Planet Occurrence Within 0.25 AU

Andrew W. Howard

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California Planet Search Team:

Geoff Marcy, Debra Fischer, John Johnson, Jason Wright, Howard Isaacson, Julien Spronck, Jeff Valenti, Jay Anderson, Nikolai Piskunov, more!

Photo credit: Laurie Hatch

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NASA: Kepler

PI: Bill Borucki & Deputy PI: David Koch

Ball Aerospace

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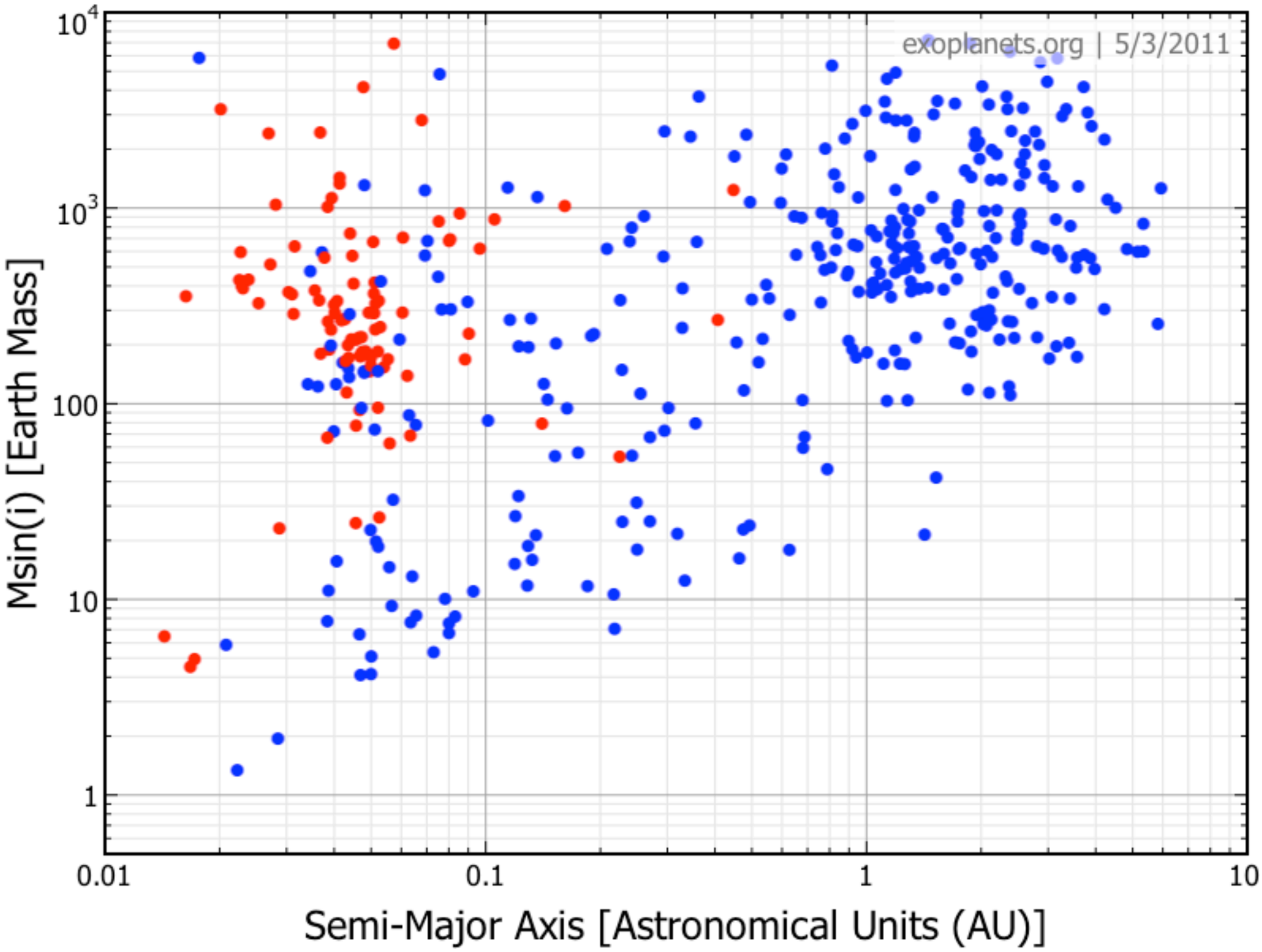
Jon M. Jenkins[1], William J. Borucki[2], David G. Koch[2], Geoffrey W. Marcy[3], William D. Cochran[4], William F. Welsh[5], Gibor Basri[3], Natalie M. Batalha[6], Lars A. Buchhave[7,8], Timothy M. Brown[9], Douglas A. Caldwell[1], Edward W. Dunham[10], Michael Endl[4], Debra A. Fischer[11], Thomas N. Gautier III[12], John C. Geary[7], Ronald L. Gilliland[13], Steve B. Howell[14], Howard Isaacson[3], John Asher Johnson[15], David W. Latham[7], Jack J. Lissauer[2], David G. Monet[16], Jason F. Rowe[2,17], Dimitar D. Sasselov[7], Andrew W. Howard[3], Phillip MacQueen[4], Jerome A. Orosz[5], Hema Chandrasekaran[1], Joseph D. Twicken[1], Stephen T. Bryson[2], Elisa V. Quintana[1], Bruce D. Clarke[1], Jie Li[1], Christopher Allen[18], Peter Tenenbaum[1], Hayley Wu[1], Søren Meibom[7], Todd C. Klaus[18], Christopher K. Middour[18], Miles T. Cote[2], Sean McCauliff[18], Forrest R. Girouard[18], Jay P. Gunter[18], Bill Wohler[18], Jennifer R. Hall[18], Khadeejah Ibrahim[18], AKM Kamal Uddin[18], Michael S. Wu[19], Paresh A. Bhavsar[2], Jeffrey Van Cleve[1], David L. Pletcher[2], Jessie L. Dotson[2], Michael R. Haas[2]

Well-Characterized Planets



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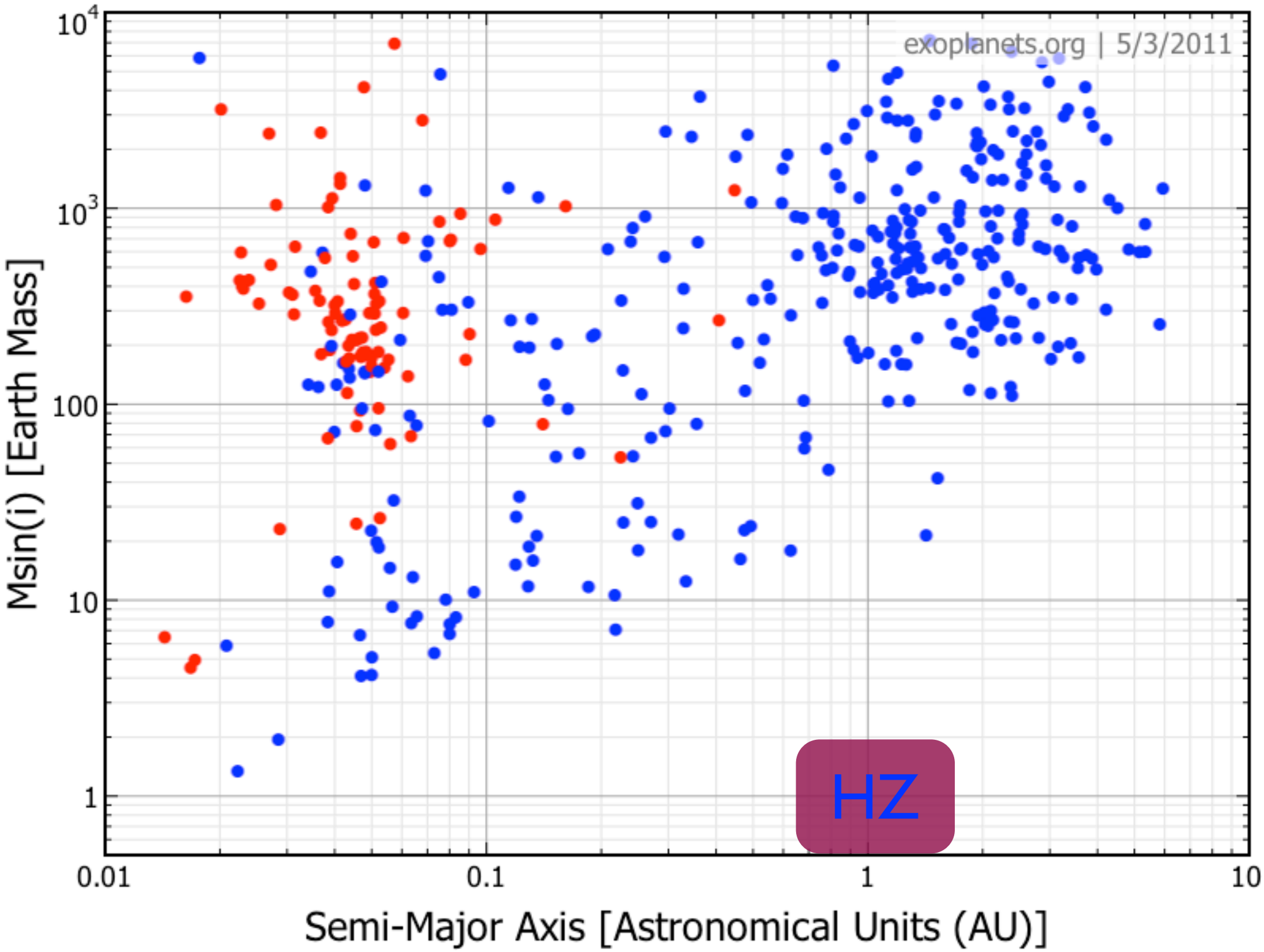

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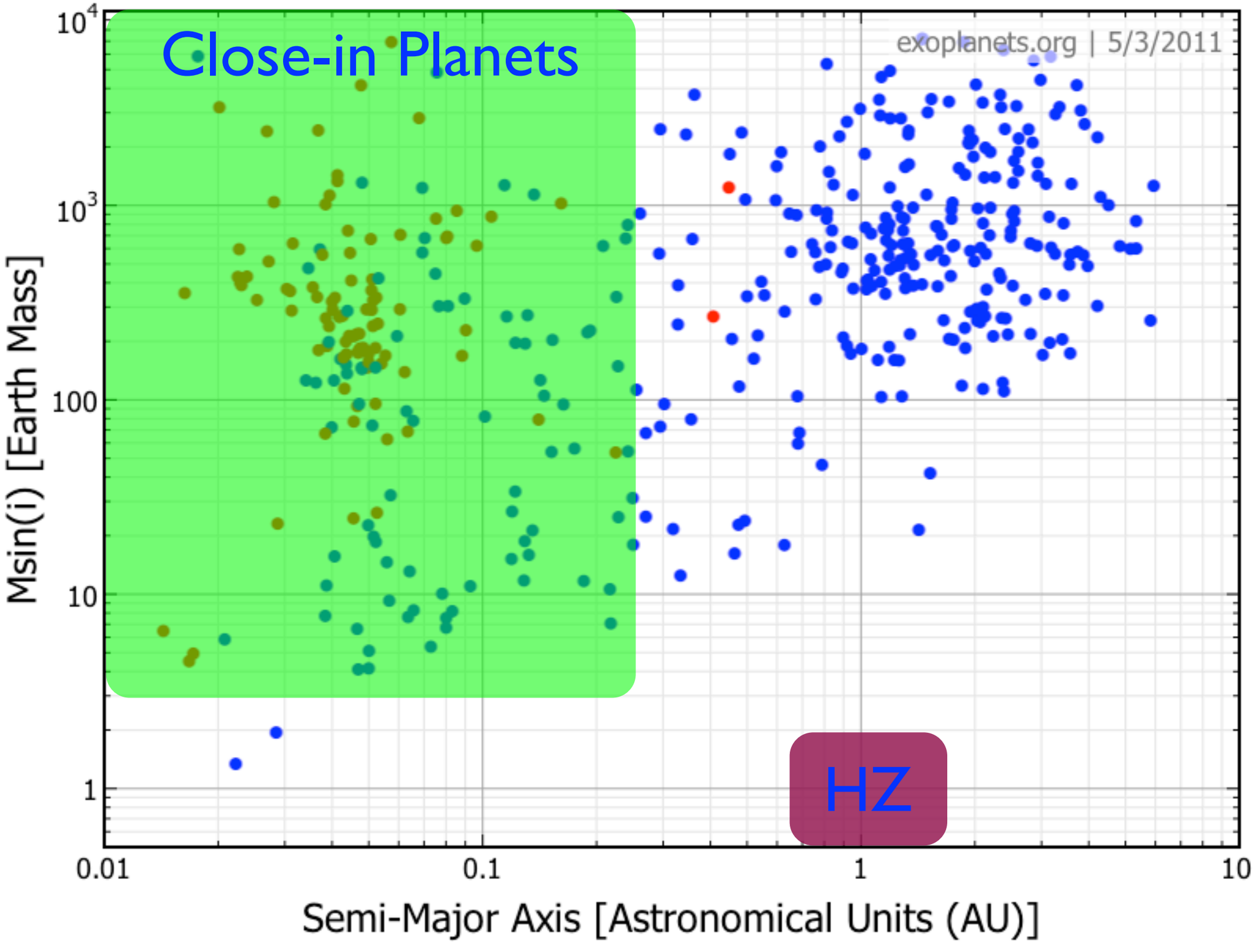

