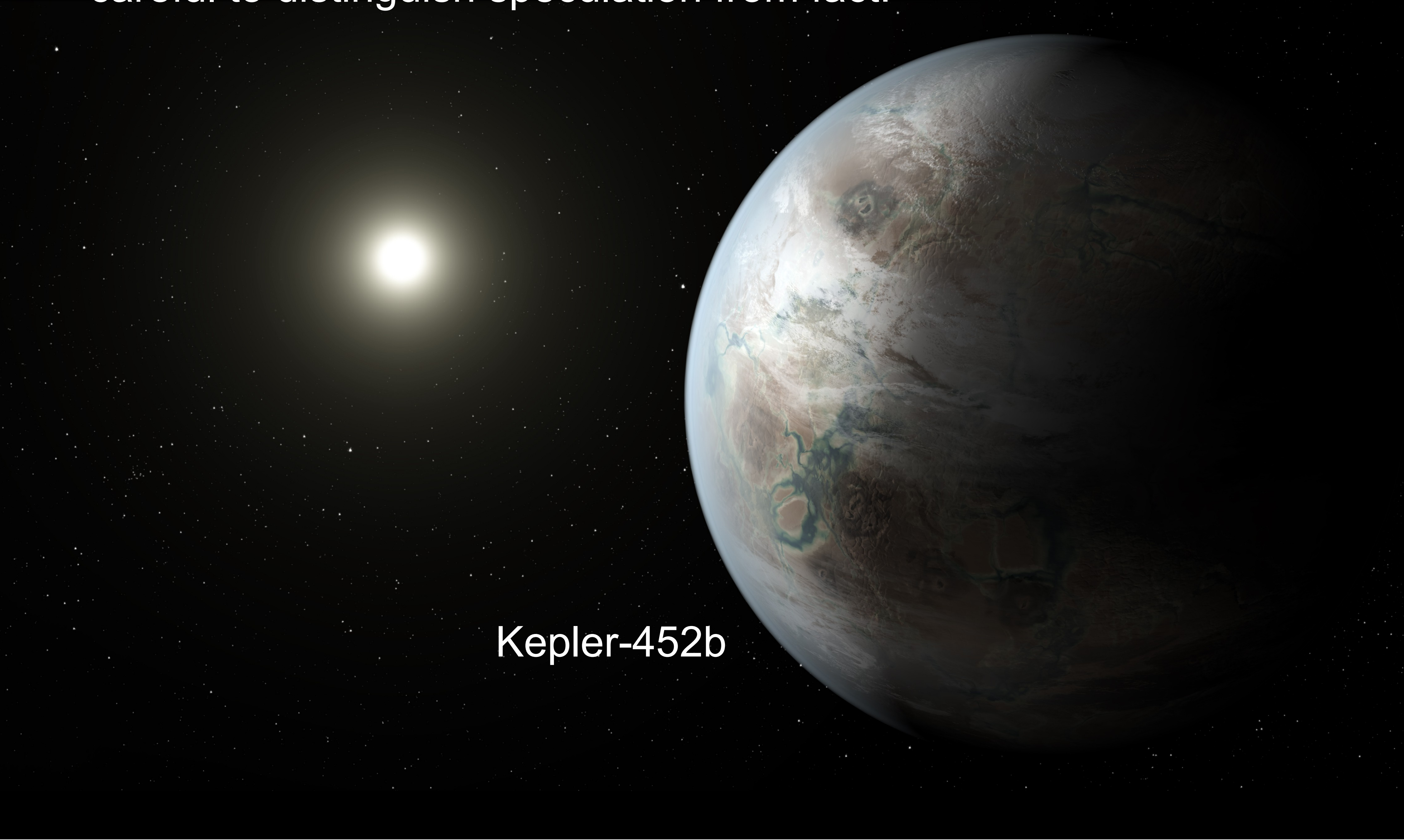
Looking at the Bigger Picture:

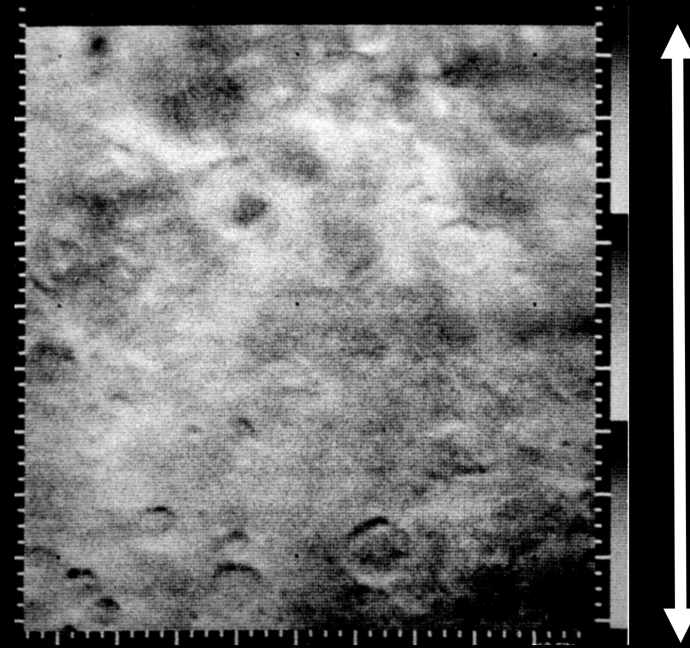
Synergistic Observations to Better Understand Planets around Other Stars

Eric Gaidos

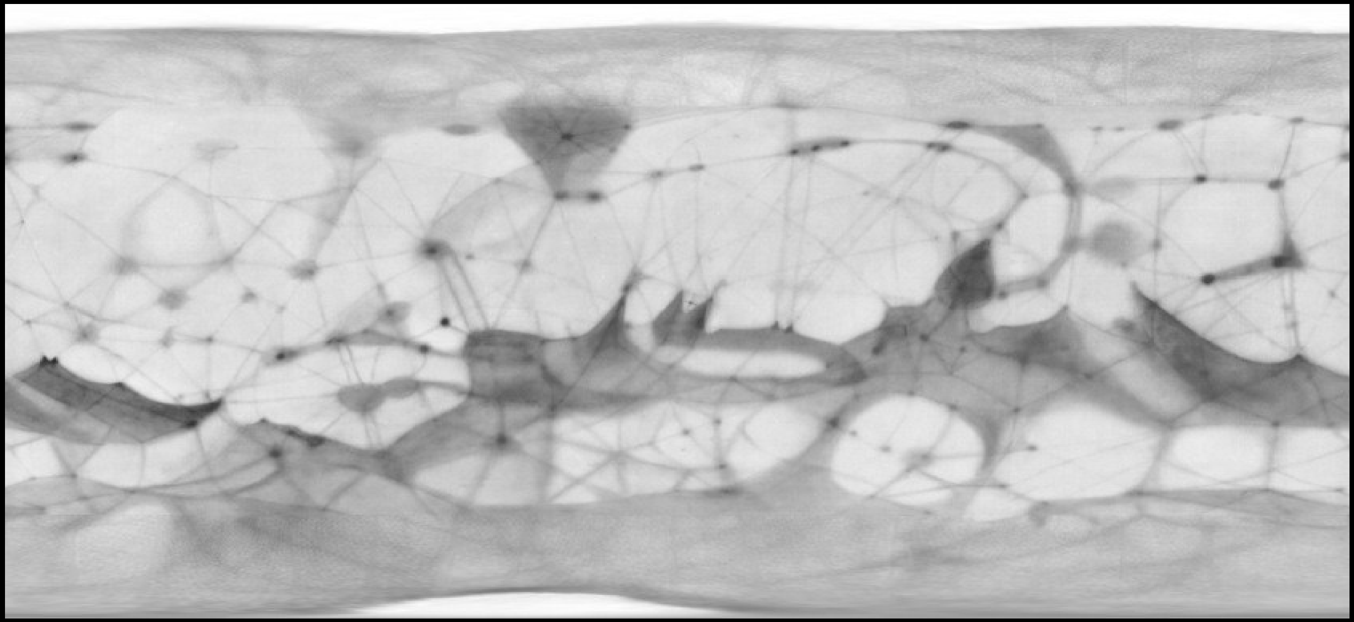
"...to find the truth we need imagination and skepticism both. We will not be afraid to speculate, but we will be careful to distinguish speculation from fact."



