TOI-1778 b: Confronting compositional confusion through the characterisation of a sub-Neptune

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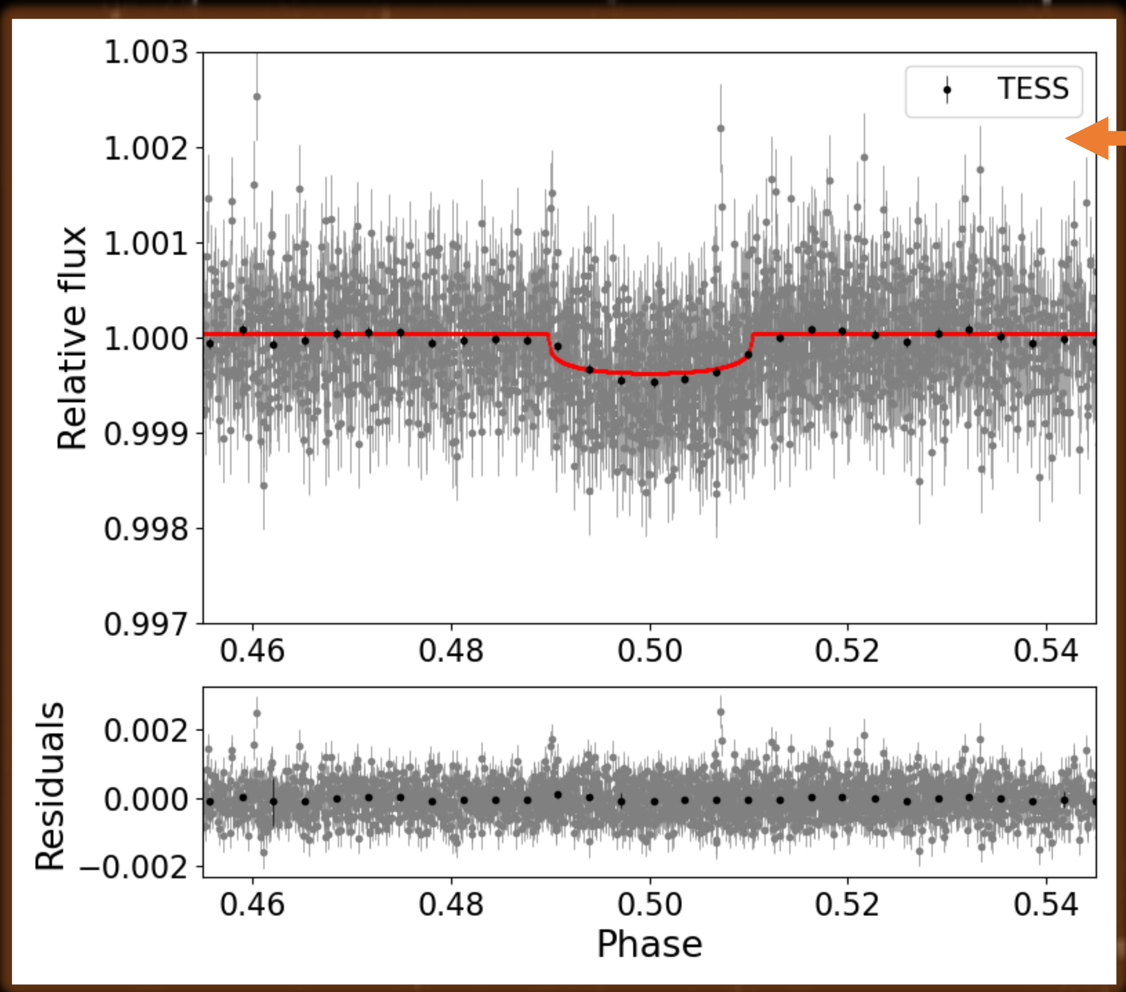
Motivation

