MASS, RADIUS AND COMPOSITION OF 55 Cnc e :

Using interferometry and correlations

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INTRODUCTION

Planet parameters are never as good as star parameters are.

$R_p = R_* \times \sqrt{D}$

$M_p \sin(i) = M_* K (P/2\pi G M_*)^{1/3}$

D = transit depth P = period

K = amplitude of RV signal

The uncertainty on M_* and R_* is often larger than that on K and D, and is too often neglected (or underestimated).

Get M_* and R_* ? From L_* and $T_{eff,*}$, fit stellar evolution models.

Internal error: old vs young solution (e.g. Bonfanti+15), uncertainty.

External error: models differ. Many unknown parameters (Ω, Z...)

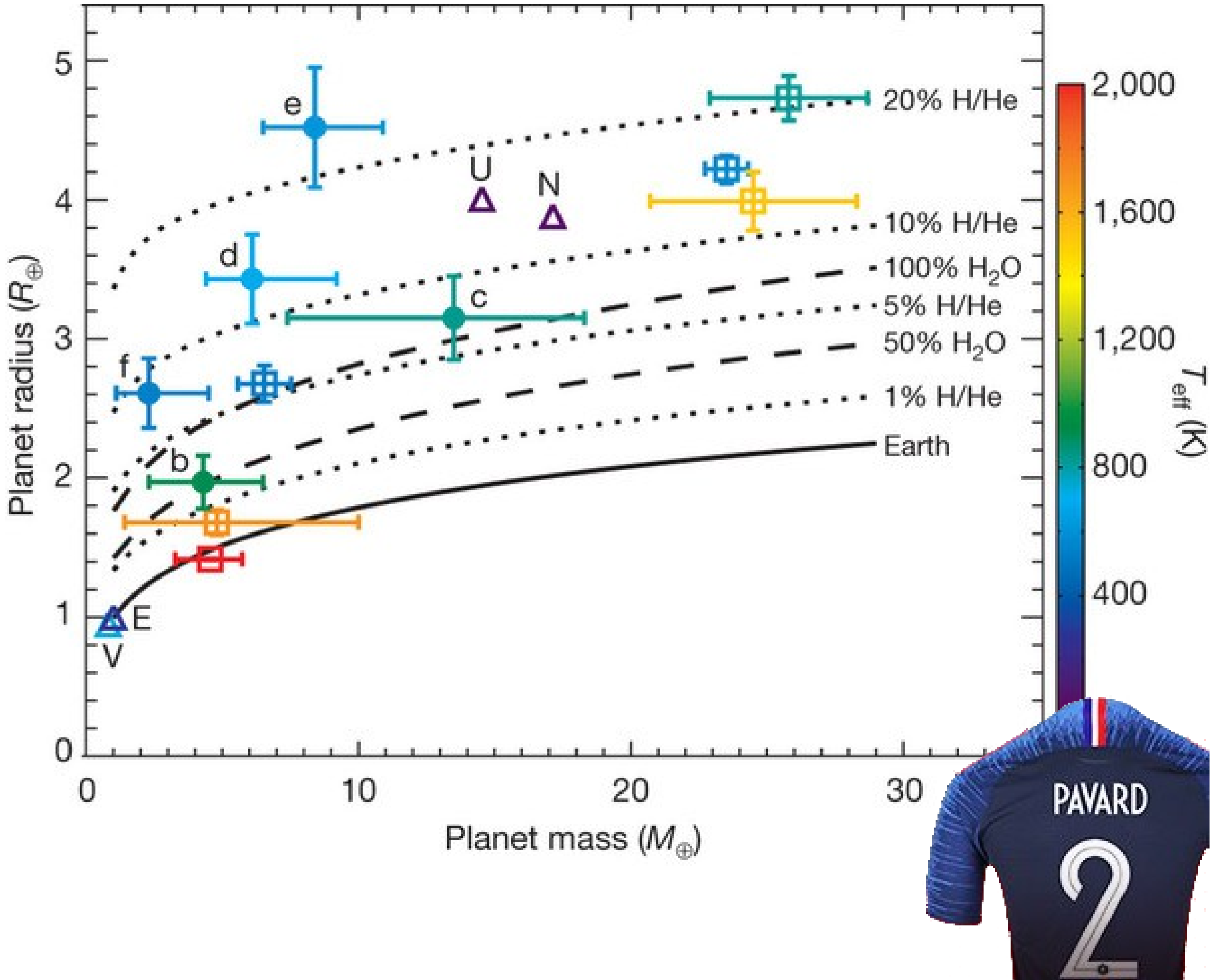
INTRODUCTION

Measure R_* directly: interferometry (e.g.: Ligi et al. 2012, 2015, 2016).

→ angular diameter θ with up to 2% precision.

This parameter constrains efficiently all the others (Creevey et al. 2007).

Here, we want to use this tool to narrow the possible radii, masses, therefore composition of transiting exoplanets.



All the next figures are for 55 Cnc.

A Bayesian approach

Observations: θ, π (parallax), m $\rightarrow$ F_{bol}, the bolometric flux.

$L = 4\, F_{bol}\, (1\ \mathrm{pc} / \pi)^2$

$T_{eff} = (4\, F_{bol} / \sigma\, \theta\,)^{1/4}$

Likelihood

(analytic)

$$\mathcal{L}_{HR}(L,T) = \frac{4\sqrt{\pi/\sigma_{\rm SB}}}{L^{3/2}T^3} \times \int_0^{+\infty} t \times f_{F_{\rm bol}}(t) \times f_{\Pi}\left(\sqrt{\frac{4\pi t}{L}}\right) \times f_{\theta}\left(\sqrt{\frac{4\,t}{\sigma_{\rm SB}\,T^4}}\right)\,\mathrm{d}t$$

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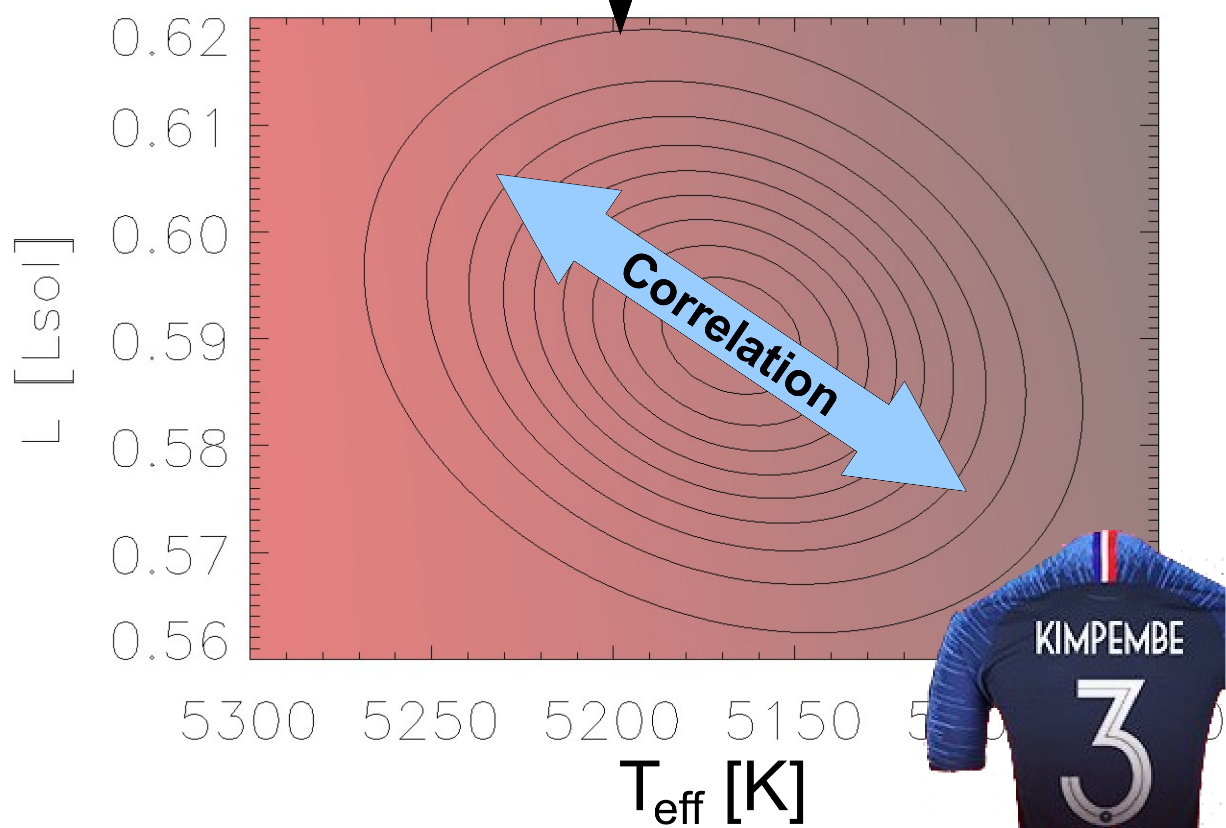
level curves

Prior: density of stars in the HR diagram of the Hipparcos sample (color).



