Occurrence Doesn't Just Happen:
Revisiting the Frequency of Earth-Size Planets around Kepler Stars

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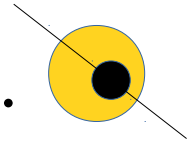
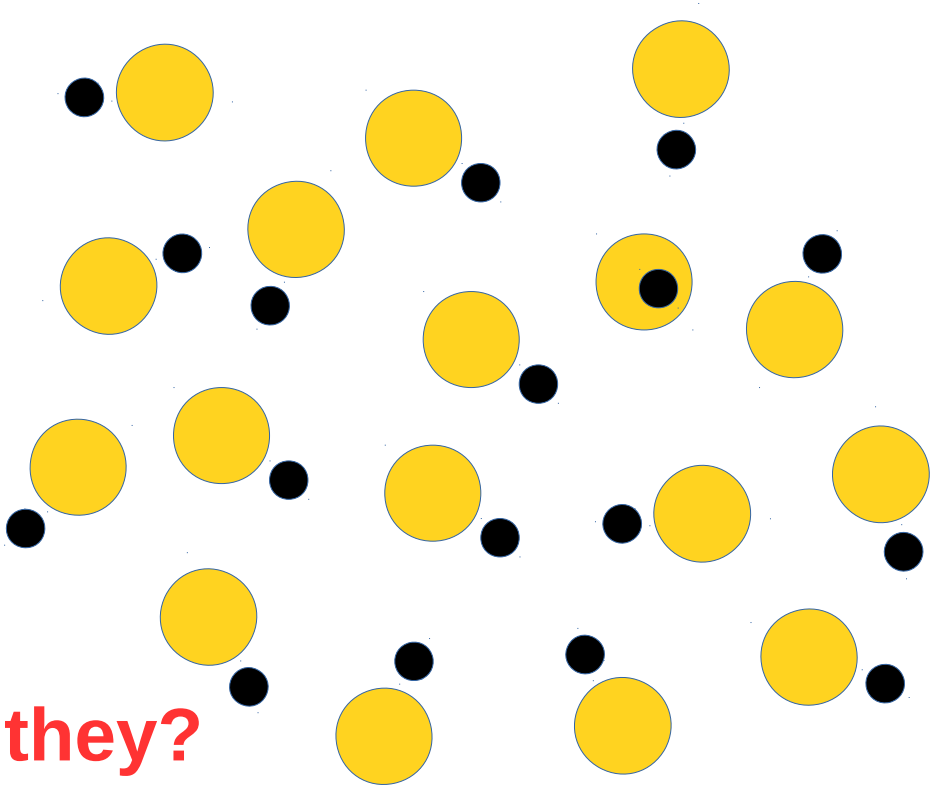
Inferring Planet Populations from *Kepler* Transit Observations

How many are there?

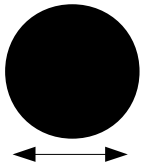
$$p = \left(\frac{\tau}{P}\right)^{2/3} \frac{1 + e\sin(w)}{1 - e^2}$$

P, δ, T...





How large are they?

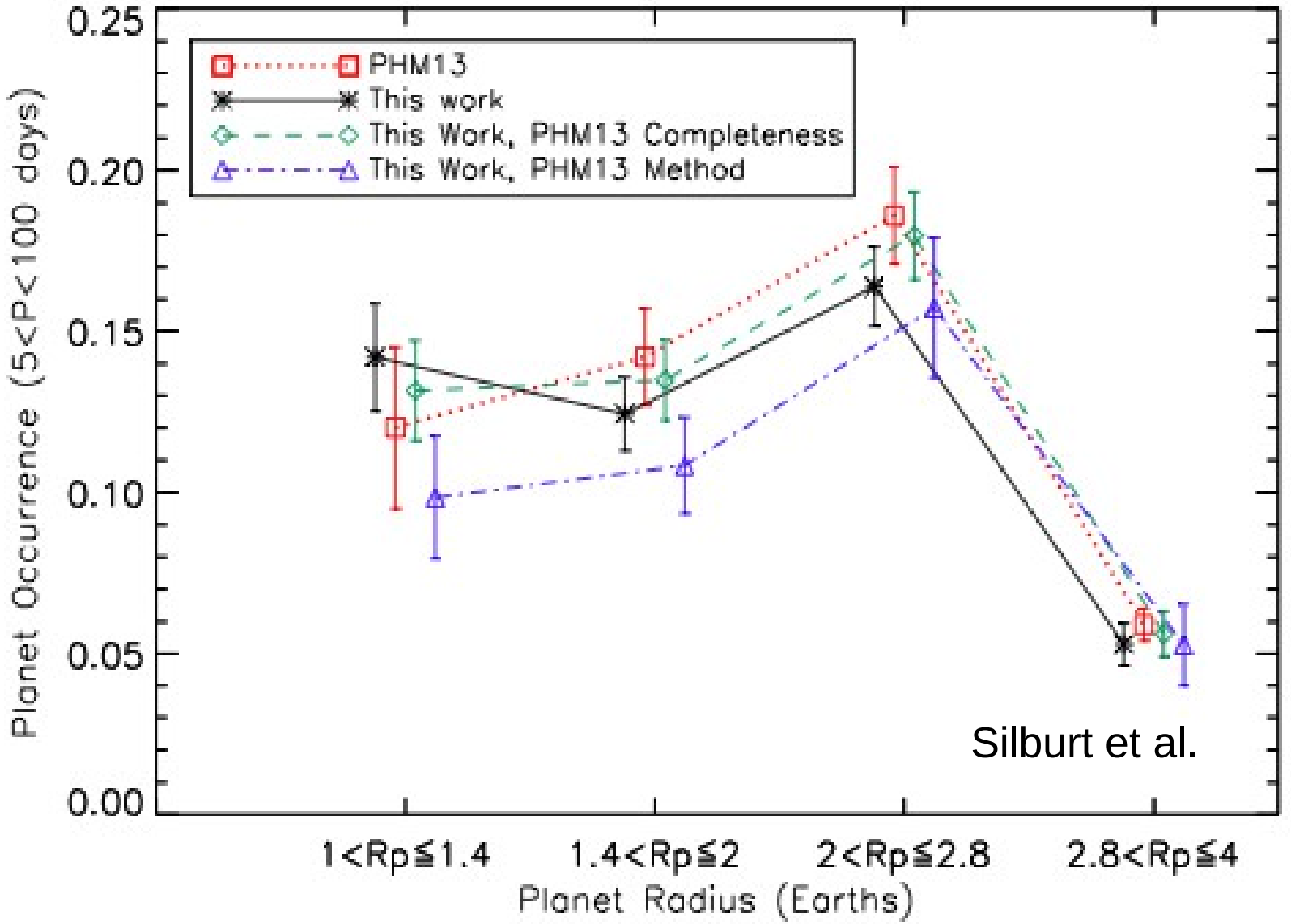


$$R_p = \delta^{1/2} R_s$$

- Some orbital elements are unknown
- Most candidate planets are not confirmed
- **Stellar properties not precisely established**

