Giant exoplanets

from case-by-case study toward statistical study

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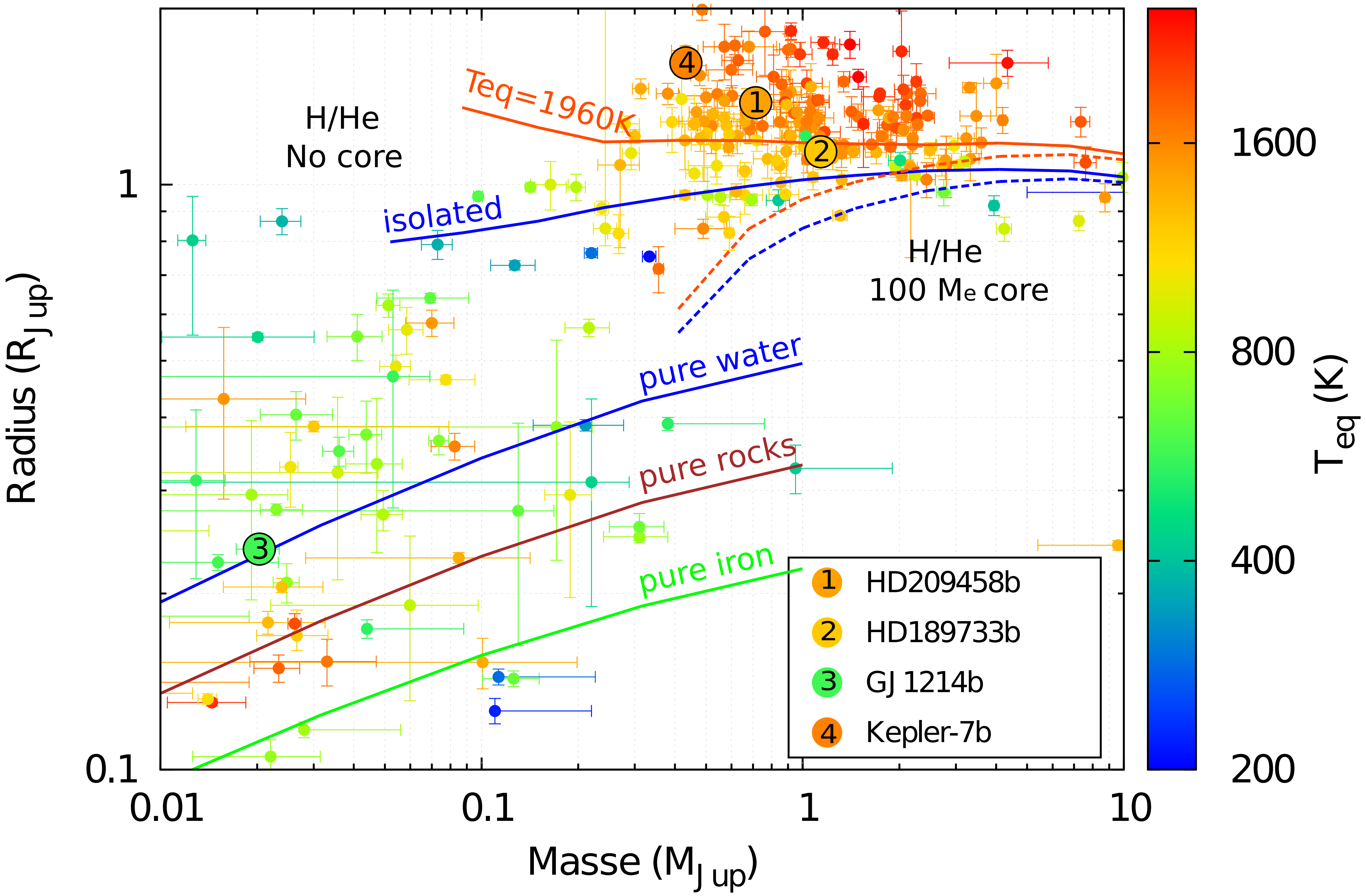


Confirmed transiting exoplanets

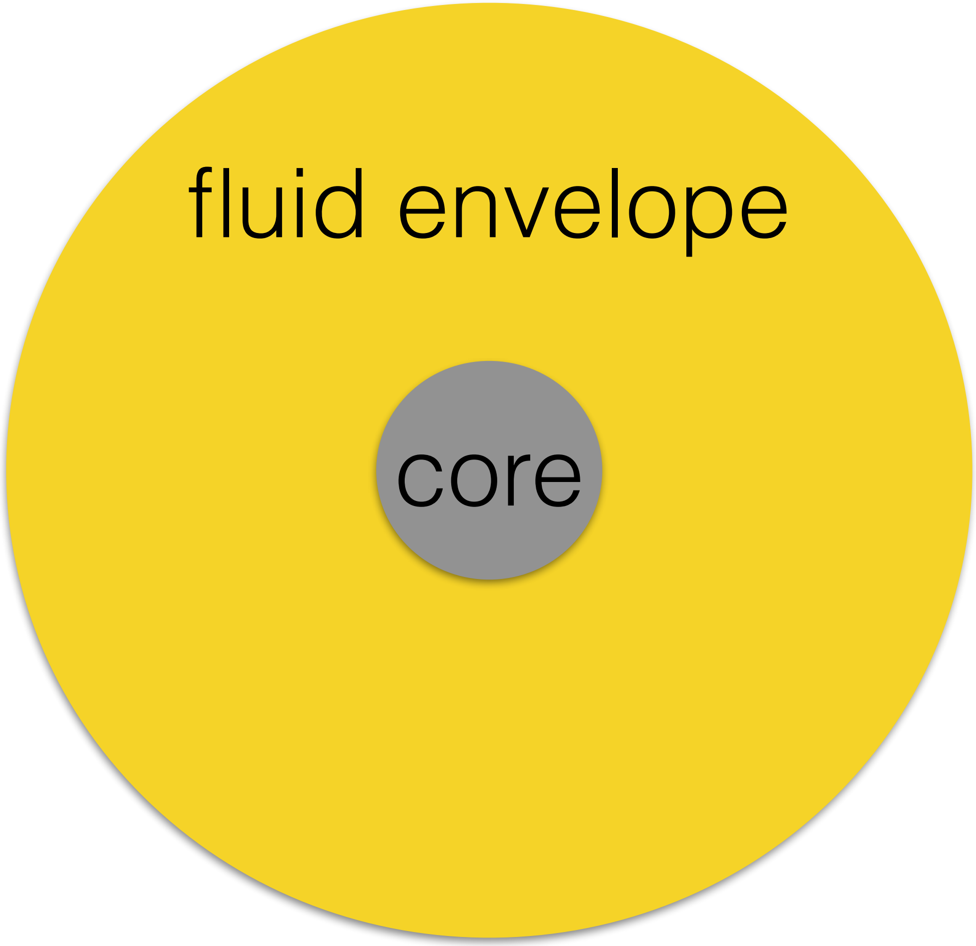
courtesy of Parmentier (PhD thesis, 2014)

Planet models:
CEPAM

Modeling planetary evolution with CEPAM

1-D equations:

$$\begin{cases} \dfrac{\partial P}{\partial m} = -\dfrac{Gm}{4\pi r^4} \\ \dfrac{\partial T}{\partial m} = \left(\dfrac{\partial P}{\partial m}\right)\dfrac{T}{P}\nabla_T, \\ \dfrac{\partial r}{\partial m} = \dfrac{1}{4\pi r^2 \rho}, \\ \dfrac{\partial L}{\partial m} = \dot{\epsilon} - T\dfrac{\partial S}{\partial t}, \end{cases}$$



Mass

Radius

Luminosity

Atmospheric T-P profile

Atmospheric composition

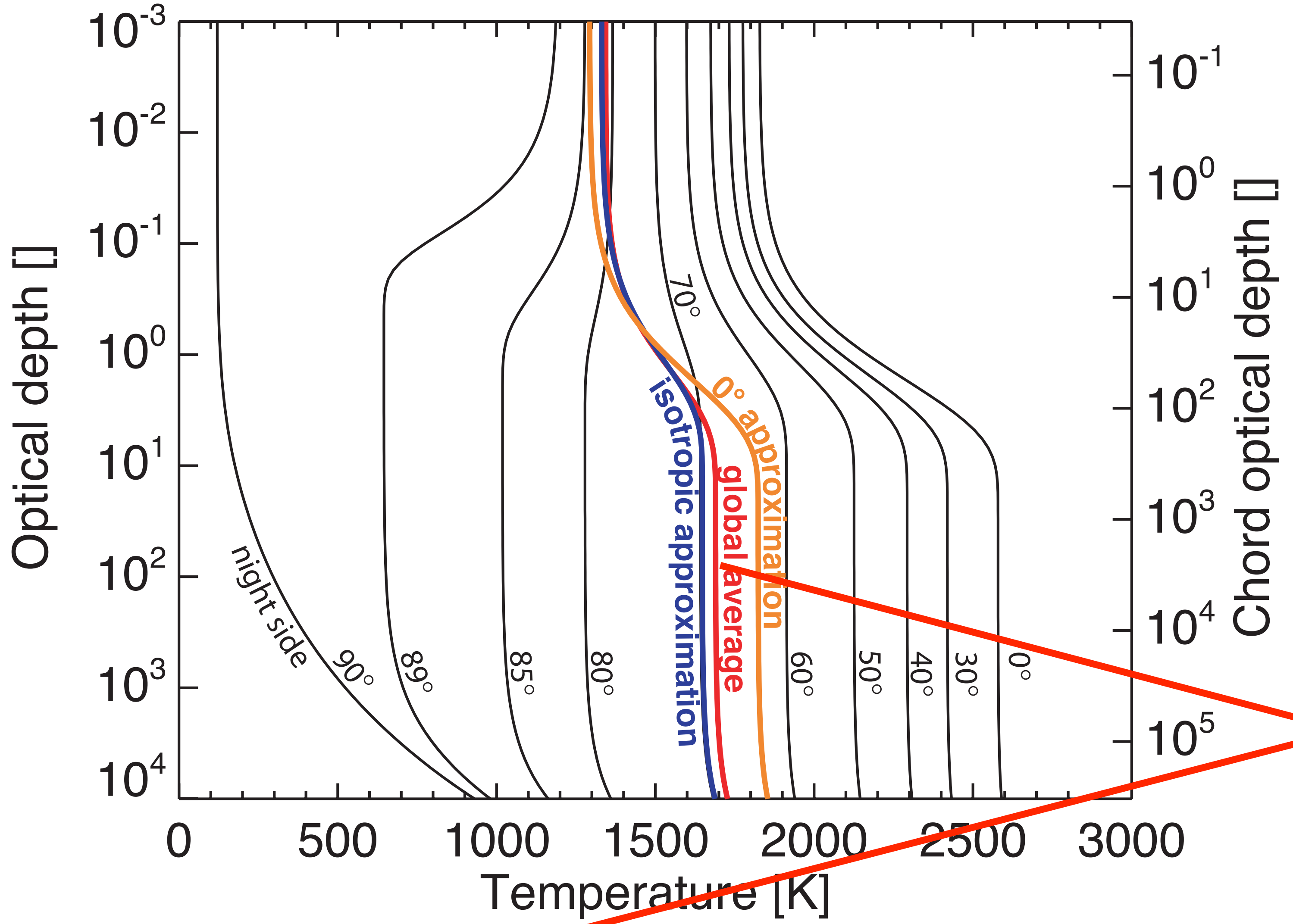
Rotation rate, gravity field

$$\rho = \rho(P, T, \{X_i\}); \qquad S = S(P, T, \{X_i\})$$

$$\begin{aligned} m = 0 &\longrightarrow r = L = 0 \\ m = M &\longrightarrow P = P_{\mathrm{phot}}(g, L) \\ & T = T_{\mathrm{phot}}(g, L) \end{aligned}$$

Guillot & Morel (1995)

