INTERFEROMETRY & EXOPLANETS

PLATO STESCI Workshop
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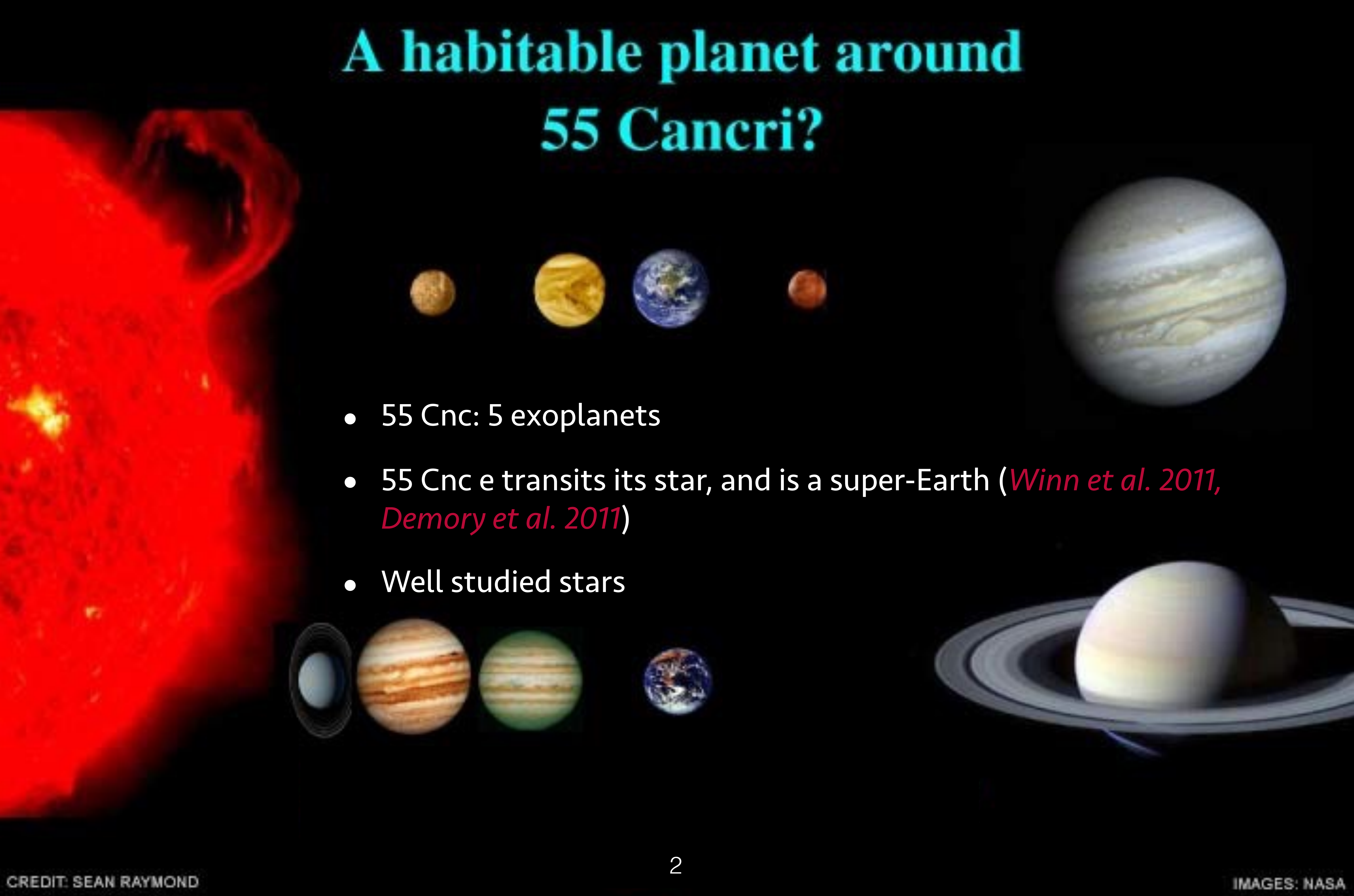
Osservatorio Astronomico di Brera INAF

Astro FIt 2 Astronomy Fellowships in Italy

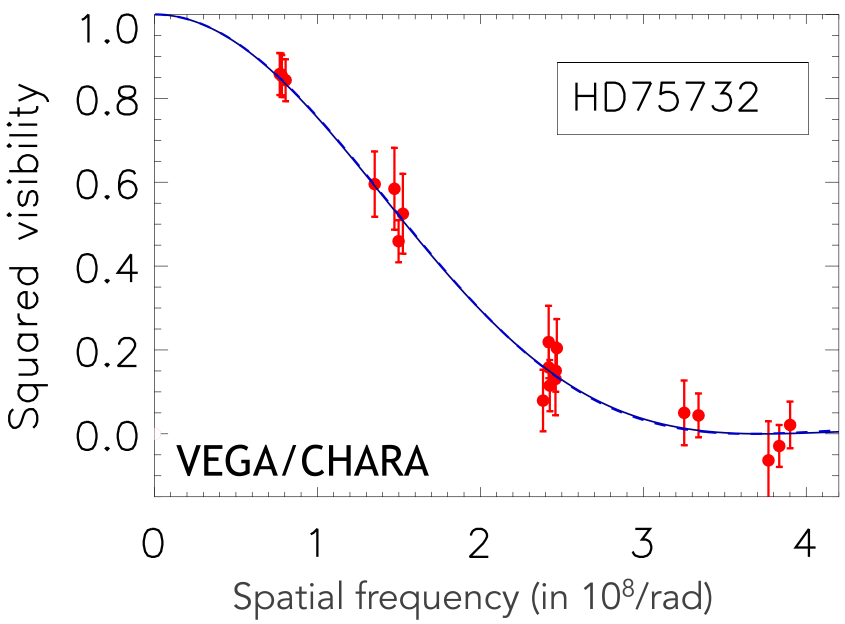
55 CNC AND ITS TRANSITING EXOPLANET

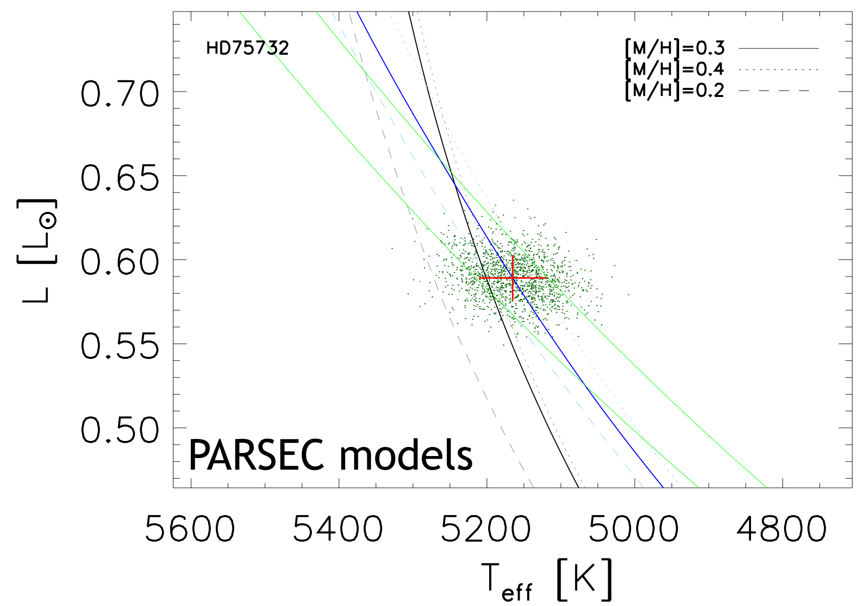


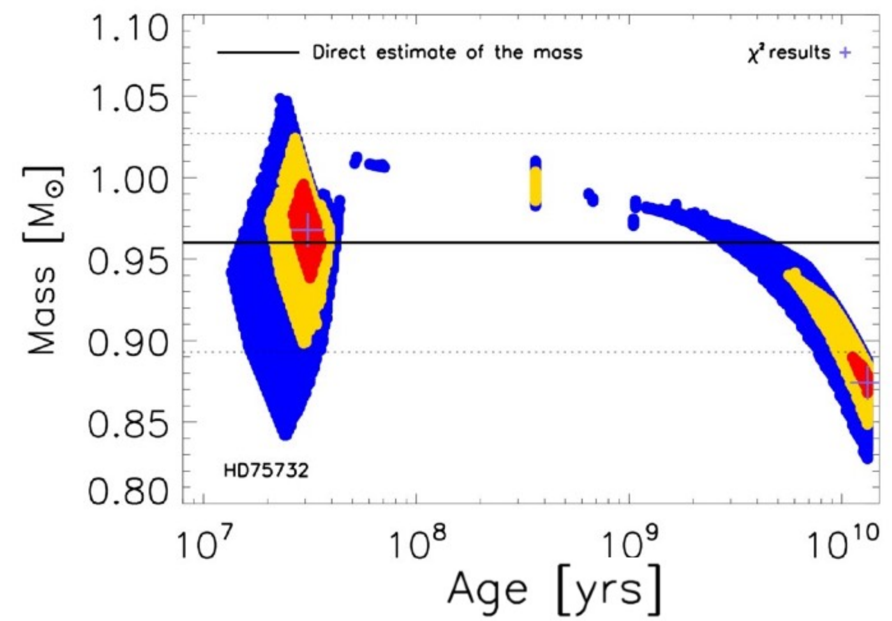
- 55 Cnc: 5 exoplanets
- 55 Cnc e transits its star, and is a super-Earth (*Winn et al. 2011, Demory et al. 2011*)
- Well studied stars

Interferometric observations

55 CNC AND ITS TRANSITING EXOPLANET







- From isochrones: 2 solutions
  - **Young solution**: $M_\star$ = 0.968 ± 0.018 $M_\odot$, 30.0 ± 3.028 Myrs
  - **Old solution**: $M_\star$ = 0.874 ± 0.013 $M_\odot$, 13.19 ± 1.18 Gyrs

Stellar parameters

55 CNC AND ITS TRANSITING EXOPLANET

Transit duration: $T = 2R_\star / a\Omega$

Period: $P = 2\pi/\Omega$

→

$$P/T^3 = (\pi^2 G/3)\,\rho_\star$$

measure of stellar density $\rho_\star$ **(Maxted et al. 2015, Seager & Mallén-Ornelas 2003)**

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Stellar parameters

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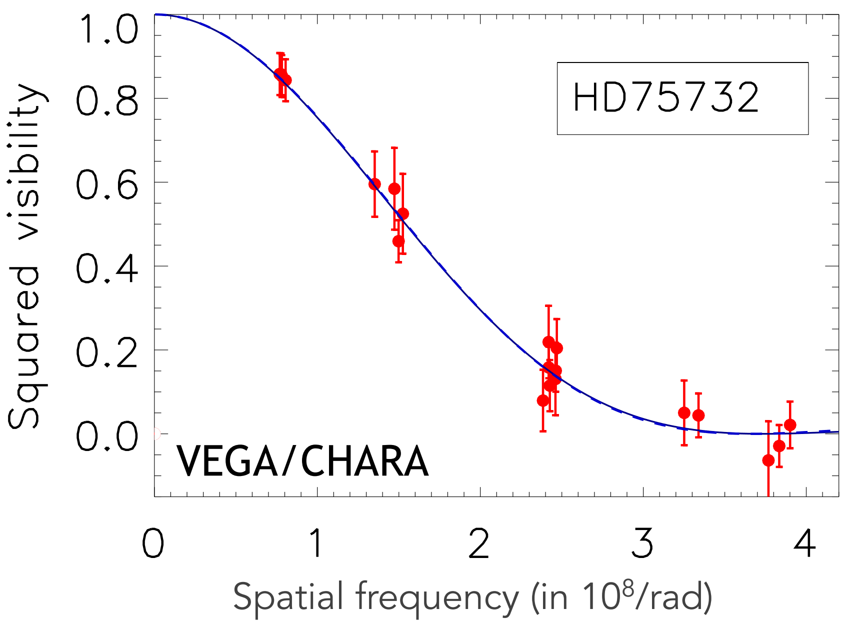

