Asteroseismology of Exoplanet Host Stars

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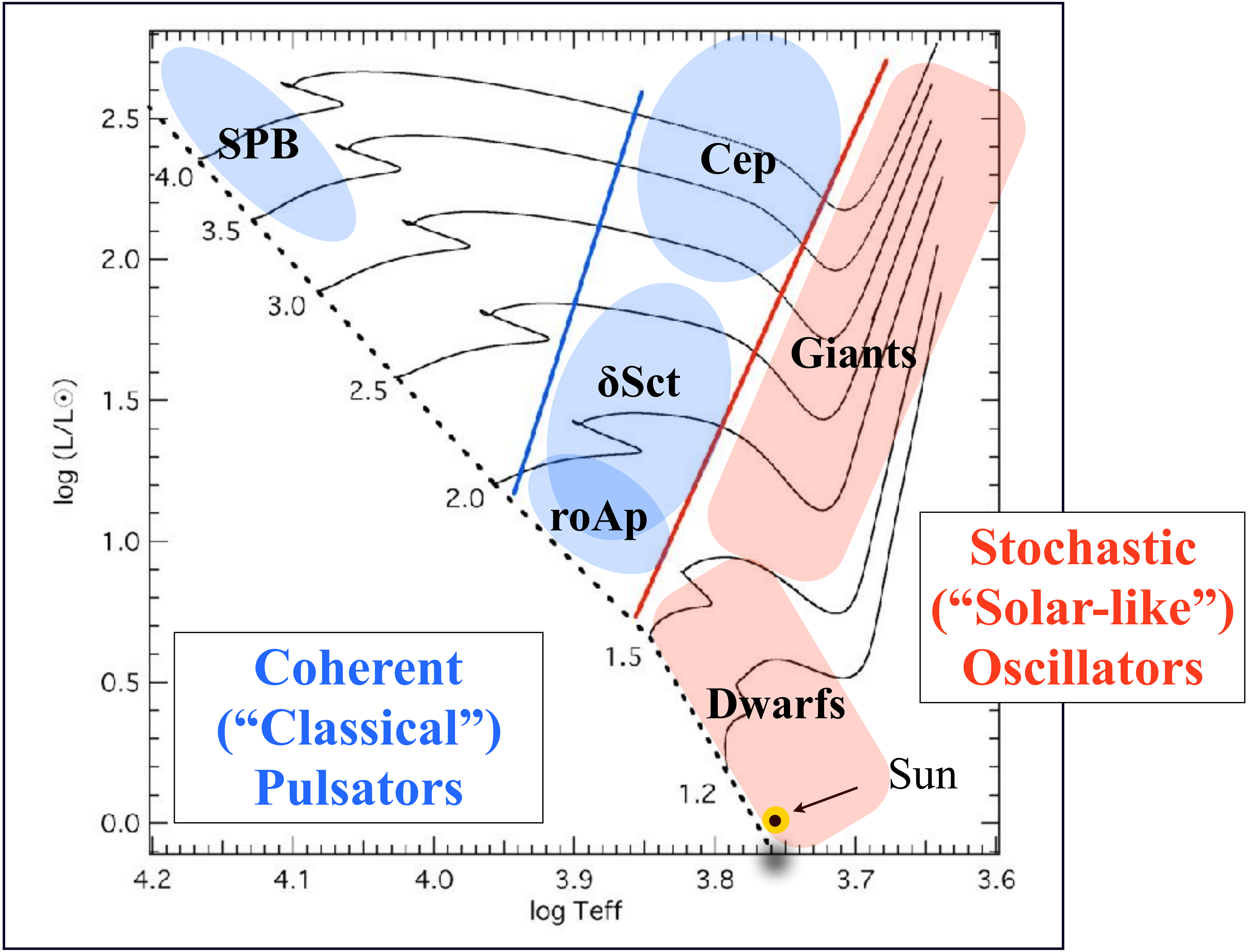
Know Thy Star, Know Thy Planet

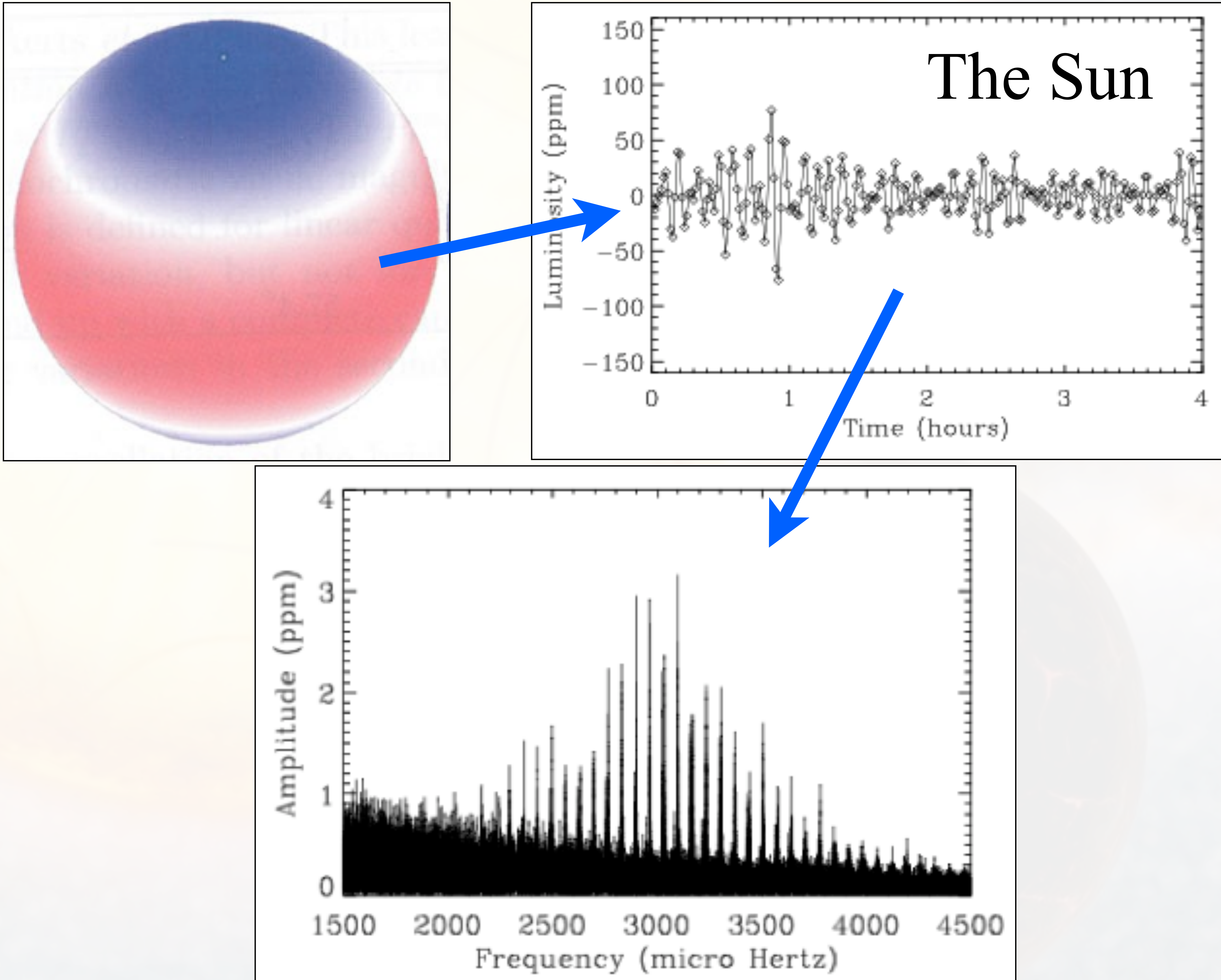
October 2017

Crash Course in Asteroseismology

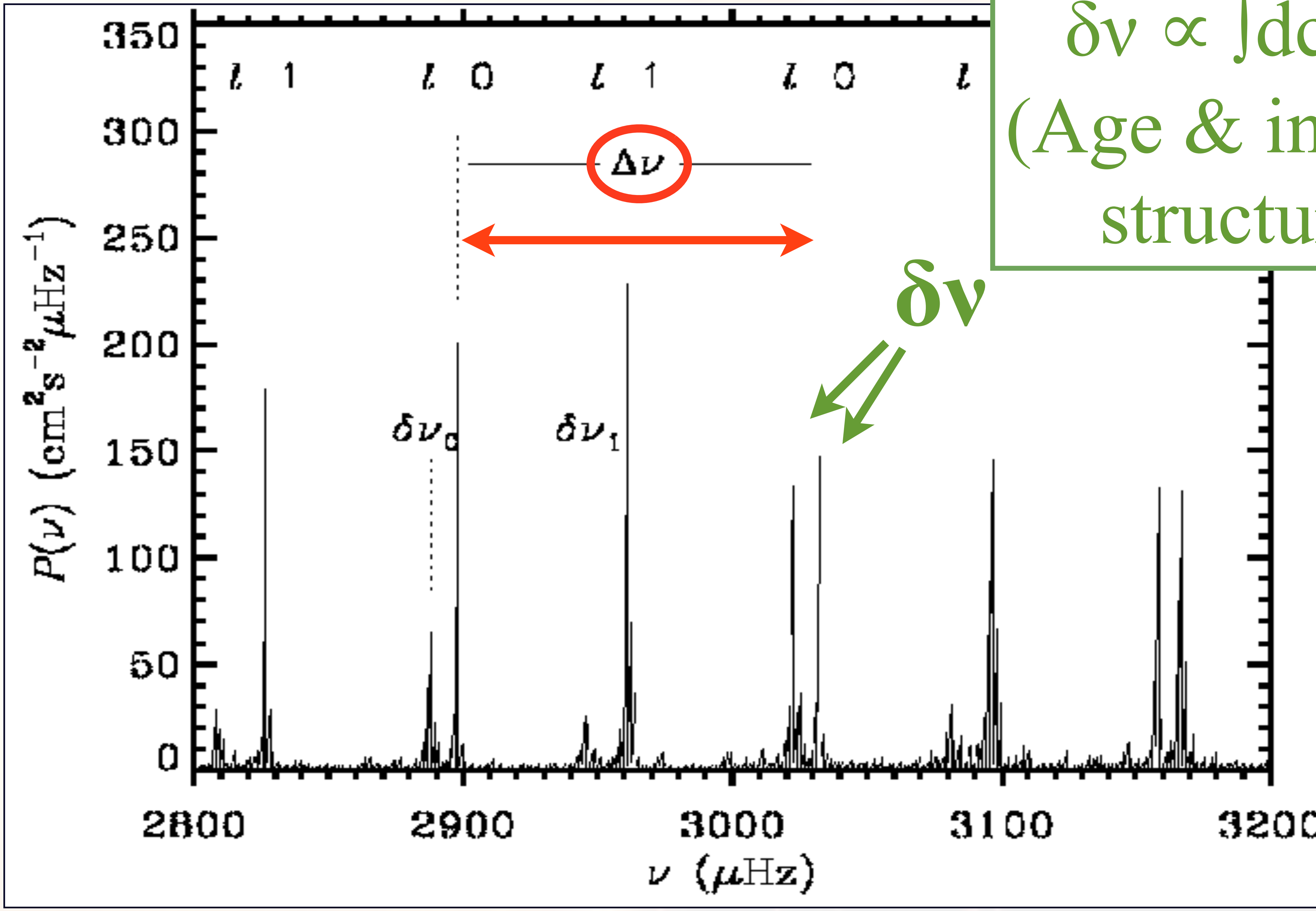
for more details:
Aerts, Christensen-Dalsgaard & Kurtz (2011, Springer)
Basu & Chaplin (2017, Princeton)



SPB
Cep
δSct
roAp
Giants
Dwarfs
Sun
4.0
3.5
3.0
2.5
2.0
1.5
1.2
log (L/L⊙)
2.5
2.0
1.5
1.0
0.5
0.0
4.2
4.1
4.0
3.9
3.8
3.7
3.6
log Teff
Coherent
(“Classical”)
Pulsators
Stochastic
(“Solar-like”)
Oscillators



The Sun
150
100
50
0
−50
−100
−150
Luminosity (ppm)
0
1
2
3
4
Time (hours)
4
3
2
1
0
Amplitude (ppm)
1500
2000
2500
3000
3500
4000
4500
Frequency (micro Hertz)



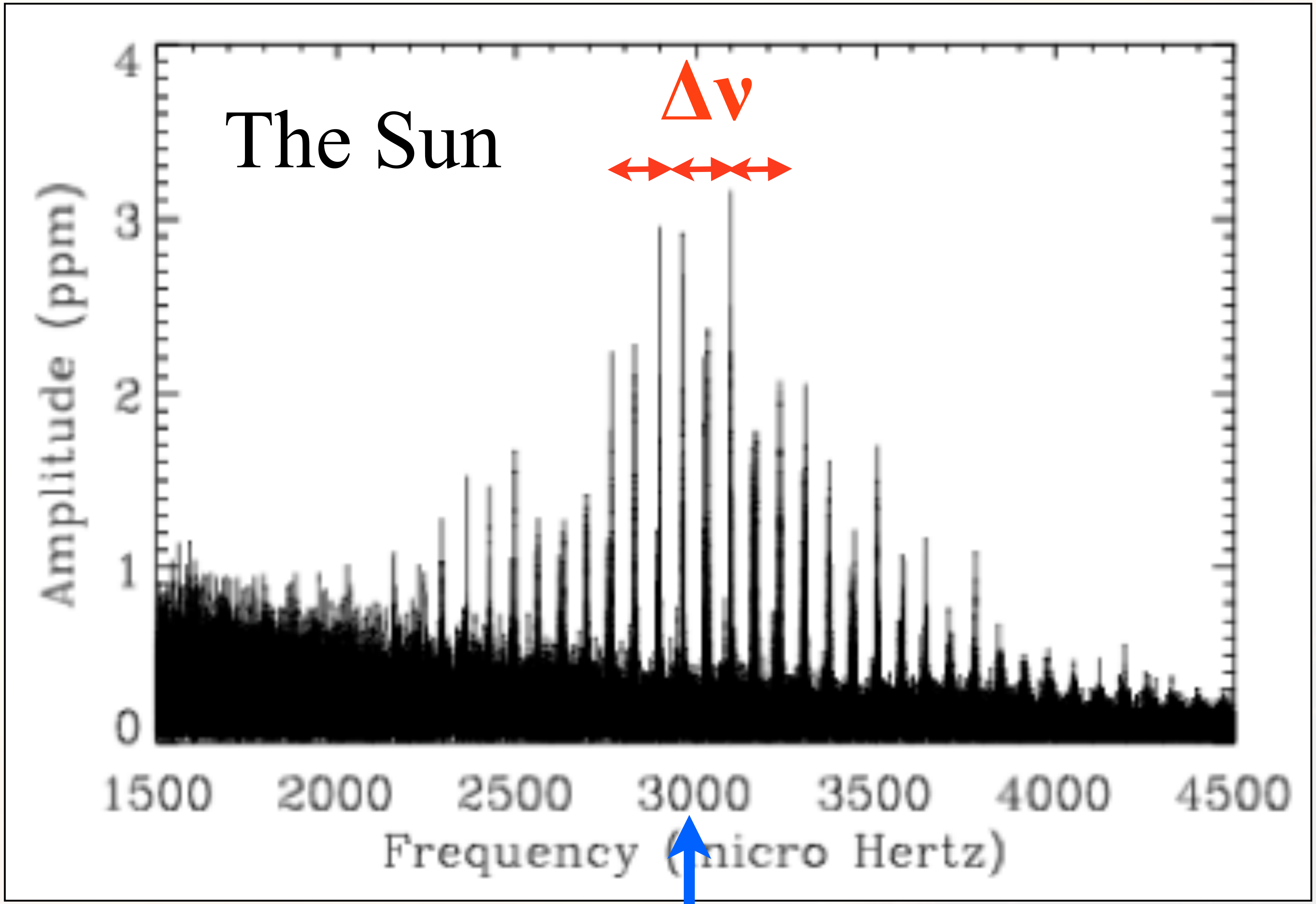
$\delta\nu \propto \int dc_s/dr$
(Age & interior structure)

sound speed c_s

$\mathbf{\Delta\nu} = (2 \int dr/c_s)^{-1} \propto \mathbf{(M/R^3)^{1/2}}$

Ulrich (1986)

$$\Delta\nu = \left(2\int dr/c_s\right)^{-1} \propto (M/R^3)^{1/2} \text{ (density)}$$



Brown et al. (1991)

ν_{max}

$$\nu_{max} \propto \nu_{ac} \propto M\,R^{-2}\,T_{eff}^{0.5} \text{ (gravity)}$$

T_{eff}

+

$\Delta\nu$, ν_{max}

↓

R **<~ 5%**

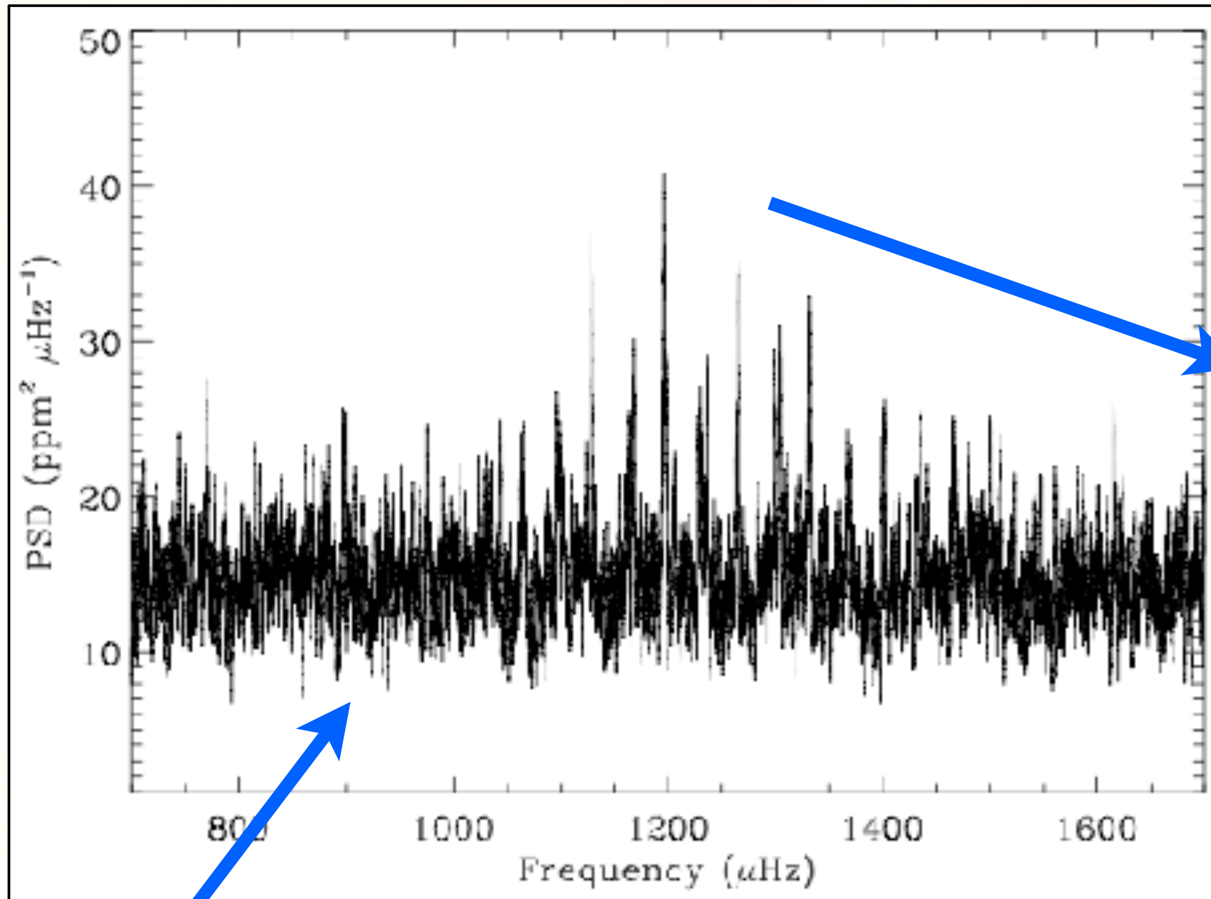
M **<~ 10%**

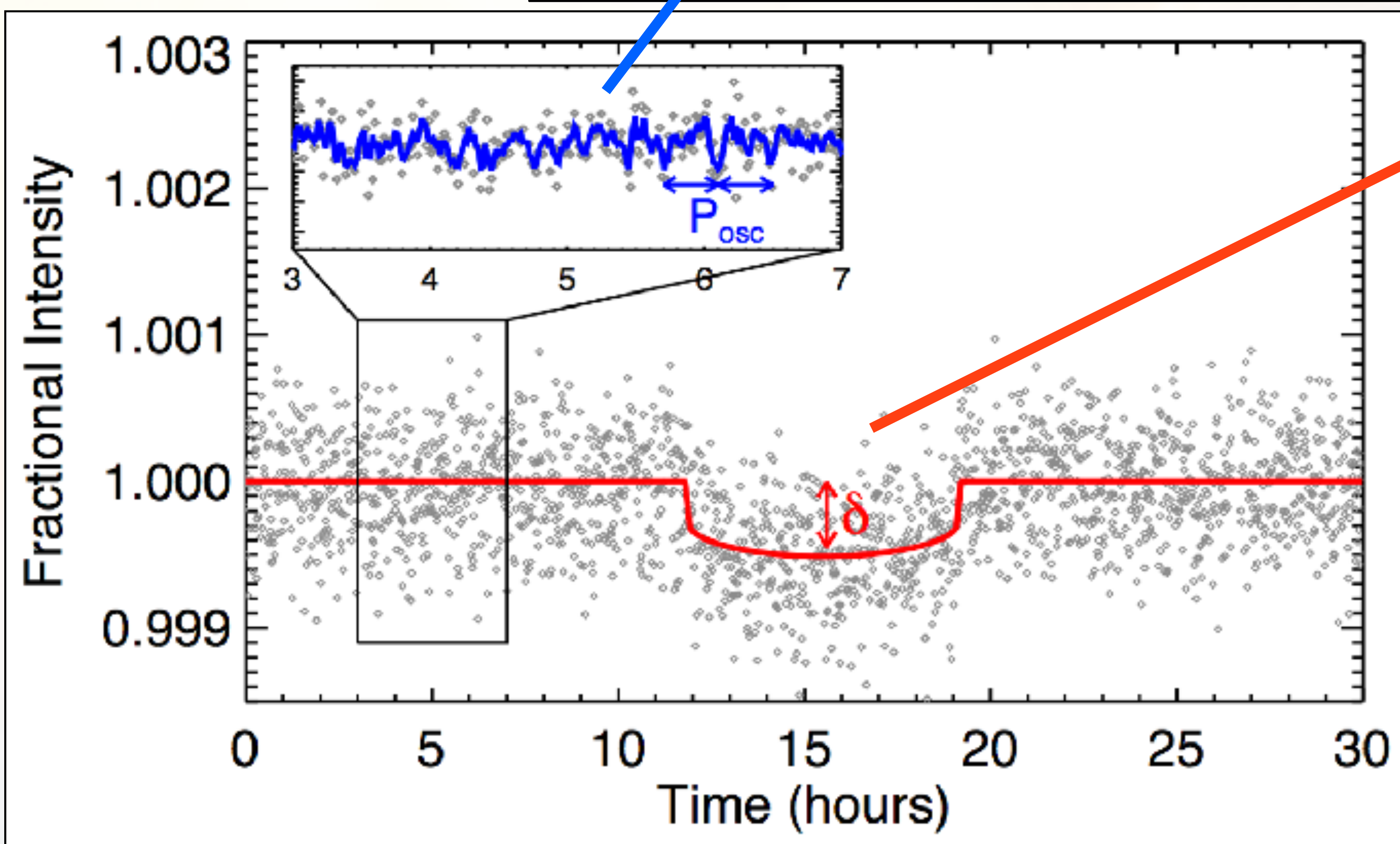
Asteroseismology & Exoplanets I:

