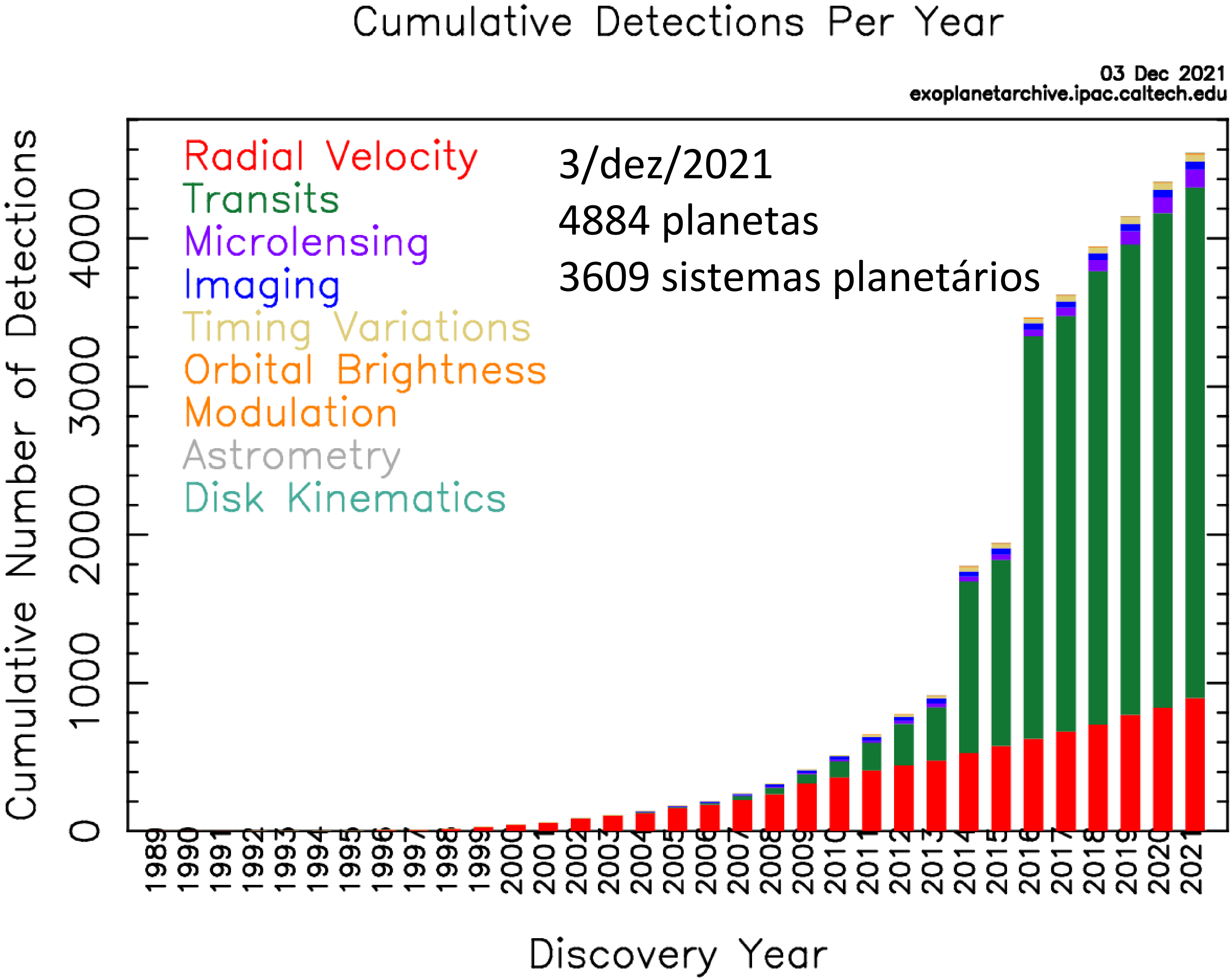
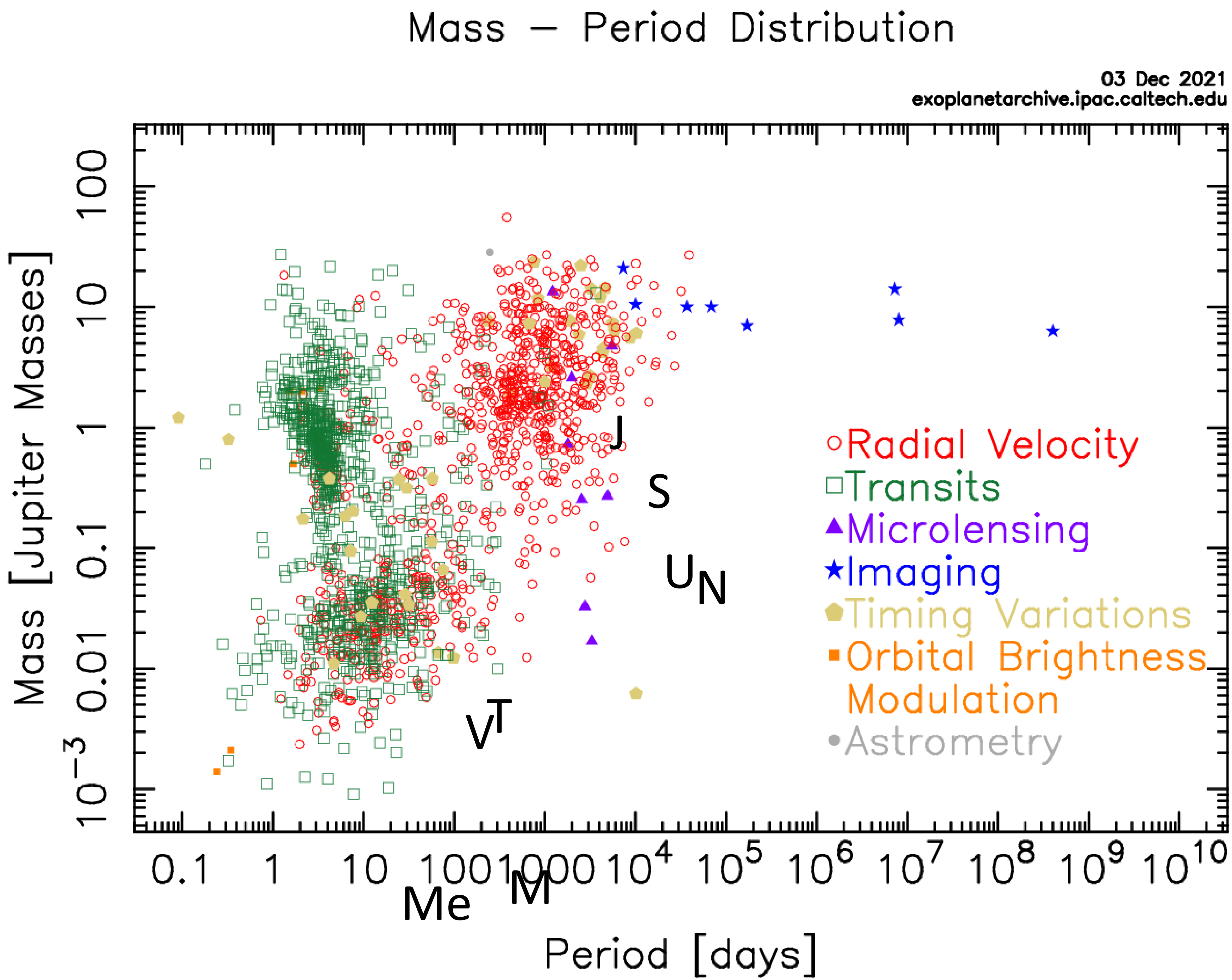
14. Diversidade de Sistemas Planetários

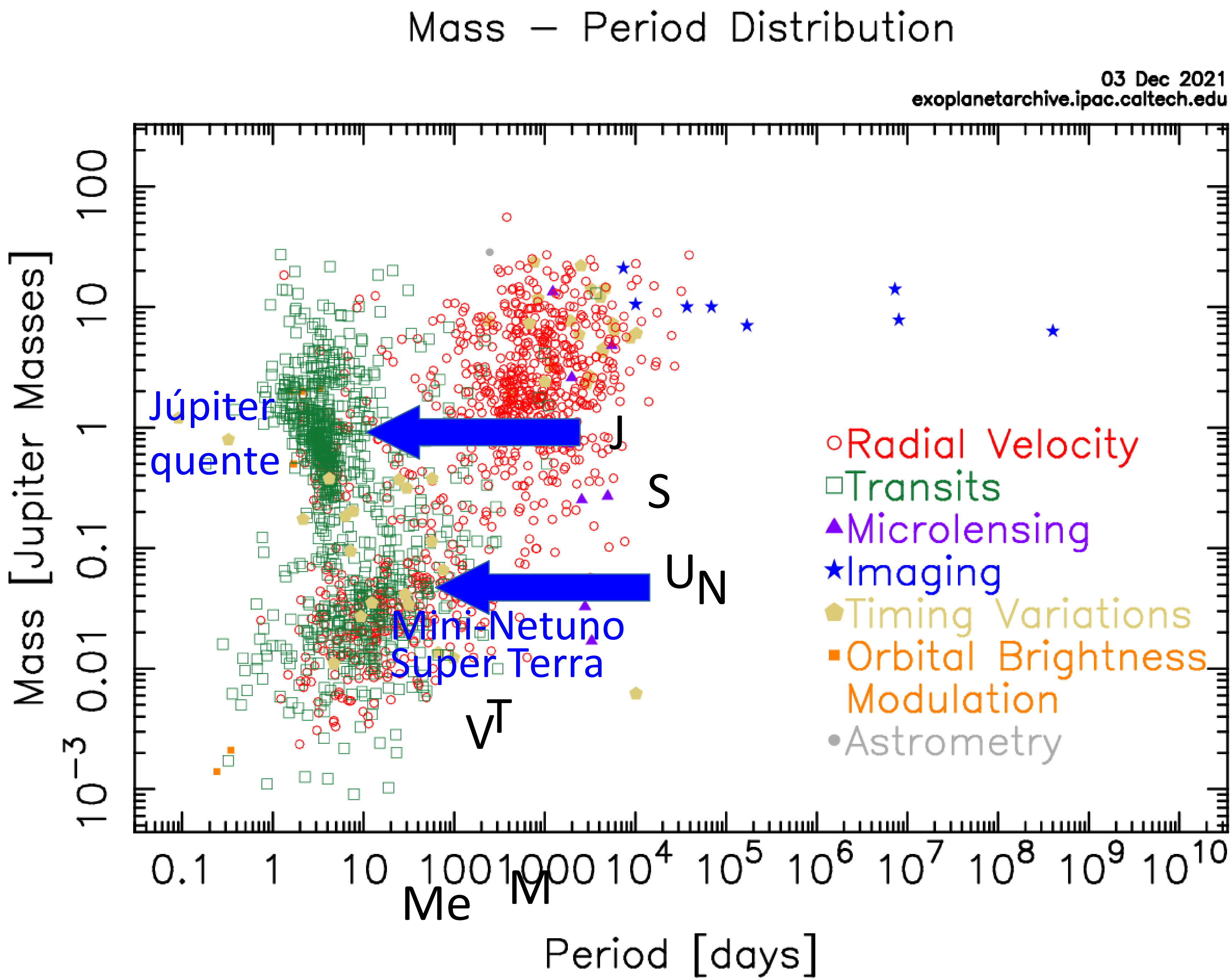
https://exoplanets.nasa.gov/news/1581/discovery-alert-a-record-haul-planet-count-hits-4000/

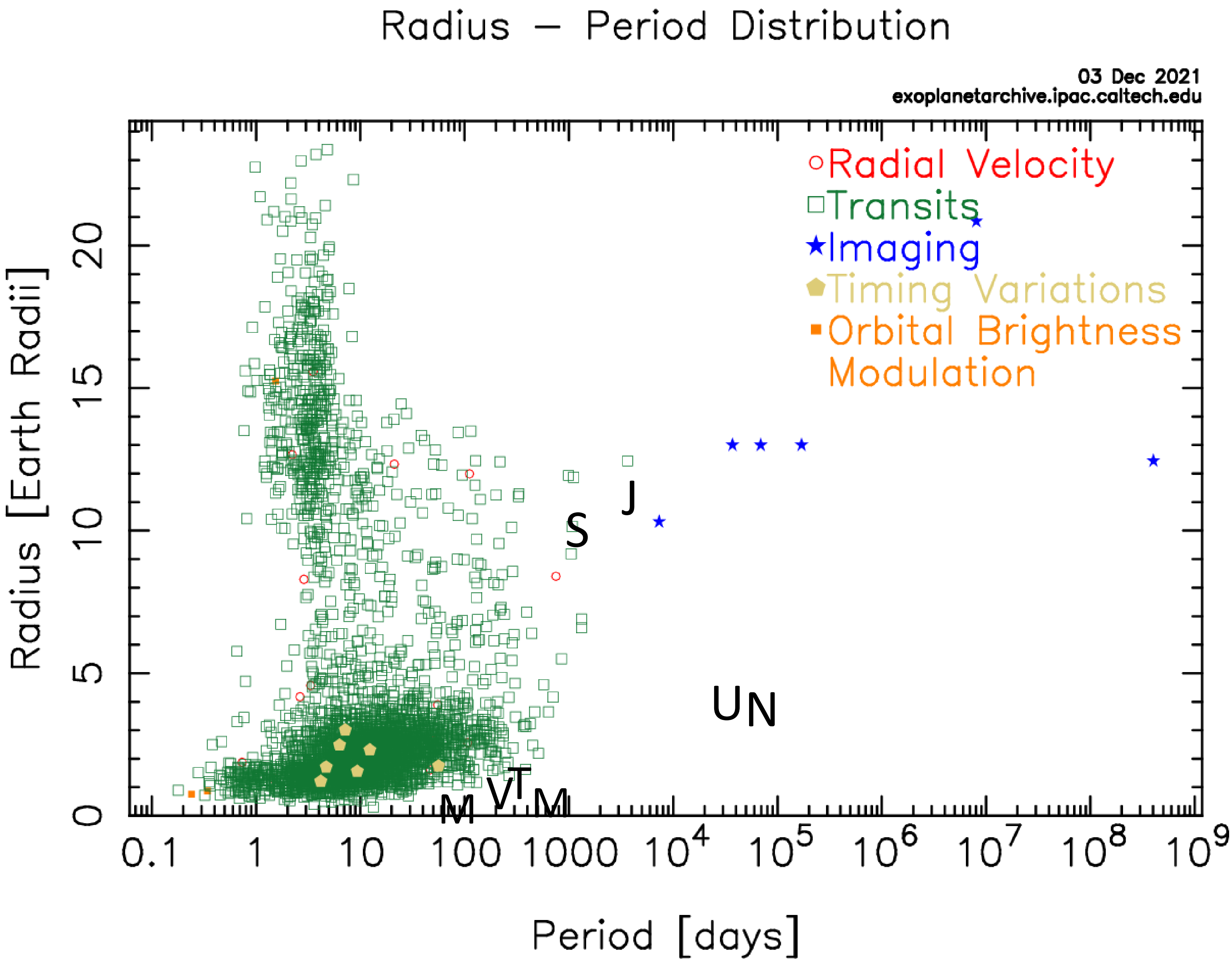
Prof. Jorge Meléndez

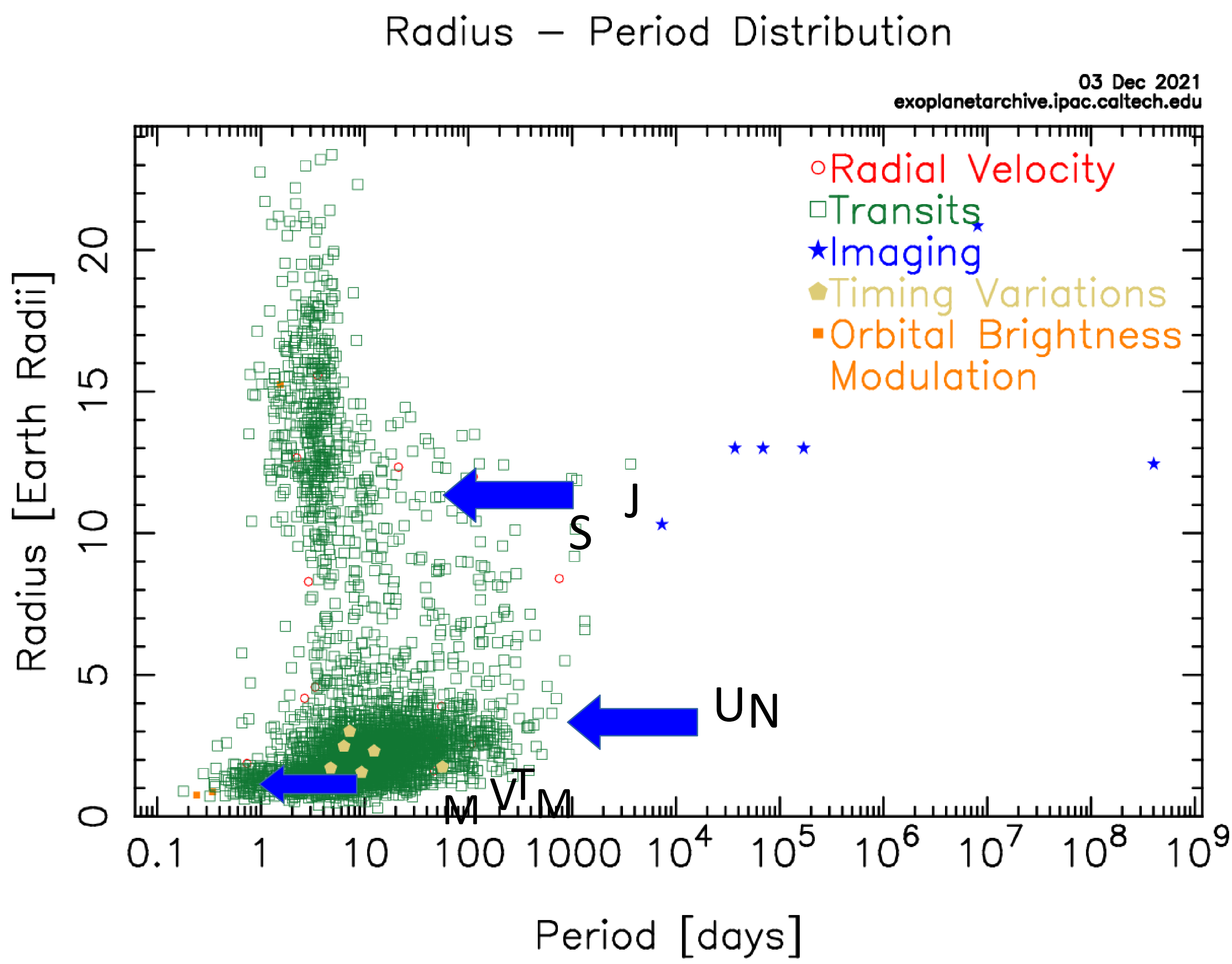
AGA0502, Planetas e Sistemas Planetários, IAG-USP


Cumulative Detections Per Year
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
Astrometry
Disk Kinematics
3/dez/2021
4884 planetas
3609 sistemas planetários
Cumulative Number of Detections
0
1000
2000
3000
4000
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Discovery Year


Mass – Period Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Mass [Jupiter Masses]
100
10
1
0.1
0.01
10^-3
Period [days]
0.1
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
10^9
10^10
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness Modulation
Astrometry
J
S
U
N
V
T
Me
M


Mass – Period Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Mass [Jupiter Masses]
100
10
1
0.1
0.01
10^{-3}
Period [days]
0.1
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
Júpiter quente
Mini-Netuno
Super Terra
J
S
U
N
V
T
Me
M
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness Modulation
Astrometry


Radius – Period Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Imaging
Timing Variations
Orbital Brightness Modulation
Radius [Earth Radii]
0
5
10
15
20
Period [days]
0.1
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
10^9
M
V
T
M
S
J
U
N



Radius — Period Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Imaging
Timing Variations
Orbital Brightness Modulation
Radius [Earth Radii]
Period [days]
0
5
10
15
20
0.1
1
10
100
1000
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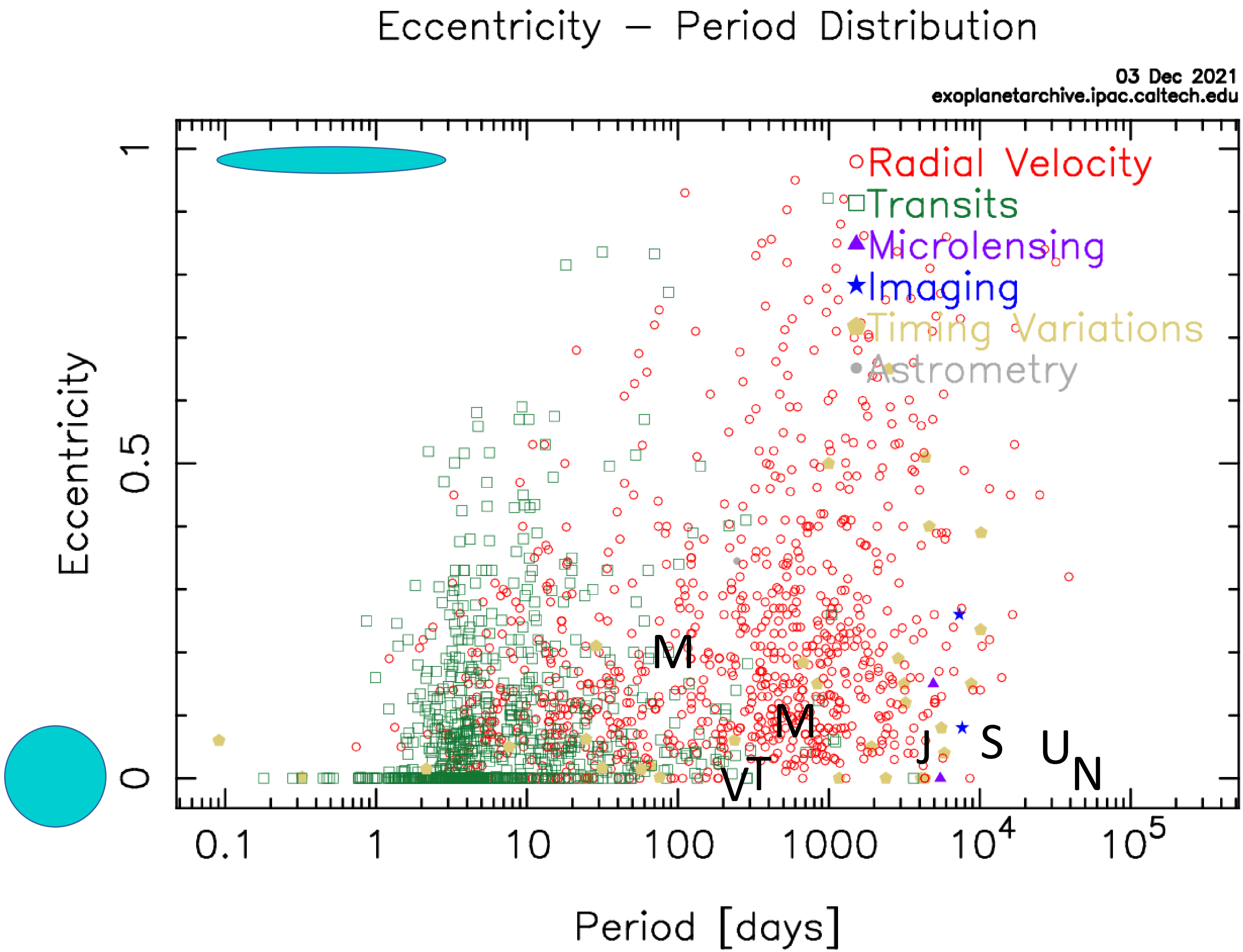
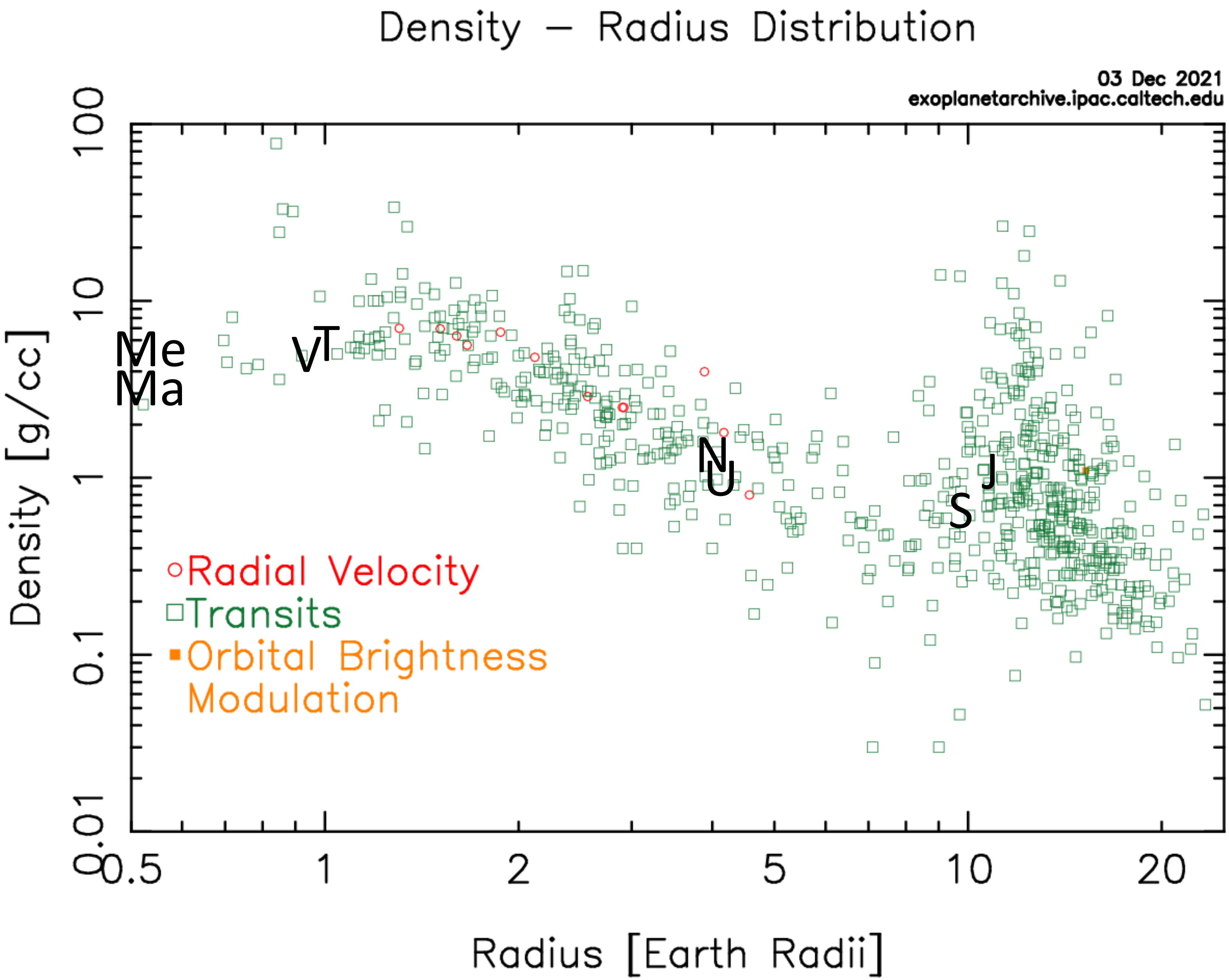
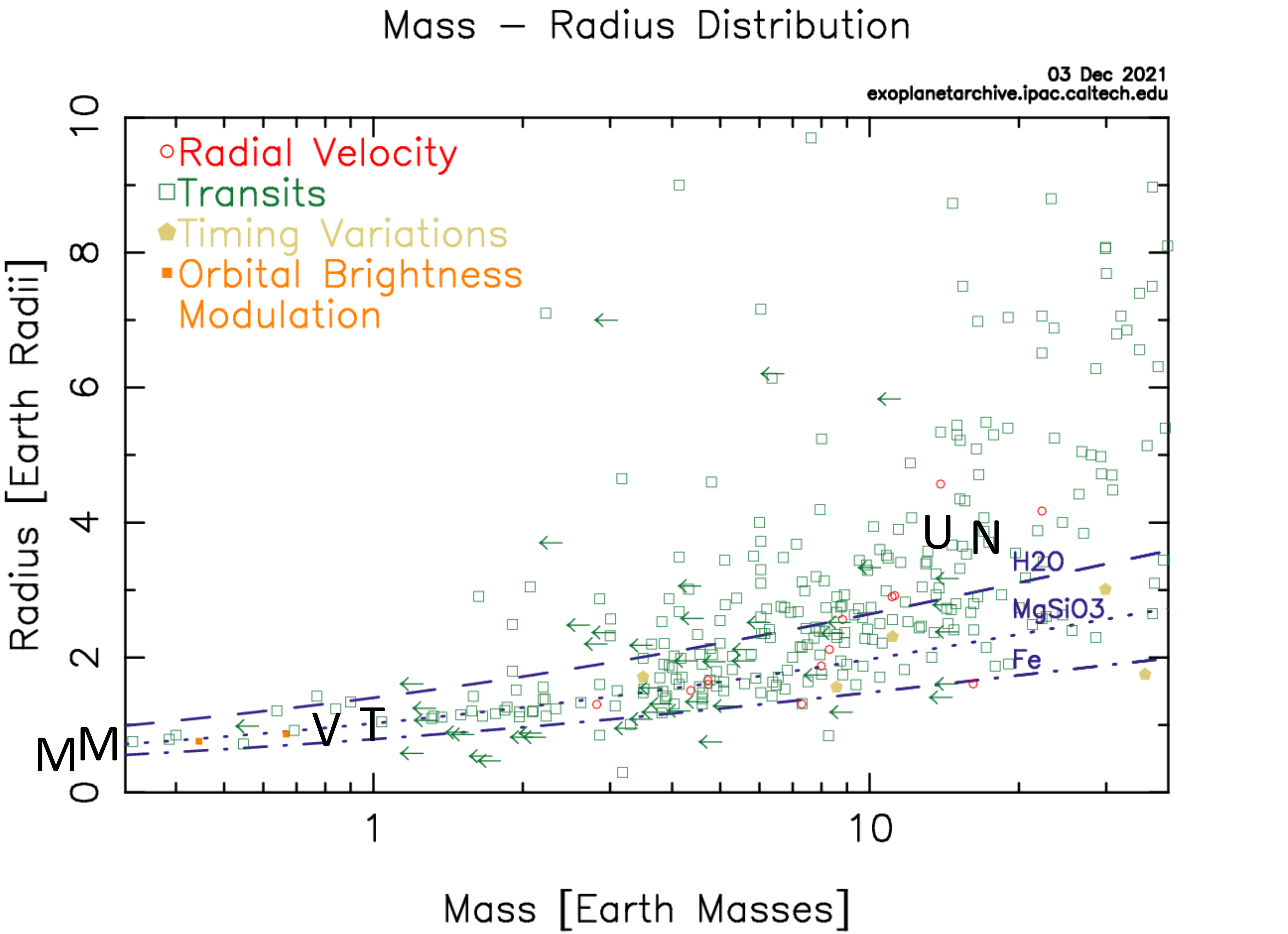
10^5
10^6
10^7
10^8
10^9
J
S
U
N
M
V
T
M



