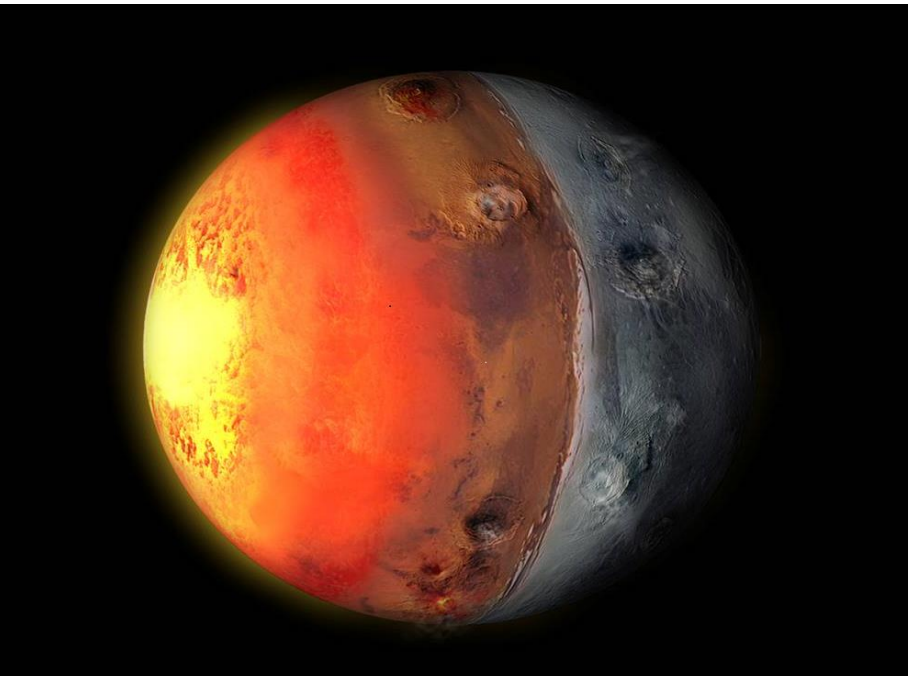
Planetas Extra-Solares ou Exoplanetas



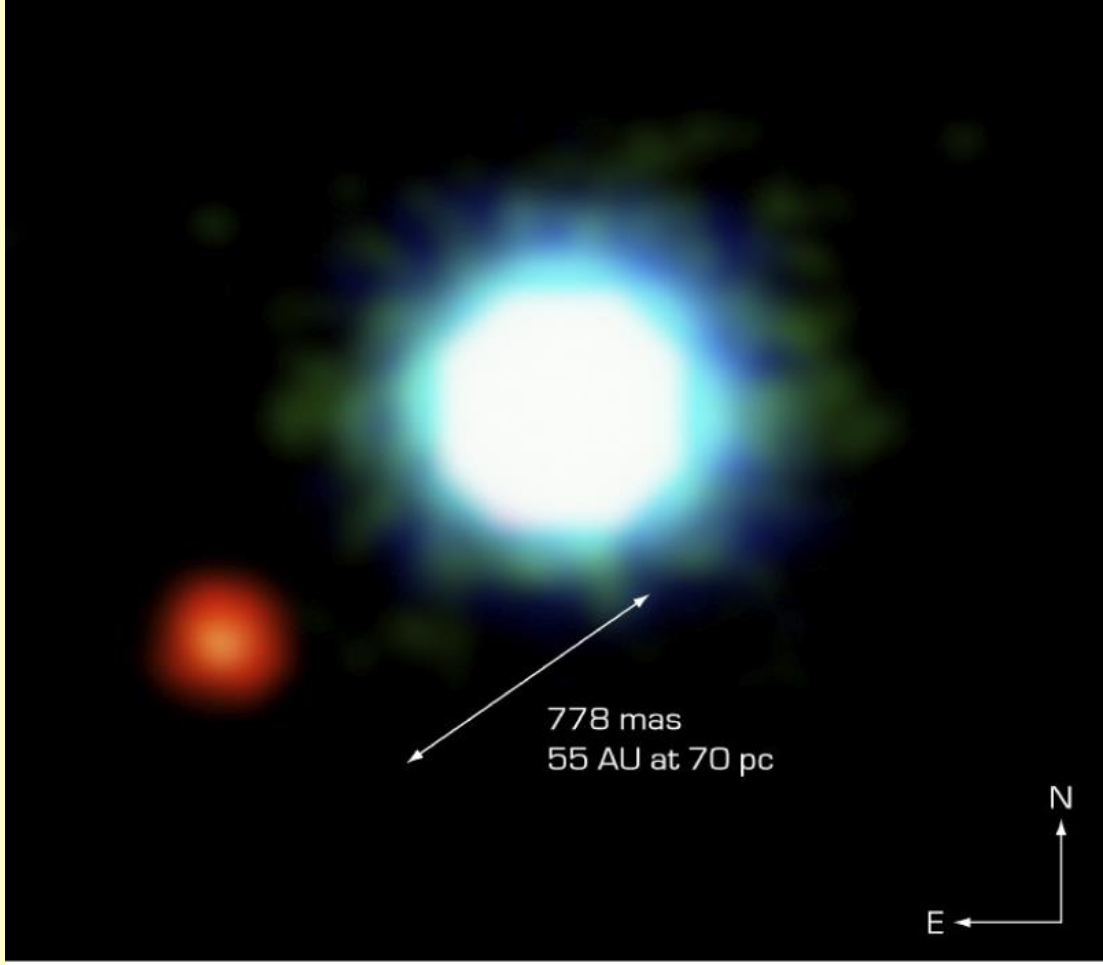
Sylvio Ferraz Mello

Instituto de Astronomia, Geofísica e Ciências Atmosféricas

Universidade de Sao Paulo

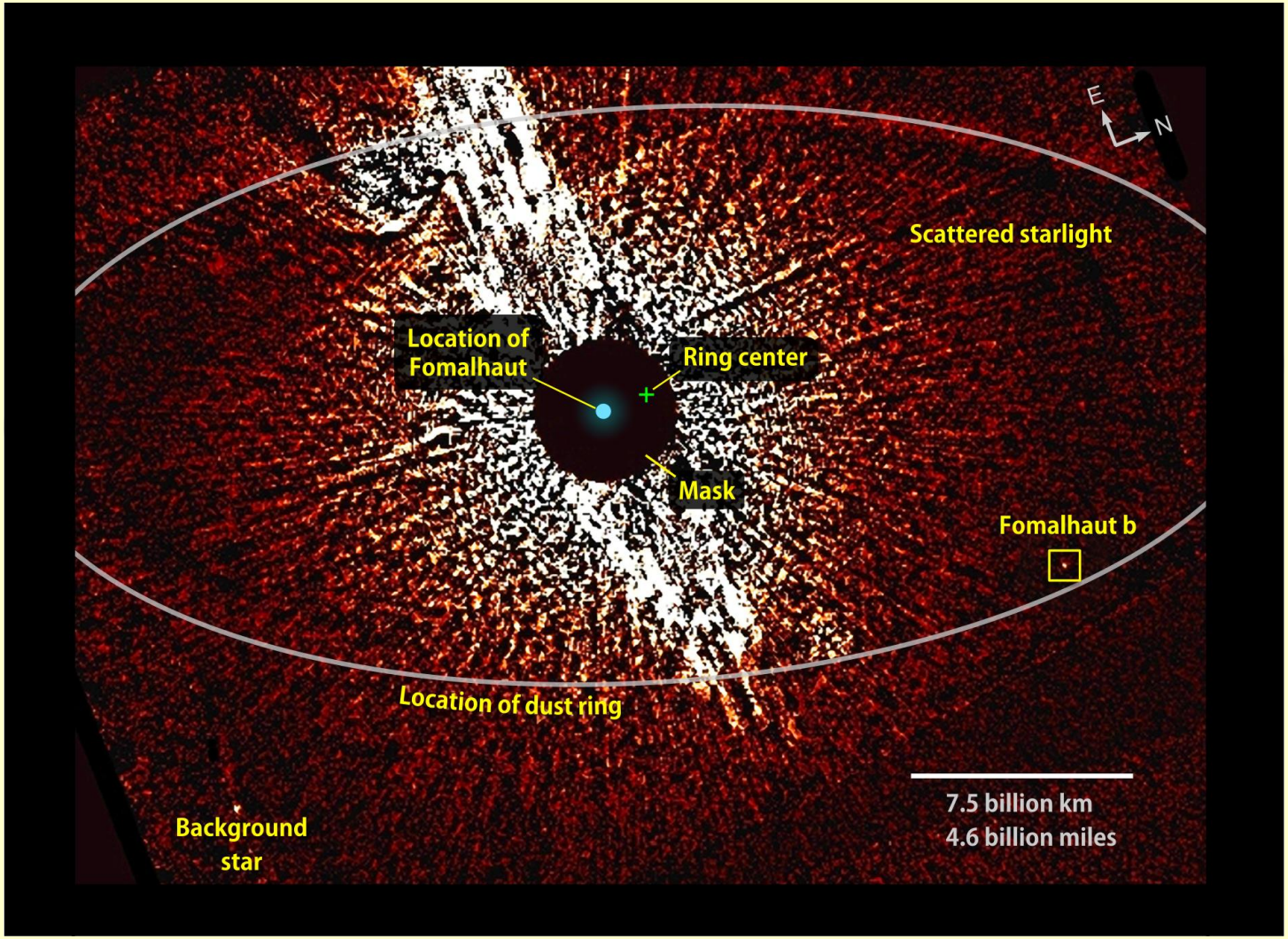
IMAGENS

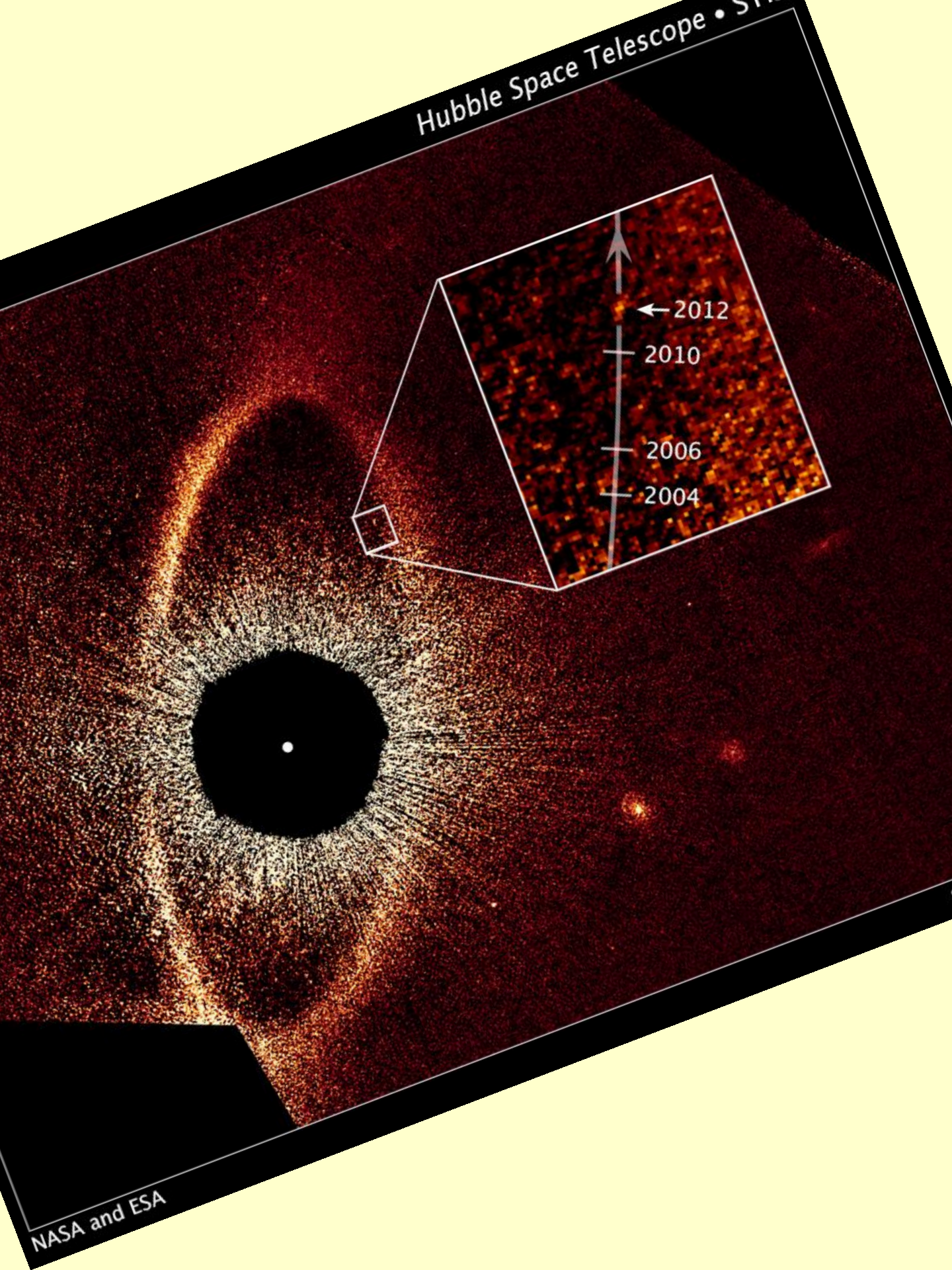
Luminosidade
de um planeta
igual a Júpiter
=
Luminosidade do Sol
1 000 000 000



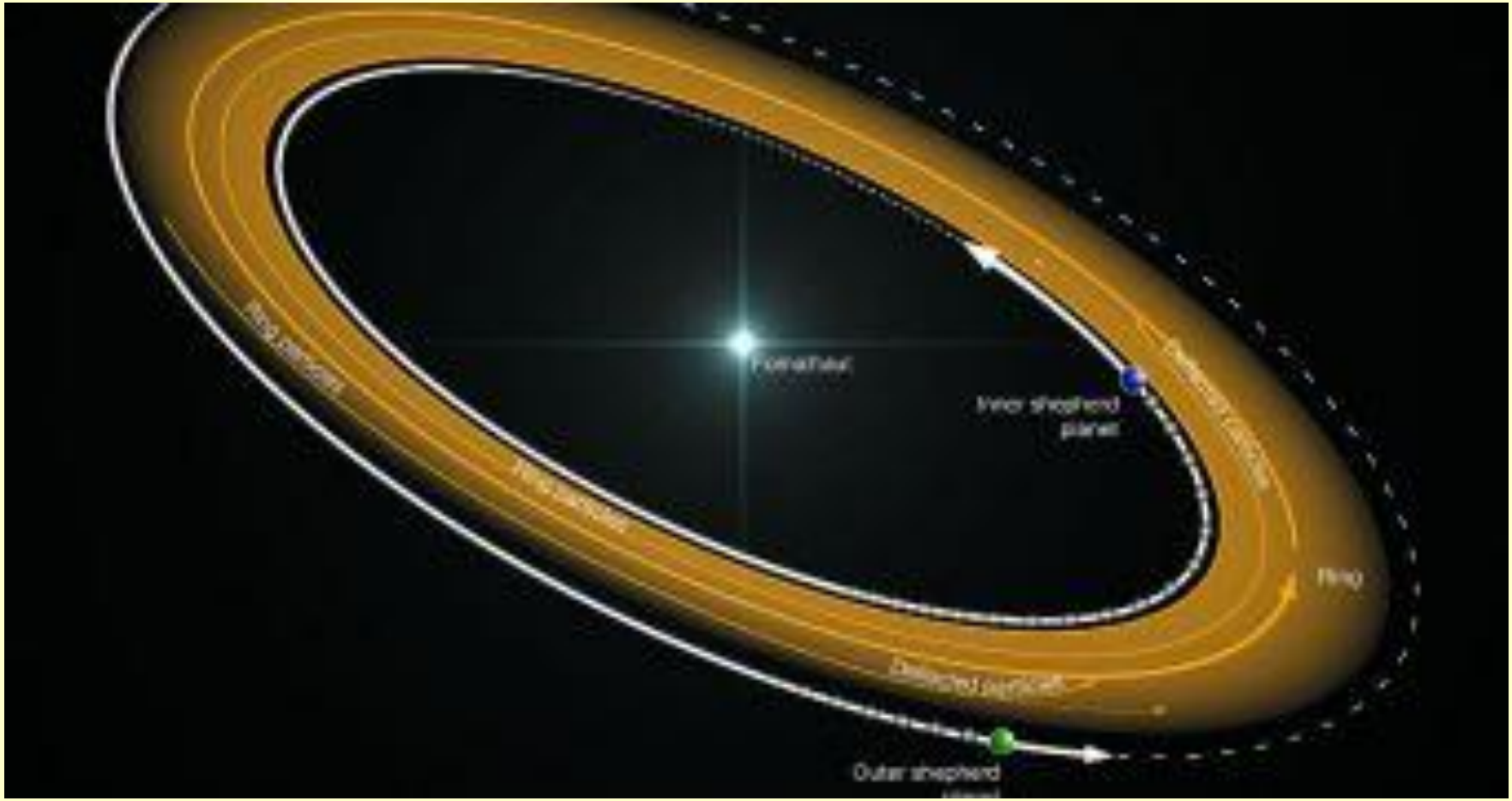
The Brown Dwarf 2M1207 and its Planetary Companion
(VLT/NACO)

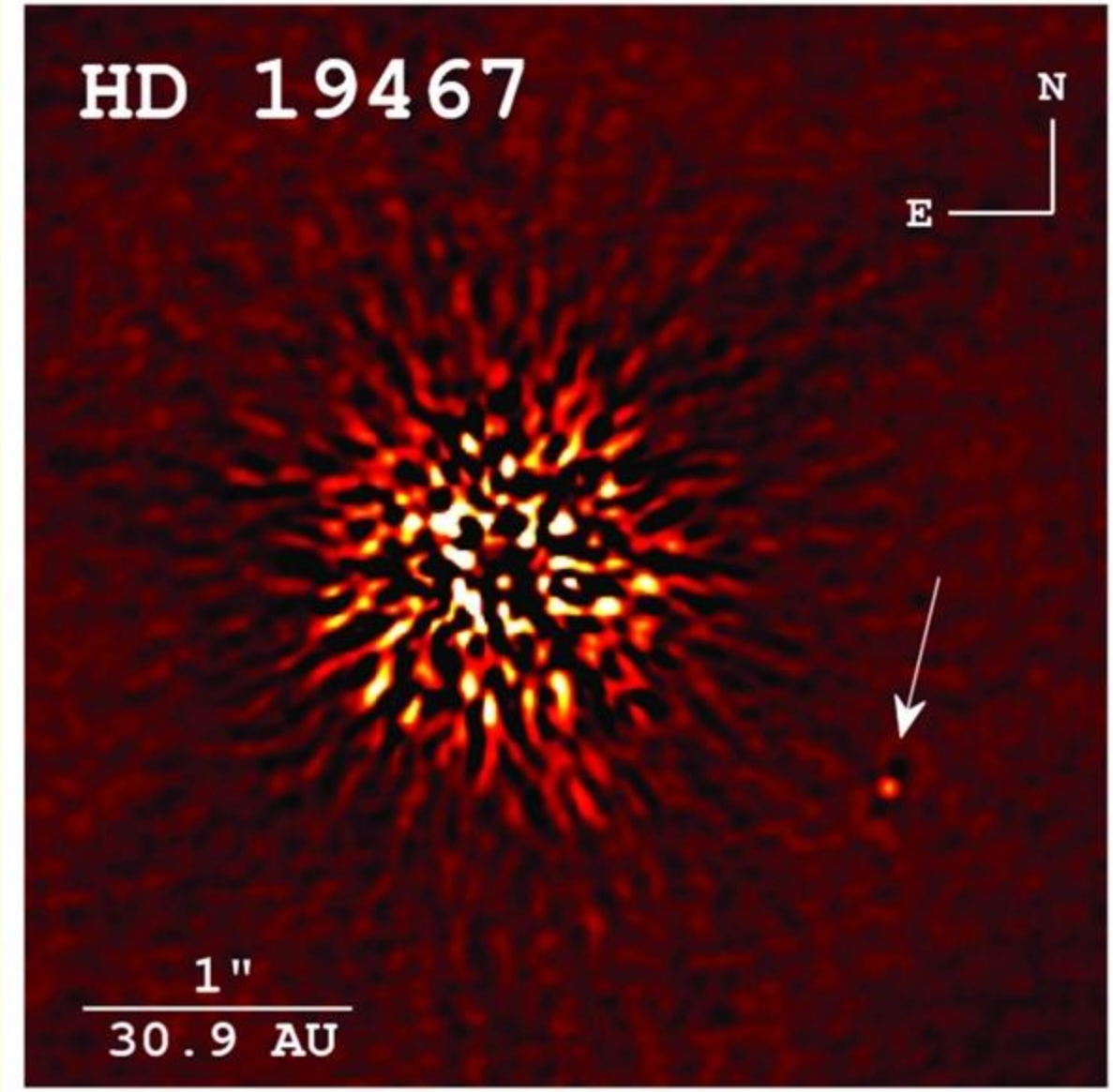
ESO PR Photo 14a/05 (30 April 2005)