Precise Planet Properties

Kepler-36

Carter et al. 2012





$M_\star$ & $R_\star$

+

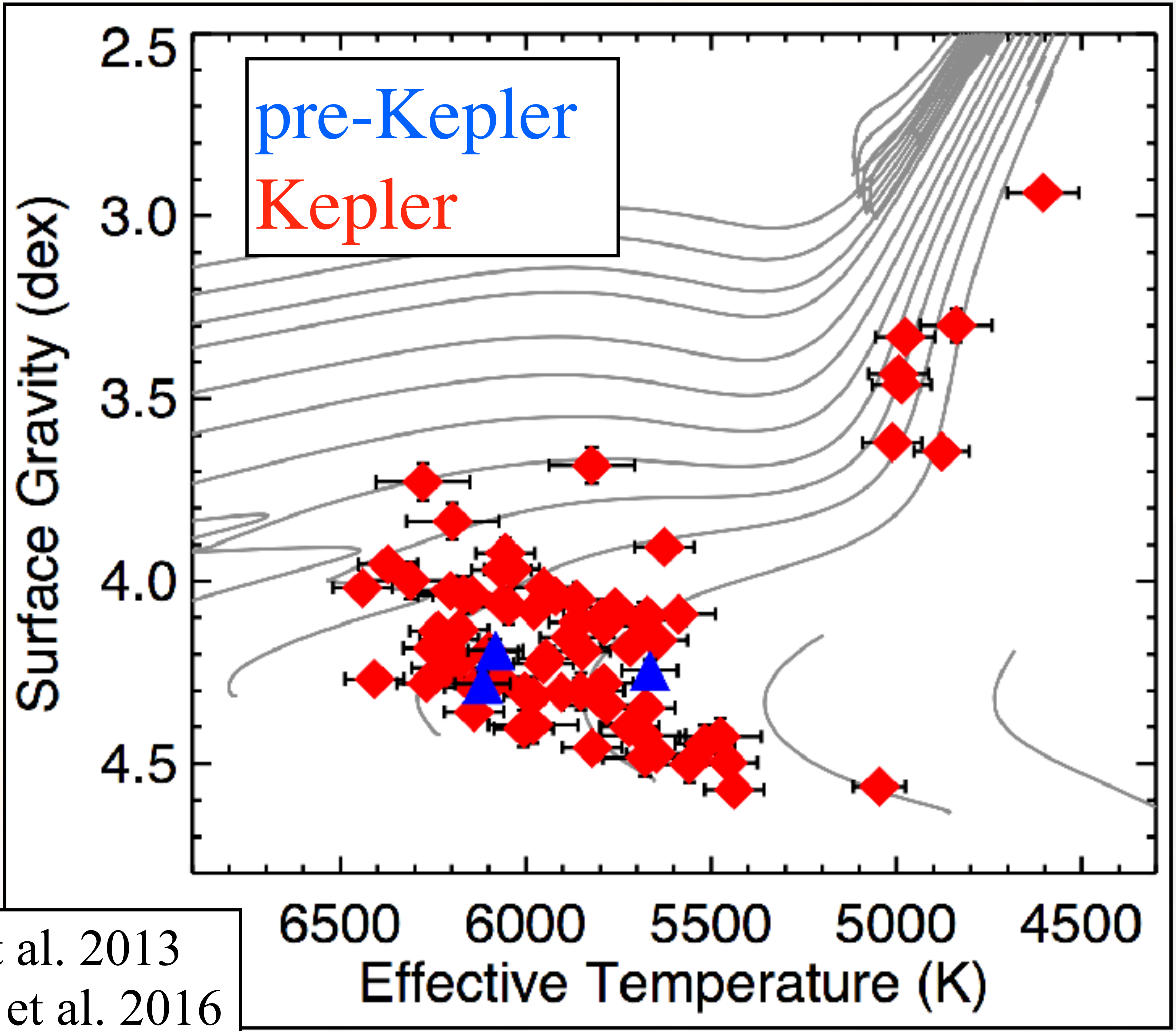
$(R_P/R_\star)^2$

↓

R_P

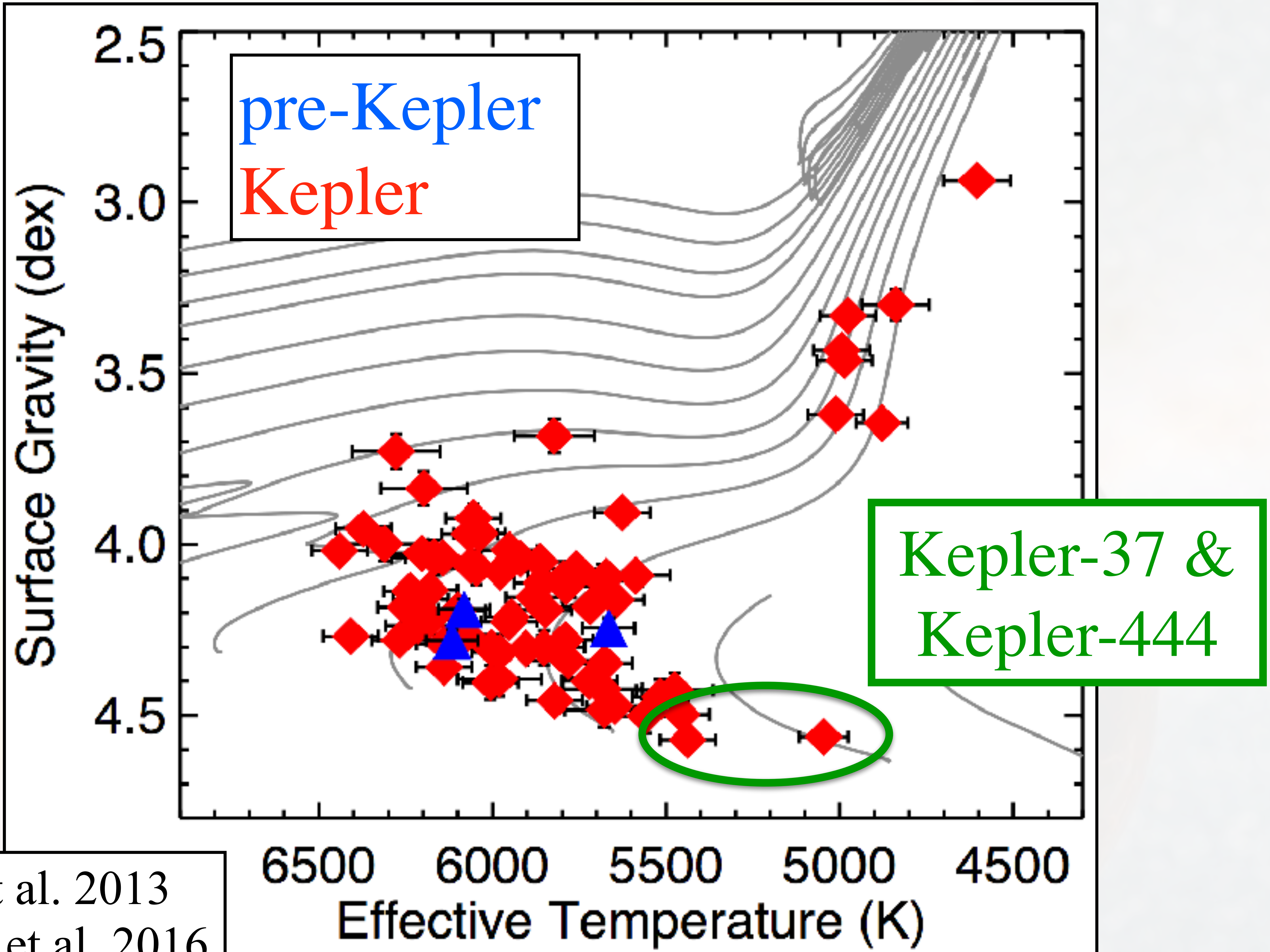
(<5% uncertainty!)

The Seismic Host Star Sample



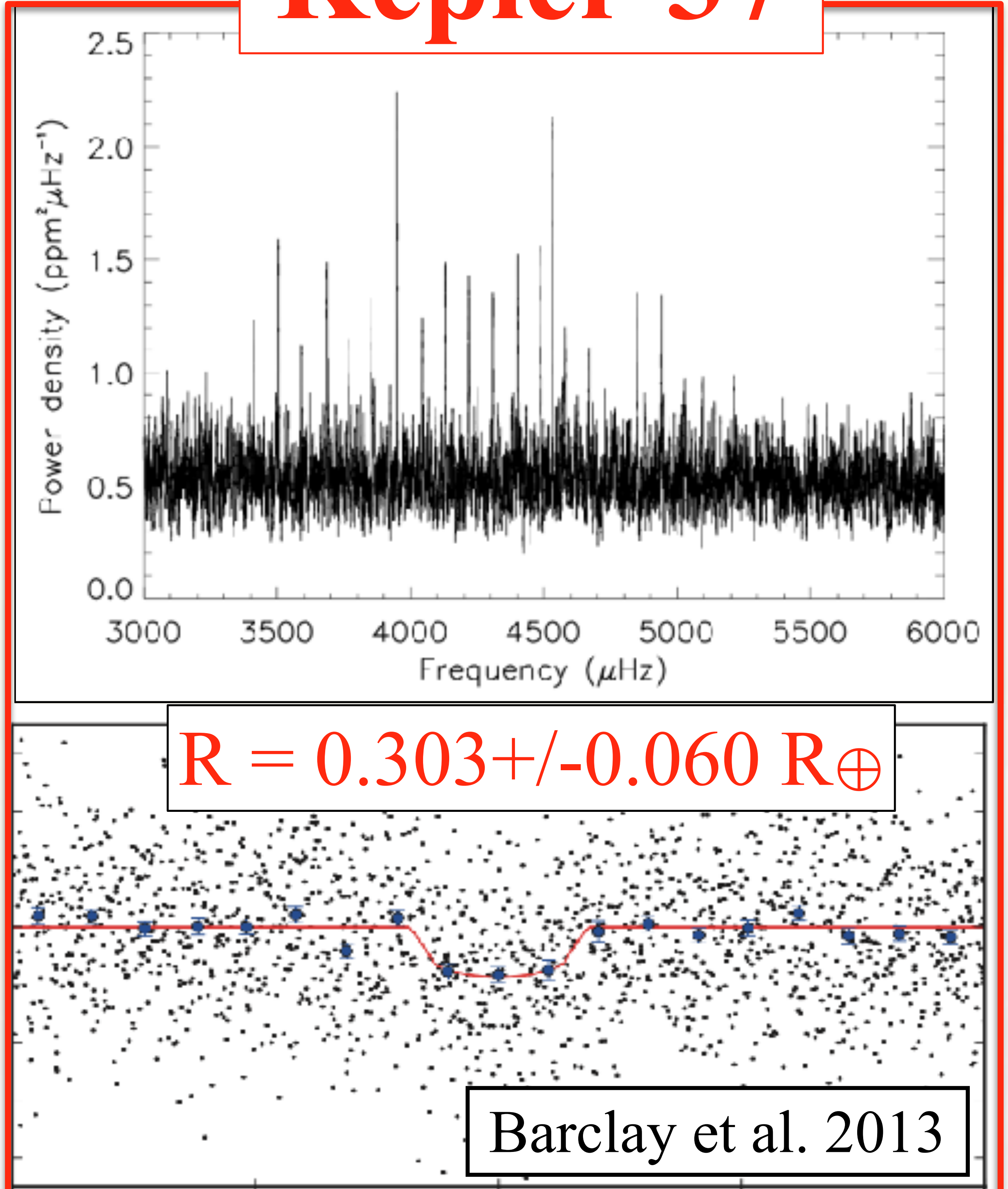
Huber et al. 2013
Lundkvist et al. 2016

The Seismic Host Star Sample



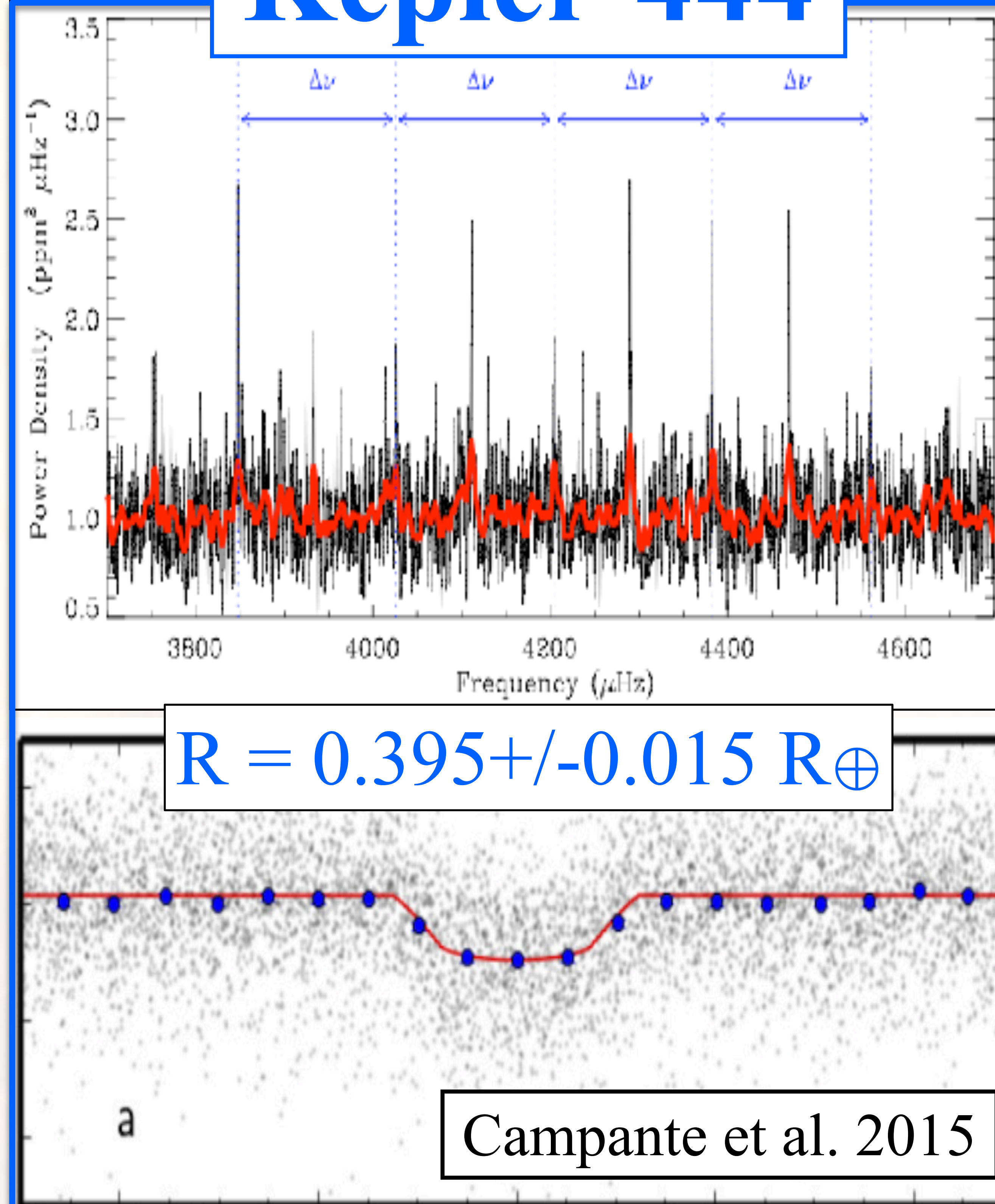
Huber et al. 2013
Lundkvist et al. 2016

Kepler-37



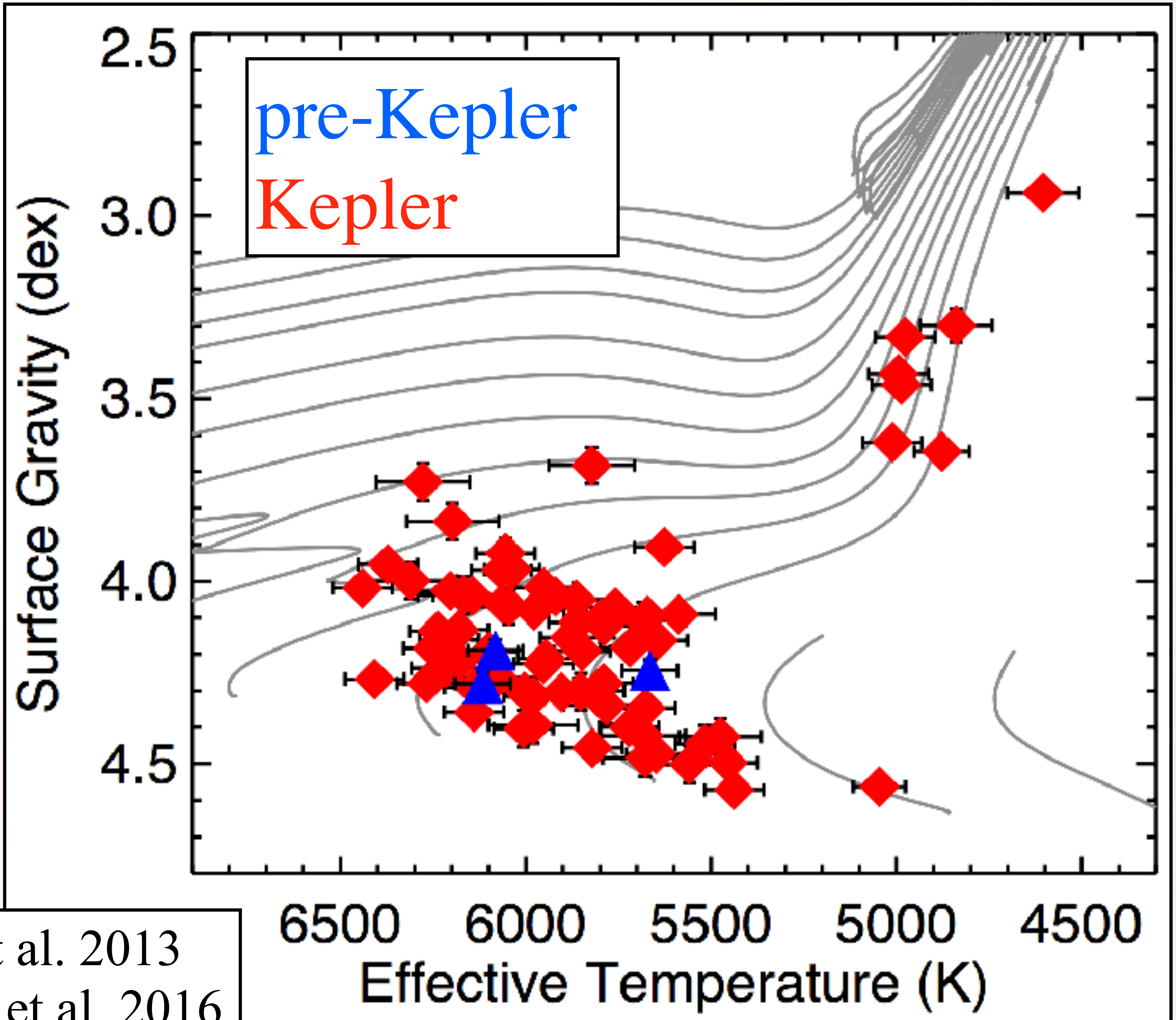
~ Moon-sized planet orbiting a late G dwarf

Kepler-444



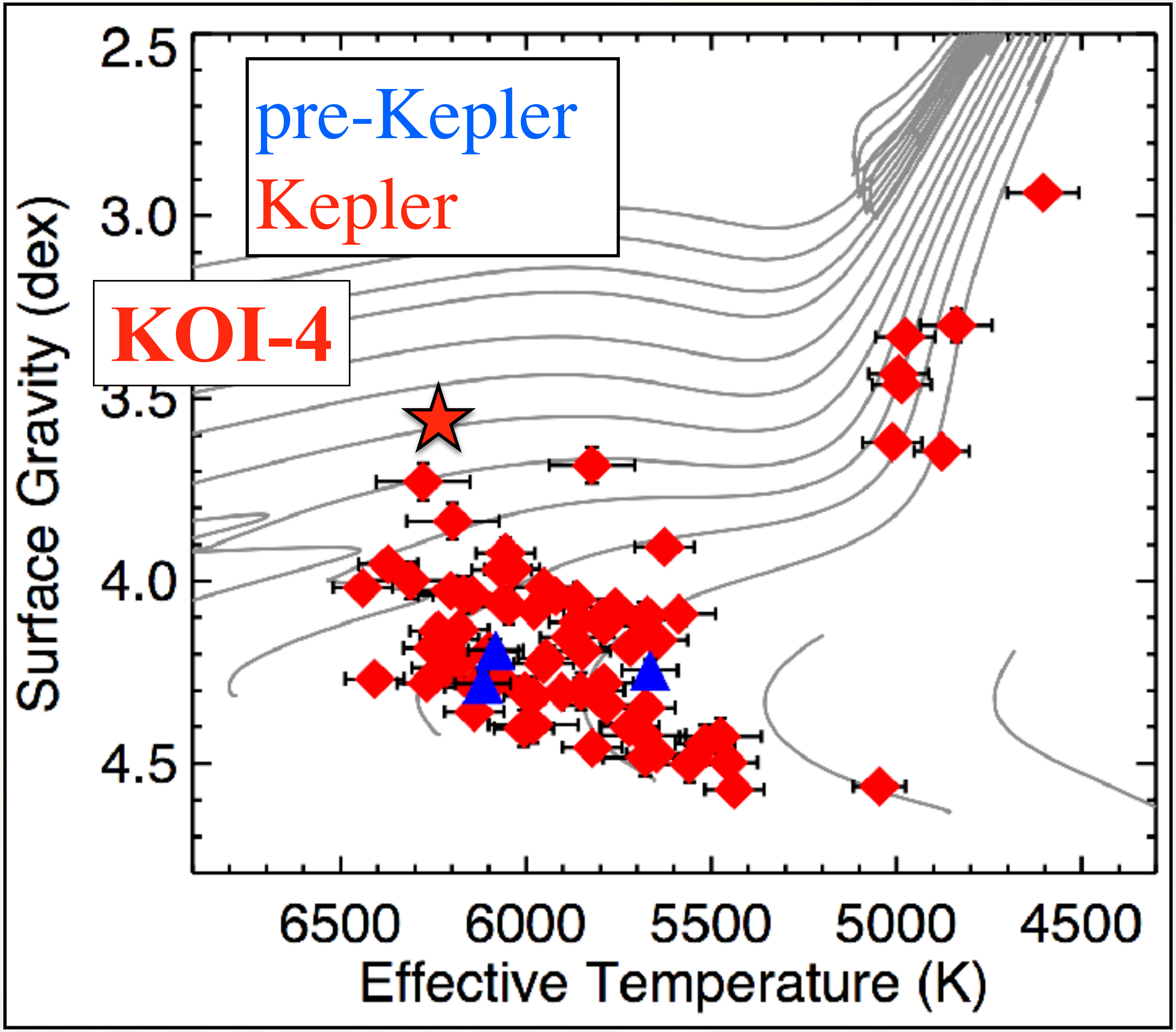
5 sub-Earth sized planets orbiting a ~12 Gyr old K dwarf

