CHEOPS Science Workshop VI

Cheops reveals the tidal deformation of WASP-103b

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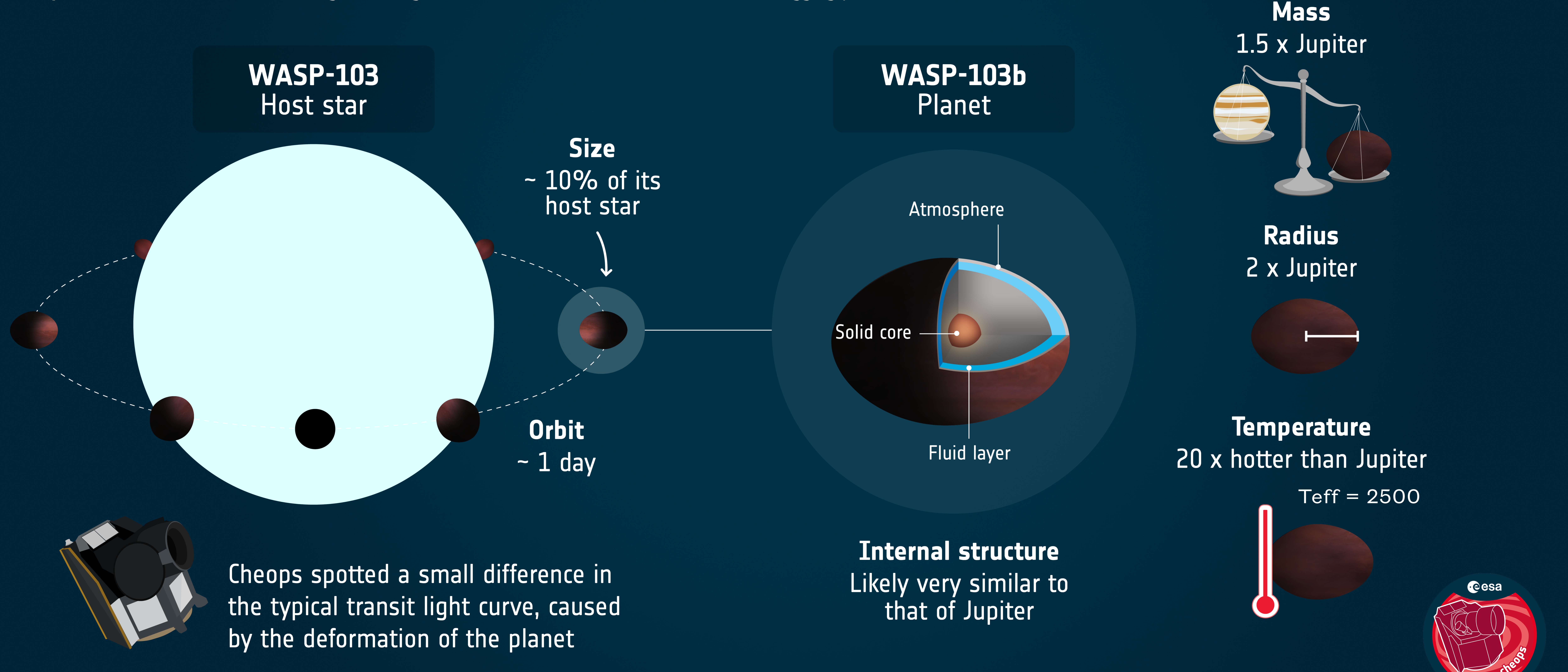
Credit: ESA

CHEOPS REVEALS A RUGBY BALL-SHAPED EXOPLANET

ESA's exoplanet mission **Cheops** has revealed that an exoplanet orbiting its host star within a day has a deformed shape more like that of a rugby ball than a sphere. **This is the first time that the deformation of an exoplanet has been detected**, offering new insights into the internal structure of these star-hugging planets.



