Planets at the stellar rotation period from ESPRESSO and TESS

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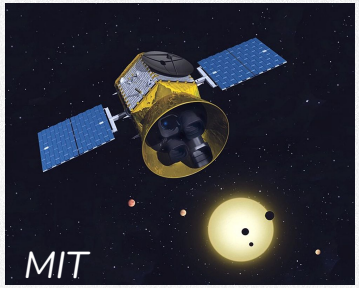
PlanetS
Fonds national suisse

Outline

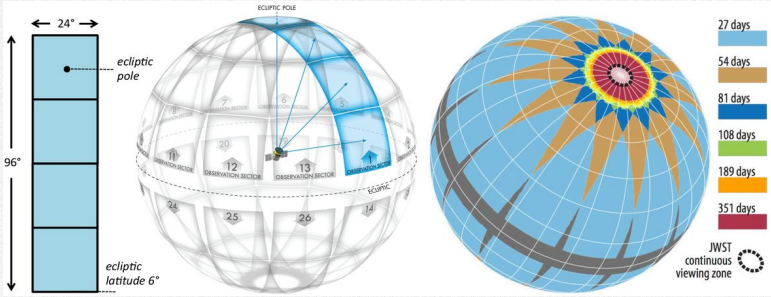
- Introduction:
  - TESS
  - ESPRESSO and the ESPRESSO GTO
- The TOI-2322 system
  - Stellar characterization
  - Preliminary fits with juliet
  - Full analysis with pyaneti
- Conclusions and future work

Introduction

TESS



- Years active: 2018 - present
- Observes ~27 day sectors, covering most of the sky in sequence
- Targets close to ecliptic poles will have ~year ~continuous coverage
- 3 missions so far



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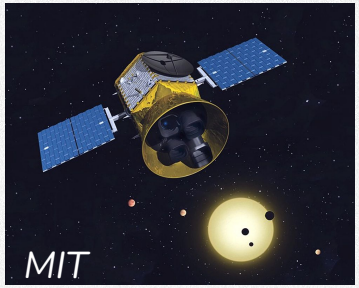

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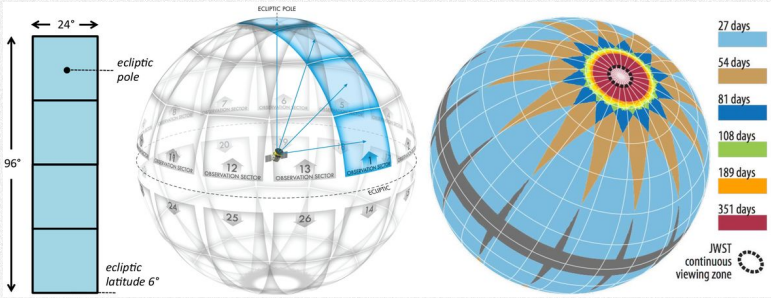
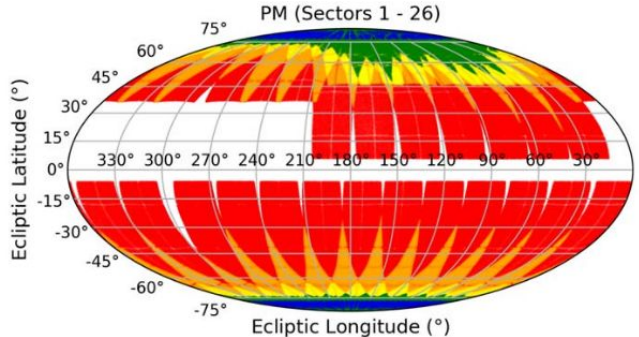
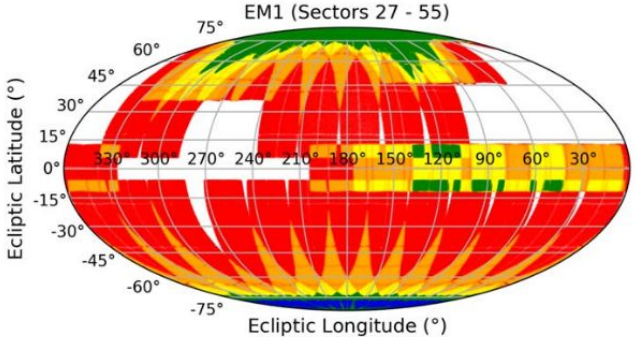
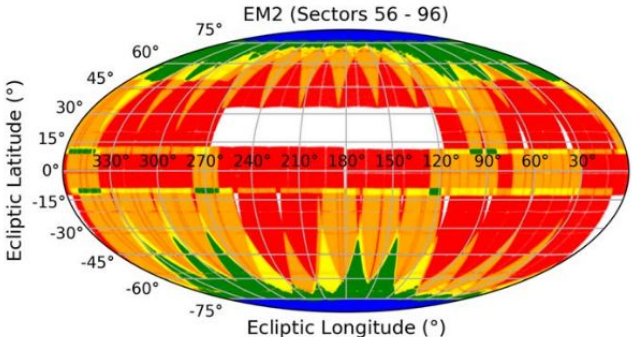


