awarded "for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos" with one half to James Peebles "for theoretical discoveries in physical cosmology", the other half jointly to Michel Mayor and Didier Queloz "for the discovery of an exoplanet orbiting a solar-type star."

Como detectar exoplanetas?

1) Detecção Direta (Imageamento)
2) Astrometria
3) Microlensing (Lentes Gravitacionais)
4) Timing (Pulsar)
5) Velocidade radial
6) Trânsito

Em geral, os exoplanetas são detectados por **métodos indiretos**, apenas para uma pequena fração deles é possível o **imageamento**.
Os métodos de detecção mais bem sucedidos são o de **trânsito** (na página exoplanet.eu, 3917 exoplanetas descobertos por esse método confirmados em 28/5/2024) e **velocidade radial** (1109). Inclusive, foi esse último método que permitiu a detecção do primeiro exoplaneta orbitando uma estrela da sequência principal por Michel Mayor e Didier Queloz em 1995, o que lhes rendeu o prêmio Nobel de Física de 2019.

Methods for detection of Exoplanets

1) Direct detection (imaging)

Only for BIG and sufficient planet-star distance: weak contrast

Tecniques

- ➔ Interferometry
- ➔ Coronagraph

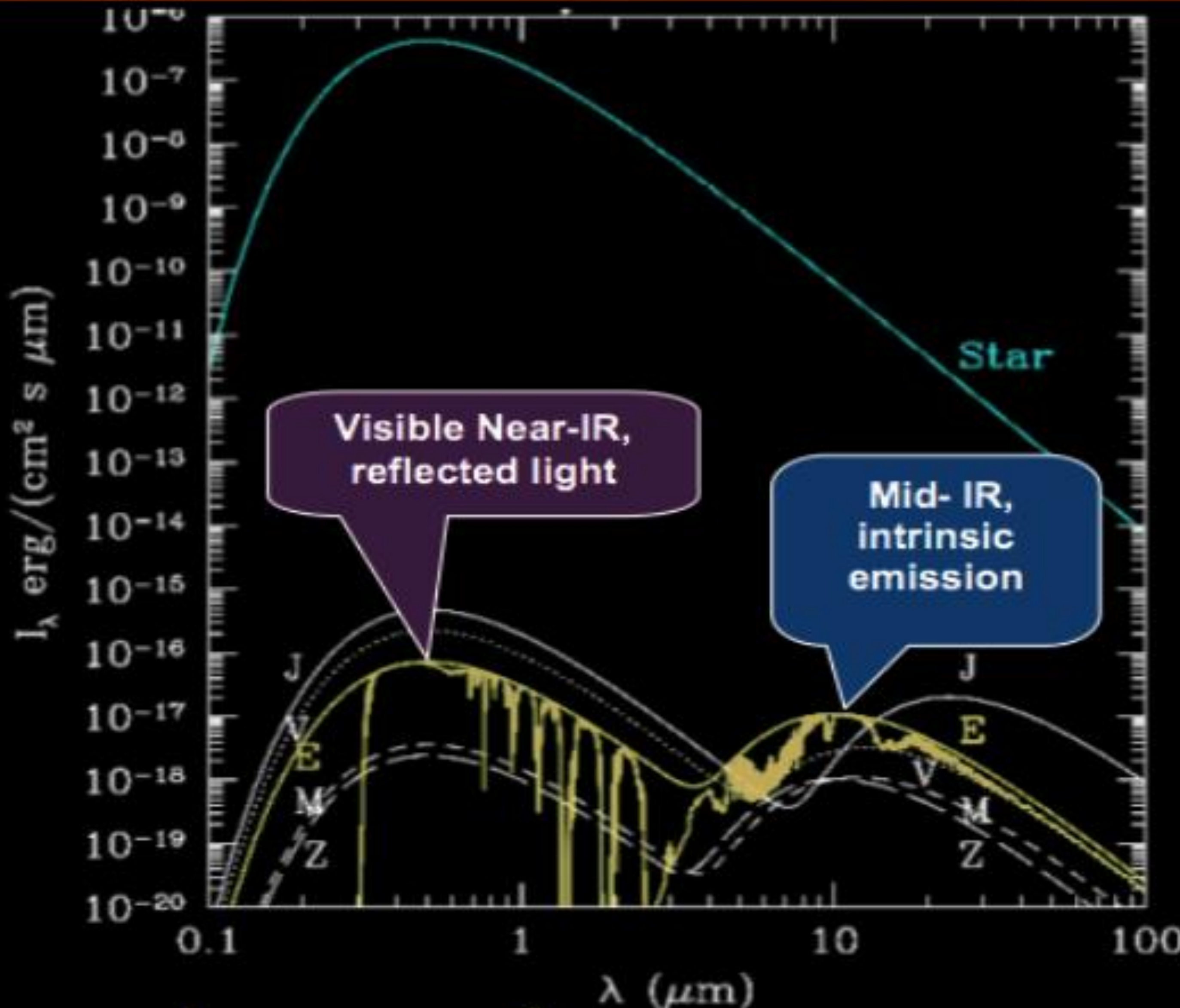
The advantage of IR observations

Contrast Star-Planet:

100,000,000 for a Jupiter-like planet in the Visible

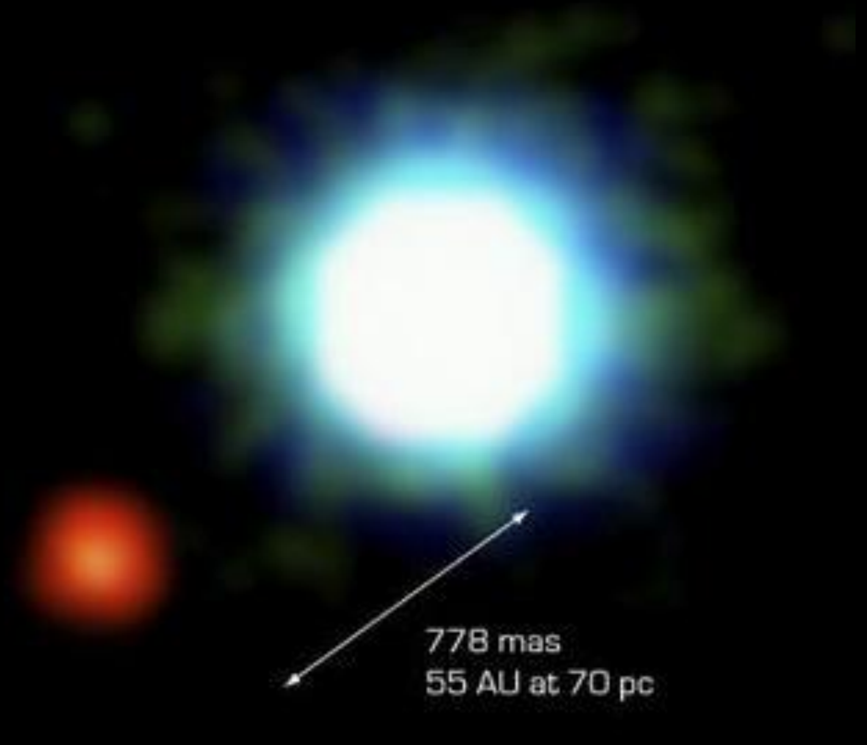
Contrast improved if observed in the IR

~ 100,000 for a Jupiter-like planet in the IR

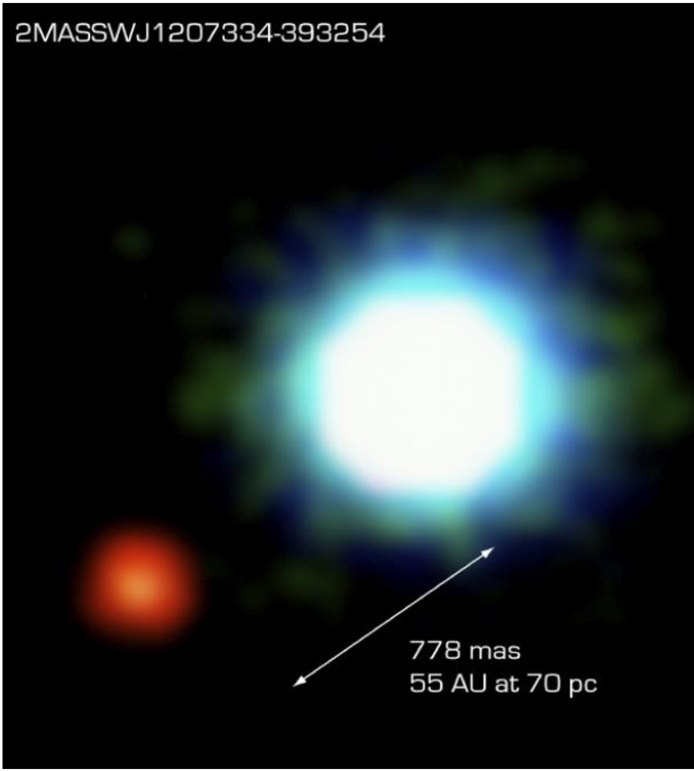


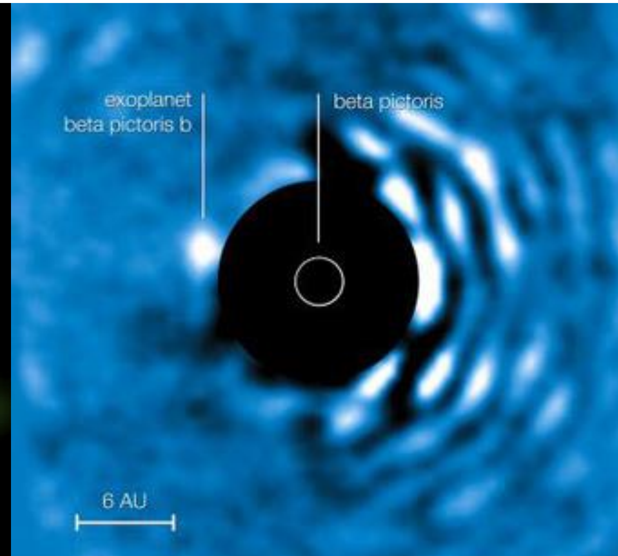
Star
Visible Near-IR, reflected light
Mid- IR, intrinsic emission
J
V
E
M
Z
J
E
V
M
Z
I_λ erg/(cm^2 s μm)
λ (μm)
0.1
1
10
100

2M1207 e 2M1207b

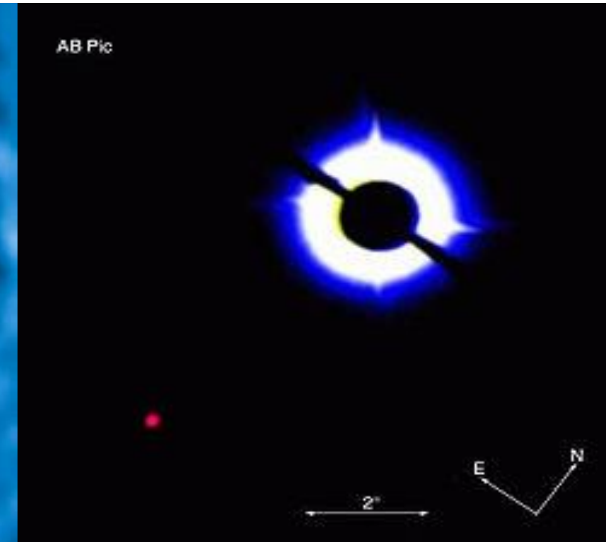


Other examples of direct detection

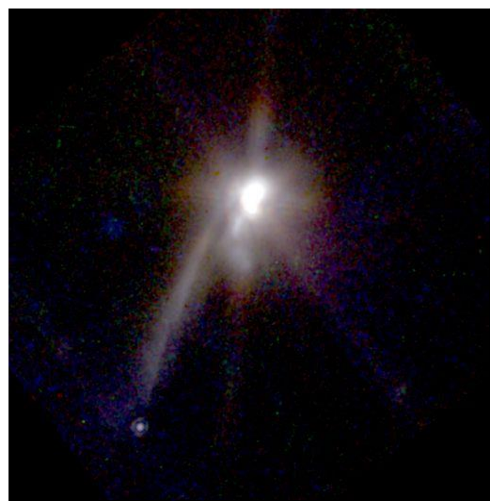




Beta Pic



AB Pic

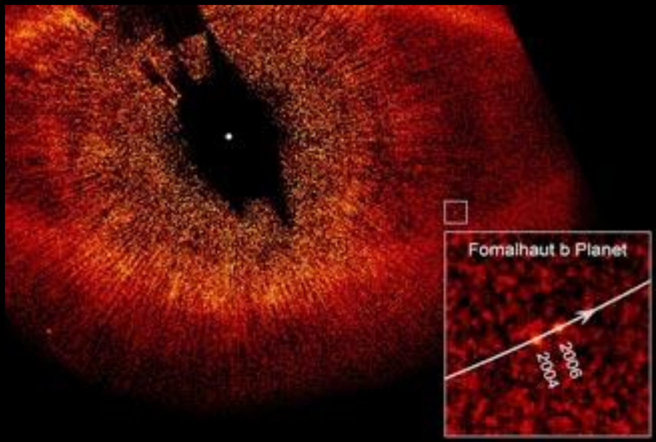


Hubble image of possible exoplanet TMR-1C (NASA)

Astrônomos fazem 1ª foto de um sistema extra-solar

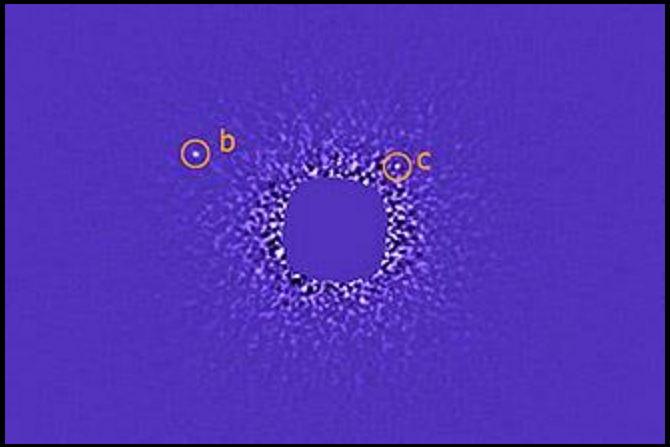
Folha Online 14/11/2008 - 10h23

Dois grupos independentes de astrônomos anunciam hoje ter conseguido avistar diretamente planetas orbitando outras estrelas. Esses corpos celestiais que orbitam outras estrelas já haviam sido detectados de modo indireto e até fotografados antes, mas as imagens obtidas dependiam de confirmação. Agora, os exoplanetas foram flagrados se movendo ao redor de suas estrelas.



Exoplaneta de Fomalhaut

Fomalhaut b $M/M_{Jup} < 3$

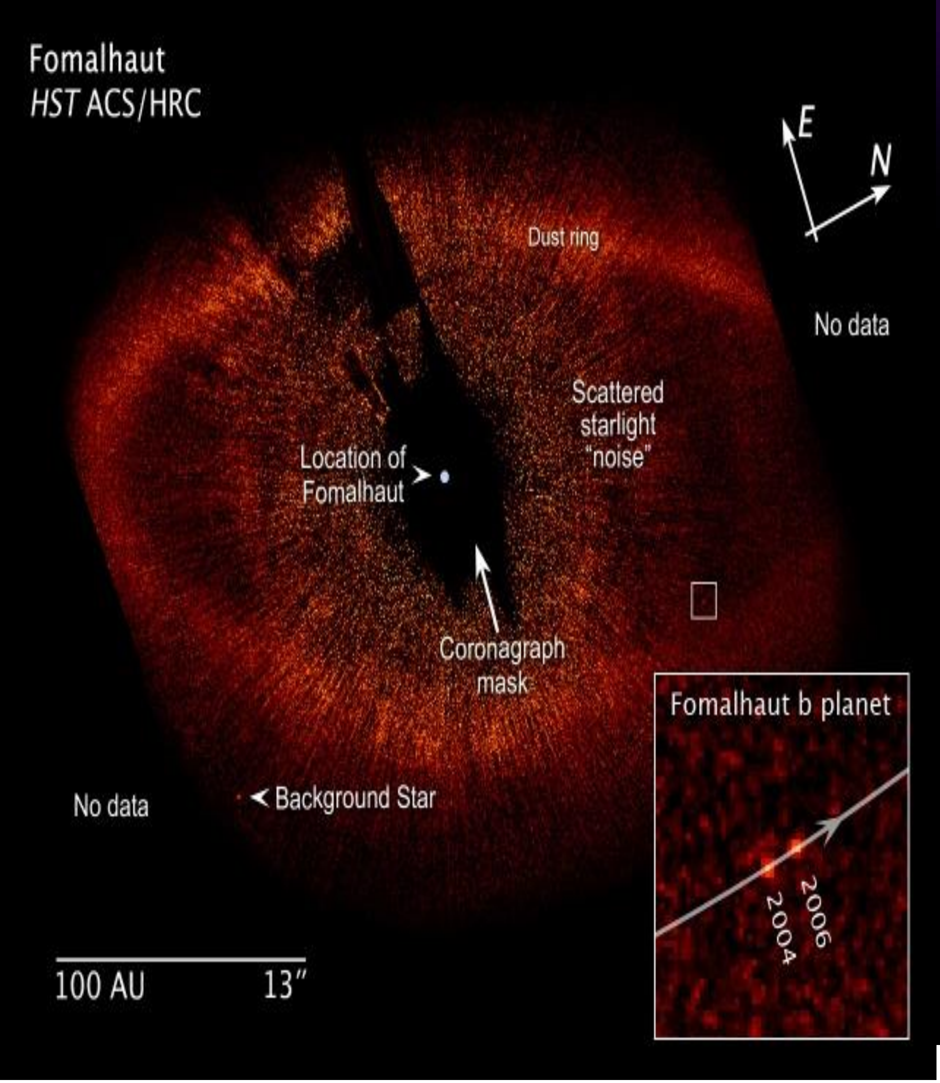


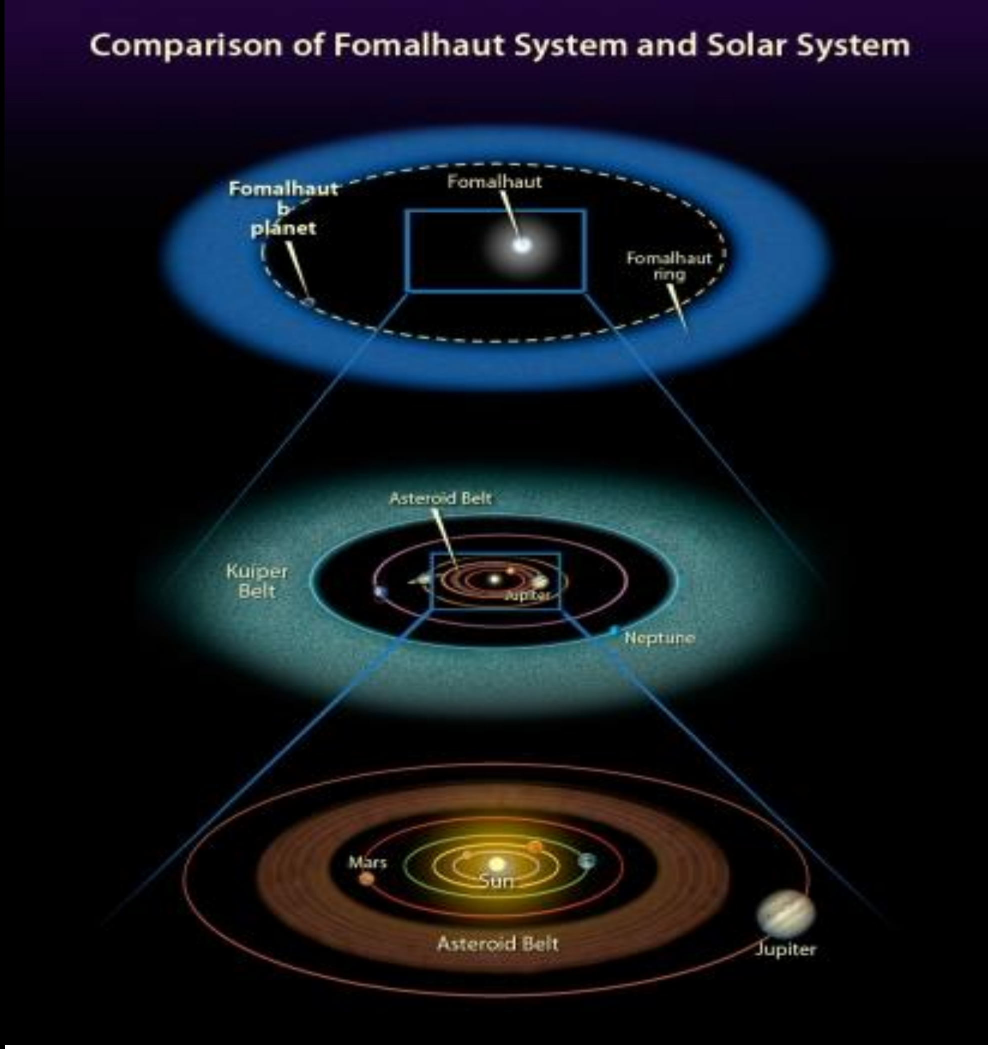
Exoplanetas de HR 8799

HR 8999d $M/M_{Jup} = 10$

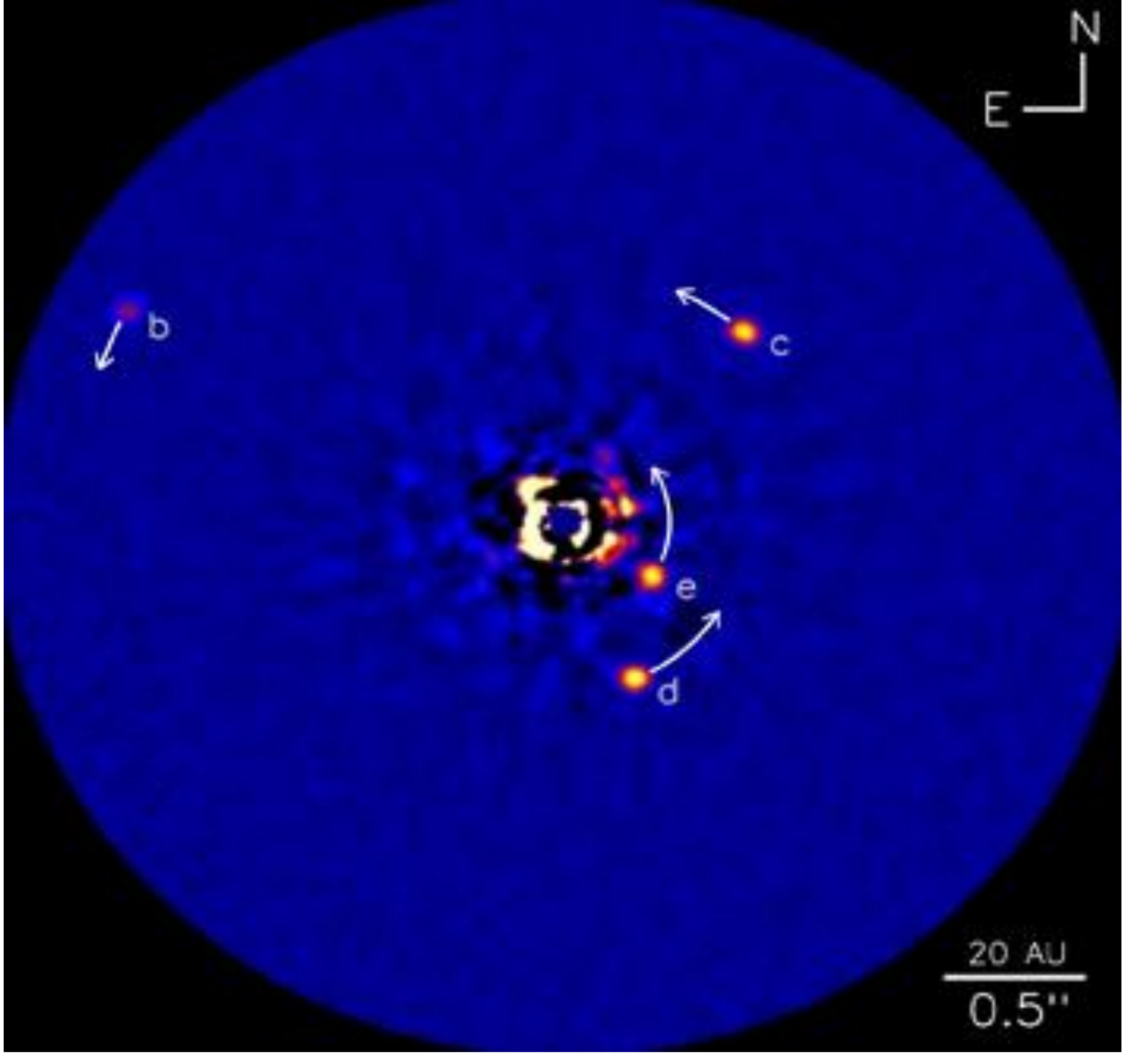
HR 8999d 10

HR 8999d 7





Direct detection: planet around star **Fomalhaut** (25 l-y from the Sun)



Four planets around HR 7899 (Palomar)

Métodos de Detecção de Exoplanetas

2) *Astrometria*: oscilações no movimento próprio da estrela

➔ Detecção do exoplaneta

Muito difícil e vários falsos positivos (ex. Estrela de Barnard)

Peter van de Kamp (~1950): placas fotográficas registrando o movimento próprio da **Estrela de Barnard** (Ofiúco, 1916):

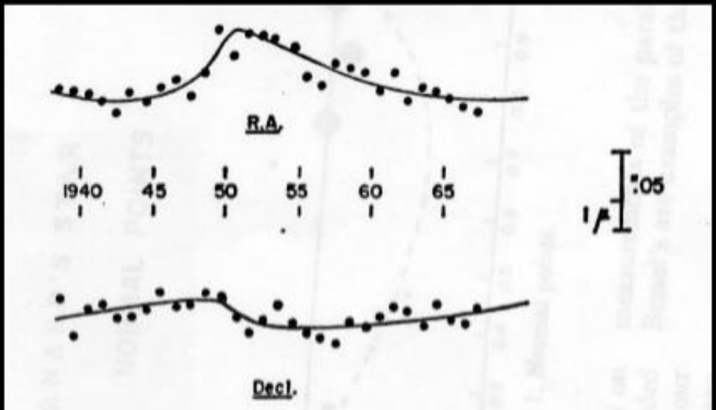


FIG. 1. Barnard's star: Yearly means, averaging 100 plates and weight 68; time–displacement curves for $P=25$ yr, $e=0.75$, $T=1950$.

Sua conclusão: o balanço (oscilação) causado por um planeta com cerca massa de Júpiter, em órbita excêntrica.

Refinando os cálculos (~1982) concluiu haver dois planetas em órbitas circulares, com 0,7 e 0,5 massa de Júpiter.

Muitos tentaram verificar os trabalhos de van de Kamp mas não encontraram oscilações; as encontradas estavam dentro da margem de erro do método utilizado. Peter van de Kamp morreu em 1995 afirmando suas conclusões.

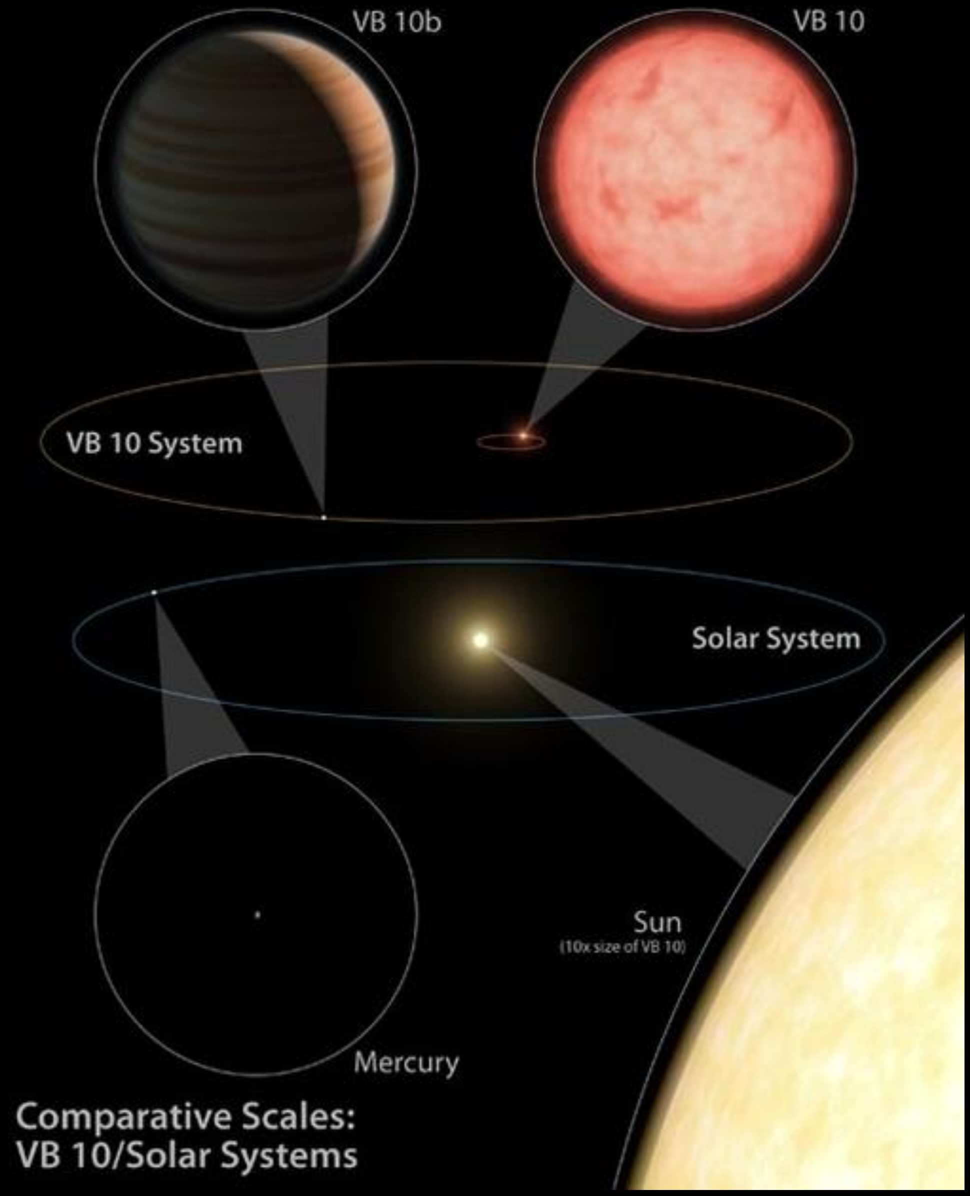
BARNARD'S STAR AND VAN DE KAMP'S PLANETS: THE BEGINNING

by George H. Bell

In the September 15, 1916 issue of The Astronomical Journal (1) and the September 7, 1916 issue of Nature, (2) an article appeared that dealt with the discovery of a rather small, insignificant star that demonstrated a large proper motion. The purpose of the article was to alert the astronomical world that indeed, E.E. Barnard detected a unique find, that is a star with a proper motion larger than any star that had been studied previously. The large proper motion was calculated by Barnard to be approximately 10.3 arcseconds per year. (3) The proper motion is defined as "the apparent angular motion per year of a star on the celestial sphere, i.e., in a direction perpendicular to the line of sight". (4) Proper

Primeiro Planeta descoberto por Astrometria?