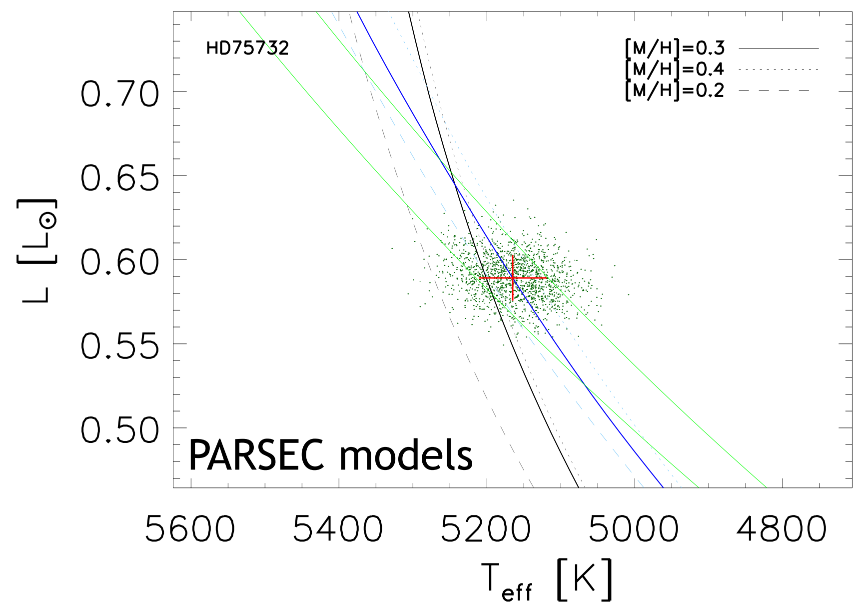

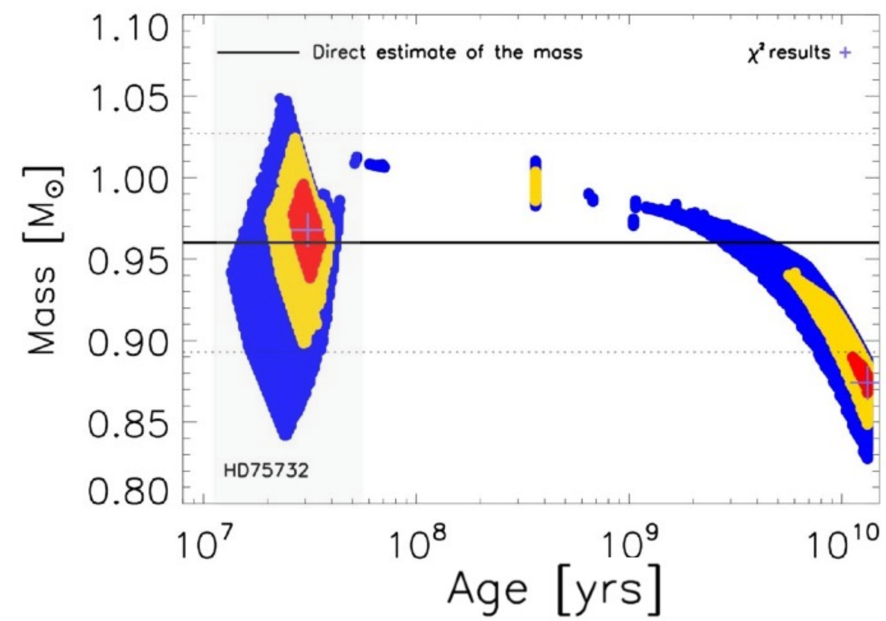

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  - **Old solution**: $M_\bigstar = 0.874 \pm 0.013\ M_\odot$, 13.19 ± 1.18 Gyrs
- Using the stellar density + interferometric radius: $M_\bigstar = 0.96 \pm 0.067\ M_\odot$

Stellar parameters

55 CNC: A BAYESIAN APPROACH

Crida, Ligi, Dorn & Lebreton, arXiv:1804.07537.
Crida & Ligi, EPSC 2017

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

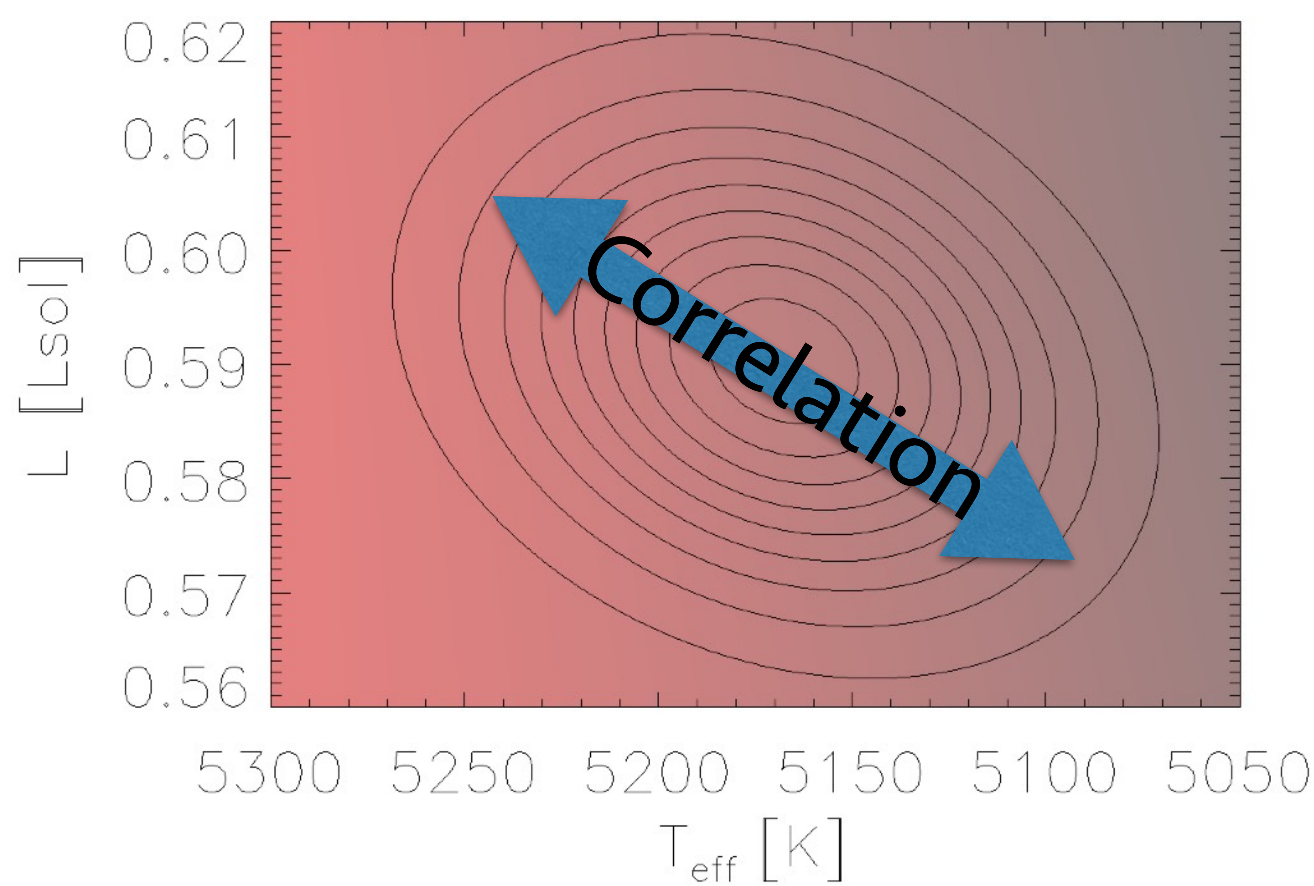
$L = 4\, F_{bol}\, (1_{[pc]} / \pi)^2$
$T_{eff} = (4\, F_{bol} / \sigma_{SB}\, \theta\,)^{1/4}$

} → Likelihood (analytic)

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

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

level curves



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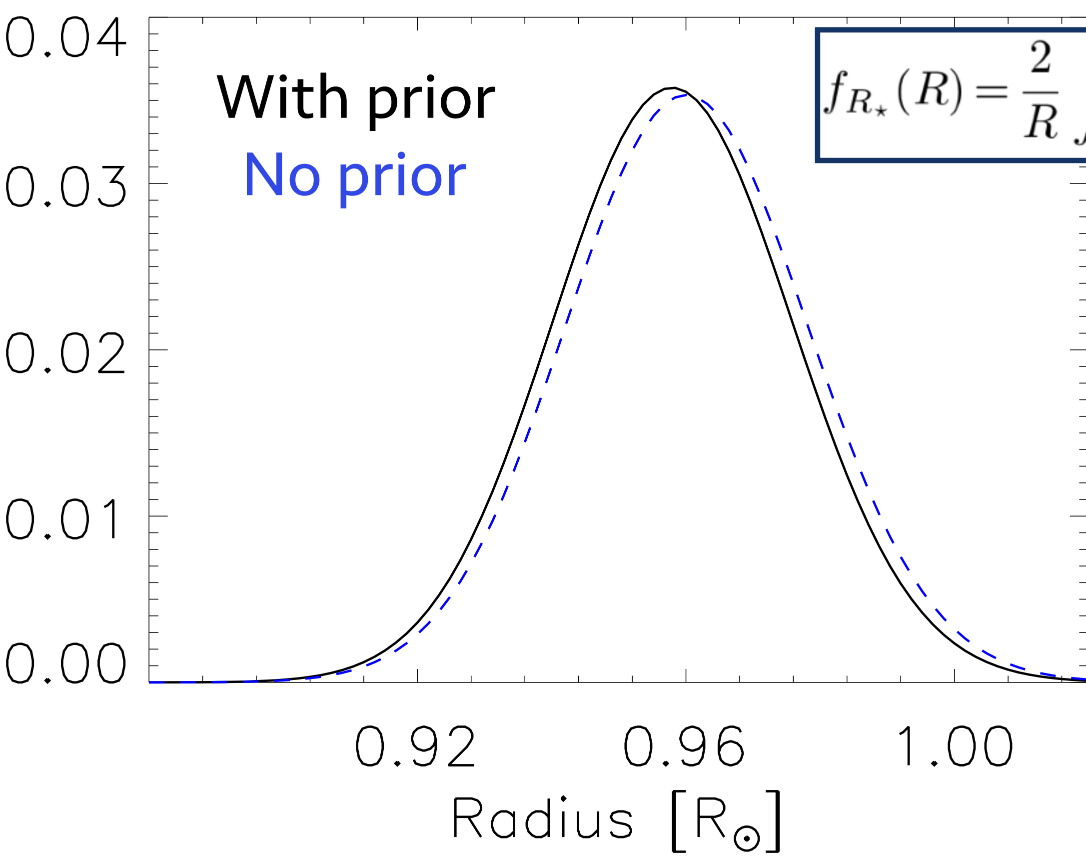
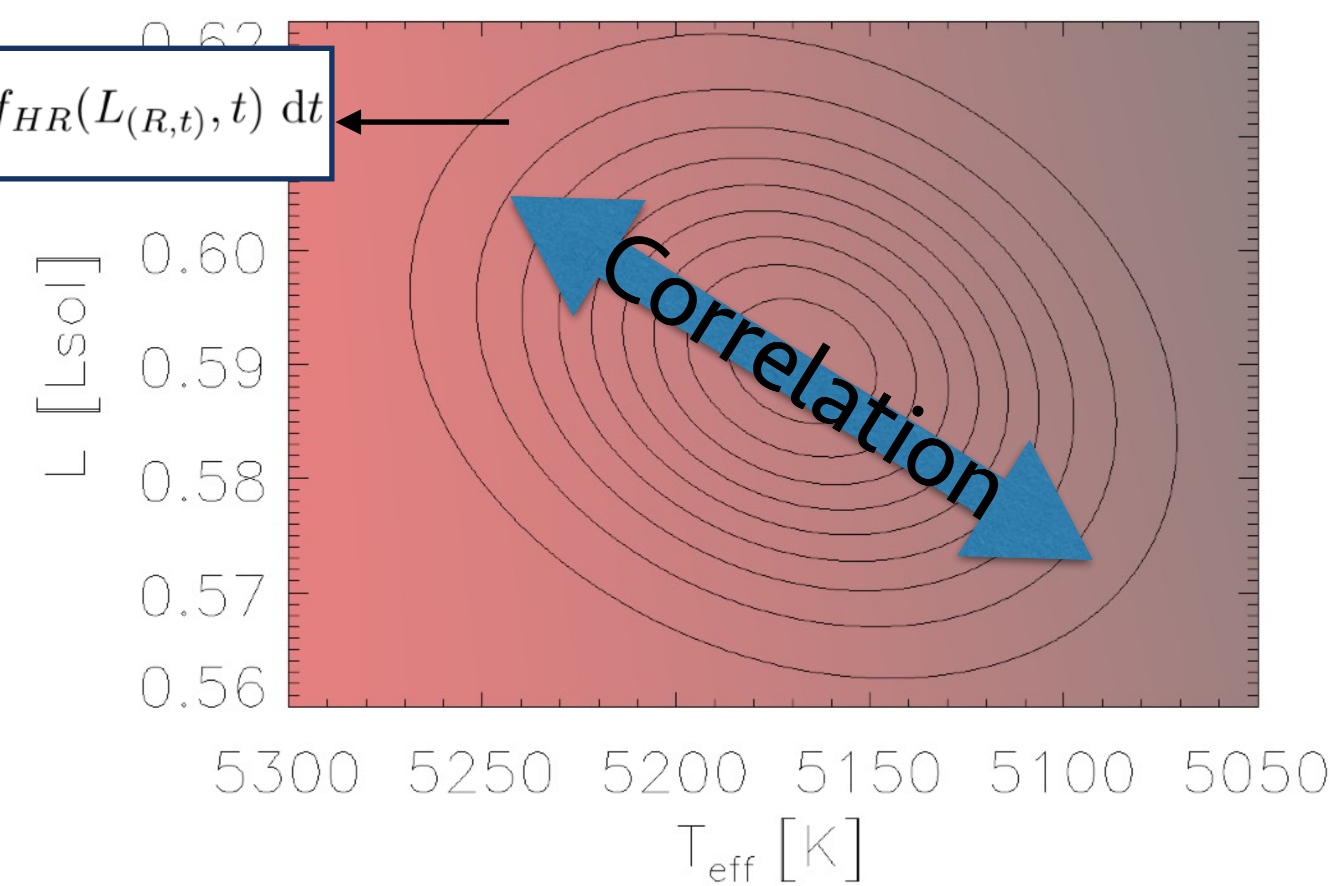
Prior: density of stars in the HR diagram of the Hipparcos sample (color).