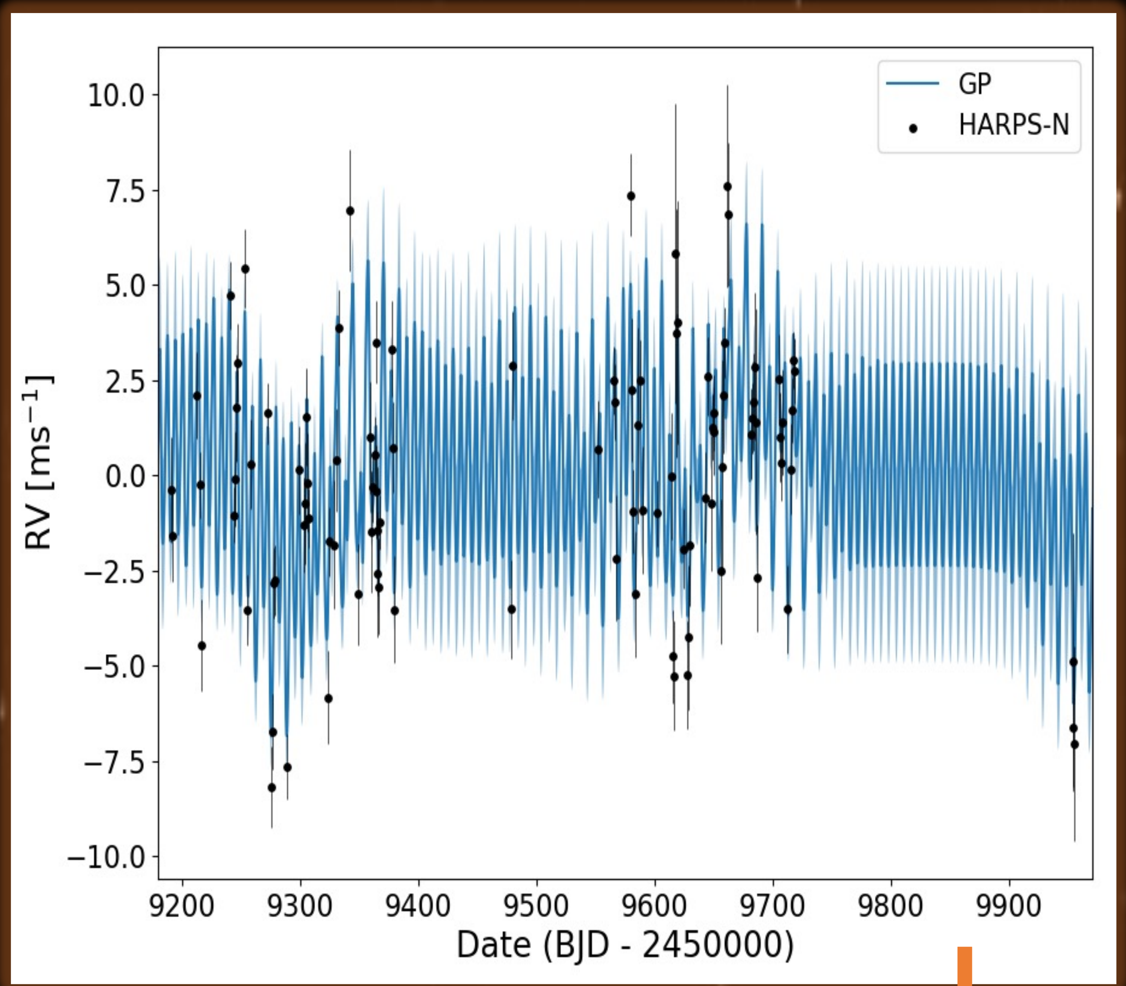
An exoplanet, called TOI-1778 b, when plotted on a mass-radius (M-R) diagram, falls in an area where there is currently a degeneracy between water-world and sub-Neptune planet composition models. Precise mass and radii measurements of exoplanets are crucial for breaking this degeneracy, and the characterisation of TOI-1778 b, adding to the small sample of well characterised sub-Neptunes, is an important step forwards on our journey to refute or confirm the existence of water-worlds, and thus constrain planet formation and evolution pathways, helping us to better understand our own place in the Universe.

Observations

- NASA'S Transiting Exoplanet Survey Satellite (*TESS*) (in orbit around Earth) first observed TOI-1778 during sector 21 (year 2) of its cycle and again in sector 47 (year 4), observing a total of 7 transits of TOI-1778 b in front of its host star.
- 2 further transits were observed with the European Space Agency's Characterising Exoplanet Satellite (*CHEOPS*) (also in orbit) in January & December 2021.
- We carried out a total of 102 follow-up radial velocity (RV) observations between December 2020 and January 2023 with HARPS-N on the ground-based Telescopio Nazionale Galileo (TNG) in La Palma, Canary Islands.

Figure 1 (below): Transit fit to the data from TESS (top). RV + GP fit (bottom).