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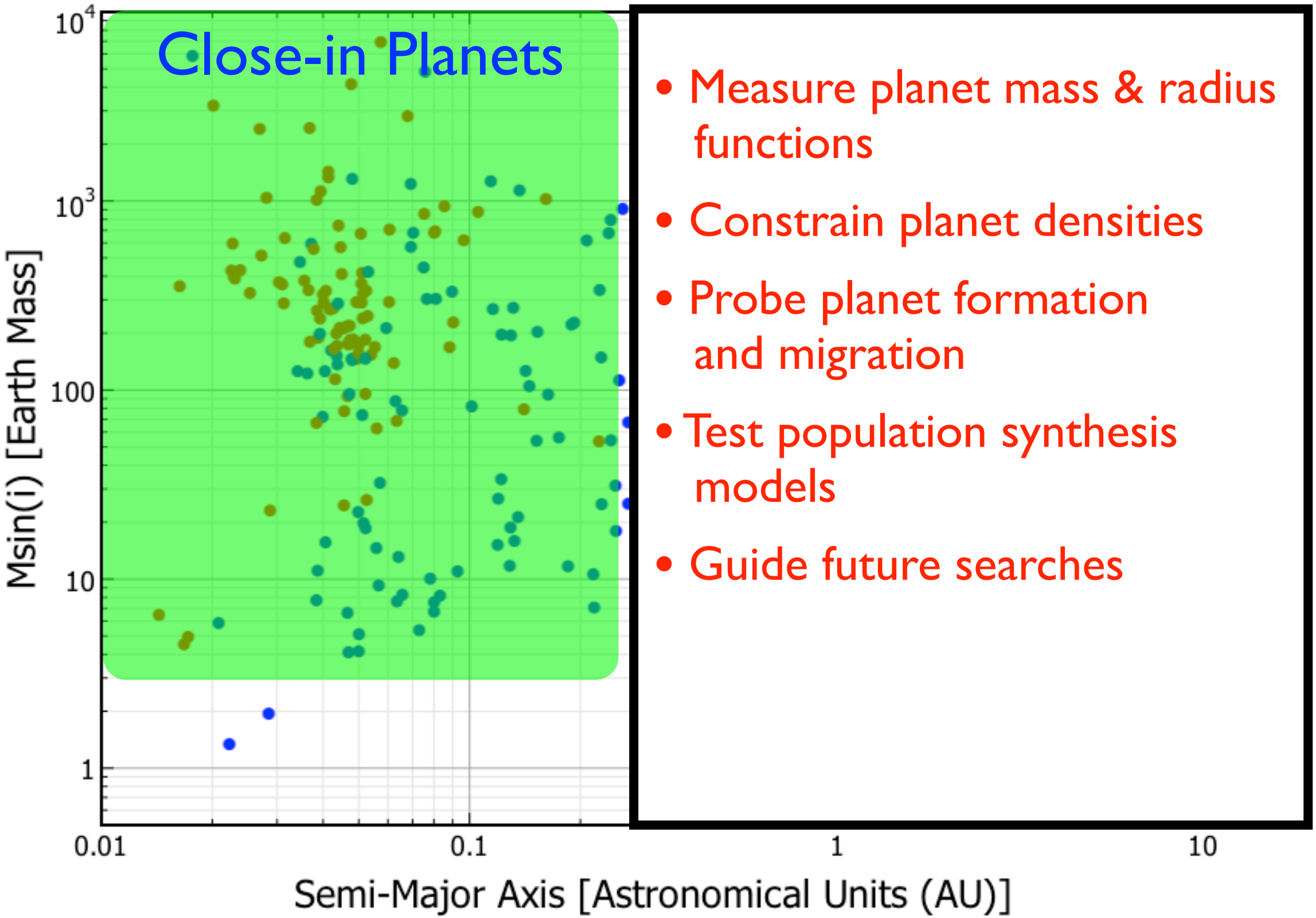
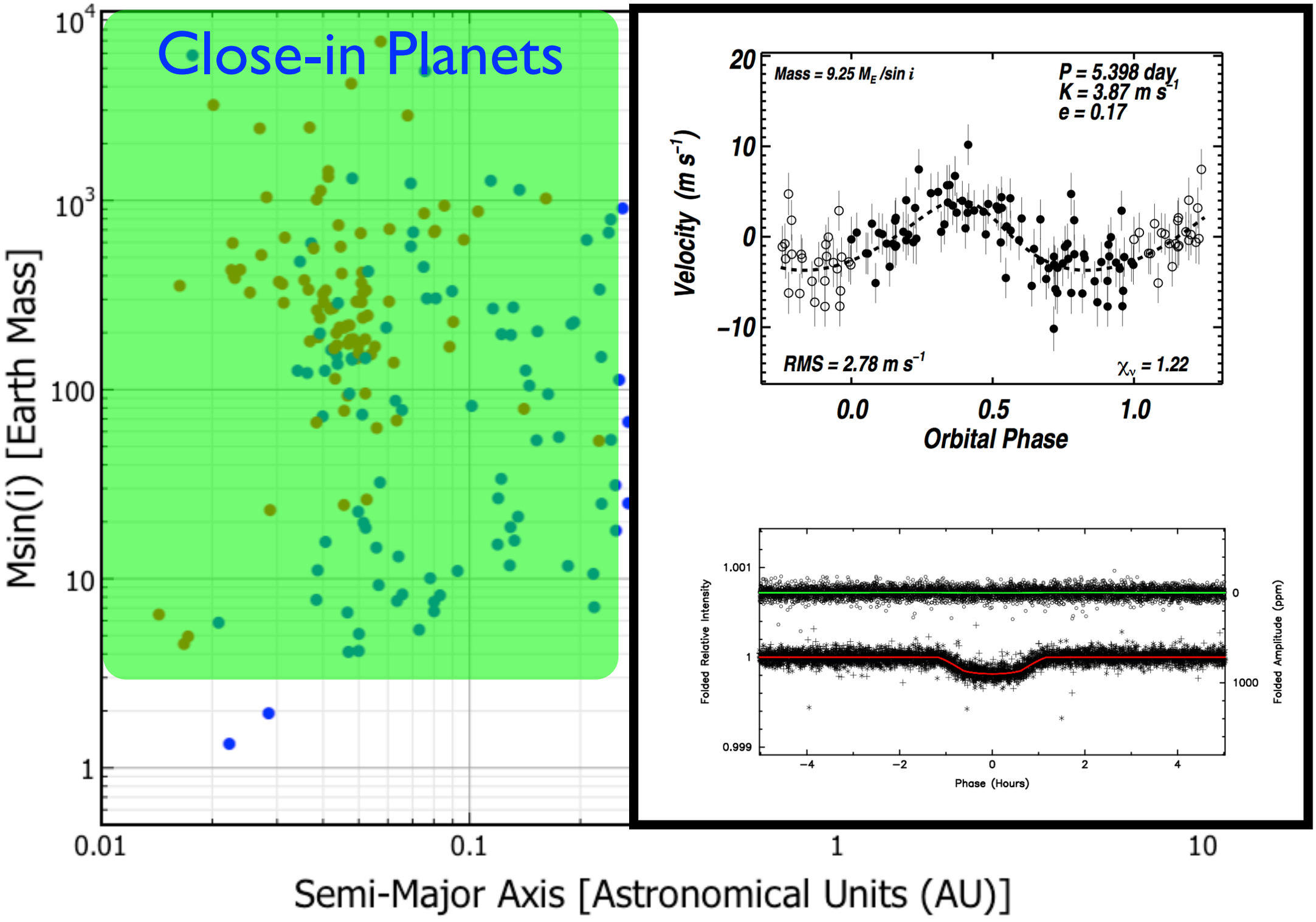
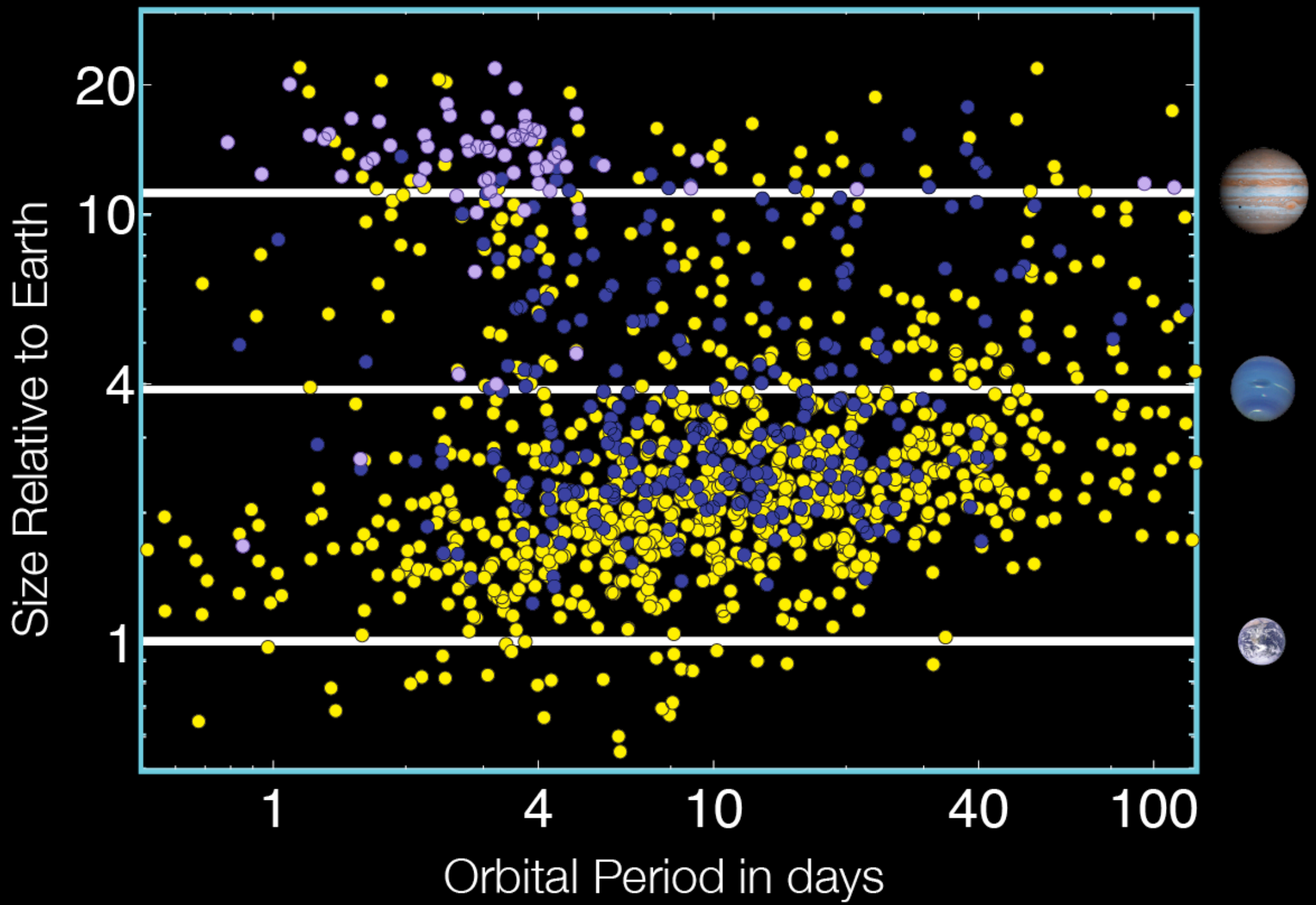


- Measure planet mass & radius functions
- Constrain planet densities
- Probe planet formation and migration
- Test population synthesis models
- Guide future searches

Well-Characterized Planets



Kepler Candidates as of February 1, 2011



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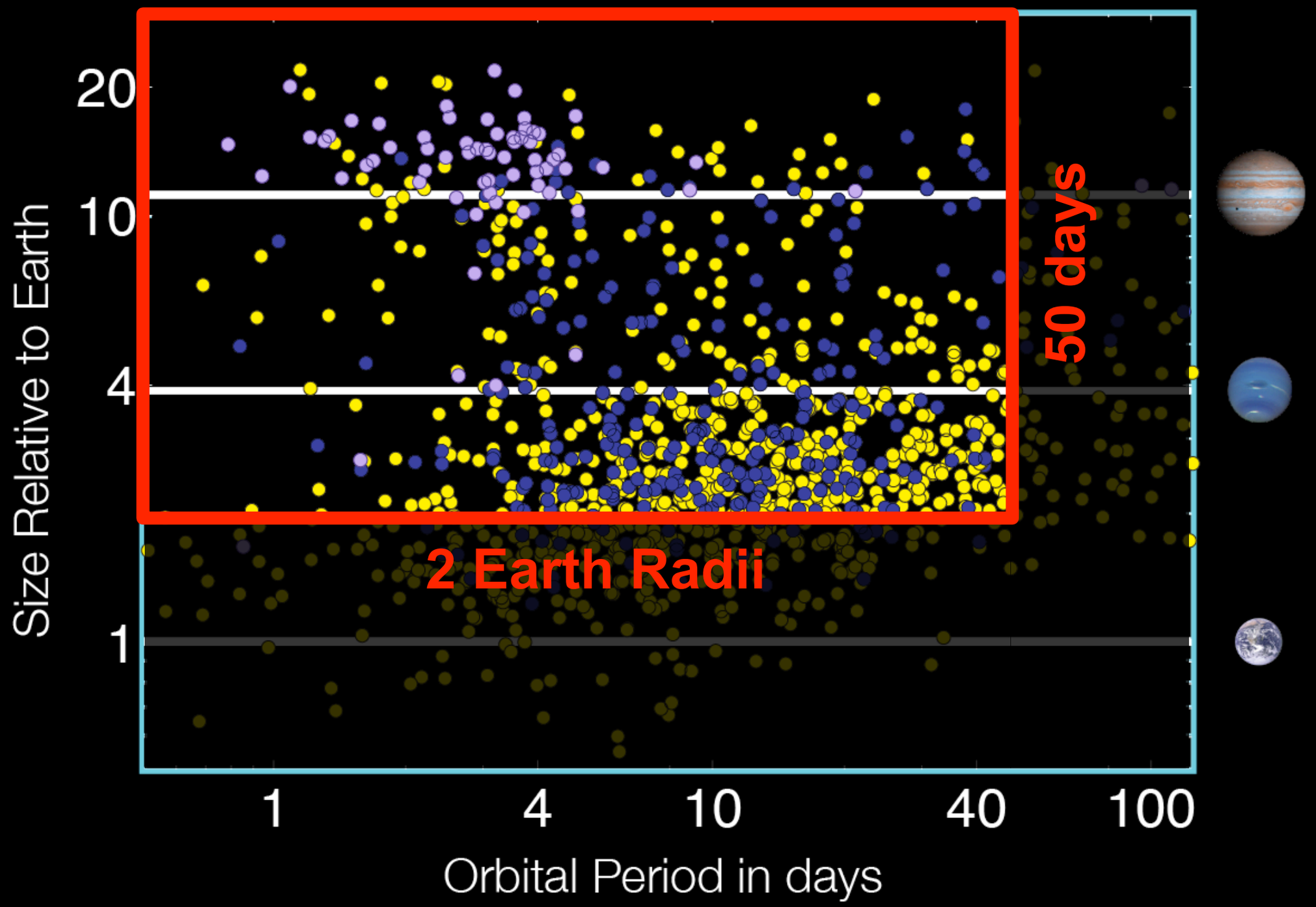
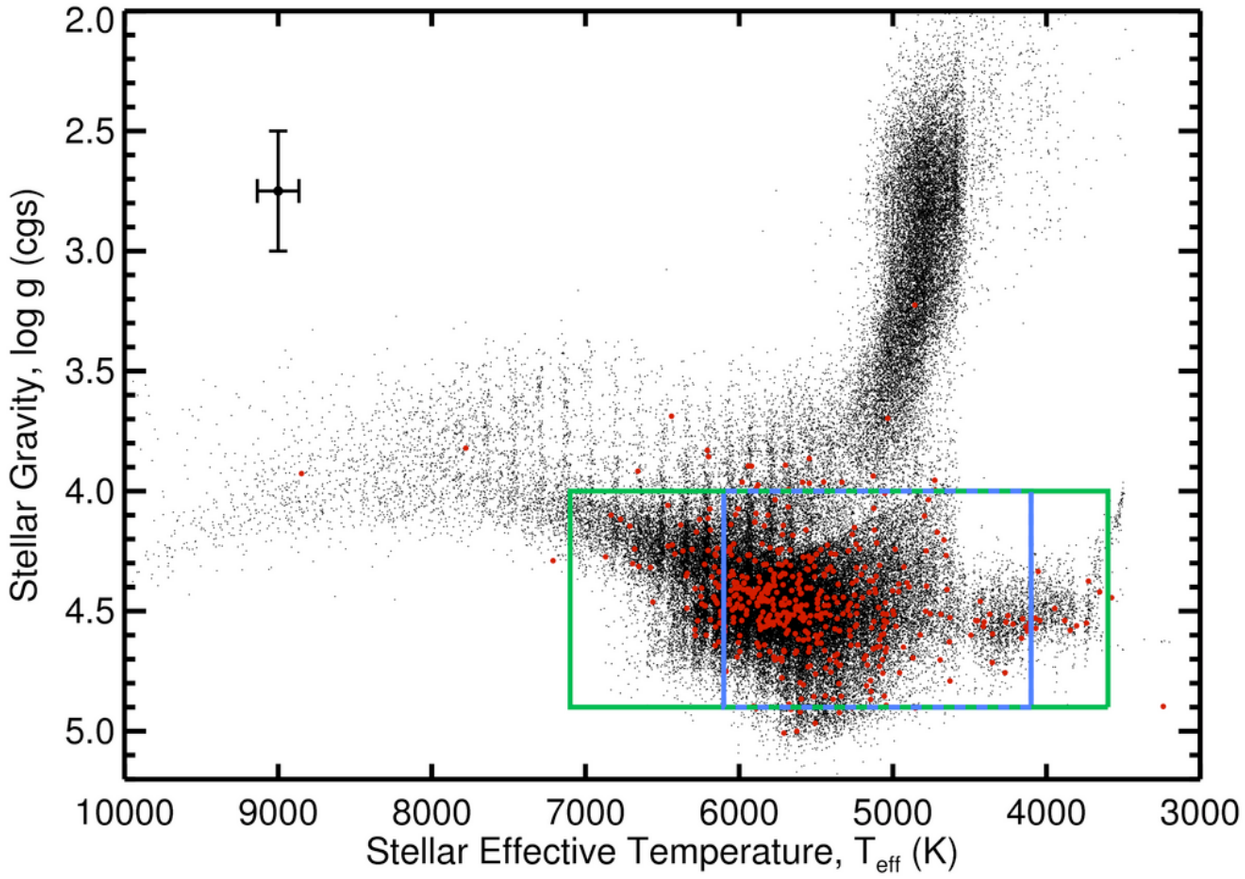


