Three Super-Earths and a Water World from TESS and ESPRESSO

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Since 2018, the ESPRESSO spectrograph at the VLT has been hunting for planets in the Southern skies. We confirm and characterize three candidate planets from TESS with precise ESPRESSO RVs. TOI-260 b transits a late K-dwarf at a 13.5 d period. With a 4.23 ± 1.60 $M_\oplus$ mass and 1.71 ± 0.08 $R_\oplus$ radius, it is most likely a rocky planet, and lies in the radius valley. TOI-286 b and c transit an early K-dwarf with 4.5 d and 39.4 d periods respectively. They span the radius valley, with TOI-286 b (4.53 ± 0.78 $M_\oplus$ mass, 1.42 ± 0.10 $R_\oplus$ radius) lying below it and having a likely rocky composition, while TOI-286 c (3.72 ± 2.22 $M_\oplus$ mass, 1.88 ± 0.12 $R_\oplus$ radius) is close to the upper border, and probably has a significant water fraction. We also update parameters for the known super-Earth TOI-134 b (L 168-9 b), which transits an M-dwarf with a 1.4 d period. We obtain a lower density than previous findings, giving a rocky or Earth-like composition.

Data and methods

	TESS photometry	Radial velocities	Ground-based photometry	High-resolution imaging
TOI-260	3 sectors	ESPRESSO 45, HIRES 42	LCO x3	'Alopeke, Zorro, NIRC2, PHARO, HRCam, NESSI
TOI-286	34 sectors	ESPRESSO 47, HARPS 6	LCO, MKO, PEST	Zorro, HRCam
TOI-134	3 sectors	ESPRESSO 48, HARPS 49, PFS 76	-	-

For each target, we fit the RVs and TESS photometry with Juliet (Espinoza et al 2019). We include Gaussian Process components to model instrumental noise (for TESS) and stellar activity (for RVs, constrained by activity indicators). We test circular and free-eccentricity models.

TOI-260 b: A super-Earth with poorly constrained eccentricity

- Highly eccentric fit (e~0.7) is favoured by Bayesian log-evidence.
  - Likely at least partly driven by a gap in phase coverage.
  - Requires increased RV jitter.
- The ESPRESSO data do not constrain the eccentricity.
  - We prefer the simpler circular model.

Parameter	TOI-260 b
Period [d]	13.475853 ± 0.000013
Mass [$M_\oplus$]	4.23 ± 1.60
Radius [$R_\oplus$]	1.71 ± 0.08
T_{eq} [K]	493 ± 12

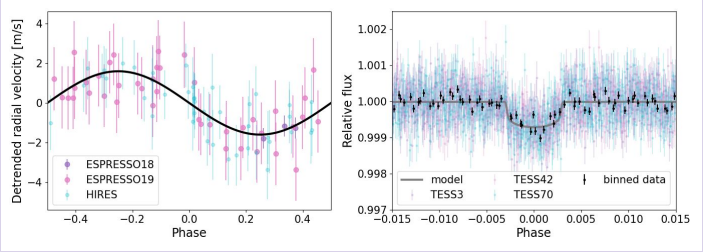

Fig. 1: Phase-folded detrended RVs (left) and TESS photometry (right) for the best-fit circular model for TOI-260 b. ESPRESSO18 and ESPRESSO19 refer to observing campaigns pre- and post- the 2019 instrumental upgrade.

TOI-286 b and c: A super-Earth and a water world spanning the radius valley

- Log-evidence comparison strongly favours two-planet over one-planet model.
- Circular orbits favoured; free-eccentricity fit gives low eccentricities.

Parameter	TOI-286 b	TOI-286 c
Period [d]	4.5117244 ± 0.0000031	39.361826 ± 0.000086
Mass [$M_\oplus$]	4.53 ± 0.78	3.72 ± 2.22
Radius [$R_\oplus$]	1.42 ± 0.10	1.88 ± 0.12
T_{eq} [K]	979 ± 31	475 ± 15

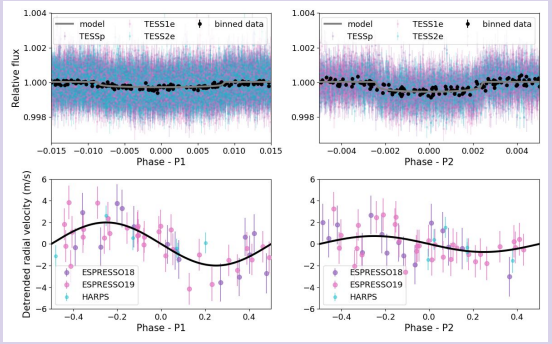

Fig. 2: Phase-folded TESS photometry (top) and detrended RVs (bottom) for the best-fit circular model for TOI-286 b (left) and TOI-286 c (right). TESSp, TESS1e, and TESS2e refer to the prime, first extended, and second extended TESS missions.

Placing the planets in a population context

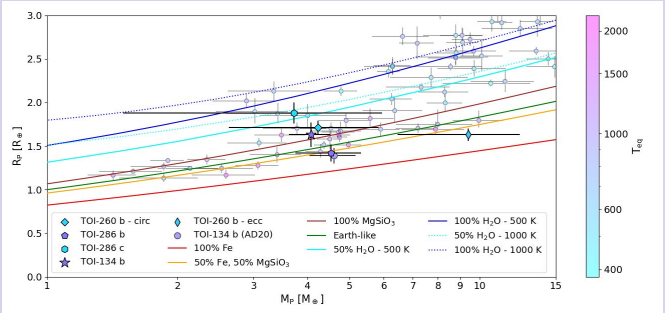

Fig. 3: Mass-radius diagram for small planets with well-constrained masses and radii hosted by early M and K stars in the PlanetS catalog, coloured by equilibrium temperature. The presented planets are highlighted. Coloured curves show the composition models of Zeng et al (2019).

- TOI-260 b:
  - Circular model: Most likely a rocky planet.
  - Eccentric model: Most likely a large iron core.
  - In the radius valley.
- TOI-286 system:
  - TOI-286 b: Probable Earth-like composition, could have formed in situ.
  - TOI-286 c: Likely has a significant water layer or volatile-rich envelope, should form beyond the snow line.
  - TOI-286 b lies below the radius valley, TOI-286 c in the upper part of it.
- TOI-134 b:
  - Lower density than previous results.
  - A super-Earth with a likely pure rock composition.

References
- Espinoza, N., Kossakowski, D., & Brahm, R. 2019, MNRAS, 490, 2262
- Zeng, L., Jacobsen, S. B., Sasselov, D. D., et al. 2019, Proceedings of the National Academy of Science, 116, 9723

Questions? Get in touch!
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