Atmospheric boundary condition



a well defined deep atmospheric temperature: 4π average

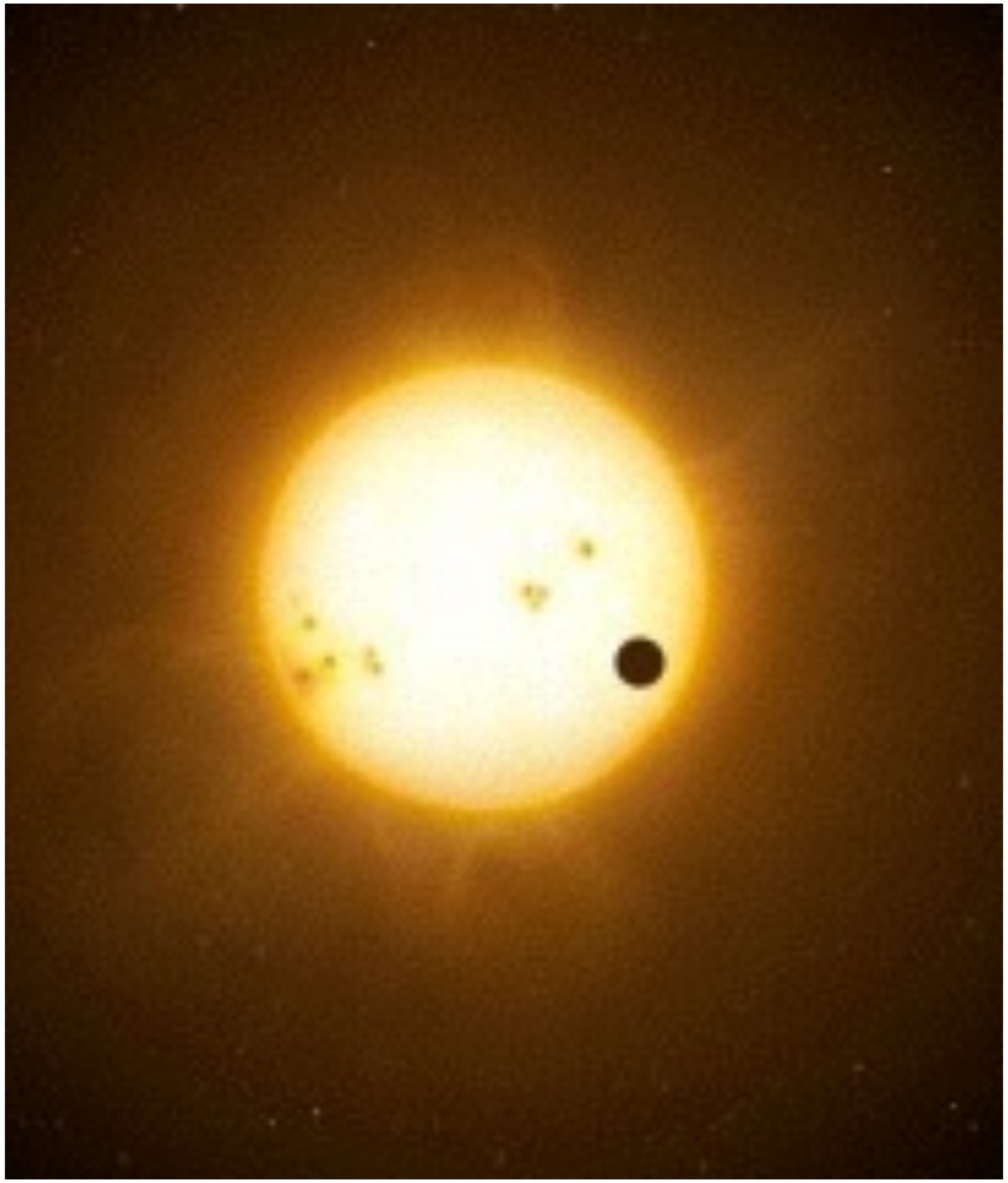
$$\overline{T^4} = \frac{3T_{\rm int}^4}{4}\left\{\frac{2}{3}+\tau\right\} + \frac{3\boxed{T_{\rm eq}^4}}{4}\left\{\frac{2}{3}+\frac{2}{3\gamma}\left[1+\left(\frac{\gamma\tau}{2}-1\right)e^{-\gamma\tau}\right]+\frac{2\gamma}{3}\left(1-\frac{\tau^2}{2}\right)E_2(\gamma\tau)\right\}$$

ratio of visible to IR opacity

Guillot (2010)

Planets… and their host star

- Planetary parameters depend on that of their host star
- Most part of the uncertainties in the planetary parameters come from that of the star



SET: Stars & Exoplanets (modeling) Tools

- modeling of the star and planet, together (but using independent models)

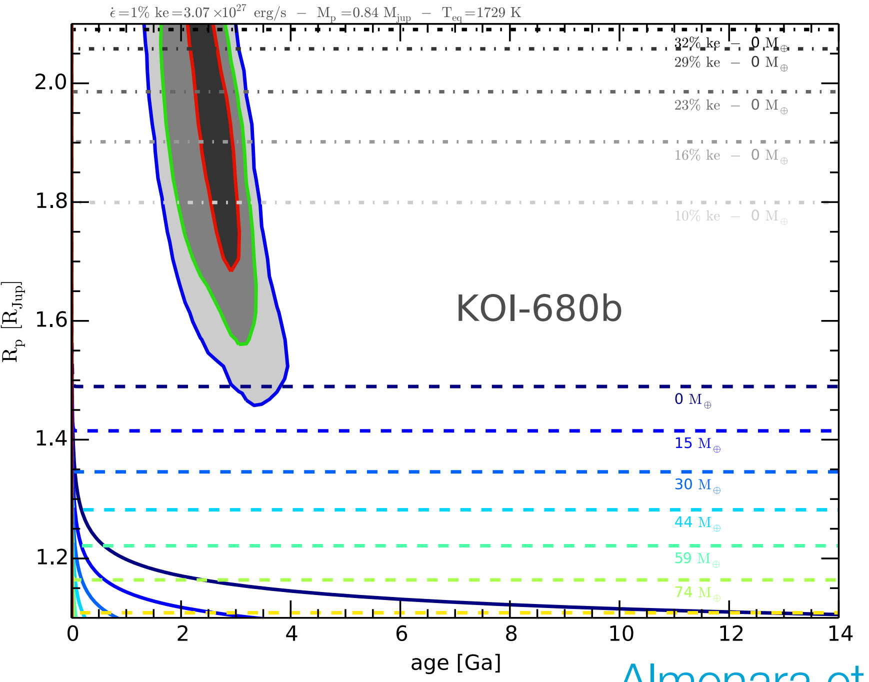
- several models at once (PARSEC, YALE, BCAH, Dartmouth, CESAM … CEPAM) —> intrinsic errors estimated

- robust statistics: MCMC —> correlation information, errors propagation, …

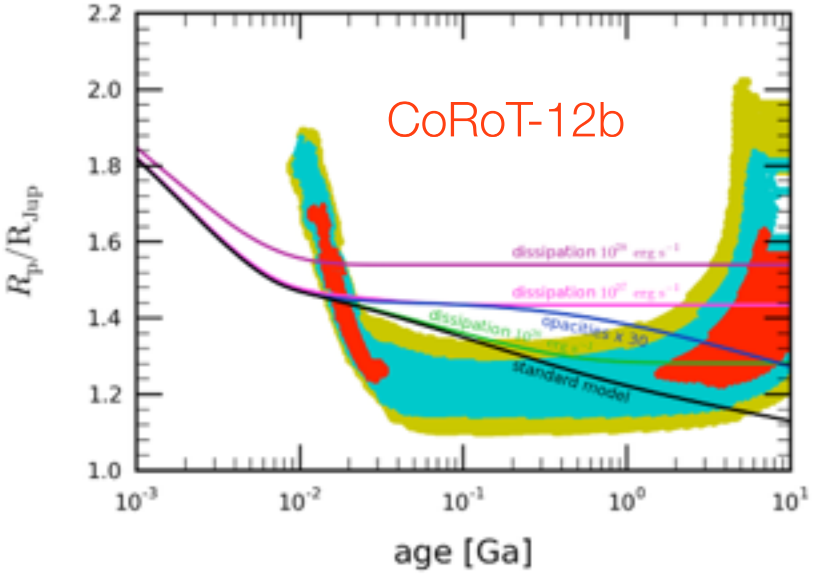
- designed for automatization of large samples from case-by-case study…

Giant planets: 3 interesting categories

Inflated

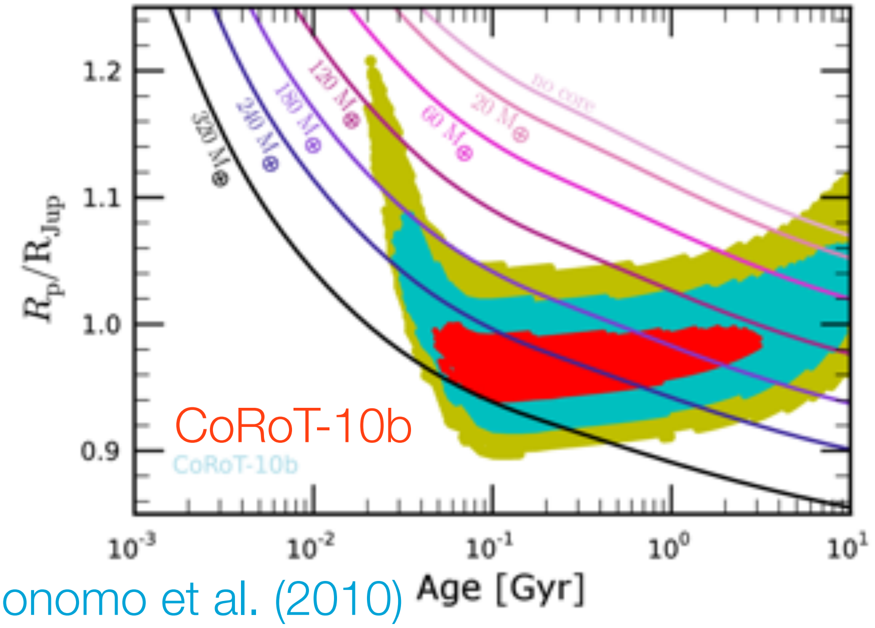


Almenara et al. (2014)

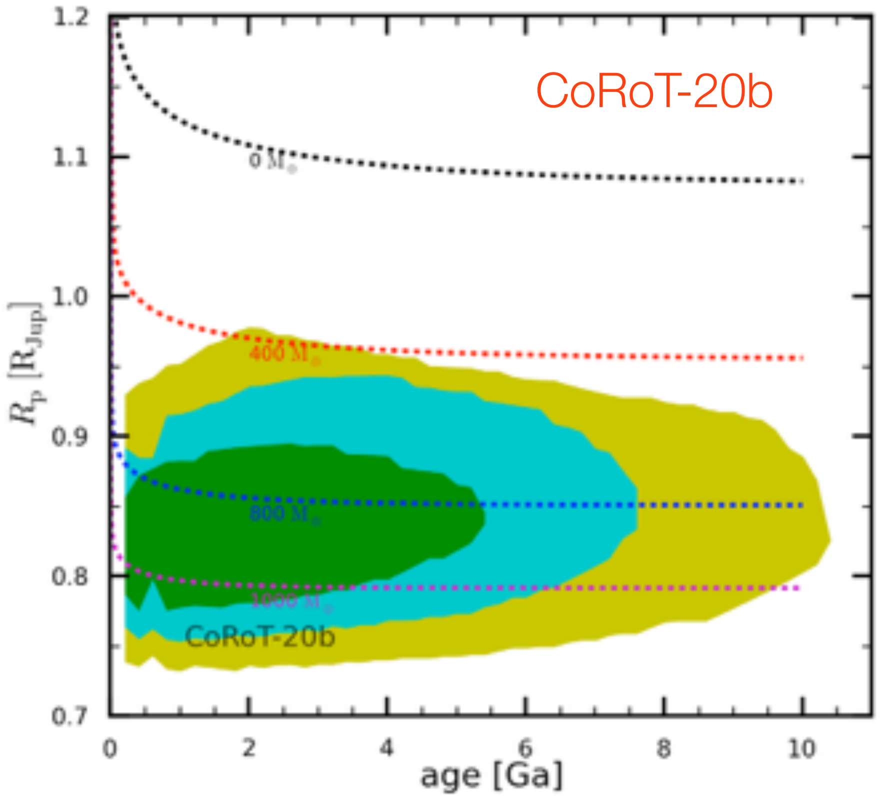


Gillon et al. (2010)

Massive core

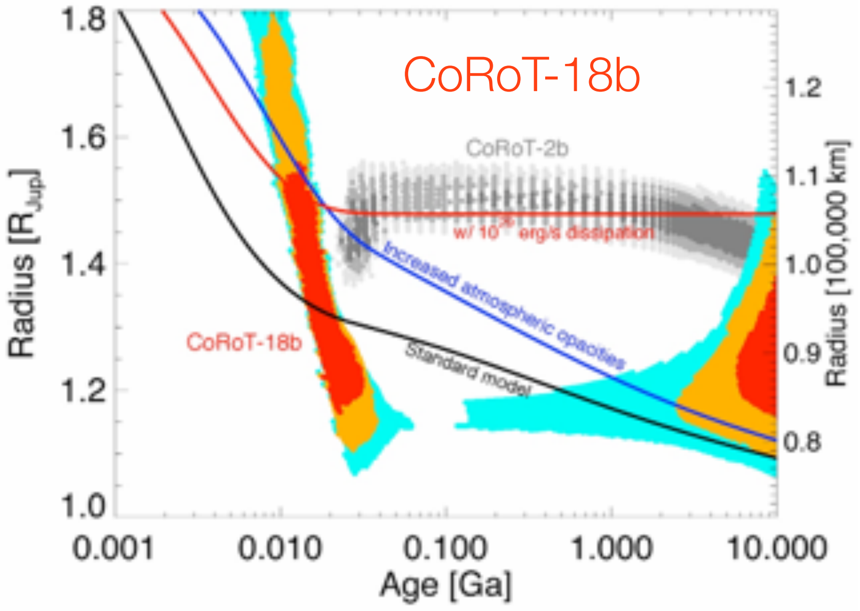


Bonomo et al. (2010)