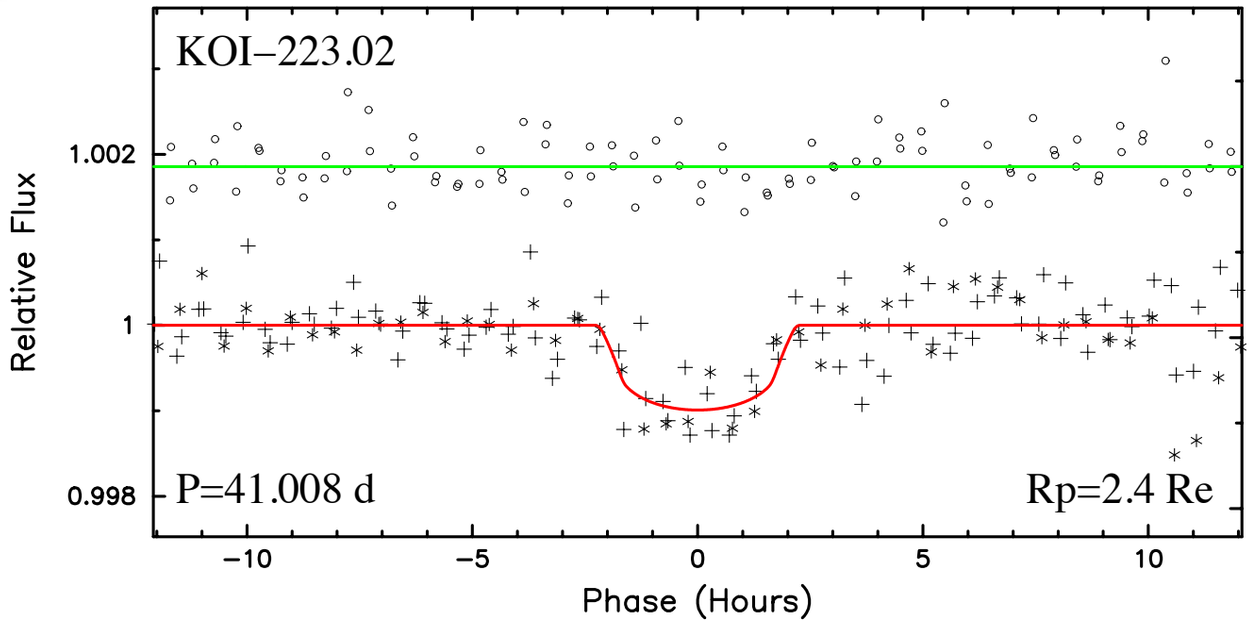
95% True planets - Morton and Johnson (2011)

Choose Subset of Planets/Stars for High Detectability



- Only GK dwarfs (T_{eff}/log$g$)
- Only bright stars (Kp < 15)
- Only high SNR transits (SNR > 10 in 90 days)

Full sample		Restricted sample
~156,000 stars	→	~58,000 stars
1,230 planets		438 planets



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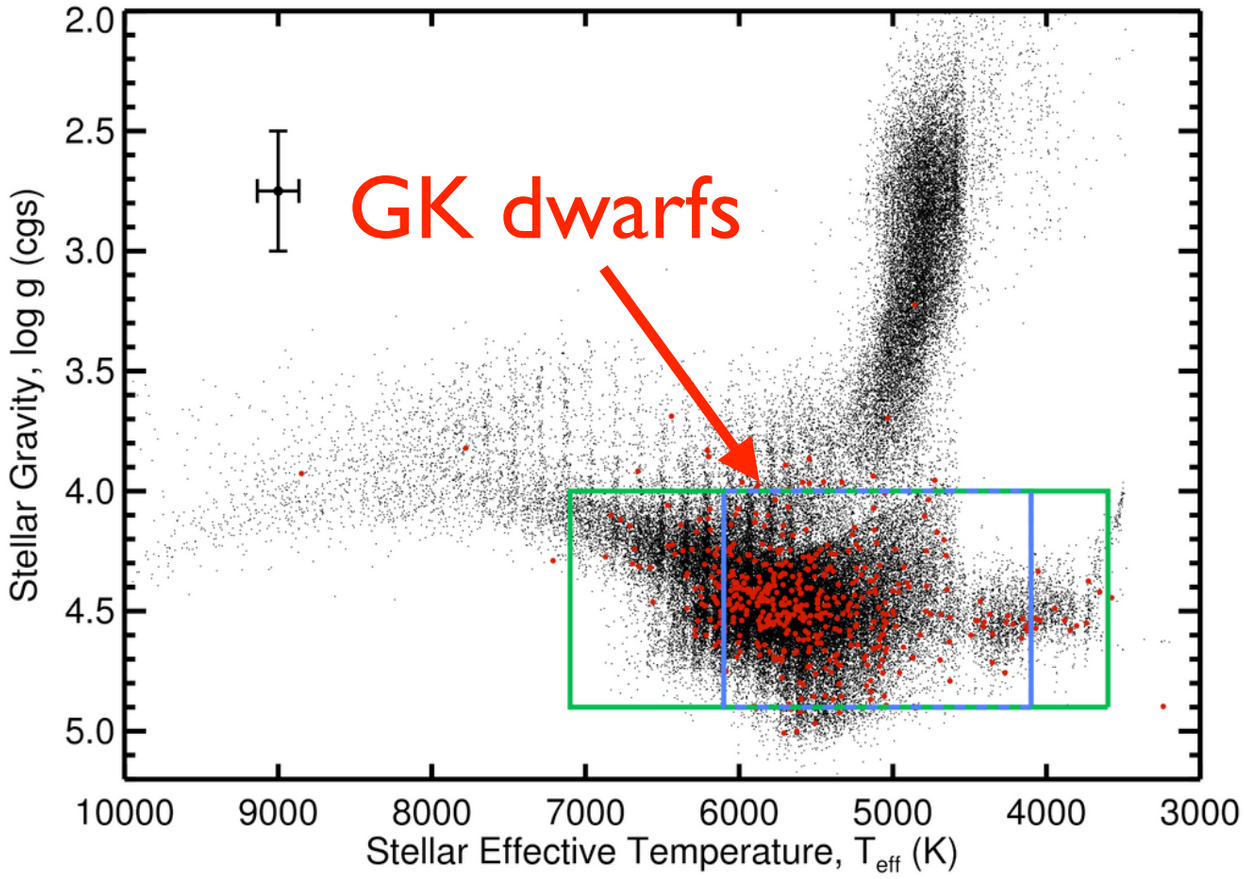

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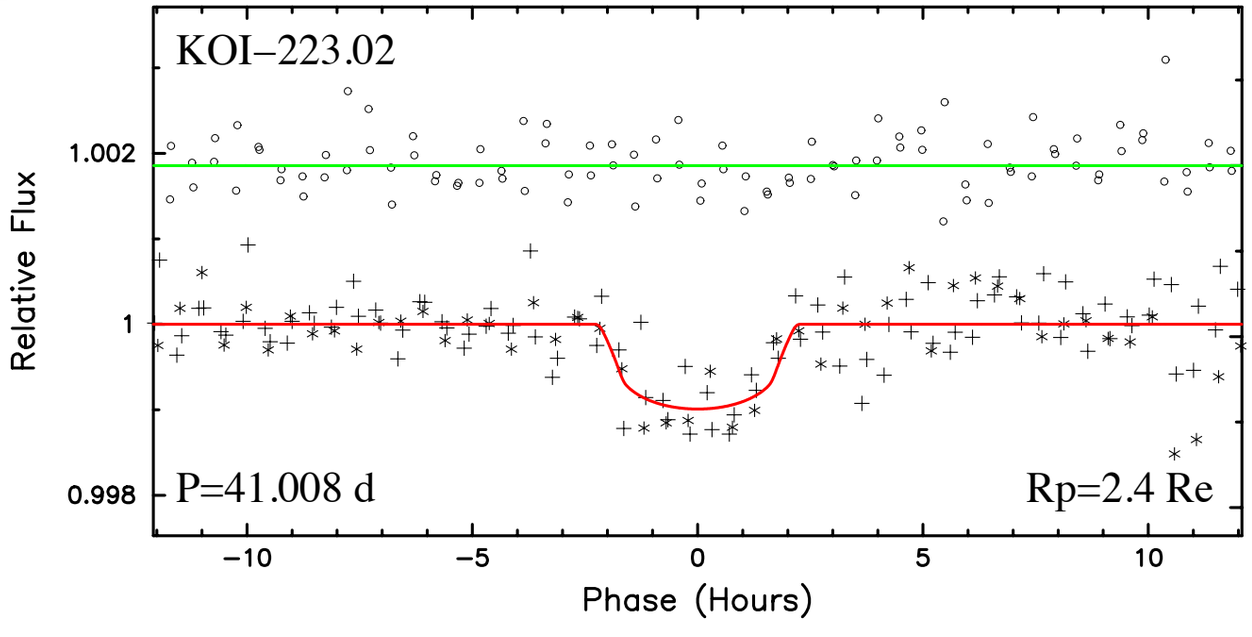

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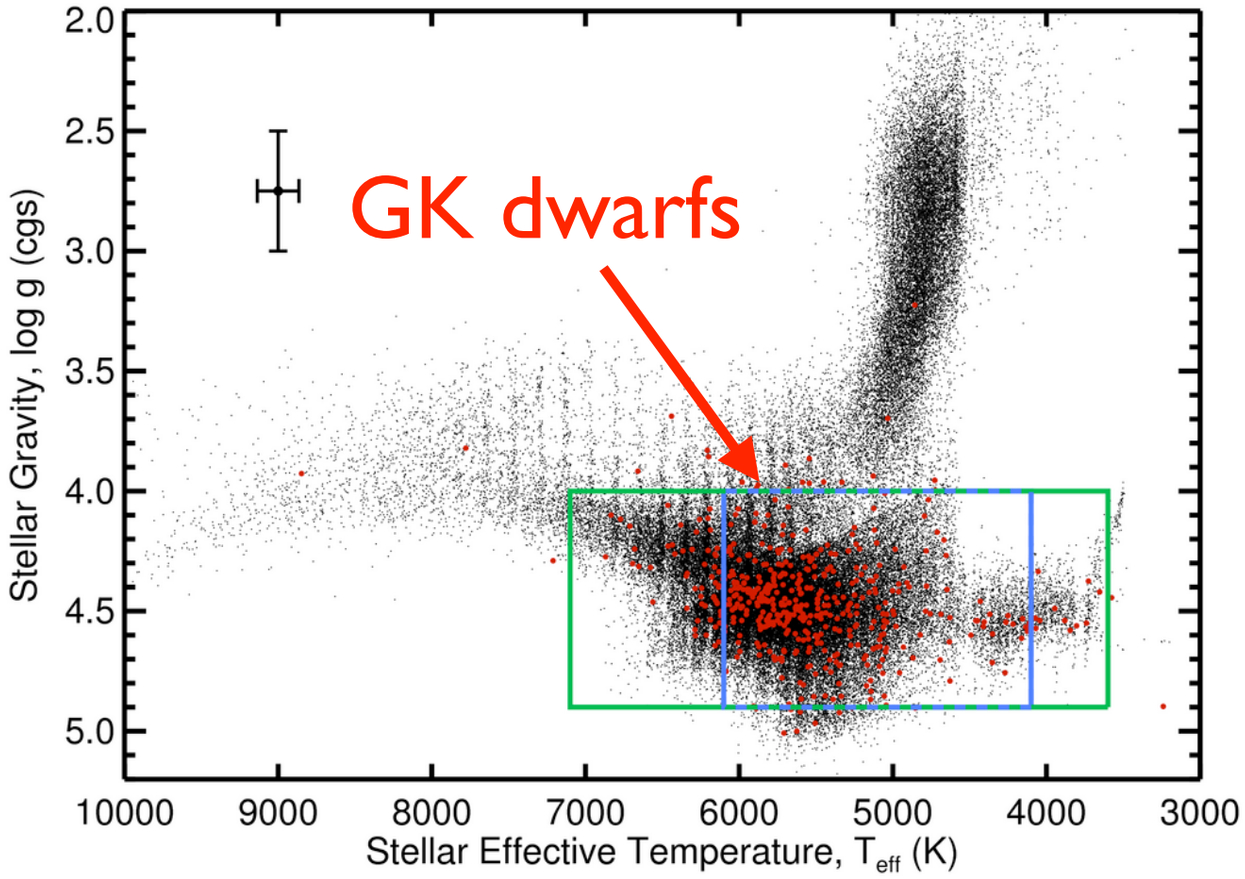