Adapted from Kunimoto et al. (2022)







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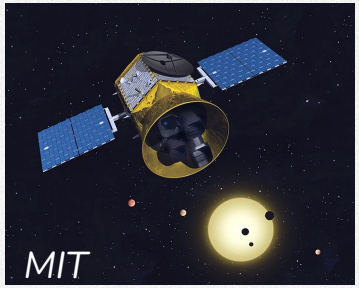

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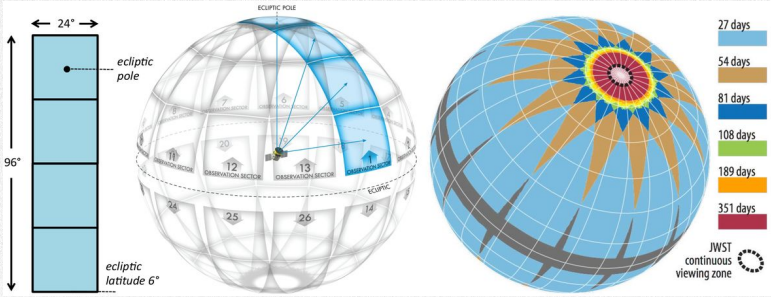
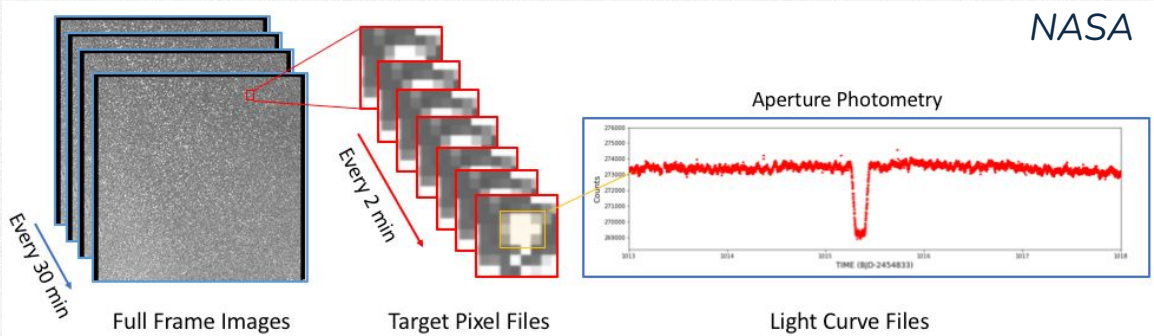
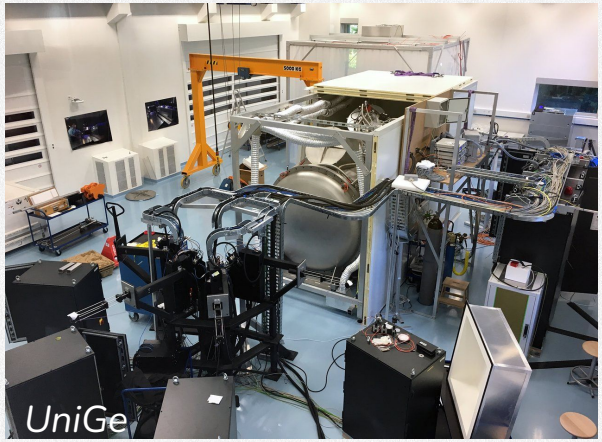
- Targets close to ecliptic poles will have ~year ~continuous coverage
- Cadence:
  - 30 min for full frame images
  - 2 min for postage stamps