Credit: ESA

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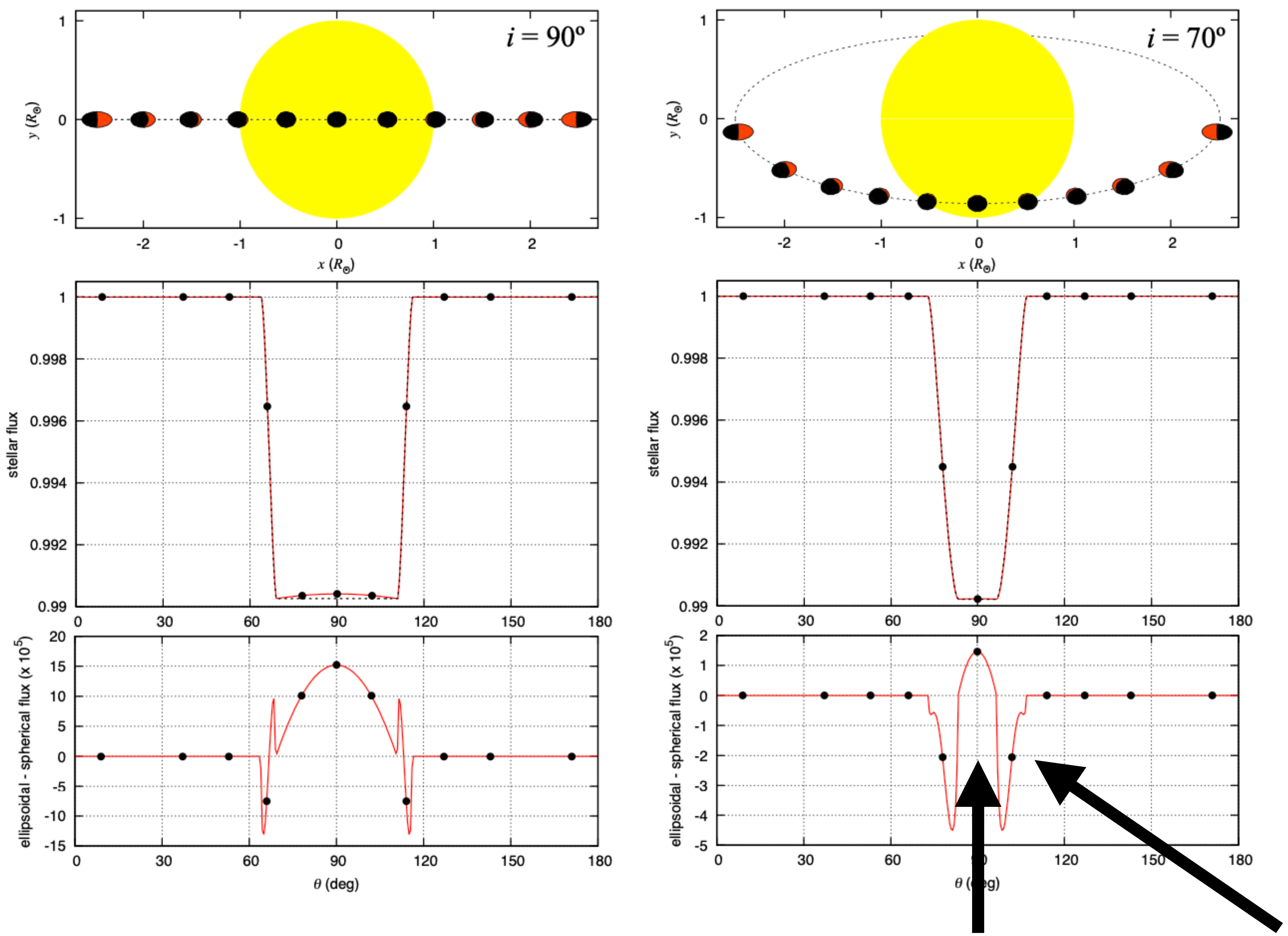
Tidal deformation