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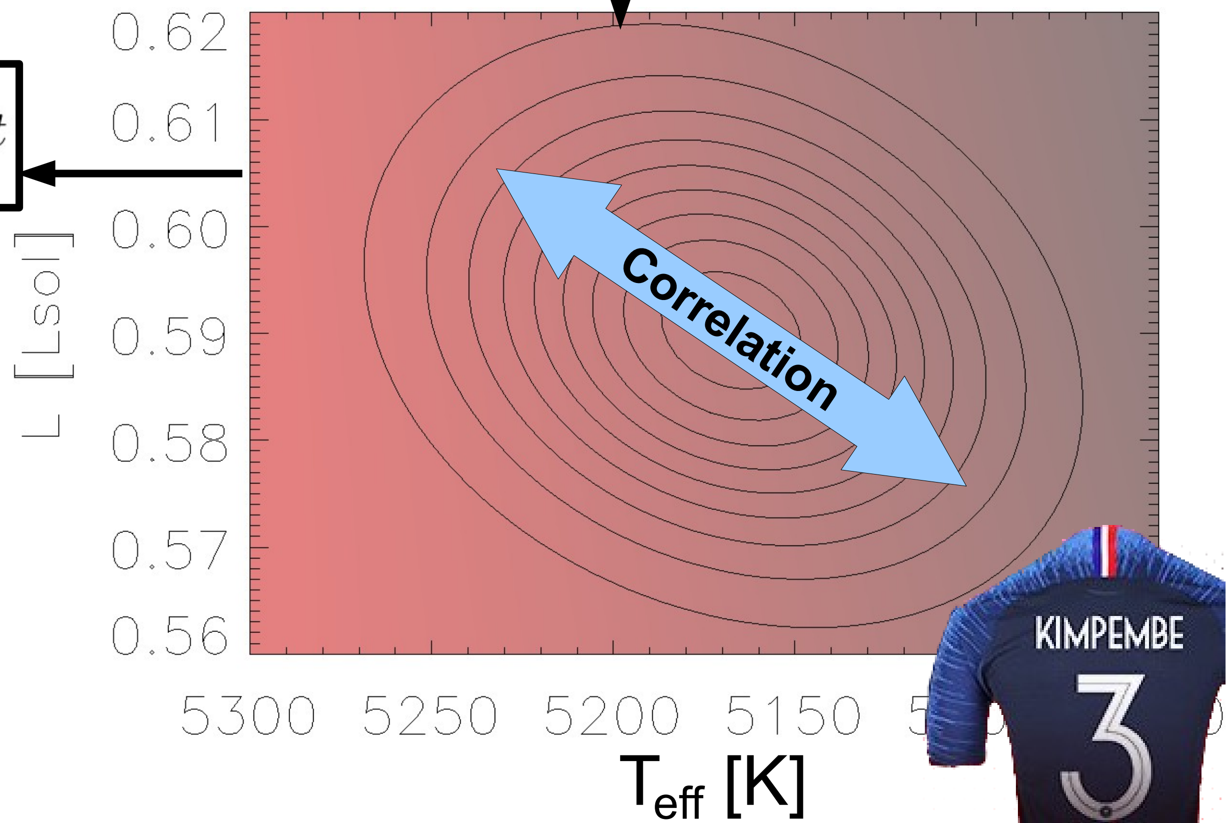
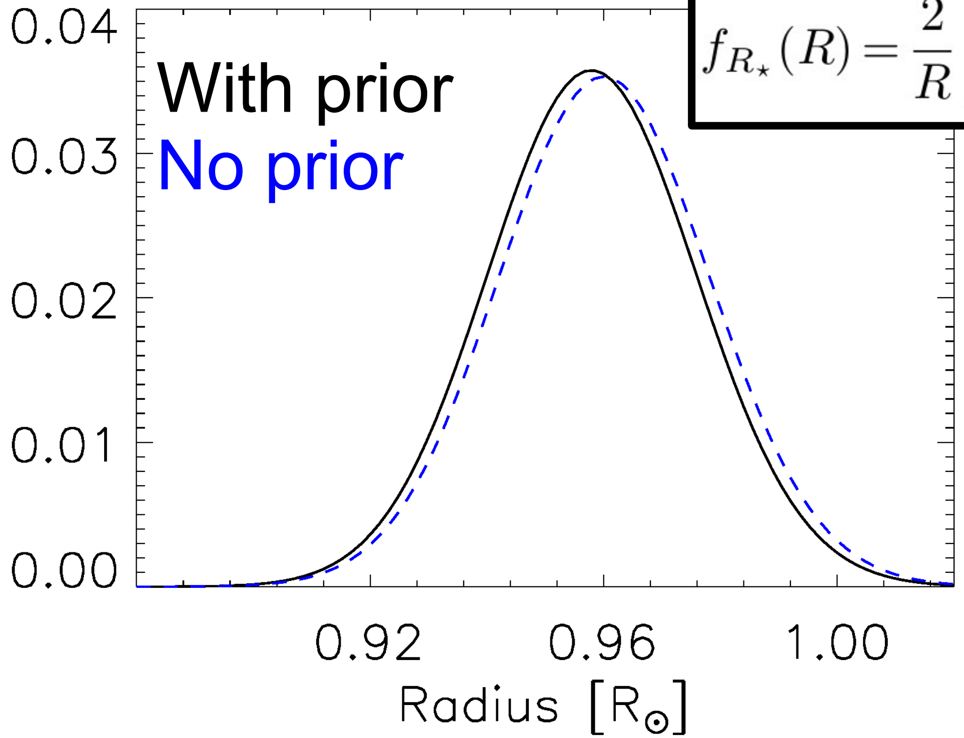


$$f_{R_\star}(R) = \frac{2}{R}\int_{t=0}^{\infty} L_{(R,t)}\, f_{HR}(L_{(R,t)}, t)\,{\rm d}t$$



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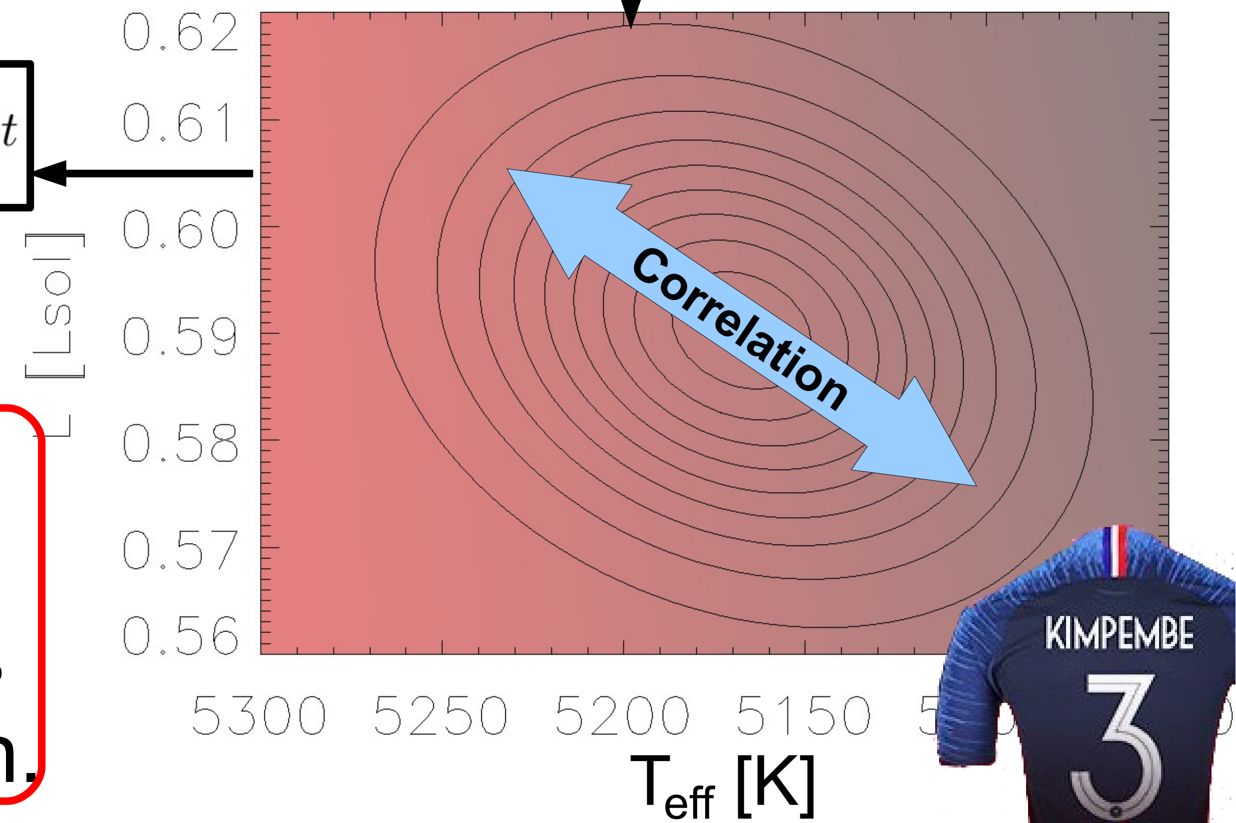

