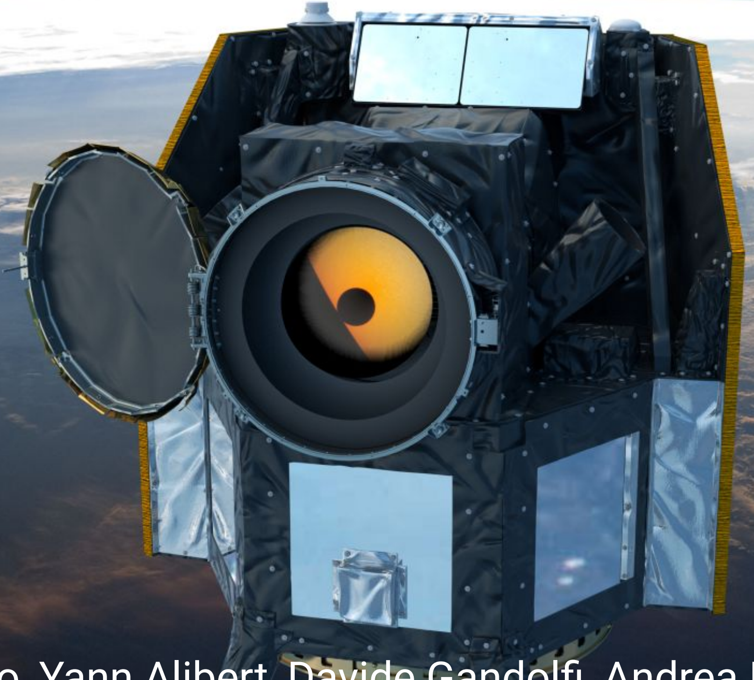
Unveiling the TOI-1064 system with TESS, CHEOPS, and HARPS

Today on arxiv!:
arXiv:2201.03570

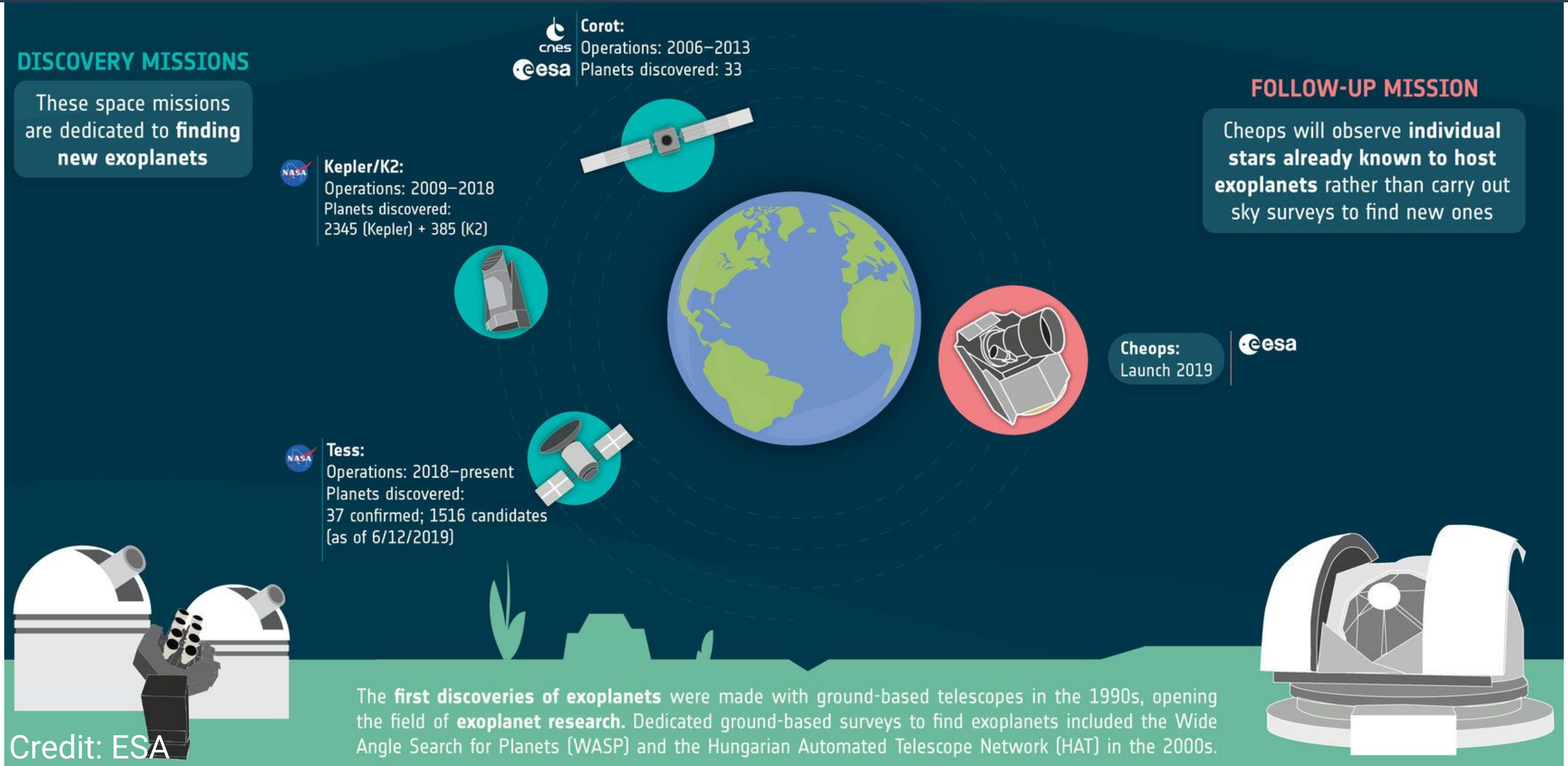


Thomas G. Wilson, Elisa Goffo, Yann Alibert, Davide Gandolfi, Andrea Bonfanti, Carina M. Persson, Andrew Collier Cameron, Malcolm Fridlund, Luca Fossati, Judith Korth & the *CHEOPS*, KESPRINT, & *TESS* consortia