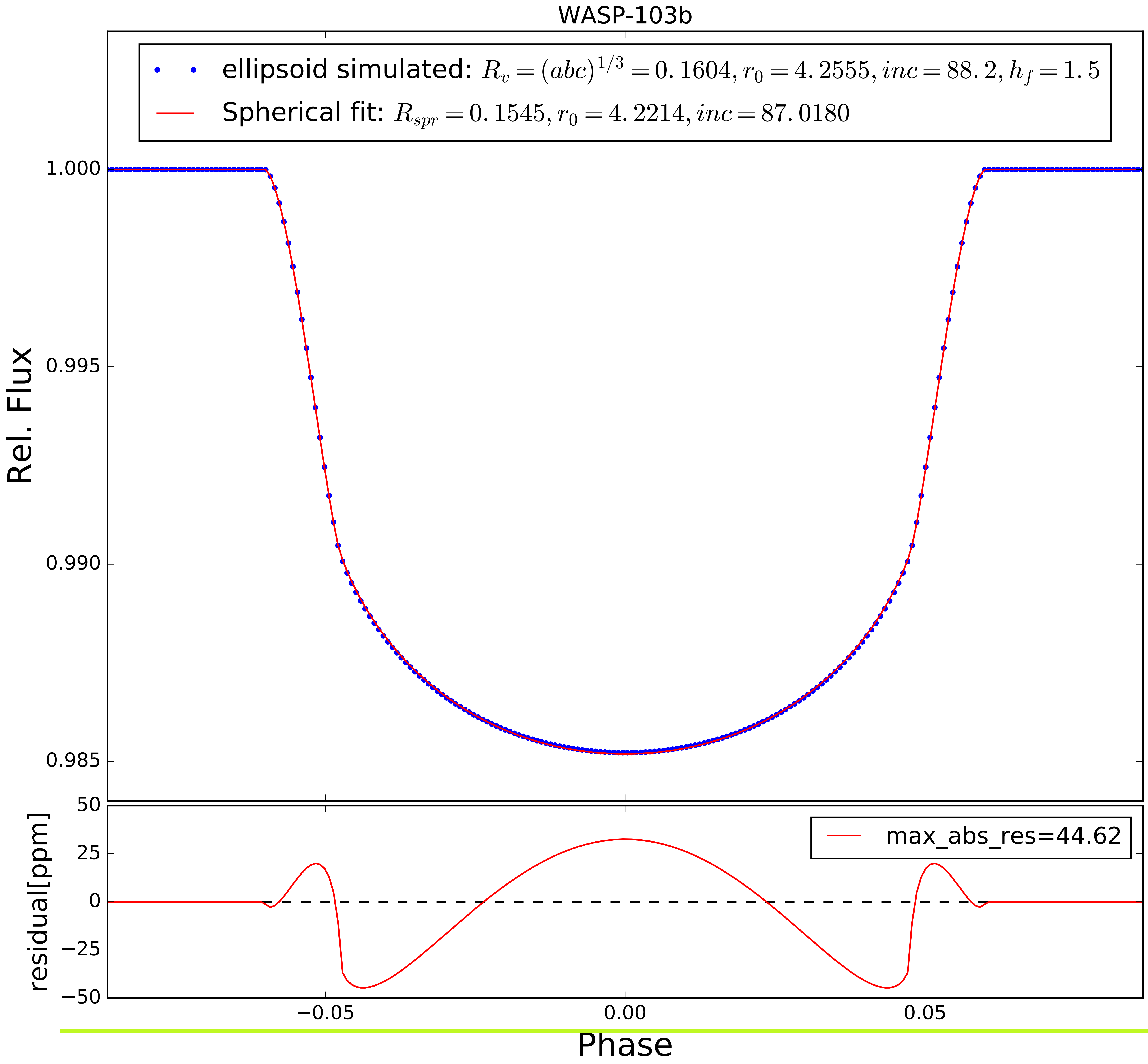
Correia, A. A&A, 2014

Tidal Bulge

Rotation

- Strong tidal forces deforme the shape of ultra Hot Jupiter into ellipsoids.
- The deformation of the three axis is related to a single parameter - Love number
- The Love number measures the distribution of mass within the planet giving insight into the planet internal structure.