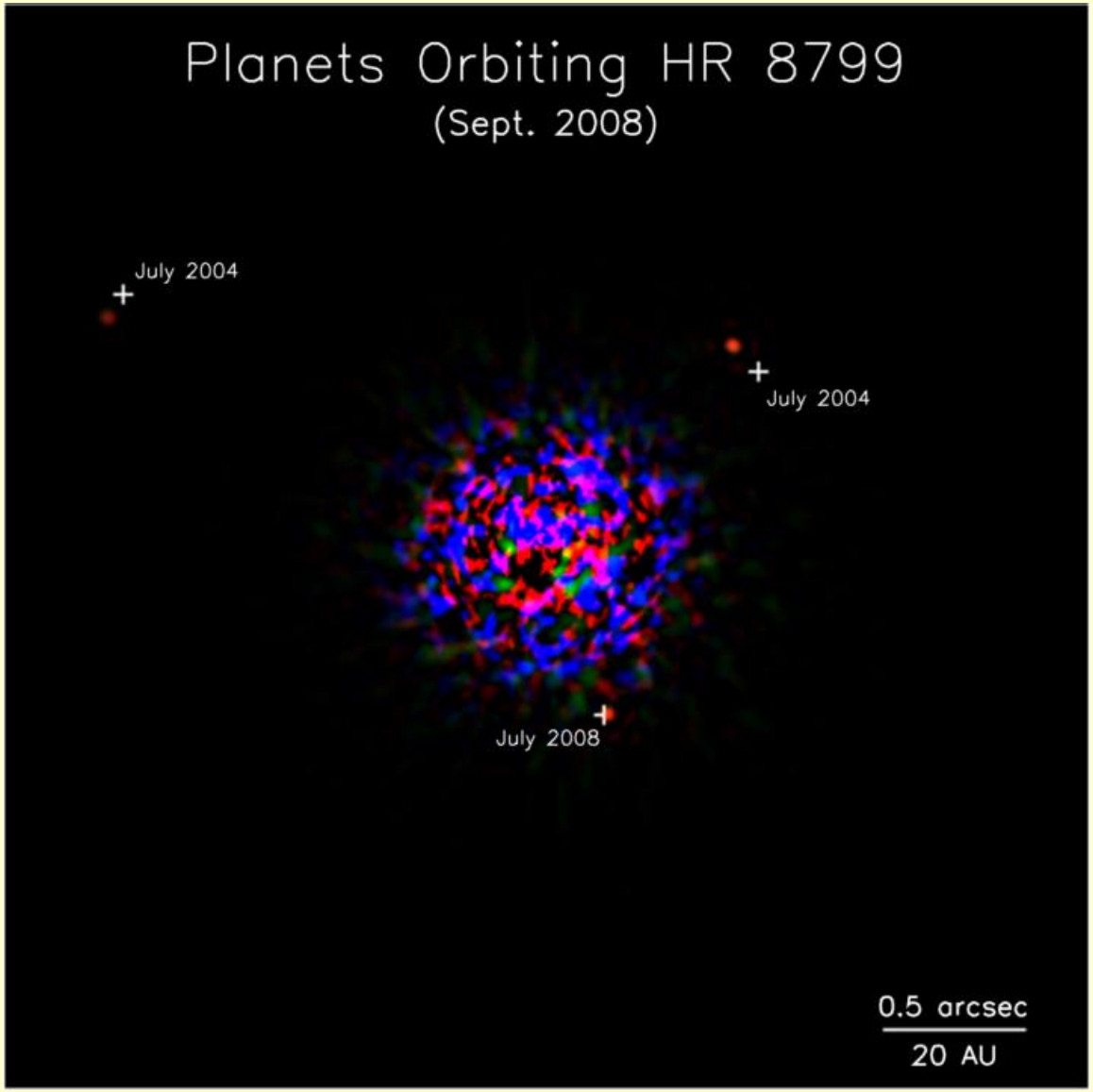

E
N
Scattered starlight
Location of Fomalhaut
Ring center
Mask
Fomalhaut b
Location of dust ring
Background star
7.5 billion km
4.6 billion miles

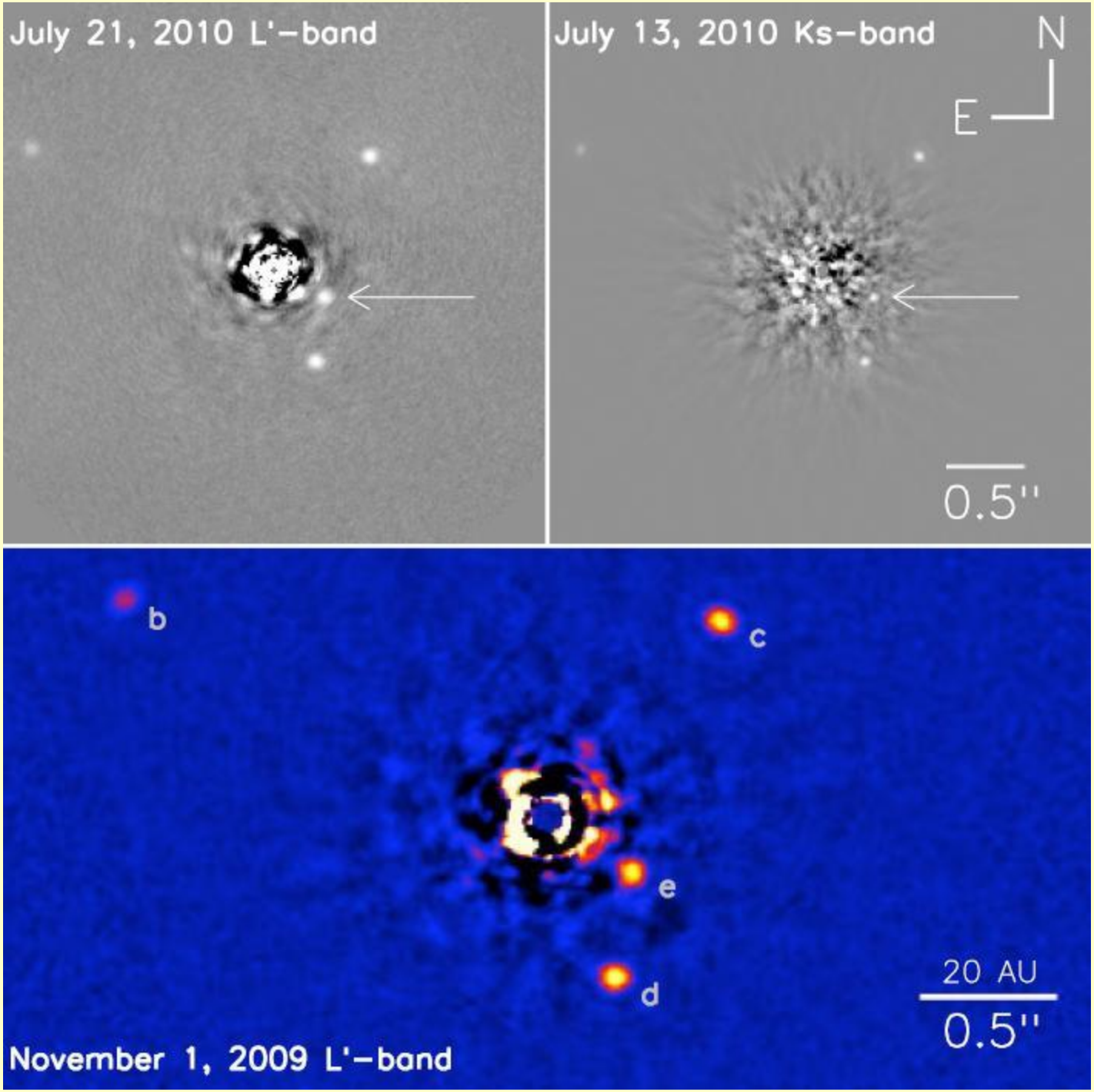

Hubble Space Telescope
2012
2010
2006
2004
NASA and ESA

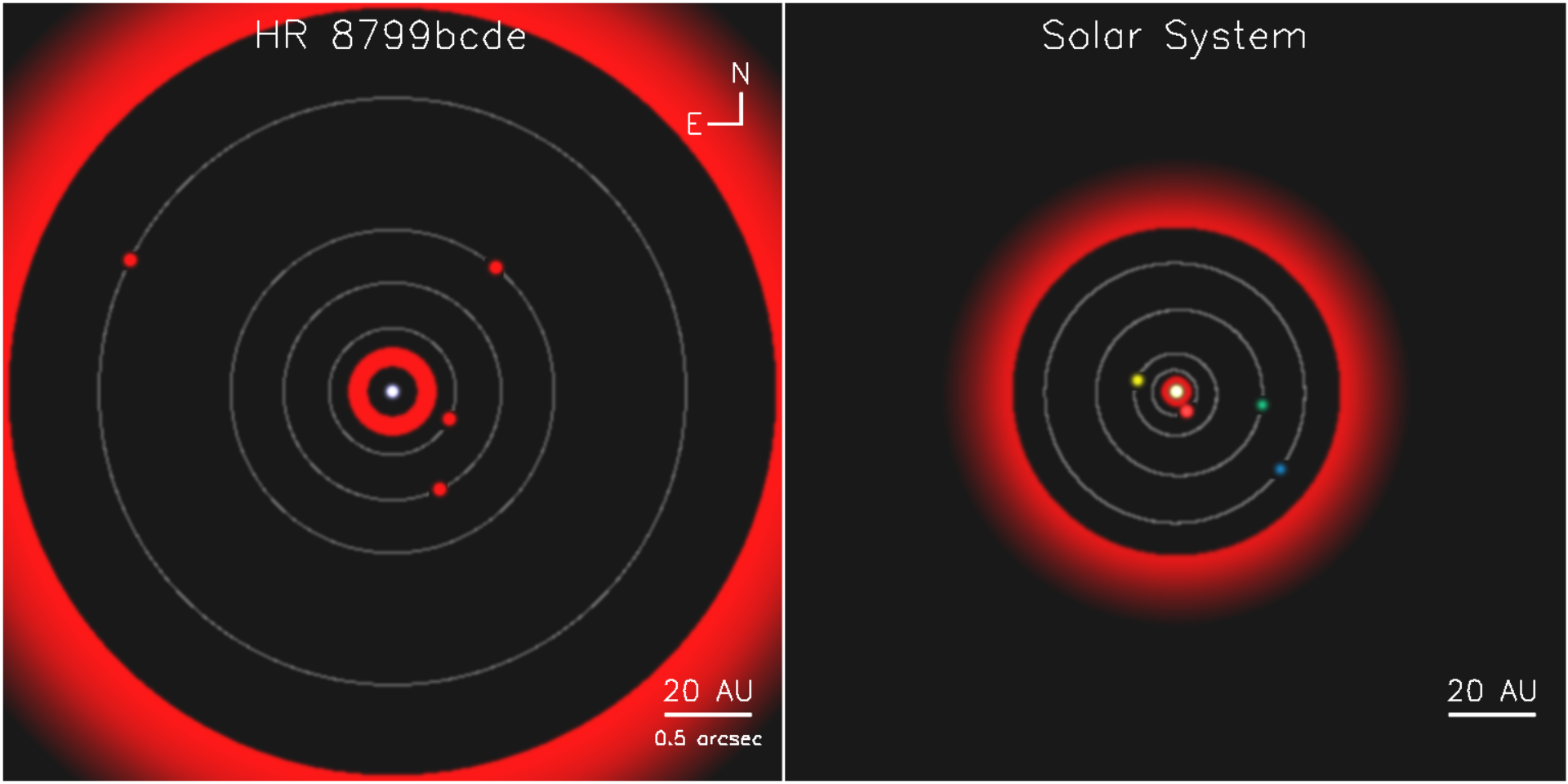
Fomalhaut's ring shepherd planets

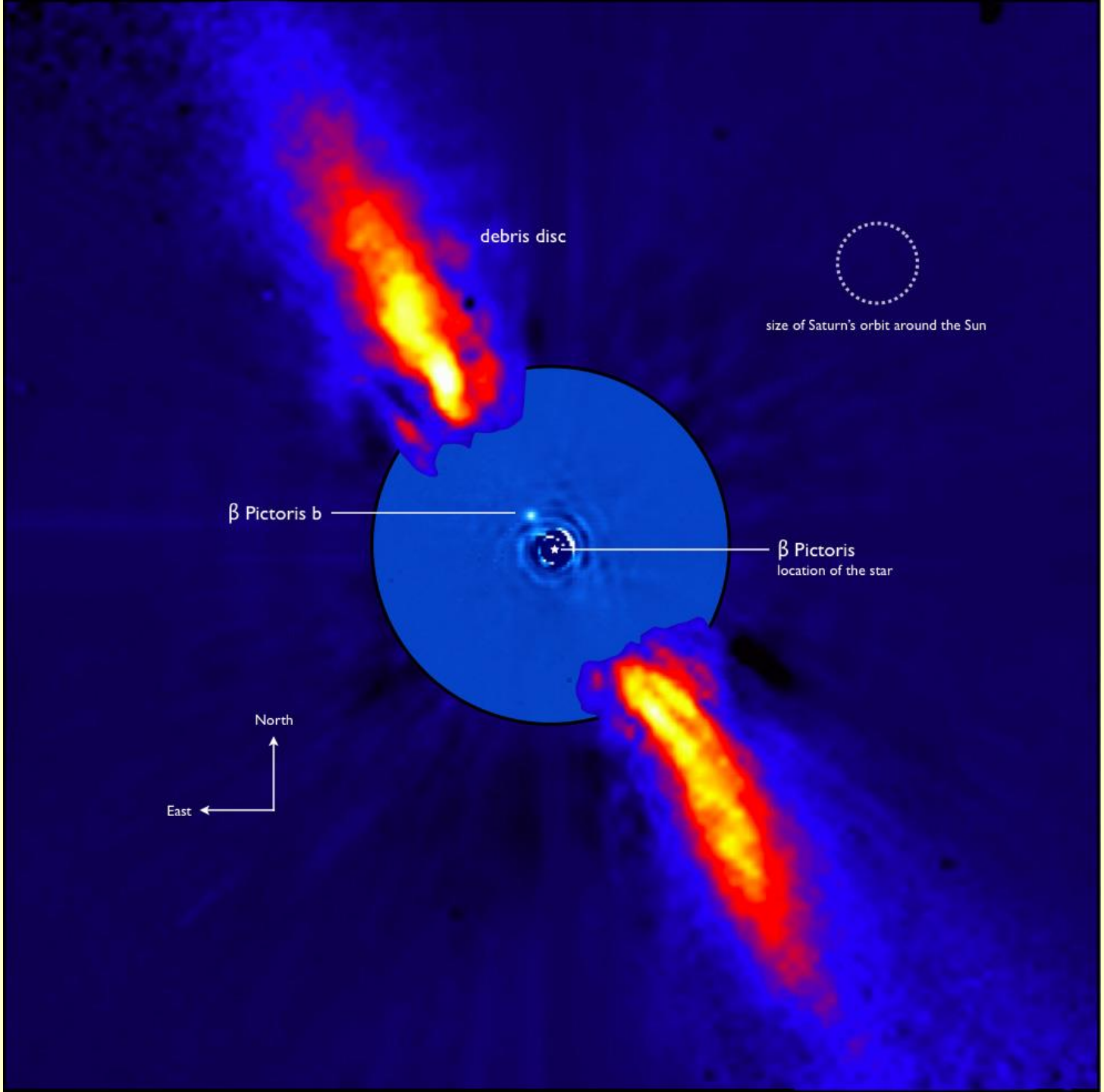


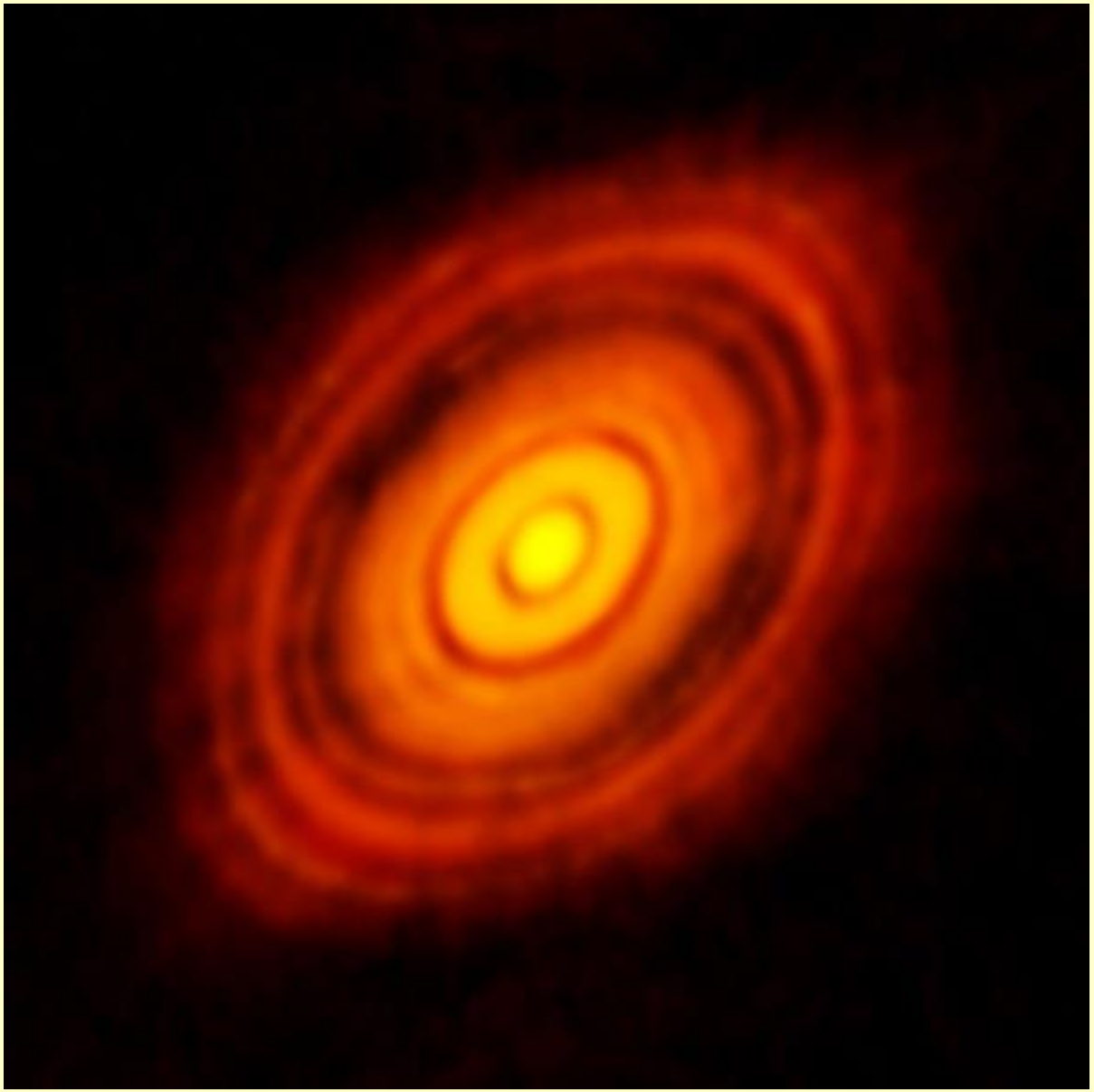

HD 19467
N
E
1"
30.9 AU


Planets Orbiting HR 8799
(Sept. 2008)
July 2004
July 2004
July 2008
0.5 arcsec
20 AU

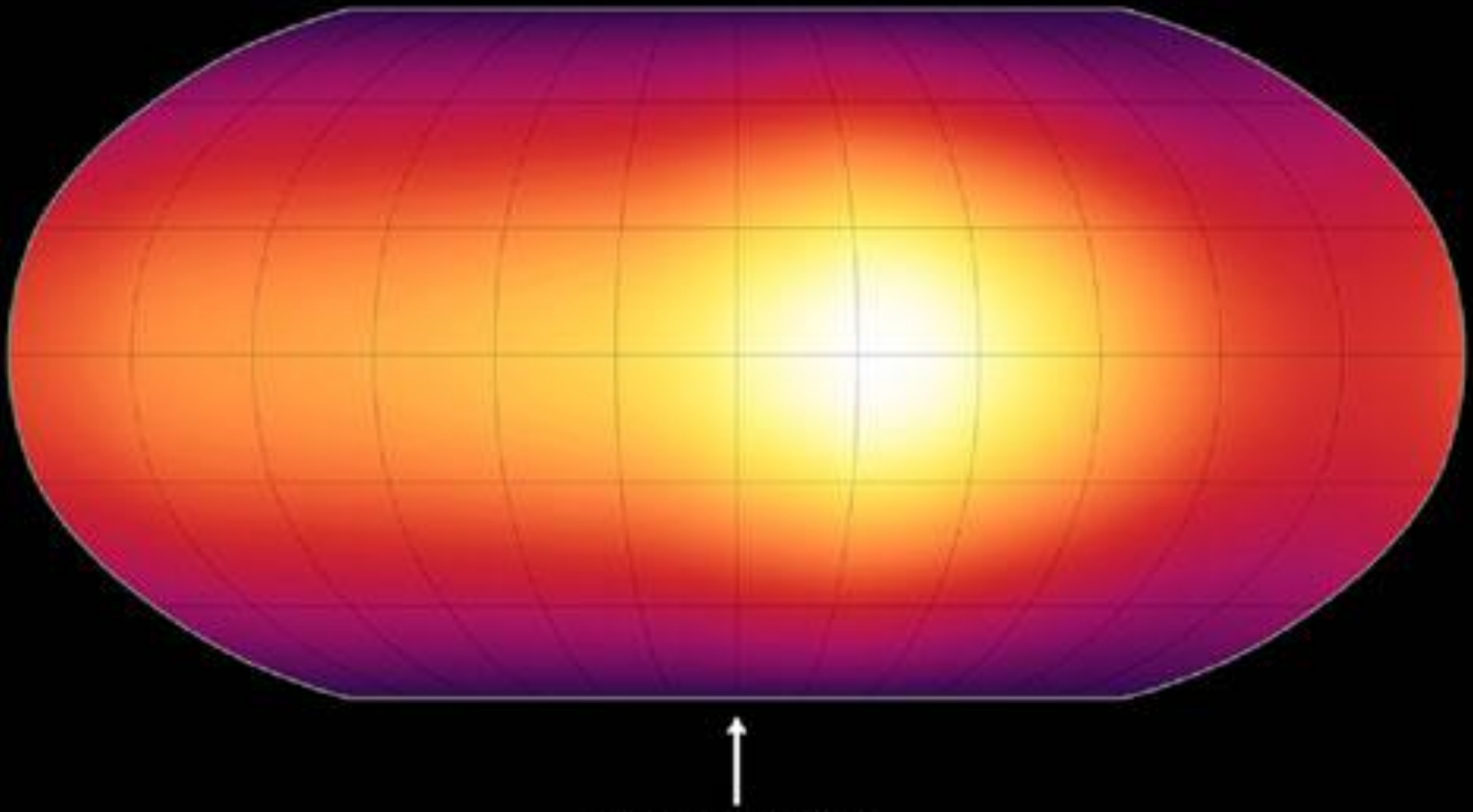

July 21, 2010 L'−band
July 13, 2010 Ks−band
N
E
0.5''
b
c
e
d
20 AU
0.5''
November 1, 2009 L'−band