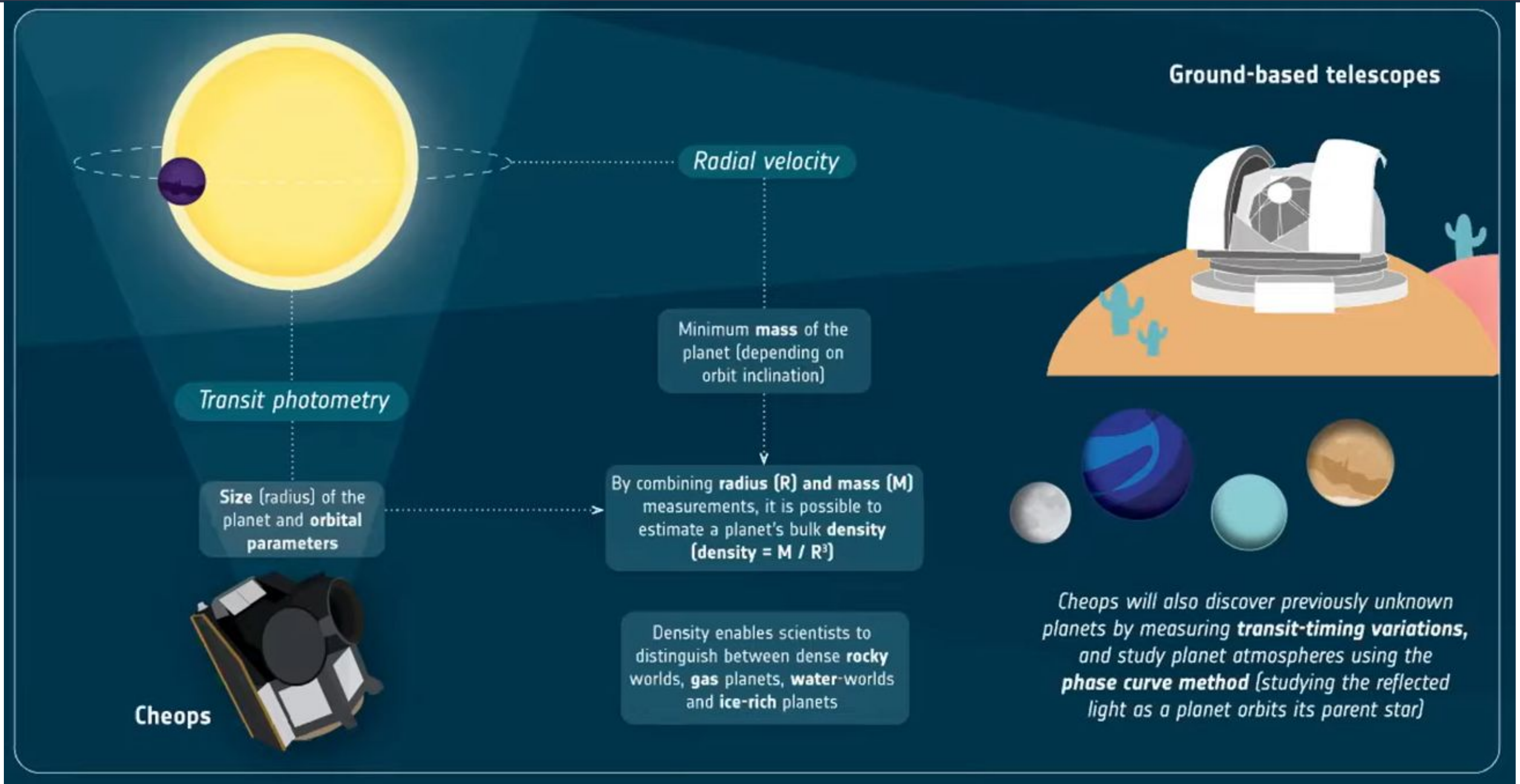
CHEOPS Workshop VI - 12/01/2022

St Andrews Centre for Exoplanet Science

With thousands of planets discovered focus can turn to characterisation

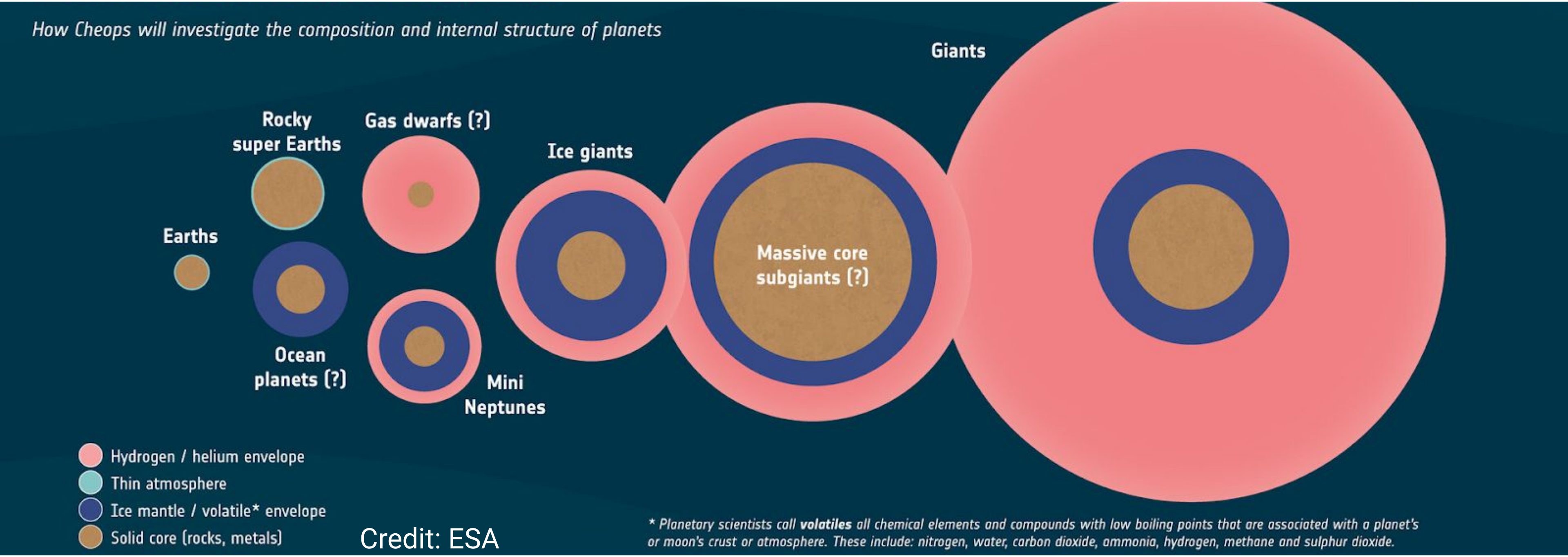


A key science aim of *CHEOPS* is the determination of accurate exoplanet densities and structures



