

A decorative vertical bar on the left side of the slide features a light gray background with a subtle circular pattern. A small yellow circle, representing a planet, is positioned near the top center of the bar, accompanied by two smaller yellow dots above and below it.

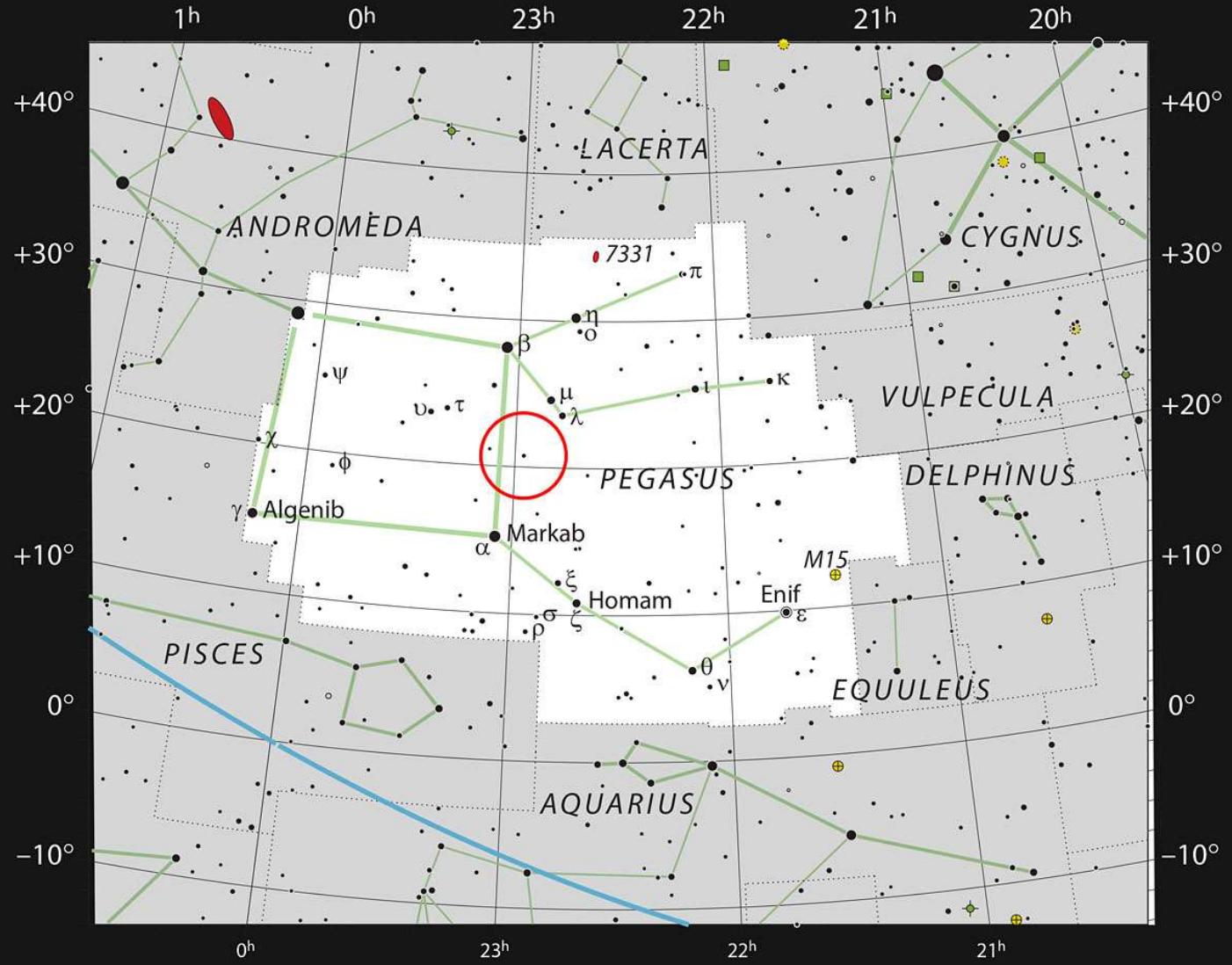
# EKSOPLANET

## *– Perjalanan Panjang Menemukan Dunia Lain*

T. HIDAYAT

Department of Astronomy – Bosscha Observatory ITB

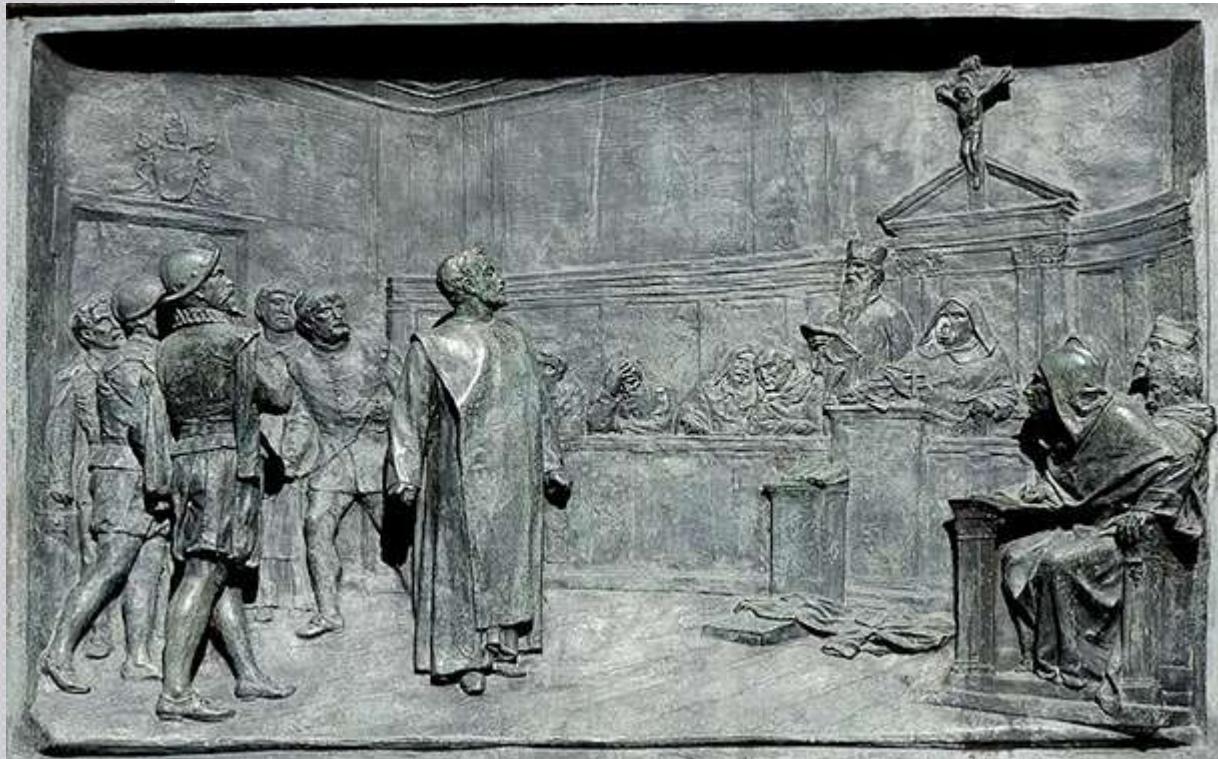
Malam Umum Virtual Observatorium Bosscha – 29 Agustus 2020



1  2  3  4  5  6

# Keyakinan adanya Eksoplanet

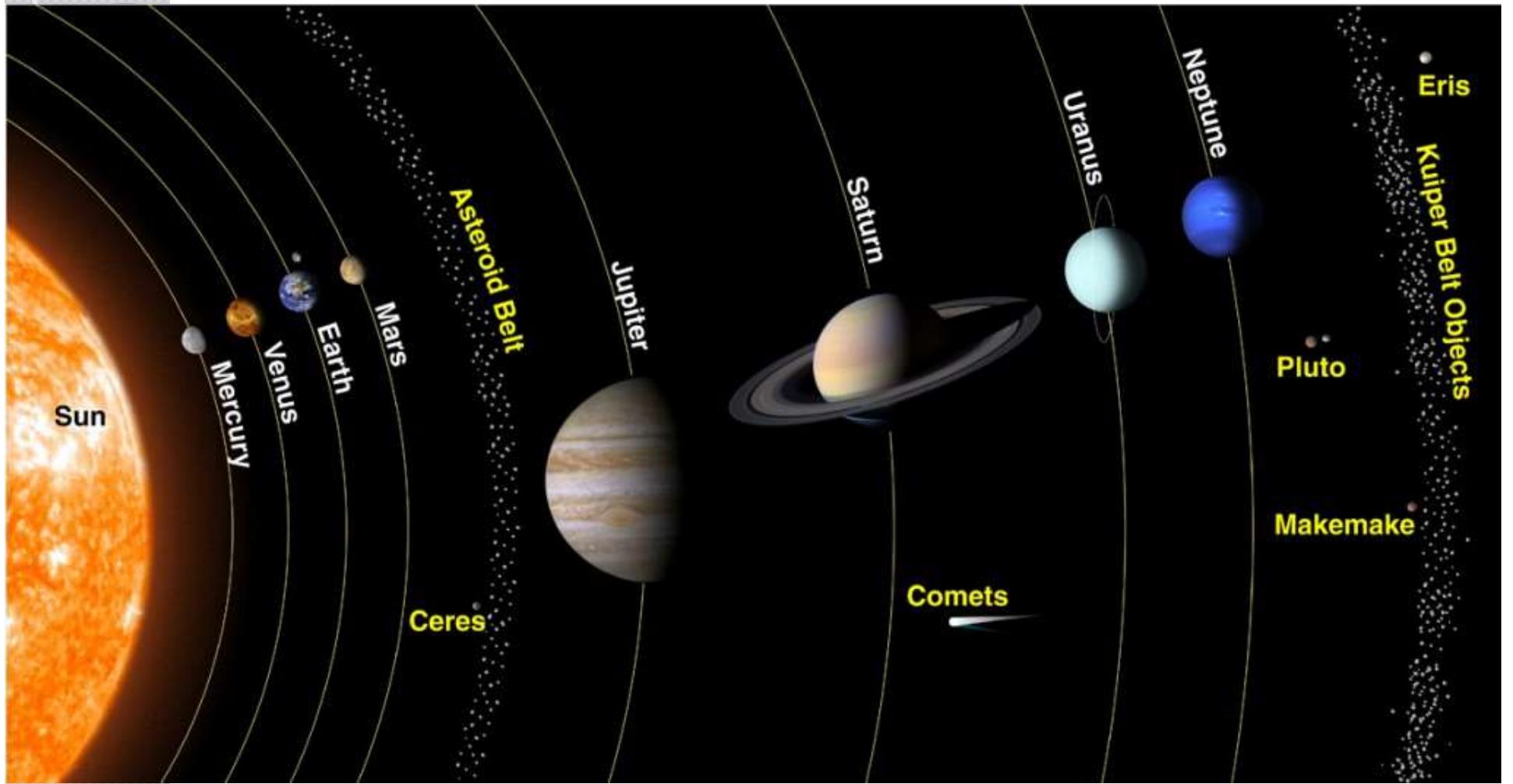
Giordano Bruno (1600):“Bumi adalah salah satu dari tak berhingga planet di alam semesta”



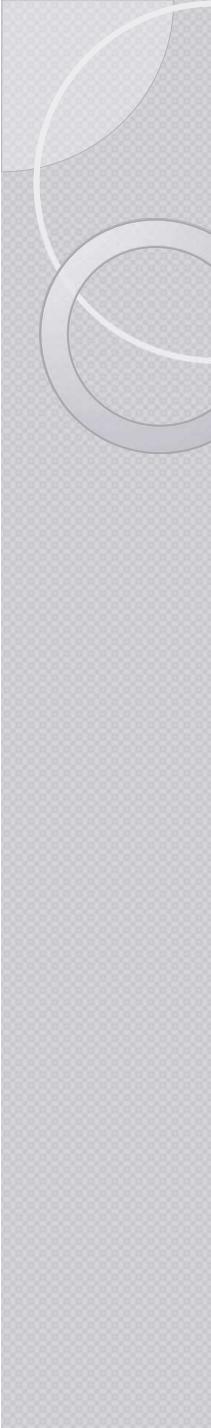
The trial of Giordano Bruno by the Roman Inquisition. Bronze relief by Ettore Ferrari, Campo de' Fiori, Rome.

Sumber: <https://www.historytoday.com/archive/giordano-bruno-executed>

# Tata Surya



Sumber: <https://theplanets.org/solar-system/>



# Mencari eksoplanet

- Planet-planet di luar Tata Surya (eksoplanet) itu betul-betul ada
- Pencarian secara “teleskopik” telah lama dilakukan (1930-an)
- Mulai 1992, jumlah yang terus bertambah...
- Apakah Tata Surya contoh typical?
- Seperti apa sistem keplanetan yang lain?