Seager & Hui 2002; Barnes & Fortney 2003

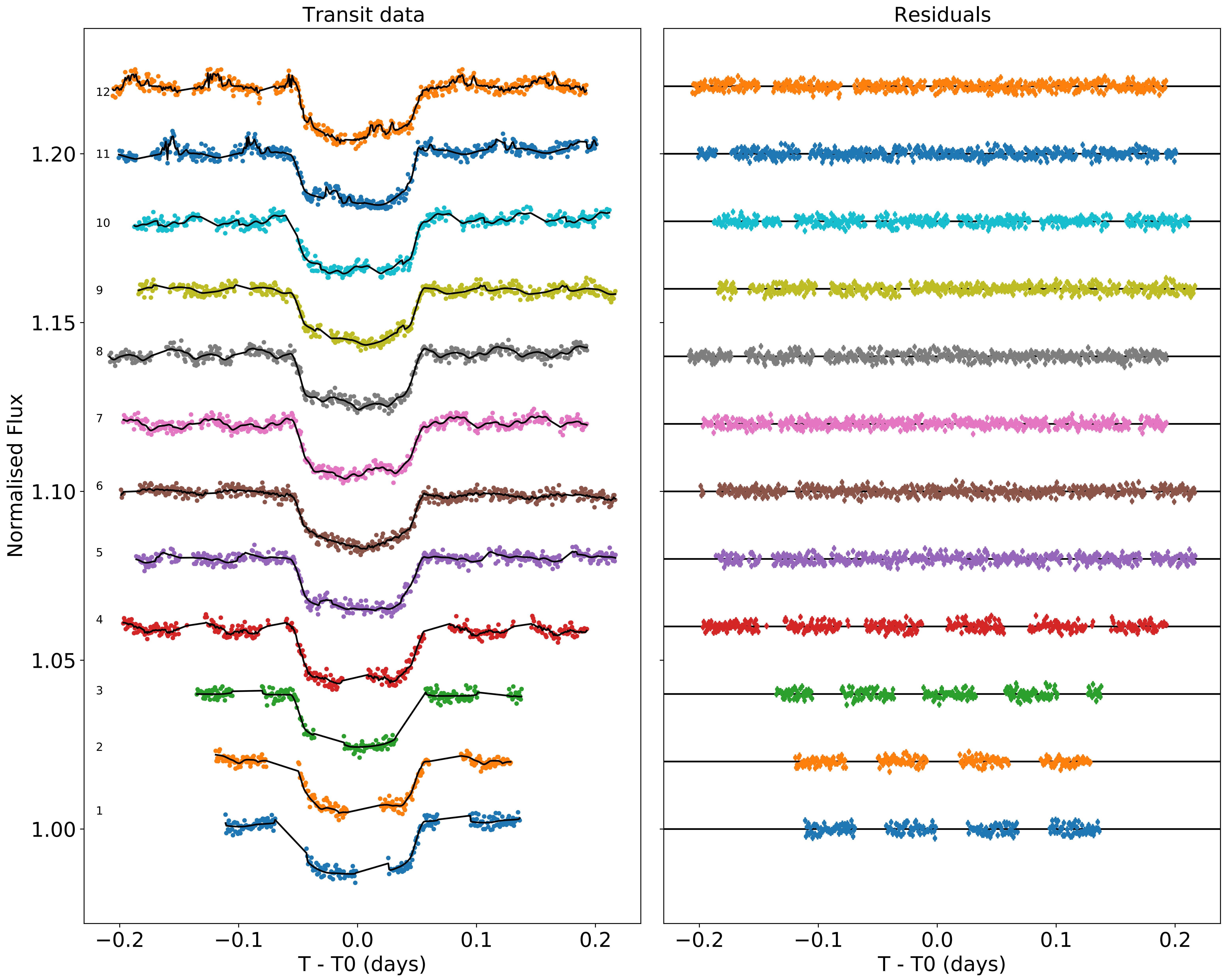


Model

- Implemented the parametrisation of Correia 2014 using the ELLC transit code.
- Signature of the tidal deformation is defined as the difference between the best spherical fit to the data and the best ellipsoidal model fit.
- Assuming hf =1.5 —>293 CHEOPS, ~100 PLATO or 1 JWST transits are needed
- Assumed a large LD error and a smaller radius ratio
- Best measurement of the Love number was for WASP-121b using 2 HST transits made by Hellard et al. 2019 —> $h_f = 1.39 \pm 0.8 - < 2\sigma$