↓ level curves

Interferometry is precise!
The prior does not bring much.



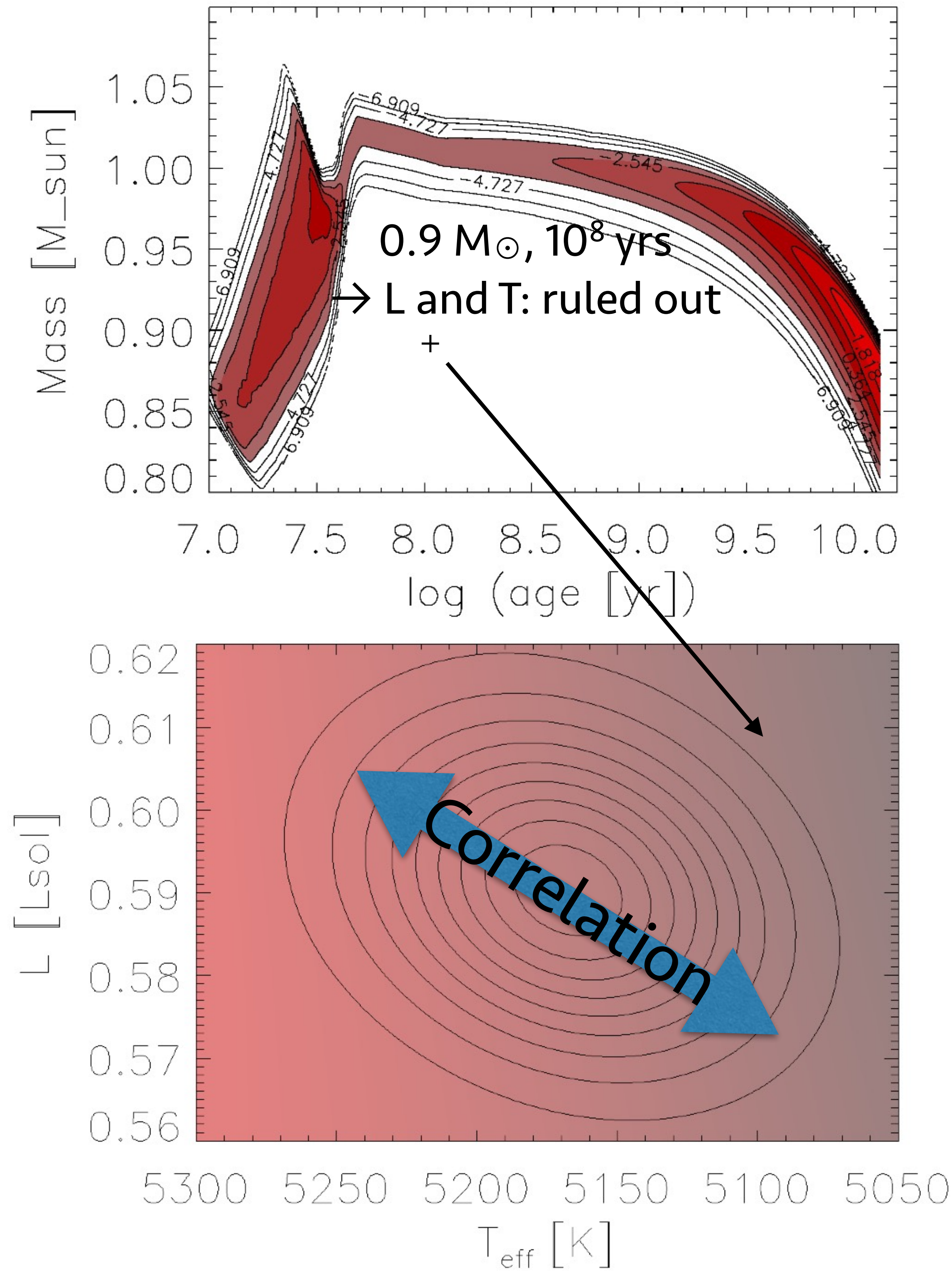
$$f_{R_\star}(R) = \frac{2}{R}\int_{t=0}^{\infty} L_{(R,t)}\,f_{HR}(L_{(R,t)},t)\,\mathrm{d}t$$



55 CNC: A BAYESIAN APPROACH

Results:

- Bayesian or not: 2 solutions
- But Lithium detection rules out the old solution! Consistent with young solution (age and mass) of Ligi et al. (2016).
- Still, different parameters in the model → different, inconsistent masses for the young solution: CES2MO (Lebreton & Goupil 2014) gives $M_\star$ from 0.950 ± 0.015 to 0.989 ± 0.020 $M_\odot$



55 CNC: A BAYESIAN APPROACH

Transit duration: $T=2R_\star/a\Omega$
Period: $P = 2\pi/\Omega$

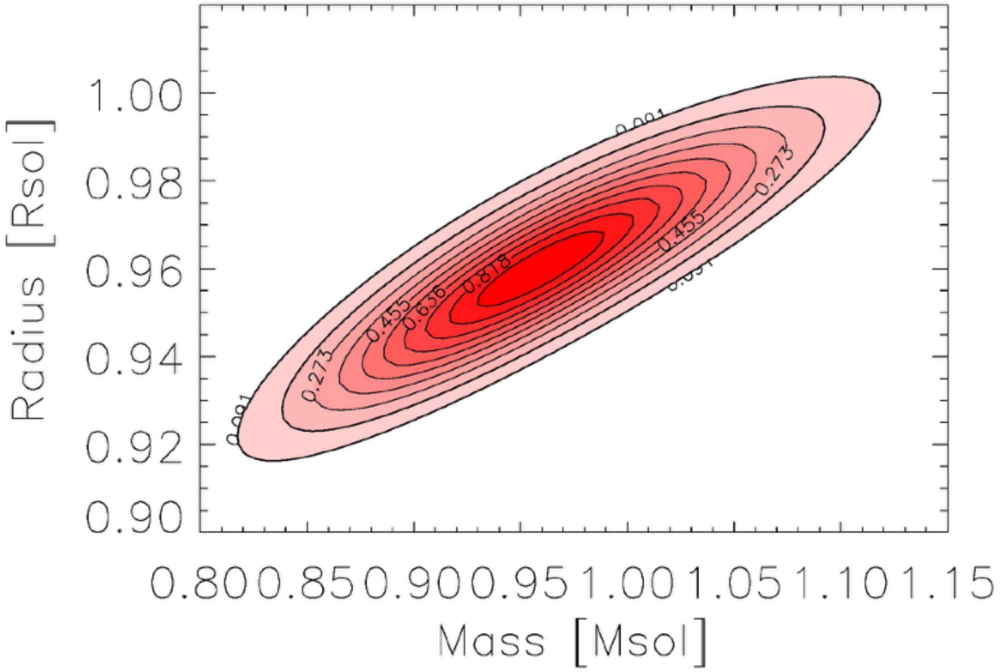
→ $P/T^3 = (\pi^2 G/3)\,\rho_\star$
measure of stellar density $\rho_\star$ **(Maxted et al. 2015, Seager & Mallén-Ornelas 2003)**

Measure of $R_\star$ by interferometry → $M_\star=(4\pi/3)R_\star^3\rho_\star$ **(Ligi et al. 2016)**

From the PDF of $R_\star$ and $\rho_\star$,
analytic joint likelihood of $M_\star$ - $R_\star$.

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

→ Strong correlation (0.85) !
→ Different $M_\star$ than von Braun et al. (2011) based on isochrones.



Stellar parameters
USING STELLAR DENSITY AND ANGULAR DIAMETERS

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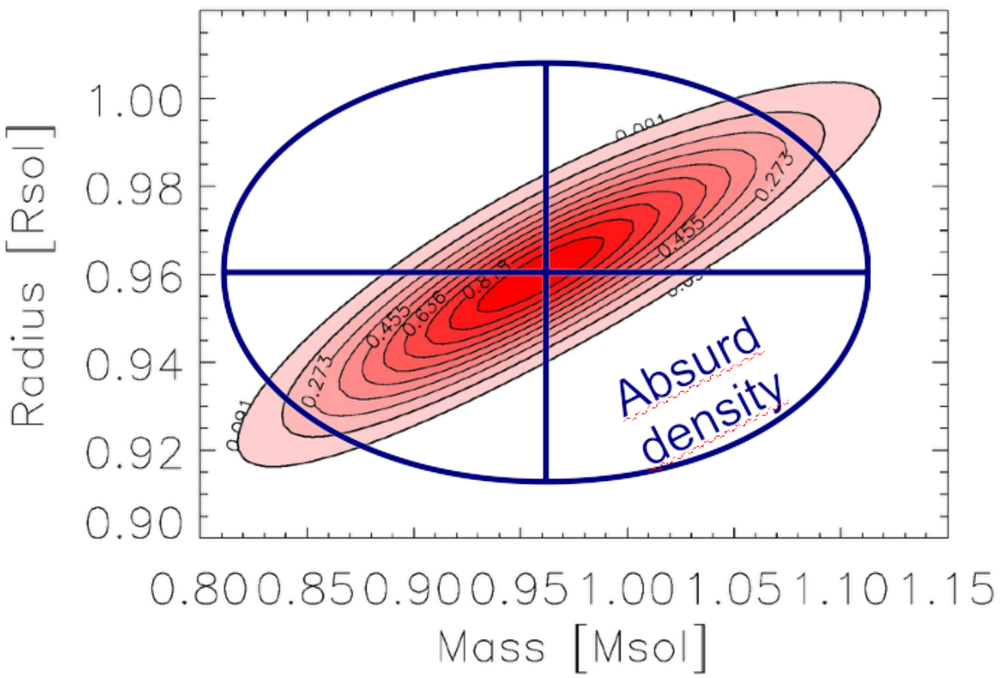
Taking the values of R★ and M★ from Ligi et al. (2016), one gets the large, wrong blue ellipse.