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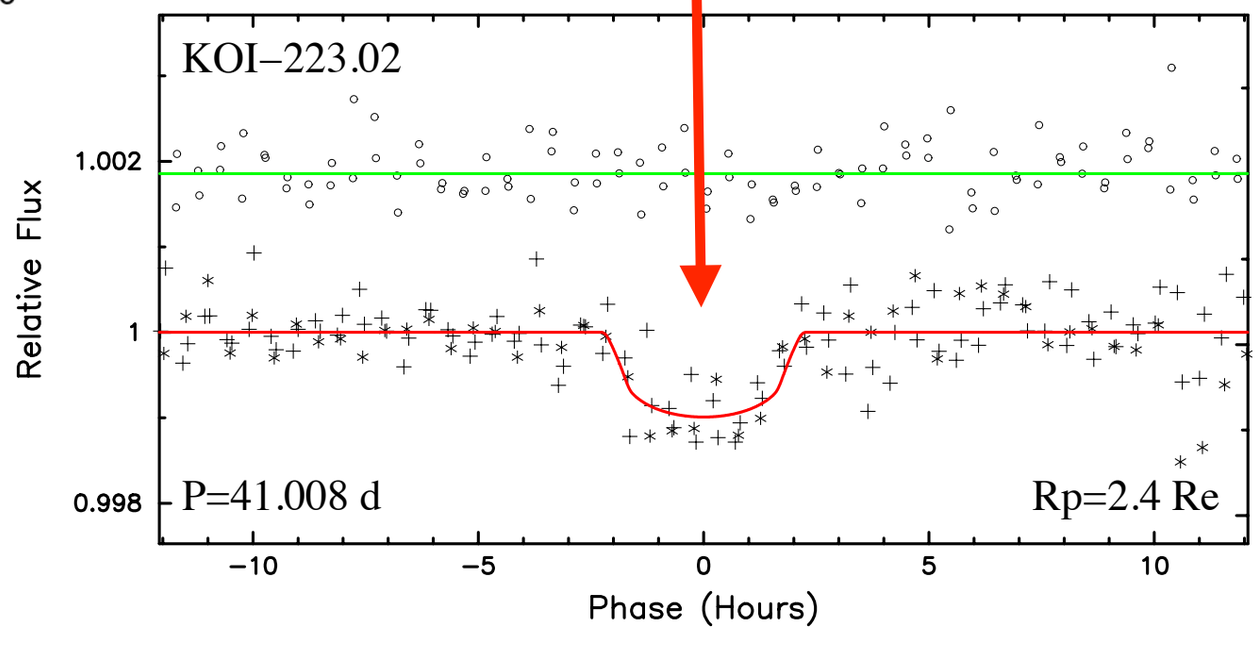
SNR ≈ 10



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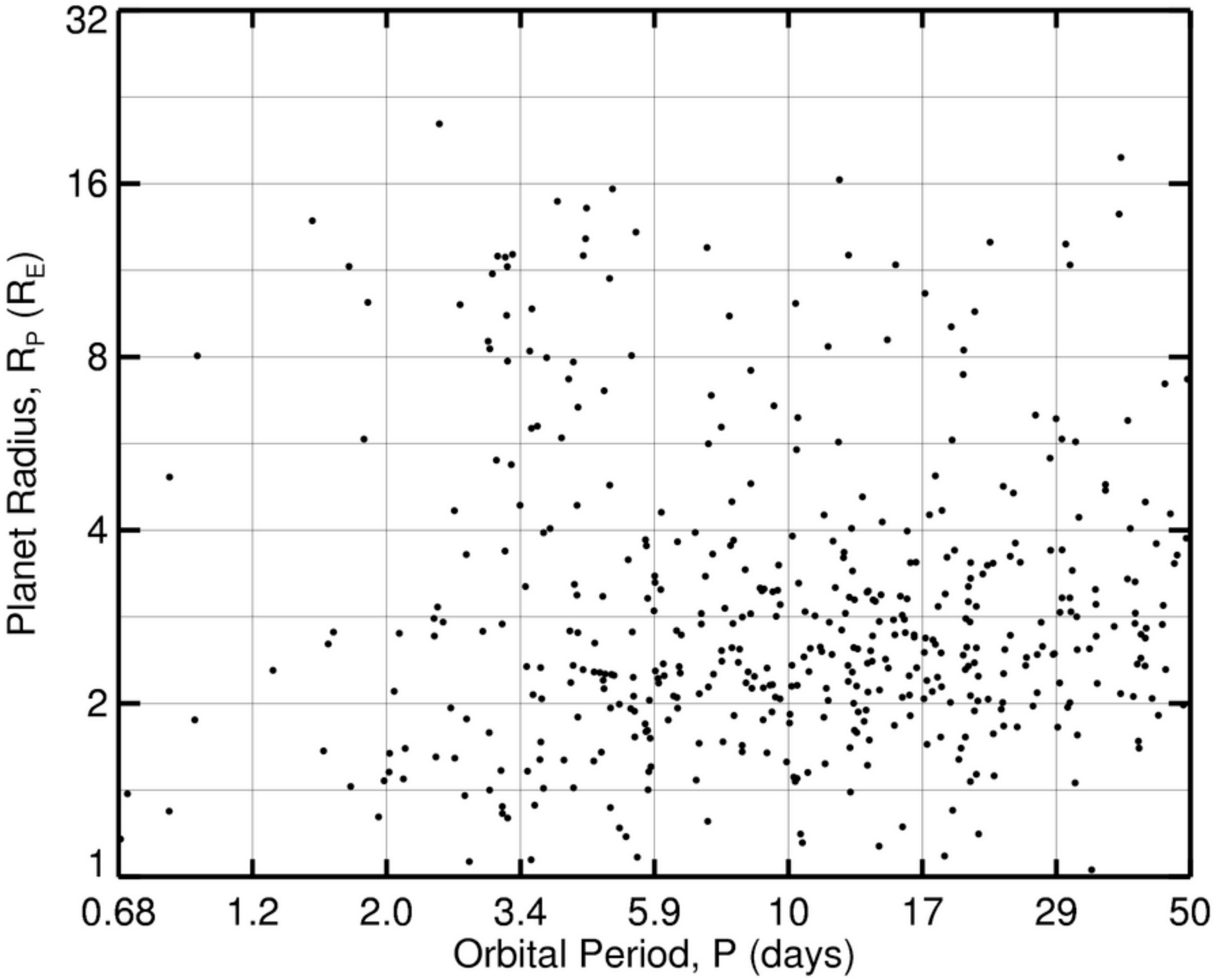

Howard et al. (2011c)

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Compute Planet Occurrence in Small Domain

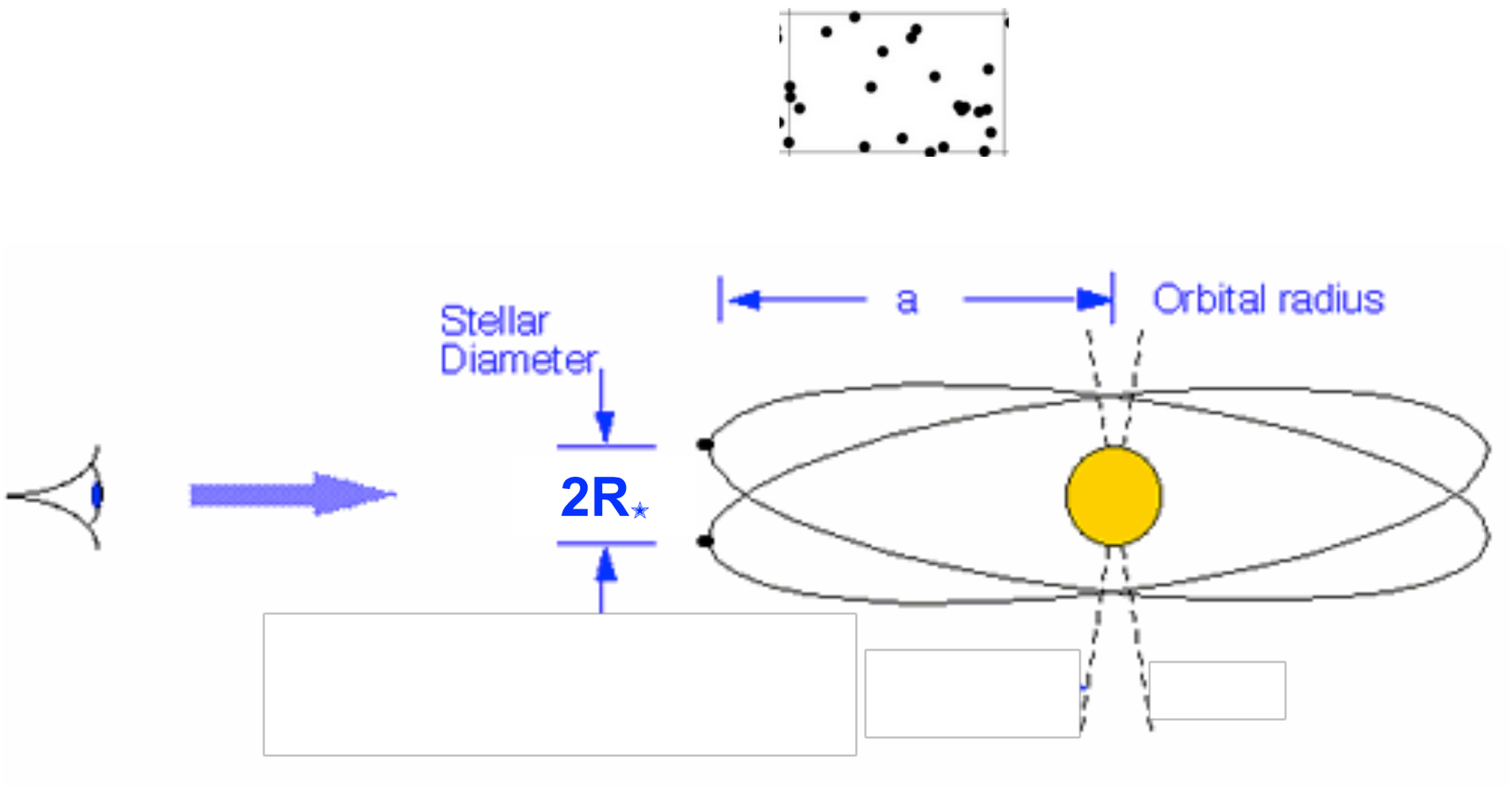
Howard et al. (2011c)

Compute Planet Occurrence in Small Domain

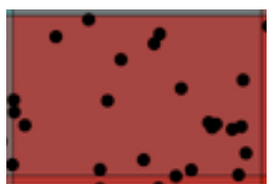
Correct for:

Transit probabilities - $p_{transit} = R_\star/a$

Incompleteness - some stars lack the photometric sensitivity



Howard et al. (2011c)



