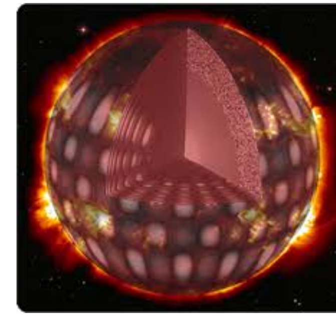
CHEOPS Science Workshop
Venice 3-4 June 2014



Characterizing planet-hosting stars

How to get the stellar mass, radius, and age

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(S. Sousa, F. Bouchy, and associates)

Université de Liège

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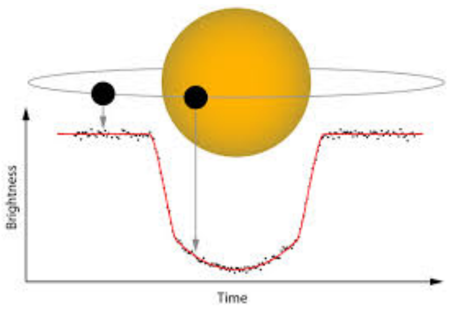
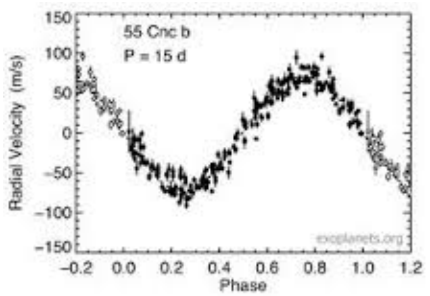
Why is stellar characterization so important ?



Transits

$$Rp \ \alpha \ R_*$$
$$Mp \ \alpha \ M_*^{2/3}$$



Radial velocities

+ the **age** of the star is the best proxy for the age of its planets

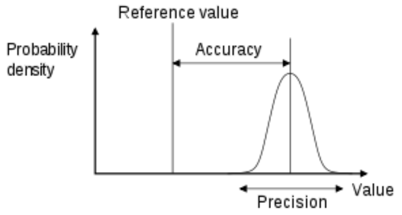
(Sun: 4.57 Gyr, Earth: 4.54 Gyr)

CHEOPS = ultra-high precision photometry

We want to be both *precise* and *accurate* on stellar target

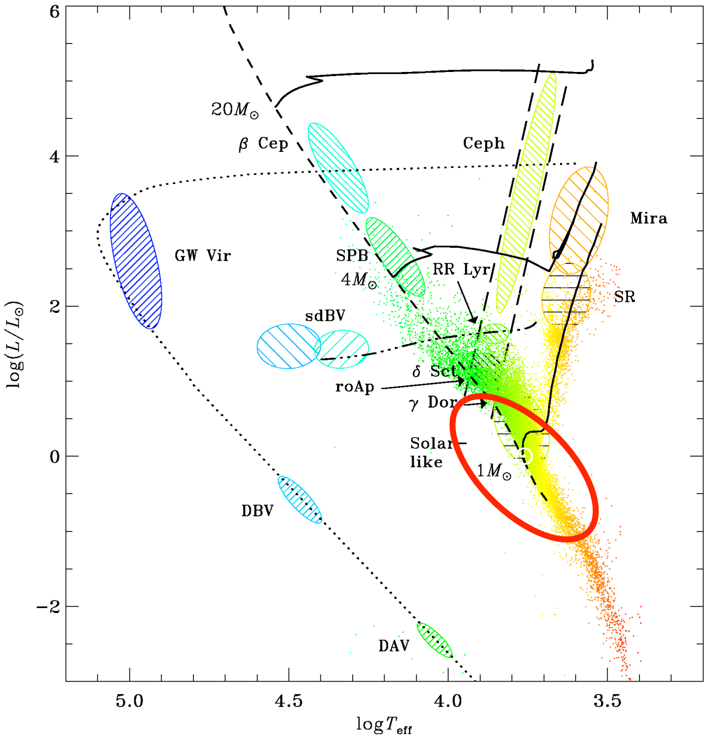
⇒

combination of techniques



The targets of CHEOPS

Main sequence nearby bright solar-like stars: F, G, and K-types



6<V<12

Direct techniques: interferometry (R_*), eclipsing binaries (M_*, R_*)