HR 8799bcde
N
E
20 AU
0.5 arcsec
Solar System
20 AU


debris disc
size of Saturn's orbit around the Sun
β Pictoris b
β Pictoris
location of the star
North
East



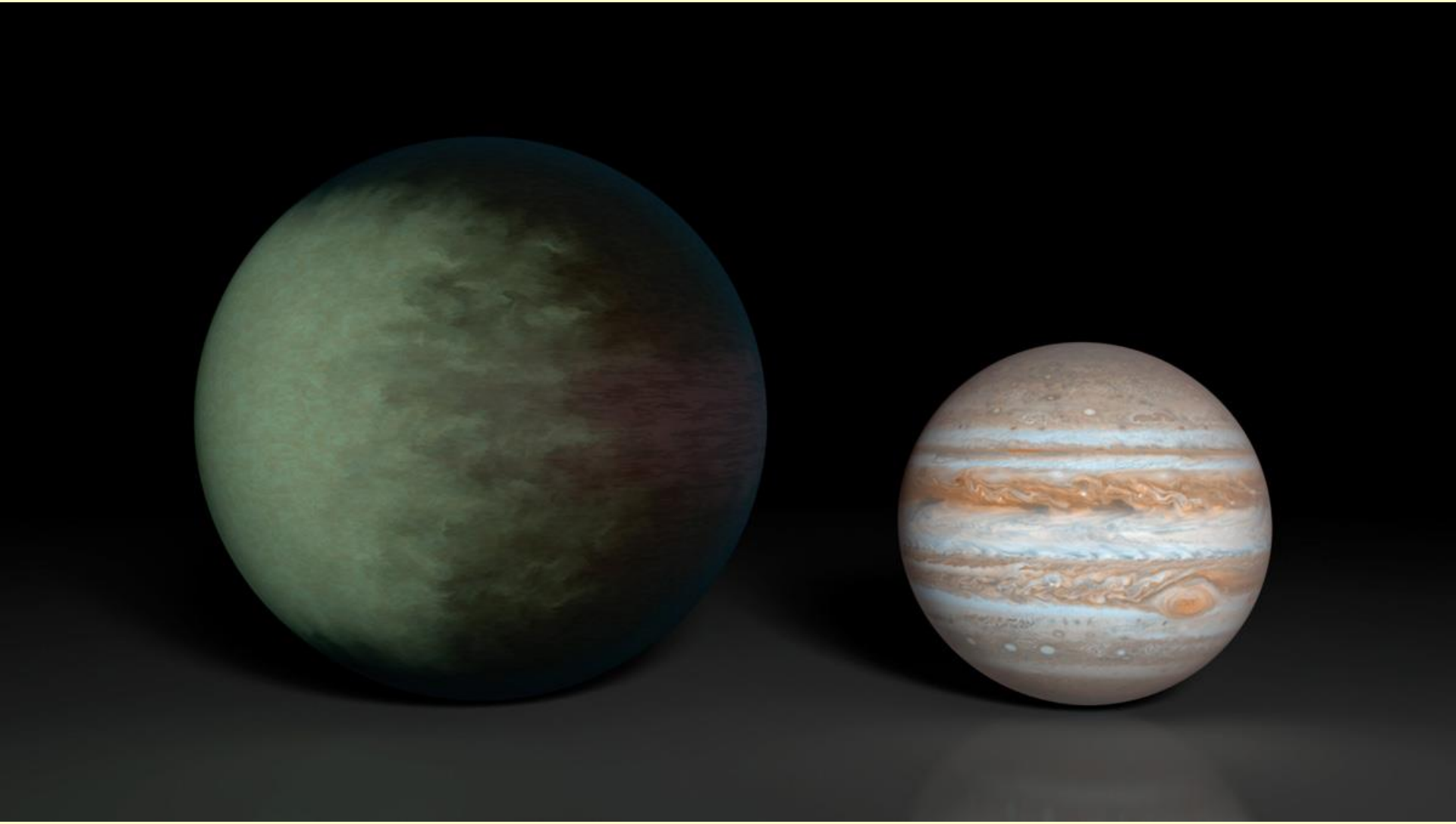
HL Tauri



Global Temperature Map for Exoplanet HD 189733b Spitzer Space Telescope • IRAC

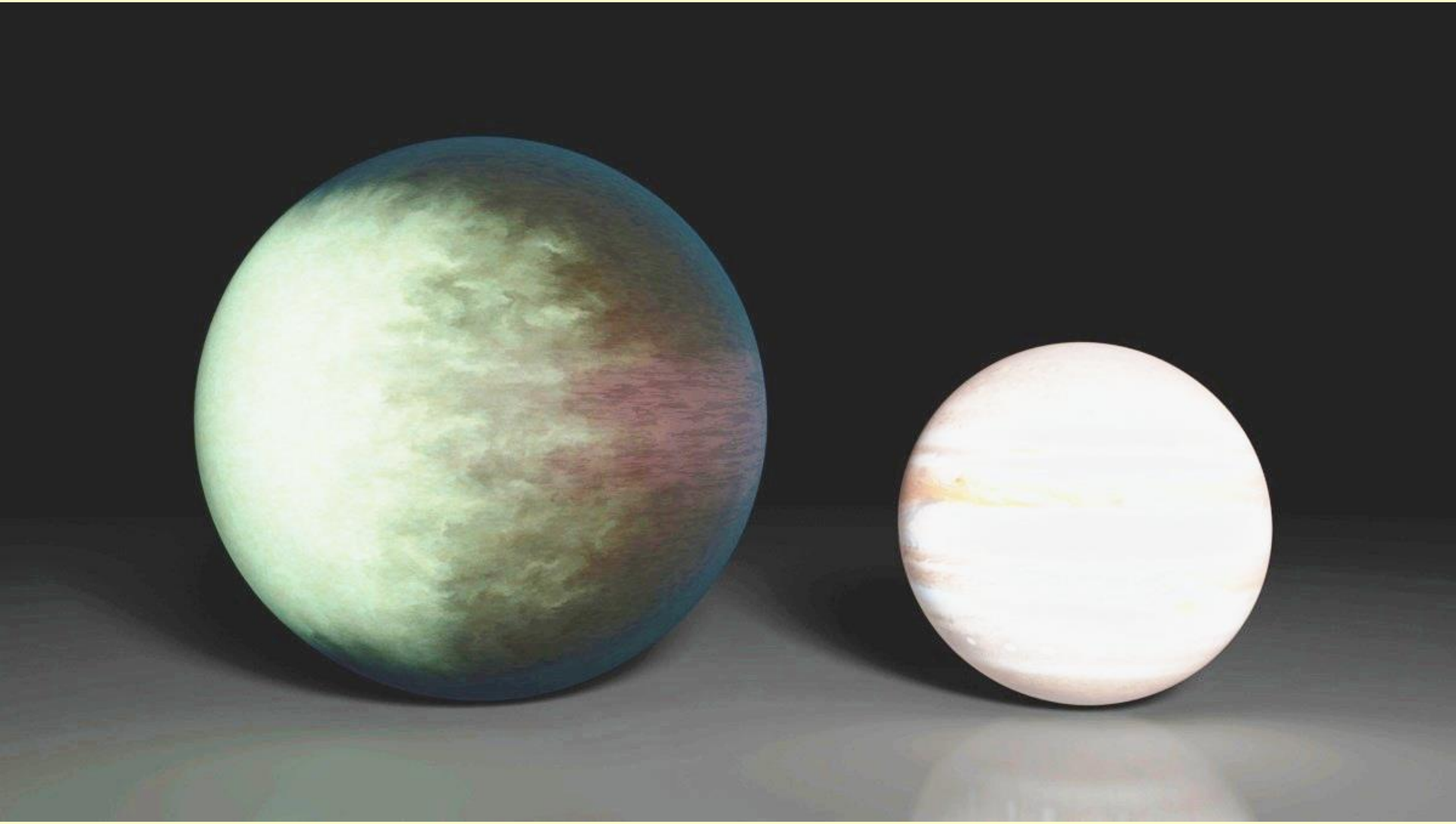
NASA / JPL-Caltech / H. Knutson (Harvard-Smithsonian CfA) ssc2007-09a

Kepler 7b (IR/Spitzer)



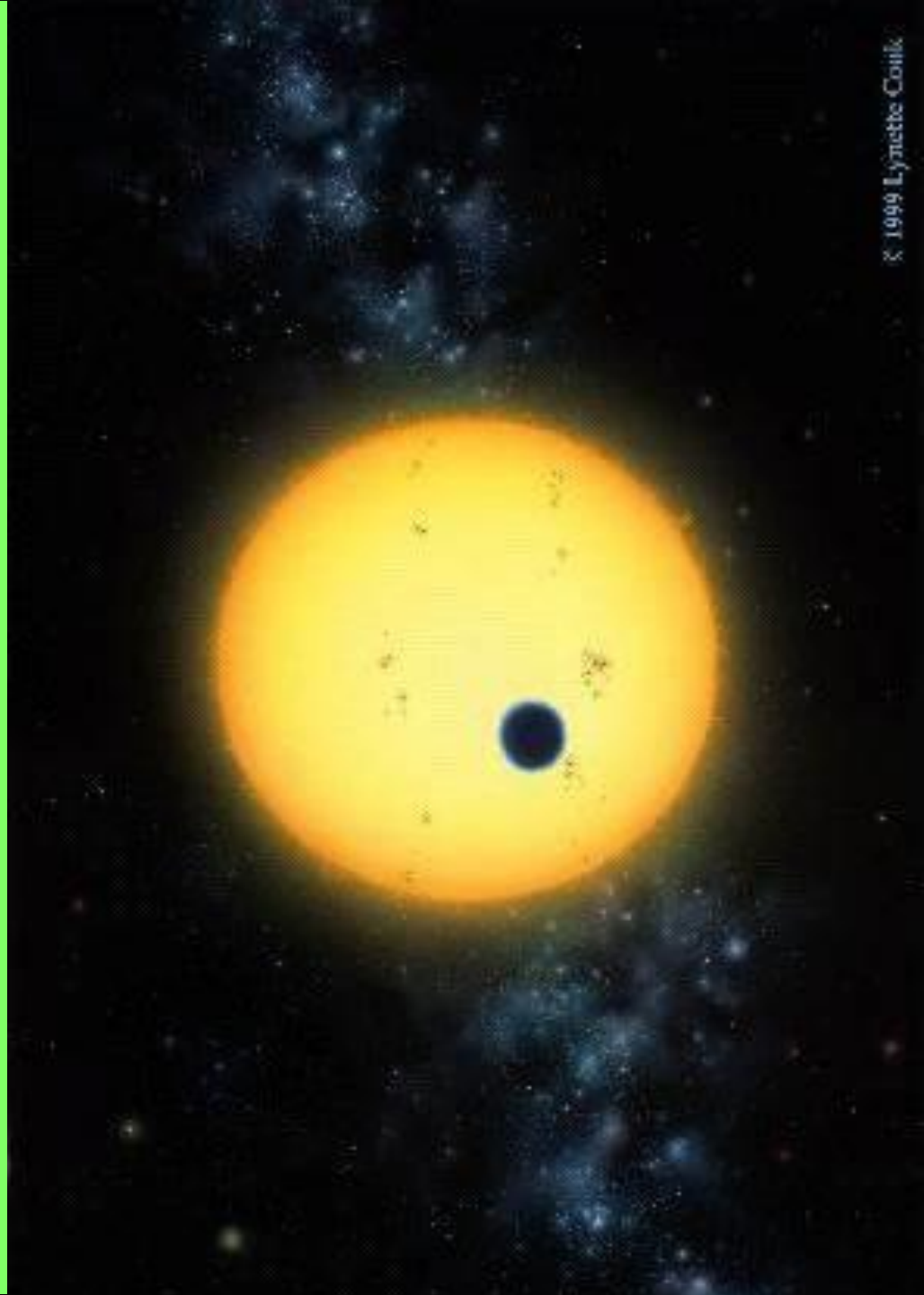
T ~ 1400 K

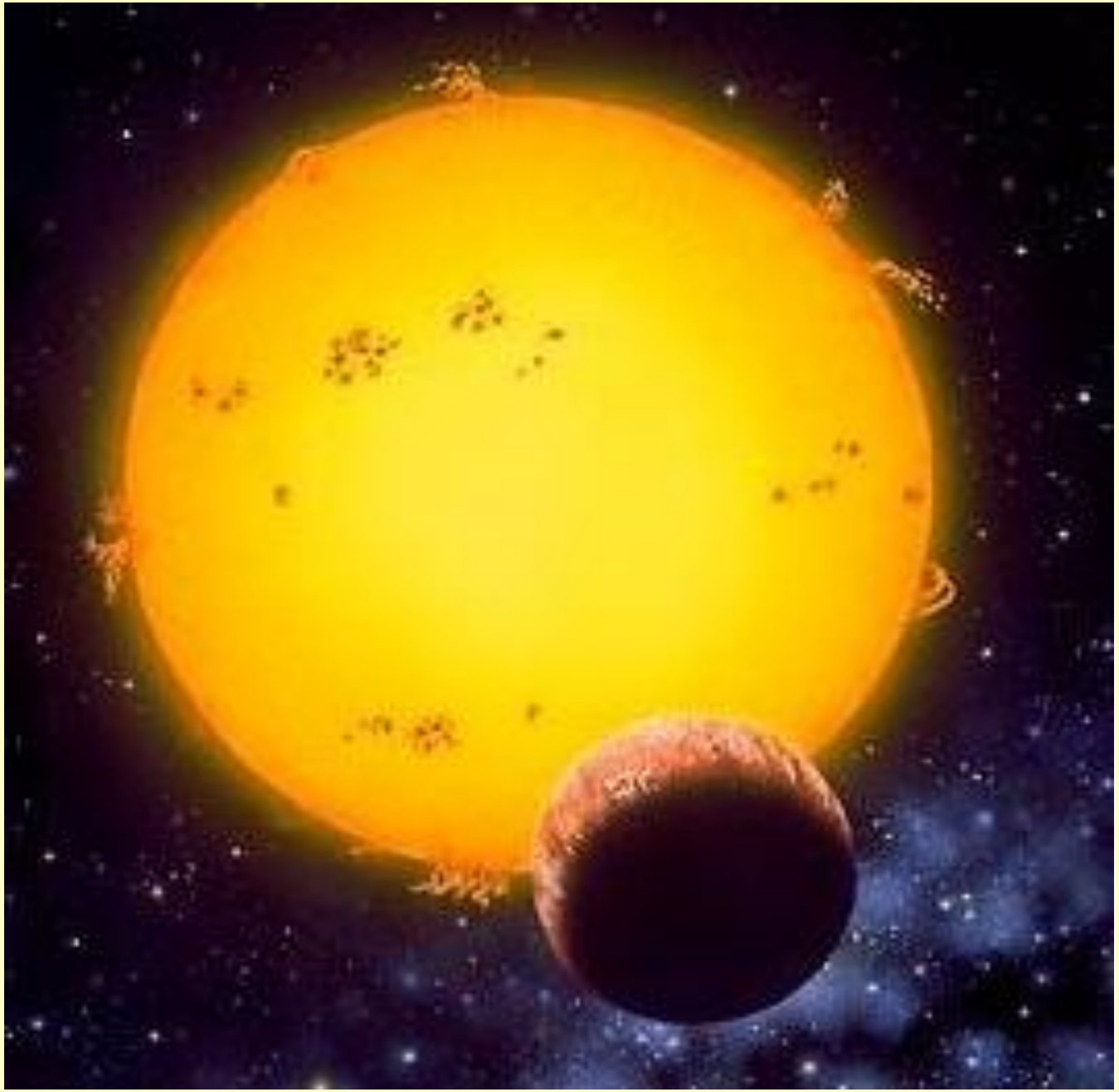
a ~9 million km

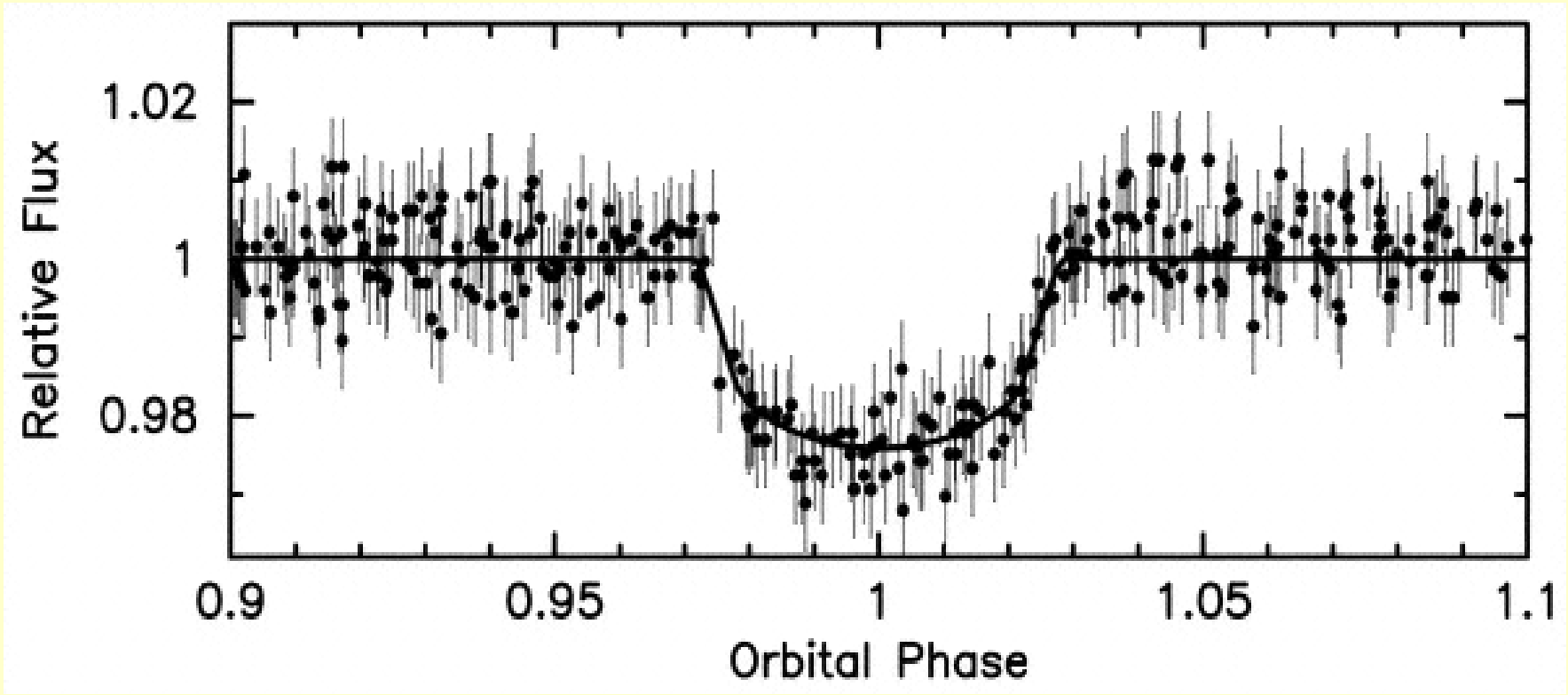


TRÂNSITOS

(O tamanho dos Planetas)