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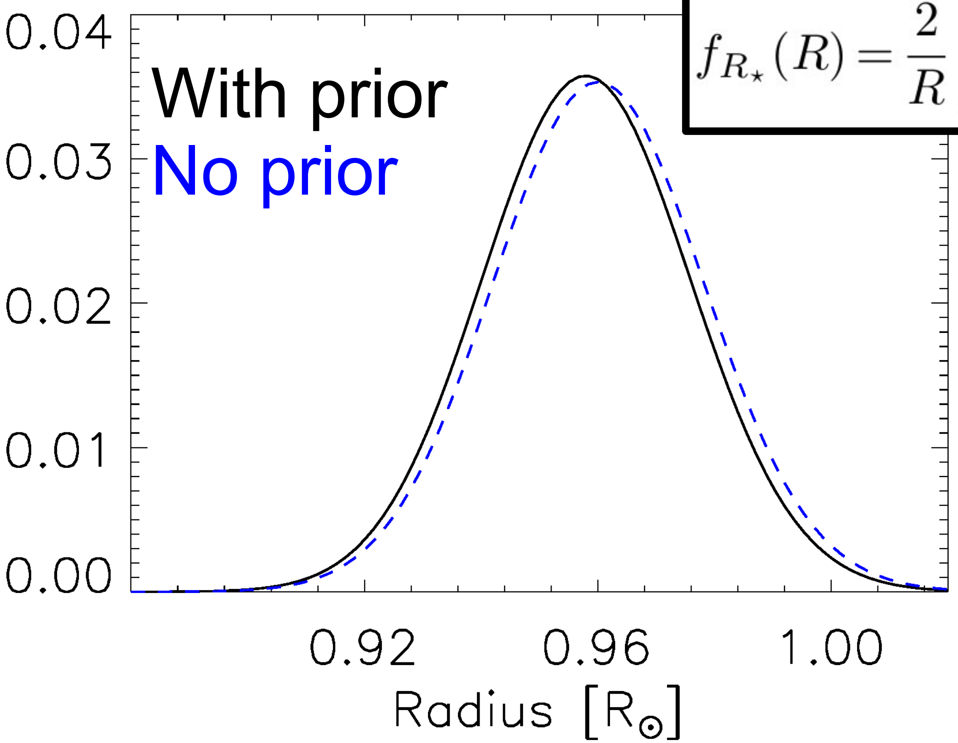
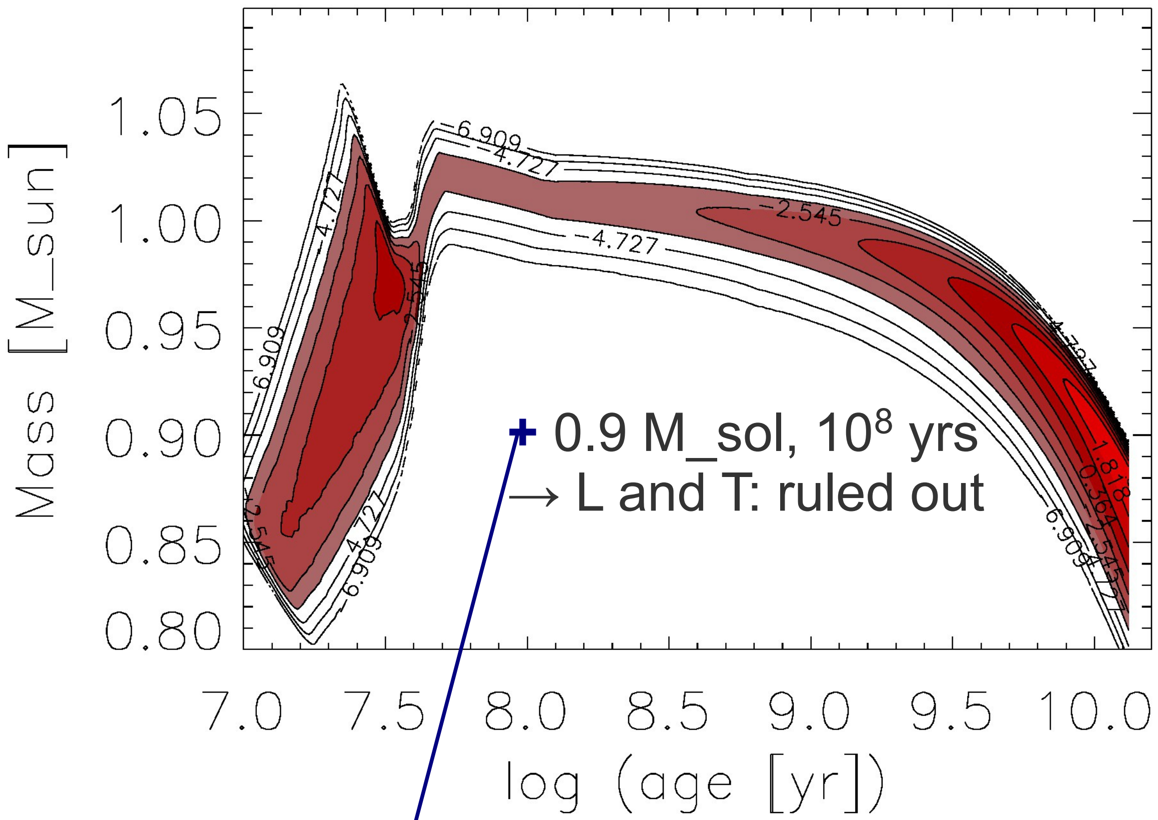


Interferometry is precise !
The prior does not bring much.

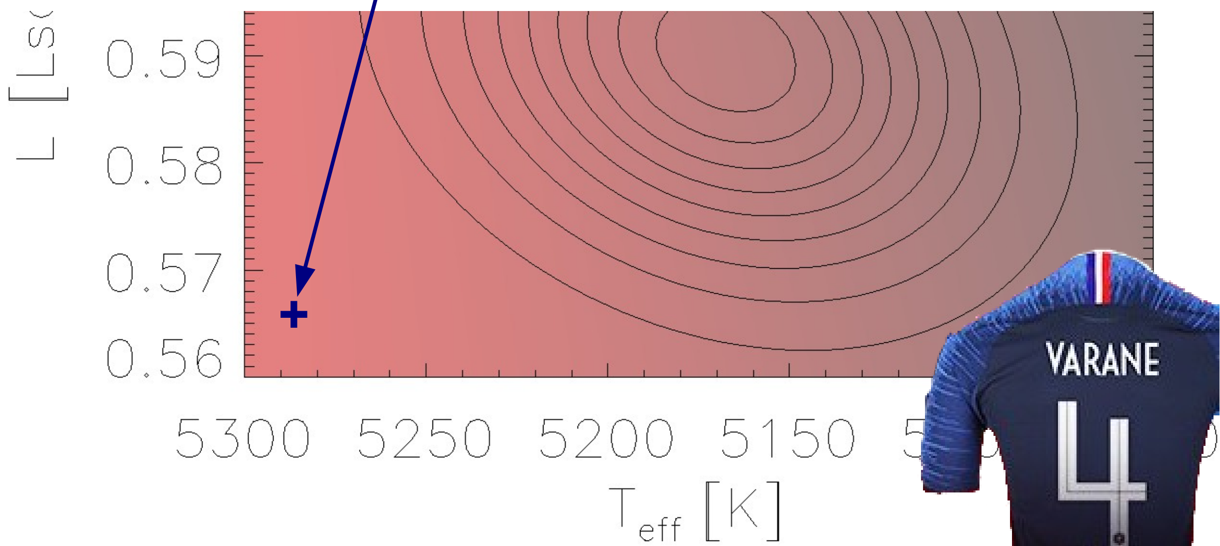
Stellar models ?

Fit stellar evolution models on the L-T distribution → mass and age.



<u>Results :</u>

a) For each model, 2 solutions
(young and old, see Ligi et al. 2016).



b) Different params in the model → different, inconsistent solutions :

CES2MO (Lebreton & Goupil 2014) gives M_* from 0.950 +/- 0.015

to 0.989 +/- 0.020 M_{sun} .

Direct Probability Density Function : the Star

Transit duration: $T = 2\,R_* / a\Omega$. Period: $P = 2\pi / \Omega$.

$\rightarrow P/T^3 = (\pi^2 G/3)\,\rho_*$ $\rightarrow$ *measure* of the stellar density.

(Seager & Mallén-Ornelas 2003)

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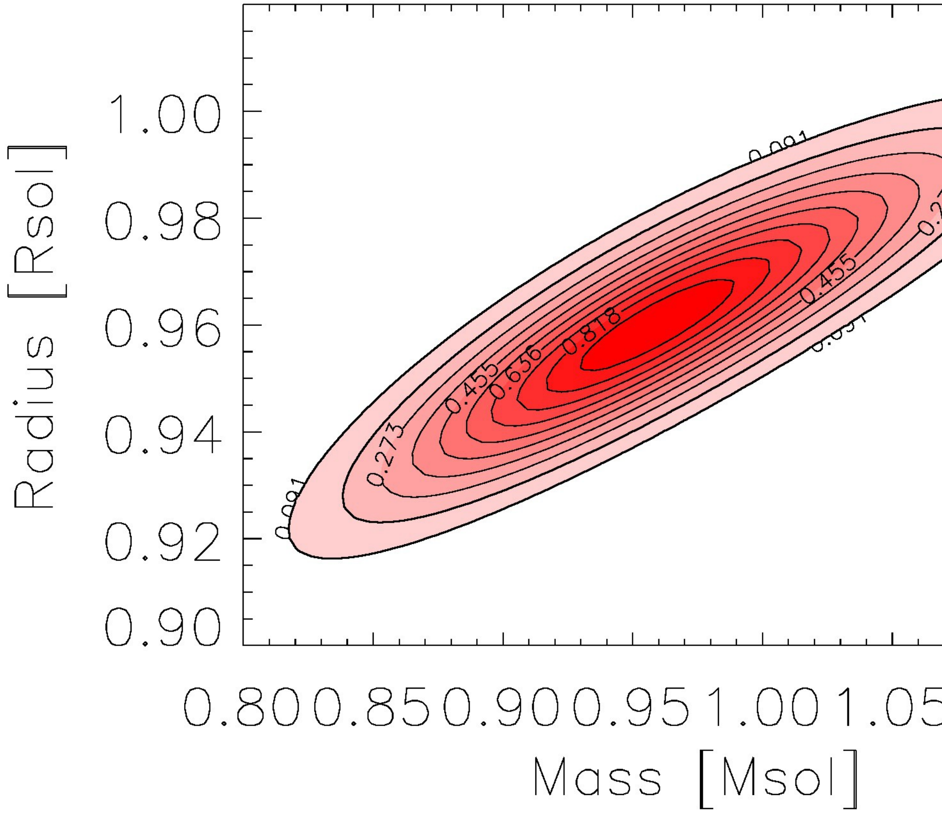
Measure of R_* by interferometry → $M_* = (4\pi/3) R_*^3\, \rho_*$ (Ligi+ 2016)

From the PDF of R_* and ρ_* ,

analytic joint PDF of M_* - R_* .

$$\mathcal{L}_{MR\star}(M,R) = \frac{3}{4\pi R^3} \times f_{R_\star}(R) \times f_{\rho_\star}\left(\frac{3M}{4\pi R^3}\right)$$



- → Strong correlation (0.85) !
- → Different M_* than VonBraun et al. (2011) based on isochrones.