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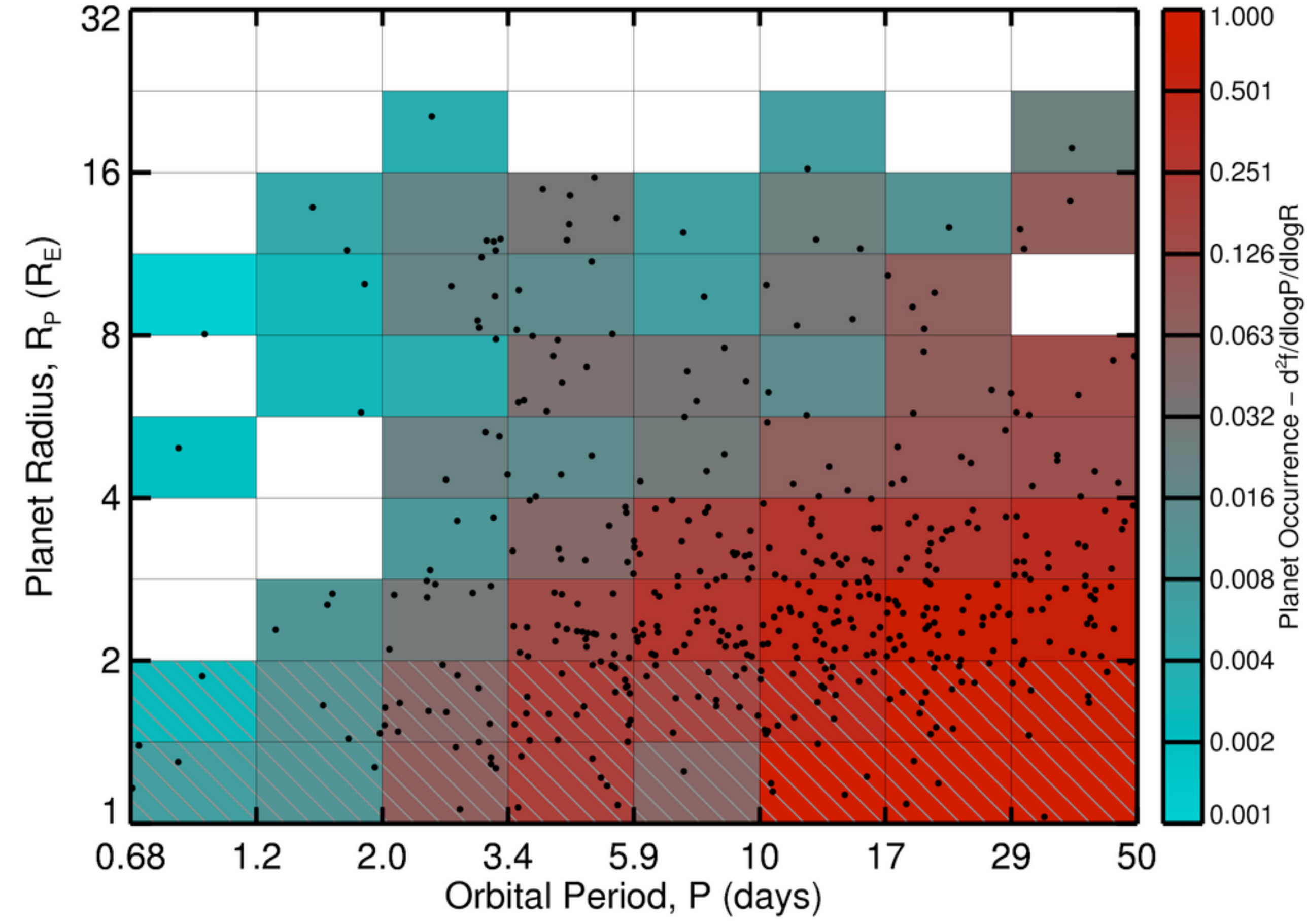
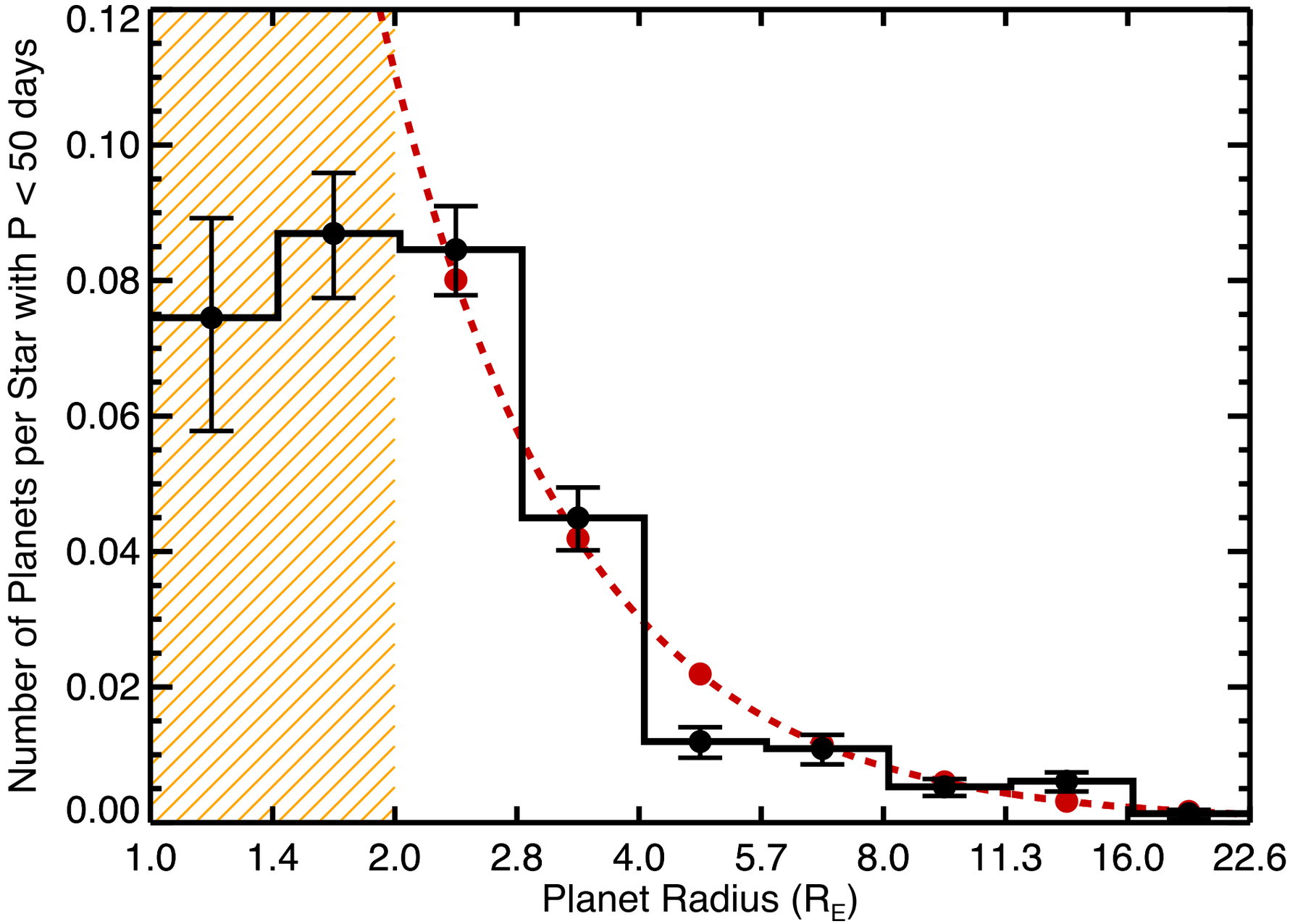


Howard et al. (2011c)

Planet Radius Distribution



Power law:

$dN/d\log R = kR^{\alpha}$

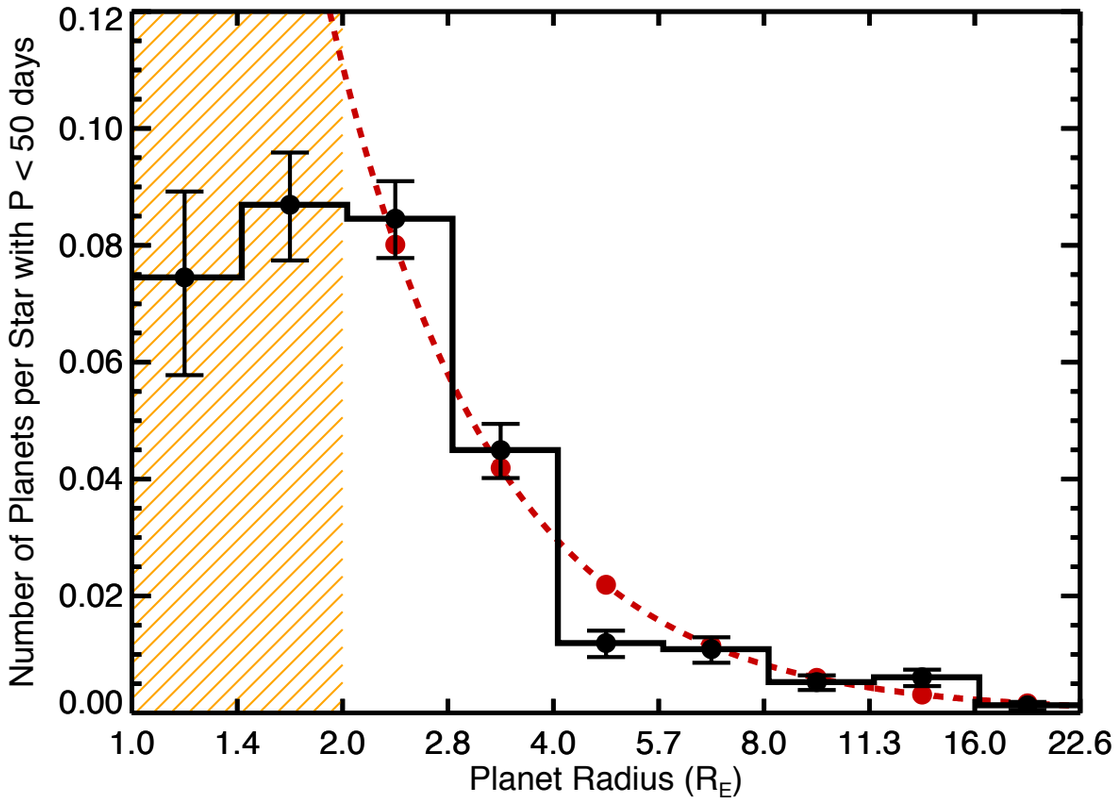
$k = 2.9 \pm 0.5$

$\alpha = -1.92 \pm 0.11$

Howard et al. (2011c)

Planet Radius Distribution
Kepler

Howard et al. 2011c, ApJ submitted, arXiv:1103.2541



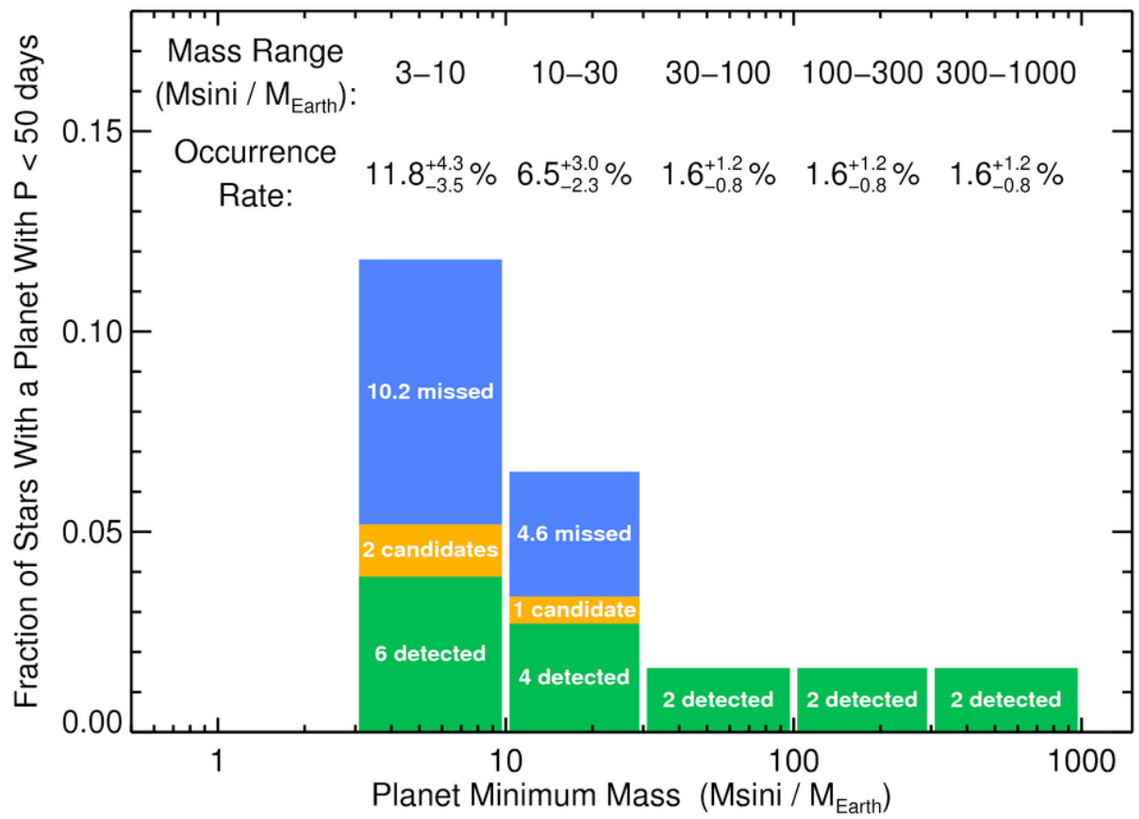
Power Law Radius Function

$df/d\log R = kR^{\alpha}$

$k = 2.9 \pm 0.5$, $\alpha = -1.92 \pm 0.5$

Planet Mass Distribution
Eta-Earth Survey (*Doppler*)

Howard et al. 2010, Science, 330, 653



Power Law Mass Function

$df/d\log M = kM^{\alpha}$

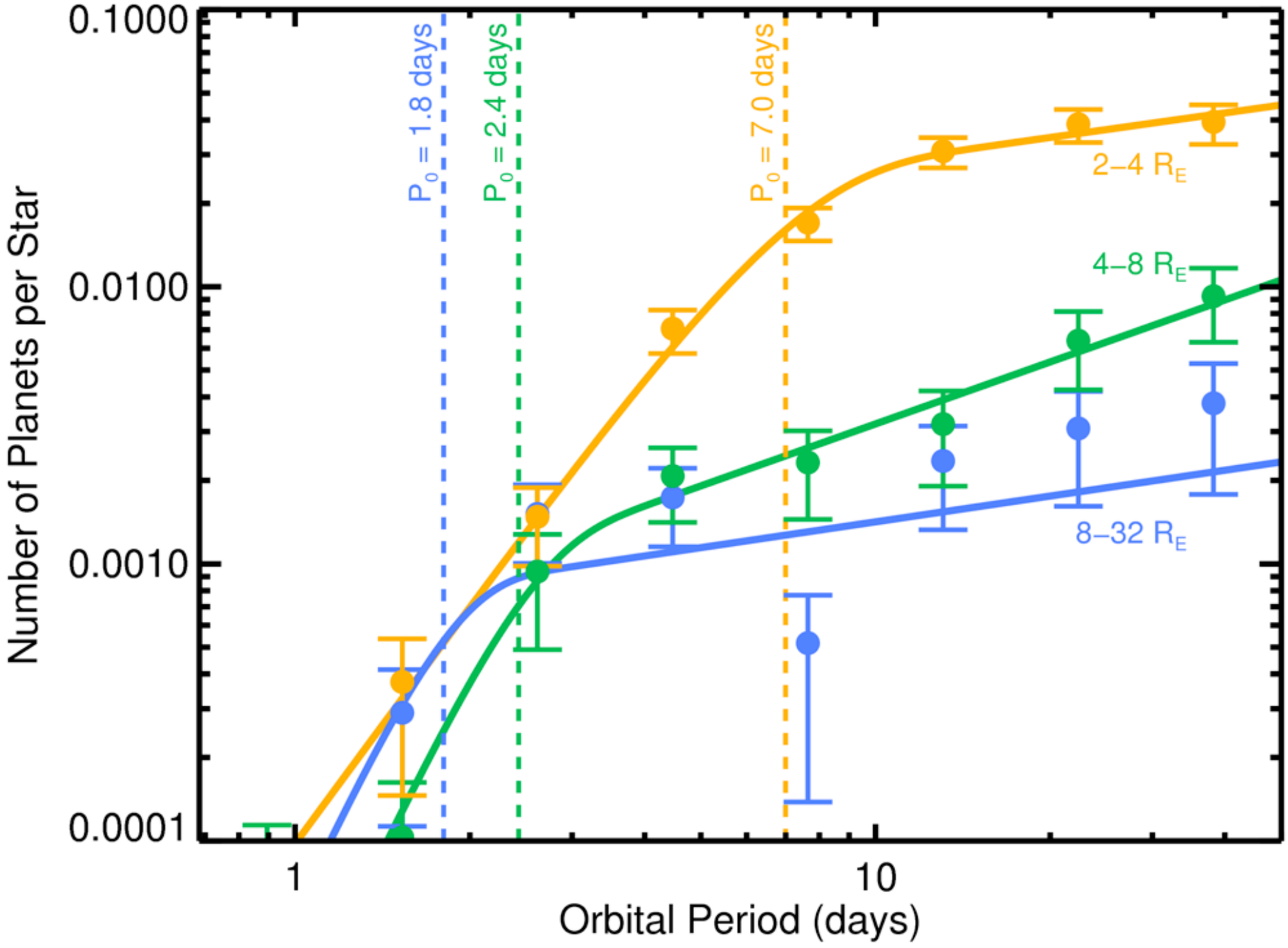
$k = 0.39^{+0.27}_{-0.16}$, $\alpha = -0.48^{+0.12}_{-0.14}$