Credit: ESA

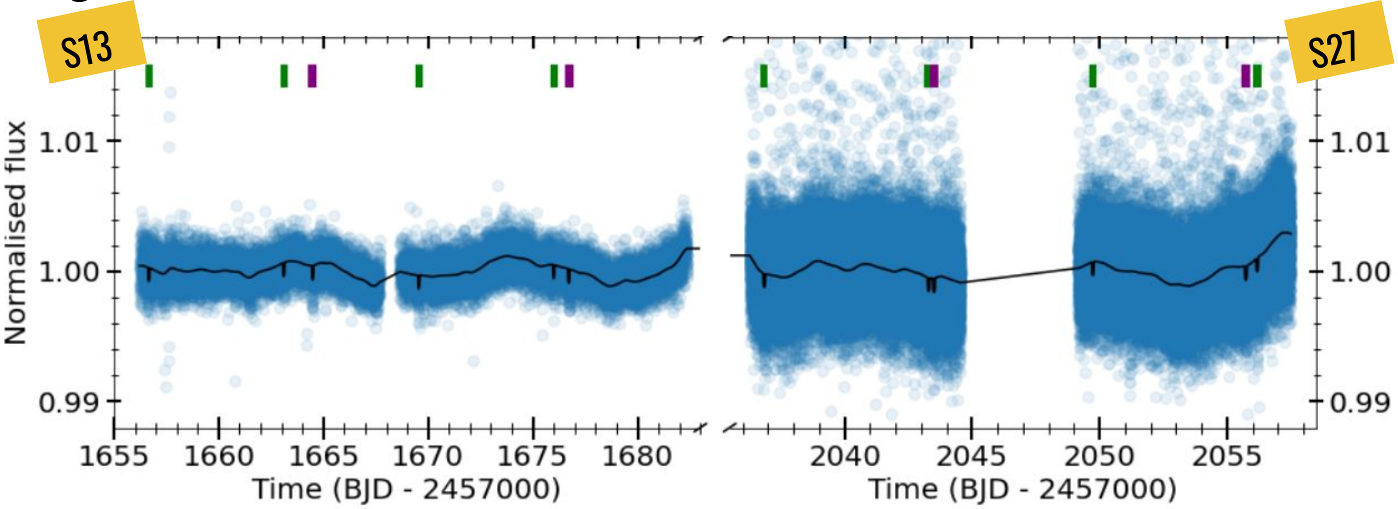
Improve the radius estimates to refine bulk densities and internal structures

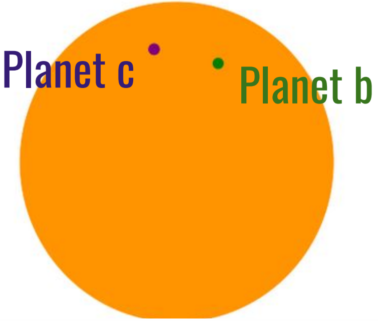


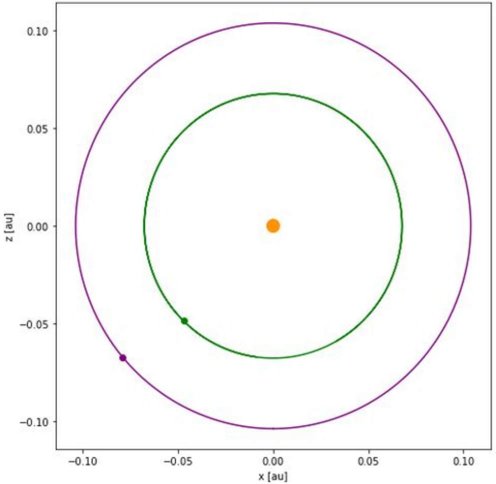
Credit: ESA

One such target is TOI-1064, K-dwarf hosting a pair of sub-Neptunes on 6.4 and 12.2 d orbits

Initially detected in *TESS* Sector 13, both planets were observed again with 20 s cadence in Sector 27