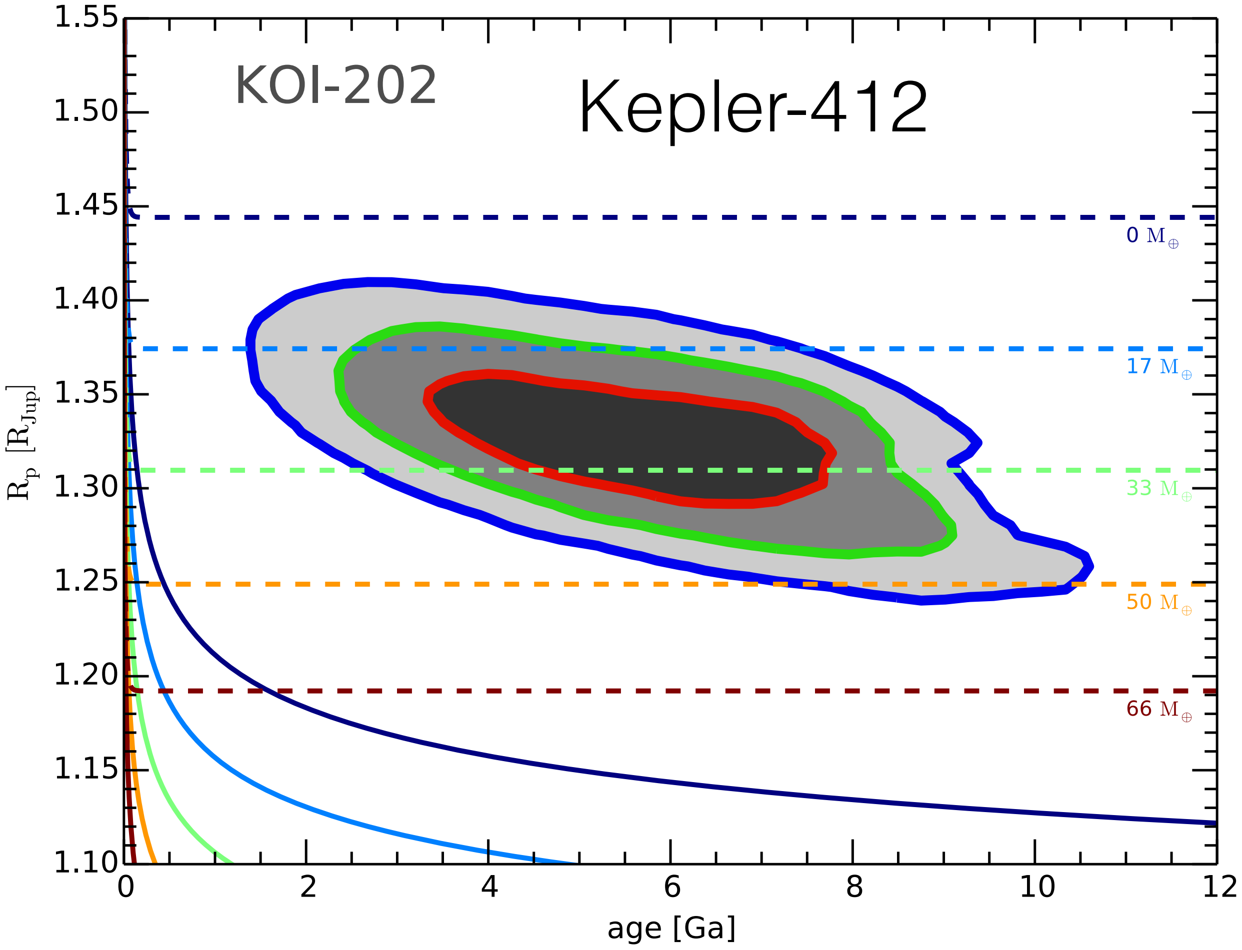


Deleuil et al. (2012)

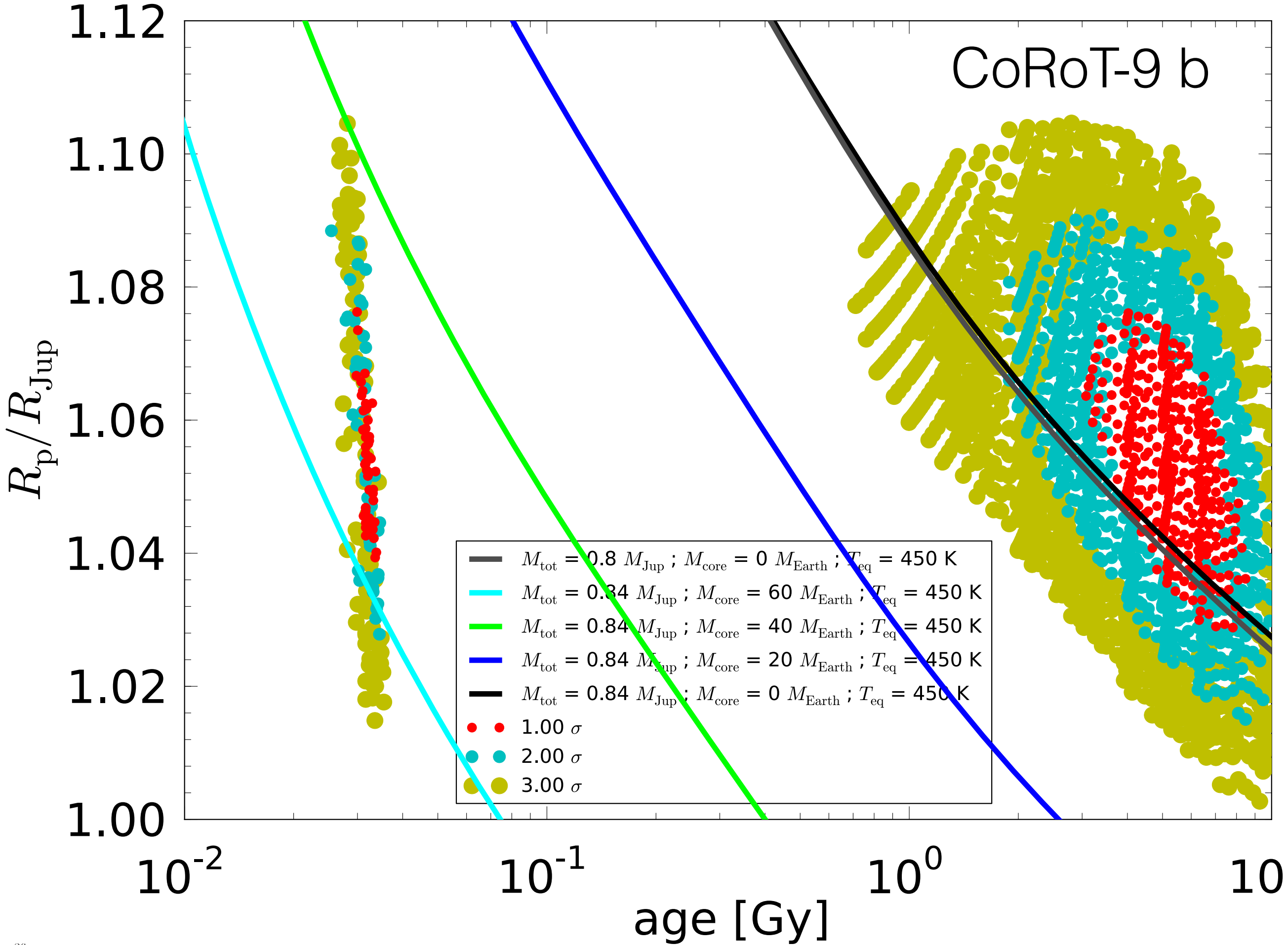
Young



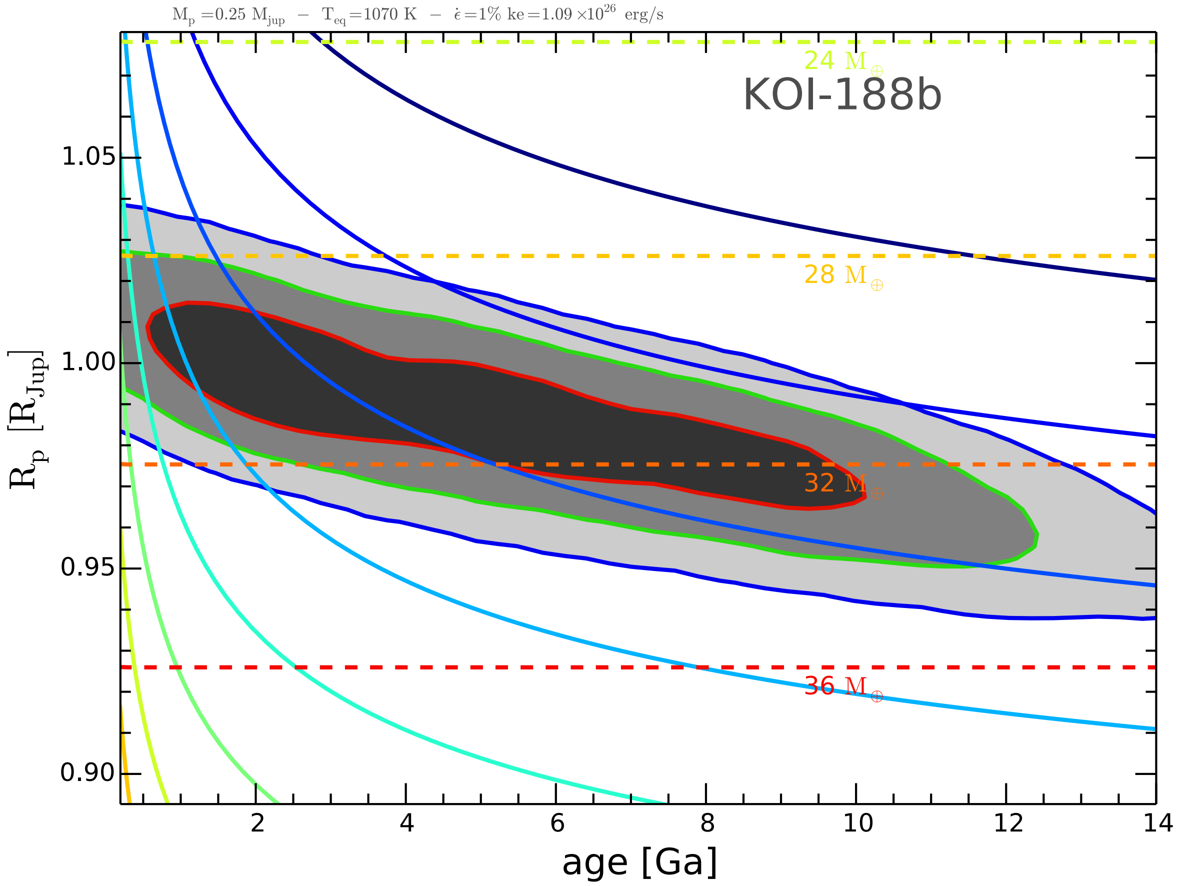
Hébrard et al. (2011)



Deleuil (2014)



Deeg (2010)



Hébrard, sub.

