YData: ExoStatistics

Exploring Extrasolar Planets with Data Science

S&DS 170/570, ASTR 445/545

Lecture 01
Exploring Exoplanet Populations

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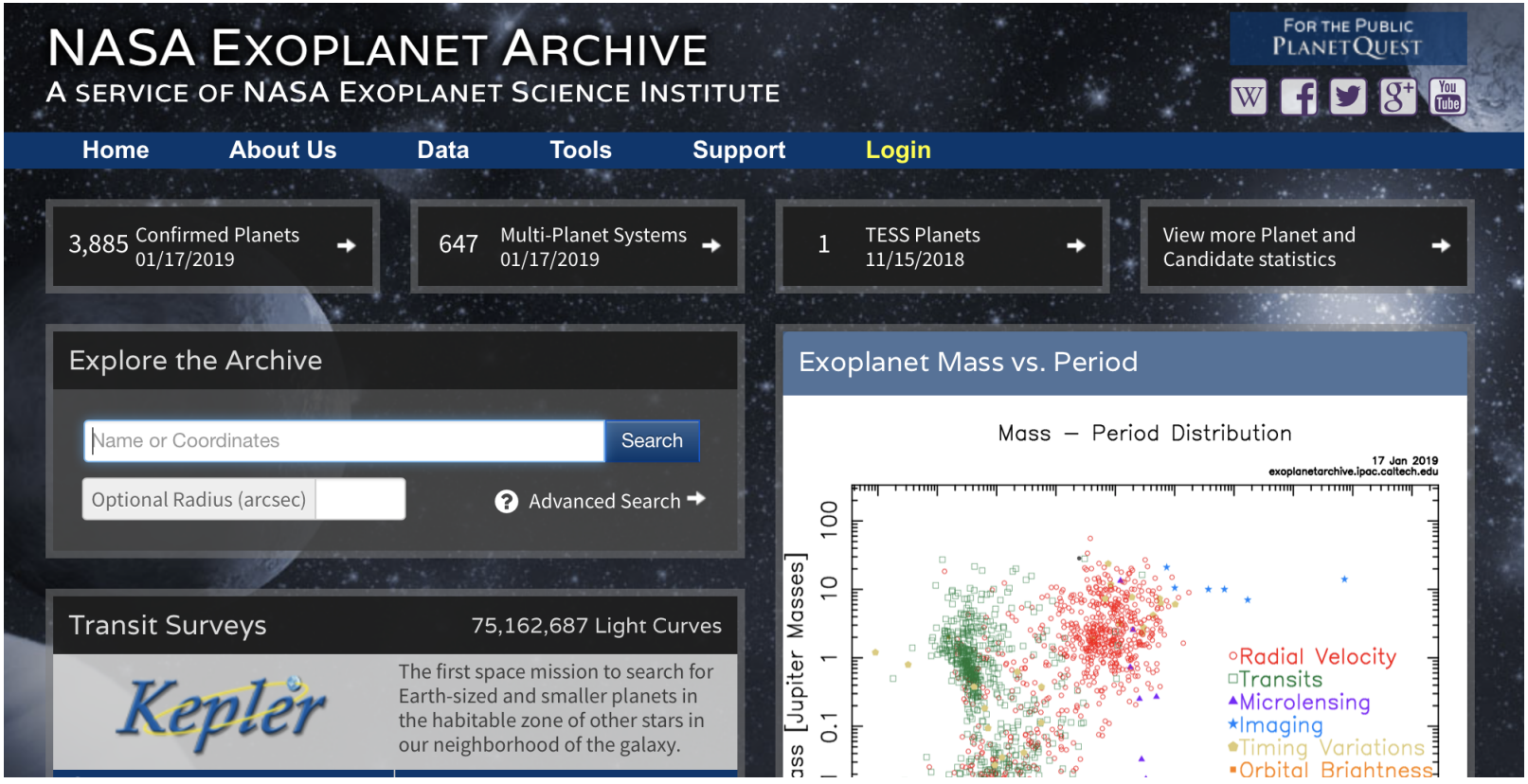
Spring 2019