Akinsanmi, Barros et al A&A 2019

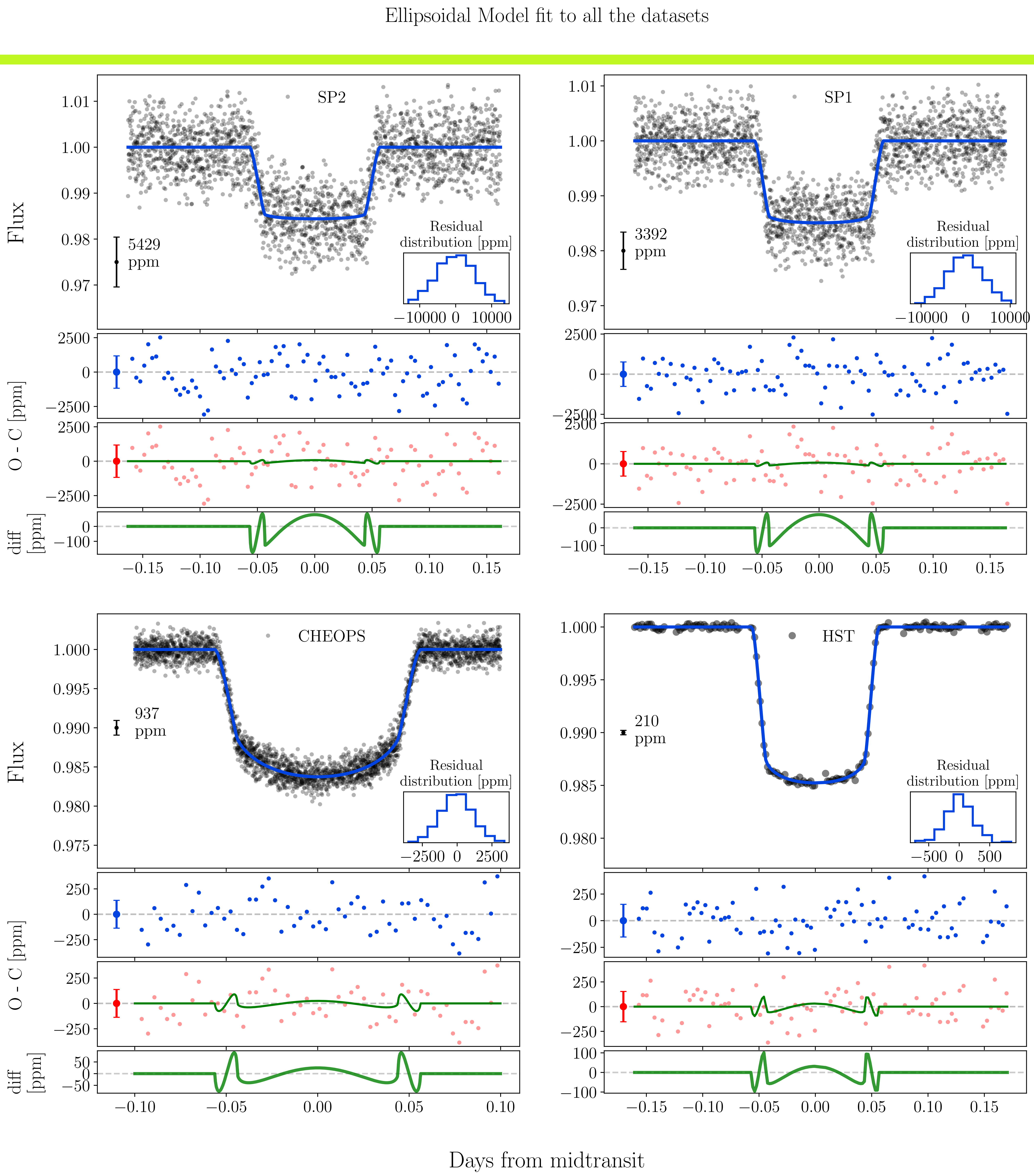
CHEOPS data



Systematics corrected with a multi-dimensional Gaussian constrained by instrumental parameters: roll angle, position of the star in CCD, target contamination and background