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Transit light curve:

$R_p = R_\star \times \sqrt{TD}$

RV measurements:

$m_p \sin(i) = M_\star\, K\, (P/2\pi G M_\star)^{1/3}$

sin(i)

R_p

m_p

ρ_p

Some calculation to decrease the error bar…

$$\rho_p = \frac{3^{1/3}}{2\pi^{2/3} G^{1/3}} \rho_\star^{2/3} R_\star^{-1}\, TD^{-3/2}\, P^{1/3}\, K\, (1-e^2)^{1/2}$$

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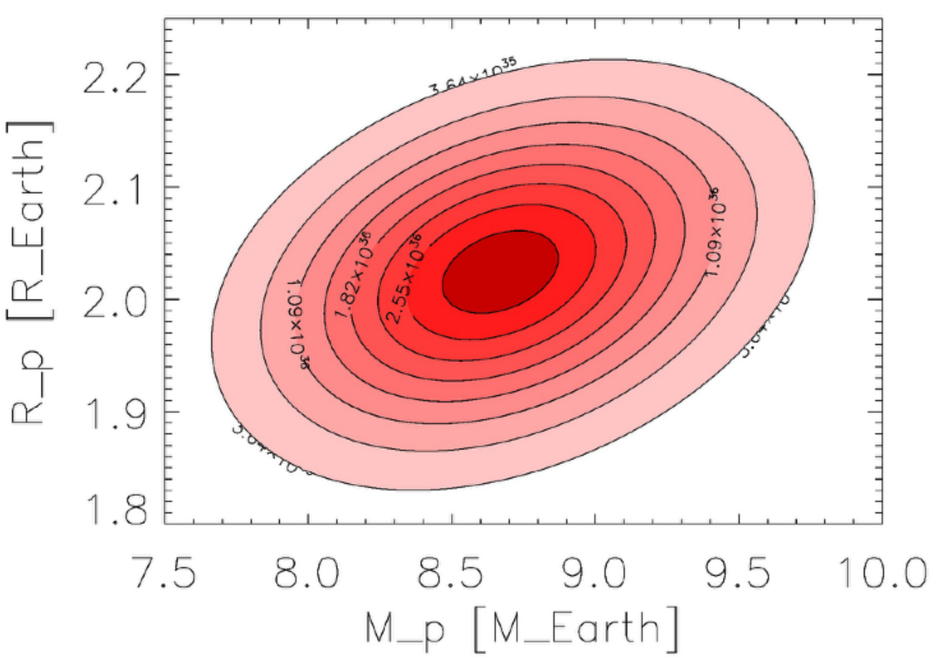
→ Analytic PDF of ρ_p

→ Joint PDF of m_p-R_p



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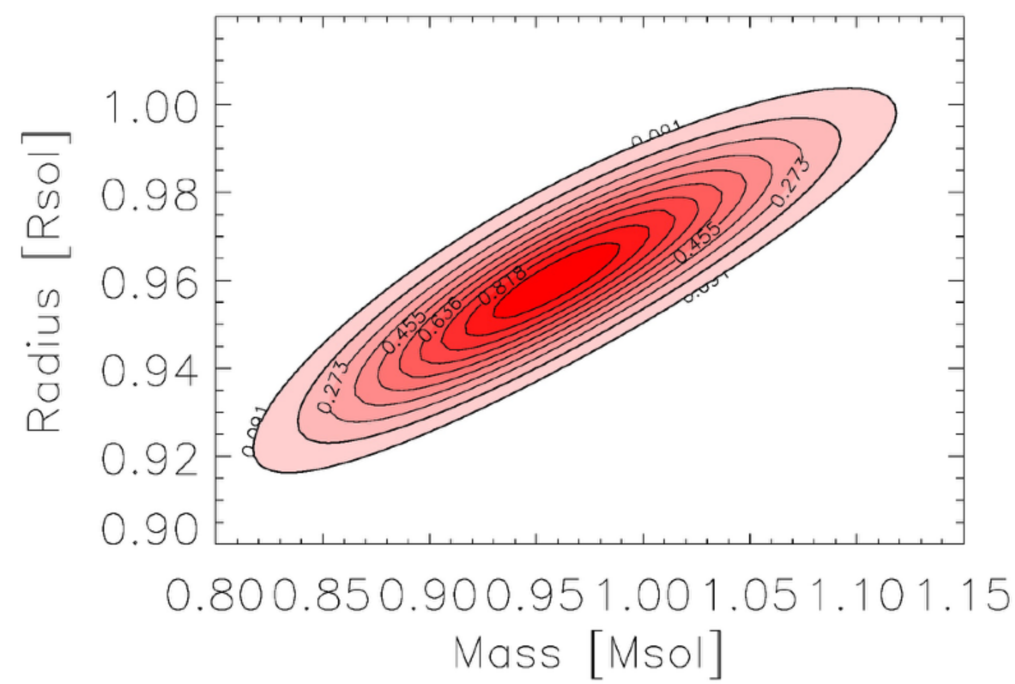

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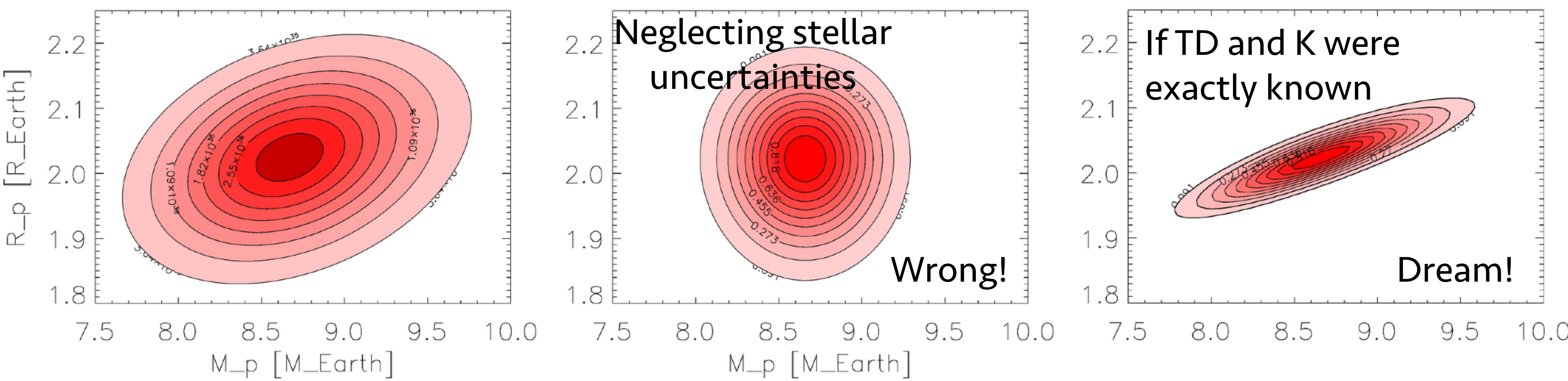
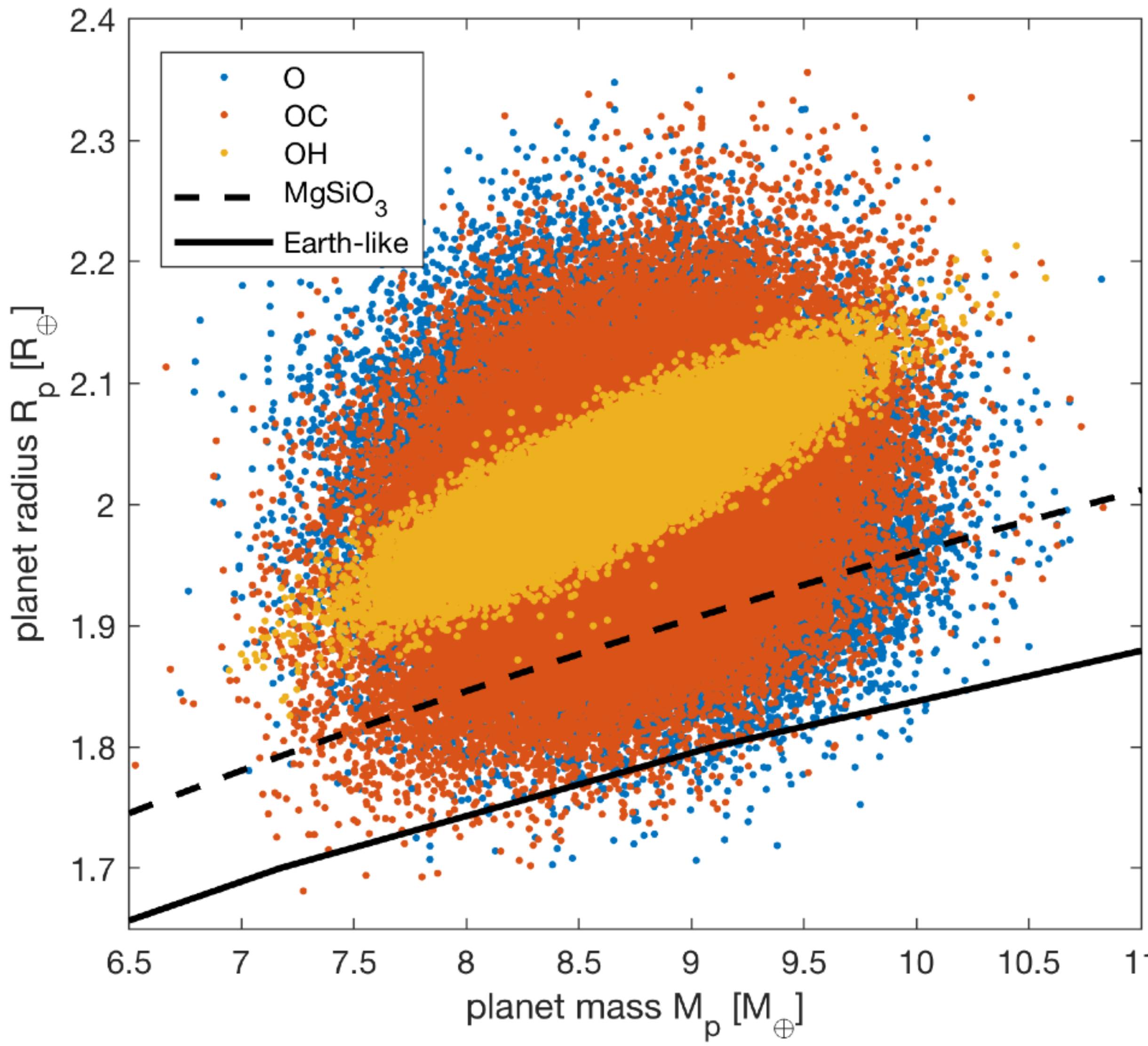


55 CNC E: INTERNAL COMPOSITION

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

Input:

Original data : m_p, R_p (uncorrelated), a, $L_\star$.
Correlation between m_p and R_p (0.30).
Hypothetical correlation (0.85).
Abundances : stellar Fe/Si, Mg/Si.