Mariner 4 Mars Encounter: July 14, 1965

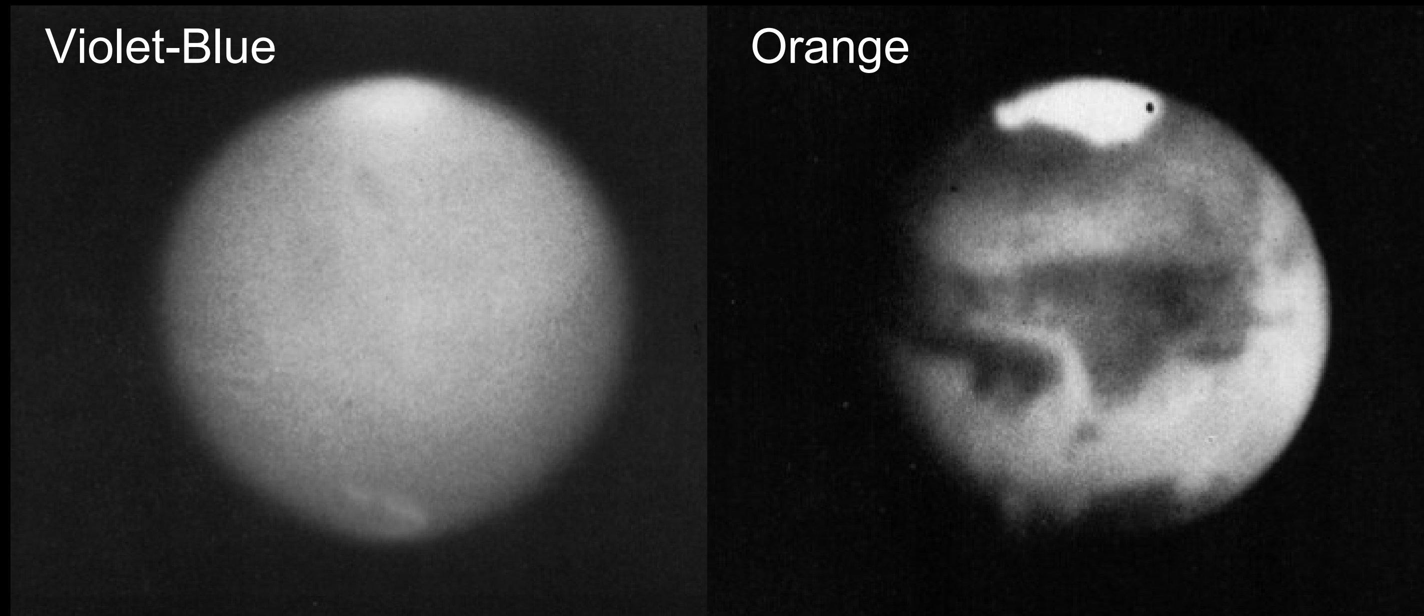


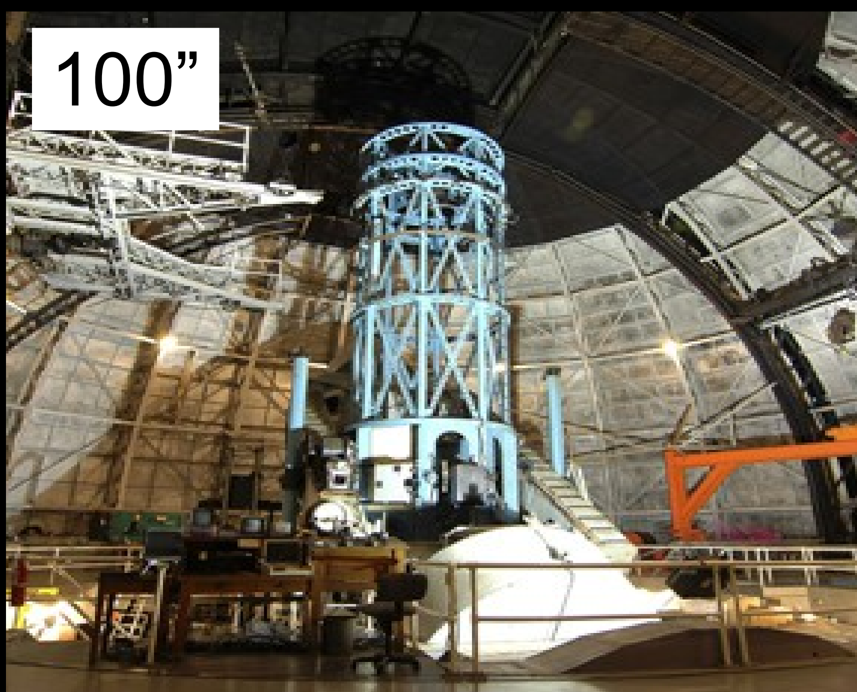
300 km

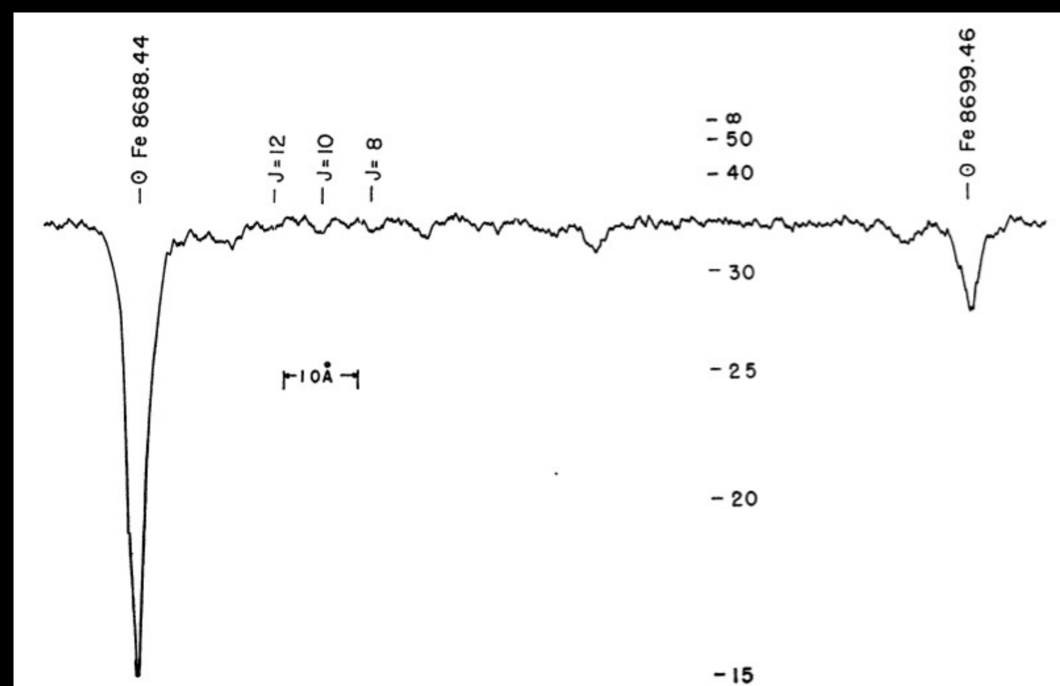


1962 US Air Force map of Mars

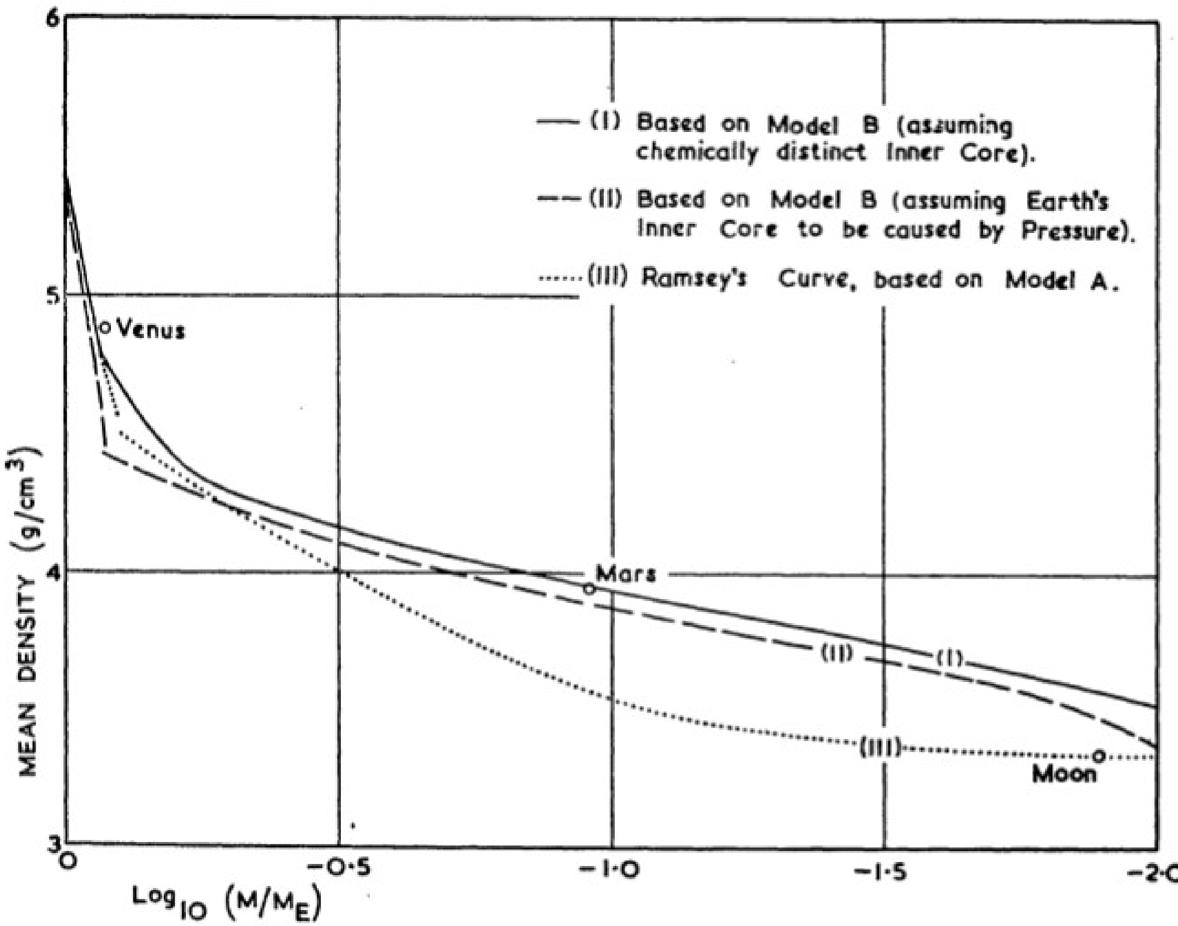
Mars from Mount Wilson







Properties of Mars			
	1956 value	Modern value	Error
Mass	6.44×10^{23} kg	6.42×10^{23} kg	+0.3%
Radius	3330 km	3390 km	-1.8%
Mean density	4.16 g cm^{-3}	3.93 g cm^{-3}	+5.9%



Bullen & Low (1952)

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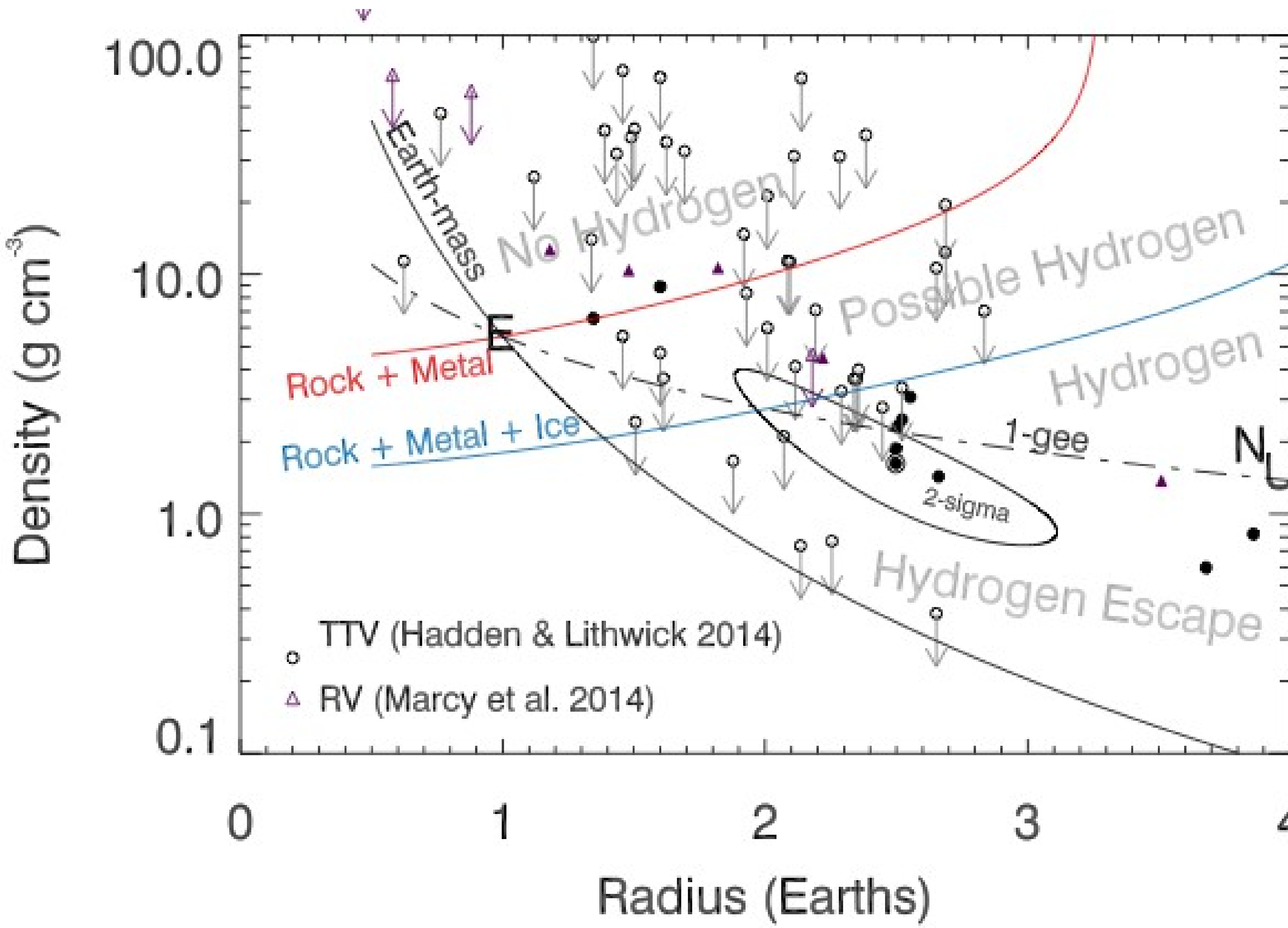
Densities of “Small” *Kepler* K/M Dwarf Planets



