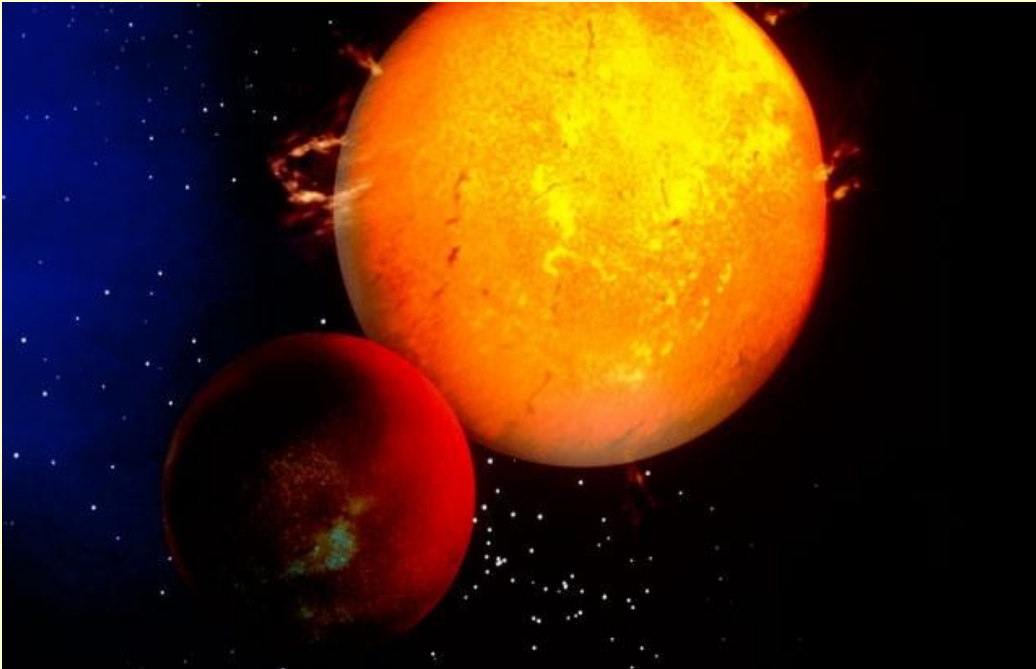


Exoplanetas: História, busca e classificação



Exoplanetas descobertos até 02/04/2013 às 12:00

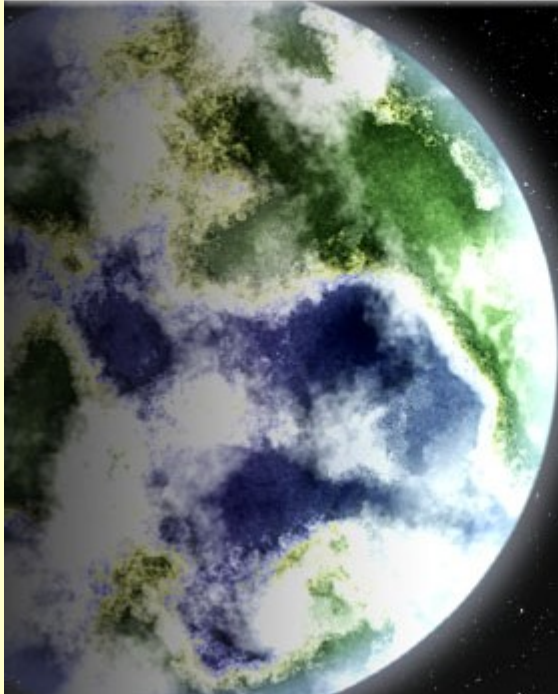
exoplanets.org

Exoplanets
Data Explorer

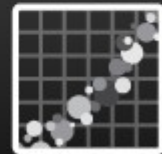
Methodology
and FAQ

Exoplanets
Links

California
Planet Survey



Table



Plots

672

EOD Planets

Planets with good orbits listed in the Exoplanet Orbit Database

24

Other Planets

Including microlensing and imaged planets

696

Total Confirmed Planets

2606

Unconfirmed Kepler Candidates

3302

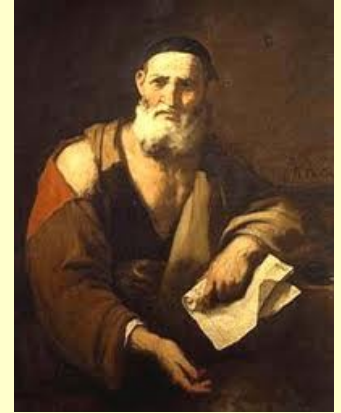
Total Planets

Confirmed planets + Kepler Candidates

História

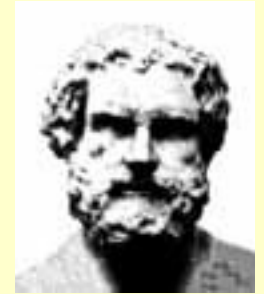
The worlds come into being as follows: many bodies of all sorts and shapes move from the infinite into a great void; they come together there and produce a single whirl, in which, colliding with one another and revolving in all manner of ways, they begin to separate like to like.

Leucippus (~480-420 A.C.)



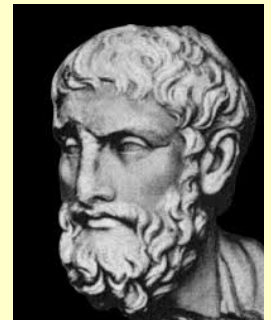
In some worlds there is no Sun and Moon, in others they are larger than in our world, and in others more numerous. In some parts there are more worlds, in others fewer (...); in some parts they are arising, in others failing. There are some worlds devoid of living creatures or plants or any moisture.

Democritus (~460~370 A.C.)



There are infinite worlds both like and unlike this world of ours. For the atoms being infinite in number, as was already proven, (...) there nowhere exists an obstacle to the infinite number of worlds.

Epicurus(341-270 A.C.)



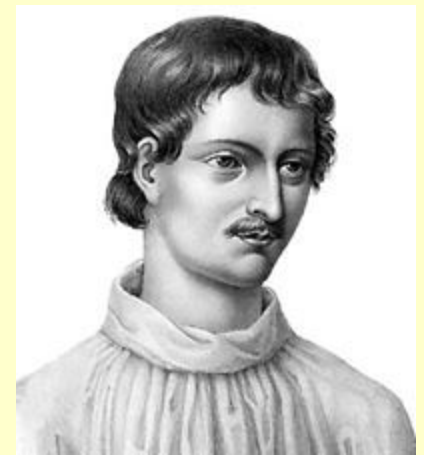
There cannot be more worlds than one.
Aristóteles(384-322 A.C.)



O pensamento de Aristoteles vigorou até começar a ser novamente discutido no século XVI...

“There are countless countless suns and countless earths all rotating around their suns in exactly the same ways as the seven planets of our system...The countless worlds in the Universe are no worse and no less inhabited than our world.”

Giordano Bruno (1548-1600)



Provavelmente influenciado pelas ideias de...

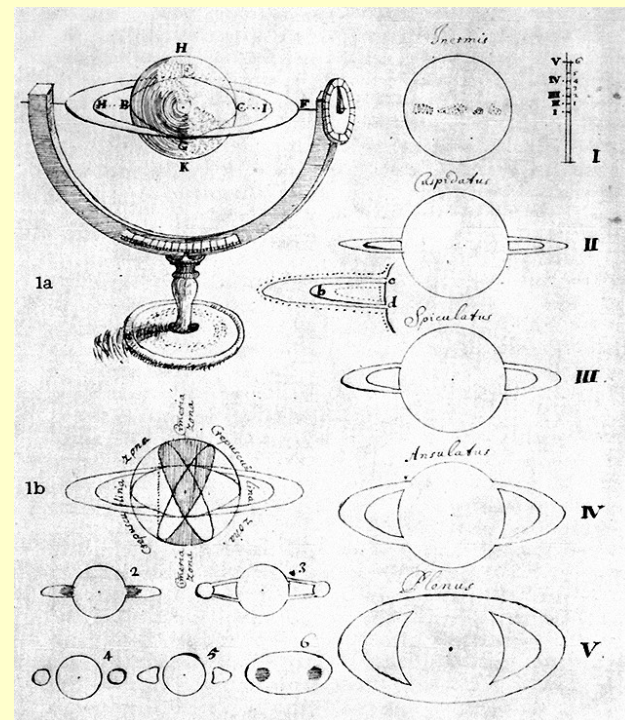
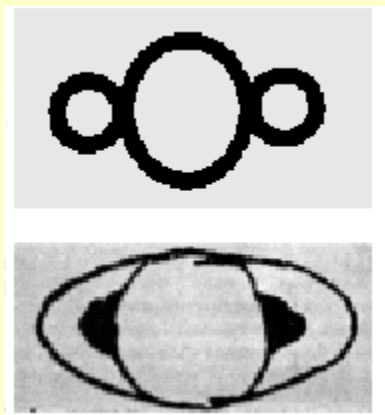
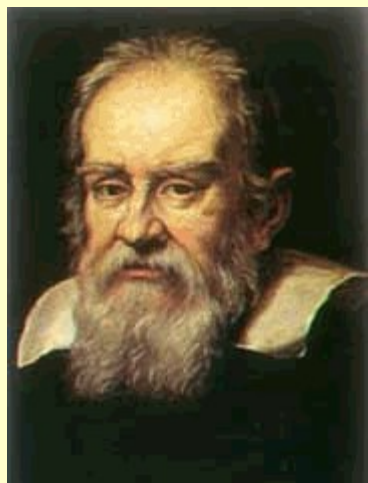
...Nicolau Copérnico e a suposição de que os planetas do nosso sistema solar giram em torno do sol.

E em 1609, com a invenção do telescópio por **Galileu Galilei**, os olhos voltam-se para o que há além da Terra.

-Descoberta das luas de Júpiter

-Anel de Saturno, o planeta com "orelhas".

Posteriormente identificado por...



...Christiaan Huygens

- Aprimoramento do telescópio.
- Identificou os anéis de Saturno e descobriu sua maior lua: Titan.
- Conhecido pelo embate com Newton sobre a natureza corpuscular x ondulatória da luz.



E então em 1781, William Herschel descobre o primeiro planeta depois de muito tempo: Urano!

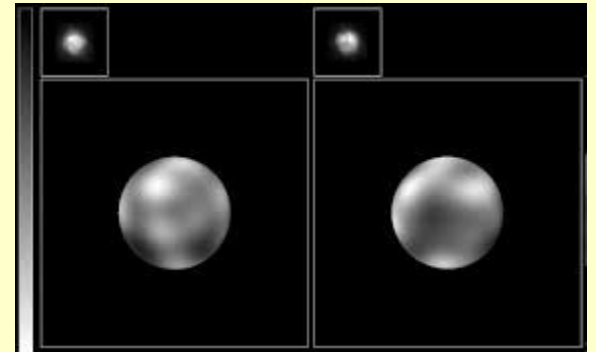
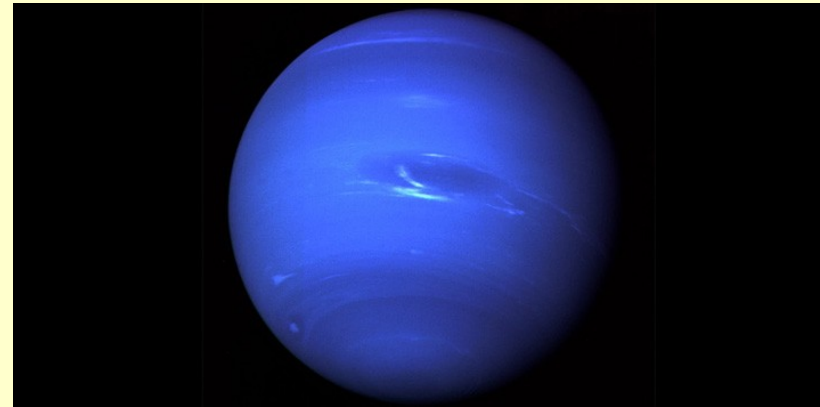


Em 1855 no East India Observatory, são encontradas anomalias orbitais na estrela binária 70 Ophiuchi pelo Capt. W.S. Jacob. Considerada uma evidência da existência de um exoplaneta. Contudo, nos próximos 140 anos, só resultaram em falsos alarmes.

Porém, durante esse tempo, outras descobertas foram feitas:

-Descoberta de Netuno, por previsões matemáticas, perturbação em Urano.

-Descoberta de Plutão.

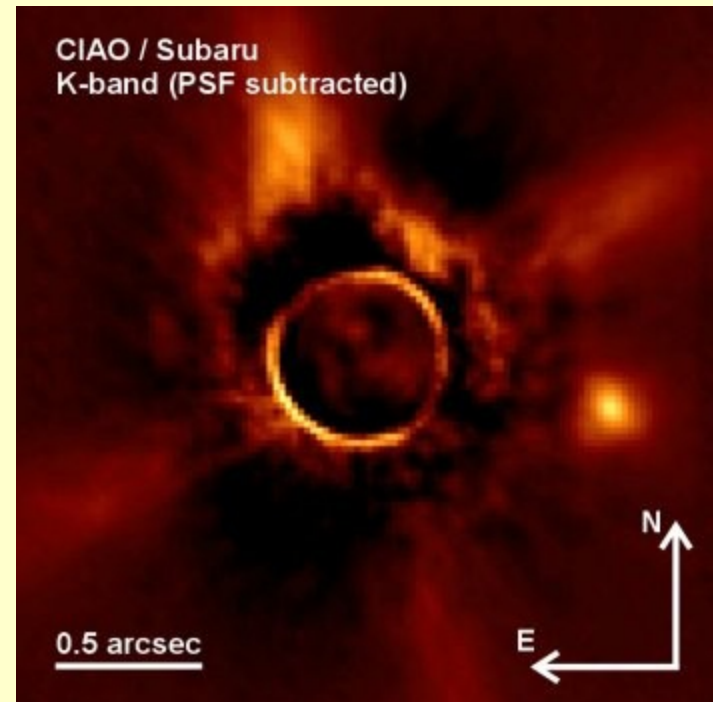


γ Cephei

-Foi descoberto em 1988 por Bruce Campbell, Gordon Walker and Stephenson Yang.

-Planeta orbitando um pulsar.

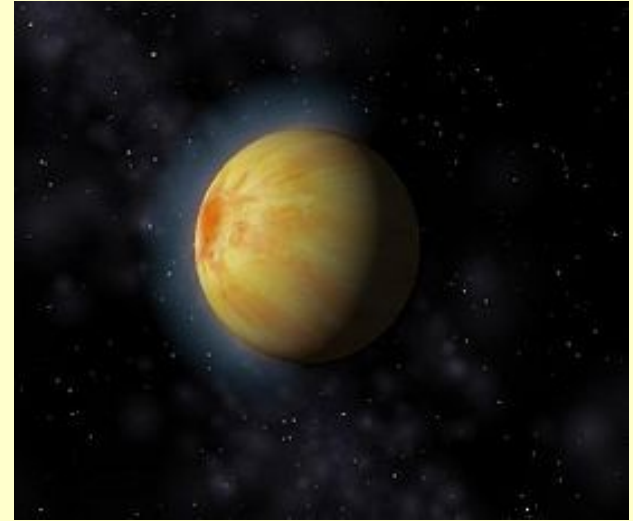
-Sua confirmação, porém, só foi realizada em 2003!
Diferentemente do...



51 Pegasi b

Descoberto por Michel Mayor e Didier Queloz, em 1995.

Sua confirmação veio apenas uma semana depois por Geoffrey Marcy da Universidade Estadual de São Francisco e Paul Butler da Universidade da Califórnia, Berkeley.



*As letras após o nome da estrela seguem a ordem de sua descoberta. Neste caso, se outros planetas forem descobertos, a eles serão atribuídas as letras, c,d,e,...

Mas como se detectou esse planeta, e como se detectam outros exoplanetas?

Métodos para detecção de Exoplanetas

- **Observação Direta,**
- **Lentes Gravitacionais,**
- **Método das Velocidades Radiais,**
- **Método do Trânsito - Fotometria**