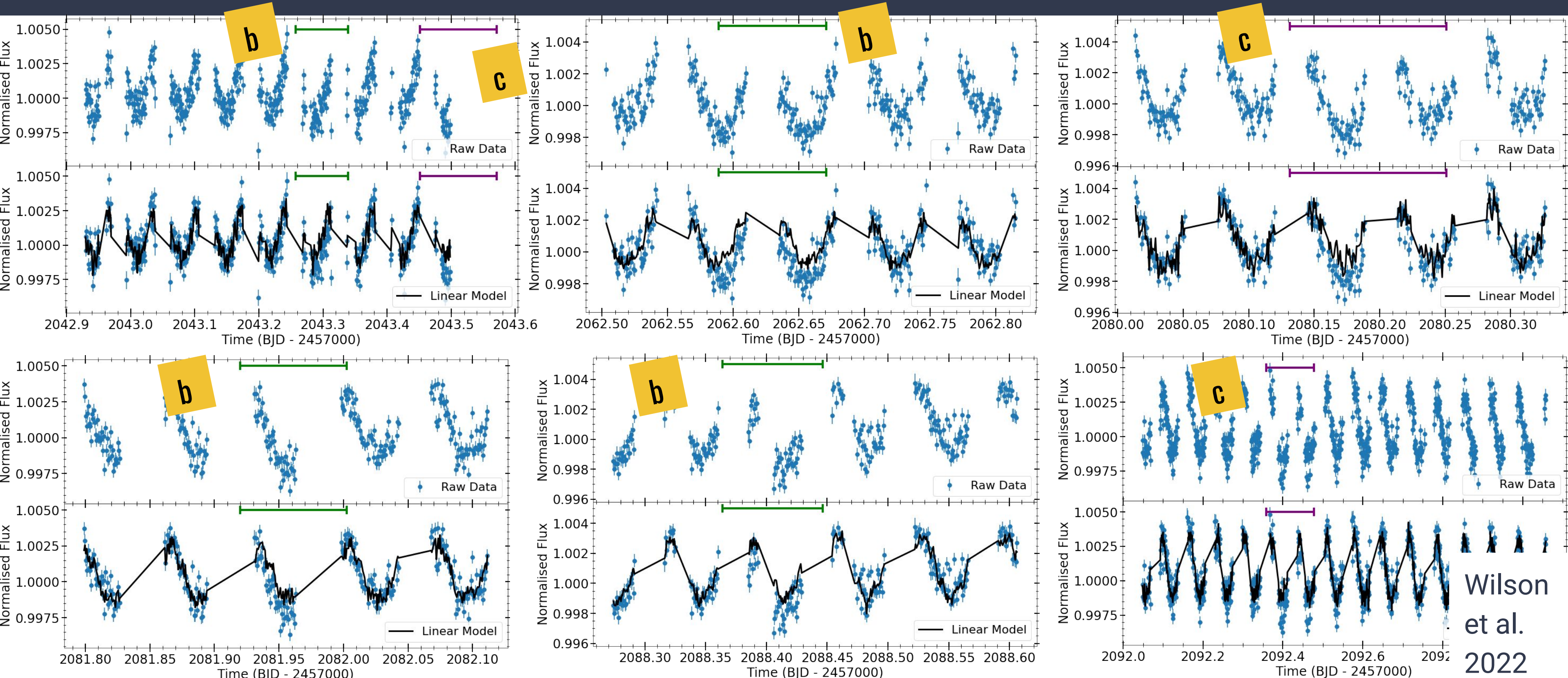






Wilson et al. 2022. A pair of Sub-Neptunes transiting the bright K-dwarf TOI-1064 characterised with *CHEOPS* (accepted in MNRAS), arXiv:2201.03570

To reach our science goals we obtained 6 *CHEOPS* observations of 7 transits



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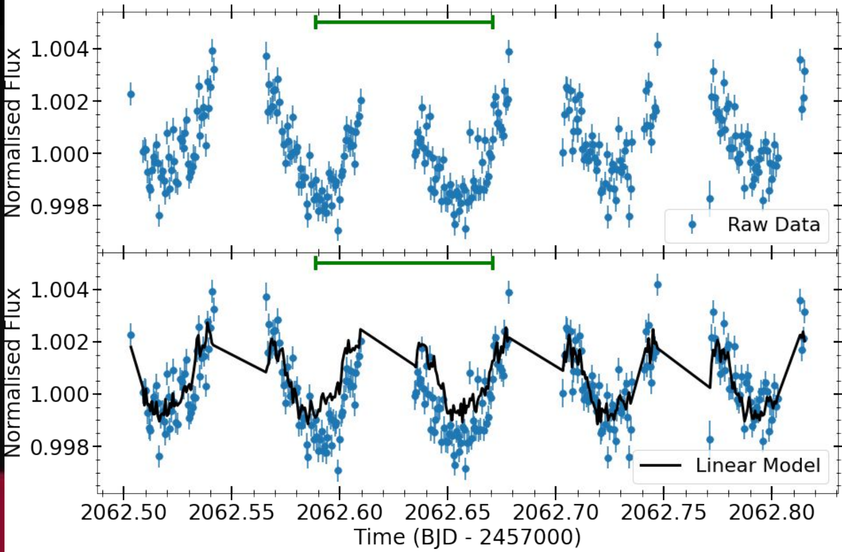
Observing with CHEOPS; roll angle trends



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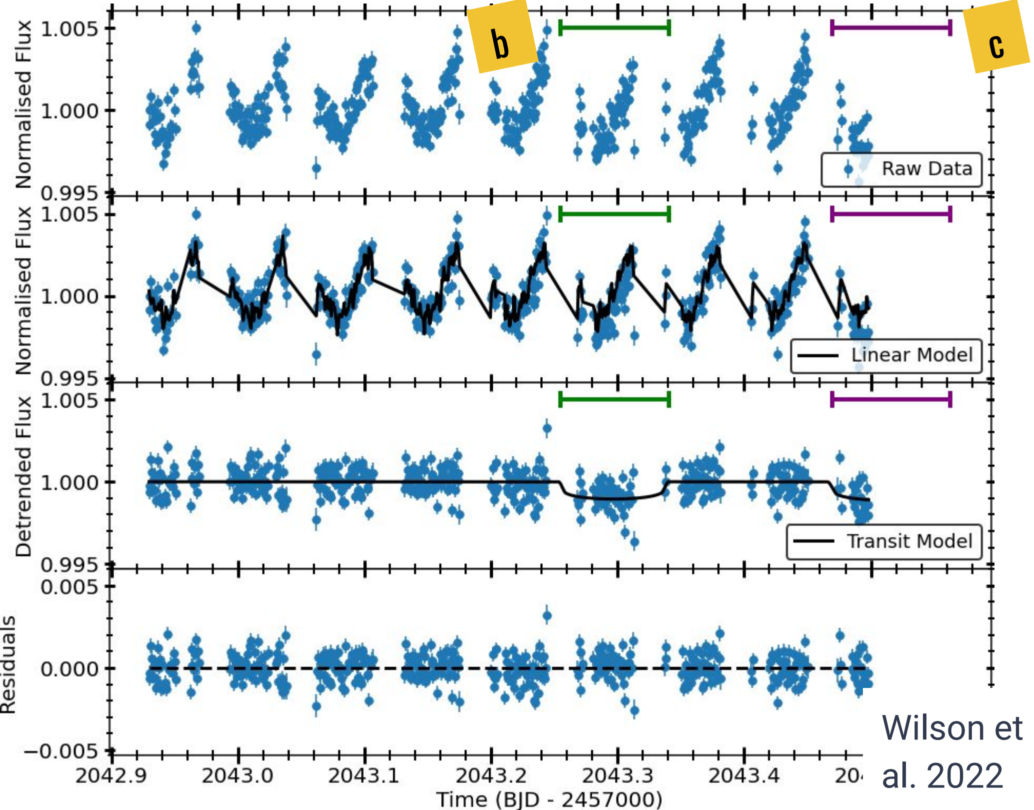
To detrend our data we developed a novel PSF-applied PCA-based method