- Today's lab data from https://exoplanetarchive.ipac.caltech.edu

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Kepler

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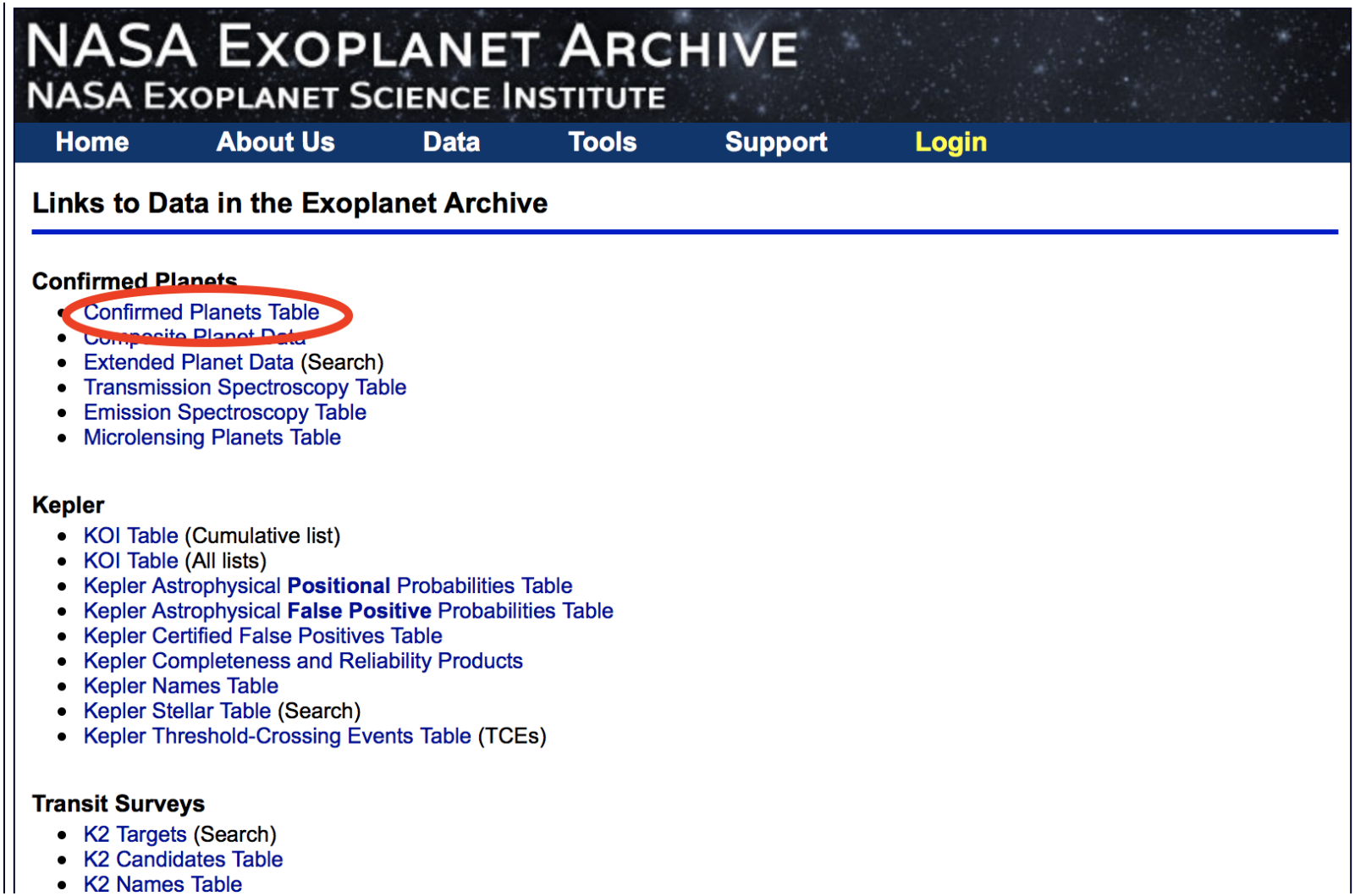
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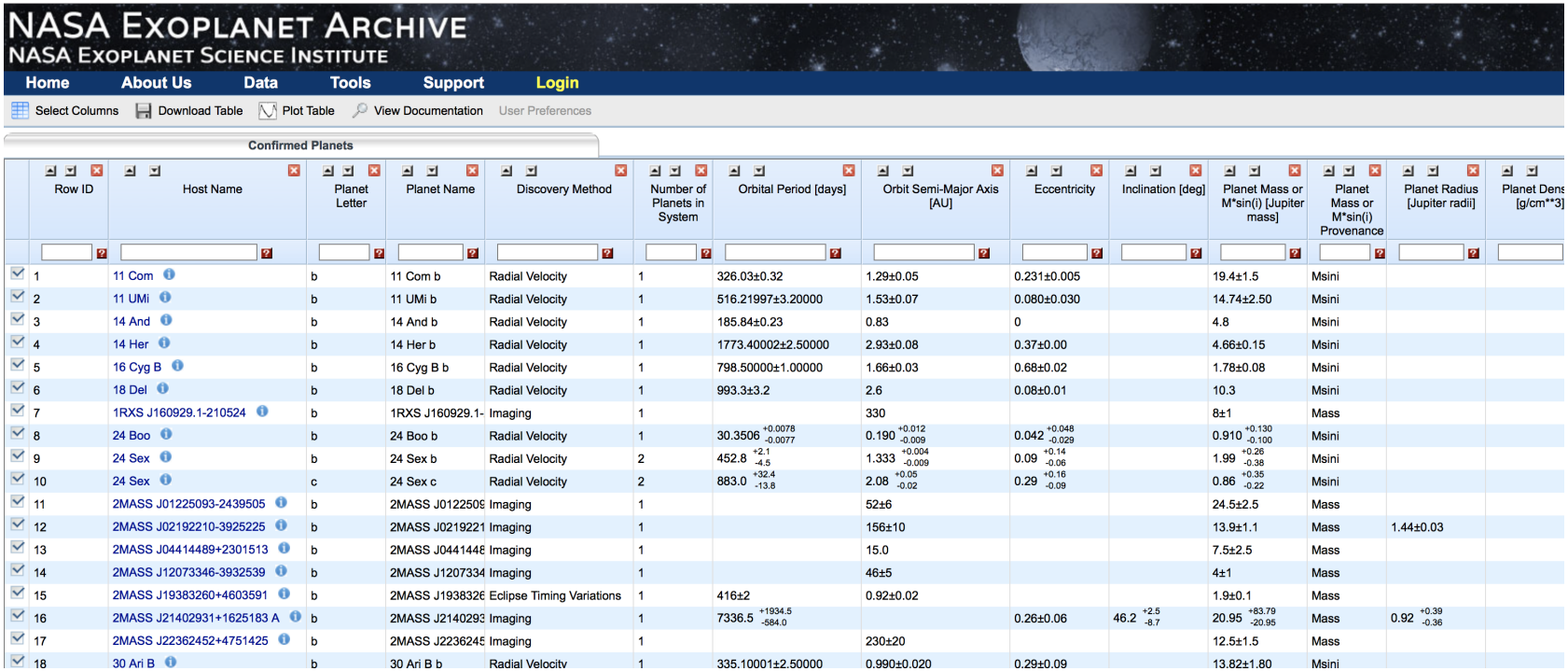