… to an ensemble study

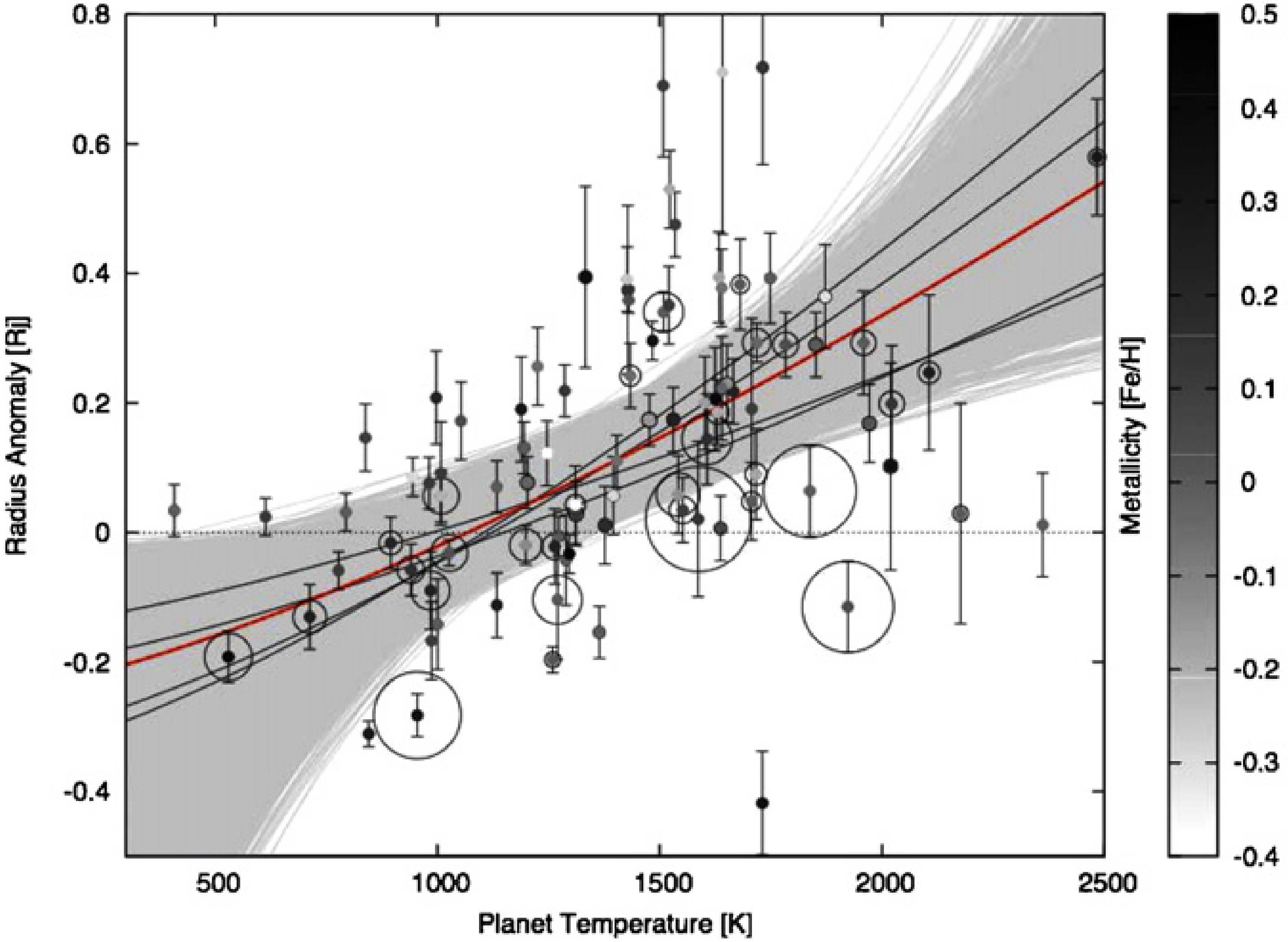
Radius anomaly

$$\mathrm{R_{anomaly} = R_{obs} - R_{std,\,no\,core}}$$

Guillot (2006)

Laughlin (2011)

$$\mathrm{R_{anomaly} \propto T_{eq}^{1.4\pm0.6}}$$

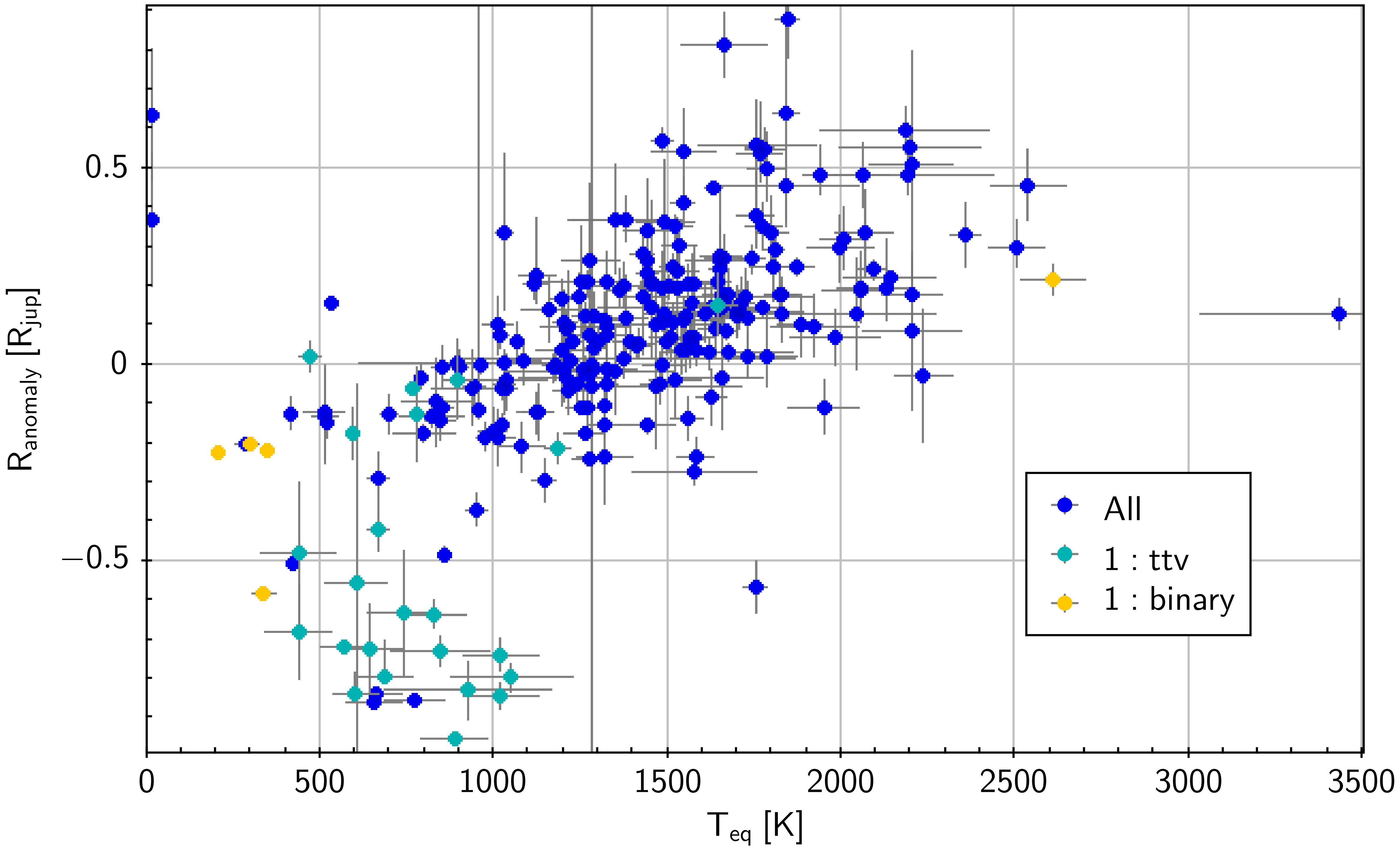


CEPAM grid

- Temperatures (eq.) from 200 to 2200 K
- Masses from 0.1 to 10 Jupiter masses
- from 0 to 50% of heavy elements (Z)
- from 0 to 50% of stellar incoming flux dissipated in the deep layers of the planet
- from 0 to 14 Gyr evolution tracks

Preliminary results for **249 exoplanets**

60% (155) of the total are inflated planets!



Preliminary results for **249 exoplanets**

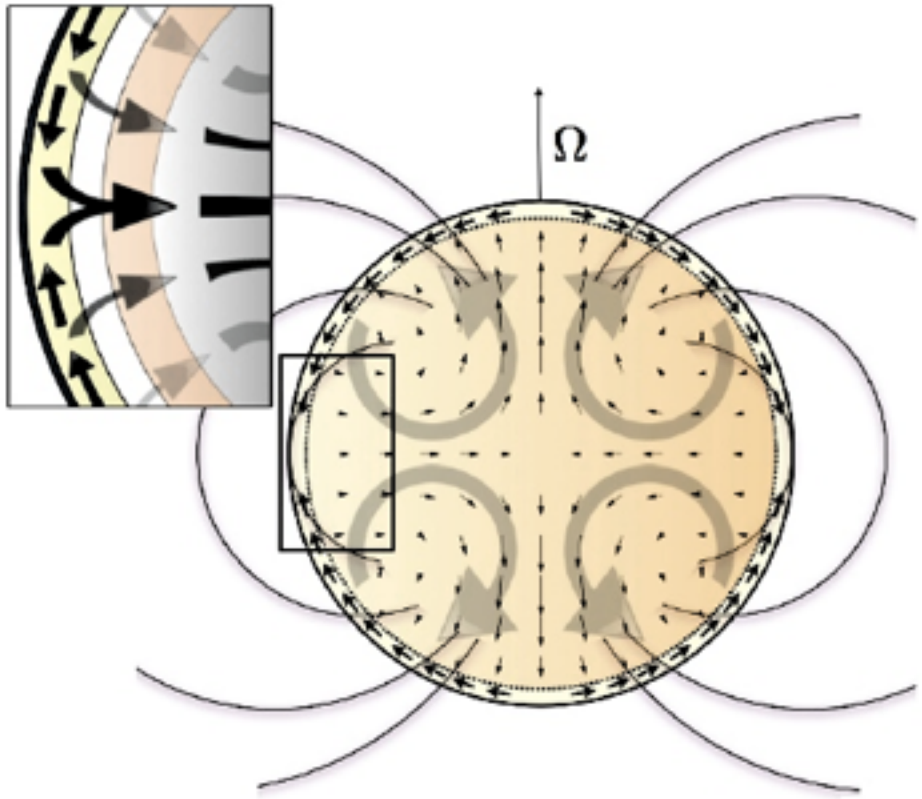
Inflation mechanisms

eg. Baraffe (2014)

- stellar-flux dissipation (kinetic heating, ohmic dissipation)
- tidal dissipation
- delayed contraction (increased opacities, reduced interior heat transport)

Some references:

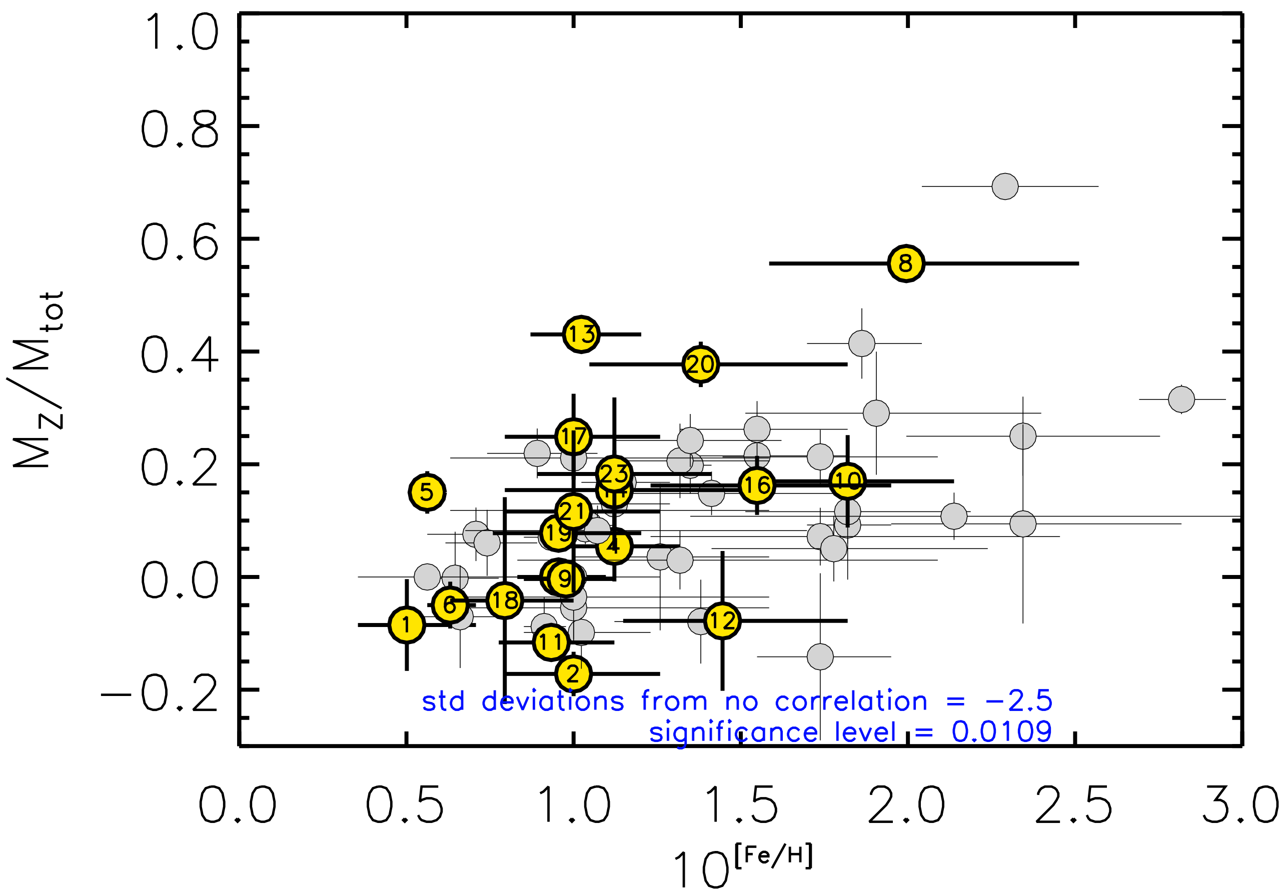
Guillot & Showman (2002),
Batygin & Stevenson (2010),
Rauscher & Menou (2012),
Leconte & Chabrier (2013)