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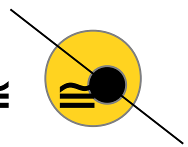
Inferring Planet Properties from a Transit Survey

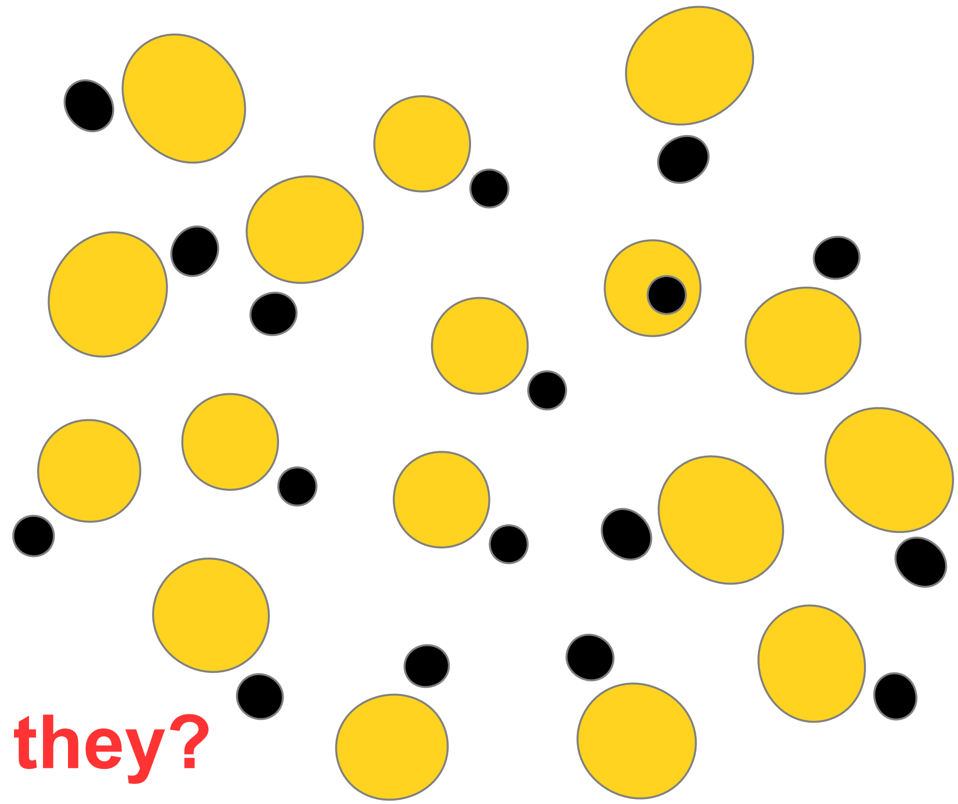
$$p = \left(\frac{\tau}{P}\right)^{2/3} \frac{1 + e\sin(w)}{1 - e^2}$$

$$\tau = 2\sqrt{\hat{R}_*^3/(\pi G \hat{M}_*)}$$

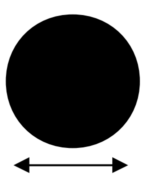
P, δ≅ ≅ ≅



How many are there?



How large are they?



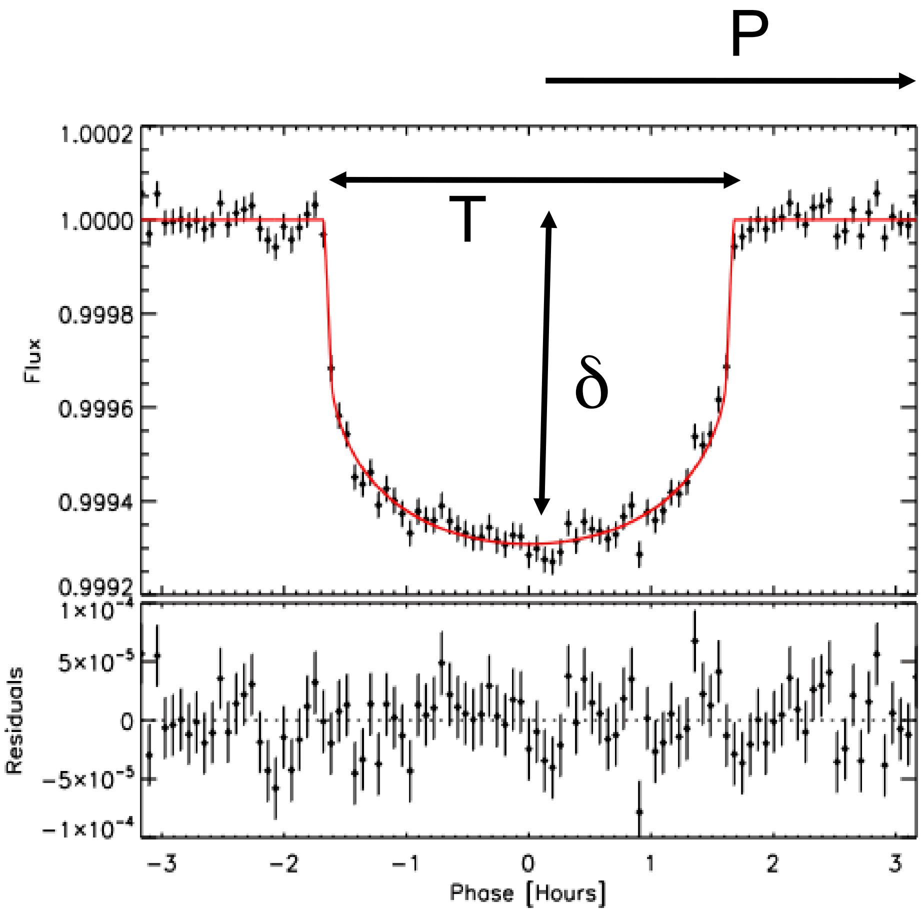
$$R_p = \delta^{1/2} R_s$$

$$S = L_s P^{-4/3} M_S^{-2/3}$$

How hot are they?

Stellar radii, densities/masses, and luminosities are needed.

Stellar Densities from Transit Observations



want to know this

don't know

$$T = \tau^{2/3} P^{1/3} \Delta$$

observed

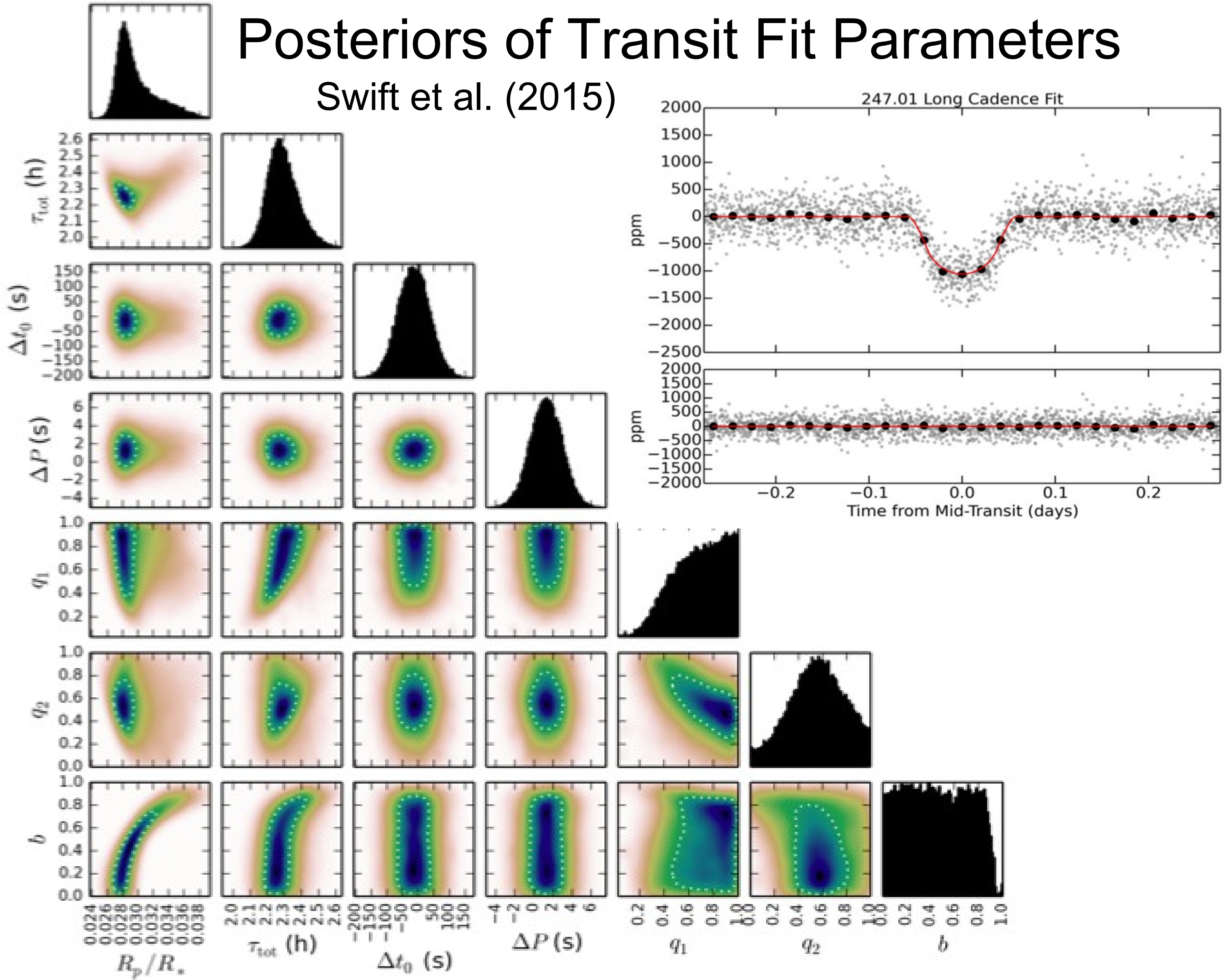
precisely known

$$\Delta = \frac{\sqrt{(1-e^2)(1-b^2)}}{1 + e\cos\omega}$$

Another unknown is limb darkening of the star

Posteriors of Transit Fit Parameters

Swift et al. (2015)