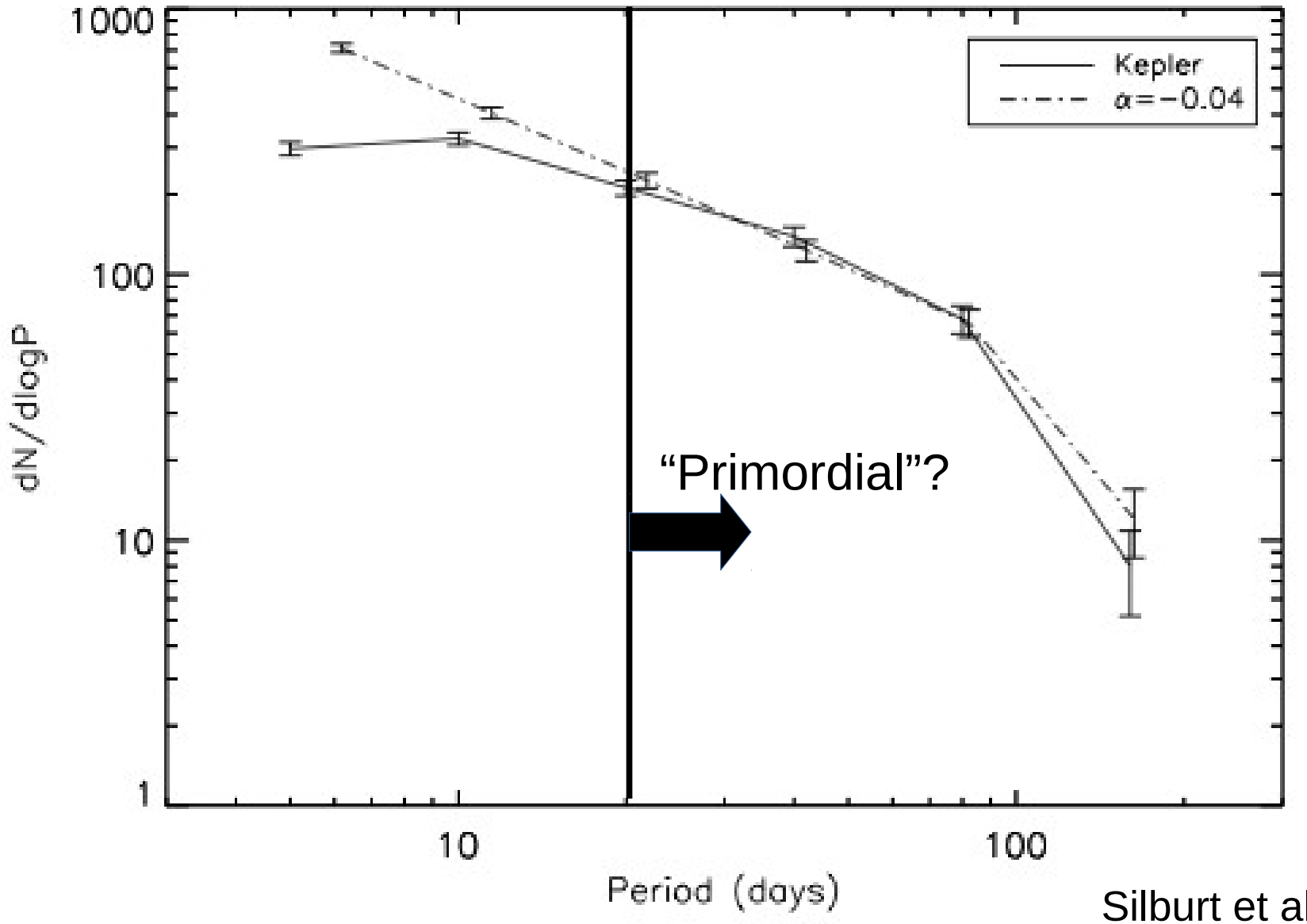
Radius Distribution of *Kepler* Planets

How many are there?



How large are they?

Period Distribution of *Kepler* “Small” Planets



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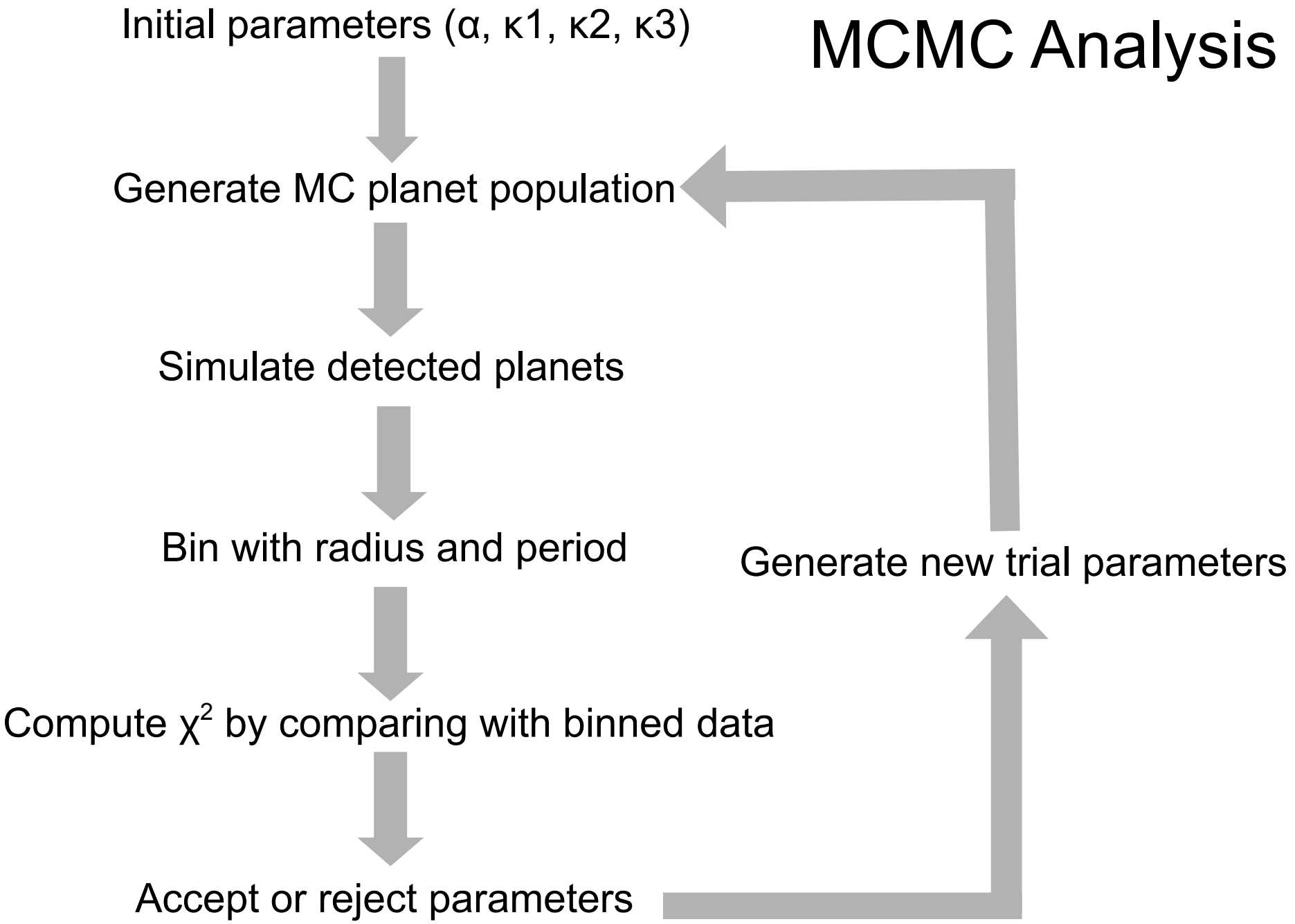
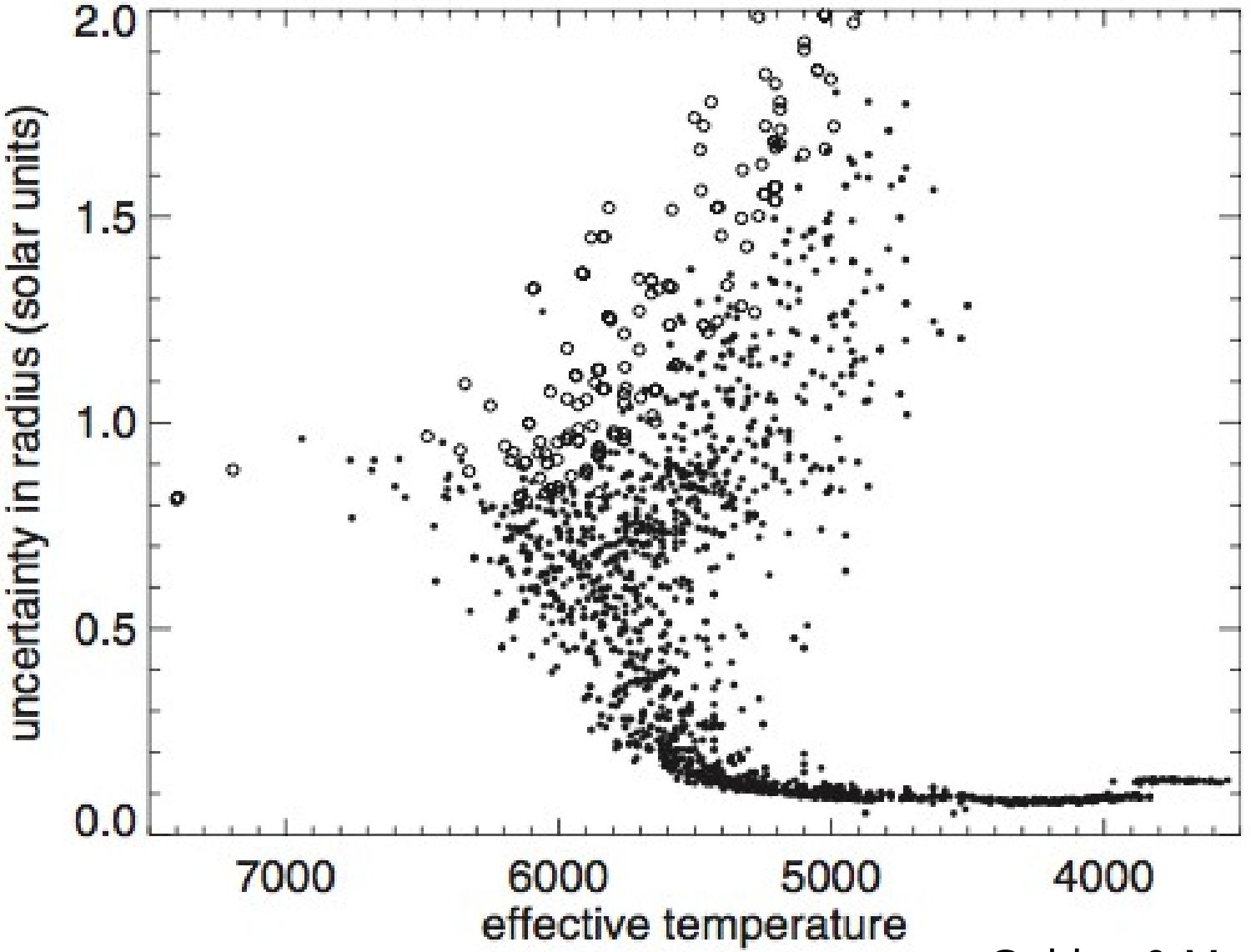
MCMC Analysis