# The Nobel Prize in Physics 2019



© Nobel Media. Photo: A.  
Mahmoud

**James Peebles**



© Nobel Media. Photo: A.  
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**Michel Mayor**

"for the discovery of an exoplanet orbiting a solar-type star"



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**Didier Queloz**

Sumber: <https://www.nobelprize.org/prizes/physics/2019/summary/>

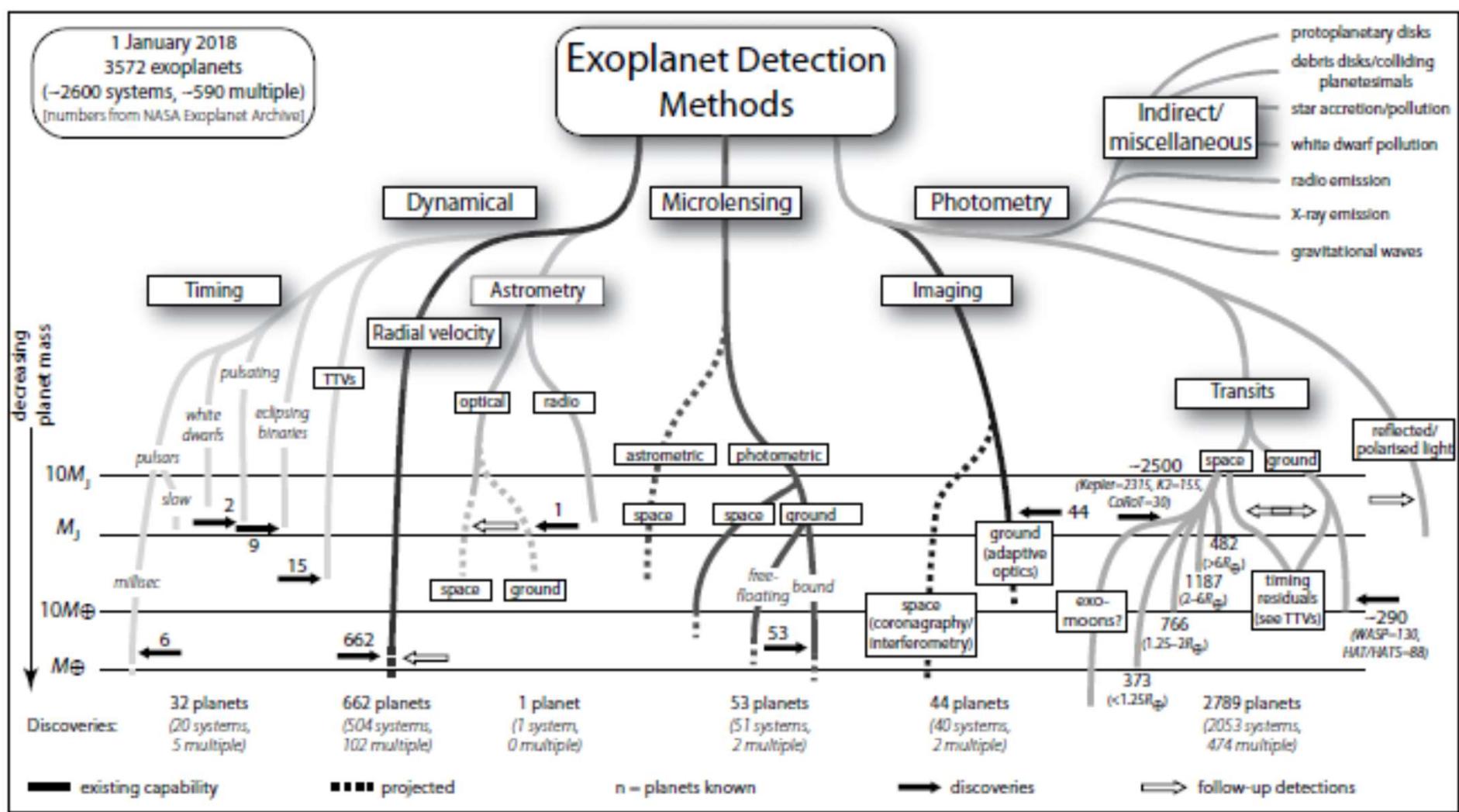
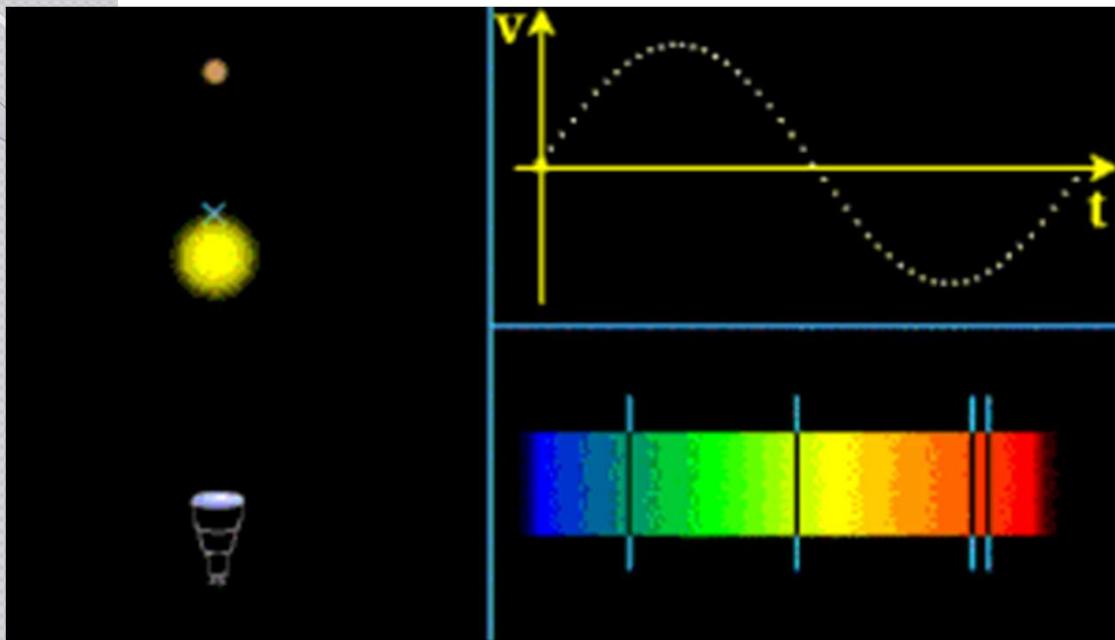
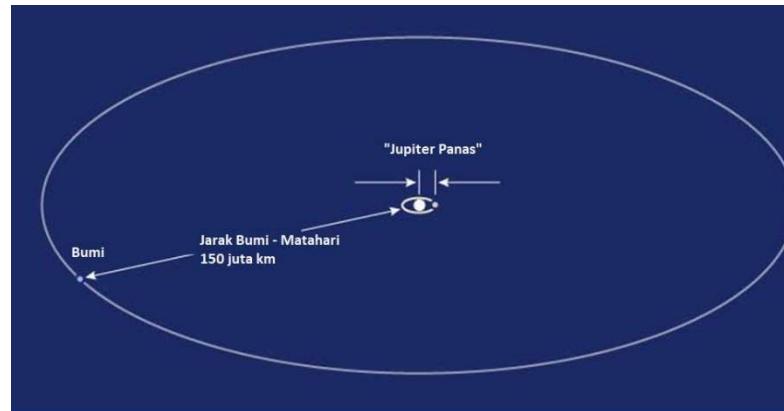


Figure 1.1: Exoplanet detection methods. The lower limits of the lines indicate masses within reach of present measurements (solid lines), and those that might be expected within the next few years (dashed). The (logarithmic) mass scale is shown at left. Miscellaneous signatures to the upper right are less well quantified in mass terms. Solid arrows show relevant discoveries. Open arrows indicate measurements of previously-detected systems. Numbers are from the NASA Exoplanet Archive, 2018 January 1.