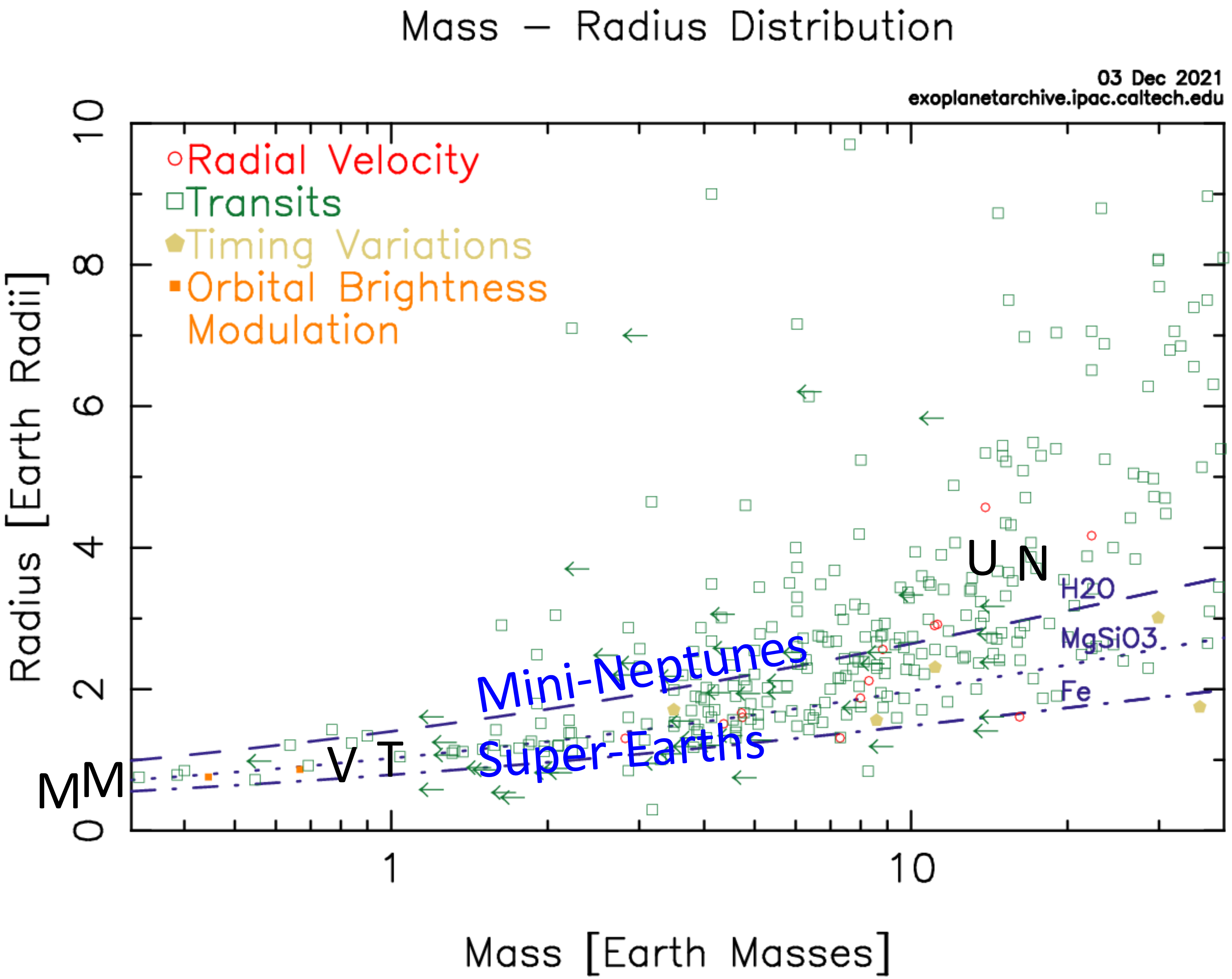
Eccentricity – Period Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Astrometry
Eccentricity
0
0.5
1
Period [days]
0.1
1
10
100
1000
10^4
10^5
M
V
T
M
J
S
U
N



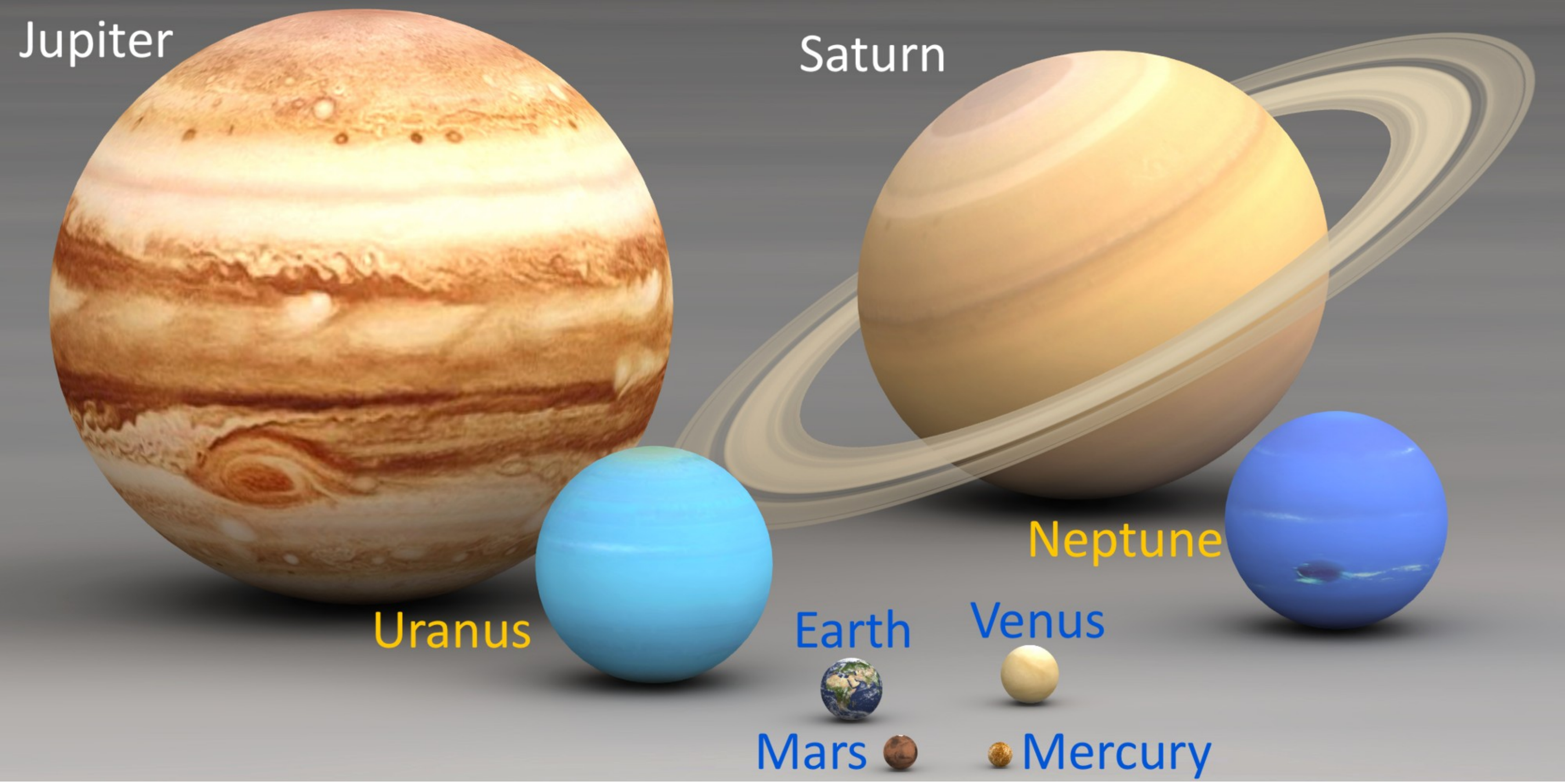
Density – Radius Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Density [g/cc]
100
10
1
0.1
0.01
0.5
1
2
5
10
20
Radius [Earth Radii]
Me
Ma
V
T
N
U
S
J
Radial Velocity
Transits
Orbital Brightness Modulation



Mass – Radius Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Timing Variations
Orbital Brightness Modulation
Radius [Earth Radii]
Mass [Earth Masses]
0
2
4
6
8
10
1
10
H2O
MgSiO3
Fe
M
M
V
T
U
N



Mass – Radius Distribution
03 Dec 2021
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Timing Variations
Orbital Brightness Modulation
Radius [Earth Radii]
0
2
4
6
8
10
Mass [Earth Masses]
1
10
H2O
MgSiO3
Fe
Mini-Neptunes
Super-Earths
M
M
V
T
U
N

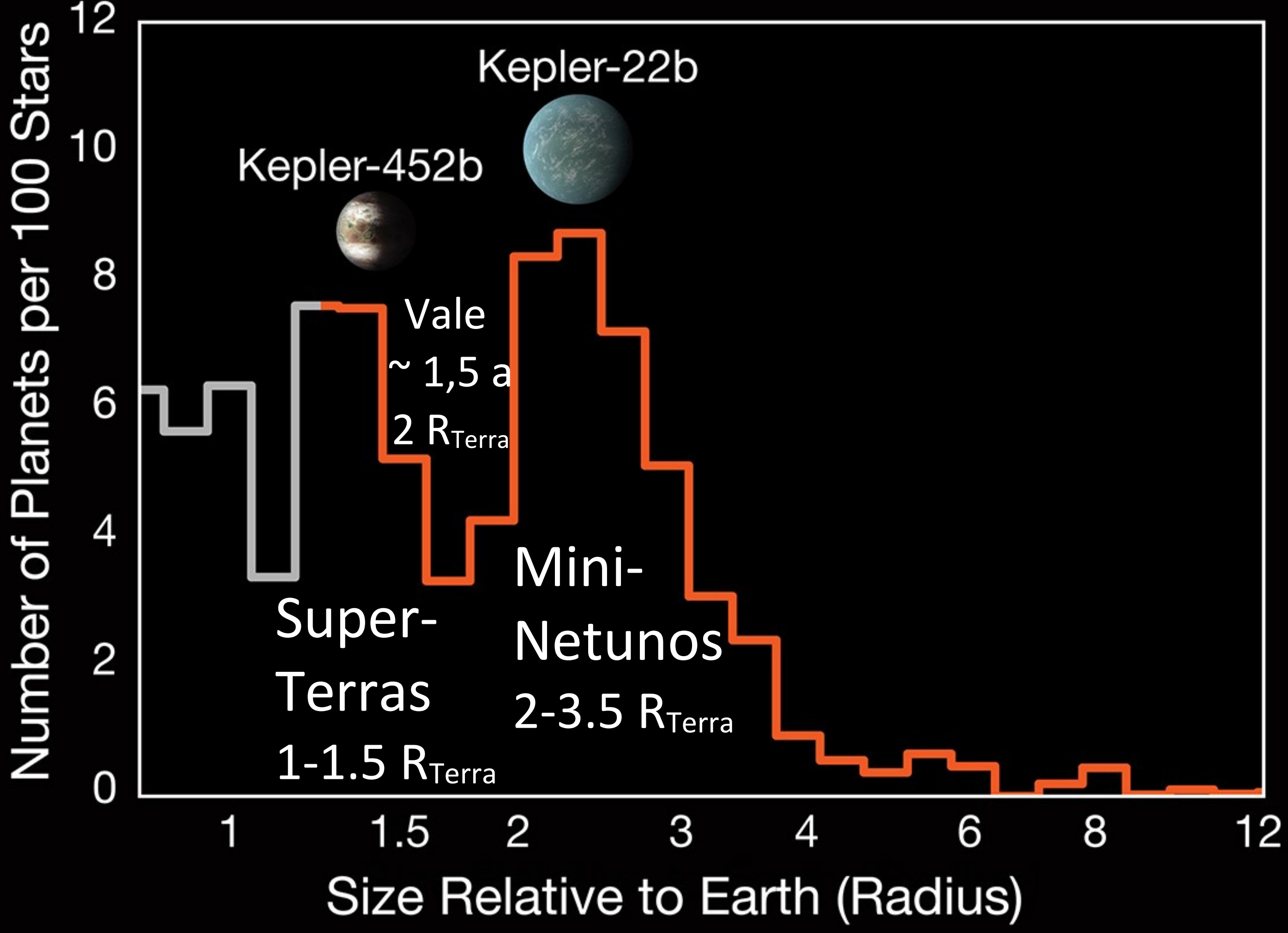


Solar system:
- Jupiters
- Neptunes
- Earths

Other systems may host:
- Hot-Jupiters
- Mini-Neptunes
- Super-Earths

http://www.lesud.com/lesud-astronomy_pageid81.html

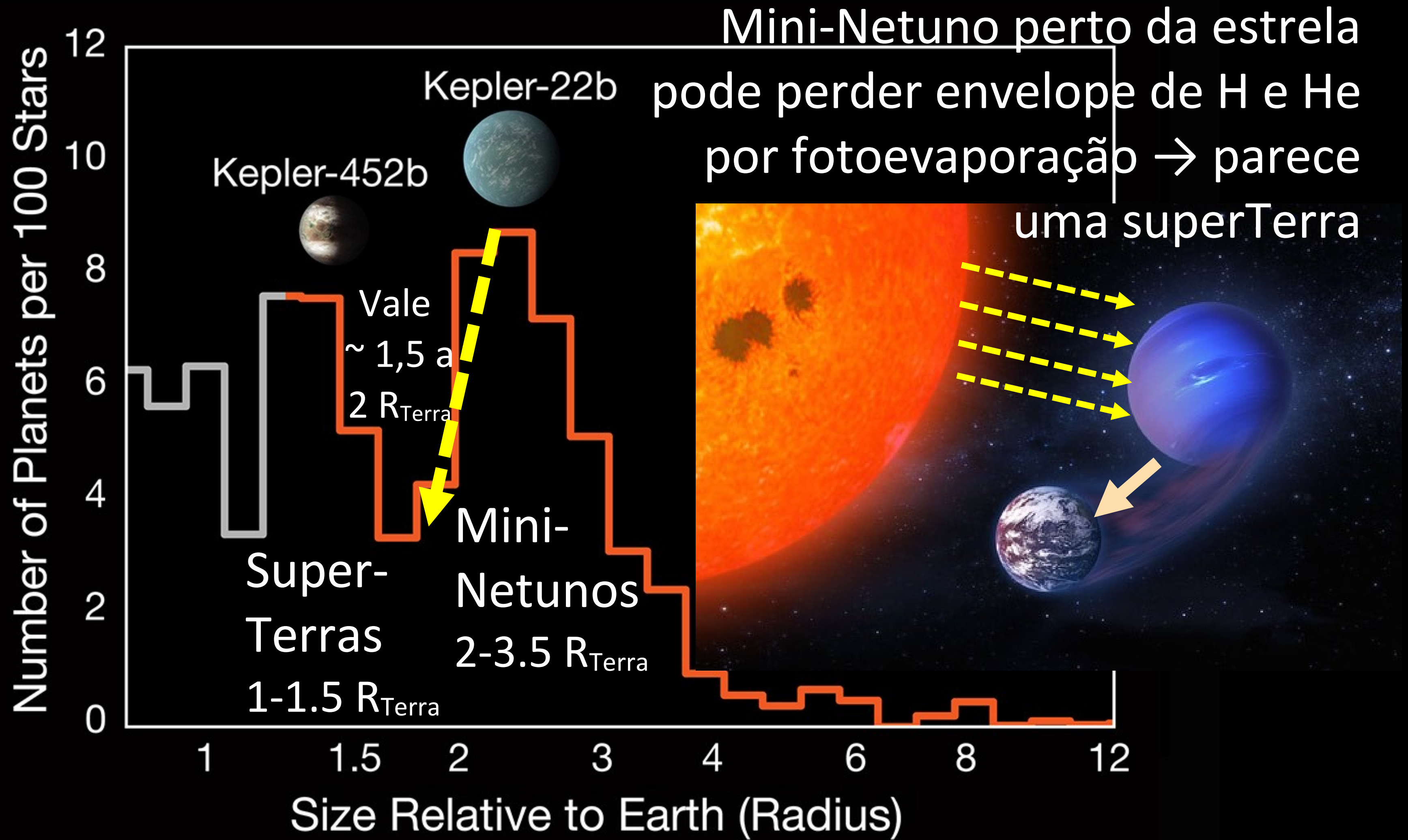
Small Planets Come in Two Sizes



Benjamin Fulton et al. 2017

https://www.nasa.gov/image-feature/ames/small-planets-come-in-two-sizes

Small Planets Come in Two Sizes



Benjamin Fulton et al. 2017

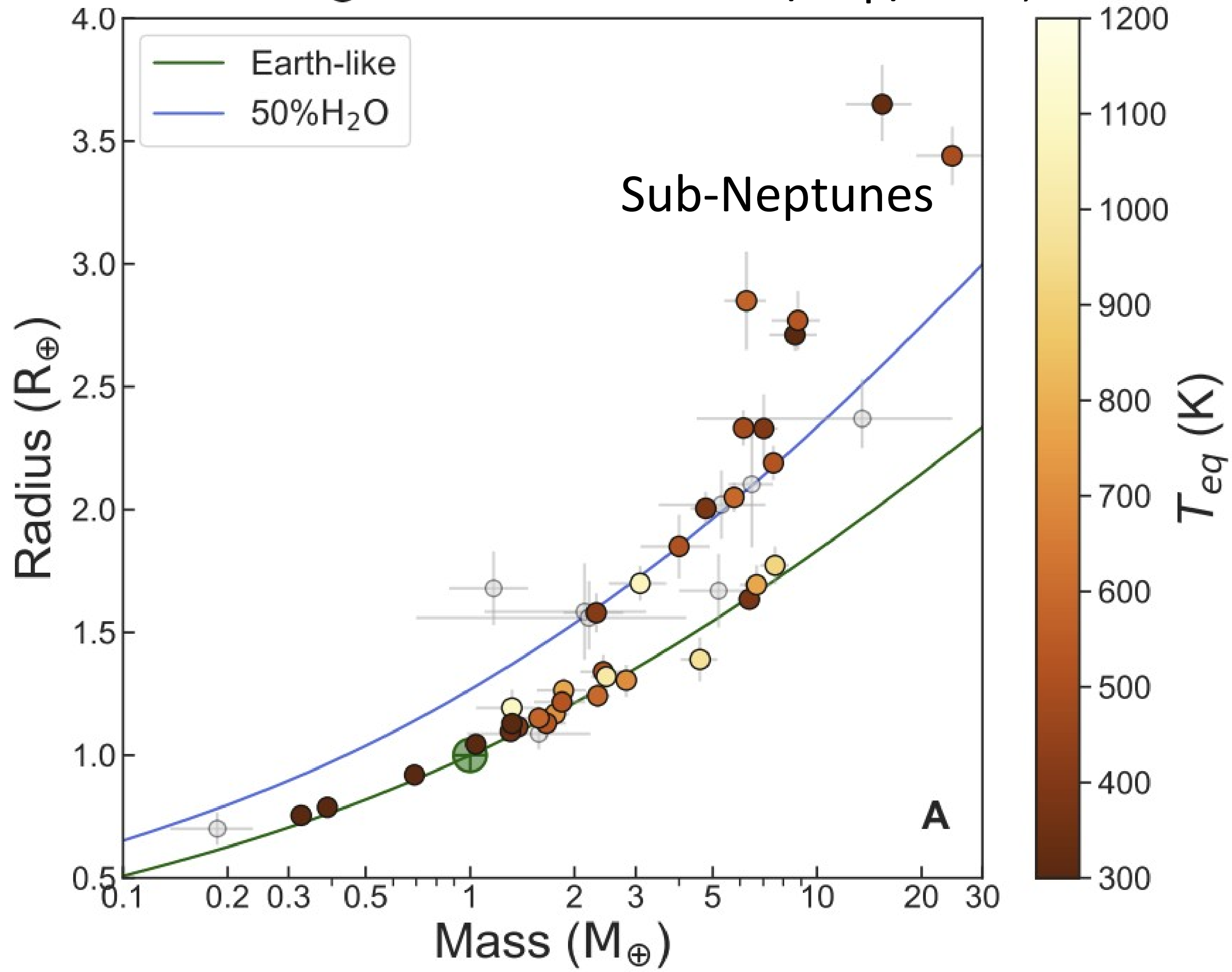
https://www.nasa.gov/image-feature/ames/small-planets-come-in-two-sizes

Mundos aquáticos em estrelas M podem ser comuns

Density, not radius, separates rocky and water-rich small planets orbiting M dwarf stars