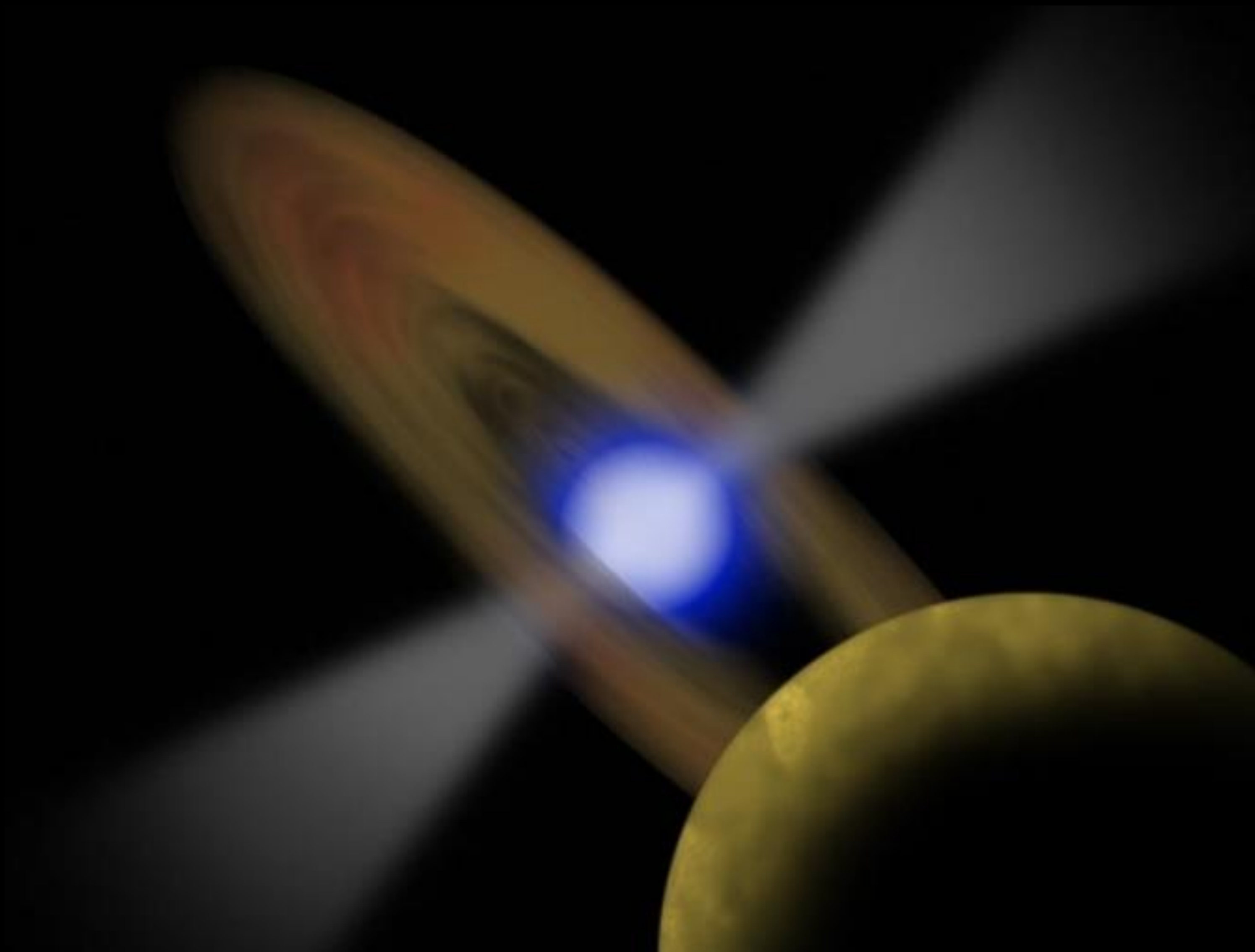
Descoberta anunciada em 2009, descartada em 2020



27/6/2023:
20 descobertos por astrometria

Métodos de Detecção de Exoplanetas

3) *Timing (Pulsar)*



Métodos de Detecção de Exoplanetas

Timing (Pulsar)

A planetary system around the millisecond pulsar PSR1257+12

A. Wolszczan* & D. A. Frail†

* National Astronomy and Ionosphere Center, Arecibo Observatory, Arecibo, Puerto Rico 00613, USA
† National Radio Astronomy Observatory, Socorro, New Mexico 87801, USA

MILLISECOND radio pulsars, which are old (~10^9 yr), rapidly rotating neutron stars believed to be spun up by accretion of matter from their stellar companions, are usually found in binary systems with other degenerate stars[1]. Using the 305-m Arecibo radiotelescope to make precise timing measurements of pulses from the recently discovered 6.2-ms pulsar PSR1257+12 (ref. 2), we demonstrate that, rather than being associated with a stellar object, the pulsar is orbited by two or more planet-sized bodies. The planets detected so far have masses of at least 2.8 $M_\oplus$ and 3.4 $M_\oplus$, where $M_\oplus$ is the mass of the Earth. Their respective distances from the pulsar are 0.47 AU and 0.36 AU, and they move in almost circular orbits with periods of 98.2 and 66.6 days. Observations indicate that at least one more planet may be present in this system. The detection of a planetary system around a nearby (~500 pc), old neutron star, together with the recent report on a planetary companion to the pulsar PSR1829−10 (ref. 3) raises the tantalizing possibility that a non-negligible fraction of neutron stars observable as radio pulsars may be orbited by planet-like bodies.

The 6.2-ms pulsar PSR1257+12 (Fig. 1) was discovered during the search at high galactic latitudes for millisecond pulsars conducted in February 1990 with the 305-m Arecibo radiotelescope at a frequency of 430 MHz (ref. 2). The characteristics of this survey and the details of data analysis are described else-

NATURE · VOL 355 · 9 JANUARY 1992

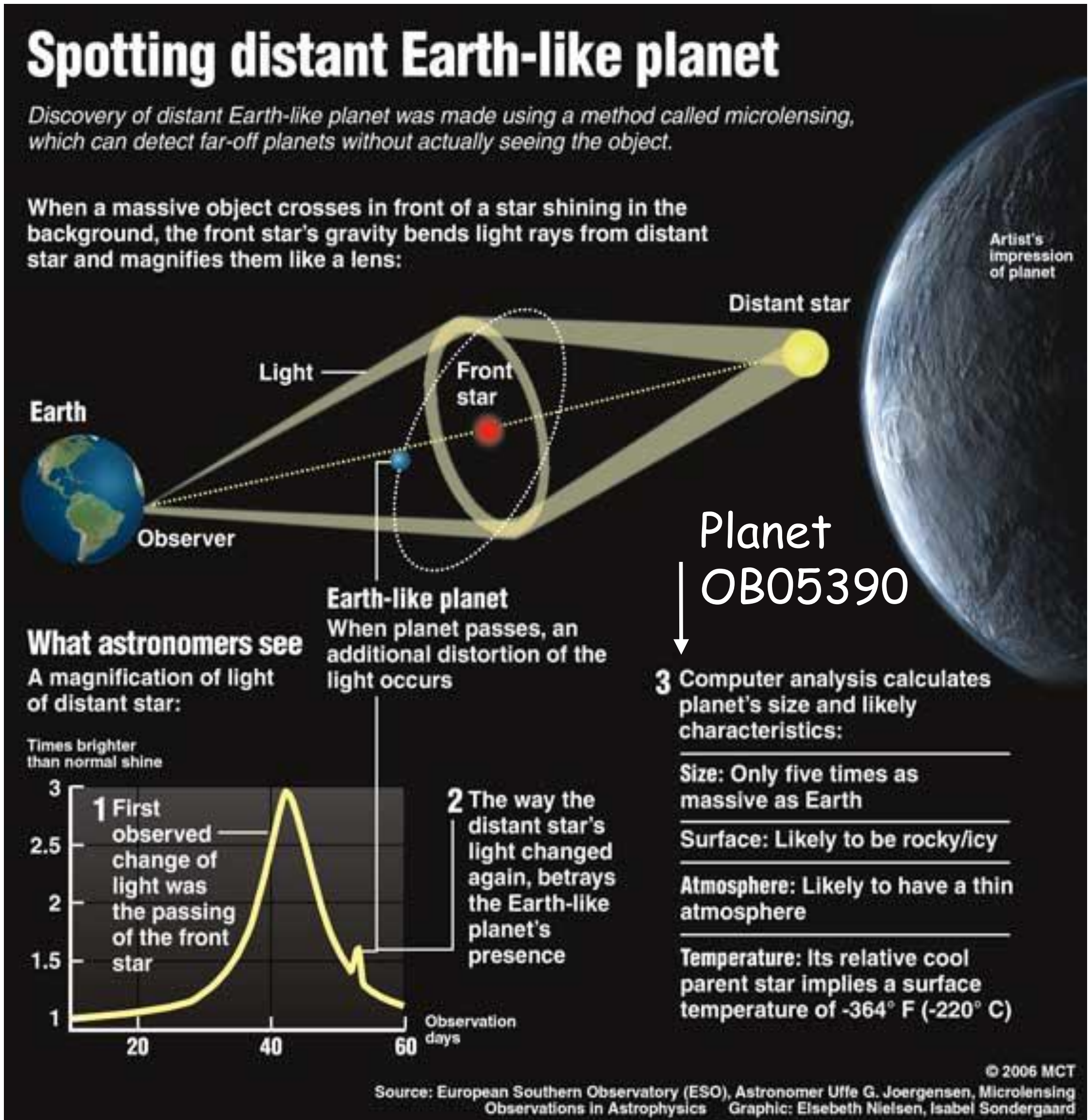
Esses foram, na realidade, os primeiros exoplanetas descobertos, porém em torno de um pulsar, que é uma estrela de nêutrons em rotação. Trata-se, portanto de um ambiente inóspito e inteiramente hostil à vida.

Em 1992, foram descobertos dois planetas PSR1257 + 12 B e C, posteriormente rebatizados (conforme a nomenclatura de designar exoplanetas por letras minúsculas, começando com a letra “b”) de PSR B1257+12 c e PSR B1257+12 d, com 4.3 e 3.9 massas terrestres, respectivamente.

Em 1994, descobriu-se um planeta ainda menor, PSR B1257+12 b, com 0.020 massas terrestres.

Methods for the detection of exoplanets

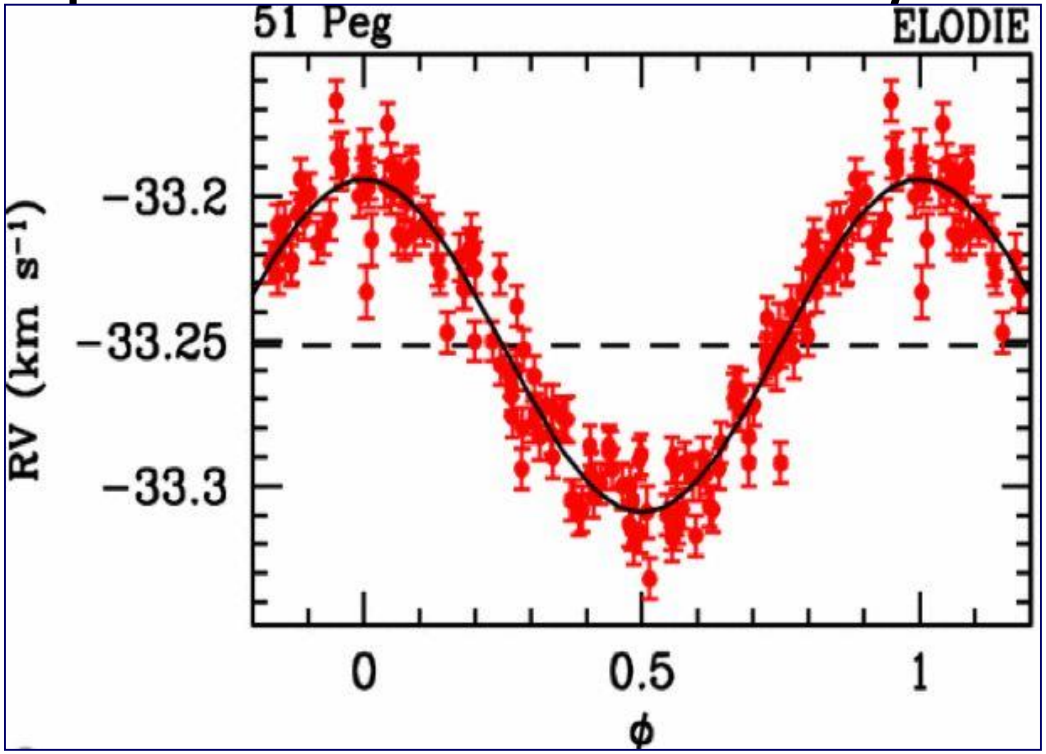
4) *Gravitational microlensing* (Einstein effect)



Some dozens exoplanets discovered with this method (Mpl ~Atm)

Methods for the detection of exoplanets

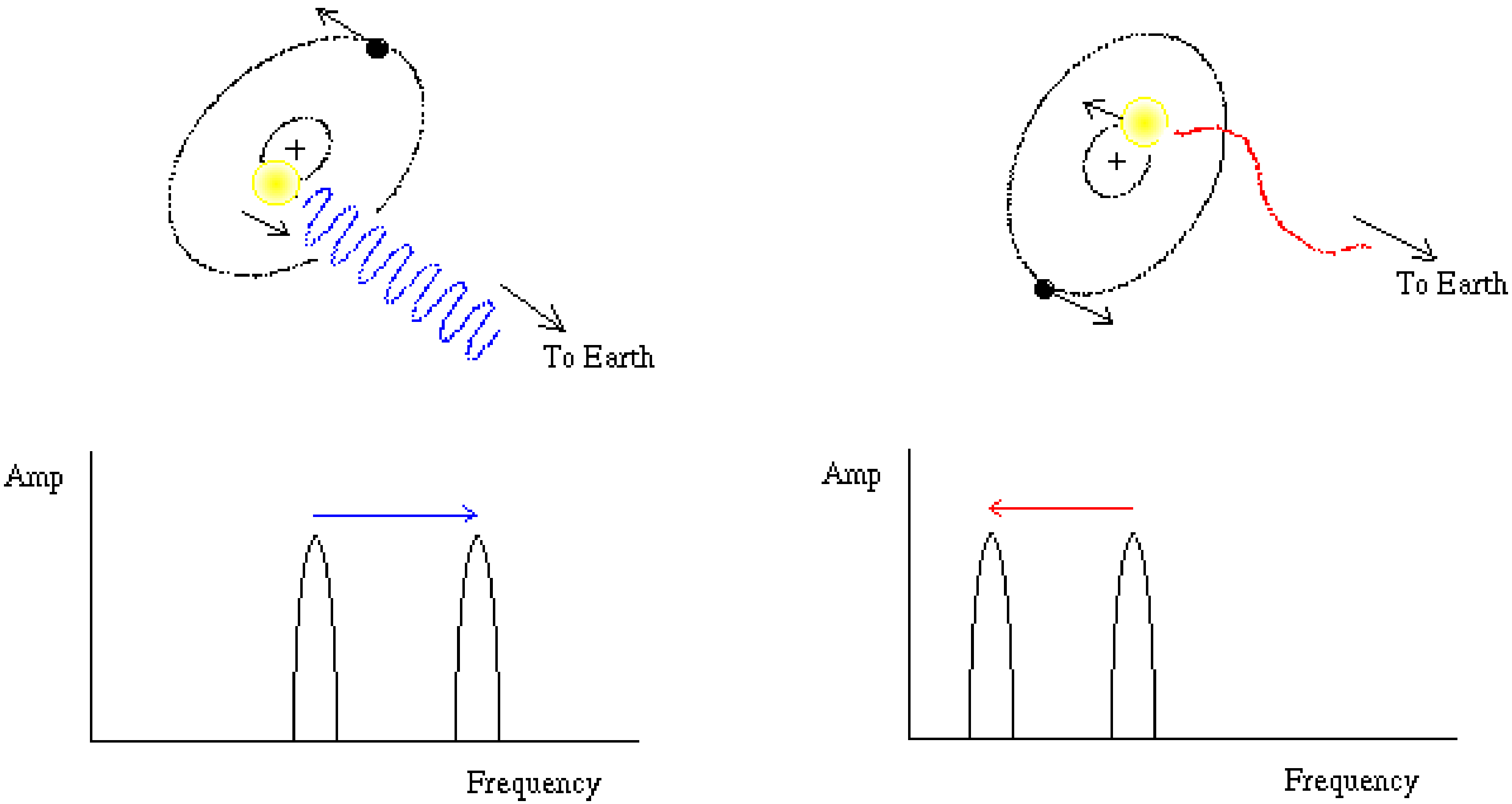
5) *Radial Velocity*: stellar radial velocity variations
➔ presence of unseen body



Many hundred exoplanets discovered by this method

Radial velocity variations + Kepler's 3rd law ➔ Mpl ; Porb

Detection of Planets- Radial Velocity Method



PROBLEM with the ***radial velocity*** method

Described by Newton's law:

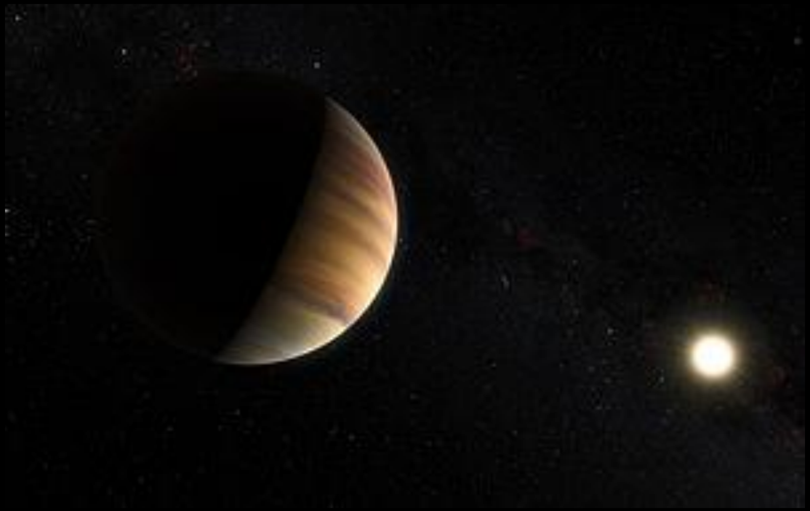
$$F = G \times M_{star} \times M_{planet} / \text{distância}^2$$

►► BIAS: detected mainly planets

more massives & nearer to their hosts

stars

1995 – Primeiro Exoplaneta Descoberto orbitando uma estrela da SP (51 Pegasi b)



Michel Mayor
+ equipe de astrônomos da Suíça, França, e Portugal.

Tipo estelar: G4-5V

Massa estelar: 1,06 $M_\odot$

Distância: 50,9 anos-luz

Período orbital: 4,23 dias

Semi-eixo maior: 0,0527 UA

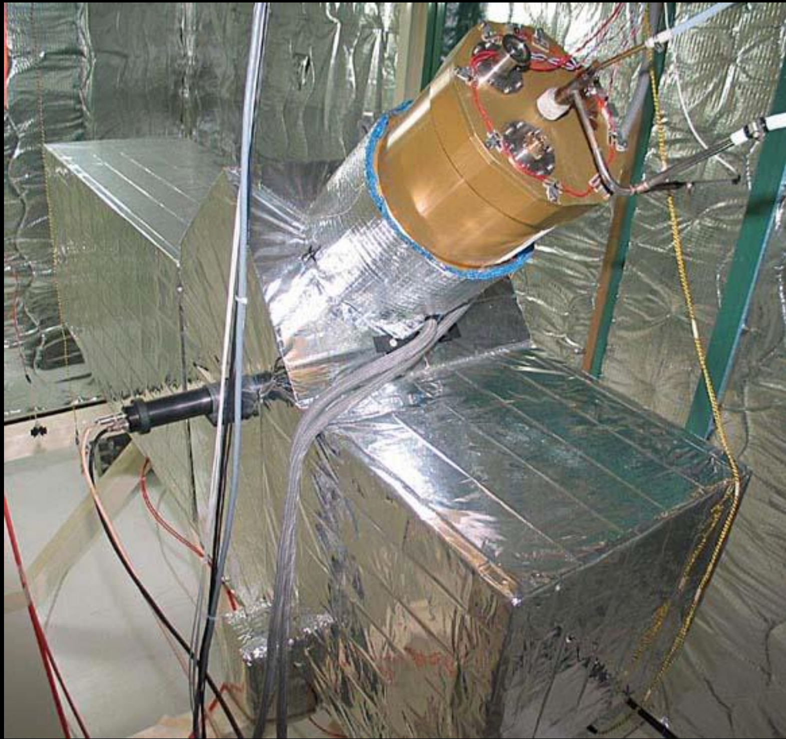
Massa mínima (m sin i): 0,47 M_J

JÚPITER QUENTE

Instrumentos utilizados na descoberta do primeiro exoplaneta, 51 Pegasi b

Telescópio de 1,93m do Observatoire de Haute-Provence, França

+ Espectrógrafo ELODIE



Efeito Doppler

Christian Doppler

- **1842 - Efeito Doppler**

$$z = \begin{matrix}\text{desvio}\\ \text{para o}\\ \text{vermelho}\end{matrix} = \frac{\text{velocidade da fonte}}{\text{velocidade da luz}} = \frac{\lambda_{obs} - \lambda_{ref\ fonte}}{\lambda_{ref\ fonte}}$$

C = 300 000 km/seg

Válido para v muito menor que c

Efeito Doppler

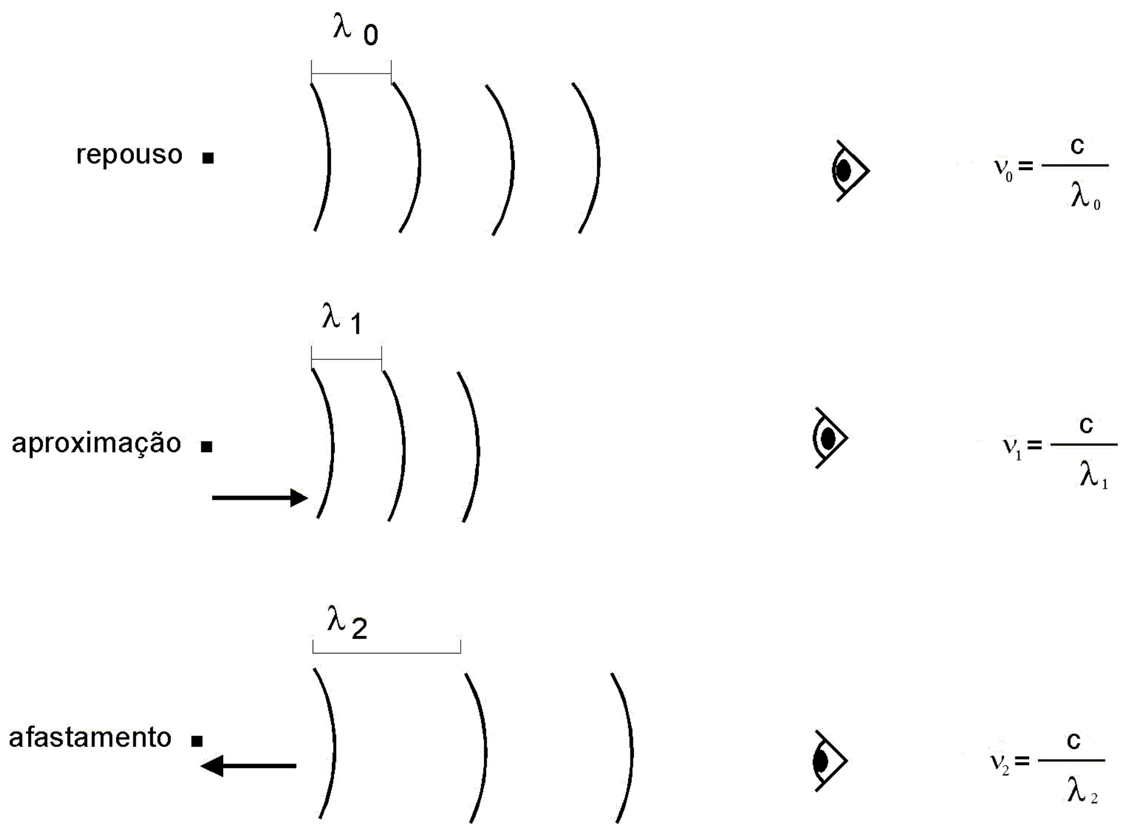
Fonte emissora desloca-se em relação ao observador.

Fonte em repouso, emitindo luz a um comprimento de onda λ_0.

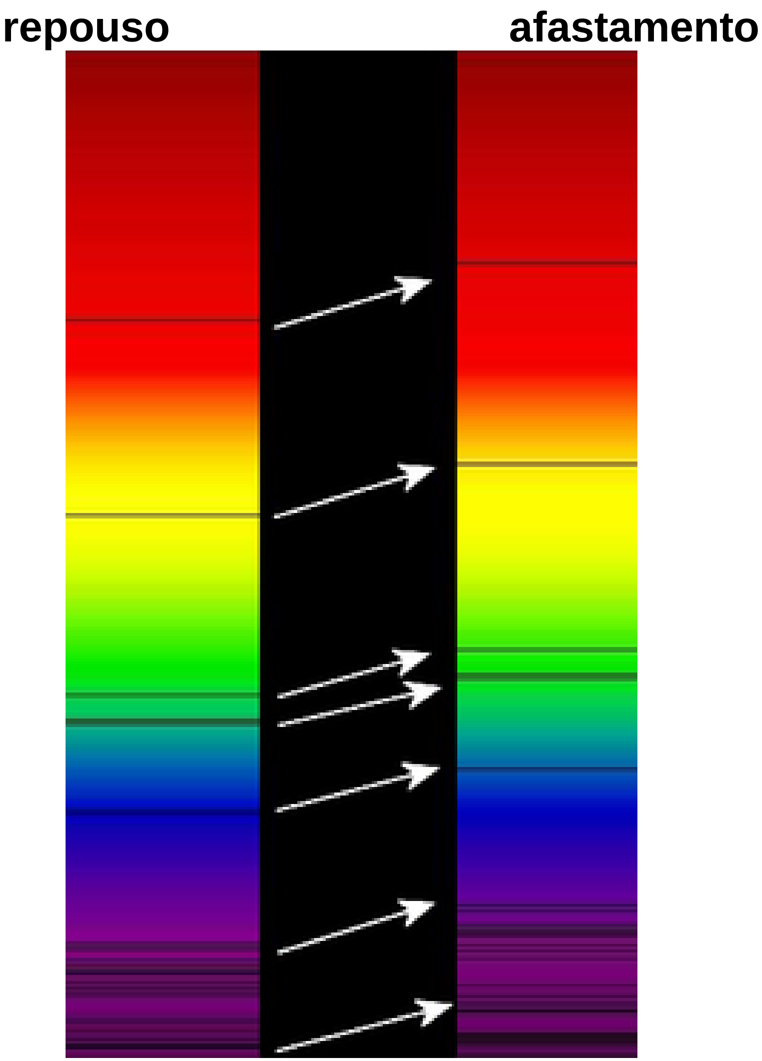
Fonte aproxima-se do observador: ⇨ comprimento de onda observado será menor ($\lambda_1 < \lambda_0$).

Fonte afasta-se: comprimento de onda observado será maior

($\lambda_2 > \lambda_0$).