A Probabilistic Description of Host Star Properties

Given a transit observation, what is the probabilty that a star has a given density

$$P(\rho) = P(\rho|D)$$

Given a transit duration, what is the probability that a star has a given density?

$$P(\rho) = \int\cong \; P(\rho|T)\, Q(T|D)\, dT$$

orbital geometry → $P(\rho|T)$

light-curve fitting → $Q(T|D)$

$$T = \tau^{2/3} P^{1/3} \Delta$$

$$\tau = 2\sqrt{\hat{R}_*^3/(\pi G \hat{M}_*)}$$

$$\overline{N(\Delta)} = \int_0^1 \eta(e) de \int_0^{2\pi} \sqrt{1 - \frac{\Delta^2 (1 + e\cos\omega)^2}{(1-e^2)}} d\omega$$

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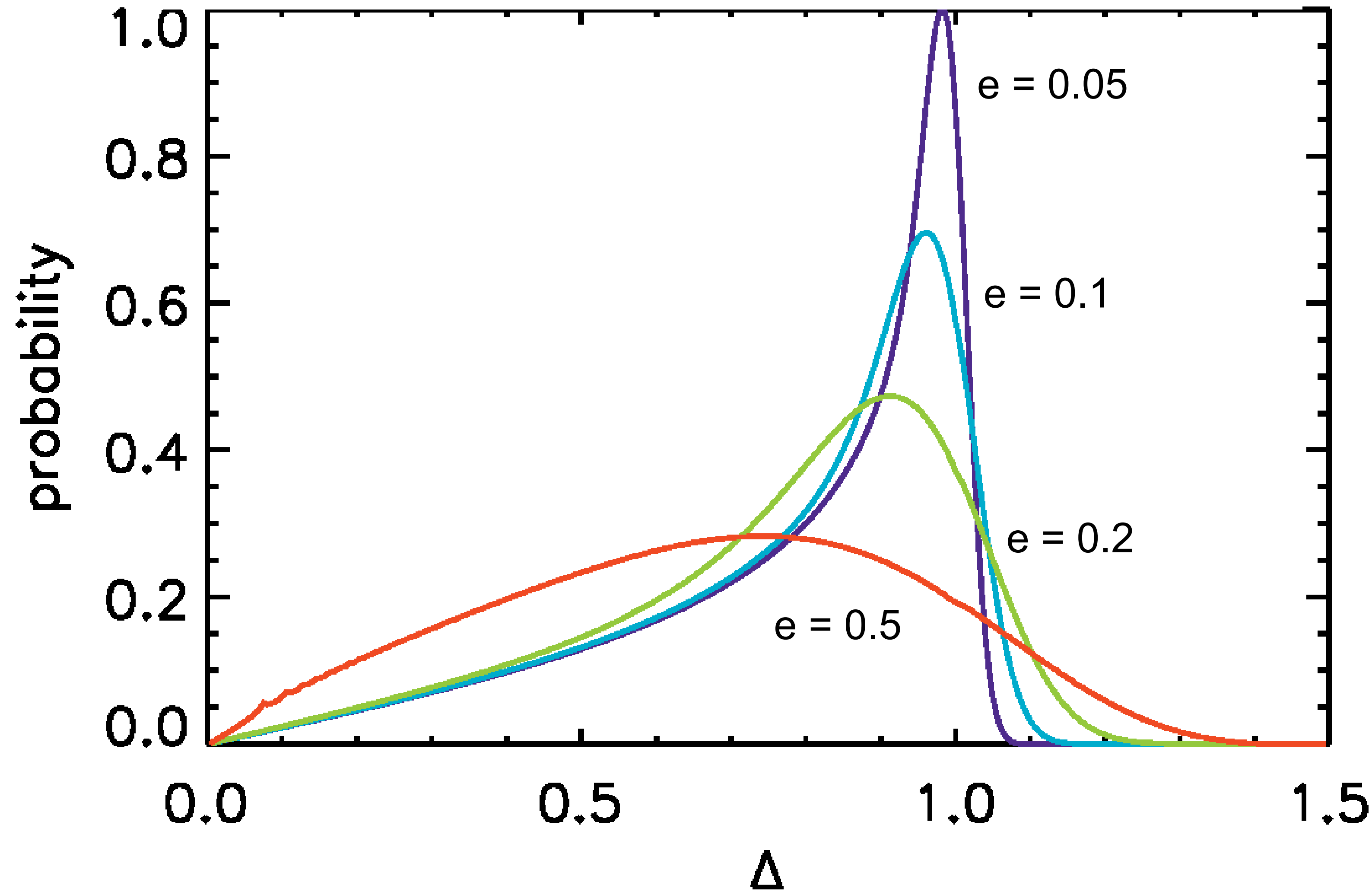
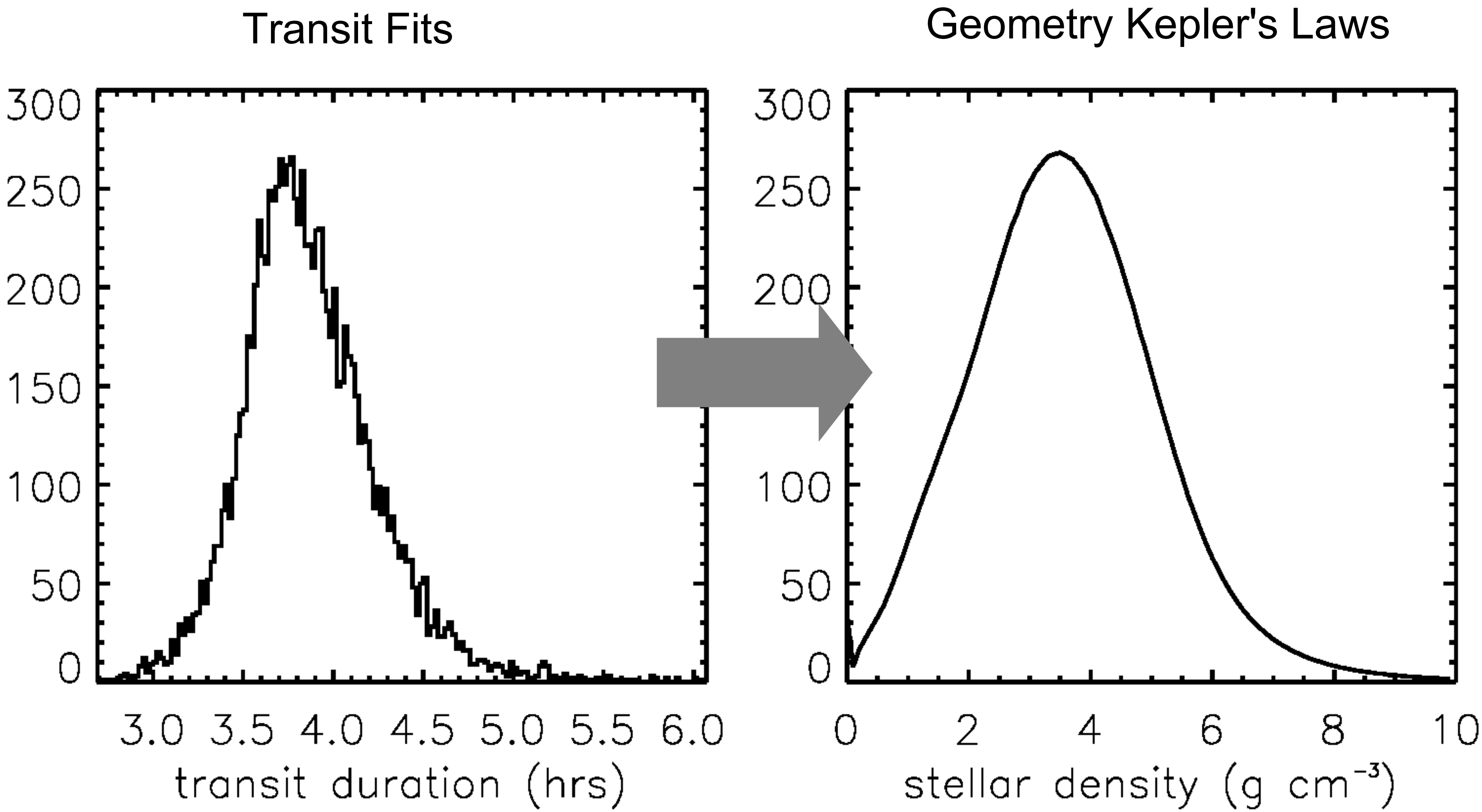
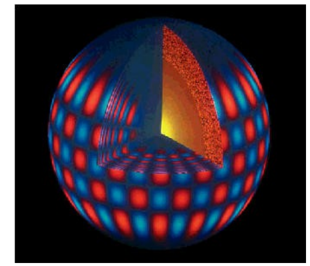



Transit Fits
Geometry Kepler's Laws
300
250
200
150
100
50
0
3.0 3.5 4.0 4.5 5.0 5.5 6.0
transit duration (hrs)
0 2 4 6 8 10
stellar density (g cm^{-3})

Direct methods of estimating stellar parameters

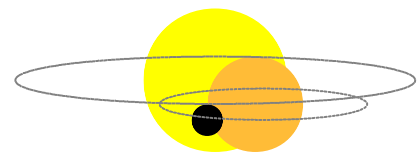
Astroseismology expensive, few

(density, age)



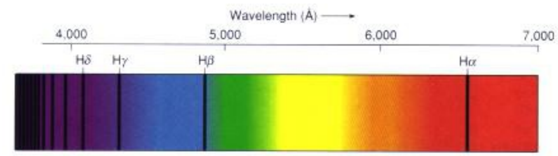
Dynamics expensive, few

(density, mass)



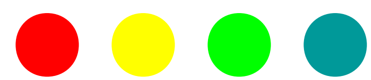
Spectroscopy expensive, many

(temperature, metallicity, gravity)