Science

8/Sep/2022, Science 377, 1211

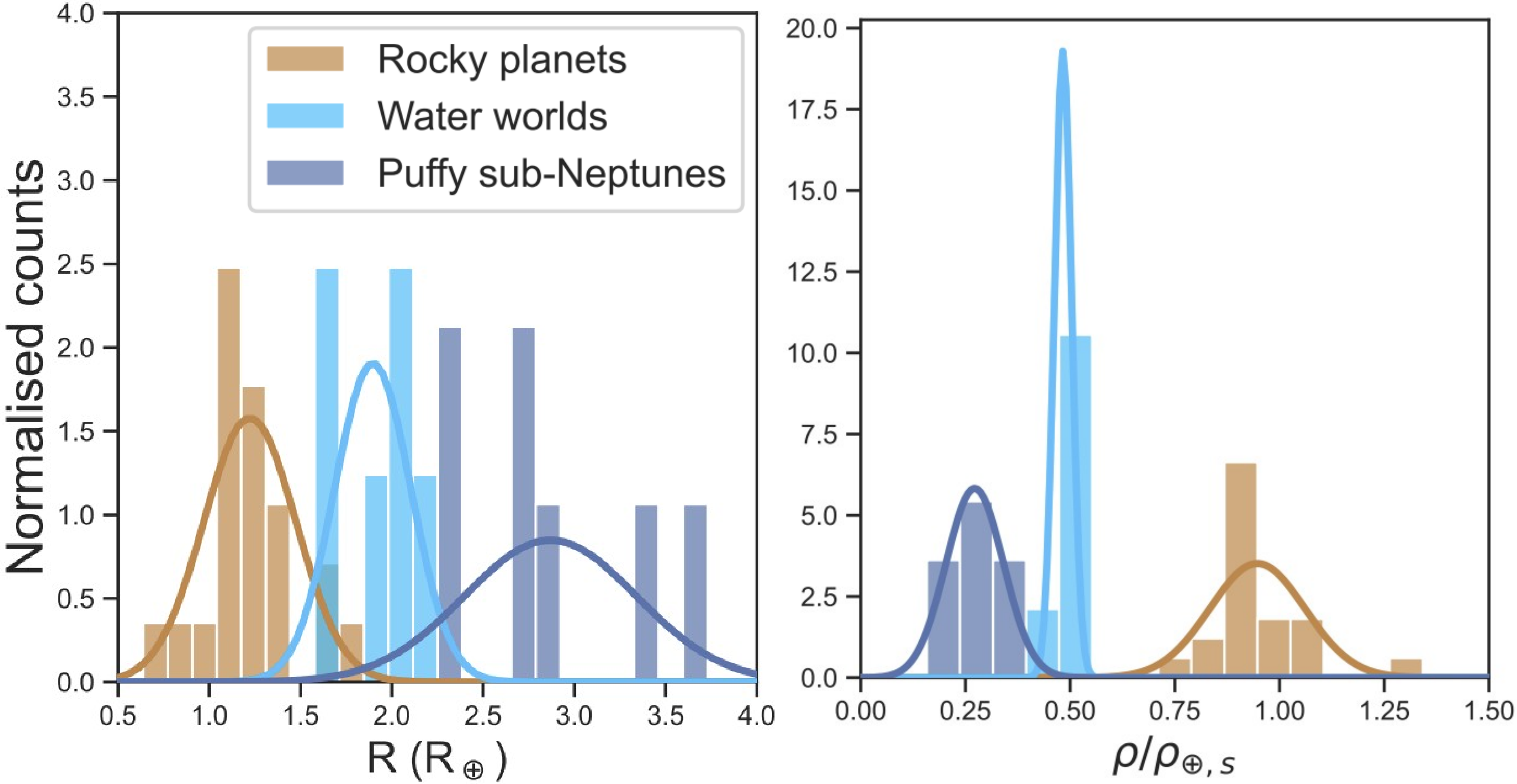


Mundos aquáticos em estrelas M podem ser comuns

Density, not radius, separates rocky and water-rich small planets orbiting M dwarf stars

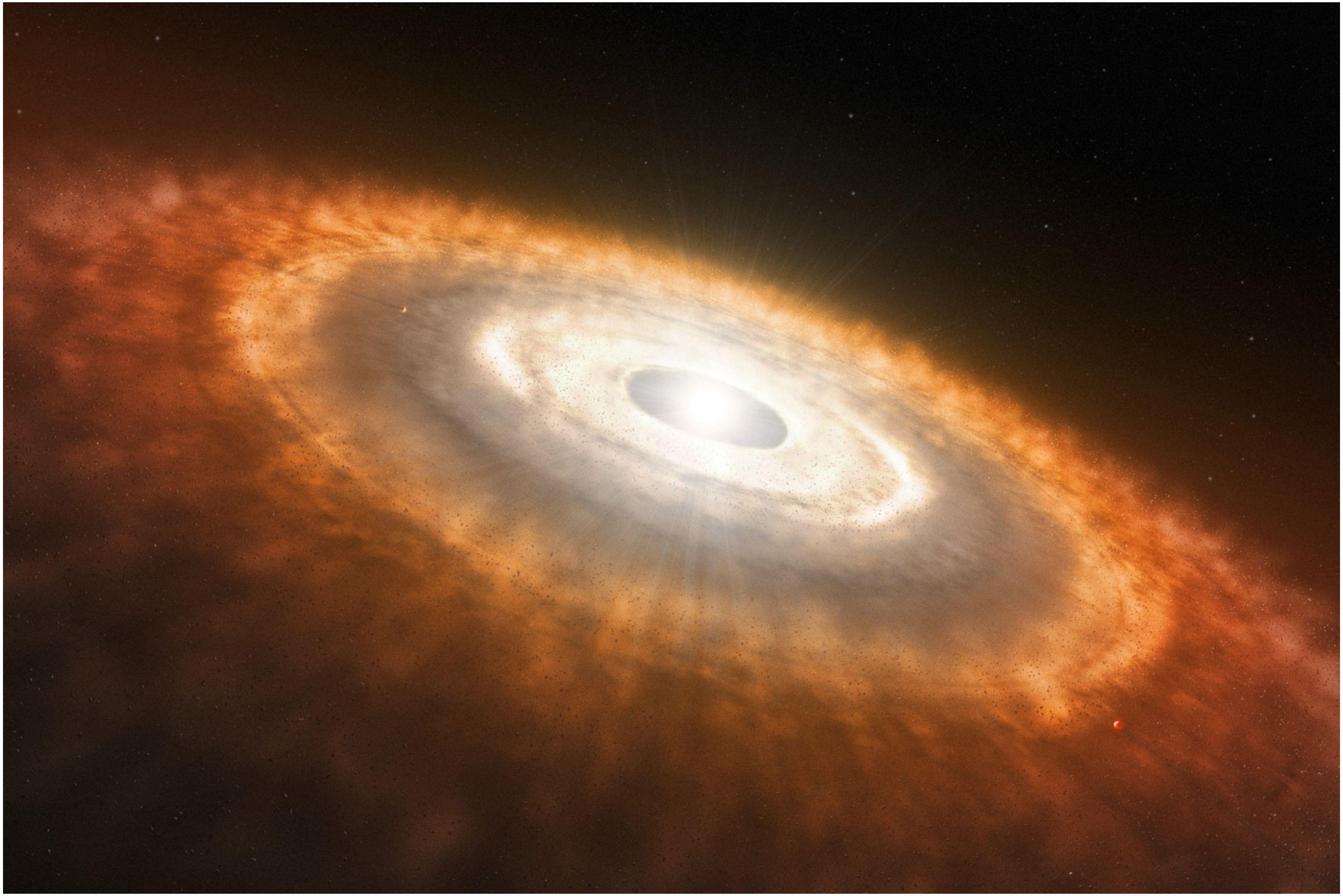
Science

8/Sep/2022, Science 377, 1211



A relação planeta – composição química da estrela

Estrela e planetas se formam a partir da mesma nuvem



Notação

- A abundância química A_X do elemento X é:
  $A_X = \log(N_X/N_H) + 12$ → hidrogênio: $A_H = 12$

- $[X/H] = A_X^{estrela} - A_X^{Sol}$

  - [Fe/H] = 0.0: abundância de ferro igual ao Sol
  - [Fe/H] = +0.3: ferro 2 vezes (= $10^{+0.3}$) maior ao Sol
  - [Fe/H] = -1.0: 1/10 (= 10^{-1}) de Fe em relação ao Sol

Conexão metalicidade – planeta gigante

Mon. Not. R. Astron. Soc. **285**, 403–412 (1997)

The stellar metallicity–giant planet connection

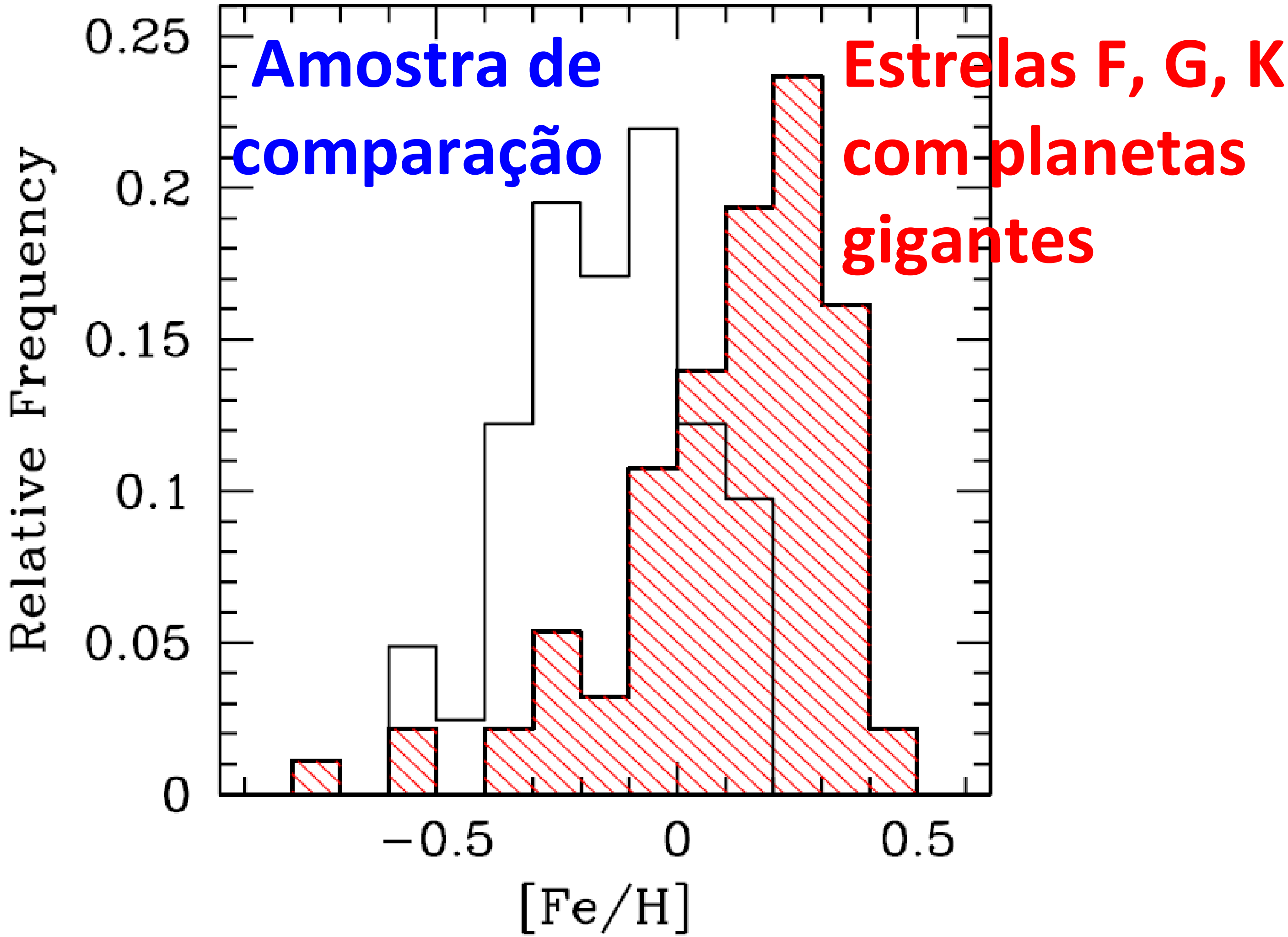
Guillermo Gonzalez★

Department of Astronomy, University of Texas, Austin, TX 78712, USA

Accepted 1996 September 24. Received 1996 September 23; in original form 1996 August 1

Conexão metalicidade – planeta gigante

N. C. Santos[1,2], G. Israelian[3], and M. Mayor[2]
A&A 415, 1153–1166 (2004)

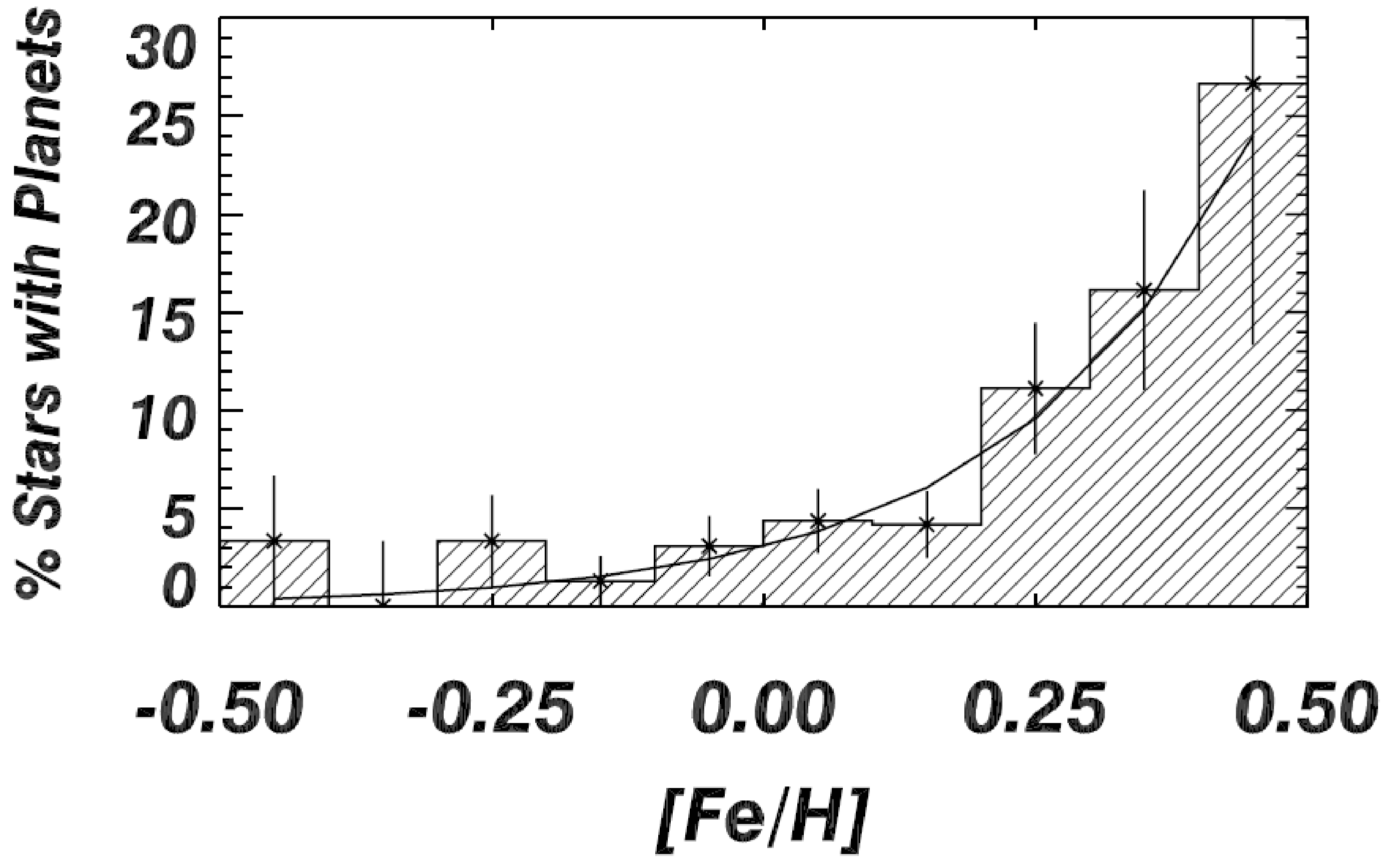


Conexão metalicidade – planeta gigante

THE ASTROPHYSICAL JOURNAL, 622:1102–1117, 2005 April 1

THE PLANET-METALLICITY CORRELATION

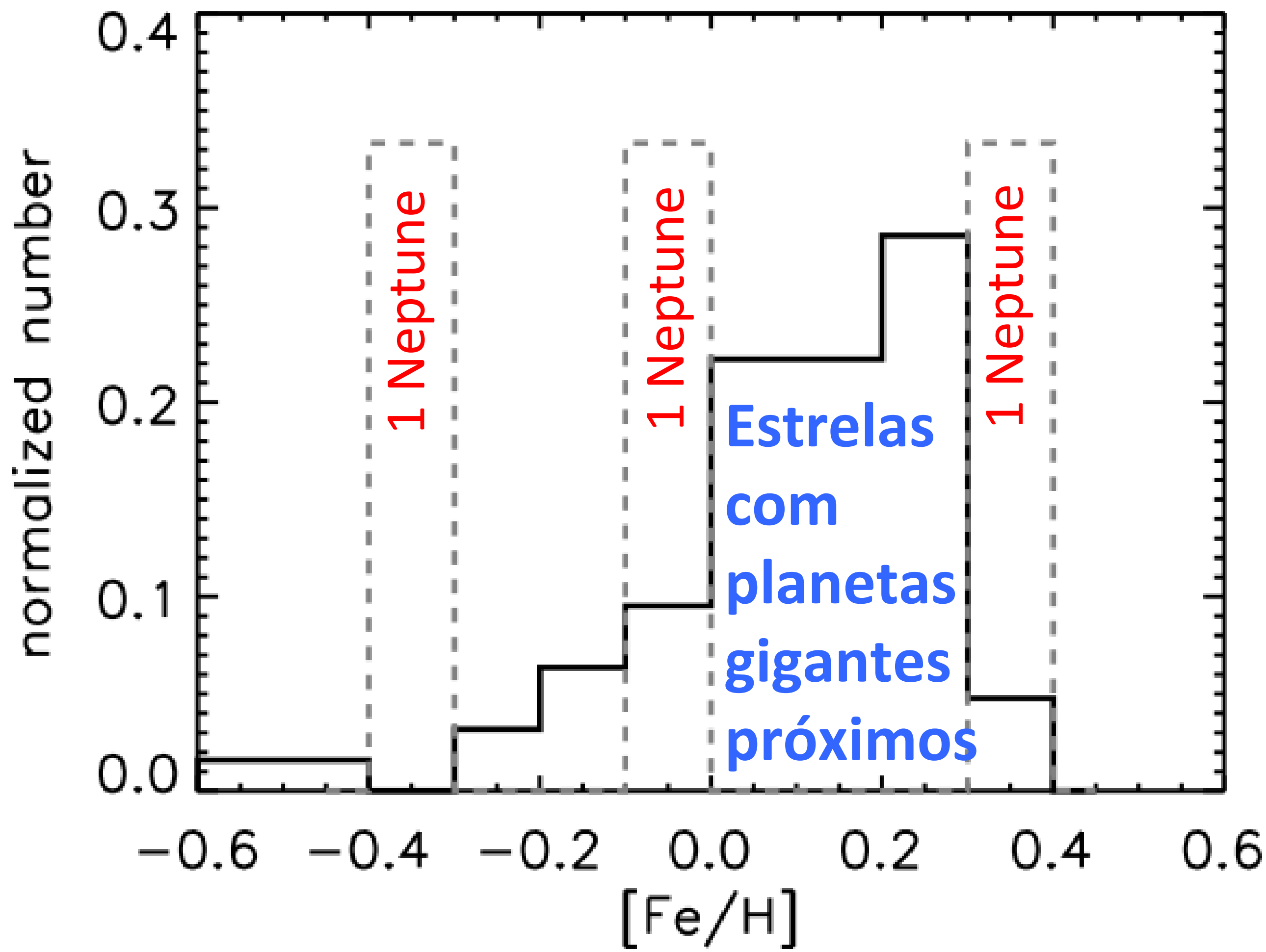
DEBRA A. FISCHER[2] AND JEFF VALENTI[3]



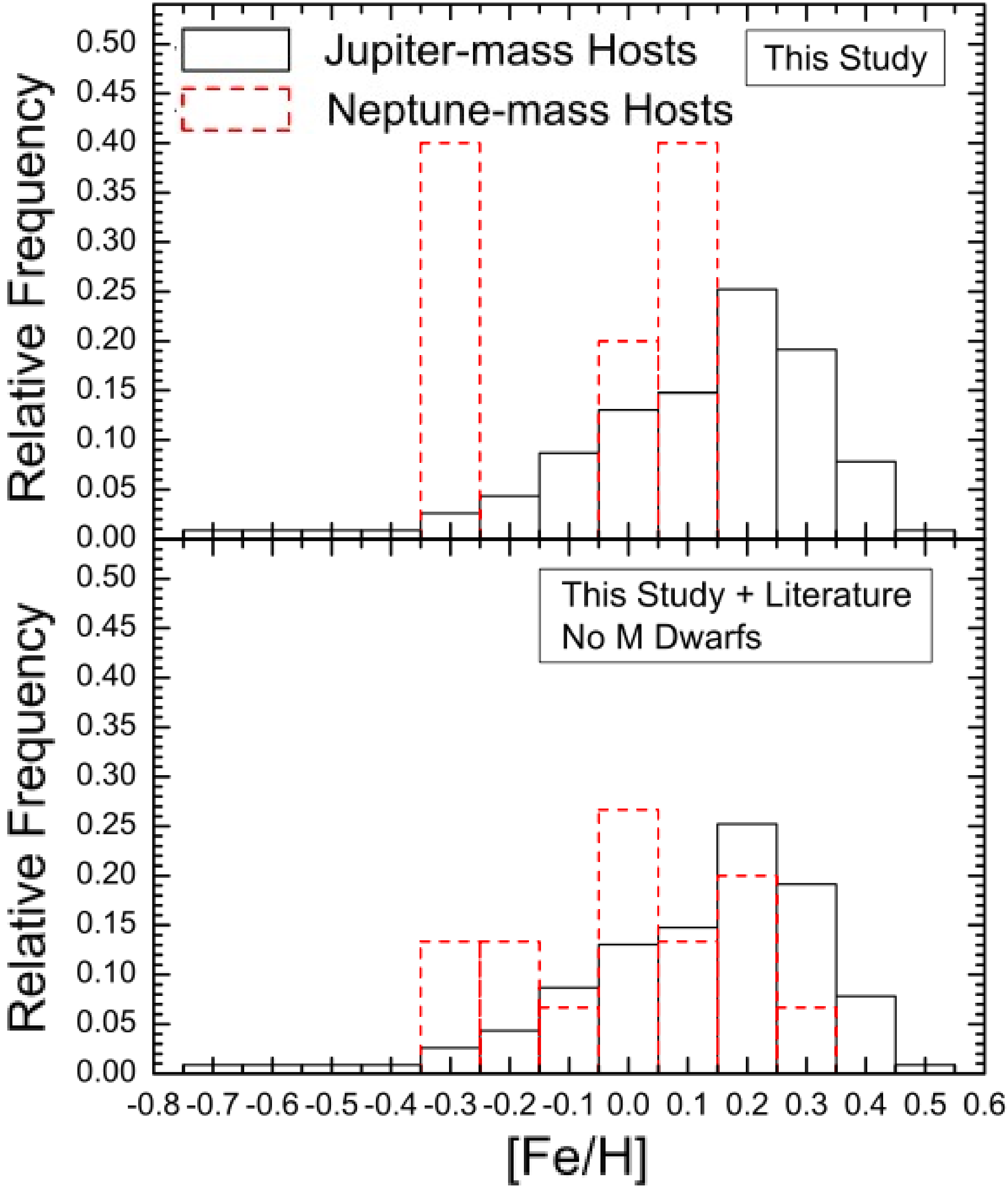
1040 estrelas de tipo FGK

Conexão metalicidade – planeta: **Netunos podem ser formados em qualquer metalicidade**

Sousa et al. 2008, A&A 487, 373

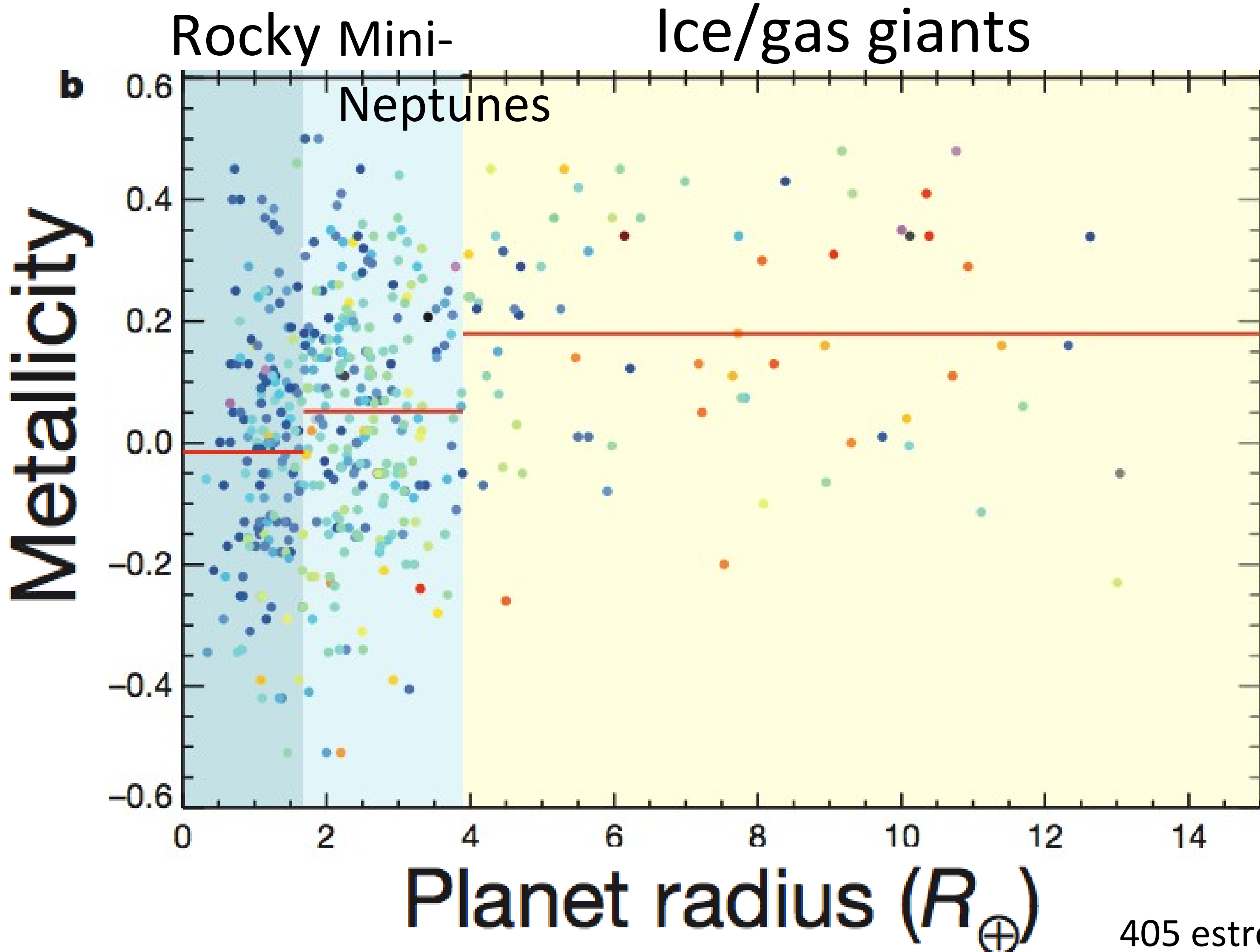


Conexão metalicidade – planeta **Netunos podem ser formados em qualquer metalicidade**