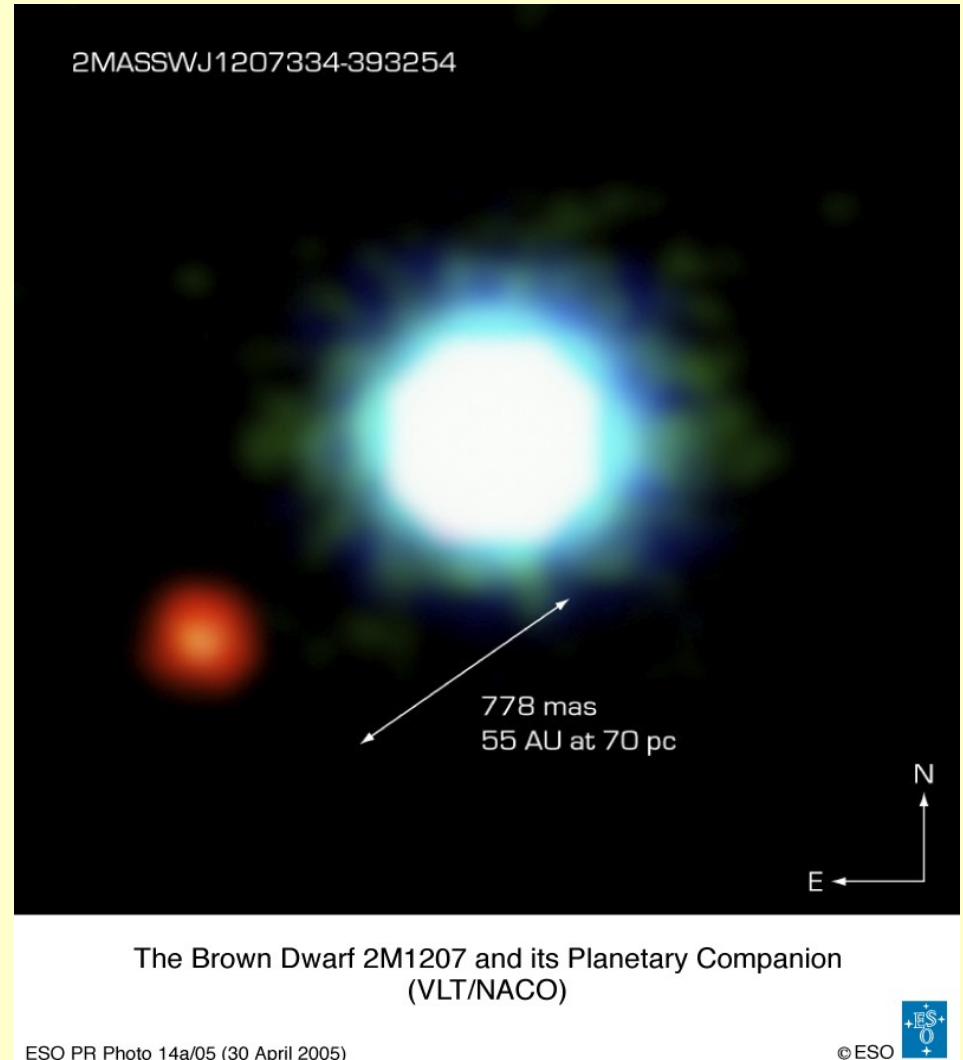
Buscando e descobrindo exoplanetas

Luminosidade
de um planeta
igual a Júpiter

=

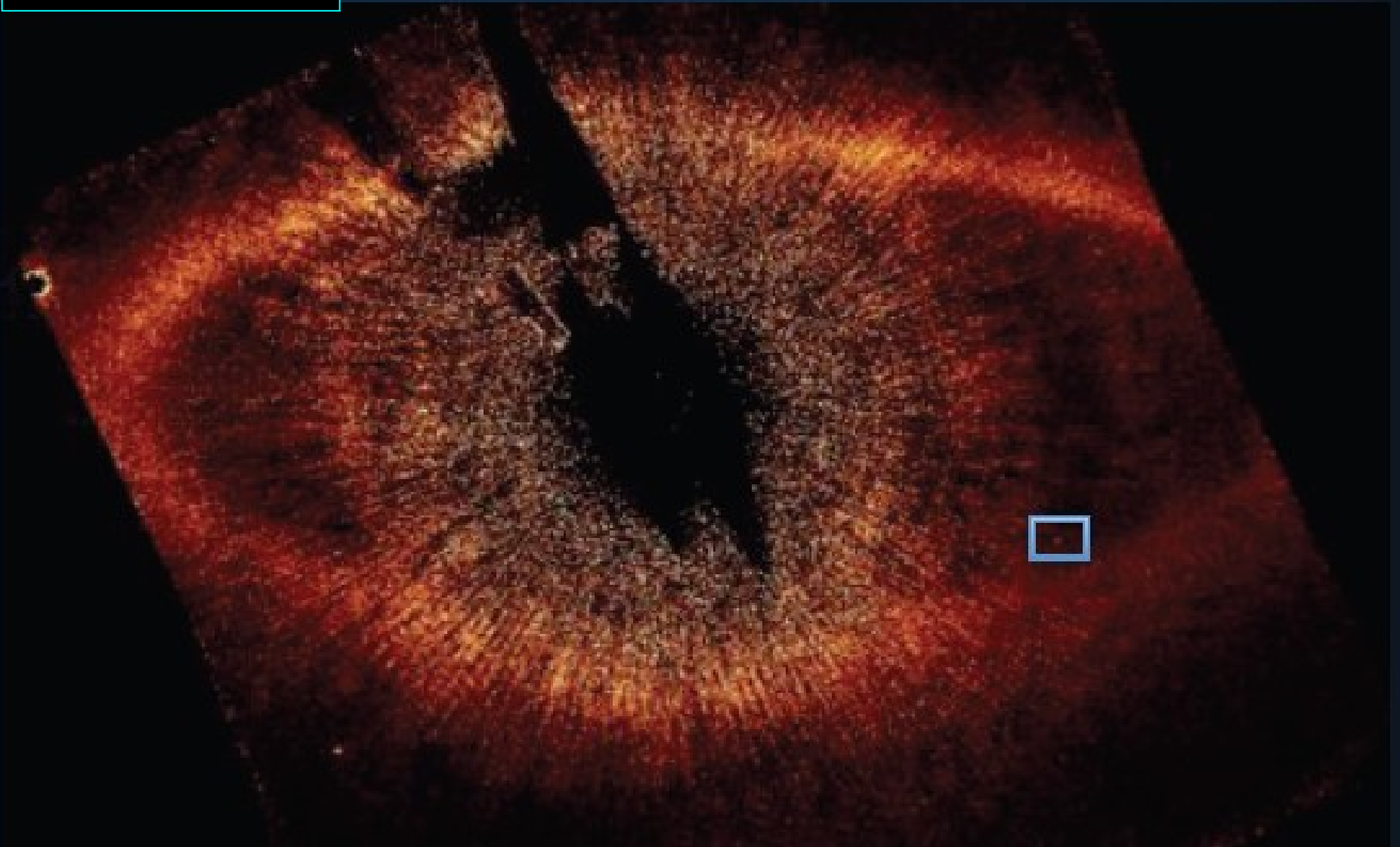
Luminosidade do Sol
1 000 000 000

Anã Marrom pouco
luminosa

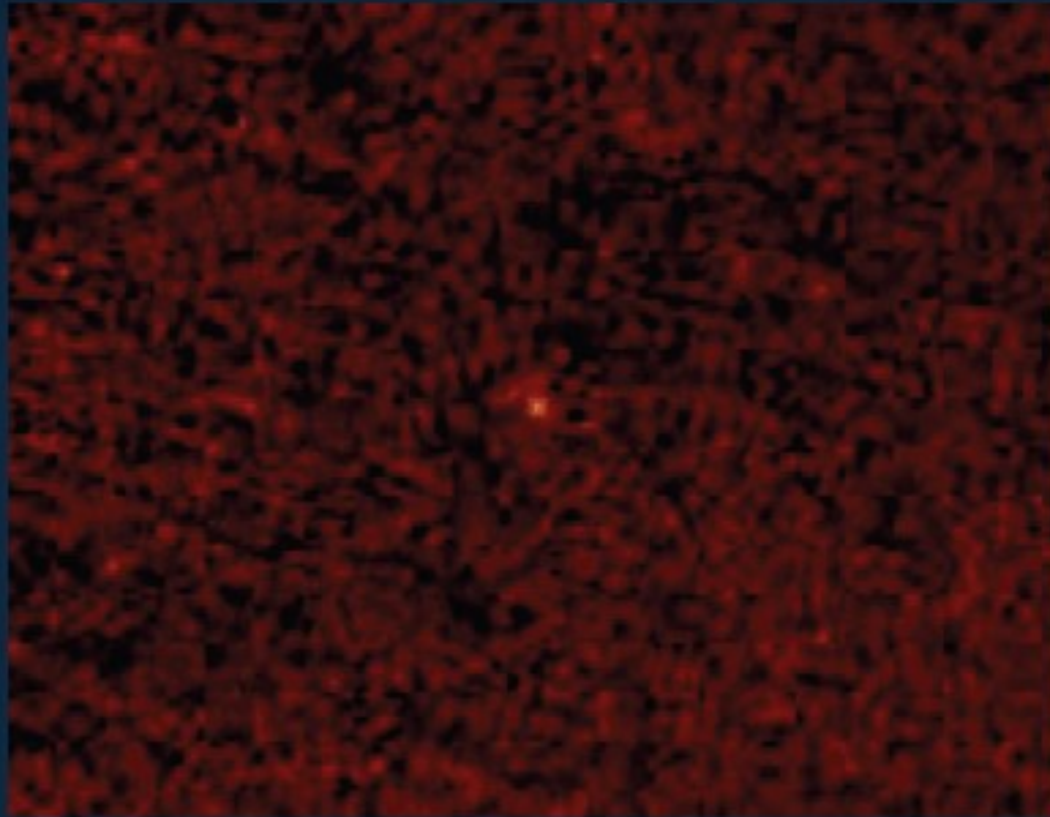


2006: *HST/ACS* deep multi-wavelength imaging
F435W, F606W, F814W

Fomalhaut b



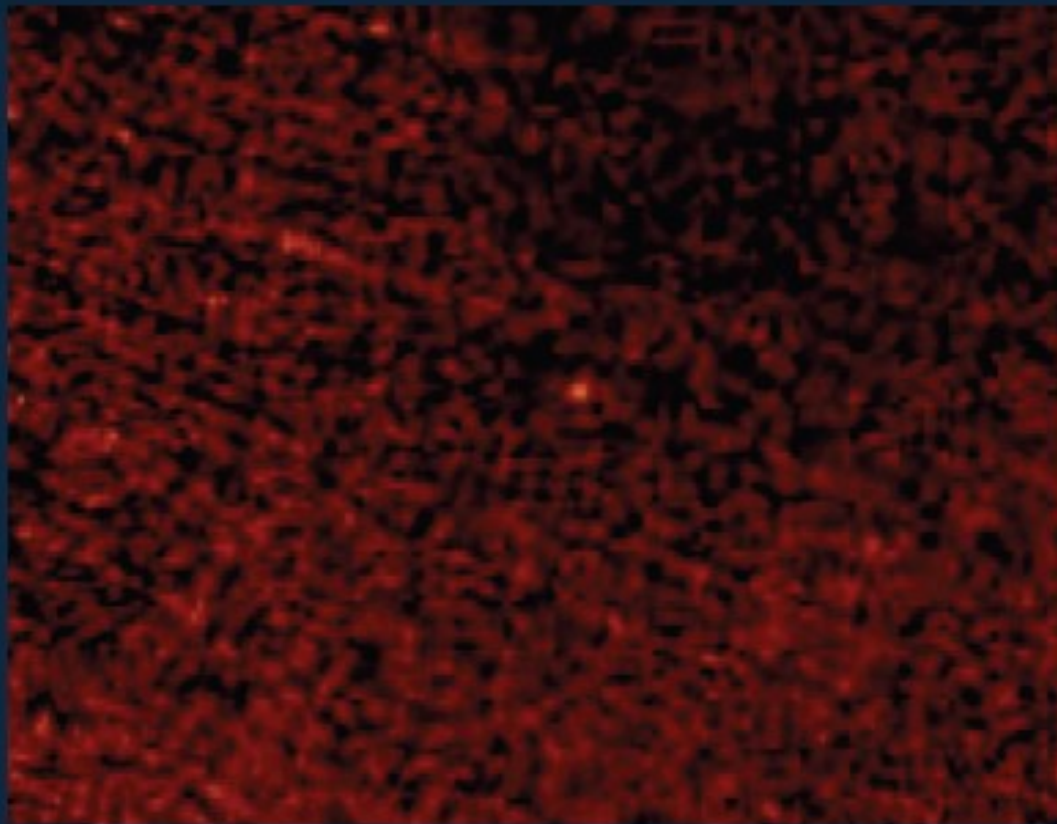
Fomalhaut b 2004



Paul Kalas (University of California, Berkeley)



Fomalhaut b 2006

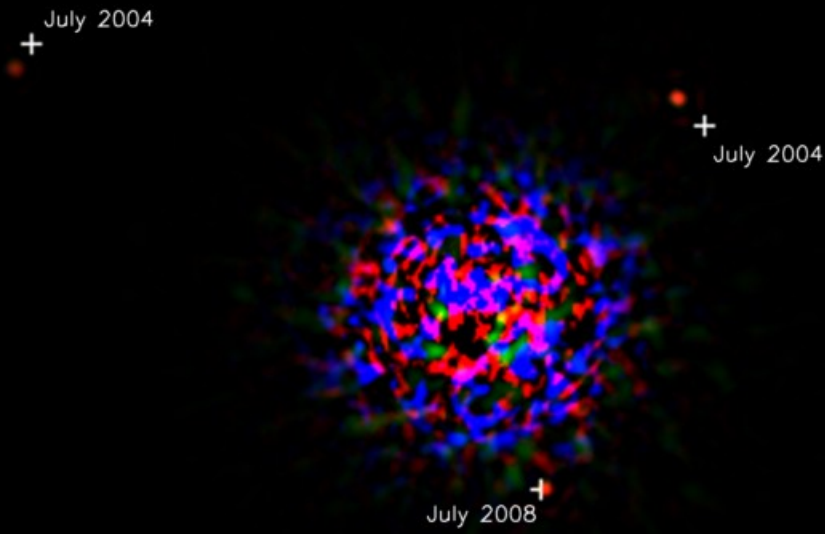


Paul Kalas (University of California, Berkeley)



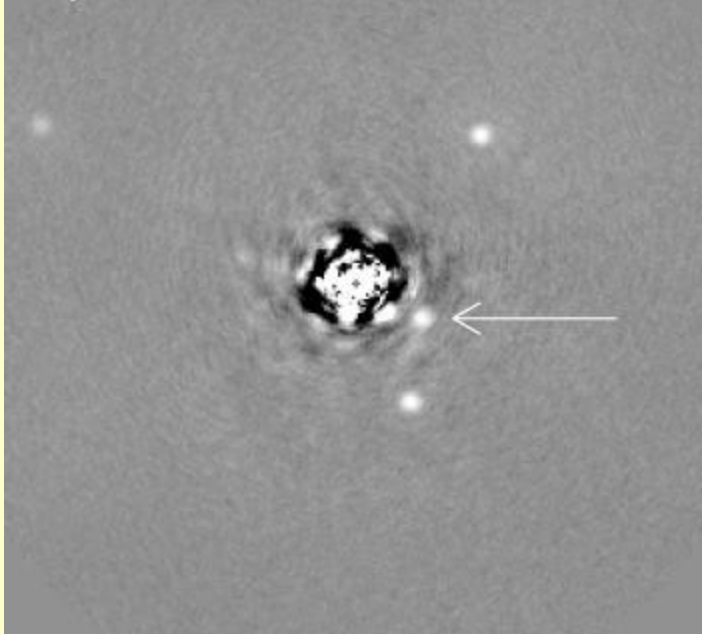
Planets Orbiting HR 8799

(Sept. 2008)

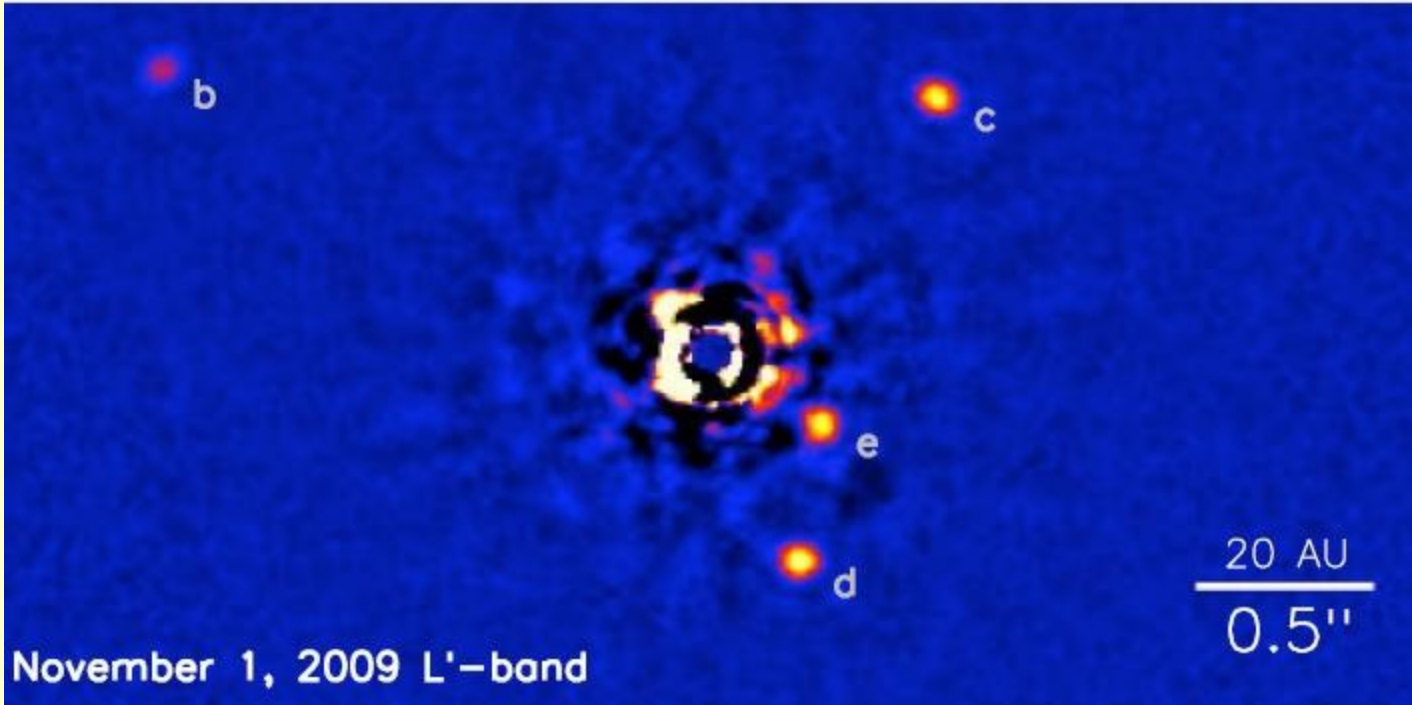
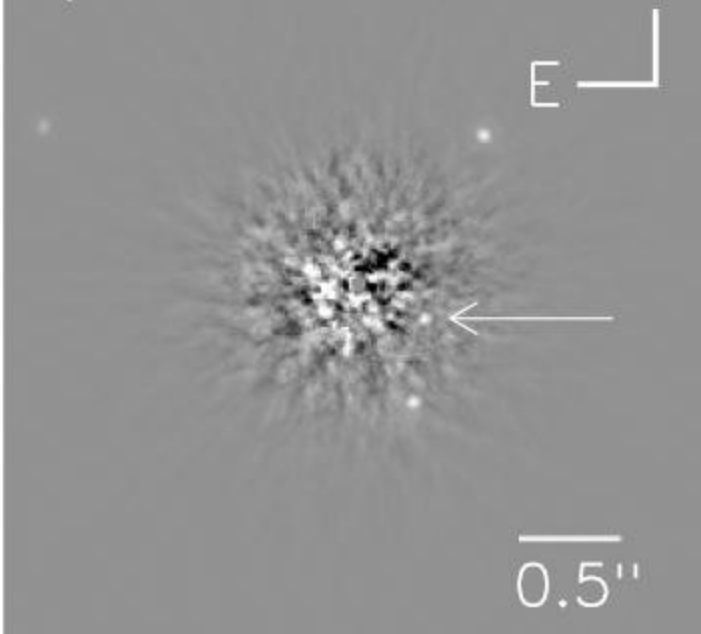


0.5 arcsec
20 AU

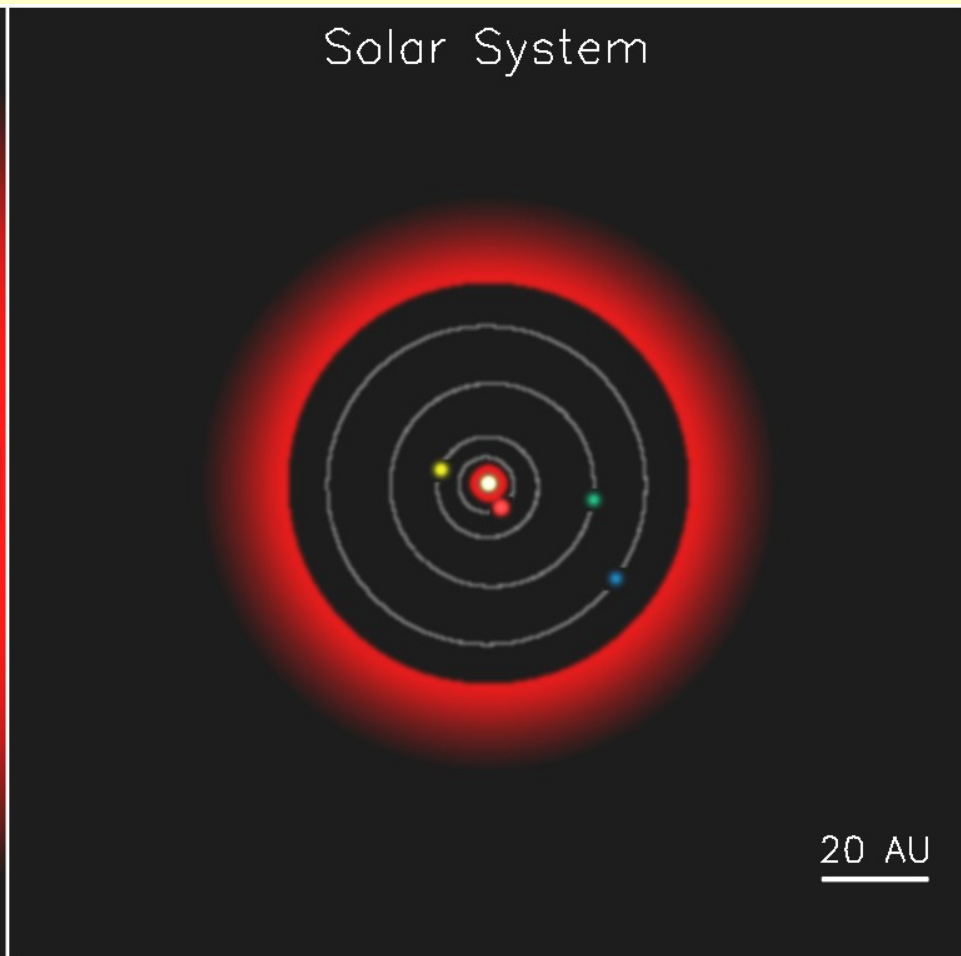
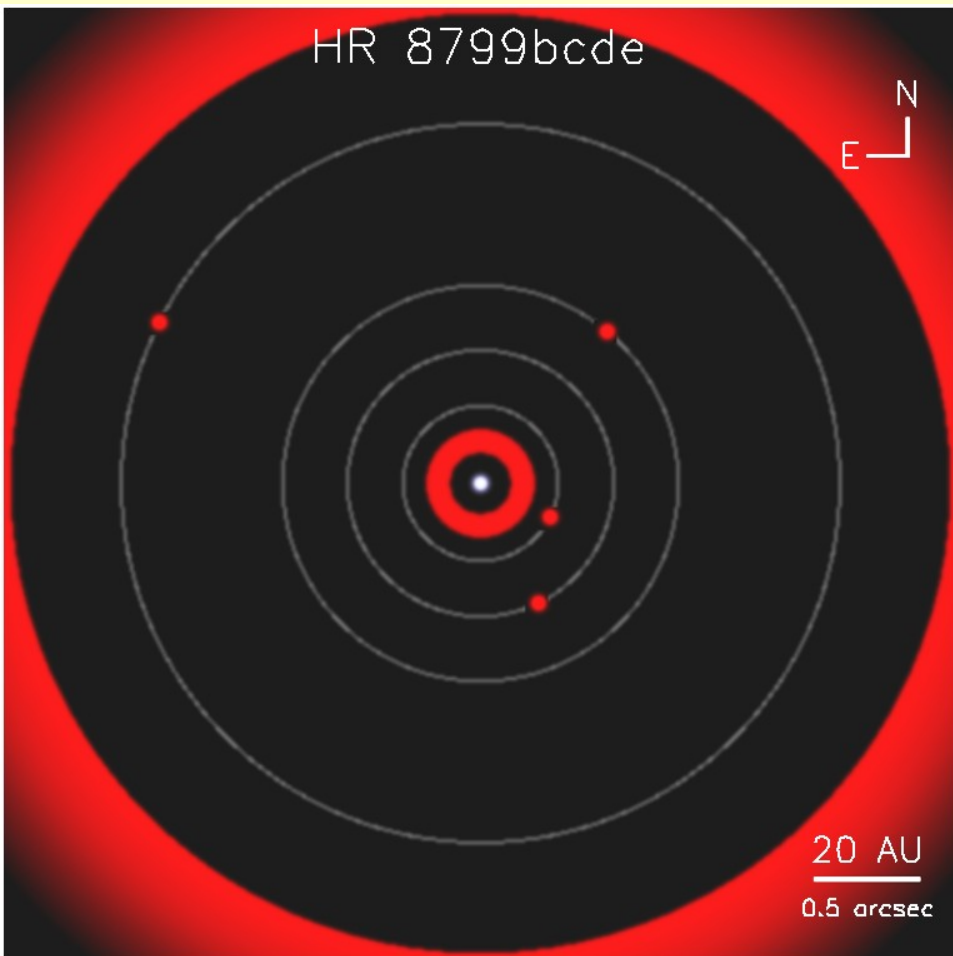
July 21, 2010 L'-band



July 13, 2010 Ks-band



November 1, 2009 L'-band



Lentes Gravitacionais

- Cerca de 15 planetas encontrados
- Variação no brilho da estrela lente.

Identification of exoplanet host star (OGLE-2003-BLG-235L/MOA-2003-BLG-53L)

A foreground red star and planet drift toward the sky position of a much-farther-distant, Sun-like background star.

In 2003, the foreground star-planet system amplifies the light of a background star that momentarily aligns with it. This is called a micro-lensing event.