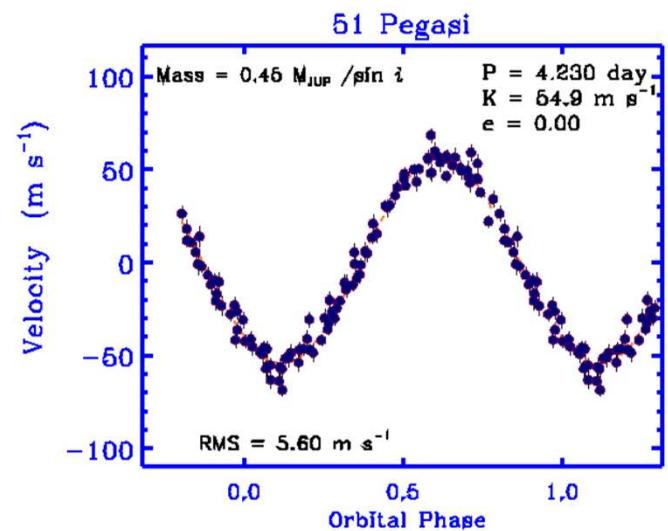
# 51 Peg b: Metode Kecepatan Radial



<https://platomission.com/2018/05/20/the-radial-velocity-method/>

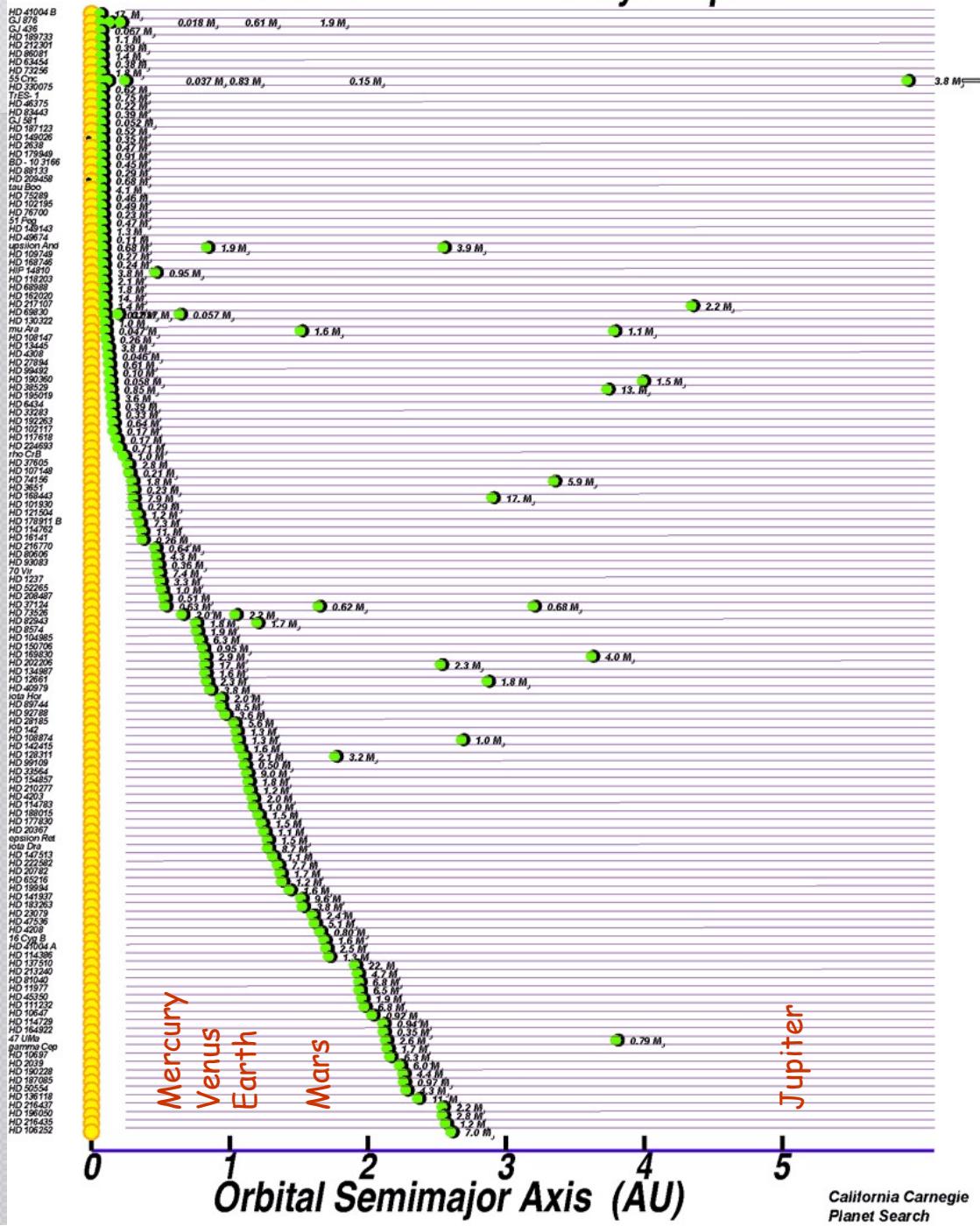


<https://www.daviddarling.info/encyclopedia/A/51Peg.html>



Mayor & Queloz, Nature 1995

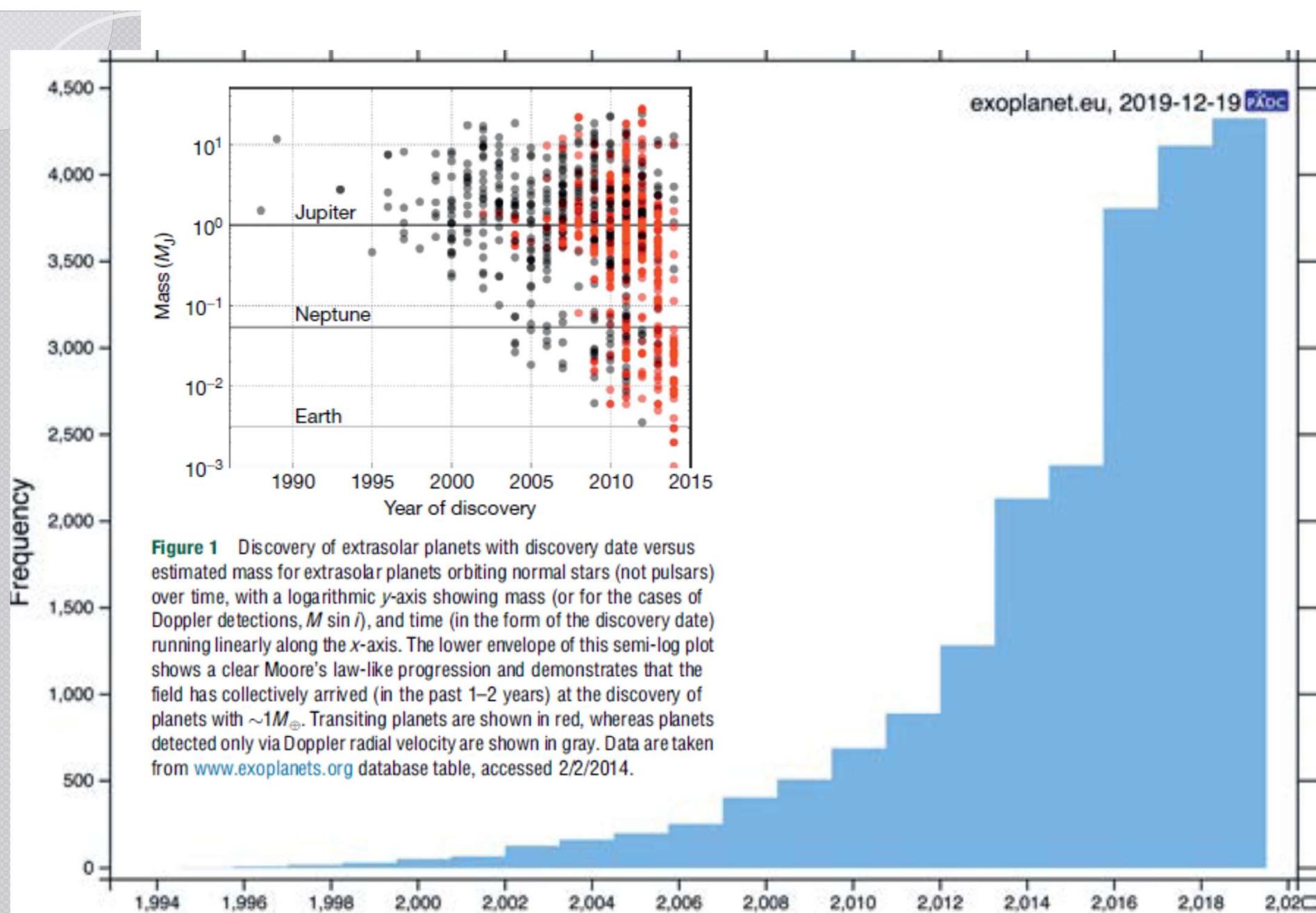
## The 178 Known Nearby Exoplanets



Pada awalnya...

Eksoplanet yang ditemukan:

- Planet raksasa seperti Jupiter atau Saturnus pada jarak orbit yang sangat dekat dengan bintang induknya (sampai 200 kali lebih dekat daripada Jupiter): "Jupiter Panas"
- Contoh lain: OGLE-TR-56b, massa =  $1,45 M_{Jup}$ , periode orbit = 1,21 hari, radius orbit = 0,0225 sa ( $\sim 3,4$  juta km)



**Figure 1** Discovery of extrasolar planets with discovery date versus estimated mass for extrasolar planets orbiting normal stars (not pulsars) over time, with a logarithmic y-axis showing mass (or for the cases of Doppler detections,  $M \sin i$ ), and time (in the form of the discovery date) running linearly along the x-axis. The lower envelope of this semi-log plot shows a clear Moore's law-like progression and demonstrates that the field has collectively arrived (in the past 1–2 years) at the discovery of planets with  $\sim 1 M_{\oplus}$ . Transiting planets are shown in red, whereas planets detected only via Doppler radial velocity are shown in gray. Data are taken from [www.exoplanets.org](http://www.exoplanets.org) database table, accessed 2/2/2014.

24 Agustus 2020:

4329 planets / 3199 planetary systems / 708 multiple planet systems

Year of Discovery (year)

# HD 209458

## Fotometri Transit

### Planetary parameters

Radius	1.35 Jupiter-radii
Mass	0.71 Jupiter-mass
Distance to host star	0.045 AU (10x closer to its star than Mercury to the sun)
Orbital Period	3.5 days
Temperature	~1100 K

[exoplanet.eu](http://exoplanet.eu)

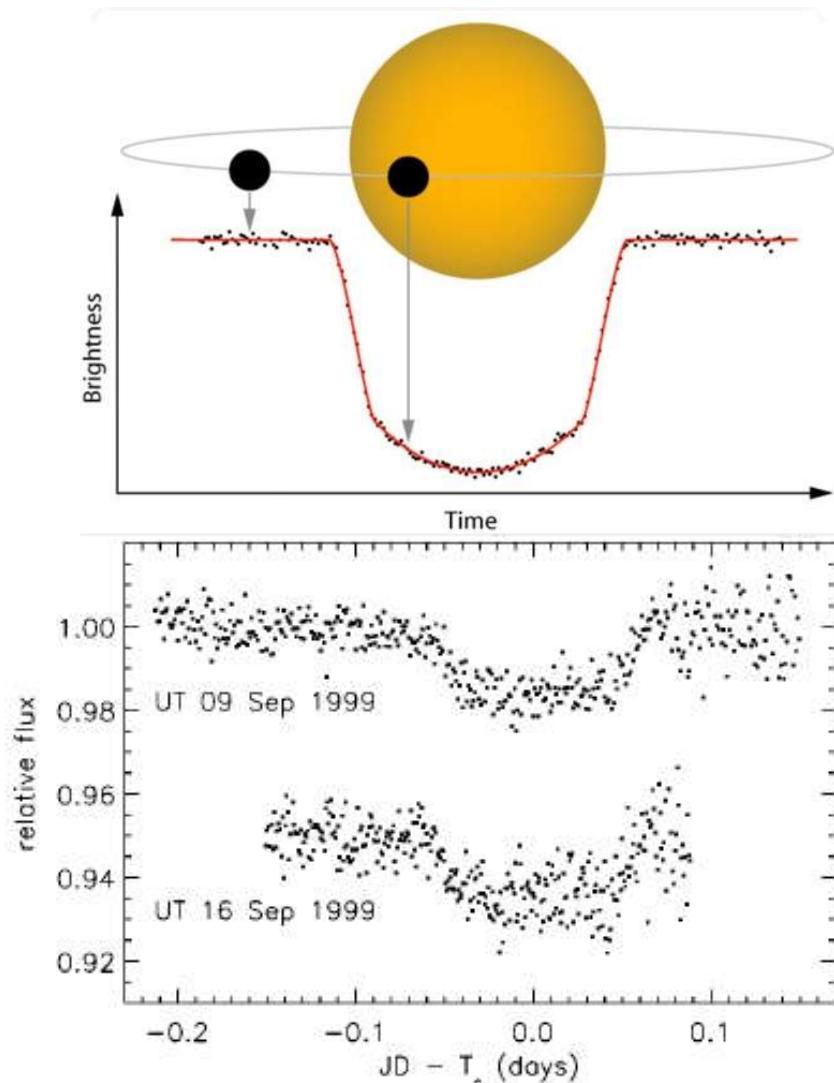


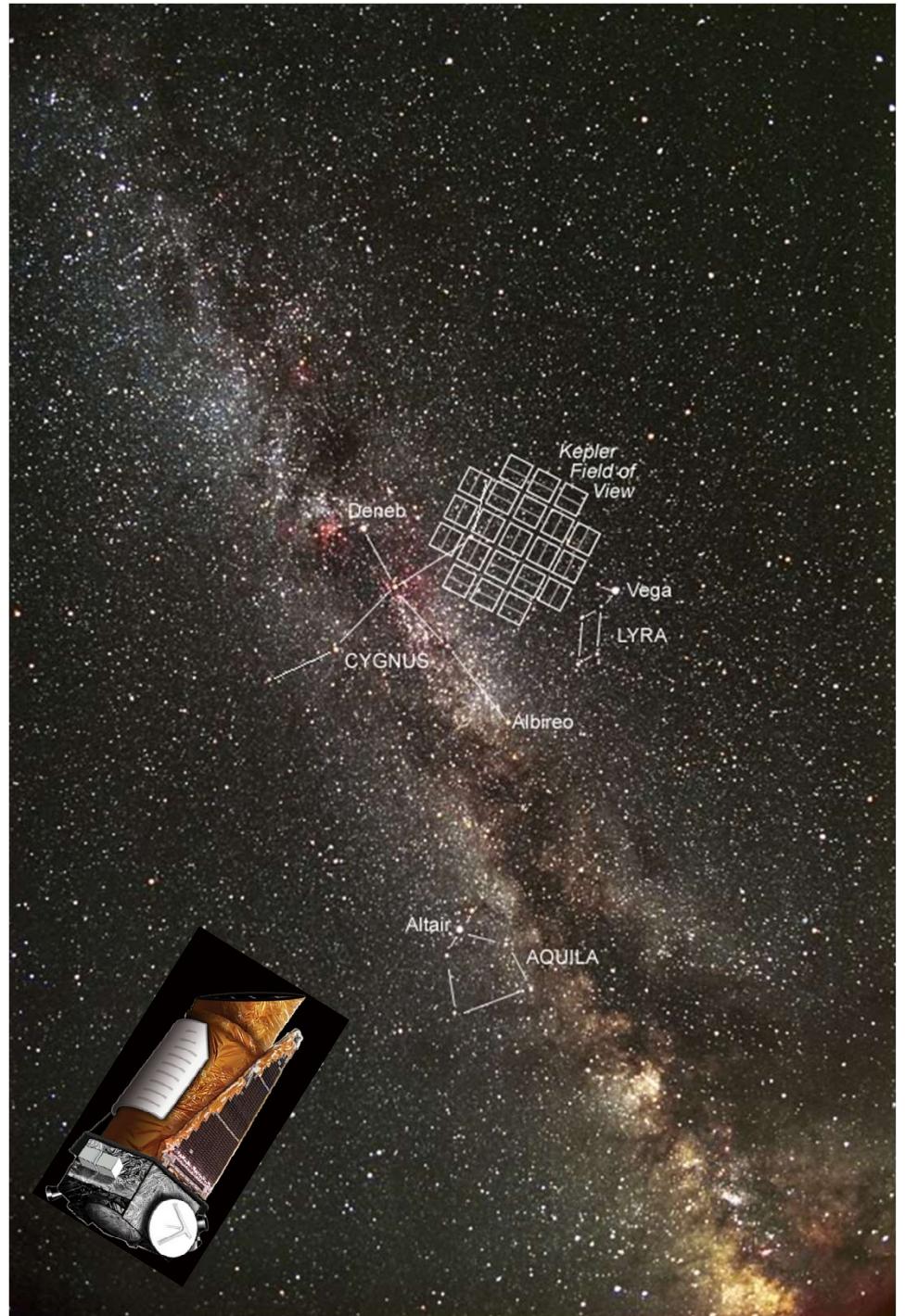
FIG. 1.—Shown are the photometric time series, corrected for gray and color-dependent extinction, for 1999 September 9 and 16 plotted as a function of time from  $T_c$ . The rms of the time series at the beginning of the night on September 9 is roughly 4 mmag. The increased scatter in the September 16 data relative to the September 9 data is due to the shorter exposure times. The data from September 16 are offset by  $-0.05$  relative to those from September 9.