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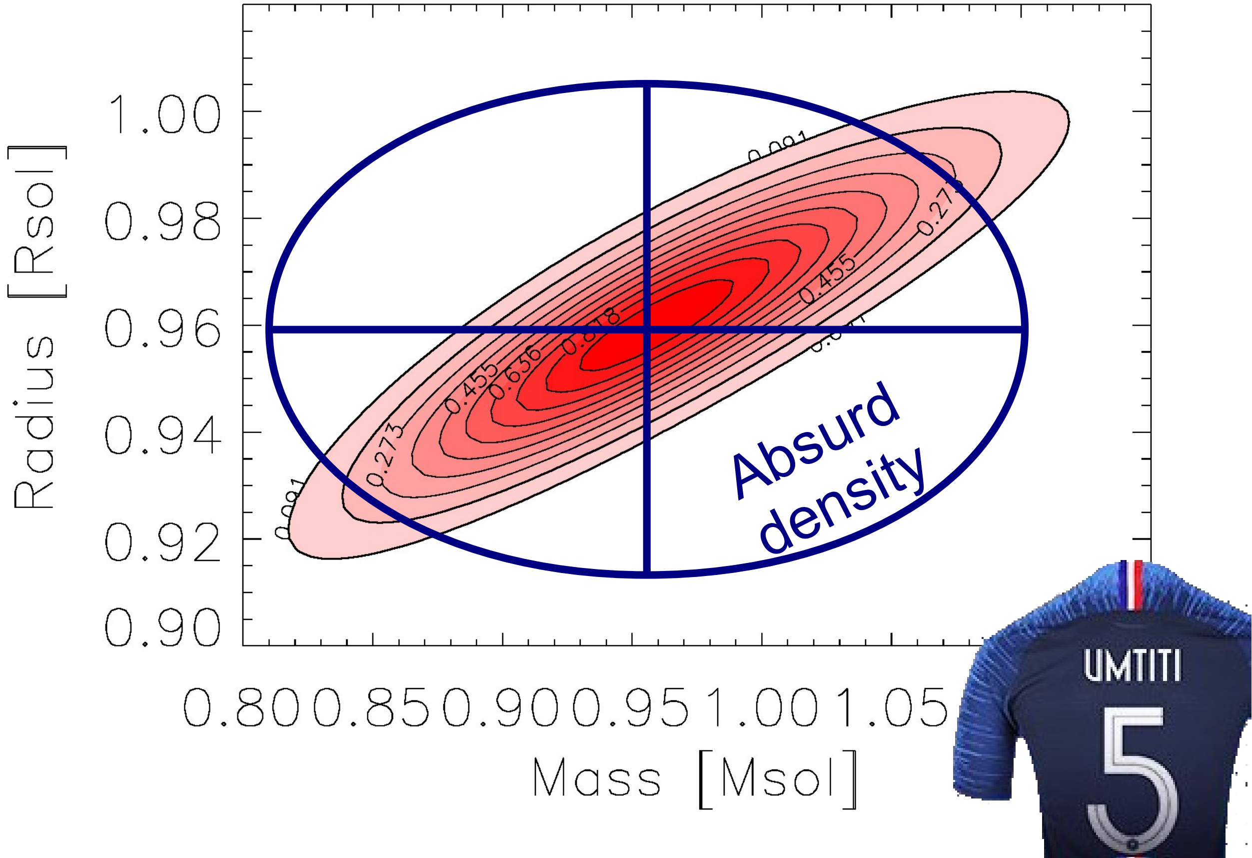
Taking the values of M_* and R_* directy from Ligi+16, one gets the large, wrong, blue ellipse.



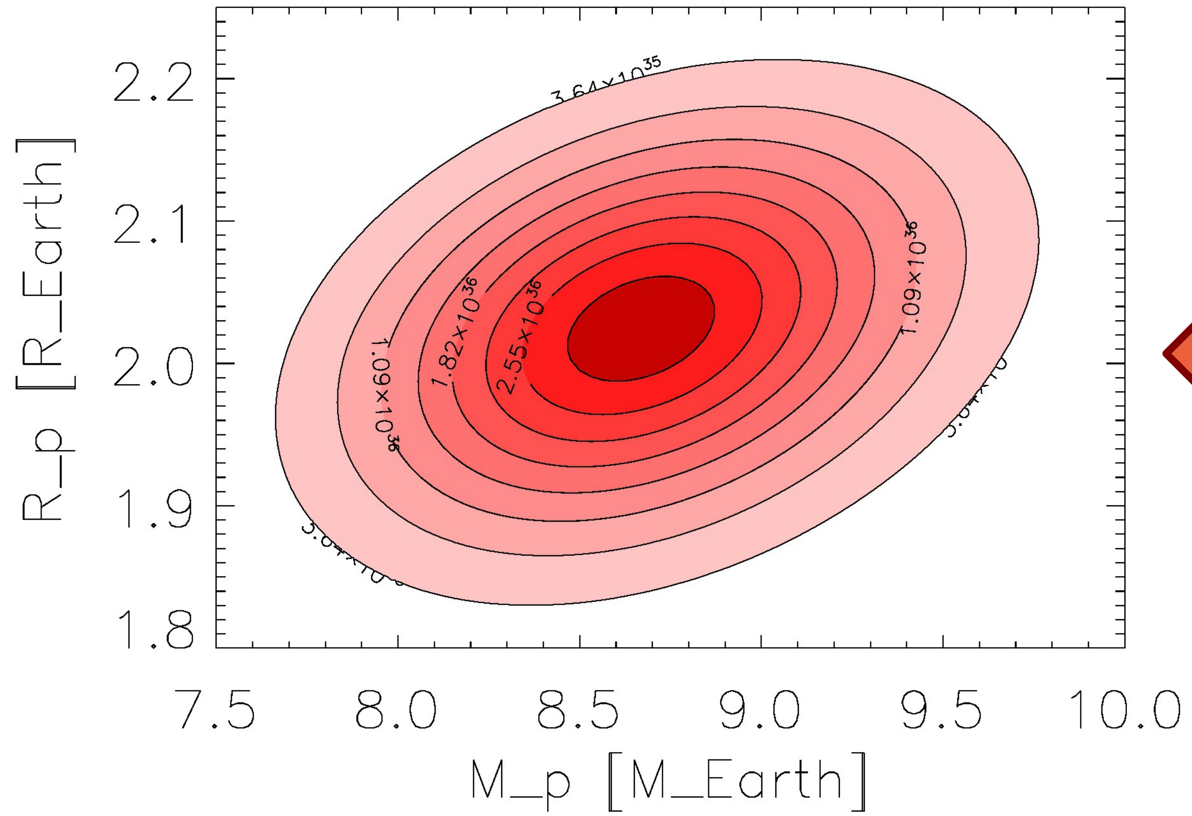
Direct Probability Density Function : the planet

