The Demographics of Exoplanets

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Where We Started:
Composition of the Solar System

Rocky Planets
Gas Giants
Ice Giants
Demographic Trends

- Mass
- Radius
- Density/Composition
- Orbital Radius/Period
- Habitable Planets and eta-Earth
- Planet Multiplicity
- Eccentricity
- Host Star Composition
- Host Star Binarity
Known Exoplanets With Masses

Bowler (2016)
Power-law mass function is a reasonable fit in the gas giants.
Mass Distribution (from RVs)

From Mayor et al. (2012) for the full HARPS sample (left) and $P < 100$ days (right). Break at Neptunes? Ambiguous.
Batalha et al. (2014). Still breaks between hot/cold Jupiters and Jupiters vs Neptunes, but no clear evidence of a lower limit aside from detection limits. Not even a break between Neptunes and rocky planets.
Kepler Radius Distribution

Howard et al. (2012)
Recent Update: A Gap in Planet Radii

Fulton et al. (2017)
The Mass-Radius Relation from Super-Earths to B stars. (Hatzes & Rauer 2015)
Mass vs Density

The Mass-Radius Relation from Super-Earths to B stars. (Hatzes & Rauer 2015)
The Wide Range of Planet Compositions

Figure 25. (a) mass–radius diagram for planets less than $30 M_\oplus$ and larger than $1 R_\oplus$: (b) planetary sizes relative to pure silicate rock as a function of incident flux. In panel (a), the curves mark Fortney et al. (2007) solutions for planets made of pure iron (purple), silicate rock (brown), or water ice (navy blue). In panel (b), planet sizes are compared to pure rock. Below the brown line, planets are denser than rock and are unlikely to retain appreciable amounts of volatiles. Above the navy blue line, planets are less dense than water ice and must retain deep atmospheres. The colors correspond to the amount of incident flux compared to Earth ($F_\oplus$), with exoplanets $< 3 F_\oplus$ in light blue, planets $> 300 F_\oplus$ in black, and orange, red, maroon, and dark gray in between, as shown in the right panel. Well outside this regime in flux, Neptune and Uranus are marked as light gray points on the mass–radius diagram. Incident fluxes were compared to Earth assuming low eccentricities ($e^2 \ll 1$) and using the following equation: $F(F_\oplus) = 4.62 \times 10^4 \left( \frac{T_{\text{eff}}}{T_\odot} \right)^4 \left( \frac{R_\star}{a} \right)^2$, with uncertainties added in quadrature. Stellar parameters were taken from the references in Table 12. The open circles mark the secure planet characterizations of this study. The open squares mark our two possible solutions for Kepler-177 b, using independently measured transit times. The range in observed planet sizes given their measured mass appears strongly anticorrelated with incident flux.

Possible punchline – close-in planets (i.e., hot planets) are rock/metal. To have lots of volatiles, planets need to live far from their star (Jontof-Hutter et al. 2016)
A 2D Gap in Planet Radii

Fulton et al. (2017)

A photoevaporation desert?
Period Distribution (RV)

Possible pileup at a few days? Then an increasing number at larger orbital radii. (Cumming et al. 2008)
Hard to Measure Actual Eta-Earth

Reaching 1 R_{\text{Earth}} at 1 AU is hard; Kepler didn’t quite make it, at least with current analyses.
Planetary Systems are Packed

Credit: NASA/Tim Pyle
Kepler Multi-Planet Systems

The Kepler Orrery III  
$t[BJD] = 2455215$

Movie by D. Fabrycky
Eccentricity: Not always circular

Most known extrasolar planets orbit their stars much more closely...

...and follow more elliptical orbits...

...than the planets in our solar system.

Circular orbits can happen, but not the rule.

Bennett et al. (2016)
Half eccentric singletons, half circular dense-packed systems?

At least among M dwarfs, the histogram for Kepler multiples has an excess of singletons (~half of all stars). Otherwise, well-modeled with dense-packed systems with modest mutual inclinations.

Ballard & Johnson (2014)
Heavy Elements Seem to be Important...

More metals = more (giant) planets (Fischer & Valenti 2005)
...but maybe not for small planets

Threshold effect for making Jupiters? Trend not clear for low-mass planets (red), but obvious for Jupiters (black). From Mayor et al. (2012)
Close Binaries: Not Good, Not Always Bad

Inside 50 AU, only 1/3 of binaries host planets. This is 20% of all stars in the Milky Way.

(Kraus et al. 2016)
Best fit: Inside 50 AU, only 1/3 of binaries host planets. This is 20% of all stars in the Milky Way (Kraus et al. 2016)
From Johnson et al. (2010), giant planet occurrence rate depends on host mass. Jupiters are more common around 1.5-2.0 Msun stars. Jupiters and Neptunes are both less common around 0.5 Msun stars. (See also Butler+04, Cumming+08, Gaidos+16 and many others).
Trends

1. Our Solar System is still on the edge of detectability
2. Small planets are more frequent than large planets, down to $\sim1$ R\textsubscript{Earth} (and $\sim1$ M\textsubscript{Earth}?)
3. Occurrence rate consistent with $>2$ discoverable planets/star (but not all stars have planets)
4. Compositions vary widely at the same mass, but thresholds (such as for holding H/He atmospheres) are emerging
5. Composition may indication insolation history, at least in inner planets
6. Period/a distribution is a power-law, not quite flat. No reason to think habitable zone is not well populated.
7. Dense systems are common. (In Kepler, we’d be a single-planet system.)
8. There's a mix of dynamically cold systems (multis) and hot systems (singletons or high mutual inclination).
9. Metals are important for gas giants (maybe not small planets). Jupiter formation is a threshold phenomenon?
10. Close binary companions suppress planet survival
11. Host mass correlates with giant planets; unclear for (super)Earths.