Ghezzi et al. 2010
ApJ 720, 1290

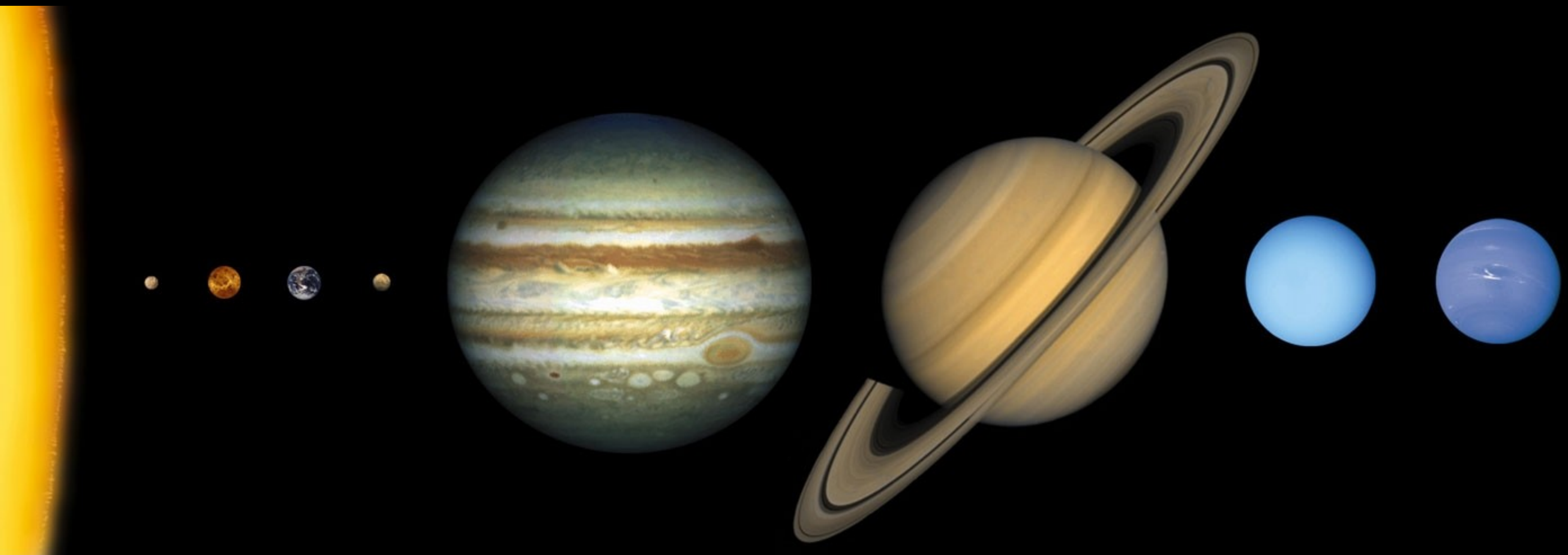
Conexão metalicidade – planeta em estrelas FGK: Planetas rochosos podem ser formados *at any* **[Fe/H]**



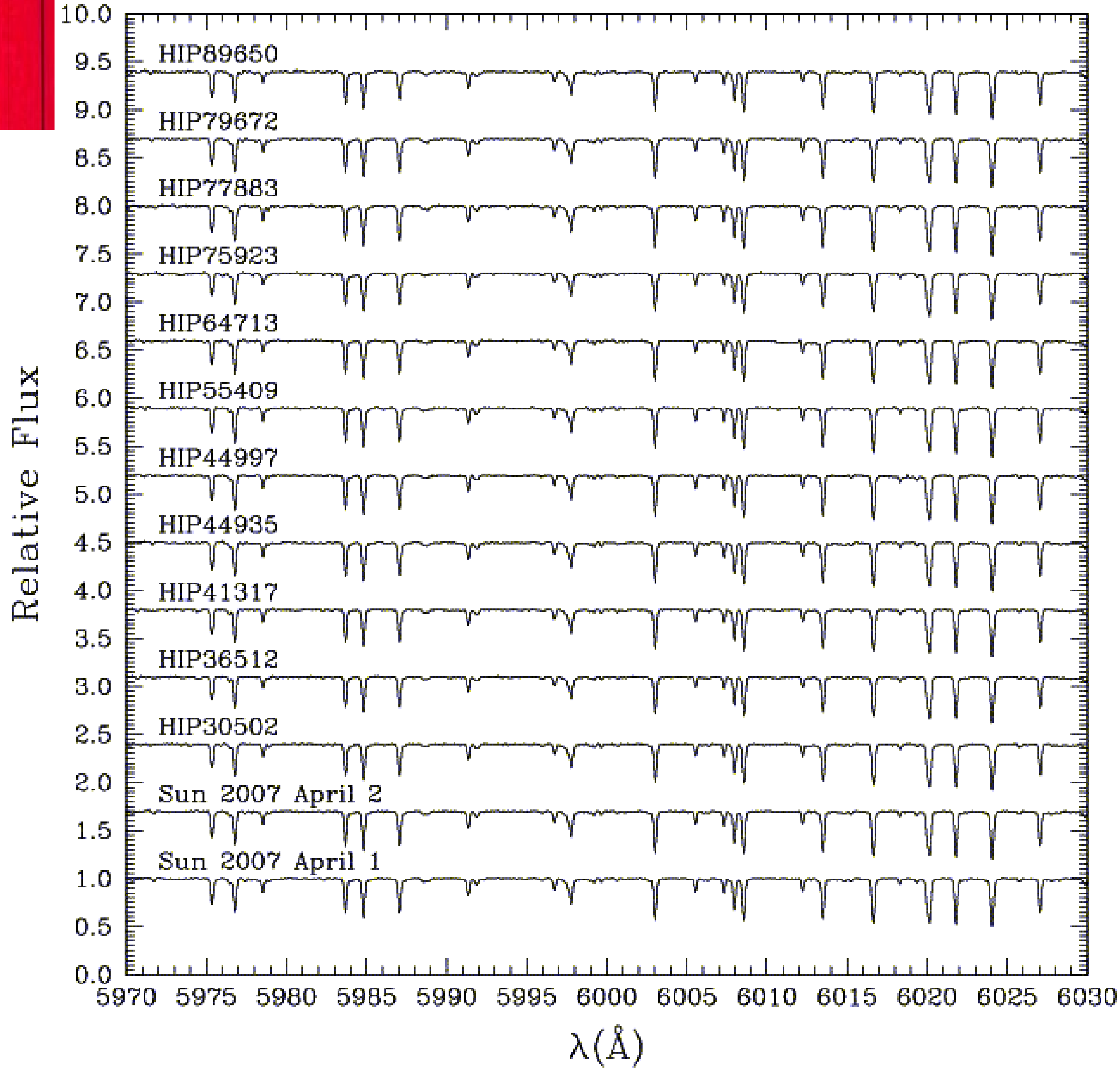
Buchhave et al. 2014 Nature 509, 593

405 estrelas com 600 exoplanet candidates

Existe alguma assinatura química da formação de planetas no Sistema Solar?



Exemplo de espectros de 11 gêmeas solares e o Sol



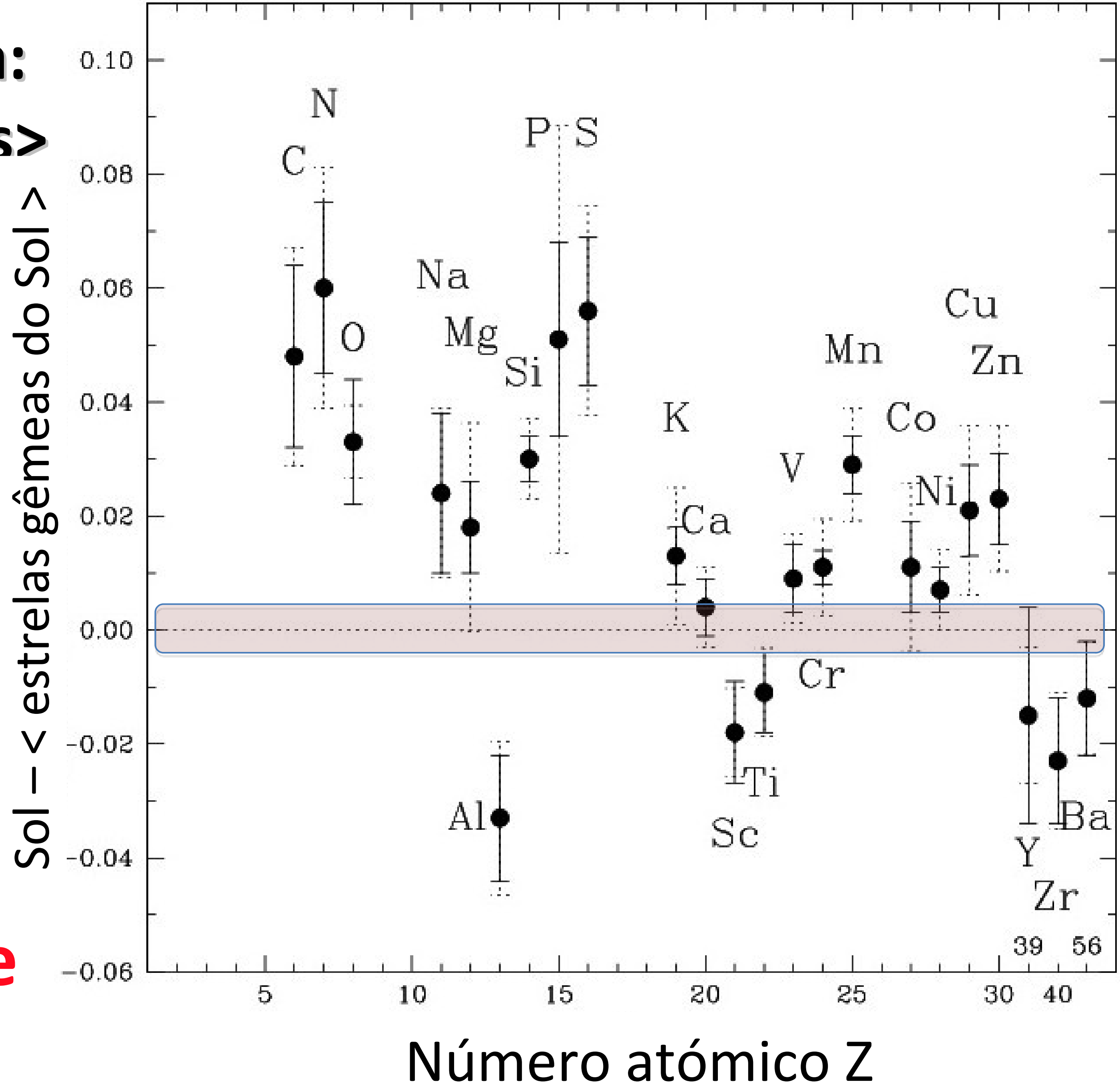
Meléndez et al. 2009, ApJ, 704, L66

Δ abundância: Sol - <gêmeas> vs. Número atómico Z

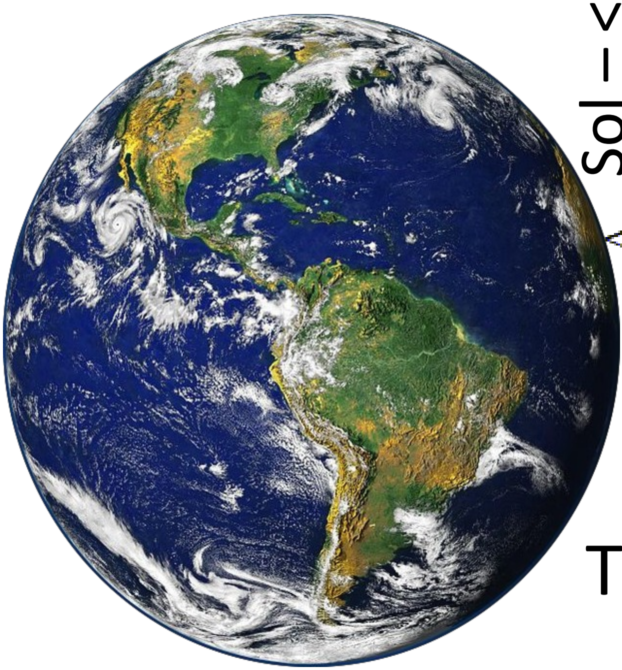
Sol normal : Δ = 0

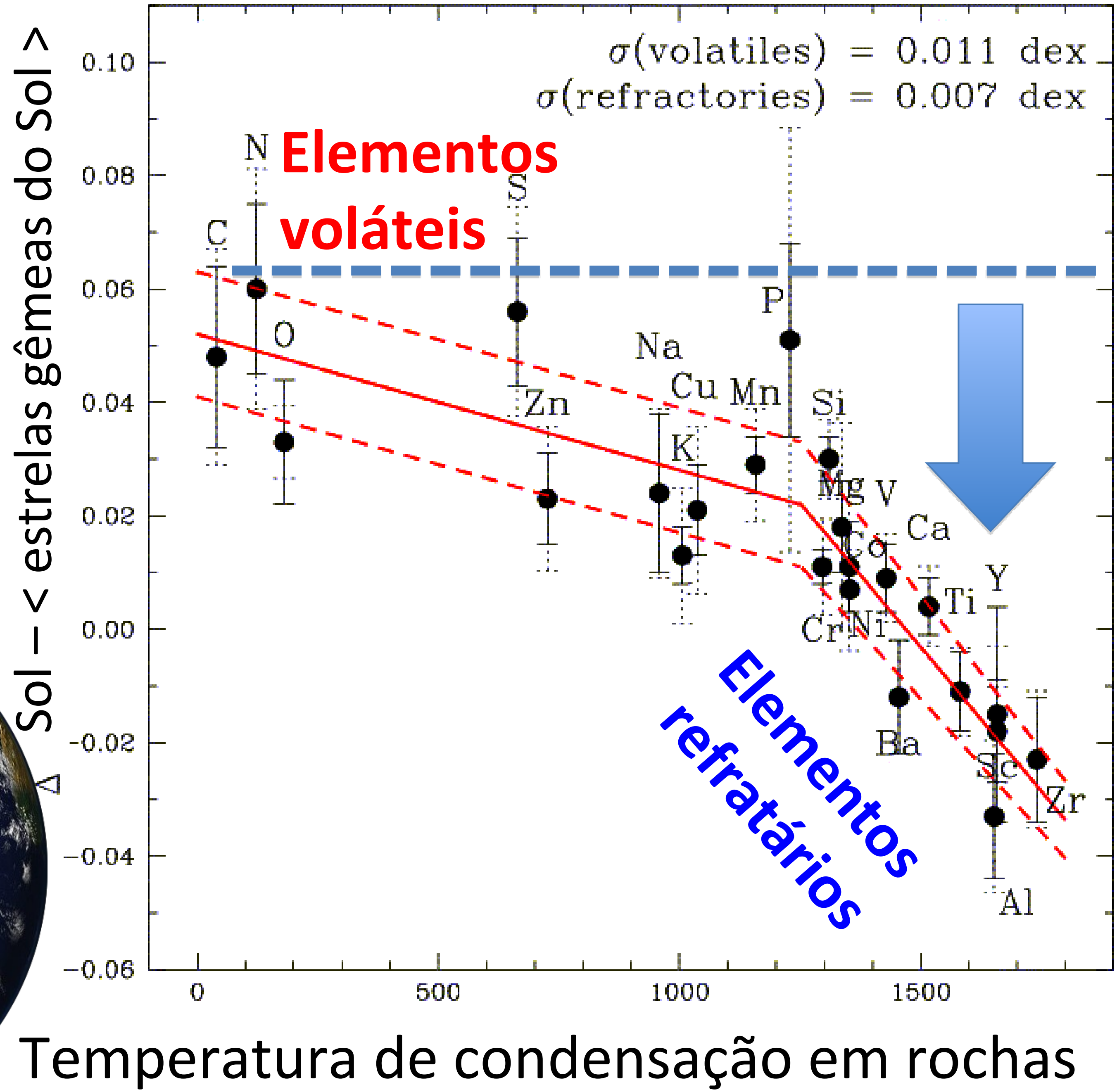
Sol anormal: Δ ≠ 0

Nossa estrela mãe é anómala



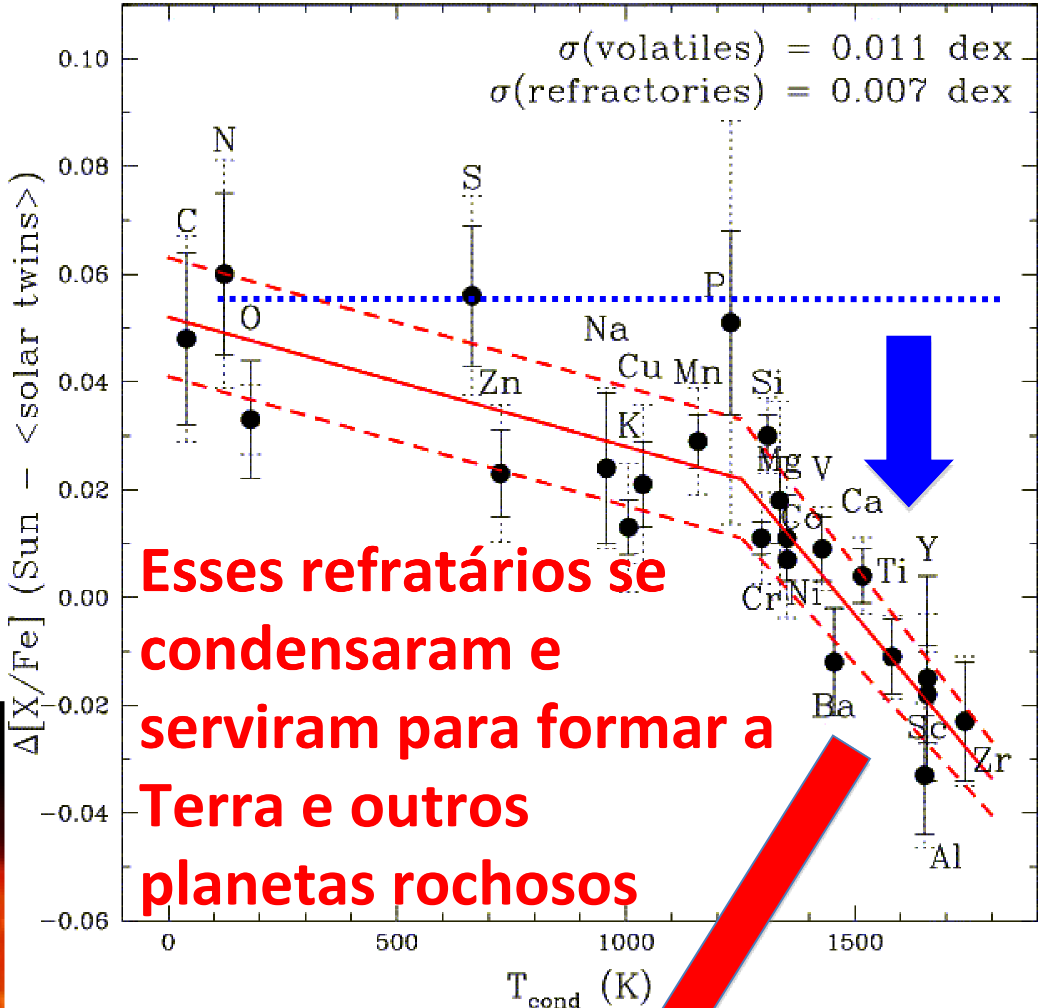
Elementos químicos que formam a Terra são mais deficientes no Sol !!!





Meléndez, Asplund, Gustafsson, Yong 2009, ApJ Letters

Meléndez et al. 2009



Esses refratários se condensaram e serviram para formar a Terra e outros planetas rochosos

Na região interna do Sistema Solar a temperatura é muito alta, permitindo a condensação de apenas elementos refratários

https://arxiv.org/abs/2211.01800 Conexão estrela - planeta

Plausible constraints on the range of bulk terrestrial exoplanet compositions in the Solar neighbourhood

Rob J. Spaargaren et al., submitted to ApJ, Nov 3, 2022

- We circumscribe probable rocky exoplanet compositions based on a population analysis of stellar chemical abundances.

- Strong correlation between stellar Fe/Mg and metallic core sizes.

- Stellar Mg/Si gives a first-order indication of mantle mineralogy.

- The element Na, which modulates crustal buoyancy and mantle clinopyroxene fraction, is affected by devolatilization the most.

- Planetary mantles mostly consist of Fe/Mg-silicates

Composição química do Sol e de estrelas dos catálogos Hypatia e Galah

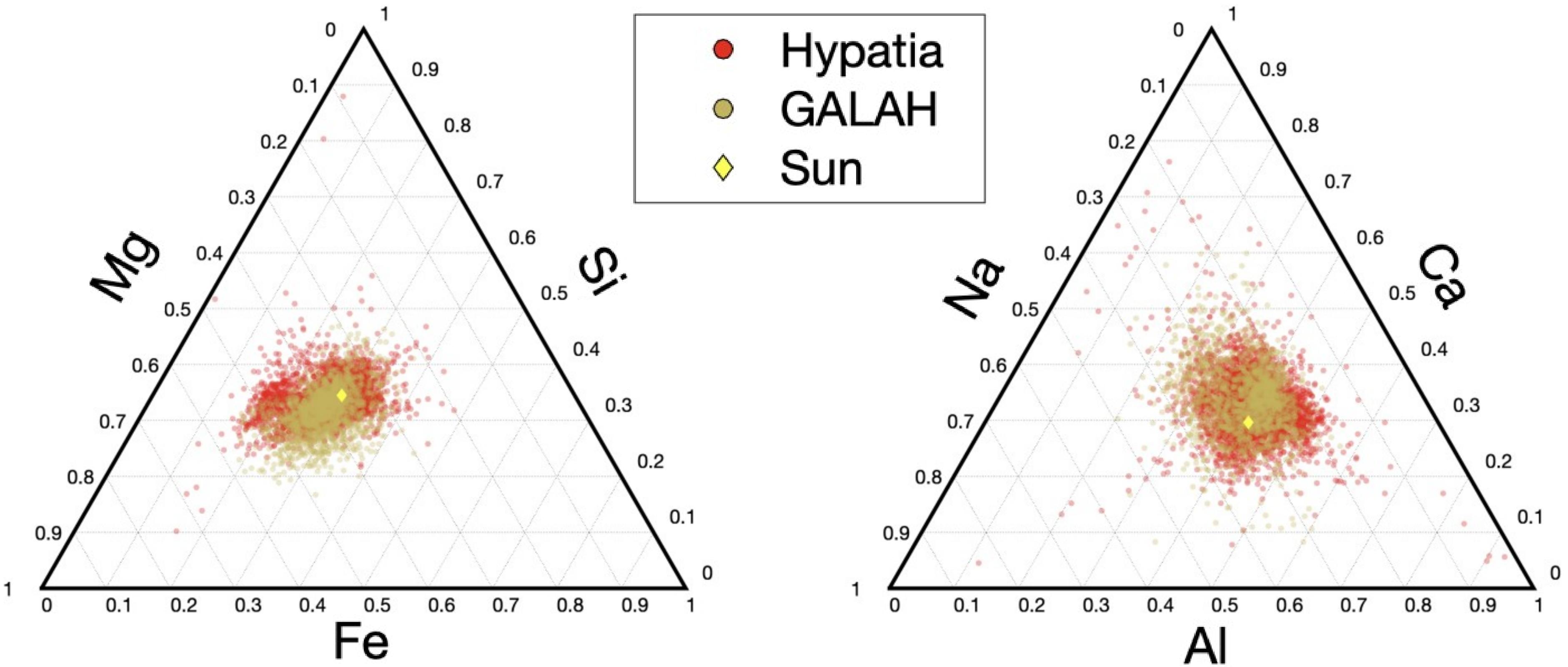


Figure 1. Stellar abundances documented in the Hypatia (red, 4236 stars) and GALAH (gold, 1971 stars) catalogues used in this study. Solar composition from Lodders et al. (2009) is plotted for comparison.