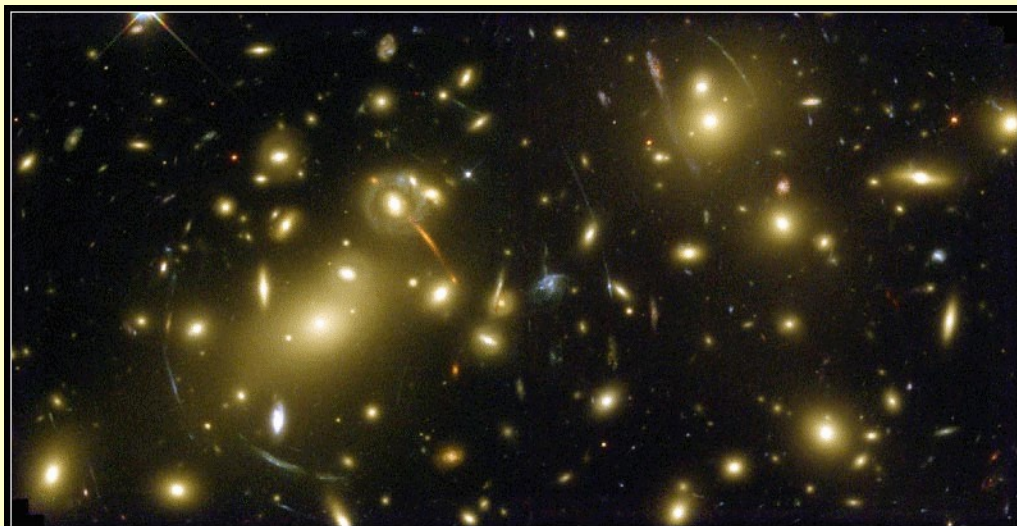
The position from each star is progressively more offset year after year as the foreground star drifts by.

In 2005, Hubble Space Telescope observations distinguish the slight offset in the positions of two stars (shown with red and blue crosshairs). Hubble can't resolve the two stars in their overlapping light, because the foreground star is a different color from the background star.

Background star

Foreground star (with Jovian planet OGLE-2003-BLG-235Lb/MOA-2003-BLG-53Lb)

0.1

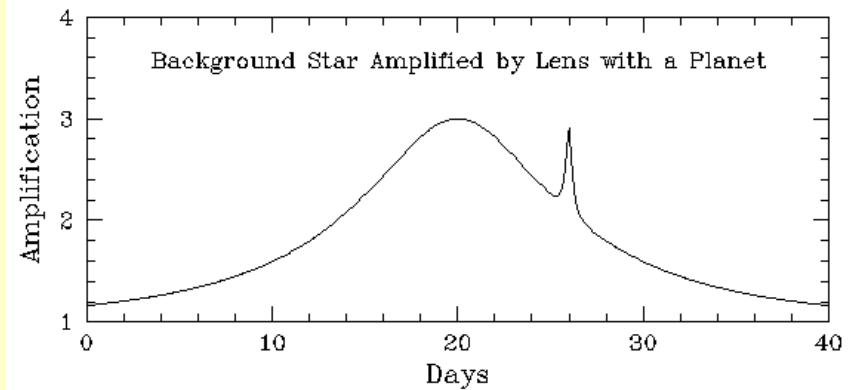
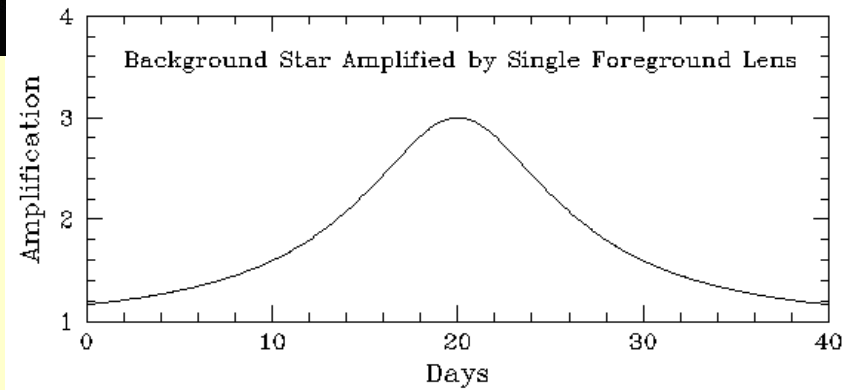


Galaxy Cluster Abell 2218

HST • WFPC2

NASA, A. Fruchter and the ERO Team (STScI, ST-ECF) • STScI-PRC00-08

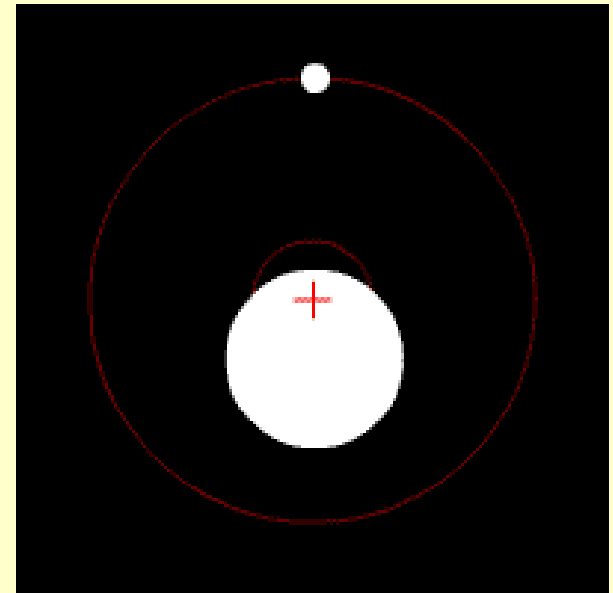
Fotometria da Luz das Estrelas

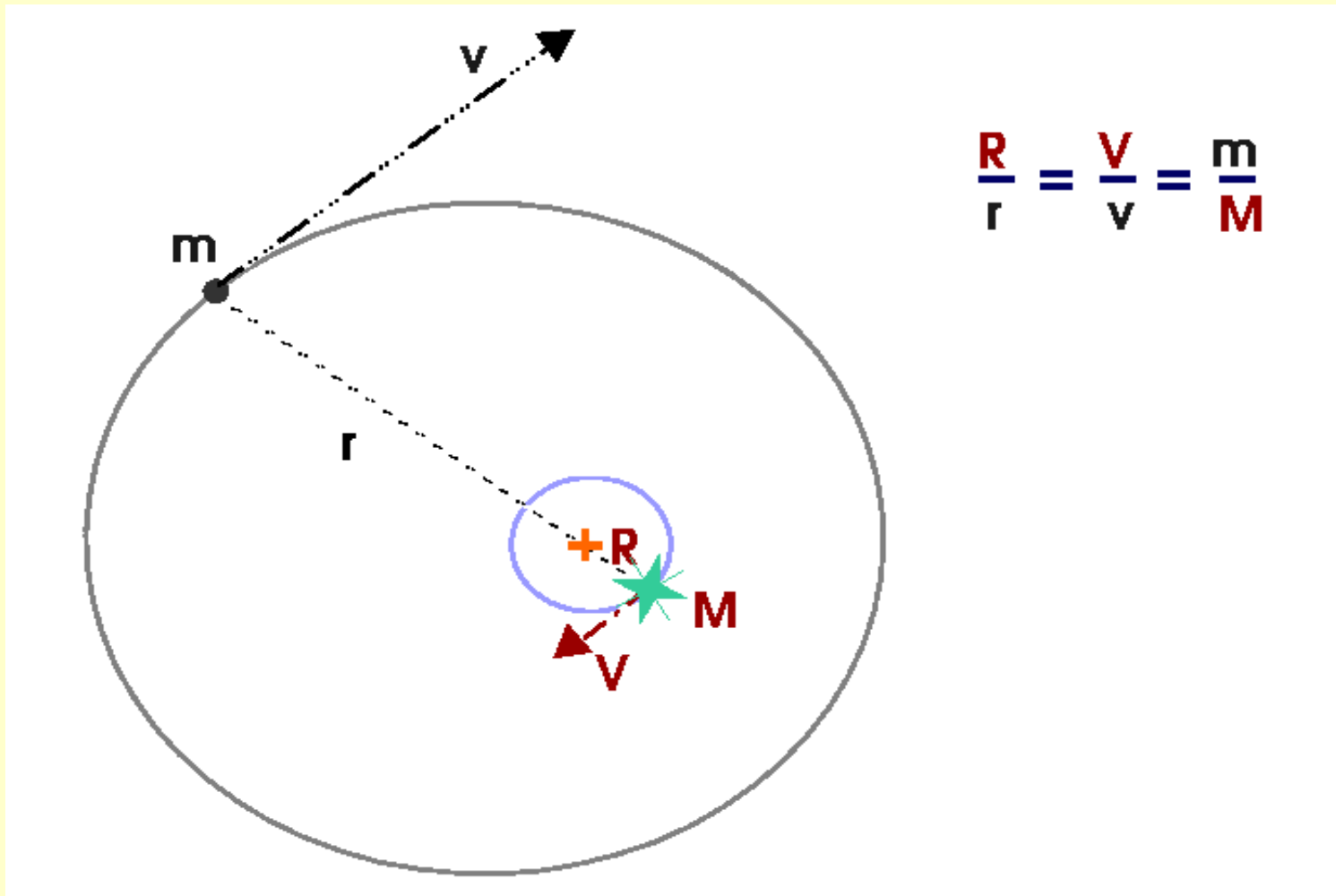


Como os planetas afetam as estrelas?

- Interação Gravitacional
- Movimento em torno do centro de massa do sistema.
- Leis de Kepler:

$$3^{\text{a}} \text{ Lei: } \frac{R^3}{T^2} = \frac{G m}{4 \pi^2}.$$





r, v, R, V são coordenadas e velocidades baricêntricas

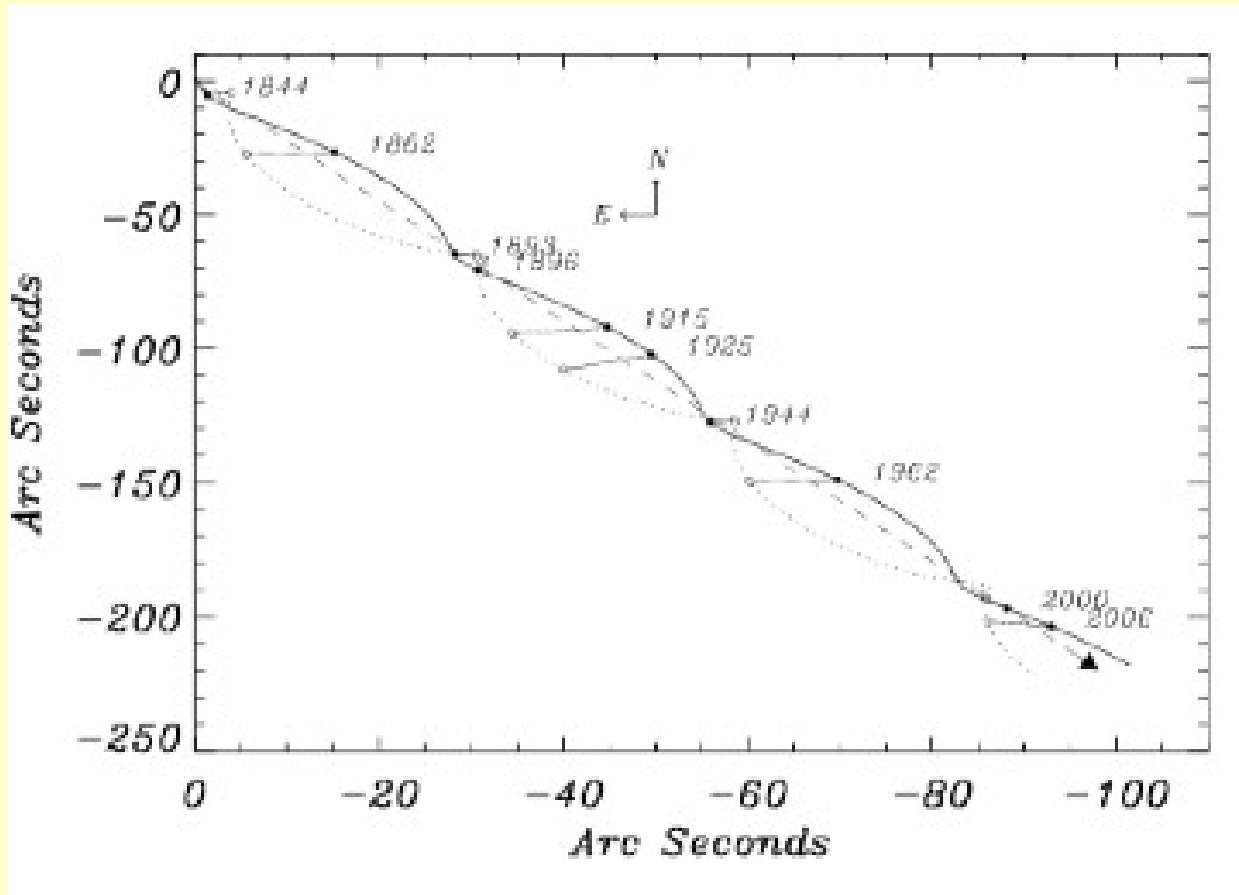
Estrela de Barnard



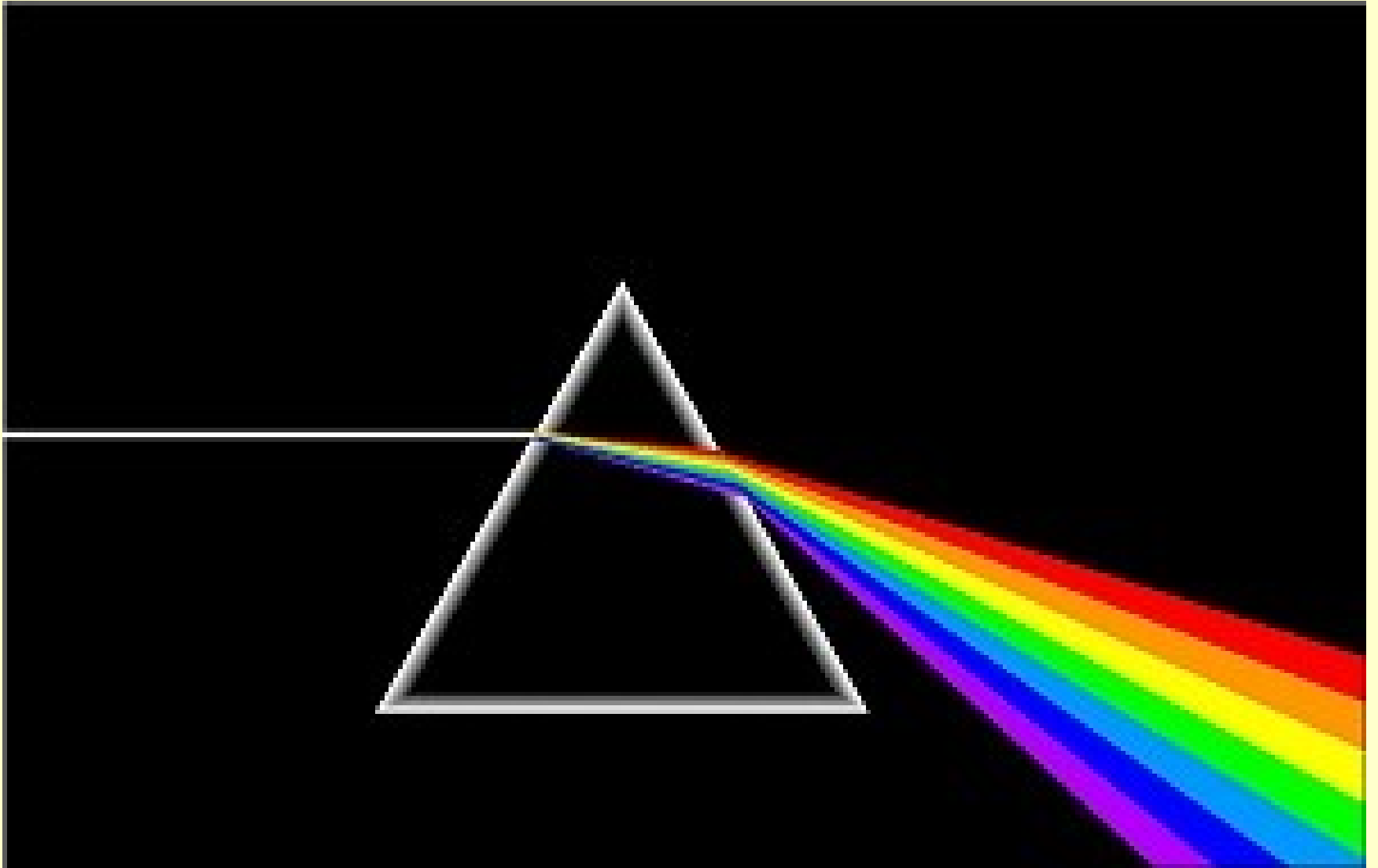
Estrelas
companheiras
afetam o
movimento uma da
outra.

E quanto a
planetas?

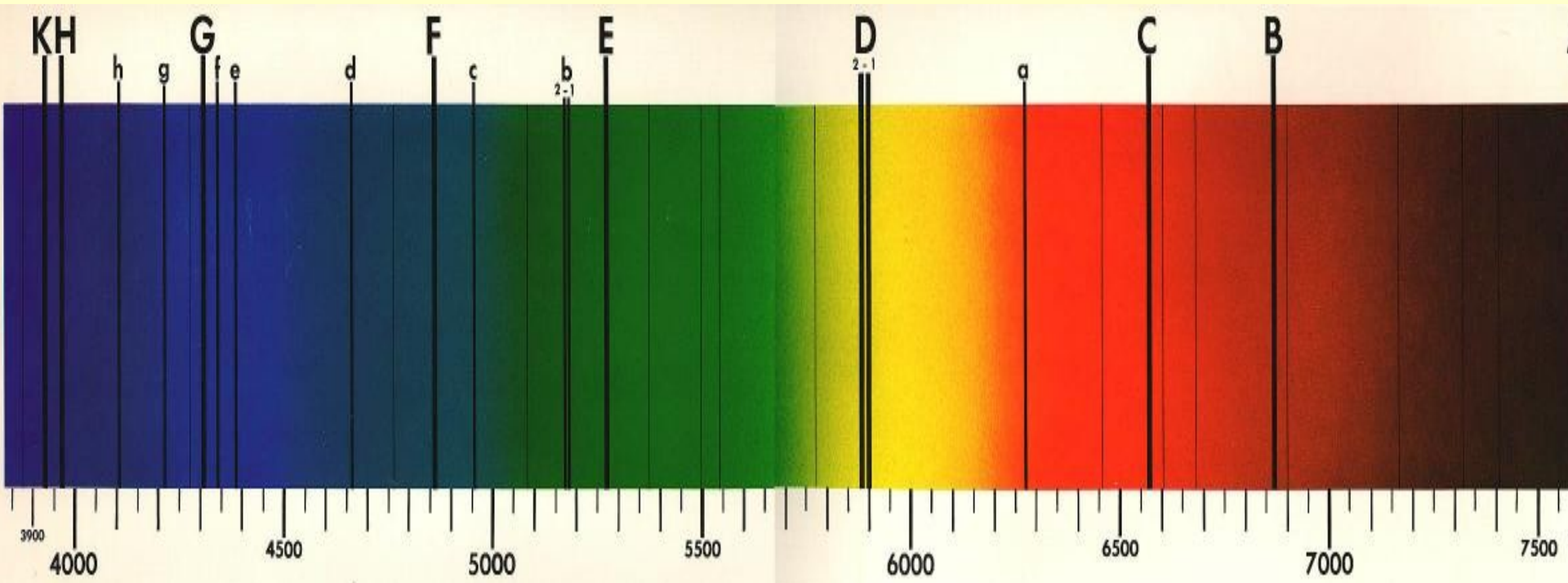
Sirius A+B



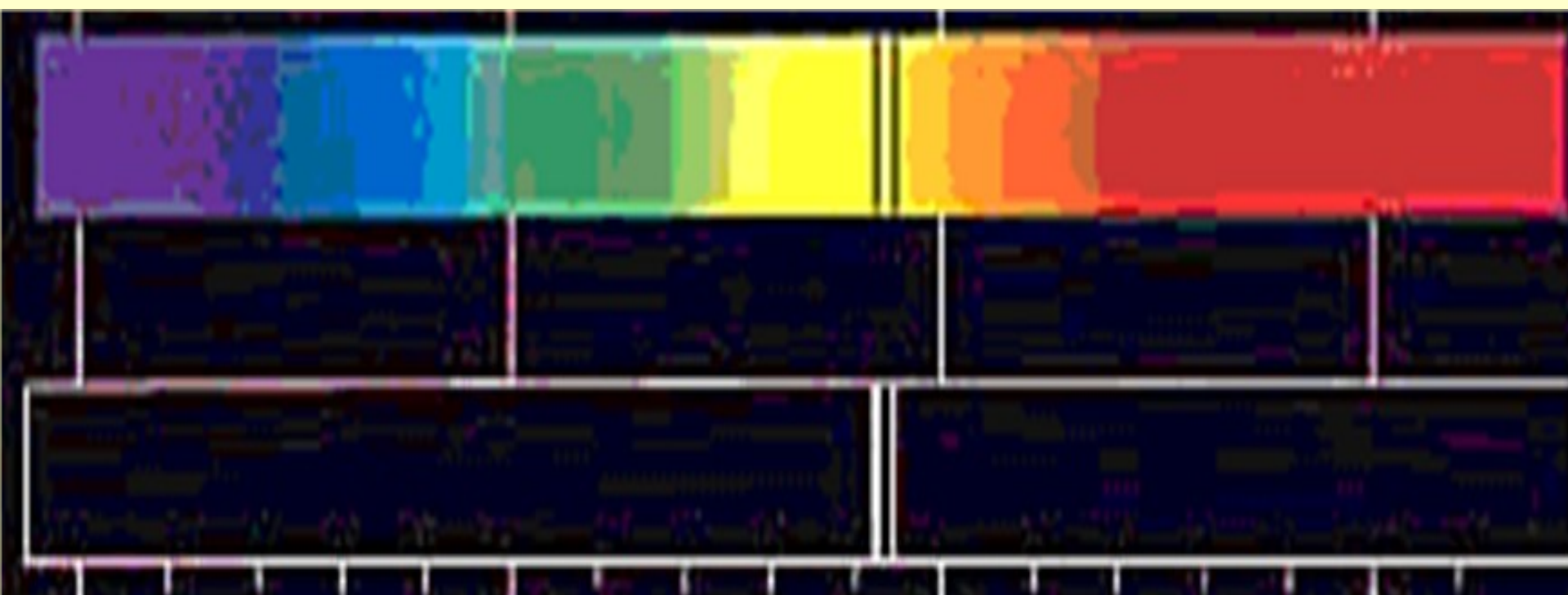
Como então, observar as pequenas variações de velocidade nas estrelas?