Charbonneau et al., ApJ, 2000

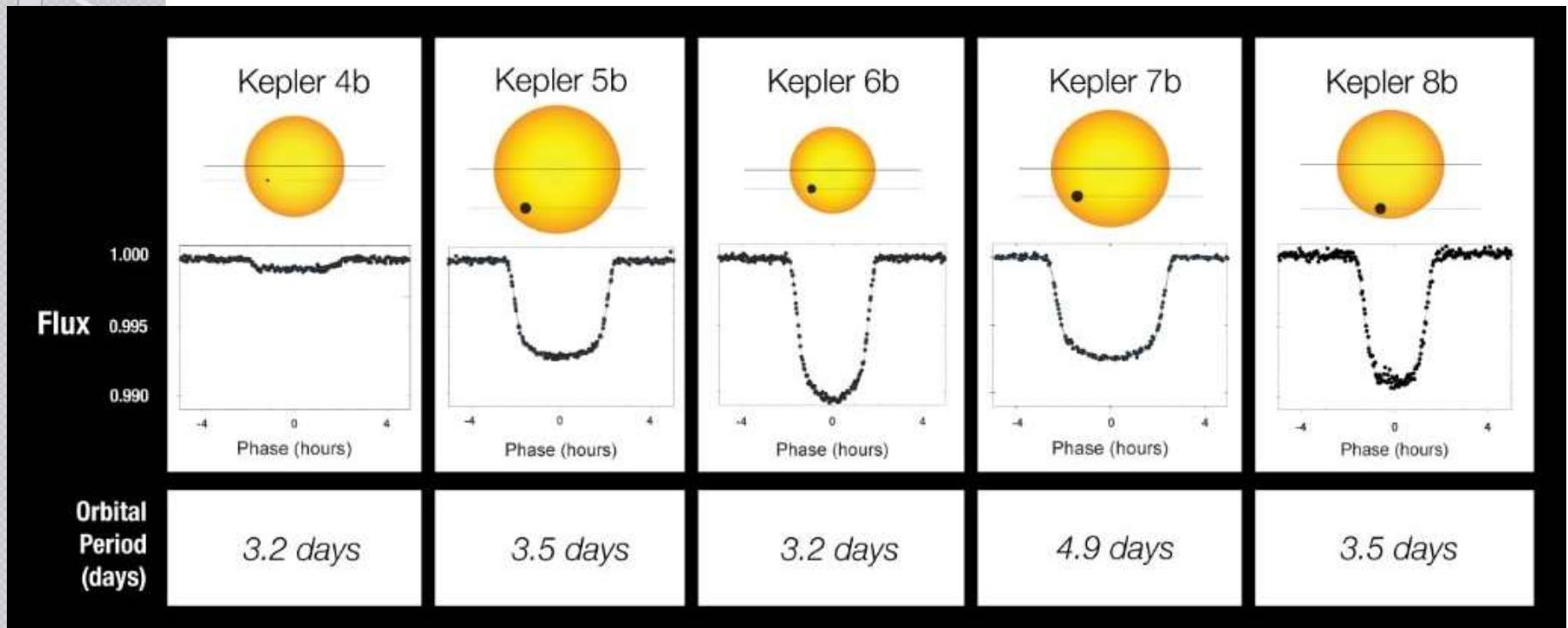
# MISI

# *Kepler*

- Menjawab: adakah planet lain seperti Bumi?
- Memonitor ~150,000 bintang (2009 – 2013)
- Kamera Schmidt dengan CCD 95 Mpx
- Nov 2015: confirmed planets: 1030, planet candidates: 4696, bintang ganda gerhana: 2165



# Kurva Cahaya Transit



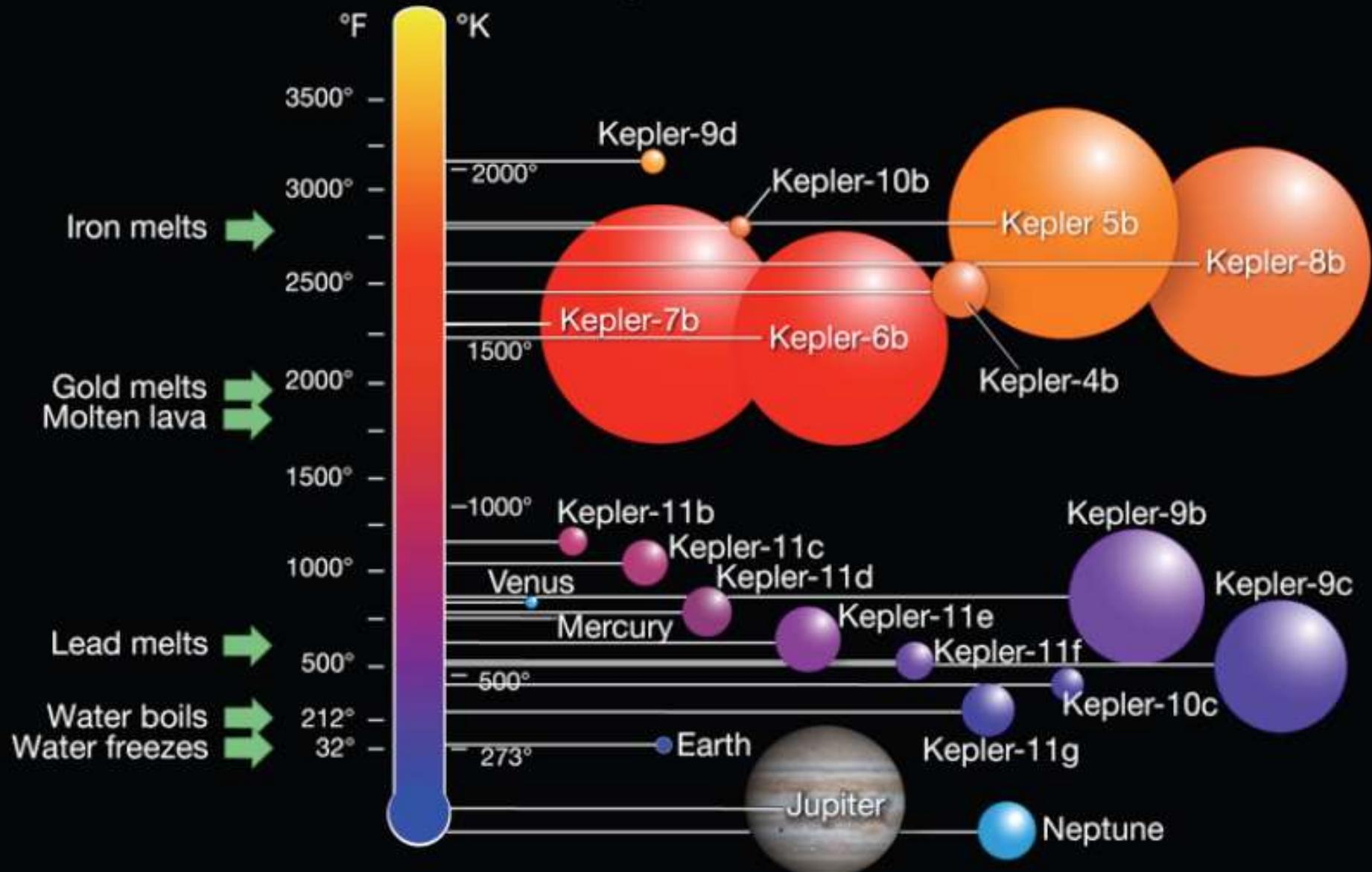
# Kepler Planets

As of February 27, 2012



Planet diversity!

# Planet Temperature & Size



# Kategori Planet

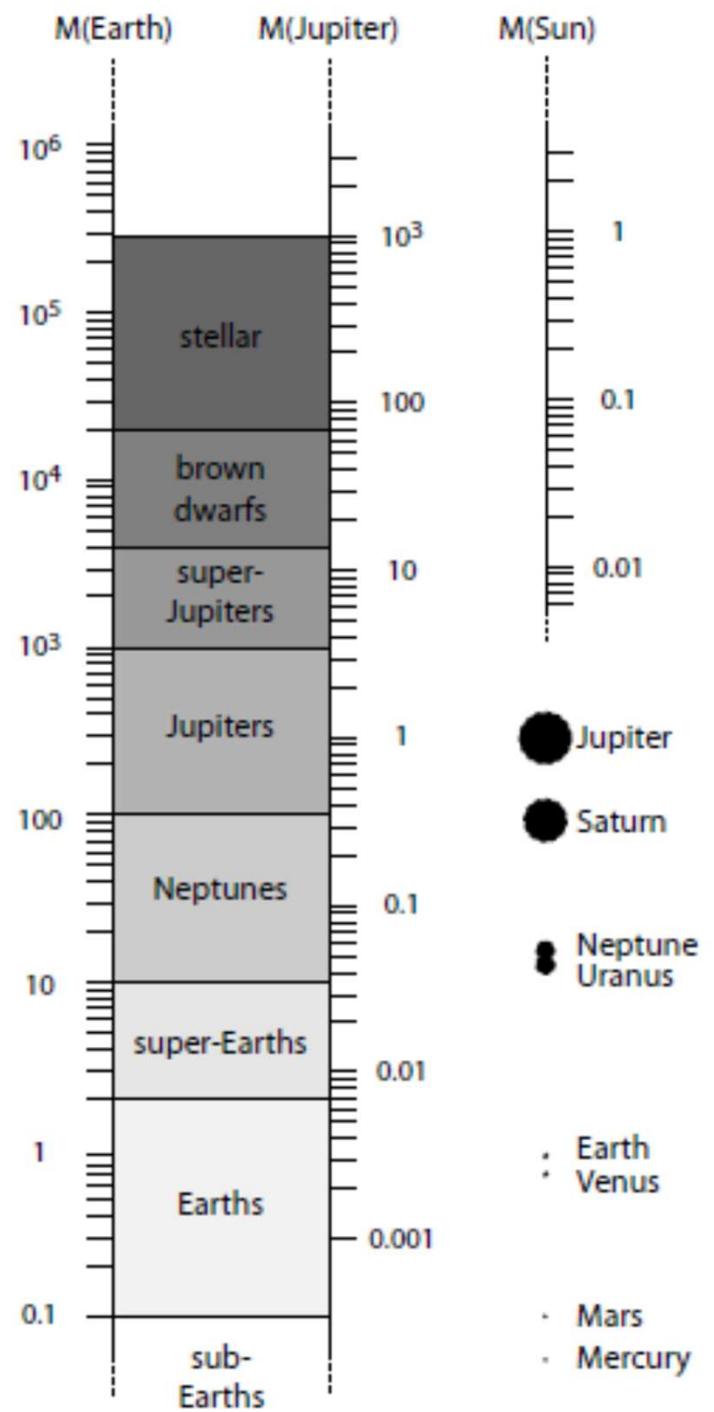
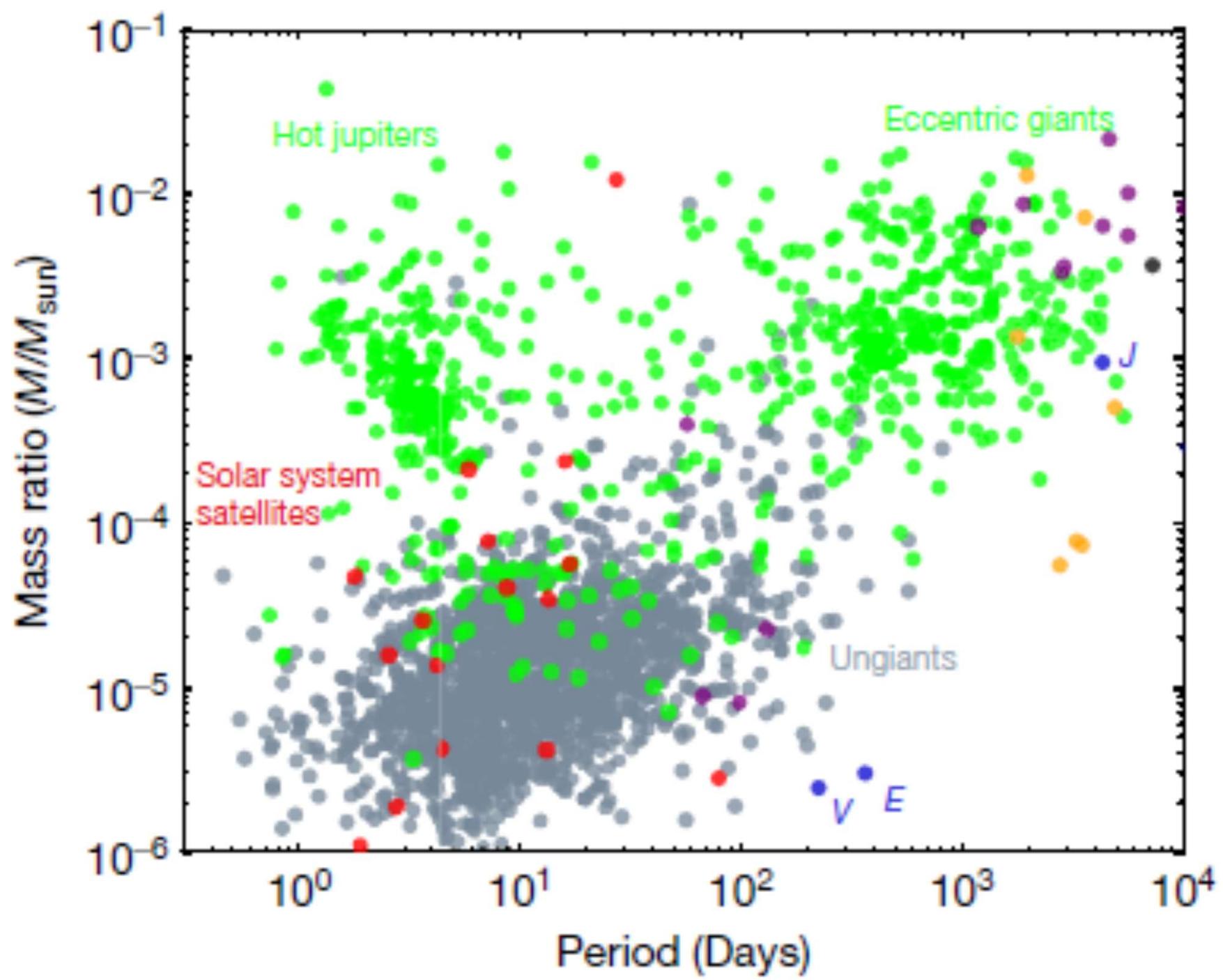
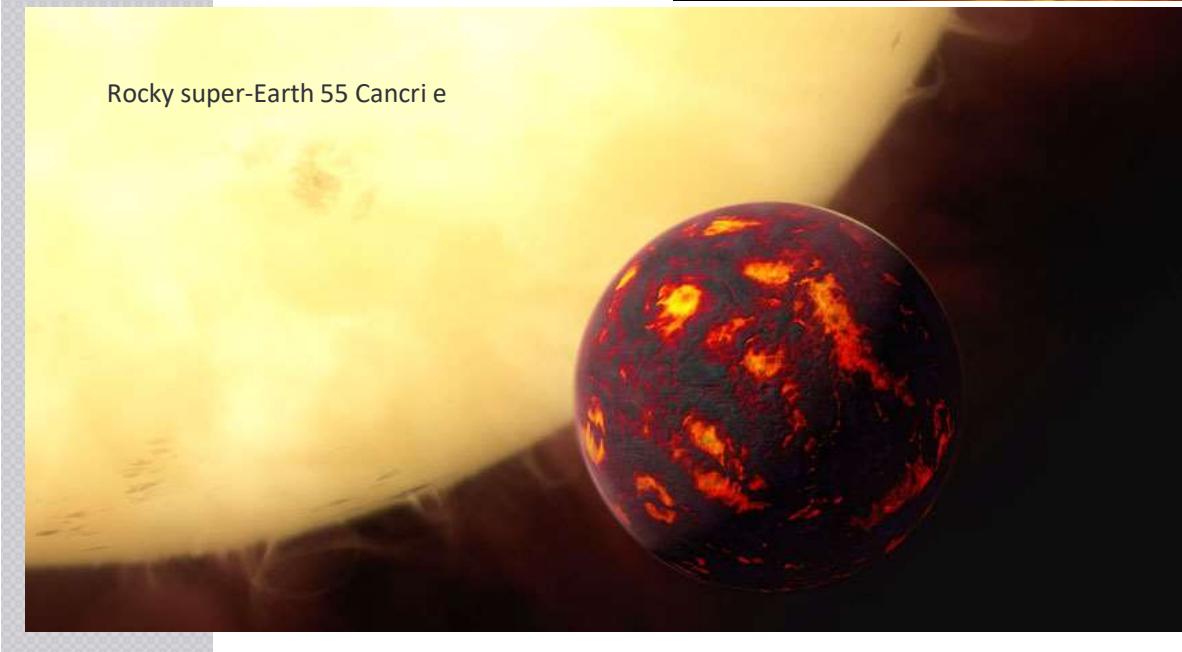
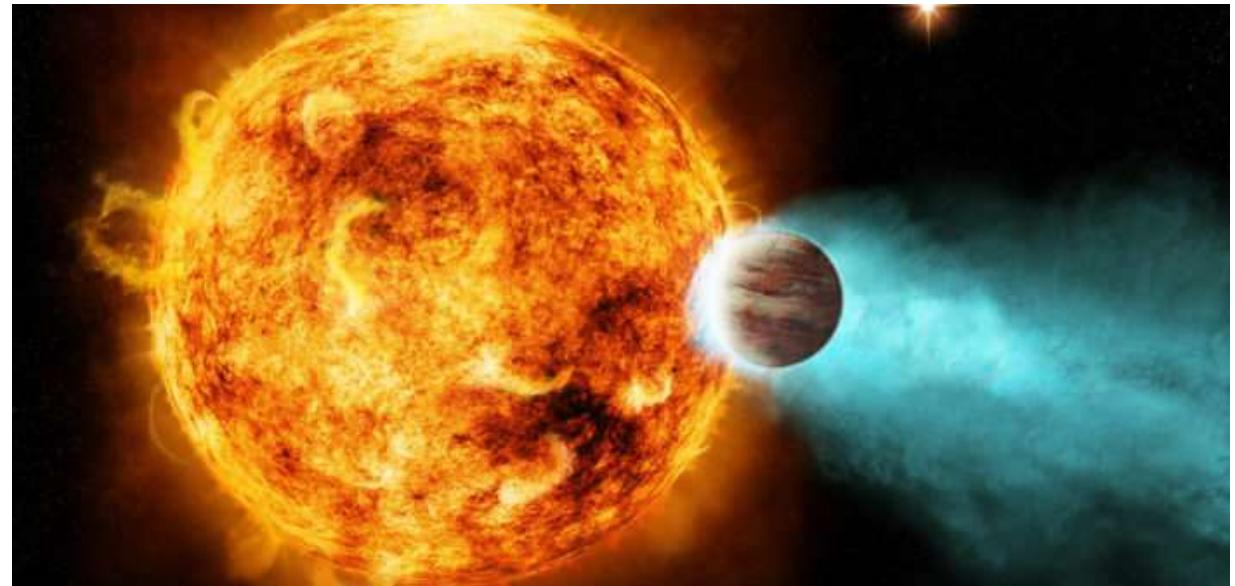