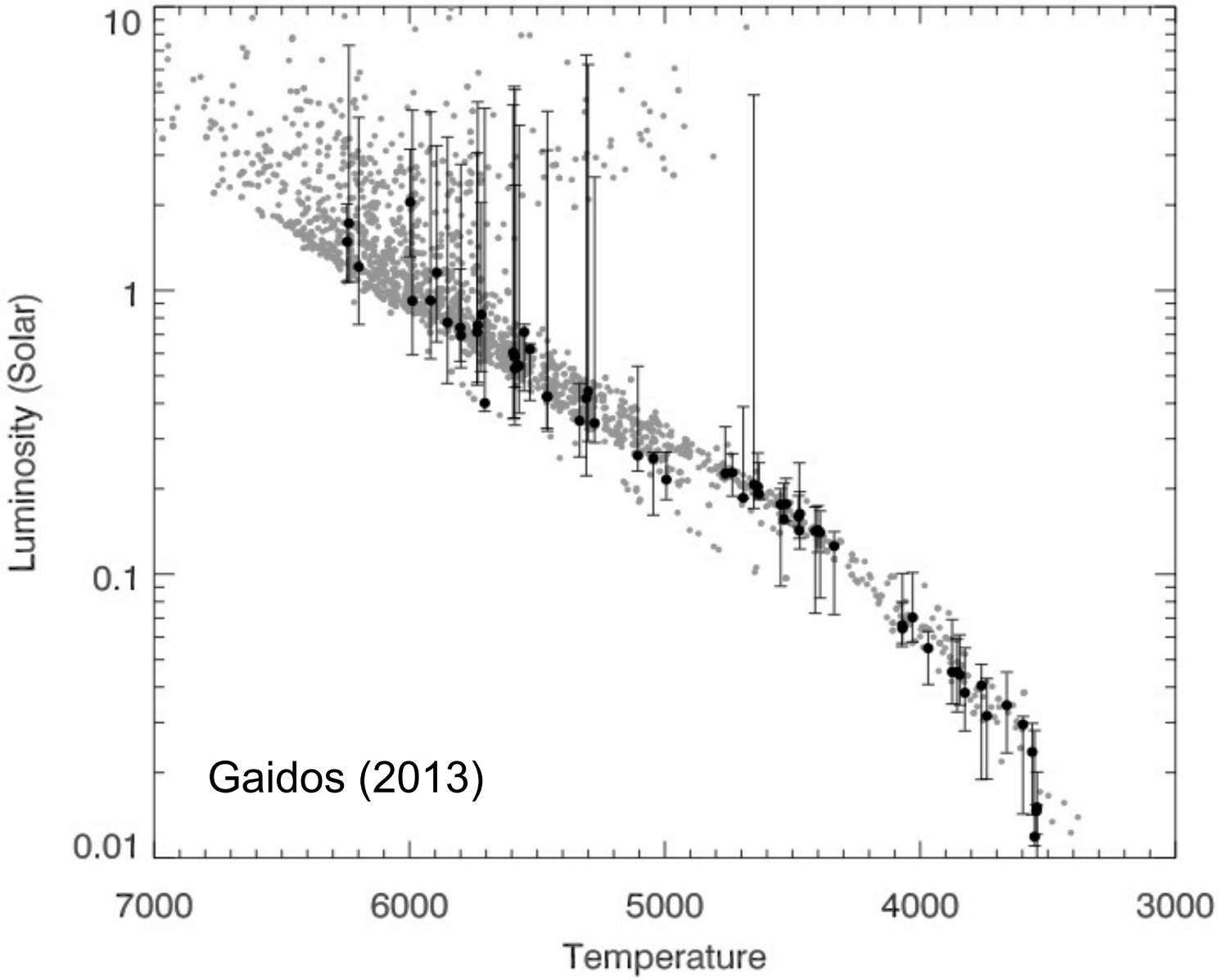


Properties of many *Kepler* Target Stars are Poorly Known

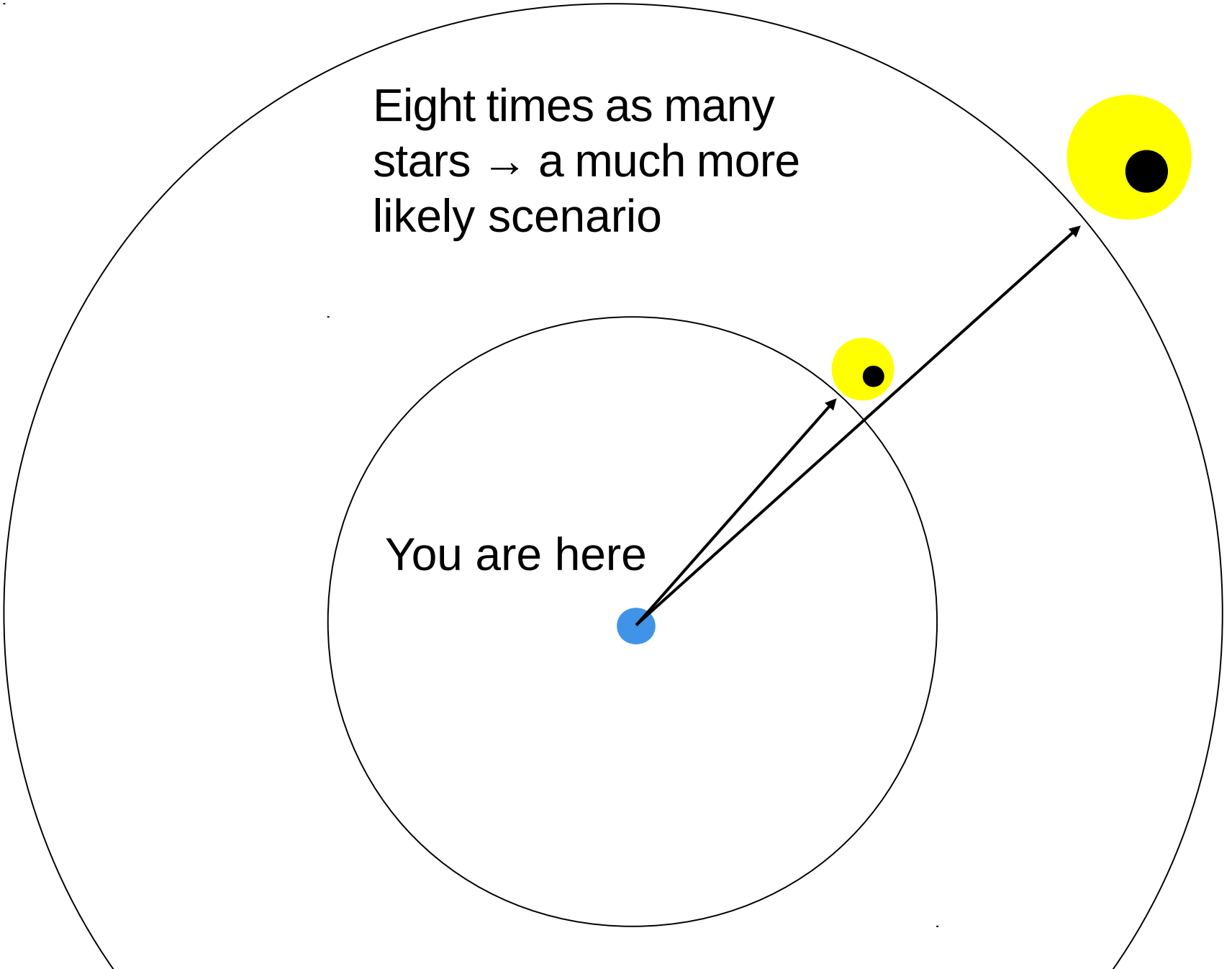


Gaidos & Mann (2013)

Uncertainties can be Very Asymmetric



Uncertainties plus Biases Produce Systematic Errors



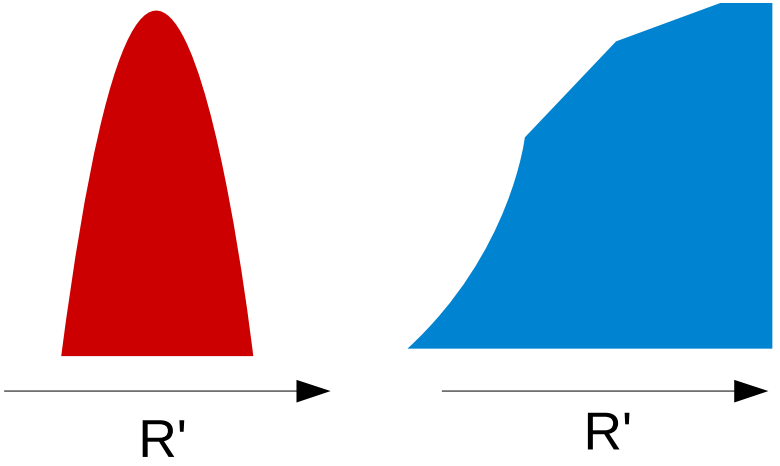
Bayesian Treatment of Radius Probability Distribution

Planet with measured radius R has true radius R'