ESPRESSO

- Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations
- Very Large Telescope, Chile
- Ultra-stable, high-SN, extremely precise RVs and activity indicators
- ESPRESSO GTO: 273 UT nights over periods 102-111 (2018-2023)
- WG3: transiting candidates follow-up
  - ~ 2700 spectra gathered for 52 targets
  - 42 planets in 16 systems published
  - ~ 10 single-system papers in prep


UniGe


ESO/B. Tafreshi

The TOI-2322 system

TOI-2322 stellar parameters

- V magnitude 11.91
- Atmospheric parameters: from ESPRESSO spectra with SteParSyn (Tabernero et al. 2022)
  - T_{eff} = 4596 ± 14 K → K4 star
  - Fe/H = -0.09 ± 0.02
  - V_{broad} = 1.71 ± 0.02 km/s
- Physical parameters: from atmospheric parameters, broadband photometry, and PARSEC isochrones
  - M = 0.705 ± 0.007 M_{Sun}
  - R = 0.662 ± 0.004 R_{Sun}

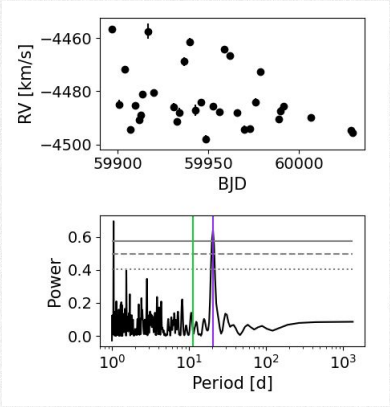
TESS photometry

- Prime mission: 12/13 southern sectors, 30min full frame images only
- Extended mission 1: 12/13 southern sectors, 120s postage stamps
- Extended mission 2: 8/9 southern sectors, 120s postage stamps
- Two candidate planets identified by TESS QLP:
  - TOI-2322.01 at 20.2 d, R = 1.90 R_{Earth}
  - TOI-2322.02 at 11.3 d, R = 1.02 R_{Earth}