The Seismic Host Star Sample

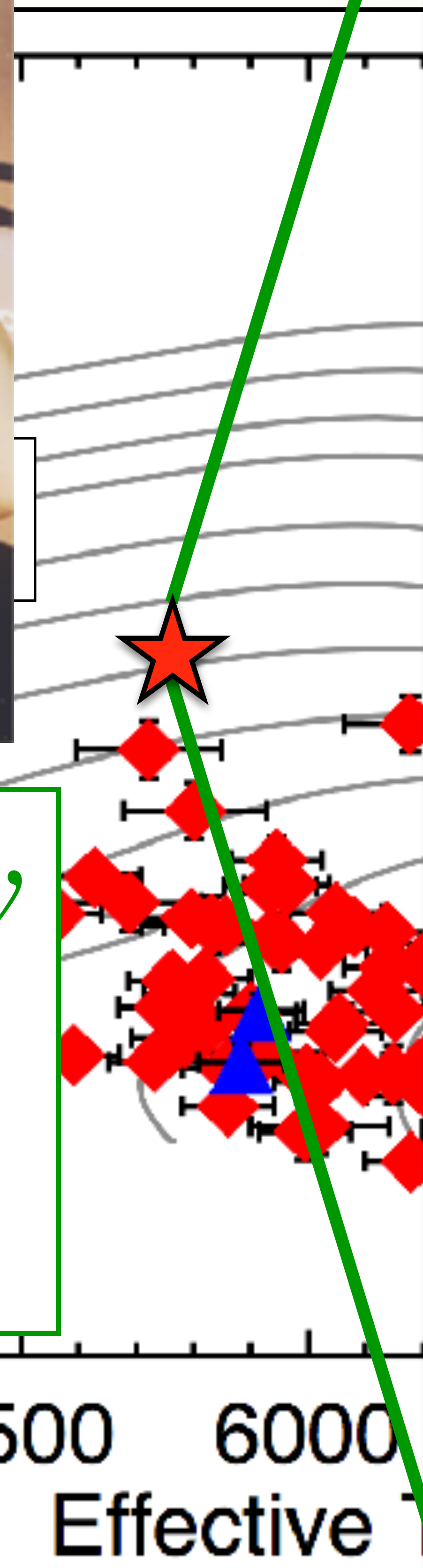


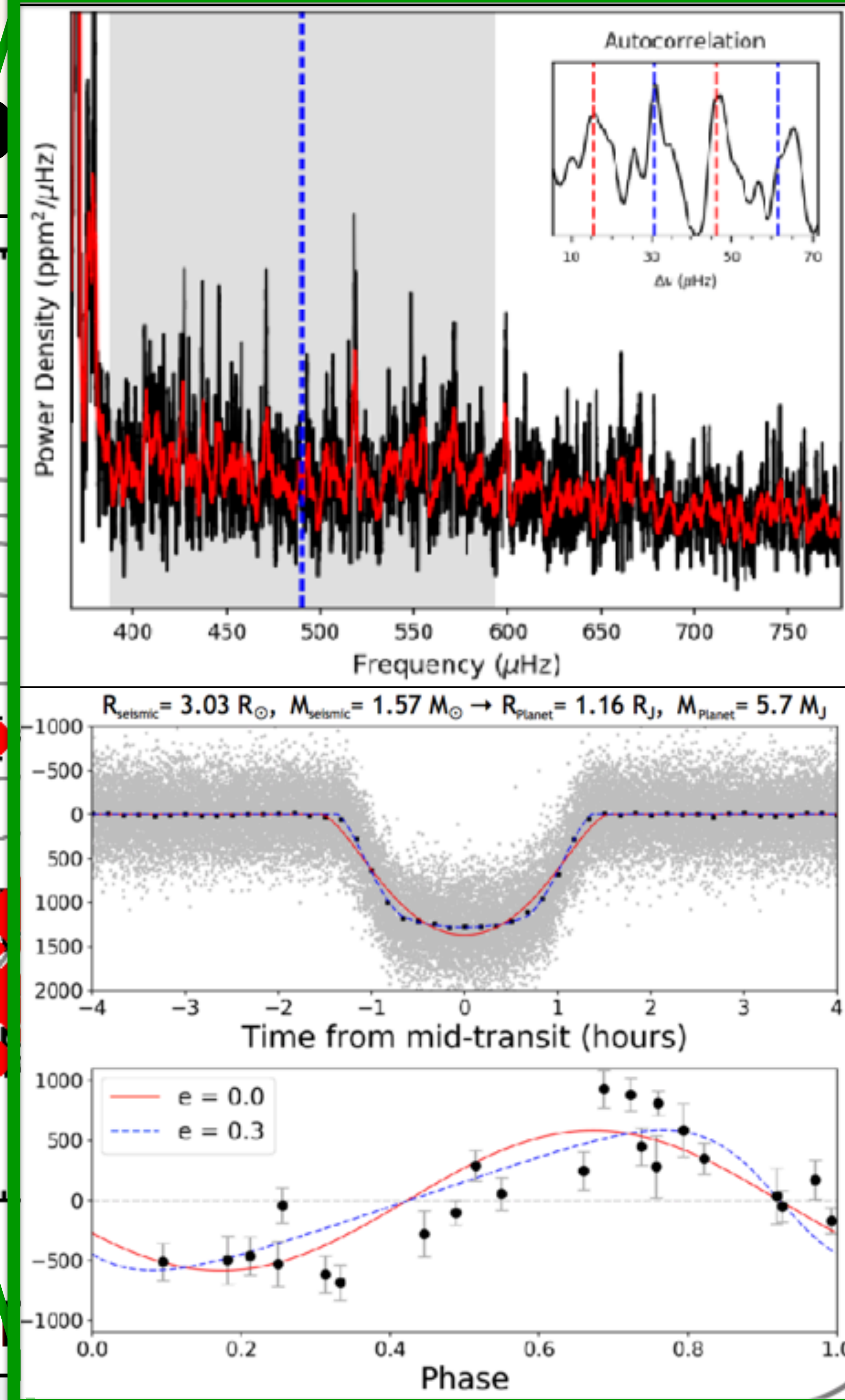
Huber et al. 2013
Lundkvist et al. 2016

The Seismic Host Star Sample



The Seismic Ho

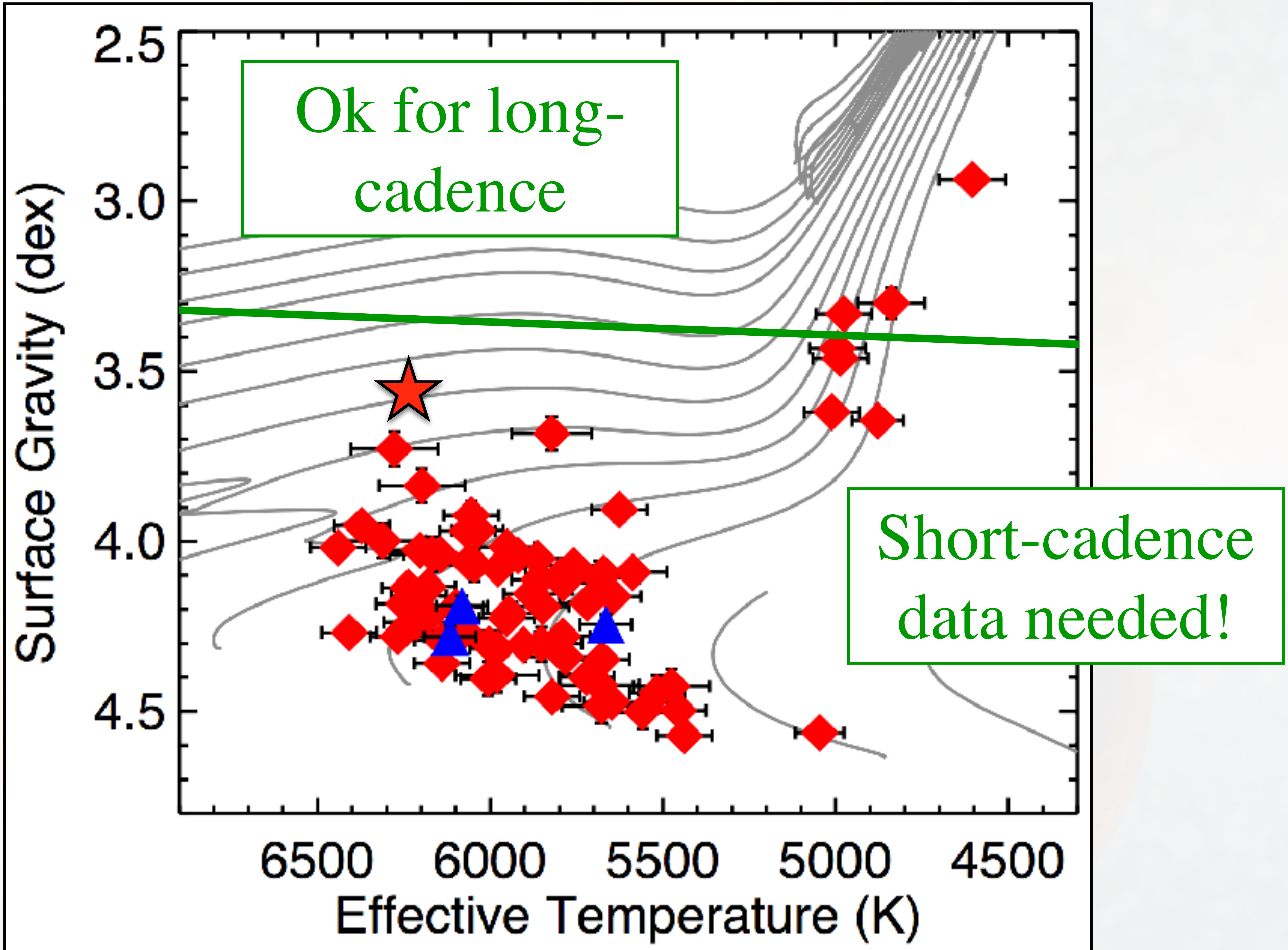




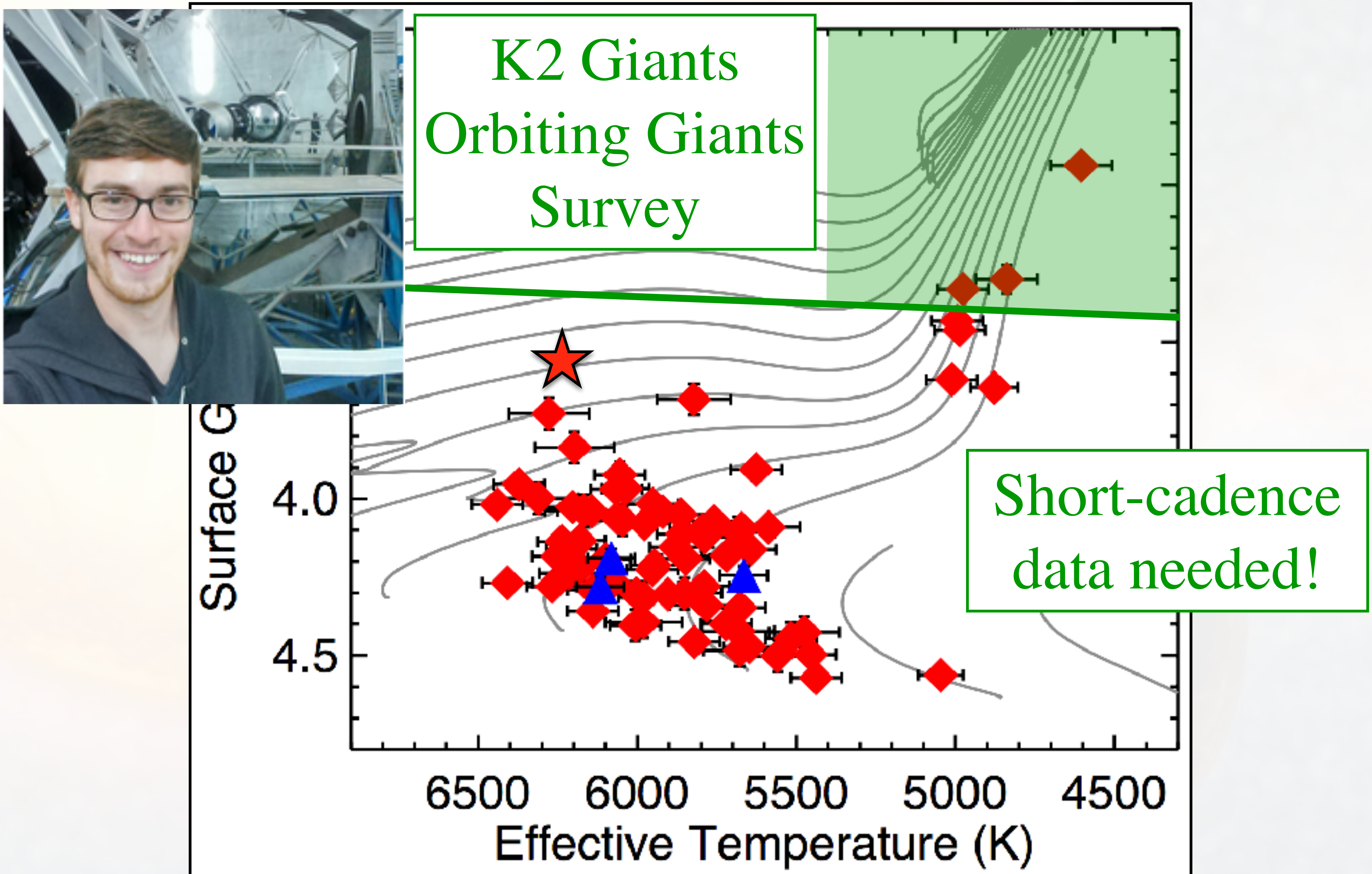
see poster by Ashley Chontos!