Planet with true radius R' has measured radius R

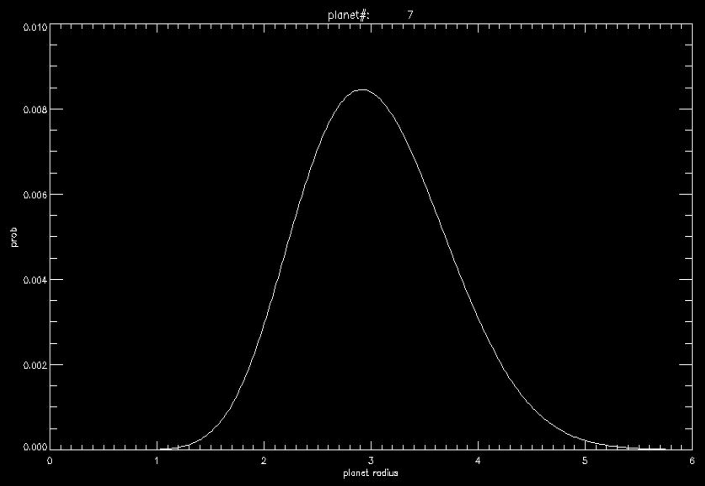
Planet with true radius R is be included in the catalog

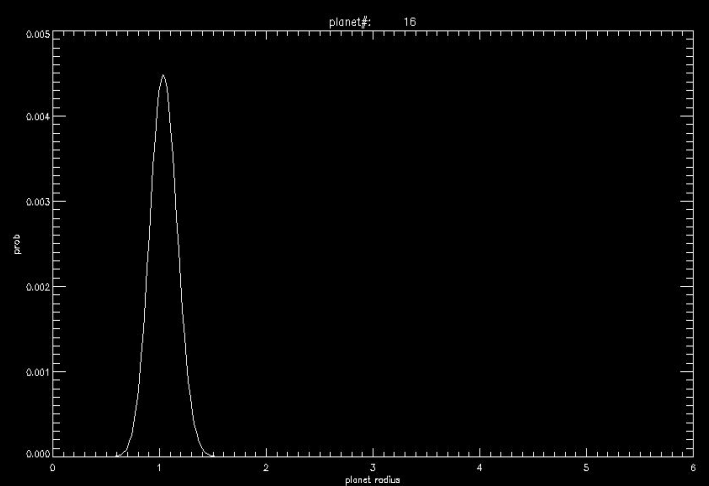
$$p(R'|R) = q(R|R')\,r(R')$$

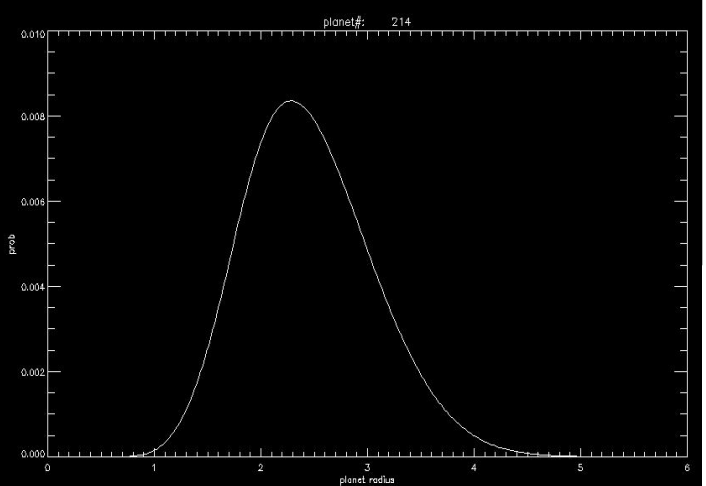


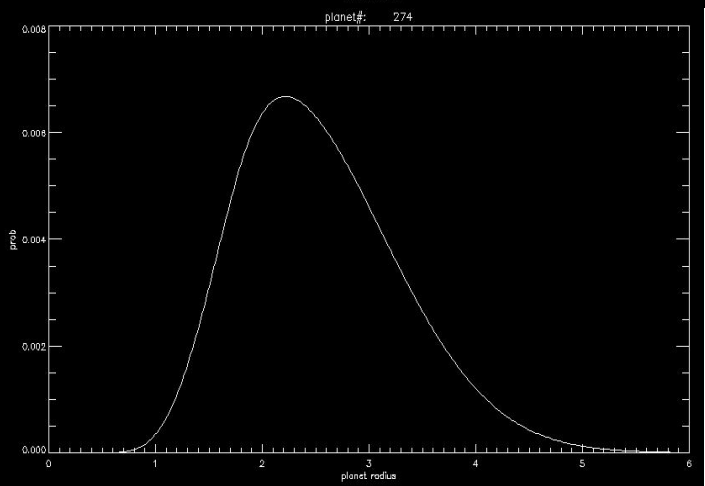
Small planet radii are more likely to be underestimates of larger values than overestimates of smaller planets

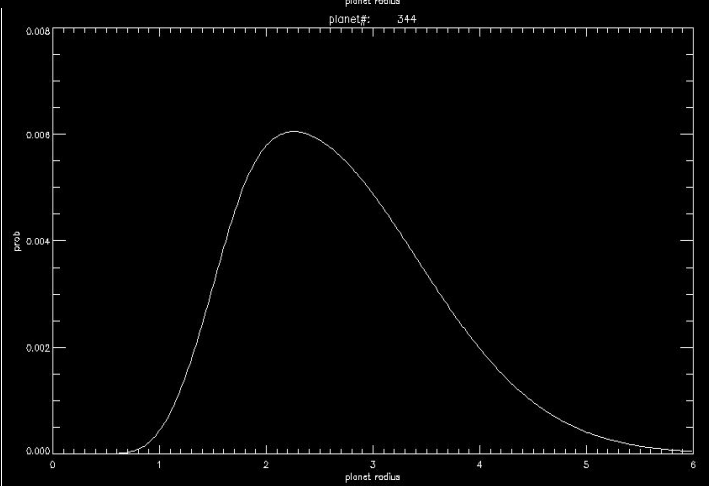
Posterior Radius Probability Distributions