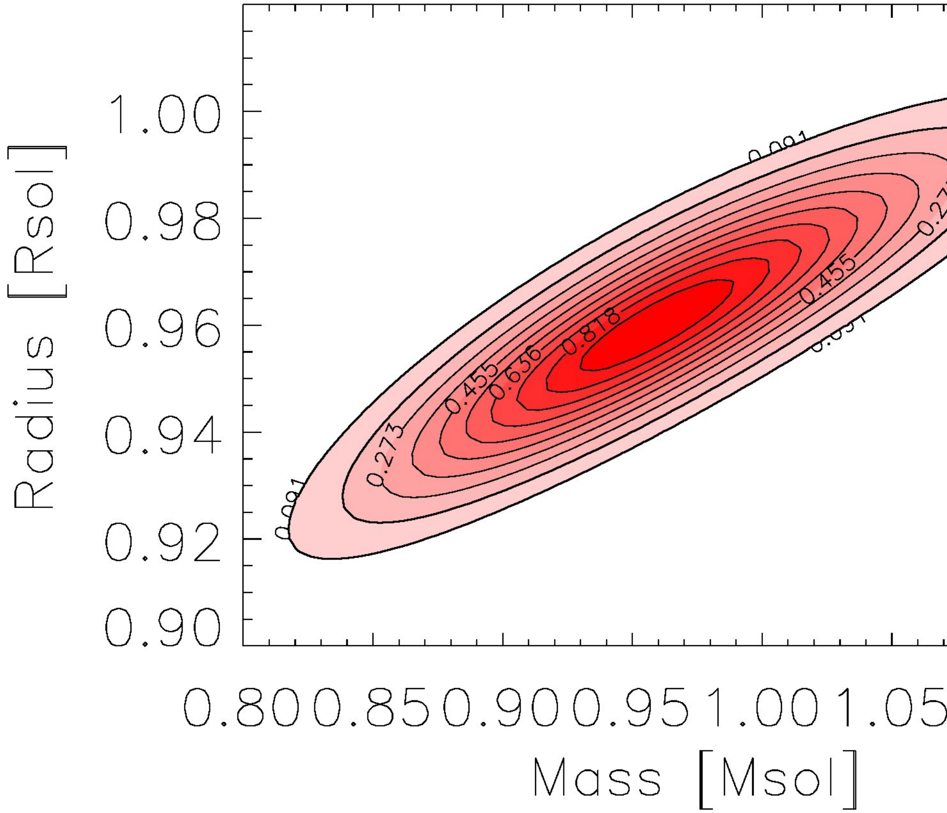
$R_p = R_* \times \sqrt{D}$

$M_p \sin(i) = M_* K (P/2\pi G M_*)^{1/3}$

→ Analytic PDF of ρ_p .

→ Joint PDF of $M_p - R_p$.





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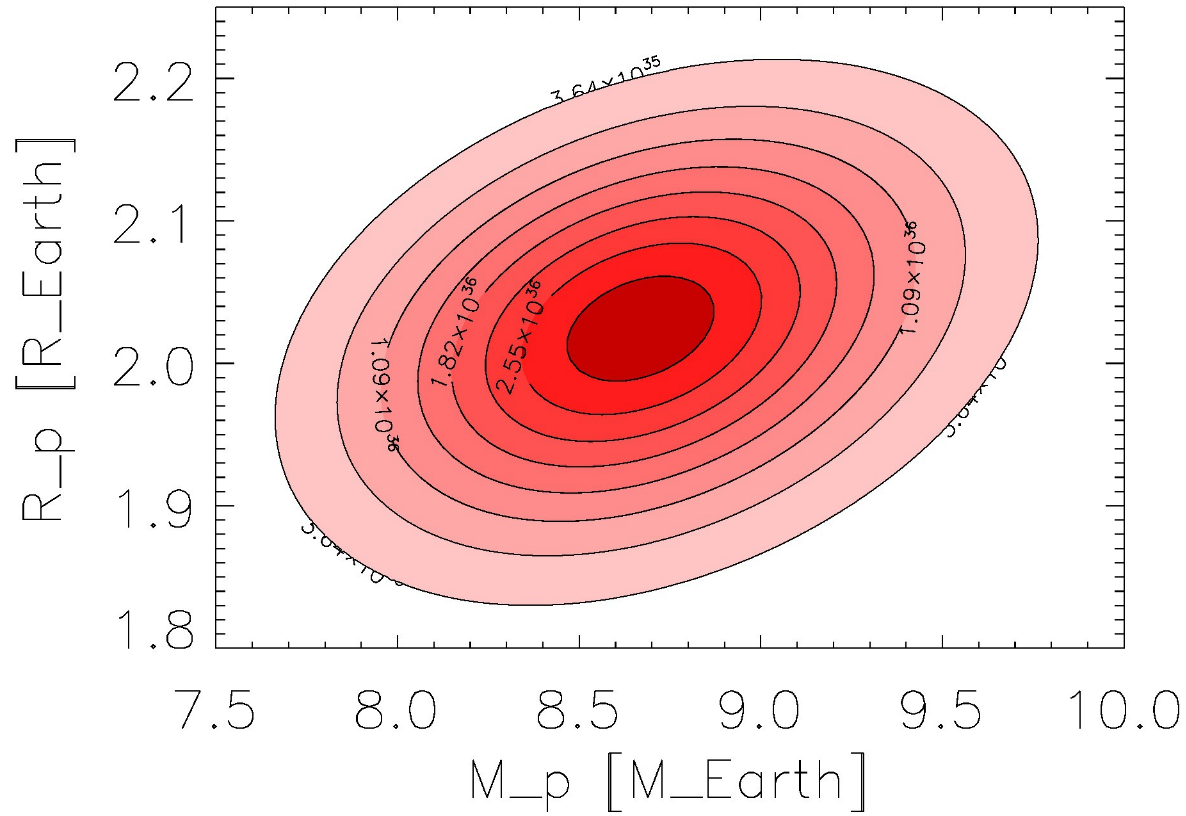