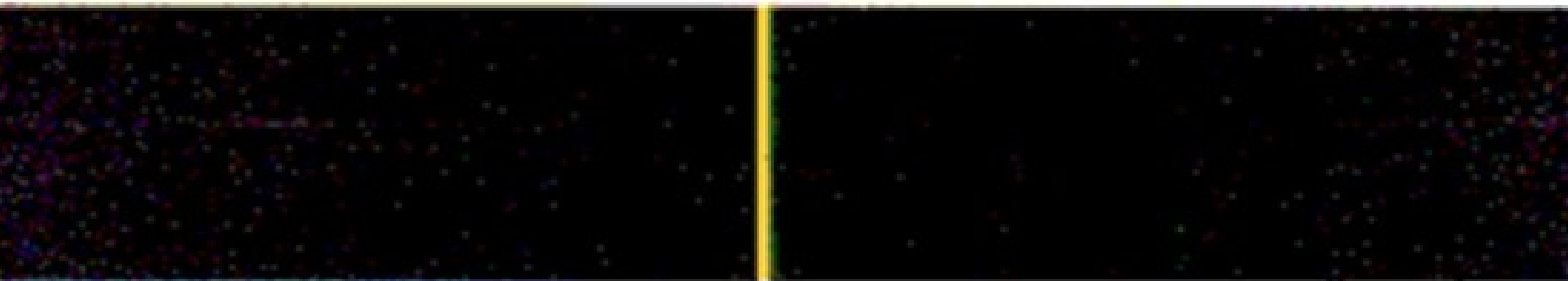
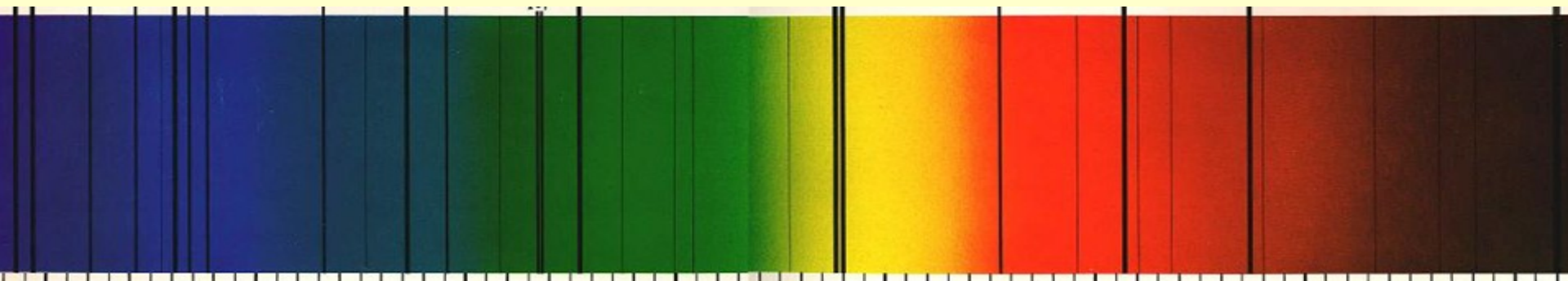


Espectro do sol - Fraunhofer



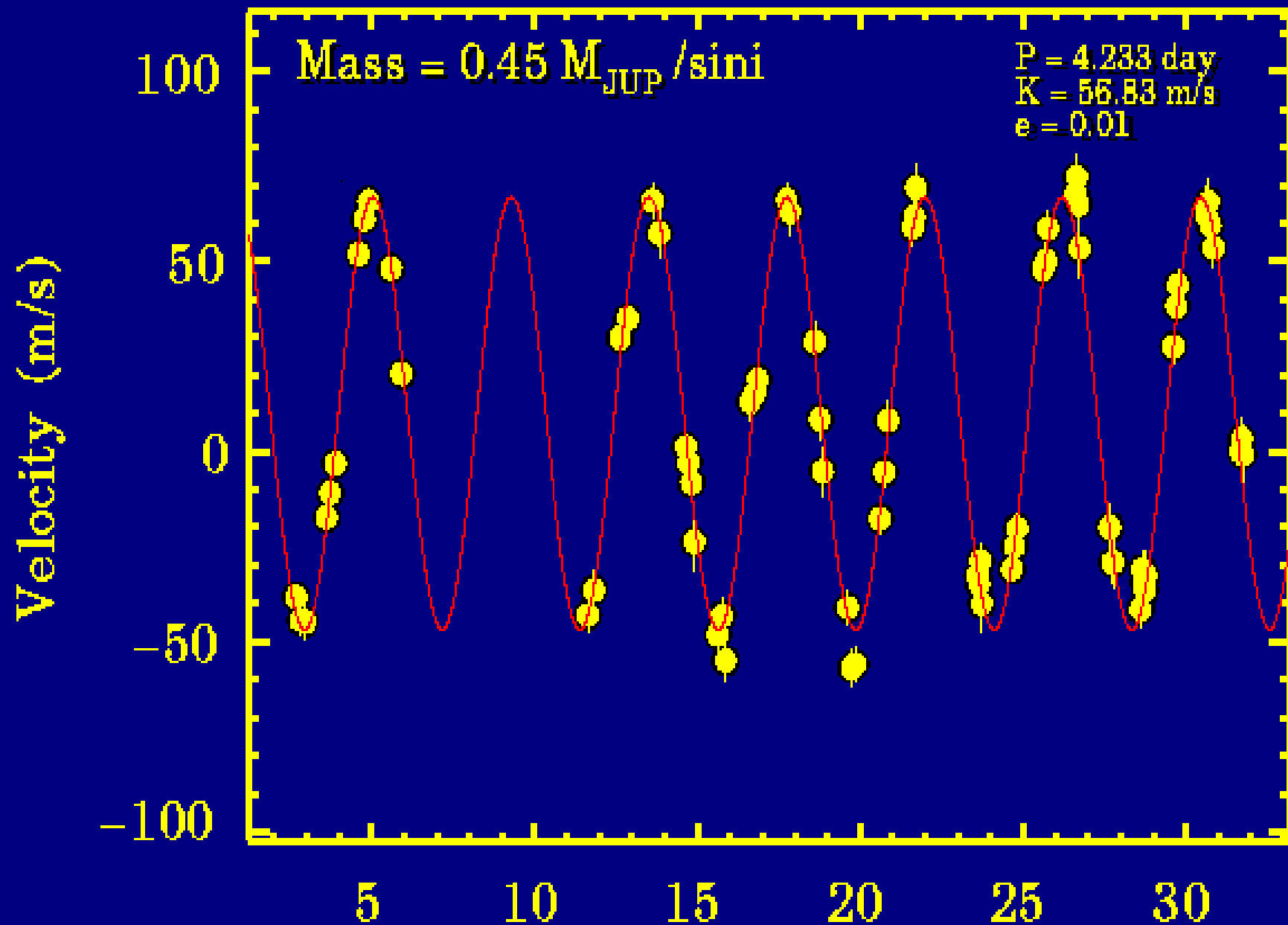




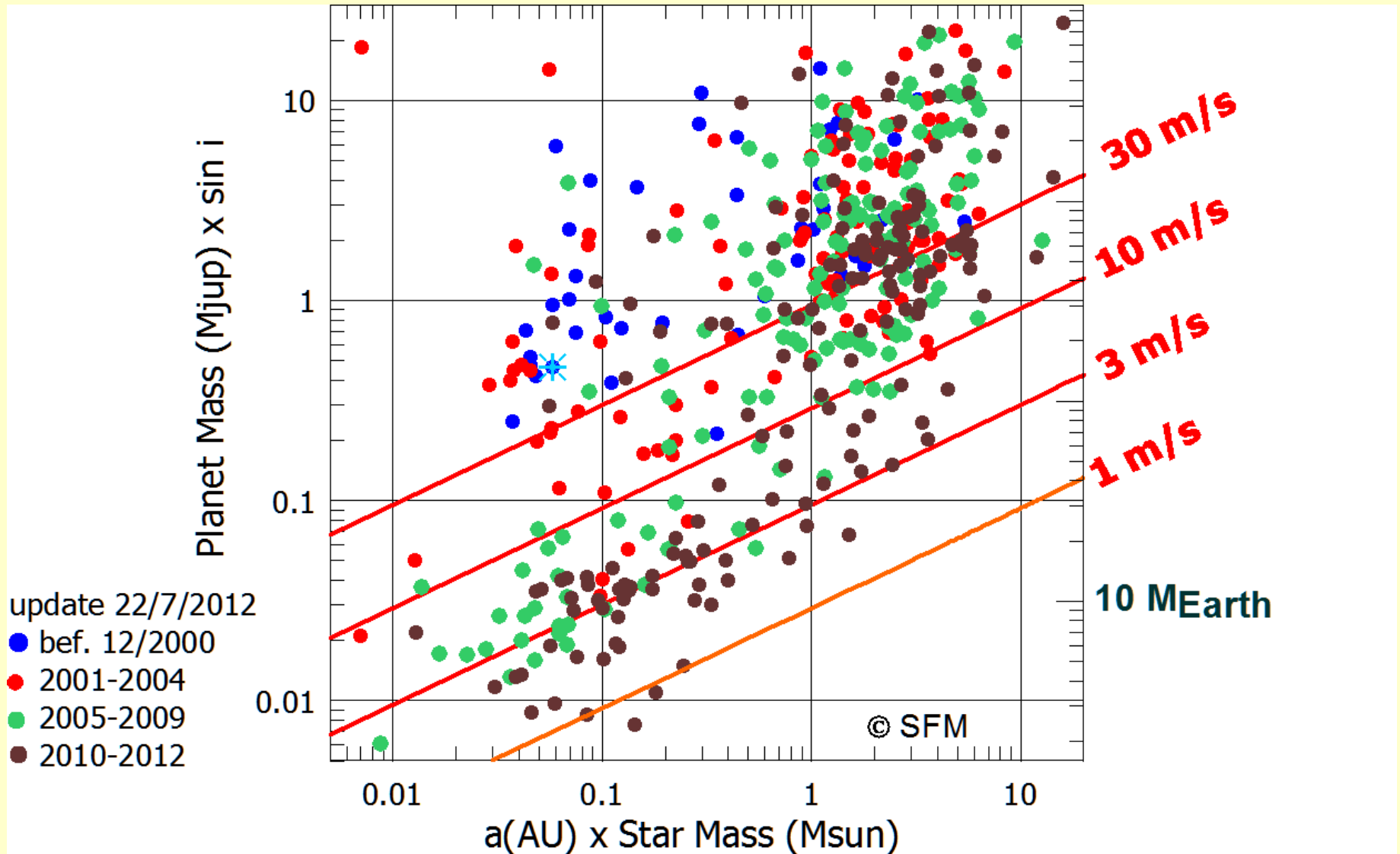


51 Pegasi

Marcy & Butler



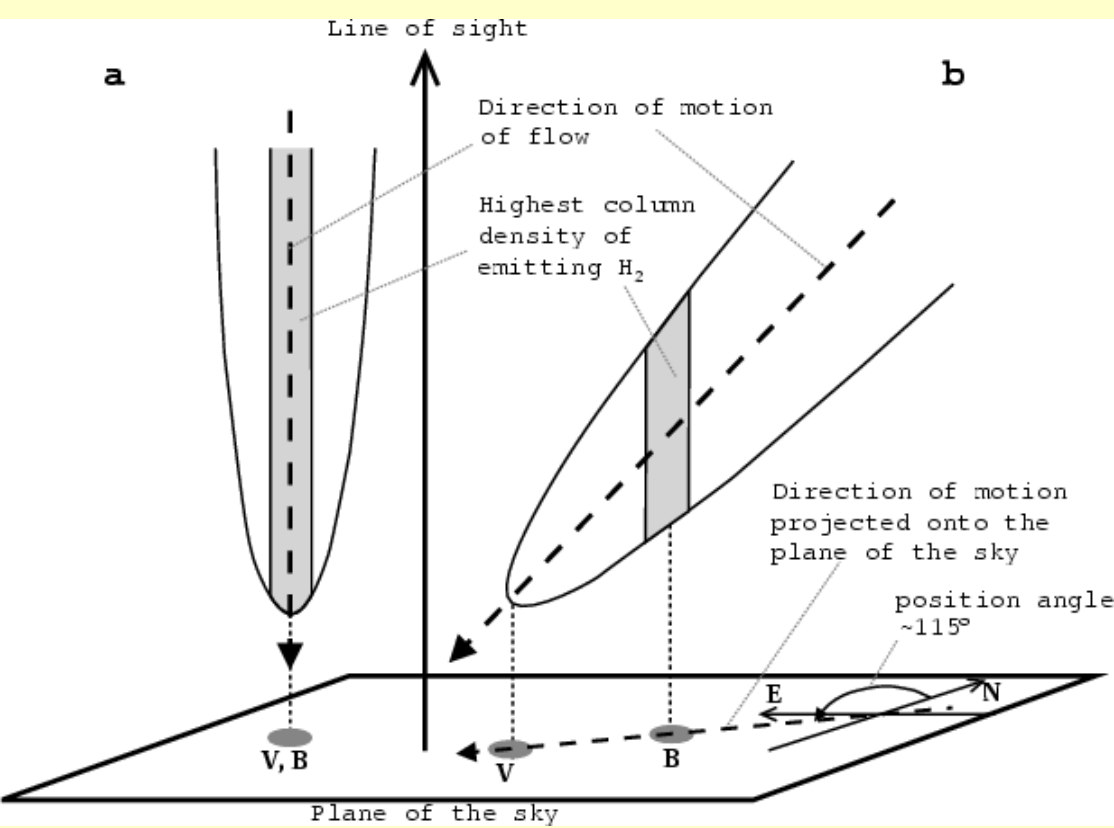
Planetas descubiertos c/ Veloc. Ra



Marcado: 51 Peg b (desc. 1995)



Harps at ESO (Chile)



Exemplos:
Sol-Júpiter ~ 13 m/S
Sol-Terra ~ 9 cm/s

Não é possível
 separar os valores
 de
M, m e sin I!

$$RV = \text{proj}_{\text{linha de visada}} \vec{V} = K [\cos(v + \omega) + e \cos \omega]$$

$$K = \frac{m}{m + M} \frac{na \sin i}{\sqrt{1 - e^2}}$$

OS PLANETAS DE UPSILON ANDROMEDA

ASSAS

idade: Júpiter]

)	0.69	5.9
)	1.93	14.57
)	3.95	10.19
)	1.06	?