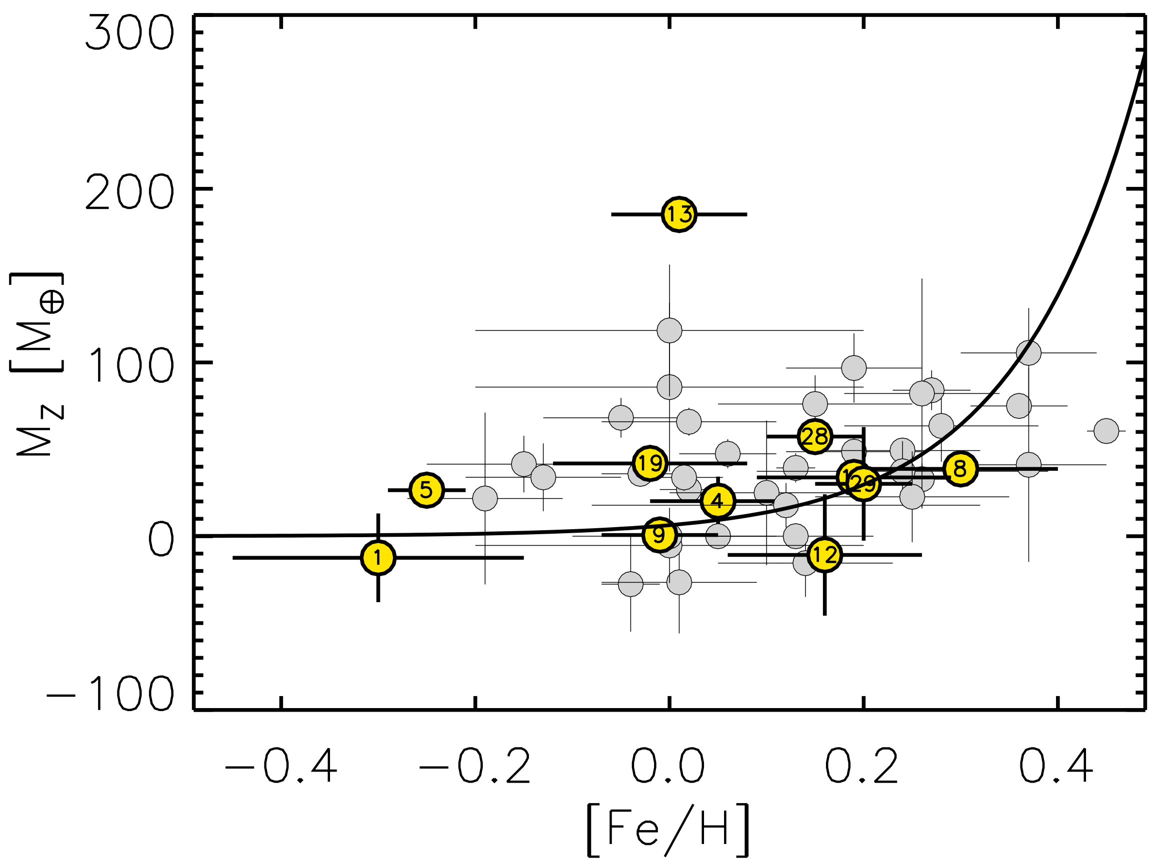


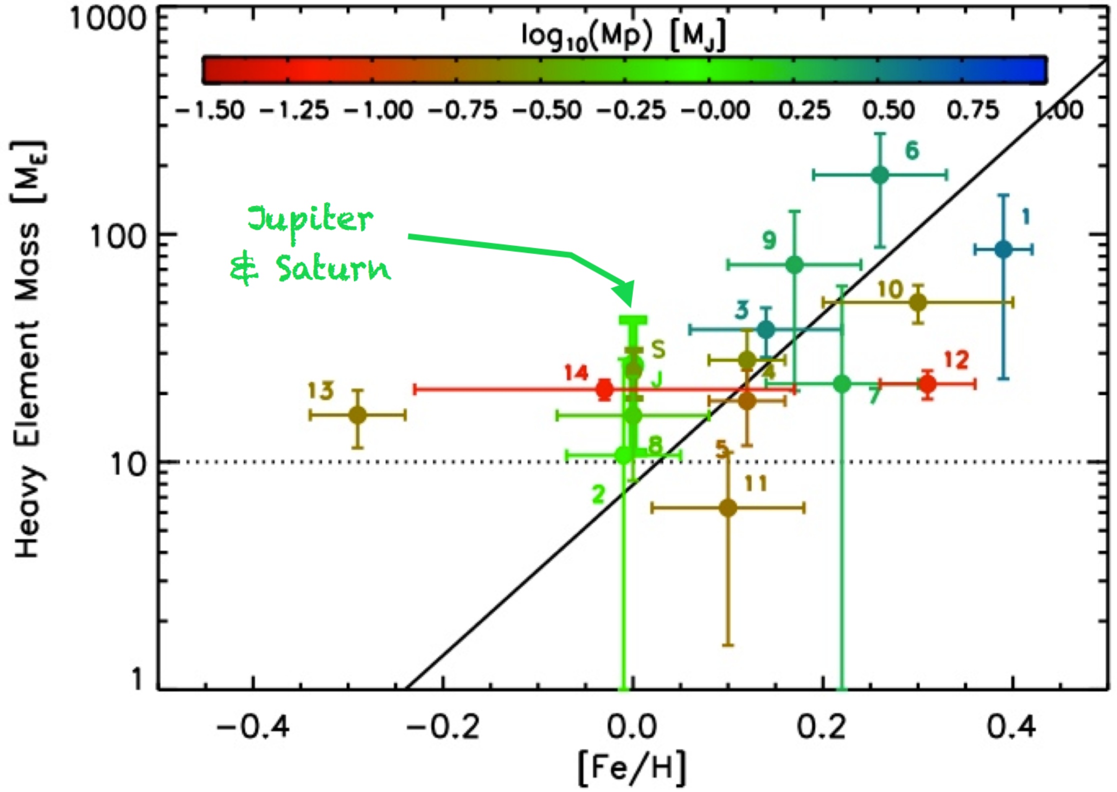
Metallicity correlation

Guillot (2006),
Guillot (2008),
Moutou et al. (2013)
Miller & Fortney (2011)