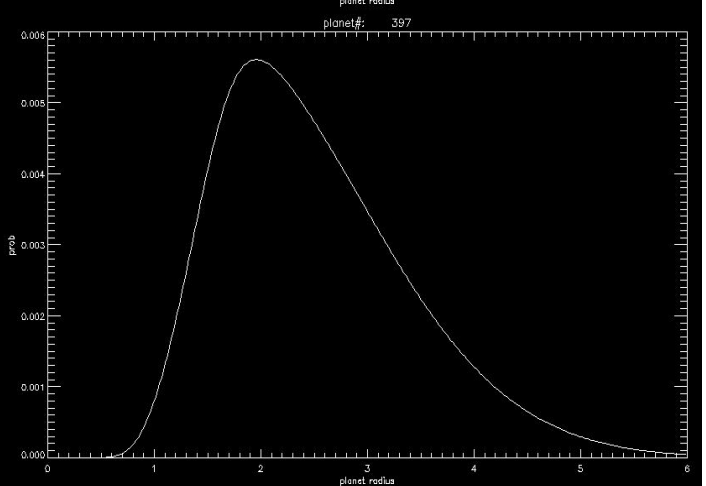


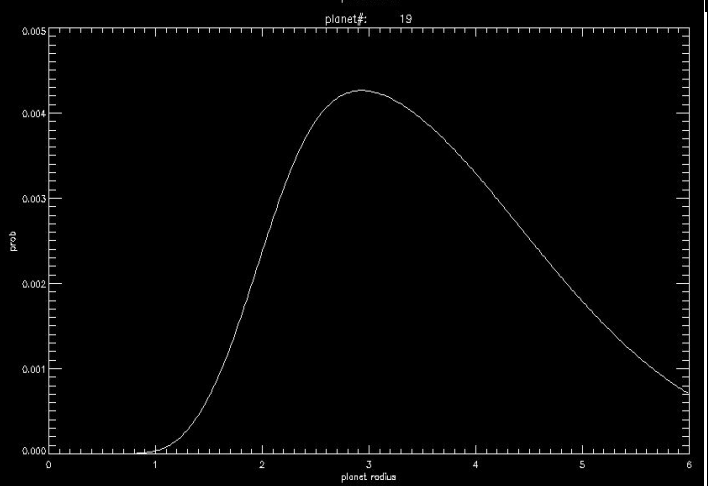


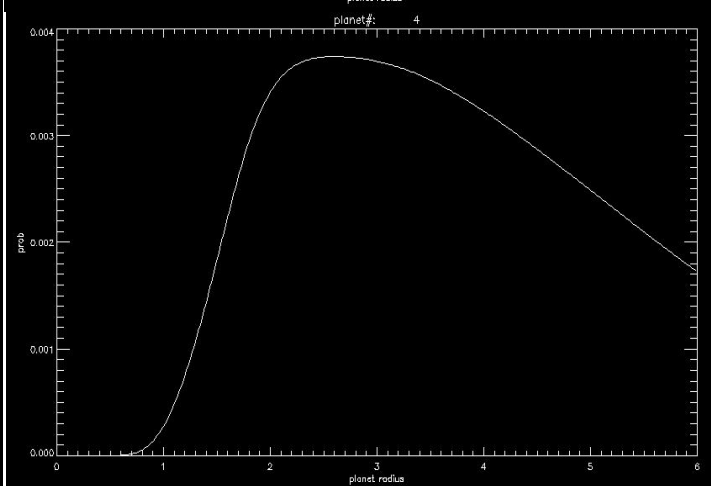


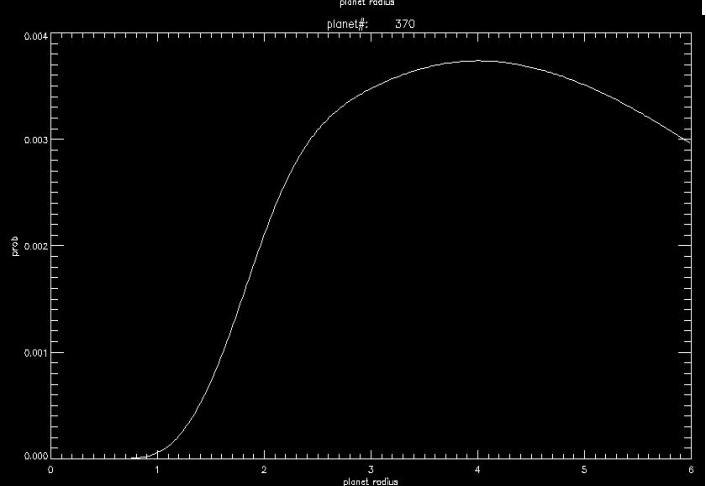




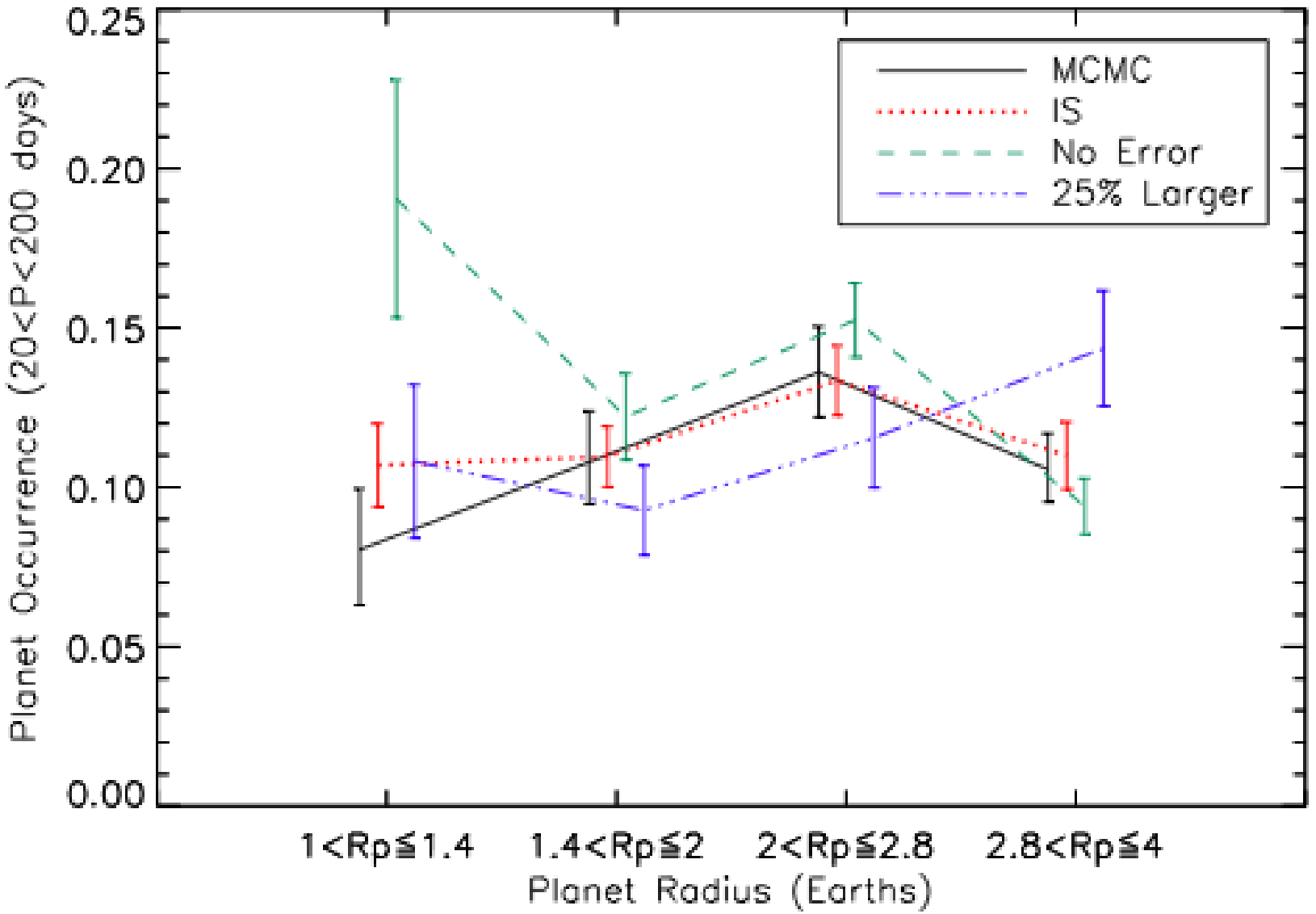








Result: Fewer Small Planets and More Larger Planets



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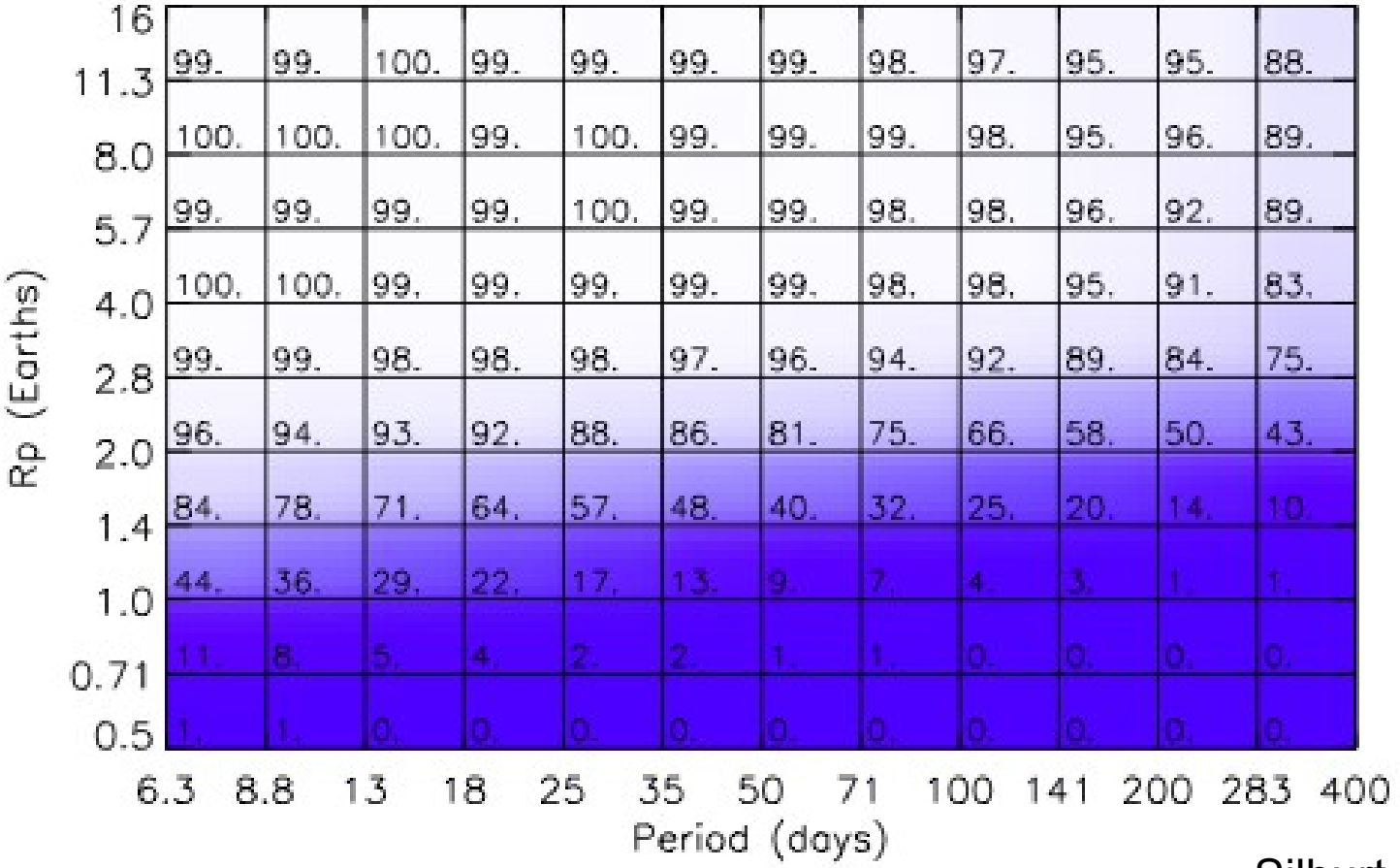
Are we losing details by binning?