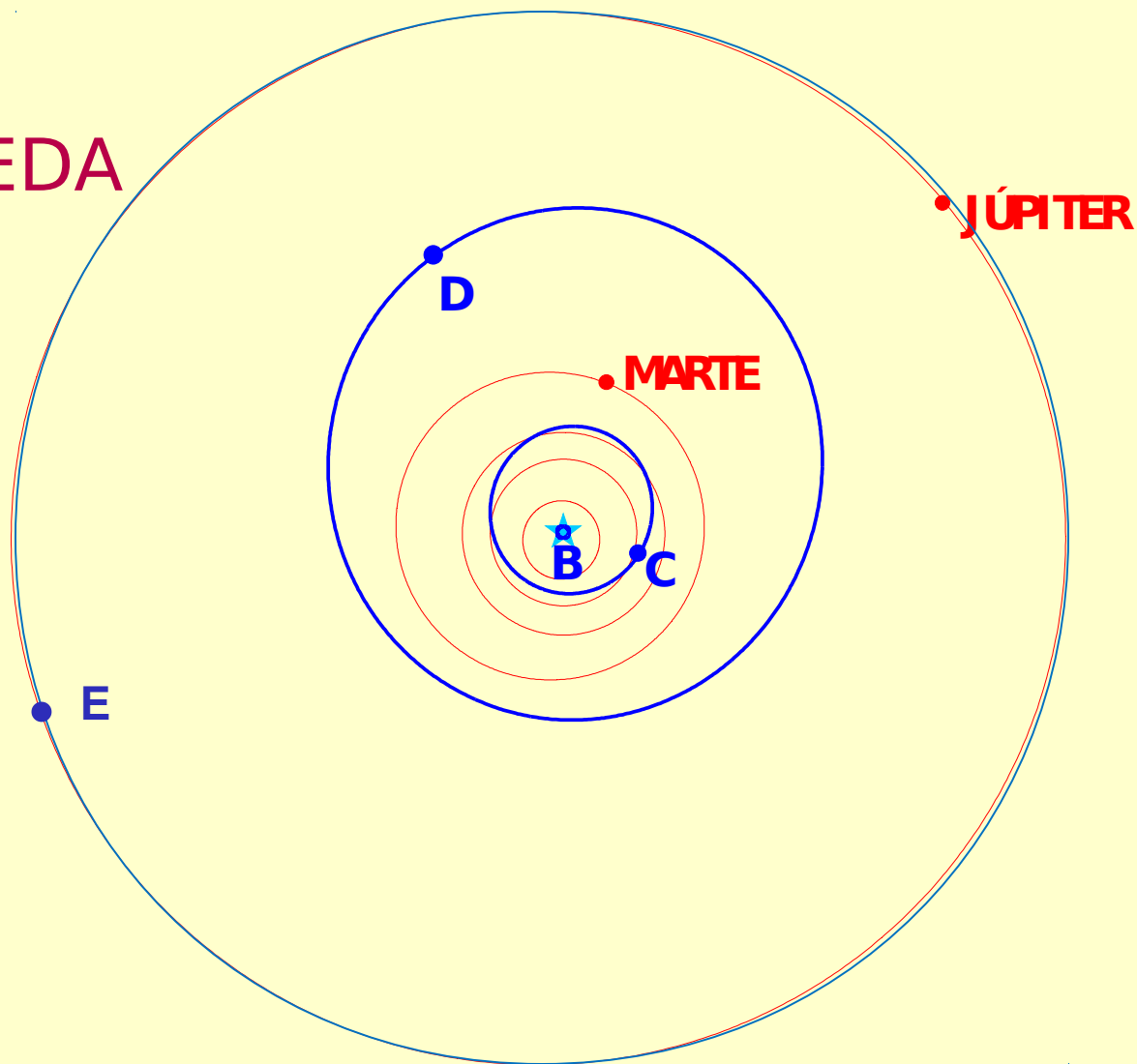
periodos: 4.6 d

241 d

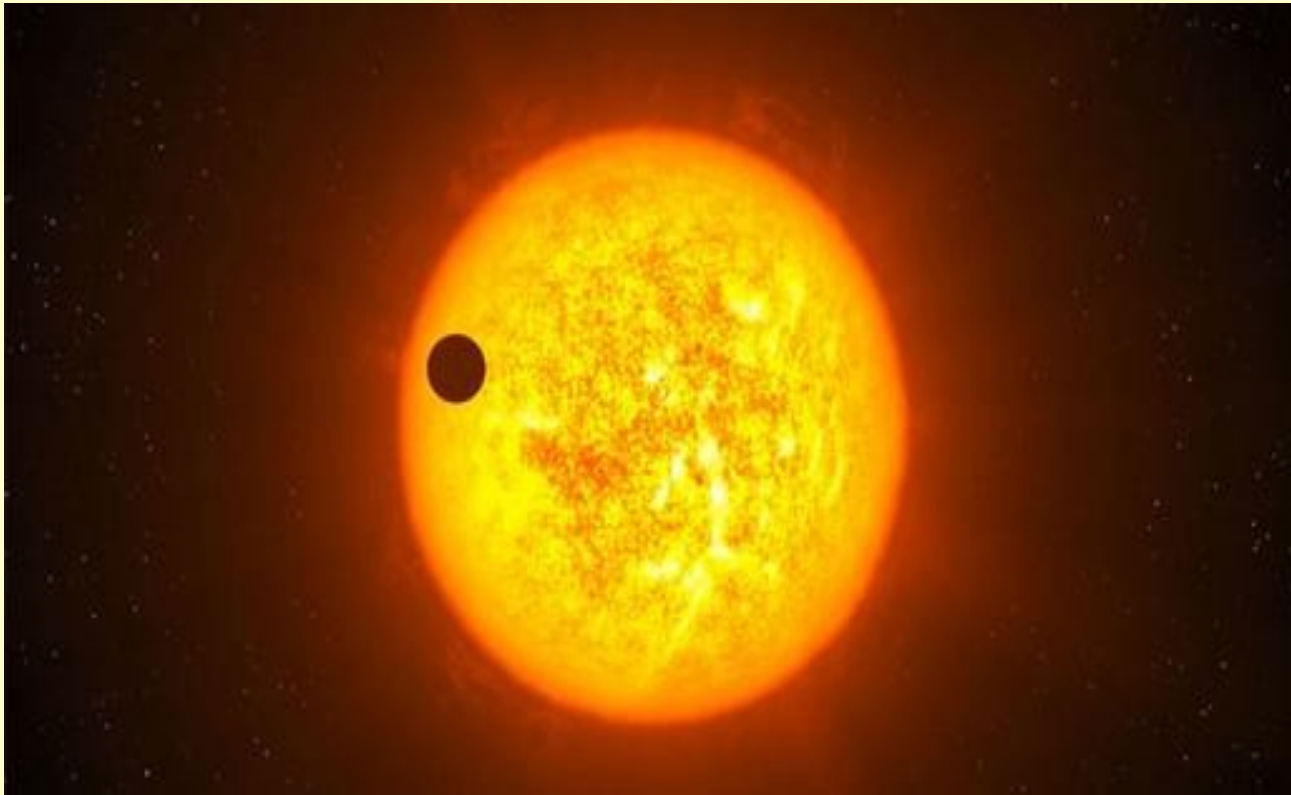
$3a + 194$ d

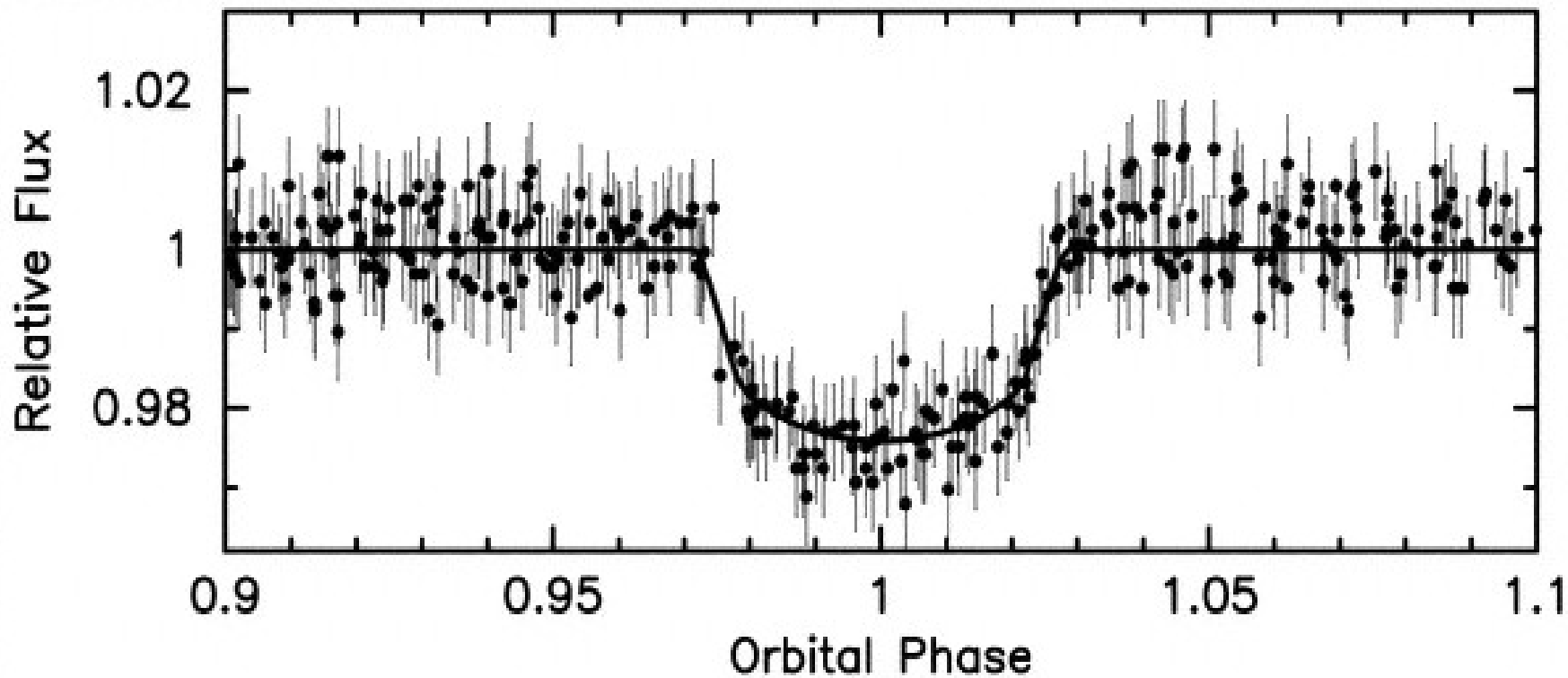
$10a + 196$ d

Inclinações: $7-15^\circ$



Buscando outras formas de detectar exoplanetas...Trânsito planetário!



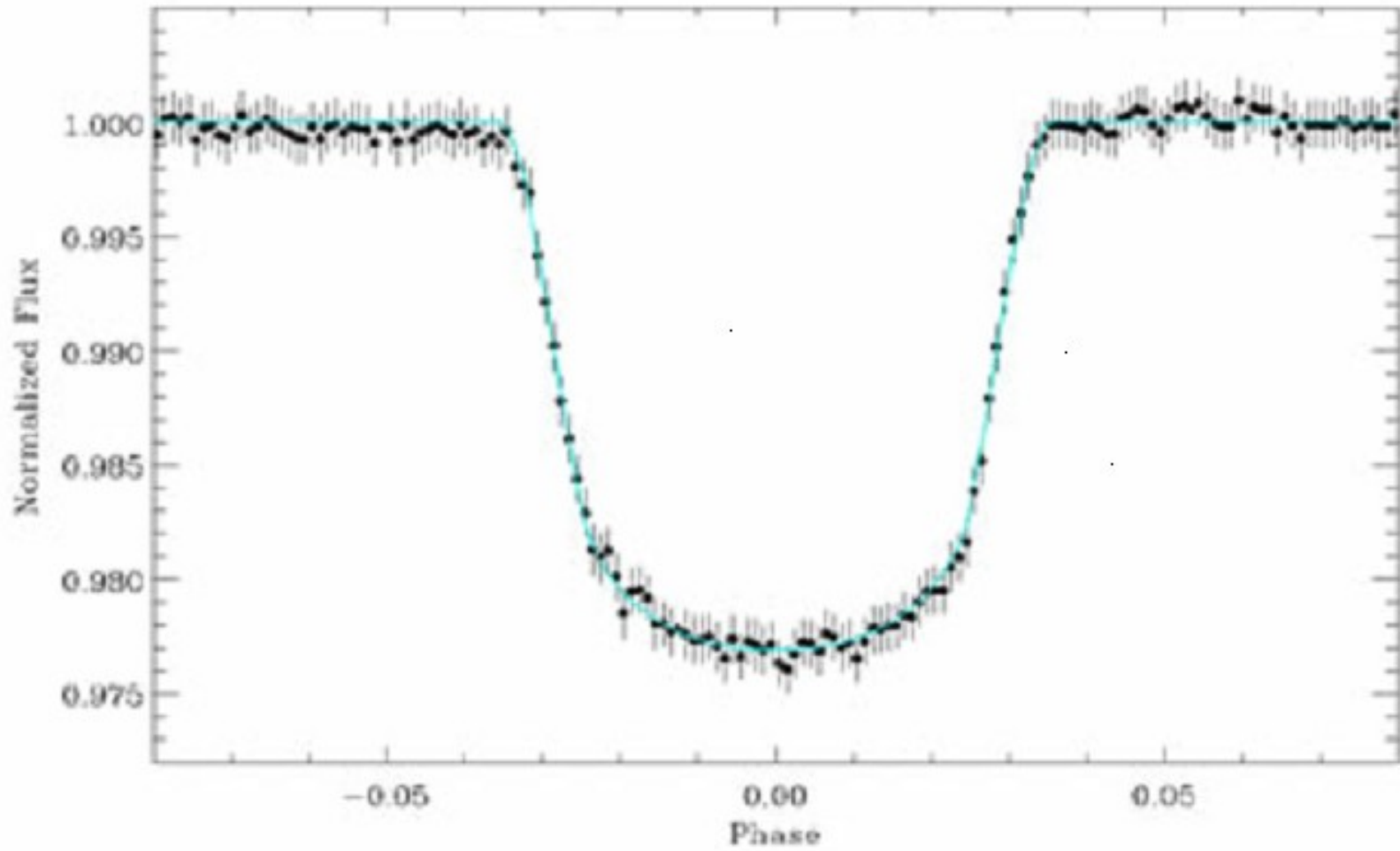




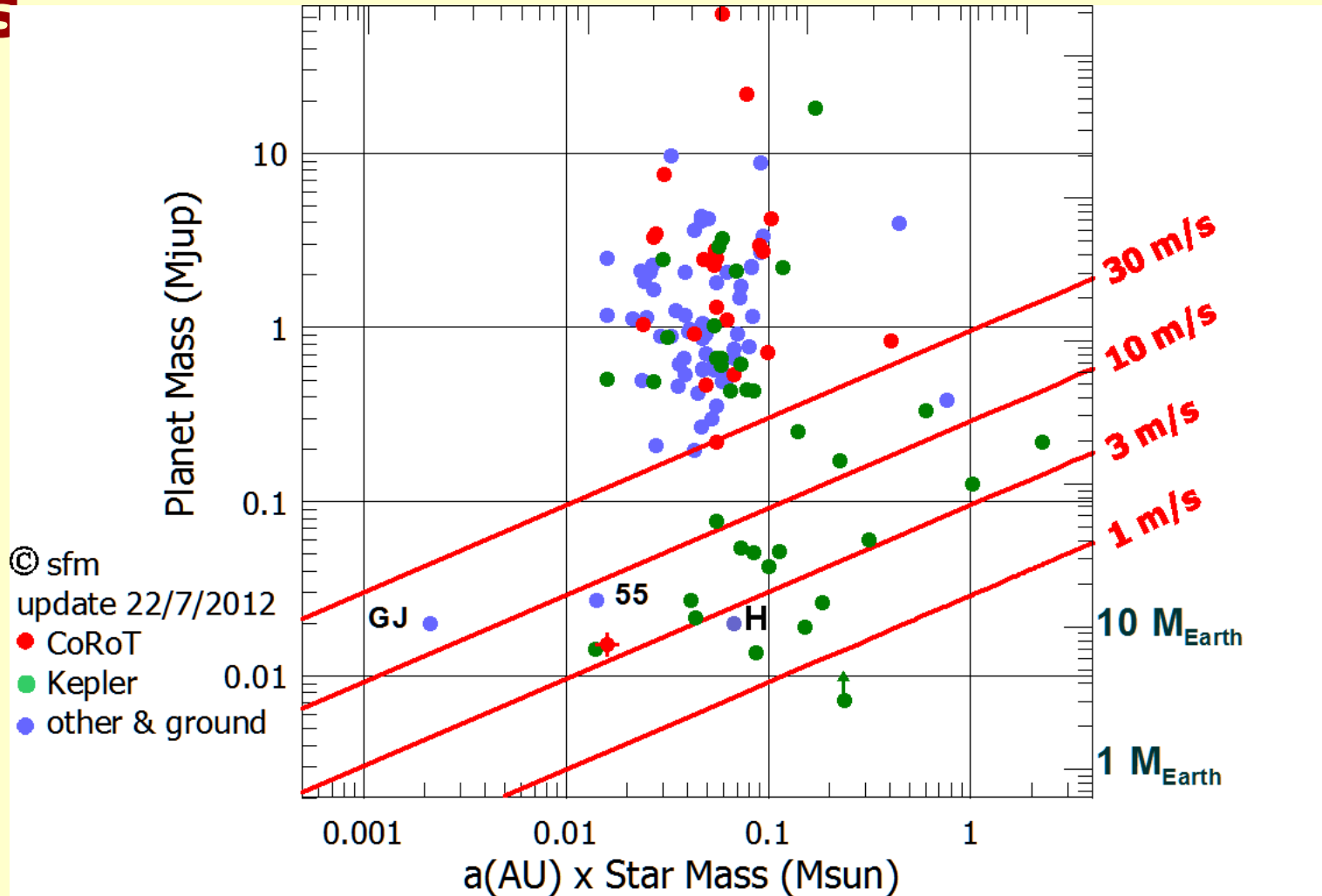
- Lançado em 2006.
- Está praticamente fora de operação desde final de 2012, devido a problemas técnicos.



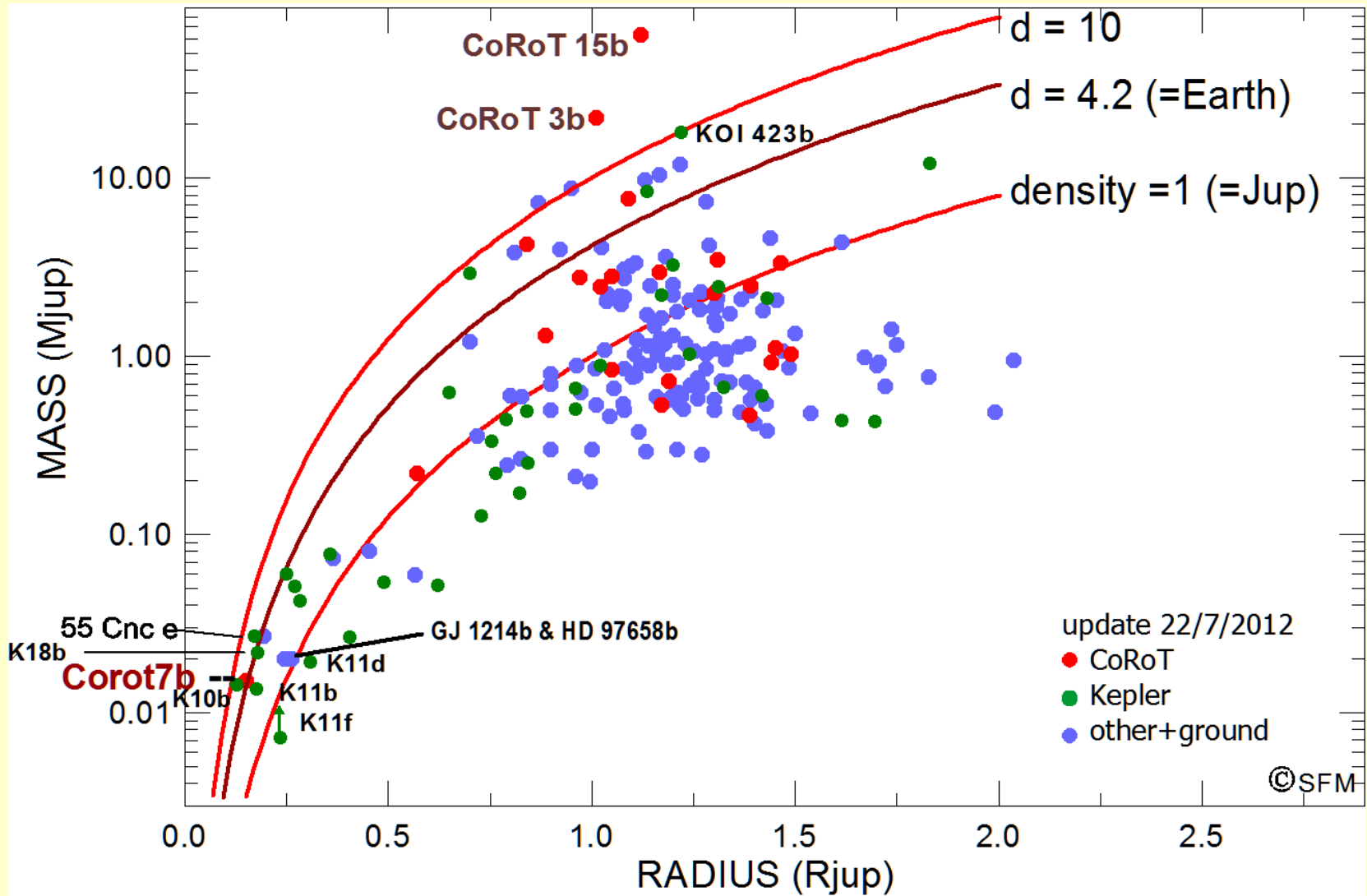
CoRoT-exo-1b



Planetas & Anãs Marrons c/ trânsitos obs



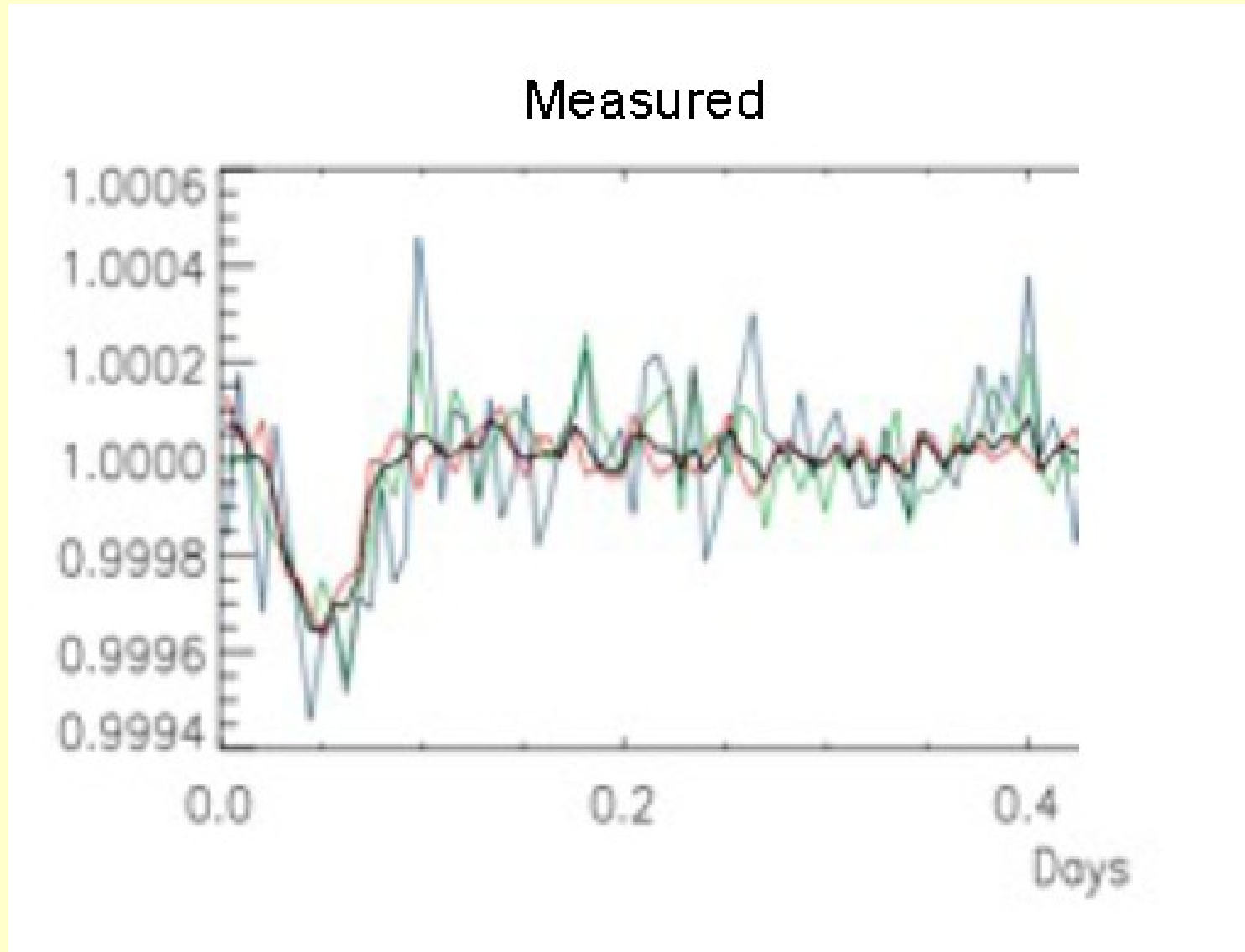
Notadas: CoRoT 7b, GJ 1214 b, 55 Cnc e, HD 97658 b



Relação Massa - Raio

Linhas de densidade (1=Jup)

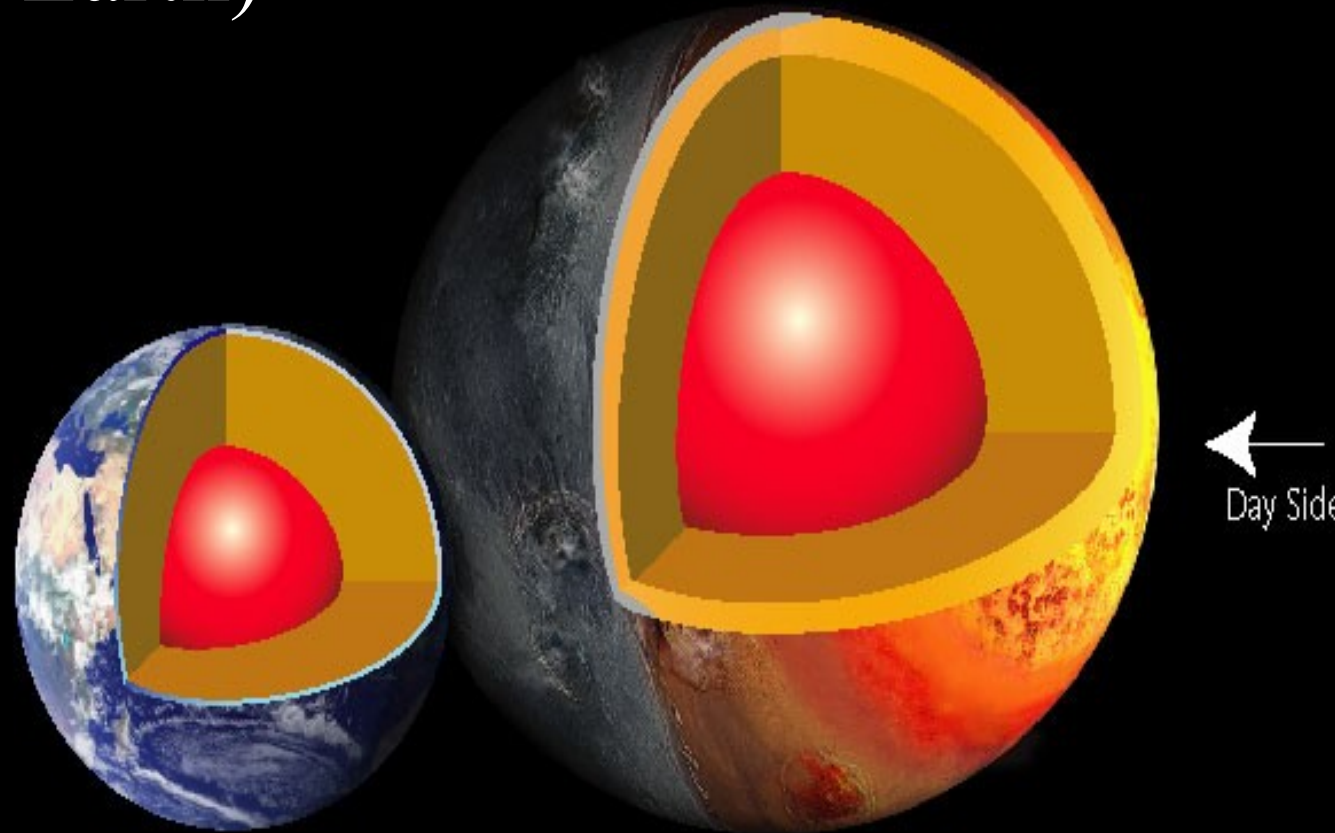
CoRoT 7b (Variação 0.0004)



V=11.7

Começamos a classificar os exoplanetas!