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Confirmed Planets

Row ID	Host Name	Planet Letter	Planet Name	Discovery Method	Number of Planets in System	Orbital Period [days]	Orbit Semi-Major Axis [AU]	Eccentricity	Inclination [deg]	Planet Mass or M*sin(i) [Jupiter mass]	Planet Mass or M*sin(i) Provenance	Planet Radius [Jupiter radii]	Planet Dens [g/cm**3]
1	11 Com	b	11 Com b	Radial Velocity	1	326.03±0.32	1.29±0.05	0.231±0.005		19.4±1.5	Msini		
2	11 UMi	b	11 UMi b	Radial Velocity	1	516.21997±3.20000	1.53±0.07	0.080±0.030		14.74±2.50	Msini		
3	14 And	b	14 And b	Radial Velocity	1	185.84±0.23	0.83	0		4.8	Msini		
4	14 Her	b	14 Her b	Radial Velocity	1	1773.40002±2.50000	2.93±0.08	0.37±0.00		4.66±0.15	Msini		
5	16 Cyg B	b	16 Cyg B b	Radial Velocity	1	798.50000±1.00000	1.66±0.03	0.68±0.02		1.78±0.08	Msini		
6	18 Del	b	18 Del b	Radial Velocity	1	993.3±3.2	2.6	0.08±0.01		10.3	Msini		
7	1RXS J160929.1-210524	b	1RXS J160929.1-	Imaging	1		330			8±1	Mass		
8	24 Boo	b	24 Boo b	Radial Velocity	1	30.3506 +0.0078 -0.0077	0.190 +0.012 -0.009	0.042 +0.048 -0.029		0.910 +0.130 -0.100	Msini		
9	24 Sex	b	24 Sex b	Radial Velocity	2	452.8 +2.1 -4.5	1.333 +0.004 -0.009	0.09 +0.14 -0.06		1.99 +0.26 -0.38	Msini		
10	24 Sex	c	24 Sex c	Radial Velocity	2	883.0 +32.4 -13.8	2.08 +0.05 -0.02	0.29 +0.16 -0.09		0.86 +0.35 -0.22	Msini		
11	2MASS J01225093-2439505	b	2MASS J0122509	Imaging	1		52±6			24.5±2.5	Mass		
12	2MASS J02192210-3925225	b	2MASS J0219221	Imaging	1		156±10			13.9±1.1	Mass	1.44±0.03	
13	2MASS J04414489+2301513	b	2MASS J0441448	Imaging	1		15.0			7.5±2.5	Mass		
14	2MASS J12073346-3932539	b	2MASS J1207334	Imaging	1		46±5			4±1	Mass		
15	2MASS J19383260+4603591	b	2MASS J1938326	Eclipse Timing Variations	1	416±2	0.92±0.02			1.9±0.1	Mass		
16	2MASS J21402931+1625183 A	b	2MASS J2140293	Imaging	1	7336.5 +1934.5 -584.0		0.26±0.06	46.2 +2.5 -8.7	20.95 +83.79 -20.95	Mass	0.92 +0.39 -0.36	
17	2MASS J22362452+4751425	b	2MASS J2236245	Imaging	1		230±20			12.5±1.5	Mass		
18	30 Ari B	b	30 Ari B b	Radial Velocity	1	335.10001±2.50000	0.990±0.020	0.29±0.09		13.82±1.80	Msini		

- Table with estimated parameters describing confirmed exoplanets
- Includes host star name, planet letter, planet name, discovery method, number of planets in the system, ...

Which are considered "confirmed" exoplanets?

- Different exoplanet data sources can have their own guidelines.
- For the NASA Exoplanet Archives, they specify the following criteria:
  1. The mass (or minimum mass) is equal to or less than 30 Jupiter masses.
  2. The planet is associated with a host star (i.e. not free floating).
  3. Sufficient follow-up observations and validation have been undertaken to deem the possibility of the object being a false positive unlikely.
  4. The above information along with further orbital and/or physical properties are available in peer-reviewed publications.

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

NASA Exoplanet Archives default parameters

Default and Multiple Parameter Values

For papers that report multiple values for an exoplanet or host star parameter, a single value is chosen as the default, and the user can access the paper for the additional values. Selection of the default parameter set is based on the number and precison of the published parameters, and the default reference is displayed in both the Confirmed Planet table and on the Overview page. For papers that report a range of values for an exoplanet or host star parameter, as opposed to a single value and uncertainties, we adopt the mean of the range as the single value and the range/2 as the uncertainty. For example, Liu et al. (2011) reports a mass for CFBDSIR J1458+1013 b of 6-15 Jupiter masses. We adopt a value of 10.5+/-4.5 Jupiter masses.

Orbital period (days) [pl_orbper]

- Description: Time the planet takes to make a complete orbit around the host star or system.

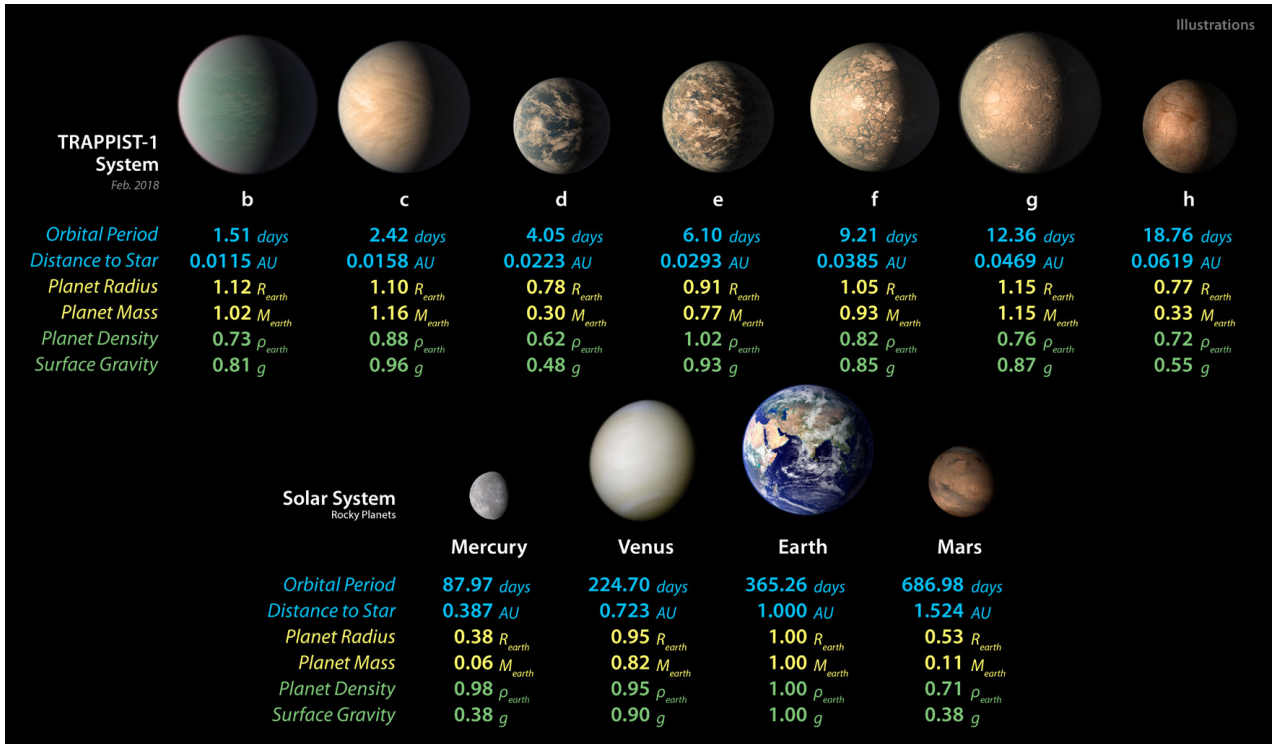

Image: https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA22094

Orbit semimajor axis (AU) [pl_orbsmax]

- Description: The longest radius of an elliptic orbit, or, for exoplanets detected via gravitational microlensing or direct imaging, the projected separation in the plane of the sky.