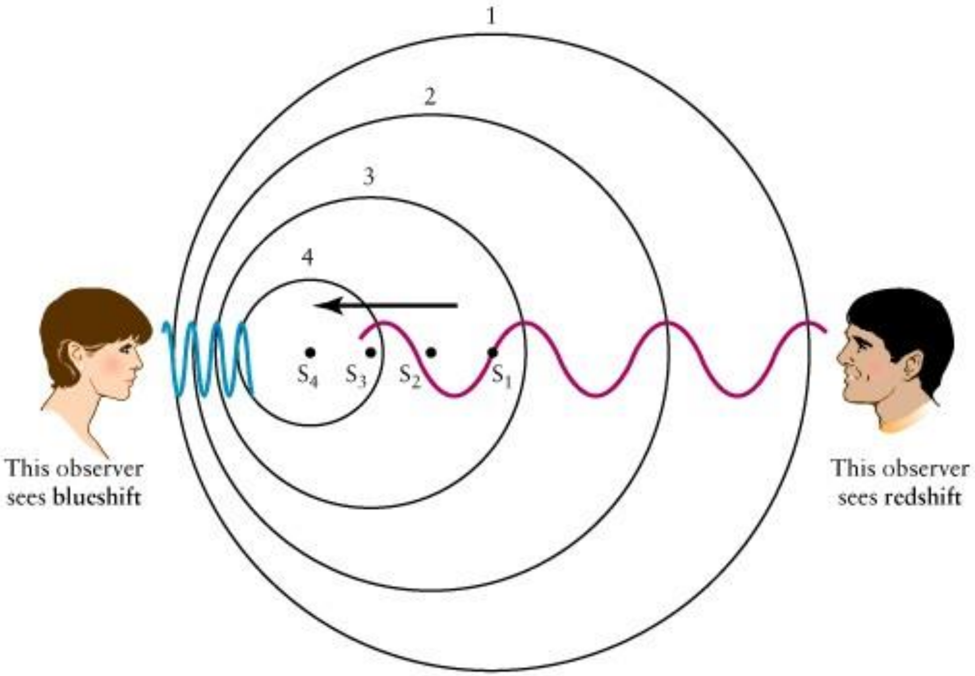


Para velocidades não-relativísticas (fonte com v << c)

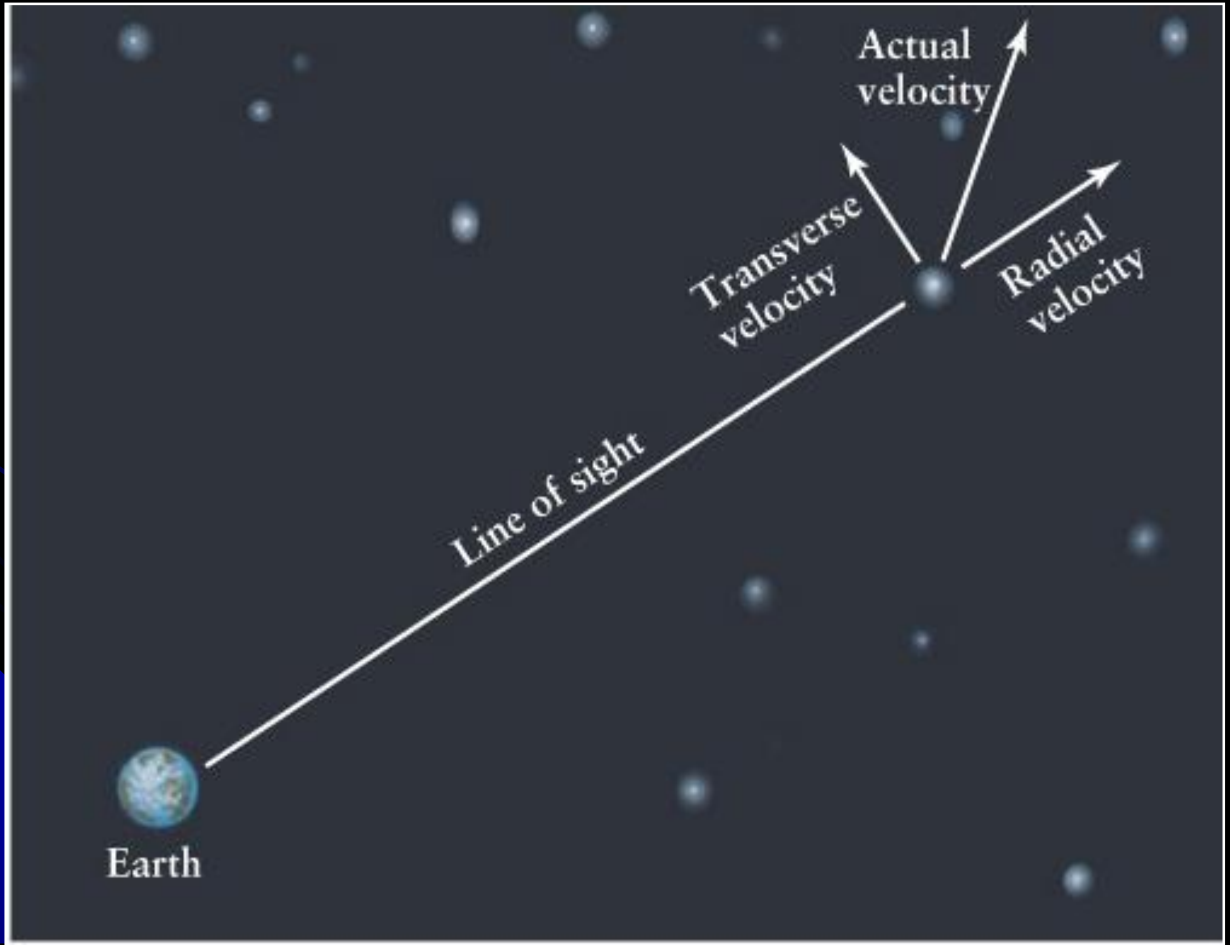


$$\Delta\lambda = \lambda - \lambda_0 = \lambda_0 \left(v/c \right)$$

$$\Delta\lambda / \lambda_0 = v/c$$



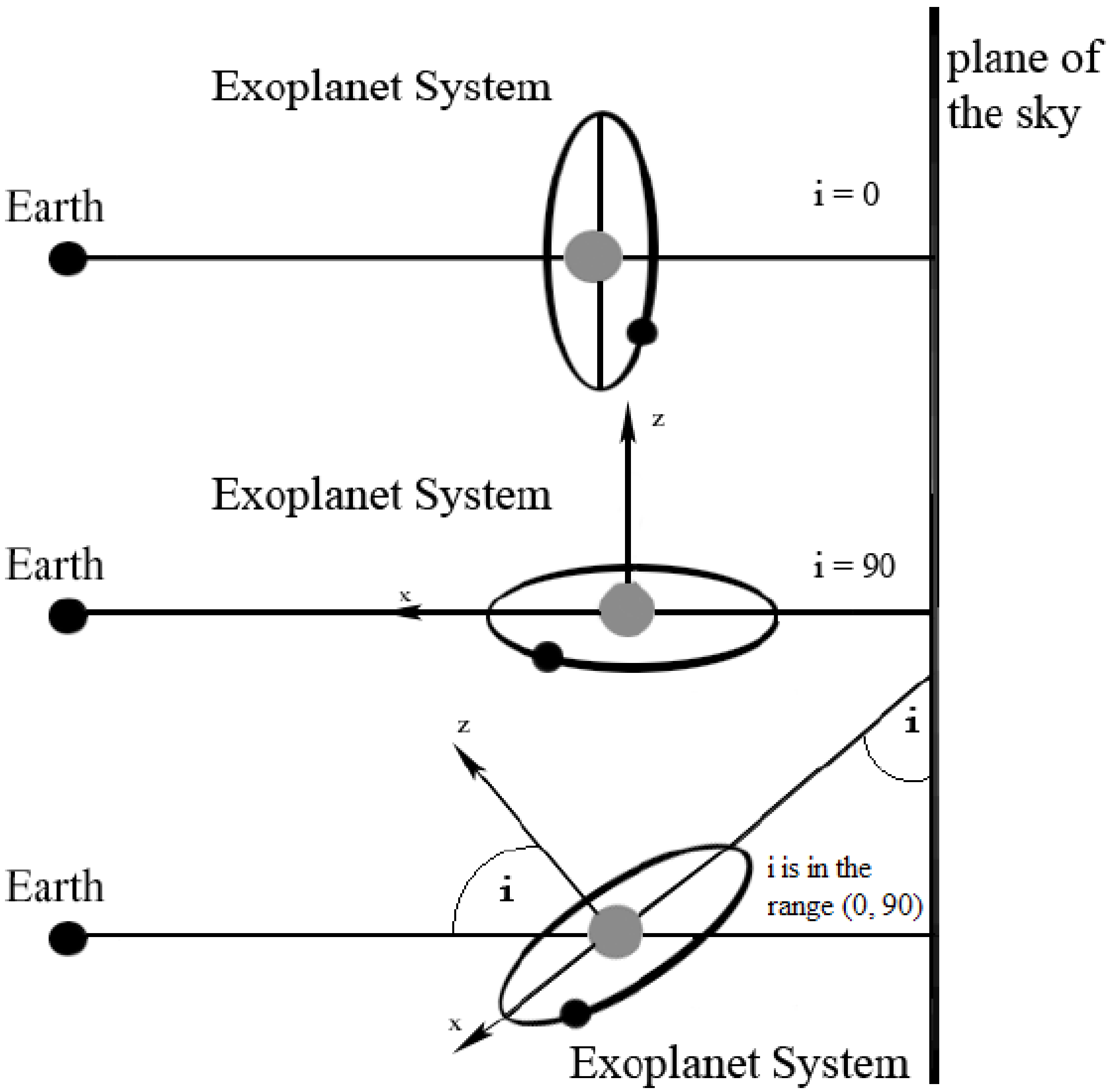
O efeito Doppler nos informa apenas sobre a parte radial do movimento do objeto em relação a nós (ou em aproximação ou em afastamento)



Ângulo de inclinação da órbita do exoplaneta *i*

(ângulo entre o plano orbital e o plano do céu)

Normalmente, o método de velocidade radial não fornece *i*



Se se conhecer *i*, a máxima velocidade radial v_r^{max} permite obter a velocidade real v da estrela

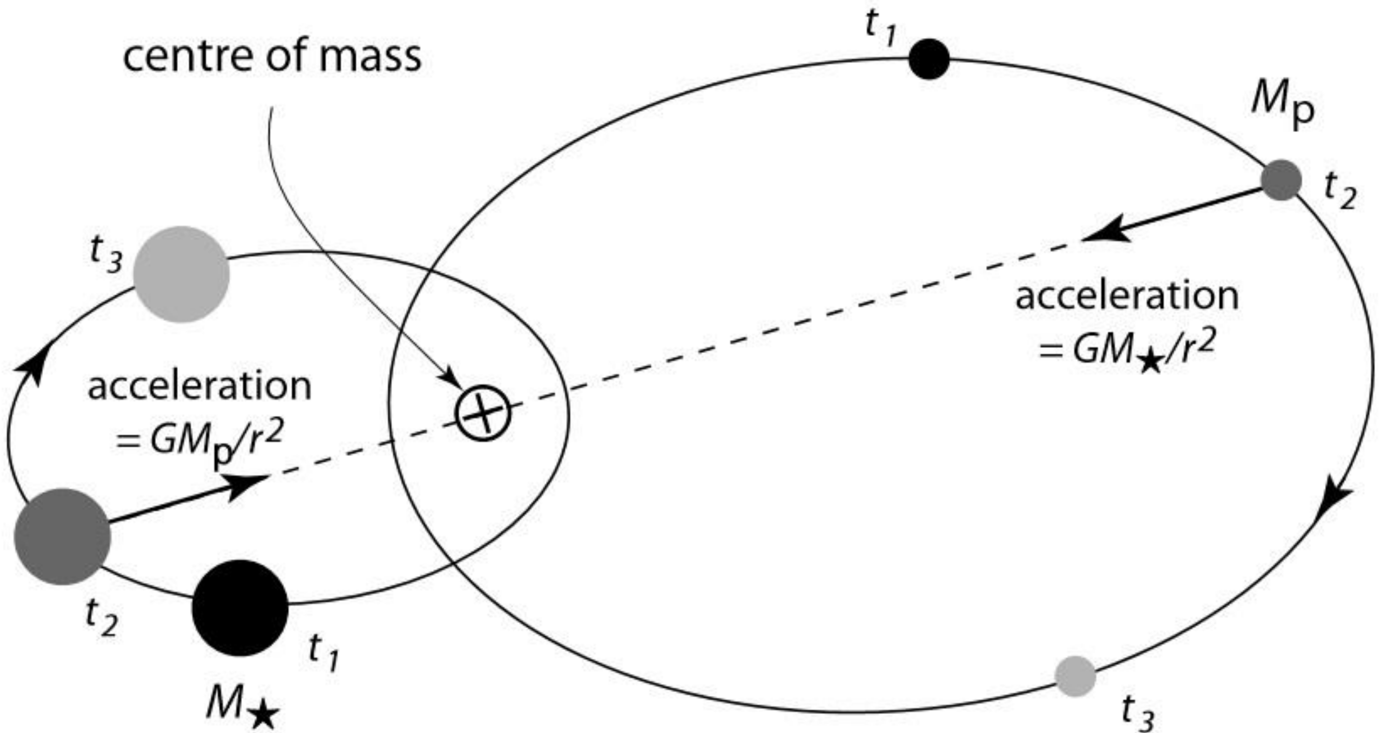
$v_r^{max} = v \text{ sen } (i)$

Só se a linha de visada estiver totalmente alinhada com o plano da órbita (i=90º) é que v_r^{max} será a velocidade real v.

Se o observador estiver na direção perpendicular ao plano orbital (i=0º), o método de velocidade radial não pode ser usado, pois v_r=0 sempre.

Movimento em torno do Baricentro (Centro de Massa)

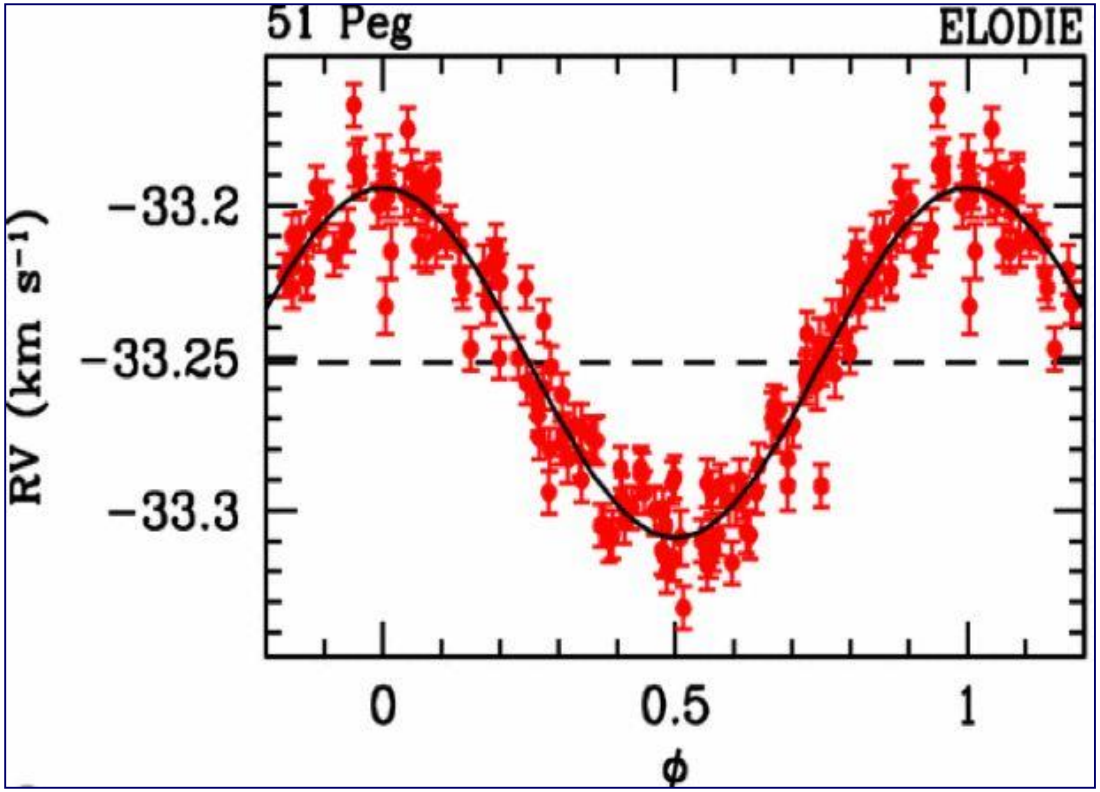
Não é verdade que o exoplaneta orbita a estrela. Na realidade, estrela e planeta orbitam o baricentro do sistema. Porém é a estrela que se observa e a partir do deslocamento Doppler das suas linhas, determina-se sua velocidade radial. Com várias observações ao longo do tempo obtém-se a curva de velocidade radial da estrela e, após, a curva do exoplaneta, usando a relação $M_p r_p = M_* r_*$.



$$M_p a_p = M_* a_*$$

a_* semieixo maior da órbita da estrela em torno do baricentro do sistema

a_p semieixo maior da órbita do exoplaneta



V_r^{max} ou K

Semi-amplitude da velocidade radial da estrela (máxima velocidade radial)

Semi-período orbital $P_{orb}/2$

Método da Velocidade Radial – Determinando M_{pl}sen(i)

- O método fornece o limite inferior para a massa do planeta $M_{pl}sen(i)$
- Não fornece a inclinação da órbita *i*
  pode-se usar a média no espaço de sen(i): π/4
- Usa-se o período orbital P_{orb}, a excentricidade *e*, e a semi-amplitude da velocidade radial **K**

$$M_{pl}\ \mathrm{sen}\ i = \mathbb{K}(1-e^2)^{1/2}\left(\frac{\mathcal{P}_{\mathrm{orb}}M^2}{2\pi\mathcal{G}}\right)^{1/3}$$

$\mathcal{G}$ é a Constante da Gravitação Universal, $\mathcal{G} = 6{,}67\times10^{-11}$N m^2 kg^{-2}

Se $M_{pl} << M_*$ e a órbita for circular (e-0), **K** toma a forma:

$$\frac{\mathbb{K}}{1ms^{-1}} = 28.4\left(\frac{\mathcal{P}_{\mathrm{orb}}}{1\ \mathrm{ano}}\right)^{-1/3}\left(\frac{M_{pl}\ \mathrm{sen}\ i}{\mathrm{M_J}}\right)\left(\frac{M_\star}{M_\odot}\right)^{-2/3}$$

Para Júpiter, **K** = 12,5 m/s e, para a Terra, **K**=9 cm/s

O semieixo maior *a* da órbita do exoplaneta vem da 3ª lei de Kepler

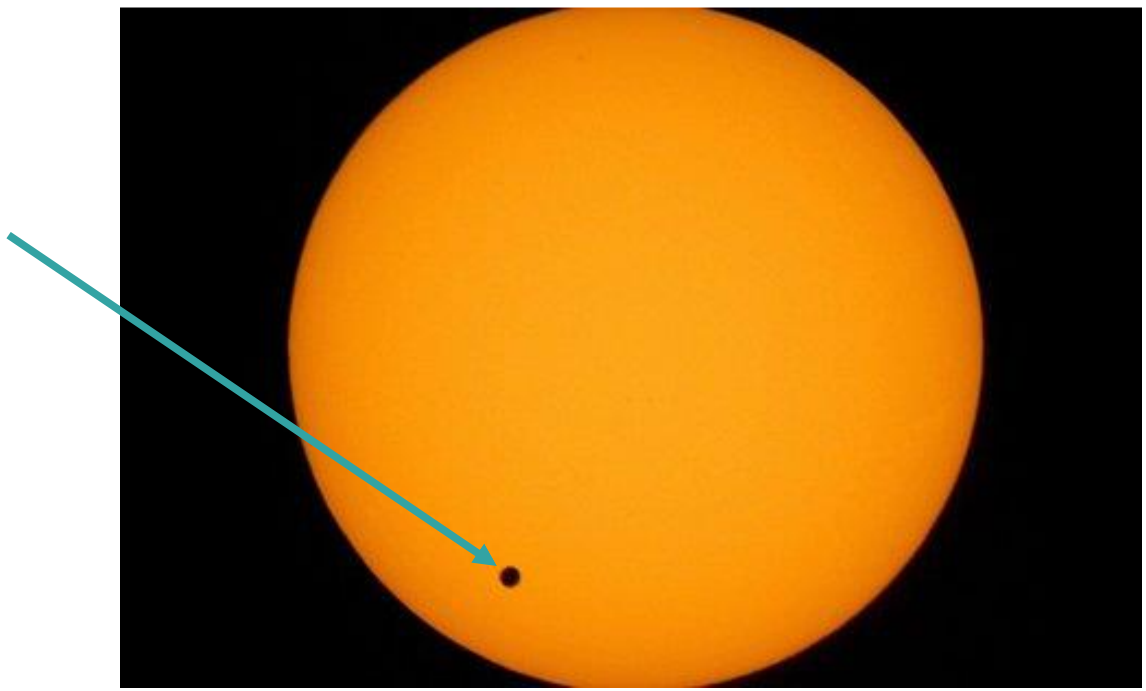
$$\frac{\mathcal{P}_{\mathrm{orb}}}{1\ \mathrm{ano}} = \left(\frac{a}{1\ \mathrm{UA}}\right)^{3/2}\left(\frac{M_\star}{M_\odot}\right)^{-1/2}$$

Methods for the detection of exoplanets

6) Transit method: detection of the tiny eclipse caused by the passage (transit) of a planet in front of its star.

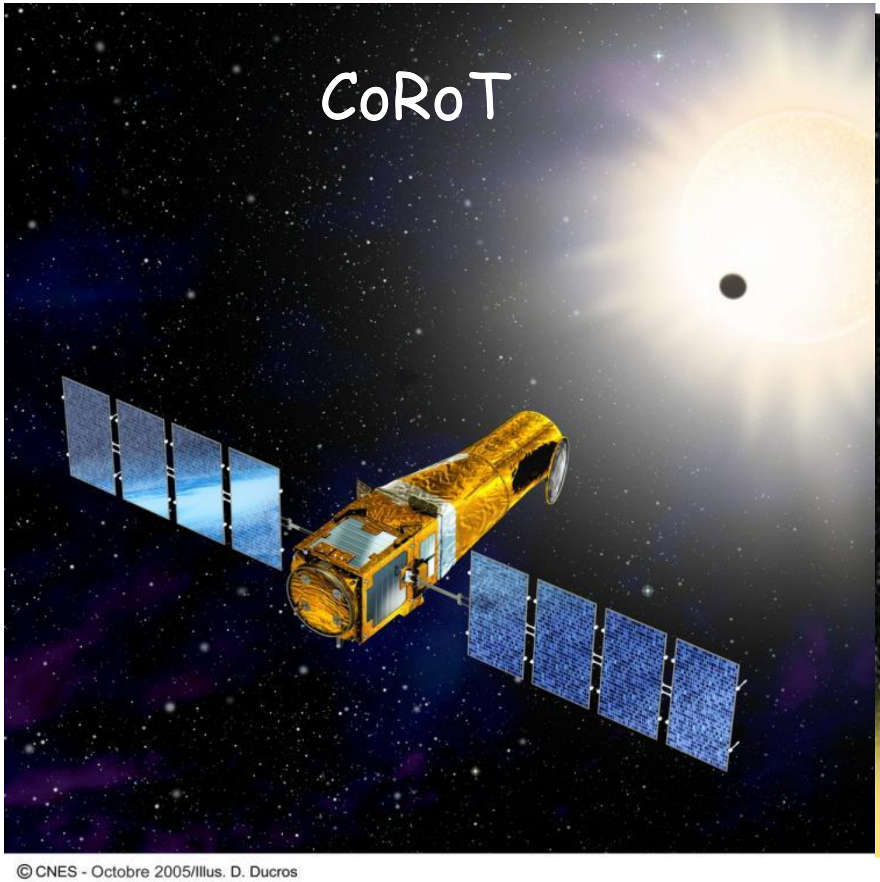
➔ R_{pl} ; P_{orb}

Transit of VENUS June 6, 2012

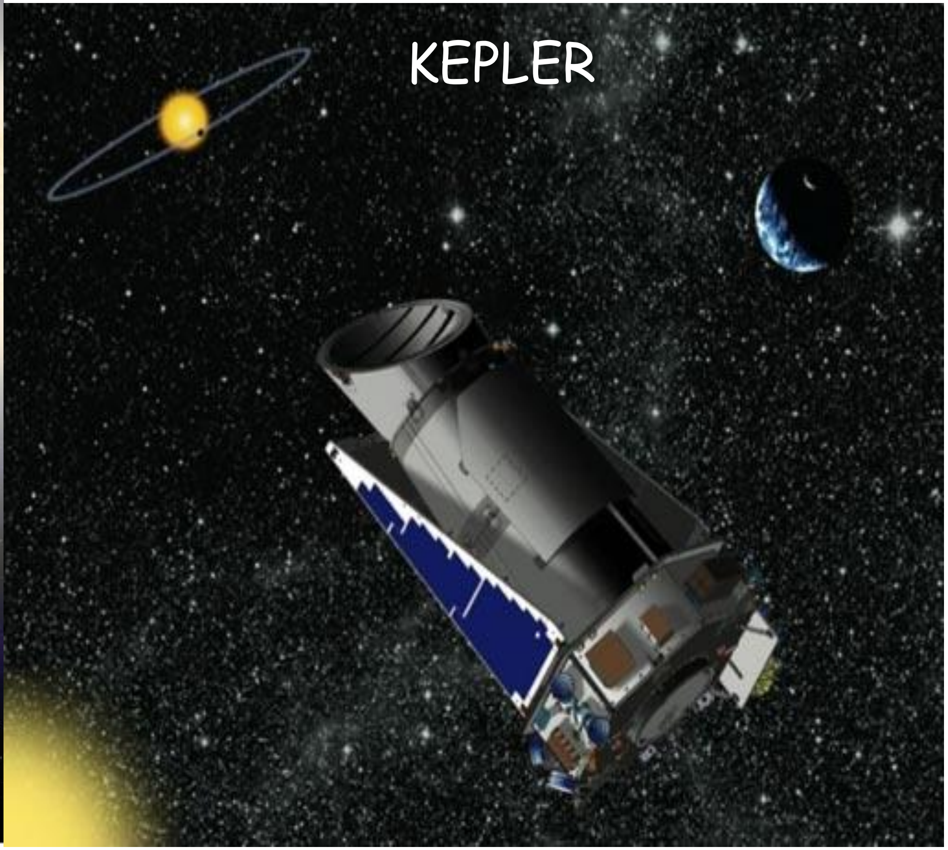


Satellites observing transits

Because drops in brightness are very small during an exoplanet transit, atmospheric turbulence is a great problem, and space observatories are used