Composição química do Sol, estrelas, Terra e exoplanetas resultantes da composição química estelar

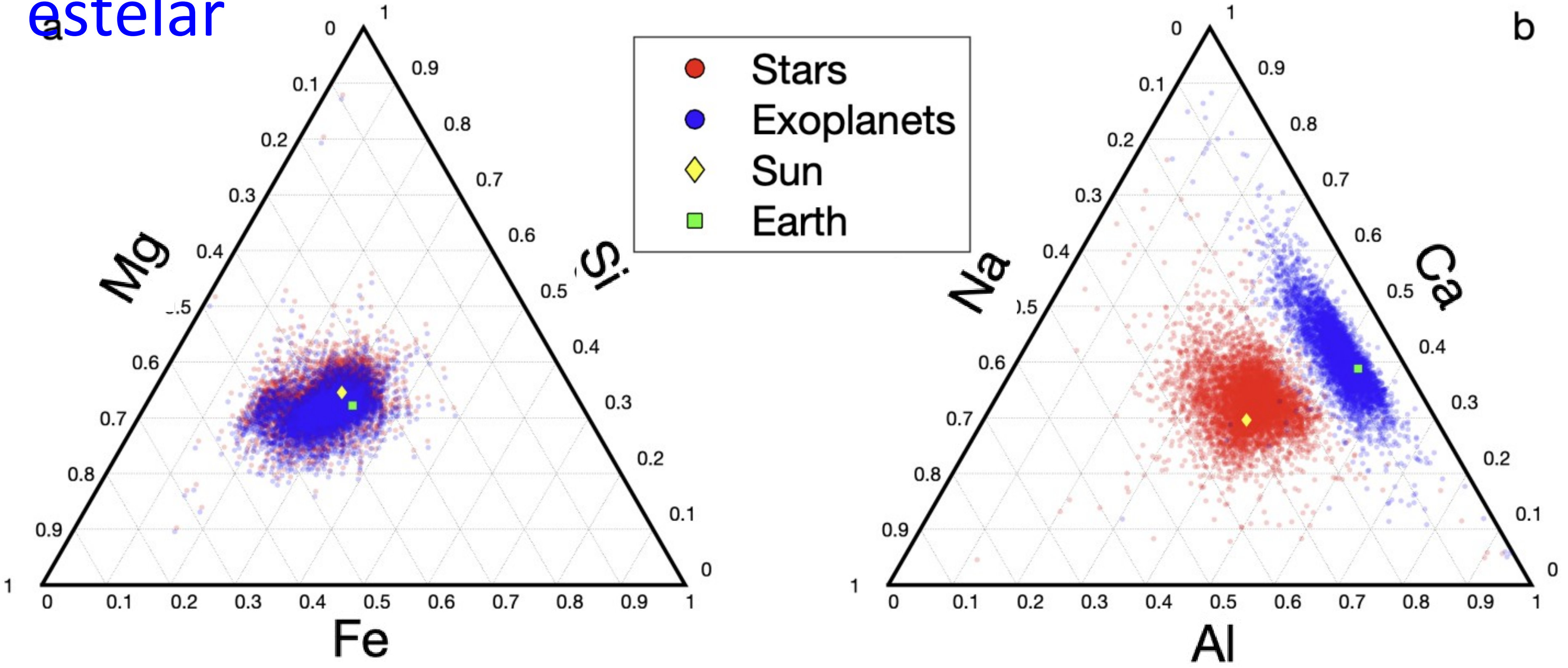


Figure 2. Bulk compositions of stars in the Solar neighbourhood (red; Hinkel et al. 2014; Buder et al. 2018), planet compositions calculated in this work (blue), Solar composition (yellow diamond; Lodders et al. 2009), and Earth composition (green square; McDonough 2003) molar compositions, in the Fe-Mg-Si (left) and Ca-Al-Na (right) systems.

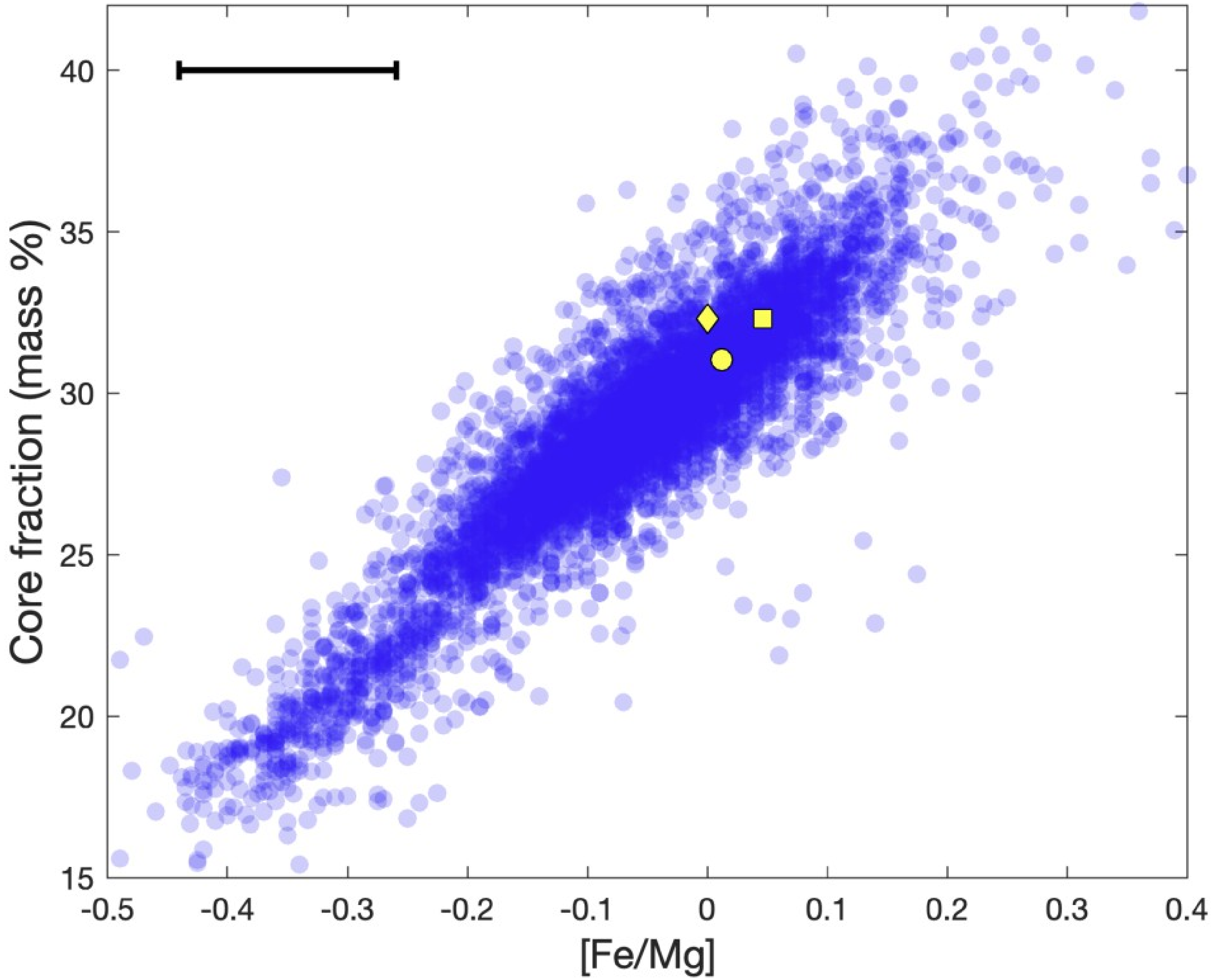


Figure 3. Core sizes of terrestrial-type exoplanets (mass fraction) as a function of stellar [Fe/Mg] (in dex, left)

Evolução química da Galáxia e interior de planetas

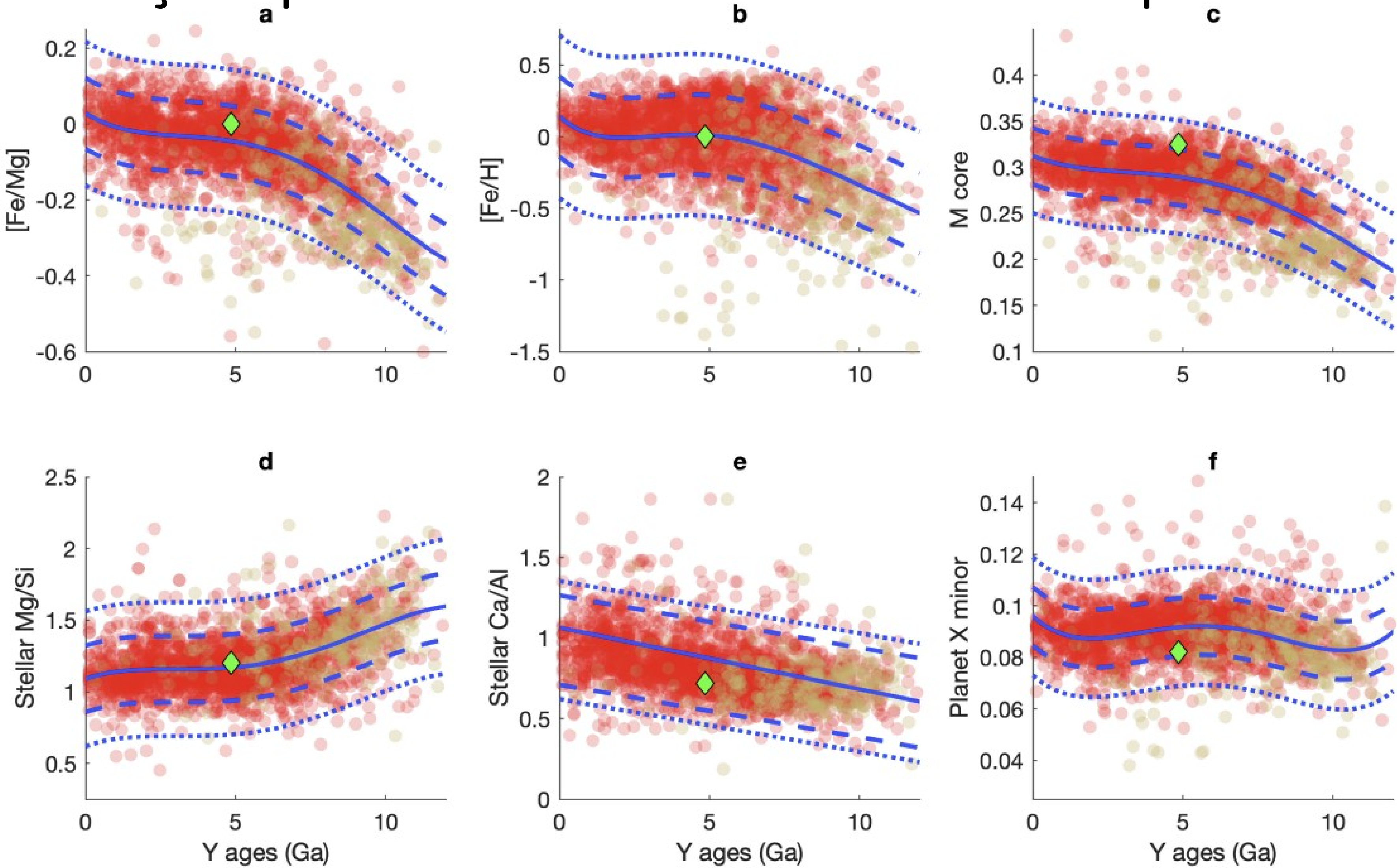


Figure S6. Stellar [Fe/Mg] (a), stellar [Fe/H] (b), core mass fraction (c), stellar molar Mg/Si (d), stellar Ca/Al (e), and planet mantle minor element fraction (f) as a function of stellar age (in Ga), estimated as a function of Y/Mg and Y/Al, based on equations 6 and 7 from Spina et al. (2018). Stellar compositions are from Hinkel et al. (2014), colour-coded for the thin disc (red) and thick disc (gold) populations of the Milky Way.

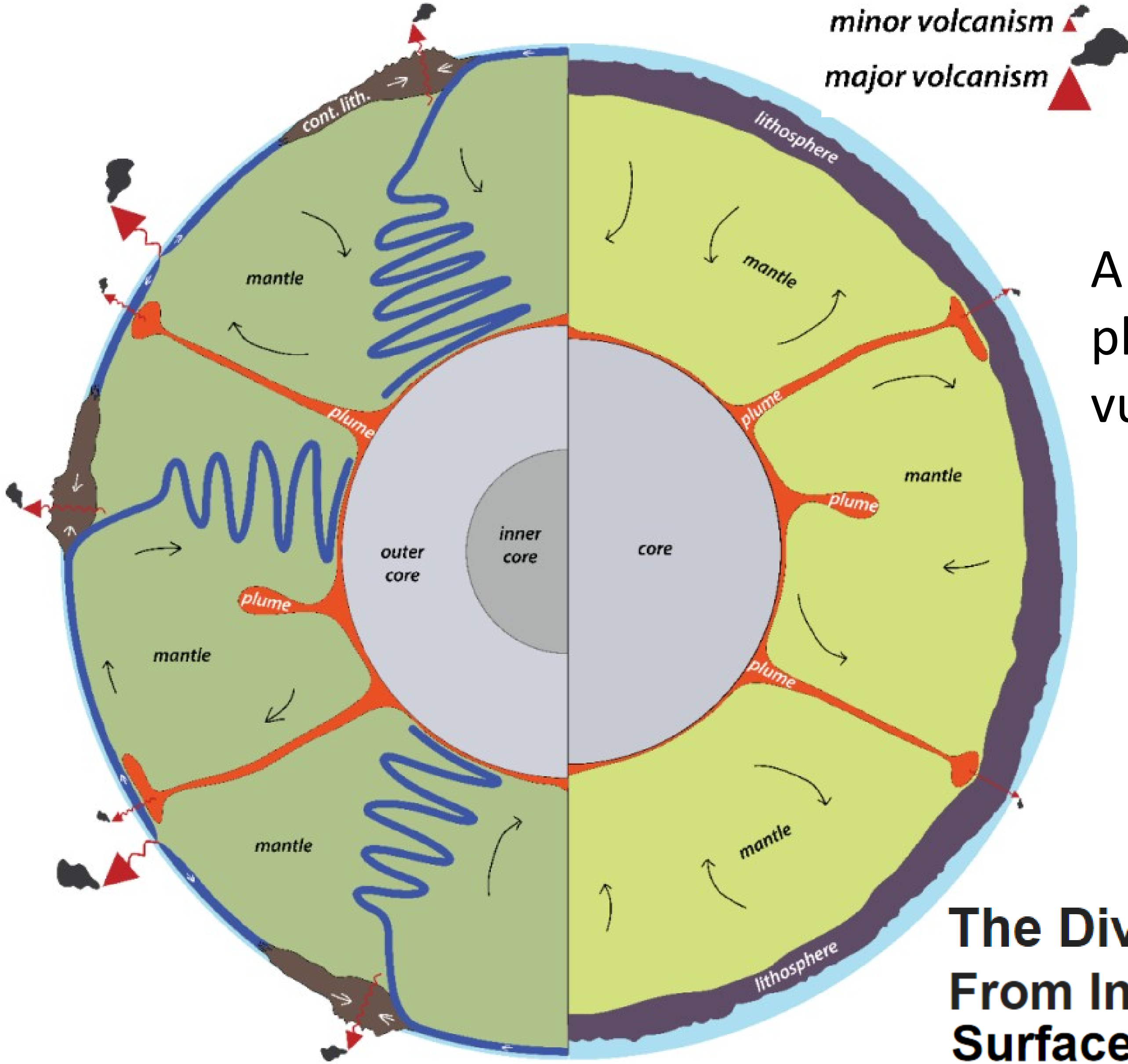


FIGURE 1 (LEFT) Dynamics of a plate-tectonic planet. (RIGHT) Dynamics of a stagnant-lid planet. Respective halves of composite planet not to scale. Continental lithosphere in dark brown; oceanic lithosphere in dark blue; stagnant lid in purplish brown; mantle in green. White arrows denote plate motion; black arrows denote mantle convection patterns. Hot upwelling plumes are orange. Triangles mark sites of more-or-less vigorous volcanism. Liquid outer core is light grey; solid inner core is dark grey. Potential oceans in light blue. The size of each planetary hemisphere is arbitrary.

A espessura da crosta planetária pode afetar o vulcanismo

The Diversity of Exoplanets: From Interior Dynamics to Surface Expressions

Maxim D. Ballmer[1,2] and Lena Noack[3]

Não existe acordo sobre a influência da massa planetária na tectônica de placas

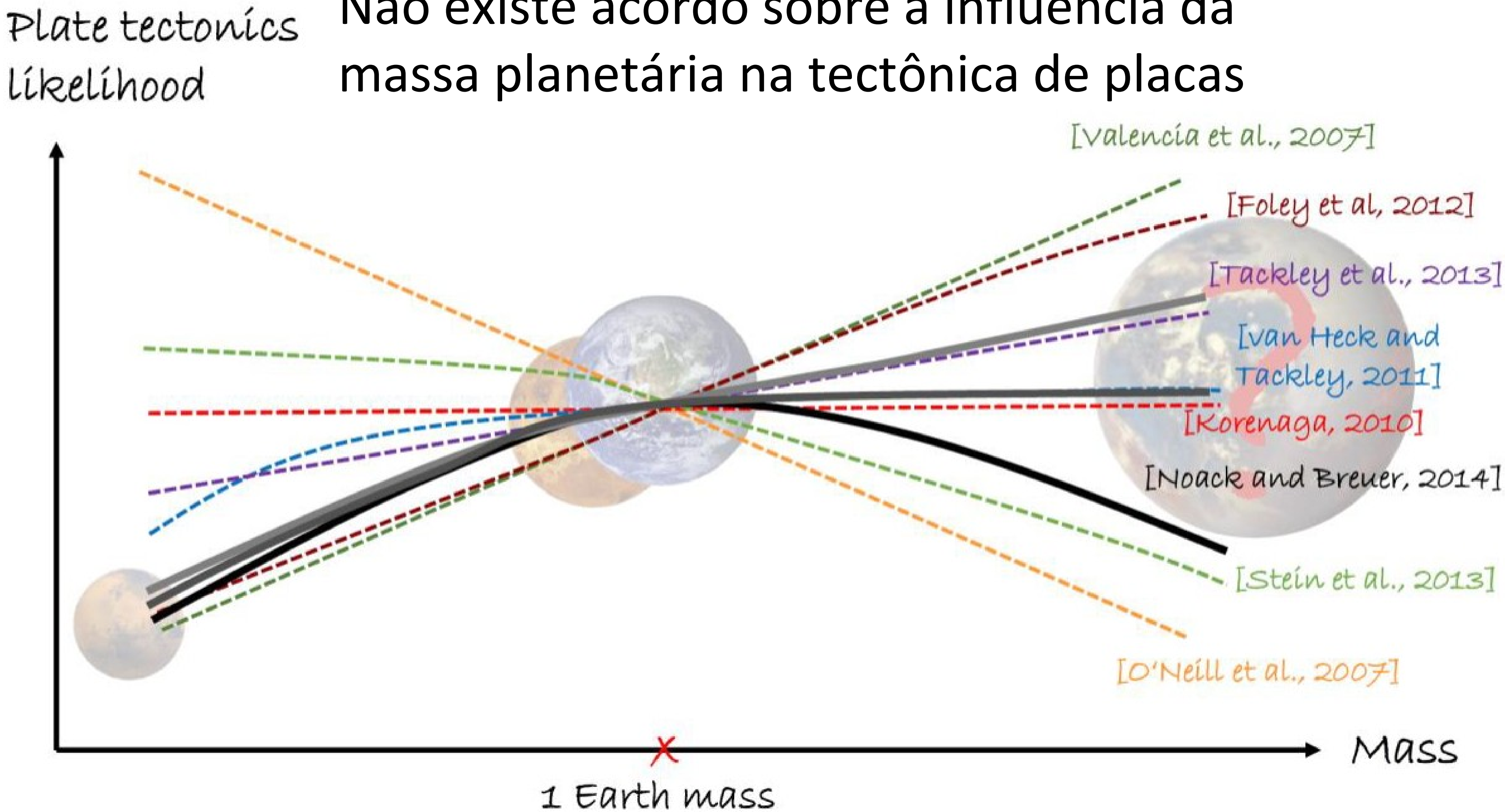


FIGURE 3 Sketch summarizing different predictions for the likelihood of plate tectonics as a function of planet mass, scaled to the same likelihood at one Earth mass (as a reference point). The grey-to-black lines indicate different trends as a function of initial mantle temperature (grey = hot; black = cold) after planet formation as found in Noack and Breuer (2014). The dashed colored lines refer to previous studies as cited in Noack and Breuer (2014).

Quantos planetas por estrela?

Estatisticamente, pelo menos 1 planeta por estrela

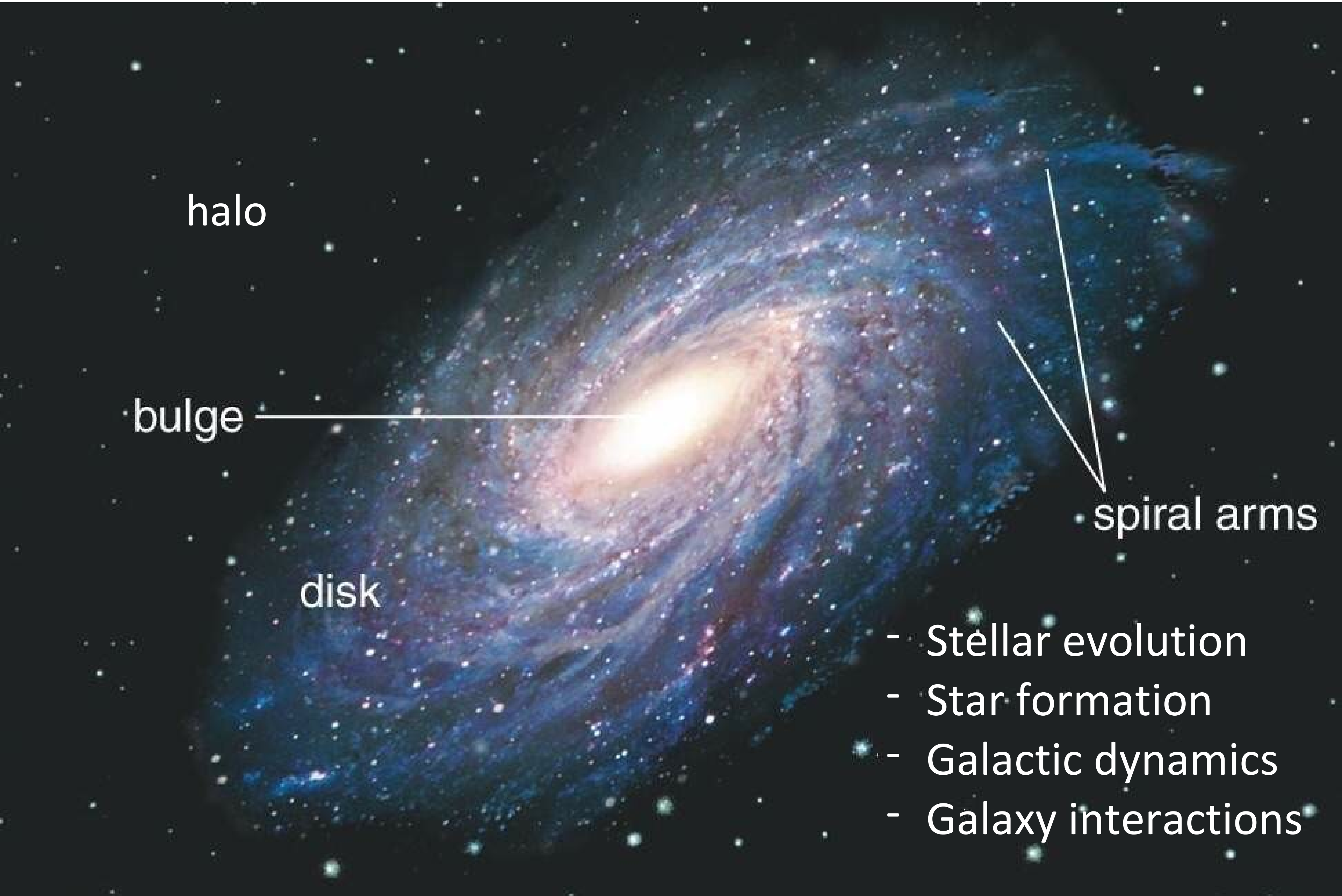
https://exoplanetarchive.ipac.caltech.edu/docs/occurrence_rate_papers.html

Author(s) and Publication Year	Title	Publication
Su et al. (2021)	Demographics of Exoplanets in Binaries (DEB). I. Architecture of S-Type Planetary Systems Revealed by the RV Sample	AJ (accepted)
Poleski et al. (2021)	Wide-orbit exoplanets are common. Analysis of nearly 20 years of OGLE microlensing survey data	AcA 71 1
Kunimoto et al. (2021)	Combining Transit and Radial Velocity: A Synthesized Population Model	AJ 161 69
Bryson et al. (2021)	The Occurrence of Rocky Habitable-zone Planets around Solar-like Stars from Kepler Data	AJ 161 36
Poleski et al. (2021)	Wide-Orbit Exoplanets are Common. Analysis of Nearly 20 Years of OGLE Microlensing Survey Data	AcA 71 1
Jin, Sheng (2021)	Relative occurrence rates of terrestrial planets orbiting FGK stars	MNRAS 502 5302
Yang, Jia-Yi, Xie, Ji-Wei, & Zhou, Ji-Lin (2020)	Occurrence and Architecture of Kepler Planetary Systems as Functions of Stellar Mass and Effective Temperature	AJ 159 164
Bashi et al. (2020)	Occurrence rates of small planets from HARPS: Focus on the Galactic context	A&A 643 A106
Lu, Schlaufman, & Cheng (2020)	An Increase in Small-planet Occurrence with Metallicity for Late-type Dwarf Stars in the Kepler Field and Its Implications for Planet Formation	AJ 160 253
Bryson et al. (2020)	A Probabilistic Approach to Kepler Completeness and Reliability for Exoplanet Occurrence Rates	AJ 159 6
Kunimoto & Bryson (2020)	Comparing Approximate Bayesian Computation with the Poisson-Likelihood Method for Exoplanet Occurrence Rates	RNAAS 4 83
Kunimoto & Matthews (2020)	Searching the Entirety of Kepler Data. II. Occurrence Rate Estimates for FGK Stars	AJ 159 248
Bryson (2020)	Exoplanet Occurrence Rates of Mid M-dwarfs Based on Kepler DR25	RNAAS 4 3
Dai et al. (2019)	Planet Occurrence Rate Correlated to Stellar Dynamical History: Evidence from Kepler and Gaia	AJ 162 46
Bashi & Zucker (2019)	Small Planets in the Galactic Context: Host Star Kinematics, Iron, and Alpha-element Enhancement	AJ 158 61
Hsu, Ford, & Ragozzine (2019)	Occurrence Rates of Planets Orbiting FGK Stars: Combining Kepler DR25, Gaia DR2, and Bayesian Inference	AJ 158 109
He, Ford, & Ragozzine (2019)	Architectures of exoplanetary systems - I. A clustered forward model for exoplanetary systems around Kepler's FGK stars	MNRAS 490 4575
Herman, Zhu, & Wu (2019)	Revisiting the Long-period Transiting Planets from Kepler	AJ 157 248
Kawahara & Masuda (2019)	Transiting Planets Near the Snow Line from Kepler. I. Catalog	AJ 157 218
Mulders et al. (2019)	The Exoplanet Population Observation Simulator. II. Population Synthesis in the Era of Kepler	ApJ 887 157
Grunblatt et al. (2019)	Giant planet occurrence within 0.2 au of low-luminosity red giant branch stars with K2	AJ 158 227

Fernandes et al. (2019)	Hints for a Turnover at the Snow Line in the Giant Planet Occurrence Rate	ApJ 874 81
Hardegree-Ullman et al. (2019)	Kepler Planet Occurrence Rates for Mid-type M Dwarfs as a Function of Spectral Type	AJ 158 75
Bryan et al. (2018)	An Excess of Jupiter Analogs in Super-Earth Systems	AJ 157 52
van Sluijs, L. and Van Eylen, V. (2018)	The occurrence of planets and other substellar bodies around white dwarfs using K2	MNRAS 474 4603
Mulders et al. (2018)	The Exoplanet Population Observation Simulator. I. The Inner Edges of Planetary Systems	AJ 156 24
Pascucci et al. (2018)	A Universal Break in the Planet-to-star Mass-ratio Function of Kepler MKG Stars	ApJ 856L 28
Narang et al. (2018)	Properties and occurrence rates of Kepler exoplanet candidates as a function of host star metallicity from the DR25 catalog	AJ 156 24
Meyer et al. (2018)	M Dwarf Exoplanet Surface Density Distribution: A Log-Normal Fit from 0.07-400 au	A&A 612 L3
Zhu et al. (2018)	About 30% of Sun-like Stars Have Kepler-like Planetary Systems: A Study of their Intrinsic Architecture	ApJ 860 101
Petigura et al. (2018)	The California-Kepler Survey. IV. Metal-rich Stars Host a Greater Diversity of Planets	AJ 155 89
Fulton et al. (2017)	The California-Kepler Survey. III. A Gap in the Radius Distribution of Small Planets	AJ 154 109
Meshkat et al. (2017)	A Direct Imaging Survey of Spitzer detected debris disks: Occurrence of giant planets in dusty systems	AJ 154 245
Mróz et al. (2017)	No large population of unbound or wide-orbit Jupiter-mass planets	Nature 548 183
Vigan et al. (2017)	The VLT/NaCo large program to probe the occurrence of exoplanets and brown dwarfs at wide orbits. IV. Gravitational instability rarely forms wide, giant planets	A&A 603A 3
Wittenmyer et al. (2016)	The Anglo-Australian Planet Search XXIV: The Frequency of Jupiter Analogs	ApJ 819 28
Gaidos et al. (2016)	They are small worlds after all: revised properties of Kepler M dwarf stars and their planets	MNRAS 457 2877
Reggiani et al. (2016)	The VLT/NaCo large program to probe the occurrence of exoplanets and brown dwarfs at wide orbits . III. The frequency of brown dwarfs and giant planets as companions to solar-type stars	A&A 586 147
Obermeier, C. et al. (2016)	Pan-Planets: Searching for hot Jupiters around cool dwarfs	A&A 587A 49O
Désert et al. (2016)	Low False Positive Rate of Kepler Candidates Estimated From A Combination Of Spitzer And Follow-Up Observations	ApJ 804 59
Mulders et al. (2016)	A Super-Solar Metallicity For Stars With Hot Rocky Exoplanets	AJ 152 187
Foreman-Mackey et al. (2016)	The population of long-period transiting exoplanets	AJ 152 206
Lannier et al. (2016)	MASSIVE: A Bayesian analysis of giant planet populations around low-mass stars	A&A 596A 83

A Via Láctea tem ~100 a 400 bilhões de estrelas → entre 100 a 400 bilhões de planetas em nossa galáxia

Galactic habitable zone



Galactic habitable zone. Dependence on R_g?