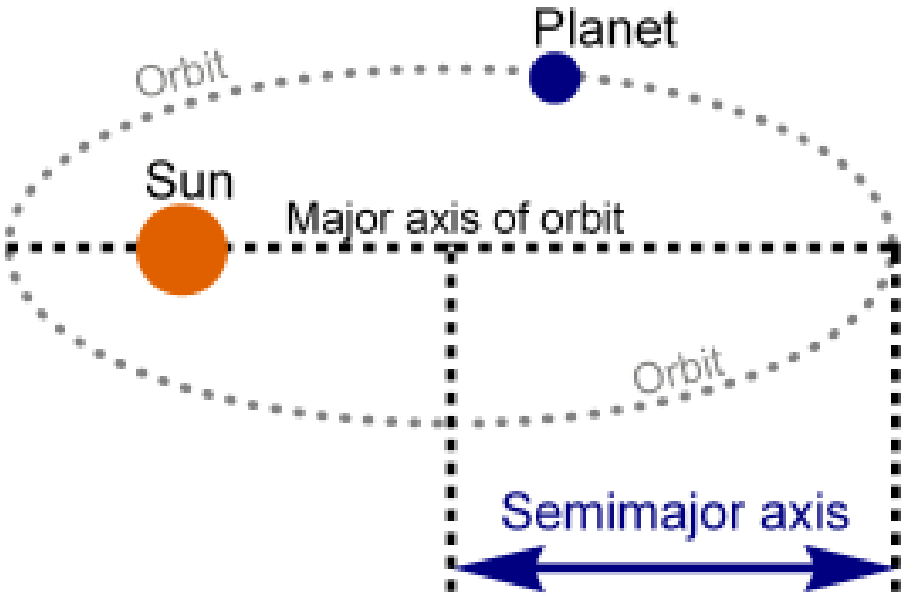

Image: http://www.calctool.org/CALC/phys/astronomy/planet_orbit

Kepler's Third Law of Planetary Motion

Period^2 $\propto$ Semimajor axis^3

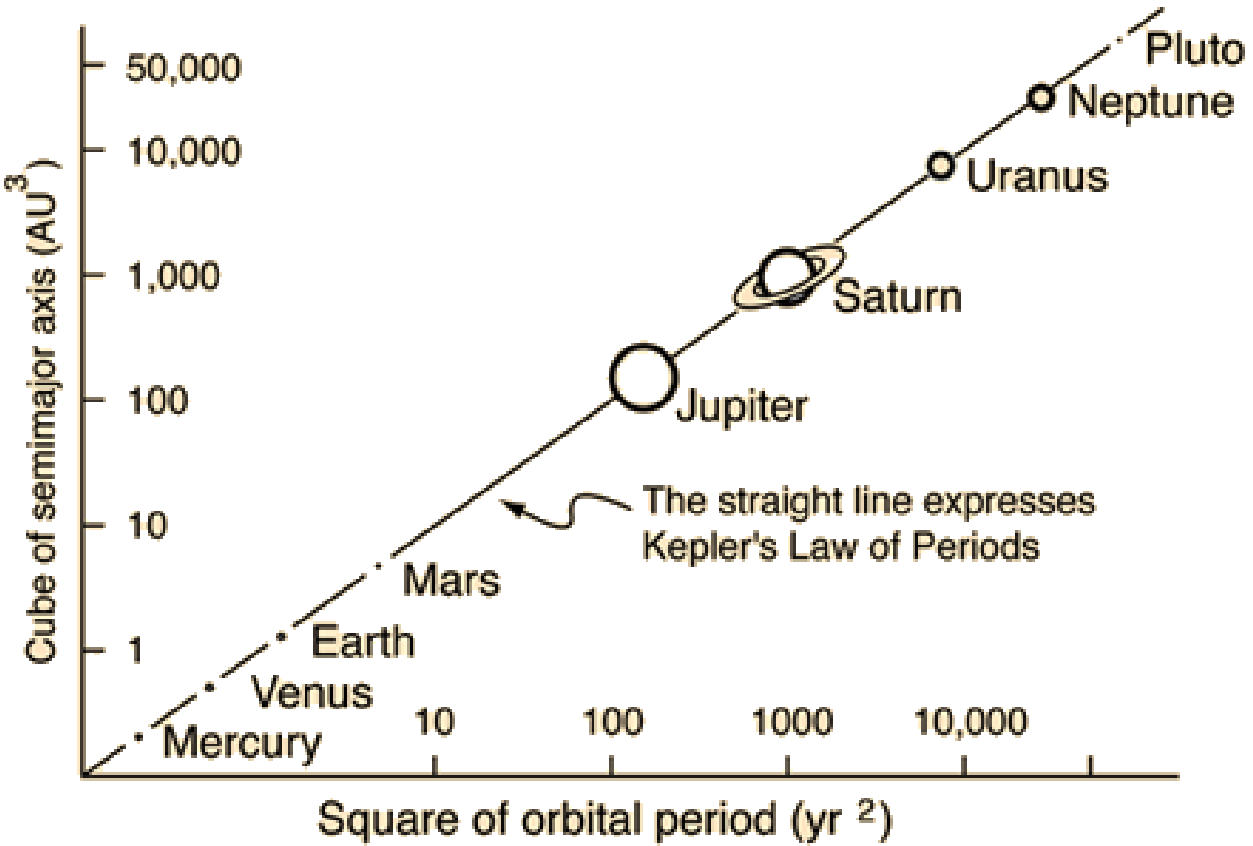

Image: http://hyperphysics.phy-astr.gsu.edu/hbase/kepler.html

K2-137 b

MNRAS **474,** 5523–5533 (2018)
Advance Access publication 2017 November 8
doi:10.1093/mnras/stx2891

K2-137 b: an Earth-sized planet in a 4.3-h orbit around an M-dwarf

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- Discovery method: Transit Method
- Orbiting a 0.463 $M_\odot$ Star
- Semi-major axis 0.0058($\pm$0.0006) AU
- Orbital period $\approx$ 4.3 hours!