Figure 1.5: The classification of planet masses according to solar system objects, following the proposal by Stevens & Gaudi (2013). Masses of the solar system planets are shown at the right, with a circle size proportional to planet radius.



# Berbagai “nasib” eksoplanet



Rocky super-Earth 55 Cancri e



Kepler 10b

# Planet Jenis Baru: Super Bumi!

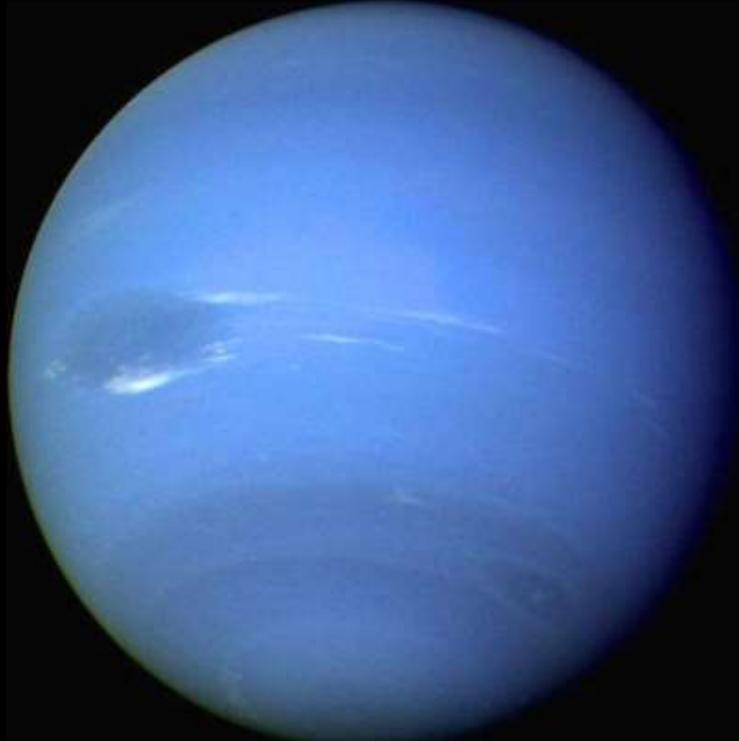
- Planet yang tidak dikenal di Tata Surya
- Berukuran antara Bumi dan Neptunus
- Bermassa sekitar 1 – 3 kali massa Bumi
- Dapat berupa planet yang didominasi oleh air (water world)