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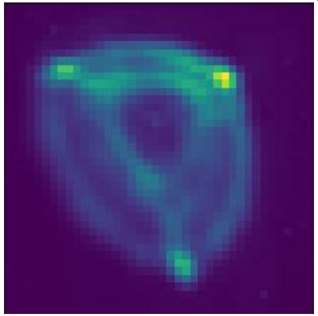
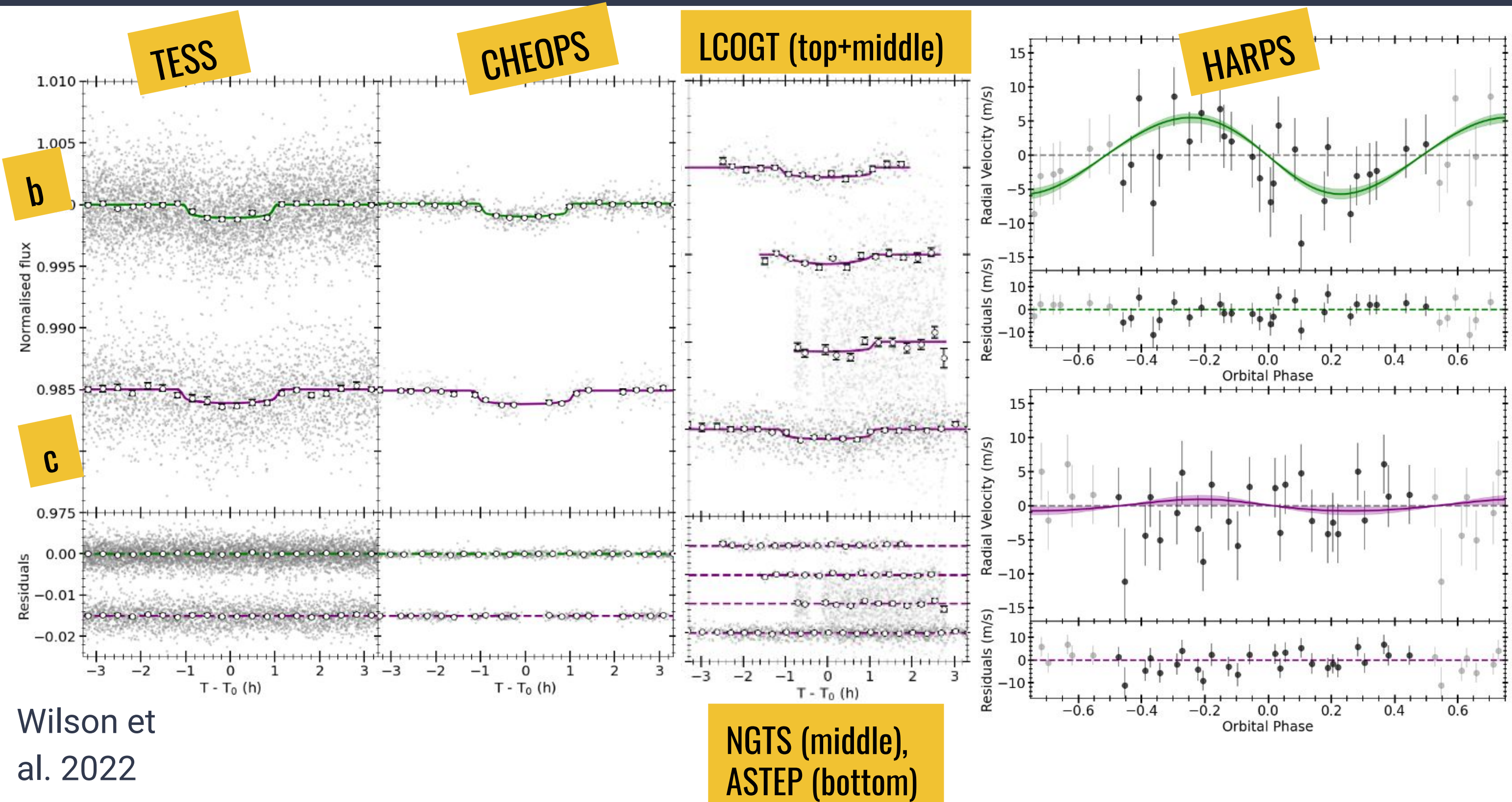
- Built off SCALPELS (Collier Cameron et al. 2021) that measures variations in RV CCFs, our tool conducts a PCA on the *CHEOPS* PSFs to measure shape changes.



- This is supported by using a Leave-One-Out Cross Validation (LOOCV) method to assess and select the vectors that contribute the most to the PSF shape changes that are then used to detrend the data.
- It is applicable to any photometric dataset in which PSF changes may cause flux variation, such as temperature, stray light, contamination, or spacecraft motion.

Combining *CHEOPS*, *TESS*, HARPS, NGTS, LCOGT, and ASTEP data we confirm the planets and find that they have similar radii, but likely significantly different masses, i.e. a different-twin pair



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TOI-1064 b:

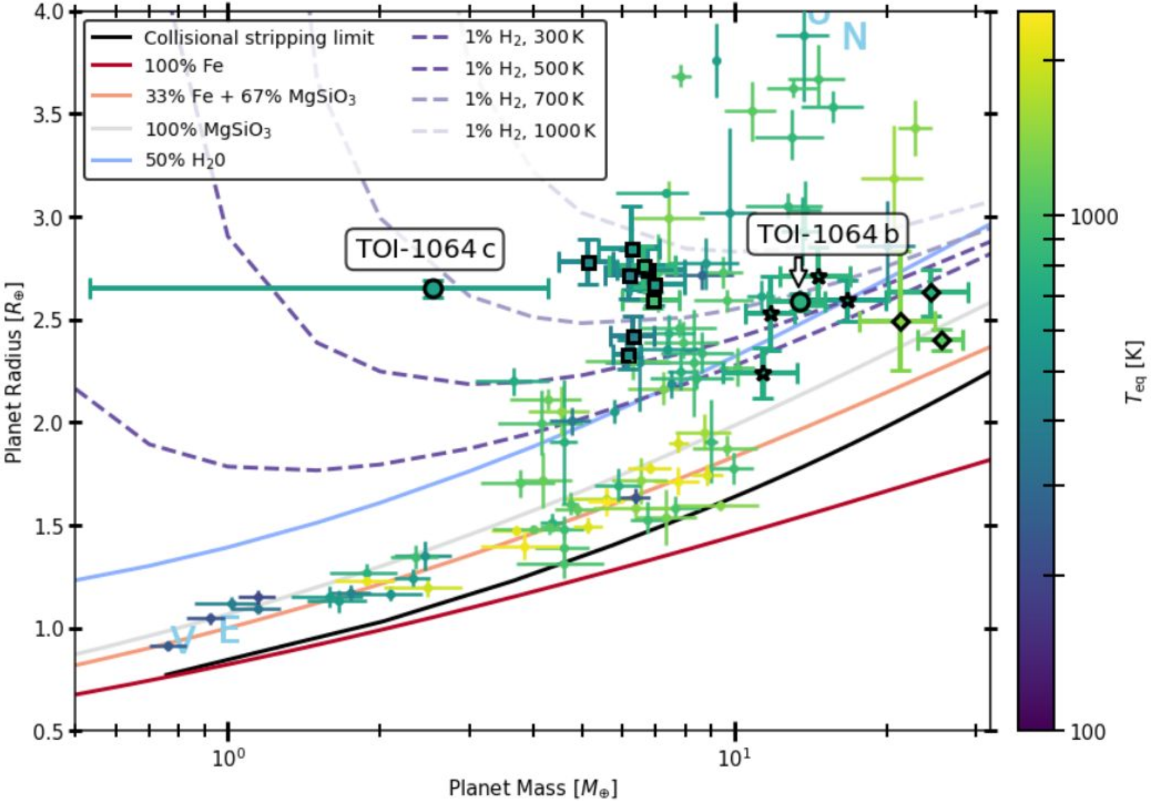
- P = 6.44387 d
- R = 2.59+/-0.04 R_{Earth} (1.6%)
- M = 13.5+/-1.8 M_{Earth}
- ρ = 4.3+/-0.6 g cm^{-3}
- T_{eq} = 784+/-13 K

TOI-1064 c:

- P = 12.22657 d
- R = 2.65+/-0.04 R_{Earth} (1.6%)
- M = 8.5 M_{Earth} (3σ up. lim.)
- ρ = 2.6 g cm^{-3} (3σ up. lim.)
- T_{eq} = 634+/-10 K

Placing TOI-1064 on a MR diagram shows that planet b is one of the densest well-characterised sub-Neptunes known

With the likely mass disparity, TOI-1064 could join other “different twin” systems such as Kepler-107 (Bonomo et al. 2019), KOI-1599 (Panichi et al. 2019), and TOI-125 (Nielsen et al. 2020).



TOI-1064 b joins a family of mildly irradiated, dense sub-Neptunes including HIP 116454 b (Vanderburg et al. 2015), Kepler-48 c (Steffen et al. 2013), K2-110 b (Osborn et al. 2017), and K2-180 b (Korth et al. 2019).

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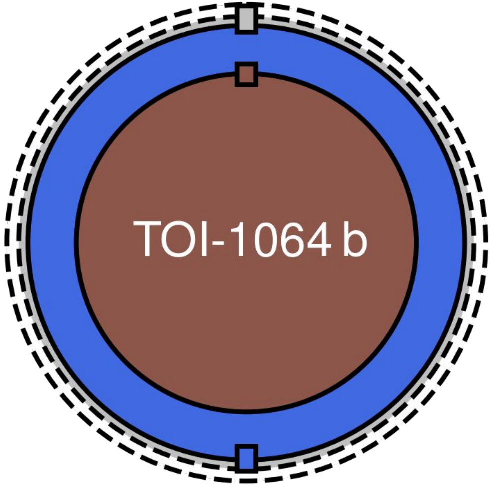
Internal structure modelling highlights the density disparity and likely small atmosphere on TOI-1064 b

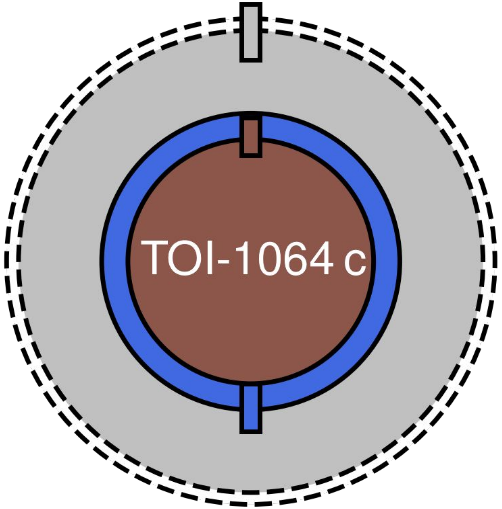
Internal structure modelling conducted with a four layer system:

- a Fe+S metallic core (EoS from Hakim et al. 2018);
- a Si, Mg, Fe, & O mantle (EoS from Sotin et al. 2007);
- a H_2O layer (EoS from Haldemann et al. 2020);
- a H+He gas layer using models from Lopez & Fortney (2014).



Planet b has a large core and a substantial water fraction, with a very tenuous atmosphere.