Combination

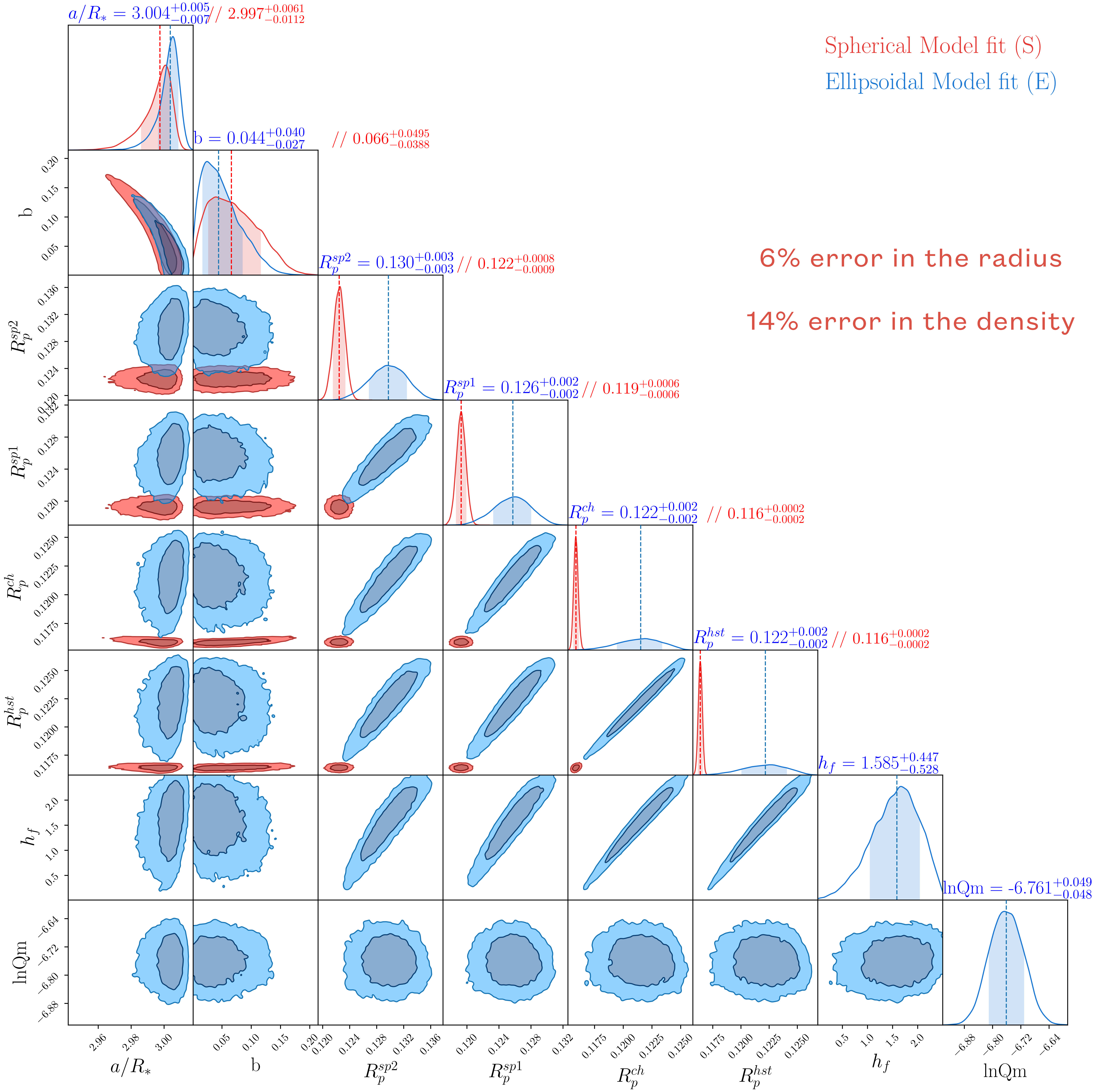
Data set	Love number	Significance
SP2, SP1	$1.36^{+0.71}_{-0.79}$	$1.7\,\sigma$
HST	$0.99^{+0.68}_{-0.59}$	1.7σ
CHEOPS	$1.74^{+0.69}_{-0.49}$	$2.5\,\sigma$
HST, SP2, SP1	$1.16^{+0.64}_{-0.63}$	$1.8\,\sigma$
All data	$1.59^{+0.45}_{-0.53}$	$3.0\,\sigma$



Results

Assuming a power-2 limb darkening law we estimated the Love number, $h_f = 1.59^{+0.45}_{-0.53}$. This is the first time that a 3σ detection of the Love number has been achieved directly from the analysis of the deformation of the transit light curve. Possible due to:

- Combination of several high precision transits
- Improvement of the model
- Strong limb darkening constrains