GU Piscium b

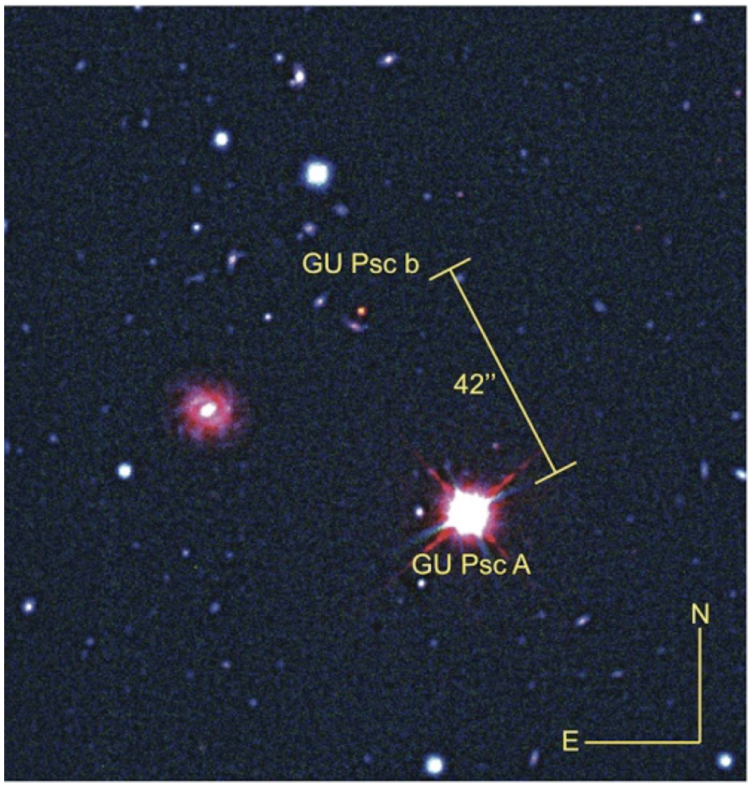
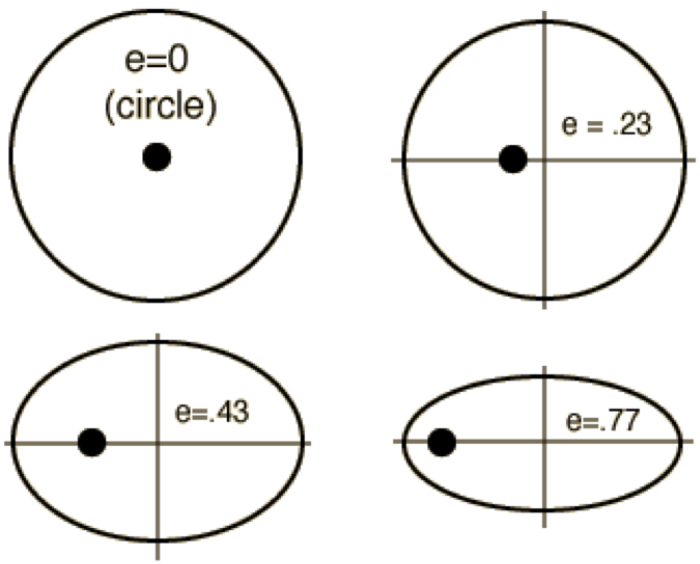


Image: The planet GU Piscium b and its star GU Piscium. This image is composed of visible and infrared images from the Gemini South telescope and an infrared image from the CFHT. Because infrared light is invisible to the naked eye, astronomers use a color code in which infrared light is represented by the color red. GU Piscium b is brighter in infrared than in other filters, which is why it appears red in this image. Credit: Gemini Observatory/OMM/CFHT/W.M. Keck Observatory.

- Discovery method: direct imaging
- Minimum mass: 9 - 13 M_J
- Semi-major axis 2,000 AU
- Orbital period $\approx 163,000$ years!

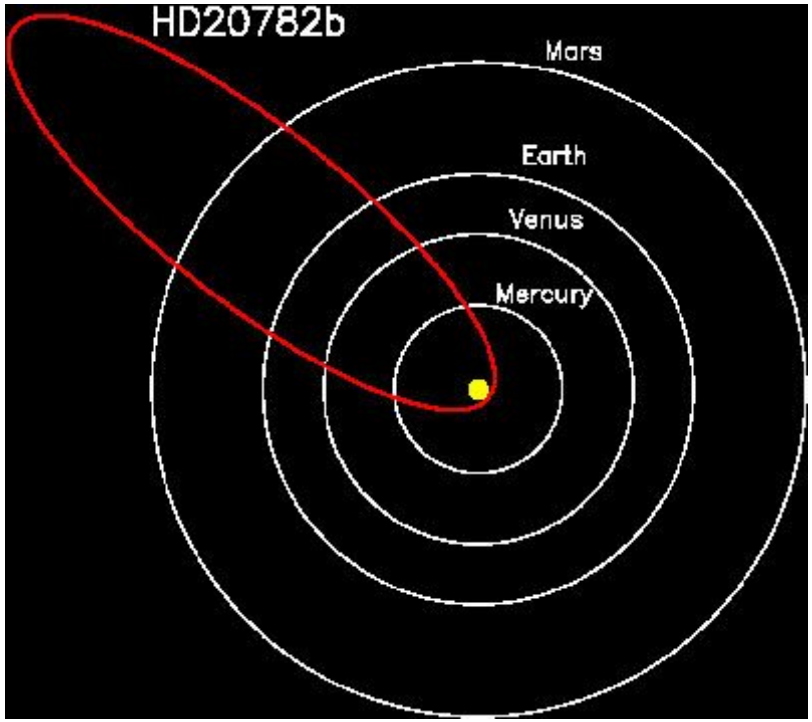
Eccentricity [pl_orbeccen]

- Description: Amount by which the orbit of the planet deviates from a perfect circle.



Planet	Eccentricity
Mercury	0.2056
Venus	0.0068
Earth	0.0167
Mars	0.0934
Jupiter	0.0483
Saturn	0.0560
Uranus	0.0461
Neptune	0.0097

HD 20782 b



- Discovery method: RV
- Semi-major axis 1.36 AU
- Minimum mass: 1.8 ± 0.23 M_J
- Eccentricity of 0.97 ± 0.01

Inclination (deg) [pl_orbincl]

- Description: Angular distance of the orbital plane from the line of sight.