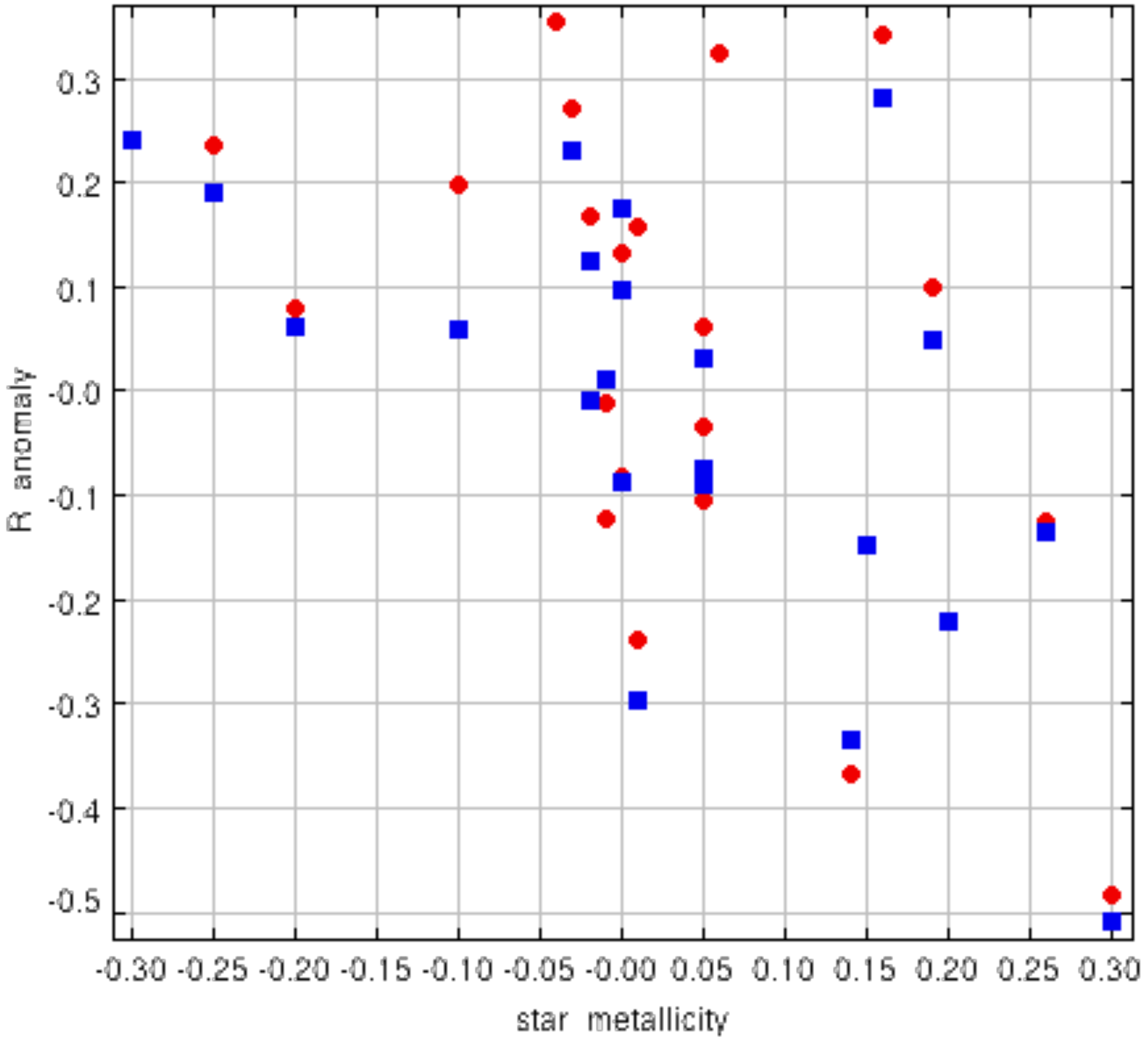
Compositions of giant planets







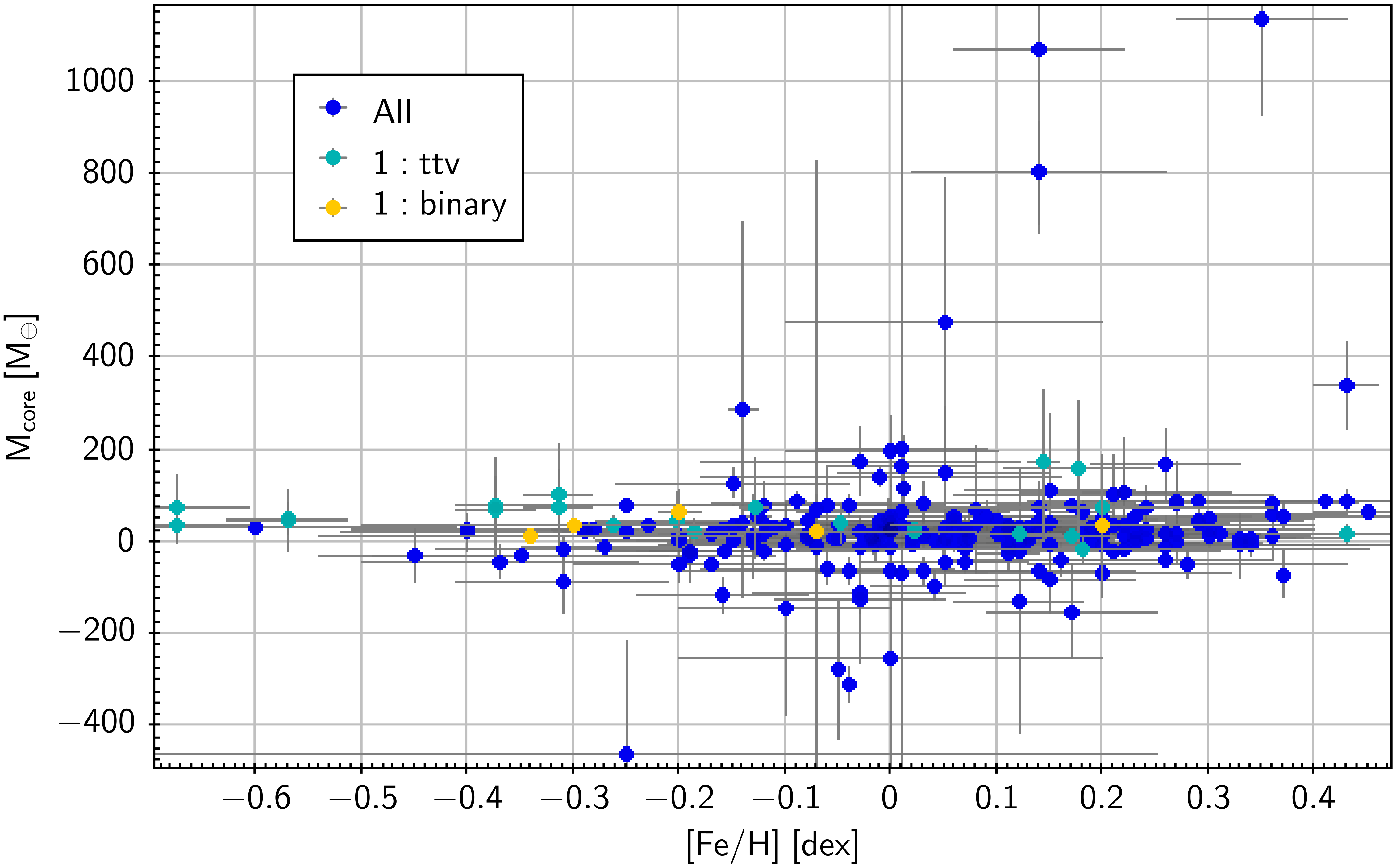
Comparison with previous studies



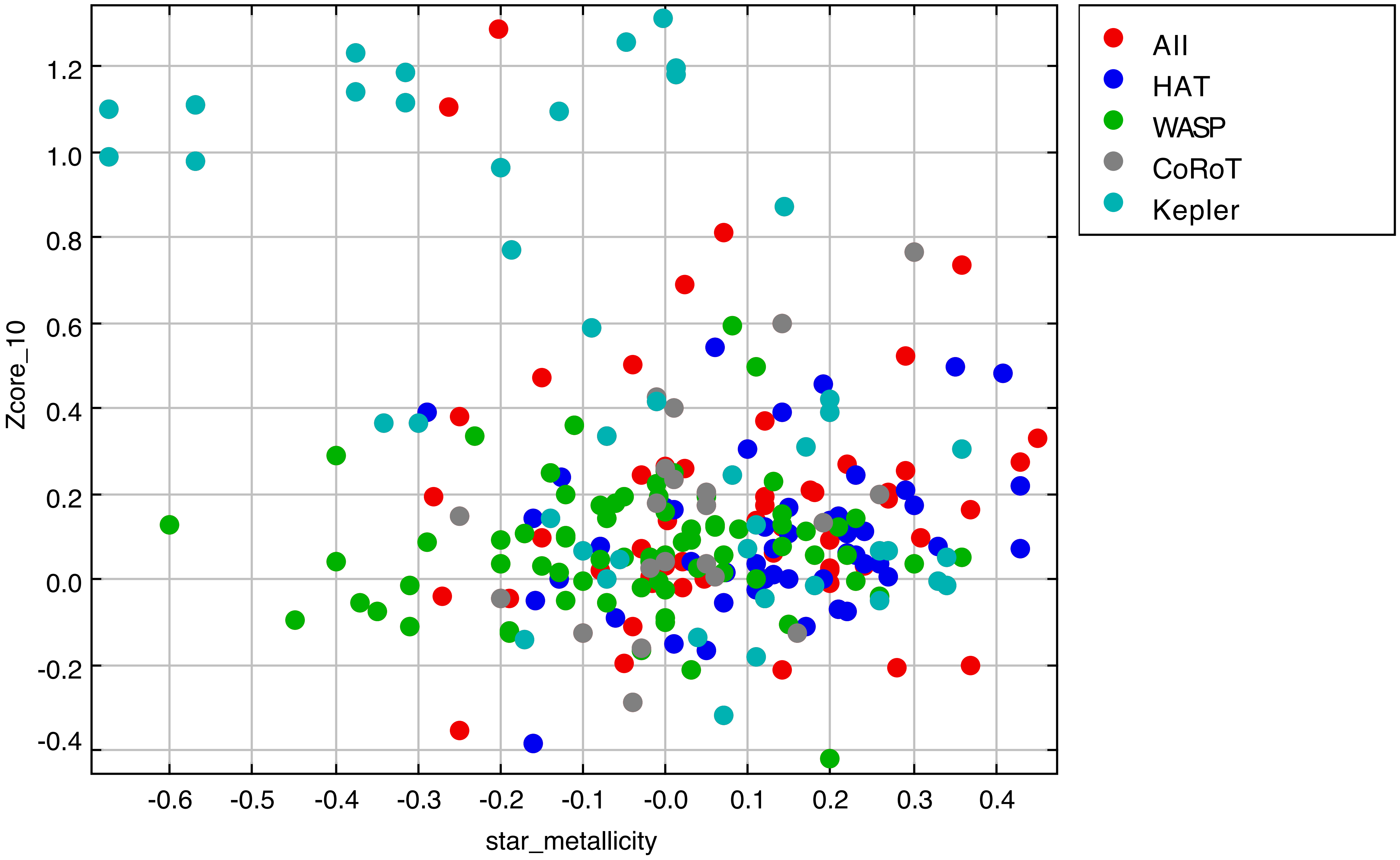
red: this study, blue: Moutou et al. (2013)

Metallicity correlation

(*preliminary results, with 1% incoming stellar flux dissipation*)



Fraction of heavies vs. metallicity



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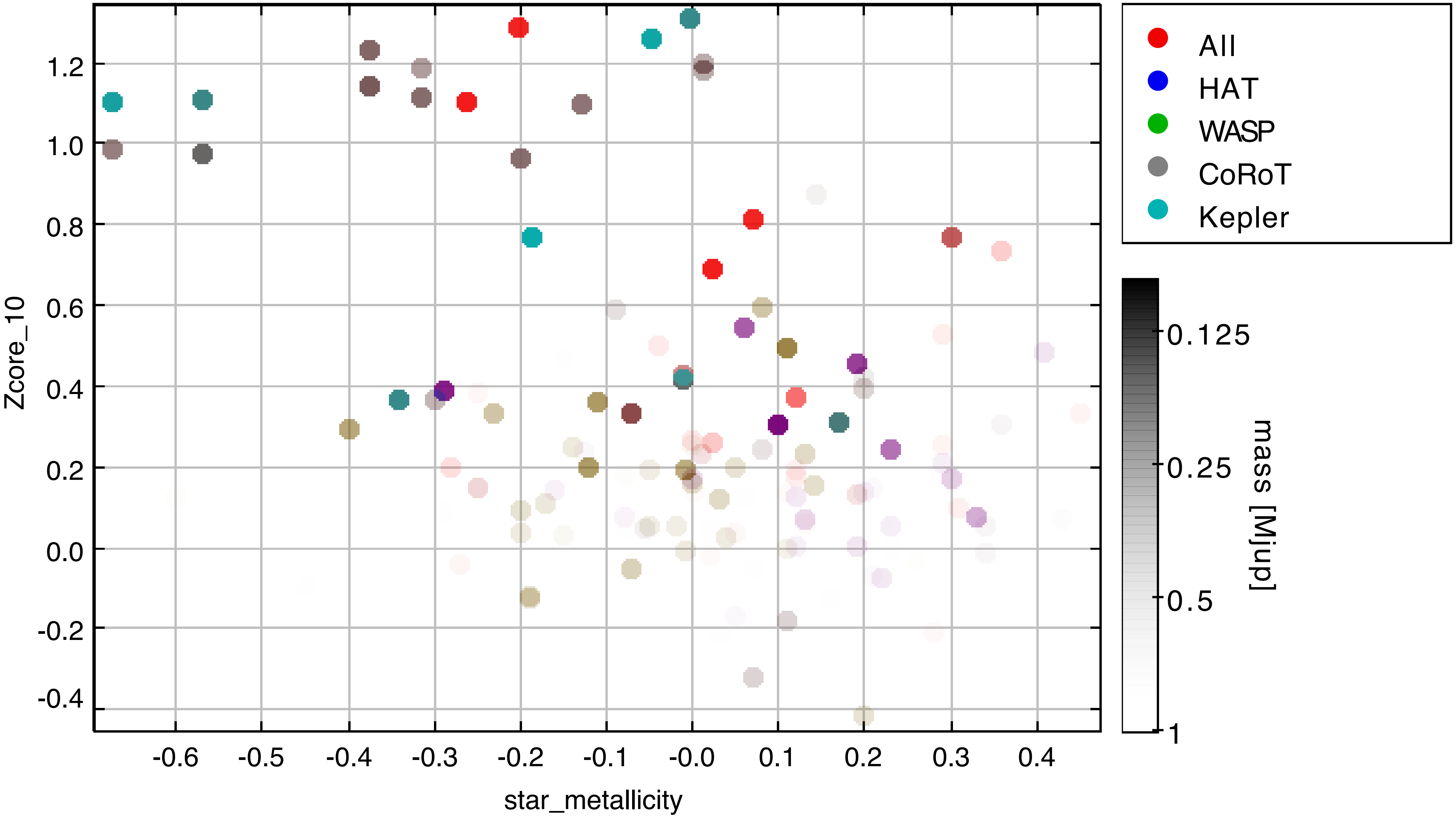