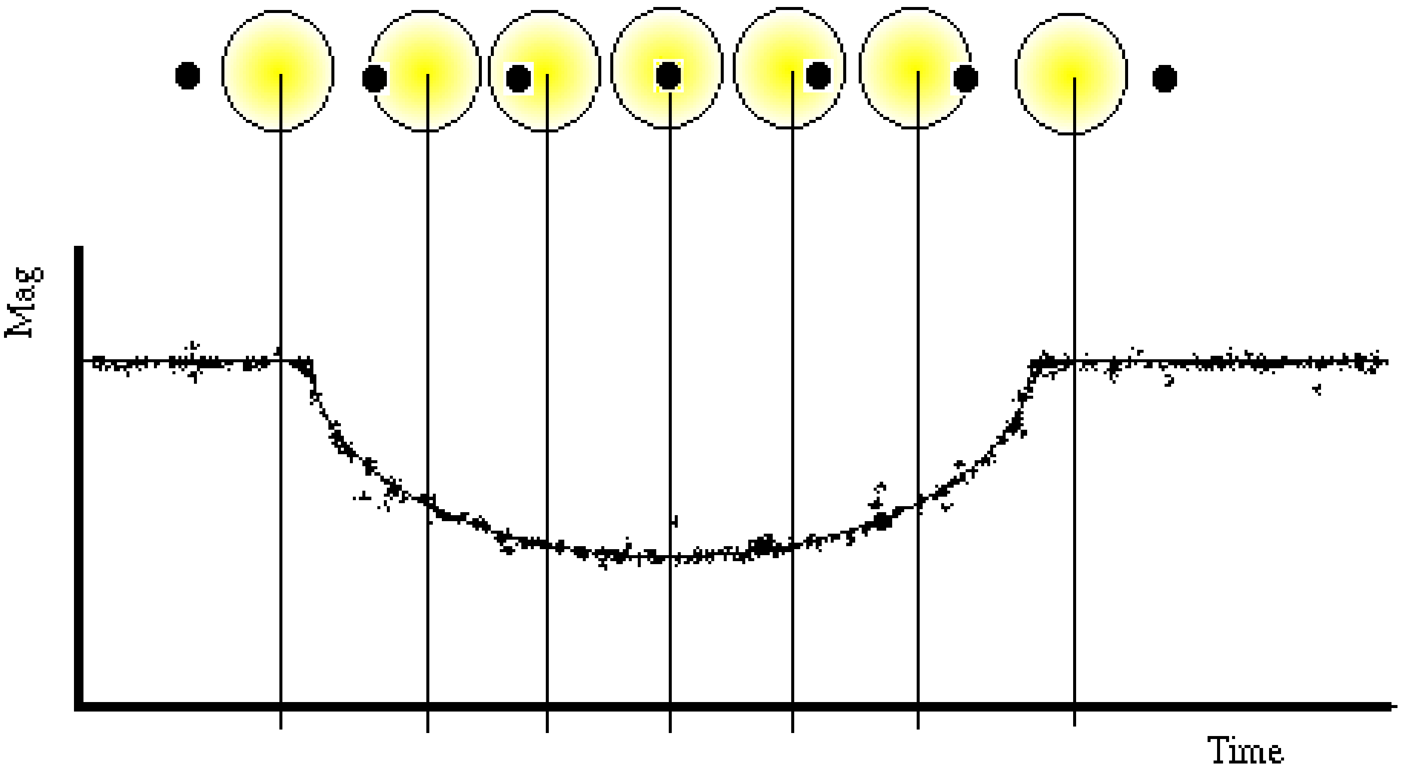


Europe + Brazil

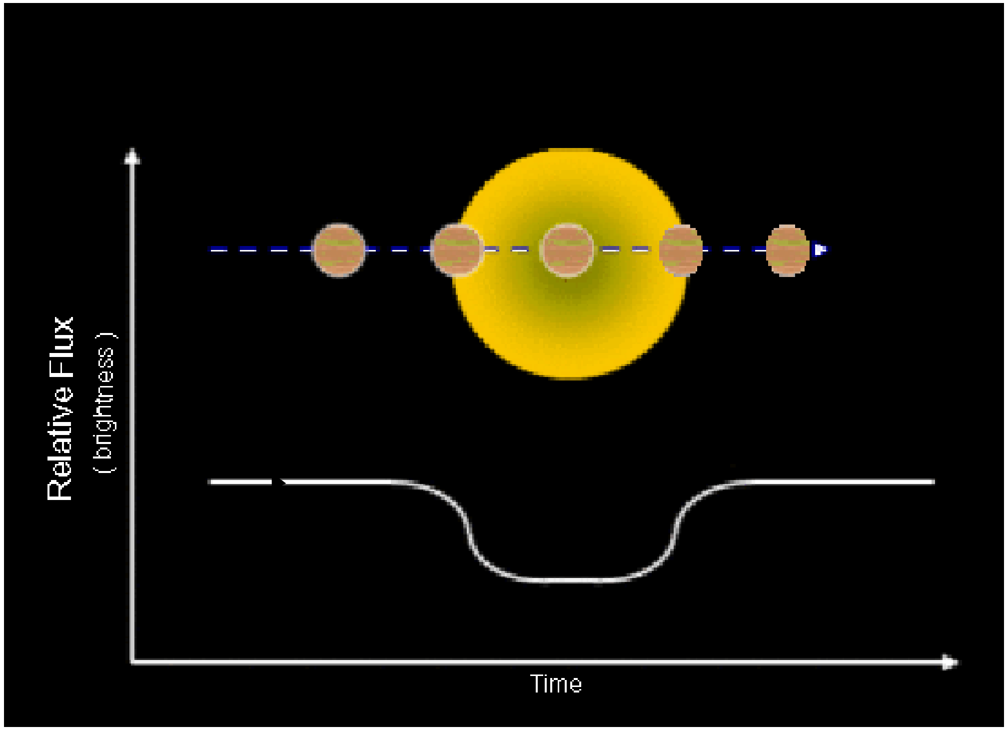


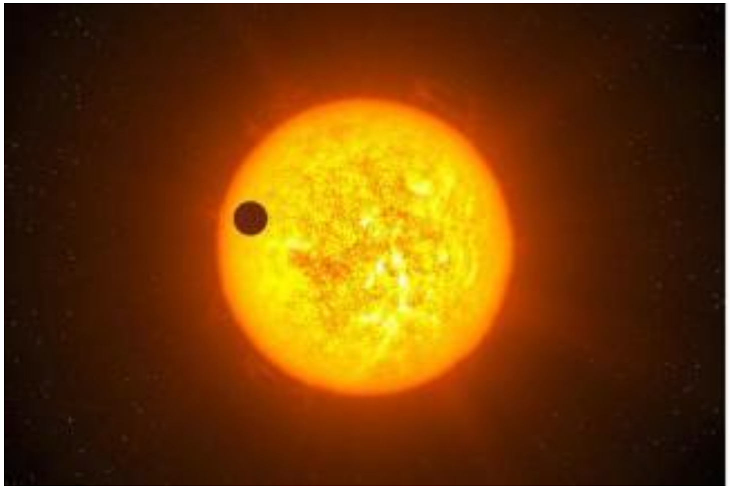
NASA

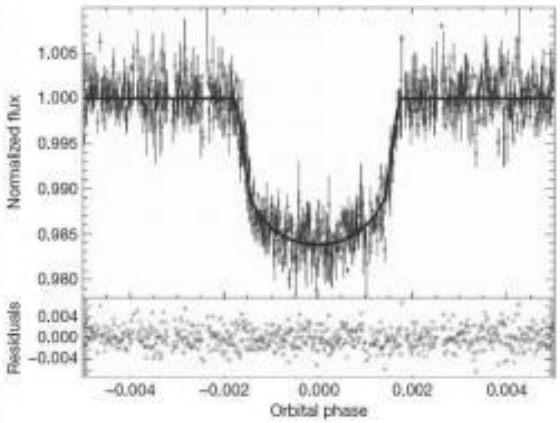
Detection of Planets-Transit Method



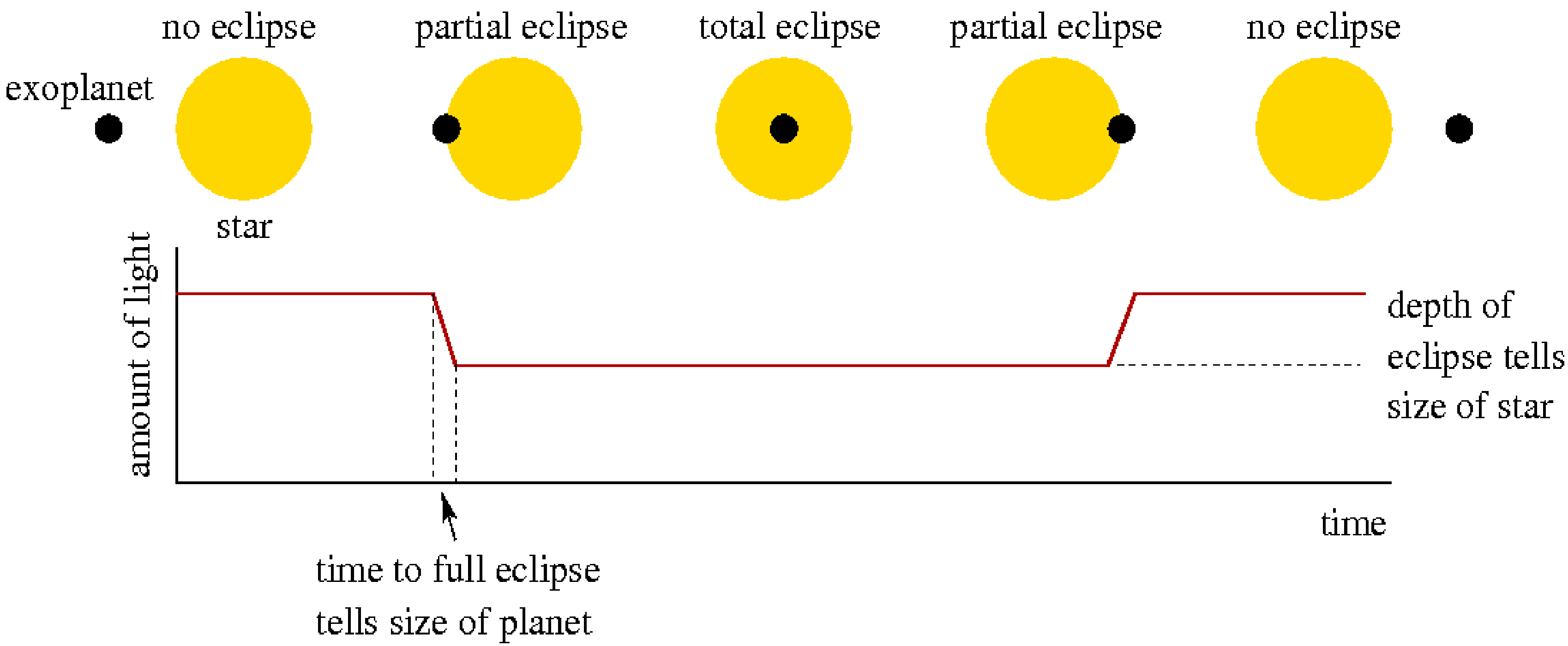
Method of planetary Transits







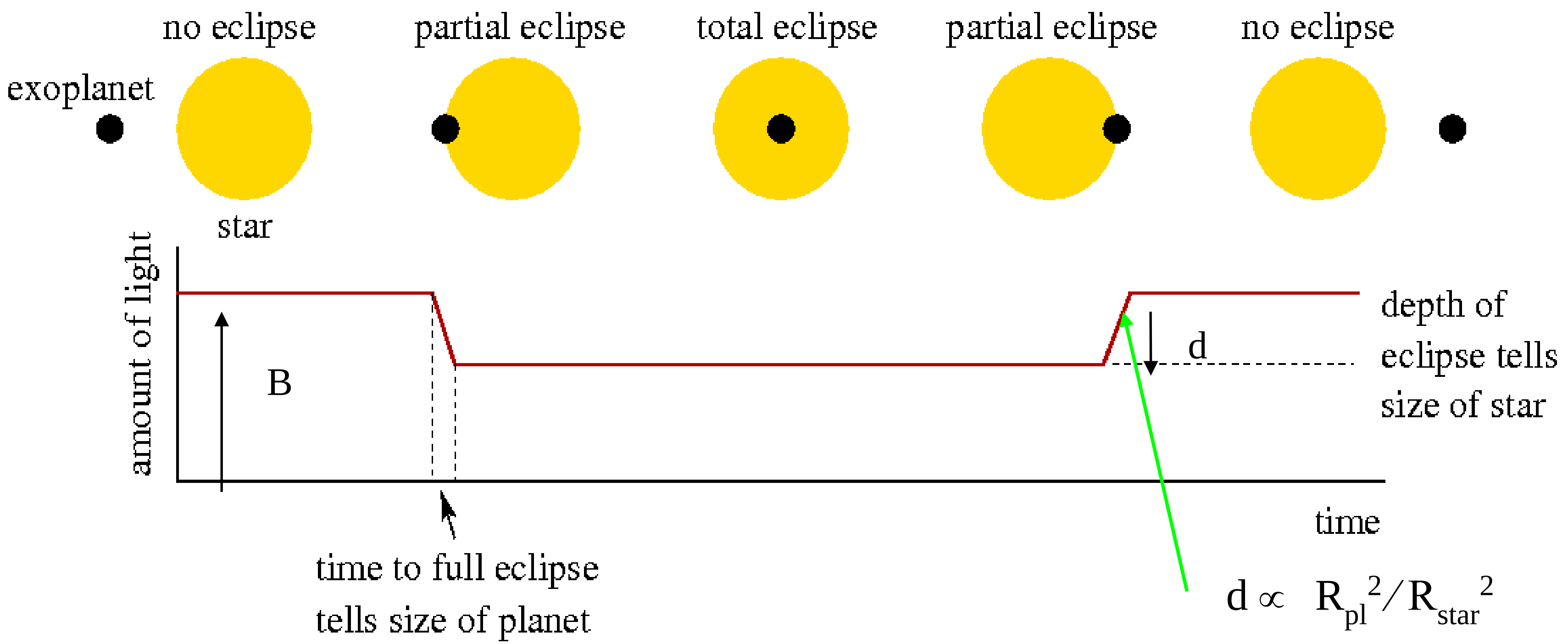
Método do Trânsito – Contatos



Durante o trânsito há 4 **contatos**, que são os instantes em que a borda do planeta toca a borda da estrela em um único ponto. Entre o contato 1 e o 2, o disco projetado do planeta está entrando no disco projetado da estrela. Por isso, o brilho da estrela diminui abruptamente. Entre os contato 2 e 3, o disco do planeta está inteiramente dentro do disco da estrela e por isso o brilho da estrela é constante. Entre os instantes de contatos 3 e 4, o disco do planeta está saindo do disco da estrela e por isso o brilho aumenta rapidamente.

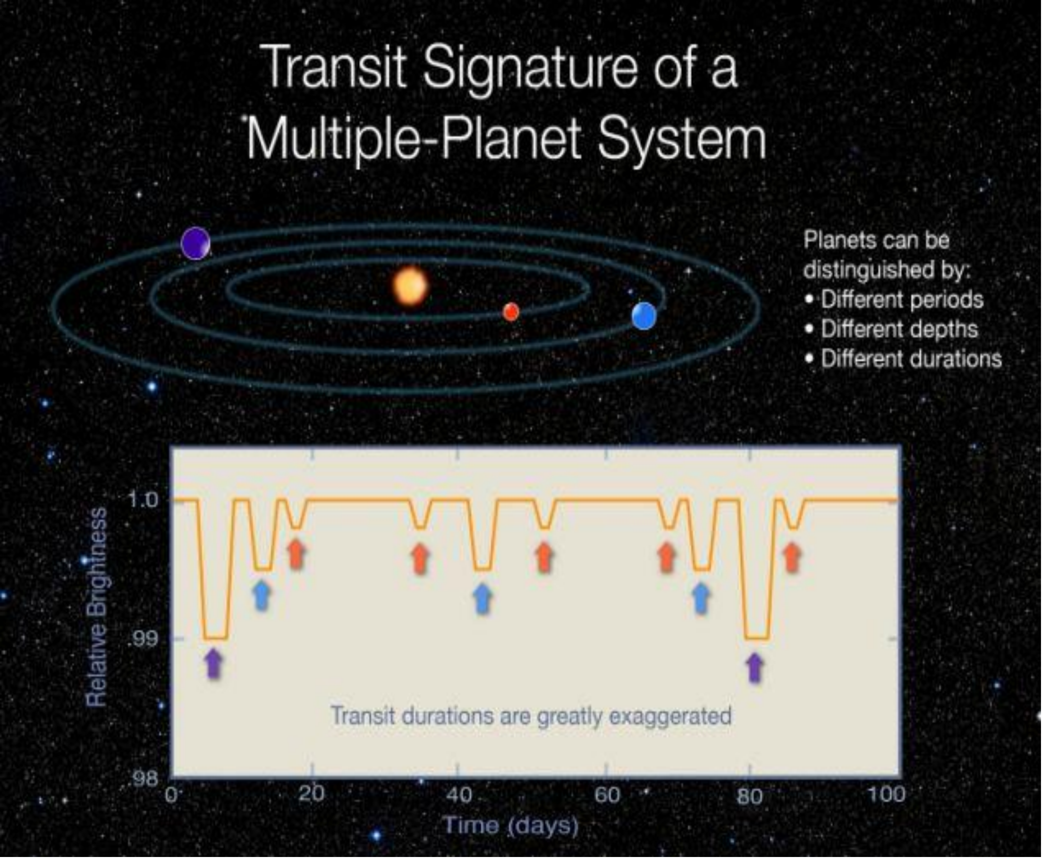
Os contatos são úteis para determinar a **composição atmosférica** do exoplaneta, pois nesses momentos uma parte significativa da atmosfera é iluminada por trás pela estrela, e elementos e moléculas são revelados por suas linhas de absorção.

Método do Trânsito – Determinando R_{pl}



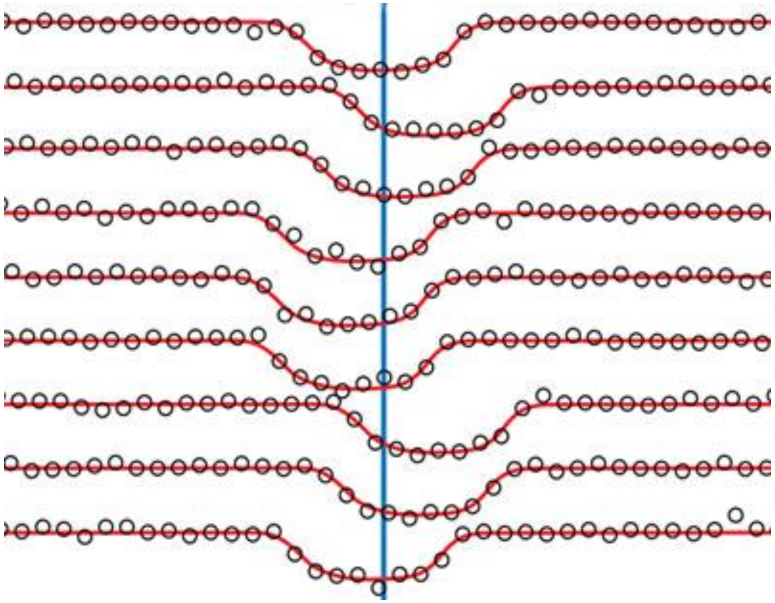
A profundidade do eclipse **d** (decremento máximo do brilho da estrela), é proporcional à razão entre as áreas do disco da planeta e da estrela ($\pi R_{pl}^2 / \pi R_{star}^2$), fornecendo o raio do planeta $\mathbf{R_{pl}}$ em termos do raio da estrela $\mathbf{R_{star}}$. Se **B** é o brilho do exoplaneta não eclipsado:

$$R_{pl}^2 / R_{star}^2 = d/B \rightarrow R_{pl} = R_{star}\,(d/B)^{1/2}$$

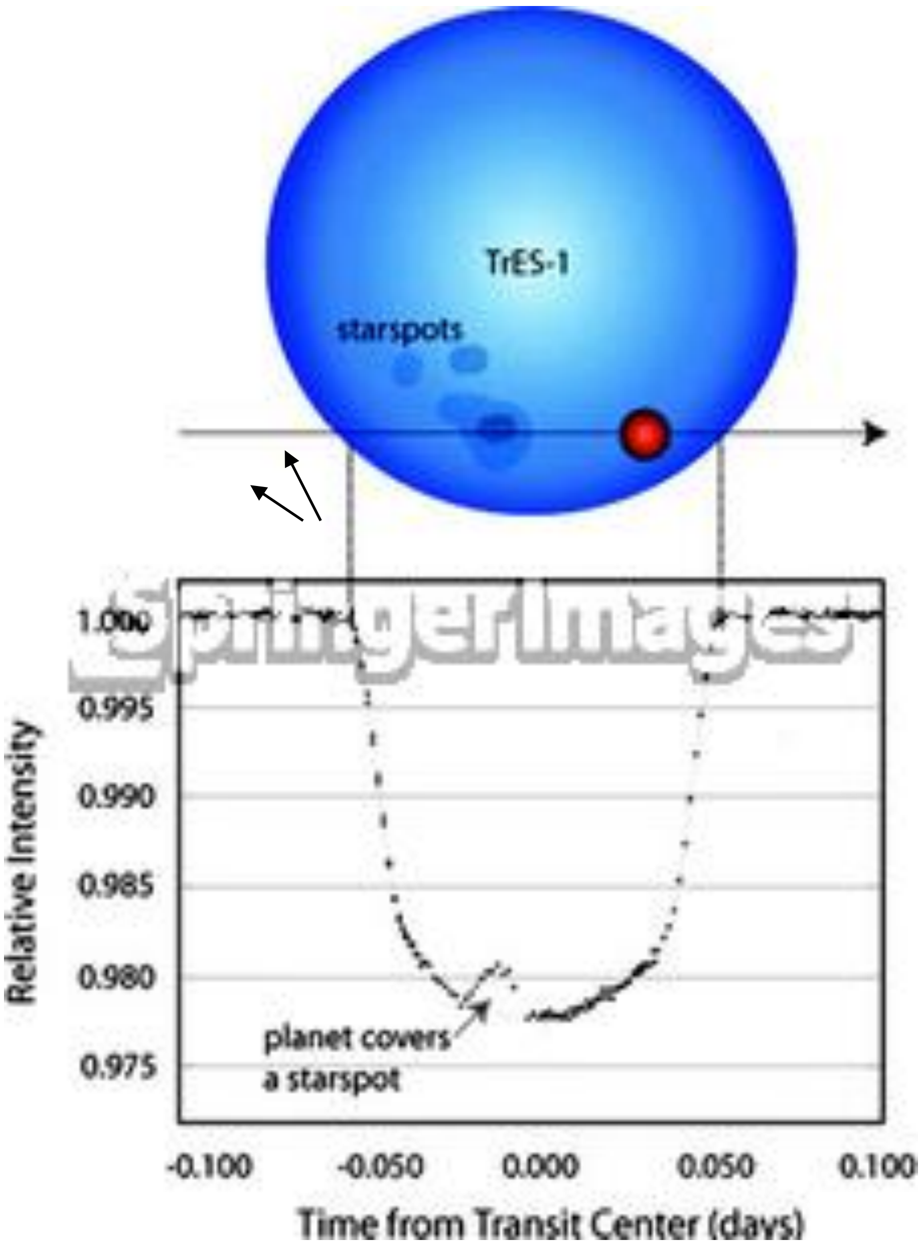


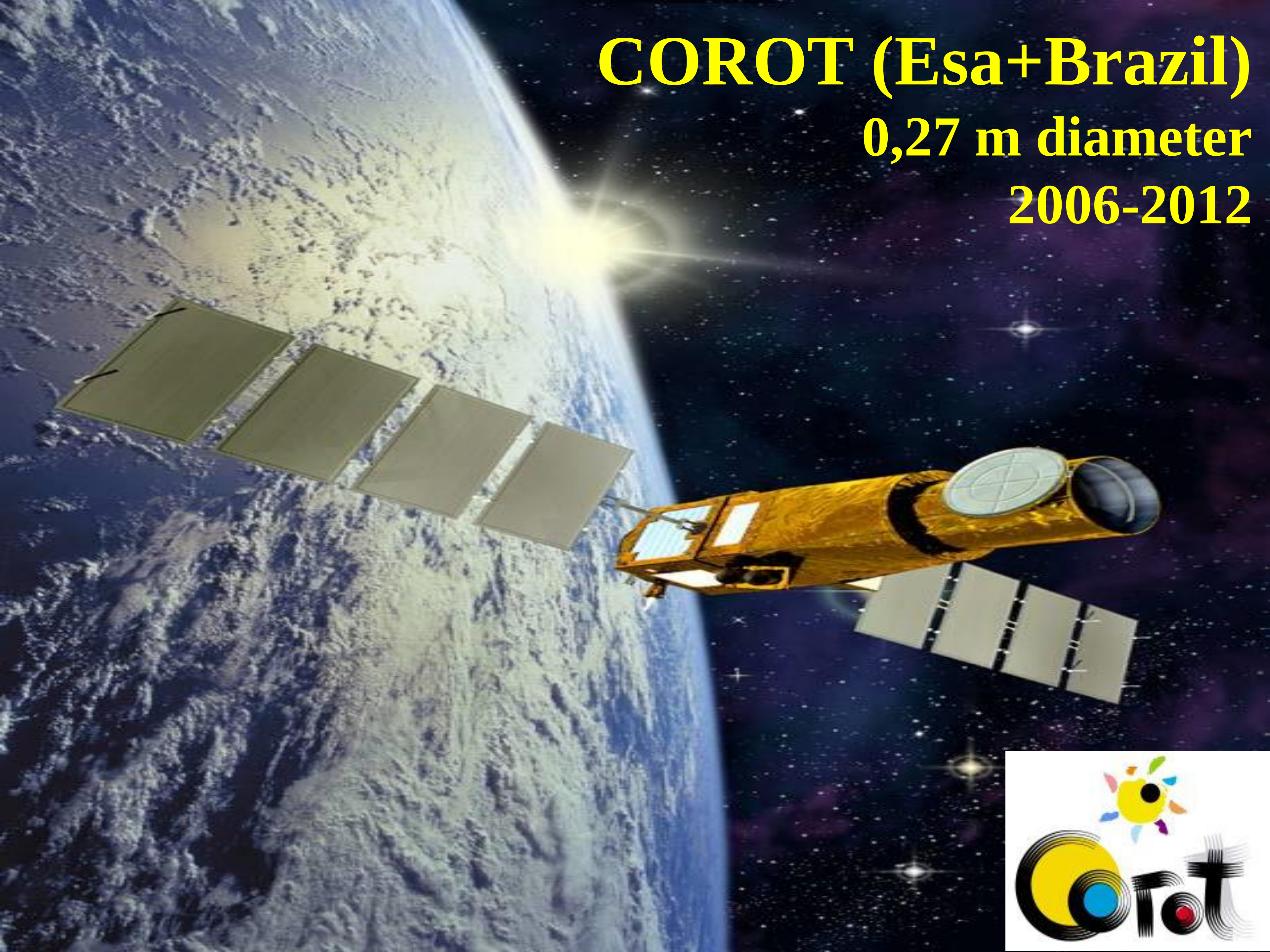
KEPLER and CoRoT have found tens of multiplanetary systems

The moment of the eclipse by one planet is perturbed by the presence of other planet(s)



Transit Method detects "starspots"




COROT (Esa+Brazil)
0,27 m diameter
2006-2012

KEPLER (Nasa) 0,95 m diameter
2009-2018/11/15 (400 years of J. Kepler’s death)

Spitzer (NASA) 0,85m diameter
(2003-2009) (2009-2020/01/30 Warm Spitzer)

IR space telescope

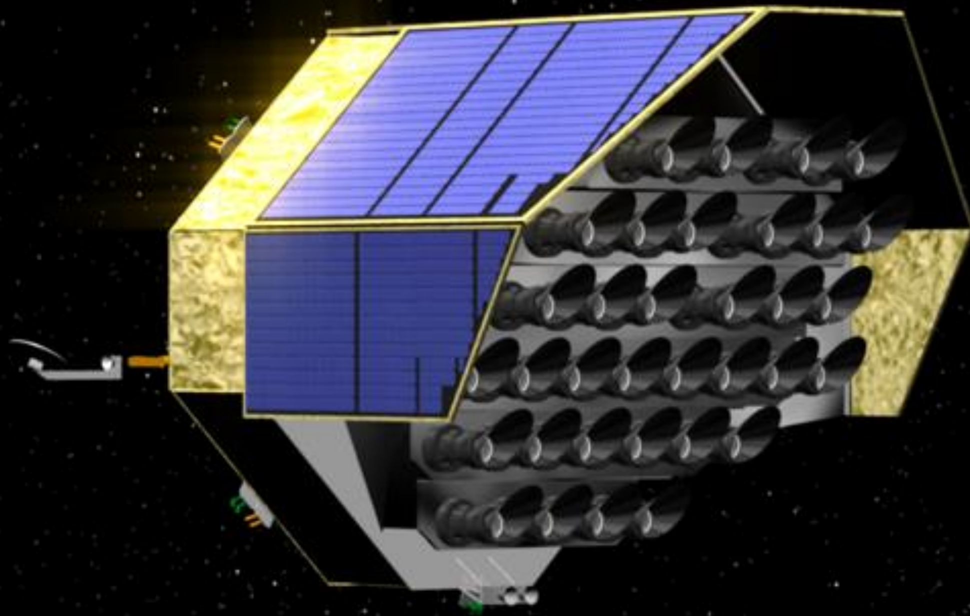
Tess

(Nasa)
4x
10.5cm dia.
refractors
2018-

PLATO

(ESA)

2026



Astrometric Method

$$\theta'' = \left(\frac{M_p}{M_*}\right)\left(\frac{a}{r}\right) \approx \frac{10^{-3}}{r(pc)}\left[\frac{P(yr)}{M_*(\odot)}\right]^{2/3} M_p(J)$$

$$V_r(m/s) \approx \frac{30}{[P(yr)]^{1/3}} \frac{M_p(J)\sin i}{[M_*(\odot)]^{2/3}}$$

Microlensing Method

$$R_E^2 = \frac{4GMD}{c^2},\quad D = \frac{D_{ds}D_d}{D_s},\quad t_0 = \frac{R_E}{V_t}$$

$$t_0 = \frac{2D_I\theta_E}{V_I} = \frac{2D_I}{V_I}\sqrt{\frac{4GM(1-D_d/D_s)}{c^2 D_d}}$$

$$A = \frac{u^2+2}{u(u^2+4)^{1/2}},\quad u = \text{impact parameter}$$

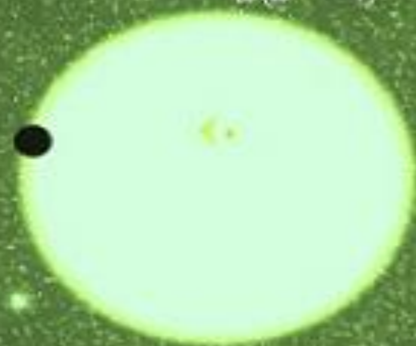
Radial Velocity Method

$$K = \left(\frac{2\pi G}{P}\right)^{1/3} \frac{M_p \sin i}{(M_* + M_p)^{2/3}} \frac{1}{\sqrt{1-e^2}}$$

$$M_p \sin i = \left(\frac{P}{2\pi G}\right)^{1/3} K M_*^{2/3}(1-e^2)^{1/2}$$

Direct Detection

$$B \geq \frac{\lambda D}{r} \approx \left(\frac{\lambda}{10\,\mu m}\right)\left(\frac{D}{10\,pc}\right)\left(\frac{r}{1\,AU}\right)^{-1} m$$



Effective Temperature

$$T_p = \frac{(1-A)^{1/4}}{\sqrt{2}}\left(\frac{R_*}{r}\right)^{1/2} T_*$$

$$A_\oplus \sim 0.39,\ T_* \sim 5770\,K,\ r_\oplus \sim 1\,AU$$

$$\Rightarrow T_p \sim 280\,K \Rightarrow \text{Greenhouse Effect!}$$

Transit Method

$$\frac{\Delta F}{F} = \left(\frac{R_p}{R_*}\right)^2,\quad t = \frac{P_p}{\pi}\left(\frac{R_*\cos\delta + R_p}{a_p}\right)$$

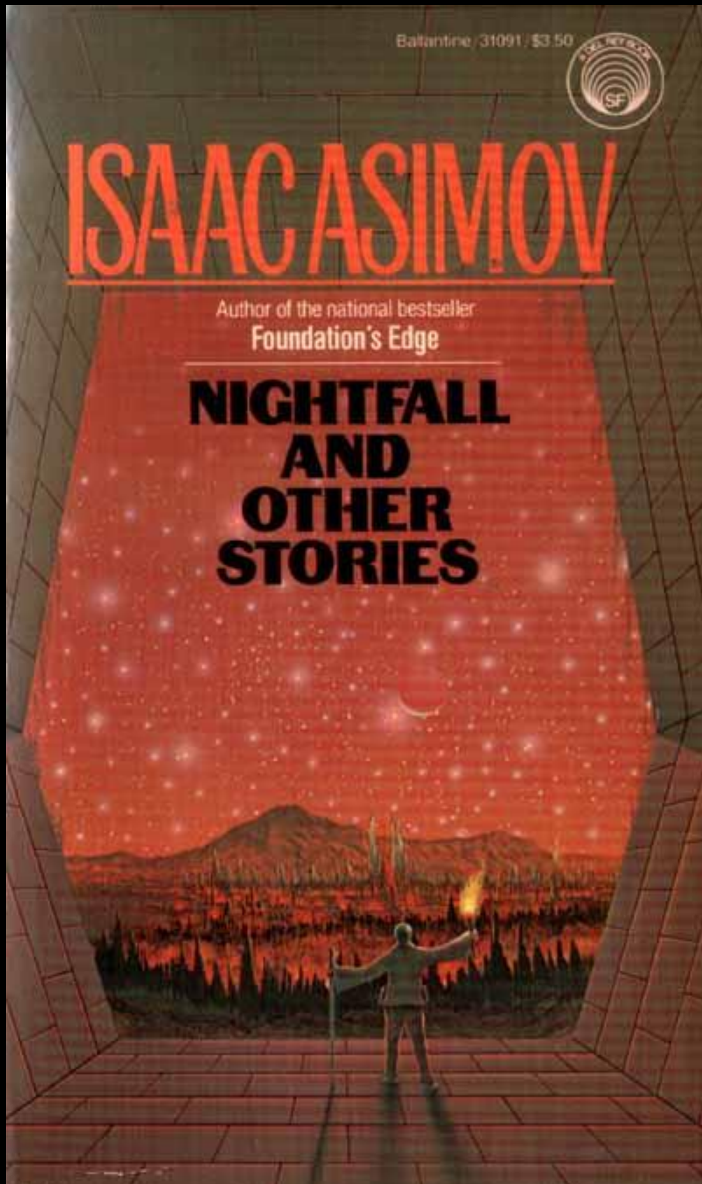
$$i_{min} = \cos^{-1}\left(\frac{R_*}{a_p}\right),\quad \cos i = \frac{R_*\sin\delta}{a_p}$$