Extrapolate:

$\eta_{\oplus} = 23^{+16}_{-10}\%$

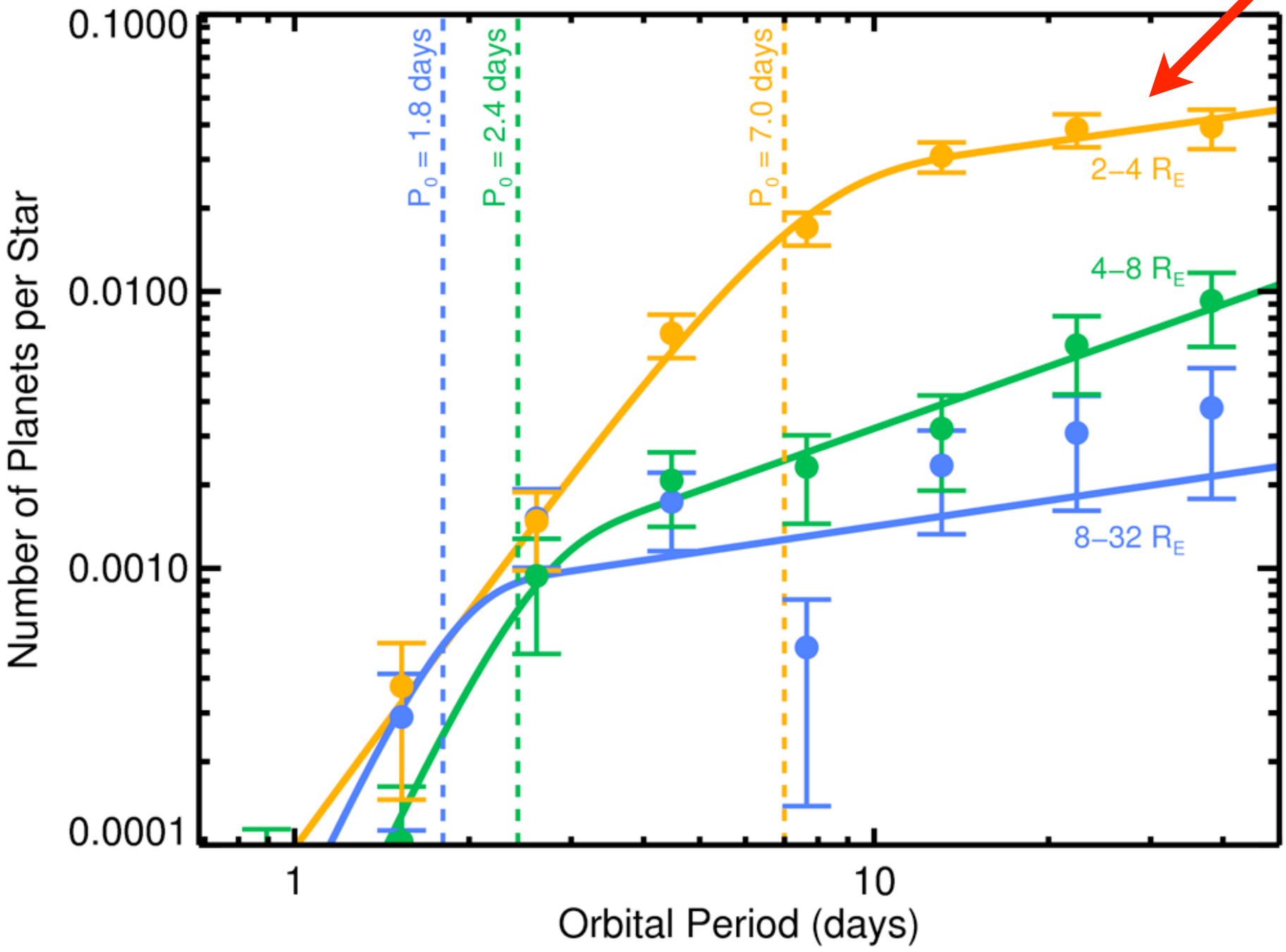
$M\sin i = 0.5\text{-}2.0\ M_E$, $P < 50$ days

Back to *Kepler*: Planet Period Distribution



Howard et al. (2011c)

Power Law



Increasing Planet Occurrence per log *P* bin

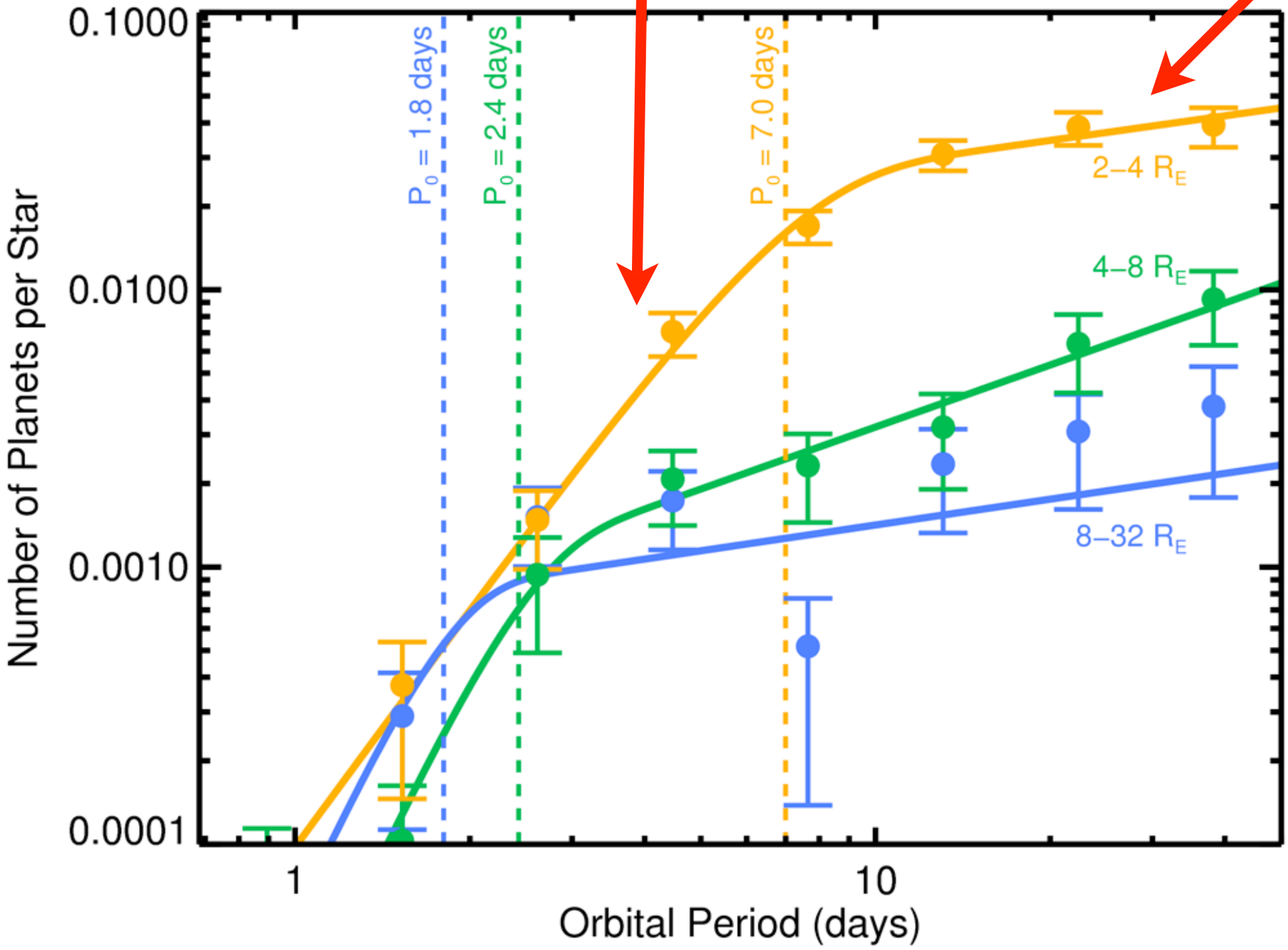
Power law with Exponential Cutoff:

$$dN/d\log P = kP^{\beta}\left(1-\exp\left((P/P_0)^{\gamma}\right)\right)$$

Howard et al. (2011c)

Exponential Cutoff

Power Law



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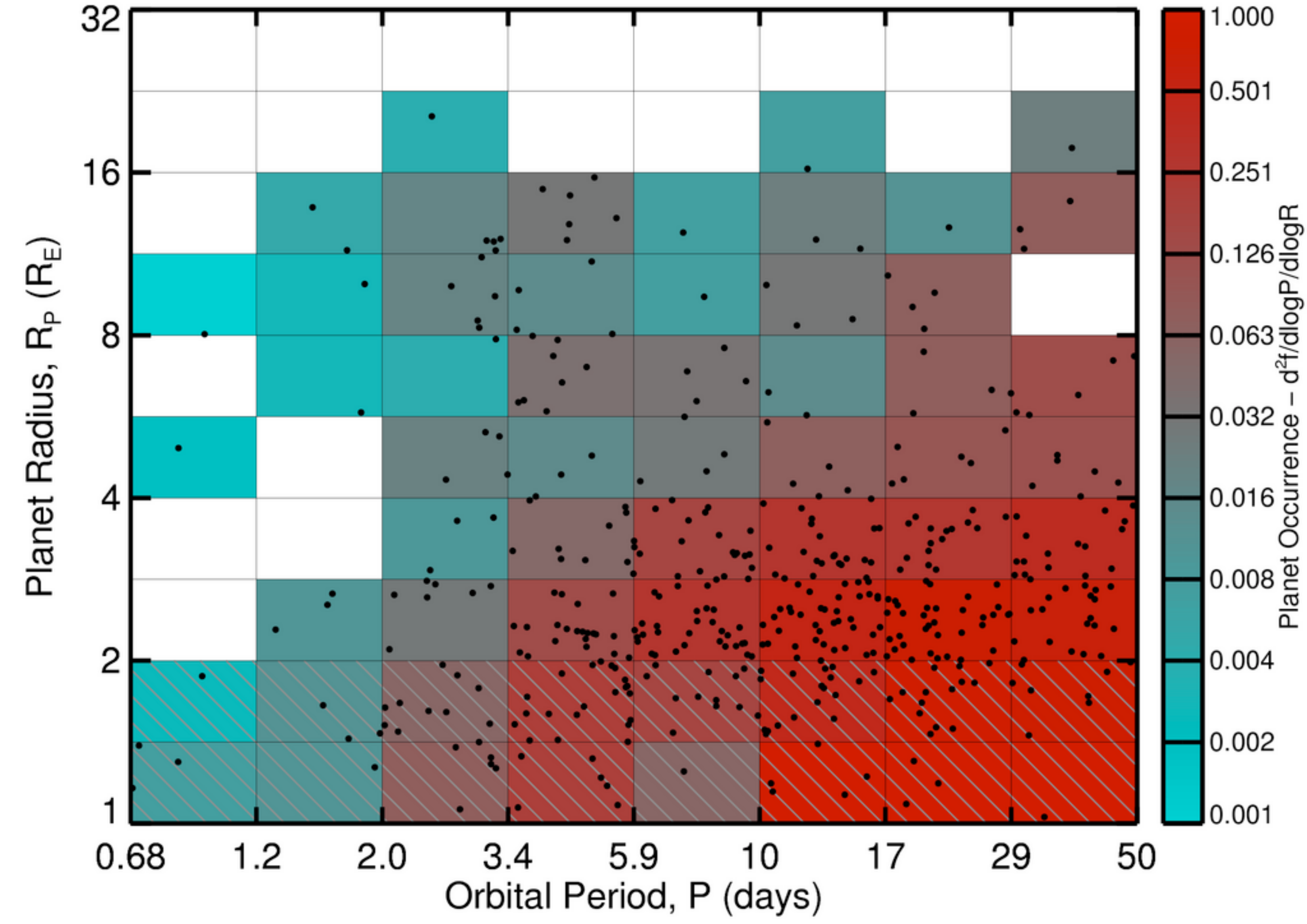

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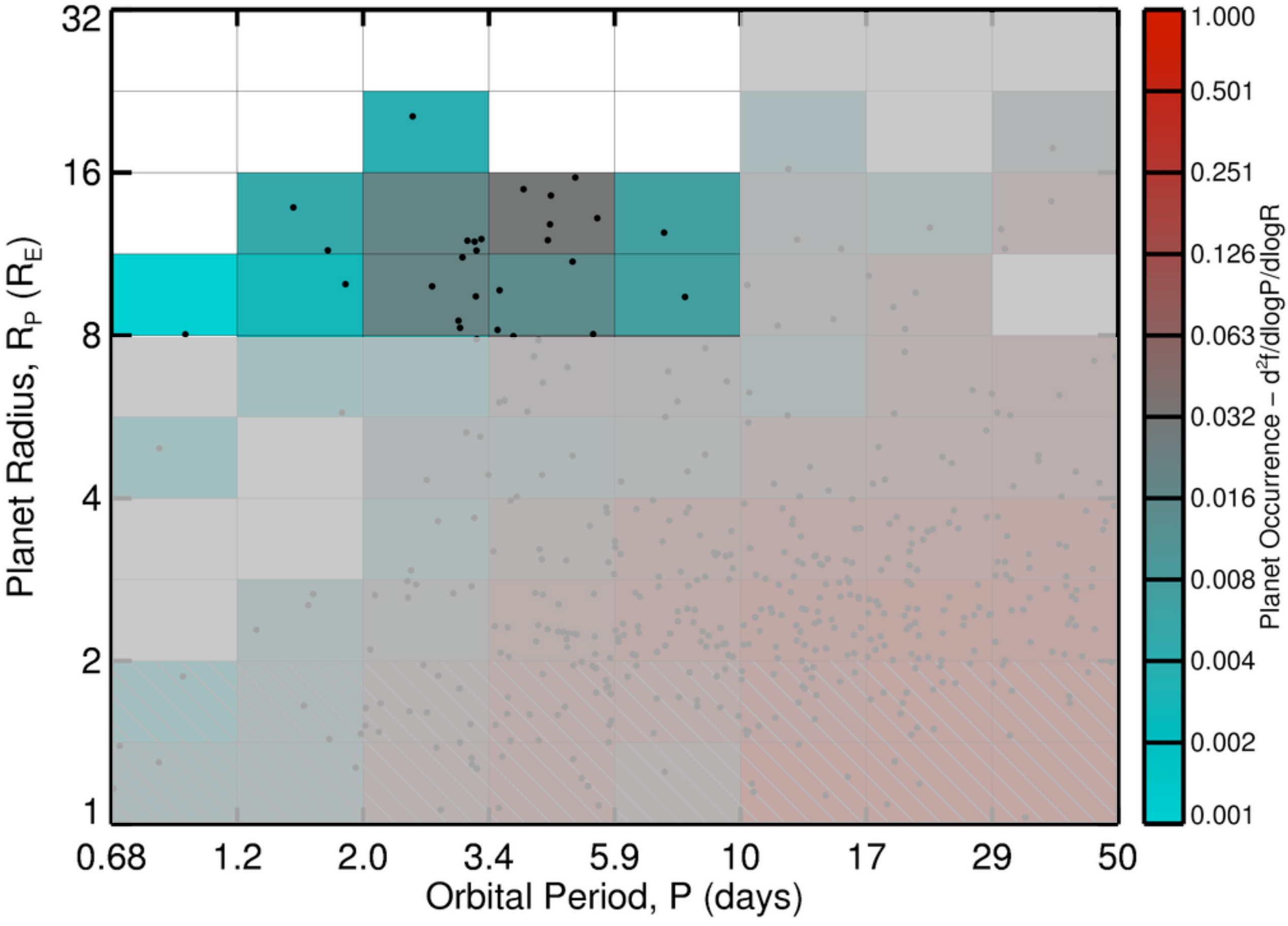