Chontos et al., in prep

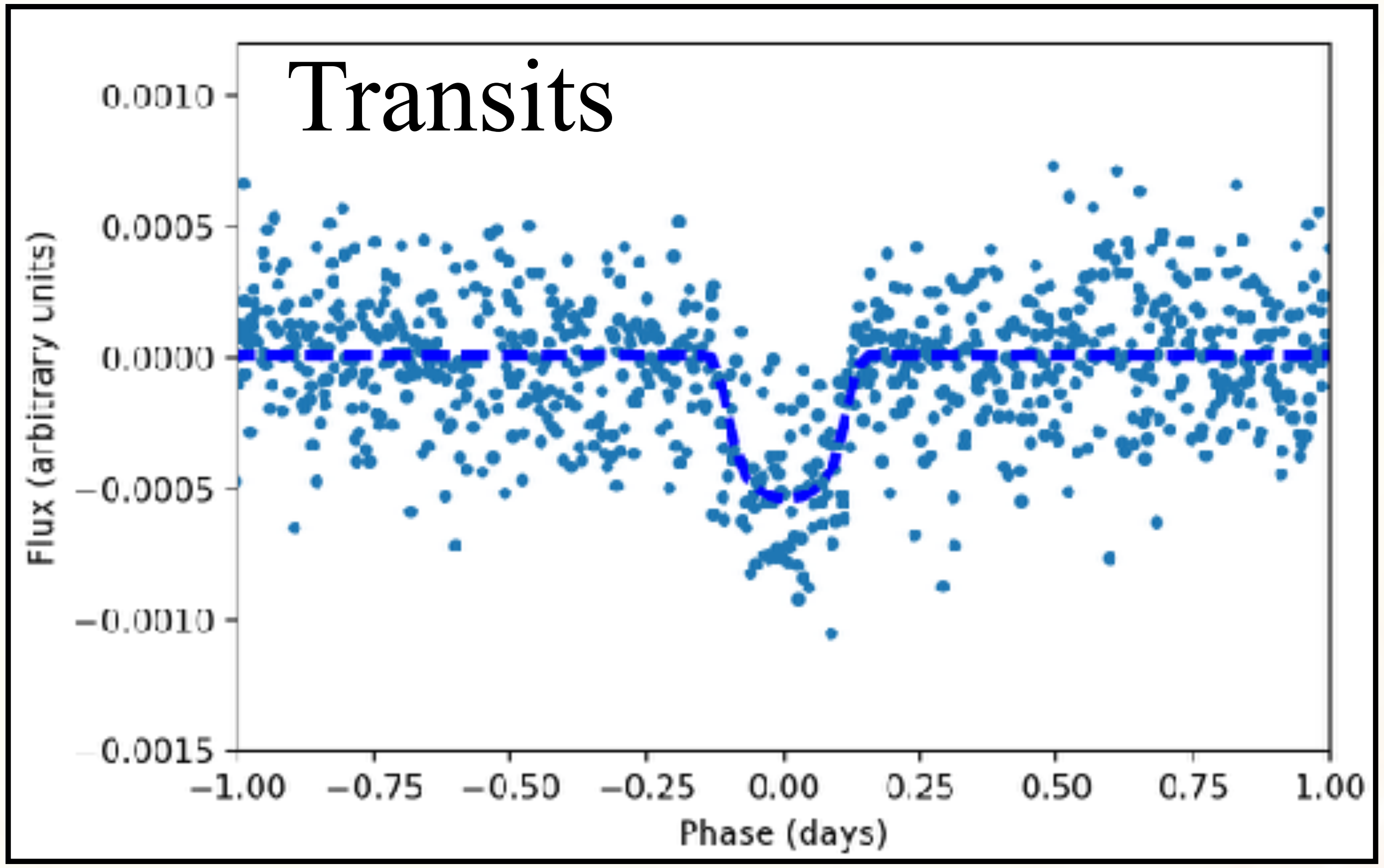
The Seismic Host Star Sample

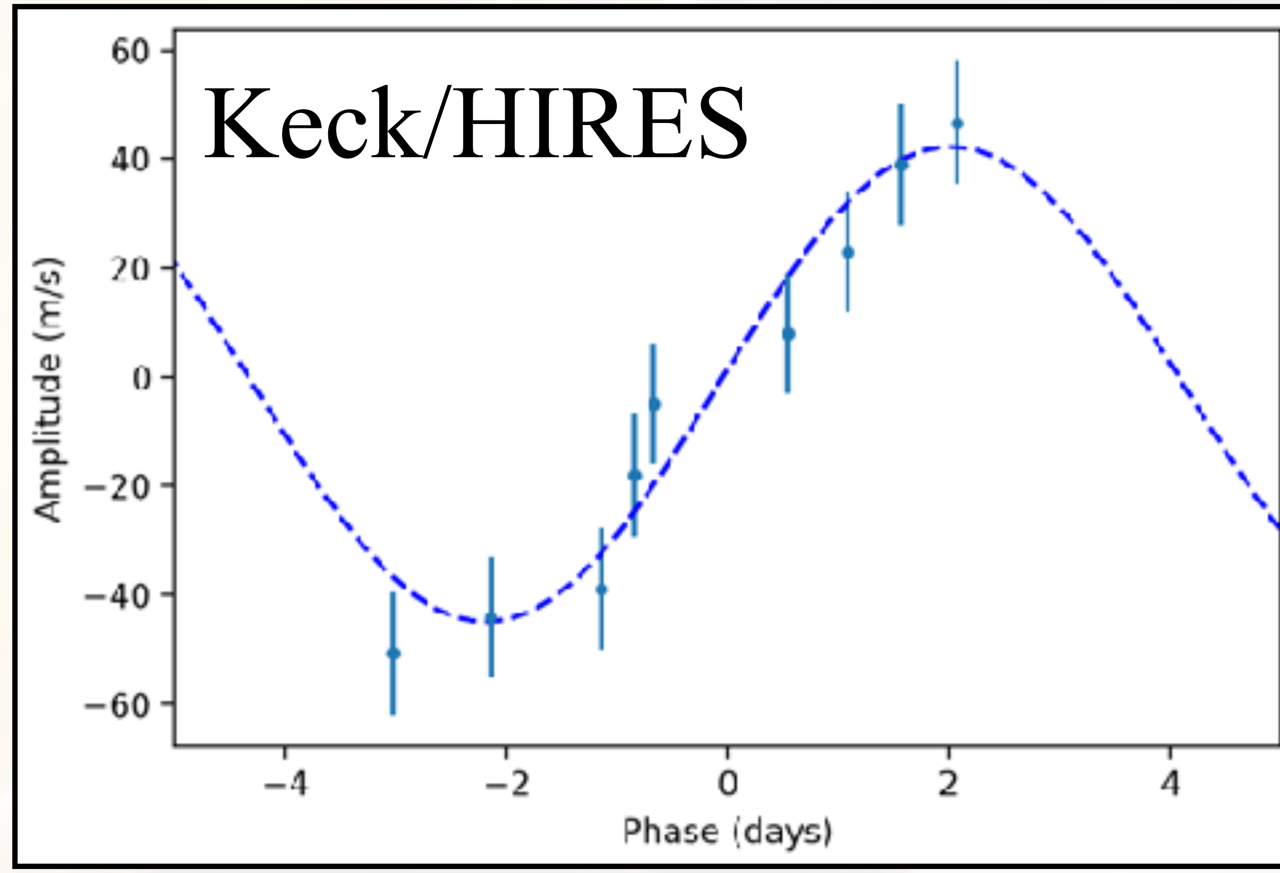


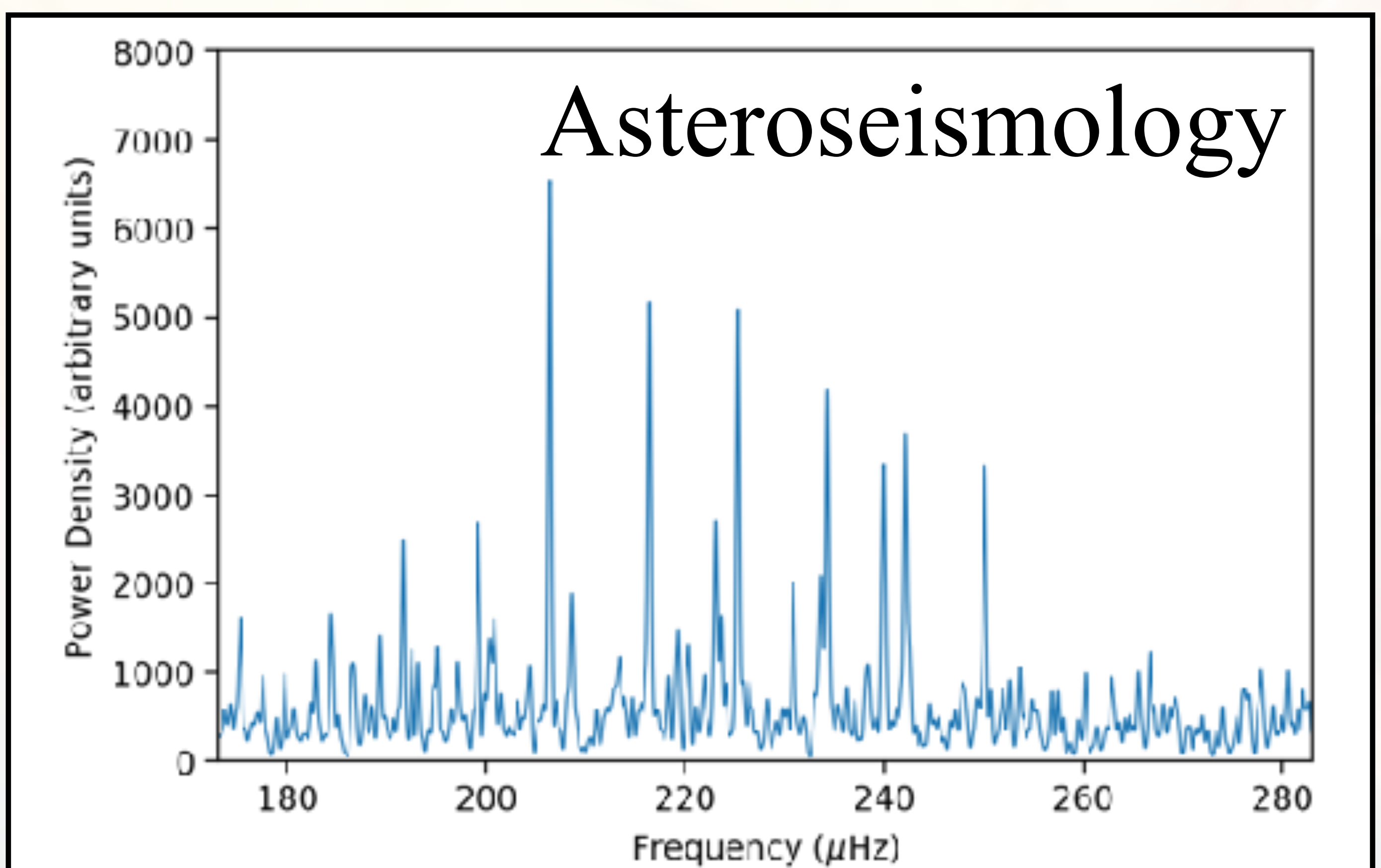
The Seismic Host Star Sample



K2-97: K2's first seismic host star





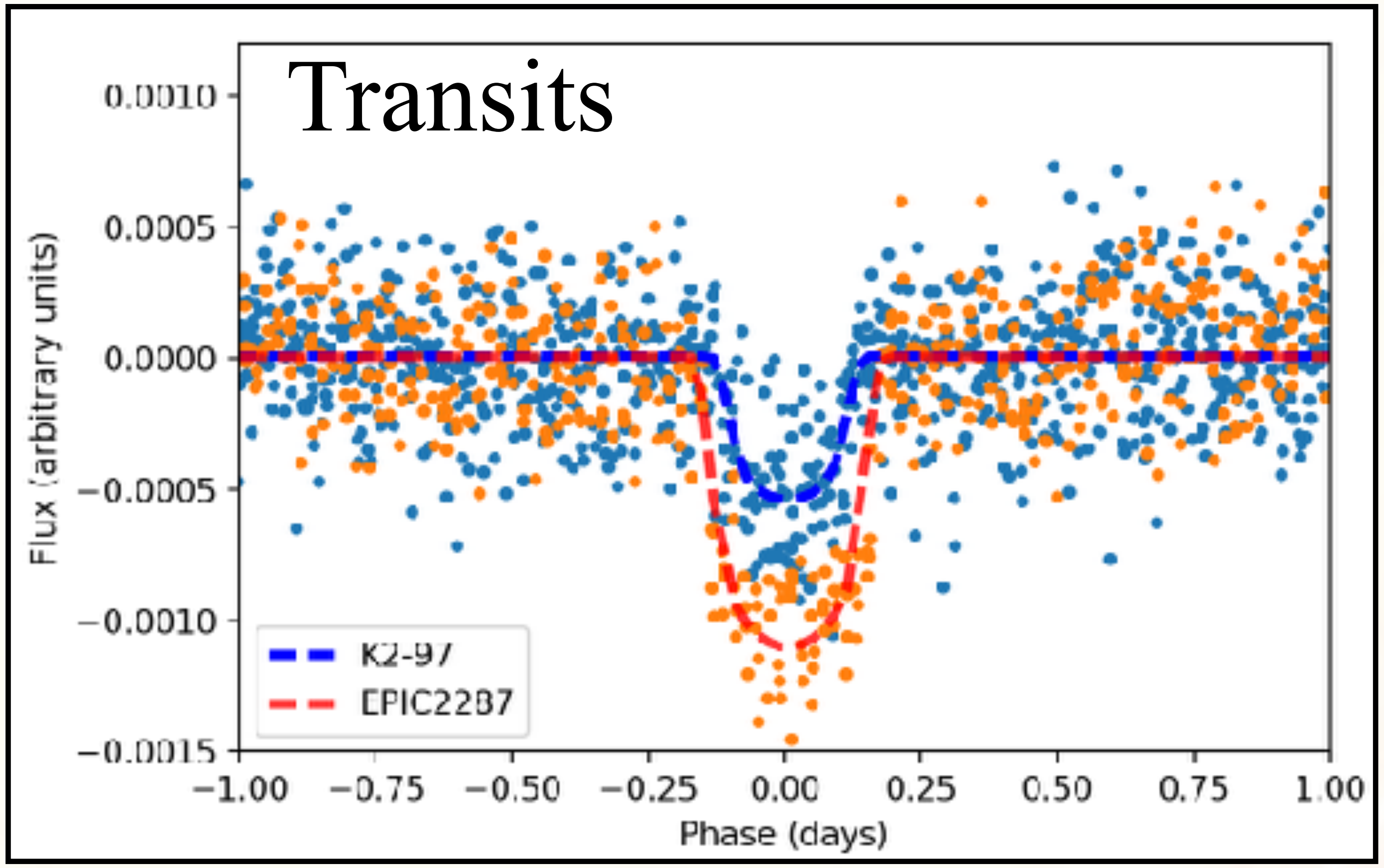


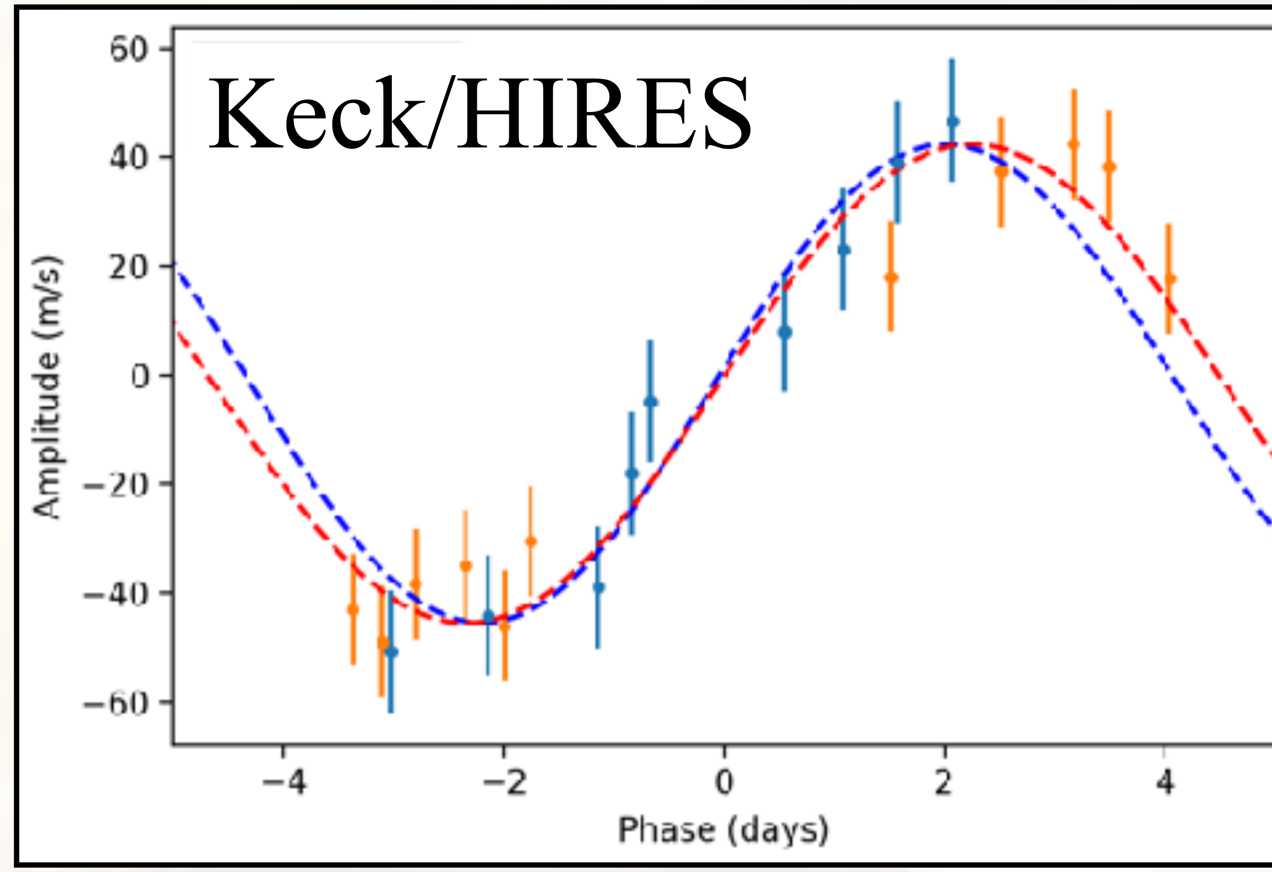
$R_\star = 4.2\ R_\odot$ $P = 8.4$ days

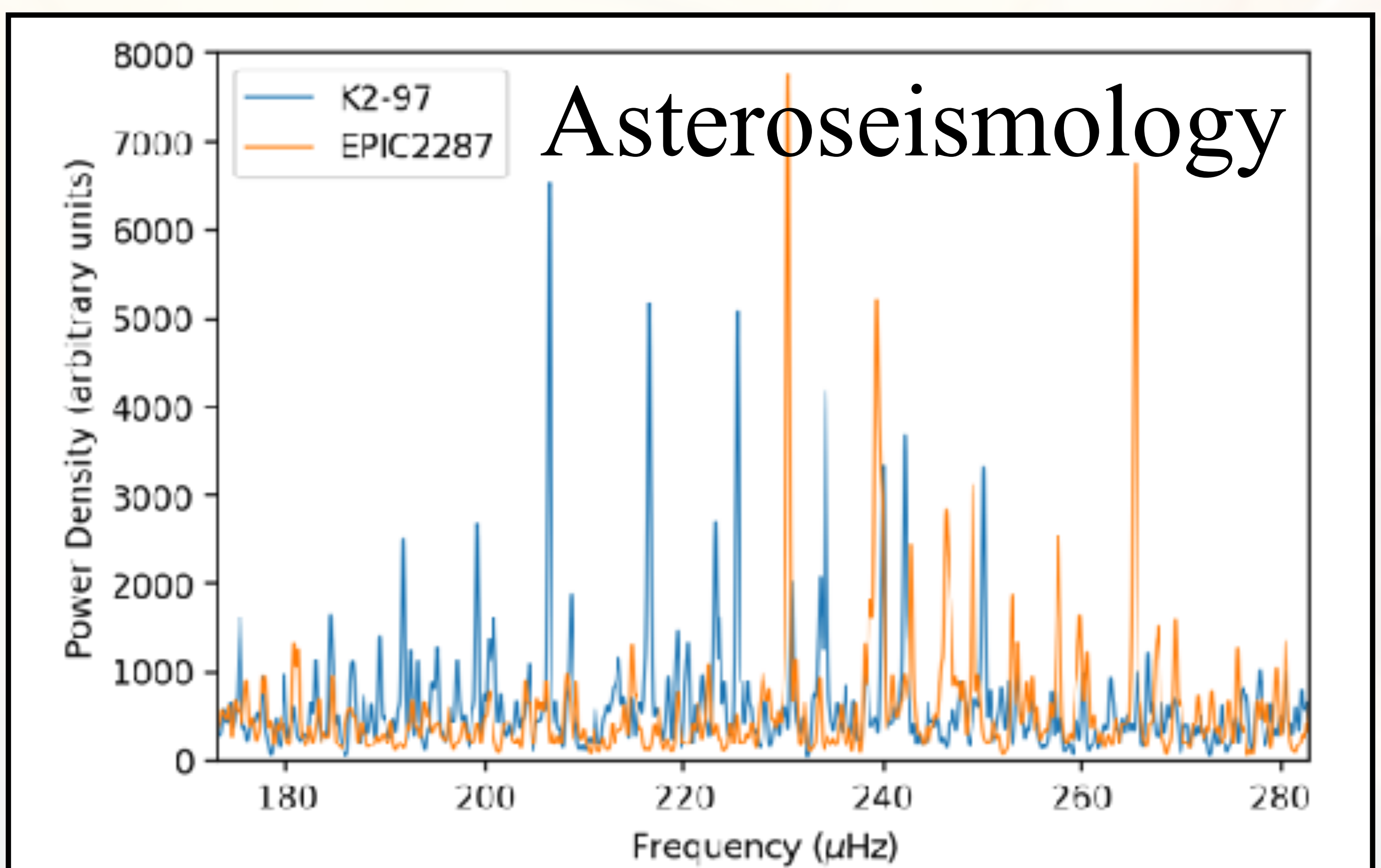
$R_P = 1.31\ R_J$ $M_P = 0.48\ M_J$

Grunblatt et al. 2016

K2 Red Giant Planet Twins!







$R_\star = 4.2\ R_\odot$ $P = 8.4$ days

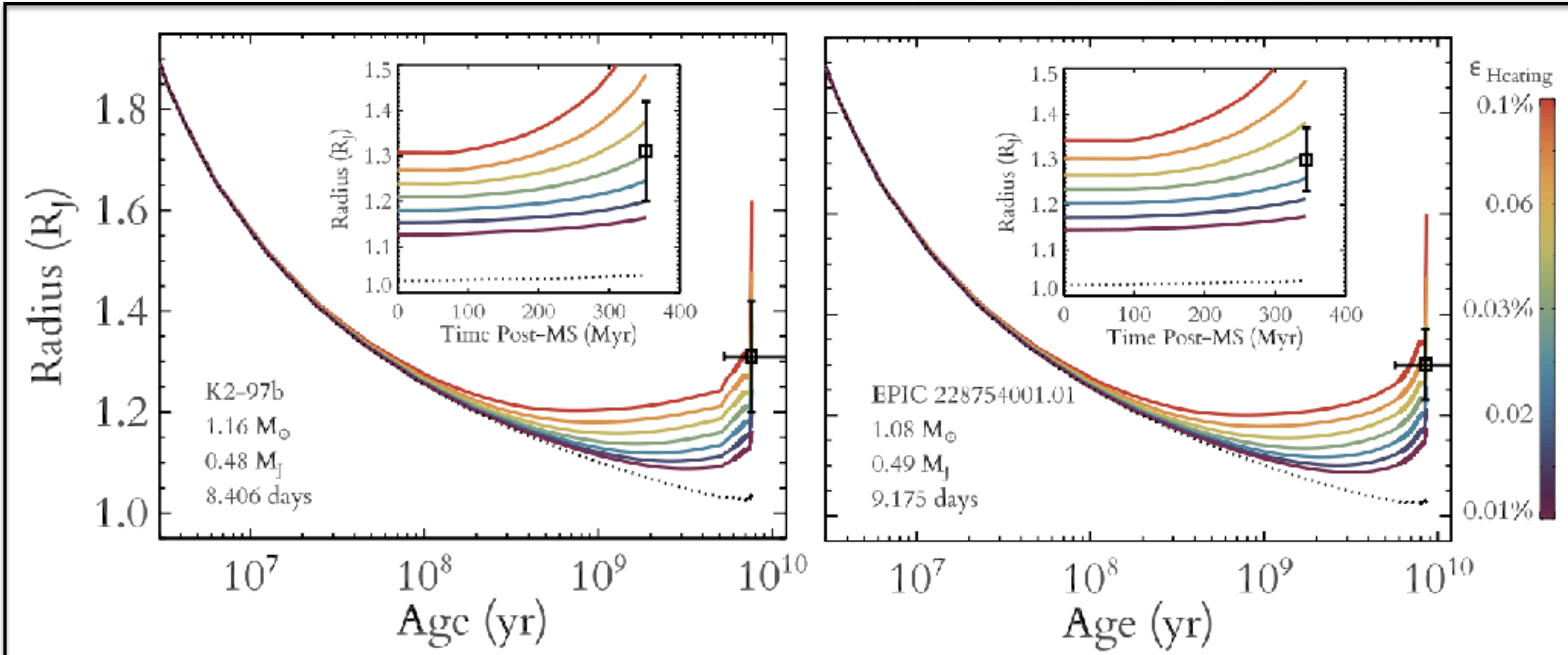
$R_P = 1.31\ R_J$ $M_P = 0.48\ M_J$

$R_\star = 3.8\ R_\odot$ $P = 9.2$ days

$R_P = 1.30\ R_J$ $M_P = 0.49\ M_J$

Grunblatt et al. 2016, 2017

(Re-)inflated Giants Orbiting Giants

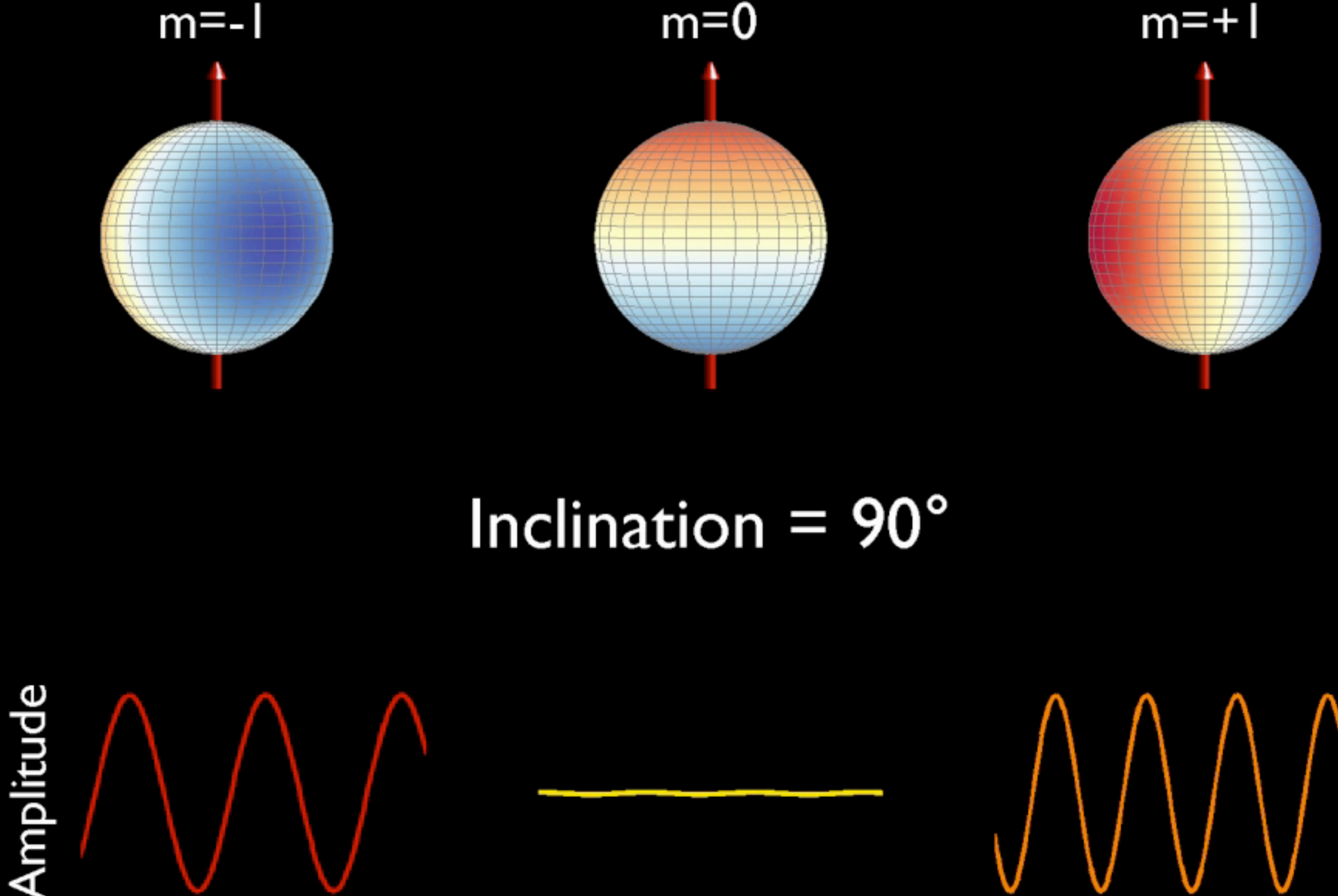


Observational evidence for direct heating as the cause for planet inflation (Lopez & Fortney 2016)

Grunblatt et al. (2016, 2017)

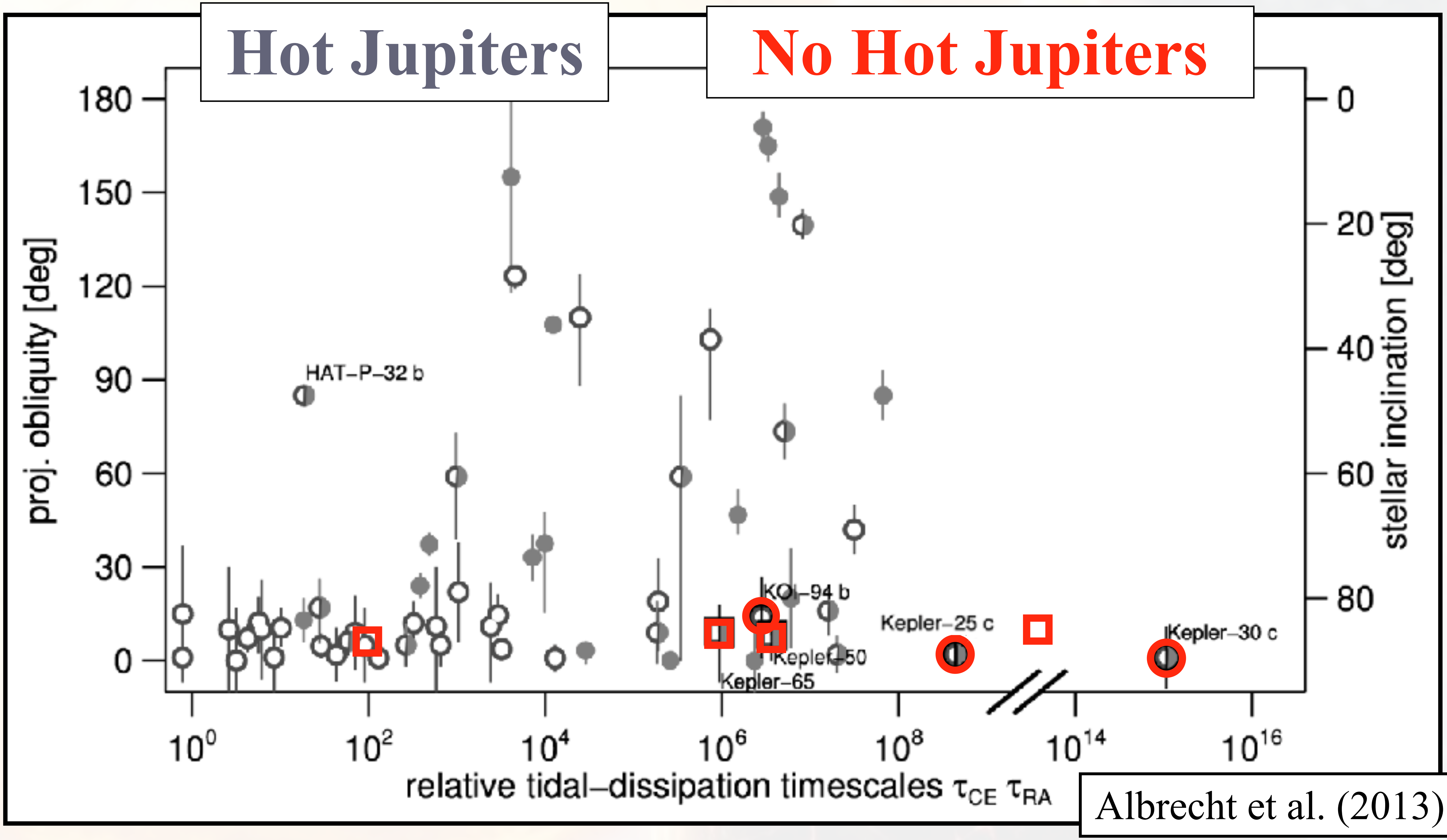
Asteroseismology & Exoplanets I:

Dynamical Architectures of Planetary Systems



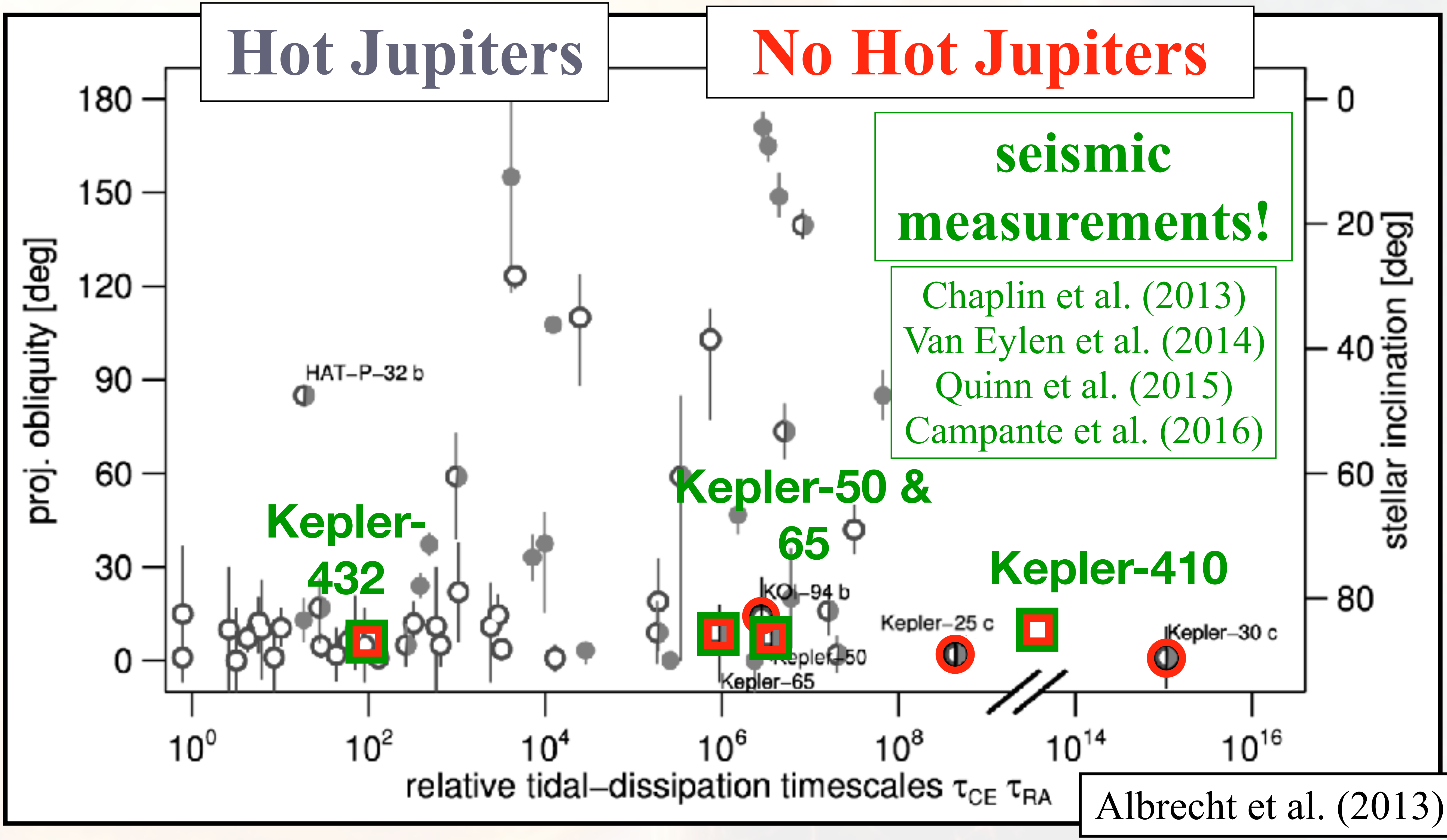
Gizon & Solanki (2003)

Andrea Miglio
University of Birmingham, UK



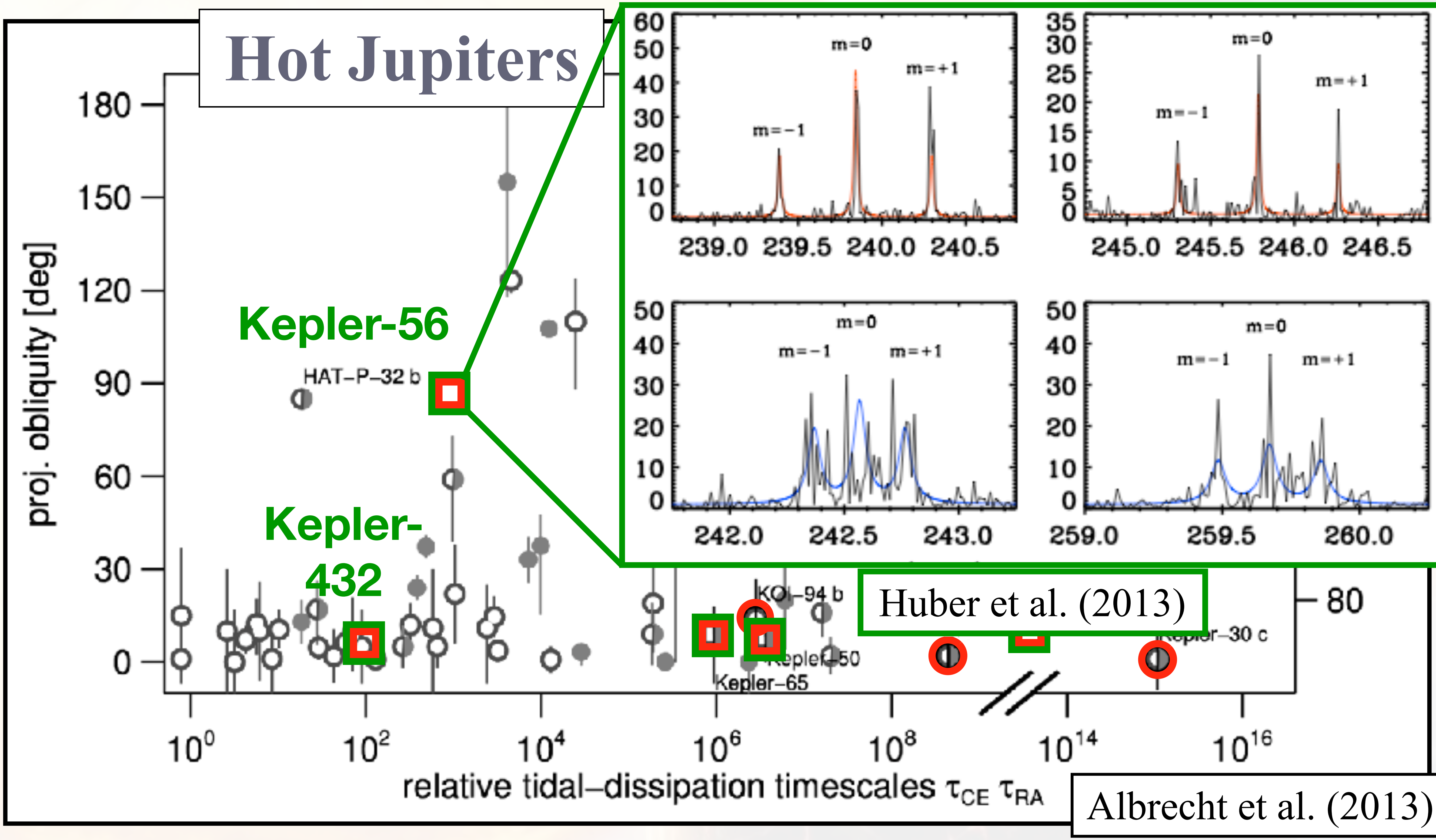
easy to re-align ⟷ hard to re-align

Do Hot Jupiters form differently than other systems?



easy to re-align ⟷ hard to re-align

Do Hot Jupiters form differently than other systems?



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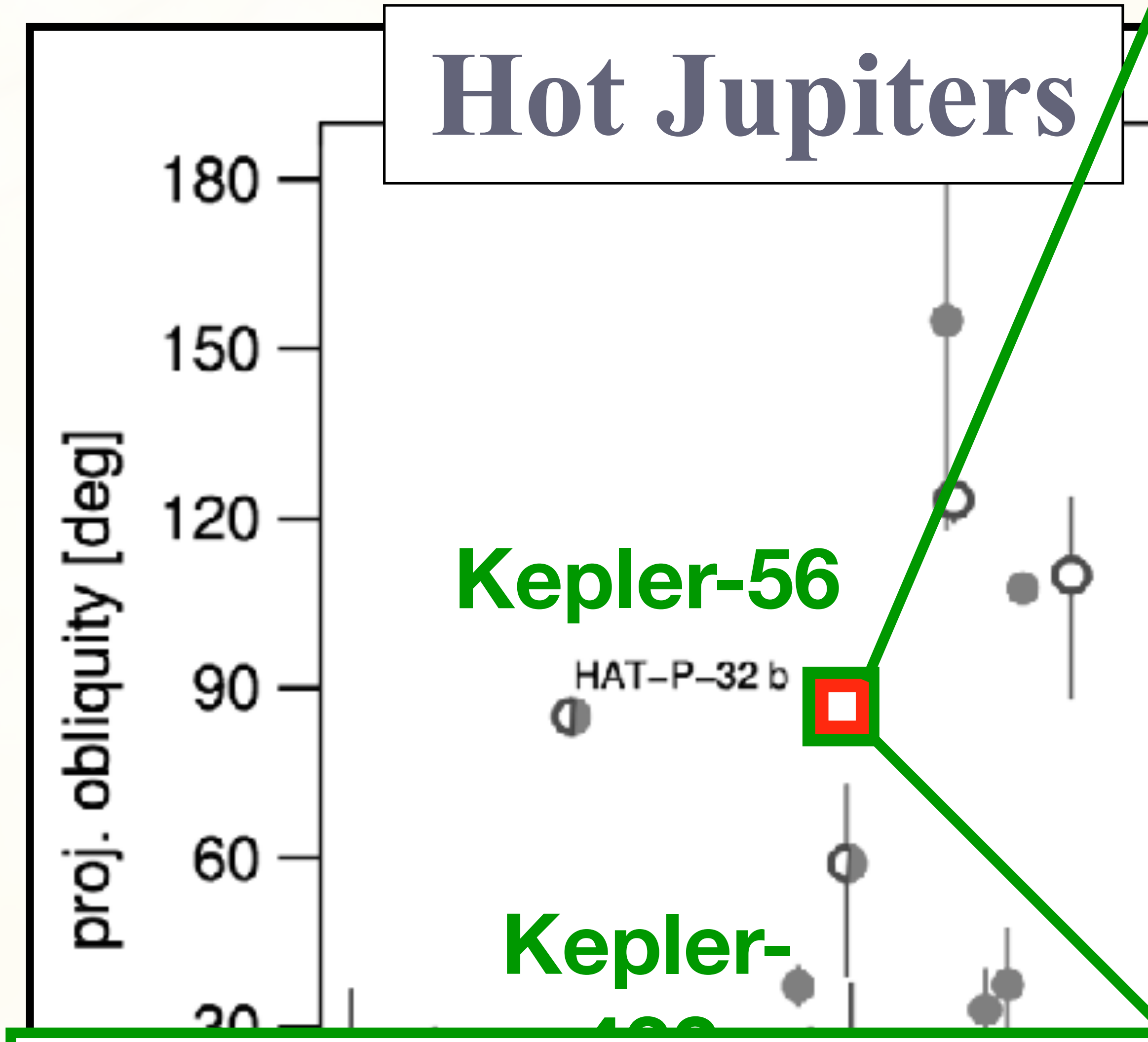
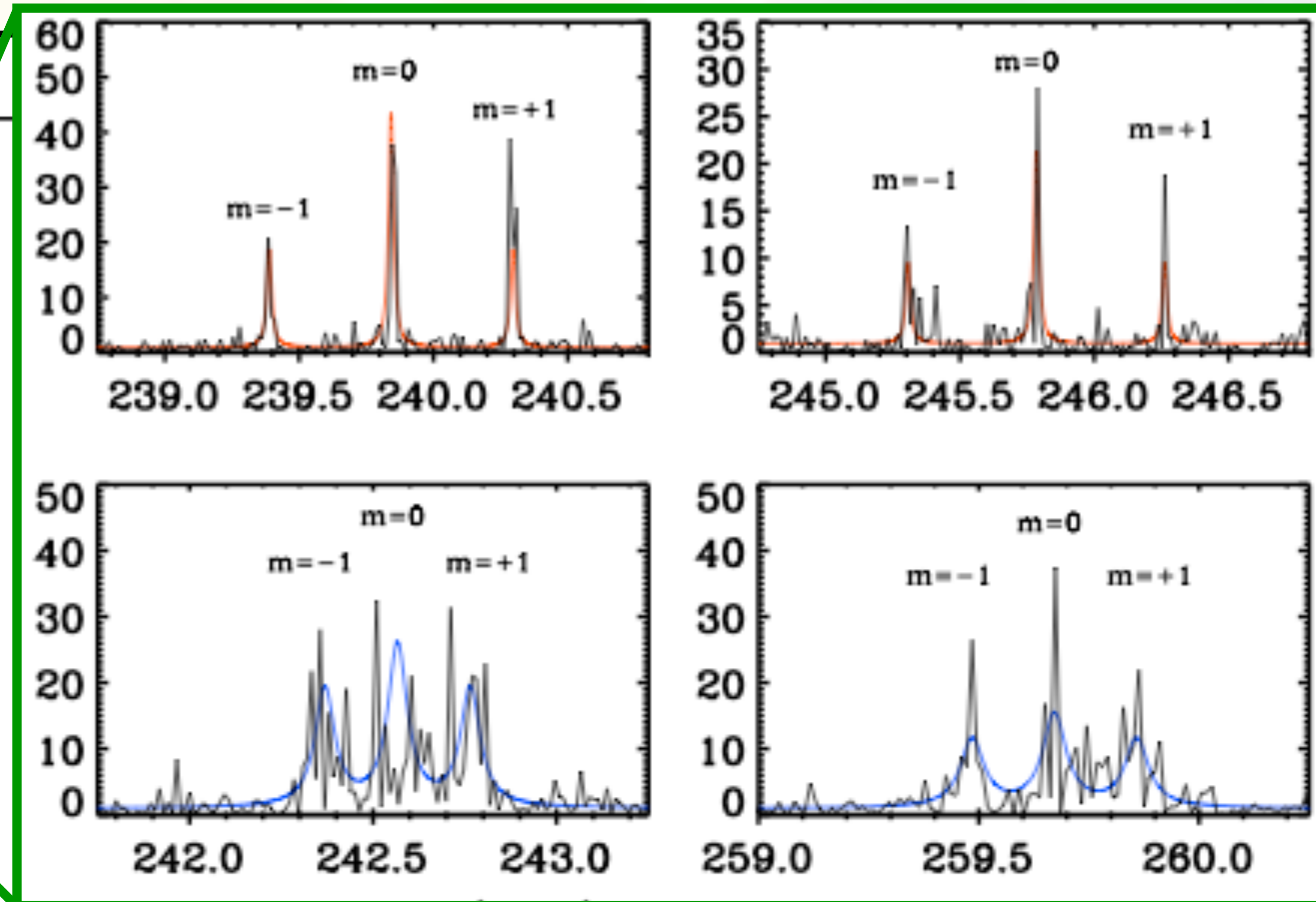
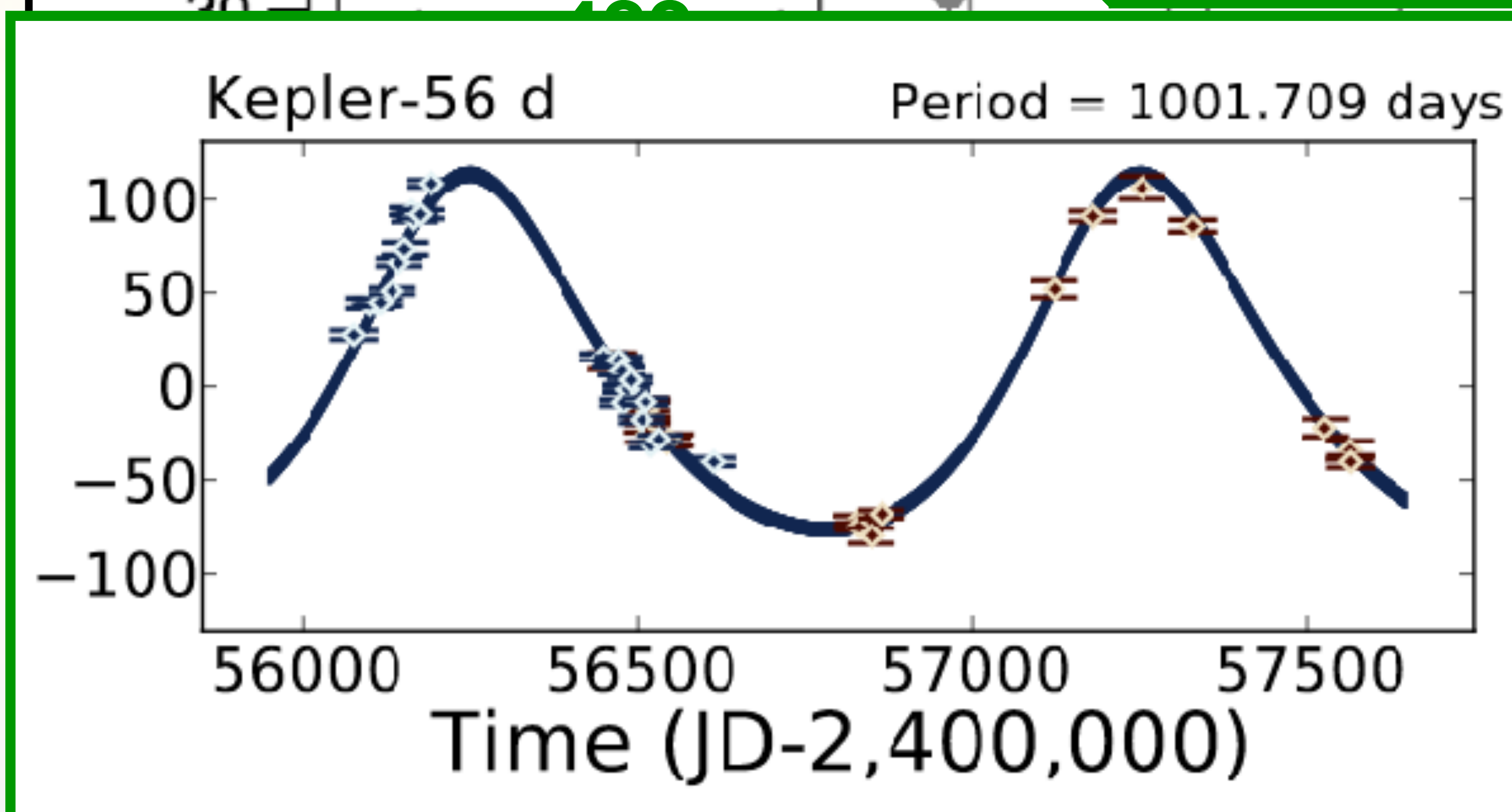
Do Hot Jupiters form differently than other systems?