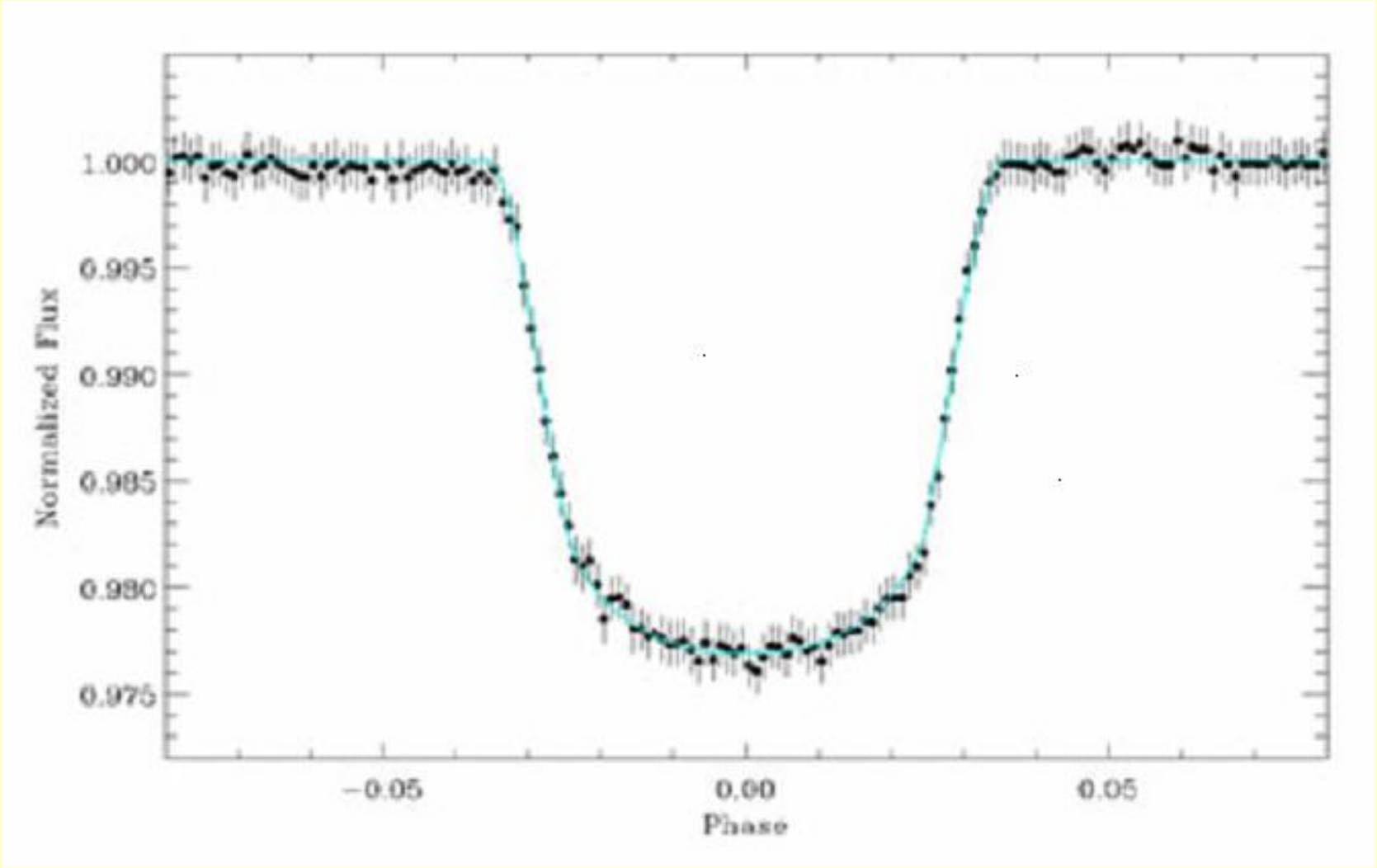




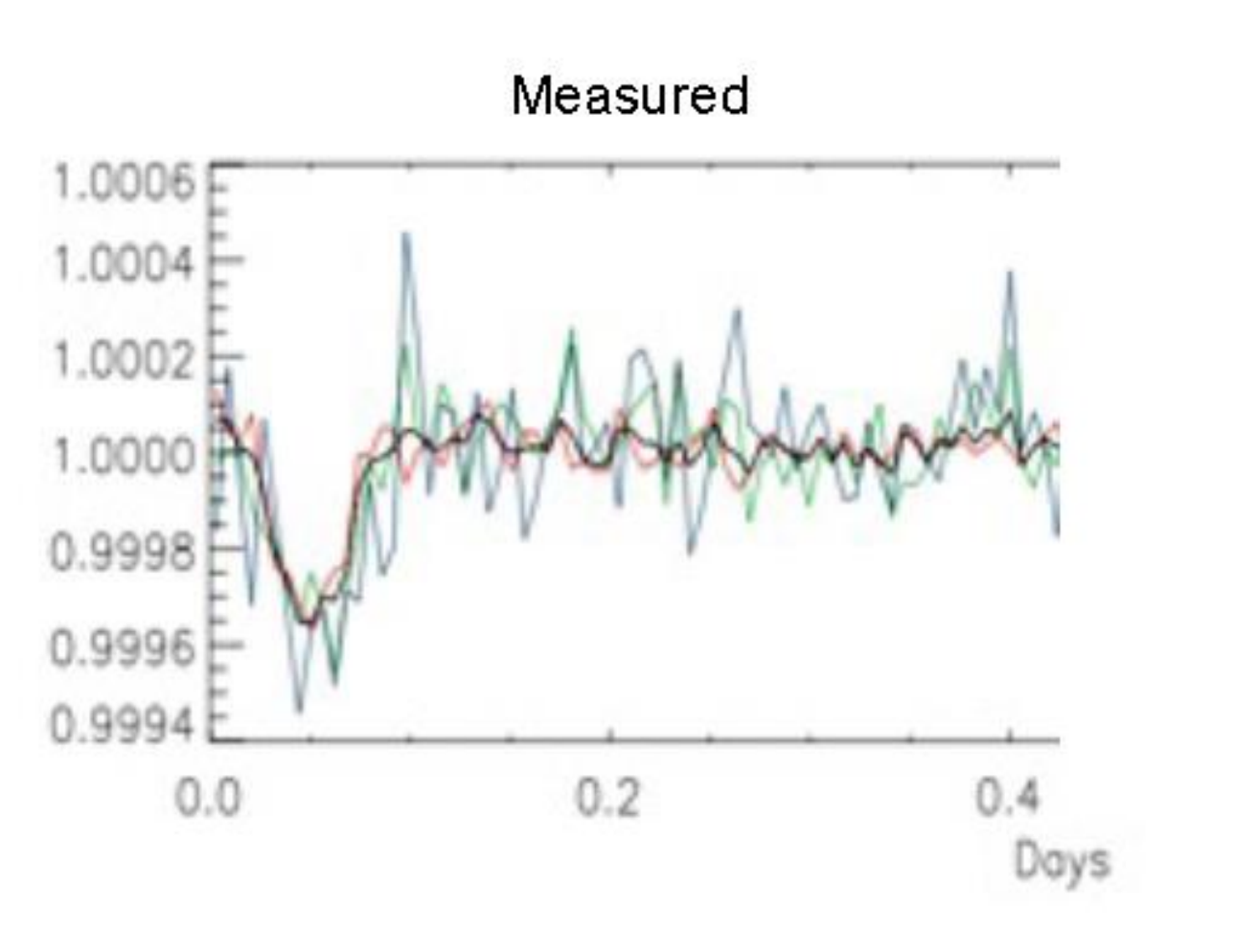

Relative Flux
1.02
1
0.98
0.9
0.95
1
1.05
1.1
Orbital Phase

(CNES+ESA+ ... + Brasil)
2006 – 2014
ø 20 cm telescope
4 fields

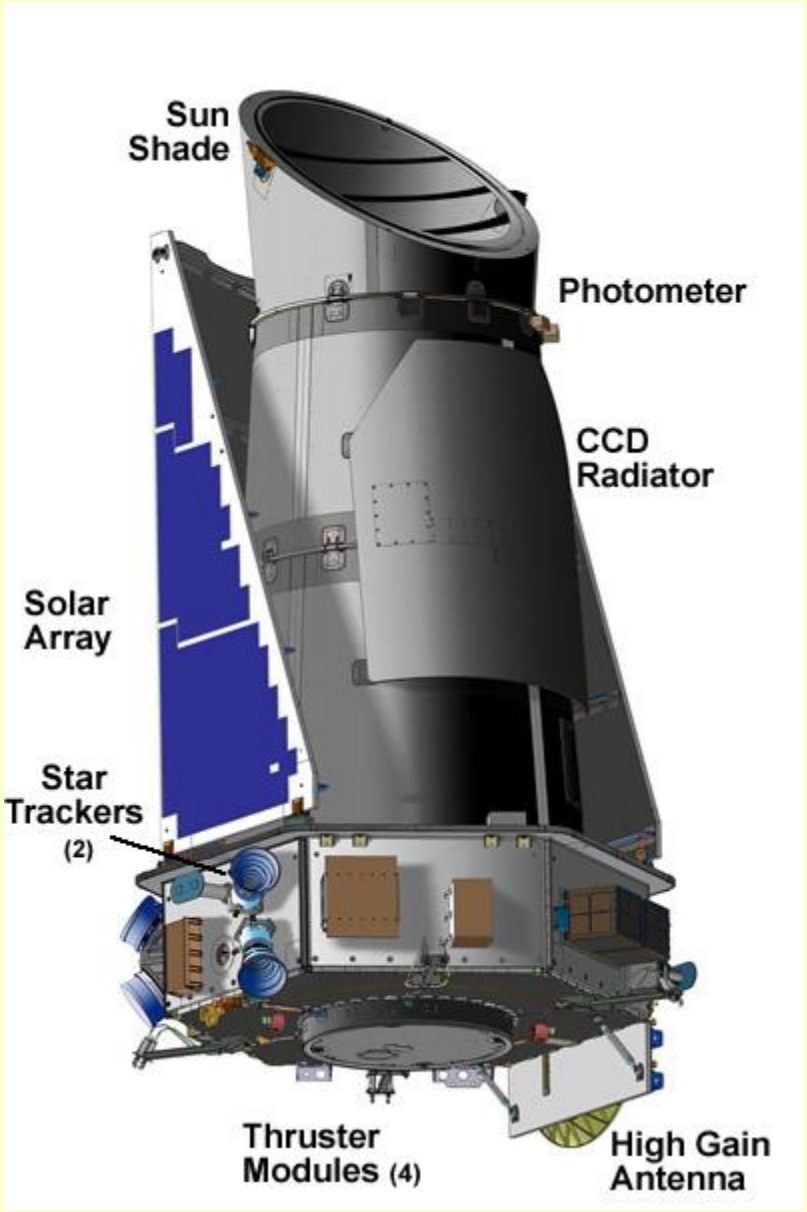
CoRoT-exo-1b

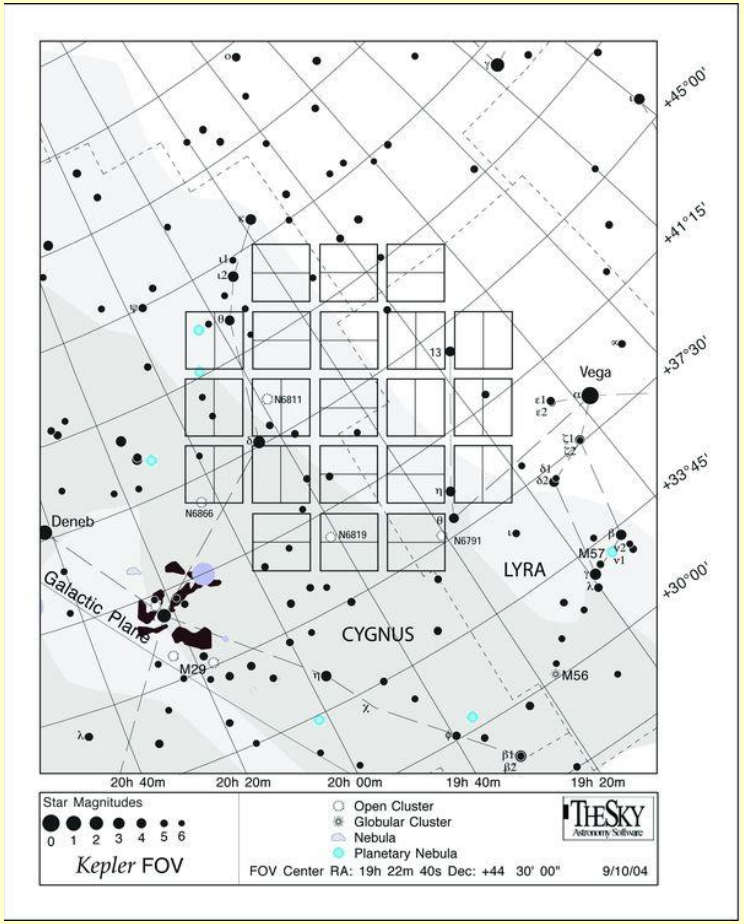

1.000
0.995
0.990
0.985
0.980
0.975
Normalized Flux
−0.05
0.00
0.05
Phase

CoRoT 7b (Variação 0.0004)



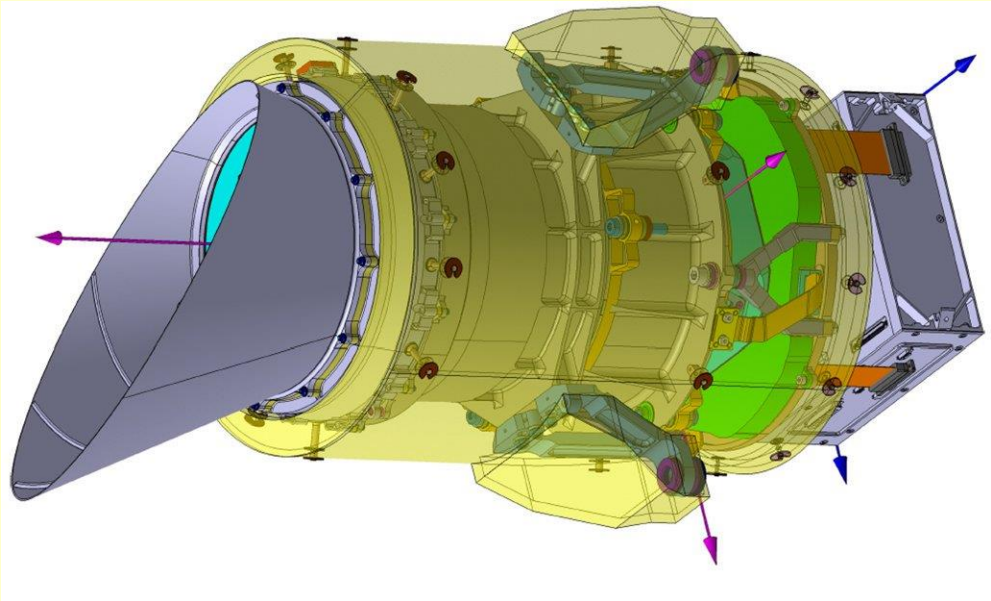
V=11.7





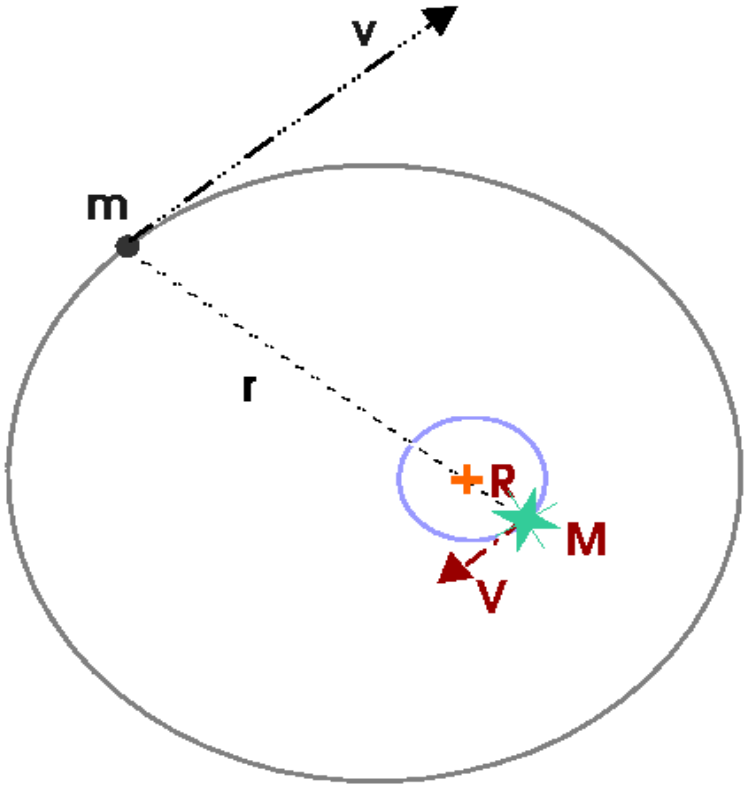
KEPLER (NASA)
2009 -
ø 1m telescope
21 fields

2018
TESS (NASA)
ø 10.5 cm telescope
4 fields



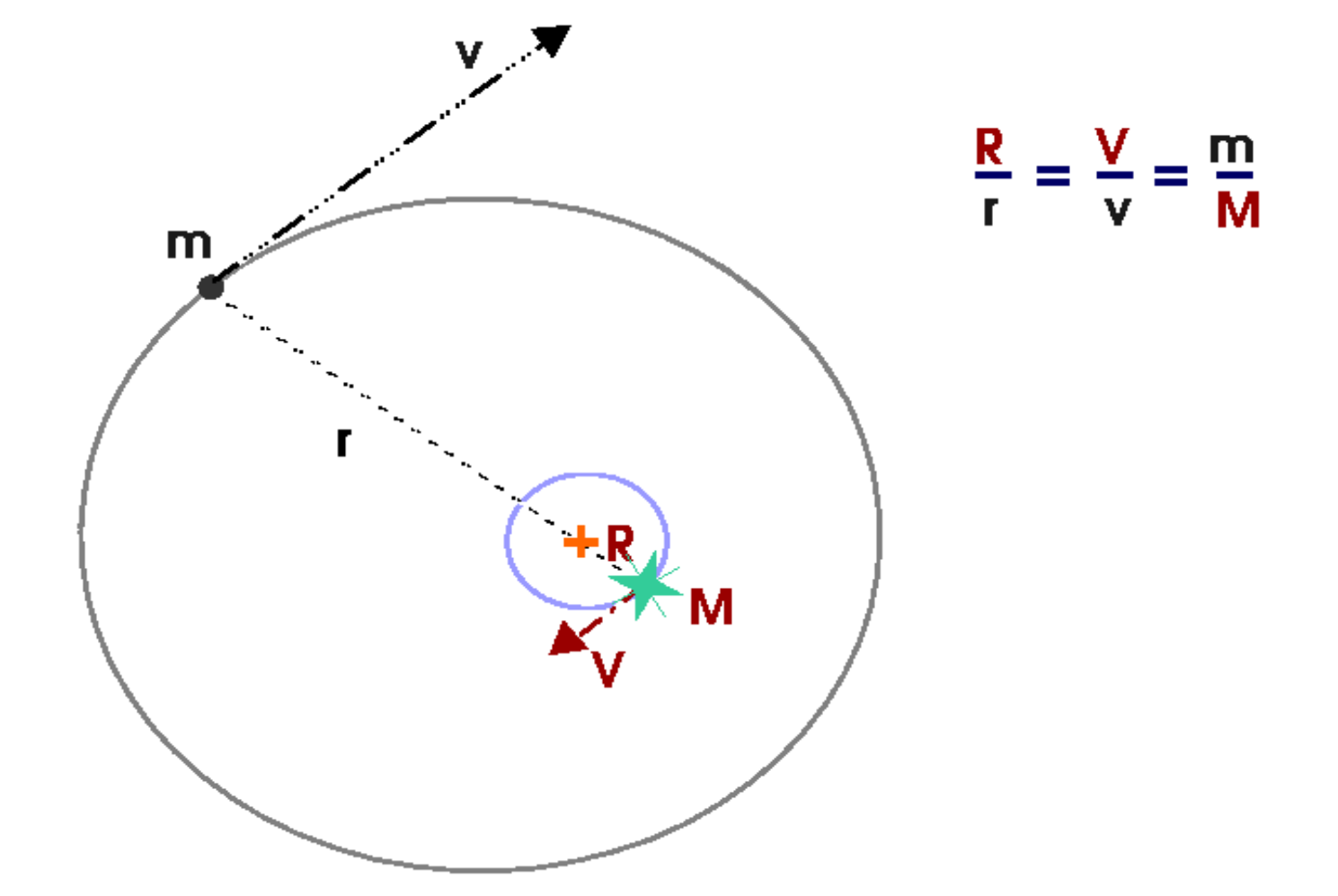
2026
PLATO (ESA + ... + Brasil)
ø 12 cm telescope
24 cameras

VELOCIDADES RADIAIS (Massas dos planetas)