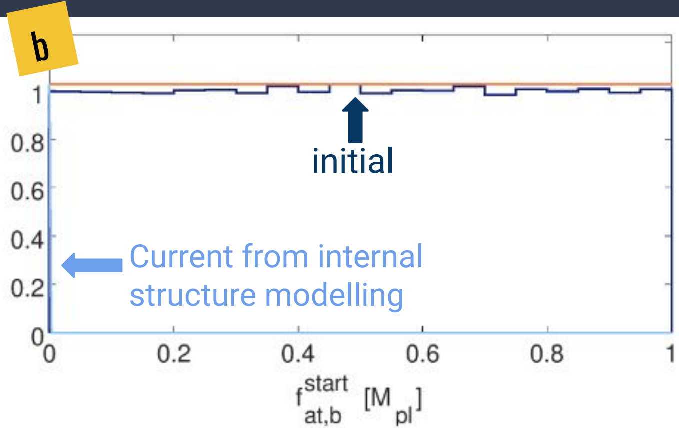
- Brown is the metallic core and rocky mantle
- Blue is the water envelope
- Grey is the gas atmosphere

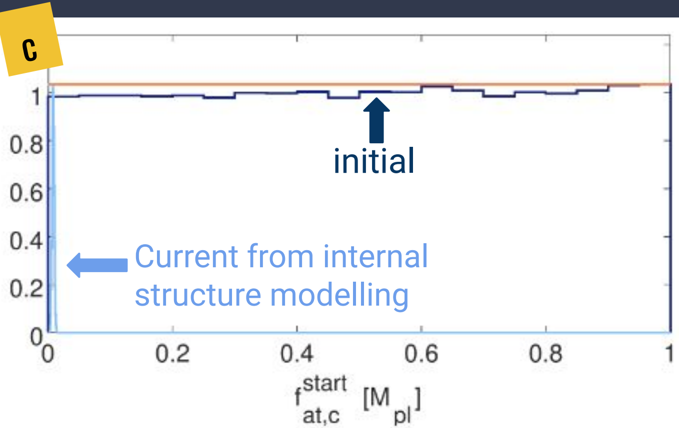


Planet c likely has a small core and water layer, with an extended gaseous envelope.

Wilson et al. 2022, work by Y. Alibert based on Dorn et al. 2015, 2017

Atmospheric mass fraction analysis suggests that most of the envelope of planet b has been lost



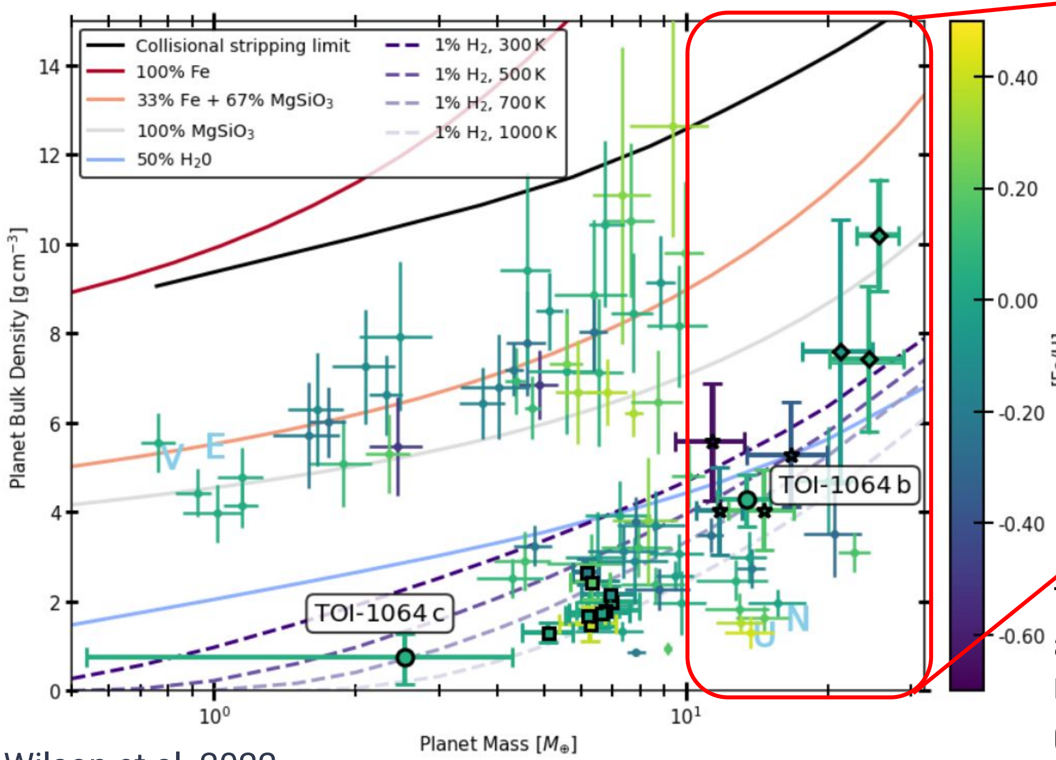


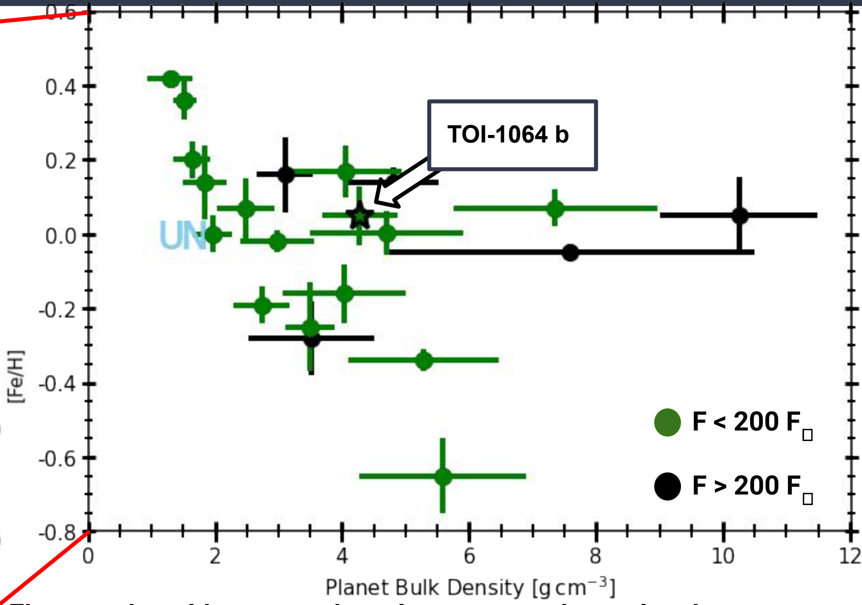
- TOI-1064 b likely accreted a larger envelope and then migrated through the protoplanetary disk onto its current 6 day orbit.
- Due to its probable current atmospheric mass fraction, TOI-1064 c may have initially accreted a larger atmosphere or underwent delayed migration after planet b.
- These scenarios can be tested by tighter mass constraints for planet c and by searching for exterior transiting planets in the system.