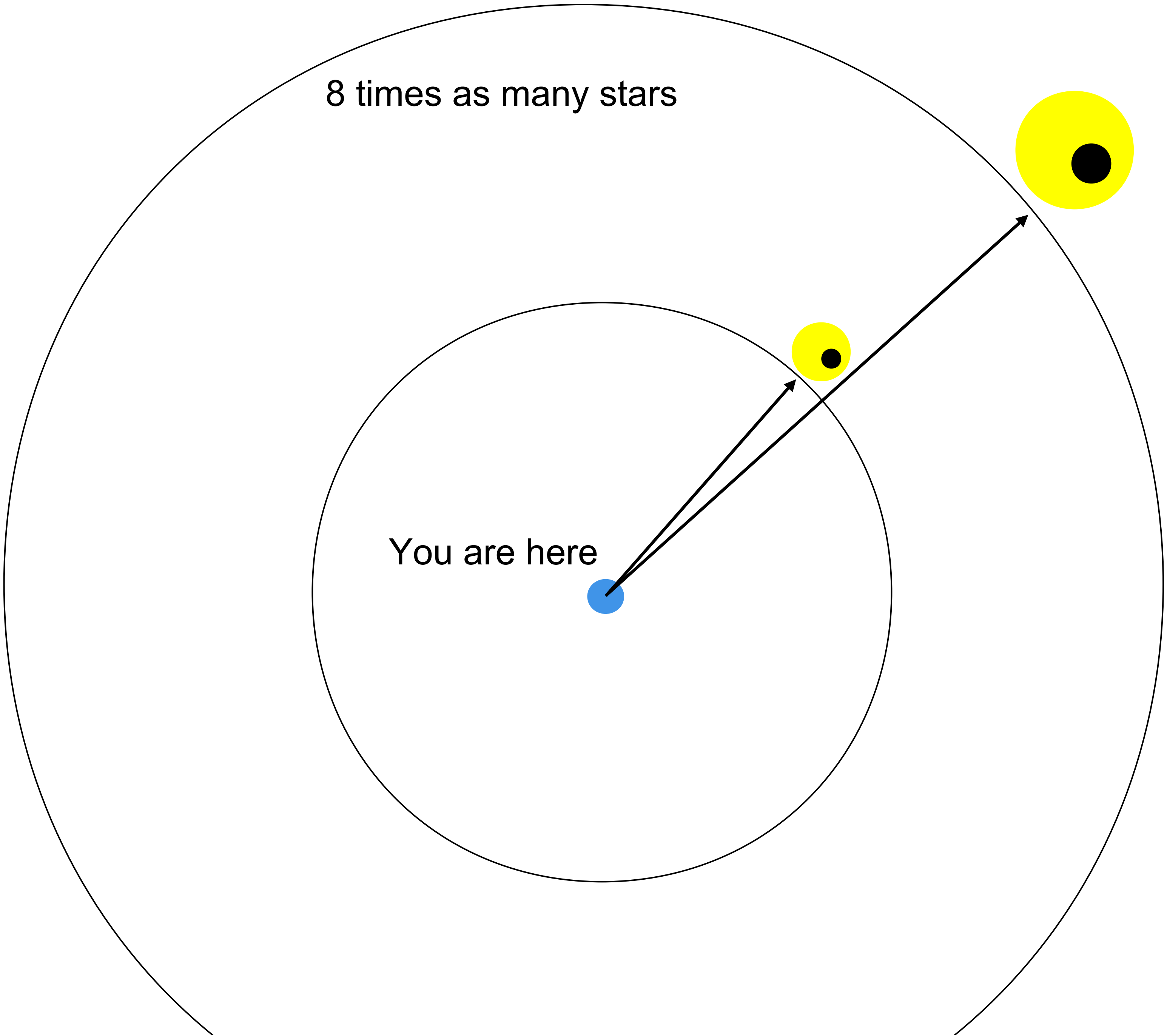


Broad-band photometry cheap, all

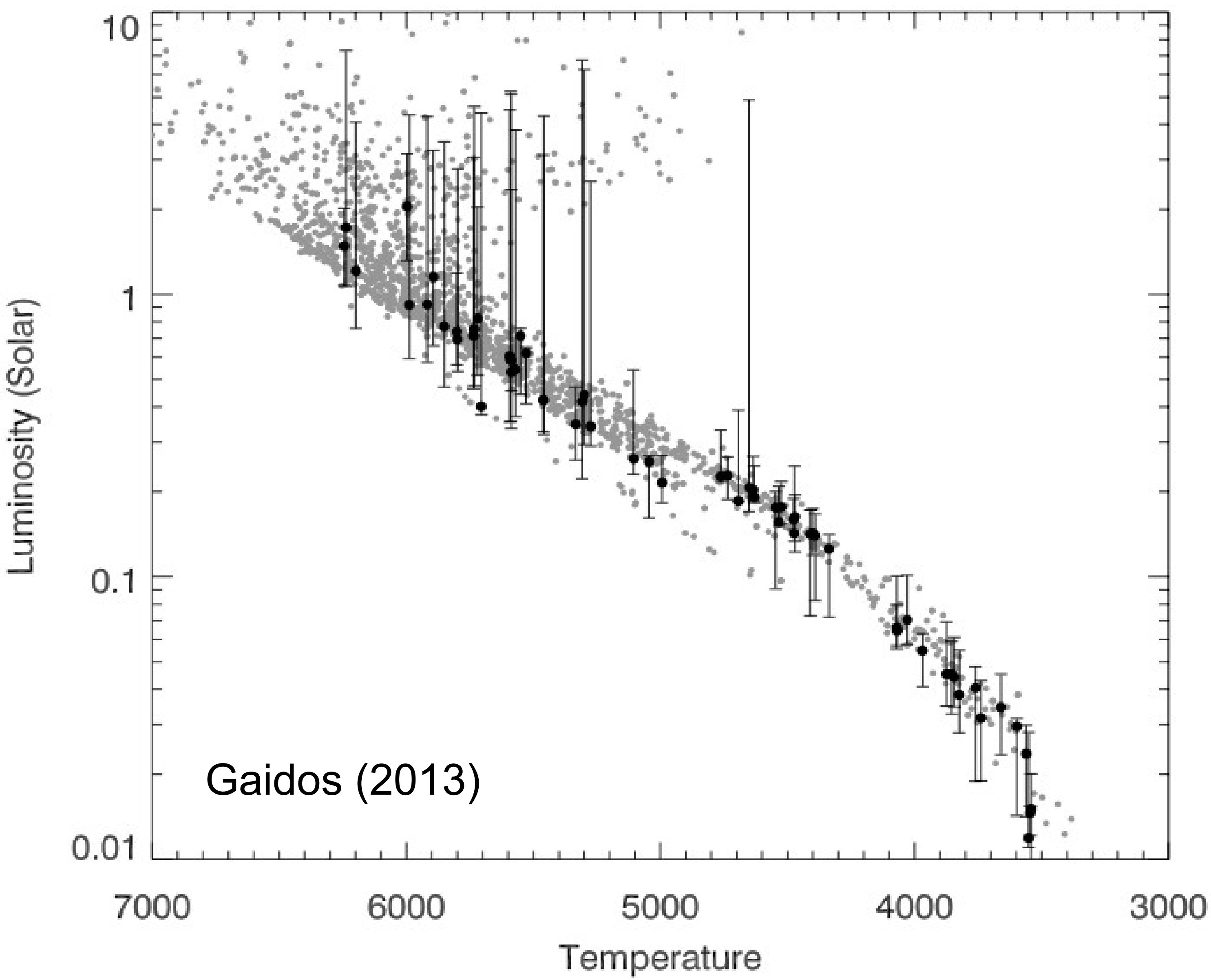
(temperature)