Indirect techniques: GAIA parallaxes (R_*), stellar evolution modeling (M_*, R_*, age), asteroseismology (M_*, R_*, age), transit light curve (ρ_*)

Note (M. Gillon): CHEOPS won't provide accurate ρ_* from transits (shape and $e \neq 0$)

Interferometry

To get R_* to ~ 1-2%

(depending on size, distance and magnitude of the star)

Available now:
- CHARA (Mount Wilson USA, 330-m baseline)
- VLTI (Chile, 150-m baseline)

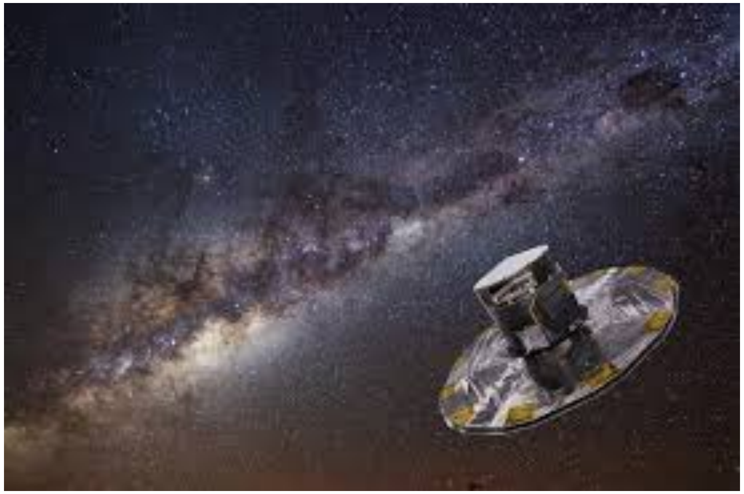
By the launch of CHEOPS: MROI (New Mexico, 400-m baseline)

GAIA parallaxes

To get R_* to ~ 1-2%

(normally not affected by GAIA's stray light issues)

Independently from interferometry ⇒ increase the *accuracy* on stellar radius



Method:

$$M_V = V + 5 + 5\log\pi - A_V$$

$$\log(L/L_{sun}) = (M_{bol,\,sun} - M_V - BC)/2.5$$

$$R = (L/4\pi\sigma T_{eff}^4)^{1/2}$$

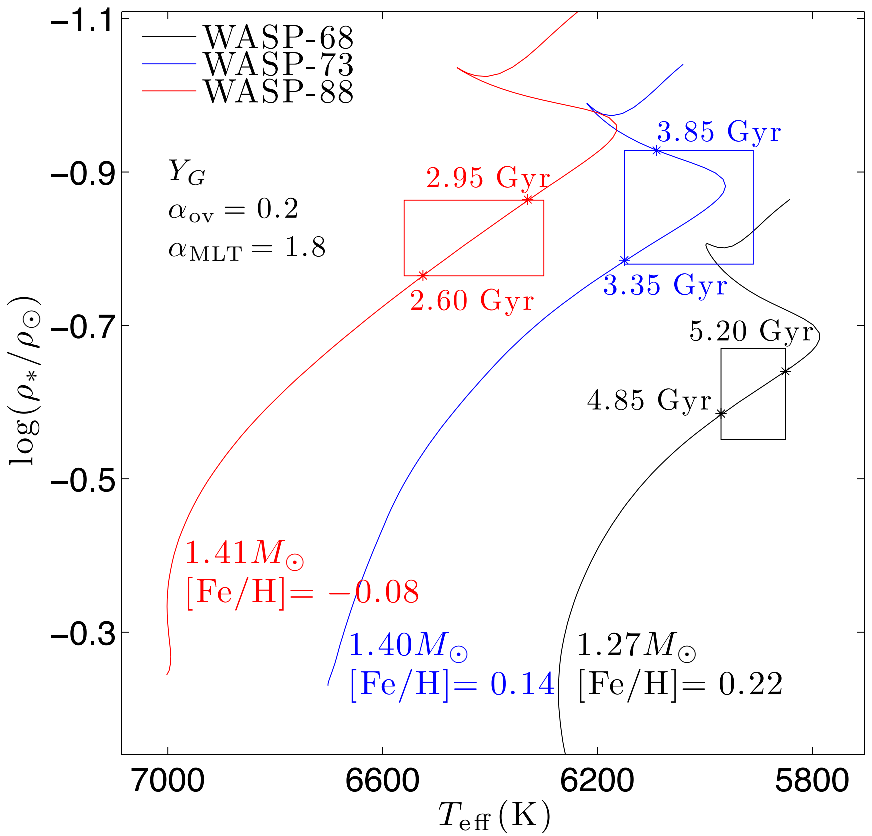
Π: parallax
Av: interstellar extinction
BC: bolometric correction
T_{eff}: effective temperature
(see Sousa et al. poster)