See Andrea's talk on Tuesday

Wilson et al. 2022, work by A. Bonfanti and L. Fossati based on Kubyshkina et al. 2019

Precise data reveals a density-[Fe/H] trend for $M_p > 10$ M_{Earth} sub-Neptunes potentially hinting at formation causes





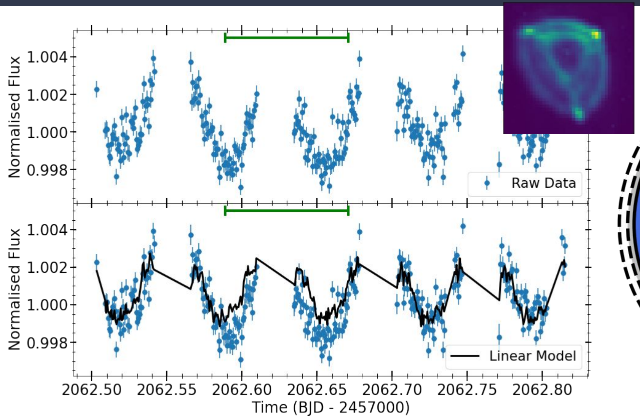
Wilson et al. 2022

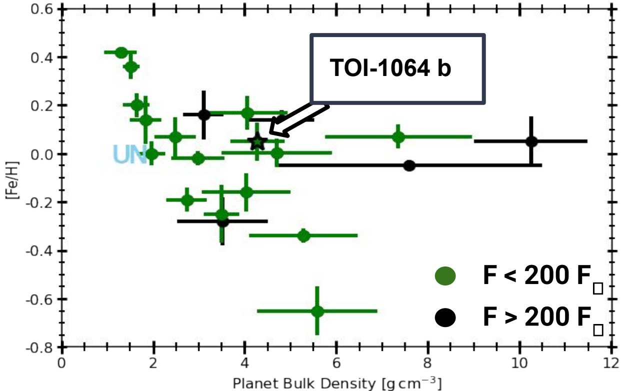
This trend could suggest that planets around metal-rich stars accrete bigger envelopes or have more massive cores and can retain their atmospheres.

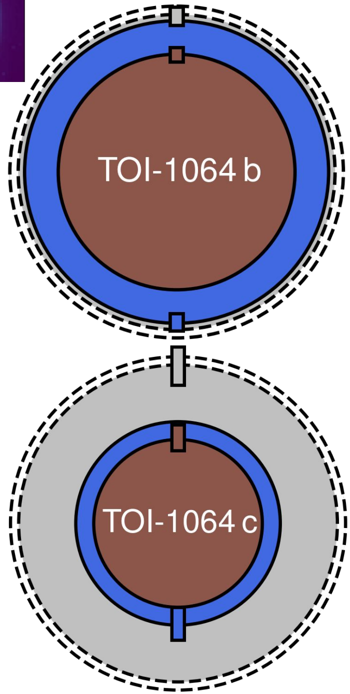
Or that planets around metal-rich stars have metal-rich envelopes that have reduced photo-evaporation atmospheric mass-loss rate.

Summary - A pair of Sub-Neptunes transiting the bright K-dwarf TOI-1064 characterised with *CHEOPS*

- We report the discovery of the pair of sub-Neptunes; TOI-1064 b and c, and characterise both planets using high-precision photometry from CHEOPS, *TESS*, LCOGT, NGTS, and ASTEP, and HARPS RVs.
- Interestingly, although TOI-1064 b and c have similar radii, the masses are significantly different resulting in a density disparity.
- Our internal structure analysis shows that TOI-1064 b has a tenuous atmosphere, that may have been lost after migration and a large volatile component. Whereas, TOI-1064 c likely has an extended gaseous envelope.
- Upon analysis of massive sub-Neptunes, we find a negative correlation between bulk density and host star metallicity that could be a result of the formation of planets or subsequent evolutionary processes.
- We also present a novel method for detrending photometric data via the monitoring of PSF shape changes and successfully apply it to the *CHEOPS* photometry.







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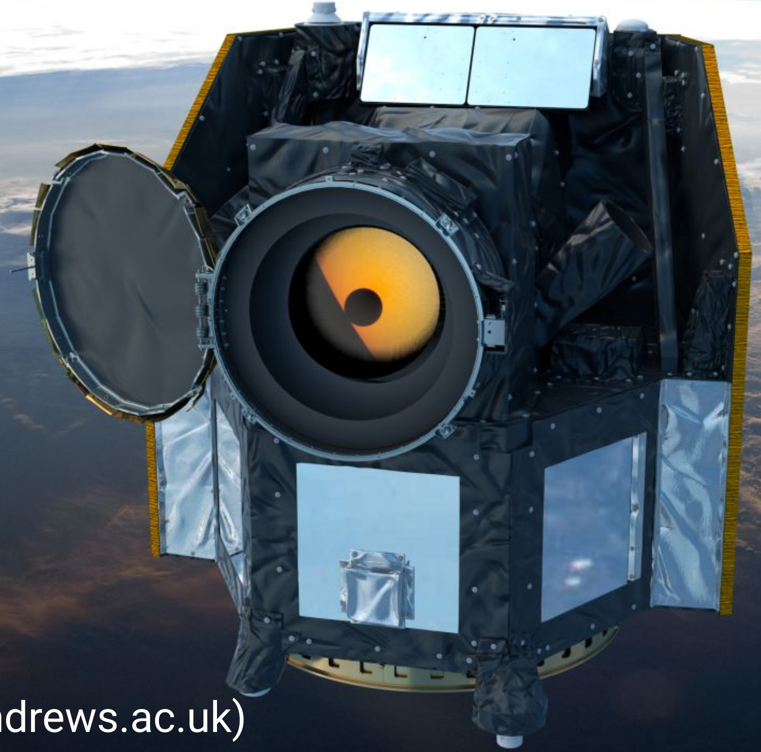
Thanks for listening. Any questions?



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