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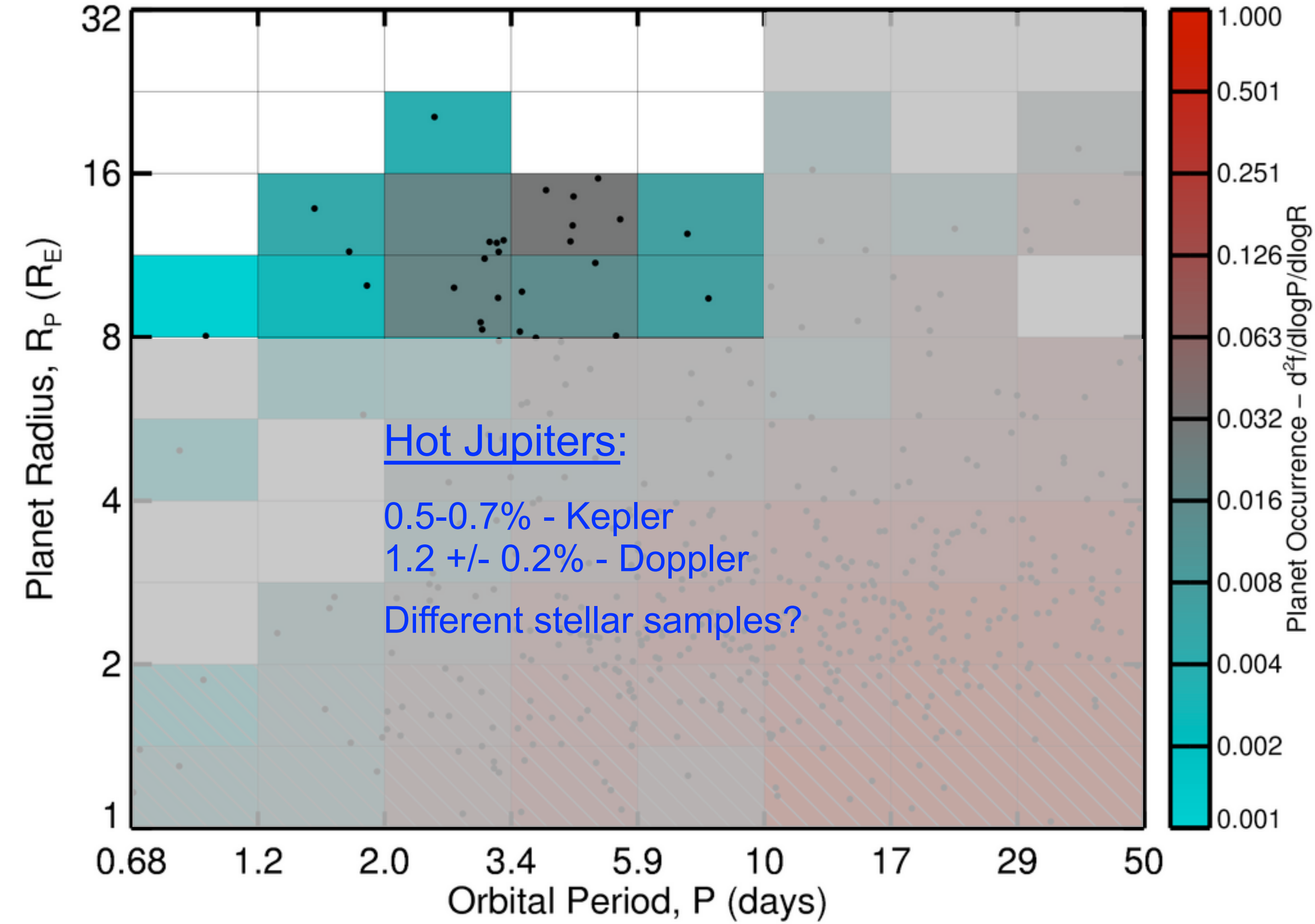
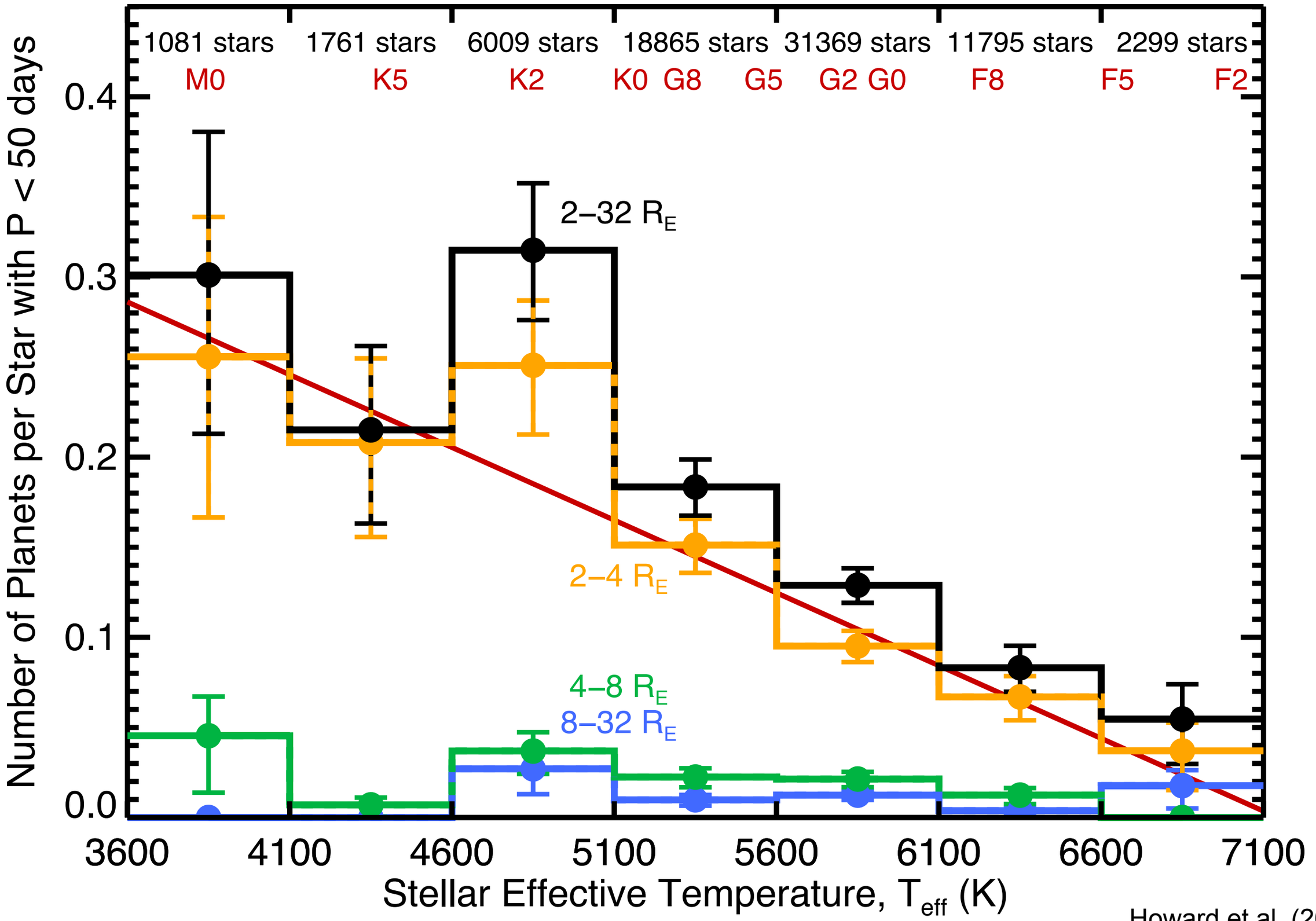


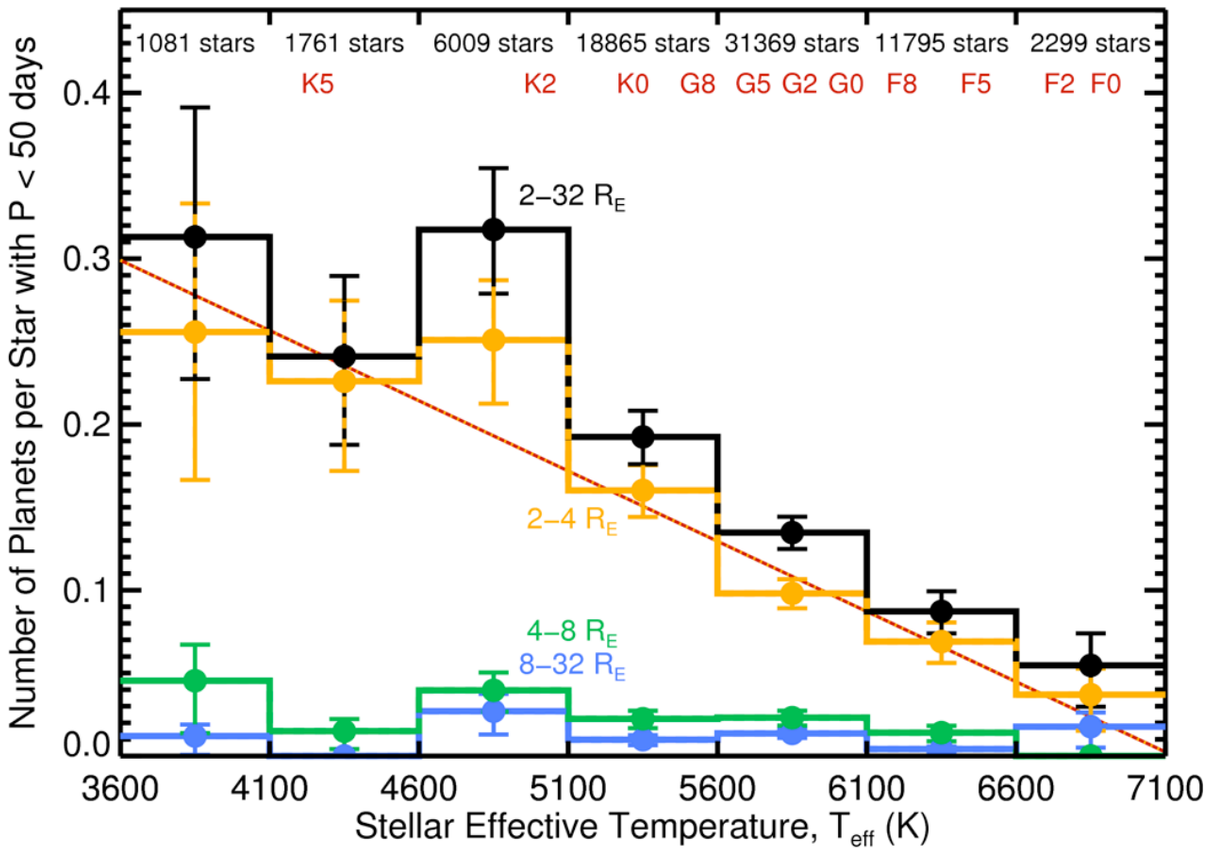
Howard et al. (2011c)

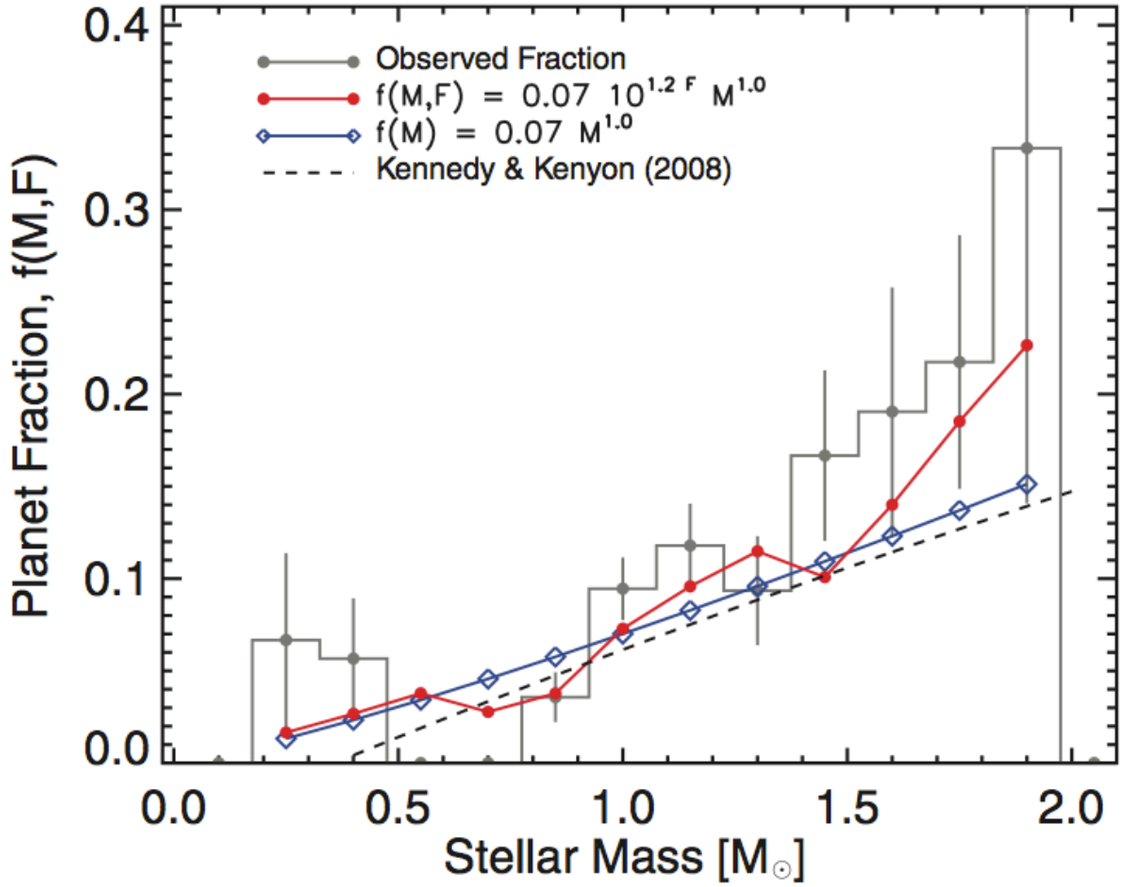
Planet Occurrence vs. Stellar Temperature