Hot Jupiters





Huber et al. (2013)

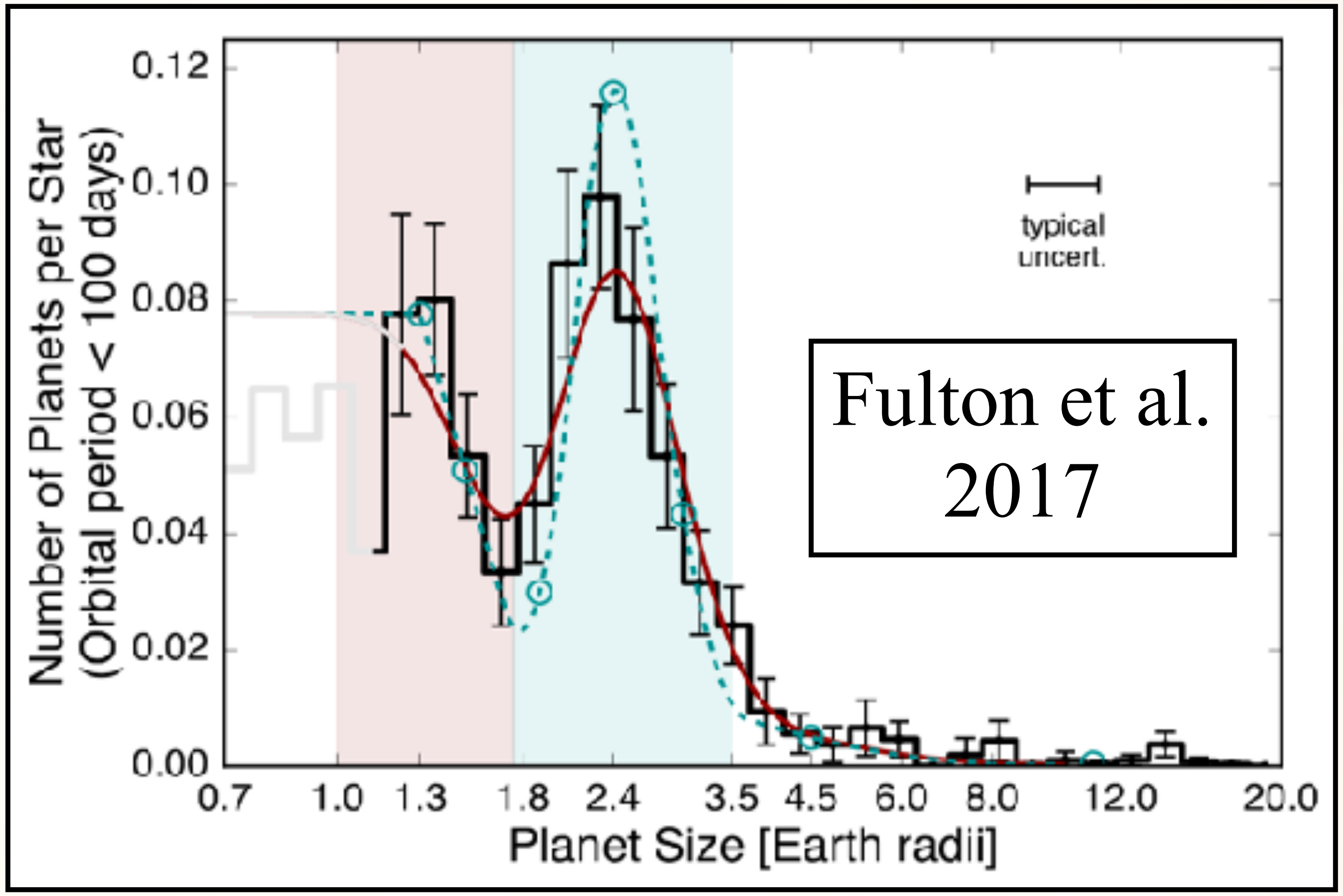


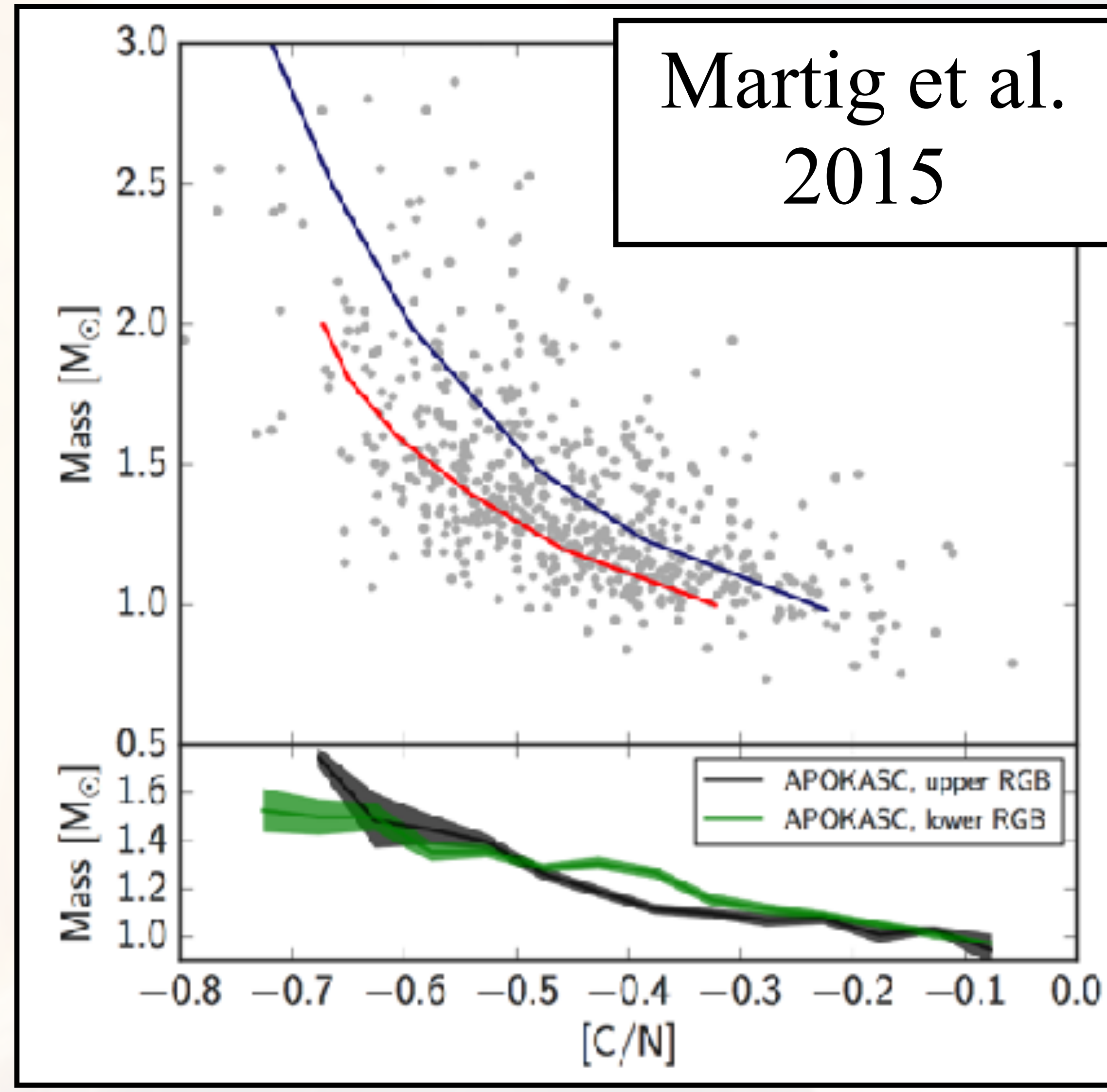
Otor et al. (2016)

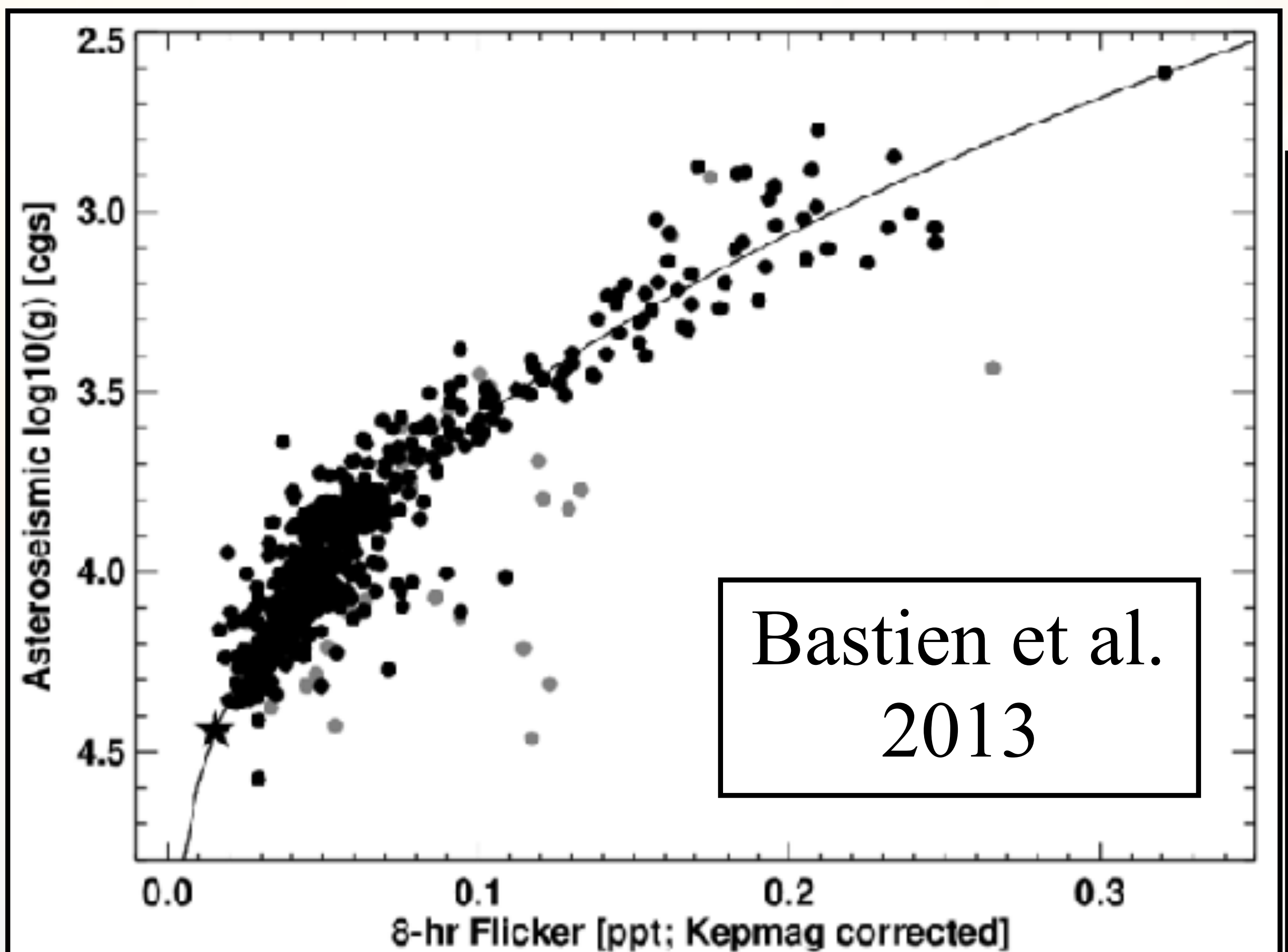
Non-transiting companion in ~600 day orbit. Culprit for misalignment?

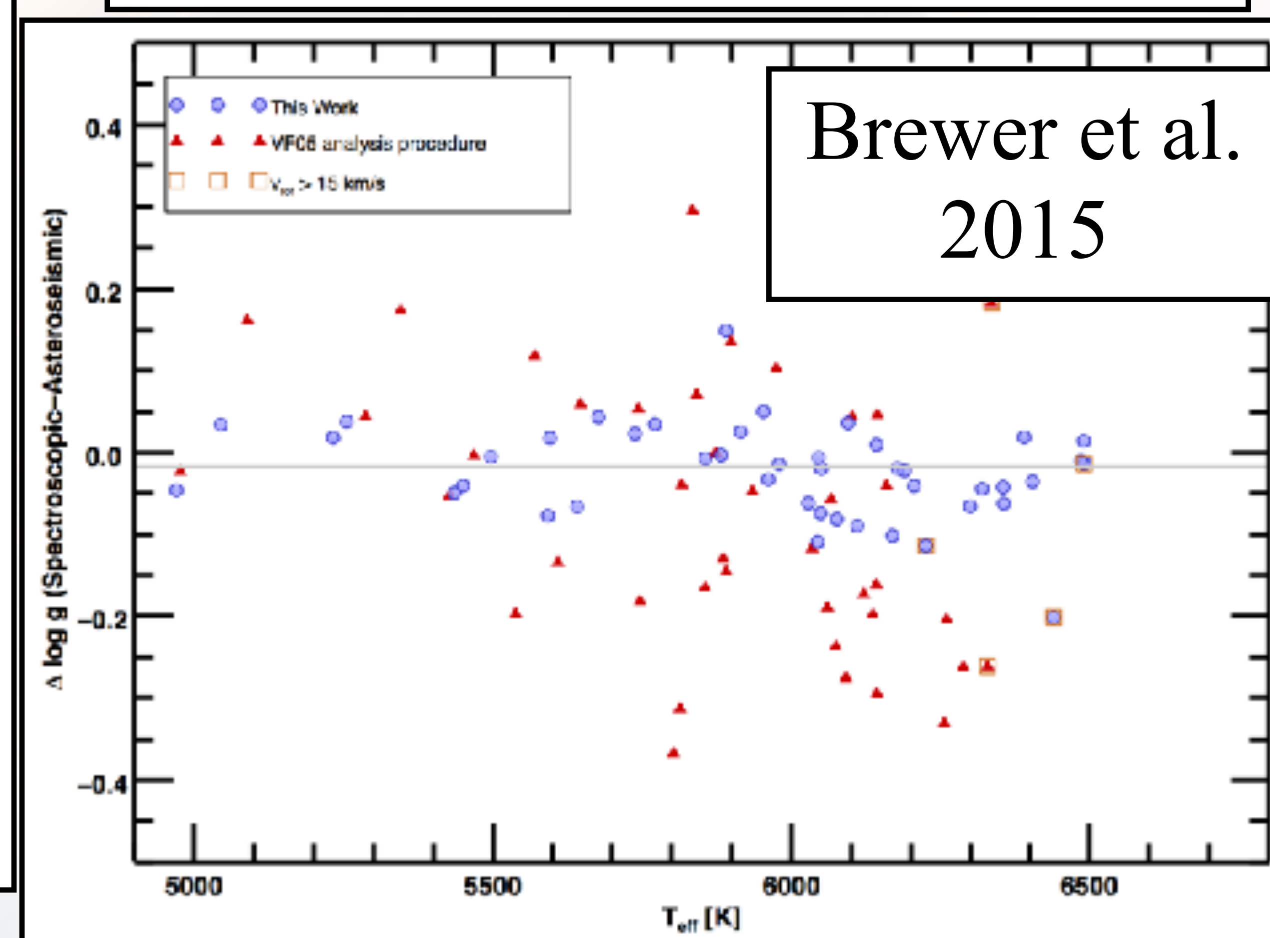
Boue & Fabrycky (2014)

That's all great …
but how accurate is asteroseismology really?


Fulton et al. 2017
Number of Planets per Star (Orbital period < 100 days)
Planet Size [Earth radii]
typical uncert.
0.00 0.02 0.04 0.06 0.08 0.10 0.12
0.7 1.0 1.3 1.8 2.4 3.5 4.5 6.0 8.0 12.0 20.0


Martig et al. 2015
Mass [M⊙]
[C/N]
APOKASC, upper RGB
APOKASC, lower RGB
0.5 1.0 1.5 2.0 2.5 3.0
1.0 1.2 1.4 1.6
−0.8 −0.7 −0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0.0

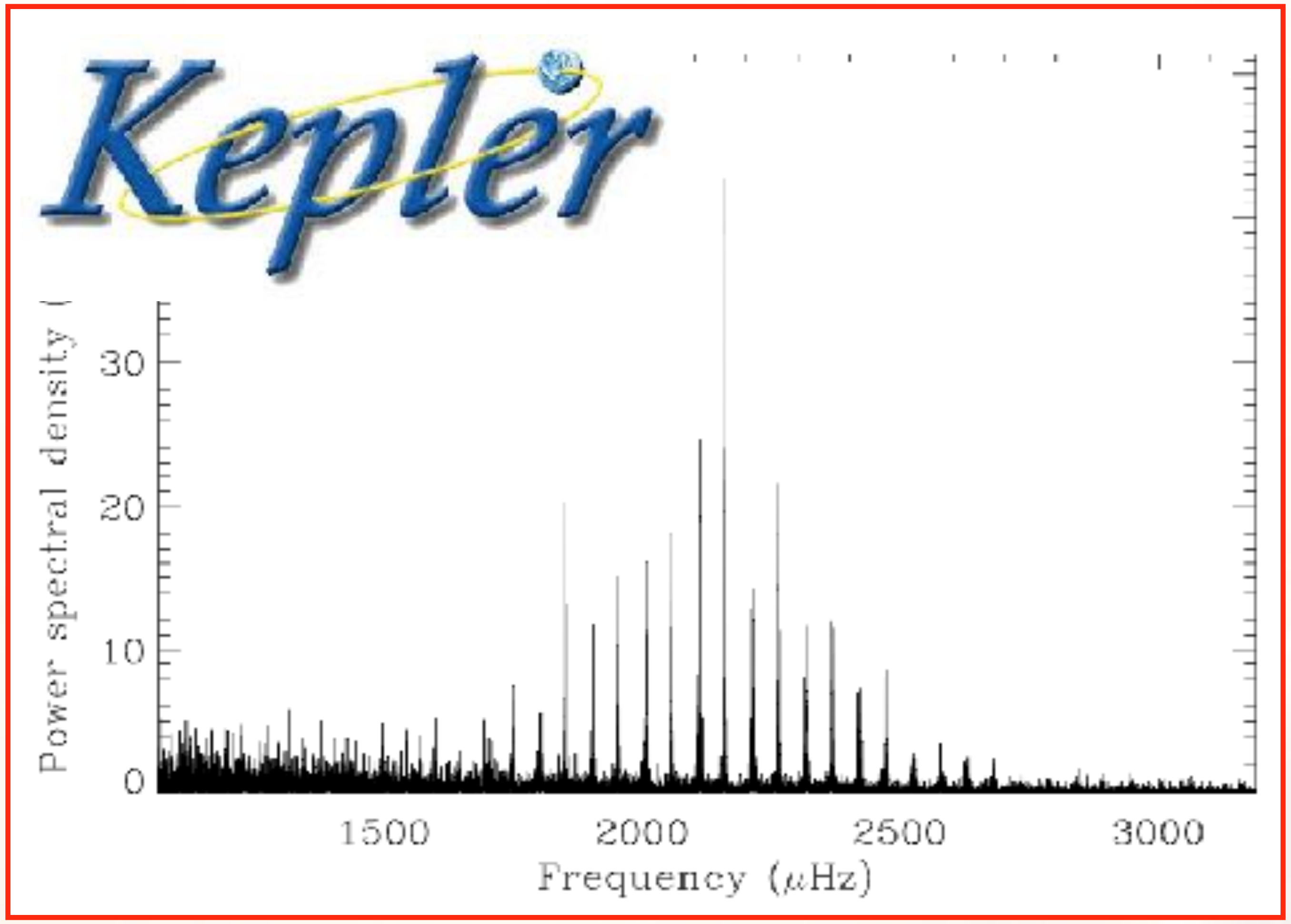

Bastien et al. 2013
Asteroseismic log10(g) [cgs]
8-hr Flicker [ppt; Kepmag corrected]
2.5 3.0 3.5 4.0 4.5
0.0 0.1 0.2 0.3

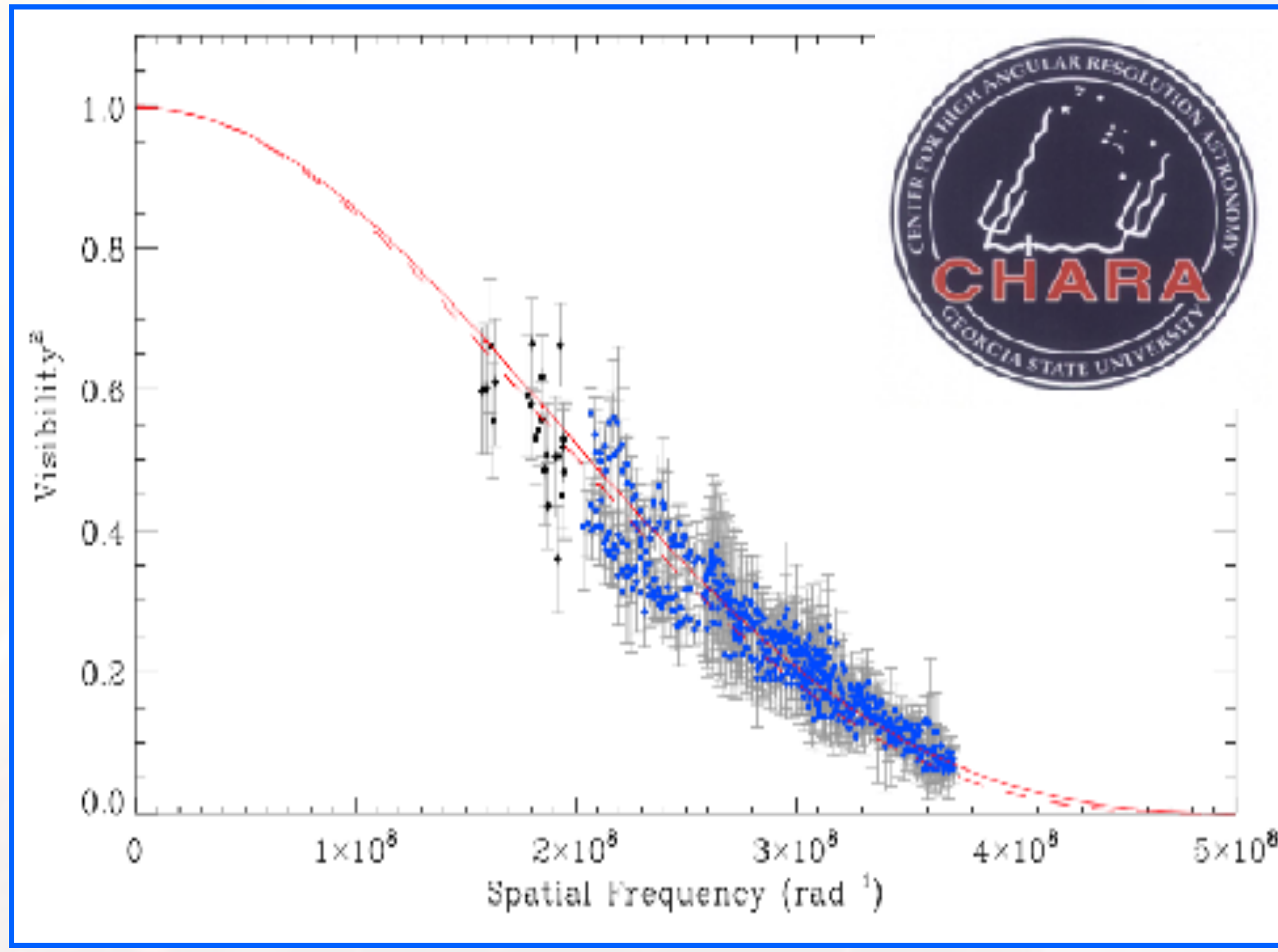

Brewer et al. 2015
This Work
VF05 analysis procedure
Δ log g (Spectroscopic−Asteroseismic)
0.4 0.2 0.0 −0.2 −0.4
5000 5500 6000 6500

CHARA Asteroseismology Program

Asteroseismology

Interferometry



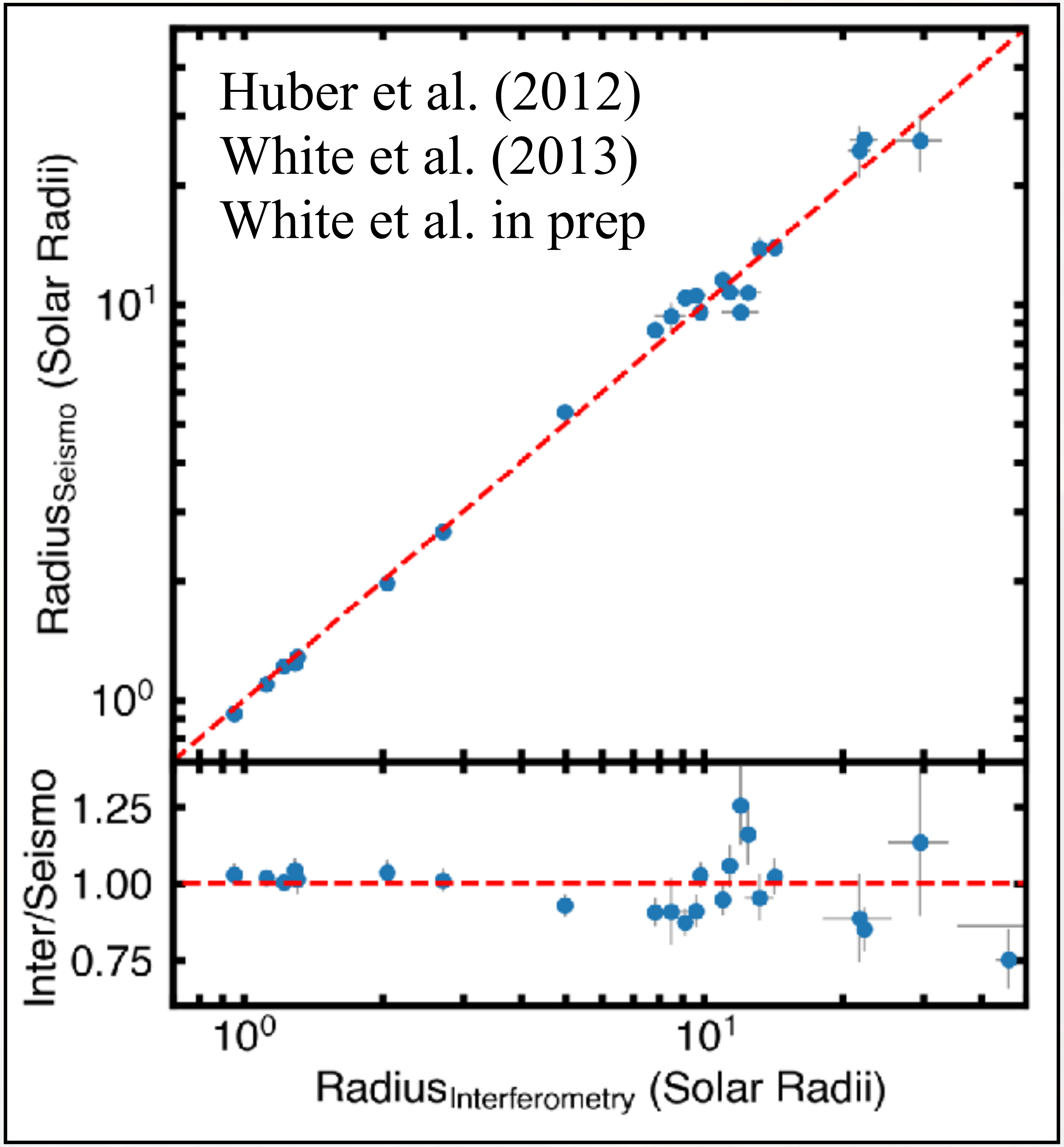


Metcalfe et al. (2015)