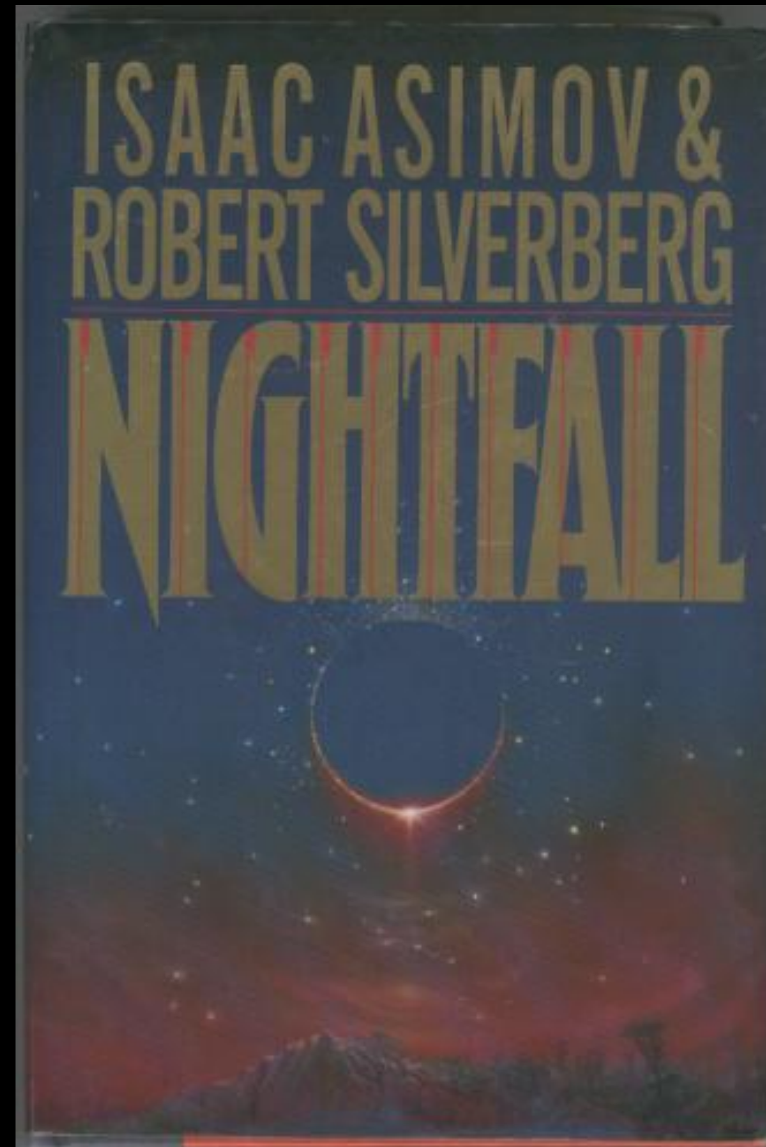
THE EXOPLANET ZOO

Number of planets in the Milky Way: ~ 400 billion

Number of **Earth-like** planets in the Milky Way: ~ 100 billion

1941


Ballantine/31091/$3.50
ISAAC ASIMOV
Author of the national bestseller
Foundation's Edge
NIGHTFALL
AND
OTHER
STORIES


ISAAC ASIMOV &
ROBERT SILVERBERG
NIGHTFALL

1990

HD 188753 Ab (2005)

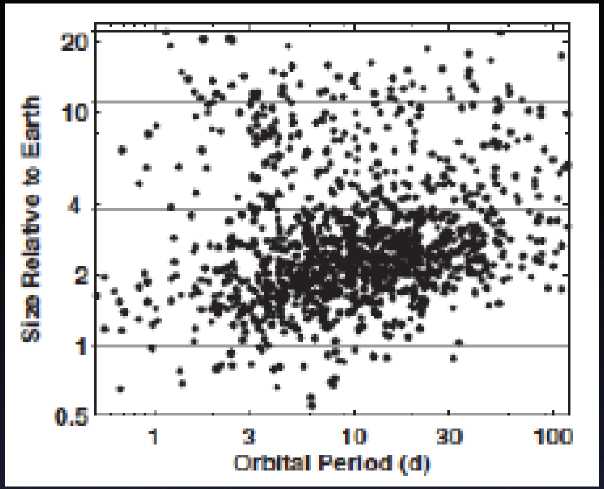
- Período(B-C)=156 dias
- Período(BC-A)=25.7 anos
- Período(P-A)=3.3 dias

Outra possibilidade interessante:

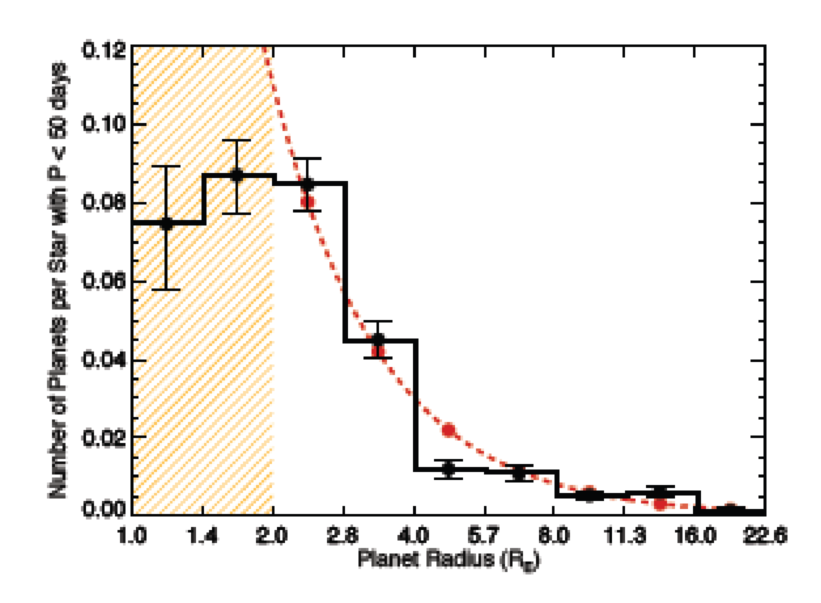
Rocky Moon orbiting a Jupiter in HZ

There are many Jupiters discovered in HZ

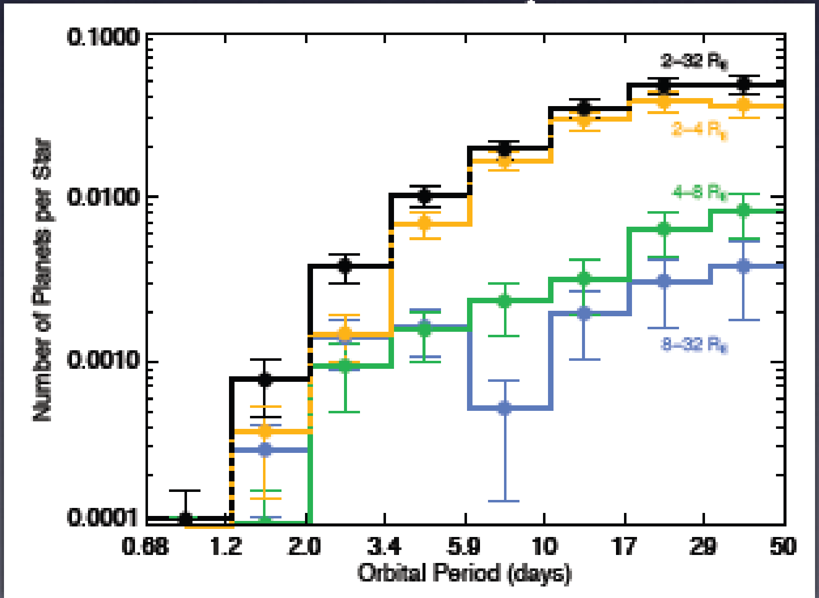
Lessons from Kepler



Borucki et al., 2011, ApJ



Howard et al., 2011, ApJ



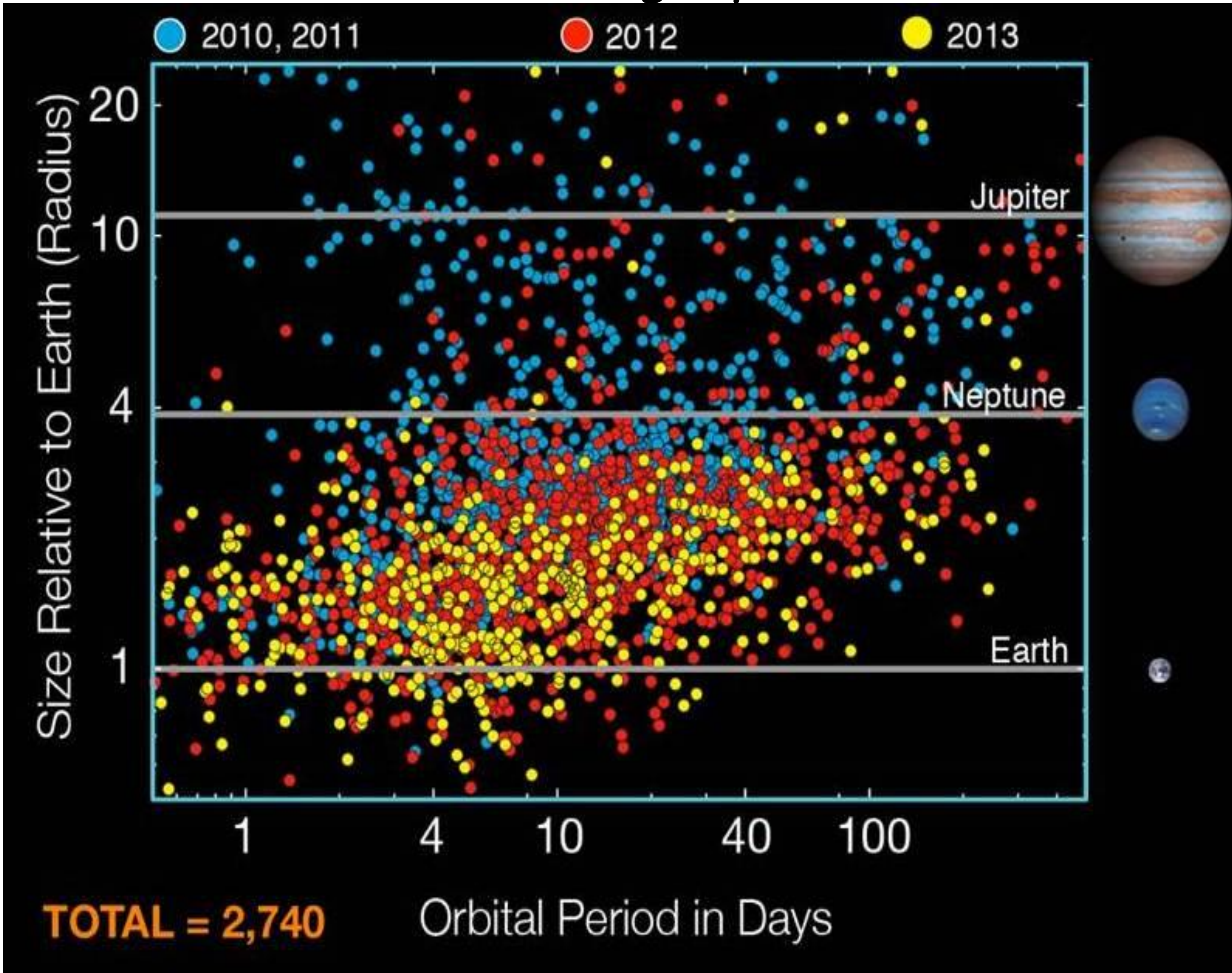
Planet population at orbital period less than 50 days :

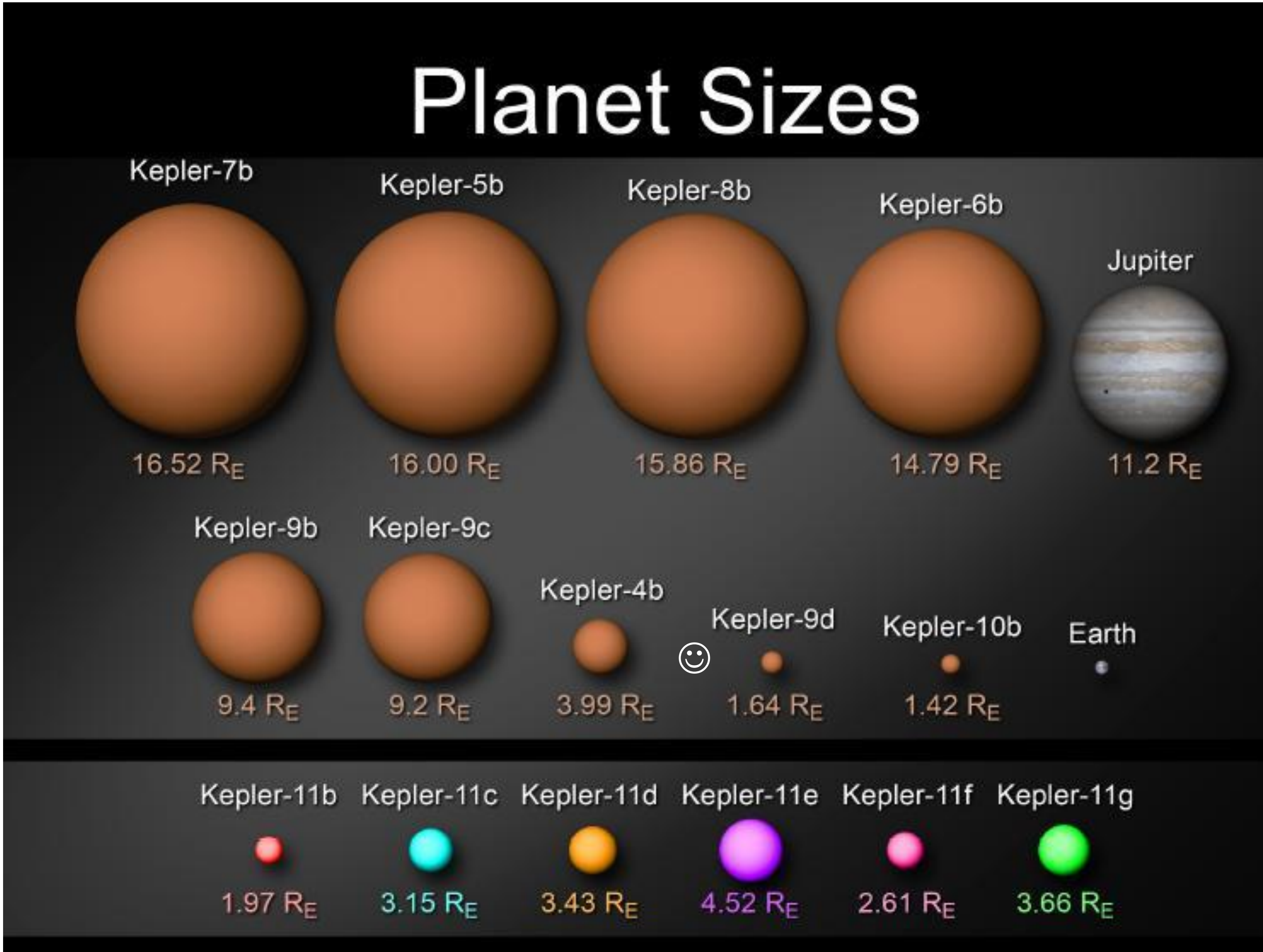
➪ small size planets (range 2 - 4 R⊕) are the most numerous

➪ their frequency increases with increasing orbital period

➪ multiple transiting systems are frequent ~18%

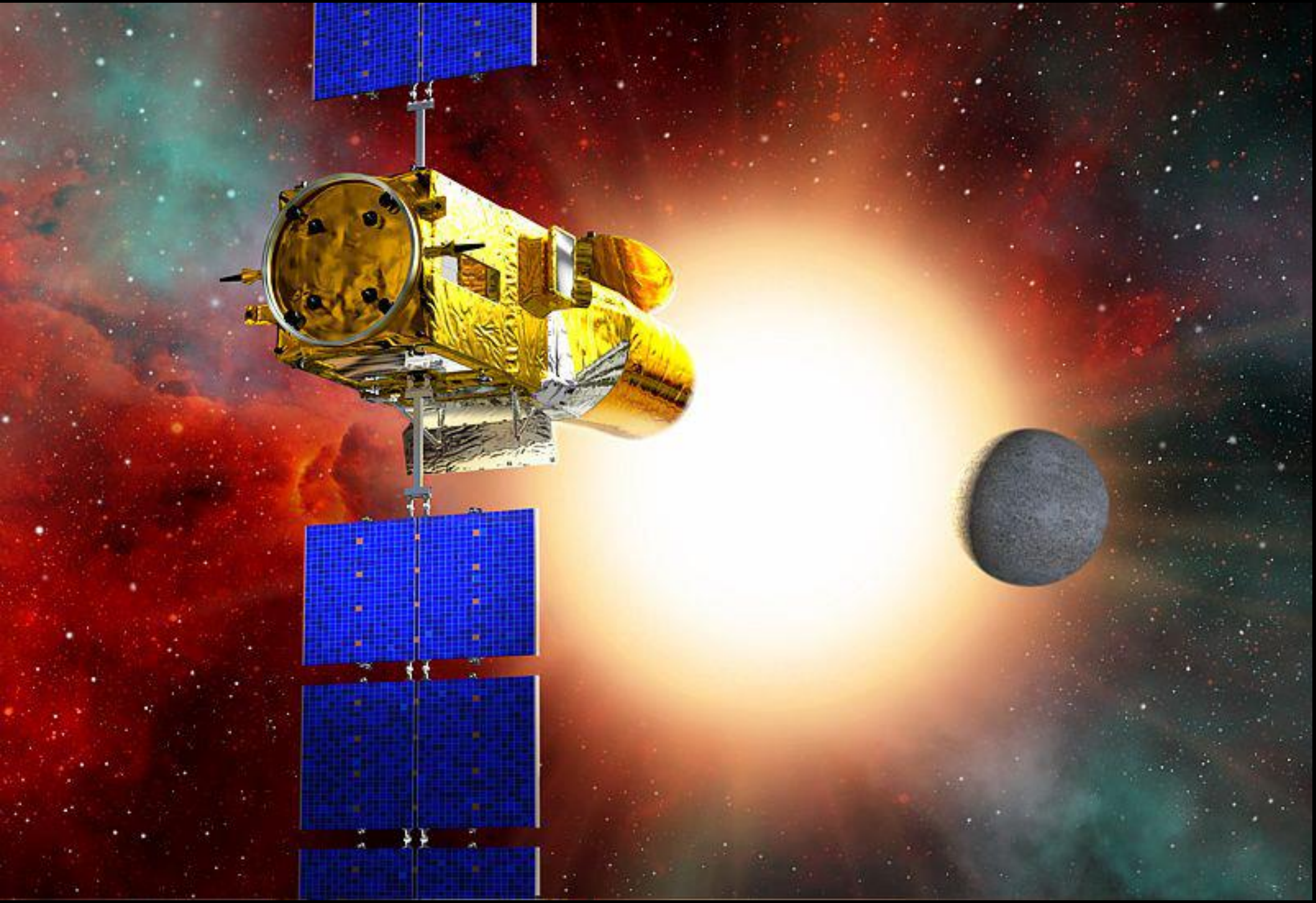
The KEPLER + CoRoT legacy (www.seti-setr.org)




Planet Sizes
Kepler-7b
Kepler-5b
Kepler-8b
Kepler-6b
Jupiter
16.52 R_E
16.00 R_E
15.86 R_E
14.79 R_E
11.2 R_E
Kepler-9b
Kepler-9c
Kepler-4b
Kepler-9d
Kepler-10b
Earth
☺
9.4 R_E
9.2 R_E
3.99 R_E
1.64 R_E
1.42 R_E
Kepler-11b
Kepler-11c
Kepler-11d
Kepler-11e
Kepler-11f
Kepler-11g
1.97 R_E
3.15 R_E
3.43 R_E
4.52 R_E
2.61 R_E
3.66 R_E

☺ = CoRoT 7b

CoRoT discovers "super Earth"

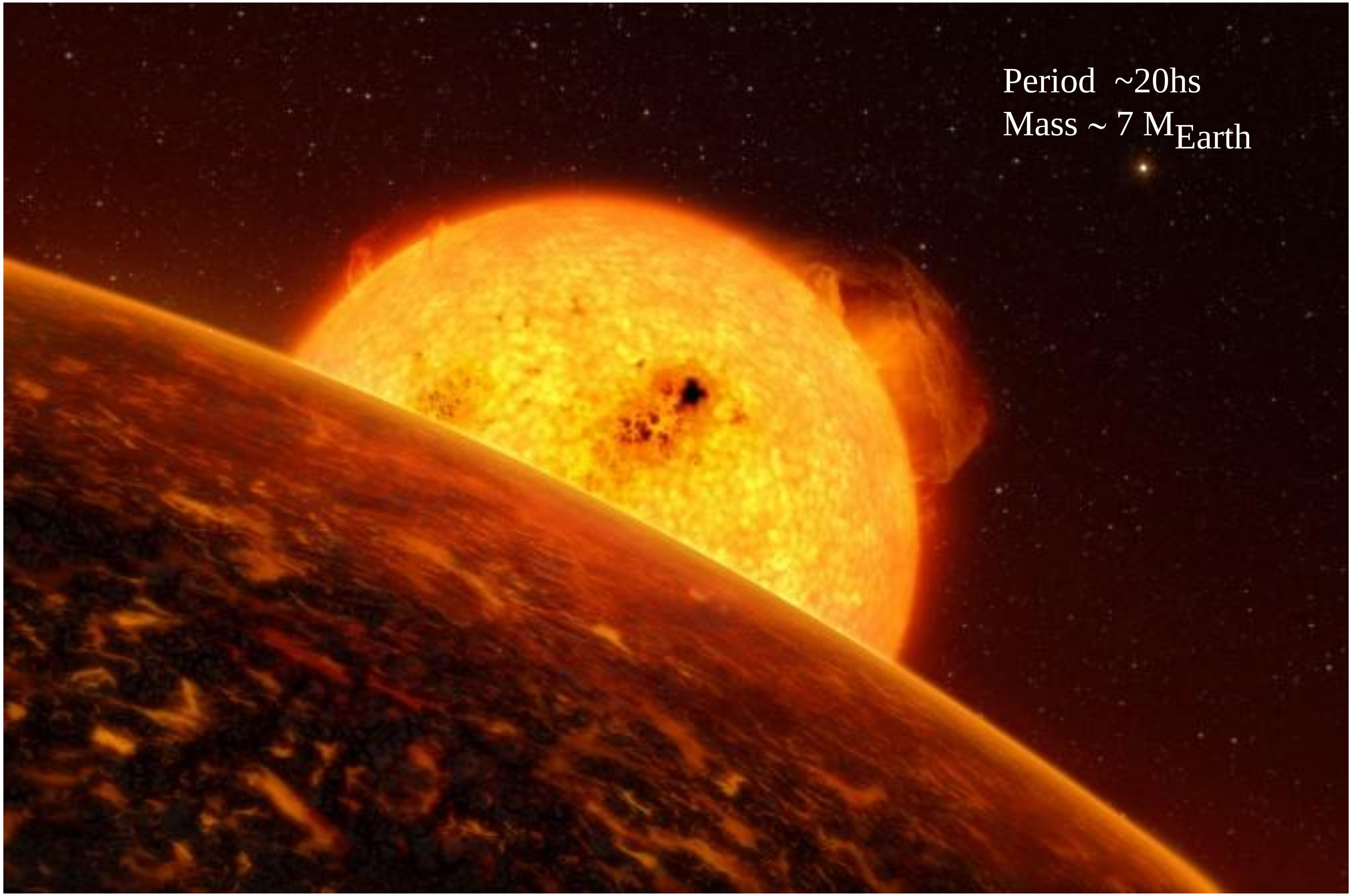


(02/09/2009)

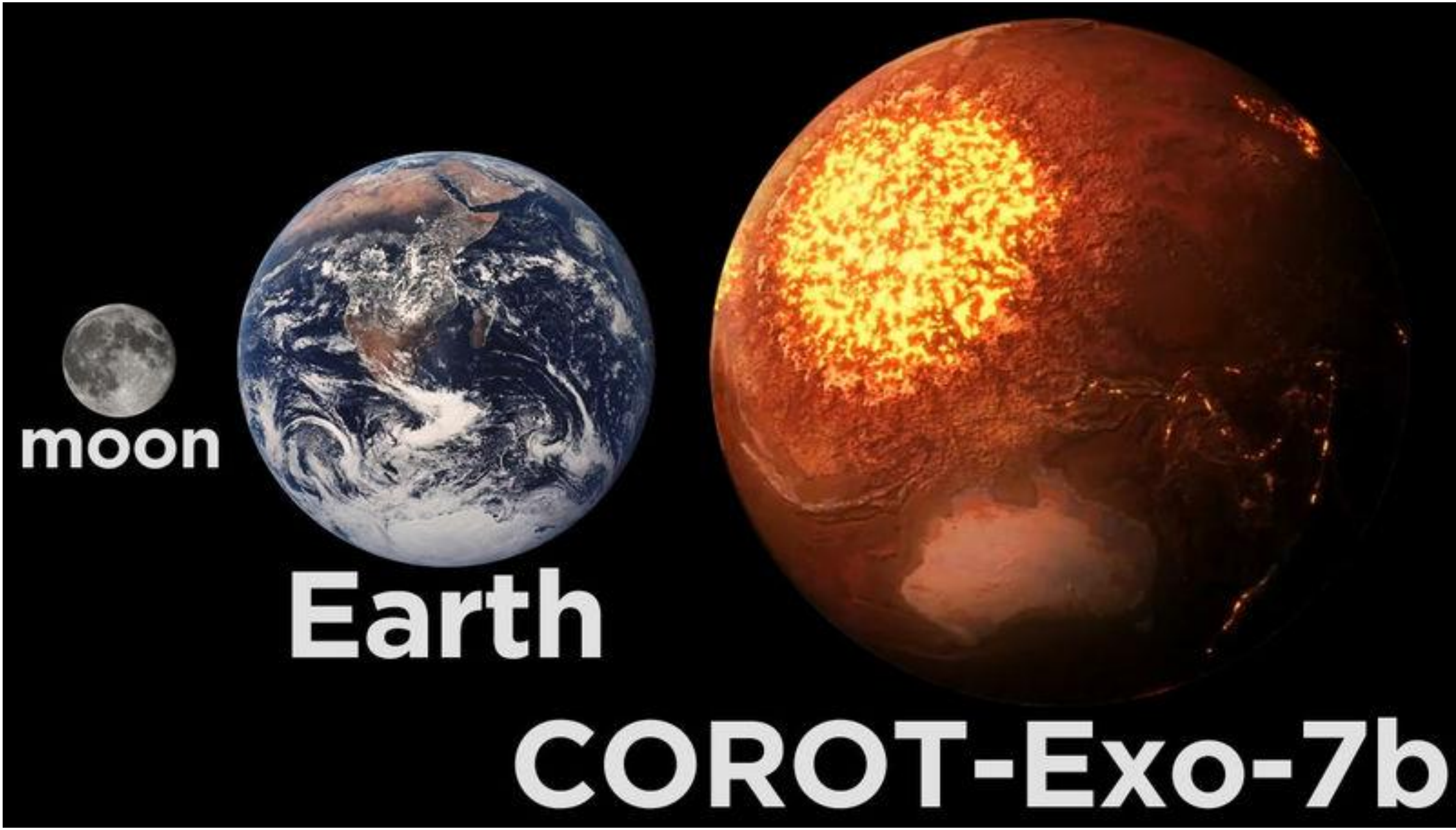
CoRoT-Exo-7b

$R \sim 1.7\ R_{Earth}$

$T \sim 1000\text{-}1500\ ^{o}C$



CoRoT 7-b, the first planet discovered with Earth-like density


moon
Earth
COROT-Exo-7b

Métodos de Detecção de Exoplanetas
Informações e Limitações

1) Período orbital P_{orb}
2) Semieixo maior da órbita a
3) Excentricidade e
4) Inclinação da órbita i
5) Massa M_{pl}
6) Raio R_{pl}
7) Composição química do planeta (rochoso/gasoso)
8) Composição atmosférica

Velocidade radial Limitação: i ≠ 0º (linha de visada não perpendicular à órbita)
P_{orb}, a, e, $\mathrm{M_{pl}sen(i)}$, composição do planeta

Trânsito Limitação: i próximo de 90º (linha de visada alinhada com a órbita)
P_{orb}, a, e, i, R_{pl}, composição do planeta, composição atmosférica

Habitabilidade

The Habitable Zone (HZ)

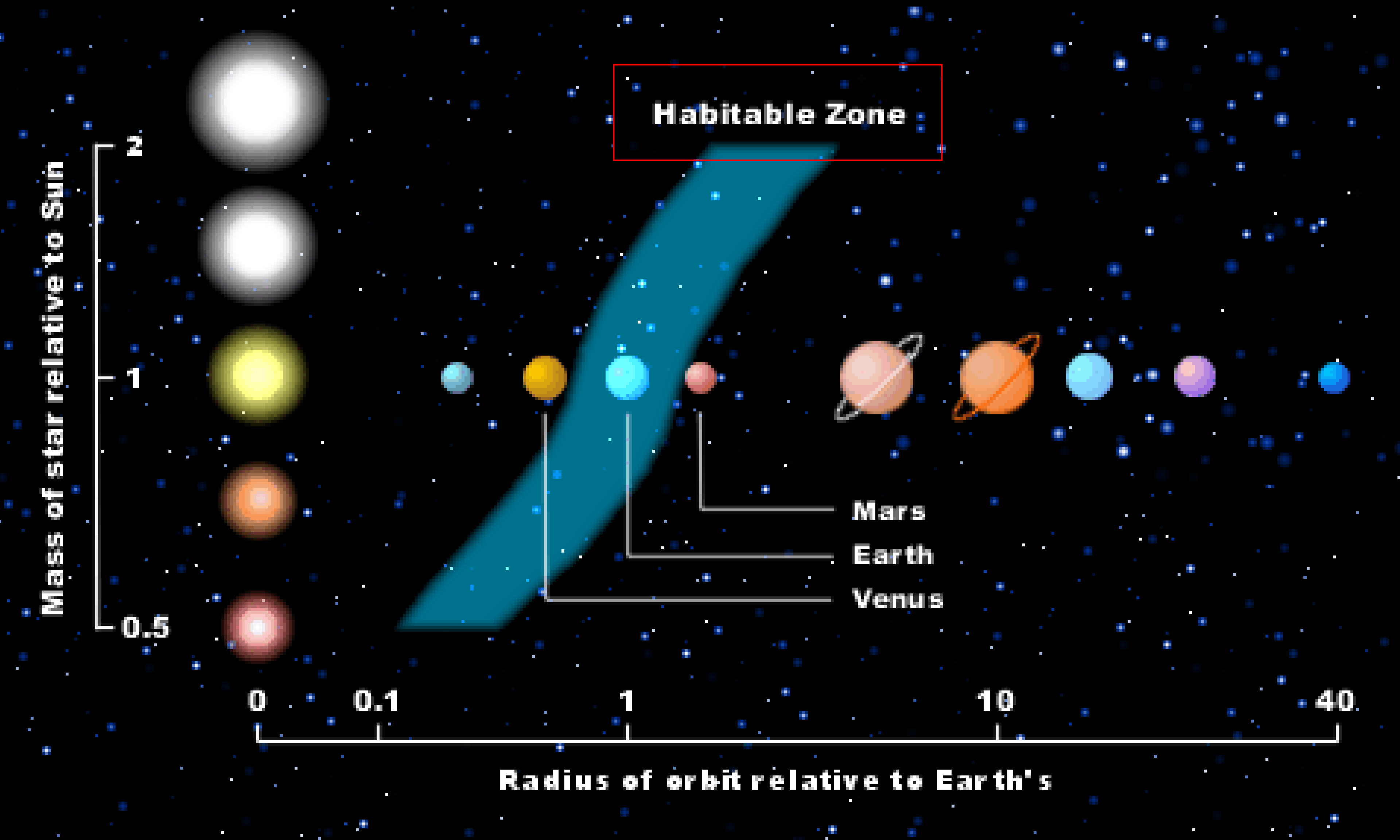
Definition: region around a star where the temperature on the surface of an eventual planet or moon can afford the presence of liquid water.