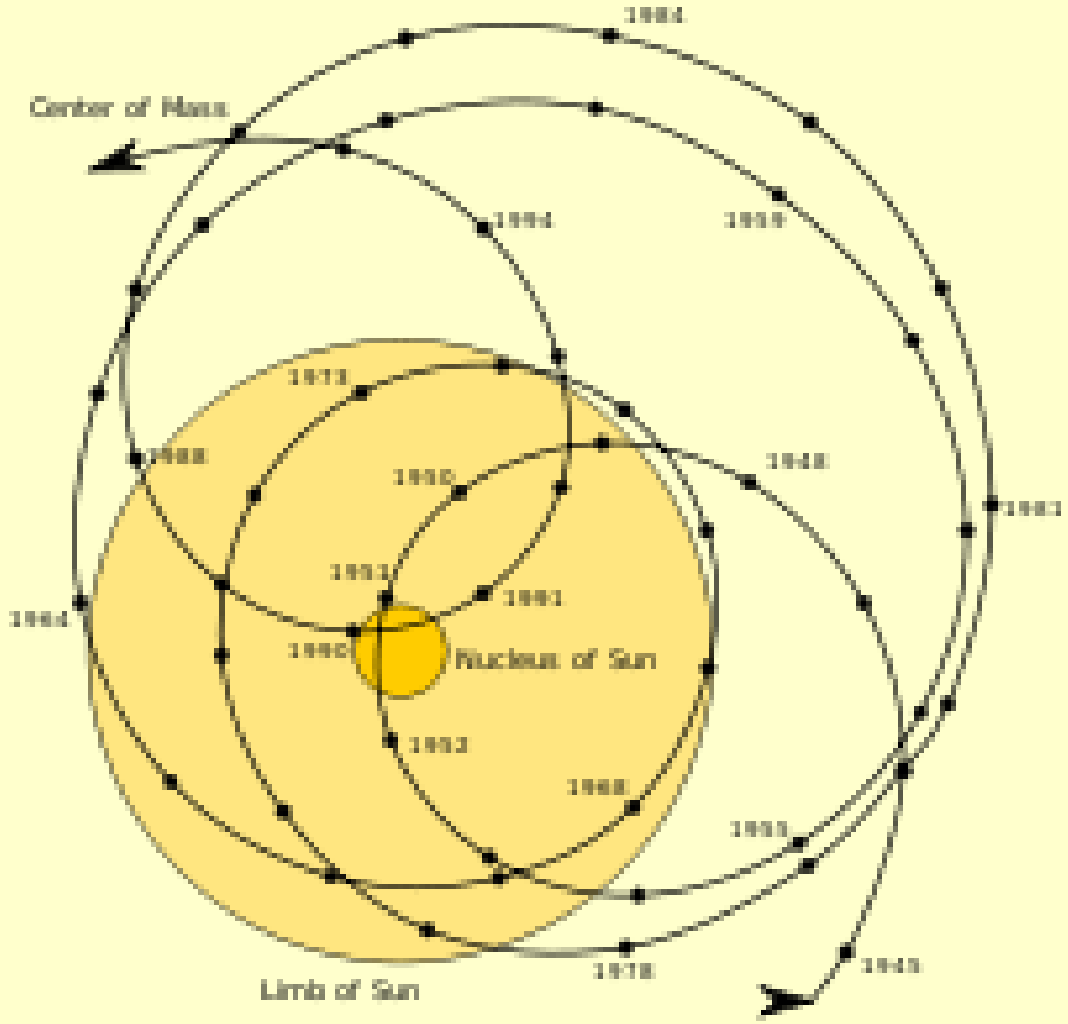


$$\frac{R}{r} = \frac{V}{v} = \frac{m}{M}$$

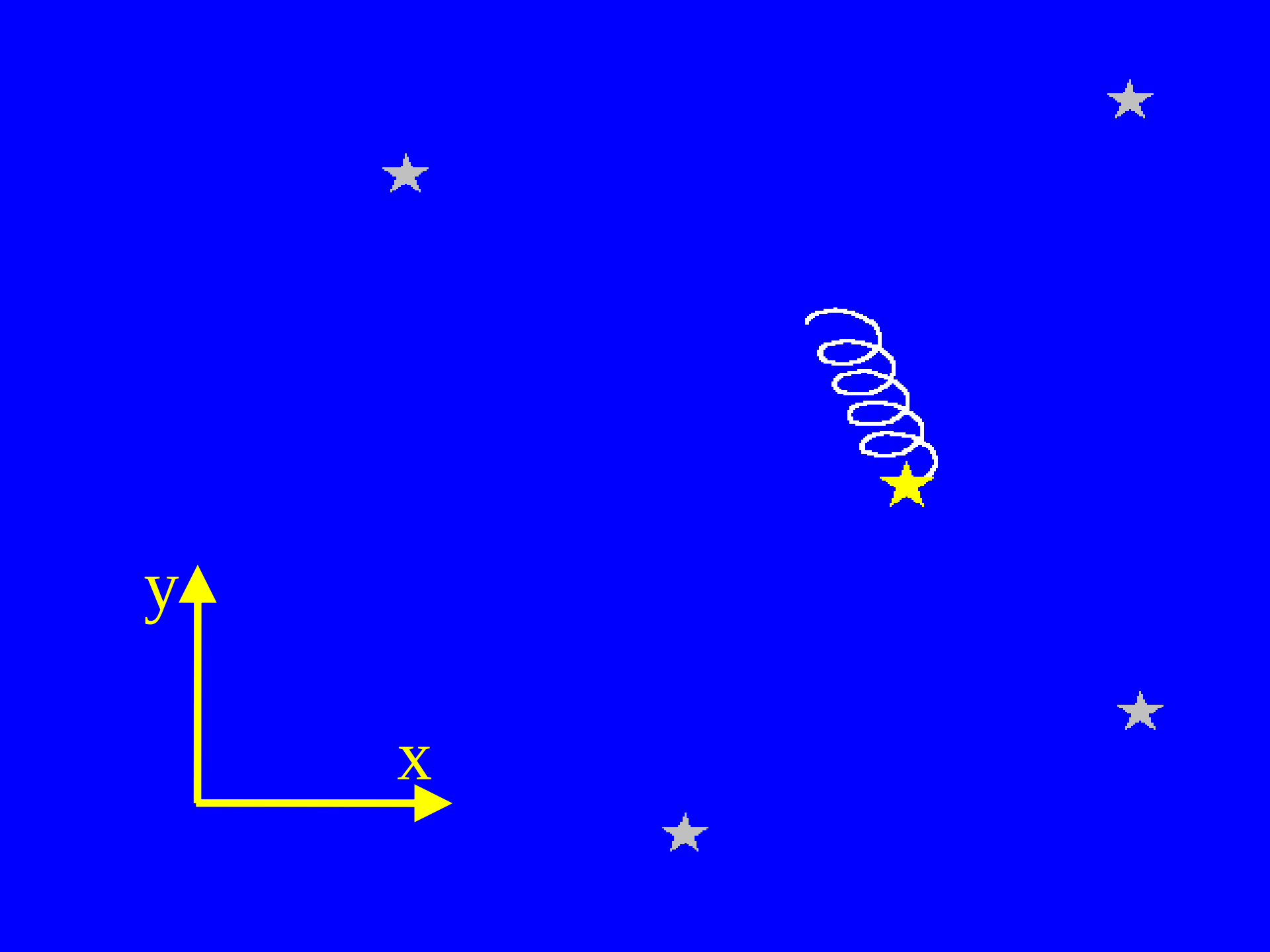
r,v,R,V são coordenadas e velocidades baricêntricas



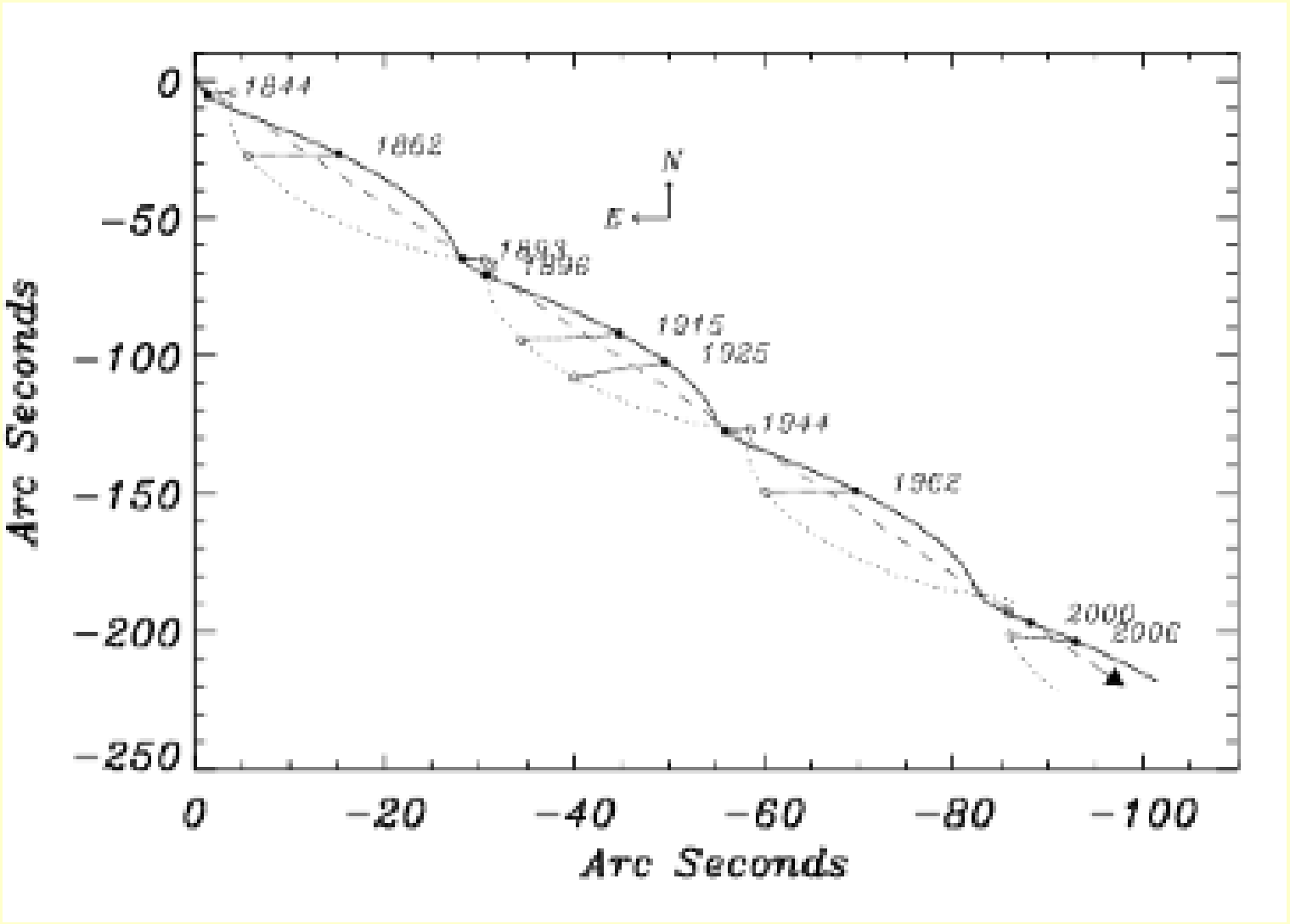
r,v,R,V são coordenadas e velocidades baricêntricas

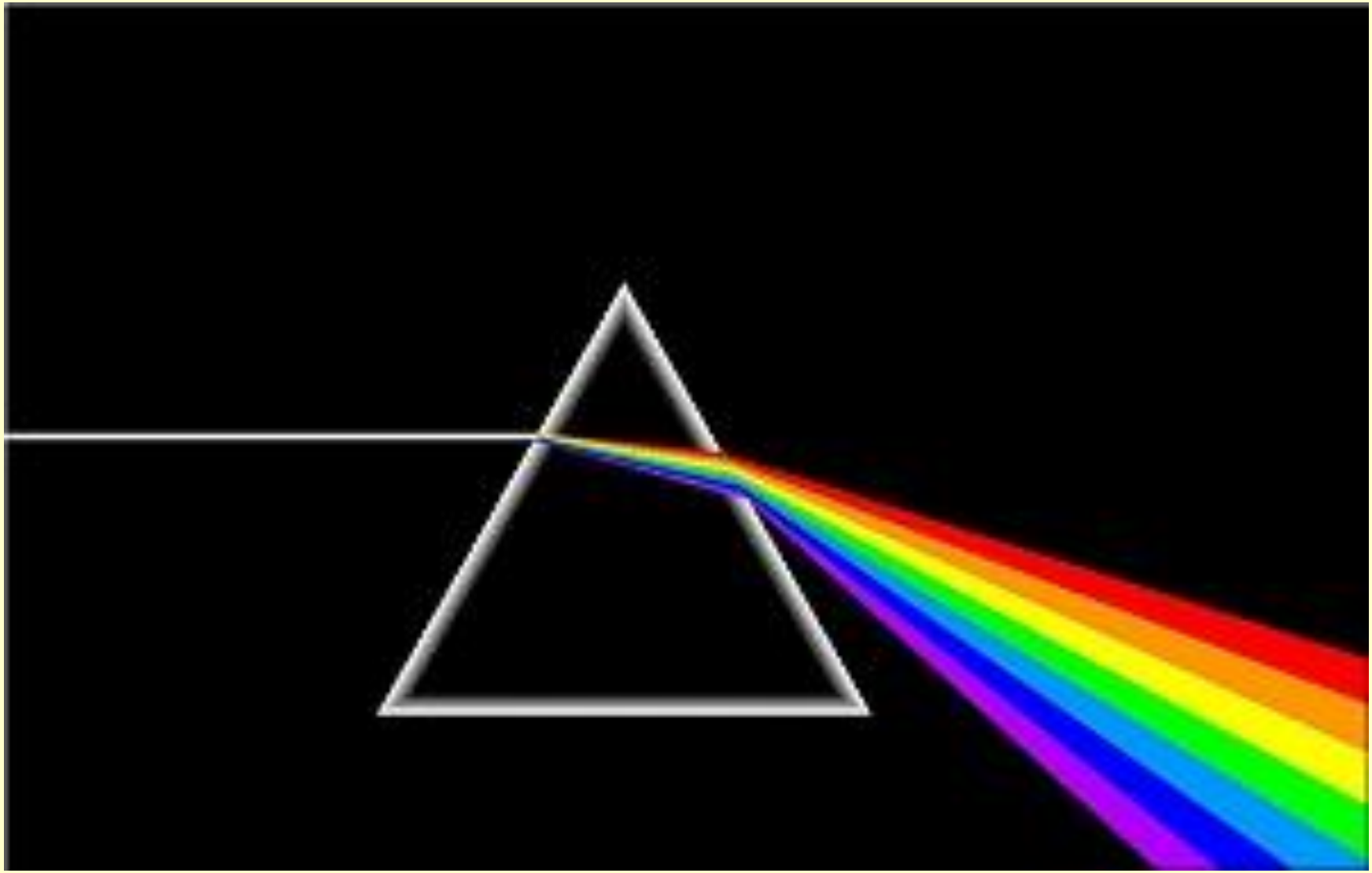


Movimento do Sol relativo ao centro do S.Solar

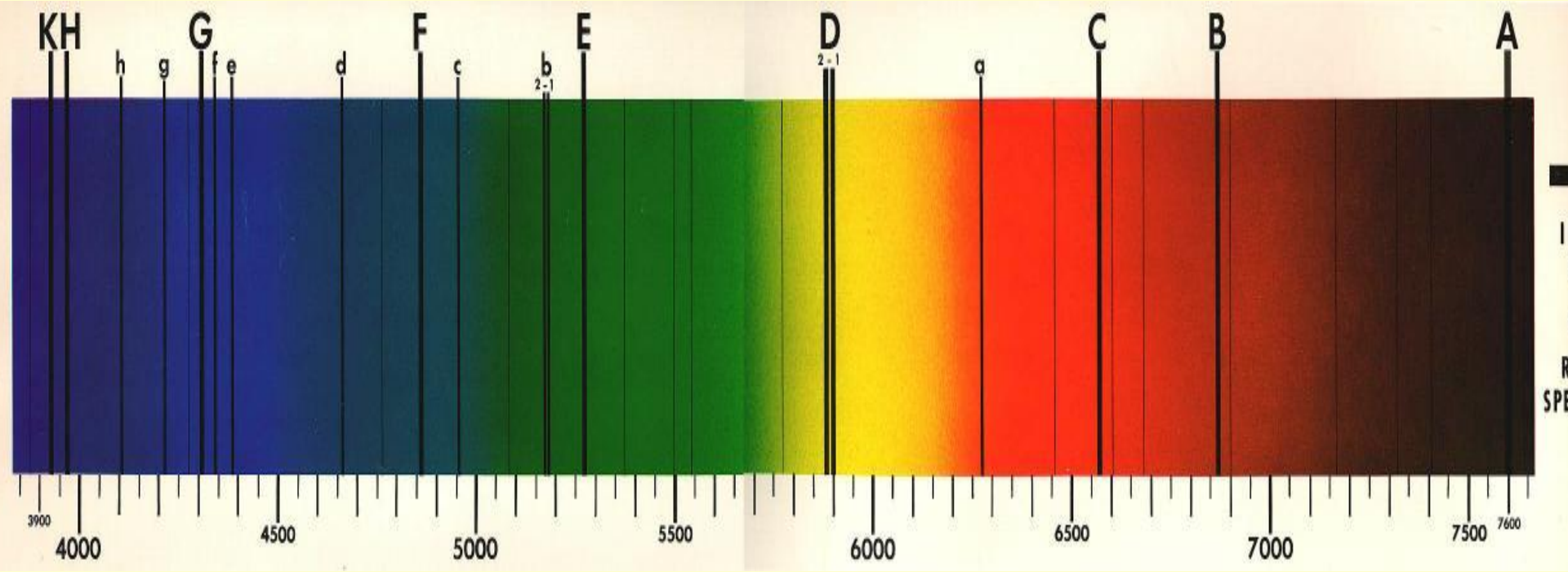

y
x

Sirius A+B

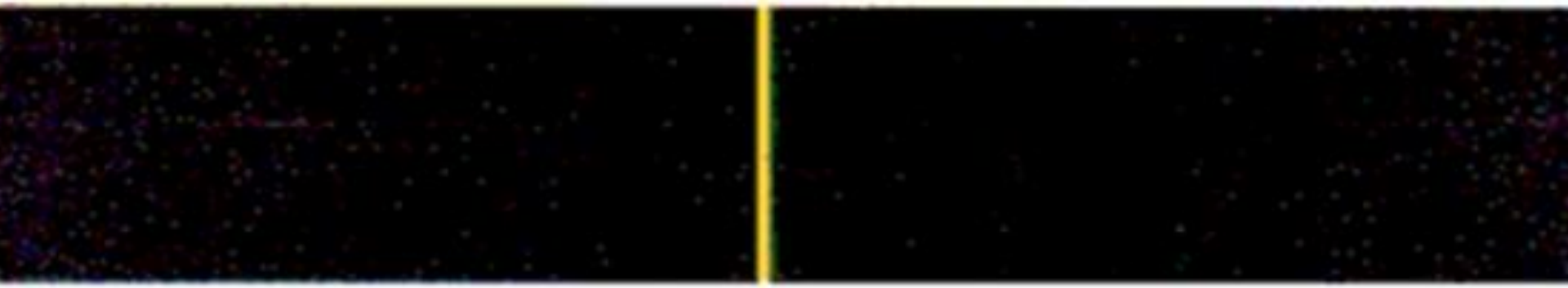

0
−50
−100
−150
−200
−250
Arc Seconds
1844
1862
1893
1896
1915
1925
1944
1962
2000
2000
N
E
0
−20
−40
−60
−80
−100
Arc Seconds

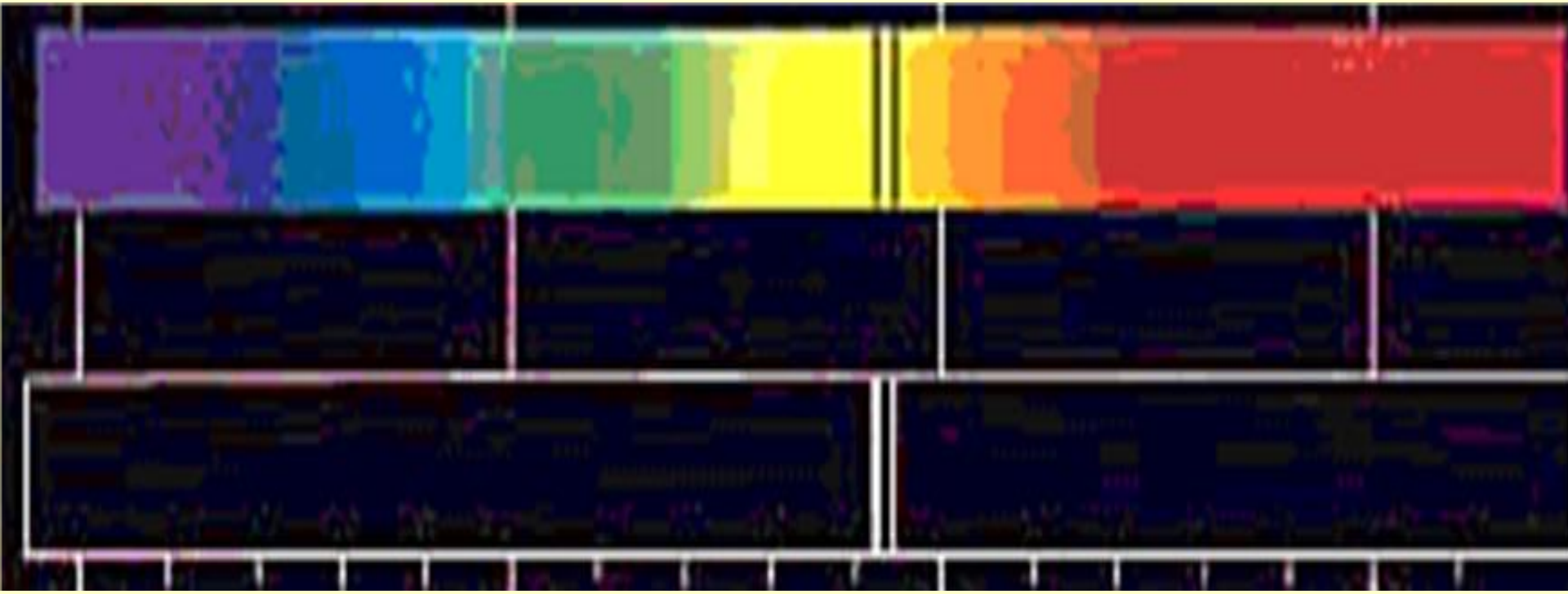


Espectro do Sol (Fraunhofer)