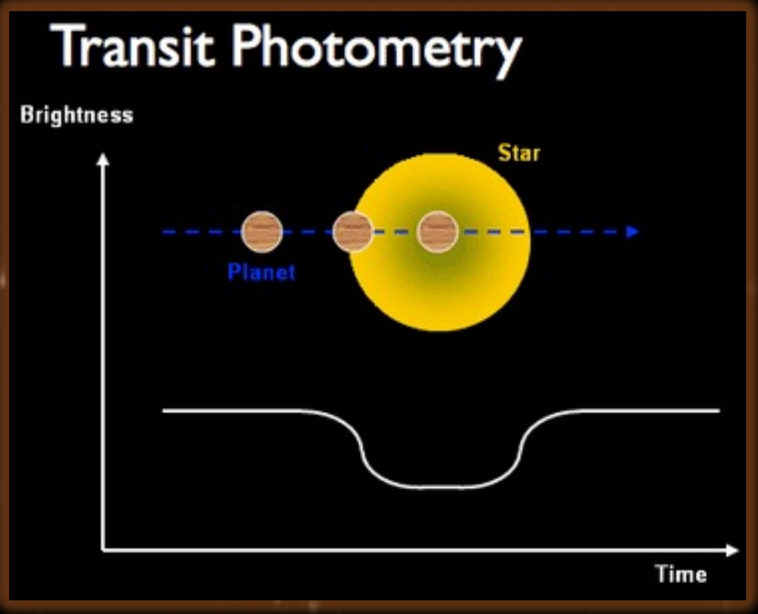


Modelling

- Joint modelling of transit and RV observations can better inform of us of the planet's composition and atmosphere.
- From joint modelling we found TOI-1778 to be a bright F type star with an effective temperature of 5881°C (~227°C hotter than the Sun), and an approximate 13.6-day stellar rotation period.
- A Gaussian Process (GP) was also used in our model to account for stellar activity and rotation. Not accounting for this can lead to severe miscalculations of a planet's mass.

Composition

- Modelling of the internal composition indicates a gaseous H/He atmosphere less than 1% of its total mass , but 1/3 of its radius. Plotting it on a M-R diagram, however, indicates the planet could have a H/He or steam atmosphere.
- Compared to the Earth the iron core makes up a smaller fraction of the total mass, whilst the mantle is bigger.
- The planet has an equilibrium temperature of ~977°C (about 4x Earth's temperature).
- At this temperature water is in a supercritical state meaning that the concept of a water-world cannot be entirely discounted.



Transit observations can be used to measure a planet's radius. Credit: NASA/AMES.

RV observations can be used to estimate a planet's mass. Credit: NASA/AMES.