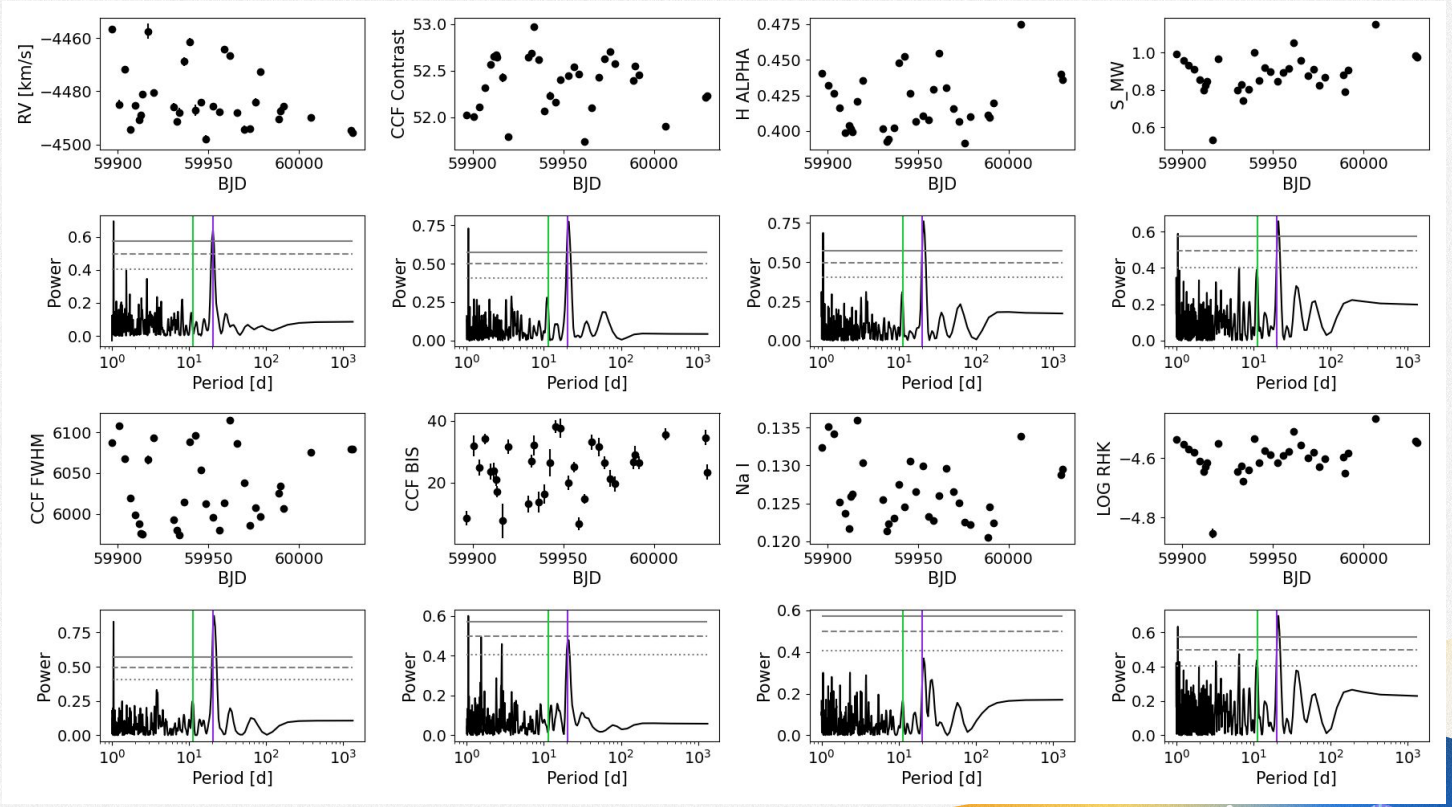
ESPRESSO spectroscopy

- 33 observations between 13 November 2022 and 26 March 2023
- Exposure time of 900 s
- Median S/N of 48 at 550 nm
- Typical RV uncertainty 1.2 m/s
- Processed with the DRS v.3.0.0