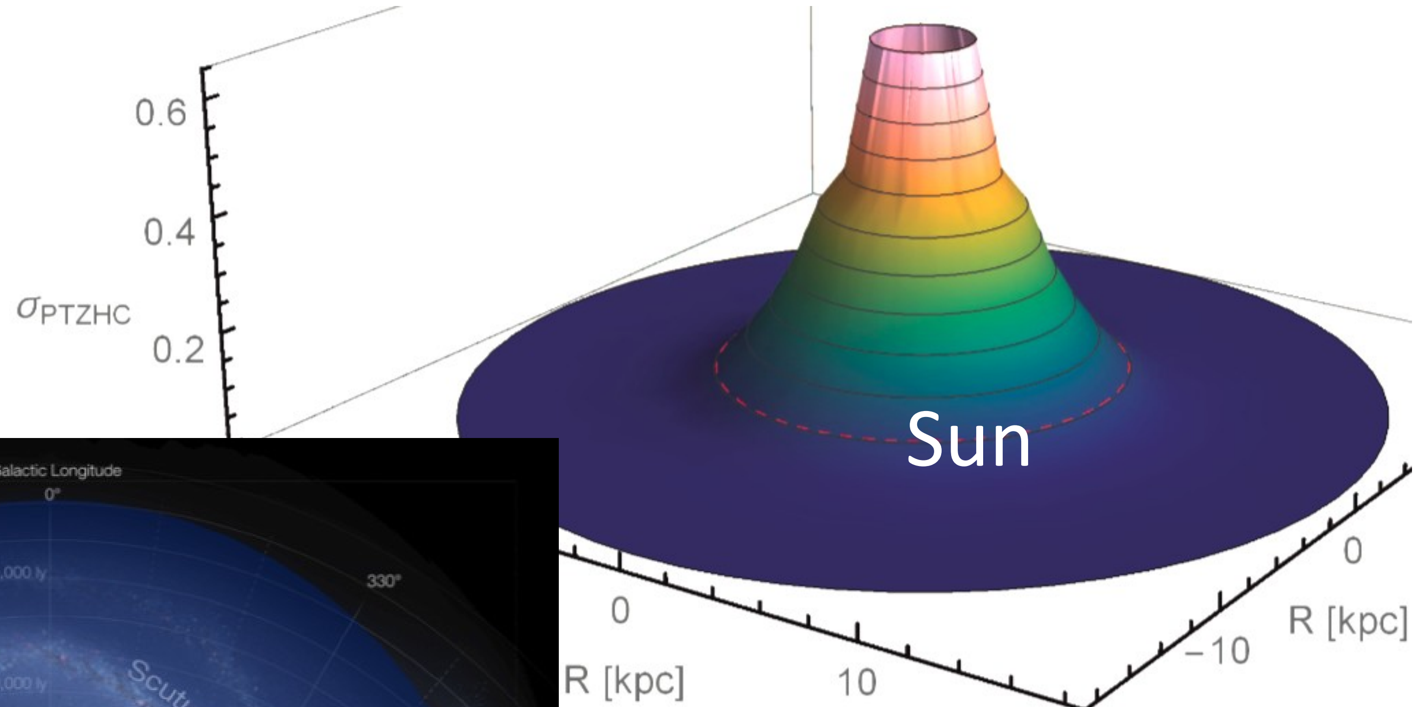
Habitabilidade na Galáxia depende do tempo e raio galactocêntrico R_g, que depende de:

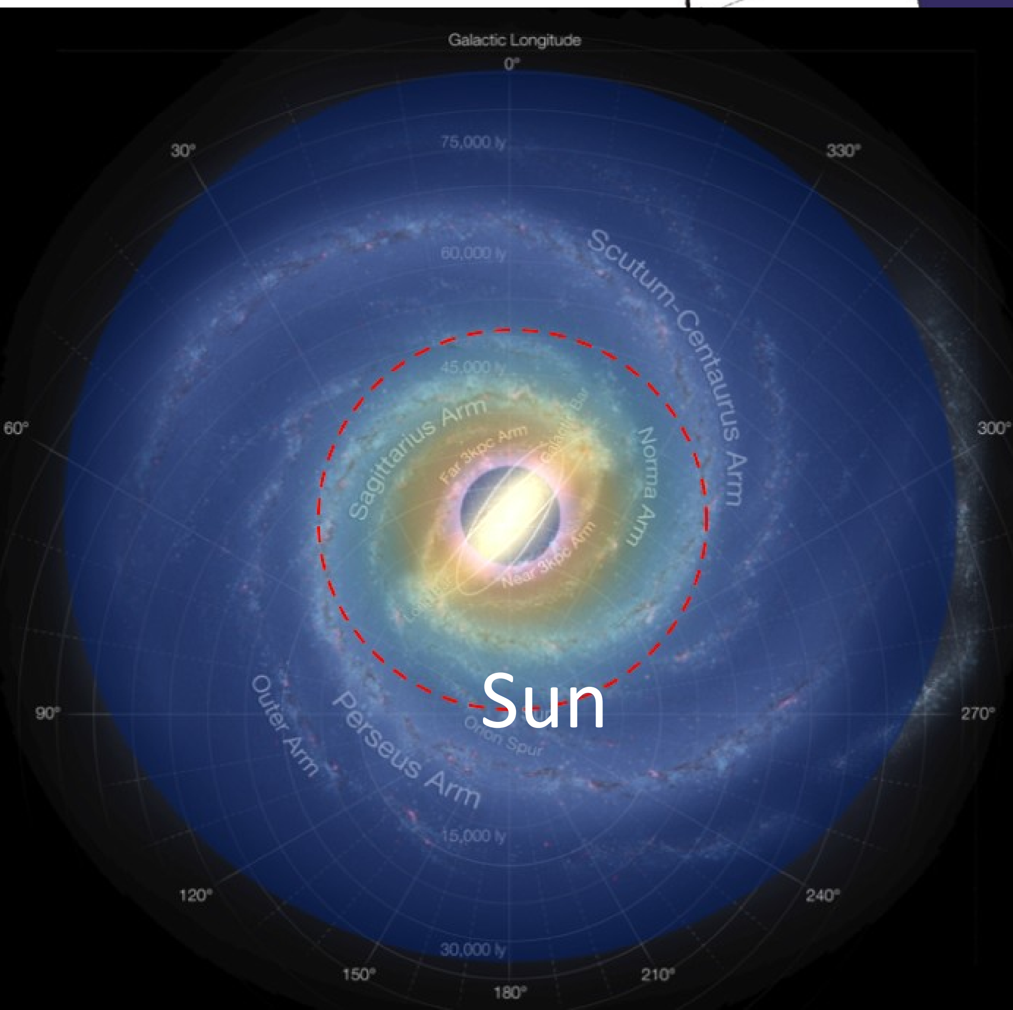
- Metalicidade
- Densidade de estrelas
- Supernovas

Modelo simples, sem considerar migração de estrelas de diferentes R_g na Galáxia

The highlighted green ring in this painting of the Milky Way Galaxy represents what some scientists suspect to be a galactic habitable zone—the only region of the galaxy in which Earth-like planets are likely to be found. However, other scientists think that Earth-like planets could be far more widespread.

© The essential COSMIC PERSPECTIVE

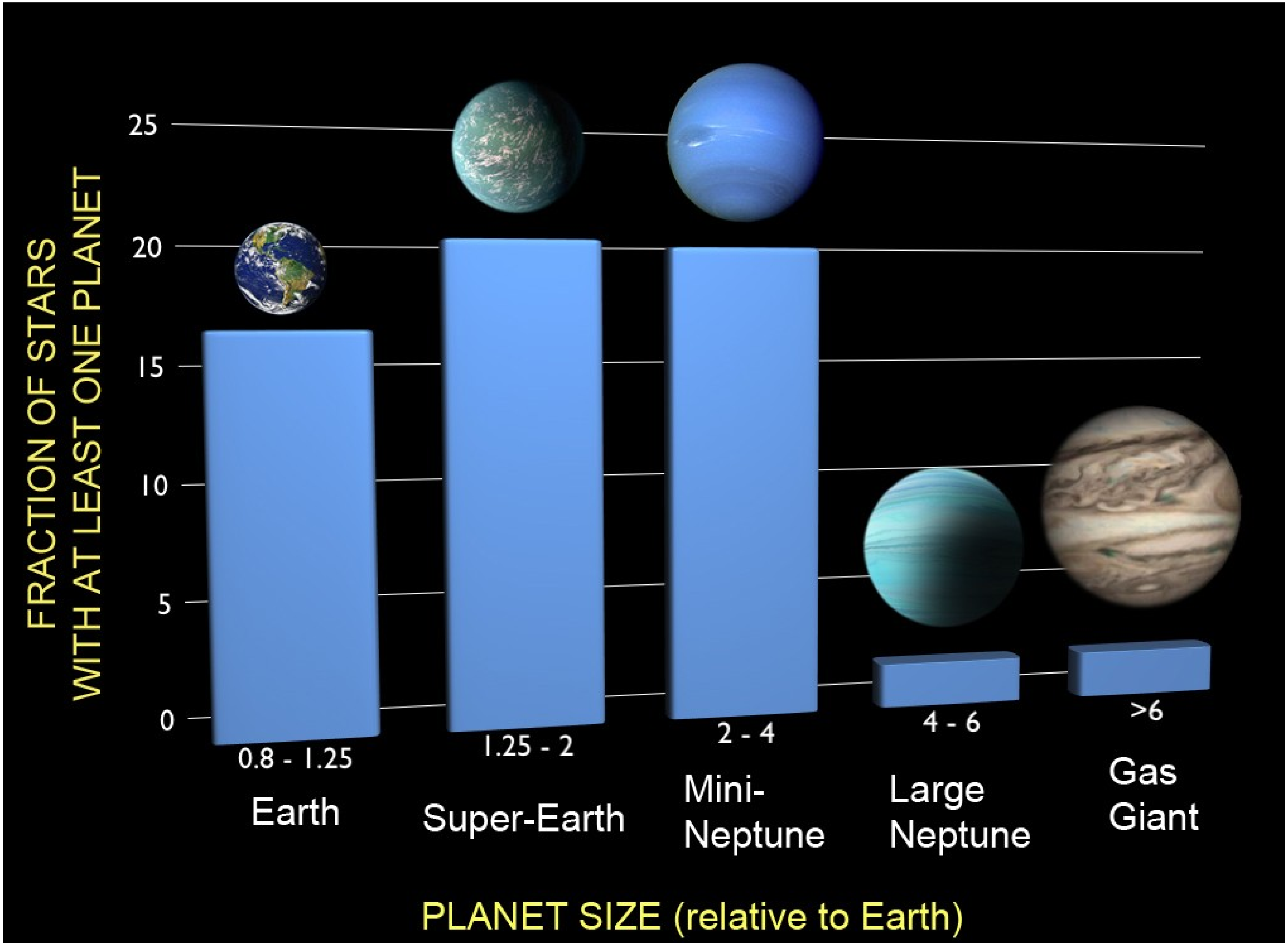




Densidade de Planetas Terrestres Habitáveis na Galáxia Hoje (sem levar em conta efeitos das supernovas)

Fernando de Sousa Mello, 2019, Doutorado, IAG/USP

Estudo usando dados do telescópio Kepler, sugere que 1 em cada 6 estrelas tem pequenos planetas como a Terra



https://www.nasa.gov/mission_pages/kepler/news/17-percent-of-stars-have-earth-size-planets.html

Terra
17%

Super
Terra
20%

Mini-
Netuno
20%

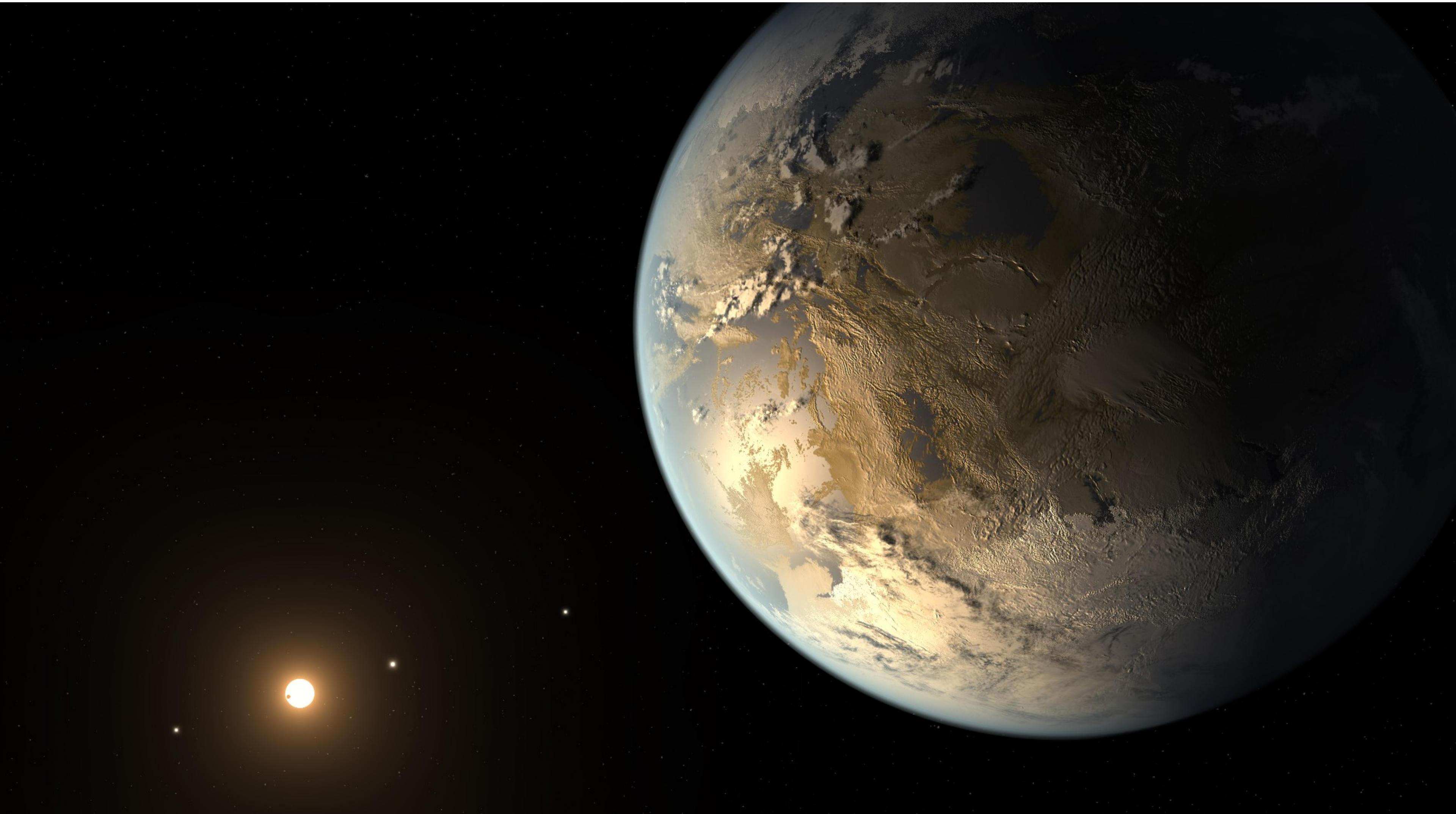
Netuno
3%

Júpiter
5%

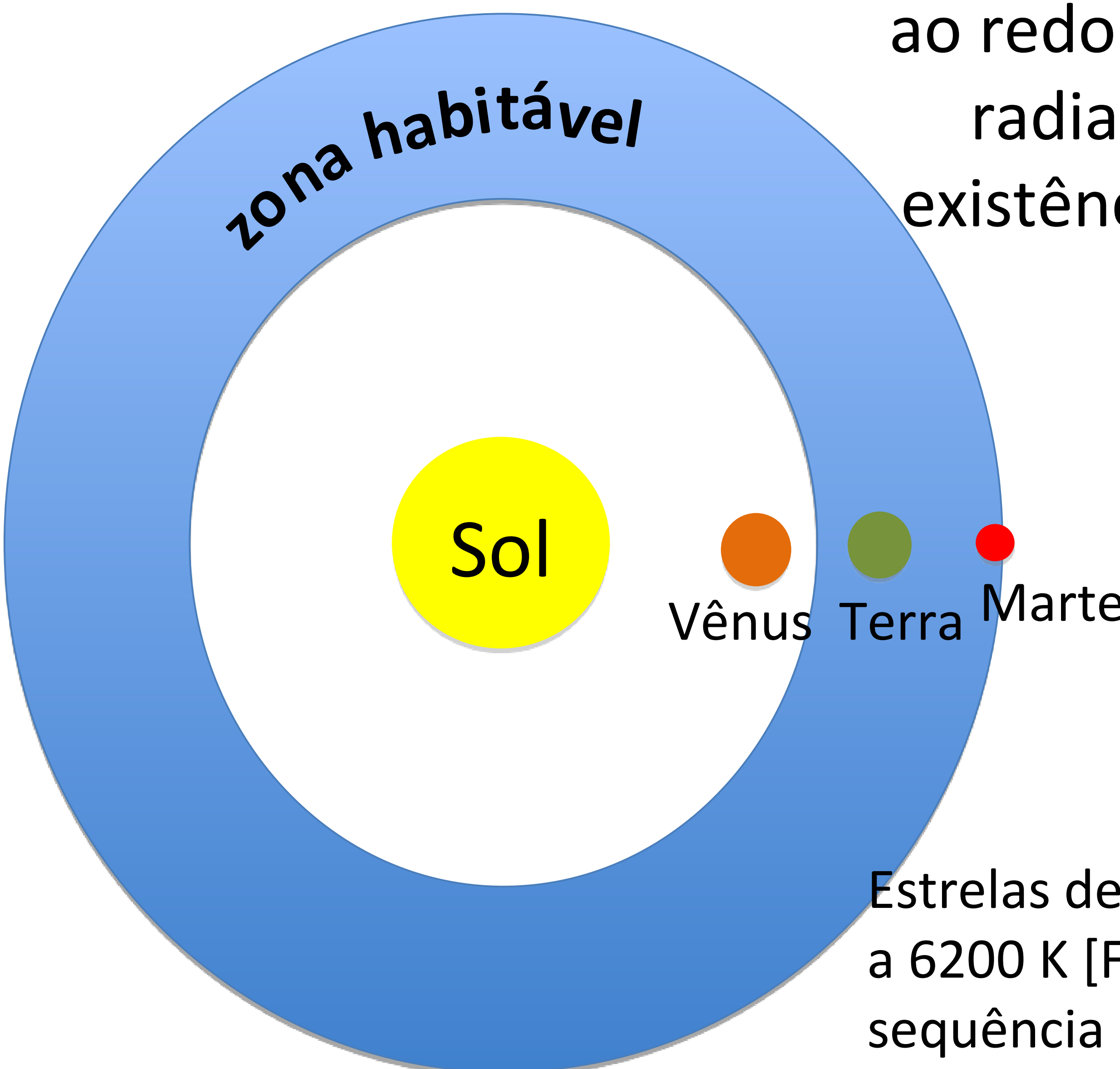
Das estrelas de tipo solar com planetas rochosos, quantas têm planetas rochosos na zona habitável (água líquida)?