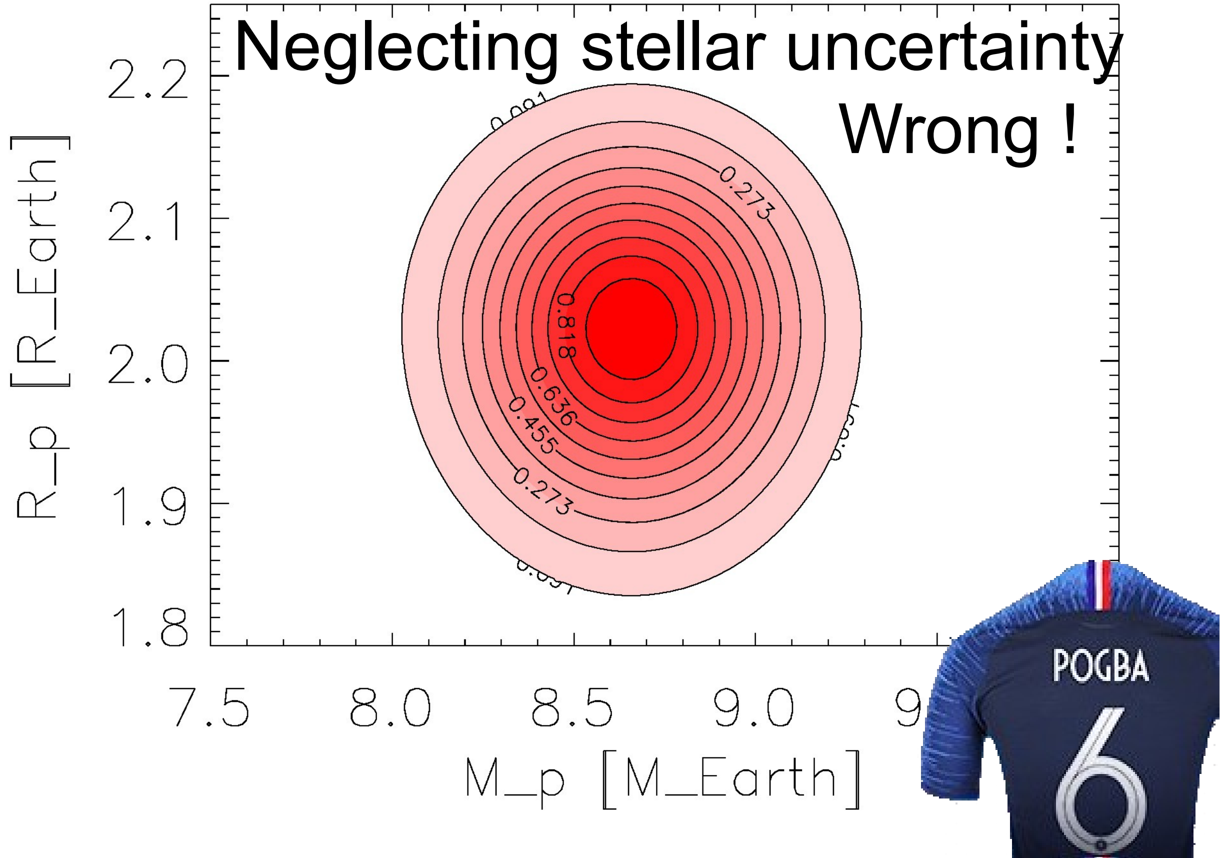

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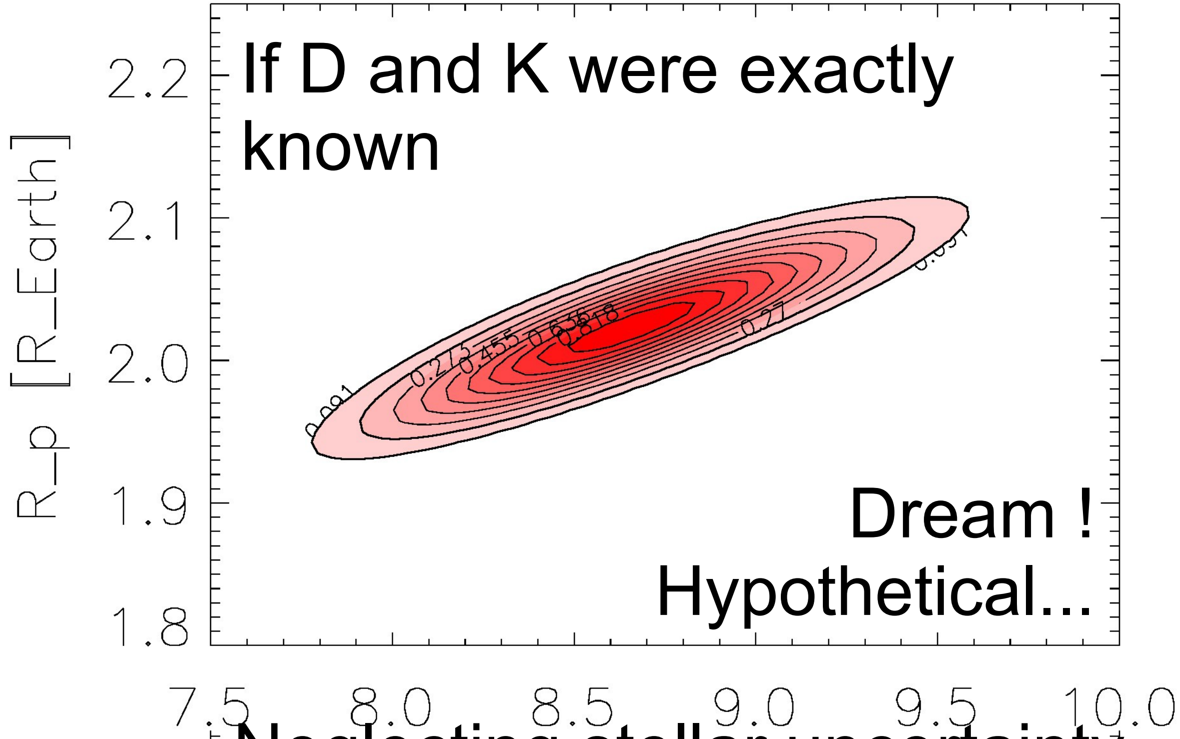
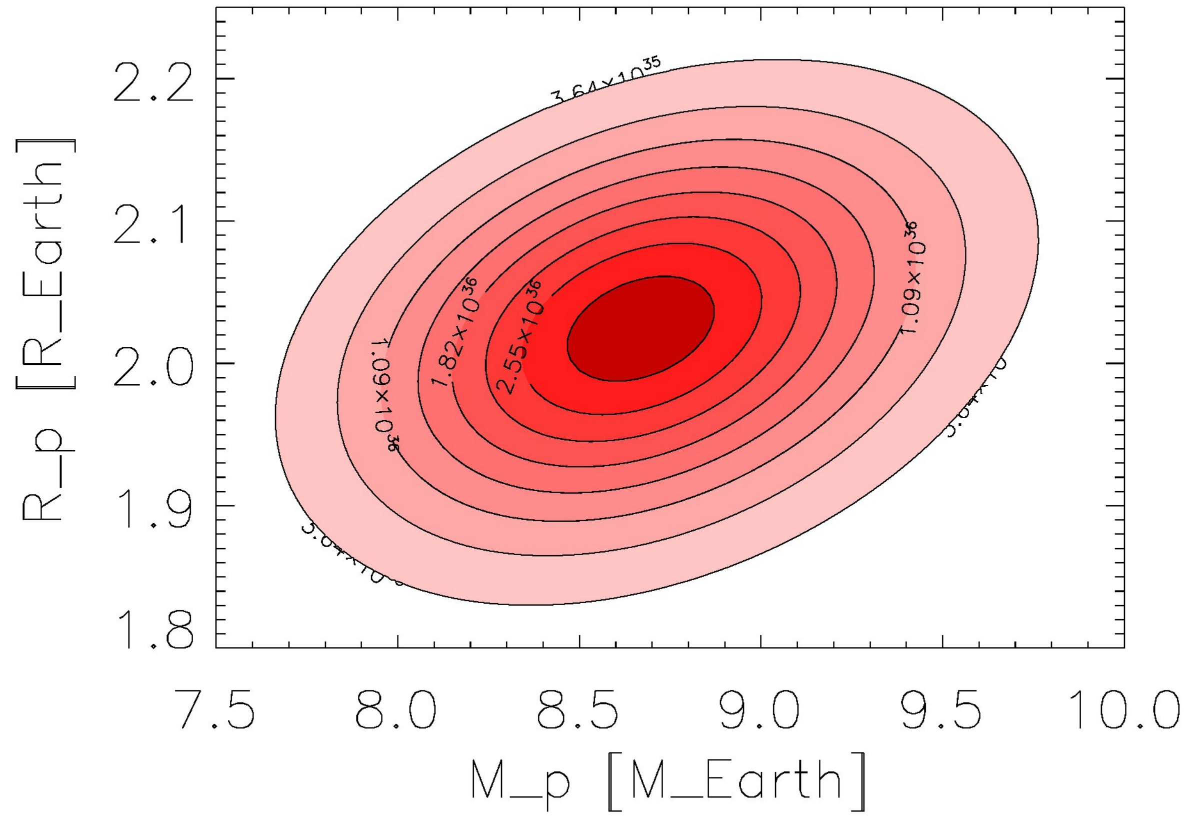
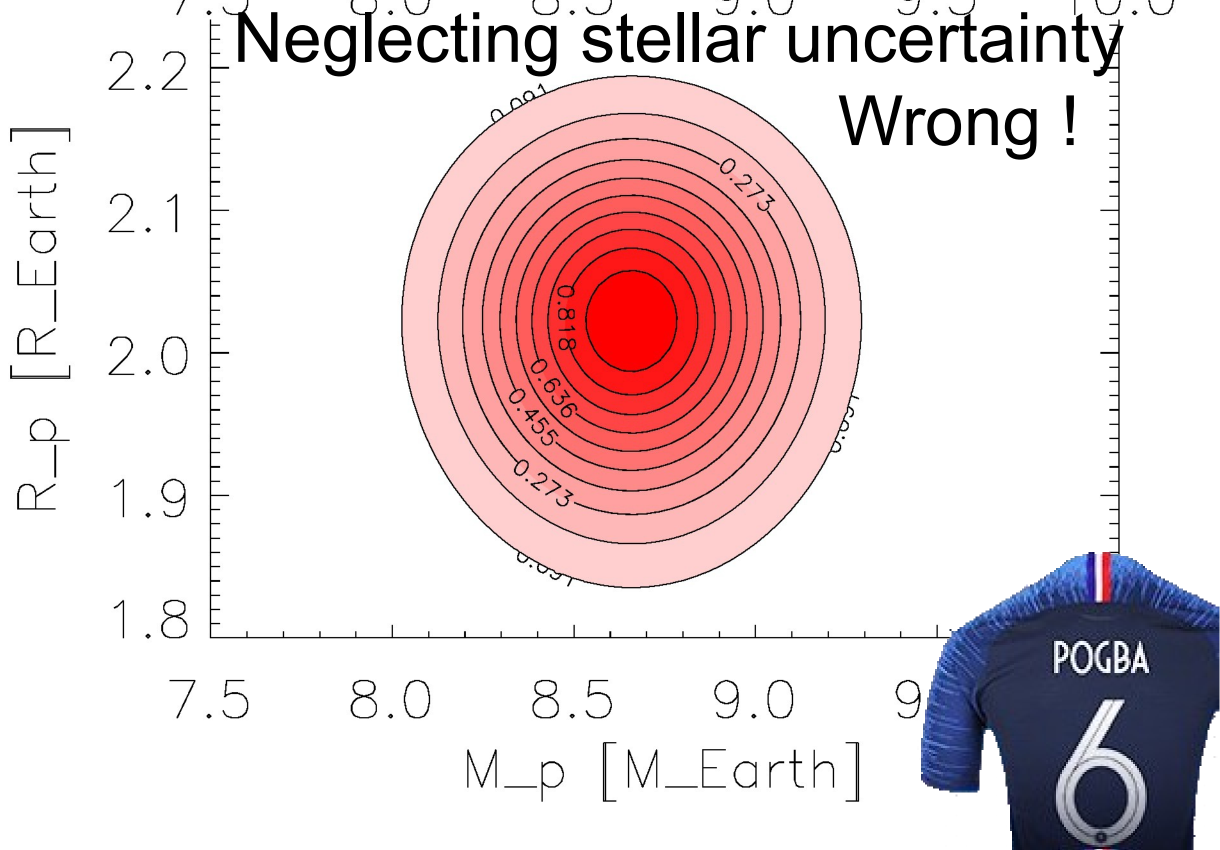






Application : composition of 55 cnc e

Internal structure model developed by Dorn et al. (2017).

Input :

Original data : M_p, R_p (uncorr.), a, L*.

Correlation between M_p and R_p (0.30).