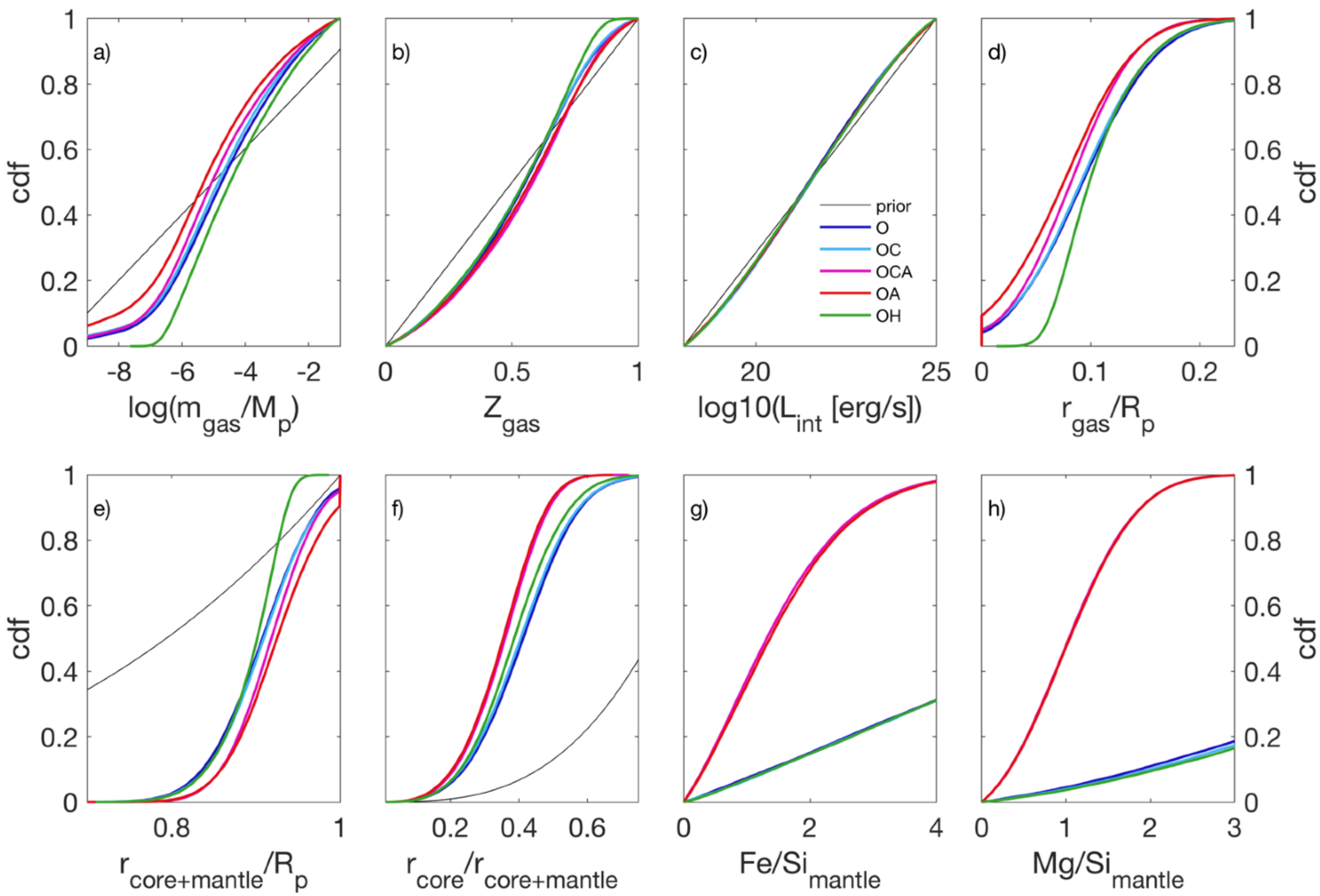


Output:

PDF (or CDF) of all the internal parameters.
We test the importance of the various data O, C, H, A.

55 CNC E: INTERNAL COMPOSITION

Input :
Original data m_p, …
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

OCA case: our best constrains on all the parameters.

Crida, Ligi, Dorn & Lebreton, ApJ, arXiv:1804.07537.

INTERFEROMETRY FOR FAINTER STARS

Combining interferometry with other methods, we:

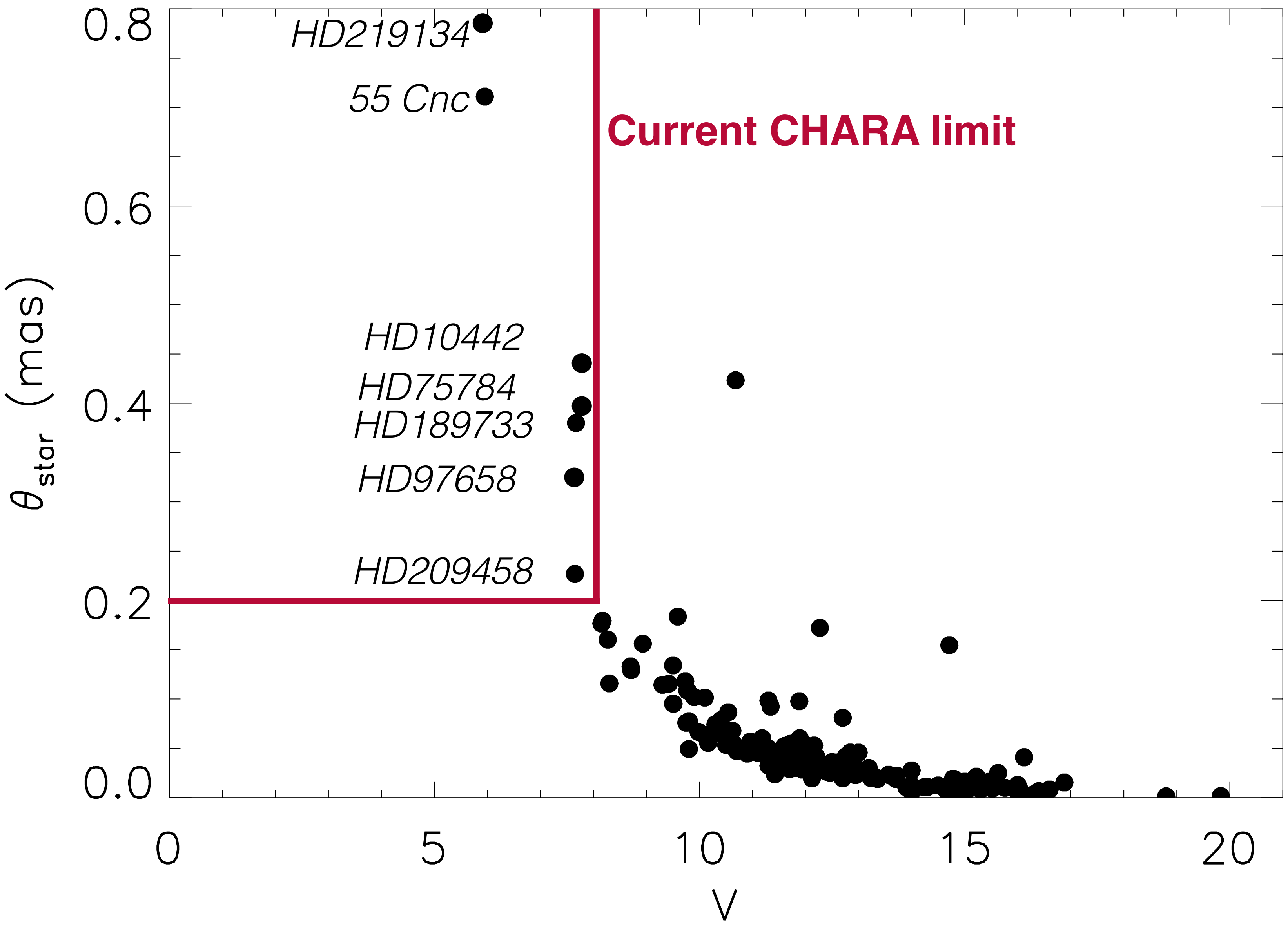
- reduced the uncertainties on the parameters of 55 Cnc, using direct measurements and an analytical approach,

- reduced the possible range of internal structures of 55 Cnc e using correlations and abundances.

  ➔ Is it possible to perform a similar analysis with other systems?