Bumi

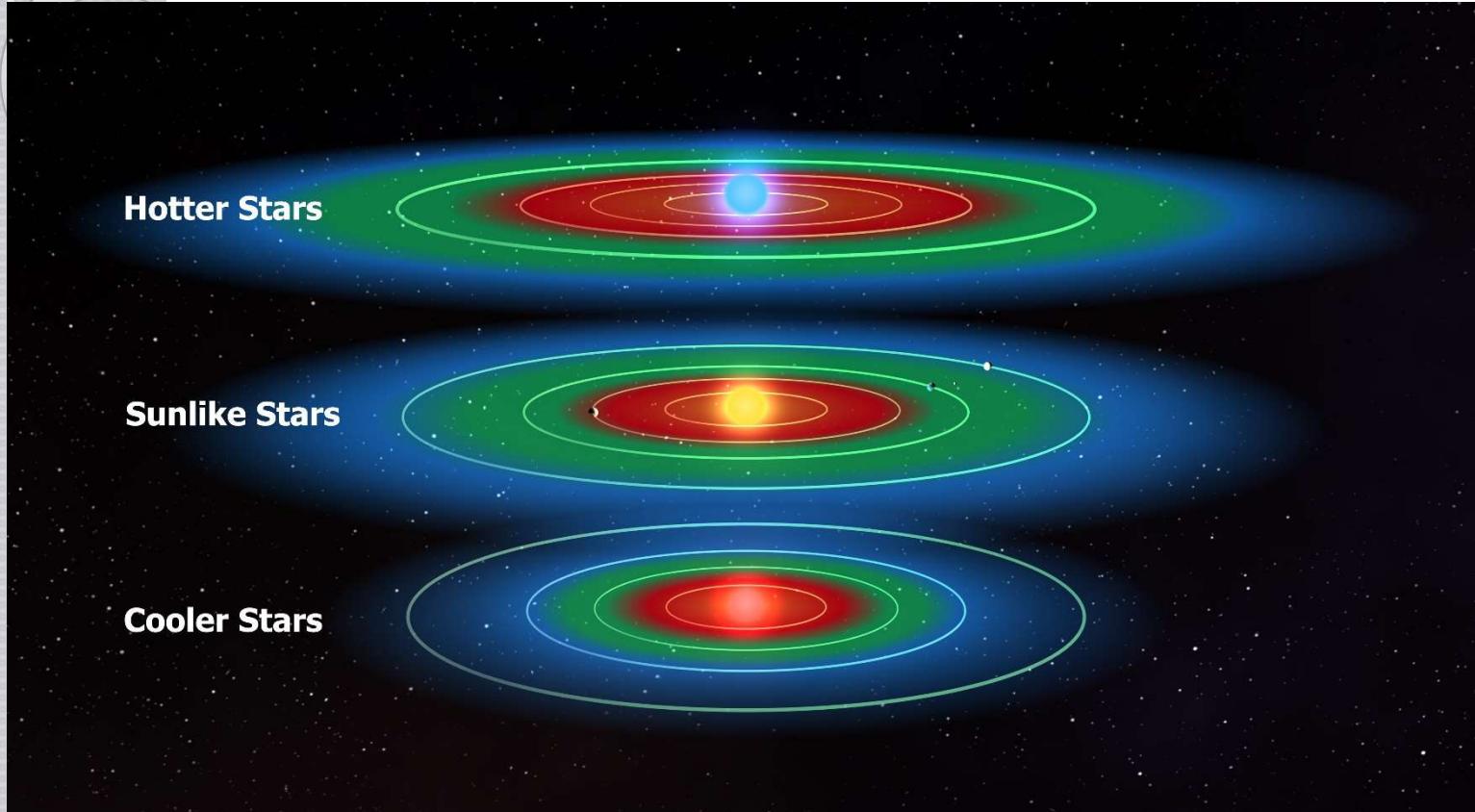


Gliese 832c  
Kepler 44b  
Corot 7b



Neptunus

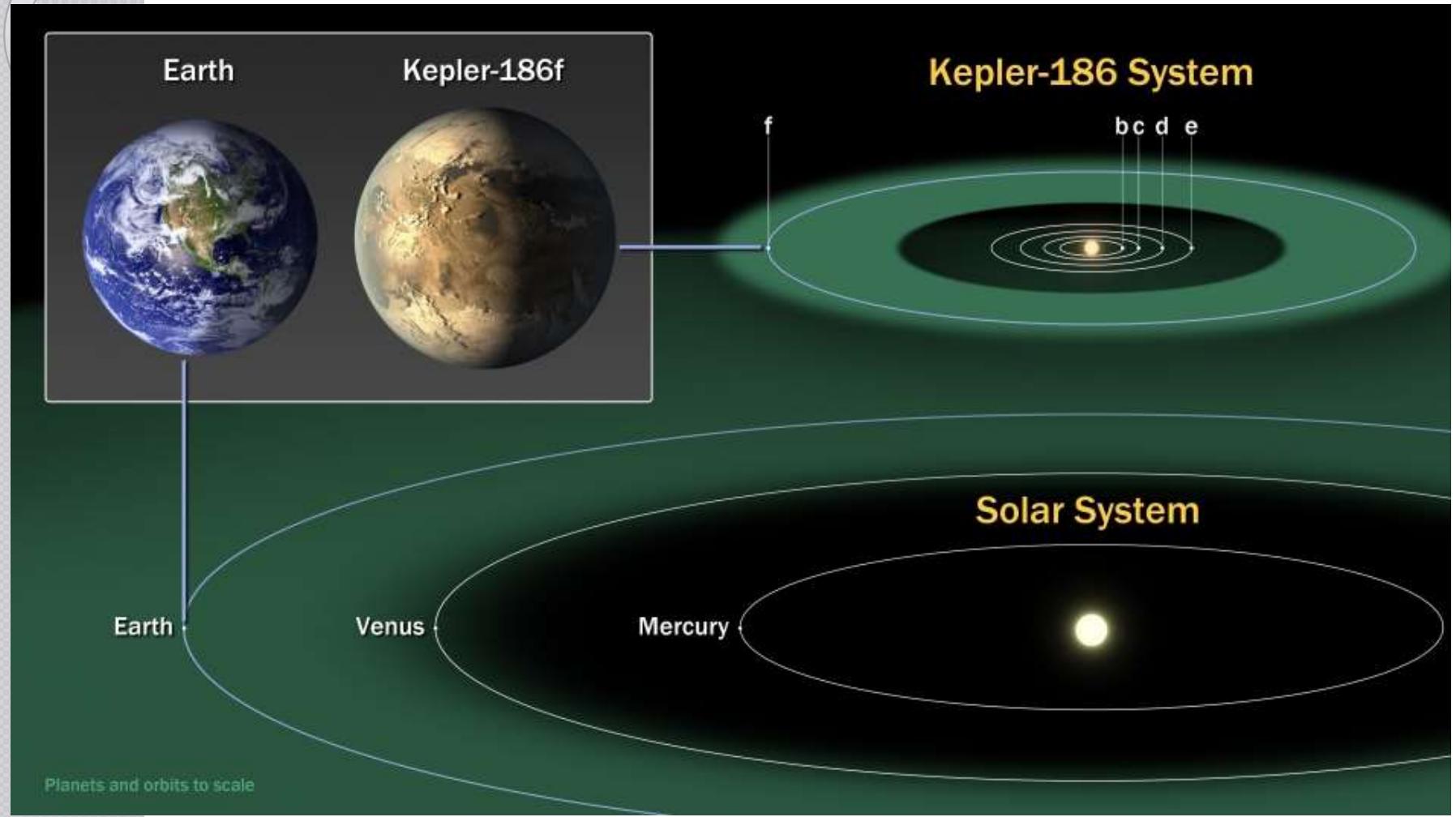
# Habitable Zone (HZ) → Goldilocks Zone

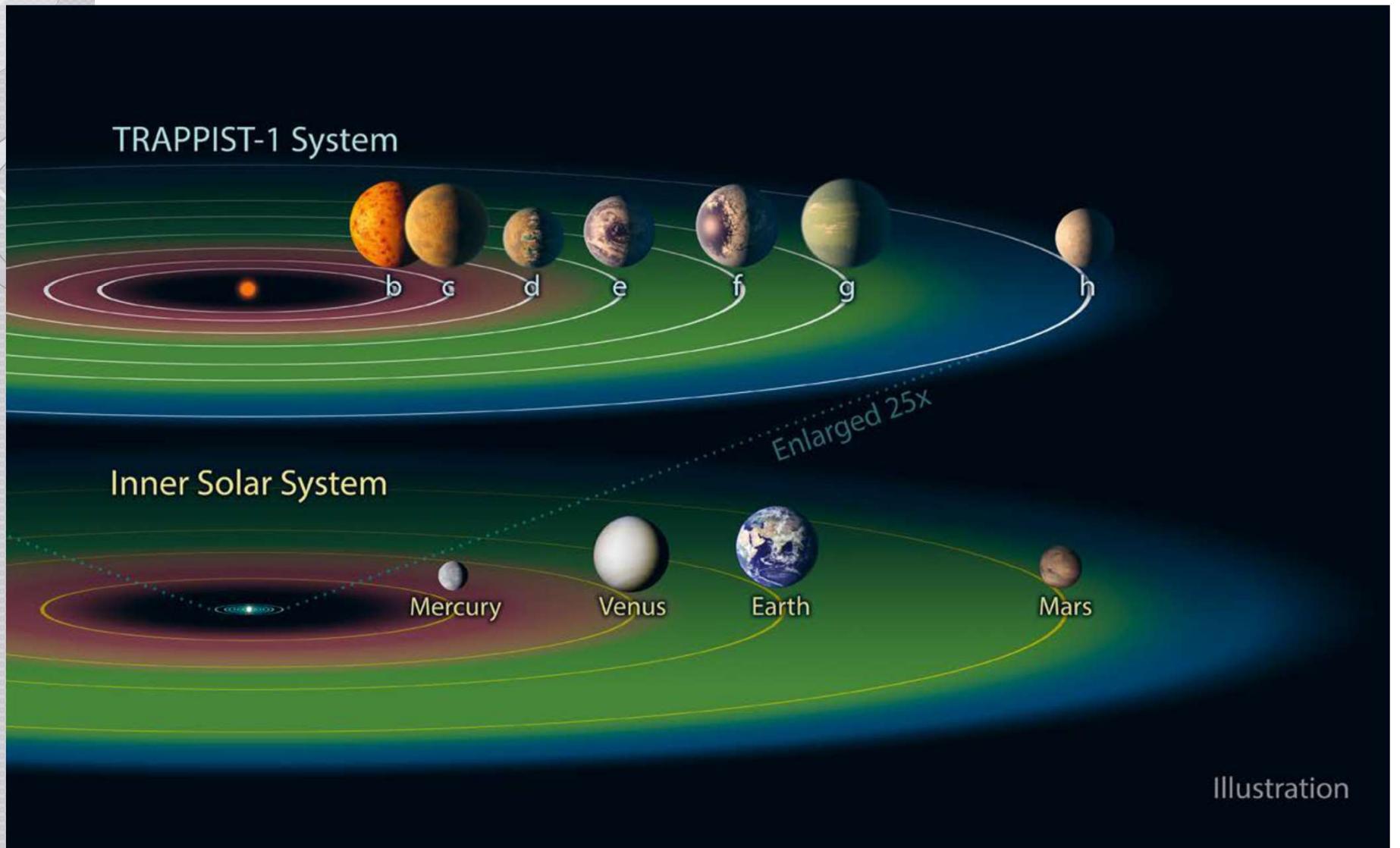


Credit: NASA  
Ames/SETI  
Institute/D.  
Berry

*Habitable zone* — daerah di mana air dalam keadaan cair dapat ditemukan di suatu planet; jaraknya bervariasi bergantung pada bintang induknya.

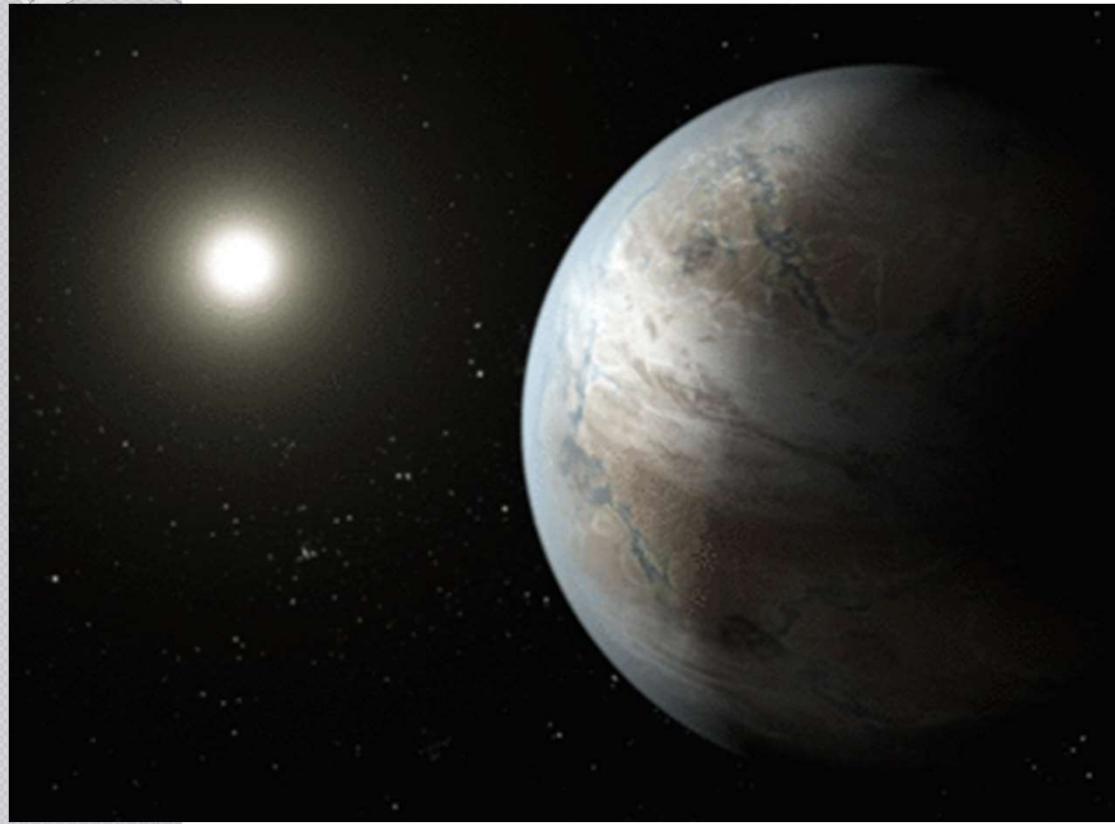
# Planet Seukuran-Bumi dalam HZ bintang katai merah





The Trappist 1 system, discovered by the Kepler mission, which comprises 7 terrestrial in the habitable zone of their host star. c NASA/JPL-Caltech

# Penemuan Kepler 452b

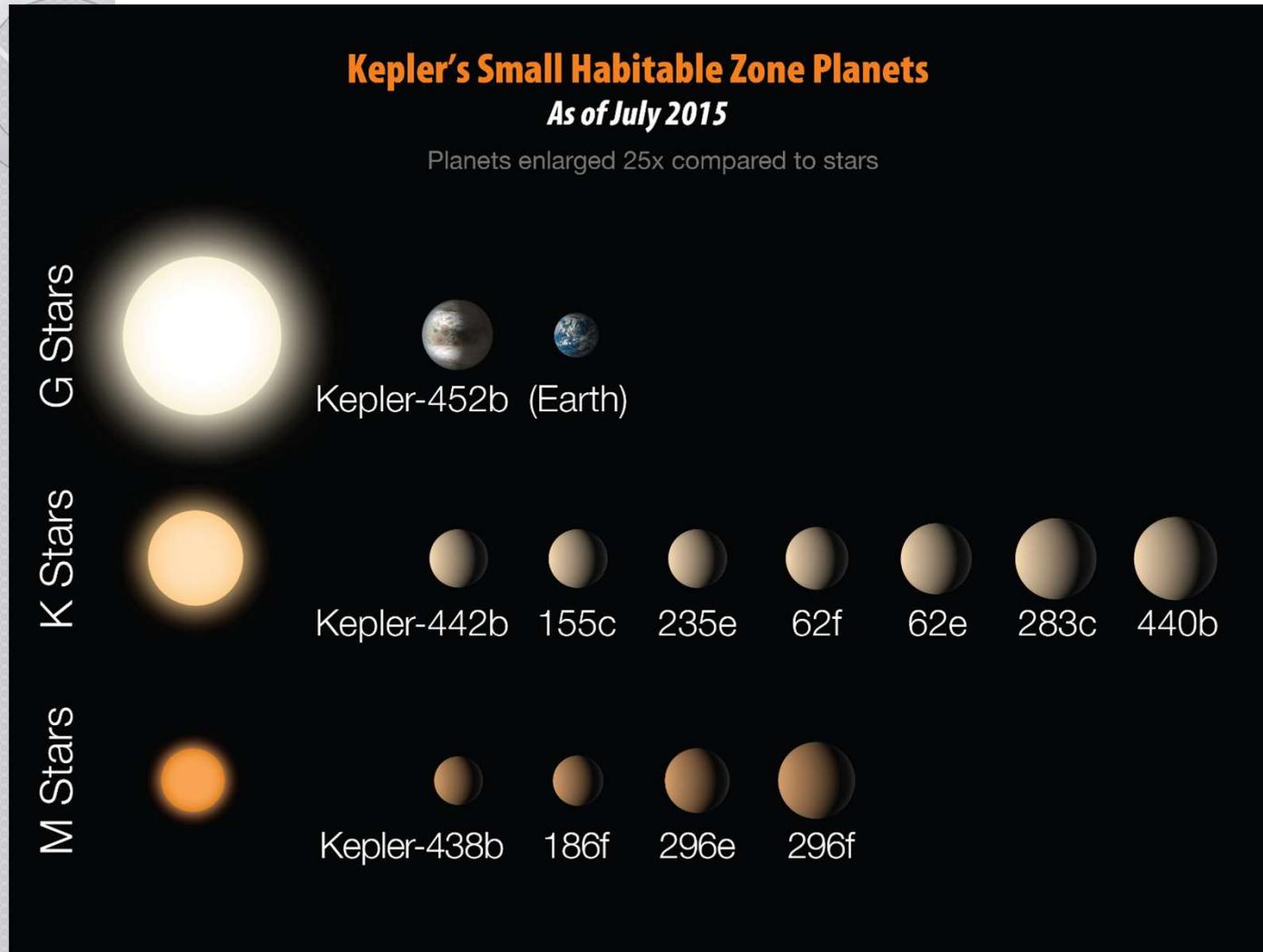


Artist's conception of Kepler-452b. NASA Ames/JPL-Caltech/T. Pyle.