ESPRESSO spectroscopy

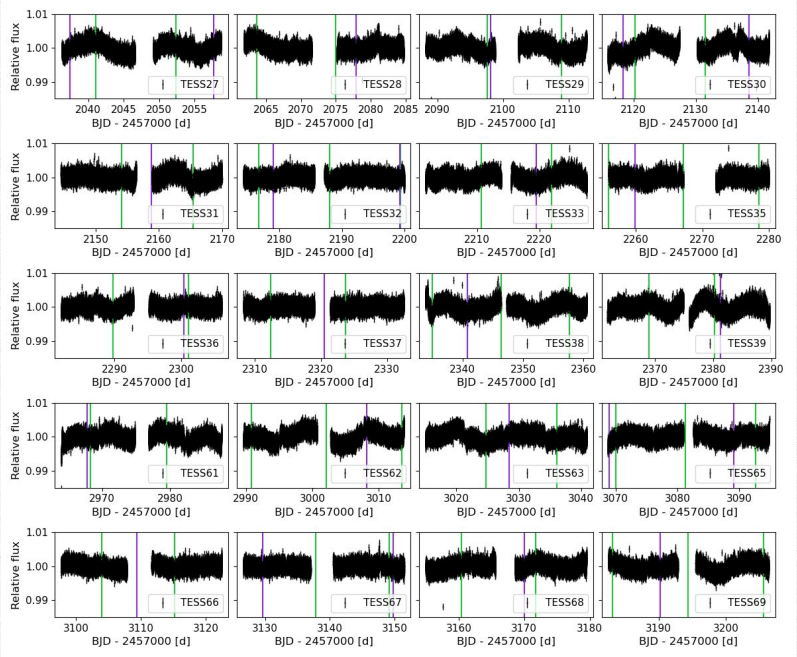


ESPRESSO spectroscopy



TESS light curves

PDCSAP light curves



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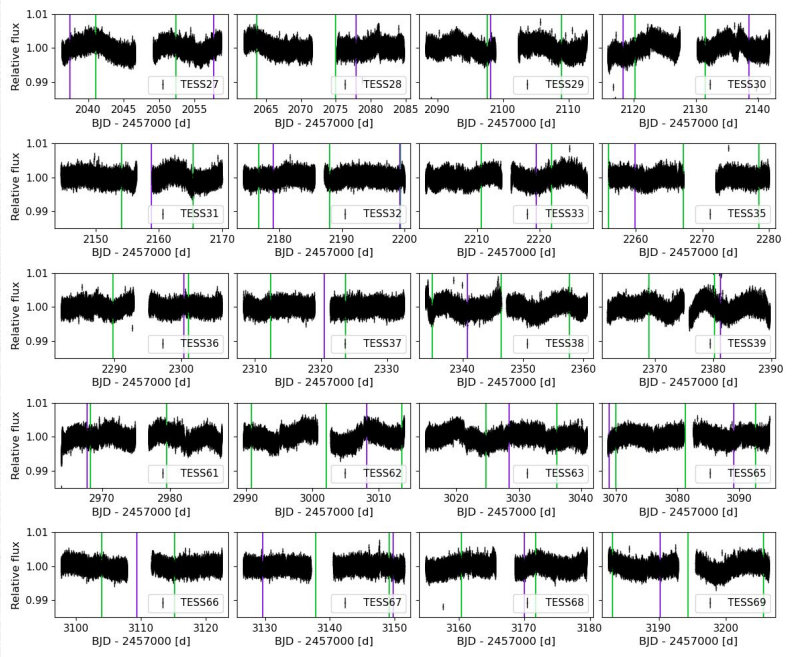
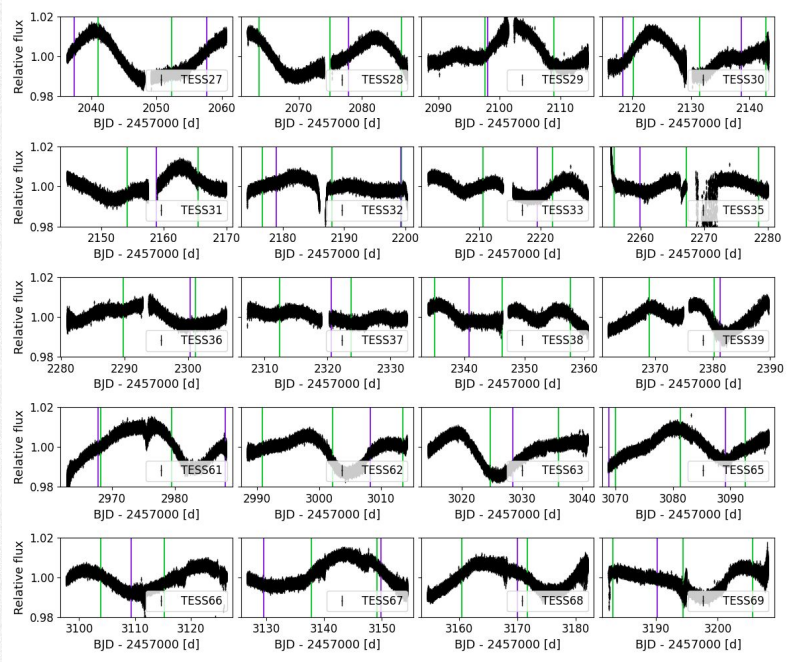