Possible internal structure (compared to Earth)



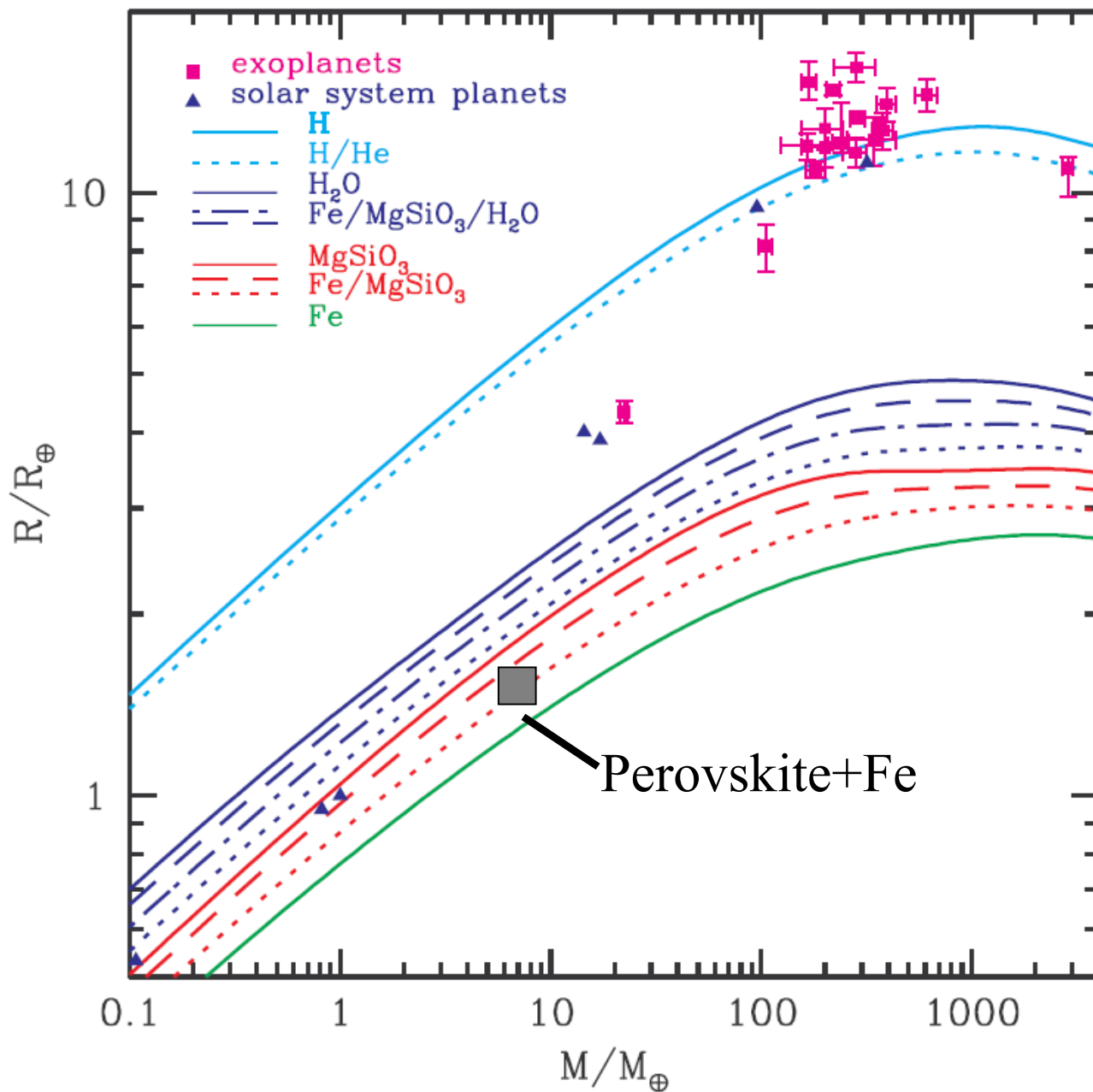
Iron core

Silicate mantle

Lava ocean

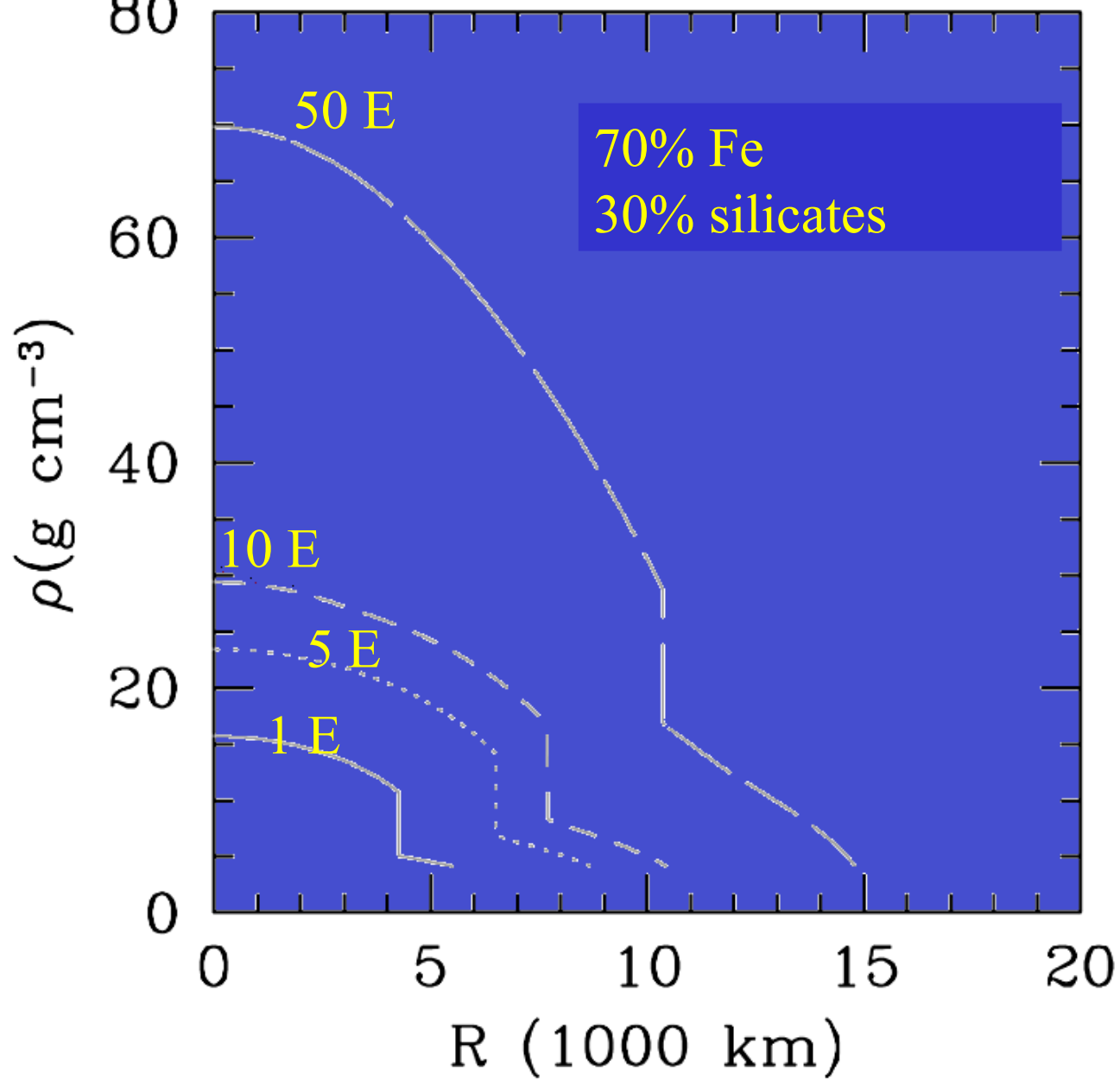
Silicate crust

Seager
et al.
ApJ 669,
2007



ABO_3

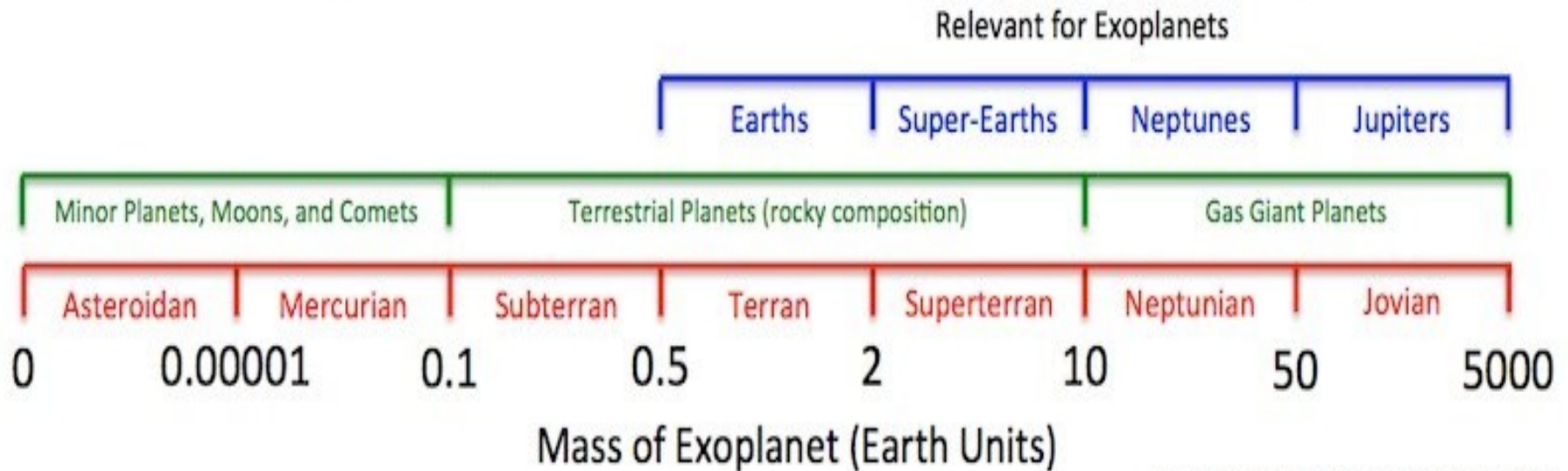
Seager
id.



Classificando os exoplanetas

- Classificação de Jornada nas Estrelas.
- Classificação Termal.
- Classificação por massas e densidades:

Exoplanets Mass Classification (EMC)



Credit: 2011, PHL @ UPR Arecibo (phl.upra.edu)

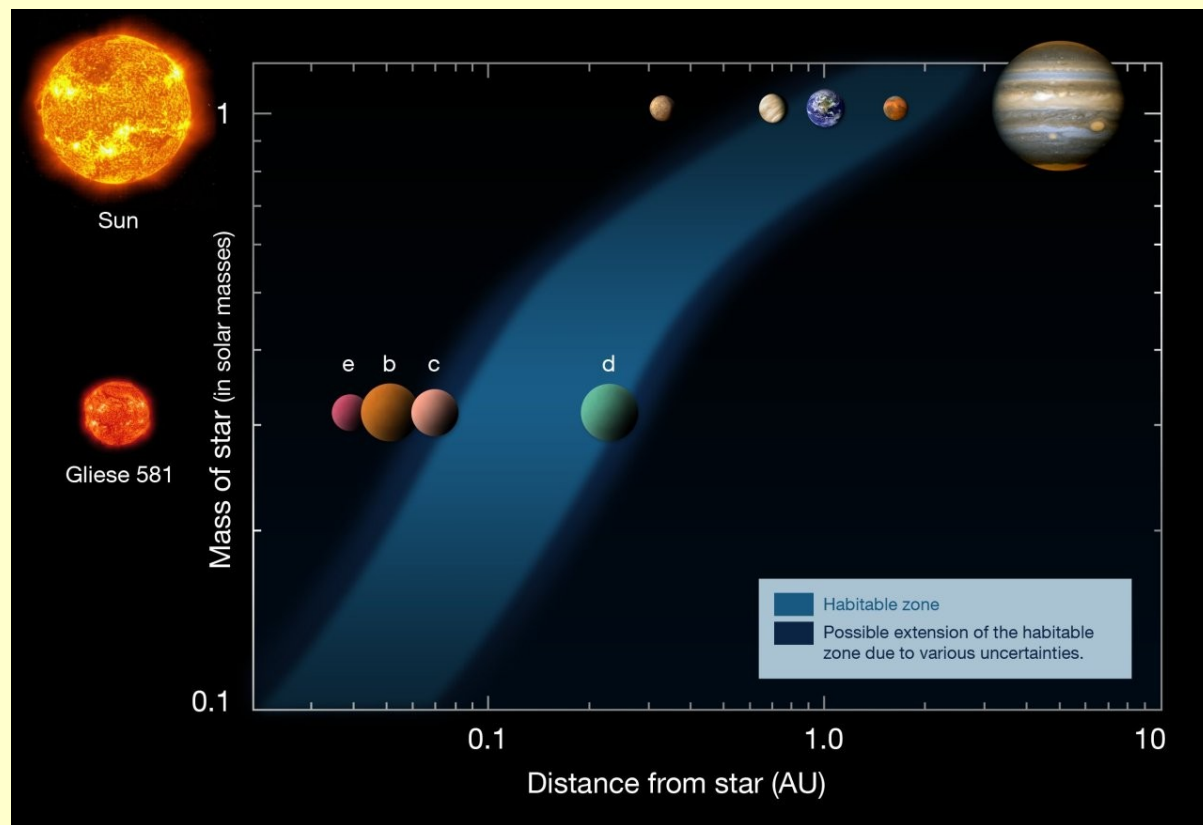
Algumas questões interessantes sobre os exoplanetas

- Existência de água líquida.

Primeira detecção de espectro da água em um sistema planetário:
HD189733 b

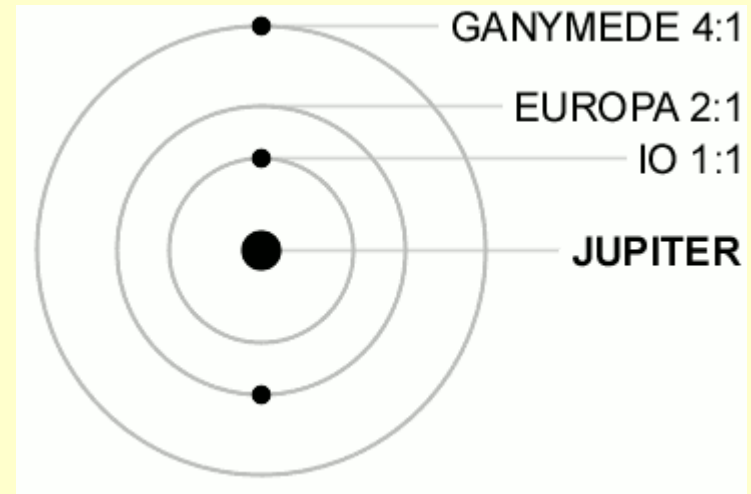
- Distância à Estrela.
- Atmosfera e composição.

Zona Habitável: Possibilidade de existência de vida?



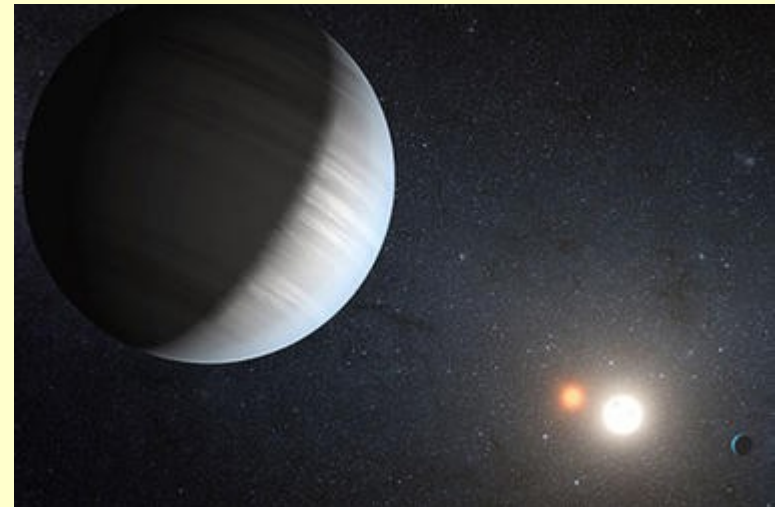
Ressonância e Planetas em sistemas múltiplos de estrelas

Planetas em ressonância!



Um planeta orbitando duas estrelas gêmeas...Tatooine?

Kepler 47 b-c



Corot - 7B

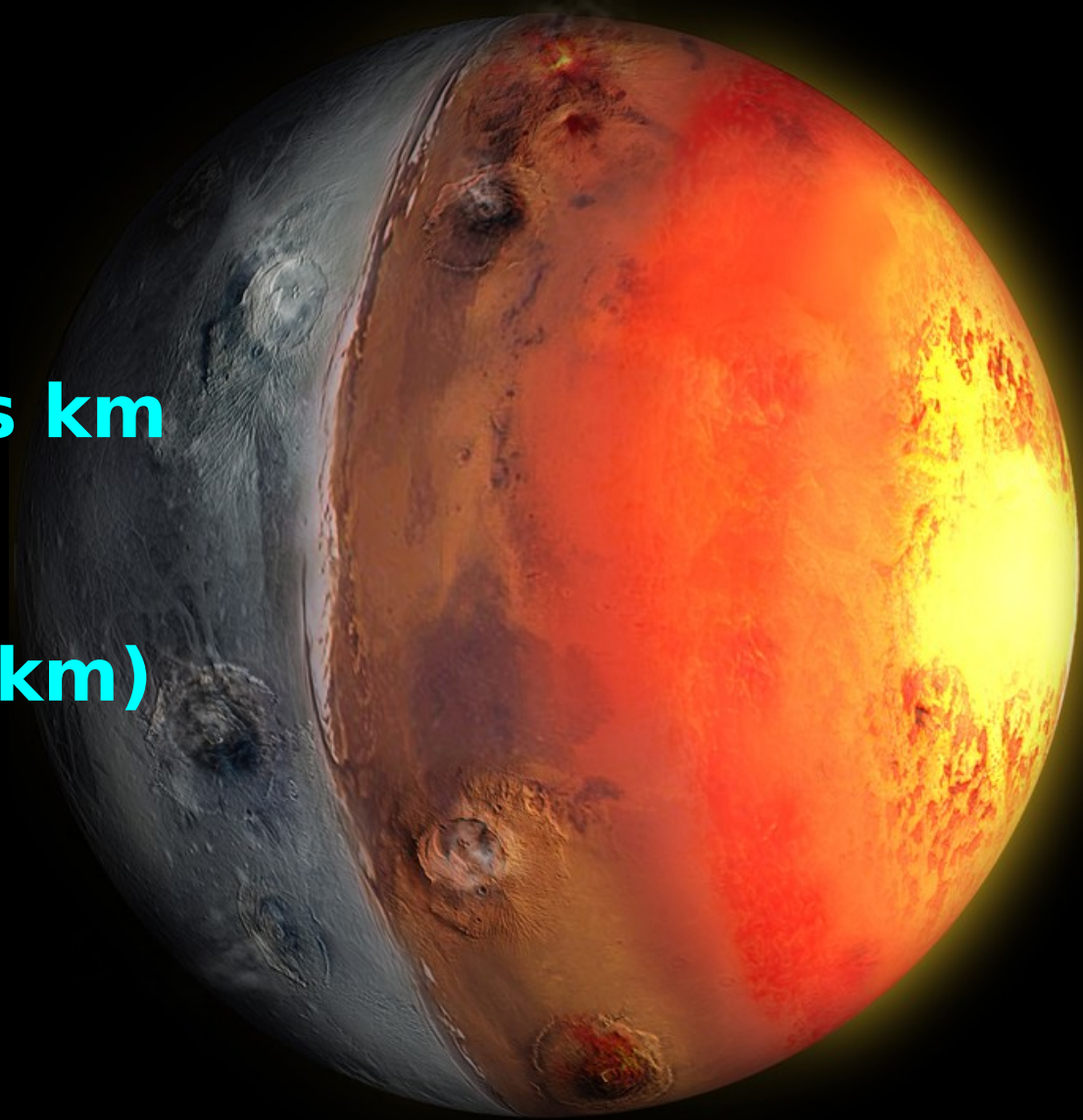
$m = 8 T \pm 1.2$

$P = 0.85 \text{ d}$

$a = 2.5 \text{ milhões km}$

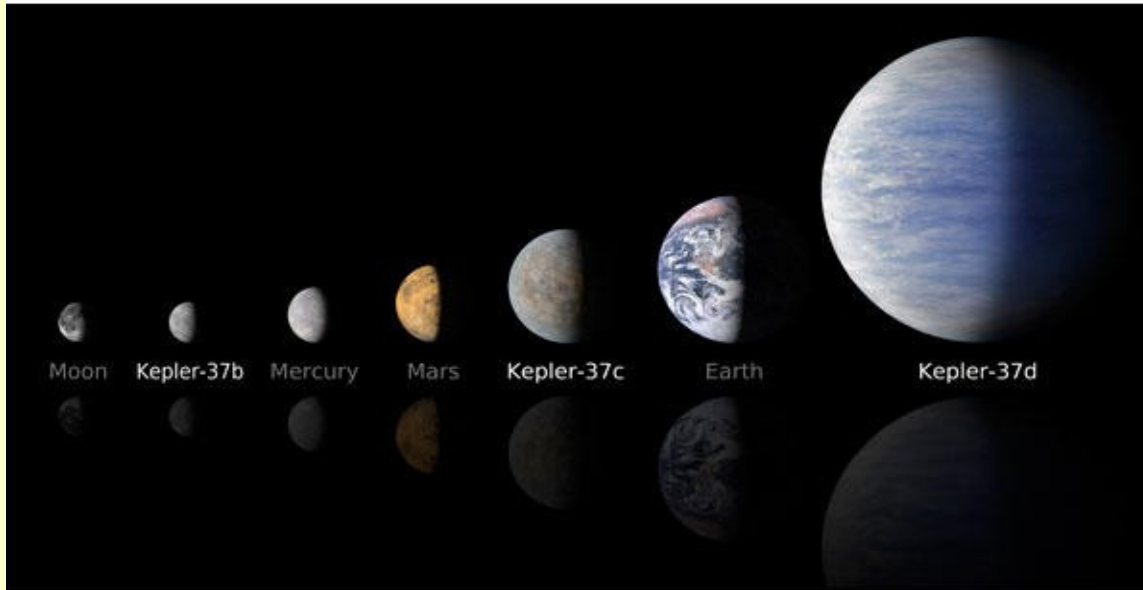
$R = 11000 \text{ km}$

(maré = +65/
-20 km)