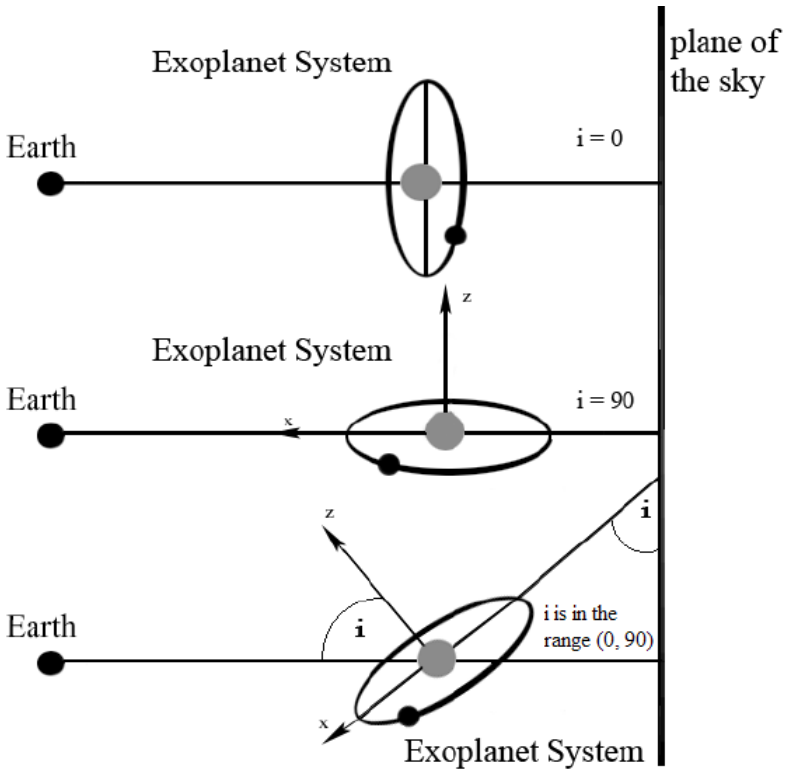
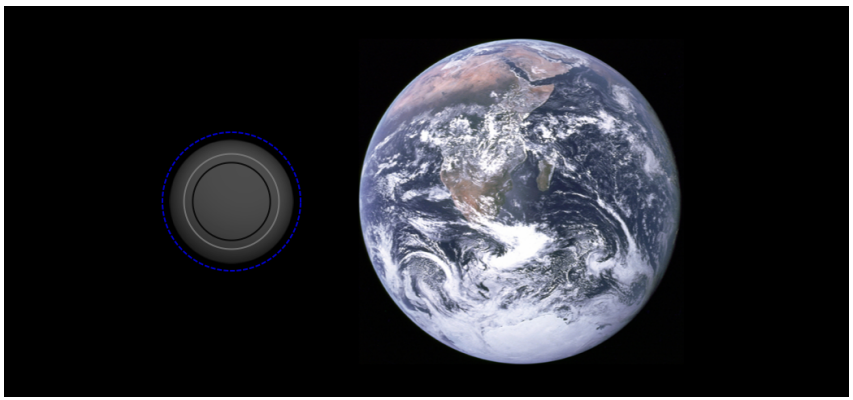


Image: (Zeilik and Gregory 1998, 236)

Planet Mass or M*sin(i) (Jupiter mass) [pl_bmassj]

- Description: Best planet mass estimate available, in order of preference: Mass, M*sin(i)/sin(i), or M*sin(i), depending on availability, and measured in Jupiter masses.

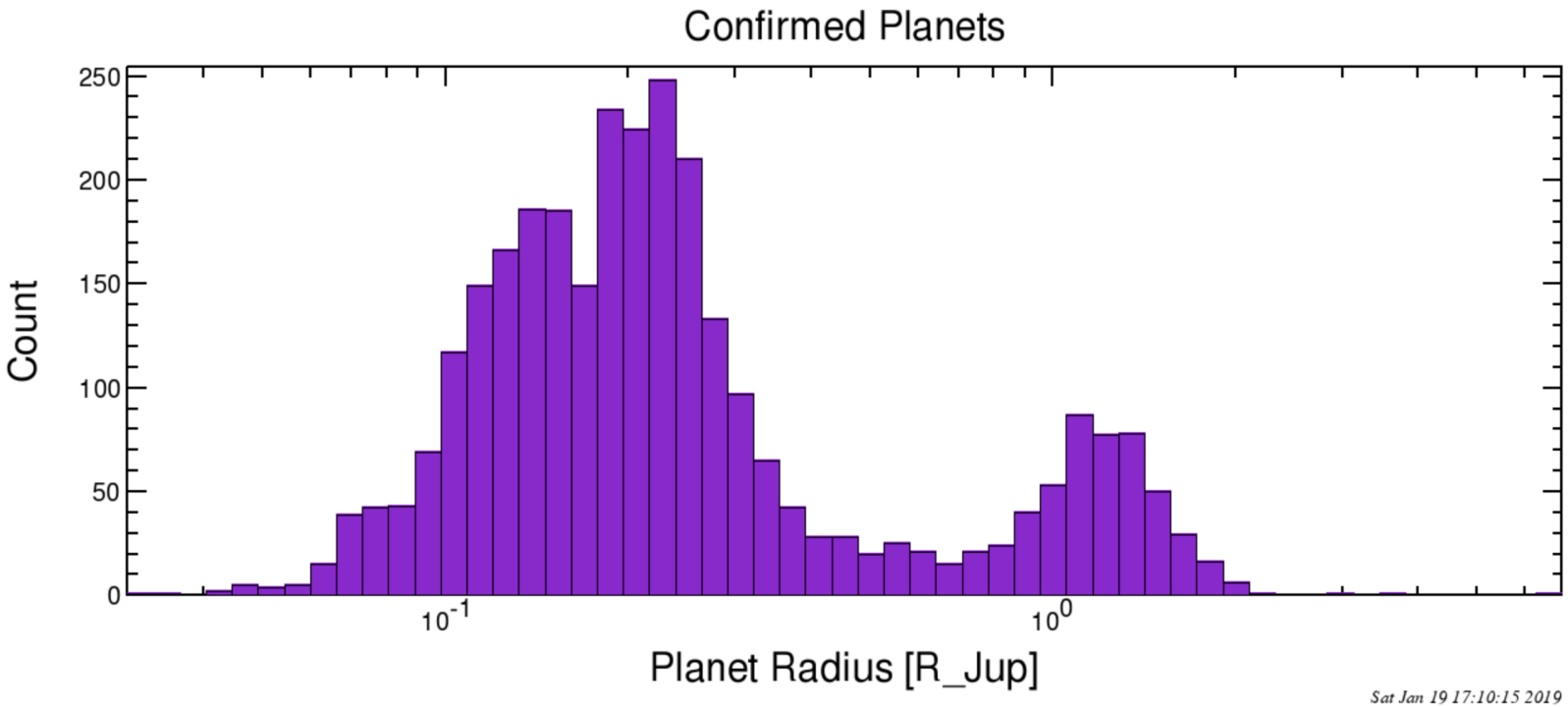


- PSR B1257+12 b orbiting a pulsar (i.e. a rotating neutron star)
- Discovery method: pulsar timing (1992)
- 0.020 ± 0.002 M_{Earth} ($\approx$ twice the mass of the Moon)

Image: https://en.wikipedia.org/wiki/

Planet Radius (Jupiter radii) [pl_radj]

- Description: Length of a line segment from the center of the planet to its surface, measured in units of radius of Jupiter.