Conditions: the position and width of the HZ depends on the presence and composition of the atmosphere (greenhouse effect - GE).

On **EARTH**: GE raises temperature by ~32 °C

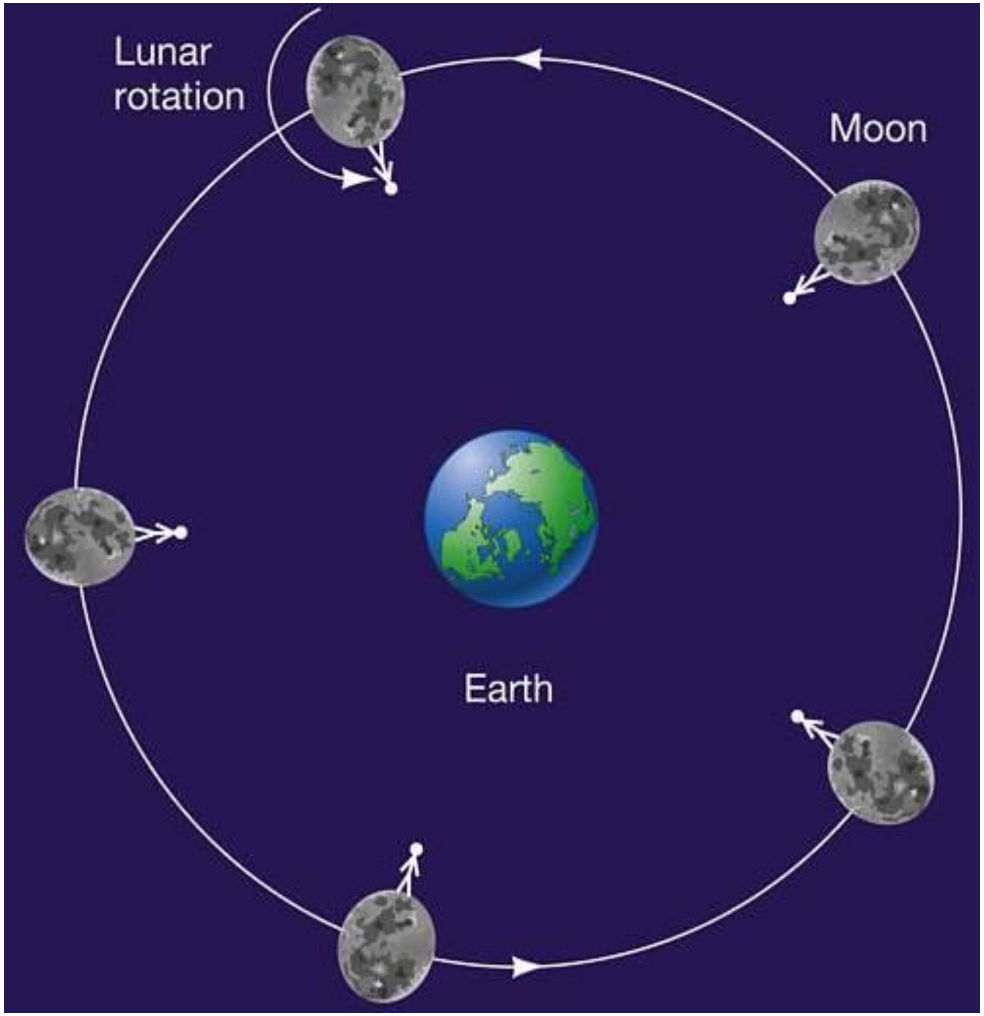
Zona Habitável Estelar

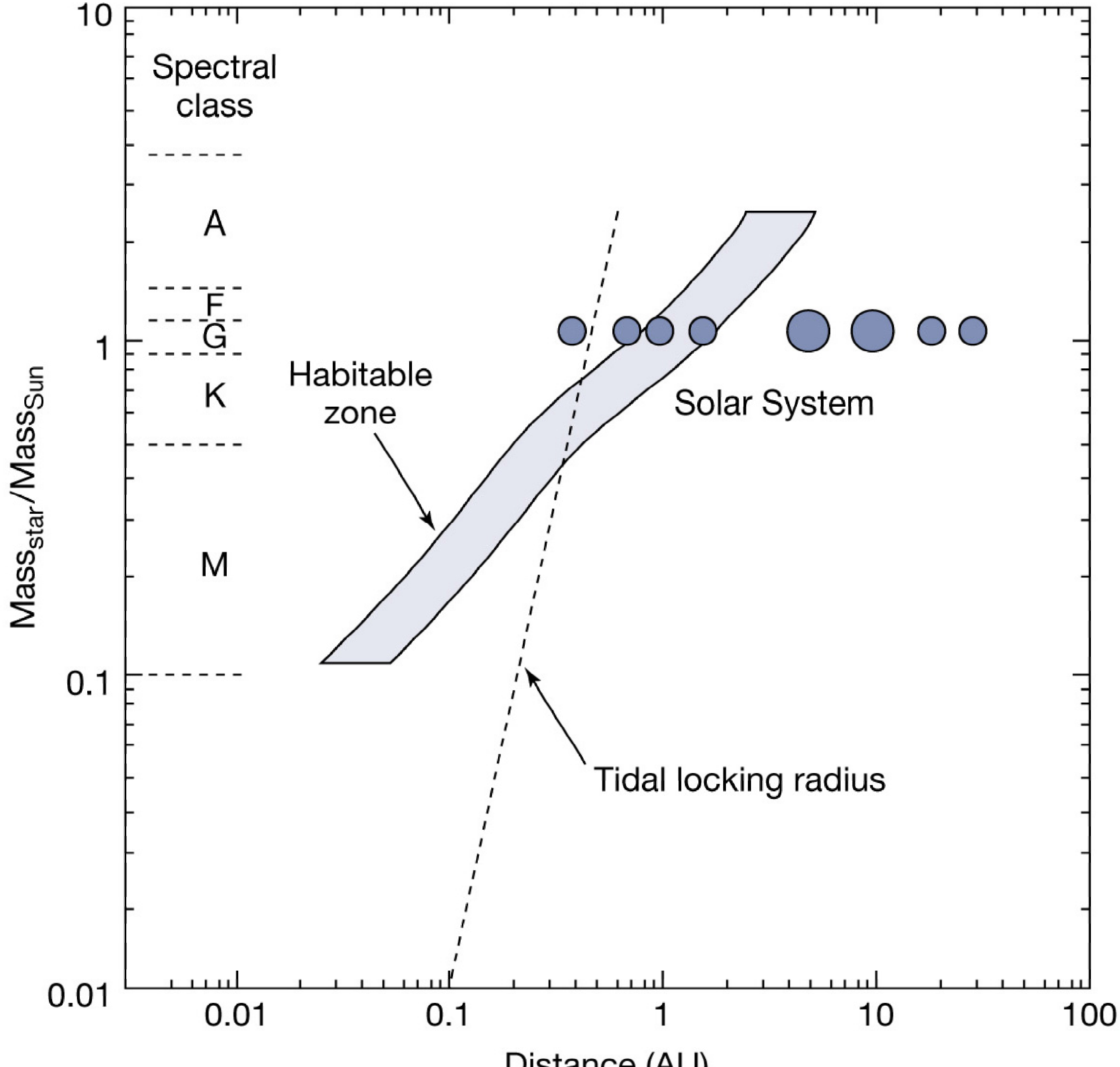
Água Líquida → Zona Habitável



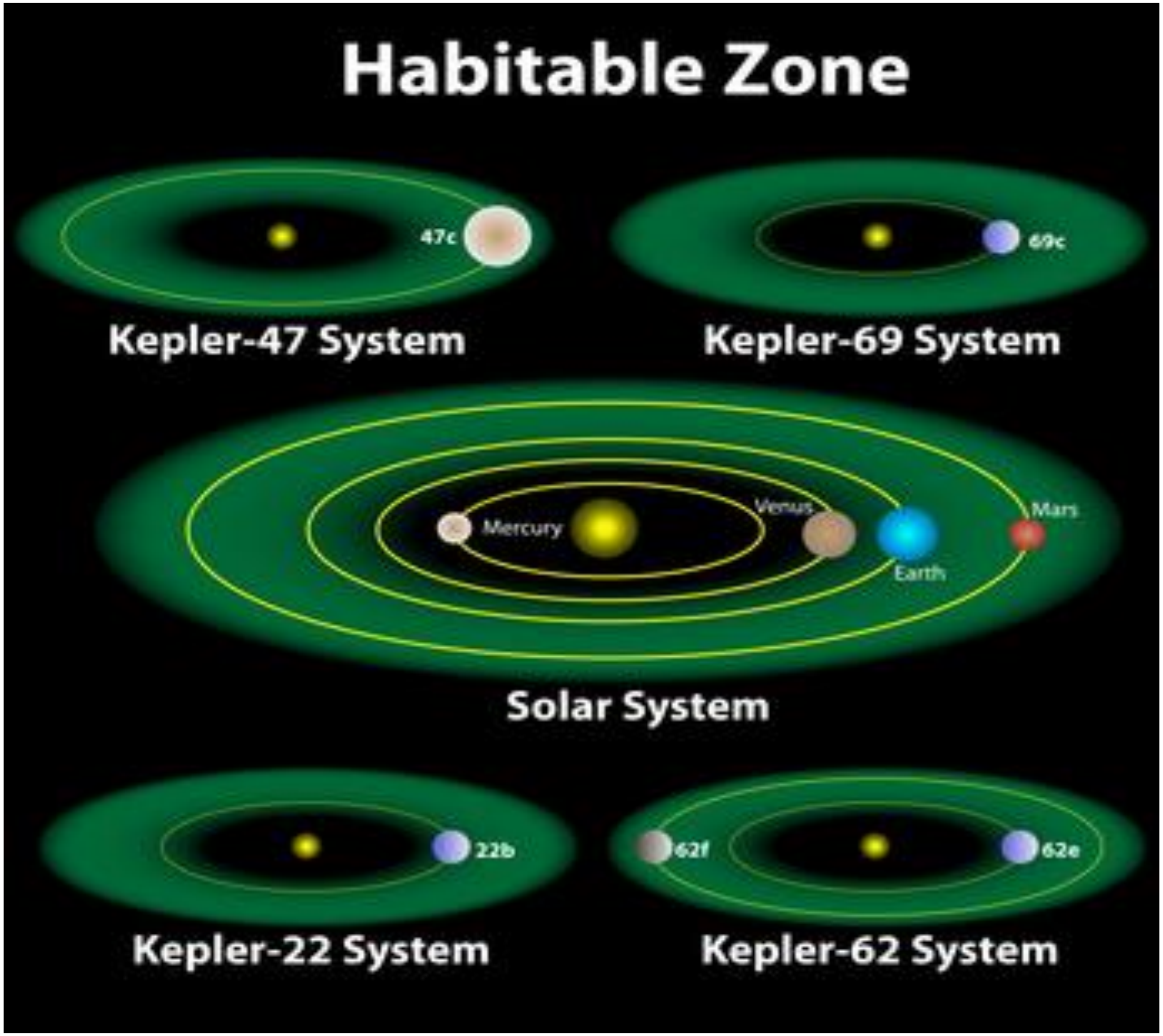
Prospects for finding habitable planets

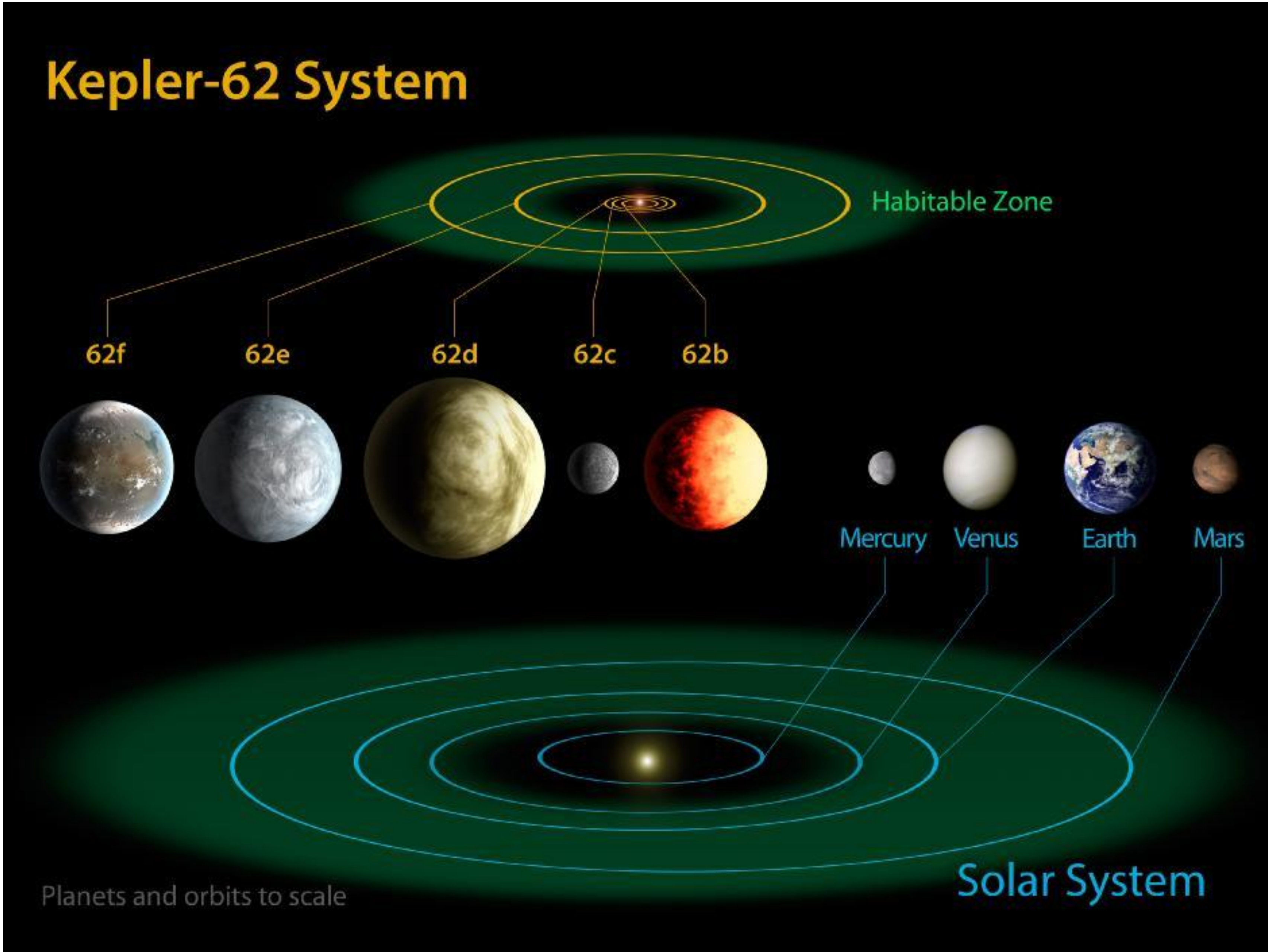
- Best candidates are F, G, and early K-type stars, *i.e.*, stars not too different from the Sun
- Early-type stars (blue stars)
  - High UV fluxes
  - Short main sequence lifetimes
- Late-type stars (red dwarfs) – M-class
  - Tidal locking
  - Lots of flares
  - But: 85% of stars in Milky Way are red dwarfs (> 100 billion planets)

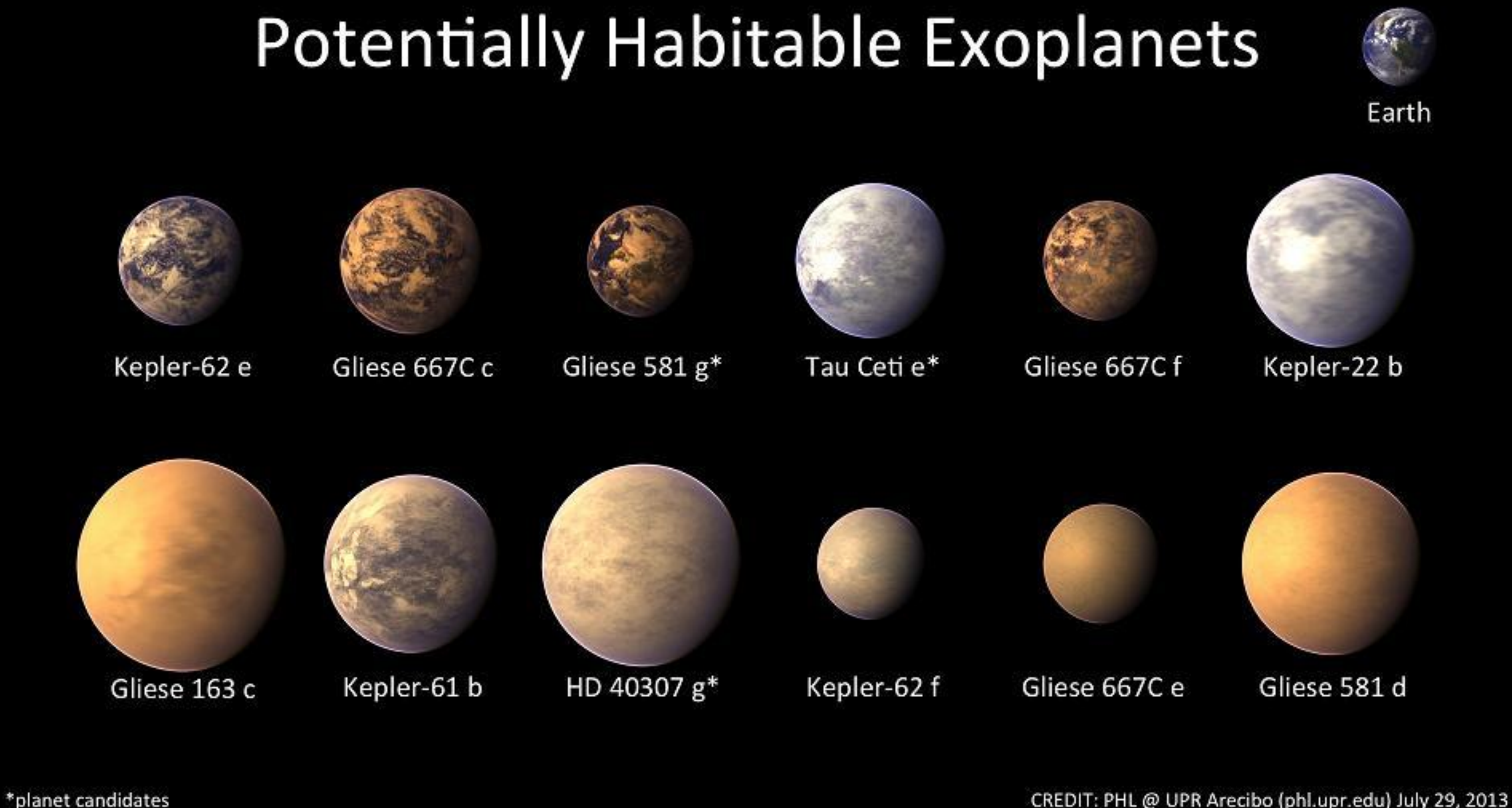

Lunar rotation
Moon
Earth



10
Spectral class
A
F
G
1
K
Habitable zone
Solar System
M
0.1
Tidal locking radius
0.01
0.01
0.1
1
10
100
Distance (AU)
$Mass_{star}/Mass_{Sun}$


Habitable Zone
47c
Kepler-47 System
69c
Kepler-69 System
Mercury
Venus
Earth
Mars
Solar System
22b
Kepler-22 System
62f
62e
Kepler-62 System


Kepler-62 System
Habitable Zone
62f
62e
62d
62c
62b
Mercury
Venus
Earth
Mars
Solar System
Planets and orbits to scale


Potentially Habitable Exoplanets
Earth
Kepler-62 e
Gliese 667C c
Gliese 581 g*
Tau Ceti e*
Gliese 667C f
Kepler-22 b
Gliese 163 c
Kepler-61 b
HD 40307 g*
Kepler-62 f
Gliese 667C e
Gliese 581 d
*planet candidates
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) July 29, 2013

O Estranho Caso do Sistema Solar de Gliese 581

Astrônomos descobrem planeta que pode ser habitável

Folha Online 24/04/2007 - 22h44

Astrônomos encontraram um planeta fora do nosso Sistema Solar que é potencialmente habitável, com temperaturas parecidas com as da Terra. A descoberta foi considerada um grande passo na procura por vida extraterrestre.

Sistema planetário de Gliese 581

O planeta tem o tamanho certo, pode ter água em forma líquida e, em termos de Universo, está relativamente perto, a cerca de 20,5 anos-luz da Terra. Ele gira em torno de uma anã vermelha --uma estrela muito menor, menos luminosa e mais fria que o nosso Sol-- chamada de Gliese 581.

O planeta, batizado de Gliese 581c, foi descoberto pelo telescópio do Observatório Europeu do Sul (ESO) em La Silla, no Chile.

O novo planeta é cinco vezes mais pesado que a Terra. Não se sabe ainda se ele é rochoso como a Terra ou se é uma esfera de gelo, com água líquida na superfície. Se for rochoso, que é o que a teoria prevalecente propõe, tem um diâmetro cerca de 1,5 vez maior que o do nosso planeta. Se for uma esfera de gelo, seria maior ainda.

Quem descobriu Gliese 581c?

Michel Mayor

Uma equipe de onze astrônomos da Suíça, França, e Portugal.

Esta equipe faz parte do grupo liderado por Michel Mayor, do Observatório de Genebra, na Suíça, responsável pela descoberta de 89 exoplanetas (até 4/6/2007)

Há 242 exoplanetas descobertos até essa data (24/04/2007)

Instrumentos utilizados da descoberta de Gliese 581c

Telescópio de 3,6m do ESO, em La Silla, Chile, a 2400m de altitude

O Estranho Sistema Solar de Gliese 581

Planeta	Massa	"Ano"	Distância
Gliese 581b	15 M_{Terra}	5,4 dias	6 milhões km
Gliese 581c	5 M_{Terra}	13 dias	11 milhões km ⇐
Gliese 581d	15 M_{Terra}	84 dias	38 milhões km

Distância "certa" para água líquida (temperatura= 0-40 C)

Gliese 581c – um mundo aquático?

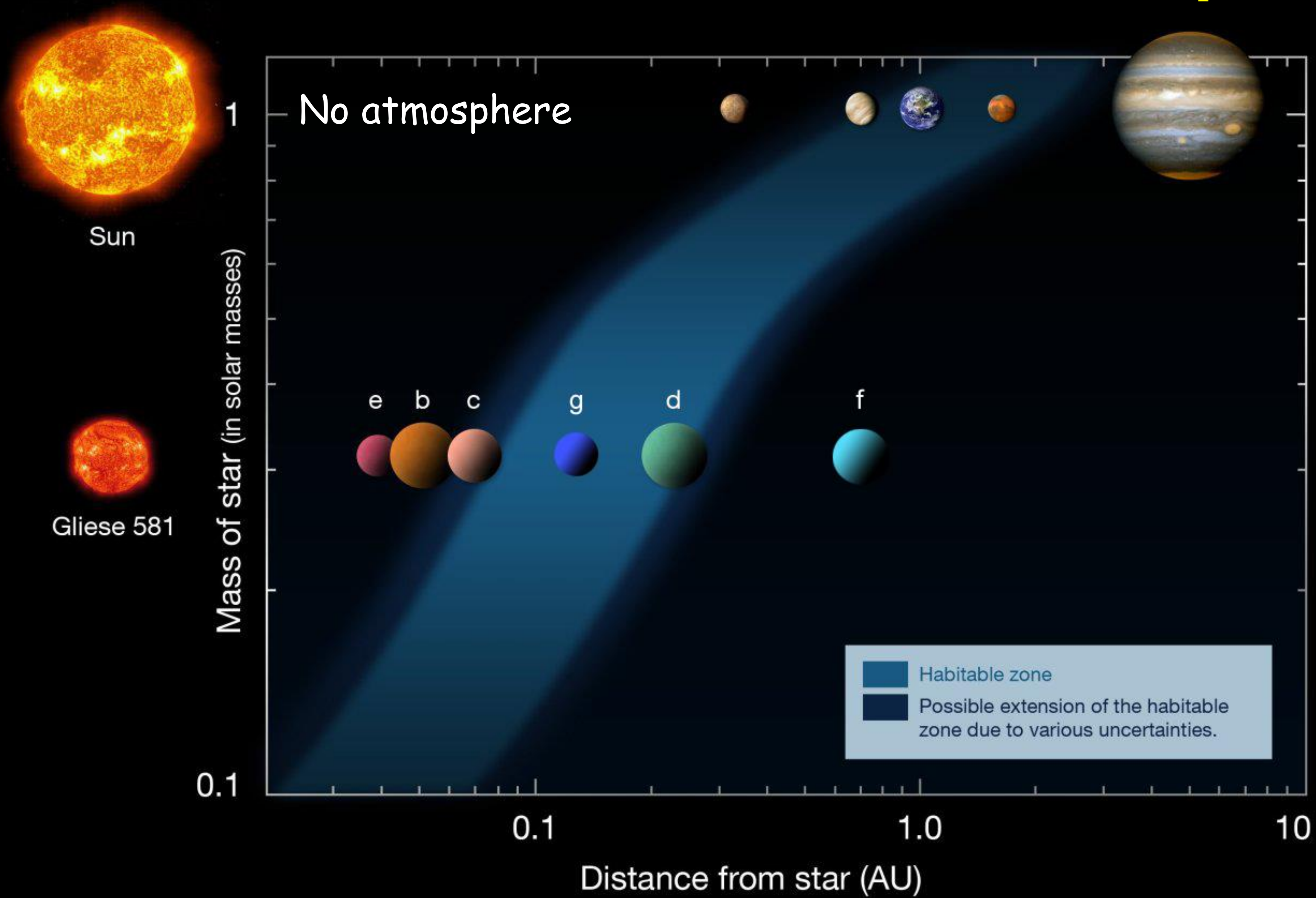
Um planeta de classe Aurélia?