INTERFEROMETRY FOR FAINTER STARS

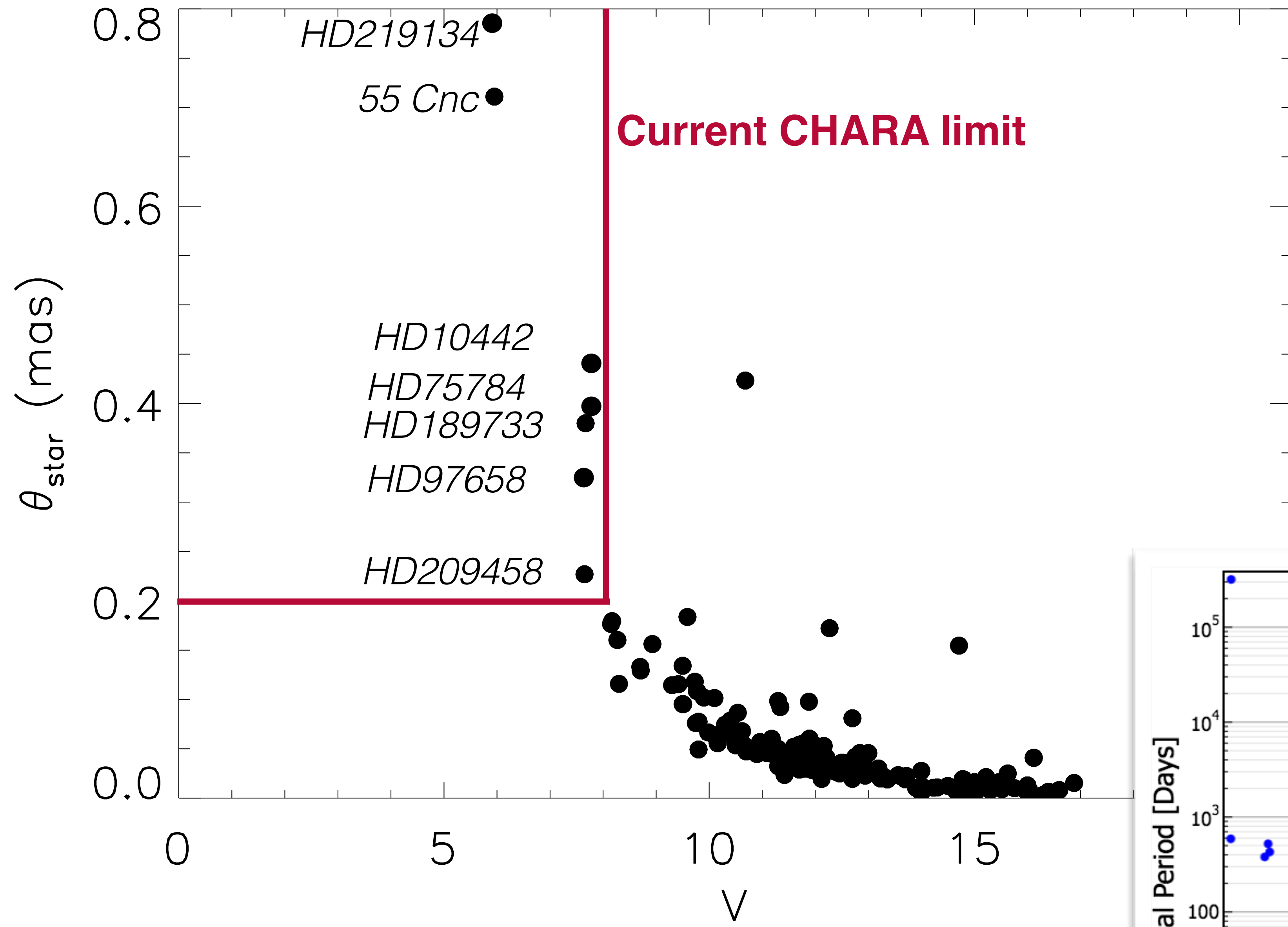
Stars harbouring transiting exoplanets



- Few systems are currently accessible with interferometers

INTERFEROMETRY FOR FAINTER STARS

Stars harbouring transiting exoplanets



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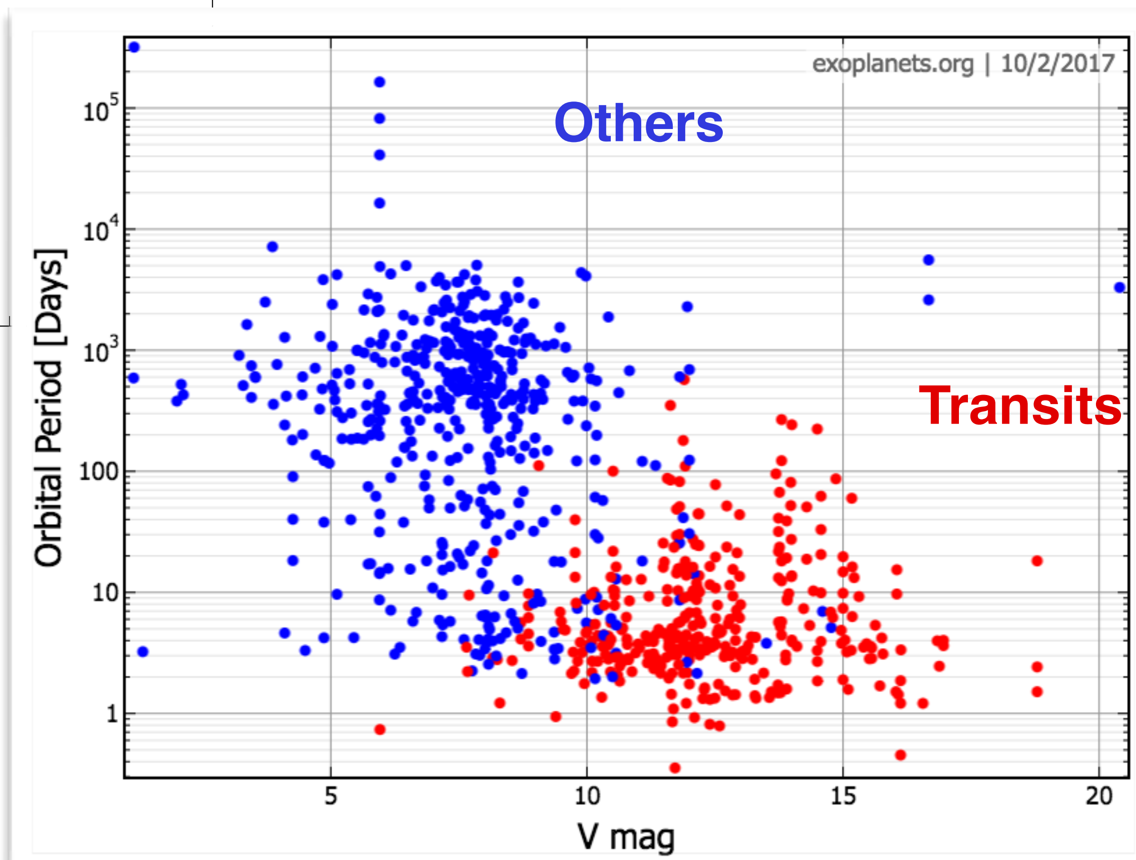
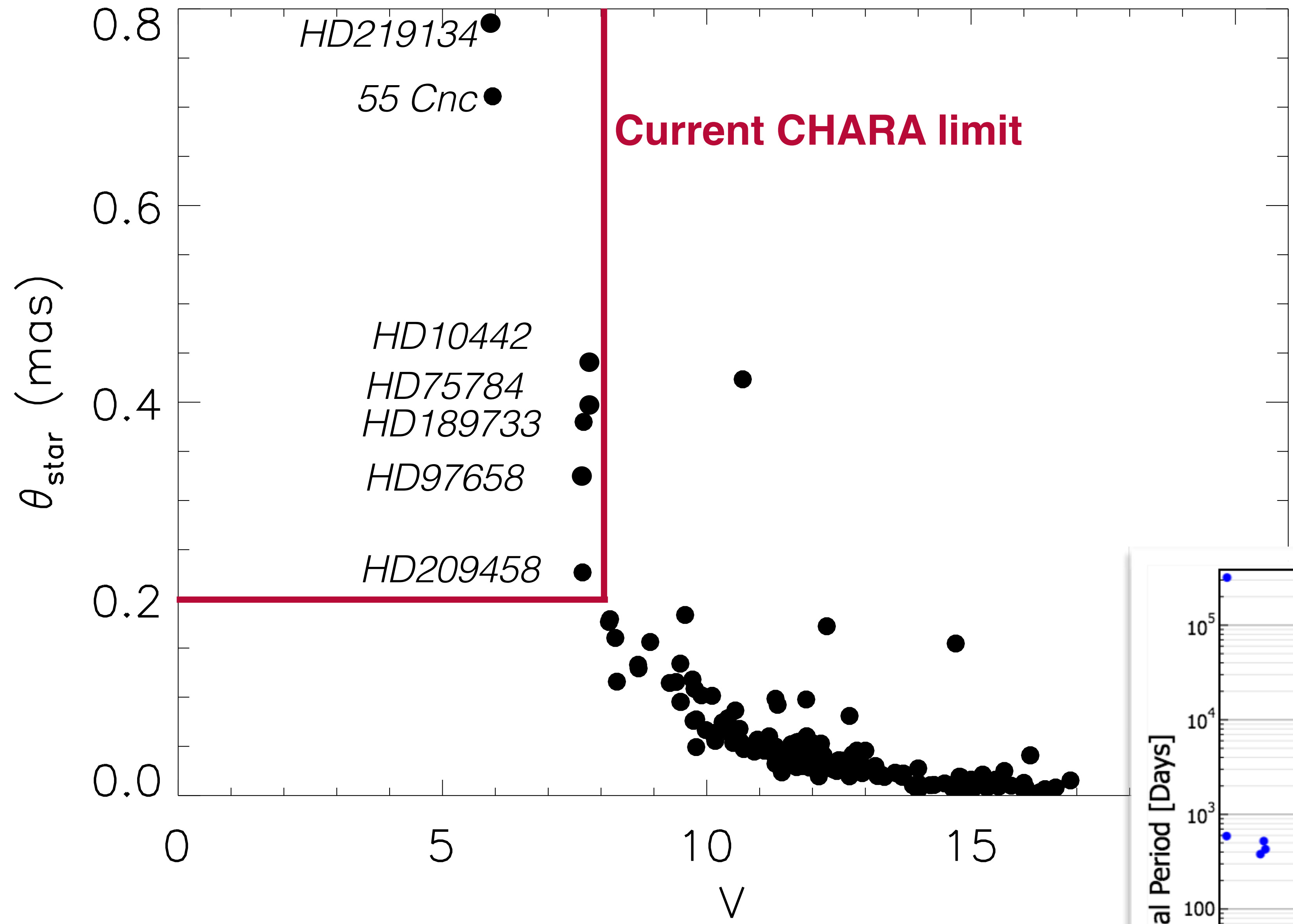
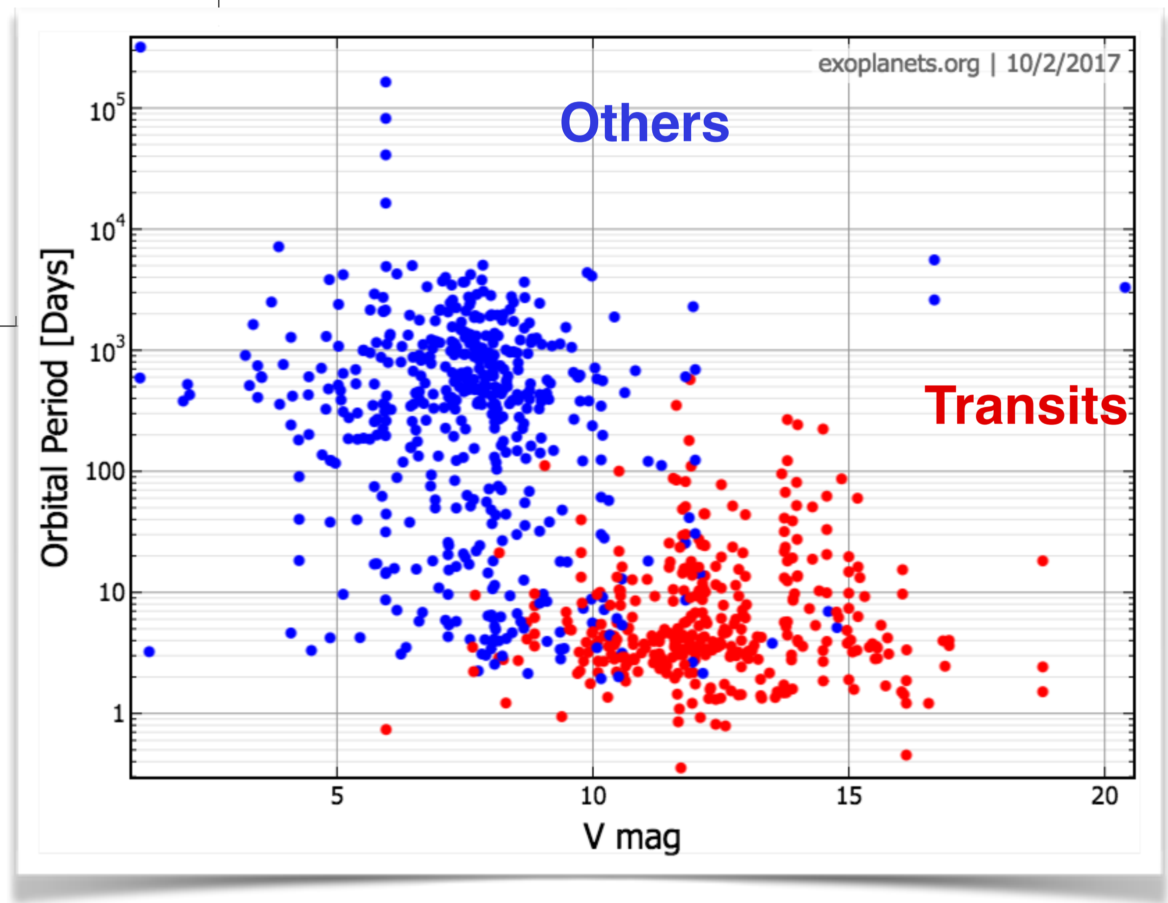


INTERFEROMETRY FOR FAINTER STARS

Stars harbouring transiting exoplanets

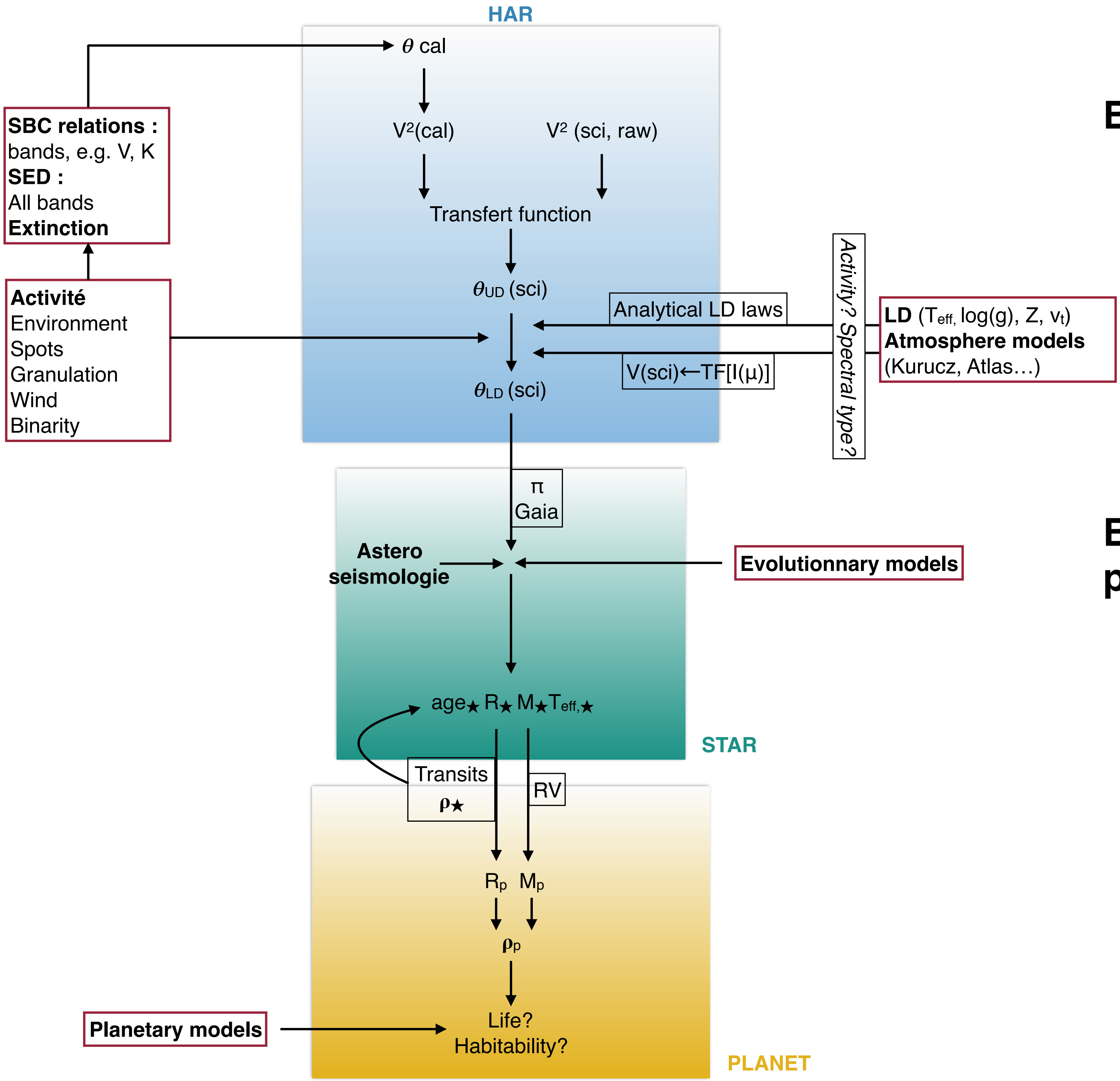


- Few systems are currently accessible with interferometers
- This will change soon with the development of future facilities (see talk of L. Bigot)
- Still, some stars will be too faint.