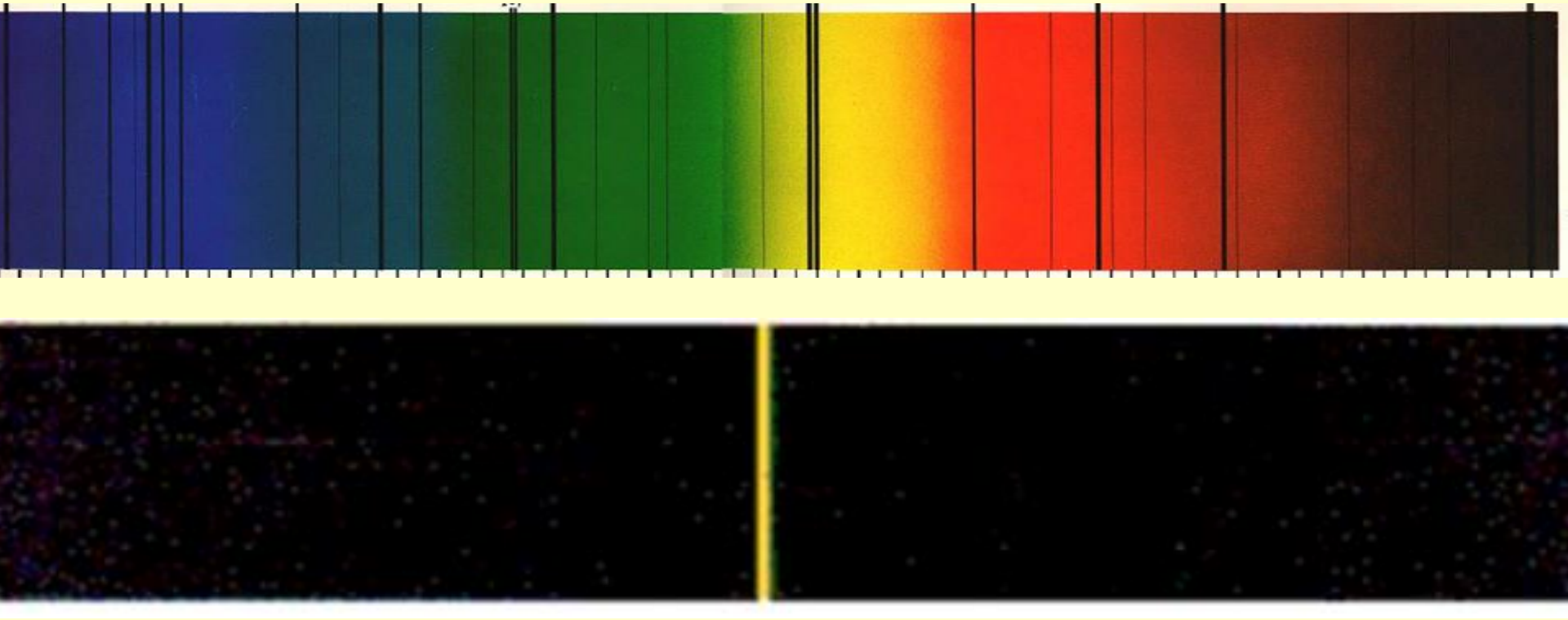


Lâmpada de Sódio



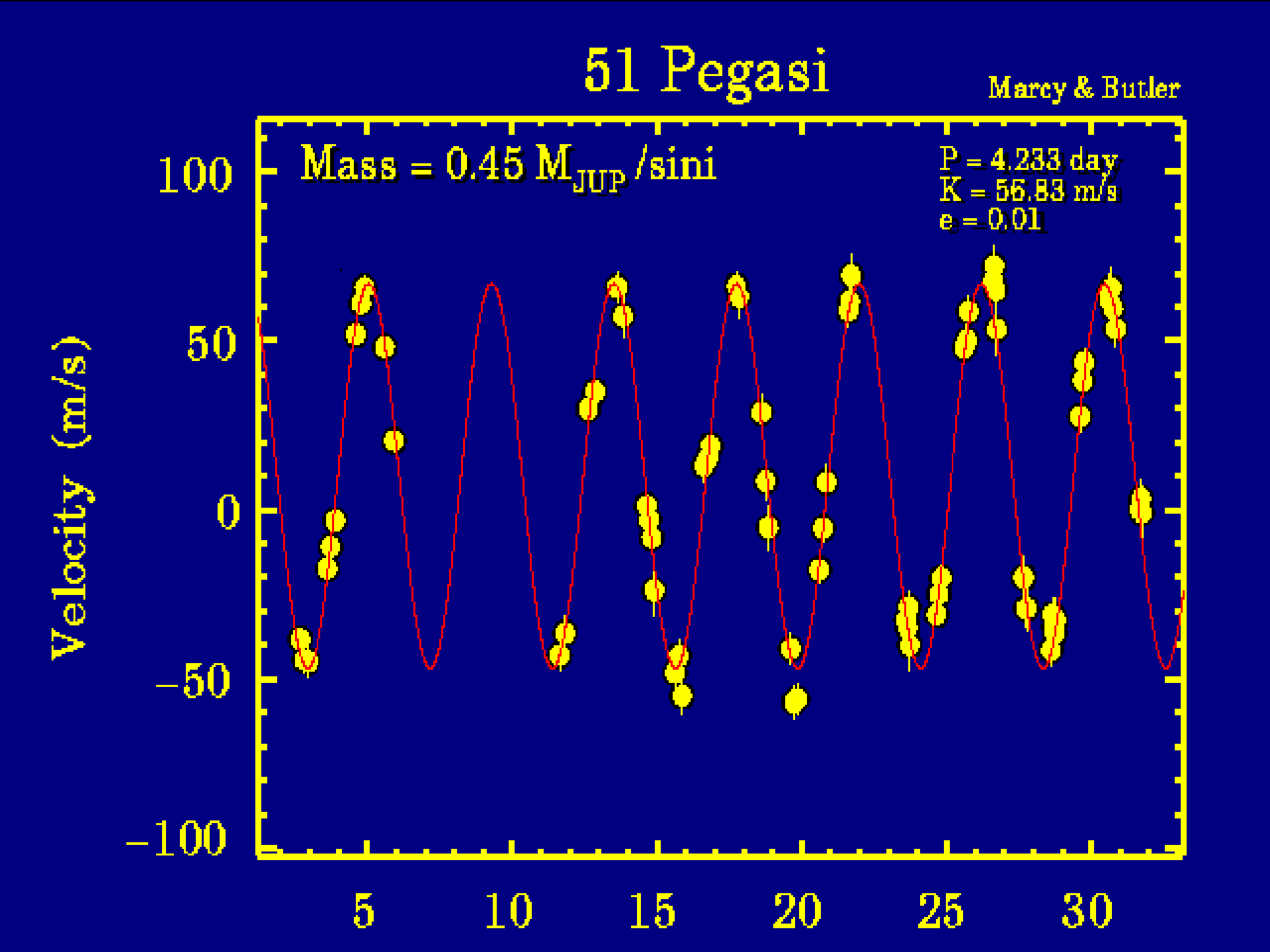


Efeito Doppler

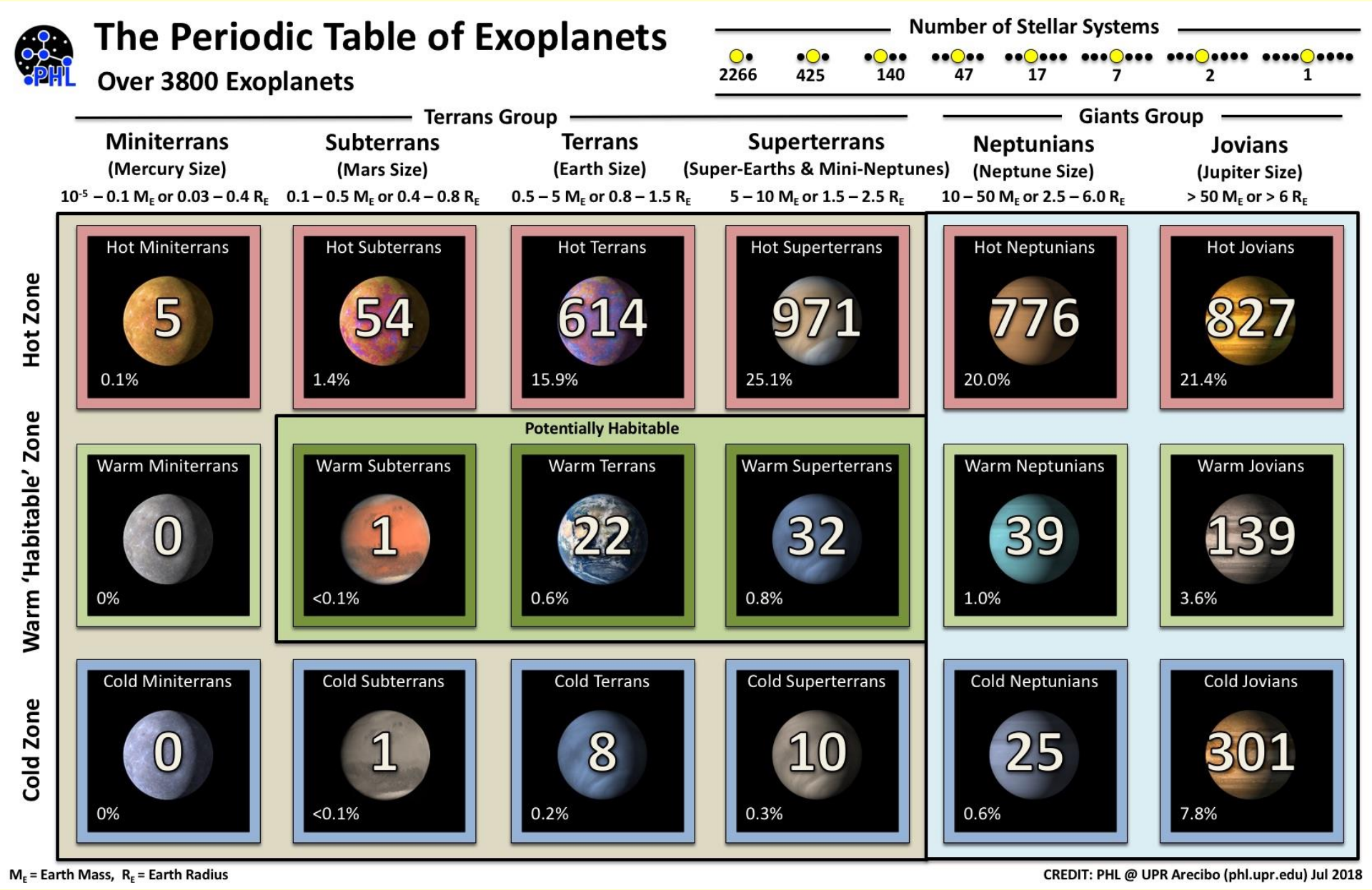


Exemplos: Sol-Júpiter ~ 13 m/s

Sol-Terra ~ 9 cm/s


51 Pegasi
Marcy & Butler
Mass = 0.45 M_JUP /sini
P = 4.233 day
K = 56.83 m/s
e = 0.01
Velocity (m/s)
100
50
0
−50
−100
5
10
15
20
25
30

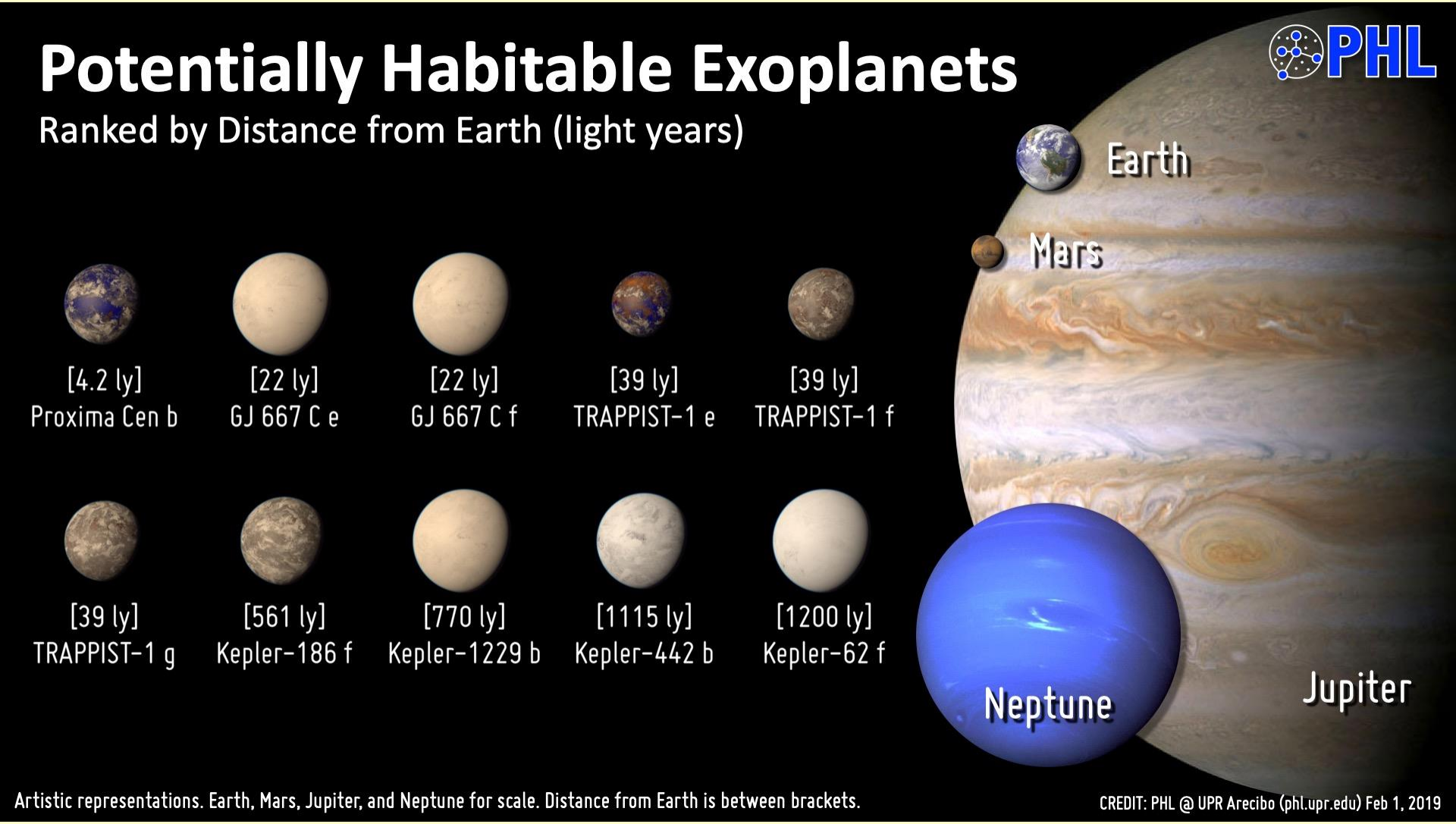
Harps at ESO (Chile)


The Periodic Table of Exoplanets
Over 3800 Exoplanets
Number of Stellar Systems
2266
425
140
47
17
7
2
1
Terrans Group
Giants Group
Miniterrans
(Mercury Size)
10-5 – 0.1 ME or 0.03 – 0.4 RE
Subterrans
(Mars Size)
0.1 – 0.5 ME or 0.4 – 0.8 RE
Terrans
(Earth Size)
0.5 – 5 ME or 0.8 – 1.5 RE
Superterrans
(Super-Earths & Mini-Neptunes)
5 – 10 ME or 1.5 – 2.5 RE
Neptunians
(Neptune Size)
10 – 50 ME or 2.5 – 6.0 RE
Jovians
(Jupiter Size)
> 50 ME or > 6 RE
Hot Zone
Warm 'Habitable' Zone
Cold Zone
Potentially Habitable
Hot Miniterrans
5
0.1%
Hot Subterrans
54
1.4%
Hot Terrans
614
15.9%
Hot Superterrans
971
25.1%
Hot Neptunians
776
20.0%
Hot Jovians
827
21.4%
Warm Miniterrans
0
0%
Warm Subterrans
1
<0.1%
Warm Terrans
22
0.6%
Warm Superterrans
32
0.8%
Warm Neptunians
39
1.0%
Warm Jovians
139
3.6%
Cold Miniterrans
0
0%
Cold Subterrans
1
<0.1%
Cold Terrans
8
0.2%
Cold Superterrans
10
0.3%
Cold Neptunians
25
0.6%
Cold Jovians
301
7.8%
ME = Earth Mass, RE = Earth Radius
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) Jul 2018

(2018)

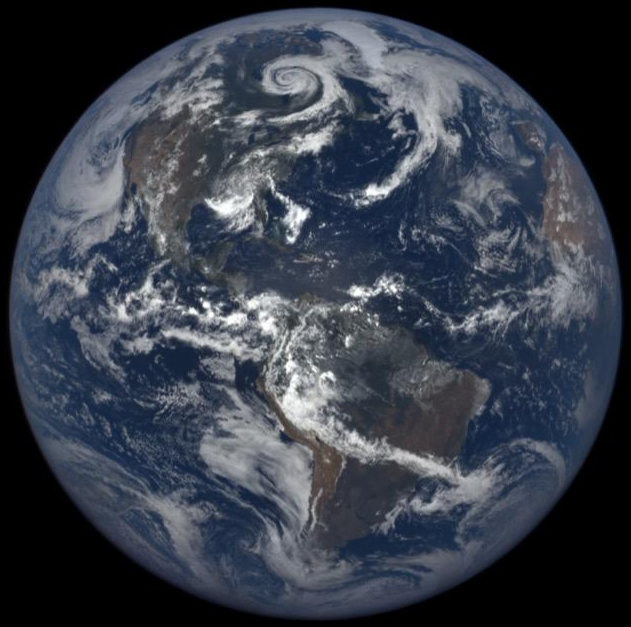
Potentially Habitable Exoplanets

Ranked by Distance from Earth (light years)

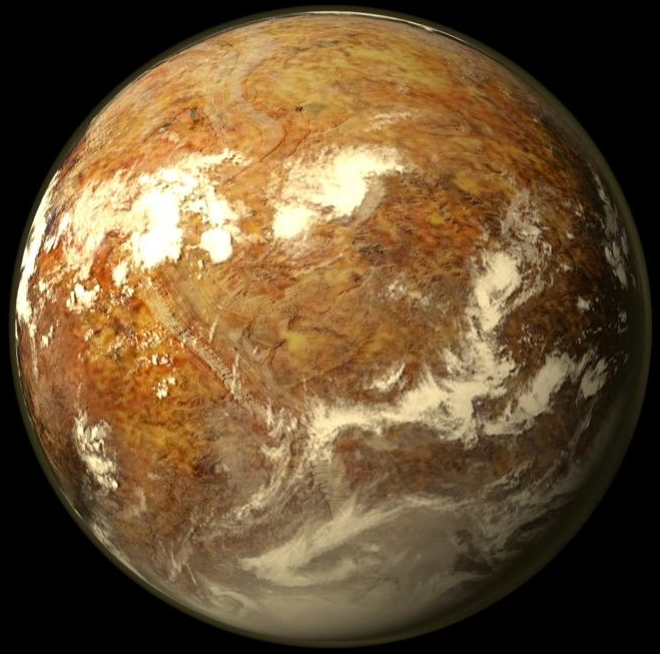


Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Distance from Earth is between brackets.

CREDIT: PHL @ UPR Arecibo (phl.upr.edu) Feb 1, 2019



Earth



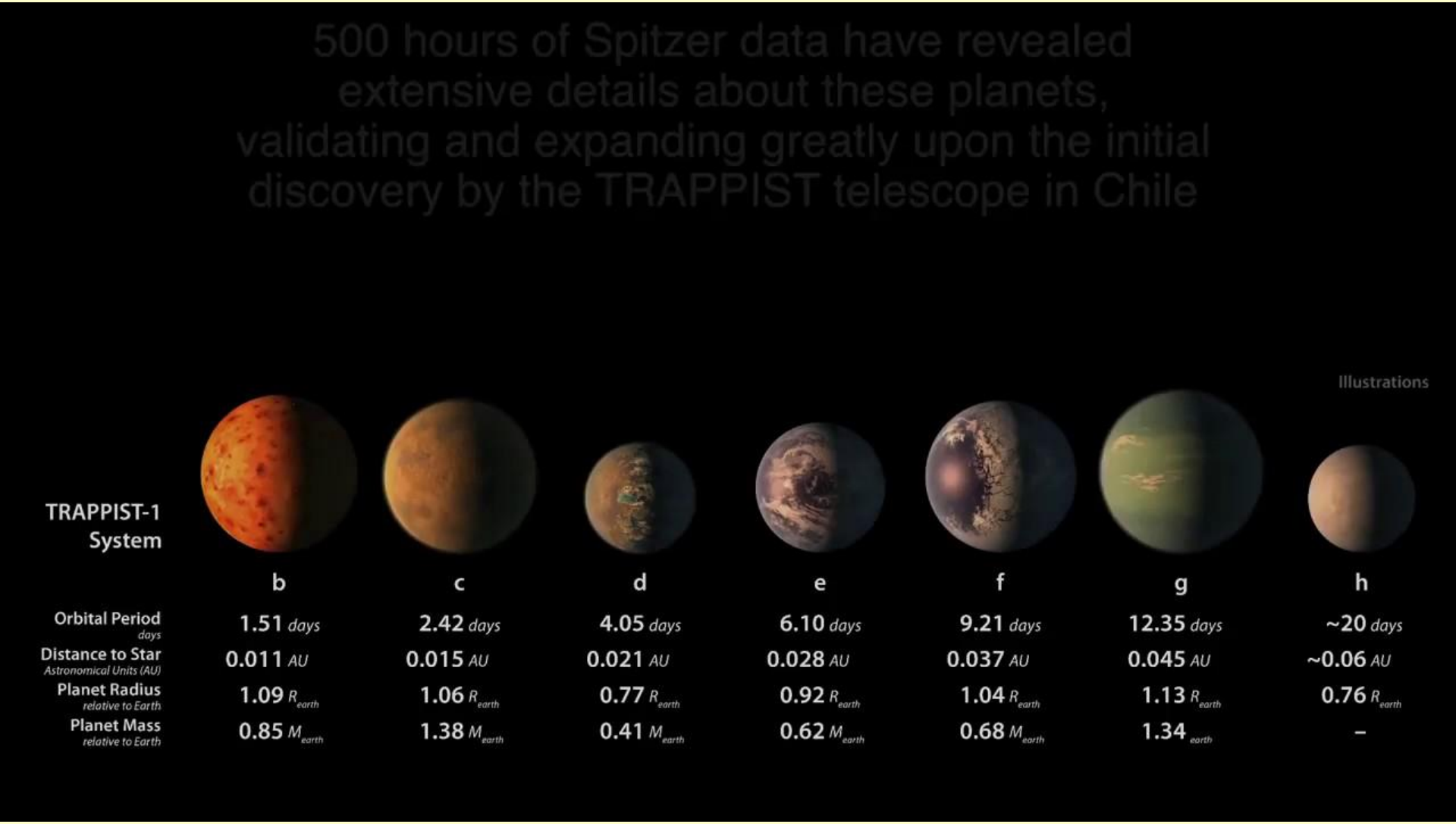
Proxima b

(artistic representation)