Um lado, dia para sempre

Outro lado, noite eterna

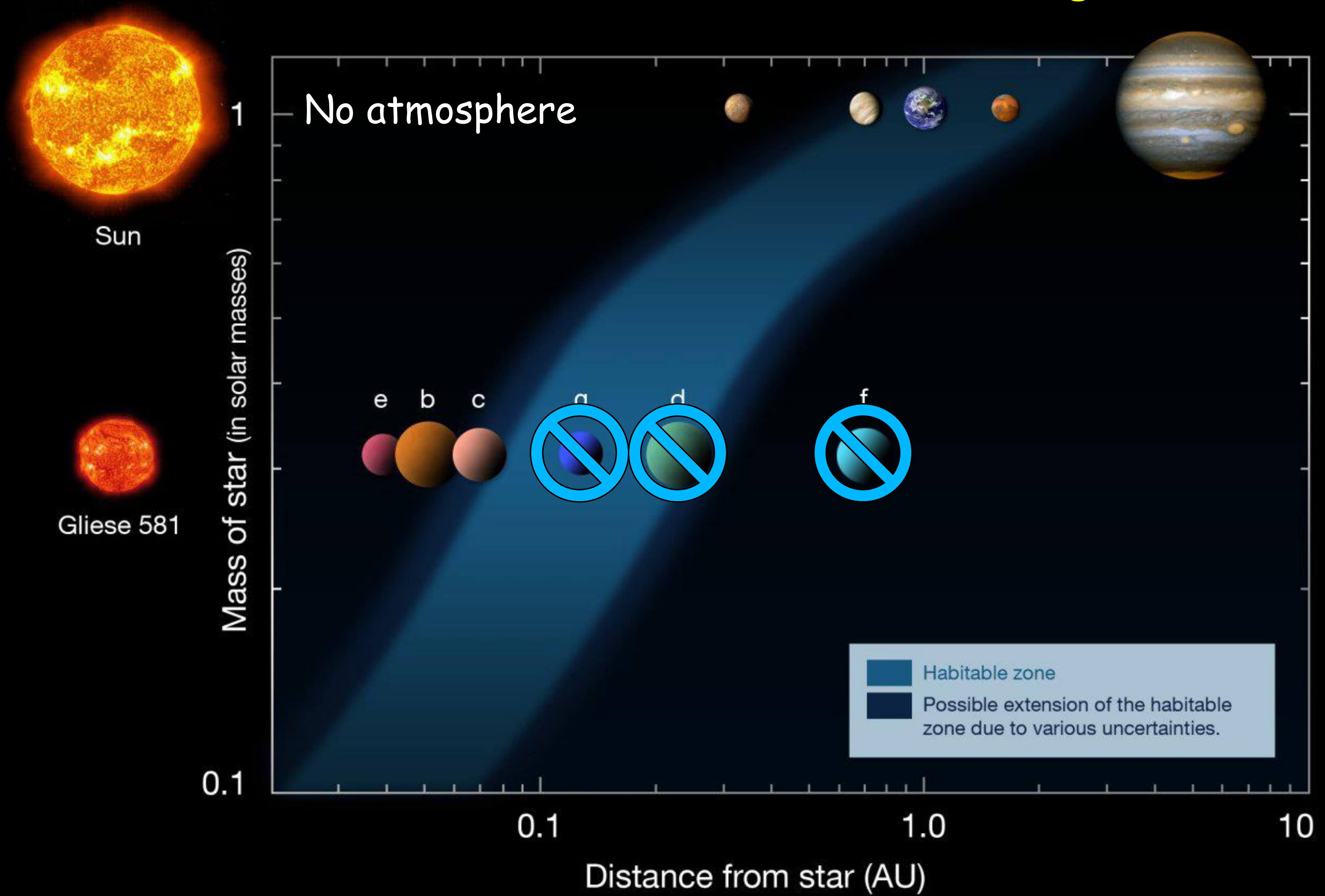
GLIESE 581 PLANETARY SYSTEM UPDATE

2007: 3 planetas
2009-2012: + 3 planetas

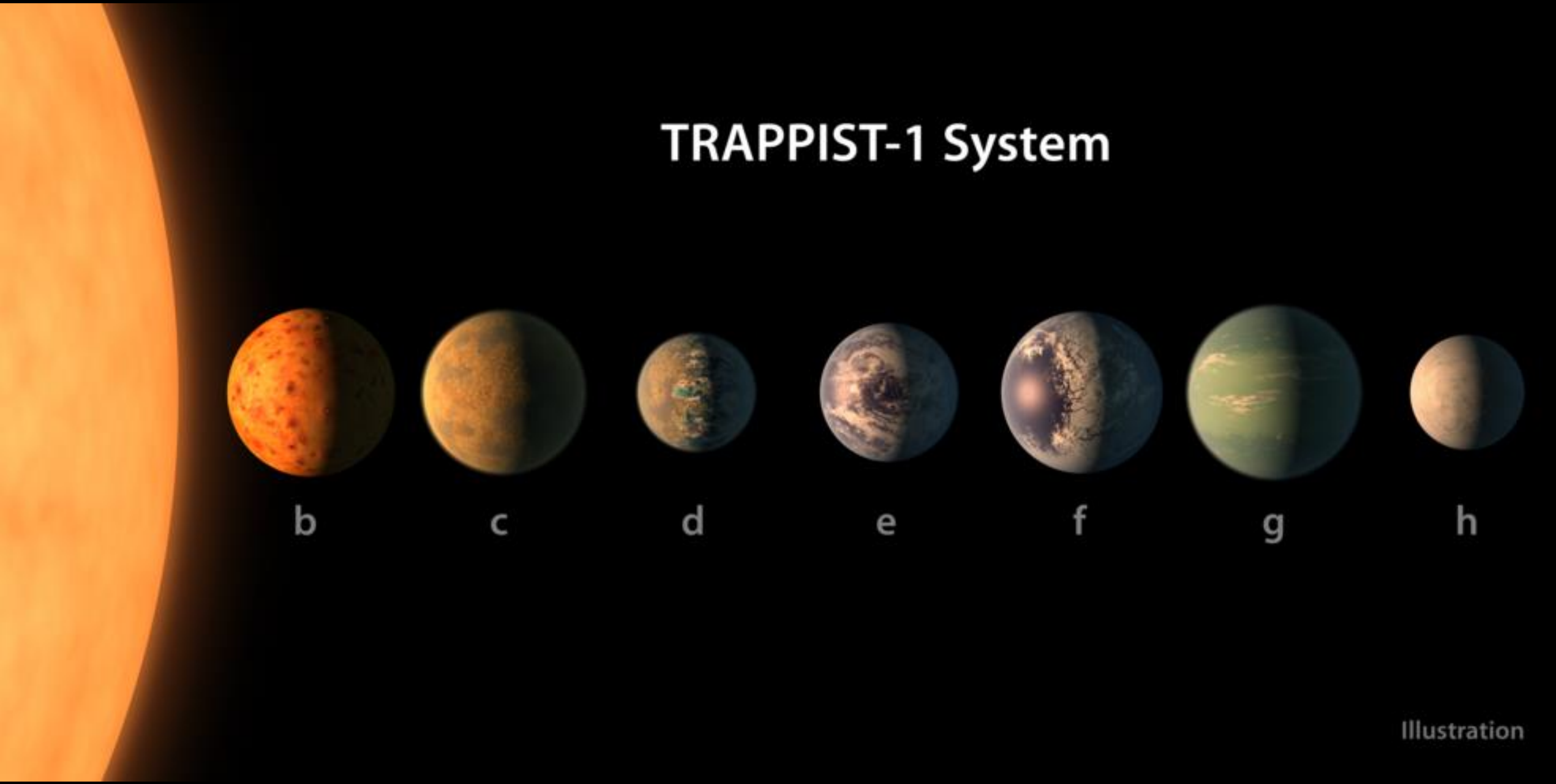


GLIESE 581 PLANETARY SYSTEM UPDATE

2013: f descartado
2014: d, g descartados



E a briga continua…


TRAPPIST-1 System
b
c
d
e
f
g
h
Illustration

Illustrations

TRAPPIST-1 System

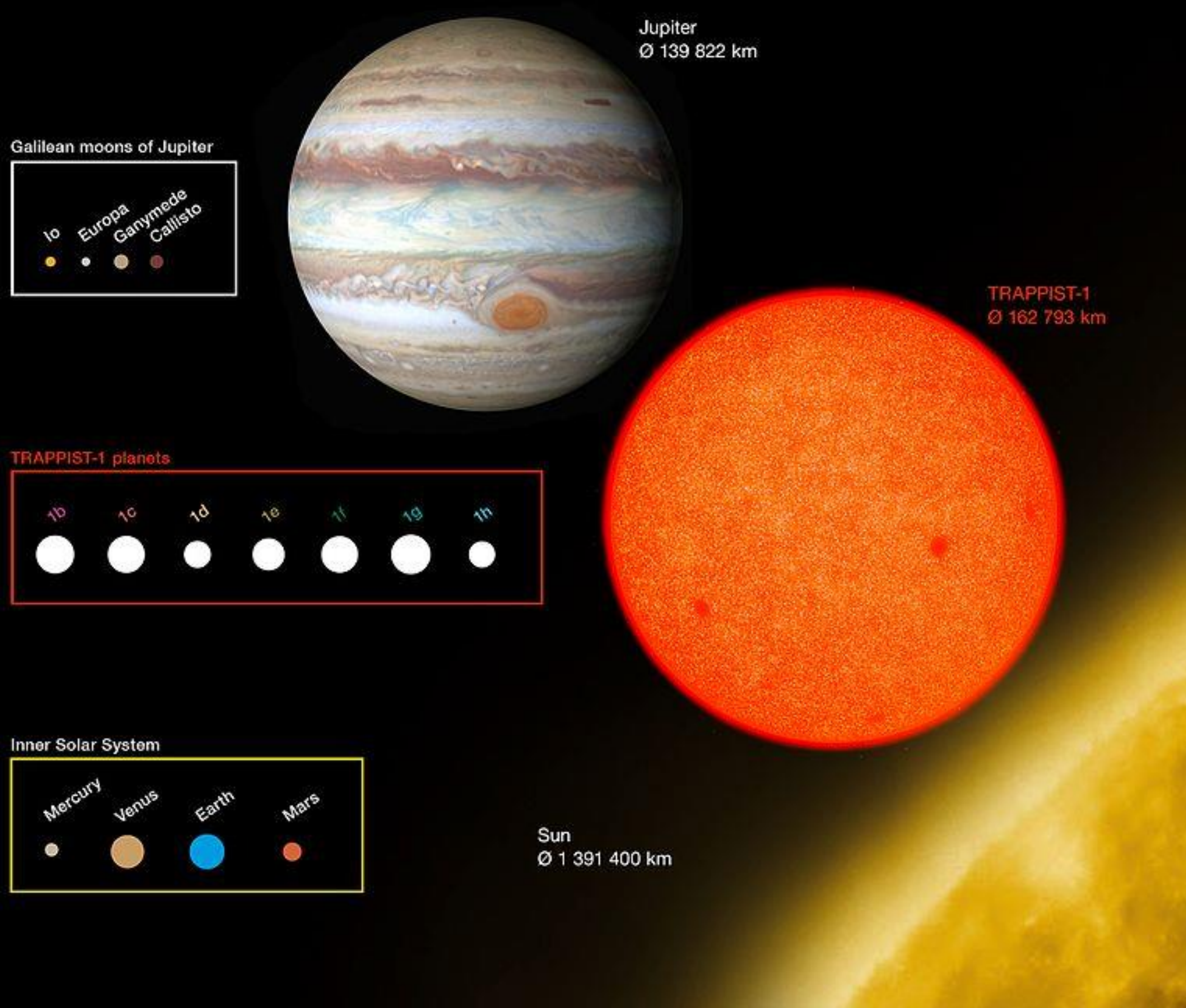
	b	c	d	e	f	g	h
Orbital Period *days*	1.51 *days*	2.42 *days*	4.05 *days*	6.10 *days*	9.21 *days*	12.35 *days*	~20 *days*
Distance to Star *Astronomical Units (AU)*	0.011 *AU*	0.015 *AU*	0.021 *AU*	0.028 *AU*	0.037 *AU*	0.045 *AU*	~0.06 *AU*
Planet Radius *relative to Earth*	1.09 R_{earth}	1.06 R_{earth}	0.77 R_{earth}	0.92 R_{earth}	1.04 R_{earth}	1.13 R_{earth}	0.76 R_{earth}
Planet Mass *relative to Earth*	0.85 M_{earth}	1.38 M_{earth}	0.41 M_{earth}	0.62 M_{earth}	0.68 M_{earth}	1.34 $_{earth}$	–

Solar System
Rocky Planets

	Mercury	Venus	Earth	Mars
Orbital Period *days*	87.97 *days*	224.70 *days*	365.26 *days*	686.98 *days*
Distance to Star *Astronomical Units (AU)*	0.387 *AU*	0.723 *AU*	1.000 *AU*	1.524 *AU*
Planet Radius *relative to Earth*	0.38 R_{earth}	0.95 R_{earth}	1.00 R_{earth}	0.53 R_{earth}
Planet Mass *relative to Earth*	0.06 M_{earth}	0.82 M_{earth}	1.00 M_{earth}	0.11 M_{earth}

Size Comparison

between **TRAPPIST-1** system, Galilean moons of Jupiter and the inner Solar System



TRAPPIST=TRAnsiting Planets and PlanetesImals Small Telescope





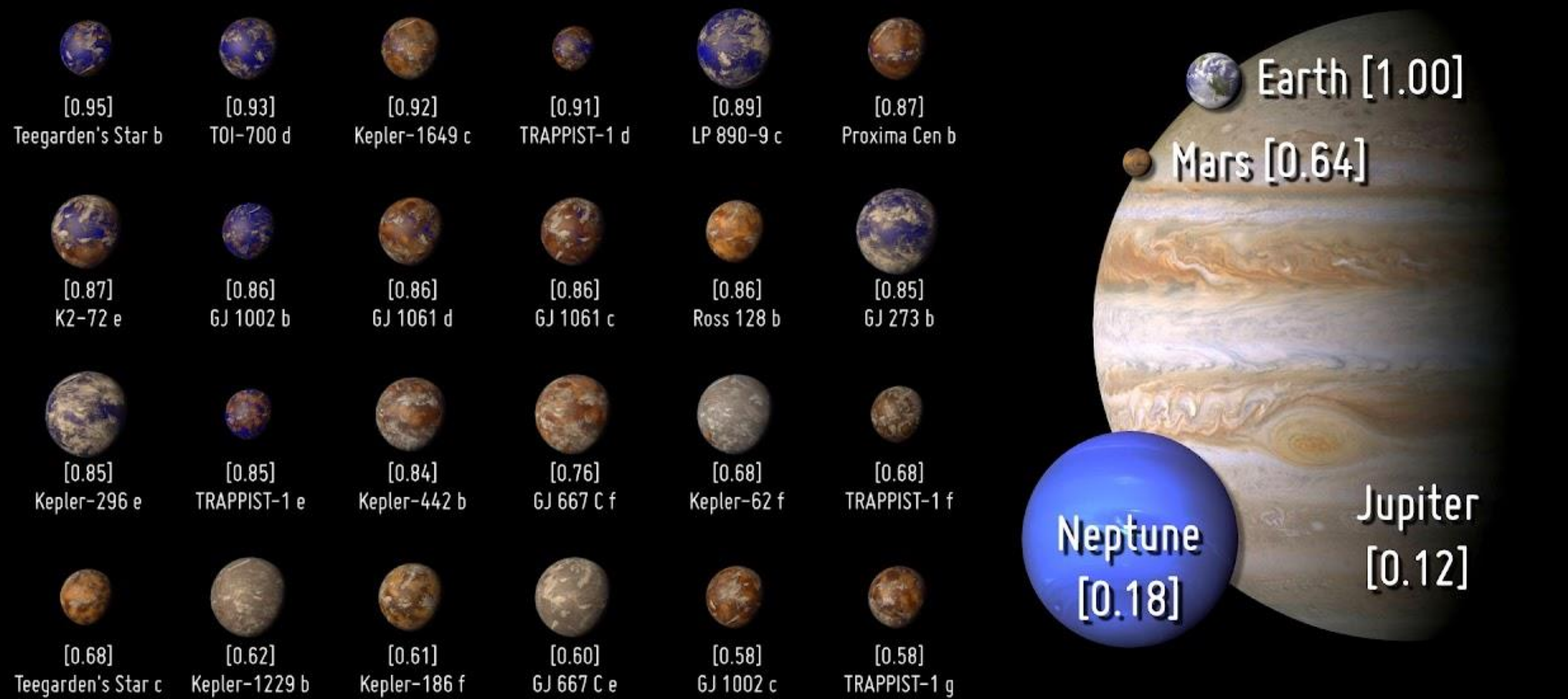
Boa Notícia!

Proxima Centauri, a estrela mais próxima de nós, abriga um planeta bem parecido com a Terra (Proxima b)

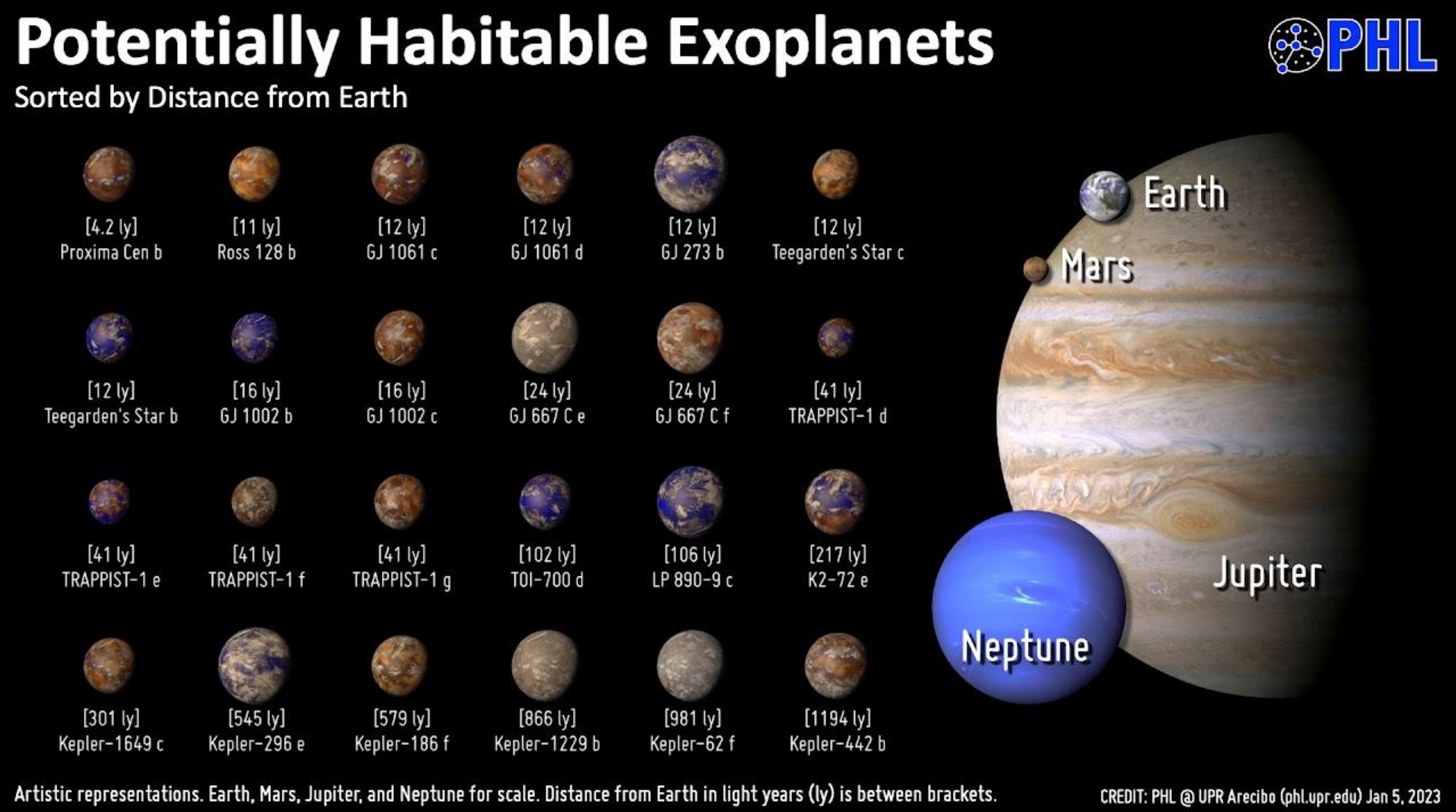
Potentially Habitable Exoplanets

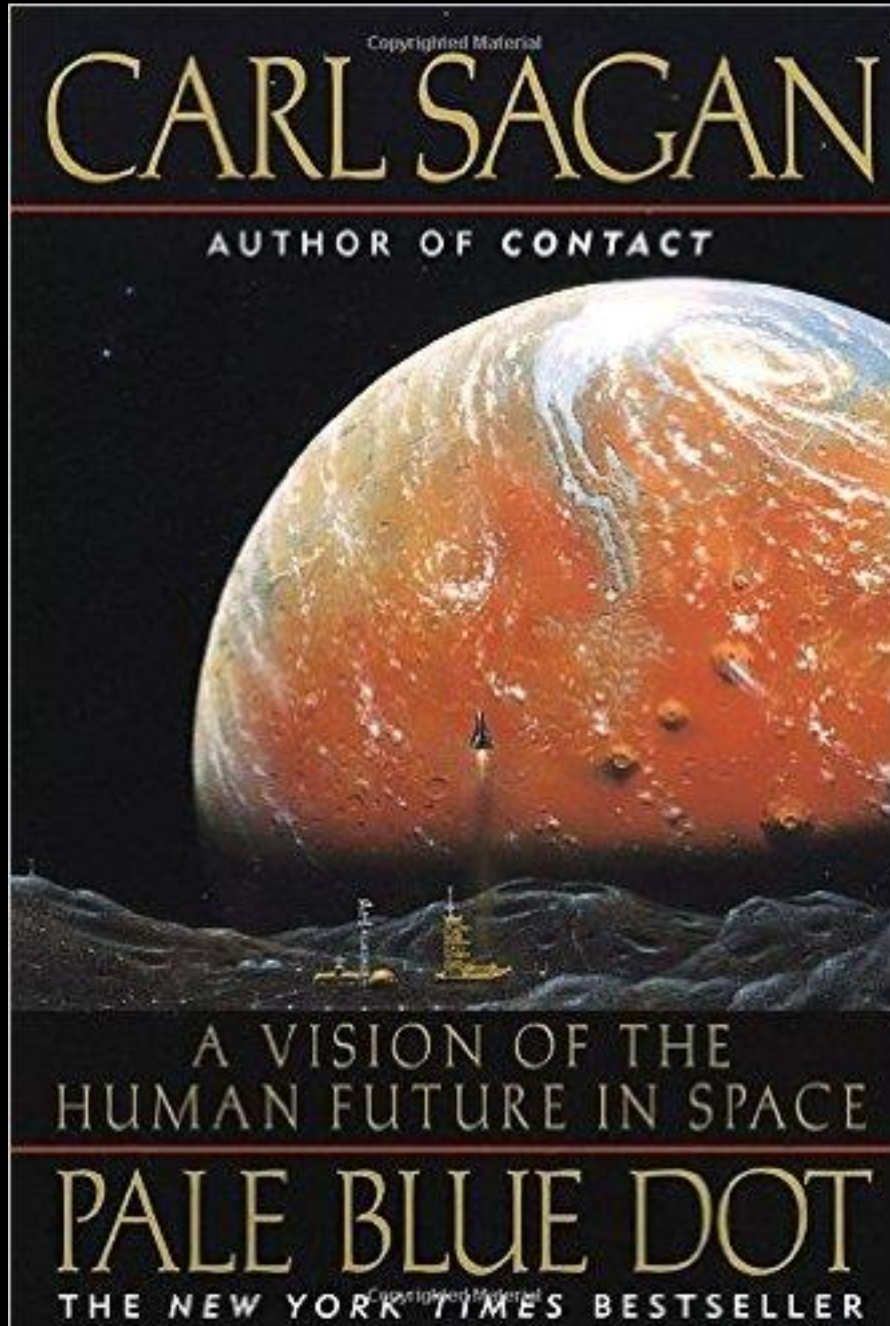
PHL

Sorted by the Earth Similarity Index (ESI)



Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Similarity (ESI) to Earth's size and insolation is between brackets.


Potentially Habitable Exoplanets
Sorted by Distance from Earth
PHL
[4.2 ly]
Proxima Cen b
[11 ly]
Ross 128 b
[12 ly]
GJ 1061 c
[12 ly]
GJ 1061 d
[12 ly]
GJ 273 b
[12 ly]
Teegarden's Star c
[12 ly]
Teegarden's Star b
[16 ly]
GJ 1002 b
[16 ly]
GJ 1002 c
[24 ly]
GJ 667 C e
[24 ly]
GJ 667 C f
[41 ly]
TRAPPIST-1 d
[41 ly]
TRAPPIST-1 e
[41 ly]
TRAPPIST-1 f
[41 ly]
TRAPPIST-1 g
[102 ly]
TOI-700 d
[106 ly]
LP 890-9 c
[217 ly]
K2-72 e
[301 ly]
Kepler-1649 c
[545 ly]
Kepler-296 e
[579 ly]
Kepler-186 f
[866 ly]
Kepler-1229 b
[981 ly]
Kepler-62 f
[1194 ly]
Kepler-442 b
Earth
Mars
Jupiter
Neptune
Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Distance from Earth in light years (ly) is between brackets.
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) Jan 5, 2023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AUTHOR OF CONTACT
A VISION OF THE
HUMAN FUTURE IN SPACE
PALE BLUE DOT
THE NEW YORK TIMES BESTSELLER

NEWS IN FOCUS

RICARDO RAMIREZ

The newly discovered planet orbits Proxima Centauri every 11.2 days.

ASTRONOMY

Nearby star hosts planet

Earth-sized world orbiting Proxima Centauri could harbour water — and life.

BY ALEXANDRA WITZE

Proxima Centauri, the star closest to the Sun, has an Earth-sized planet orbiting it at the right distance for liquid water to exist. The discovery, reported this week in *Nature*[1], fulfils a longstanding dream of science-fiction writers — a potentially habitable world that is close enough for humans to send their first interstellar spacecraft to.

"The search for life starts now," says Guillem Anglada-Escudé, an astronomer at Queen Mary University of London and leader of the team that made the discovery.

Humanity's first chance to explore this nearby world may come from the recently announced Breakthrough Starshot initiative, which plans to build fleets of tiny laser-propelled interstellar probes in the coming decades. Travelling at 20% of the speed of light, they would take about 20 years to cover the 1.3 parsecs from Earth to Proxima Centauri.

Proxima's planet is at least 1.3 times the mass of Earth. The planet orbits its red-dwarf star — much smaller and dimmer than the Sun — every 11.2 days. "If you tried to pick the type of planet you'd most want around the type of star you'd most want, it would be this," says David Kipping, an astronomer at Columbia University in New York City. "It's thrilling."

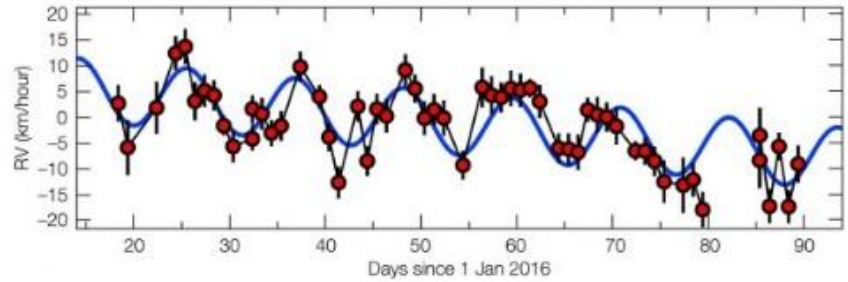
GRAVITATIONAL HINTS

Earlier studies had hinted at the existence of a planet around Proxima. Starting in 2000, a spectrograph at the European Southern Observatory (ESO) in Chile looked for shifts in starlight caused by the gravitational tug of an orbiting planet. The measurements suggested that something was happening to the star every 11.2 days. But astronomers could not rule out whether the signal was caused by an orbiting planet or another type of activity, such as stellar flares.

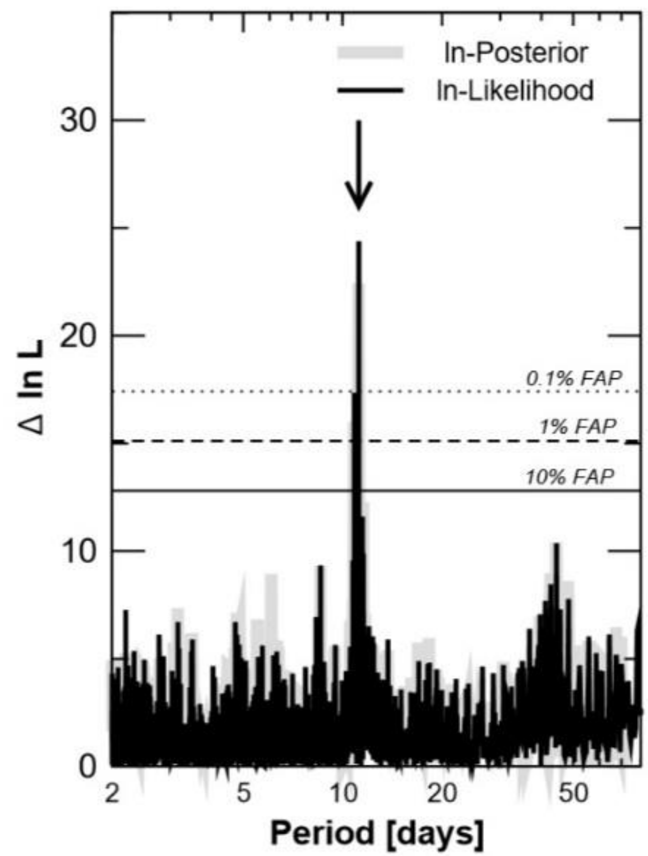
In January 2016, Anglada-Escudé and his colleagues launched a campaign to nail down the suspected Proxima planet. ESO granted their request to observe using a second planet-hunting instrument, on a different telescope, for 20 minutes almost every night between 19 January and 31 March. "As soon as we had 10 nights it was obvious," Anglada-Escudé says.

The team dubbed the work the 'pale red dot' campaign, after the famous 'pale blue dot' photograph taken of Earth by the Voyager 1 spacecraft in 1990. Because Proxima is a red-dwarf star, the planet would appear reddish or orangeish, perhaps bathed in light similar to the warm evening tints of Earth.

Although the planet orbits at a distance that would permit liquid water, other factors ▶



This plot shows how the motion of Proxima Centauri towards and away from Earth is changing with time over the first half of 2016. Sometimes Proxima Centauri is approaching Earth at about 5 kilometres per hour — normal human walking pace — and at times receding at the same speed. This regular pattern of changing radial velocities repeats with a period of 11.2 days. Careful analysis of the resulting tiny Doppler shifts showed that they indicated the presence of a planet with a mass at least 1.3 times that of the Earth, orbiting about 7 million kilometres from Proxima Centauri — only 5% of the Earth-Sun distance.



LETTER

doi:10.1038/nature19106

A terrestrial planet candidate in a temperate orbit around Proxima Centauri

Guillem Anglada-Escudé[1], Pedro J. Amado[2], John Barnes[3], Zaira M. Berdiñas[2], R. Paul Butler[4], Gavin A. L. Coleman[1], Ignacio de la Cueva[5], Stefan Dreizler[6], Michael Endl[7], Benjamin Giesers[6], Sandra V. Jeffers[6], James S. Jenkins[8], Hugh R. A. Jones[9], Marcin Kiraga[10], Martin Kürster[11], María J. López-González[2], Christopher J. Marvin[6], Nicolás Morales[2], Julien Morin[12], Richard P. Nelson[1], José L. Ortiz[2], Aviv Ofir[13], Sijme-Jan Paardekooper[1], Ansgar Reiners[6], Eloy Rodríguez[2], Cristina Rodríguez-López[2], Luis F. Sarmiento[6], John P. Strachan[1], Yiannis Tsapras[14], Mikko Tuomi[9] & Mathias Zechmeister[6]

At a distance of 1.295 parsecs[1], the red dwarf Proxima Centauri (α Centauri C, GL 551, HIP 70890 or simply Proxima) is the Sun's closest stellar neighbour and one of the best-studied low-mass stars. It has an effective temperature of only around 3,050 kelvin, a luminosity of 0.15 per cent of that of the Sun, a measured radius of 14 per cent of the radius of the Sun[2] and a mass of about 12 per cent of the mass of the Sun. Although Proxima is considered a moderately active star, its rotation period is about 83 days (ref. 3) and its quiescent activity levels and X-ray luminosity[4] are comparable to those of the Sun. Here we report observations that reveal the presence of a small planet with a minimum mass of about 1.3 Earth masses orbiting Proxima with a period of approximately 11.2 days at a semi-major-axis distance of around 0.05 astronomical units. Its equilibrium temperature is within the range where water could be liquid on its surface[5].

reduction codes[10]. As systematic calibration errors produce correlations among the observations for each night[11], we consolidated the Doppler measurements through nightly averages to present a simpler and more conservative signal search. This led to 72 UVES, 90 HARPS pre-2016 and 54 HARPS PRD epochs. The PRD photometric observations were obtained using the Astrograph for the South Hemisphere II telescope (ASH2 hereafter[12], with S II and Hα narrowband filters) and the Las Cumbres Observatory Global Telescope network[13] (with Johnson B and V band filters), over the same time interval and similar sampling rates as the HARPS PRD observations. Further details about each campaign and the photometry are detailed in Methods. All of the time series used in this work are available as Supplementary Data.