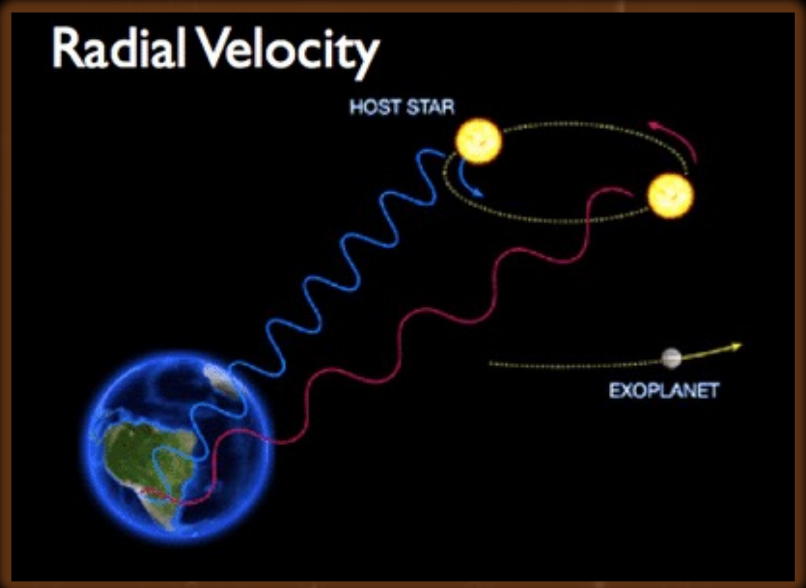
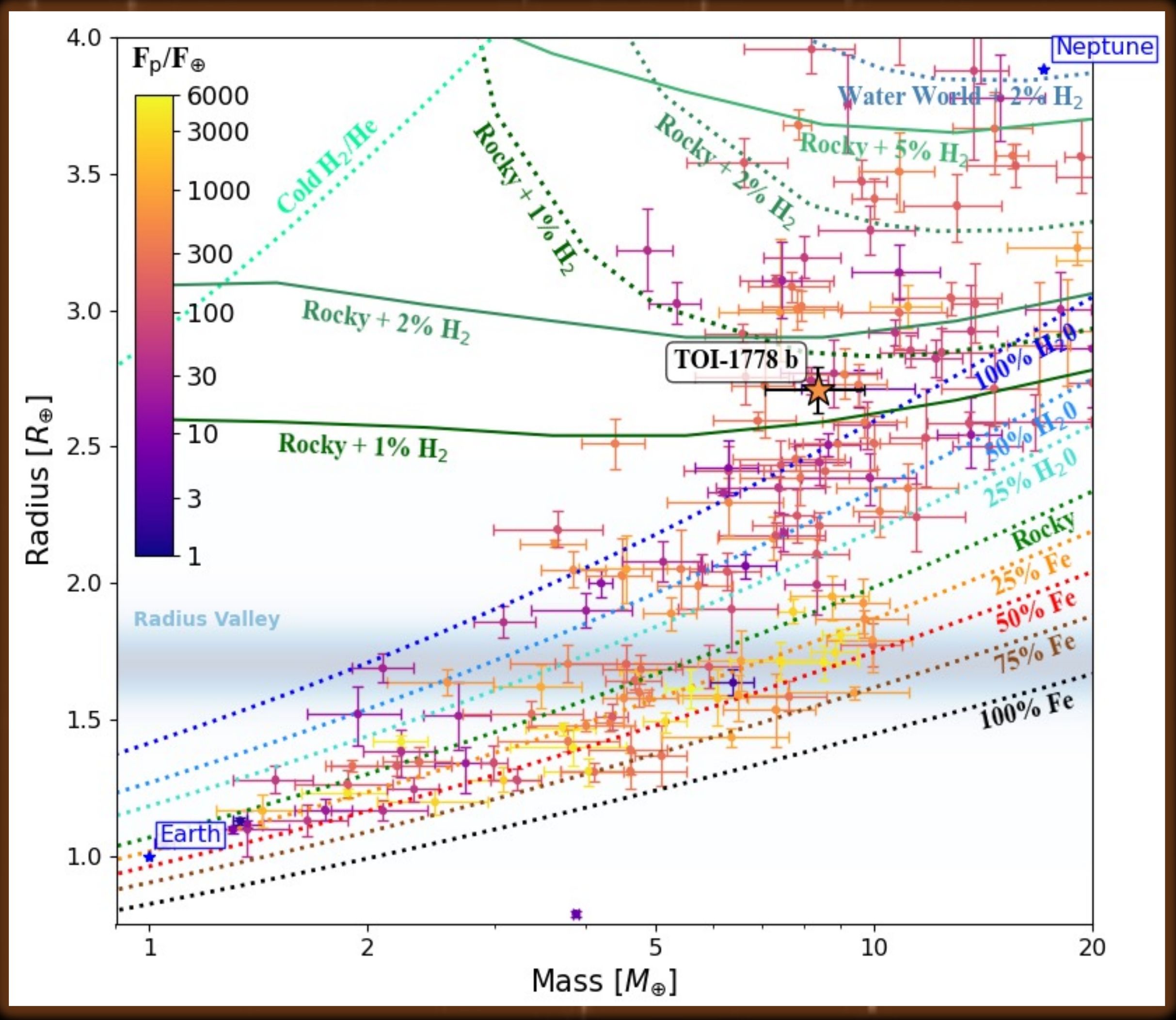


Figure 3 (below): *M-R diagram. TOI-1778 b is indicated by the star and confirmed planets with masses and radii measured to better precision than 10% and 20% respectively are also shown, colour-coded by the temperature of the planet. The dotted and solid lines show different composition models. TOI-1778 b falls in a region between 2 composition models – water-worlds (100% H_20) and sub-Neptunes (rocky + 1% H_2).*



Key Points

- We modelled a 2.71 $R_\oplus$ and 8.38 $M_\oplus$ sub-Neptune with a 6.53 d period orbiting a hot bright star.
- We estimate TOI-1778 b has a ~1% H/He atmosphere and is one of the hottest planets in this region of the M-R plot.
- Further atmospheric observations of TOI-1778 b with NASA's *JWST* would help confirm its composition.
- Confirming or refuting the existence of water-worlds could have strong implications for the understanding of our own solar system.

Results

- We find TOI-1778 to host one small ($M = 8.38\ M_\oplus$, $R = 2.71\ R_\oplus$, $P = 6.53$ day) transiting sub-Neptune.
- The precision of our results places it in the top 10 mass and radius measurements for confirmed small F star planets.
- This result contributes to the highlighted degeneracy between water-worlds and sub-Neptune models.
- TOI-1778 b is in the top 5 candidates of small planets around hot stars for follow-up atmospheric observations with NASA's James Webb Space Telescope (*JWST*).

Further in-depth results are presented in Palethorpe et al. (2024).