July 2015, NASA mengumumkan penemuan “kembaran” paling mirip Bumi pada data yang telah dikumpulkan Kepler selama 4 tahun.

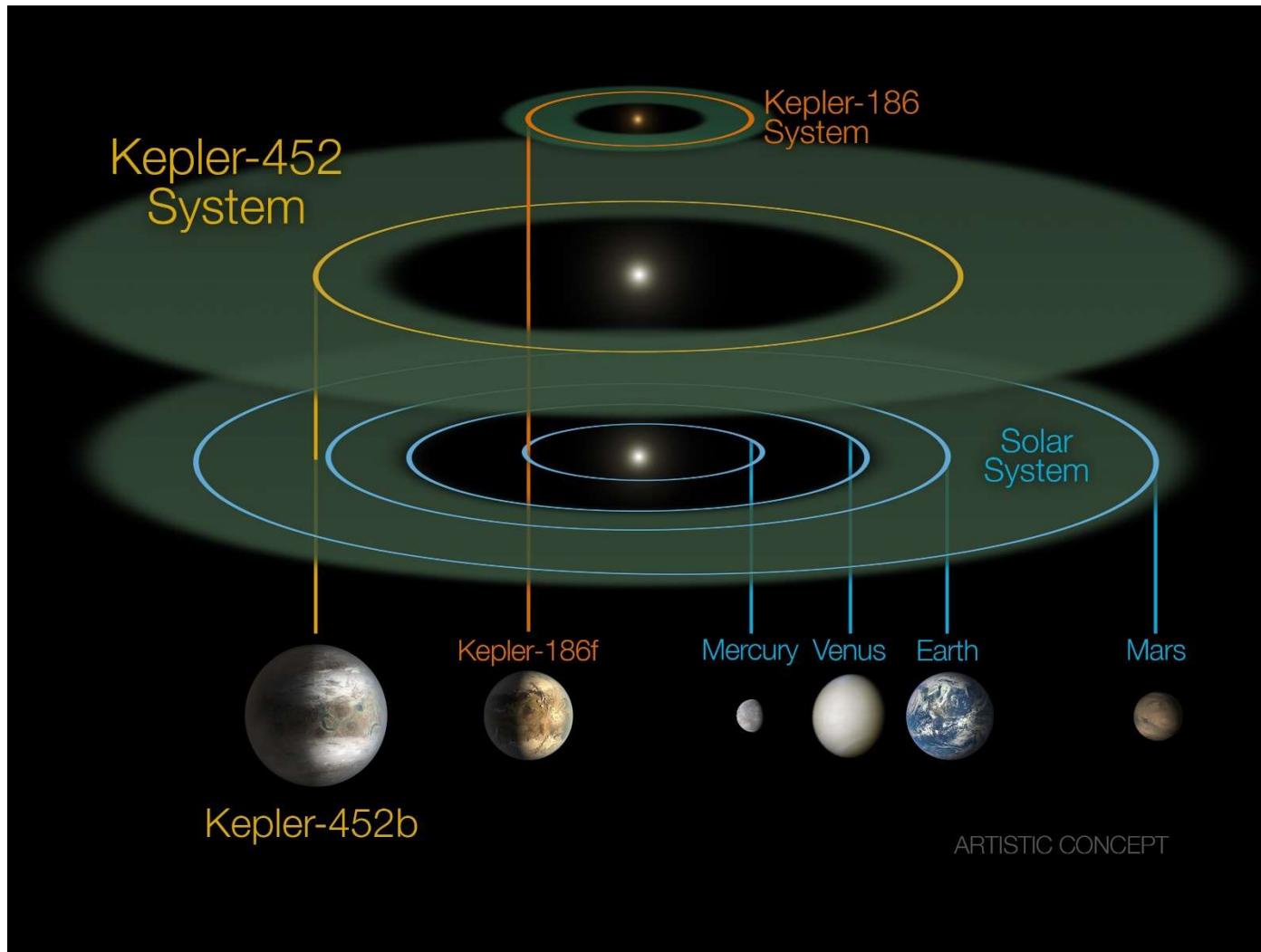
Planet itu diberi nama Kepler-452b, sekitar 1.6 kali diameter Bumi, periode orbit 385 hari dalam “habitable zone” bintang mirip Matahari, namun 20% lebih terang.

# Planet dalam Zona Habitasi



Credit: NASA/JPL-Caltech/R. Hurt

# Perbandingan (planet batuan)



Perbandingan sistem keplanaian dalam HZ: Kepler-186,  
Kepler-452, dan Tata Surya.  
Credit: NASA/JPL-CalTech/R. Hurt

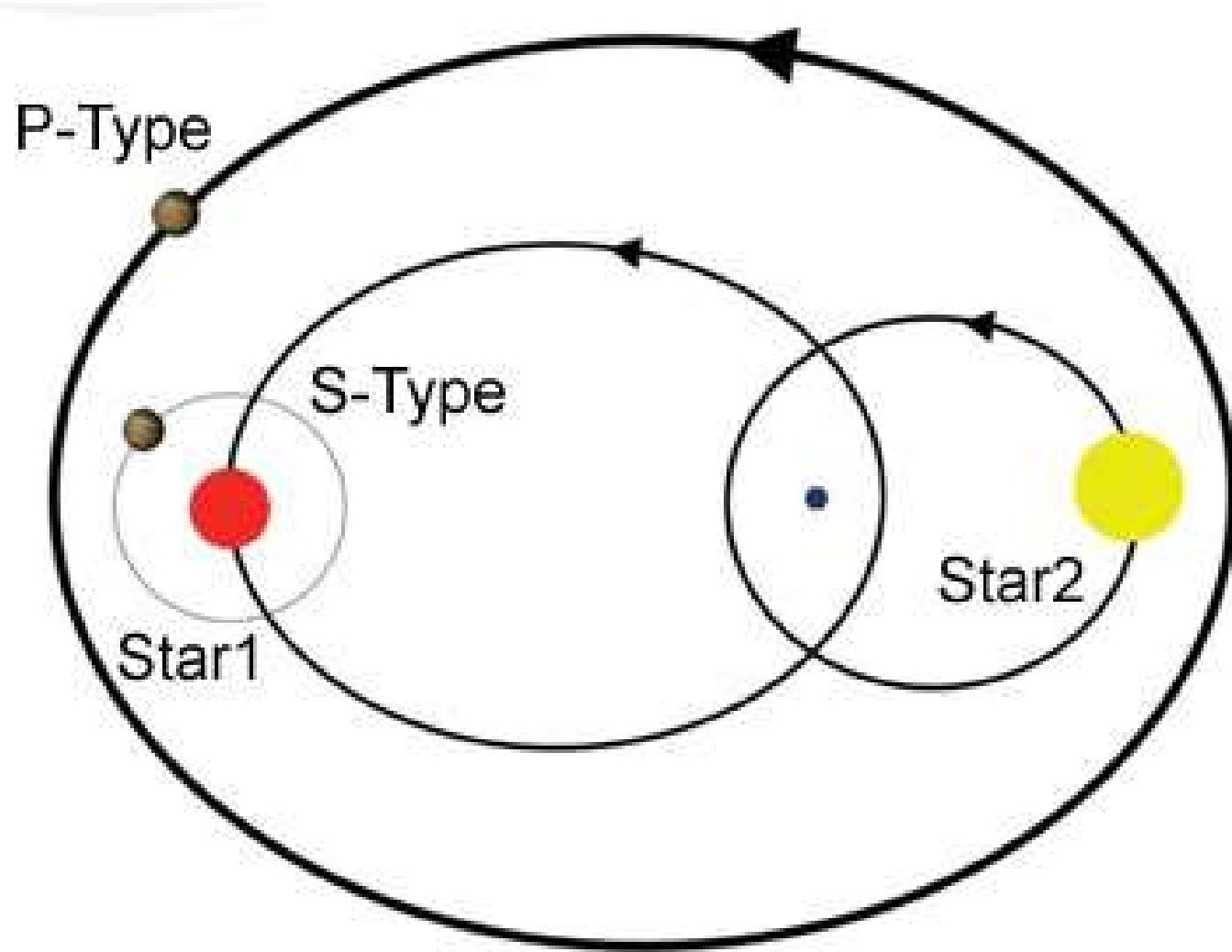
# Kepler 16b: Circumbinary Planet...



Kepler-16b; Radius =  $8.4 R_{\oplus}$   
Periode Orbit = 228.8 hari  
Kerapatan =  $0.964 \text{ gr/cm}^3$   
 $T_{eq} = -88^{\circ} \text{ C}$

Luke Skywalker di Planet Tatooine  
dari "Star Wars" yang telah dikoreksi

# Planet di bintang ganda



## Kepler-47: Sistem keplanetan mengitari bintang ganda dengan satu planet berada dalam HZ



# Kepler 47:Tiga Planet di Bintang Ganda

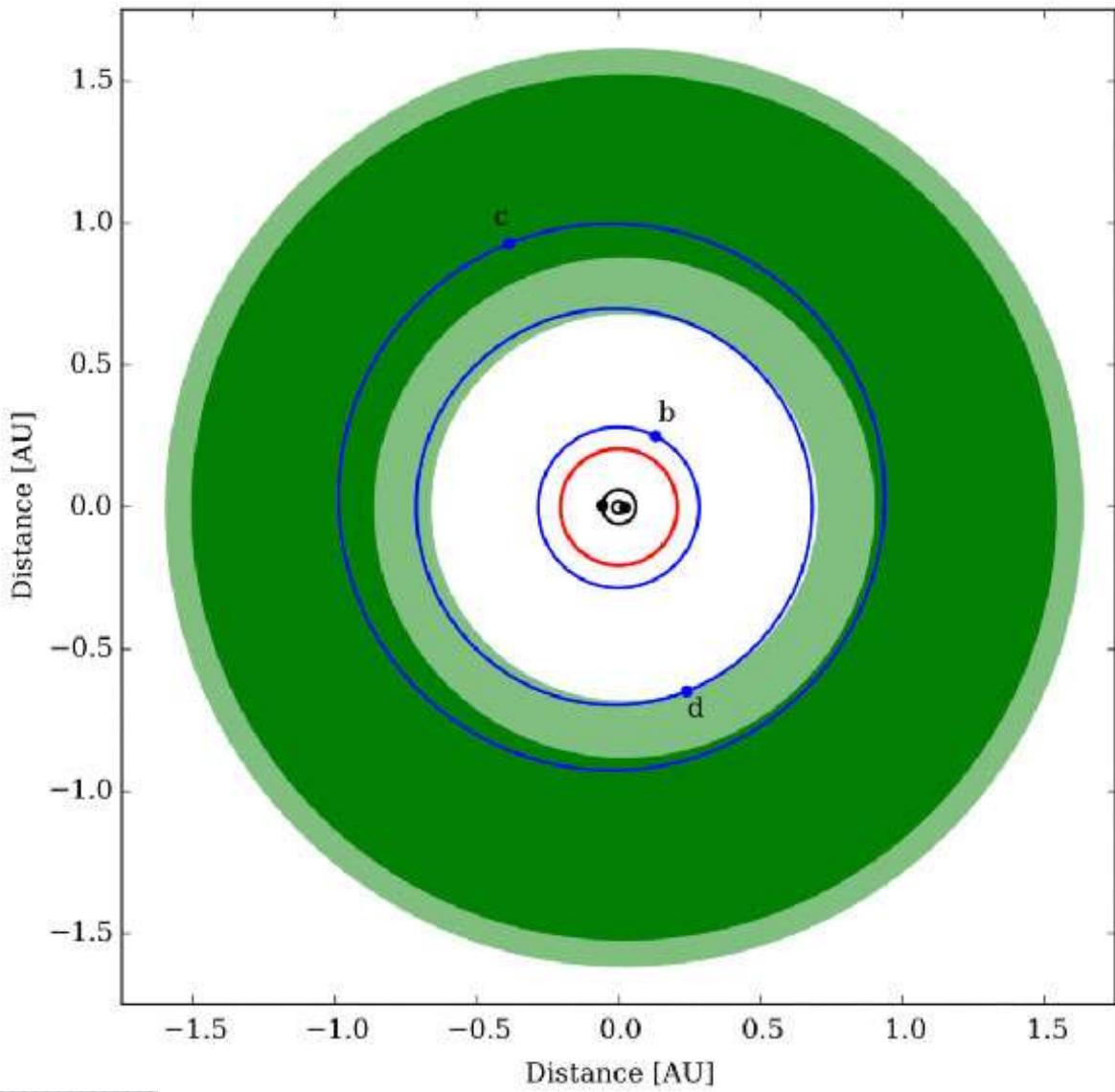
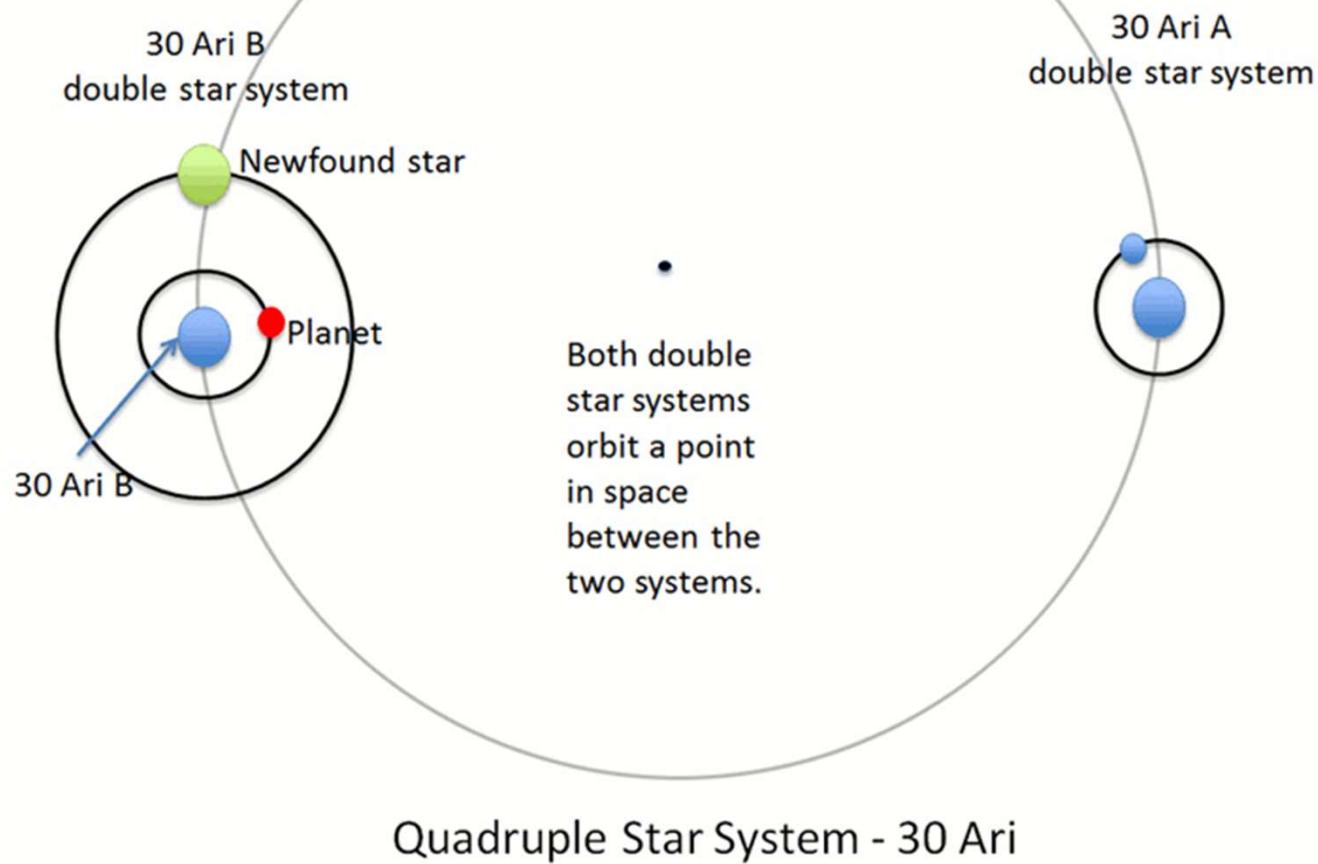