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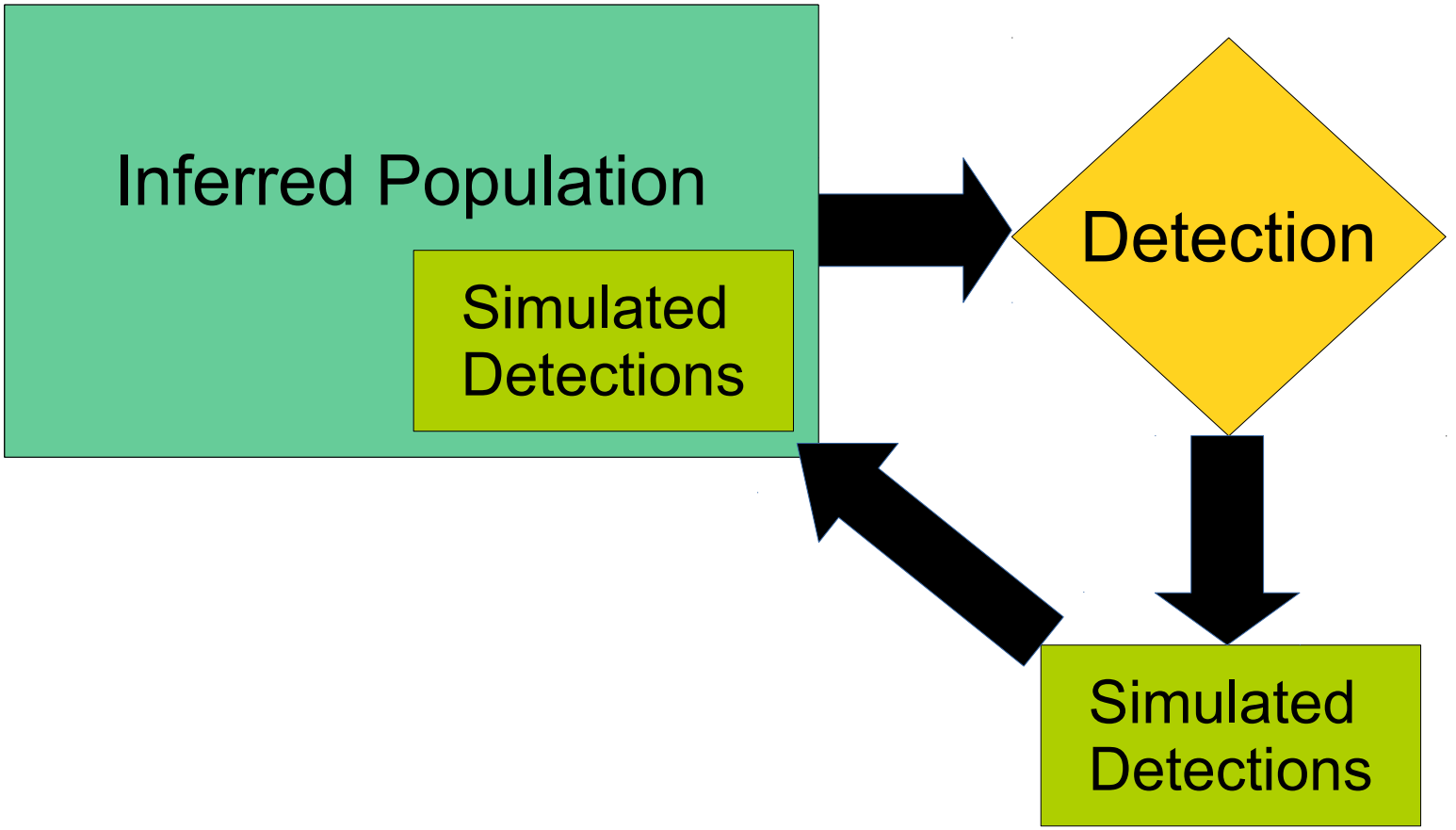
Sequential Monte Carlo Method with Boostrap Filter ("Iterative Simulation")

See: e.g., Cappé, Godsil & Moulines (2006)

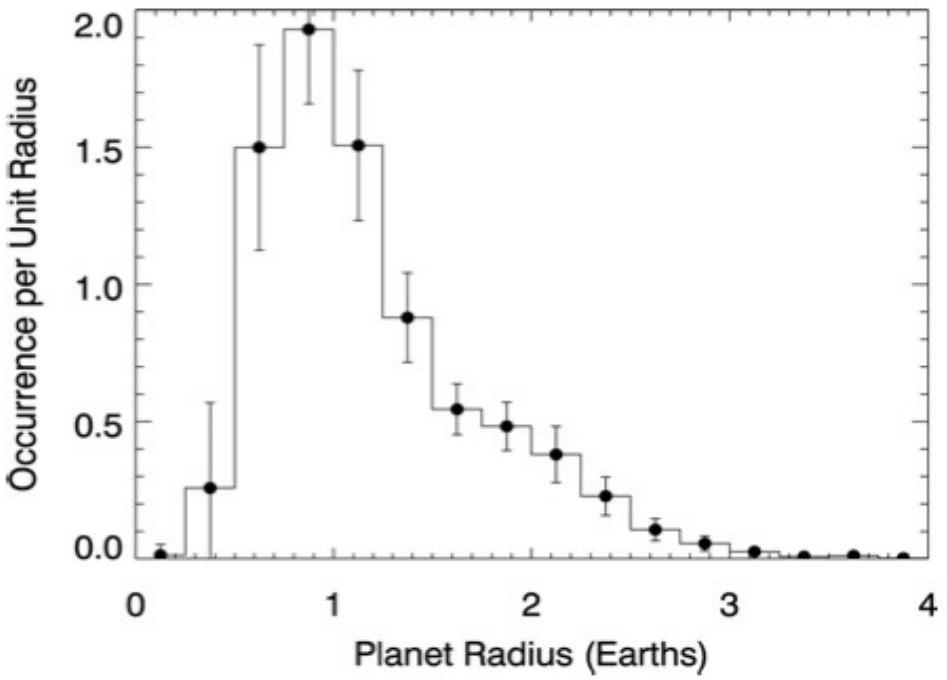


Iterative Simulation Estimation of Planet Occurrence around Late K and M Dwarf Stars (T_{eff} < 4200K)

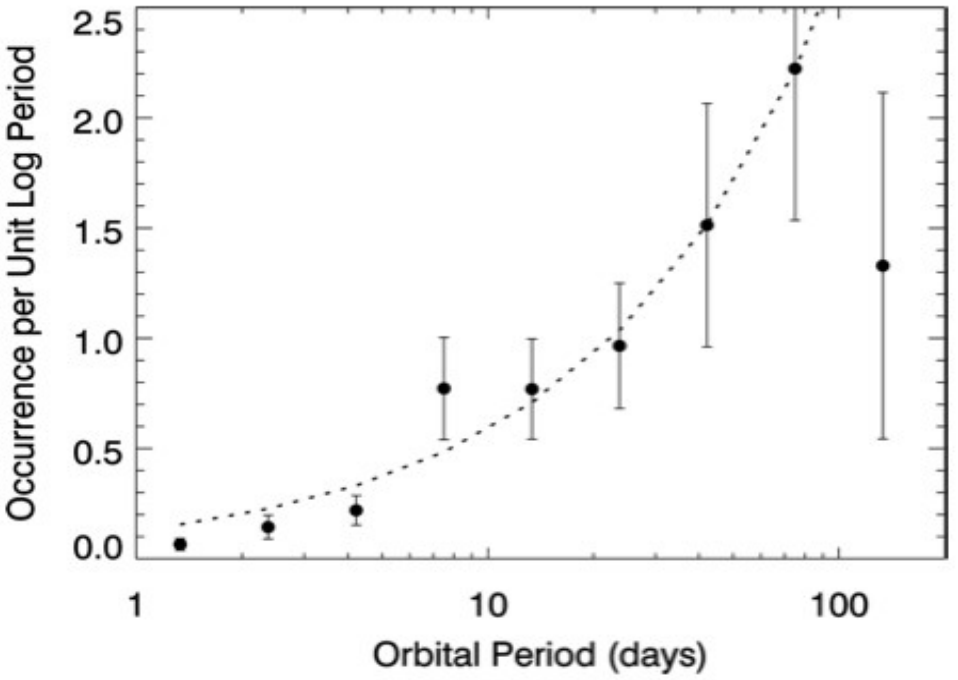
(Stellar parameters from Dartmouth stellar model fitting)