6% error in the radius

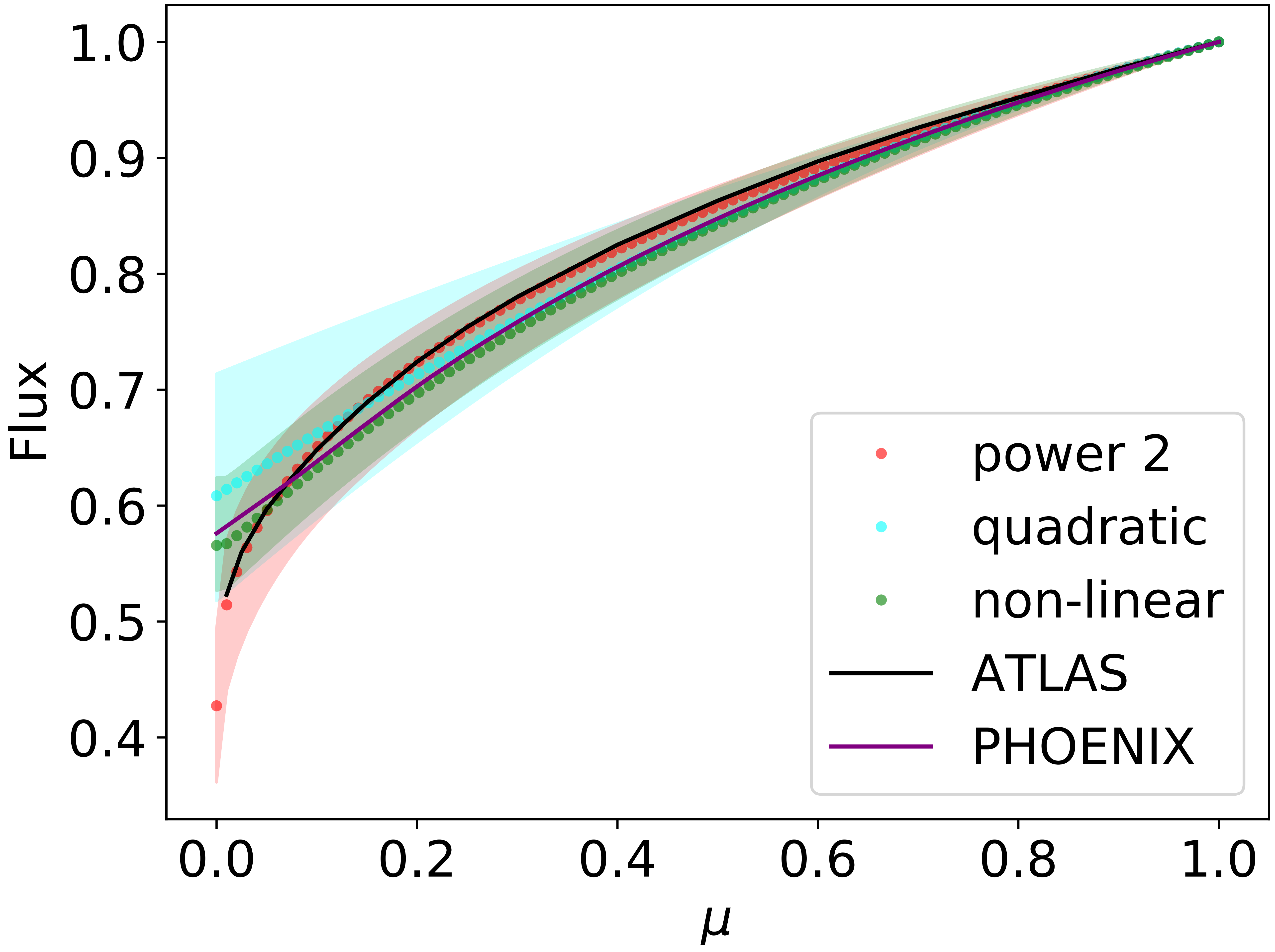
14% error in the density

Significance of the detection

- Bayesian model comparison requires computing the odds ratio between two hypotheses.
  $Odds\ ratio = prior\ odds \times Bayes\ factor$ Is the planet deformed?
- Prior odds strongly favours the ellipsoidal model ~ infinity
- Bayes factor is 9.1 X prior odds —> very strong odds ratio YES

How much the planet deformed?