➜ The SPICA project

THE SPICA PROJECT: PROBLEMATICS



Bias on diameters

- limb-darkening
- rotation
- pulsation
- circumstellaire environment
- activity

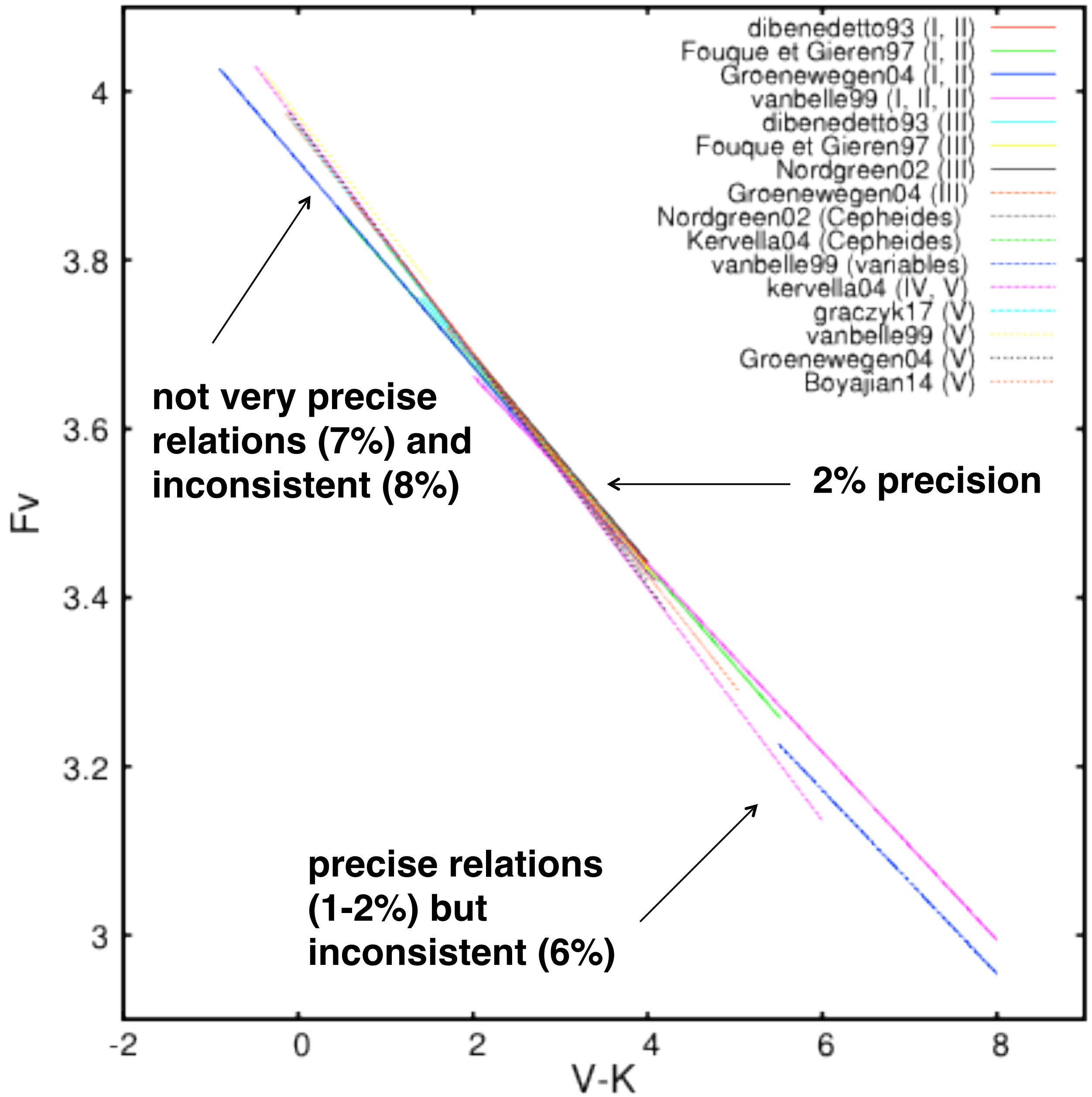
But need for an accurate and precise estimation

- to improve surface brightness-color (SBC) relations,
- to have reliable measurements of stellar diameters and stellar parameters
- SED fitting

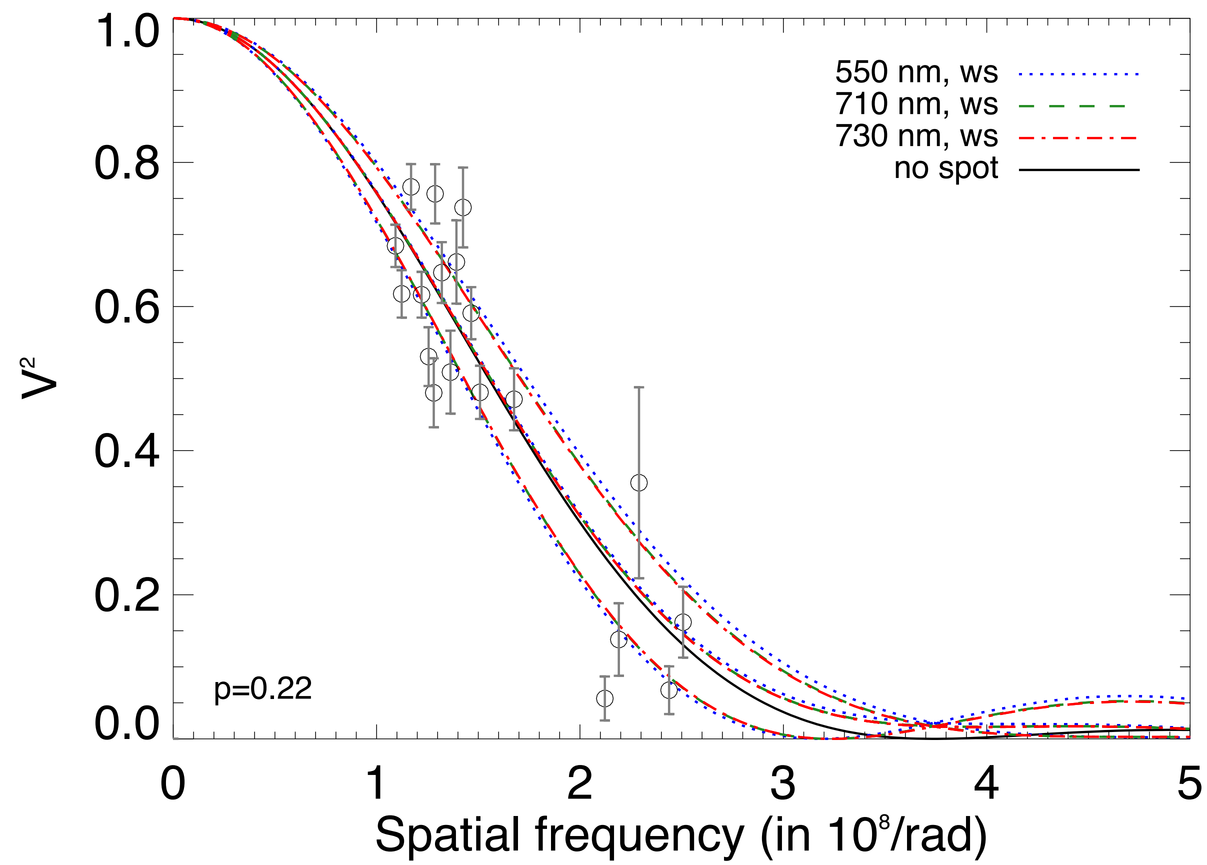
(See talk of L. Bigot)