Stellar evolution modeling

To get R_*, M_* and age

Stellar evolution codes: CLES (Liege), MESA (open source), Padova,…

Inputs:
- T_{eff}, Z (from spectroscopy); Z~[Fe/H] (better if other abundances)
- log g (spectroscopy), and/or ρ_* (transits), and/or L_* (parallax)



Delrez, Van Grootel et al. (2014)

Stellar evolution modeling

To get R_*, M_* and age

Pros:
- General method, always applicable
- Only require spectroscopic information, generally available (see S. Sousa et al. poster for specific issues on spectroscopy)
- Get R*, M* **and** age

Cons:
- Not very precise:

Providing ~50 K on T_{eff}, 0.05 dex on [M/H] and 1% on L_* (GAIA):

R_* to ~ 1-2%

M_* to ~ 5-10%

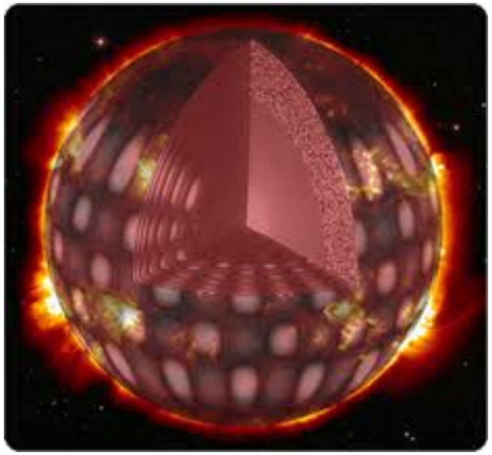
Age to 2-3 Gyr

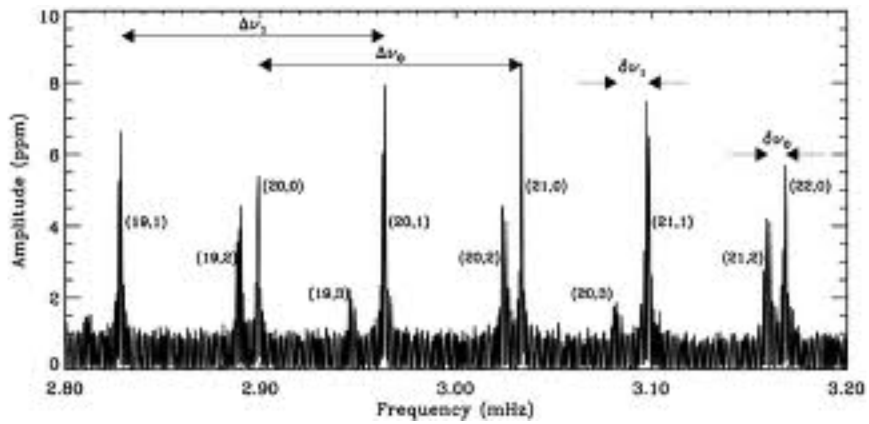
Main uncertainties: from stellar interiors (helium initial abundance, efficiency of convection, importance of mixing processes)

Will be improved in the coming years from bulk asteroseismic results from CoRoT and Kepler ?

Asteroseismology

To get R_*, M_* and age





Principle:

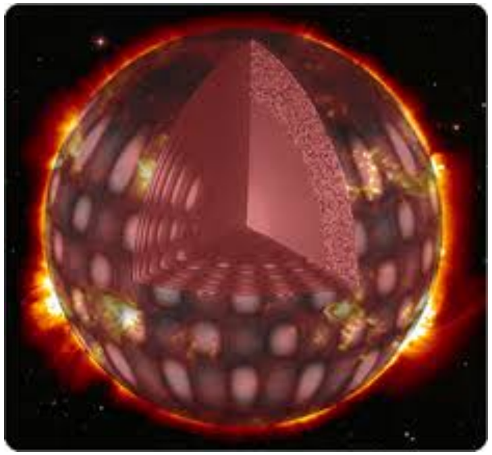
Use stellar oscillations to constrain stellar interiors and to get structural parameters