SAP light curves

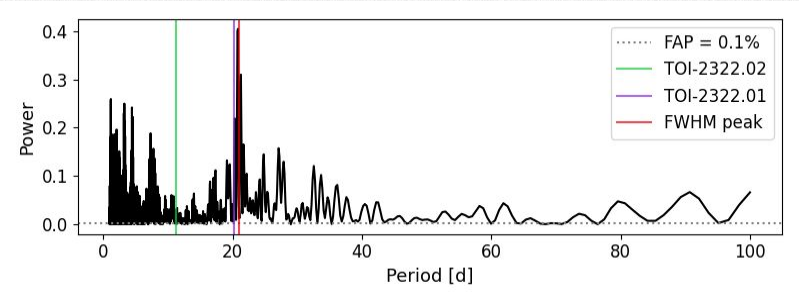


Measuring the rotation period

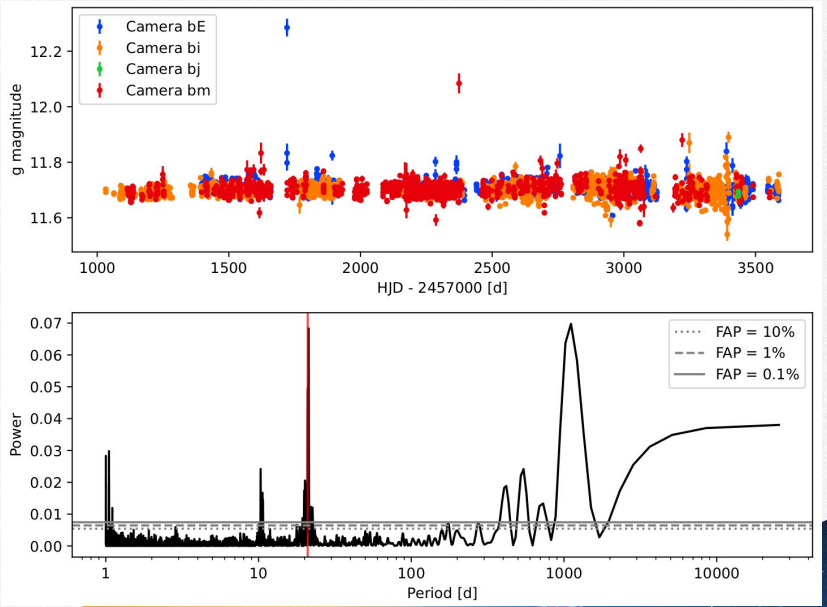
- ESPRESSO FWHM: peak at 21.3 d
- TESS SAP data: peak at 20.8 d
- ASAS-SN data: peak at 21.28 d

→ Rotation period: 21.28 ± 0.08 d

TESS SAP

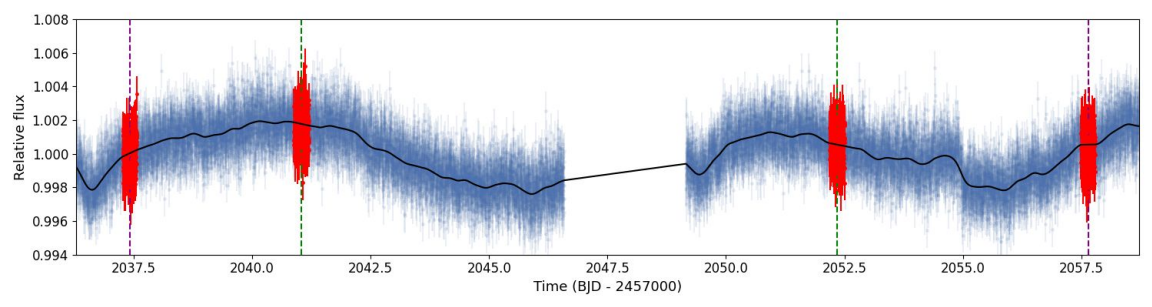


ASAS-SN



Preliminary fits with juliet

- Juliet: Espinoza et al. (2019), https://github.com/nespinoza/juliet
- Joint fit of TESS photometry + ESPRESSO RVs
- Detrend from activity with Gaussian Processes
  - Lots of TESS photometry
    - Pre-detrend and cut to only data around the transits

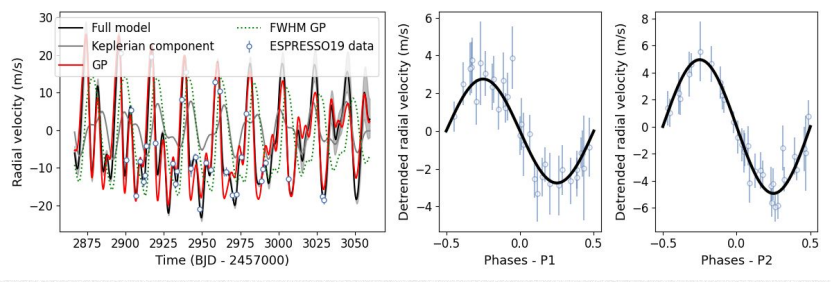


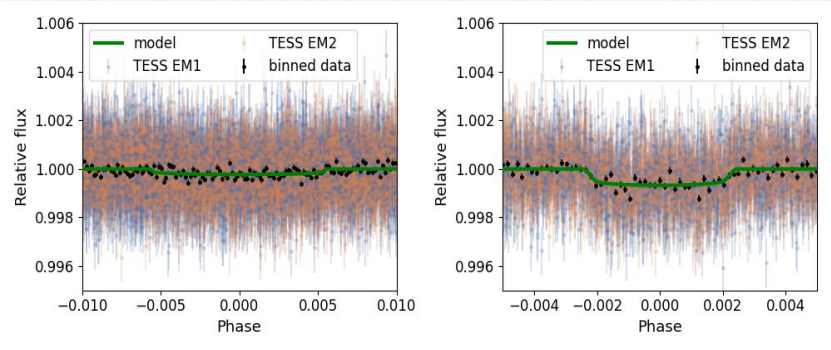
Preliminary fits with juliet

- Joint fit of TESS photometry + ESPRESSO RVs
- Detrend from activity with Gaussian Processes
  - RV GP fitted simultaneously to planet(s)
  - Quasi-periodic kernel:
    - GP_{Prot} prior constrained by rotation period
    - $GP_{\alpha,\sigma,\Gamma}$ constrained by fit to FWHM