- Muita incerteza, entre 7 a 50% dessas estrelas

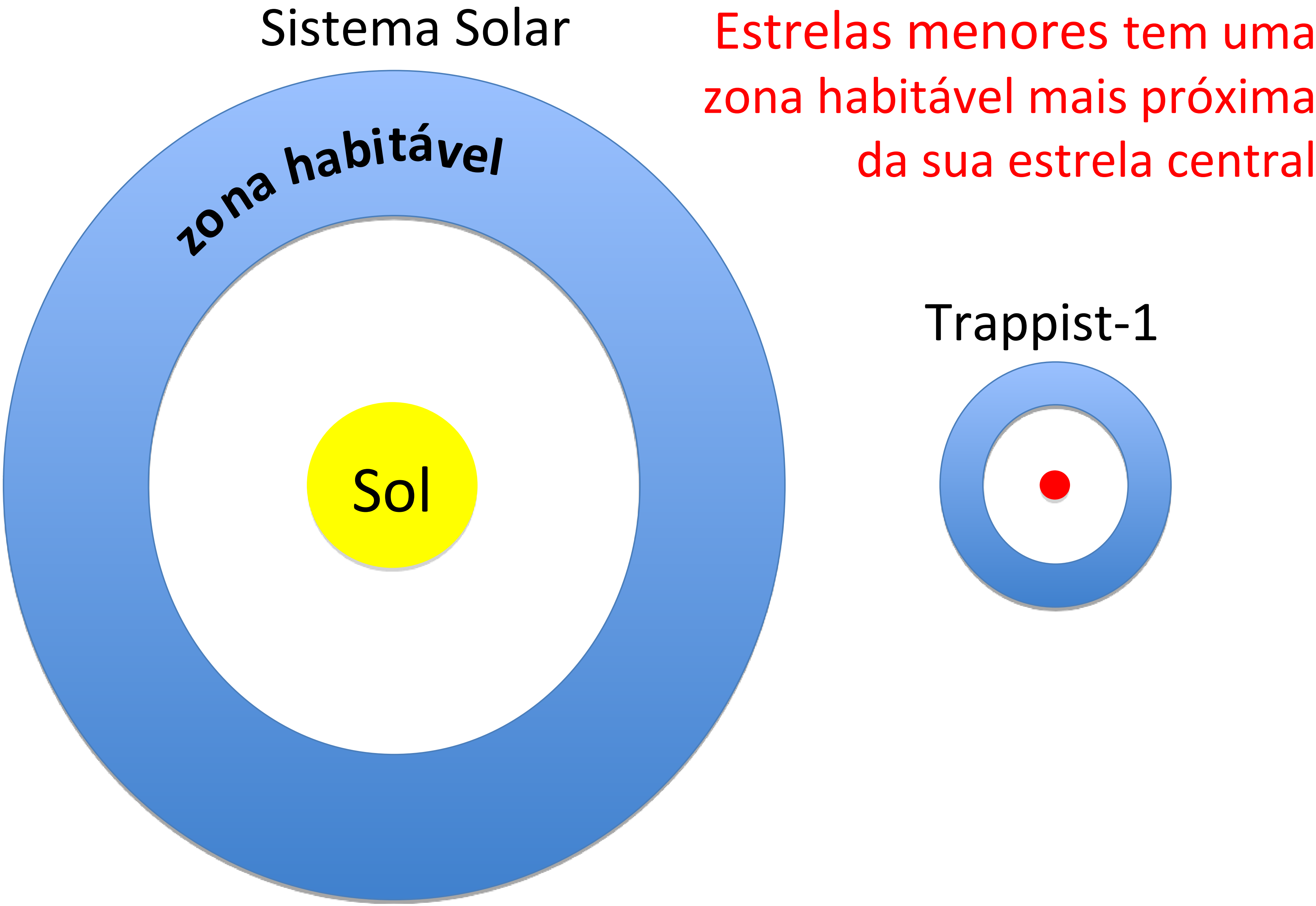
https://www.nasa.gov/feature/ames/kepler-occurrence-rate



A **zona habitável** é uma região ao redor da estrela onde a radiação dela permite a existência de **água líquida**



Estrelas de tipo solar (~5100 [K2V] a 6200 K [F8V] de temperatura) na sequência principal são astrobiologicamente interessantes


Sistema Solar
Estrelas menores tem uma zona habitável mais próxima da sua estrela central
zona habitável
Sol
Trappist-1

O GLOBO MENU SOCIEDADE

POR **CESAR BAIMA** **22/2/2017**

CIÊNCIA

Trappist-1

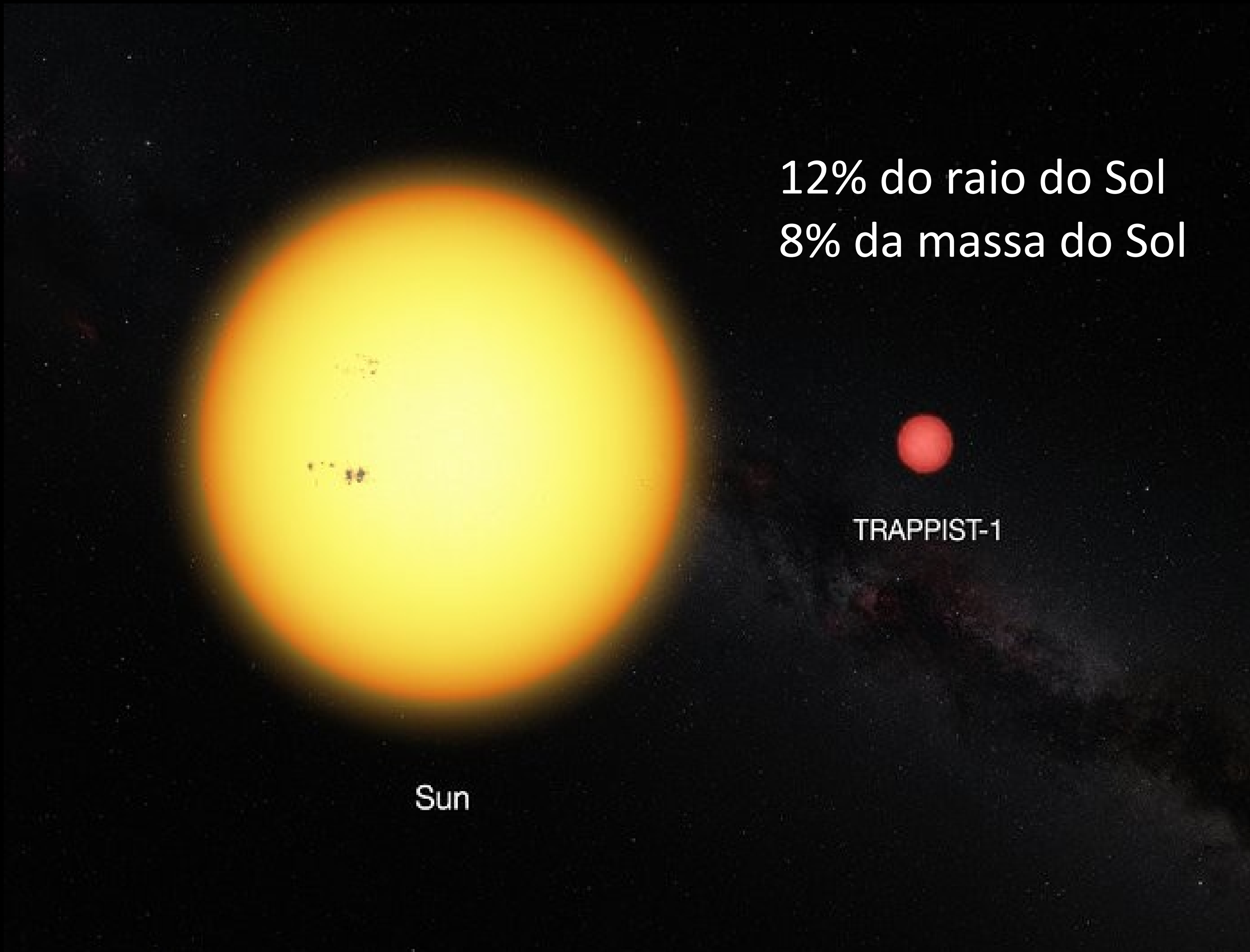
DESCOBERTO SISTEMA COM SETE PLANETAS SIMILARES À TERRA

Objetos orbitam estrela anã a distâncias que permitiram existência de água em estado líquido na sua superfície, condição para abrigar vida como conhecemos

TRAPPIST:
TRAnsiting Planets
& PlanetesImals
Small Telescope–
South

Telescópio Trappist (60 cm) no Observatório La Silla do ESO

12% do raio do Sol
8% da massa do Sol



O GLOBO ☰ MENU SOCIEDADE

POR **CESAR BAIMA**

22/02/2017

CIÊNCIA

DESCOBERTO SISTEMA COM SETE PLANETAS SIMILARES À TERRA

Objetos orbitam estrela anã a distâncias que permitiram existência de água em estado líquido na sua superfície, condição para abrigar vida como conhecemos

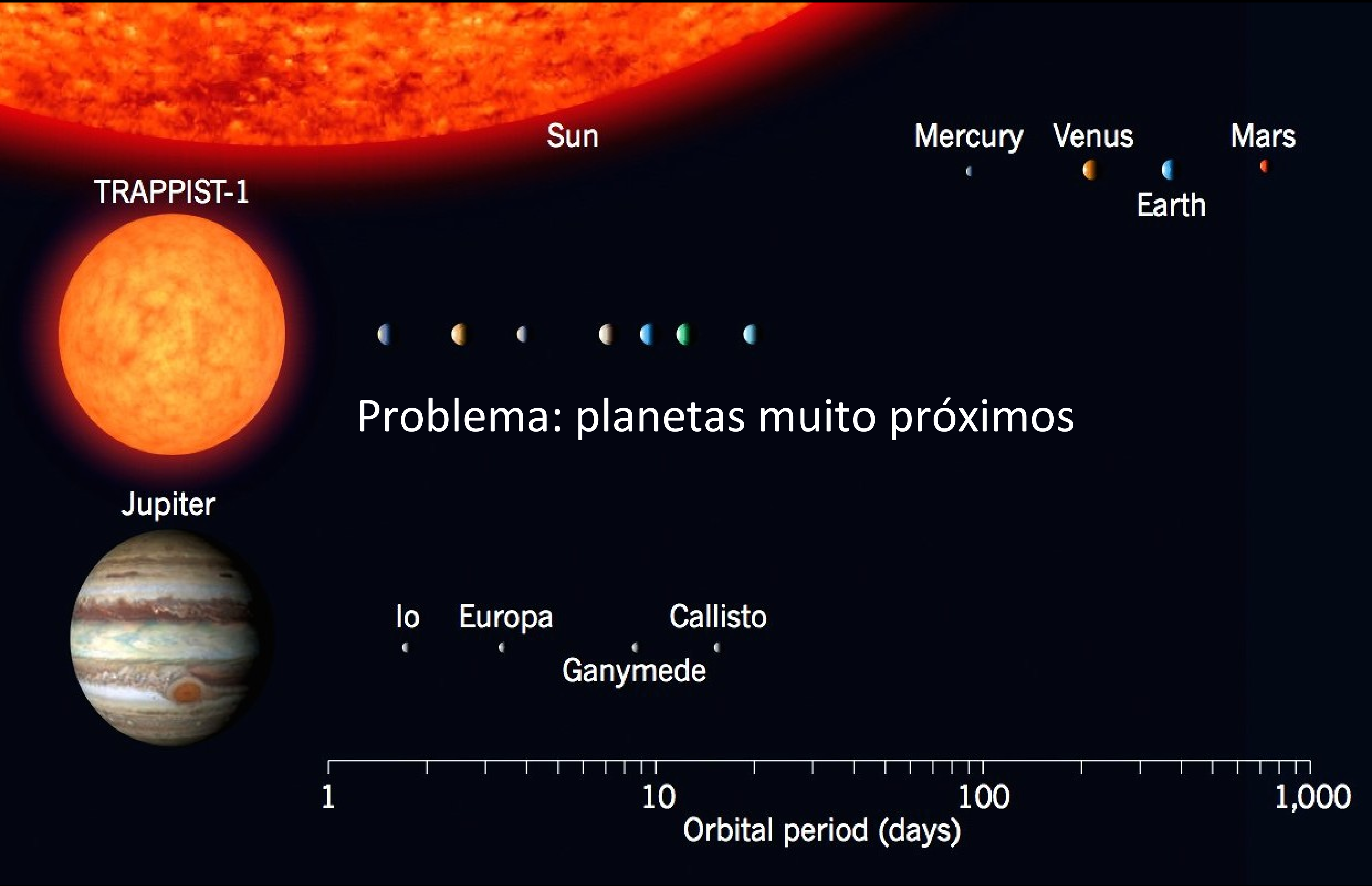
NASA

Spitzer

ESO

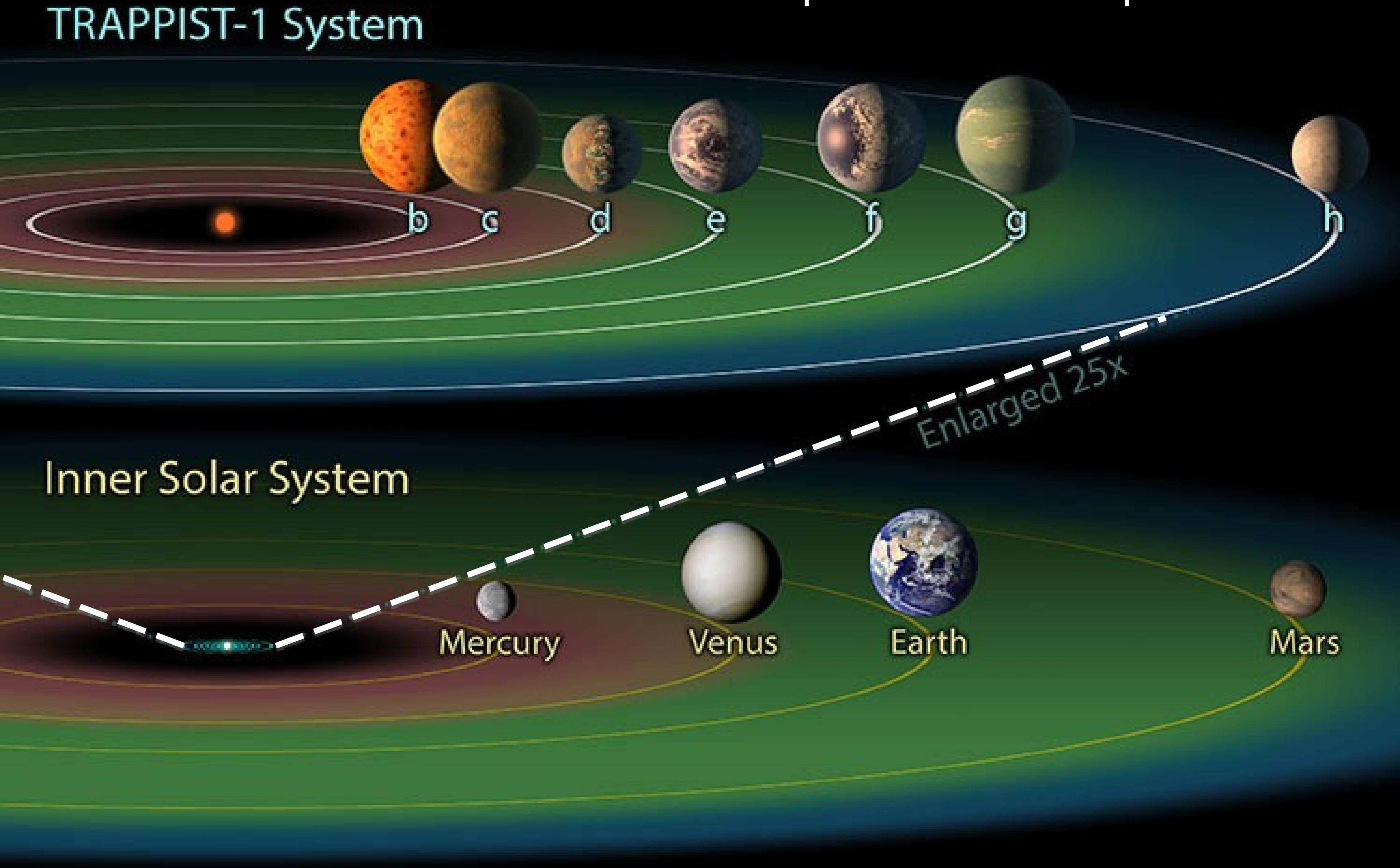
Trappist
VLT

+ outros telescópios

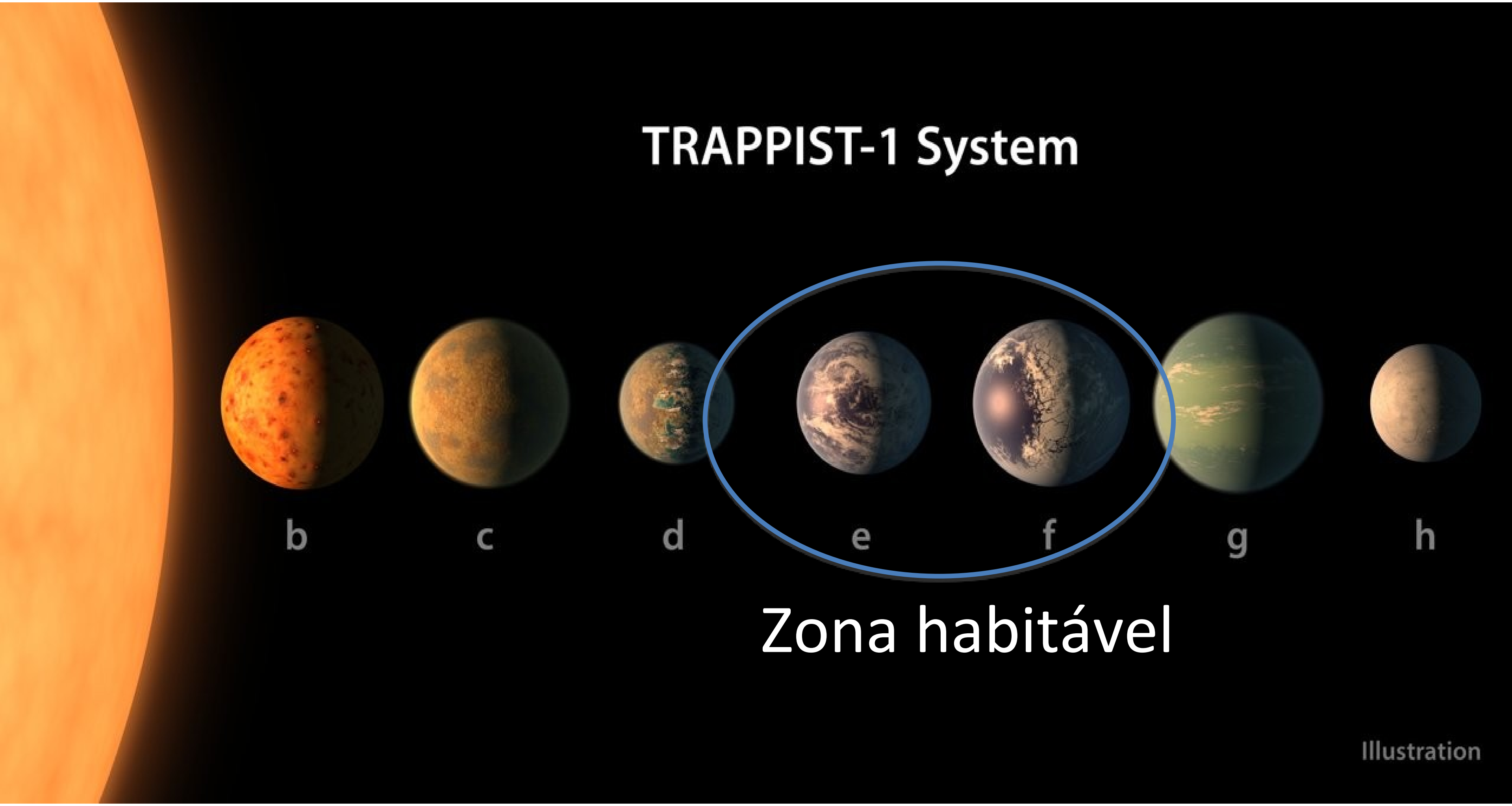


Problema: planetas muito próximos

Problema: planetas muito próximos

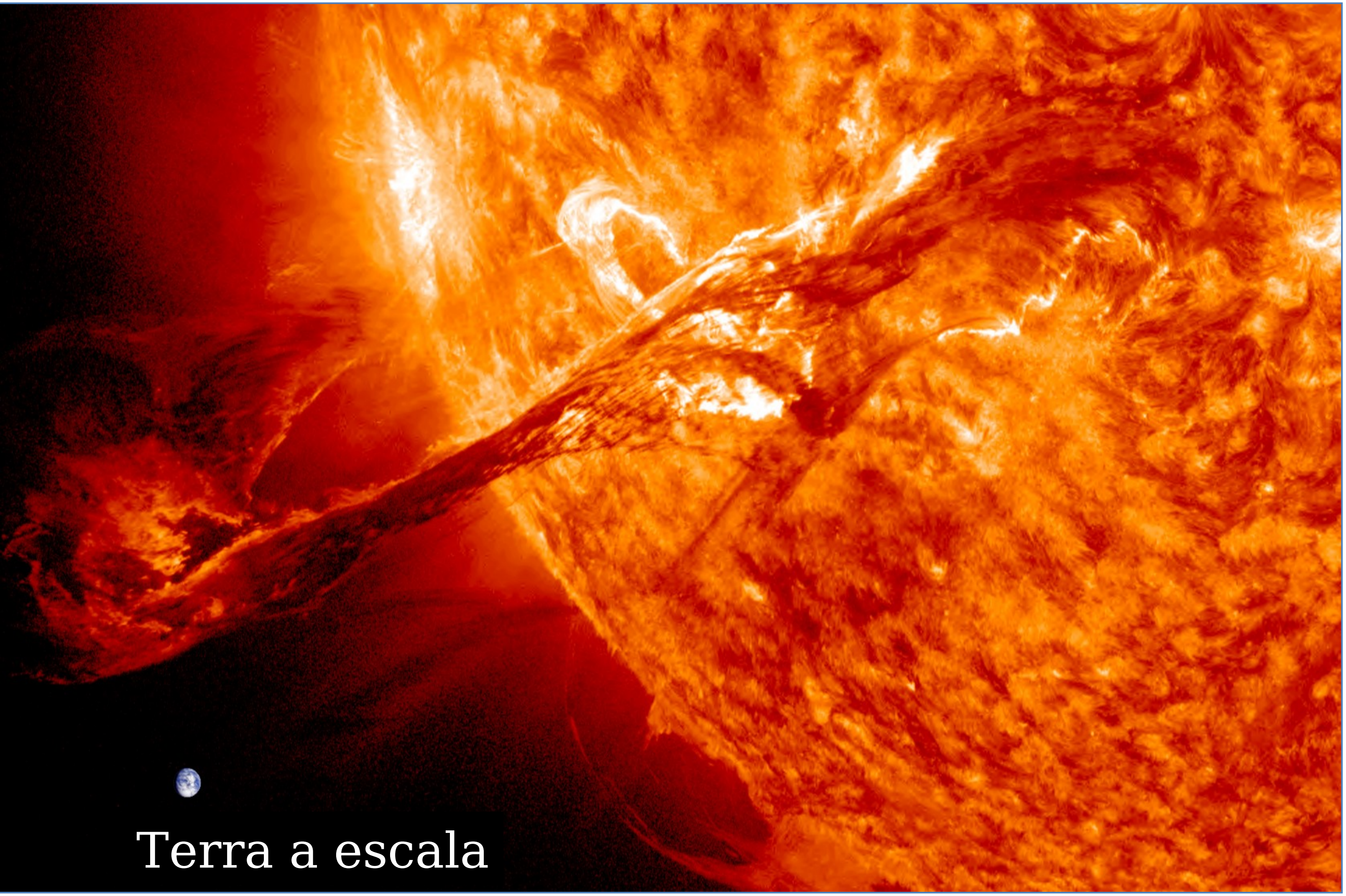


Afetados por forças de maré, planetas de Trappist-1 apresentam sempre a mesma face à estrela → forte contraste de temperatura



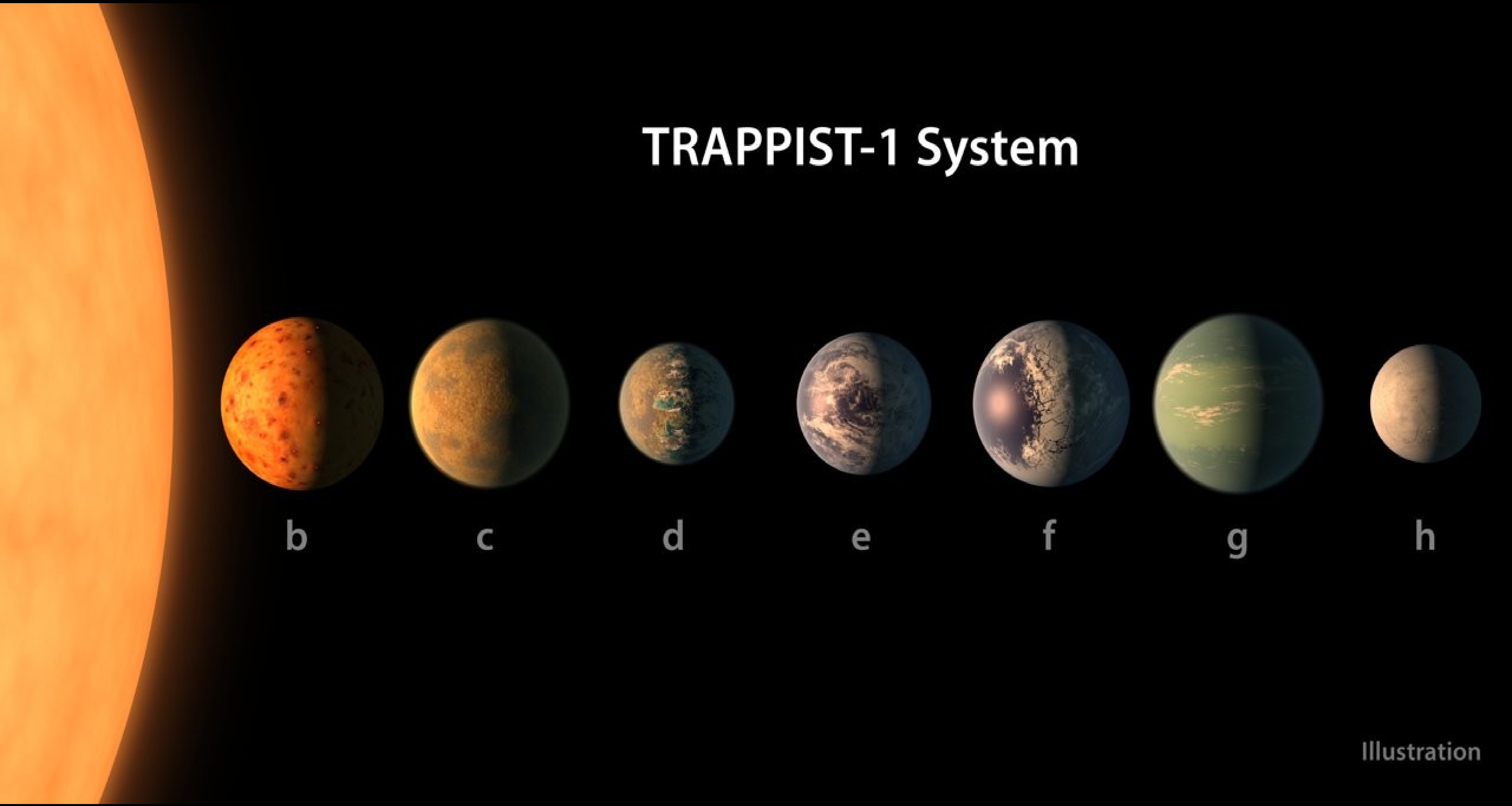

Explosão do Sol
Trappist-1e: 0,028 UA
(36 vezes mais próximo
que a Terra ao Sol)
Terra

Trappist-1 tem super explosões, 100 X maiores que no Sol



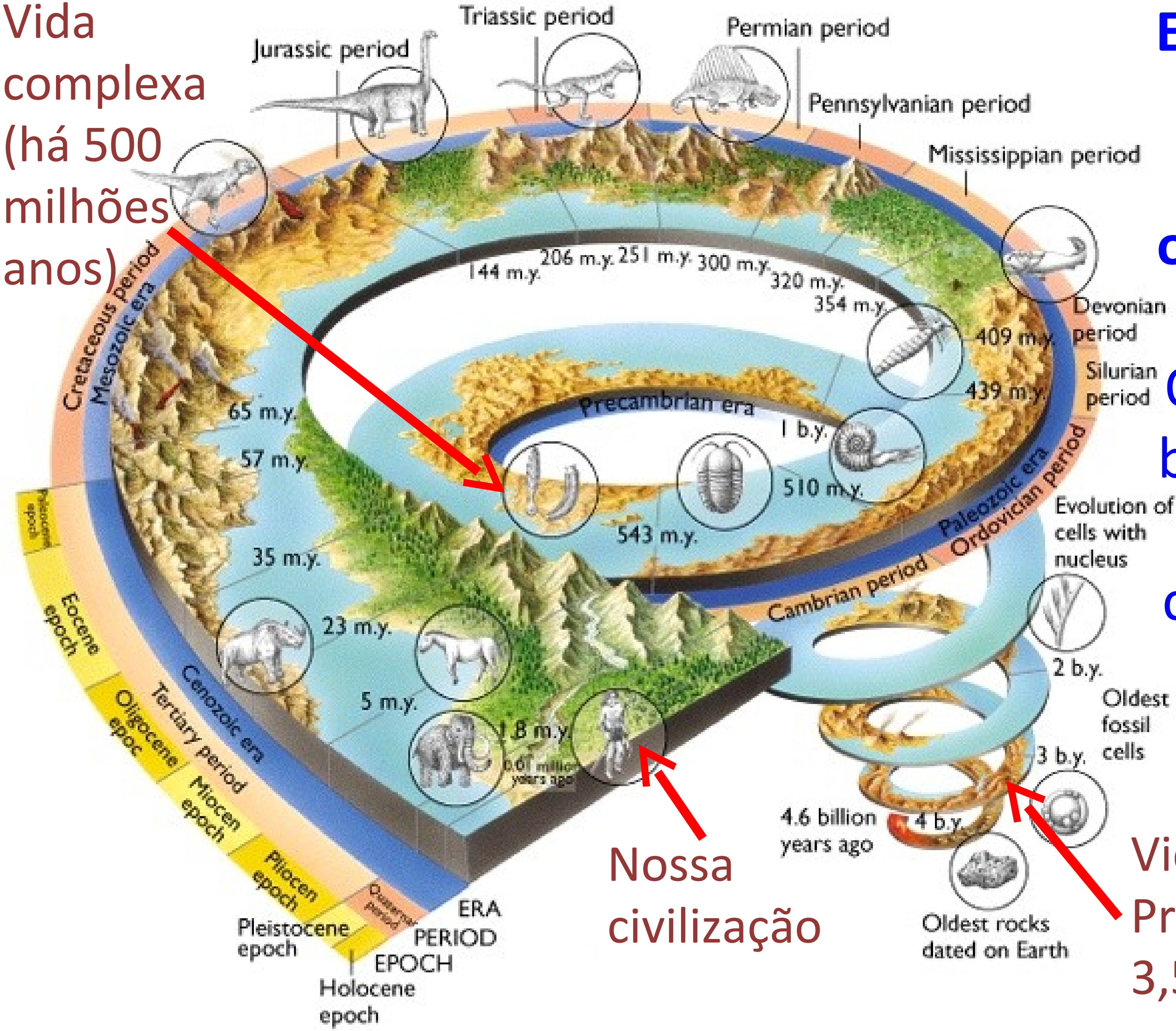
Sol no 31/8/2012

Conclusão: poucas chances para a vida em planetas da Trappist-1



Escalas de tempo desde a origem da Terra.