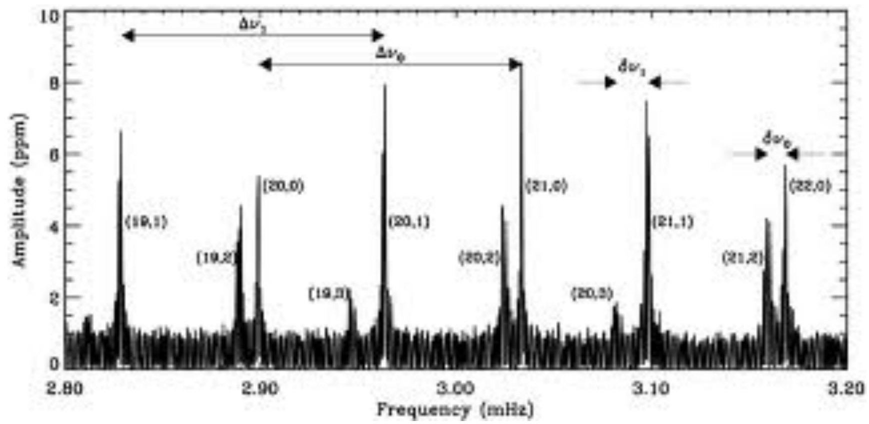
For solar-like stars, main seismic indicators:

the large separation $\Delta\nu$ (α ρ_*), frequency at maximum power ν_{max} (α $g/T_{eff}^{0.5}$), small separations $\delta\nu$ (α age)

Asteroseismology

To get R_*, M_* and age





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Asteroseismology

For CHEOPS targets:

- Low-quality seismic data: only $\Delta\nu \sim \rho_*$ to 5%

  ρ_* + R_* (~1-2% by parallaxes/interferometry)

  ➔ M* to 8-10%

- Mid-quality seismic data: 1-month TESS, ground-based (ESPRESSO)

- $\Delta\nu \sim \rho_*$ to 0.5% (V=6) + R_* (~1-2% by parallaxes/interferometry)

  ➔ M* to ~3-4%

- $\Delta\nu \sim \rho_*$ to 2% (V=9) + R_* (~1-2% by parallaxes/interferometry)

  ➔ M* to ~5%

- Age still difficult to do better than 2-3 Gyr

- High-quality seismic data: not for CHEOPS ☹ (waiting for PLATO ☺)

  R_* ~ 1-2%, M_* ~ 2-4%, age ~ 10% (!)

About Eclipsing Binary Law

Enoch et al. (2010) proposed a $M_*(\rho_*, Fe/H, T_{eff})$ relation

$$\log M = a_1 + a_2 X + a_3 X^2 + a_4 \log \rho + a_5 \log \rho^2 + a_6 \log \rho^3 + a_7 [\mathrm{Fe/H}]$$

	Mass, a_i
const.	0.458 ± 0.017
X	1.430 ± 0.019
X^2	0.329 ± 0.128
$\log \rho$	-0.042 ± 0.021
$\log \rho^2$	0.067 ± 0.019
$\log \rho^3$	0.010 ± 0.004
[Fe/H]	0.044 ± 0.019

($X=\log(T_{eff})-4.1$)

based on 19 eclipsing binaries (38 stars) of Torres et al. (2010)
(M_* and R_* model-independent)

Applied to Exoplanet-hosting stars (e.g. Gillon et al.):
Precision of 3-4% on M_* (and then R_* from ρ_*)