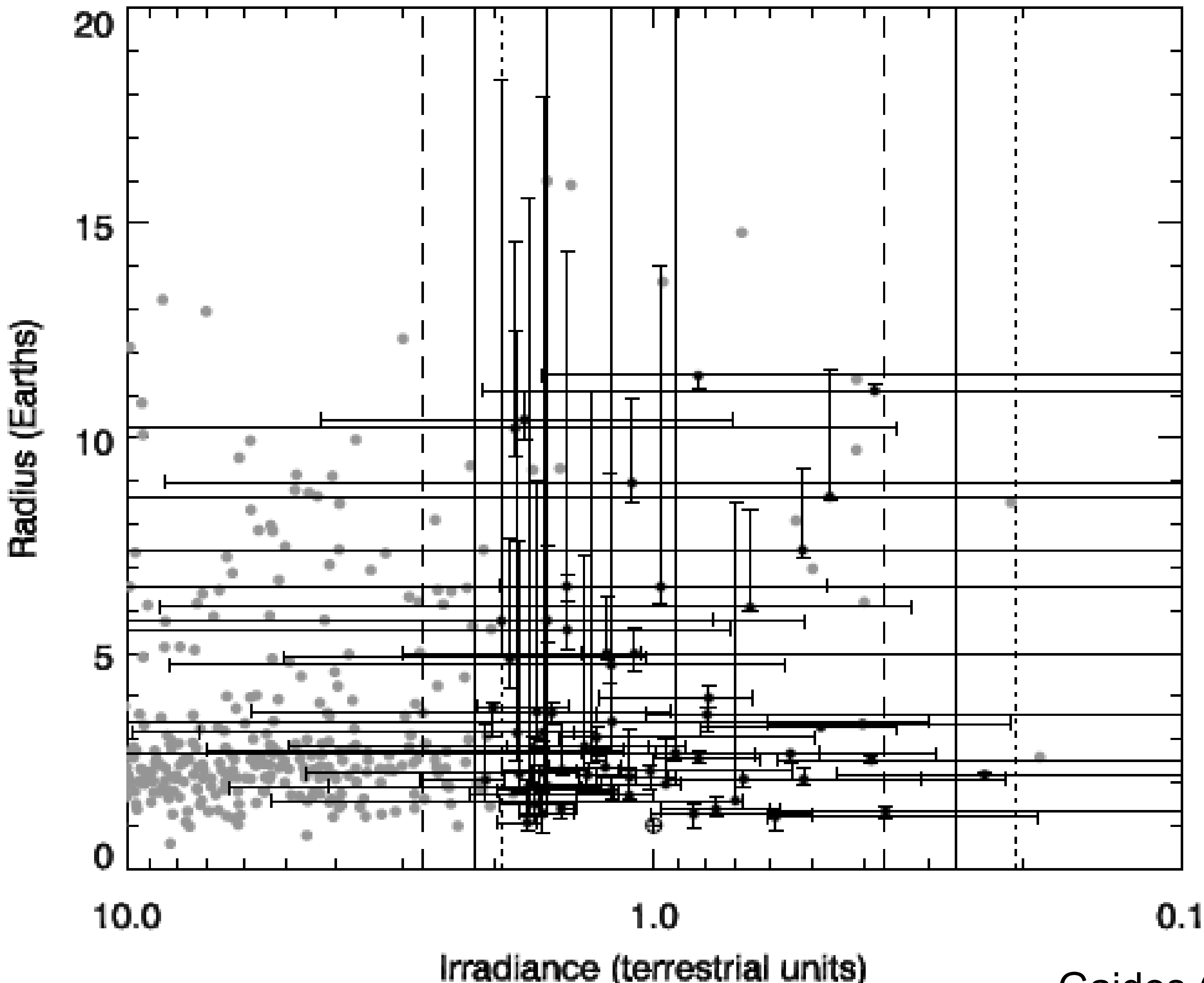
Malmquist bias



Uncertainties can be Very Asymmetric

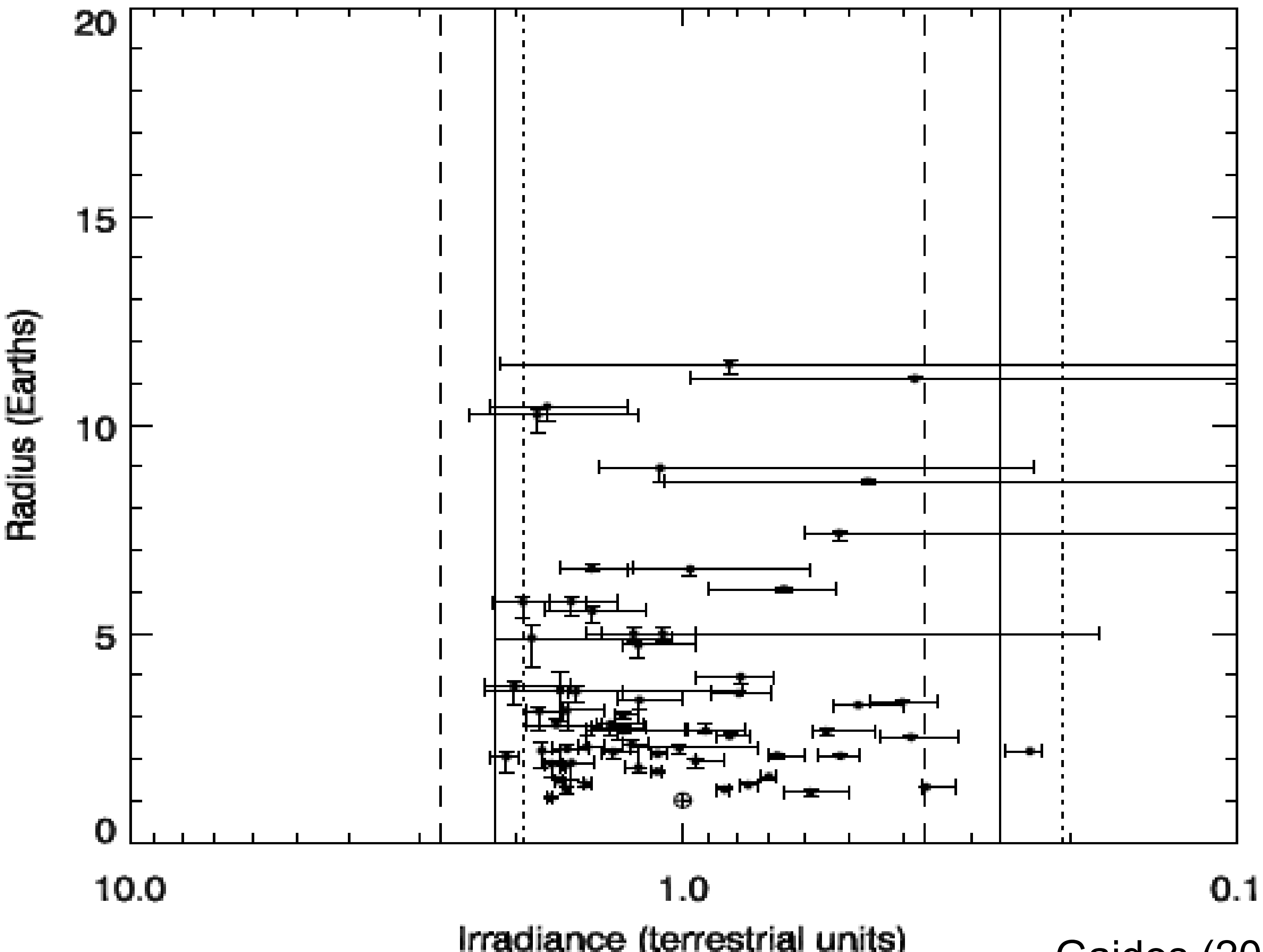


Kepler Planet Properties using Stellar Colors Alone

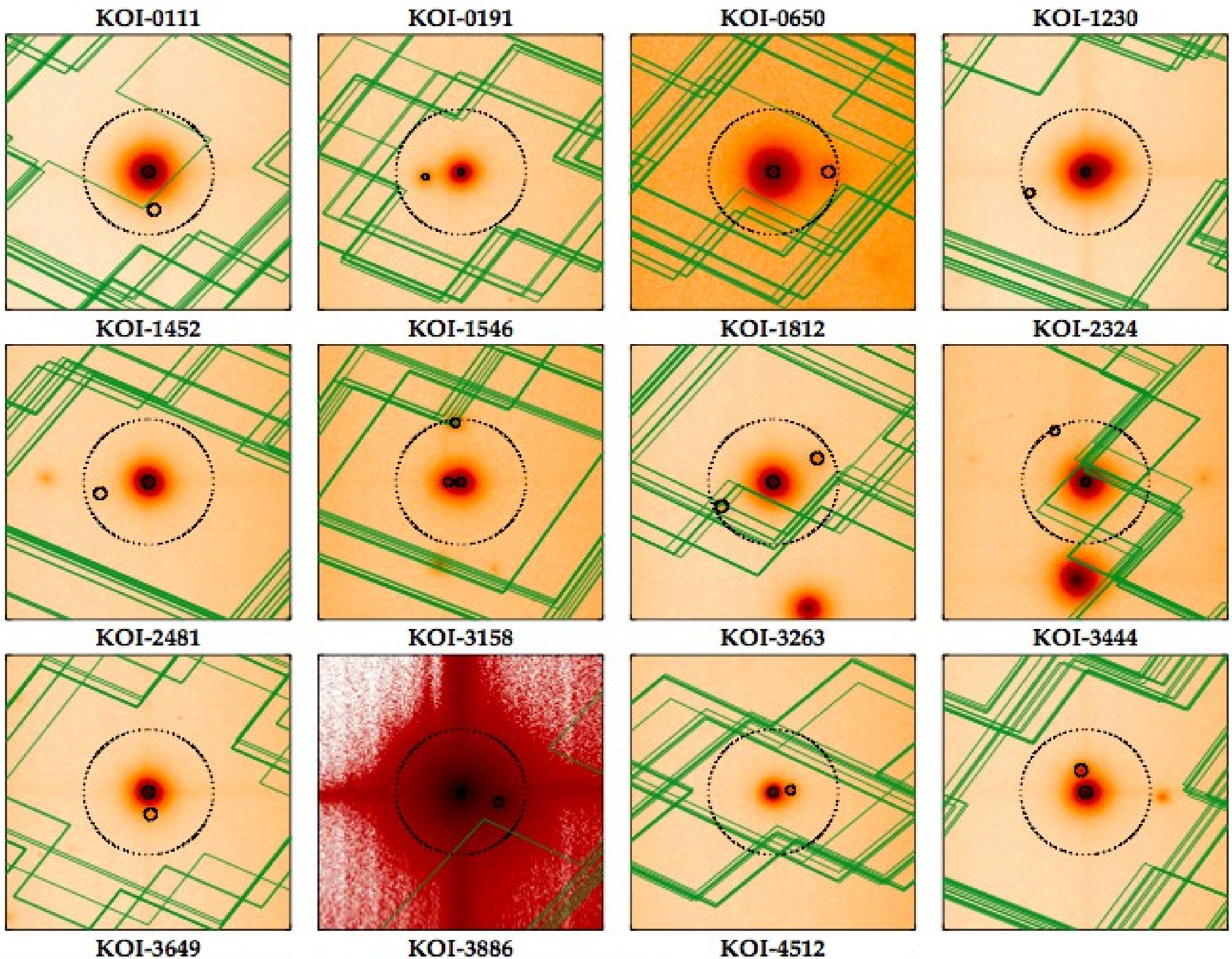


Gaidos (2013)

Uncertainties with Stellar Colors and *Gaia* Parallaxes

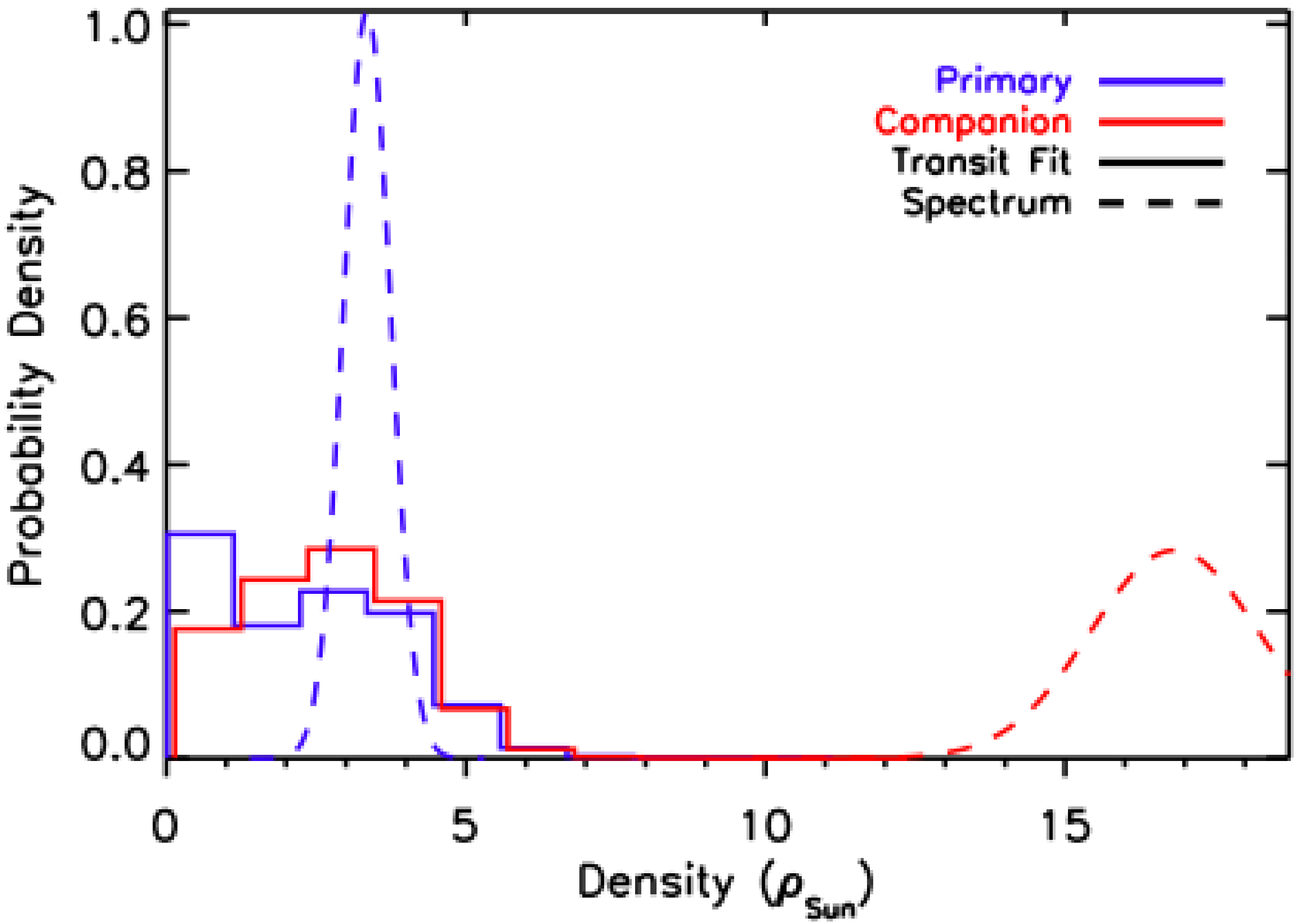


Gaidos (2013)