Quase 4,6 bilhões de anos até civilização



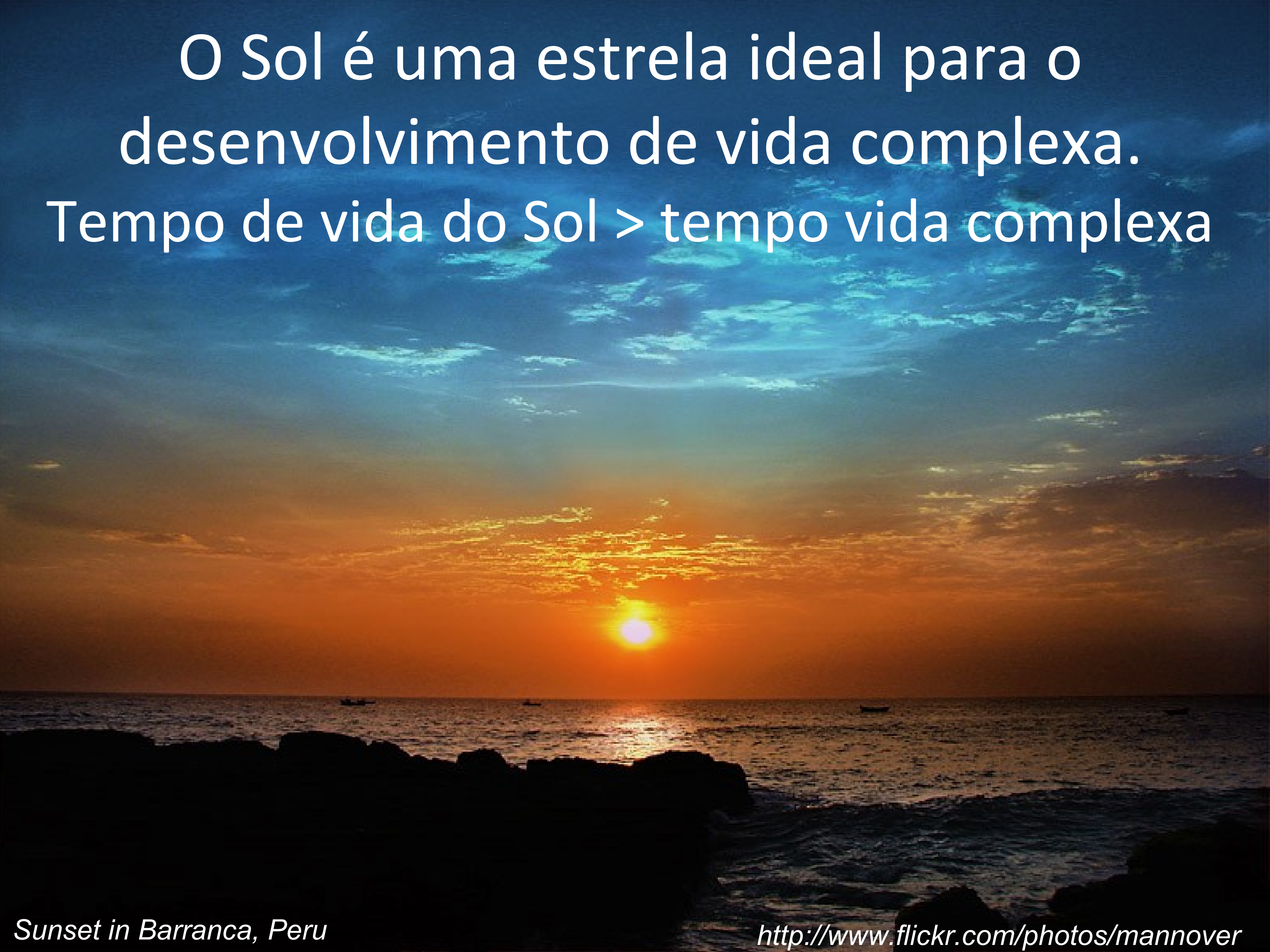
Vida complexa (há 500 milhões anos)

Nossa civilização

Vida Primitiva há 3,5 bi anos

O Sol é uma estrela ideal para o desenvolvimento de vida complexa.

Tempo de vida do Sol > tempo vida complexa



Sunset in Barranca, Peru

http://www.flickr.com/photos/mannover

Sol (G2V)

1 Massa Sol
1 Raio Sol
1 Lumin. Sol

Idade: 4,6 bilhões anos
Vida total: 10 bilhões anos

Ups And (F8V)

1,3 Massa Sol
1,5 Raio Sol
3,5 Luminosidade Sol

Idade: 3 bilhões anos
Vida total: 4,5 bilhões anos

Procura de planetas em gêmeas do Sol, no Observatório **ESO La Silla: 100 noites** (88+12)

Projeto internacional liderado pela USP (Prof. Jorge Melendez).

Brasil, EUA, Alemanha, Austrália

HARPS, precisão de 1m/s

© Ana M. Molina at La Silla

A&A 581, A34 (2015)

The Solar Twin Planet Search

II. A Jupiter twin around a solar twin★

M. Bedell[1,★★], J. Meléndez[2], J. L. Bean[1], I. Ramírez[3], M. Asplund[4], A. Alves-Brito[5]

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e-mail: mbedell@oddjob.uchicago.edu

[2] Departamento de Astronomia do IAG/USP, Universidade de São Paulo, Rua do Matão 1226, Cidade Universitária, 05508-900 São Paulo, SP, Brazil

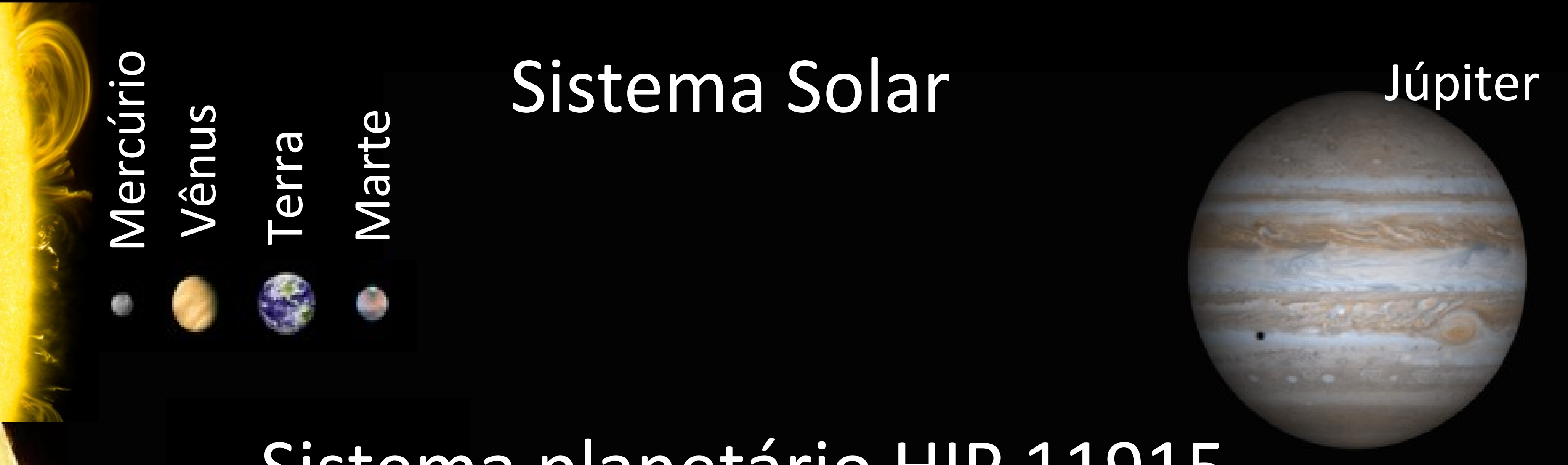
[3] McDonald Observatory and Department of Astronomy,

[4] Research School of Astronomy and Astrophysics, The

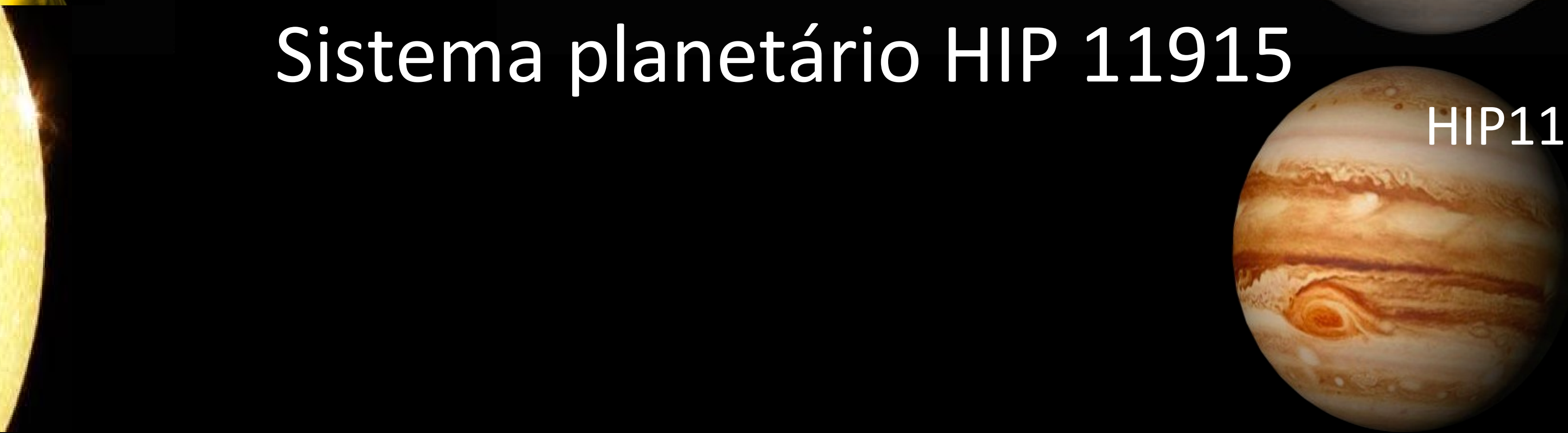
[5] Instituto de Fisica, Universidade Federal do Rio Grand

Parameter		Value
P	[days]	3830
K	[m s^{-1}]	12.9
e		0.10
$\omega + M_0$	[rad]	3.0
ω - M_0	[rad]	2.4
α	[m s^{-1} (unit S_{HK})$^{-1}$]	160
C	[m s^{-1}]	–11.0
σ_J	[m s^{-1}]	1.8
$m_p \sin(i)$	[M_{Jup}]	0.99
a	[AU]	4.8

Sistema Solar



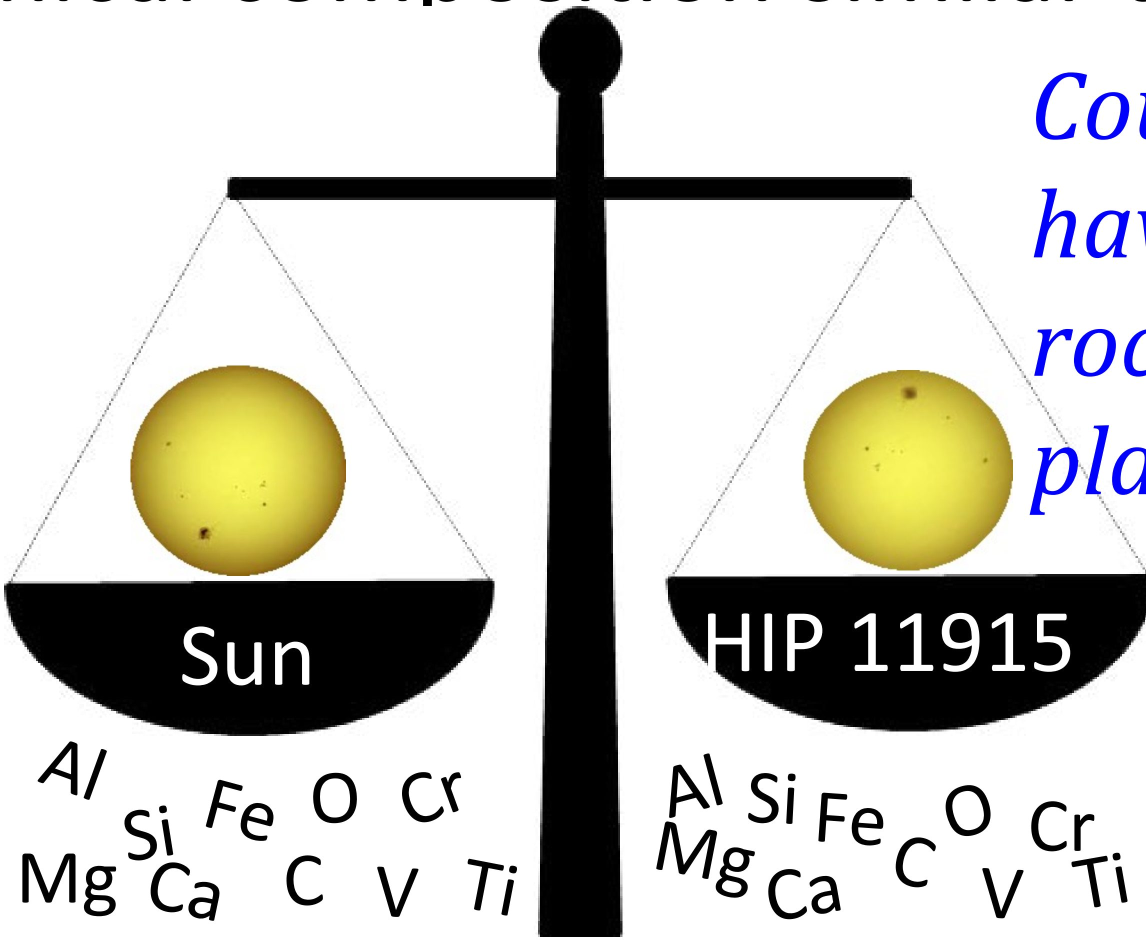
Sistema planetário HIP 11915



Sistema potencialmente habitável e com idade ~10% inferior ao Sol (vida complexa)

HIP 11915

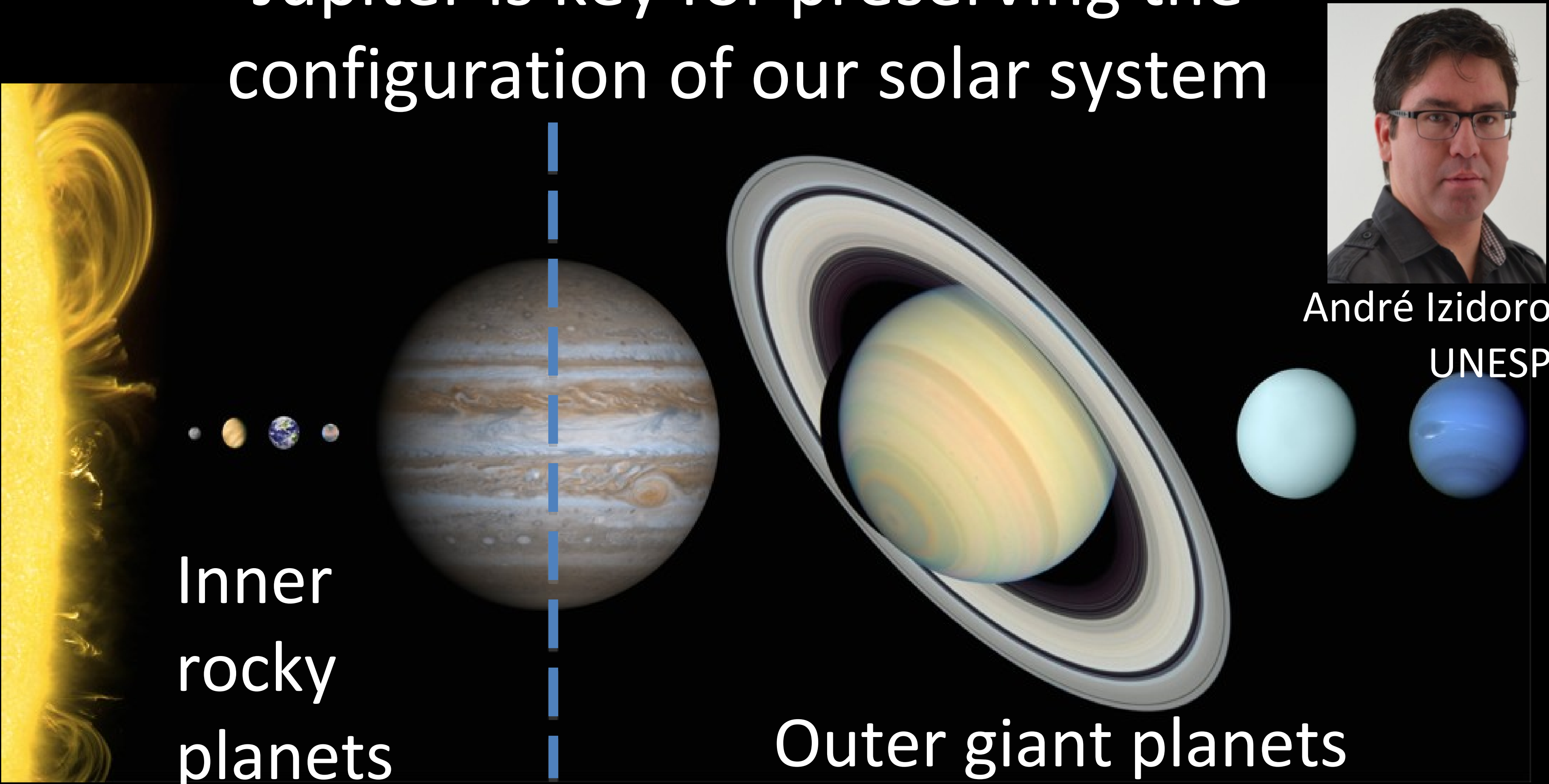
Chemical composition similar to the Sun



Could also have formed rocky planets !

Jupiter is key for preserving the configuration of our solar system

André Izidoro
UNESP

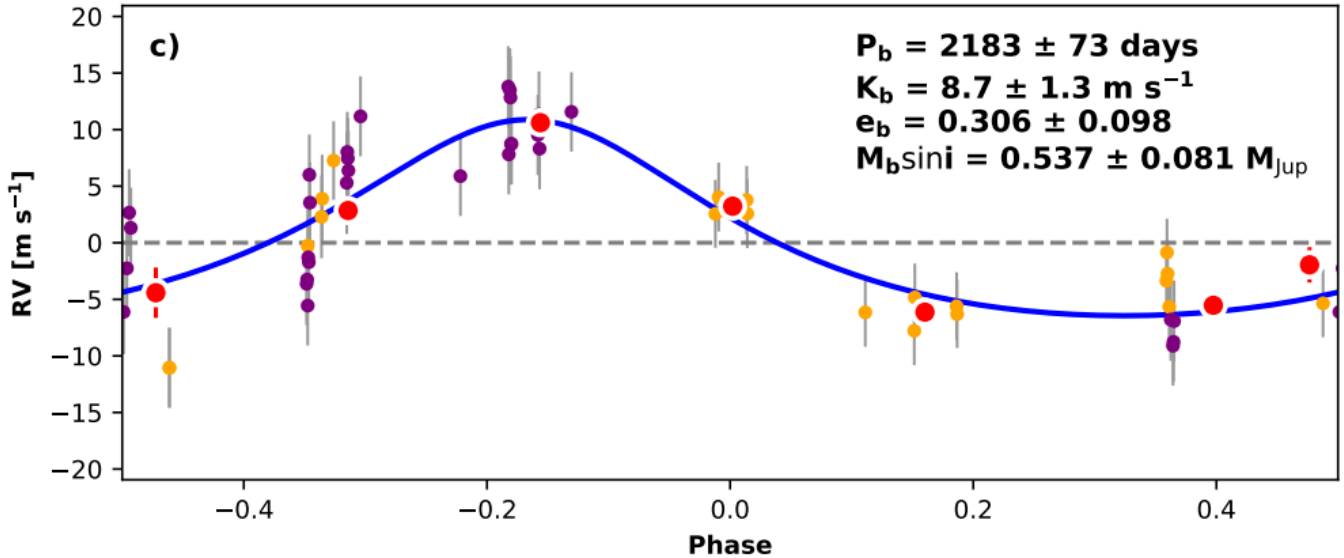


Gas Giant Planets as Dynamical Barriers to Inward-Migrating Super-Earths

Izidoro et al. 2015, ApJ Letters, 800, L22

Here, we use a suite of dynamical simulations to show that gas giant planets act as barriers to the inward migration of super-Earths initially placed on more distant orbits. Jupiter's early formation may have prevented Uranus and Neptune (and perhaps Saturn's core) from becoming hot super-Earths.

A new Jupiter analog



Jupiter analog (Wittenmyer et al. 2016; Rowan et al. 2016):

$M > M_{Saturn} = 0.3\ M_{Jup}$

Period = 5 – 15 years

a ~ 3 – 6 AU

e ≤ 0.3

A Jupiter analogue orbiting the solar-twin star HIP 104045

Thiago Ferreira,[1★] Jorge Meléndez[1], Diego Lorenzo-Oliveira[1], Jacob L. Bean[2], Lorenzo Spina[3], and Megan Bedell[4].

[1] *Universidade de São Paulo, Instituto de Astronomia, Geofísica e Ciências Atmosféricas, 05508-090, São Paulo, Brazil.*
[2] *Department of Astronomy & Astrophysics, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA.*
[3] *INAF Osservatorio Astronomico di Padova, vicolo dell'Osservatorio 5, 35122, Padova, Italy.*
[4] *Center for Computational Astrophysics, Flatiron Institute, 162 5th Avenue, New York, NY 10010, USA*

Period: 8 years

Mass [M_{Jup}]: 0.5 ± 0.1

Eccentricity: 0.3 ± 0.1

Semi-major axis [AU]: 3.3 ± 0.1

How many Jupiter analogs?

$M > M_{Saturn} = 0.3\ M_{Jup}$
Period = 5 – 15 years
a ~ 3 – 6 AU
$e \leq 0.3$

We (in prep.)
66 solar twins, HARPS/ESO: 3 ± 2 %, or 4.5 ± 1.7 %

Wittenmyer et al. 2016
1122 stars, Keck/HIRES: 3 [-2,+1] %

Rowan et al. 2016
202 stars, AAT: 4 [-1,+2] %, or 6 [-2,+3] %

➡ **Só ~ 3 - 5% de estrelas de tipo solar têm planetas análogos a Júpiter**

- Pelo menos 100 bilhões de estrelas na Galáxia
- 10% (10 bilhões) são estrelas de tipo solar
- 3% têm gêmeos de Júpiter → 300 milhões de estrelas com planetas potencialmente habitáveis na Via Láctea!

S E T I

Search for Extraterrestrial Intelligence

- Active SETI: send messages to other civilizations
- Passive SETI: detect signals

- How many planets out there?
- How many potentially habitable?
- How many with life?
- How many with civilizations?
- How long civilizations last?

Equação de Drake: muito incerta: 1? 100? 1 milhão?

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

Carl Sagan: A Terra, um pálido ponto azul

"Aquele é o nosso lar. Somos nós. Nele estão todos aqueles que você ama, todos aqueles que você conhece, todos de quem você já ouviu falar, todos os seres humanos que já existiram, todos que já viveram suas vidas."

"Nosso lar. A totalidade de nossas alegrias e sofrimentos, milhares de religiões, ideologias e doutrinas econômicas, todos os caçadores e saqueadores, todos os heróis e covardes, cada criador e destruidor de civilizações, cada rei e camponês, cada jovem casal de namorados"