Total occurrence (P< 180d) = 2.01 ± 0.36

Radius Distribution



Period Distribution

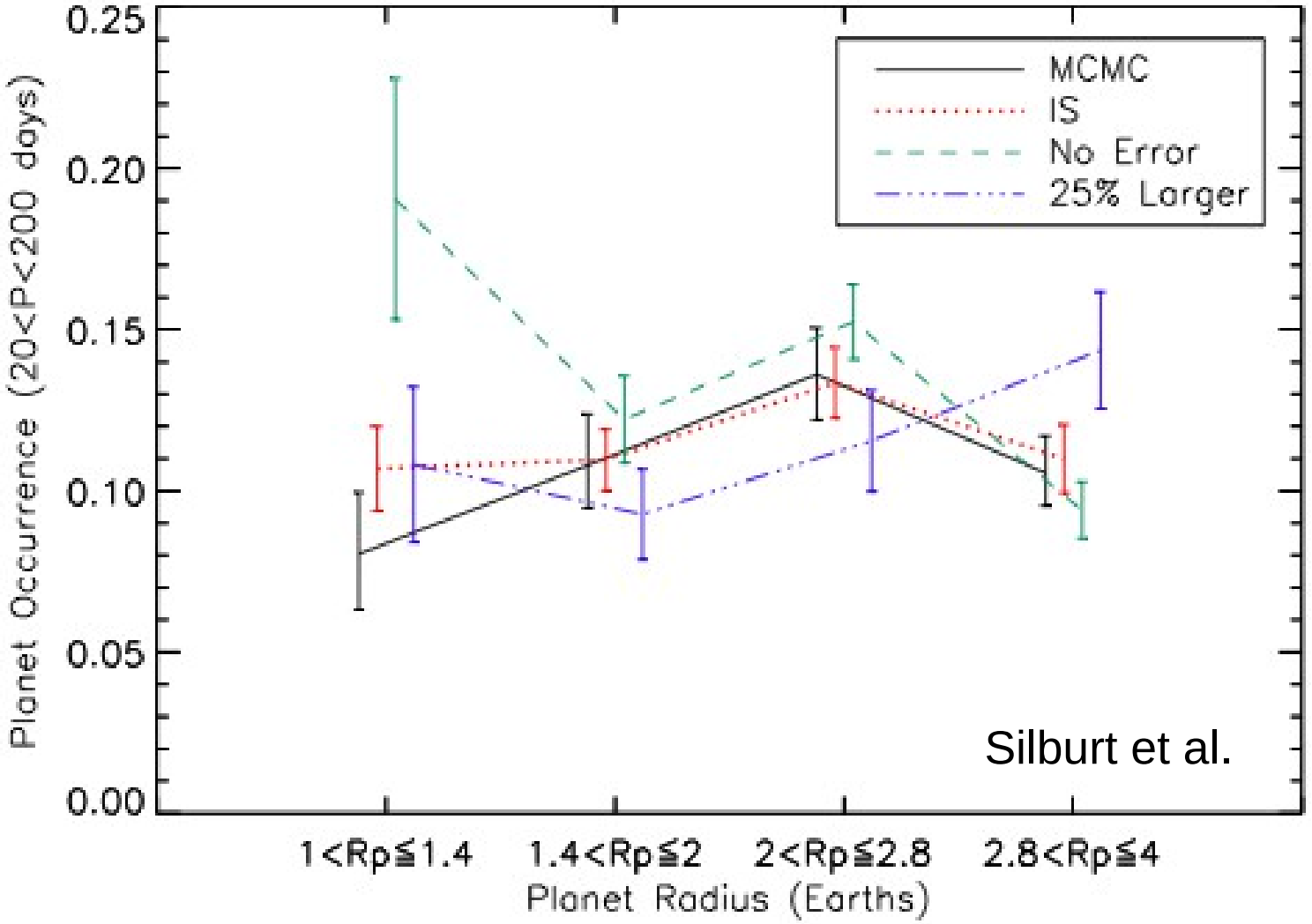


Gaidos et al. (2014)

Come listen to Courtney Dressing's talk this afternoon!

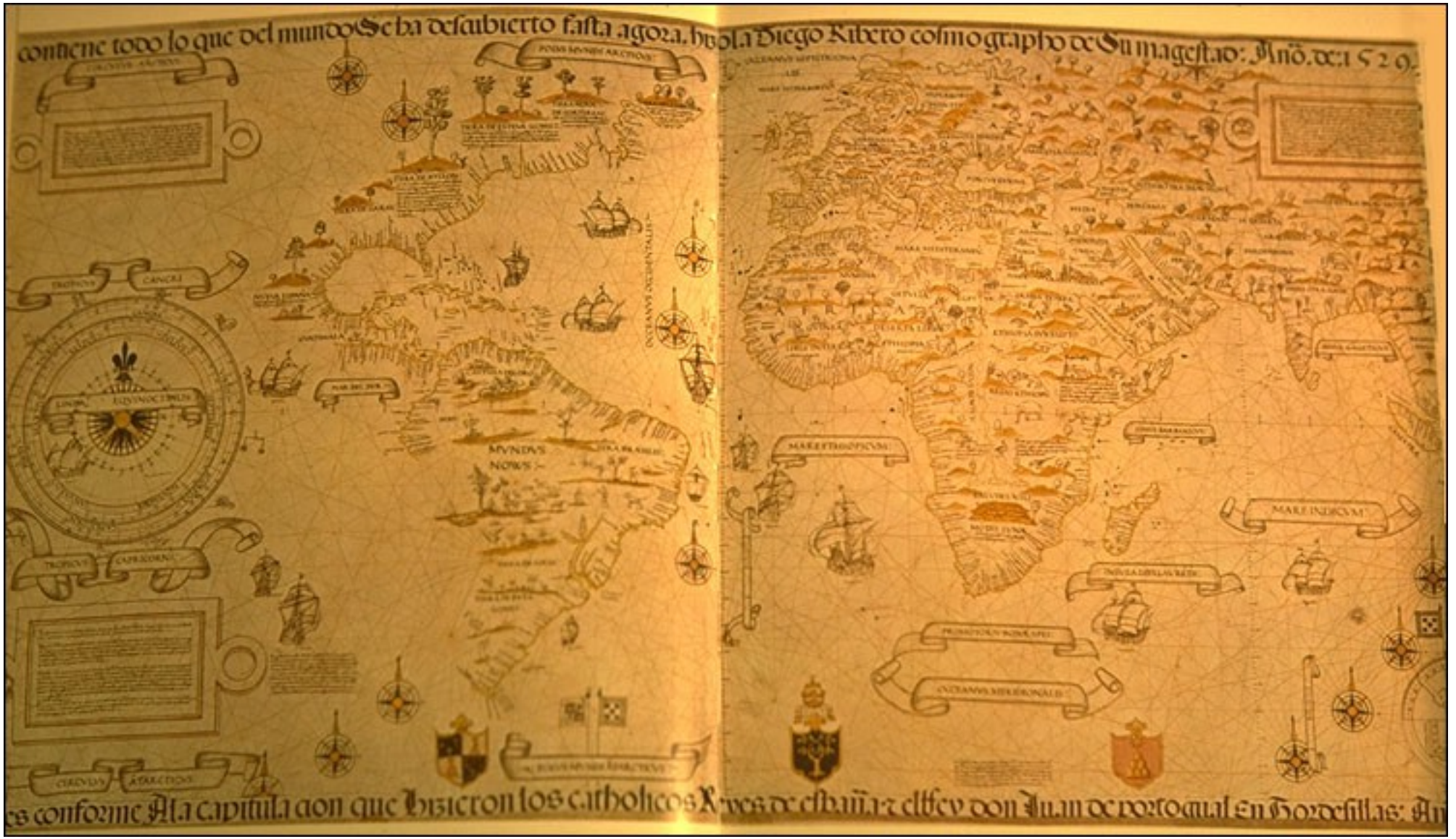
How sensitive to stellar population is the planet population?

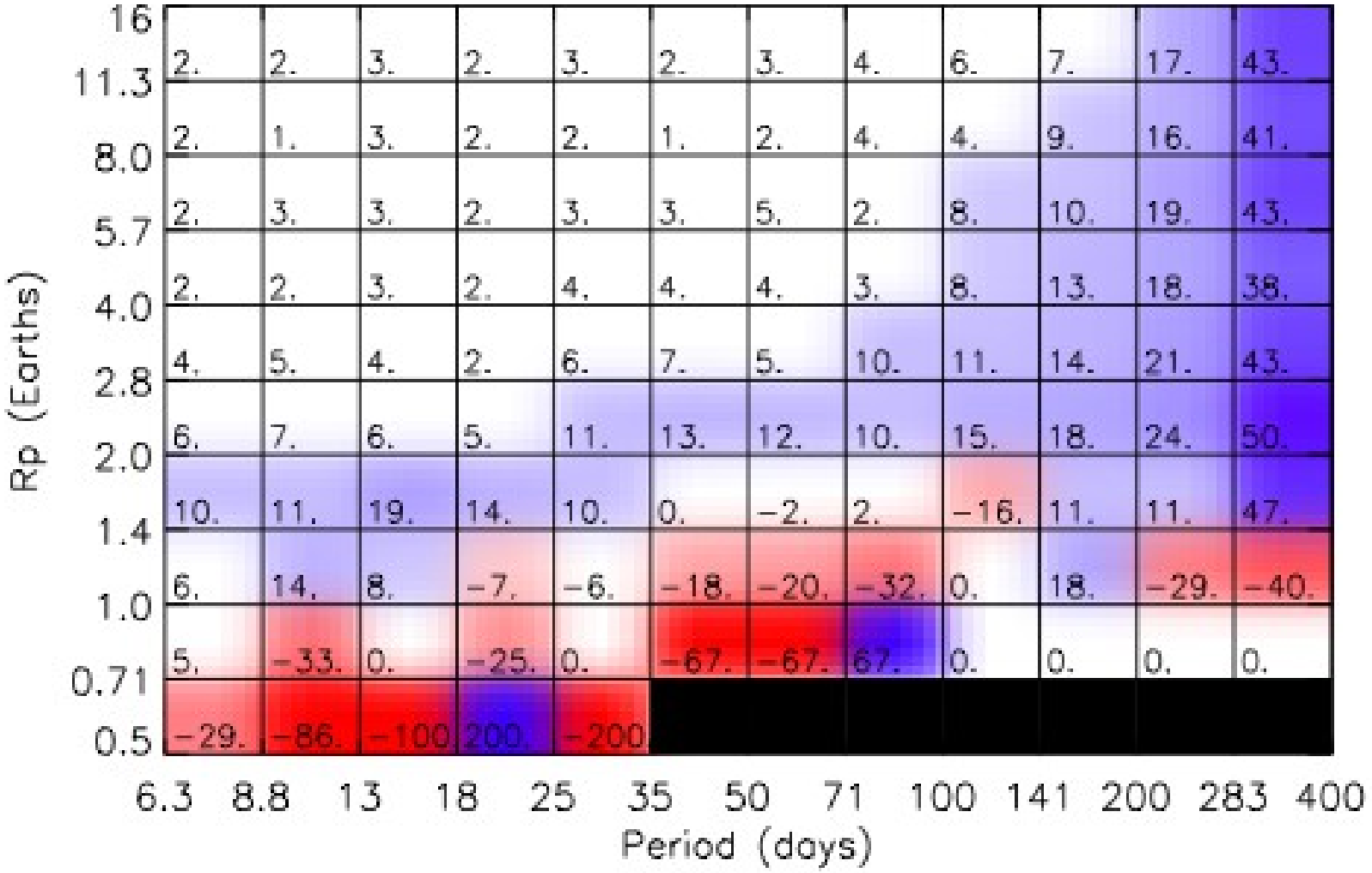
Total occurrence (20d<P< 200d) = 0.43 ± 0.03