About Eclipsing Binary Law

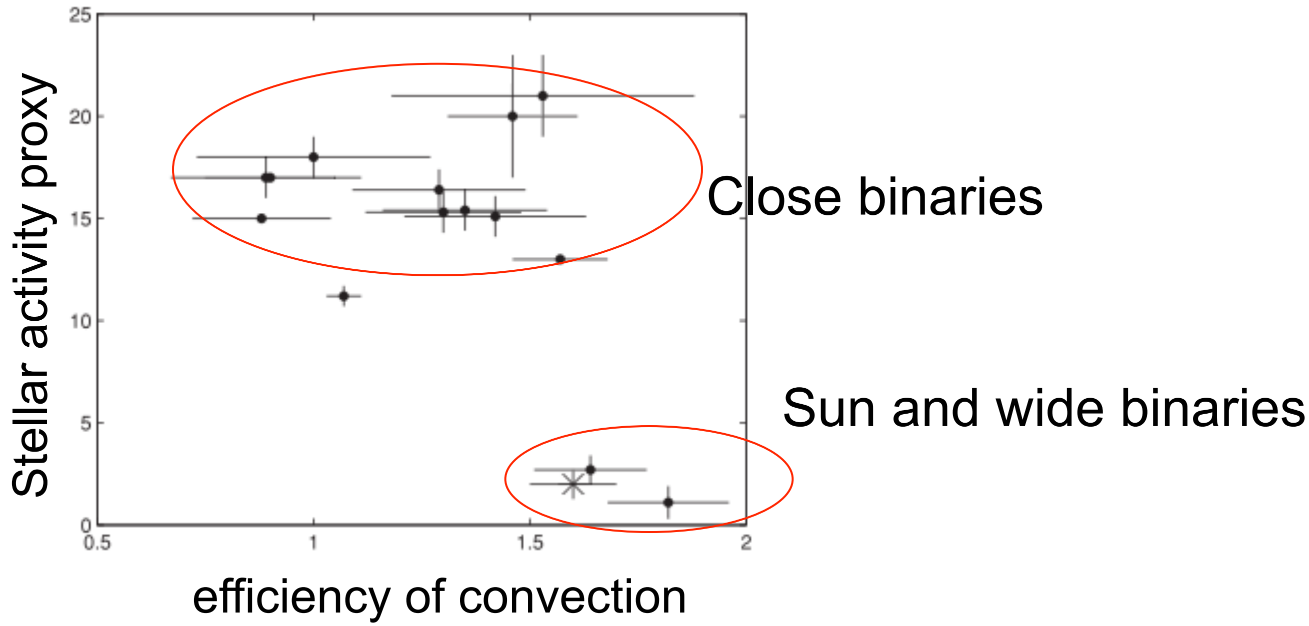
Are eclipsing binaries representative stars?

No: they are in binaries, generally close (P_{orb} < 5 d)

⇒ More active stars than "normal"

⇒ Efficiency of envelope convection (M_*<1.1 M_{sun}) is lower

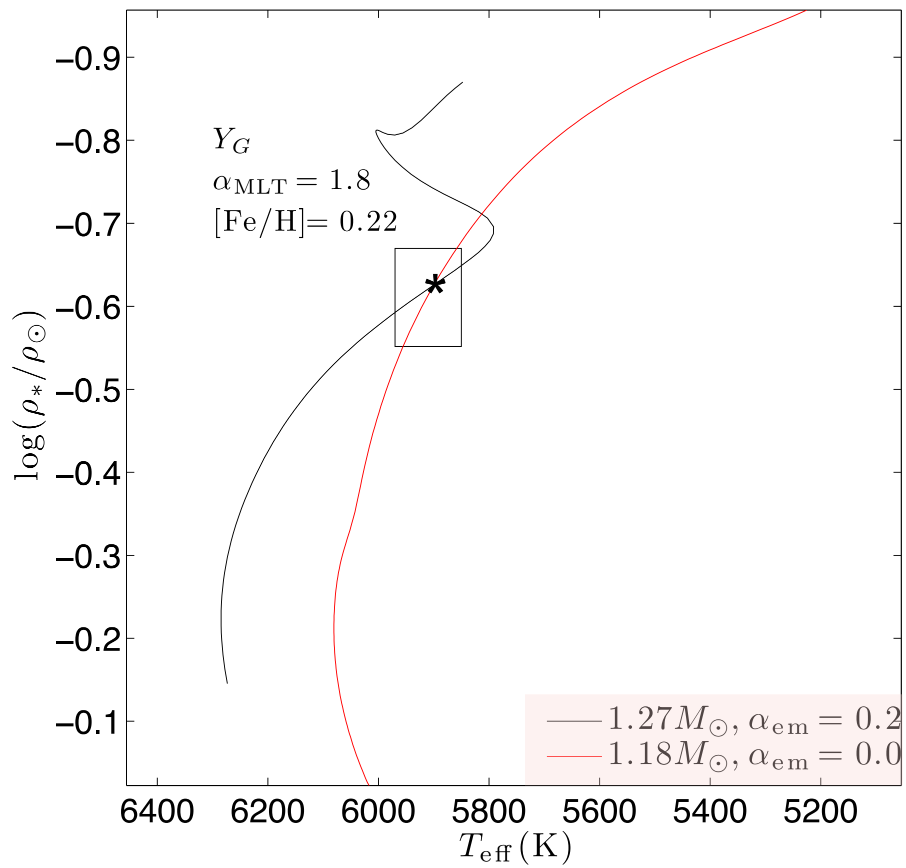
⇒ Stellar Radius is larger (and density lower) than "normal"