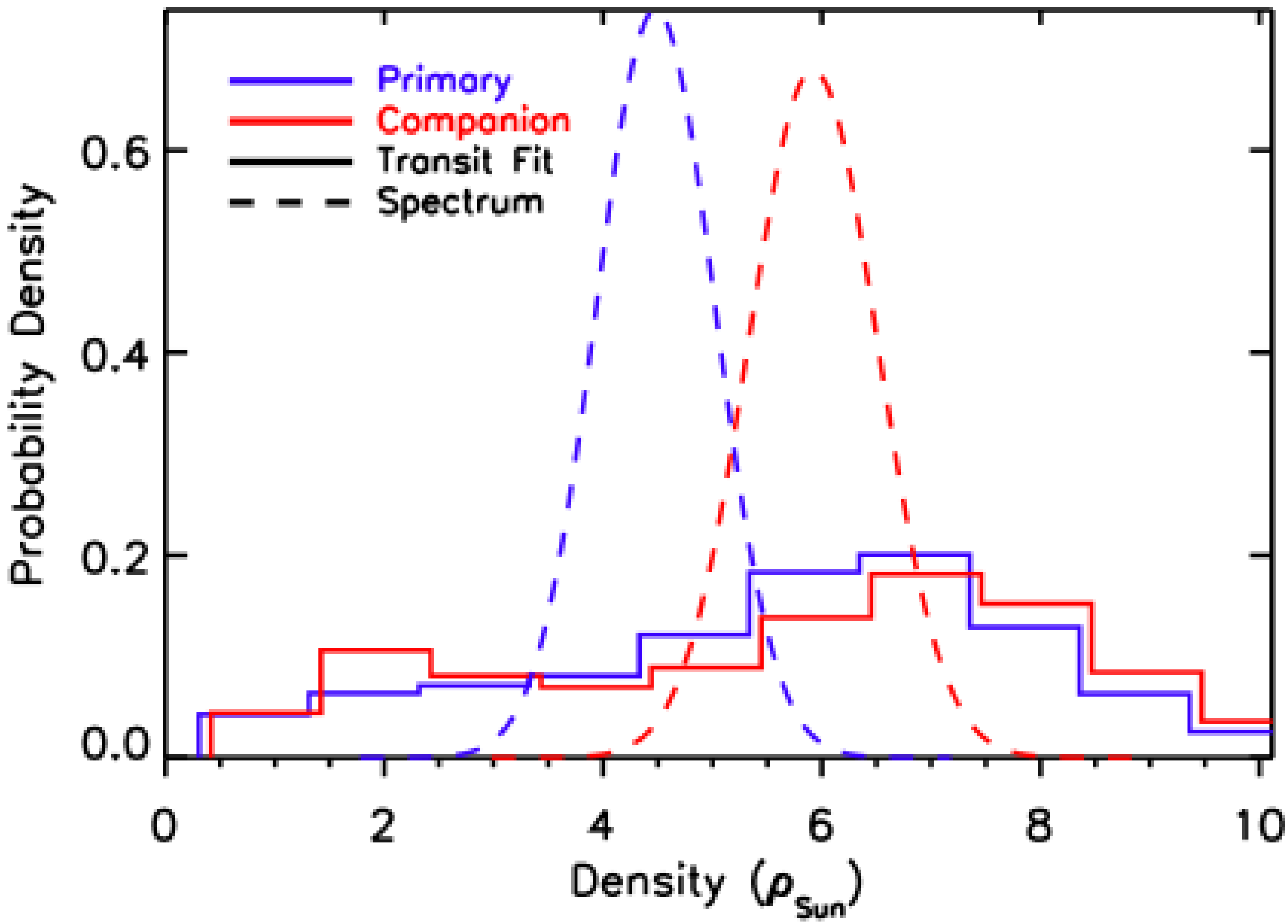


Lillo-Box et al. (2014)

Case 1: Unambiguous Identification of the Host Star



Case 2: Identity of Host Star is Ambiguous



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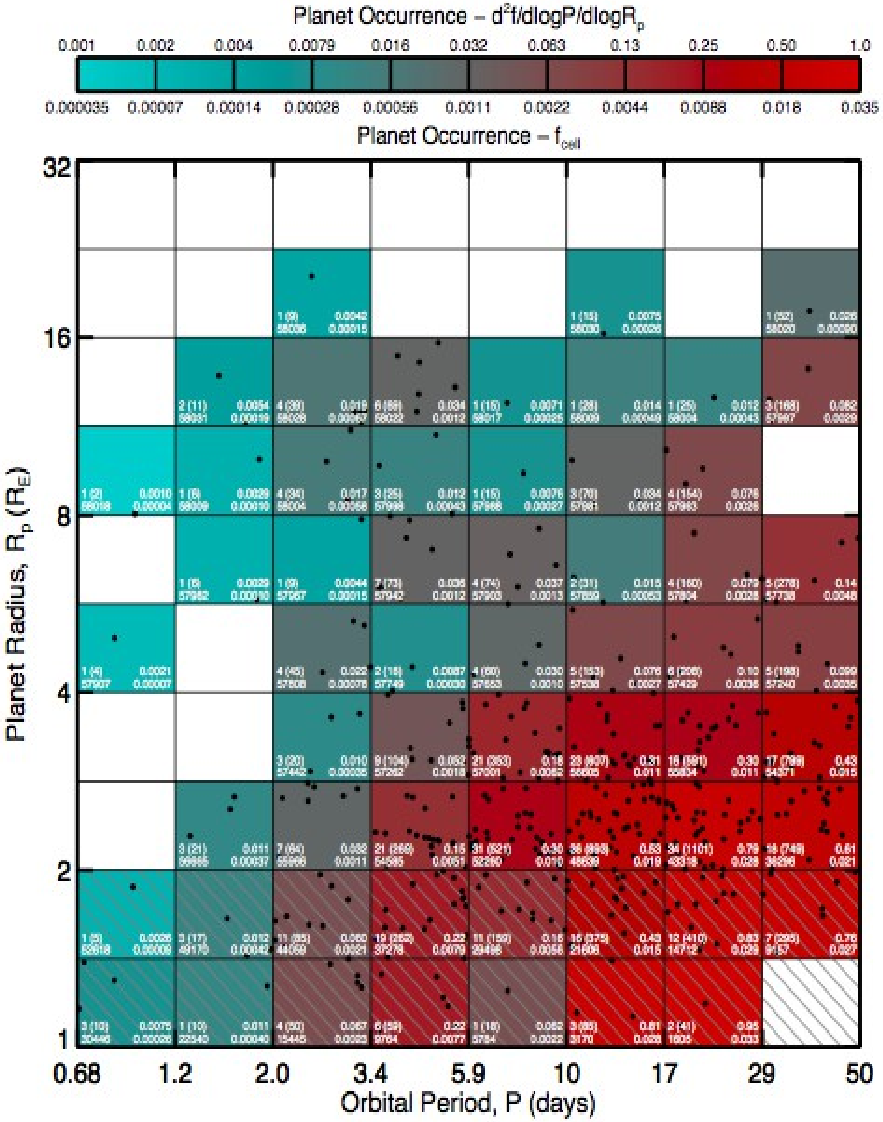
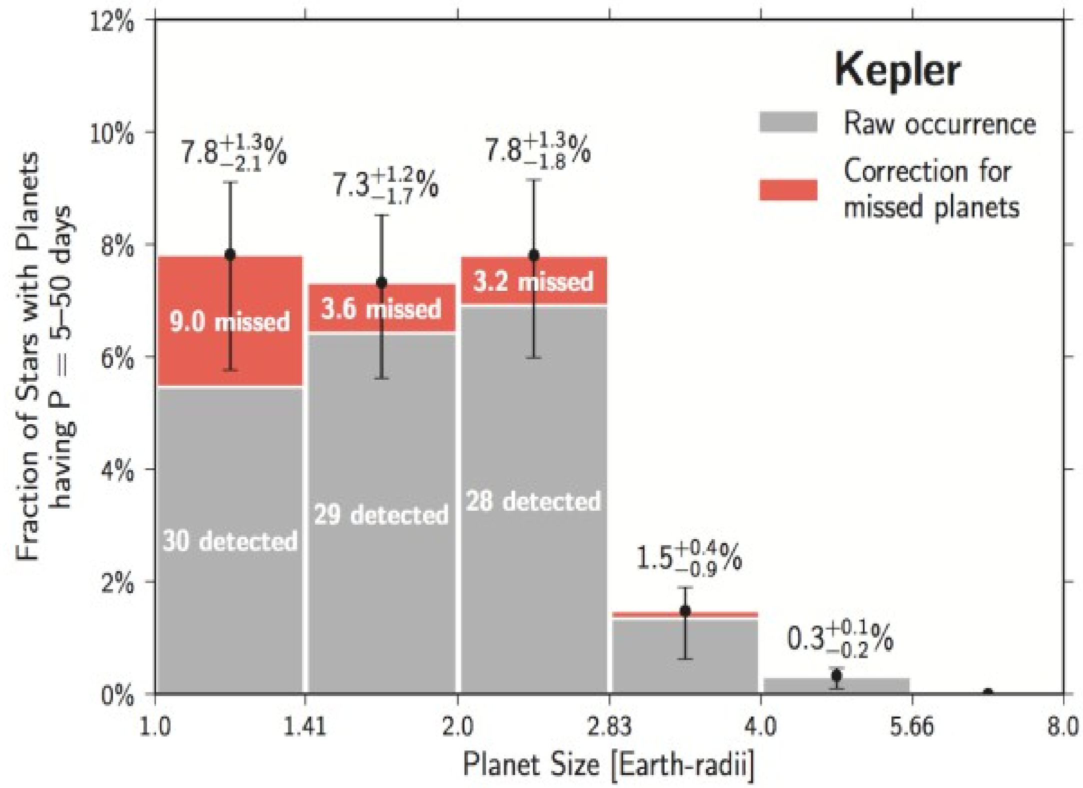
Demographics by Binning



Howard et al. (2012)

