An Eta-Earth Projection, Based on a New Analysis of Kepler Completeness

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Select 3200-7000K, log g > 4.0
Missing small planets at long periods

Very few small planets at longer periods:

Nature or Bias?
Missing small planets at long periods

Average noise-limited minimum radius (scaled by 70%)

Must be a noise bias
Minimum detectable planet

From first principles, for SNR = 7 detection criterion, for $T_{\text{mission}} = 2$ yr & duty cycle = 92%, & $S/N \sim 1/t^{0.32}$ (not $1/t^{0.50}$), the minimum detectable planet radius is $r_{\text{min}}$:

$$r_{\text{min}}/r_\oplus = 0.0389$$

$$\times (\text{cdpp6}_{\text{ppm}})^{1/2}$$

$$\times (r_{\text{star}}/r_{\text{sun}})^{0.947}$$

$$\times (P_{\text{days}})^{0.197}$$

$$\times 10^{0.0533 \log(g)}$$

p.264-266, 6/5/2013
Faint stars have more noise

The graph shows the distribution of star noise (CDPP, ppm) for different values of $K_p$: $K_p = 16$, $K_p = 14$, $K_p = 12$, and $K_p = 10$. The number of stars is represented on a logarithmic scale on the y-axis, while the star noise is on a logarithmic scale on the x-axis.
**Median noise (CDPP) vs magnitude**

CDPP is RMS noise per 6-hour observation, in units of ppm

The middle curve is the median CDPP for all stars averaged over quarters 1 – 8

The best-fit curve is a simple function of Kepler magnitude

\[ \text{CDPP} = 30.2 + 10^{0.377K_p - 3.485} \]
Calculated vs observed noise (CDPP)
Relative scatter of observed – calculated noise
Missing small planets at large distance

Very few small planets at large distances: Nature or Bias?
Missing small planets at large distance

Average noise-limited minimum radius (scaled by 70%)

Must be a noise bias
Salient regions of the \((P, r)\) diagram

- **\(P < 7\) days, \(r > 2\) Earths**
  - Nature bias against short periods

- **\(P < 5\) days, \(r = 1-2\) Earths**
  - Nature bias against short periods

- **\(R < r(\text{min})\)**
  - Instrument bias against noisy signals
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Short-period fall-off

Shallow fall-off for small planets

Steep fall-off for large planets

Number of planets

Period (days)

1 10 100

2.8–22.6
2.0–2.8
1.4–2.0
1.0–1.4
Tentative bottom line: Fitting all 3 areas of the $(P,r)$ diagram, using random planets assigned to 134,000 Kepler target stars, & using power-law functions, I find a best fit

\[ \frac{N(\text{planets})}{N(\text{stars})} = A \times r^a \times P^b \times \Delta \ln(r) \times \Delta \ln(P) \]

where $A = 0.168$, $a = -2.4$, $b = 0.4$

which gives $\eta_\oplus = 0.70$

for $r = 1$-$2$ Earth radius
& $P = 225$-$687$ days (Venus to Mars around Sun-like star)
Backup charts
Example: \( O \) vs \( C: \quad f \sim r^0 P^0 \quad \text{per bin, poor fit} \)

Generate simulated data:

For each Kepler star, assign a random planet radius and period, using power laws in \( r \) & \( P \)

If radius is greater than the minimum, then “detect” the planet, otherwise reject it.

Compare observed data with simulated data.

In this case (flat power laws) the fits are not good.
Observed-calculated vs magnitude and distance: best (P,r) fit
Observed-calculated vs $T_{\text{eff}}$: best $(P,r)$ fit
Distance vs magnitude

- 5900-6870 K
- 5670-5900 K
- 5430-5670 K
- 4990-5430 K
- 3520-4990 K

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mag_dist_3 10/7/2012
Reasonable clustering in absolute magnitude vs distance
Reasonable scatter in period vs magnitude
Reasonable scatter with magnitude (except for depth vs mag)
Ratio of 3/6 hr and 6/12 hr noise vs magnitude