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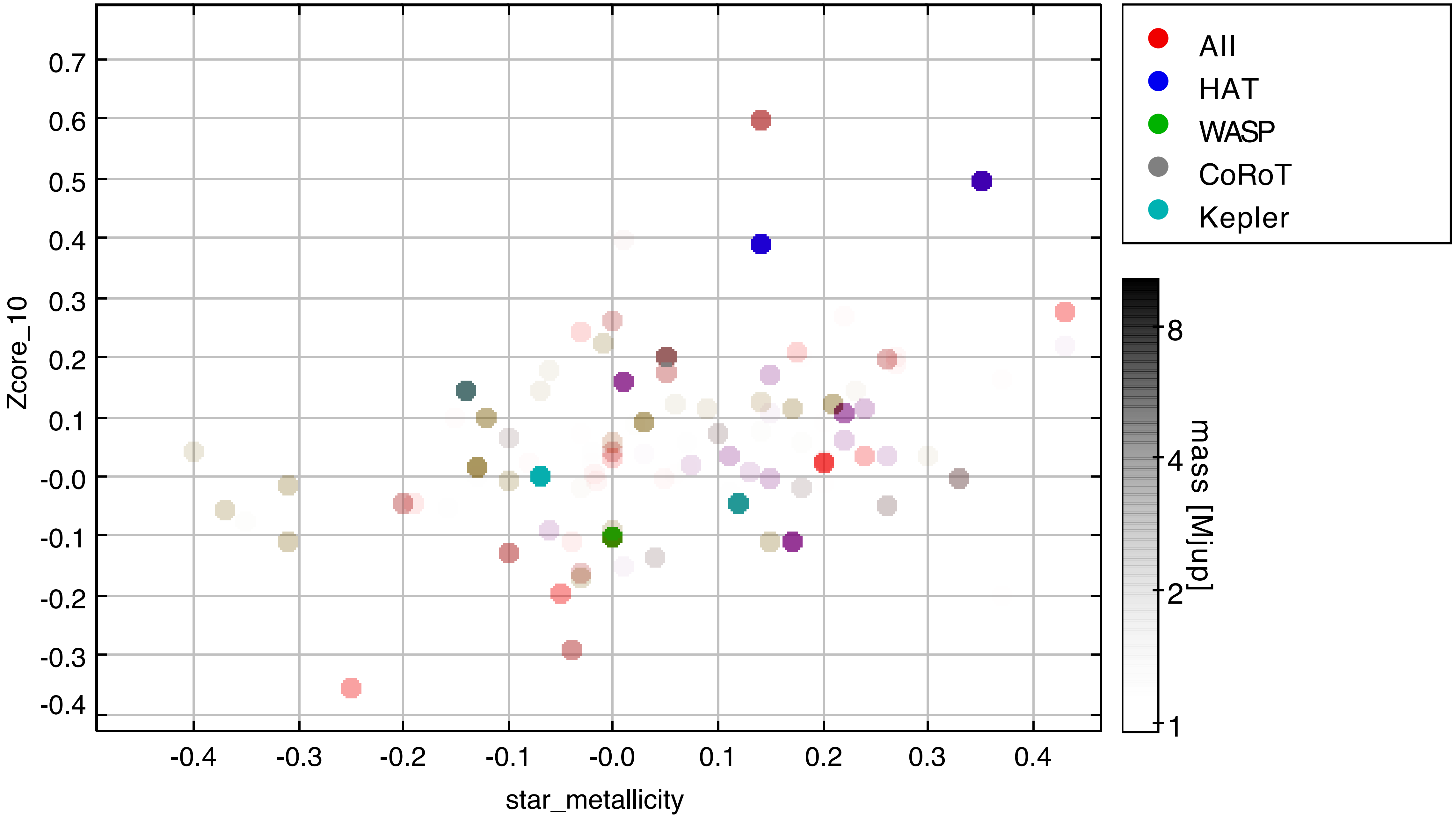
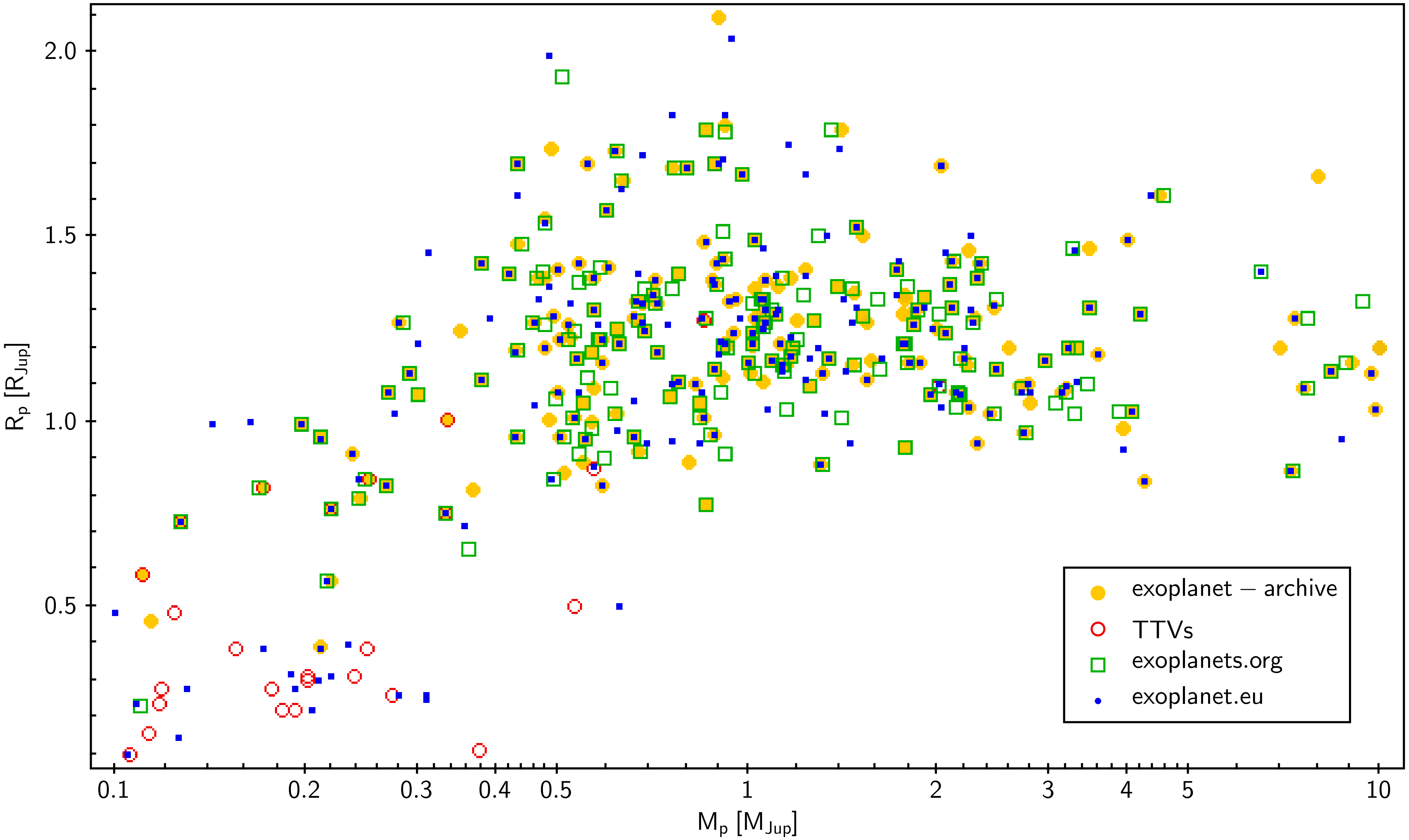


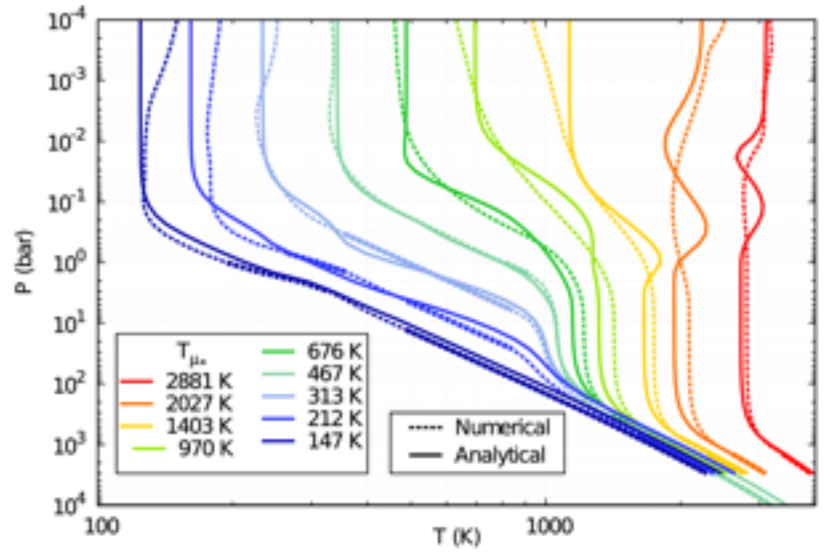
Perspectives

- data mining!



Perspectives

- data mining!
- updated atm. model
  (Parmentier et al., sub.)

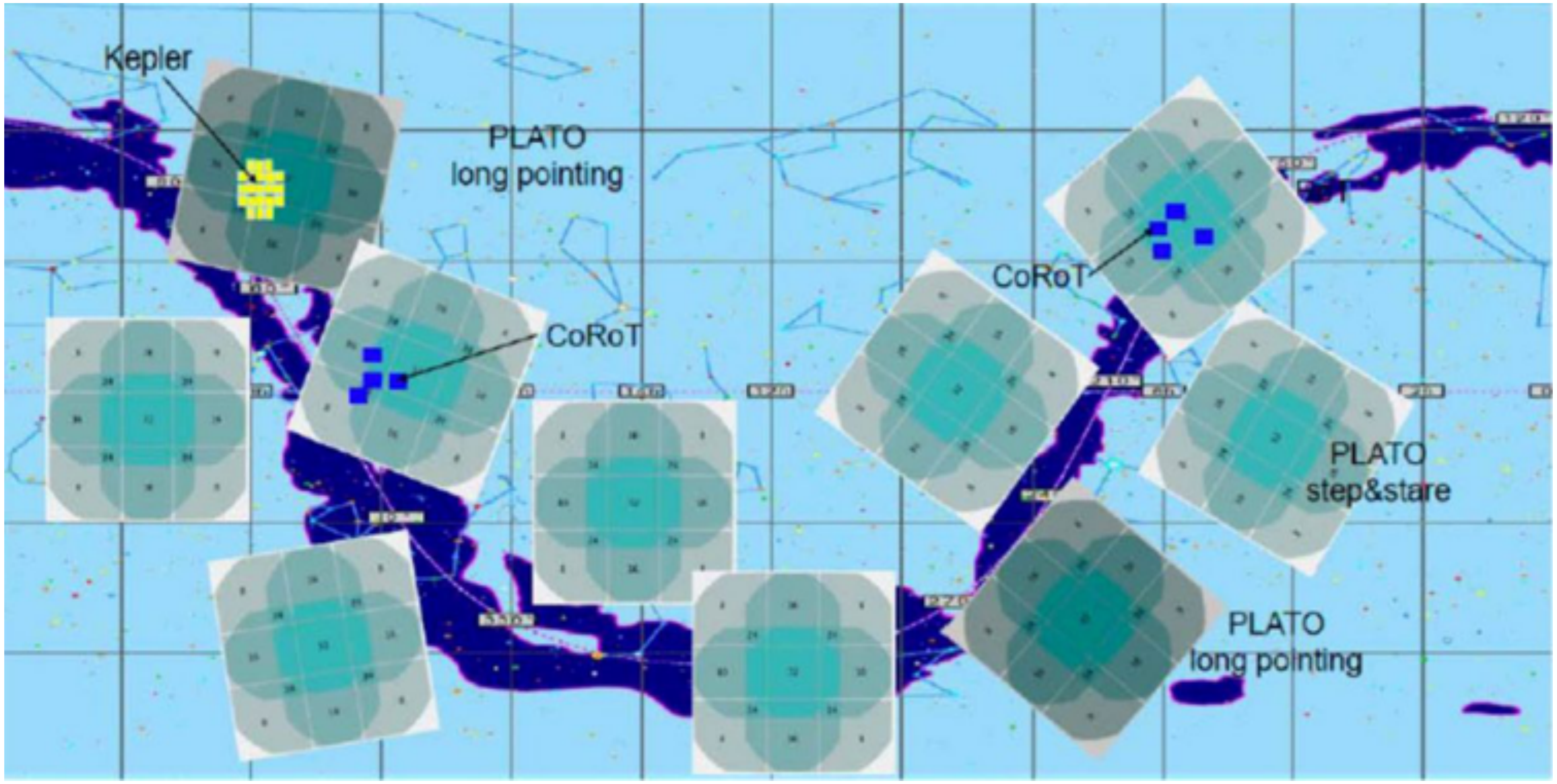


Perspectives

- data mining!
- updated atm. model
  (Parmentier et al., sub.)
- modeling of star and planet together for the whole sample (249+ planets)