Fernandes et al. (2012)

About Eclipsing Binary Law

The $M_*(\rho_*, Fe/H, T_{eff})$ relation is **not** unique

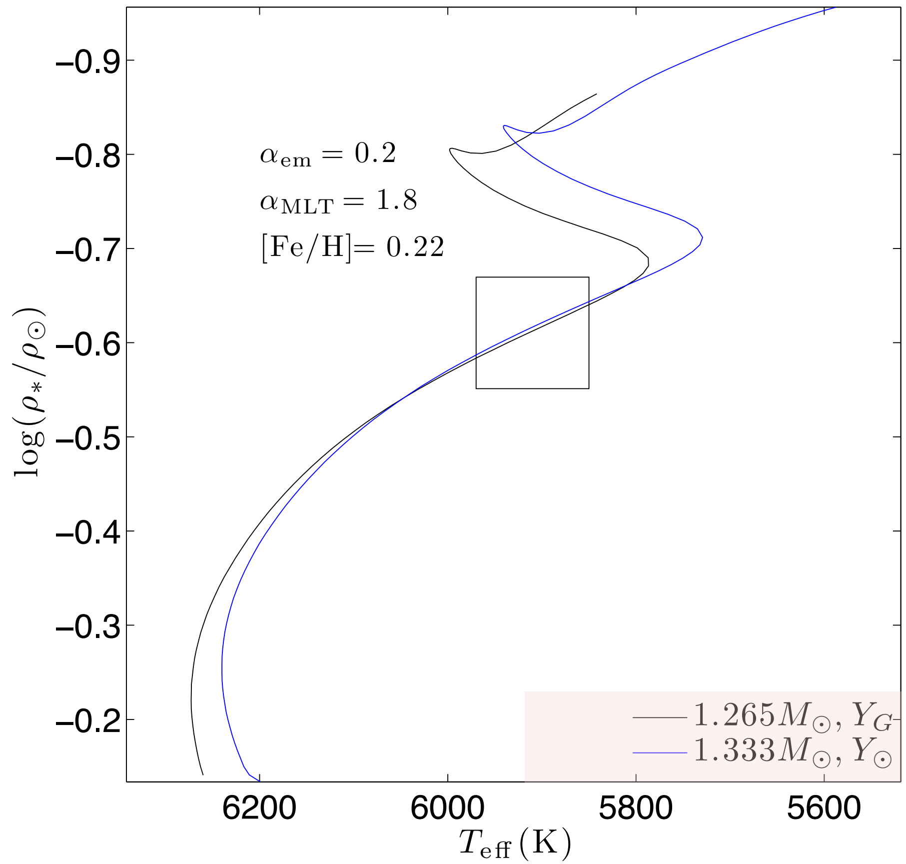


same ρ_*, Fe/H, T_{eff}, but not same M*

(only the core extra-mixing is varied, in very reasonable proportion)

About Eclipsing Binary Law

The $M_*(\rho_*, Fe/H, T_{eff})$ relation is **not** unique



same ρ_*,Fe/H,T_{eff} **for a while**, but not same M_*

(only the initial He abundance is varied, in very reasonable proportion)

Conclusion

- Stellar radius: accurate and precise up to 1-2% (GAIA, interferometry)
- Stellar mass:
  - Brightest targets with TESS seismic data: $M_* \sim$ 3-4% (asteroseismology)
  - More generally ($9<V<12$): $M_* \sim$ 5-10% (ρ_* + R_*, stellar evolution modeling)
- Stellar age: not better than 2-3 Gyr (stellar evolution modeling, empirical methods)

Work to do in years to come:

✓Explore the validity of Eclipsing Binary Law for any star

✓ Fully exploit high-quality seismic data from CoRoT and Kepler to improve accuracy on stellar mass and age from stellar models (constrain He, efficiency of convection, mixing processes)