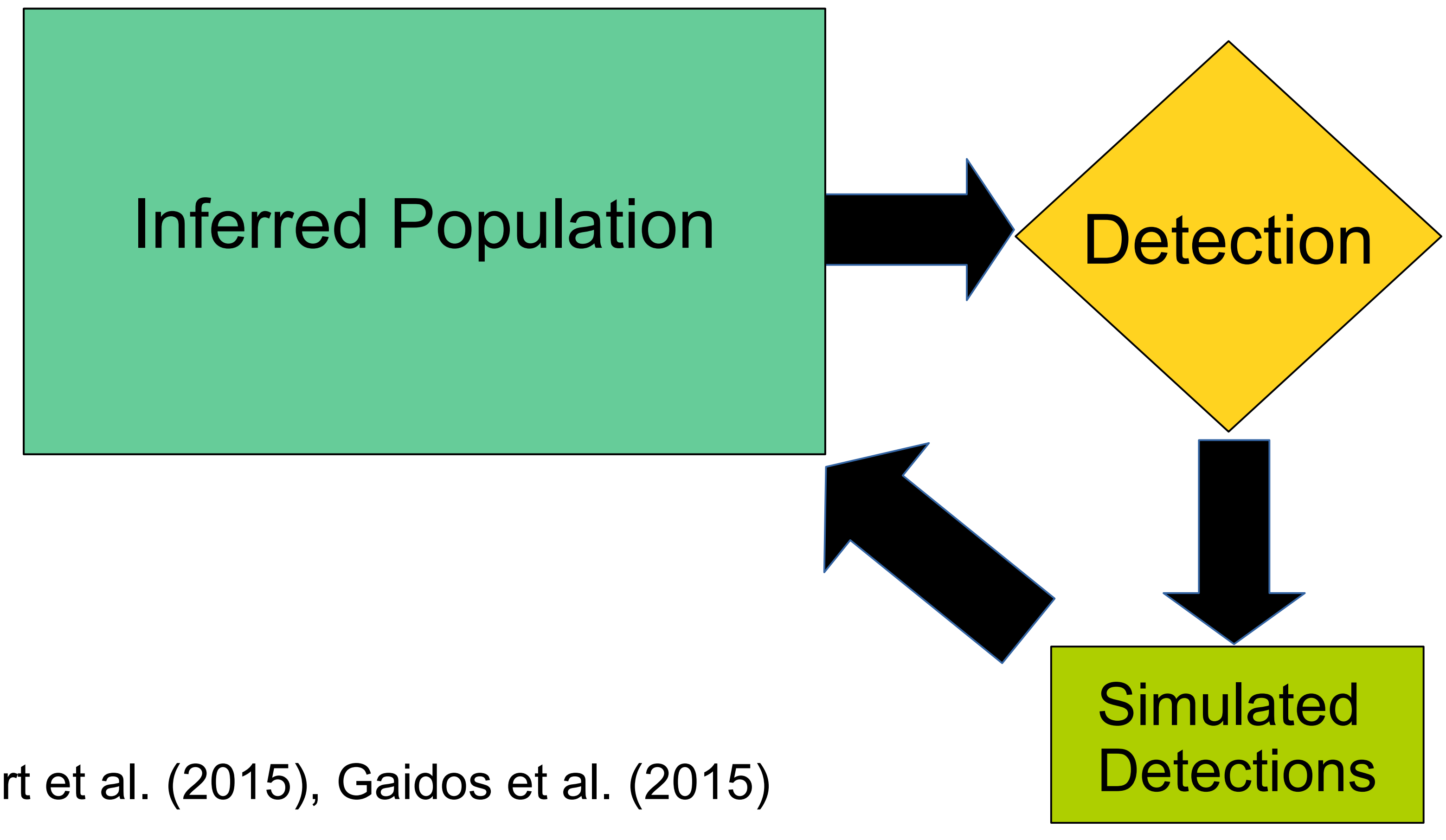


Petigura et al. (2013)

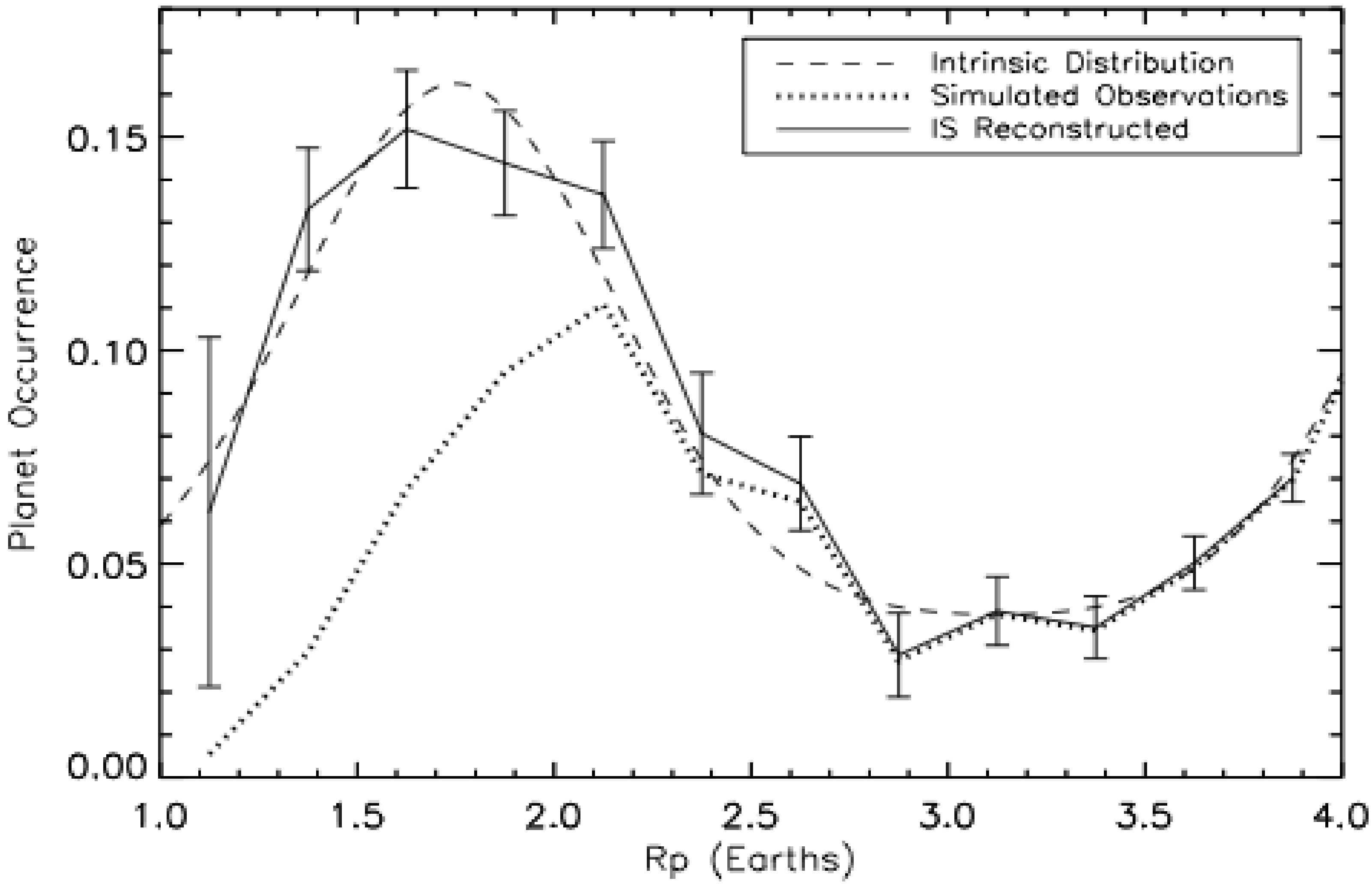
Demographics without Binning

Method of Iterative Monte Carlo (MIMC)

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

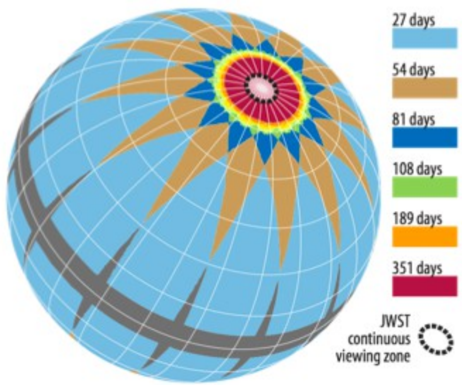


Silburt et al. (2015), Gaidos et al. (2015)

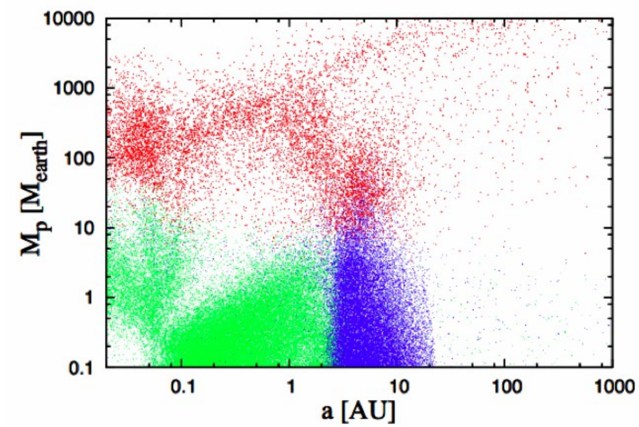


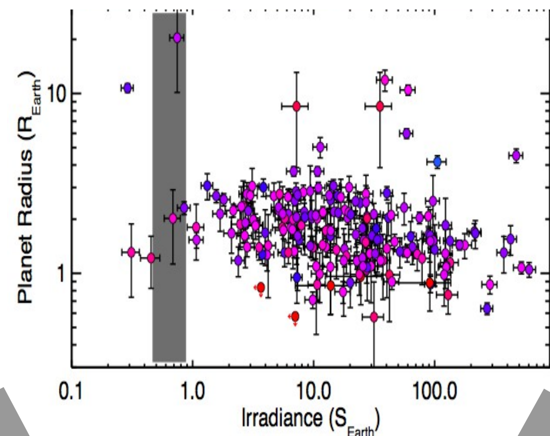
Silburt et al. (2015)

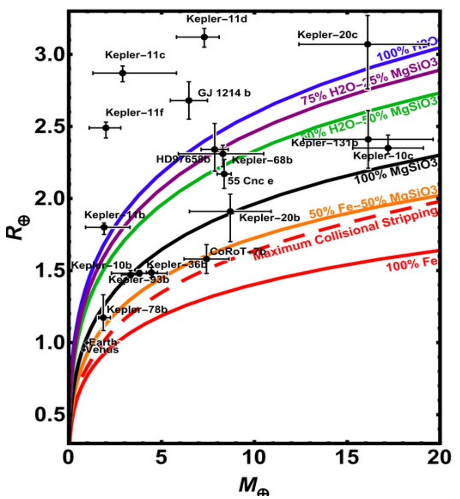
Predicting yields of exoplanet surveys



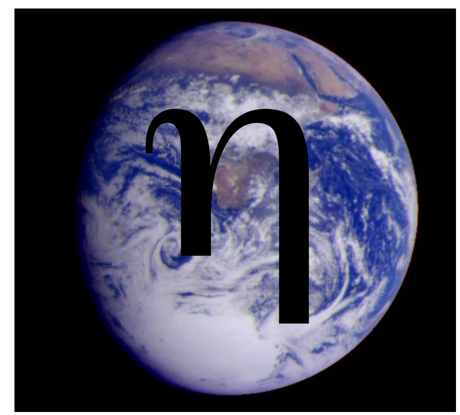
Testing population synthesis models







Constructing mass-radius diagrams & interior models



Astrobiological inquiry

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