Credit: NASA Exoplanet Archive

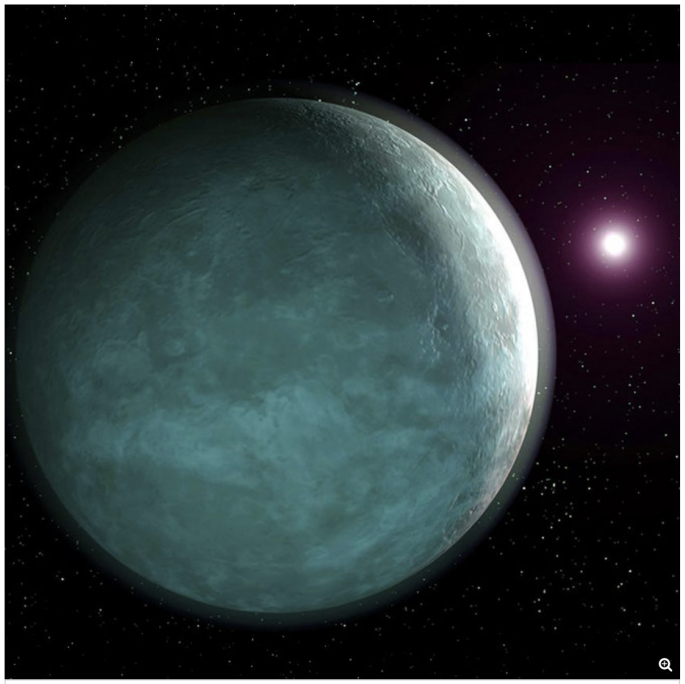
Planet Density (g/cm^3) [pl_dens]

- Description: Amount of mass per unit of volume of the planet.

Sweet Super-Puffs: These 2 Exoplanets Have the Density of Cotton Candy

By Nola Taylor Redd, Space.com Contributor | July 26, 2018 06:58am ET

0 0 MORE



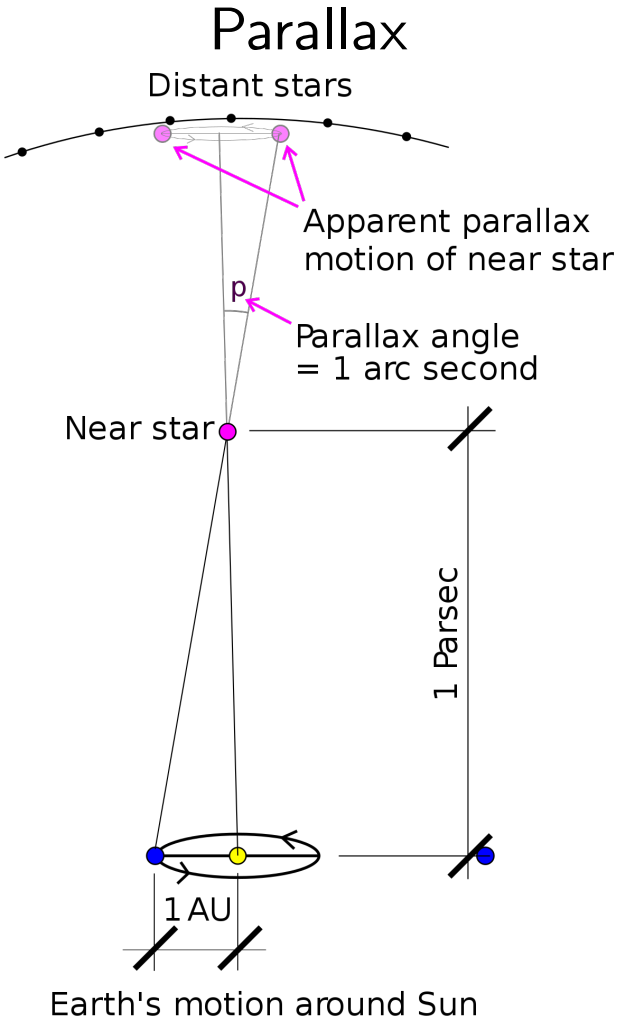
An artist's image of an exoplanet with a bulging atmosphere.

Credit: NASA

- Kepler-51b and Kepler-51d (densities are 0.03 grams to 0.06 g/cm^3) (Earth's density is 5.514 g/cm^3; Jupiter's density is 1.33 g/cm^3)

Distance (pc) [st_dist]

- Description: Distance to the planetary system in units of parsecs.



- 1 parsec $\approx$ 3.26 light years
- Las Cumbres Observatory video on Parallax:

  https://www.youtube.com/watch?time_continue=118&v=iwlMmJs1f5o

Image: https://commons.wikimedia.org/wiki/File:Stellarparallax_parsec1.svg

Stellar parameters

- Stellar Mass (solar mass) [st_mass]

  Description: Amount of matter contained in the star, measured in units of masses of the Sun.

- Stellar Radius (solar radii) [st_rad]

  Description: Length of a line segment from the center of the star to its surface, measured in units of radius of the Sun.