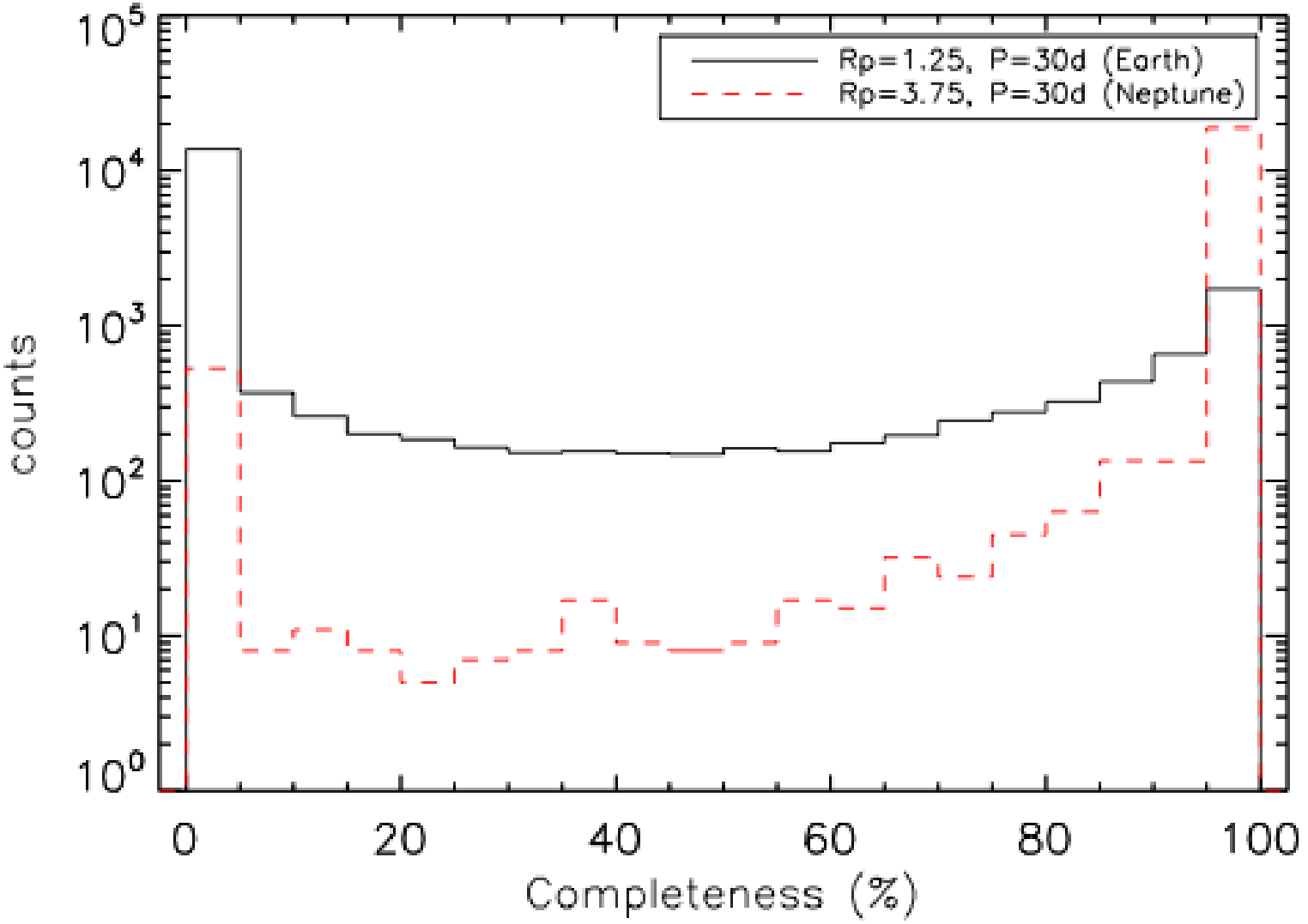
See poster by Mulders et al. and arXiv:1406.7356 on this topic

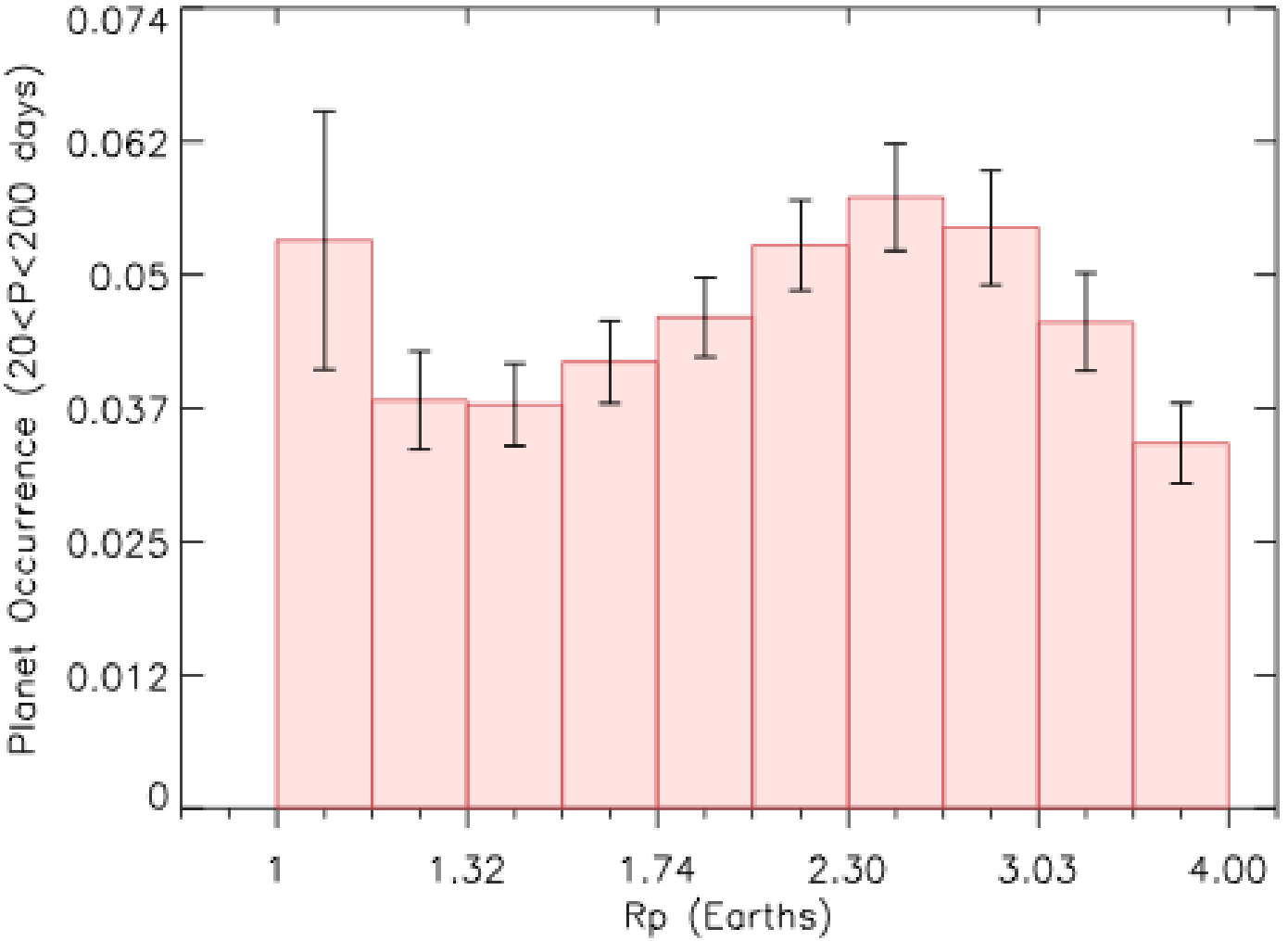
Ribero World Map (1529)





Silburt et al. (2014)


Rp=1.25, P=30d (Earth)
Rp=3.75, P=30d (Neptune)
counts
10^5
10^4
10^3
10^2
10^1
10^0
0
20
40
60
80
100
Completeness (%)


0.074
0.062
0.05
0.037
0.025
0.012
0
Planet Occurrence (20<P<200 days)
1
1.32
1.74
2.30
3.03
4.00
Rp (Earths)