The search and assessment of the statistical significance (see below and Methods for more details) of the signals were performed using frequentist[14] and Bayesian[15] methods. The periodograms in Fig. 1

PROJECT UPDATES

PROXIMA B IS OUR NEIGHBOR… BETTER GET USED TO IT!

AUGUST 24, 2016 PALE RED DOT 8 COMMENTS

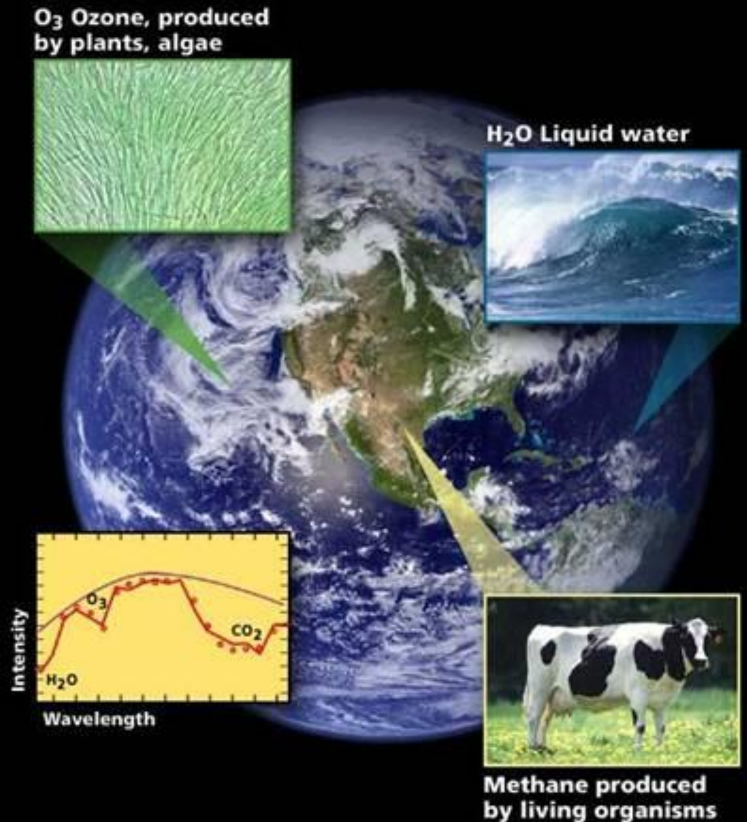
It is true. We are convinced that there is a planet orbiting Proxima now. The evidence goes as follows : a signal was spotted back in 2013 on previous surveys (UVES and HARPS). The preliminary detection was first done by Mikko Tuomi, our in-house applied mathematician and his Bayesian codes. However, the signal was not convincing as the data was really sparse and the period was ambiguous (other possible solutions at 20 and 40 days, plus a long period signal of unknown origin). We followed up Proxima in the next years but our two observing runs were 12 days, barely sufficient to secure a signal which ended up being 11.2 days. So the Pale Red Dot was designed with the sole purpose of confirming or refuting its strict periodicity, plus carefully monitor the star for activity induced variability. We got very lucky with the weather so we obtained 54 out of 60 observations. The photometric monitoring telescopes (ASH2 and several units of Las Cumbres Observatory Global Telescope network), worked flawlessly so we could see the effect of spots, flares and rotation of the star, which also had a footprint on the spectra. However, nothing indicated that spurious variability would be happening at 11.2 days.

Bioassinaturas

How Will We Know A Planet Supports Life?

Look for evidence of oxygen

Analyze the reflected light from the planet to see if the planet has an atmosphere



Look for liquid water

Look for signs of biological activity (methane)

And Rule Out Other Explanations?

NATURE · VOL 365 · 21 OCTOBER 1993

A search for life on Earth from the Galileo spacecraft

Carl Sagan[*], W. Reid Thompson[*], Robert Carlson[†], Donald Gurnett[‡] & Charles Hord[§]

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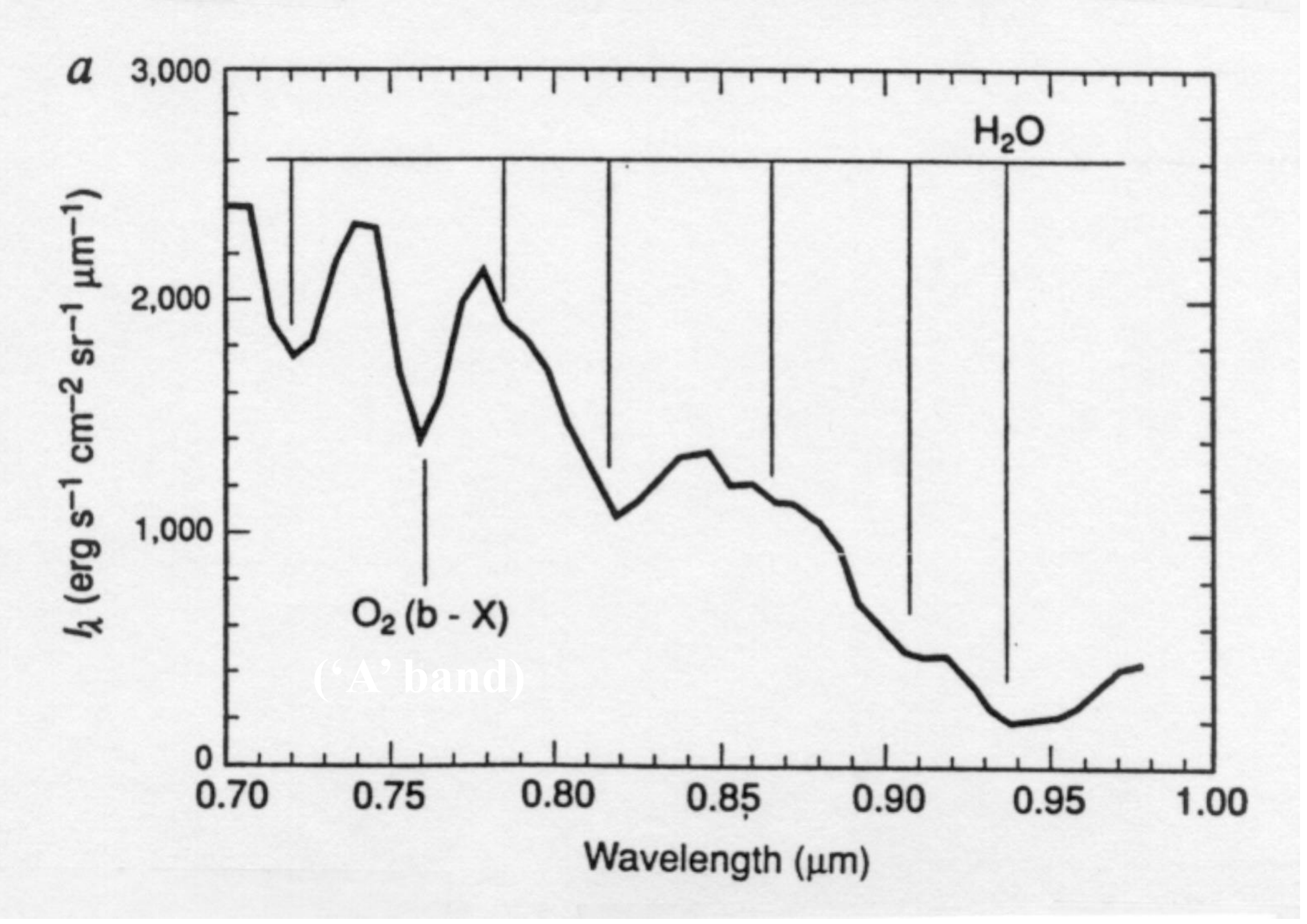
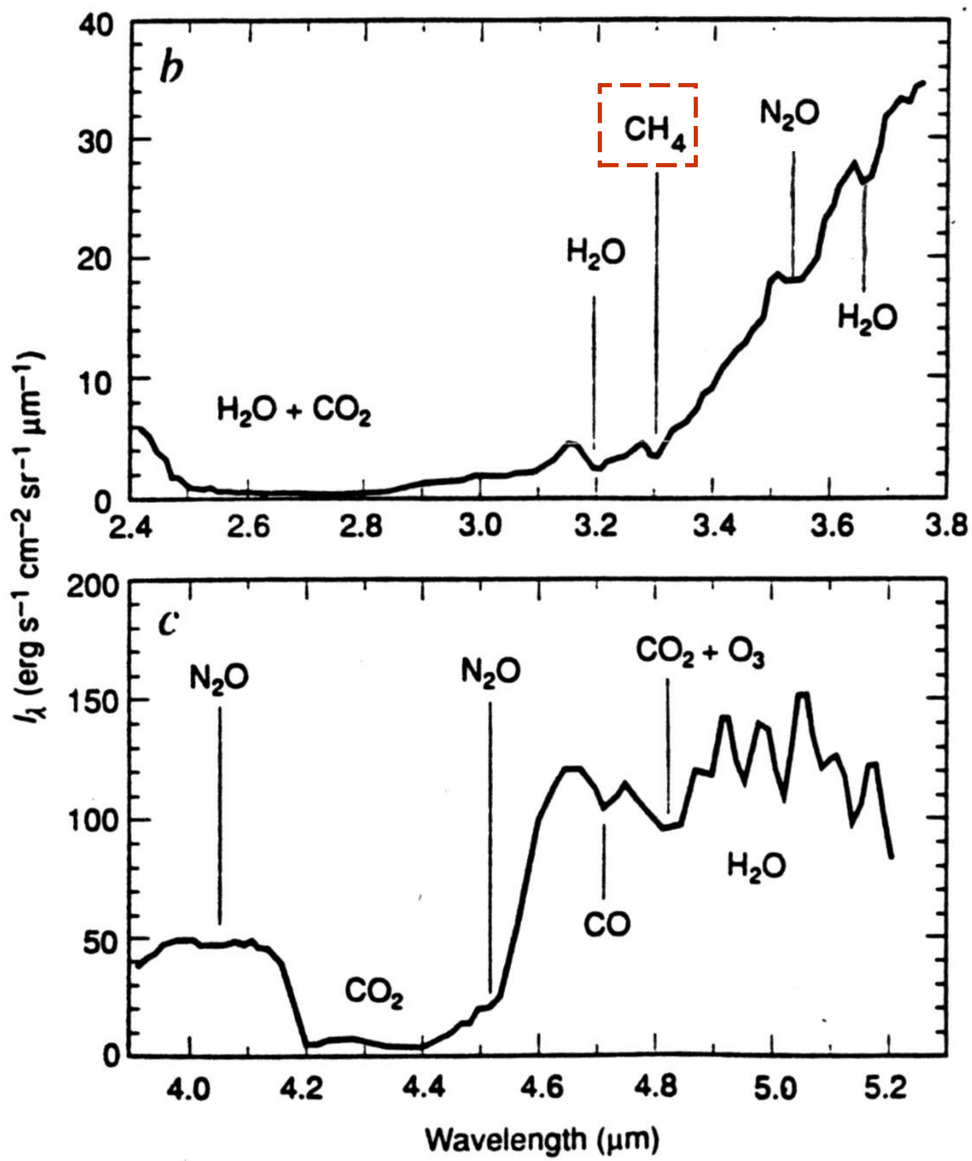
In its December 1990 fly-by of Earth, the Galileo spacecraft found evidence of abundant gaseous oxygen, a widely distributed surface pigment with a sharp absorption edge in the red part of the visible spectrum, and atmospheric methane in extreme thermodynamic disequilibrium; together, these are strongly suggestive of life on Earth. Moreover, the presence of narrow-band, pulsed, amplitude-modulated radio transmission seems uniquely attributable to intellig-ence. These observations constitute a control experiment for the search for extraterrestrial life by modern interplanetary spacecraft.

NIMS Data for the Earth (from Galileo)



Sagan et al. (1993)*

*But credit Toby Owen for pointing this out (1980)

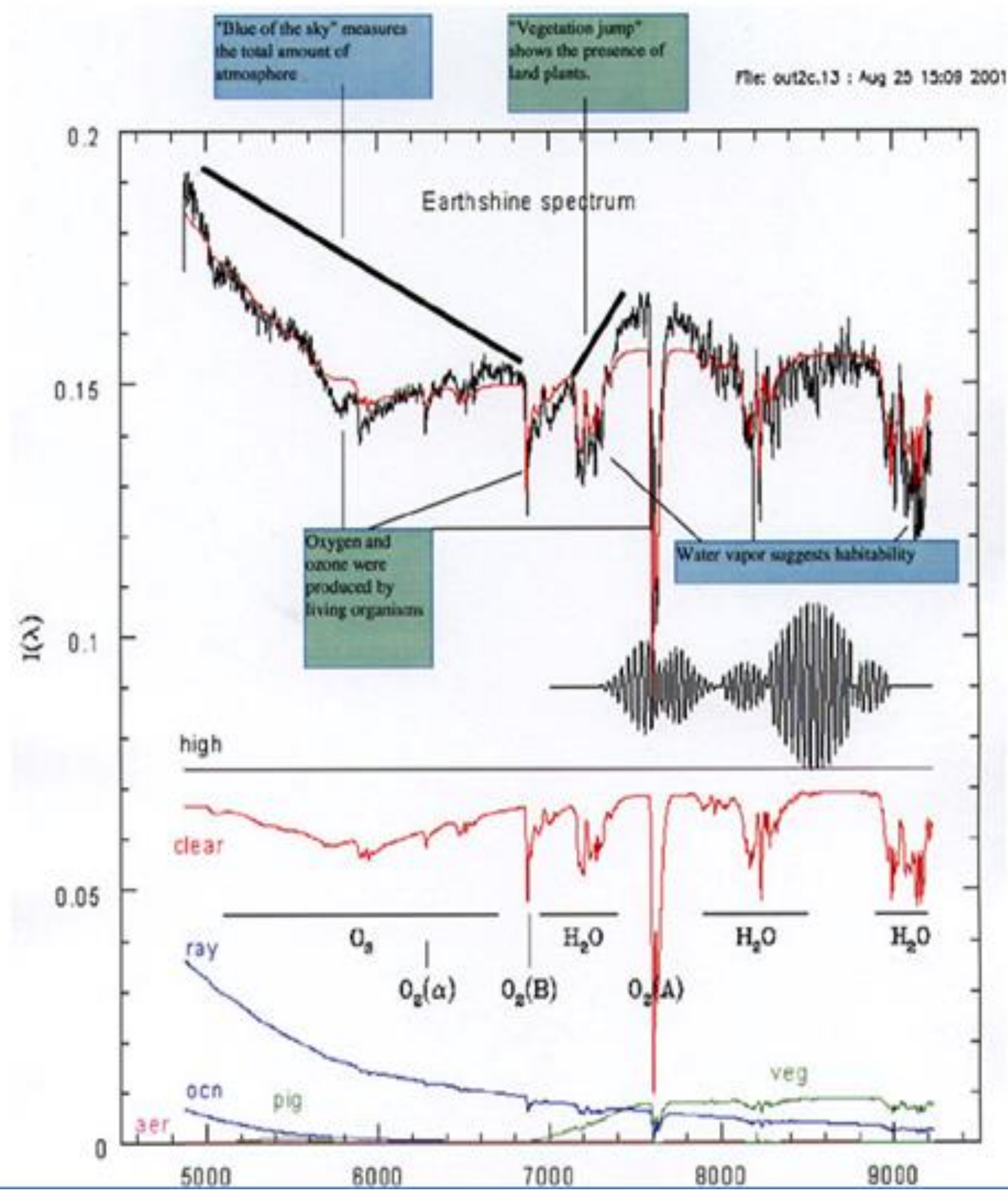


NIMS data in the near-IR

- Simultaneous presence of O_2 and a reduced gas (CH_4 or N_2O) is the best evidence for life

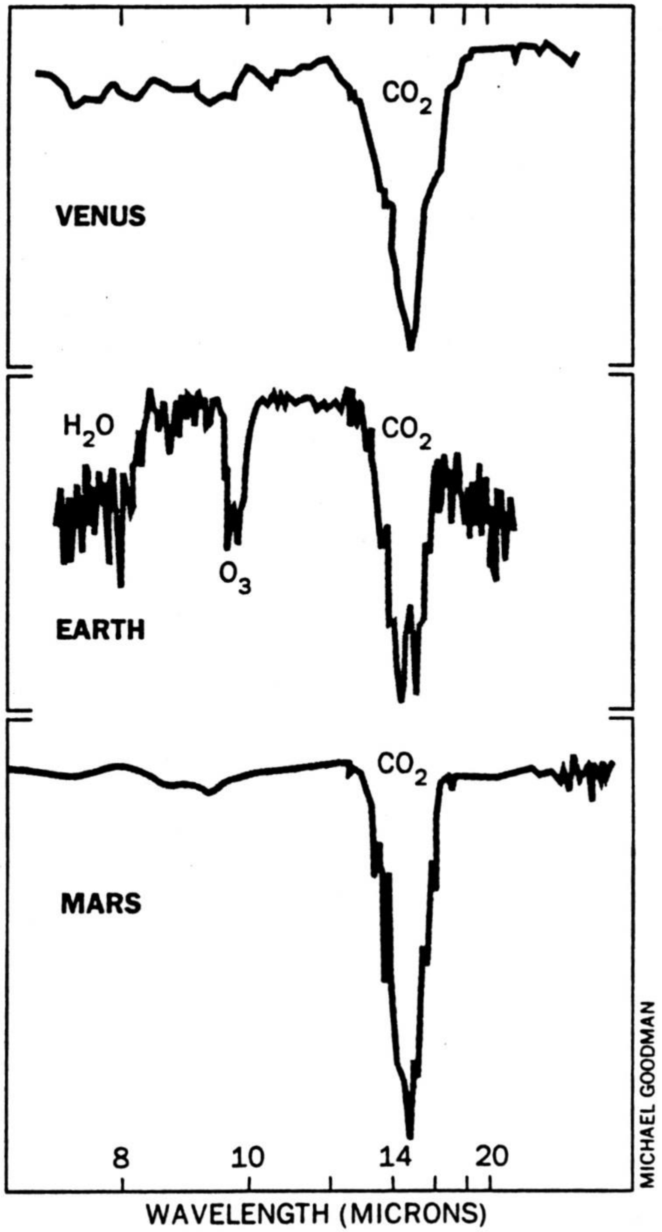
*Credit Joshua Lederburg and James Lovelock for the idea (1964)

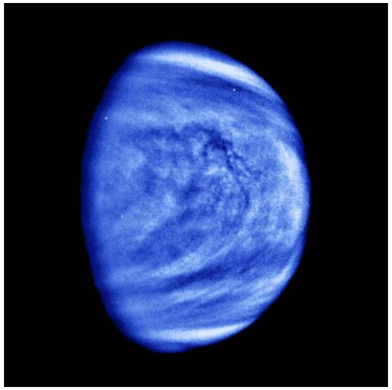
Sagan et al. (1993)*



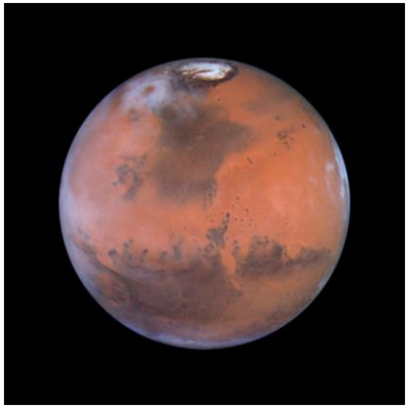
"Blue of the sky" measures the total amount of atmosphere
"Vegetation jump" shows the presence of land plants.
File: out2c.13 : Aug 25 15:09 2001
Earthshine spectrum
Oxygen and ozone were produced by living organisms
Water vapor suggests habitability
high
clear
ray
ocn
aer
pig
veg
O_3
$O_2(\alpha)$
$O_2(B)$
H_2O
$O_2(A)$
H_2O
H_2O
$I(\lambda)$
0.2
0.15
0.1
0.05
0
5000
6000
7000
8000
9000

Wavelength





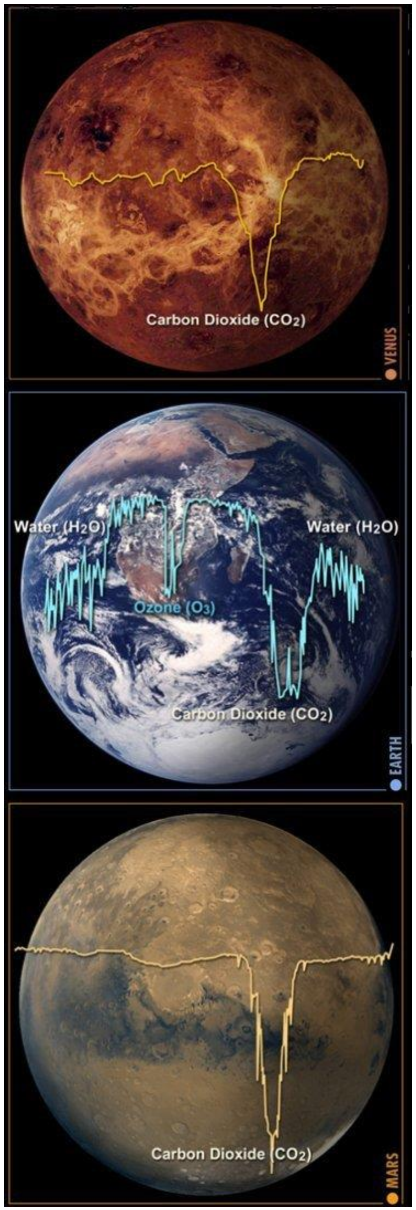
Thermal IR spectra

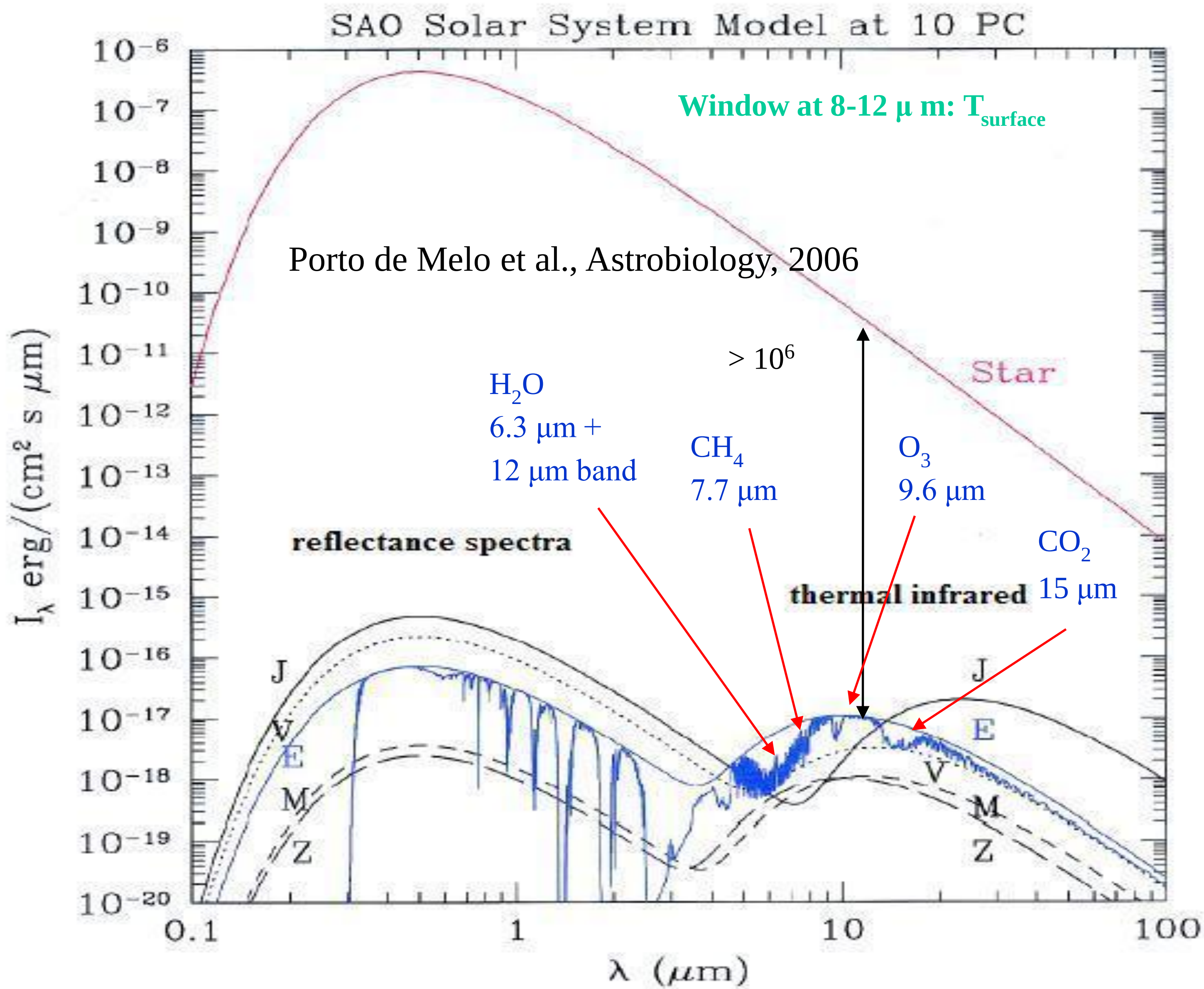


Source:
R. Hanel, Goddard Space Flight Center

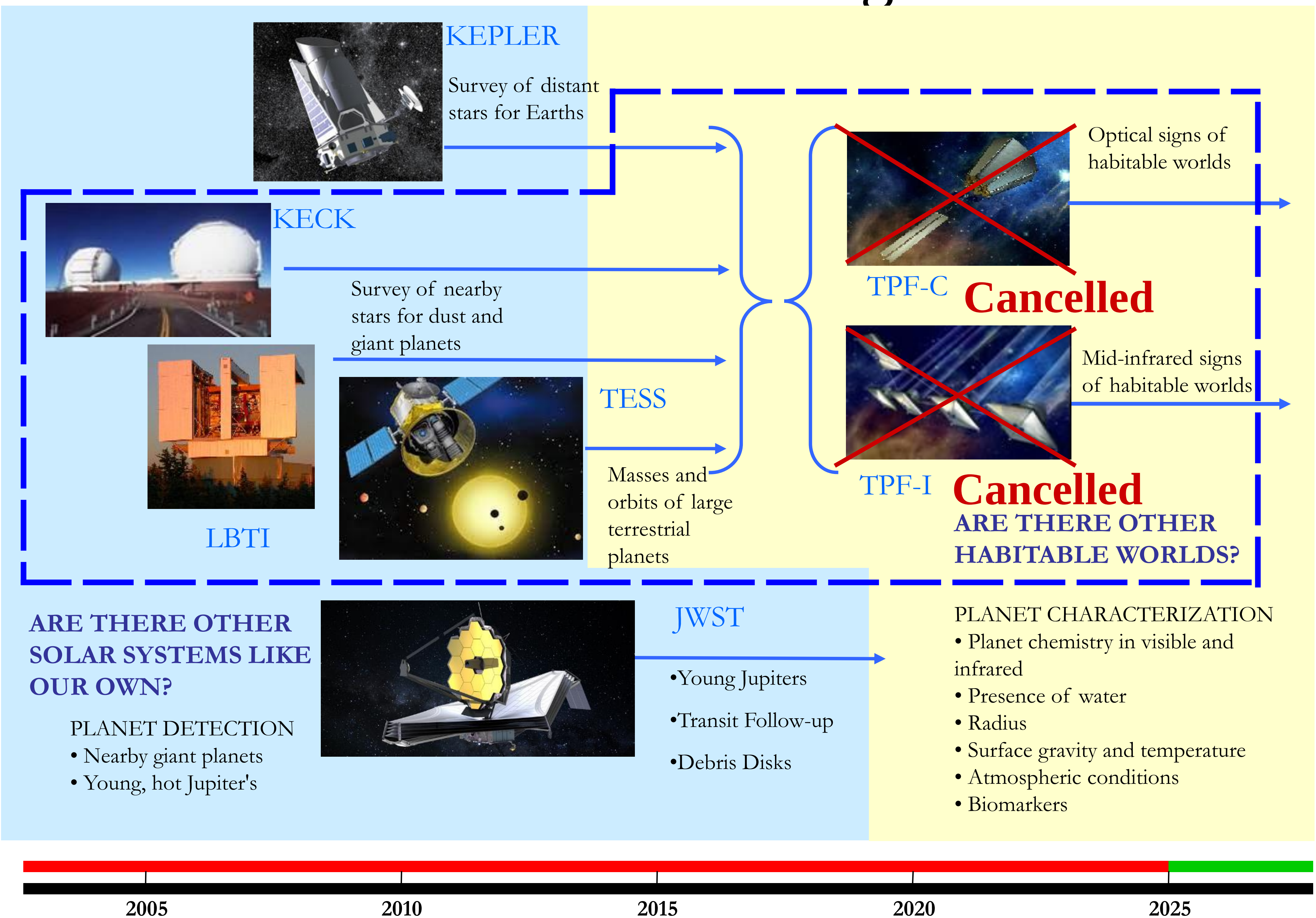
Possibility of remote detection of life

Explore the contrast star/planet in **thermal IR** (Des Marais et al. 2002, Segura et al. 2003)





Planet Hunting



MISSÕES PROGRAMADAS PARA 2020-2030 SOBRE EXOPLANETAS

PLATO (ESA)
ARIEL (ESA)
TOLIMAN (NASA, Breakthrough Initiatives)
ORIGINS (NASA)

ALMA (Atacama Large Milimmeter Array),
MATISSE (espectro-interferômetro, IV)