Howard et al. (2011c)

Planet Occurrence vs. $M_\star$





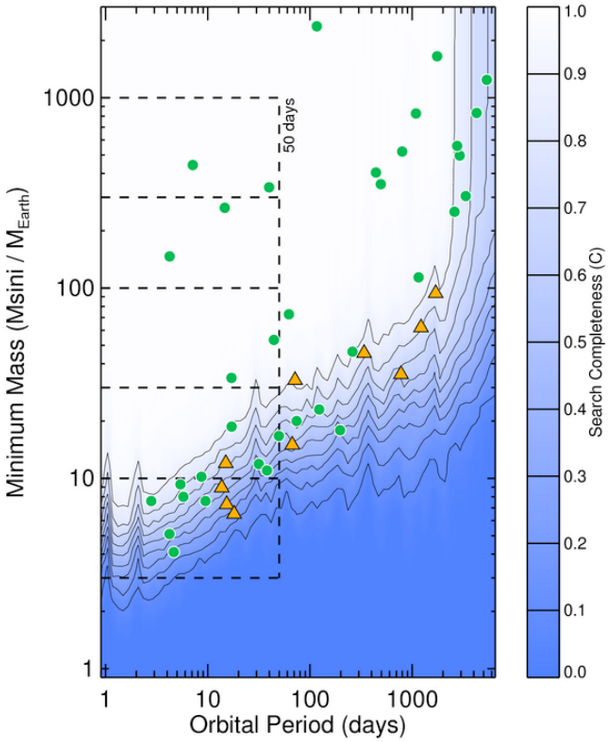
Occurrence within 0.25 AU of small planets *decreases* with $M_\star$

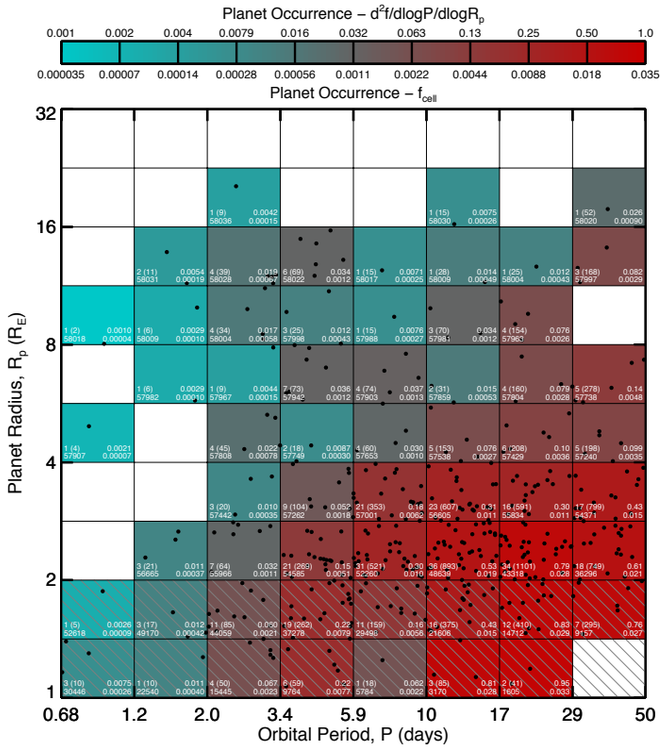
Howard et al. (2011c)

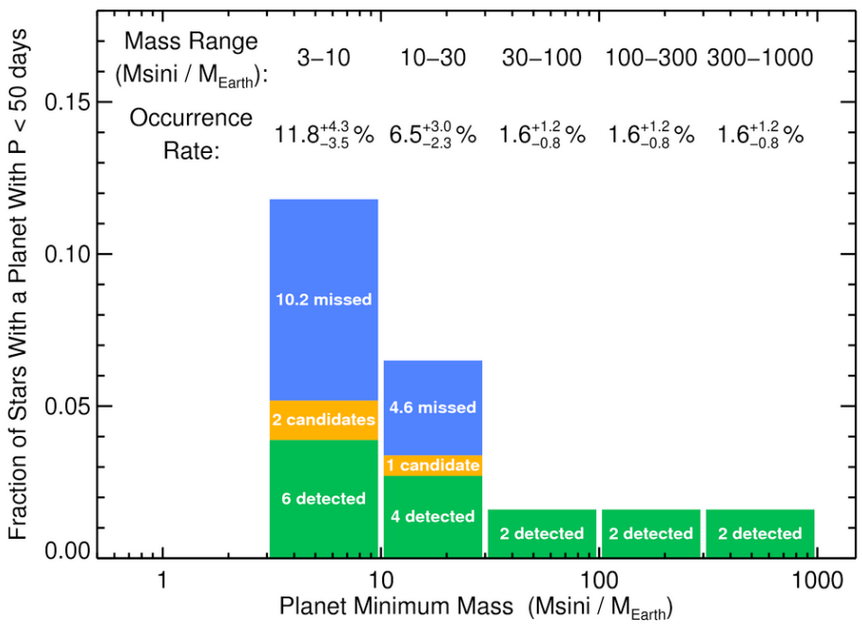
Occurrence within 2.5 AU of giant planets *increases* with $M_\star$

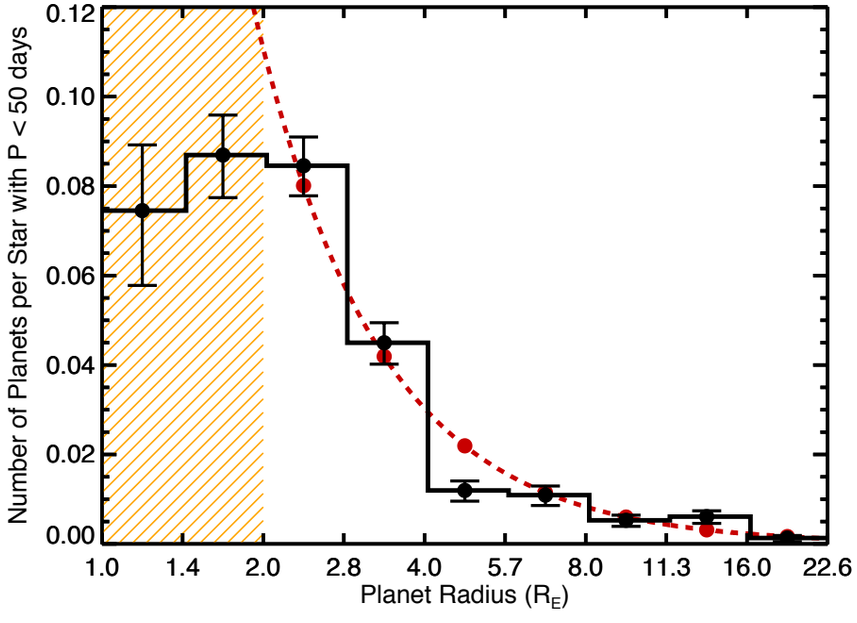
Johnson et al. (2010)

Take Home Message:









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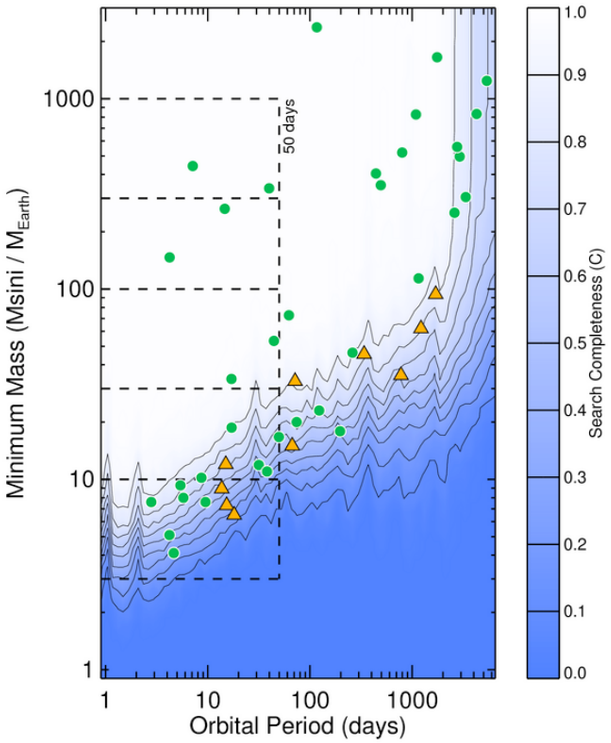
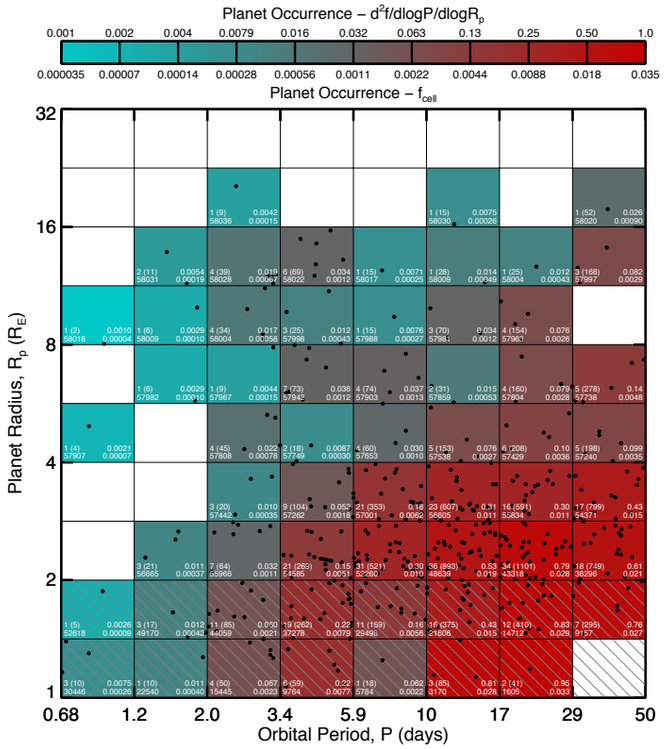
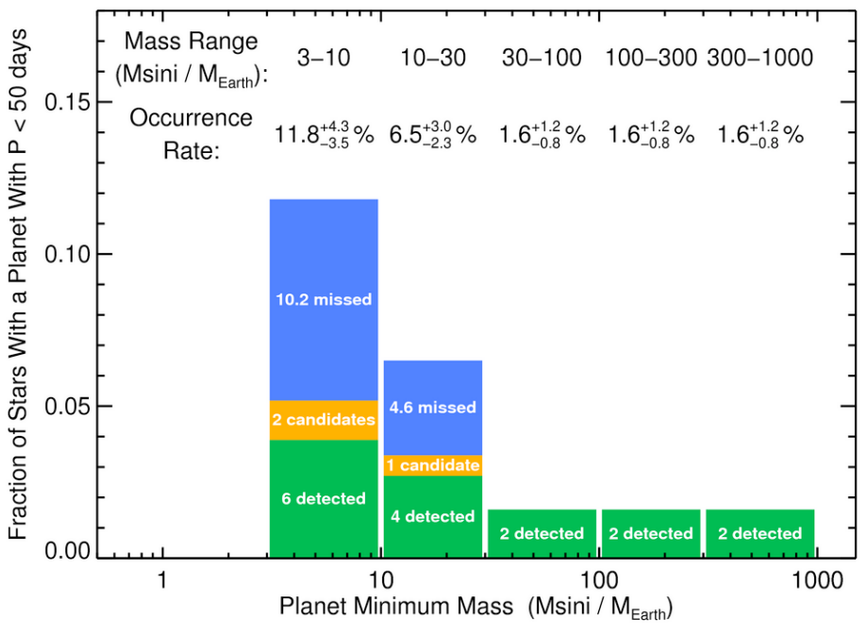
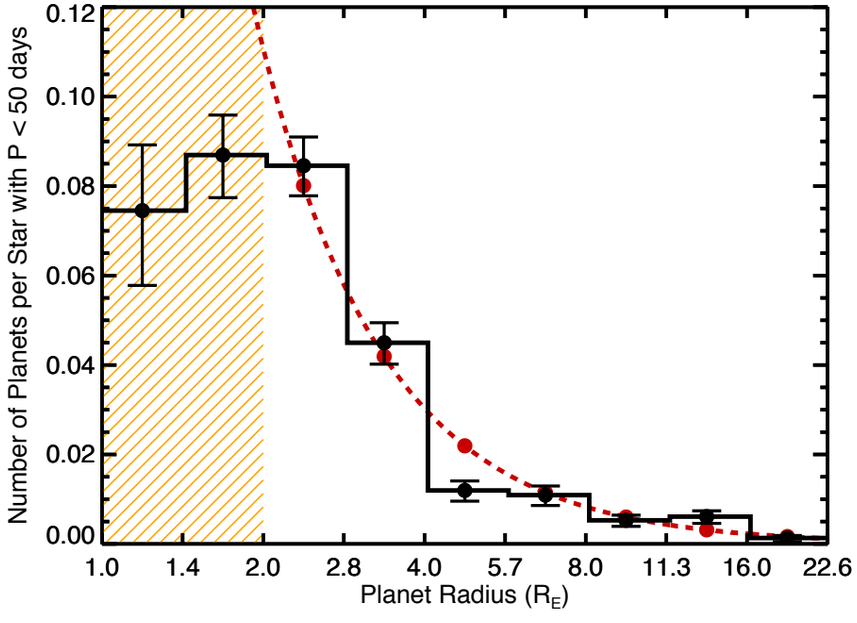


Small Planets are Common







Questions?