Credit: PHL @ UPR Arecibo, NASA EPIC Team

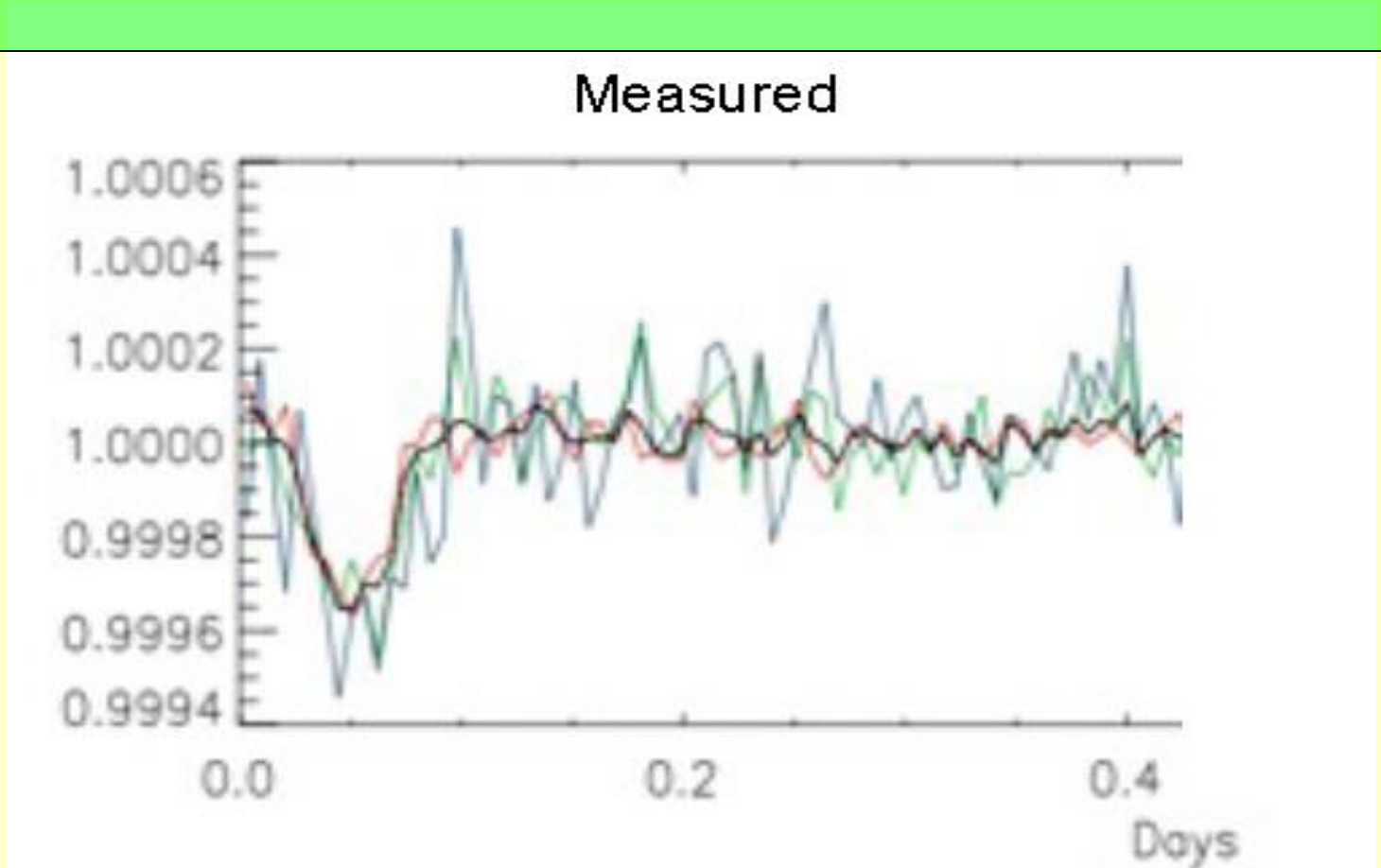

Three Potentially Habitable Worlds
Around Gliese 667C
Gliese 667C c
Gliese 667C f
Gliese 667C e
Earth

TRAPPIST-1 System

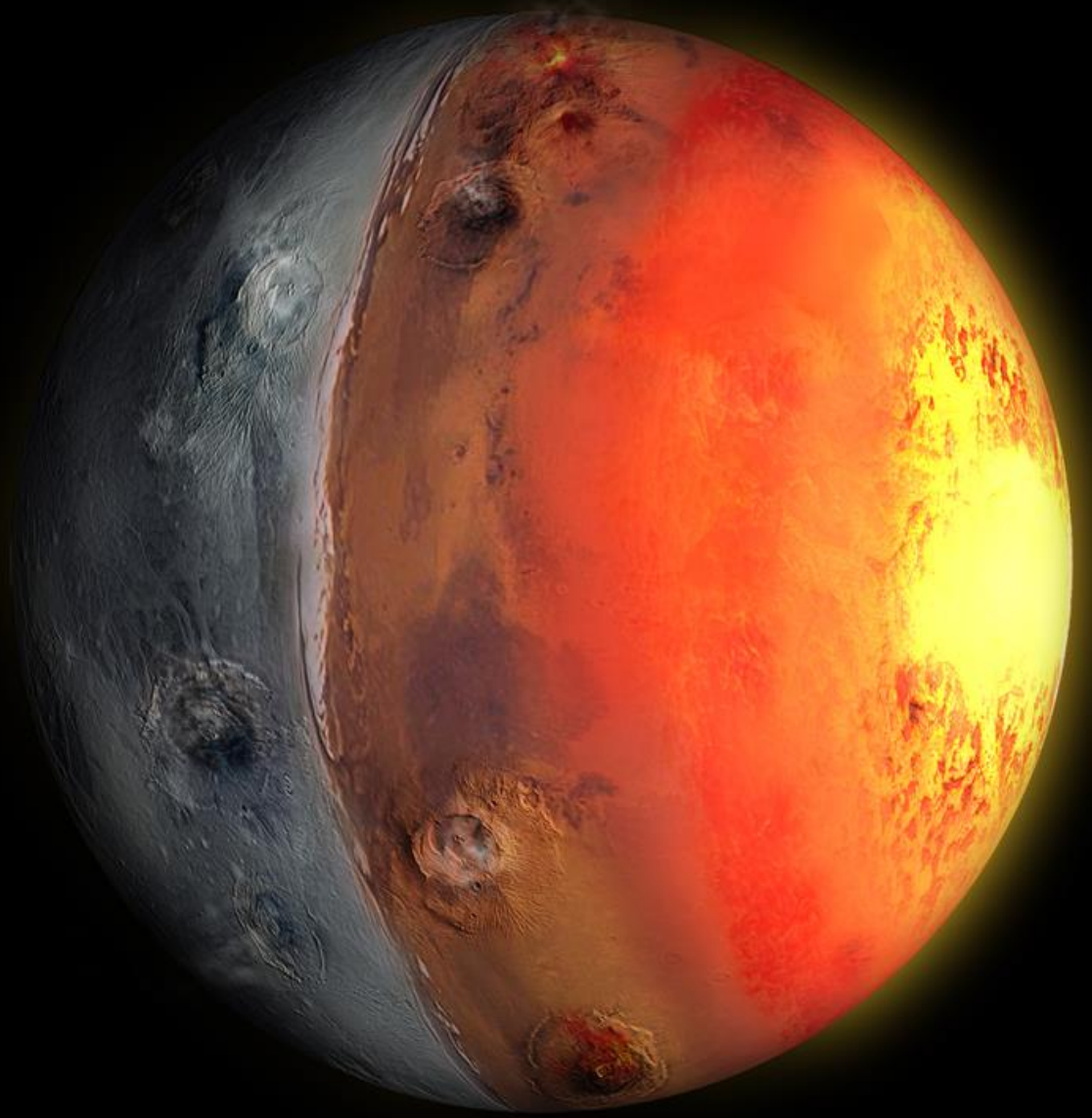


FIM

CoRoT-7b


Measured
1.0006
1.0004
1.0002
1.0000
0.9998
0.9996
0.9994
0.0
0.2
0.4
Days

Corot - 7B



m = 5 T

P = 0.85 d

a = 2.5 milhoes km

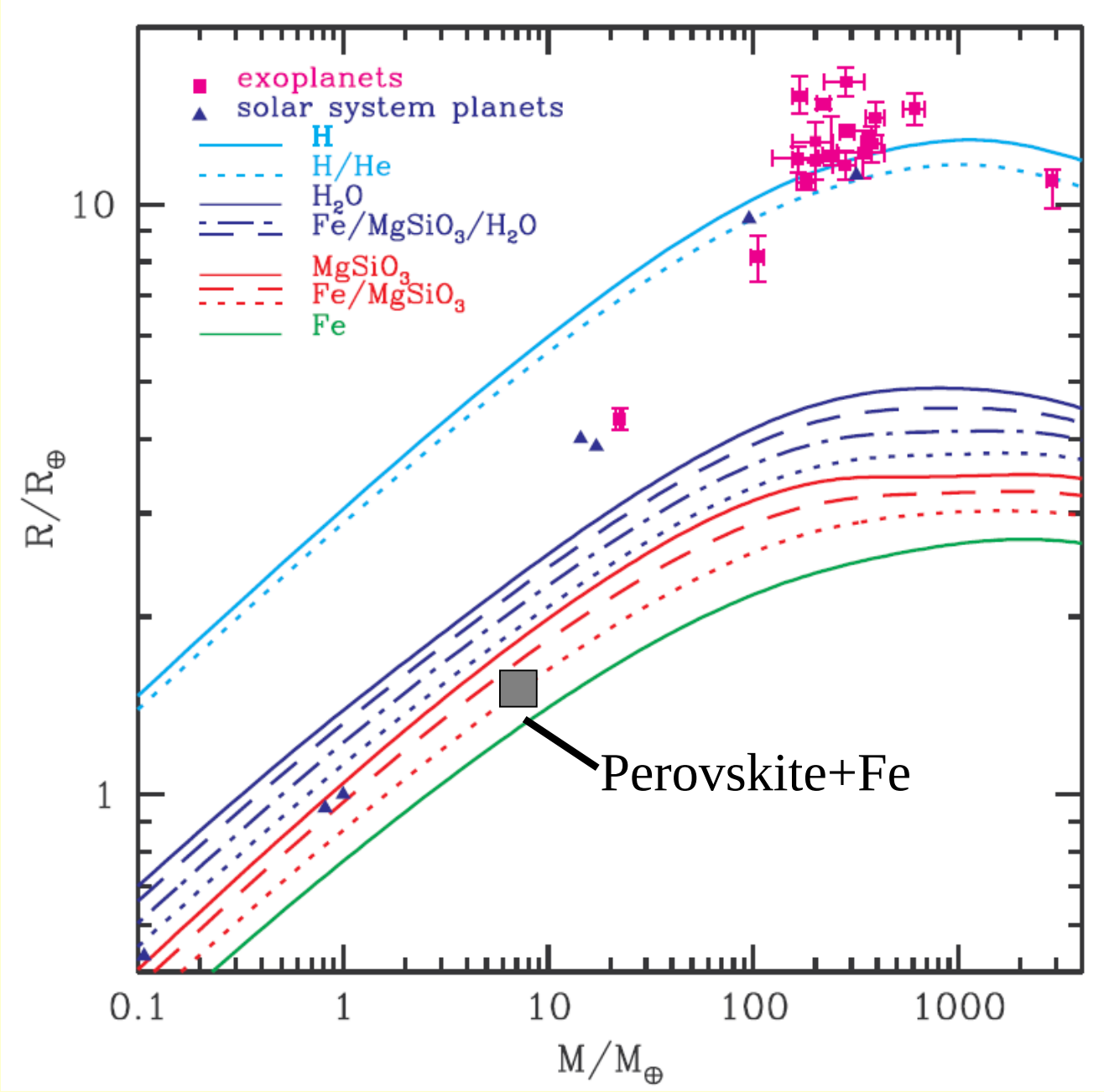
R = 11000 km

(maré = +65/

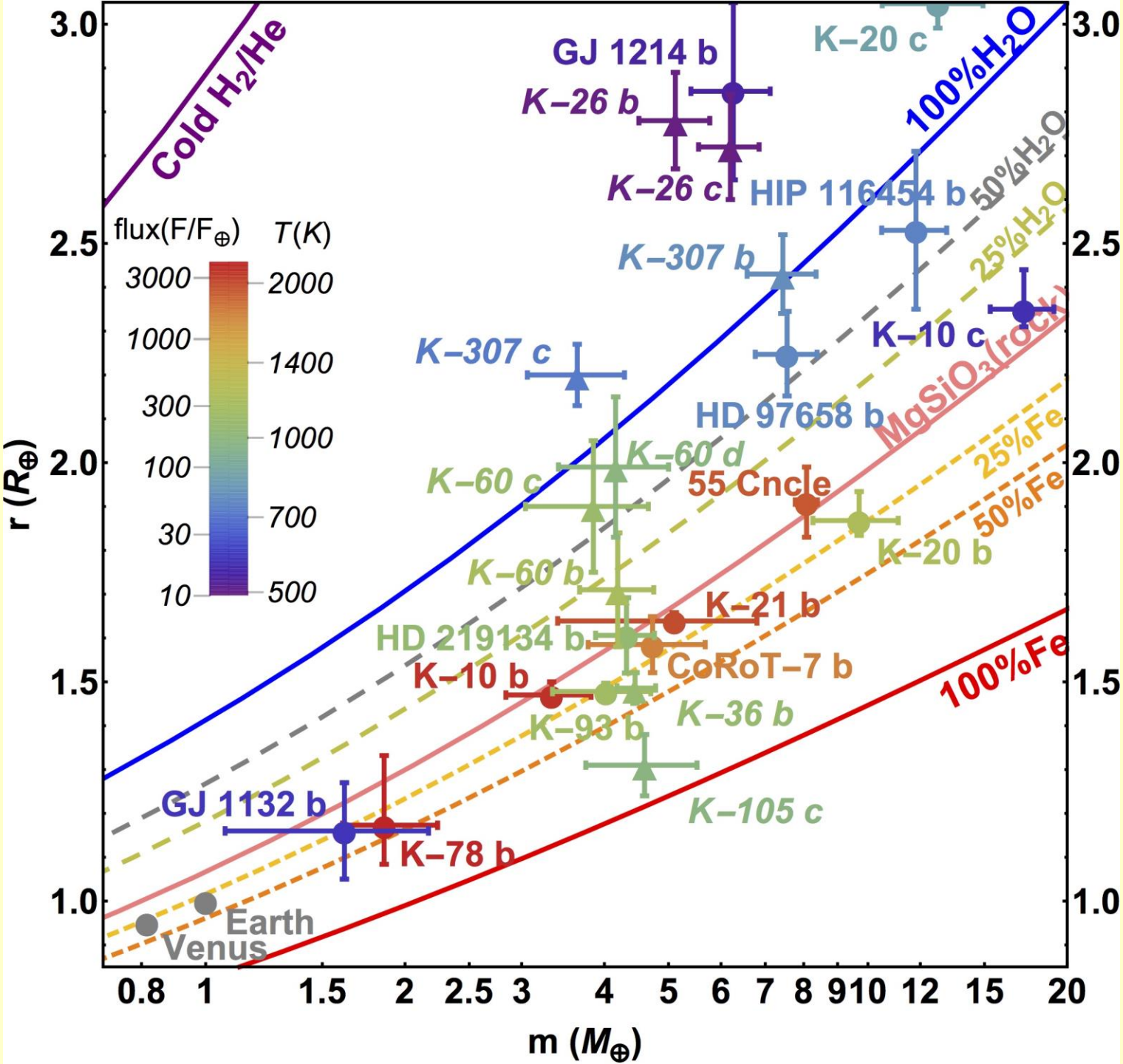
-20 km)