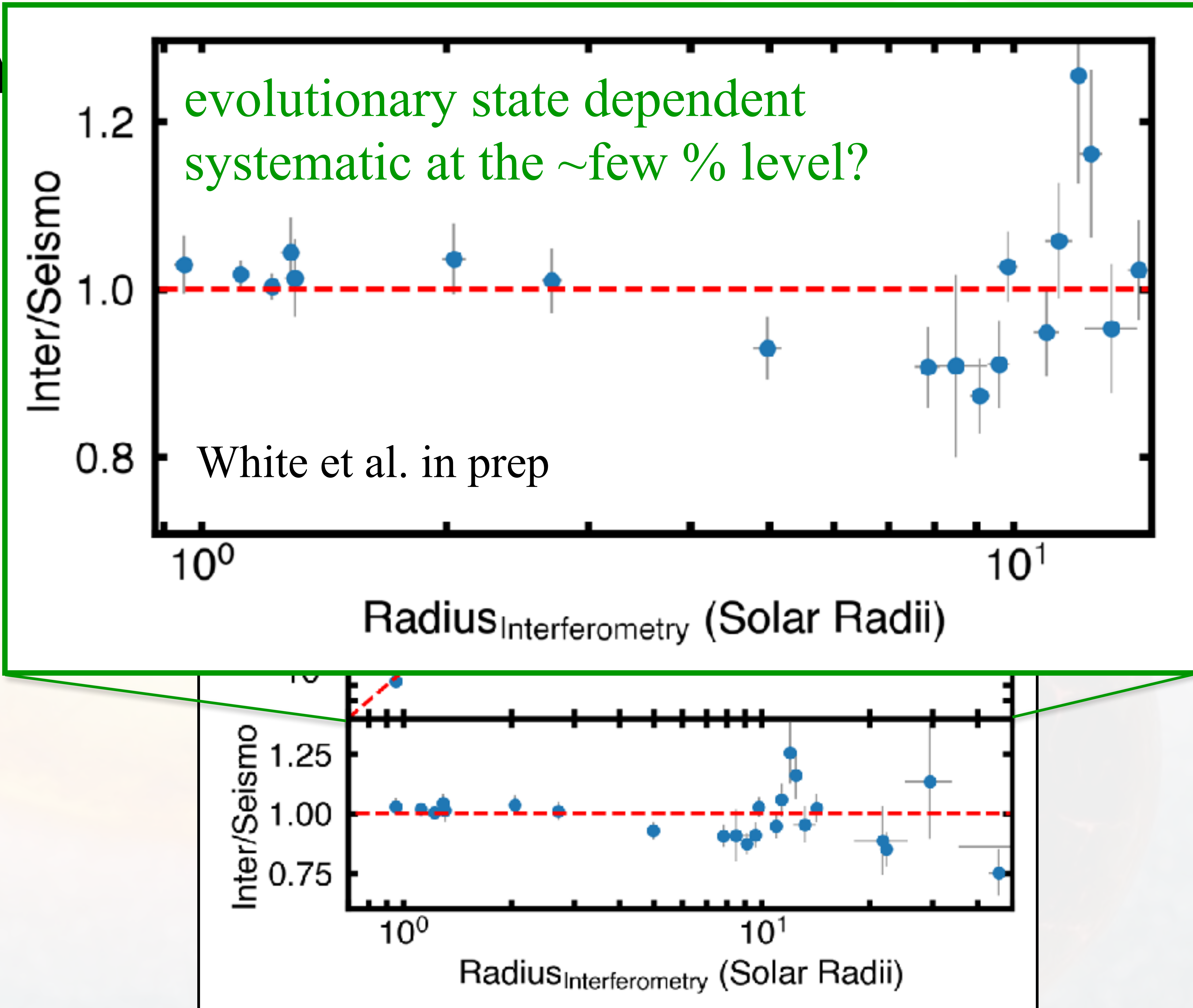
White et al. (2013)

"Direct" measurement of R★ through angular diameter + parallax. How does this compare with asteroseismic scaling relations?

Asteroseismology vs Interferometry

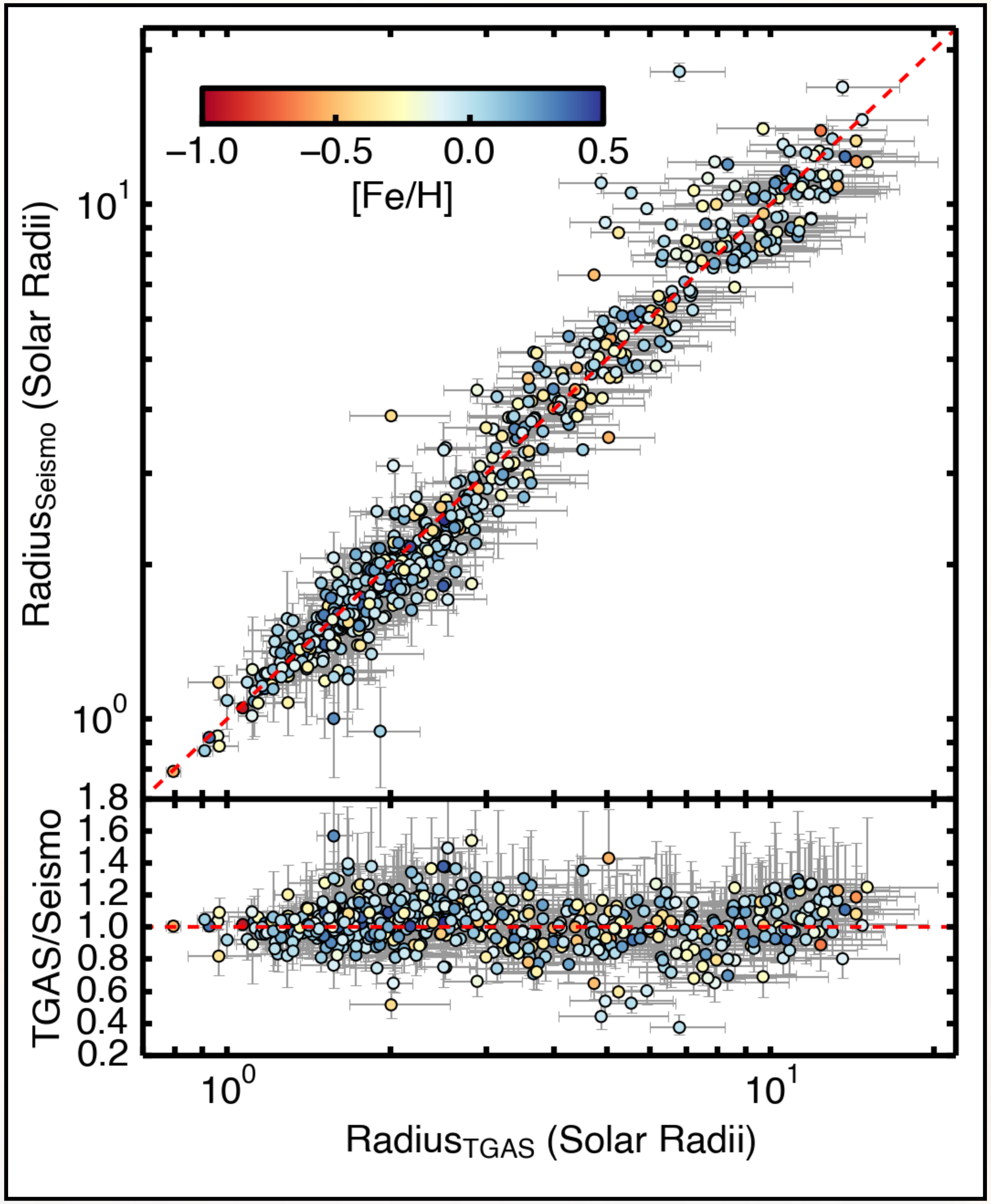


A ry



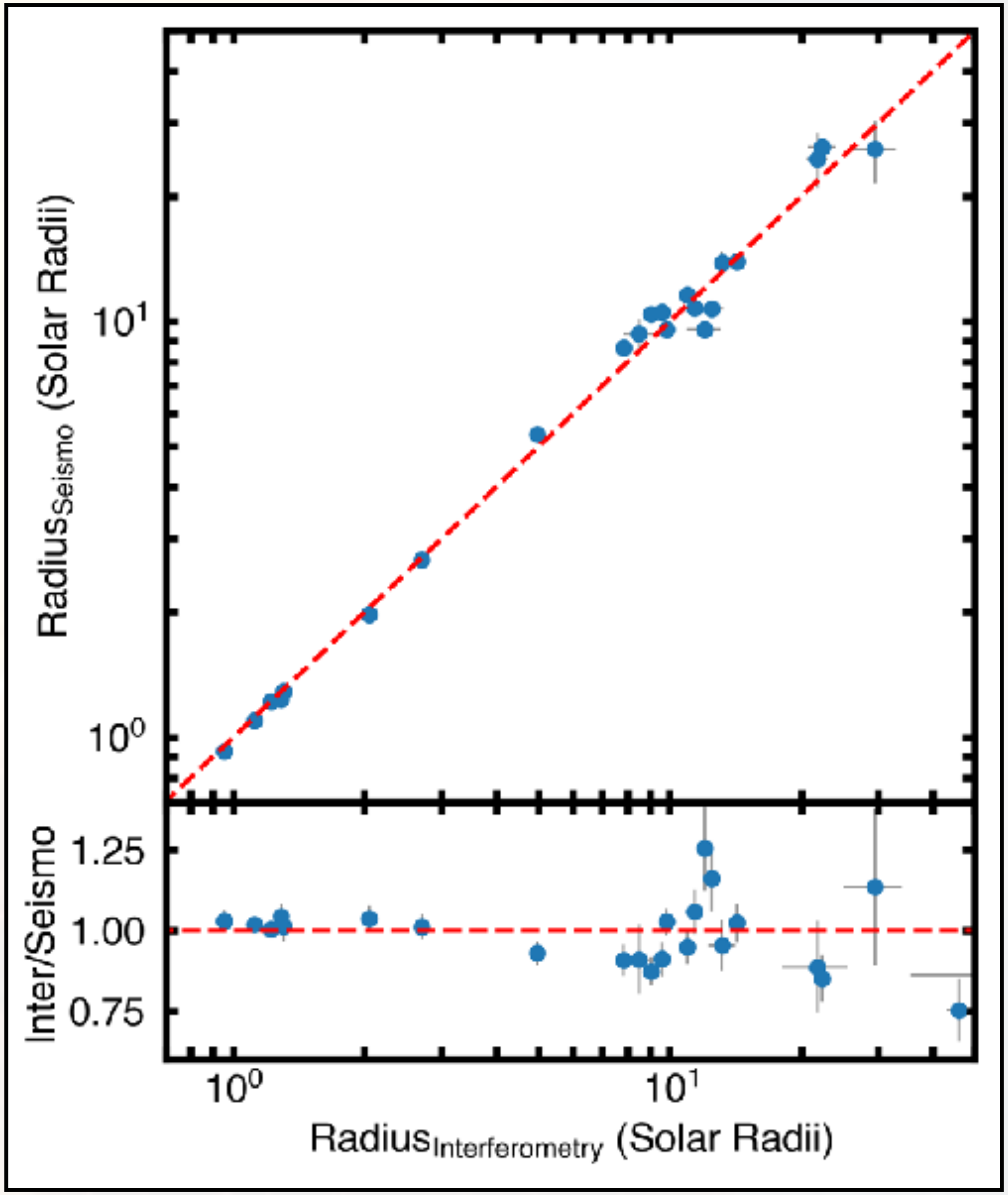
evolutionary state dependent
systematic at the ~few % level?
White et al. in prep
Inter/Seismo
1.2
1.0
0.8
10^0
10^1
Radius Interferometry (Solar Radii)
Inter/Seismo
1.25
1.00
0.75
10^0
10^1
Radius Interferometry (Solar Radii)

Seismo vs Gaia

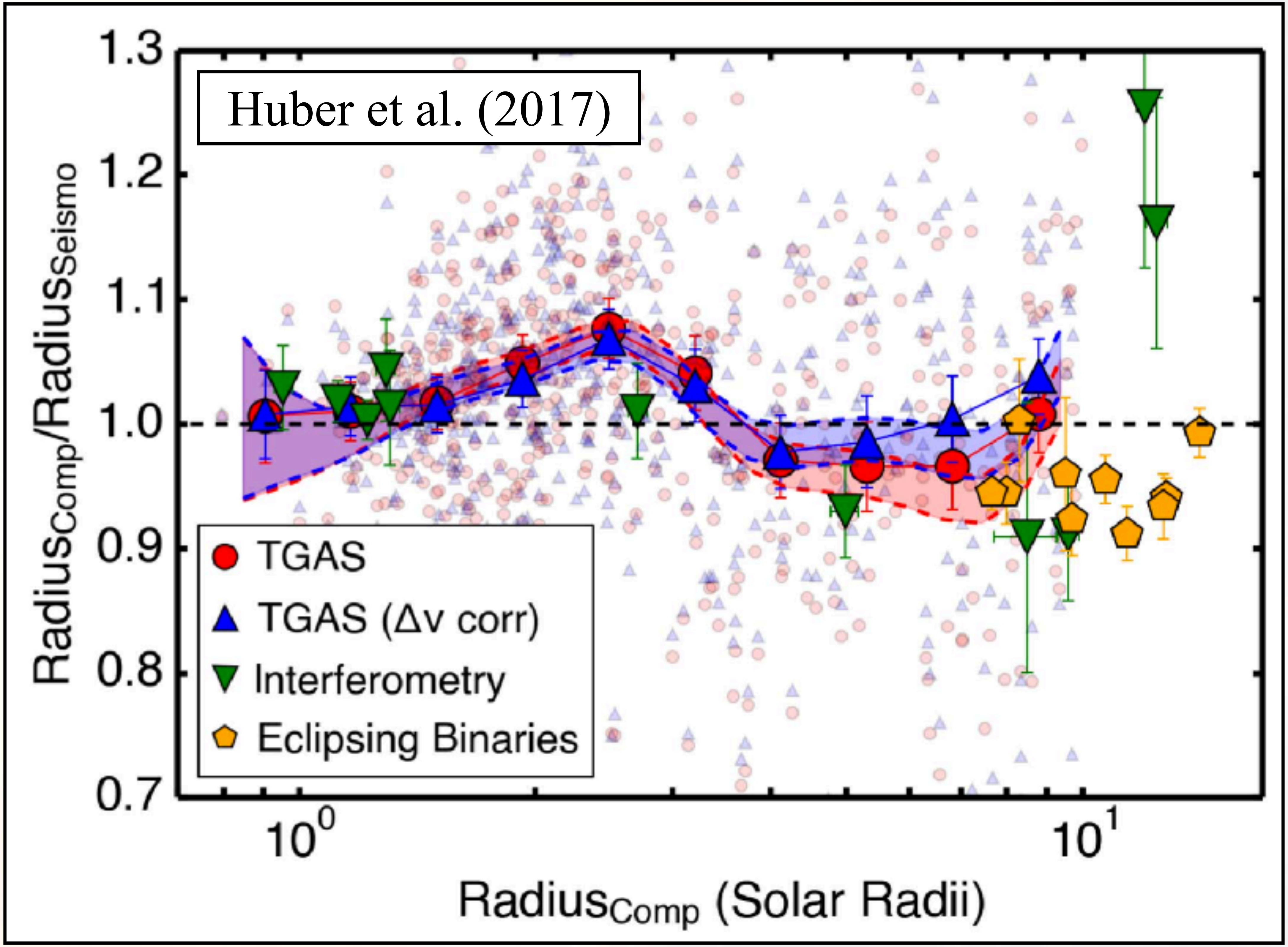


Huber et al. (2017)

Seismo vs CHARA



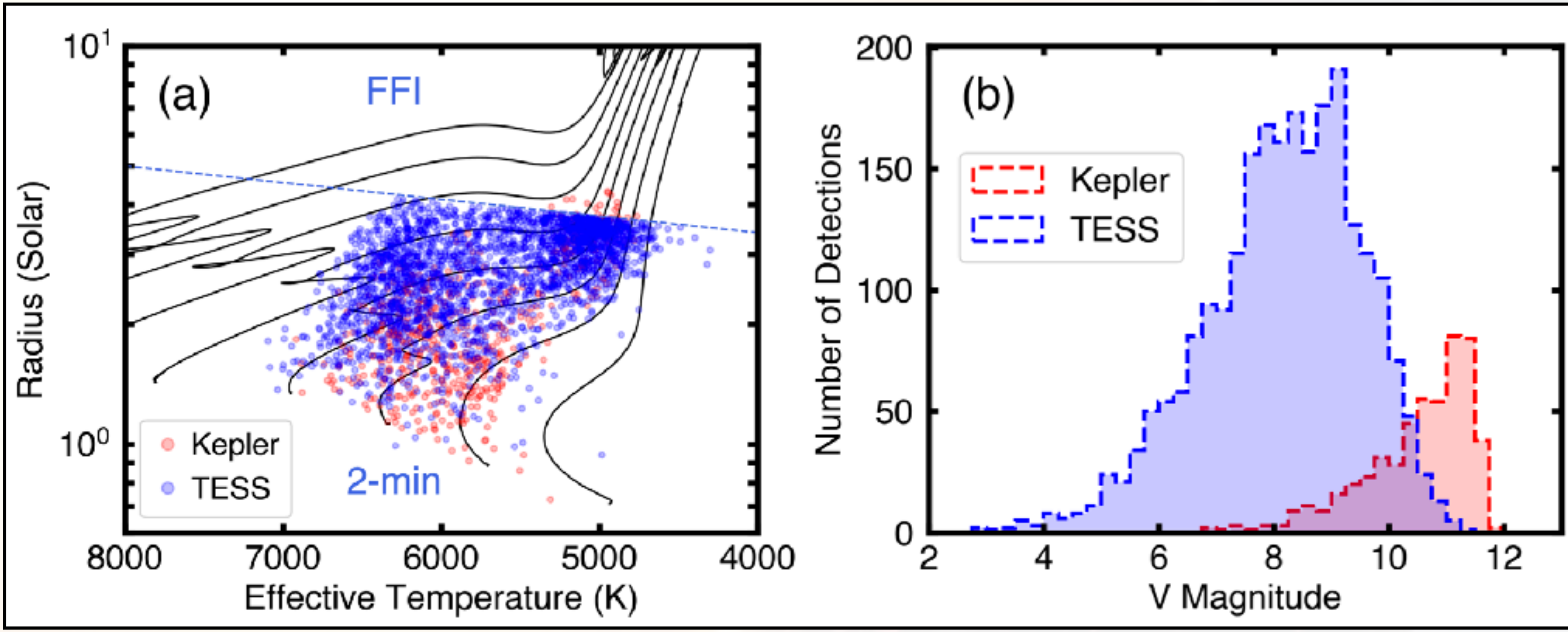
White et al. in prep



Bottom Line: systematics at the <5% level in R★ (~ 0.03 dex in logg) between "fundamental methods" are not trivial

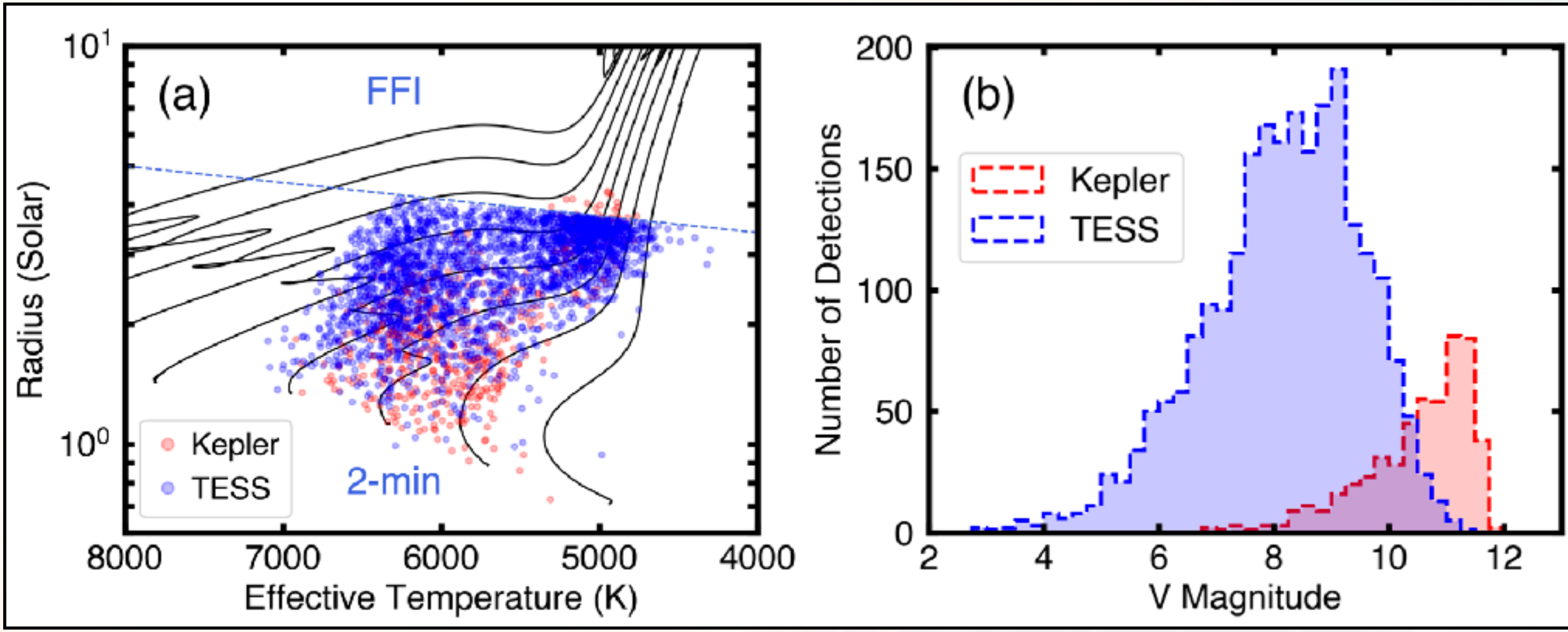
What will we learn from TESS?