Future

PLATO, GAIA, TESS, E-ELT, JWST…
—> ~1000+ new giant transiting exoplanets



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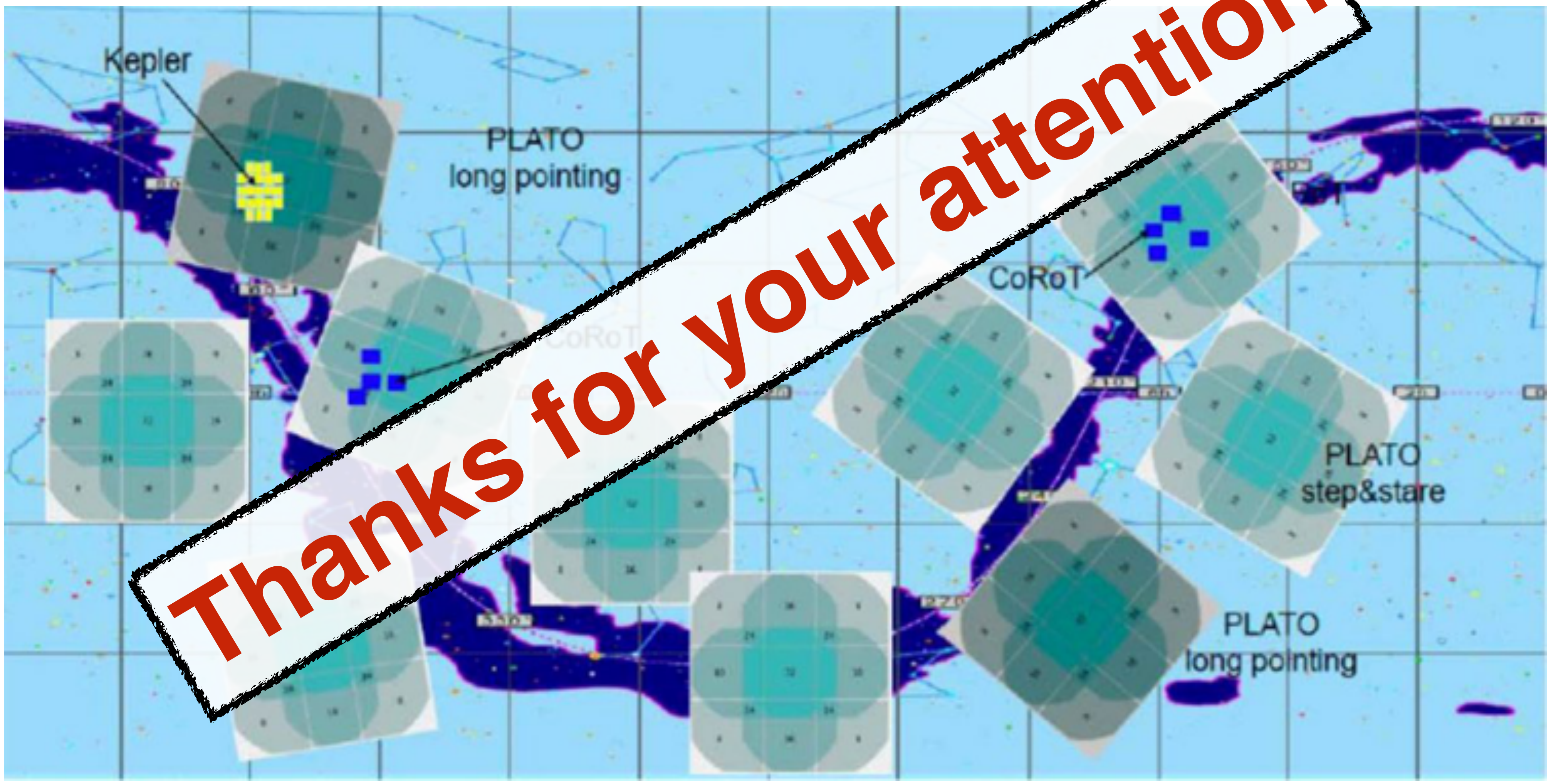
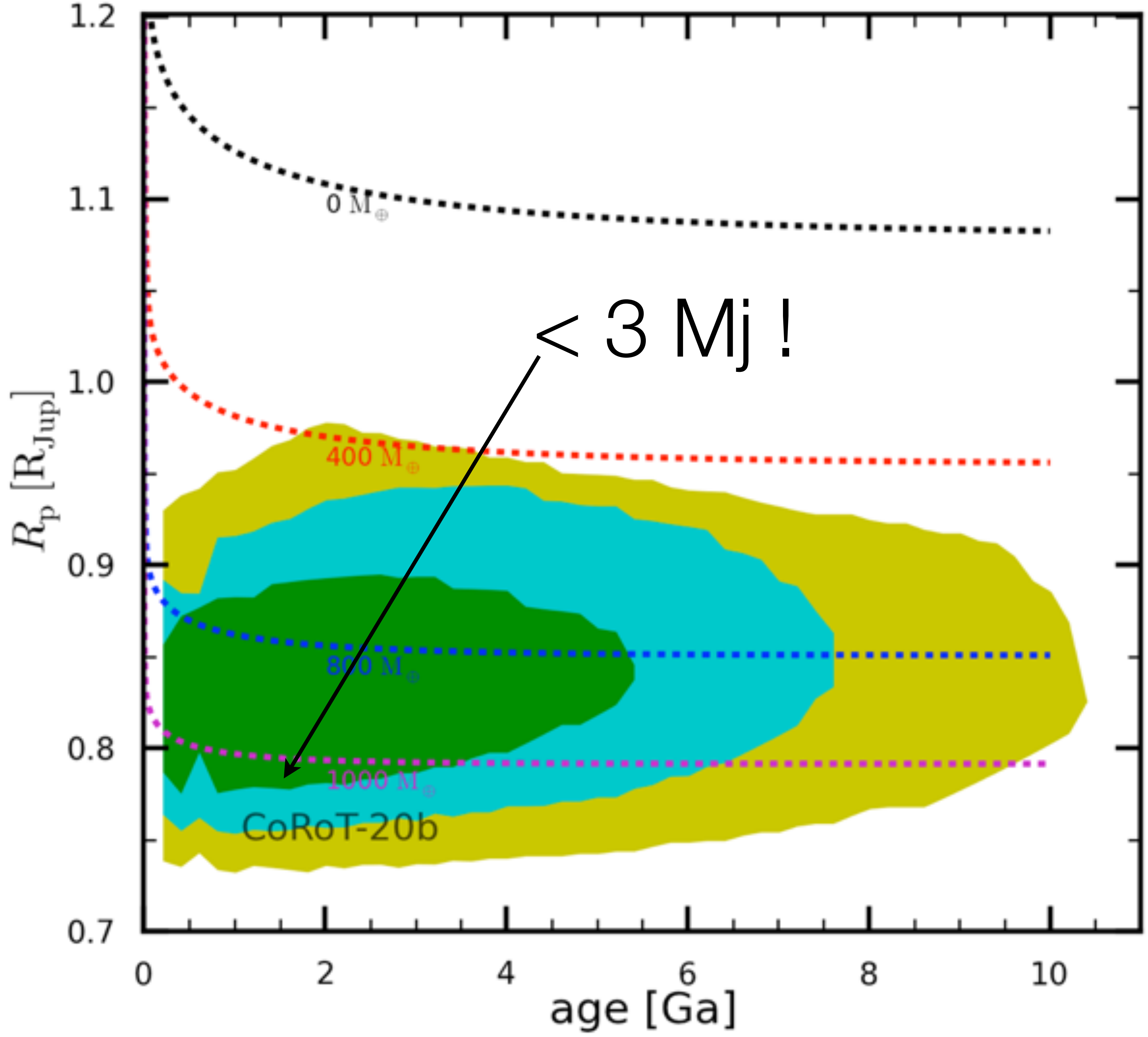


Thanks for your attention

Backup slides

CoRoT superdense planets: CoRoT-20b



< 3 Mj !

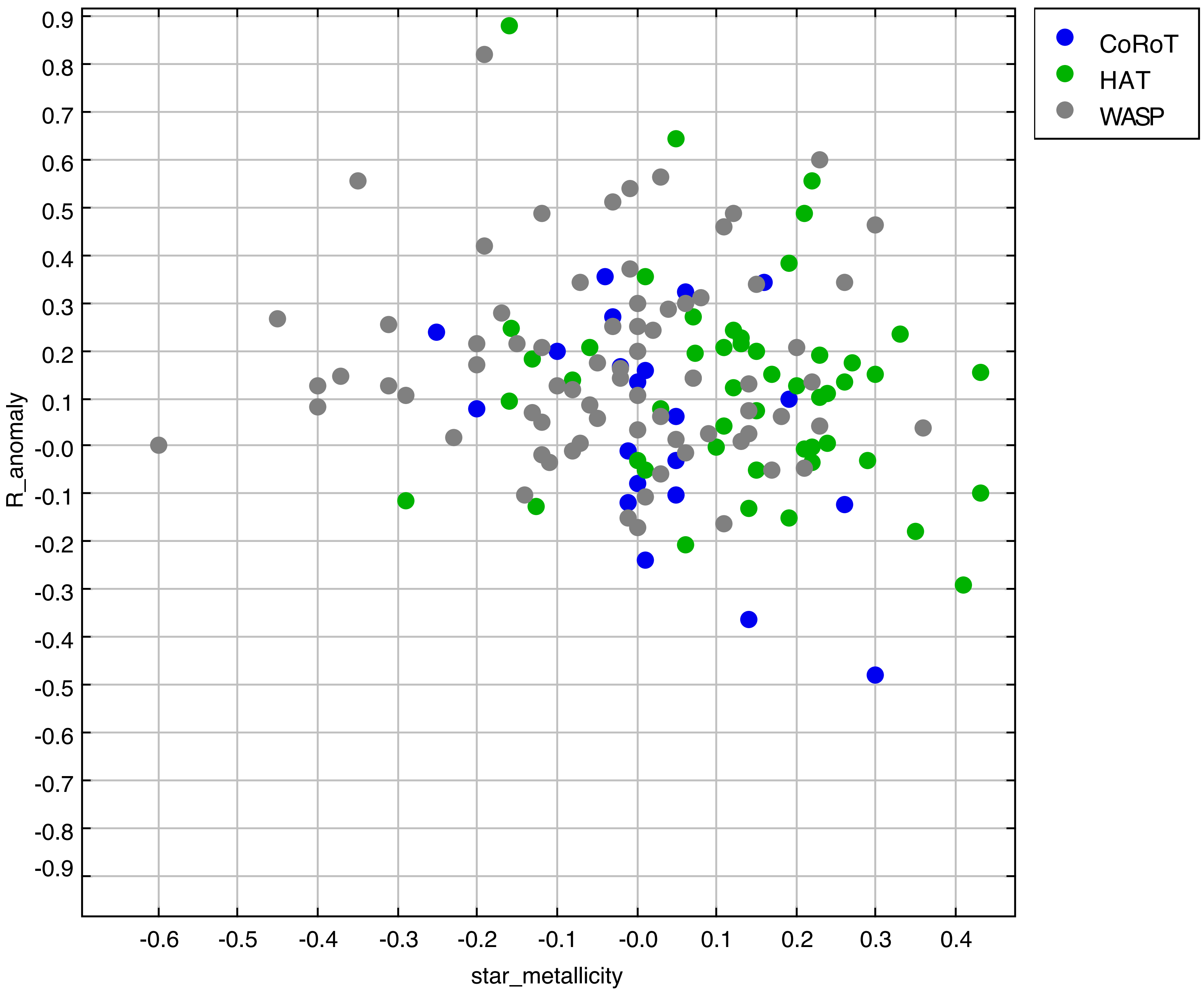
- planet: 4.24 M_{Jup} and 0.84 R_{Jup} (~ 7 × ϱ_{Jup}!)
- star: G2V, 1.14 $M_\odot$ and 1.02 $R_\odot$
- orbit: P ~ 9.2 days; e = 0.56

However, Southworth et al. (2012) derived a much larger radius of 1.16 +/- 0.26 Rj...

Believed to be young: < 1 Ga (Li)

(Deleuil et al. 2012)

Separating data sets…



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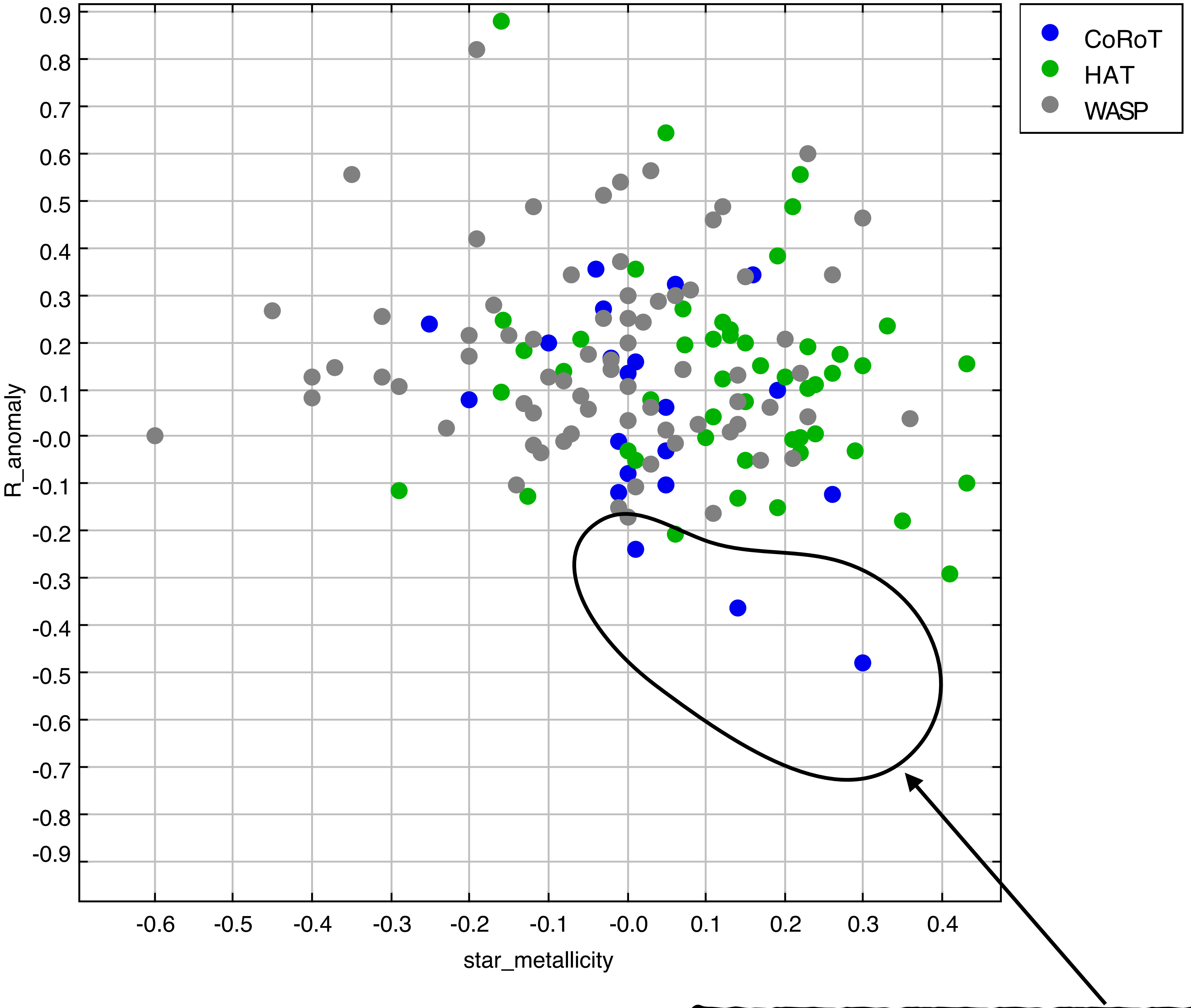

Are we sure of all points?

Separating data sets…