Ref: CoRoT + IAG 2010

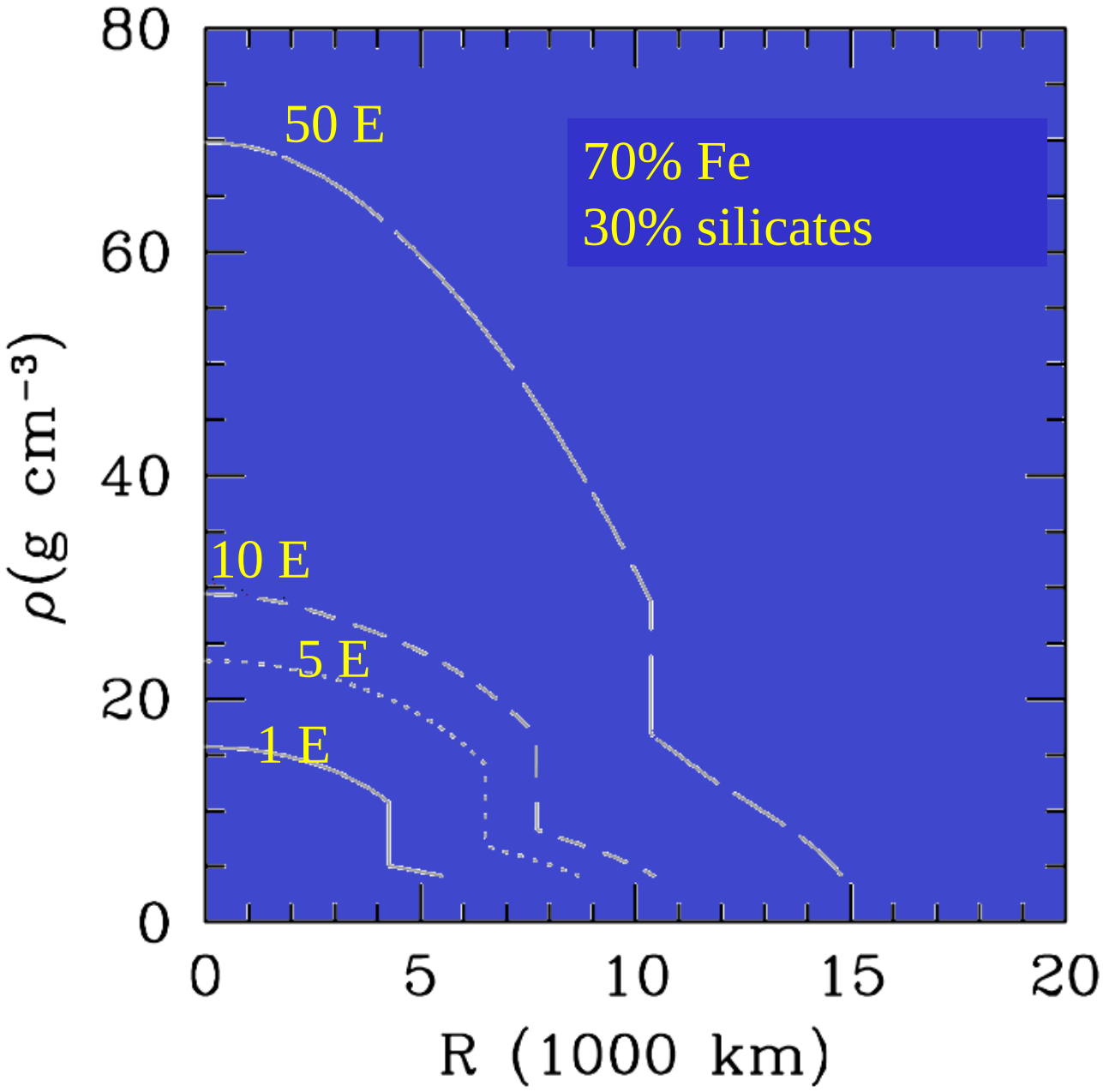
Seager
et al.
ApJ 669,
2007



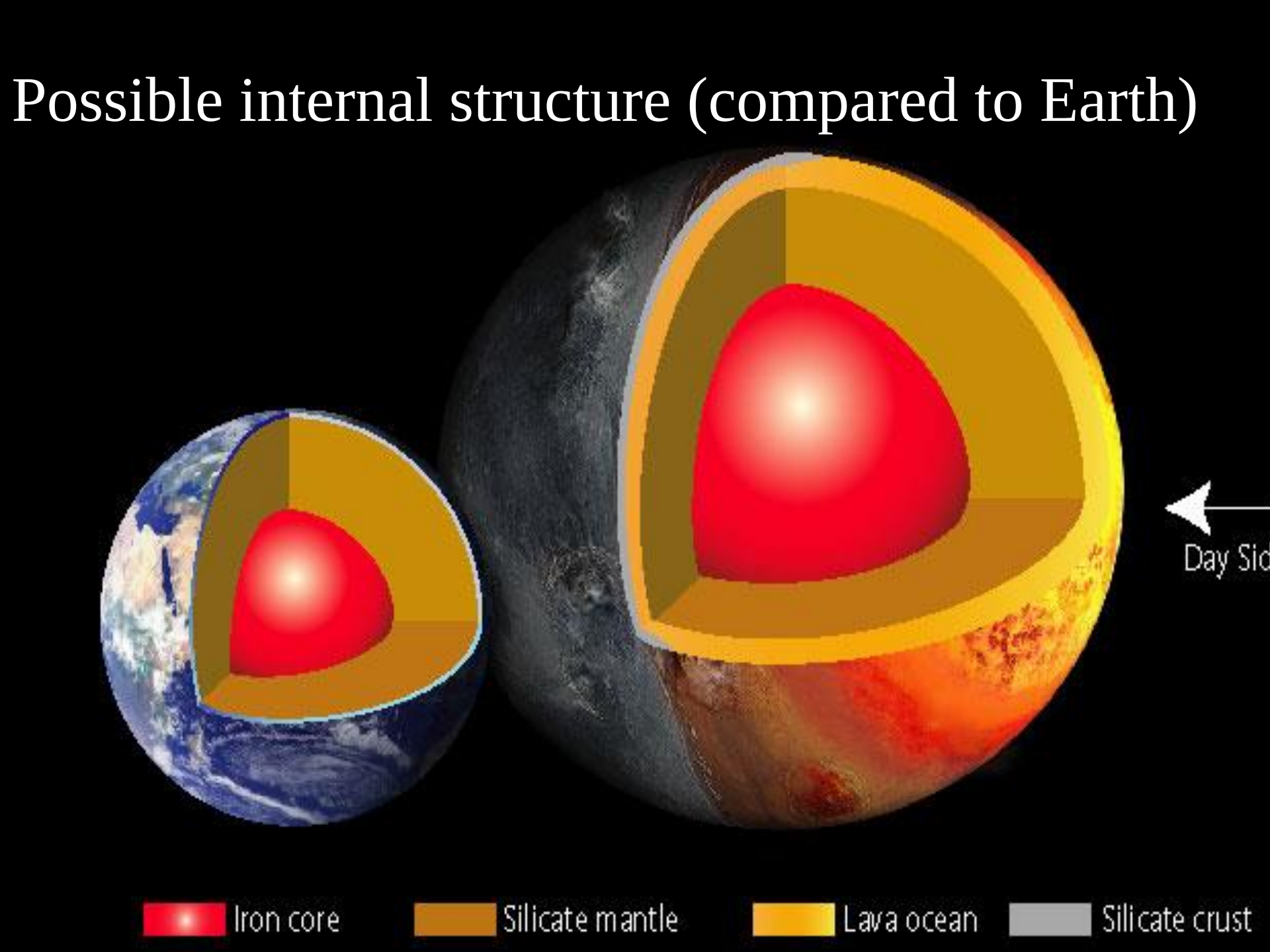
ABO_3

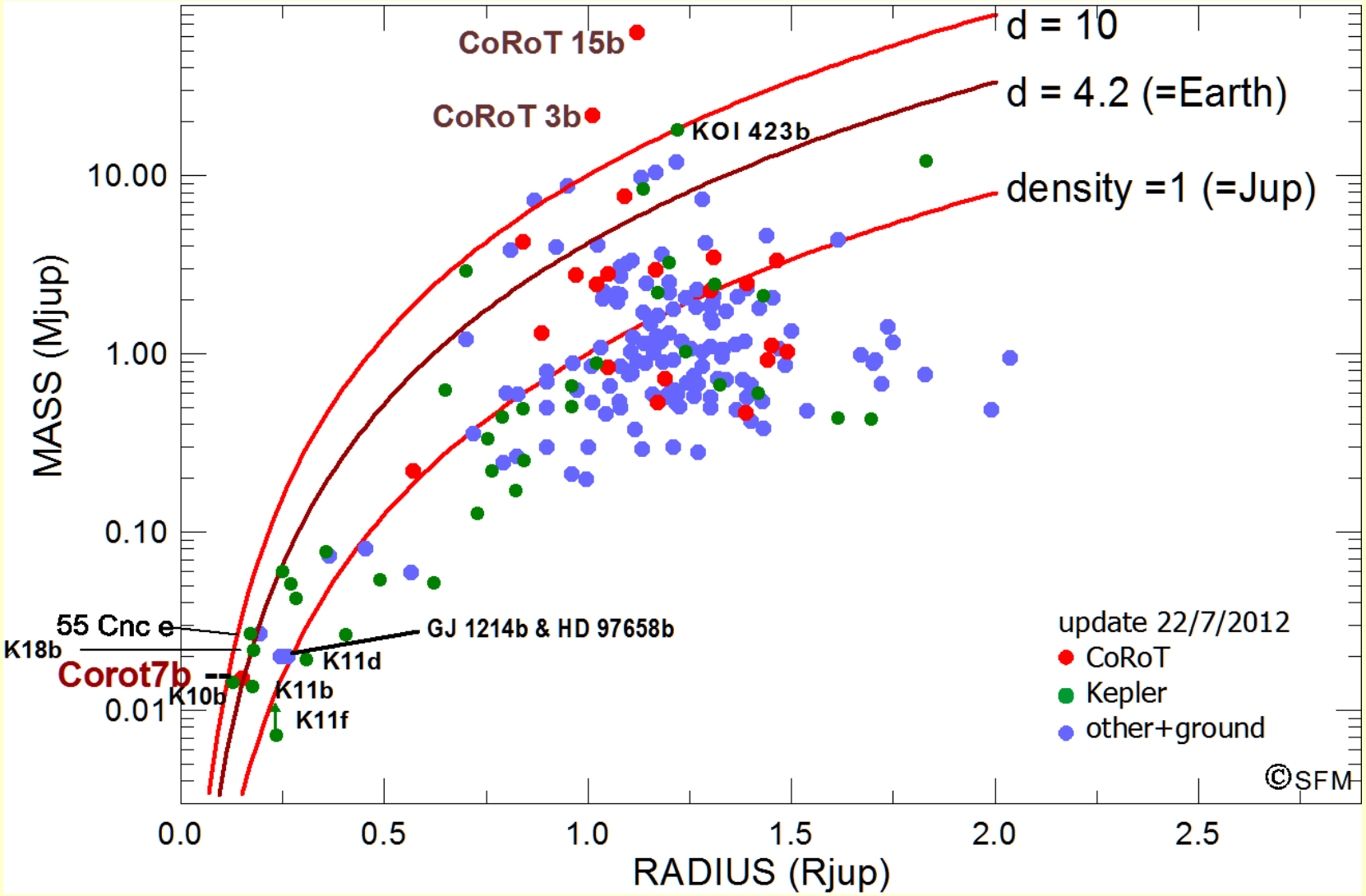

Cold H_2/He
100%H_2O
50%H_2O
25%H_2O
$MgSiO_3$(rock)
25%Fe
50%Fe
100%Fe
flux($F/F_\oplus$)
T(K)
3000
1000
300
100
30
10
2000
1400
1000
700
500
GJ 1214 b
K–26 b
K–26 c
K–20 c
HIP 116454 b
K–307 b
K–307 c
K–10 c
HD 97658 b
K–60 d
K–60 c
K–60 b
55 Cncle
K–20 b
K–21 b
HD 219134 b
CoRoT–7 b
K–10 b
K–36 b
K–93 b
K–105 c
GJ 1132 b
K–78 b
Earth
Venus
r ($R_\oplus$)
m ($M_\oplus$)
3.0
2.5
2.0
1.5
1.0
0.8
1
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20

Seager id.


80
60
40
20
0
ρ(g cm⁻³)
50 E
10 E
5 E
1 E
70% Fe
30% silicates
0
5
10
15
20
R (1000 km)

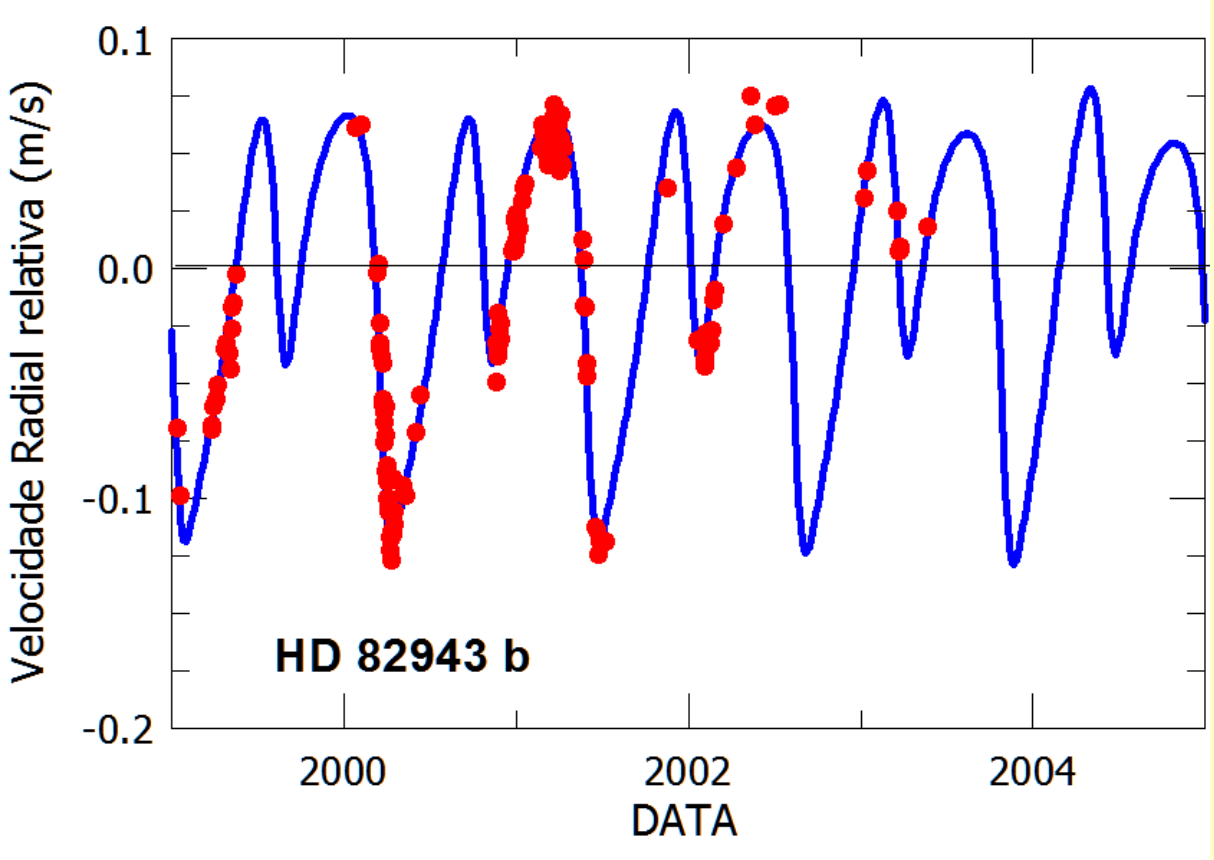
Possible internal structure (compared to Earth)



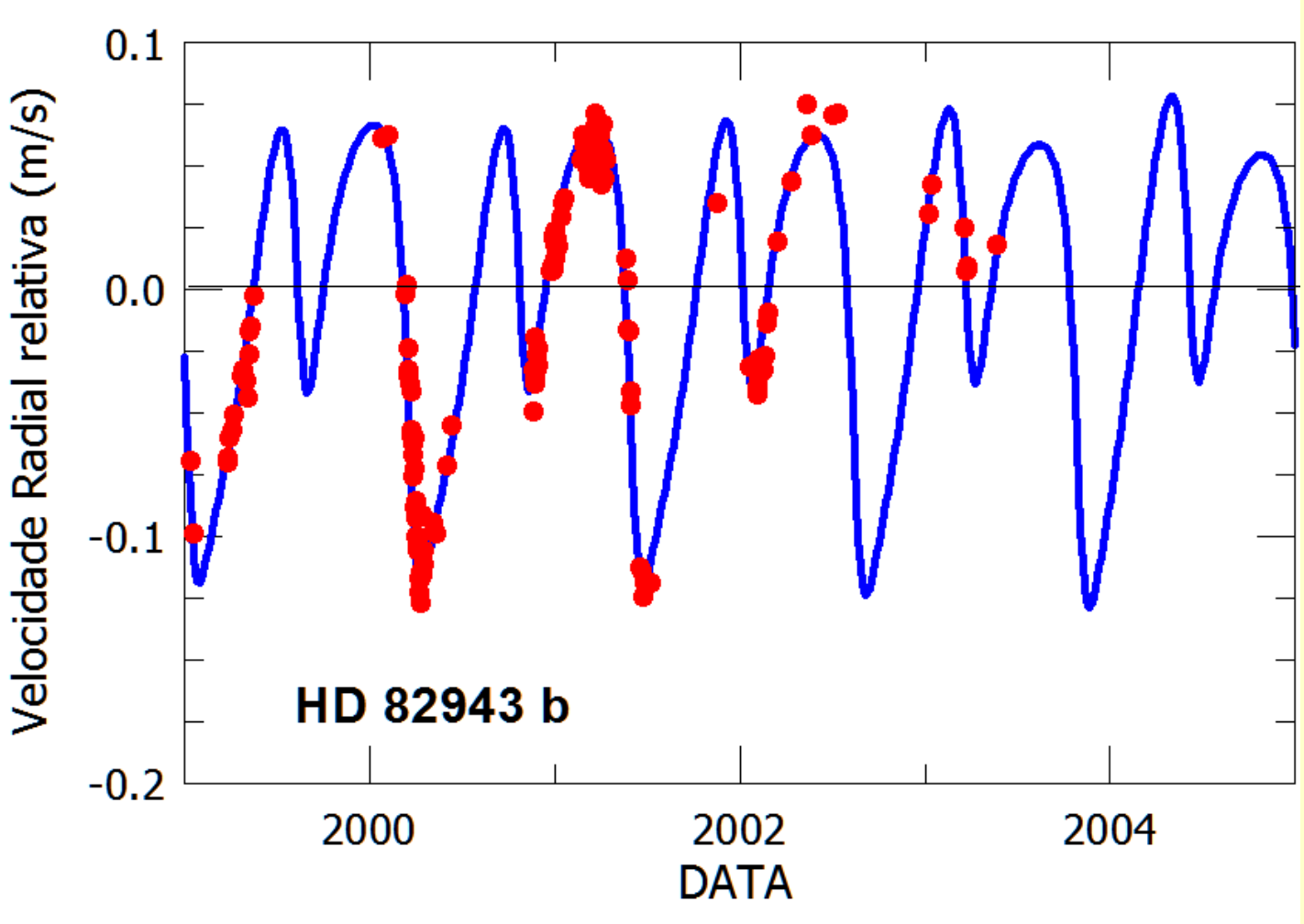


Relação Massa – Raio
Linhas de densidade (1=Jup)

SISTEMAS COM MÚLTIPLOS PLANETAS



Radial velocity of a star with two planets (variation)



Masses (x Sin I)
1.78 Jup
1.84 Jup

Periods
219.44 d
436.90 d

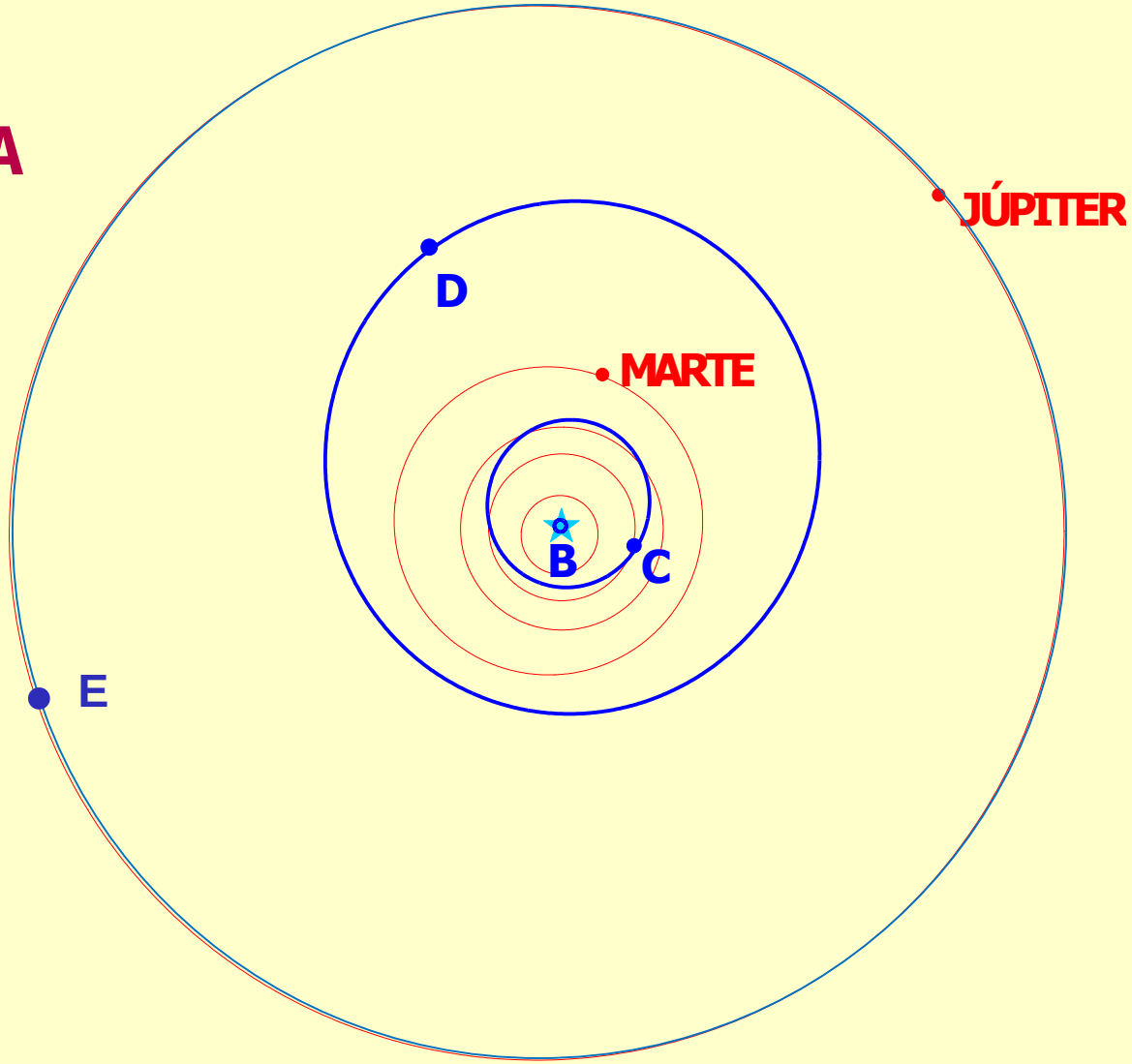
SFM et al. 2005

OS PLANETAS DE UPSILON ANDROMEDA

MASSAS
[unidade: Júpiter]

(B) 0.69 5.9
(C) 1.98 14.57
(D) 3.95 10.19
(E) 1.06 ?

Periodos: 4.6 d
241 d
3a + 194 d
10a+196 d



Inclinações: 7-15º

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

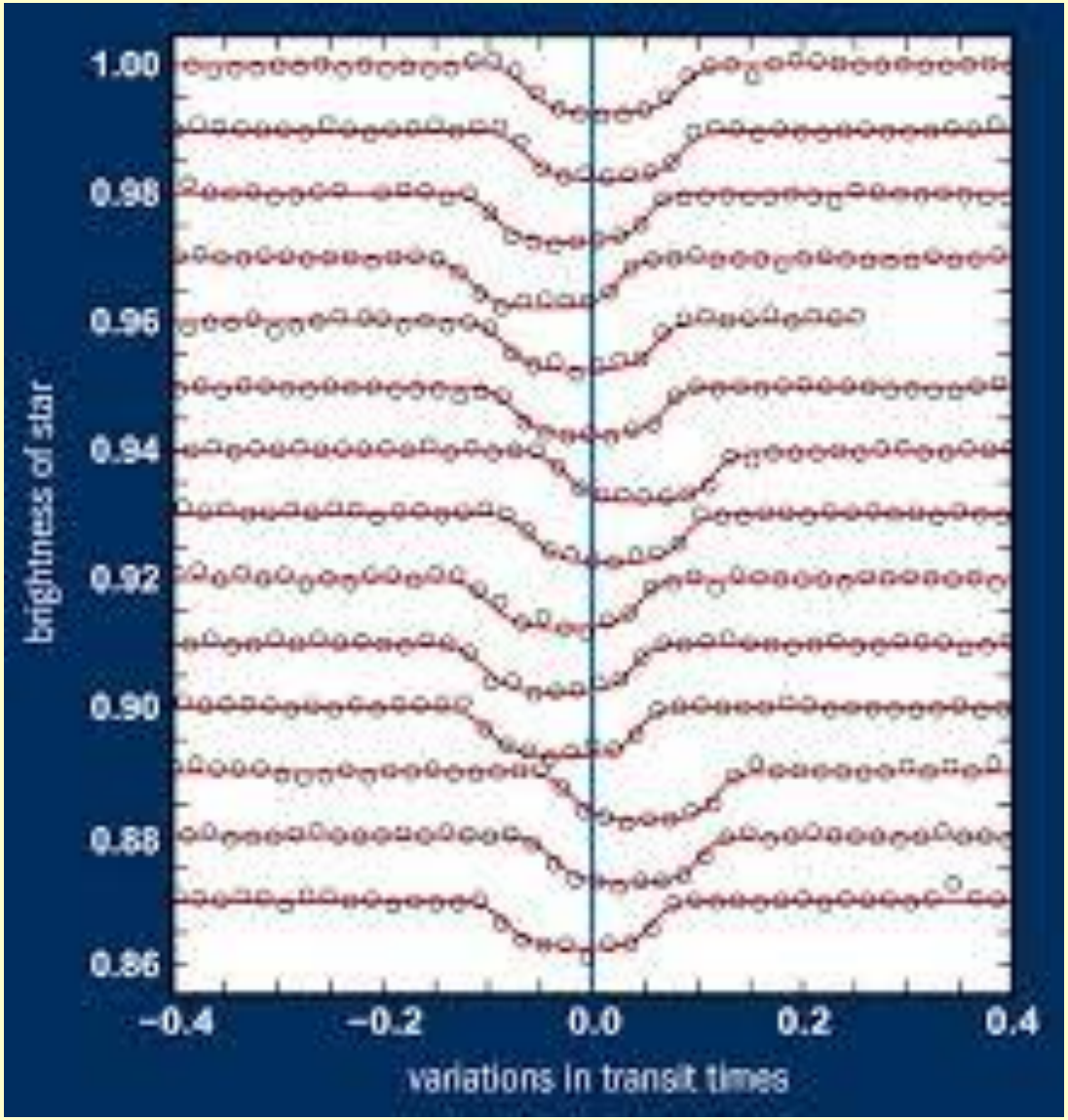
$$\mathbf{K} = \frac{m}{m+M}\,\frac{na\sin i}{\sqrt{1-e^2}}$$

Exemplos: Sol-Júpiter ~ 13 m/s

Sol-Terra ~ 9 cm/s

Não é possível separar os valores de **M, m** e **sin i.**

TTV = Transit time variations



Super-terras
A zona habitável