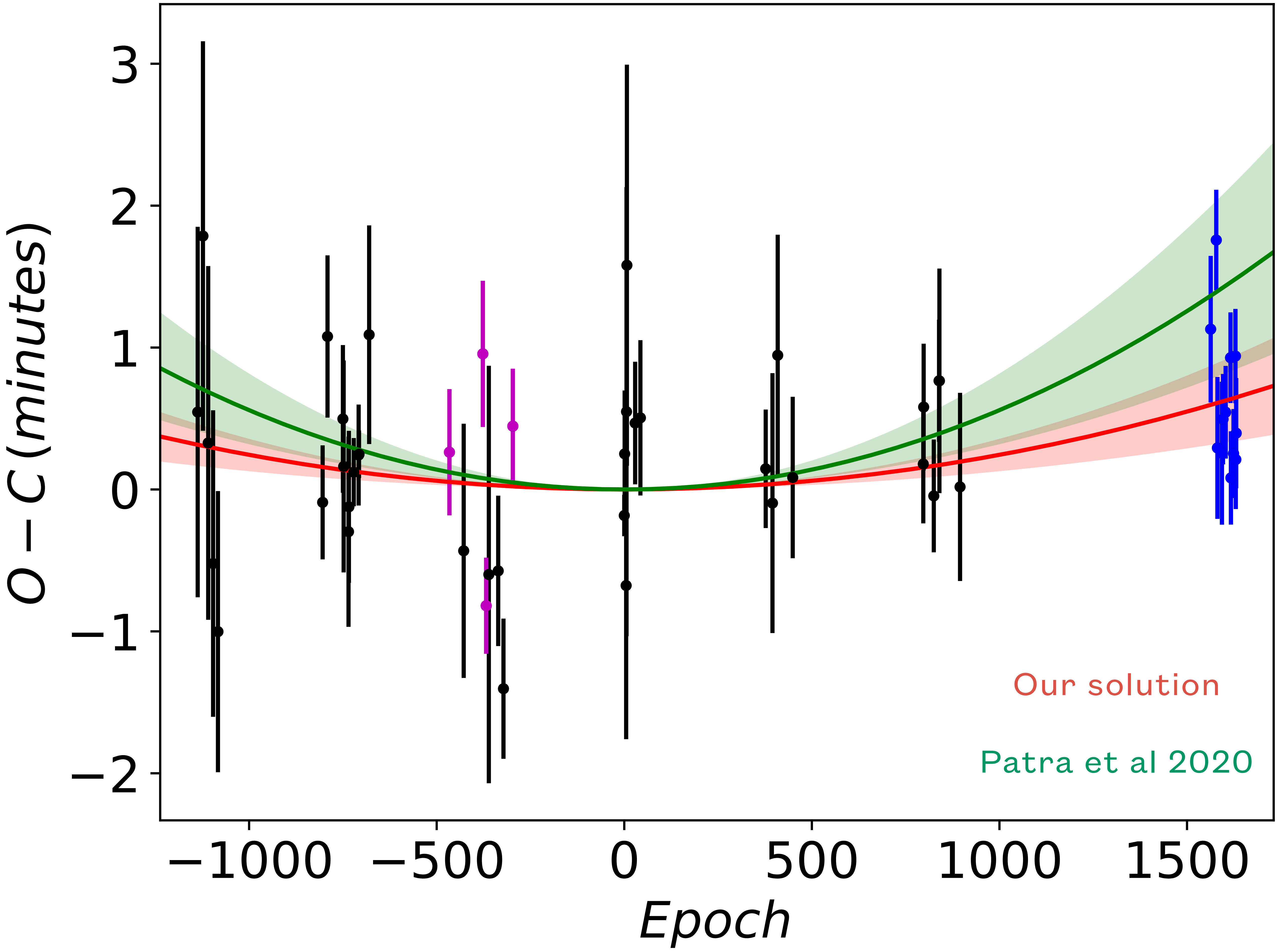
- Parameter inference should be used instead of model comparison in this case
- Bayes factor as a proxy of which model is favoured by the data. Will require some modifications like not penalising for complexity of the model. This increases the Bayes factor to 17.2. So the ellipsoidal model is 17X more probable then the spherical model.



Limb darkening

- Wide priors don't allow to constrain the Love number. Wide priors give too much freedom to the data and don't account for correlations between the four different colours. In particular for the Spitzer the LD erros should be small.
- Estimate what was the smallest priors that was still reasonable. Used 3 limb darkening laws and 2 stellar intensity profiles increasing the errors to encompass the two limb darkening laws.

LD law	Love number	Significance	Bayes factor
Power-2 law	$1.59^{+0.45}_{-0.53}$	3σ	9.1(17*)
Quadratic	$1.37^{+0.51}_{-0.59}$	2.3σ	4.6(6.6*)
Non-linear	$1.69^{+0.42}_{-0.48}$	3.5 σ	16(26.9*)



Literature values from Maciejewski et al. 2008

Tidal Decay

- $\dot{P} = 3.5 \pm 1.8 \times 10^{-10}$ days/day
- Q > 1.6×10^6 at $3\,\sigma$ (99.7% confidence interval)

- RV acceleration due to a companion
- Applegate effect
- Apsidal precession

Future

- Longer time span of the monitoring of transit time variation will help us understand the period evolution of the system.
- Other AO observations and GAIA paralaxes will allow to constrain the possible companion.
- Improve the precision of the tidal deformation:

One transit of JWST $h_f = 1.62^{+0.12}_{-0.13}$ 12 sigma - unprecedented constrain on the internal structure of a hot Jupiter planet

48 CHEOPS transits to reach 4 sigma and 72 to reach 5 sigma

Thanks to the CHEOPS team

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