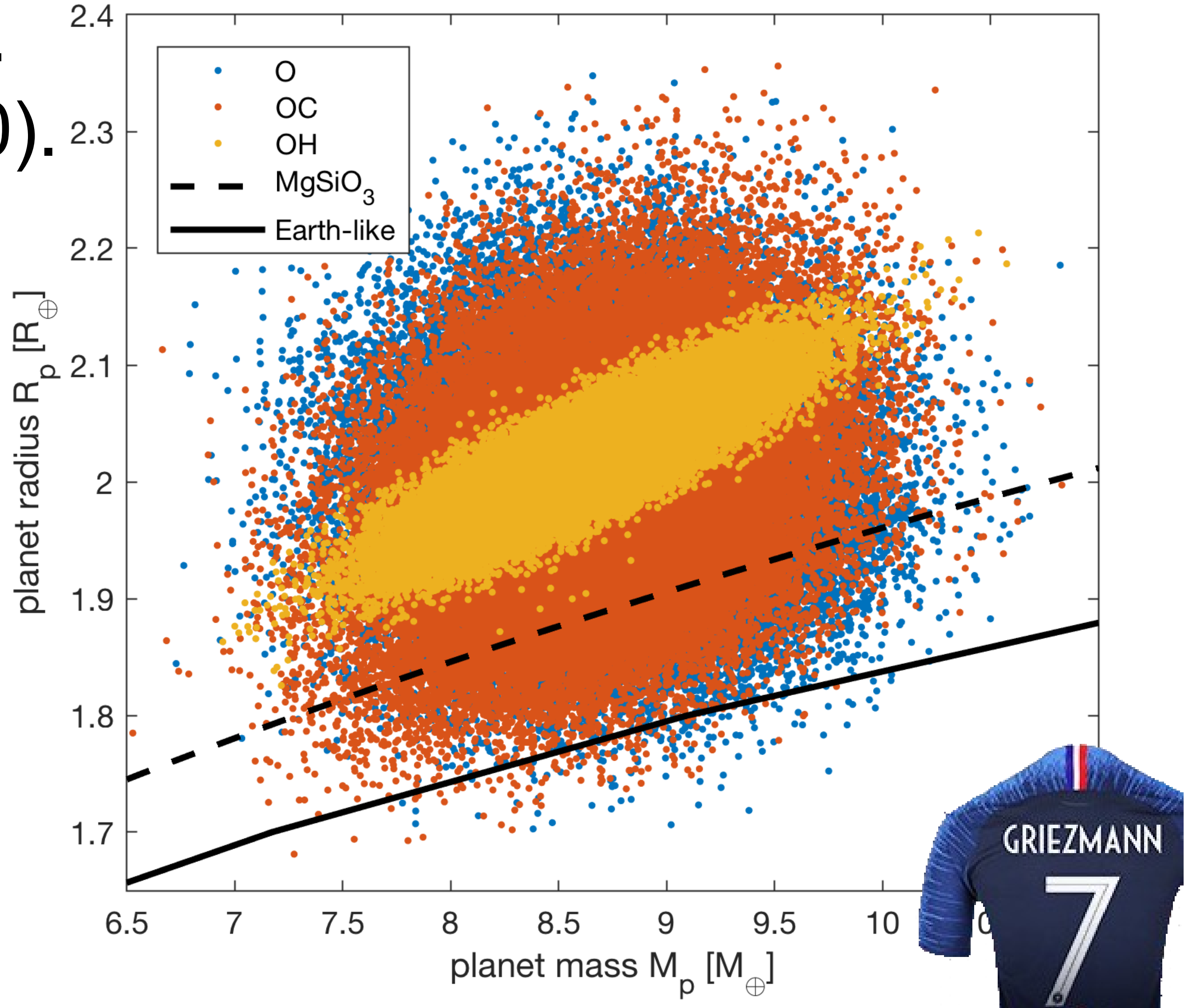
Hypothetical correlation (0.85).

Abundances : stellar Fe/Si, Mg/Si.

Output :

PDF (or CDF) of all the internal parameters.

We test the importance of the various data O, C, H, A.



Application : composition of 55 cnc e

Input :

Original data

Correl. M_p-R_p (0.30)

Hypothetical corr. (0.85)

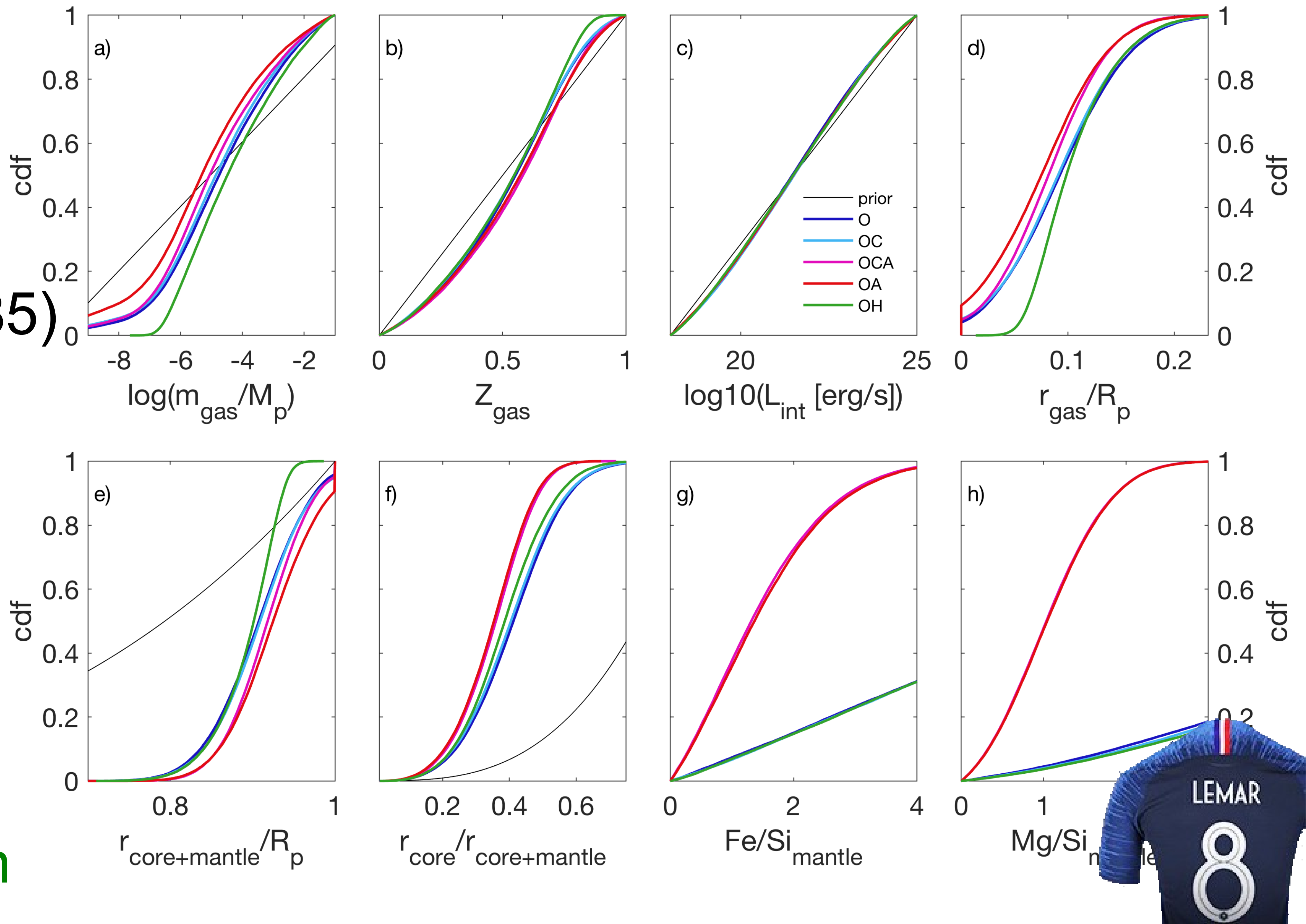
Abundances

Results :

A → composition of the mantle

C → gas layer

H → could rule out pure solid composition



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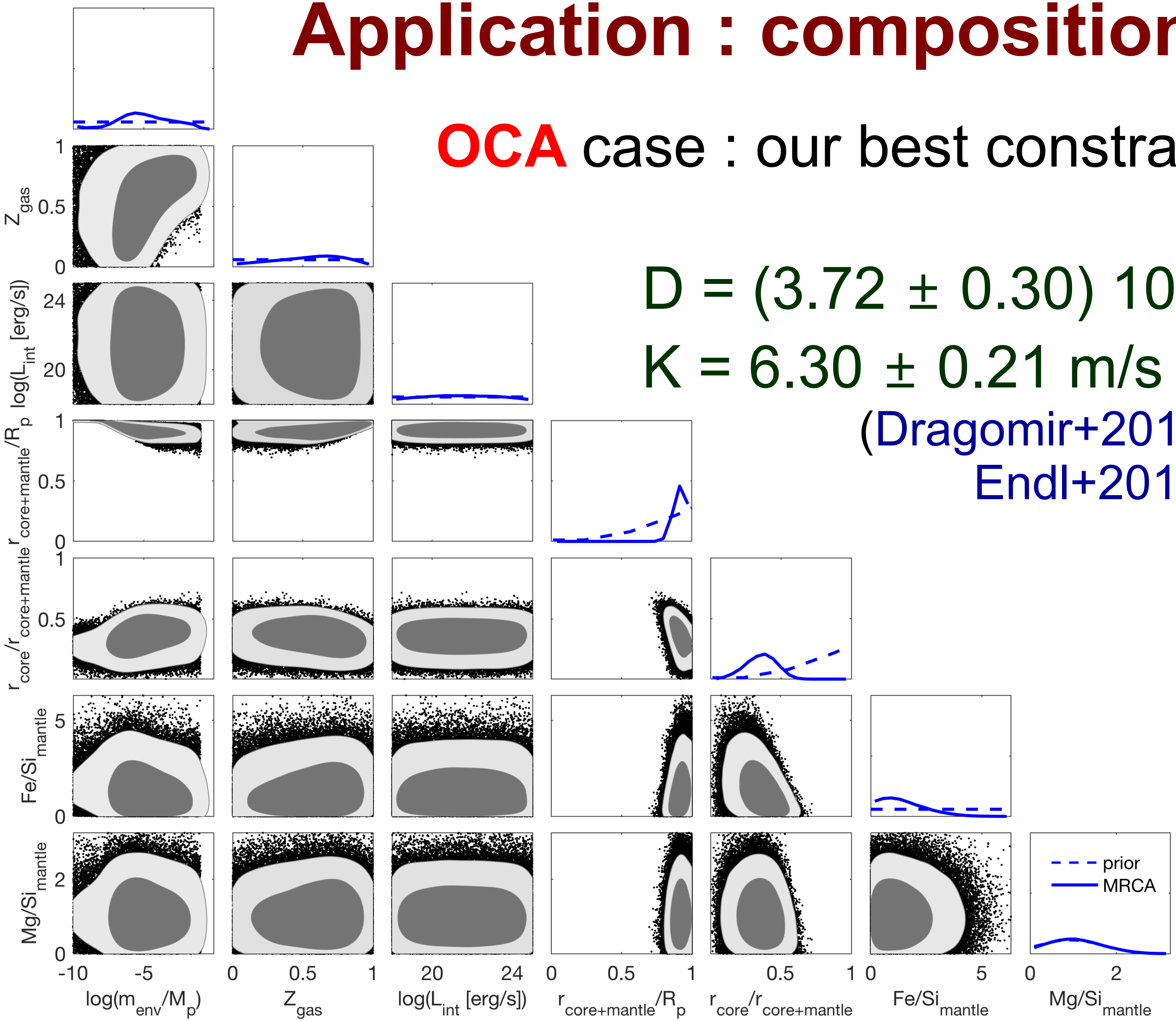