Ref: CoRoT + IAG 2010

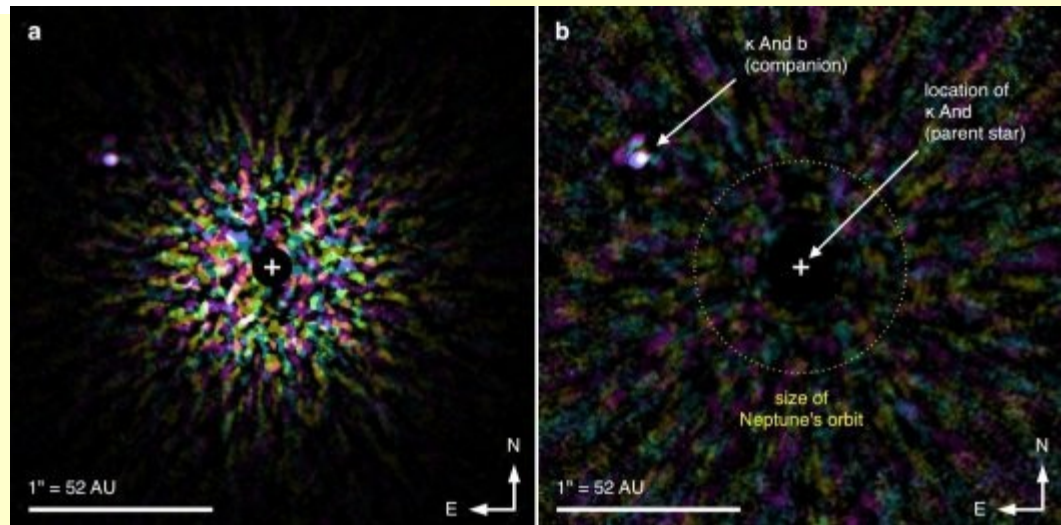
Menor planeta descoberto? Kepler 37-b



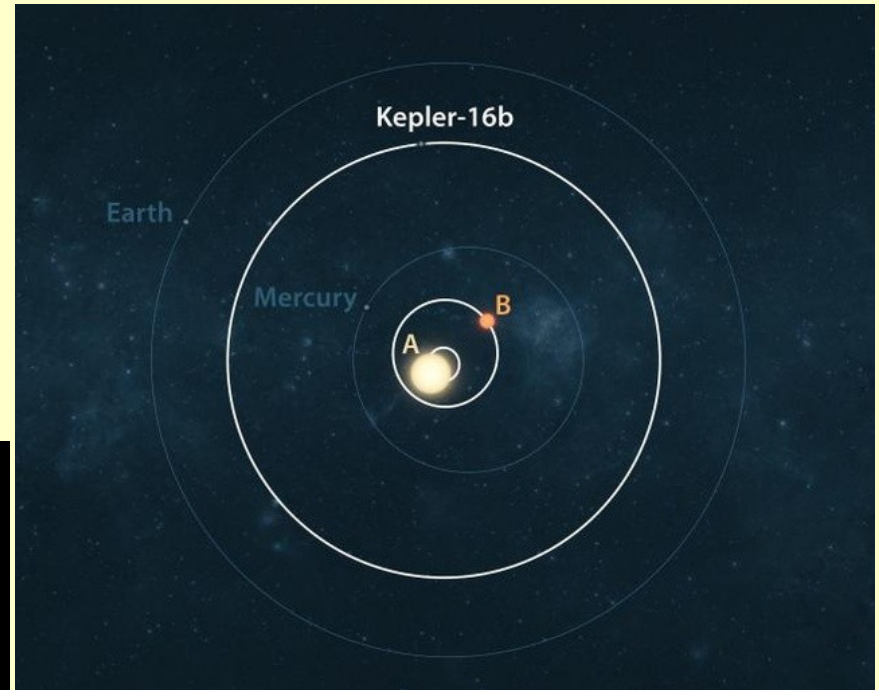
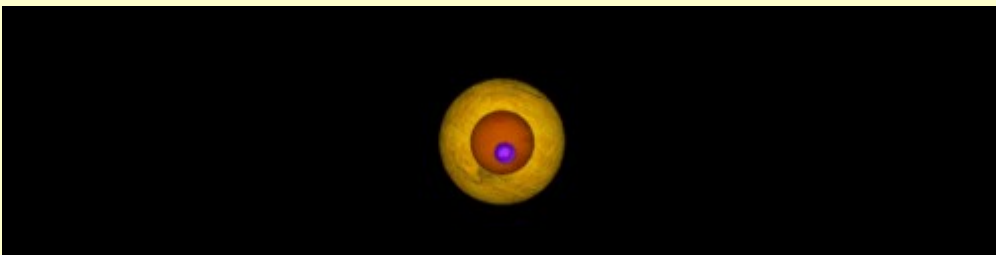
Incertezas...

E o maior exoplaneta descoberto? Kappa Andromedae System

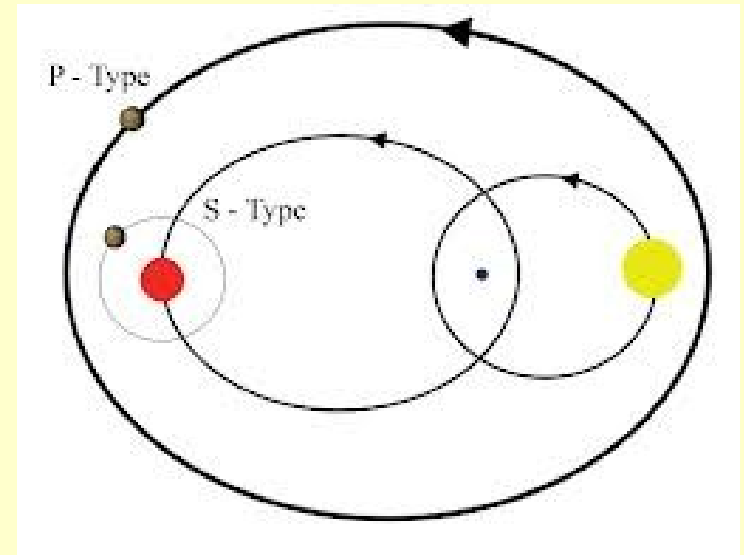
Também incertezas...



Planeta Kepler 16-b
com órbita externa ao
sistema binário
Kepler-16: P-type ou
Circumbinária.



E planetas orbitando
apenas uma das estrelas
em um sistema binário?
Chamados de S-Type.
Existem! E um dos mais
conhecidos



Alpha Centauri possui planetas em duas das três estrelas que compõem o sistema!

Alpha Centauri System

Alpha Centauri, the brightest "star" in the constellation of Centaurus is, when seen through a telescope, actually three stars orbiting around one another. This binary star system consists of two Sun-like stars, Alpha Centauri A and Alpha Centauri B, and a red dwarf, Alpha Centauri C, or Proxima Centauri. Its distance from Earth is approximately 4.37 light years, making it the closest star system in the galaxy to the Solar System.

The astronomical coordinates for the Centaurus star system are right ascension 14h 39m, declination -59 degrees 57'. Alpha Centauri A and B are located approximately 4.37 light years or 277,500 Astronomical Units from Earth (one AU is the average distance of Earth from the Sun, about 93,000,000 miles or 1.496 km). Alpha Centauri C (also called "Proxima Centauri" because it is the closest of the three stars to Earth) is about 0.15 light years closer.

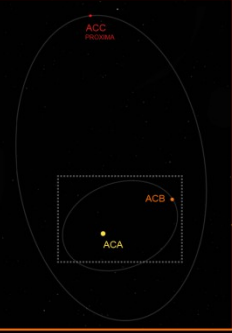


Figure 1: Stellar trajectory of the Alpha Centauri System.

Polyphemus

Polyphemus is the second of three gas giants and the fourth planet orbiting the star Alpha Centauri A (ACA) in the Alpha Centauri System. Slightly smaller and denser than Jupiter, Polyphemus has no rings and fourteen moons, the most notable being Pandora. Originally, the planet's name was Coeus.

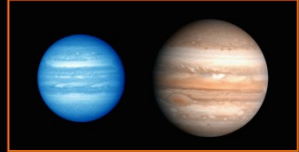
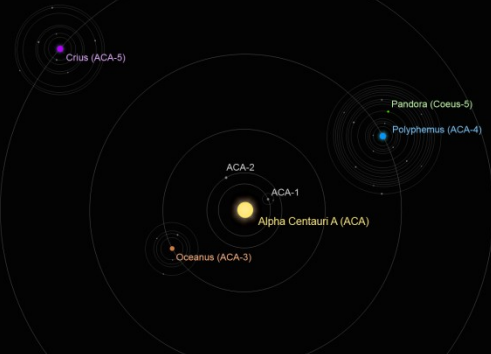


Figure 3: Polyphemus compared with Jupiter.

Visually, Polyphemus resembles a slightly smaller, blue and purple version of Jupiter, with less prominent bands and a larger vortex storm. This large, eye-shaped storm is the source of the planet's name, being that Polyphemus is the gigantic, cyclops son of Poseidon and Thetis in Greek mythology, appearing in Homer's epic "The Odyssey". Unlike other gas planets, Polyphemus has no visible rings.



Alpha Centauri A (ACA)

The system's largest star, Alpha Centauri A (or "ACA" to astronomers), is about twenty percent larger than our Sun, but otherwise very similar. ACA would be unremarkable were it not for the fact that it serves as the sun for Pandora, a large moon that orbits Polyphemus. It was on Pandora that explorers encountered the NAYs, the only intelligent species yet discovered in outer space. Pandora is also the only known source of uranium, a high temperature superconductor essential for many of Earth's technologies.

Planetary Bodies:

Two inner rocky planets and three outer gas giants are orbiting ACA. The three gas giants around ACA were not found until after the co-orbiting synchronized telescopic interferometer network (COSTIN) went into full operation. Upon their discovery they were named Coeusus, Crisus, and Cielus. Coeus was later renamed, or perhaps nicknamed, Polyphemus.

Alpha Centauri B (ACB)

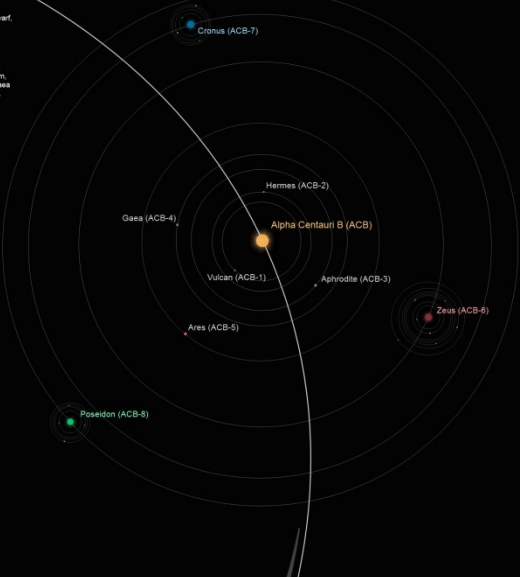
Alpha Centauri B (ACB) is about fifteen percent smaller than our Sun, and noticeably orange because it is 500 degrees K cooler than its neighboring star, Alpha Centauri C (ACC), also known as Proxima Centauri, is a red dwarf, only twenty percent of the size of the Sun and less than half its temperature. ACC gives off only a dim red glow instead of the bright yellow-glow of the Sun and ACA.

Planetary Bodies:

The three gas giant planets orbiting Alpha Centauri B were discovered by terrestrial observatories. The five rocky planets were discovered two decades later. Since the arrangement of the planets resembled our own solar system, they were named for their counterparts: Vulcan (inside Mercury's orbit), Hermes (Mercury), Aphrodite (Venus), Gaea (Earth), Ares (Mars), Zeas (Jupiter), Cronus (Saturn), and Poseidon (chosen instead of another name for Uranus, because it occupies the equivalent of Neptune's orbit).



Figure 2: Star comparison of our Solar System and the Alpha Centauri System.



Pandora

Pandora is the fifth moon of the gas giant Polyphemus (both are figures in Greek mythology), which orbits the closest star to the sun, Alpha Centauri A.



Figure 4: Pandora compared with Earth.

Discovered by the first interstellar expedition in 2129, Pandora has been the single most interesting thing to happen to the human race in hundreds of years. The naive survivors love to run ships of the wild scenery on Pandora and its bizarre flora and fauna.

Day-Night Cycle:

Pandora receives significant light from Alpha Centauri B (ACB). As a result, Pandora nights are never dark during half of the Polyphemus year, but instead are more like Earth's dawn. At the closest point in its orbit, ACB is about 2,300 times as bright as Earth's full moon; at its furthest point, it is still one hundred and seventy times as bright. During the other half of the year when ACB is in the daytime sky, many Pandora nights are illuminated by both Polyphemus's huge disk and the reflected light from other nearby moons. Truly dark nights are uncommon. Polyphemus occasionally eclipses ACB at night for about one hundred minutes, but the light reflected by the planet still keeps the night from being dark.



Figure 5: Alpha Centauri B (ACB), Polyphemus, and five of Polyphemus' moons, seen on the Pandora night sky.

When ACB shares the daytime sky with ACA, at its closest it adds about half a percent to the total illumination. When the 2 stars are close together in the sky, the effect of ACB's more orange light is unnoticeable. But as they separate over the years, an orange tint may be seen in areas shadowed from ACA's disc illumination. At its most distant, ACB is about 2,700 times dimmer than ACA and does not produce noticeable lighting effects. However, it still appears as a blindingly-bright tiny orange disk in the sky.

Because of its high axial tilt (23°), Pandora exhibits considerable annual variation in the day-to-night ratio. In addition, its elliptical orbit produces seasonal temperature variations and a range in daytime illumination of about ten percent.

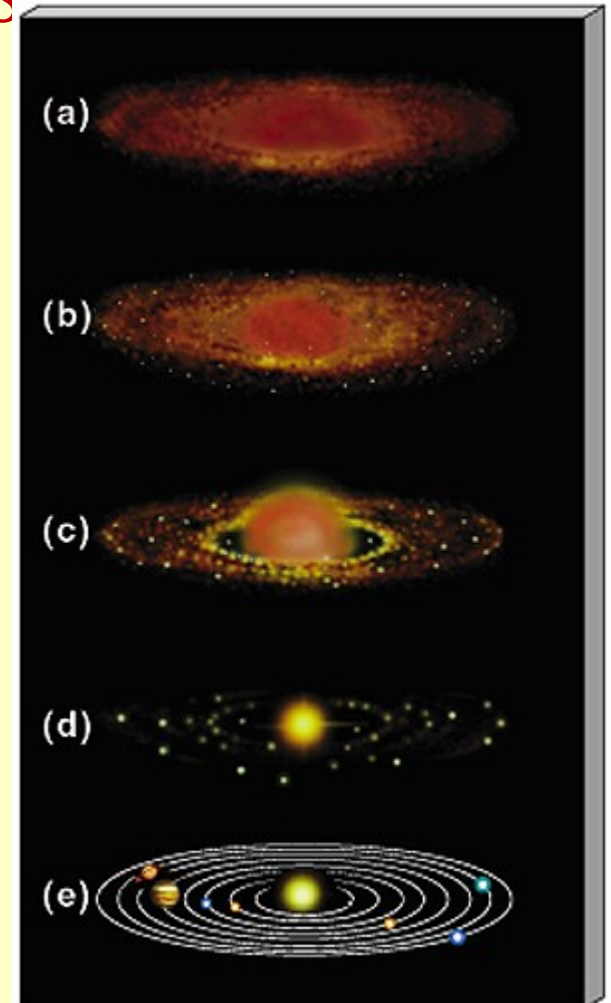


Formação e Evolução de Sistemas Exoplanetários

Assunto ainda bastante nebuloso.
Mesmo nosso sistema solar não se tem certeza da forma como se formou e evoluiu até o momento!

Nebular hypothesis: Proposta mais aceita!

- Migração Planetária.
- Estabilidade a longo prazo.