Preliminary fits with juliet

- Tested four models: inner planet only, outer planet only, two circular planets, two eccentric planets
- Favoured model: 2-planet circular





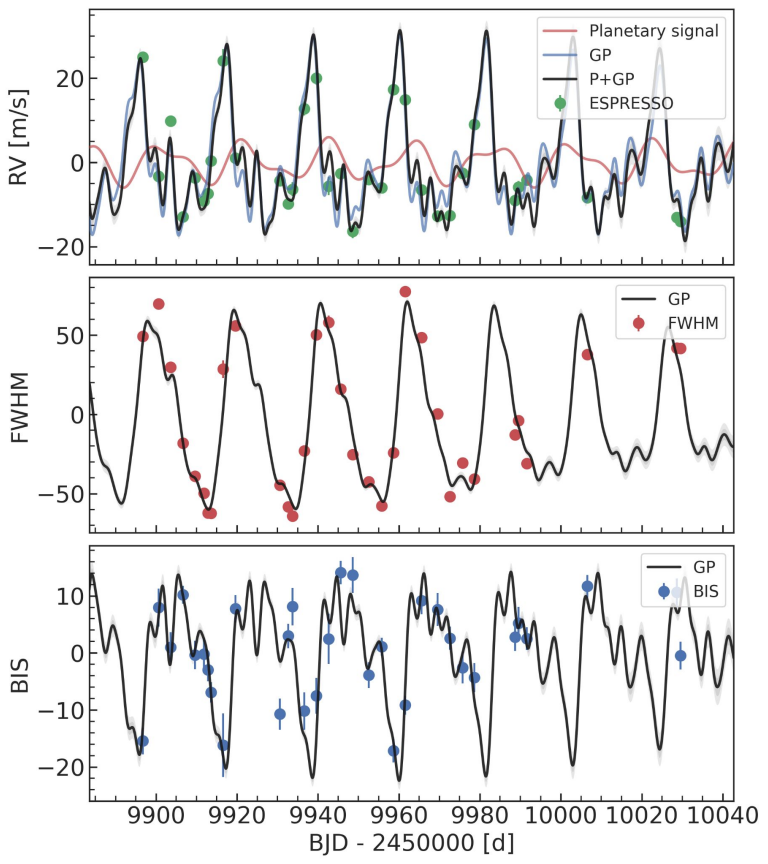
$P_1 = 11.30727 \pm 0.00029$ d
$K_1 = 2.76^{+2.28}_{-1.72}$ m/s
$M_1 < 27\ M_{Earth}$
$R_1 = 1.01 \pm 0.08\ R_{Earth}$

$P_2 = 20.225520 \pm 0.000041$ d
$K_2 = 4.90^{+2.99}_{-2.94}$ m/s
$M_2 < 47\ M_{Earth}$
$R_2 = 1.94 \pm 0.13\ R_{Earth}$

Full fits with pyaneti

- Pyaneti: Barragán et al. (2019, 2022) https://github.com/oscaribv/pyaneti
- Joint modelling of:
  - (Pre-detrended) TESS photometry
  - ESPRESSO RVs, FWHM, BIS
- Using multivariate GPs (Rajpaul et al. 2015):
  - $RV = A_0 \times G + A_1 \times G'$
  - $FWHM = A_2 \times G$
  - $BIS = A_4 \times G + A_5 \times G'$
  - With G a zero-mean GP with quasiperiodic covariance kernel