THE SPICA PROJECT: PROBLEMATICS

Examples of SBC relations



GJ504: the age determines the nature of the detected companion

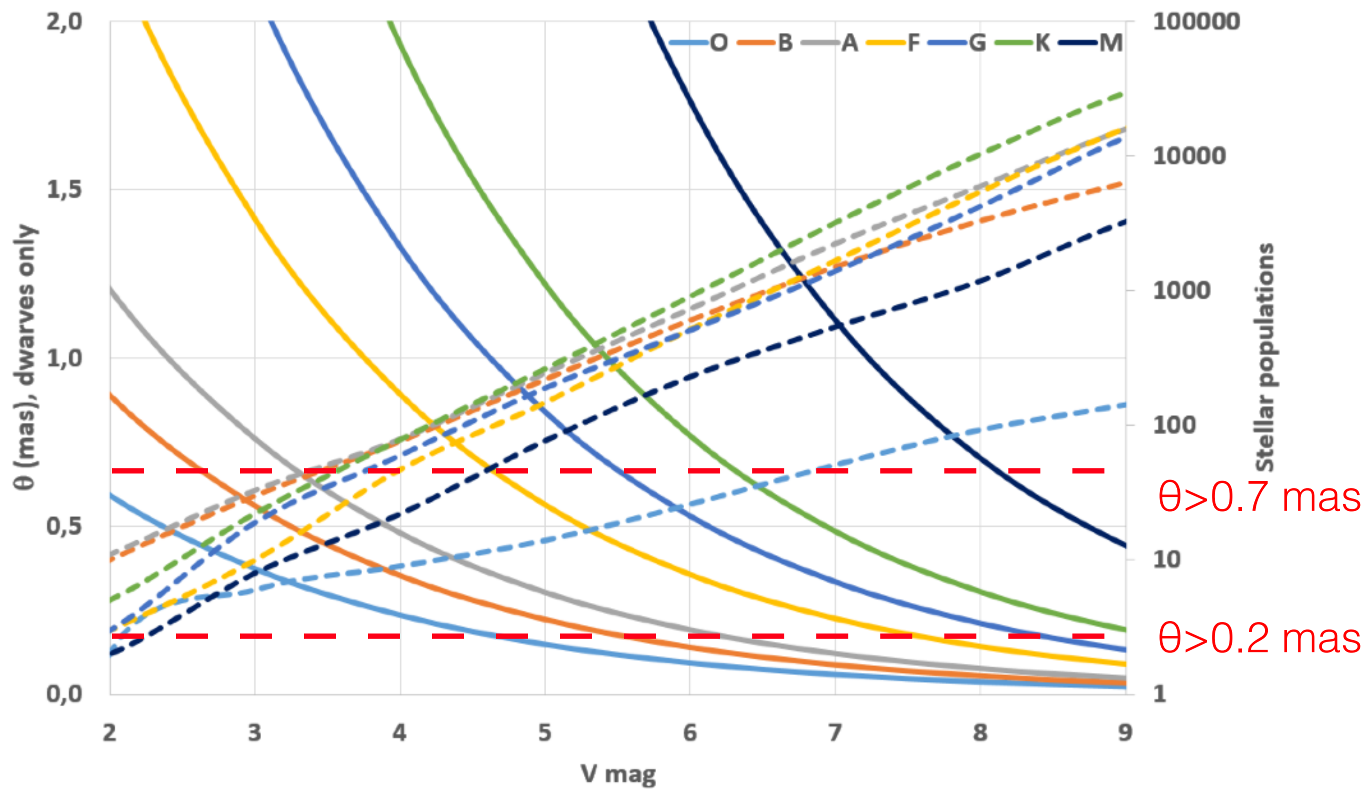


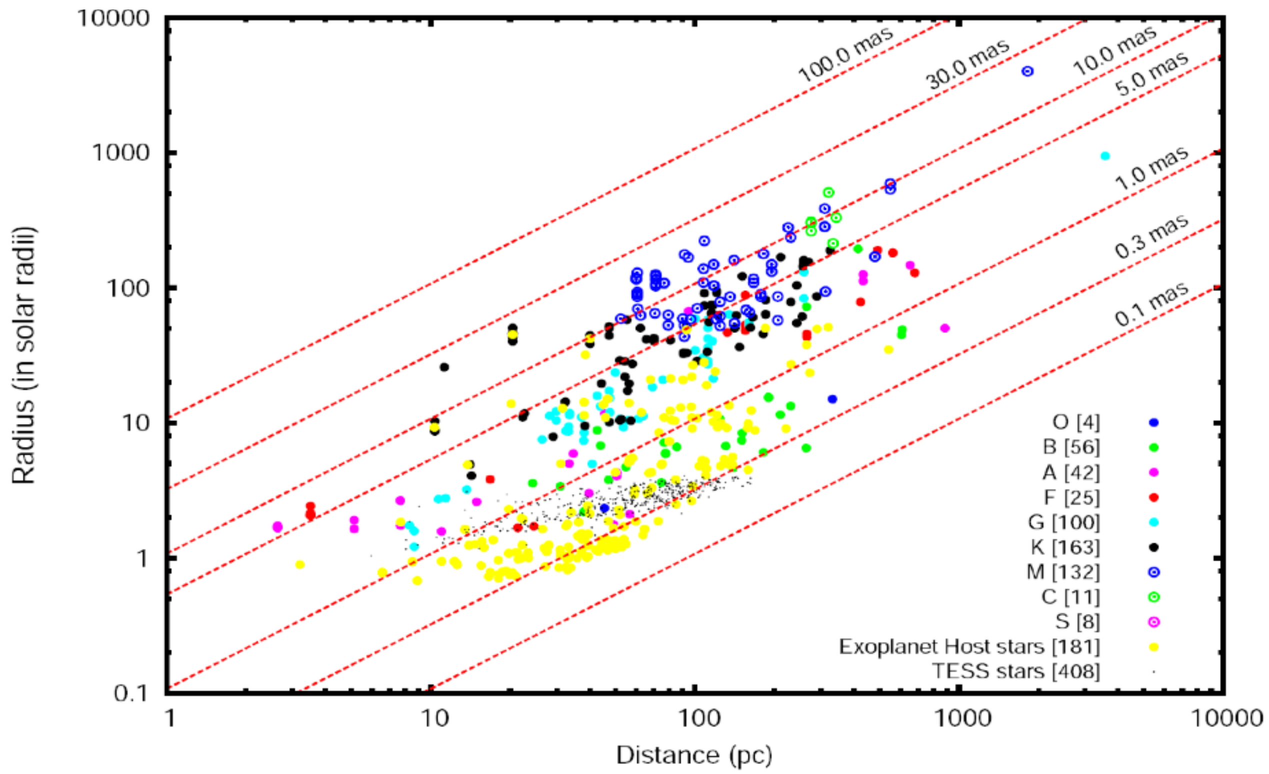
GJ504, Bonnefoy et al., accepted, using COMETS code (Ligi et al. 2015)

Effects of spots on the visibility curve could change the diameter.

THE SPICA PROJECT: GOAL

Diameters and stellar populations of CHARA





A large program for:

- interferometric measurements of angular diameters of stars compatible with PLATO/TESS/CHEOPS →**brights stars** (mag~8, then 9)
- improving SBC relations→ **faint stars**
- imaging stellar surfaces → **effects of activity, rotations…**

Requirements:

- Coverage of class I-V and spectral types OBAF + K-IV/V et M-IV/V
- Host stars ans seismic stars
- Expected to measure the limb-darkening
- Taking into account stellar activity
- Precision of ~1% on diameters and SBC relations

Complementarity between PLATO and interferometry

THE SPICA PROJECT: GOAL

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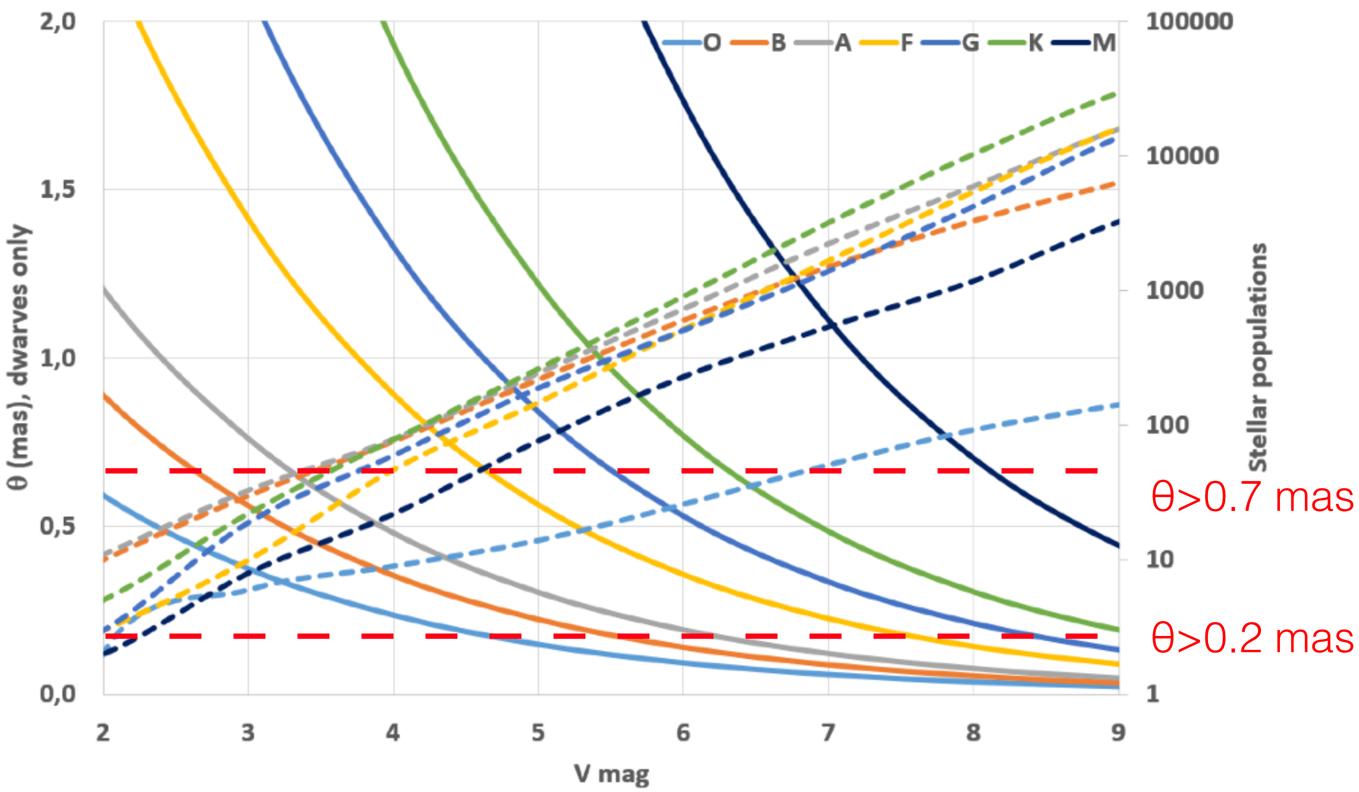

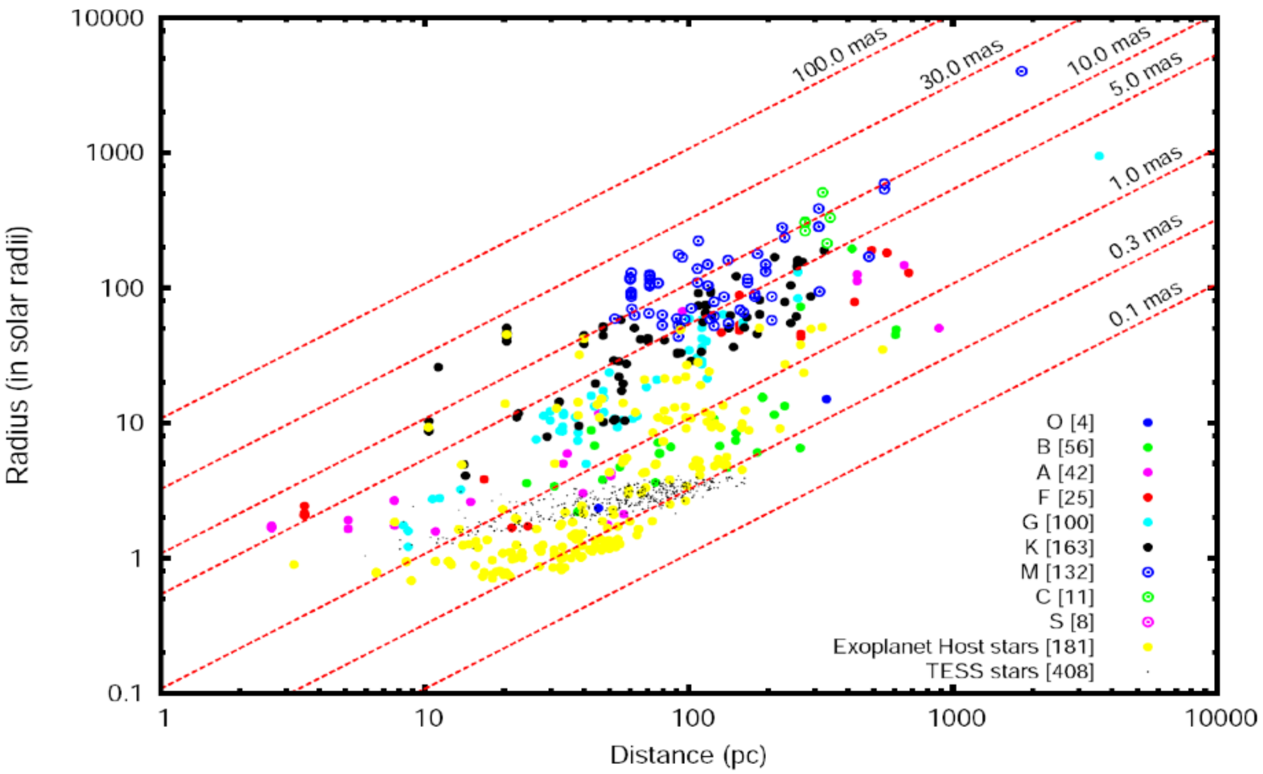

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Use of AO recently installed on CHARA
+
6 telescopes at the same time

THE SPICA PROJECT: CONCLUSION

Interferometry is complementary to PLATO data:

- Asteroseismology cannot be applied to every stellar types
  - Ex: not possible for sp. types K ➜ M
- Stellar models: difficulties for some stellar types (see talks of yesterday)
  - Ex: M stars

Interferometry can be applied to all type of stars, given that:

- they are bright (direct measurements; PLATO/TESS/CHEOPS targets)
- we have a good photometry (SBC relations)

Most direct technique for the measurement of stellar diameters.

➜ Expected to follow-up many PLATO targets.

INTERFEROMETRY & EXOPLANETS