TESS Asteroseismology



~5000 detections in dwarfs & subgiants (factor ~10 increase over Kepler)

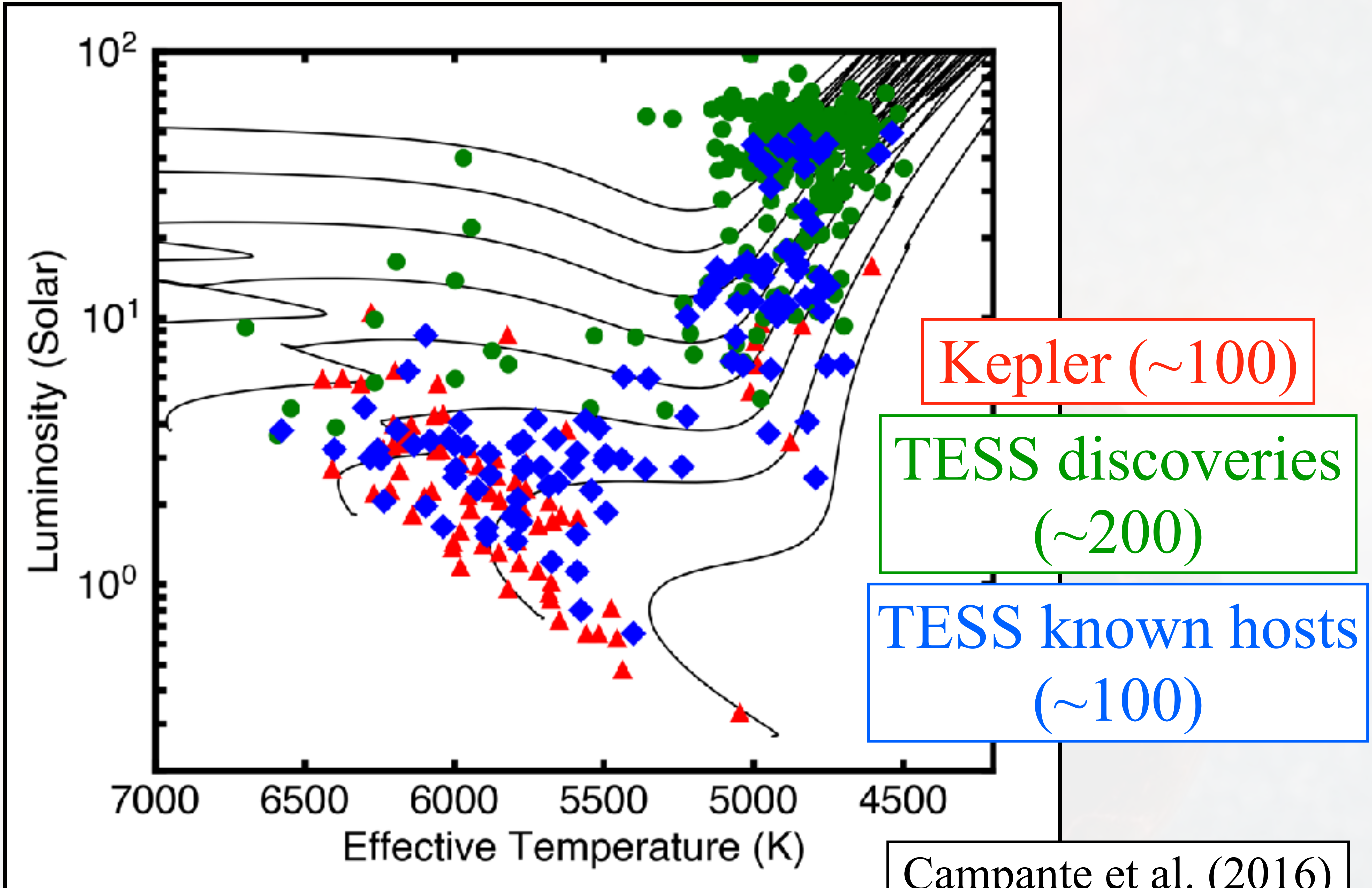
TESS Asteroseismology



~5000 detections in dwarfs & subgiants (factor ~10 increase over Kepler)

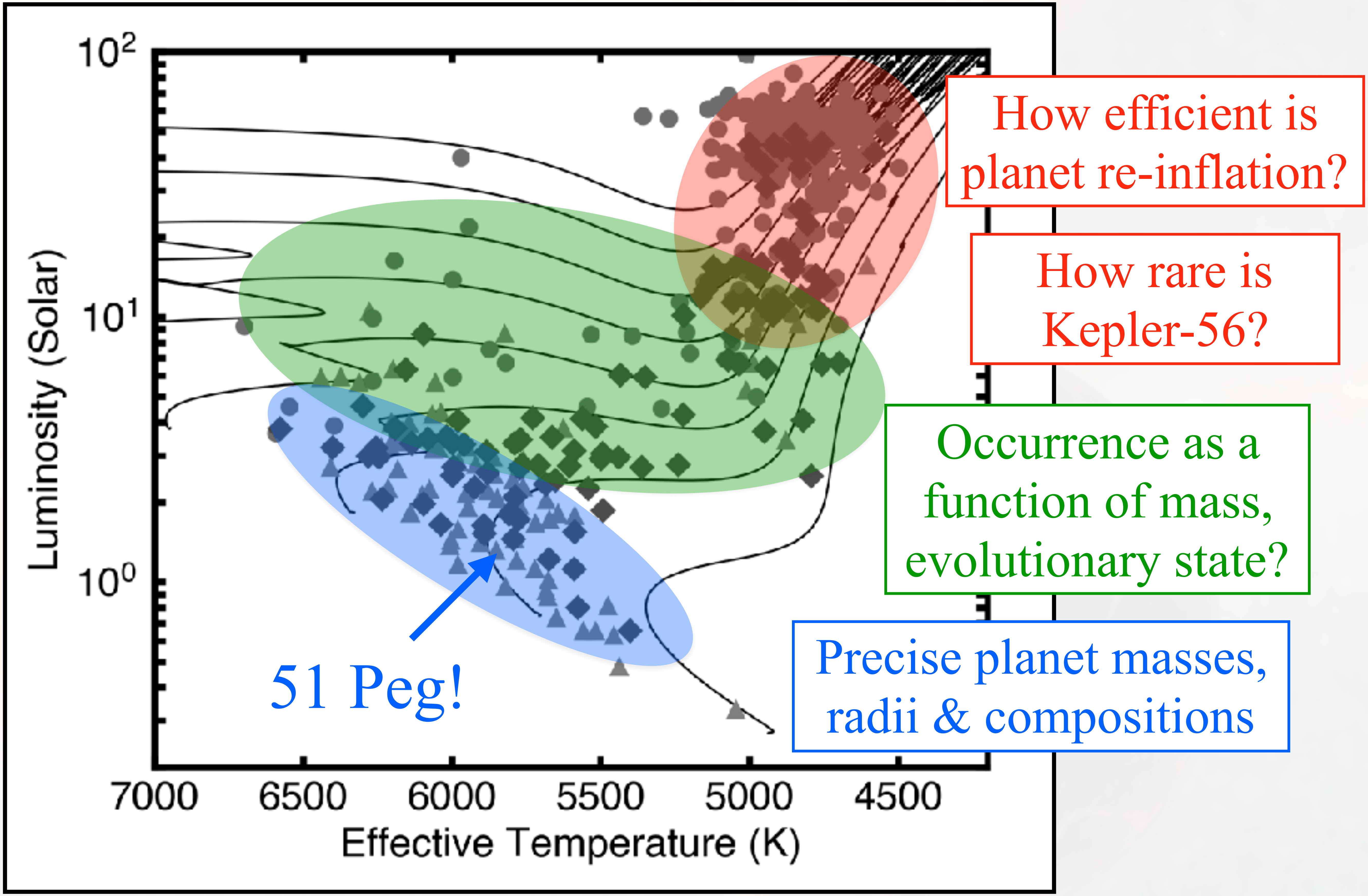
(for giants: ~1e6+ detections expected)

Seismic TESS Exoplanet Hosts



Campante et al. (2016)

Seismic TESS Exoplanet Hosts



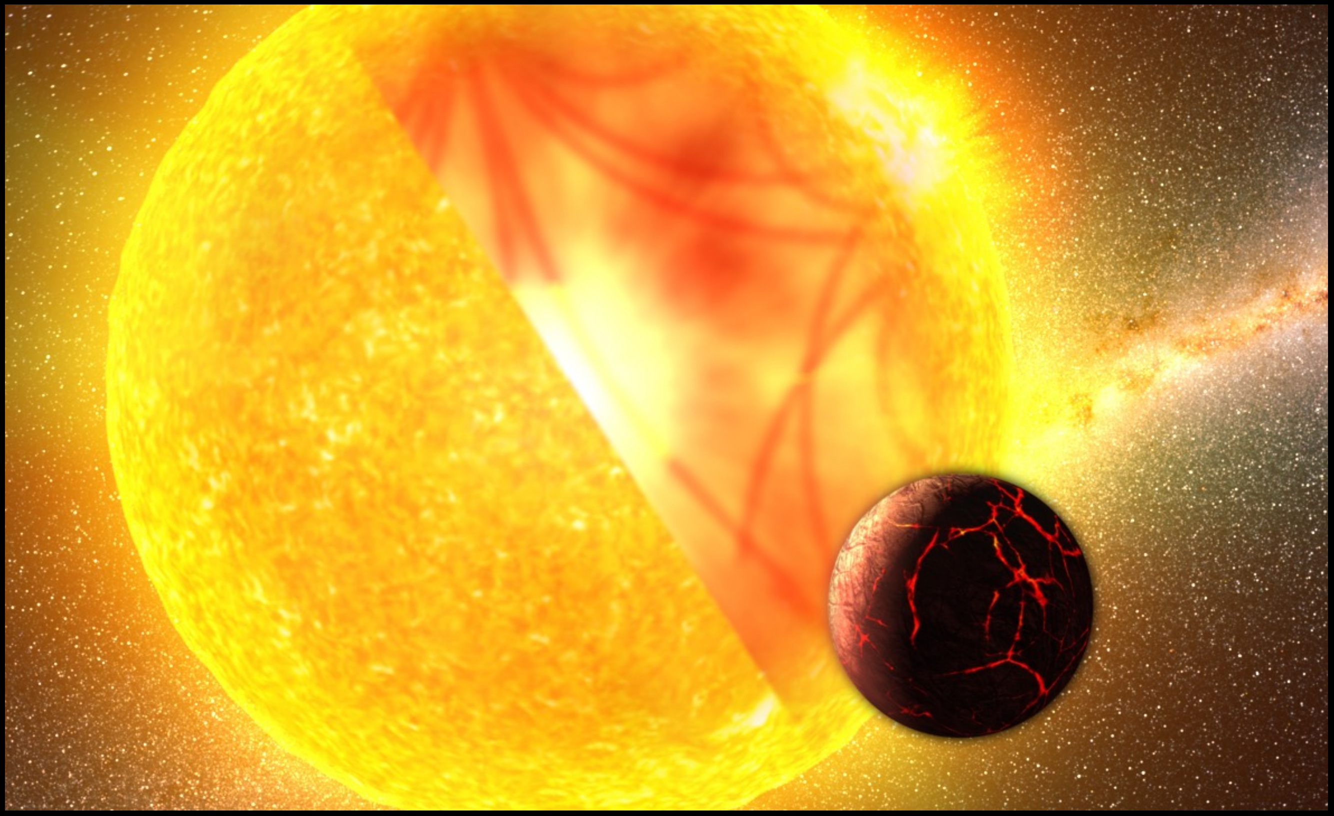
Conclusions

- Asteroseismology is a powerful tool to precisely characterize host stars *and* dynamical architectures of exoplanet systems

- Empirical validations of asteroseismic scaling relations (e.g. using interferometry) are promising, but beware of systematics at the few % level!

- TESS will continue Kepler's revolution of asteroseismology, increasing (mostly) the seismic subgiant sample by a factor of 10 (~1e6 giants!)

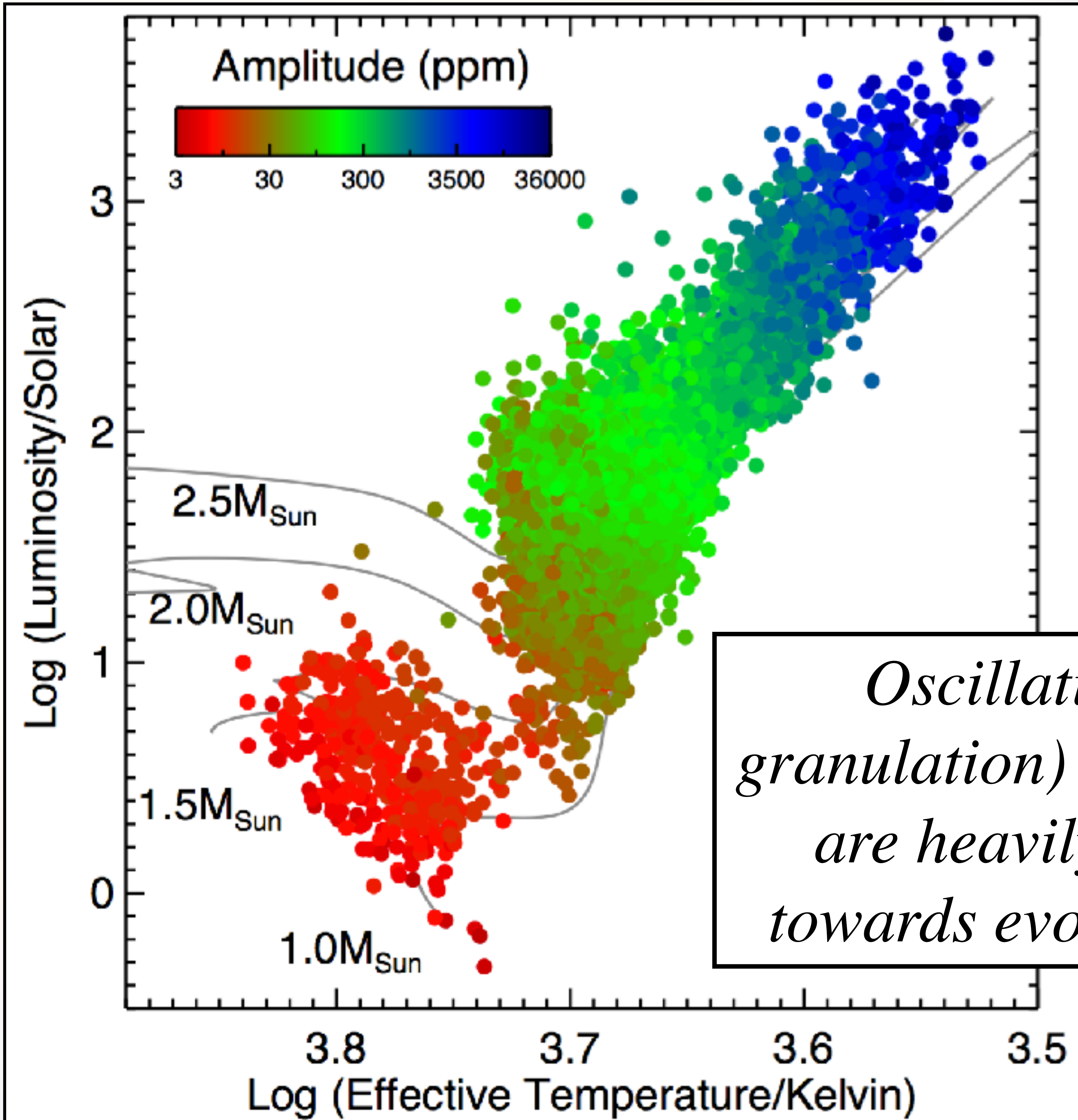
Better Stars, Better Planets: Exploiting the Stellar - Exoplanet Synergy (exostar19)



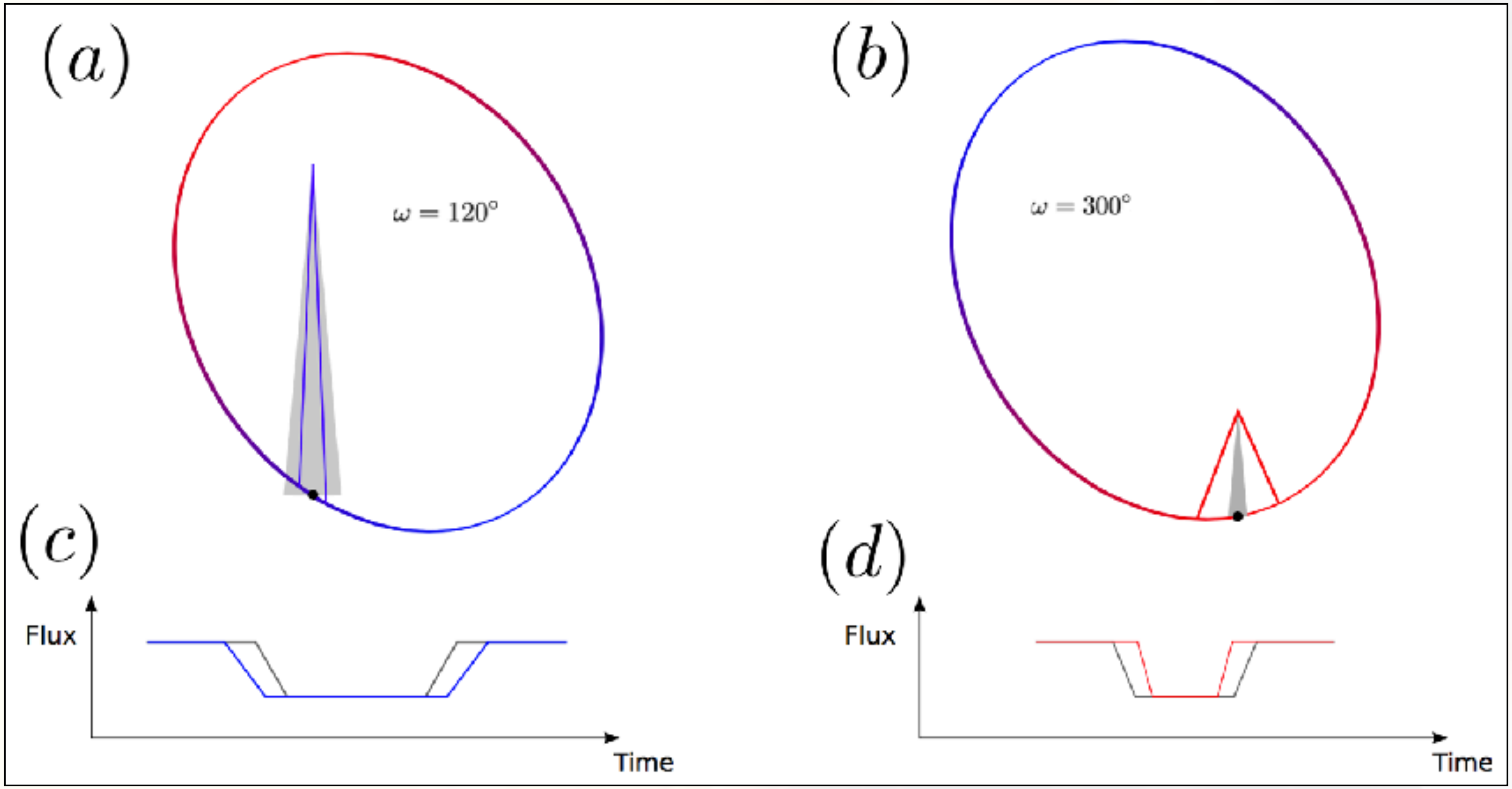
April - June 2019 (Conference May 20-24 2019)
KITP Santa Barbara

Coordinators: Victor Silva Aguirre, Rebekah Dawson, Jim Fuller, Daniel Huber, Katja Poppenhaeger

Science Advisors: Josh Winn & Eric Agol



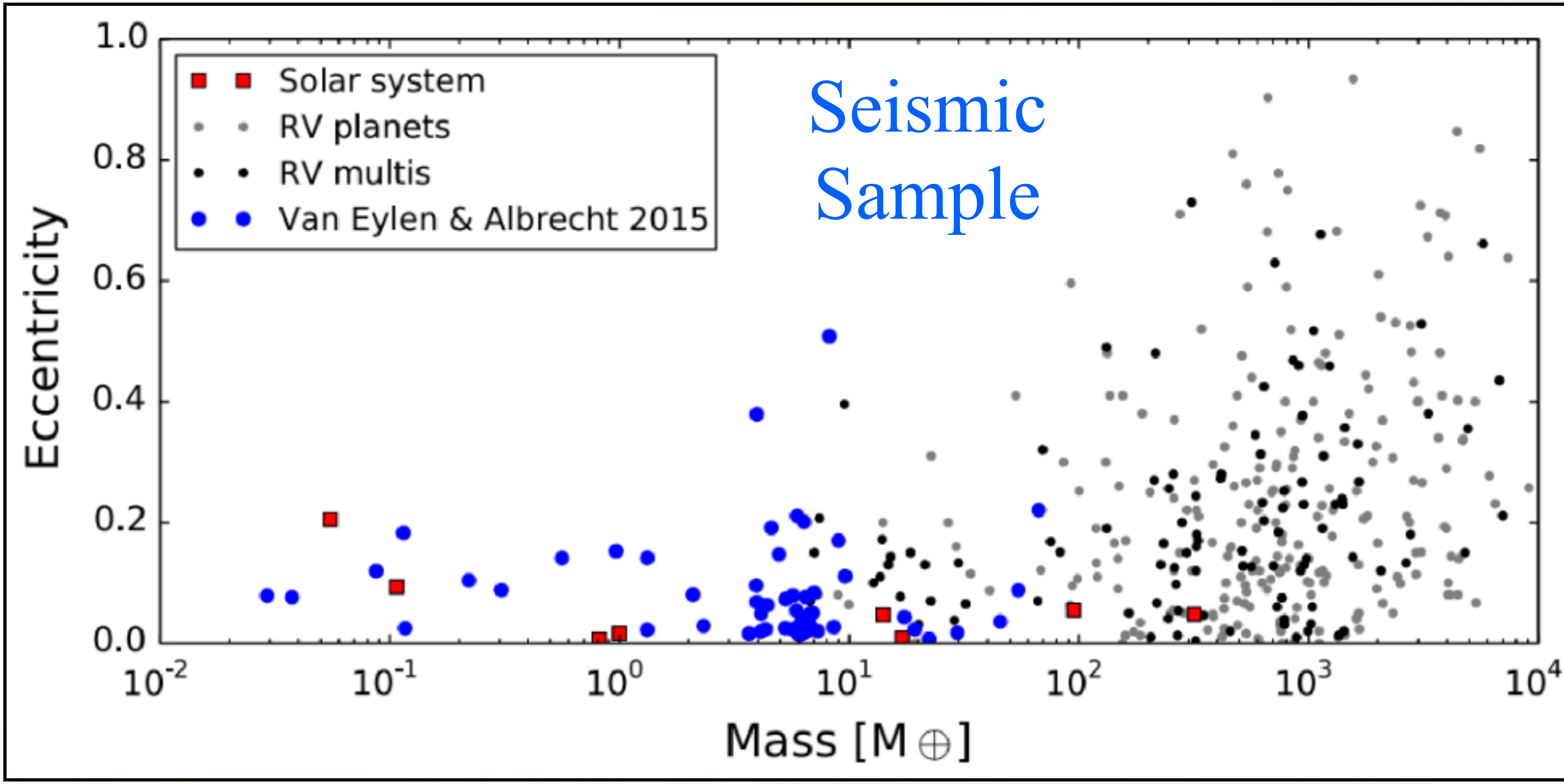
Oscillation (& granulation) amplitudes are heavily biased towards evolved stars



$$\frac{\rho_\star}{\rho_{\star,\mathrm{transit}}} = \frac{(1-e^2)^{3/2}}{(1+e\sin\omega)^3},$$

seismic density lifts degeneracies to constrain eccentricities

Sliski & Kipping 2015, Van Eylen & Albrecht 2015



Small planets are preferentially on circular orbits ➔ important assumption e.g. for planet occurrence rates!

Van Eylen & Albrecht 2015