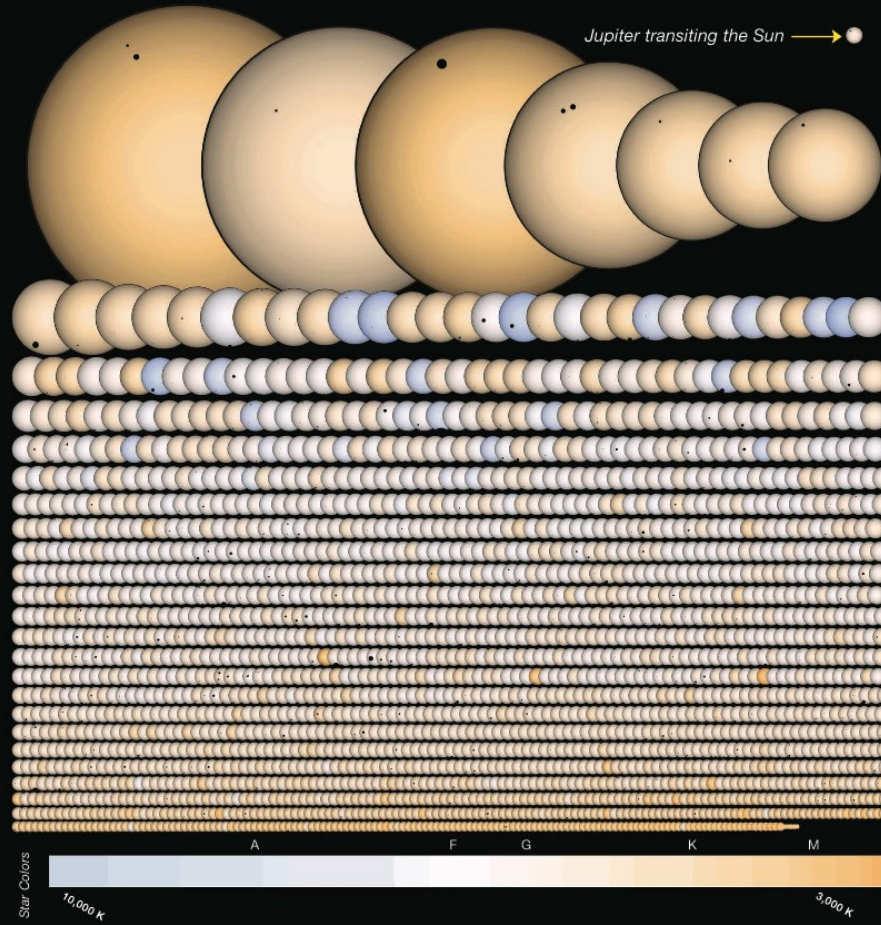


FIM

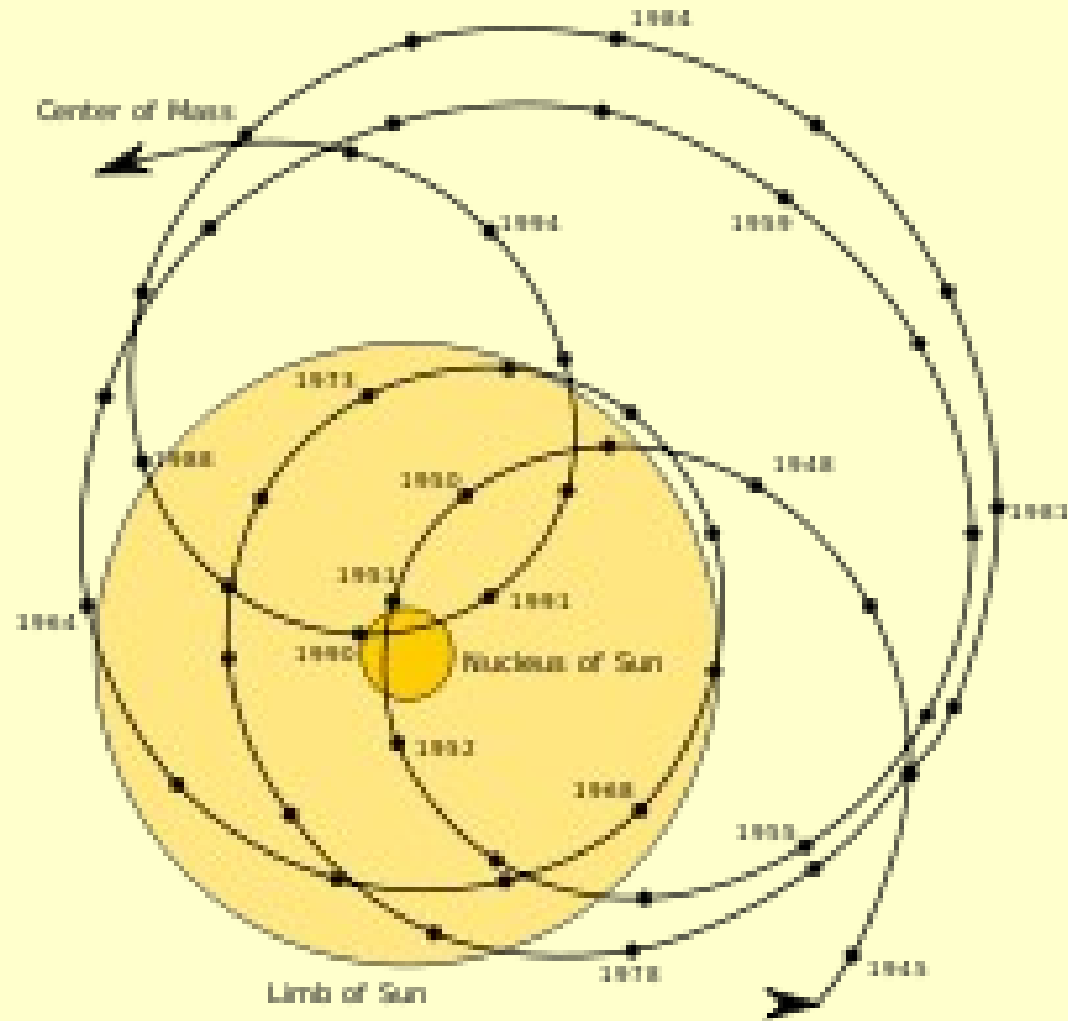


KEPLER'S PLANET CANDIDATES

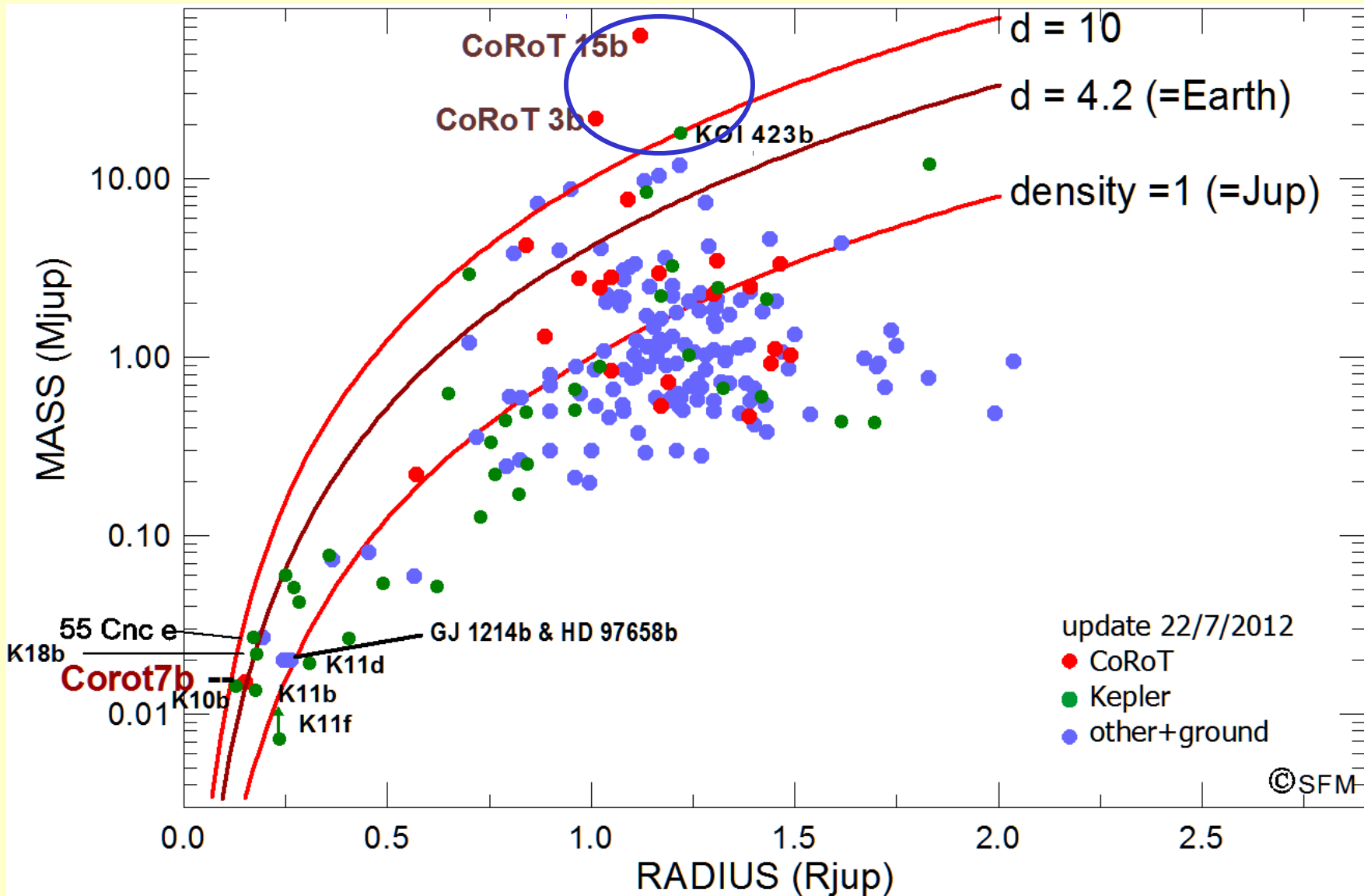
2,740 AS OF JANUARY, 2013



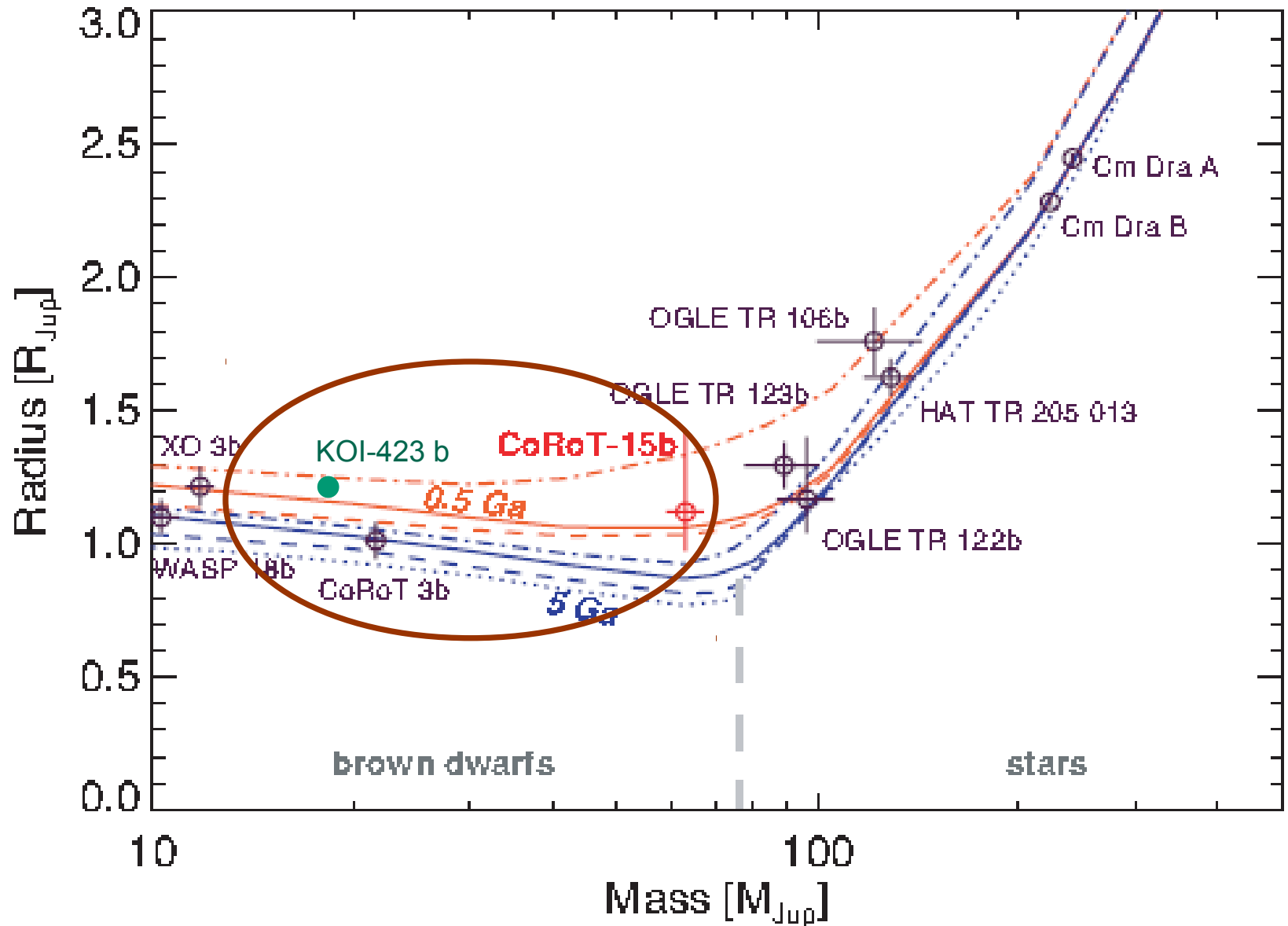
Using NASA's planet-hunting Kepler spacecraft, astronomers have discovered 2,740 planet candidates orbiting 2,036 other suns in a search for Earth-size worlds. The search began in 2009. Kepler monitors a rich star field for planetary transits, which cause a slight dimming of starlight when a planet crosses the face of its star. In "Kepler's Planet Candidates," the systems are ordered by star diameter. The star's color represents its temperature as shown in the lower scale, and the letters (A, F, G, K, M) designate star types. The simulated stellar disks and the planet silhouettes are shown at the same scale, with saturated star colors. Look carefully: some systems have multiple planets. For reference, Jupiter is shown transiting the Sun. Higher resolutions of this graphic are available at <http://Kepler.NASA.gov/images/graphics>



Movimento do Sol relativo ao centro do S.Solar



O deserto das anãs marrons



Campbell, Walker & Yang, 1988
Planeta ao redor de γ Cep A
(retirado)

Redescoberta em 2002

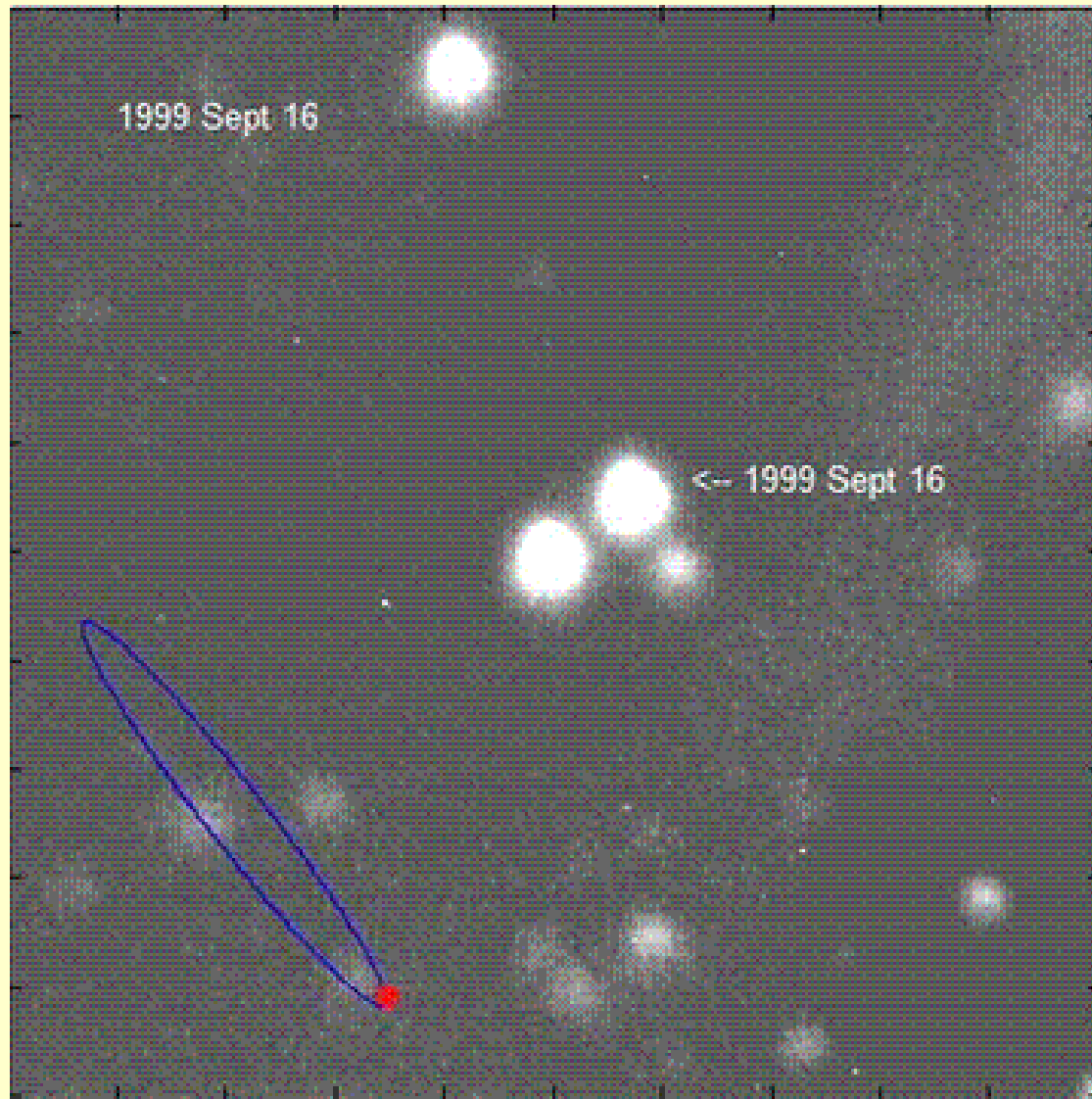
$K=27.5$ m/s

$M.\sin(i)=1.7$ Jup

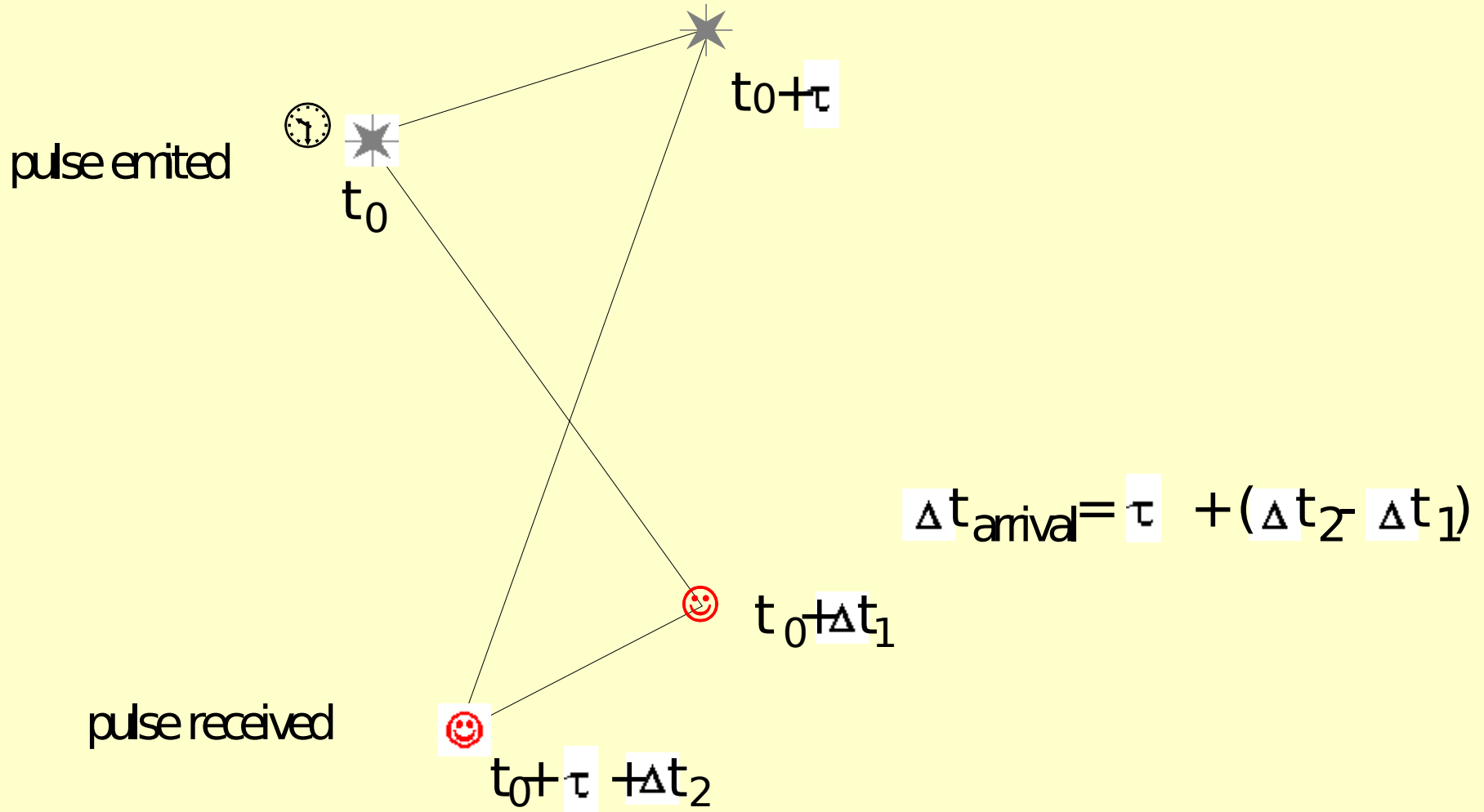
$P=2.48$ yr

VB 10 – Palomar 2009

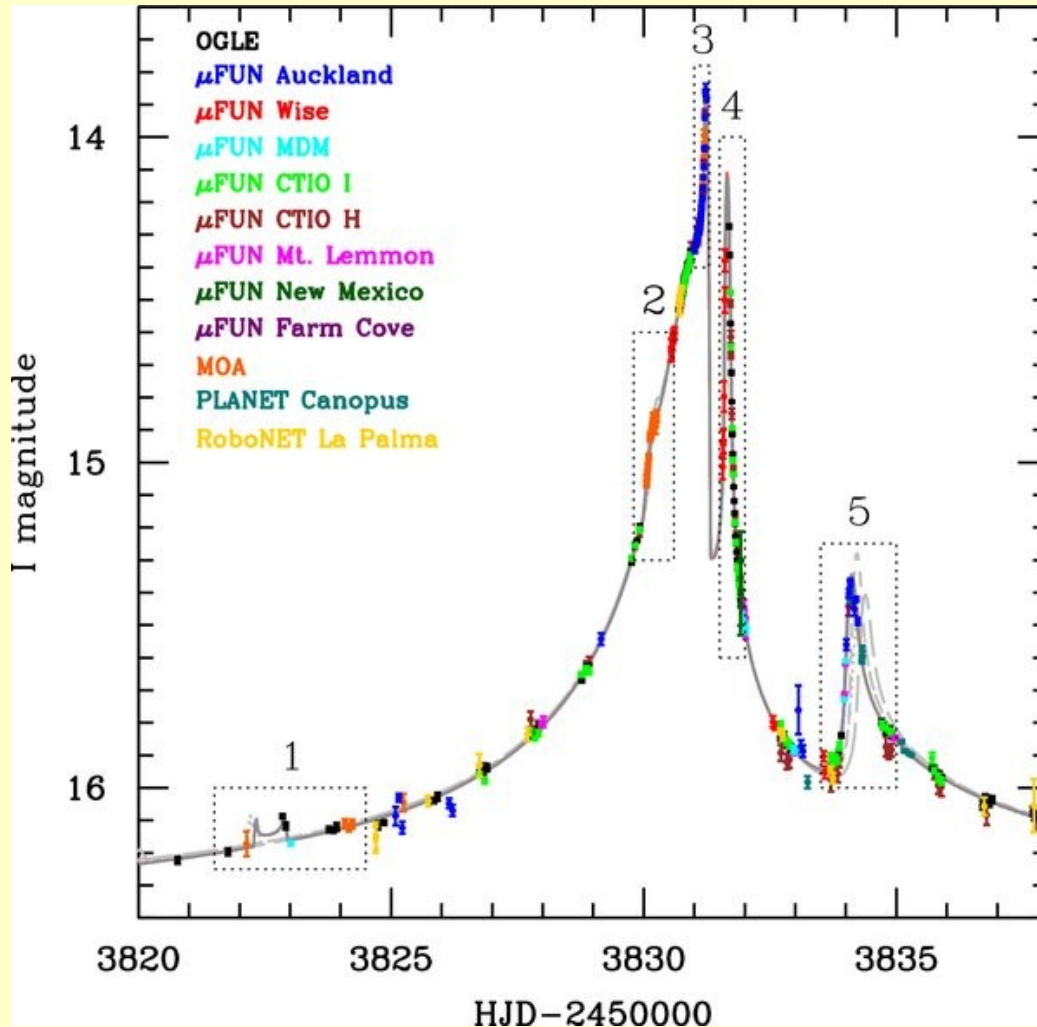
(Obs: $m=0.08$ Sol)



Pulse timings (Nonrelativistic model)



OGLE-2006-BLG-109Lb,c JUPITER/SATURN ANALOG



Masses:
0.727 Jup
0.271 Jup

Distances:
2.3 au
4.5 au

cf D.P.Bennett et al. *Astroph. J* **713**, 837 (2010)

Planetas descobertos com outras técnicas