OCA case : our best constrains on all the parameters.

D = (3.72 ± 0.30) 10^{-4}

K = 6.30 ± 0.21 m/s

(Dragomir+2014, Endl+2012)

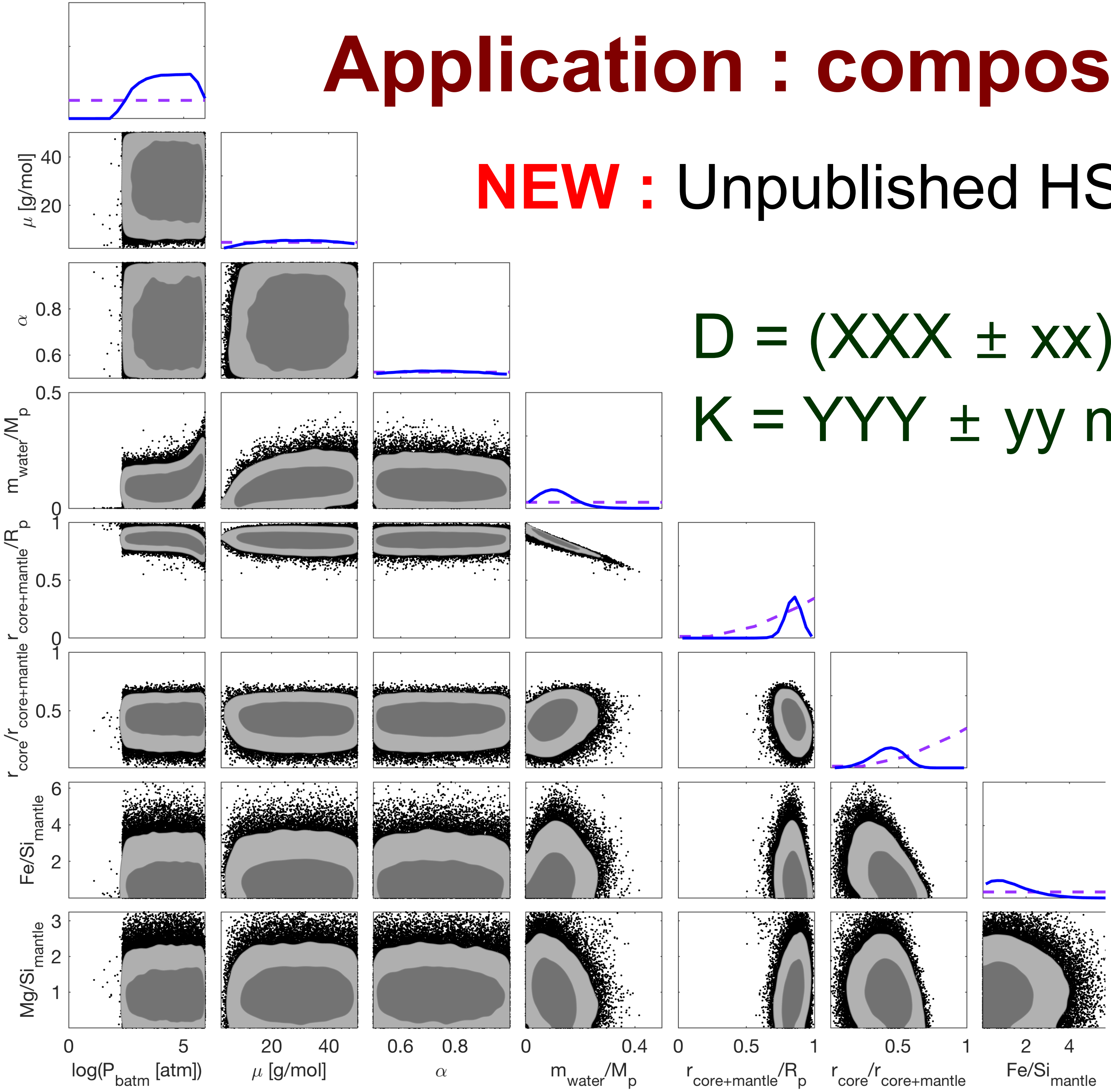
interior parameter	OCA
$\log_{10}(m_{gas}/M_p)$	$-5.07^{+2.14}_{-1.61}$
Z_{gas}	$0.58^{+0.22}_{-0.30}$
$\log_{10}(L_{int})$	$21.49^{+2.13}_{-2.14}$
r_{gas}	$0.08^{+0.05}_{-0.05}$
$r_{core+mantle}/R_p$	$0.92^{+0.05}_{-0.05}$
$r_{core}/r_{core+mantle}$	$0.36^{+0.10}$ [illegible]
Fe/Si_{mantle}	1.[illegible]
Mg/Si_{mantle}	1.[illegible]

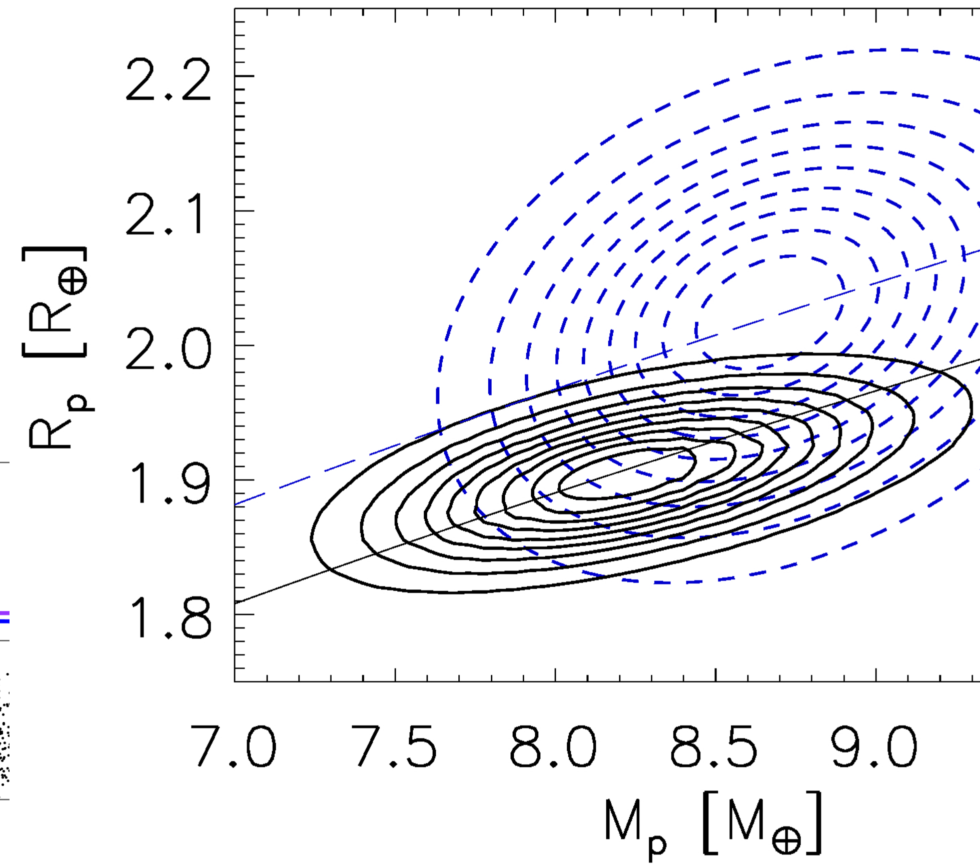
Application : composition of 55 cnc e

NEW : Unpublished HST observations (Bourrier+, accepted)

$D = (XXX \pm xx)\ 10^{-4}$

$K = YYY \pm yy$ m/s





CONCLUSION

1) Do not trust too small error bars: stellar parameters are killers !

2) Measuring the radius of a star with a transiting exoplanet provides the mass and the mass-radius correlation.

3) Use as many constraints as possible : stellar abundances, M-R correlation...
→ Aim for better estimates of K and D for stronger correlations.

Ref : Crida, Ligi, Dorn & Lebreton (2018, ApJ)

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4) ALLEZ LES BLEUS !

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