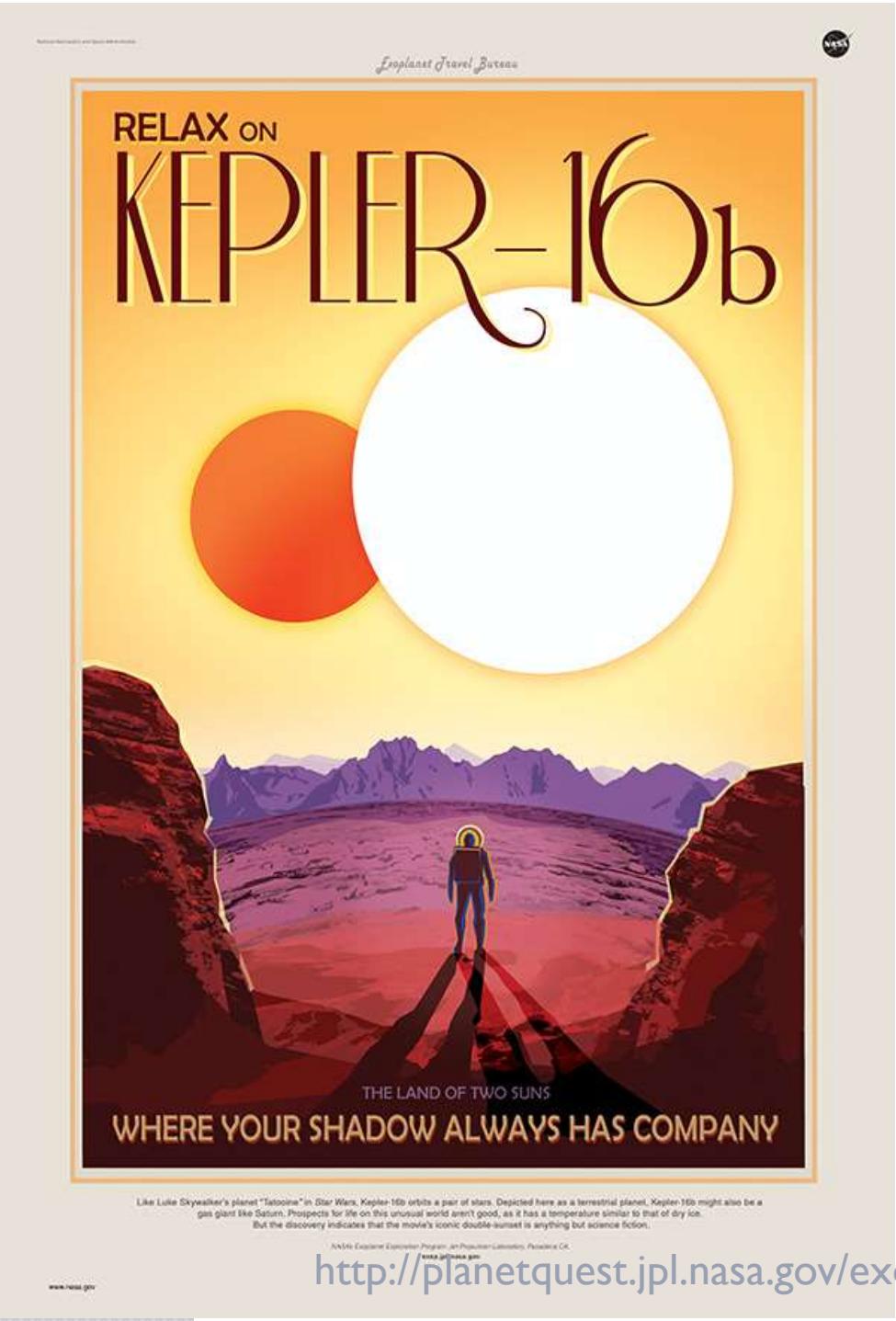
Diagram orbit  
planet di Kepler 47:  
Daerah hijau tua:  
habitable zone;  
Hijau muda: estimasi yang  
lebih optimistik  
Lingkaran merah: orbit  
planet stabil

(Orosz et al. Astronomical Journal 2019)

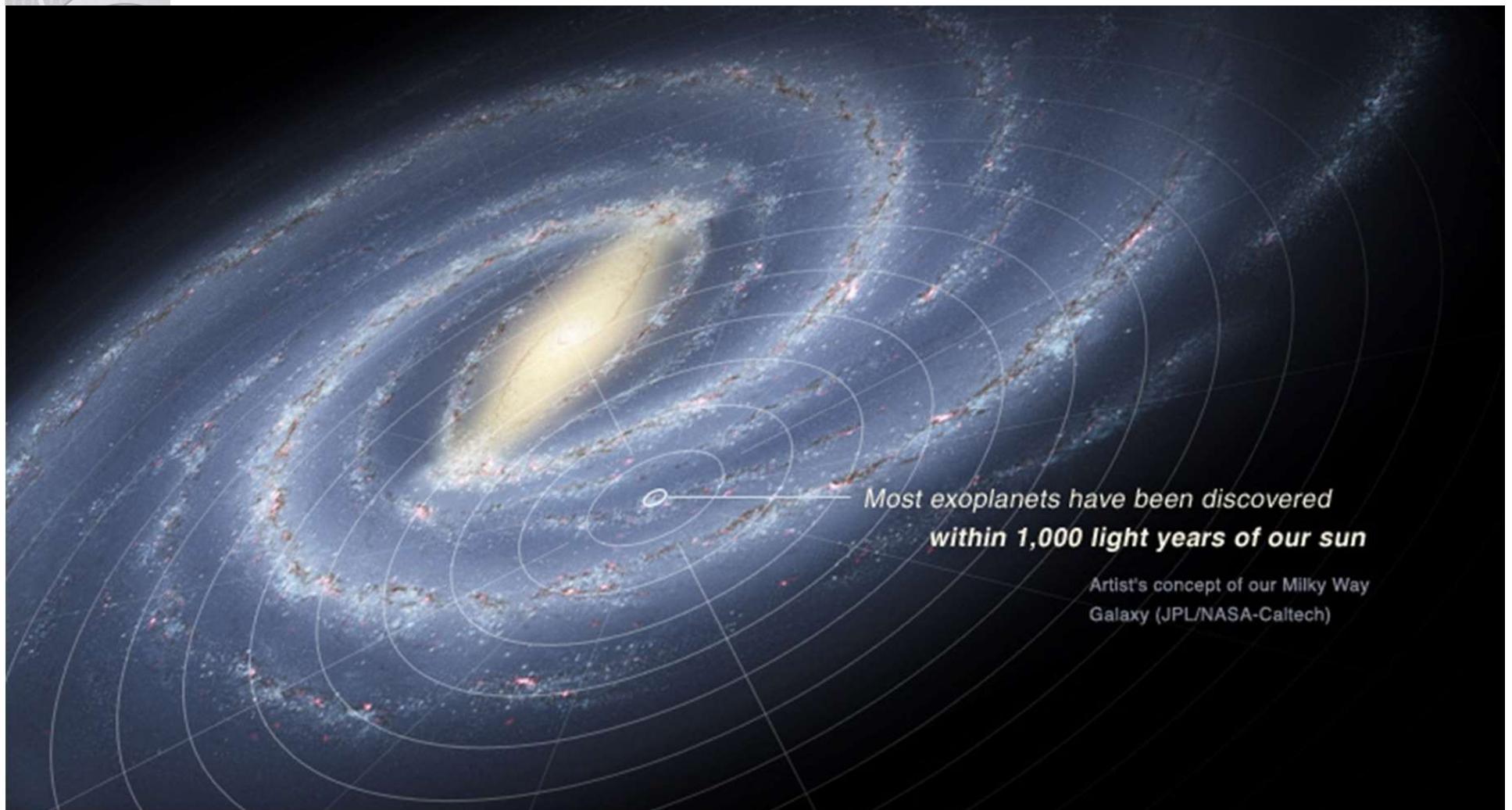
<https://astronomynow.com/2015/03/07/enormous-planet-found-to-be-in-a-quadruple-star-system/>



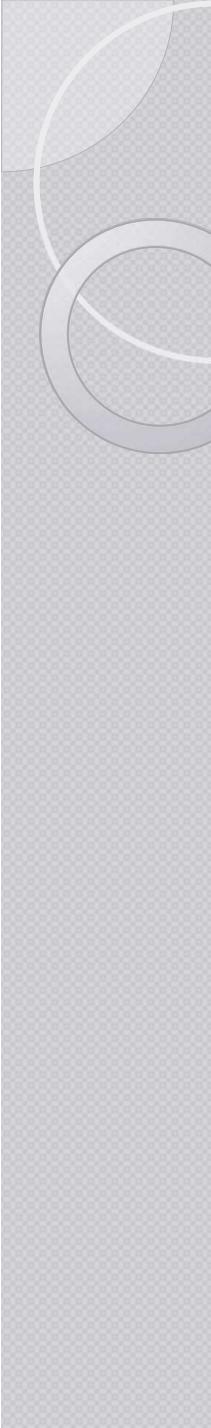
The four stars and one planet of the 30 Arietis system are illustrated in this diagram. This quadruple star system consists of two pairs of stars: 30 Ari B and 30 Ari A. The discoveries were made using instruments fitted to telescopes at the Palomar Observatory in San Diego: the Robo-AO adaptive optics system, developed by the Inter-University Center for Astronomy and Astrophysics in India and the California Institute of Technology in Pasadena, and the PALM-3000 adaptive optics system, developed by NASA's Jet Propulsion Laboratory in Pasadena, California, and Caltech. Image credit: NASA/JPL-Caltech



# Kita ada di mana (dalam Bima Sakti)?



- Sekitar 5–10% bintang seperti matahari di daerah tetangga Tata Surya memiliki planet masif
- Kemungkinan 30% atau lebih, memiliki planet dengan massa lebih kecil dan orbit yang lebih jauh
- Jika jumlah ini diekstrapolasi, maka ada miliaran planet di galaksi kita yang sedang menanti ditemukan



**Terima Kasih!**