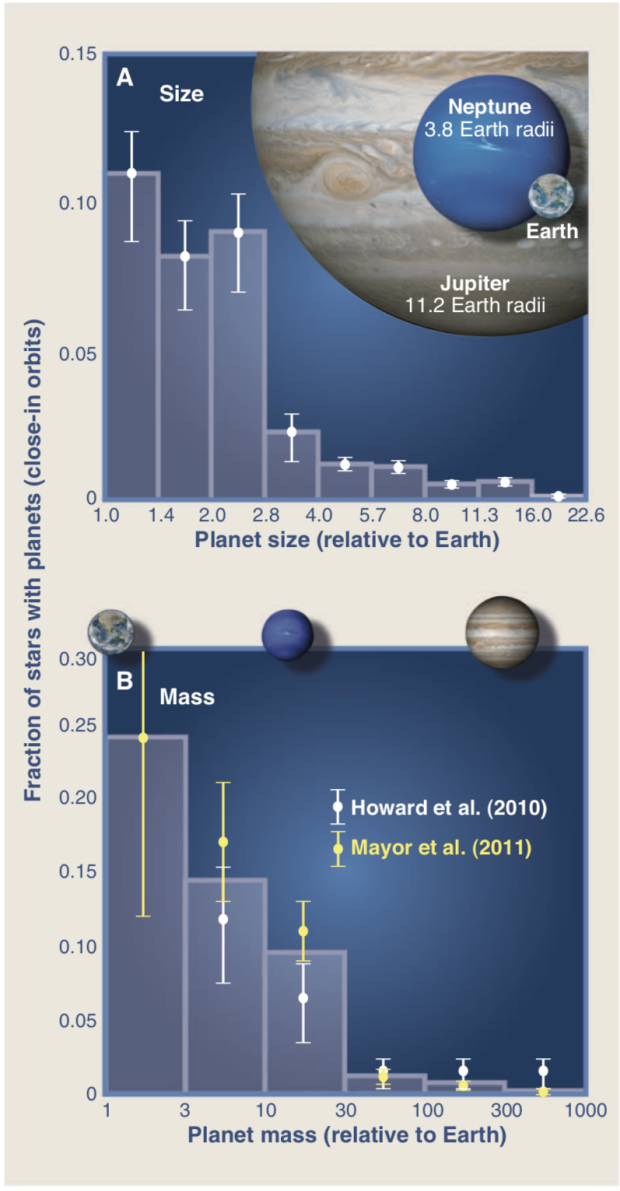


Fig. 2. The (A) size and (B) mass distributions of planets orbiting close to G- and K-type stars. The distributions rise substantially with decreasing size and mass, indicating that small planets are more common than large ones. Planets smaller than 2.8 R_E or less massive than 30 M_E are found within 0.25 AU of 30 to 50% of Sun-like stars. (A) The size distribution from transiting planets shows occurrence versus planet radius and is drawn from two studies of Kepler telescope data: (*16*) for planets smaller than four times Earth's size and (*17*, *59*) for larger planets. The inset images of Jupiter, Neptune, and Earth show their relative sizes. The mass ($M\sin i$) distributions (B) show the fraction of stars having at least one planet with an orbital period shorter than 50 days (orbiting inside of ~0.25 AU) are from the Doppler surveys from (*14*) (white points) and (*15*) (yellow points), whereas the histogram shows their average values. Inset images of Earth, Neptune, and Jupiter are shown on the top horizontal axis at their respective masses. Both distributions are corrected for survey incompleteness for small/low-mass planets to show the true occurrence of planets in nature.

(Howard, 2013)

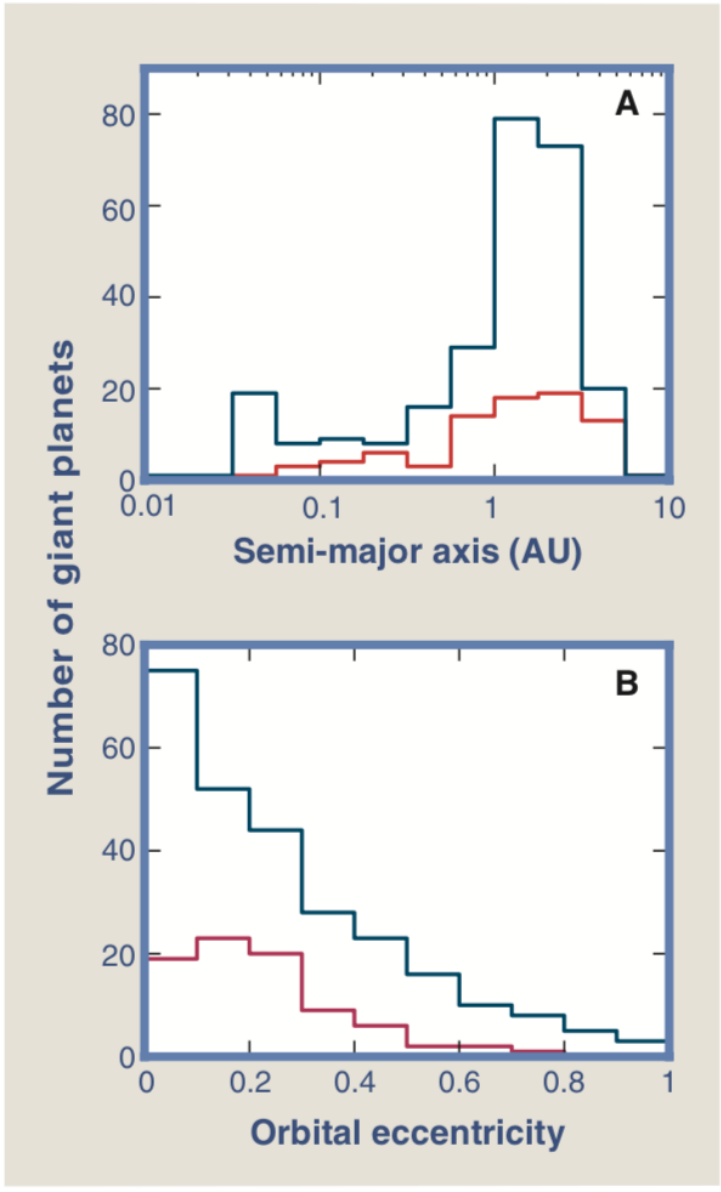


Fig. 4. Orbital characteristics of giant planets ($M \sin i$ > 0.2 Jupiter masses) detected by Doppler surveys (*1*, *60*). (**A**) The number distribution of semi-major axes shows that apparently single planets (blue) preferentially orbit at distances of ~0.05 AU and at ~1 to 3 AU from their host stars. These preferred orbits are diminished in multi-planet systems (red). The decline in number of detected planets for orbits outside of ~3 AU is not significant; fewer stars have been searched for such planets as compared with the closer orbits. (**B**) The distribution of orbital eccentricities for apparently single planets (blue) span the full range, with low-eccentricity orbits being more common. Giant planets in multi-planet systems (red) have orbits that are more commonly close to circular (eccentricity = 0). The larger eccentricities of single planets suggests that they were dynamically excited from a quiescent, nearly circular origin, perhaps by planet-planet scattering that resulted in the ejection of all but one detectable planet per system.

(Howard, 2013)

References

Howard, A. W. (2013), "Observed properties of extrasolar planets," *Science*, 340, 572–576.