Full fits with pyaneti



$A_{0,RV}$ = 0.119 ± 0.064 m/s

$A_{1,RV}$ = 4.05 ± 0.14 m/s

$A_{2,FWHM}$ = 4.994 ± 0.011

$A_{4,BIS}$ = 0.159 ± 0.050

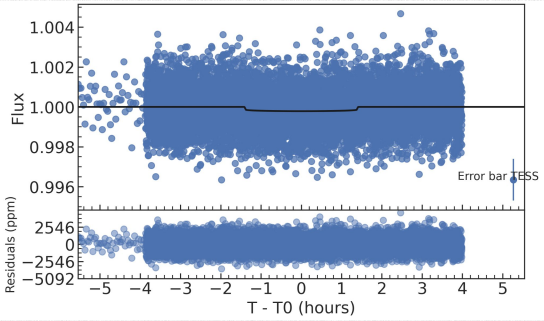
$A_{5,BIS}$ = -3.15 ± 0.20

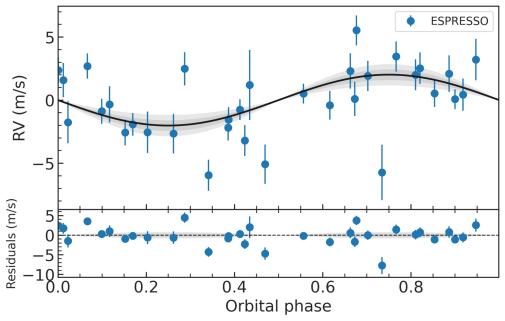
λ_e = 79.4 ± 6.2 d

λ_p = 0.2192 ± 0.0084

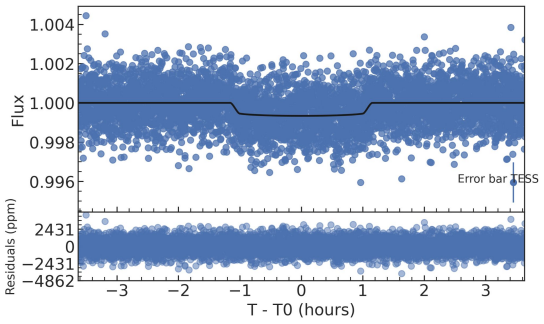
P_{GP} = 21.439 ± 0.029 d

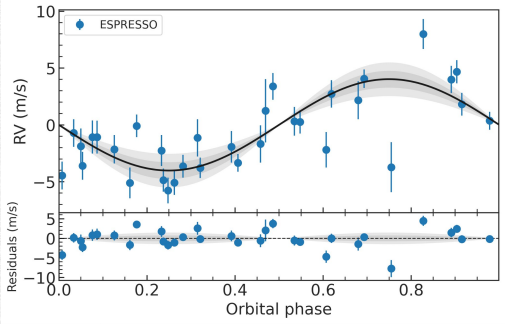
Full fits with pyaneti





P_1 = 11.307192 ± 0.000086 d
K_1 = 2.02 ± 0.47 m/s
M_1 = 5.6 ± 1.3 M_{Earth}
R_1 = 1.00 ± 0.05 R_{Earth}
ρ_1 = 31 ± 10 g/cm^3





P_2 = 20.225511 ± 0.000038 d
K_2 = 4.02 $^{+ 0.79}_{- 0.84}$ m/s
M_2 = 13.6 $^{+ 2.7}_{- 2.8}$ M_{Earth}
R_2 = 1.87 ± 0.07 R_{Earth}
ρ_2 = 11 ± 3 g/cm^3

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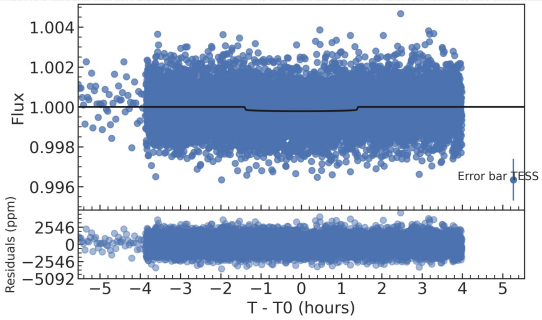

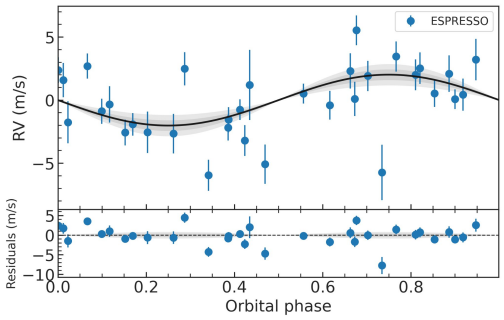

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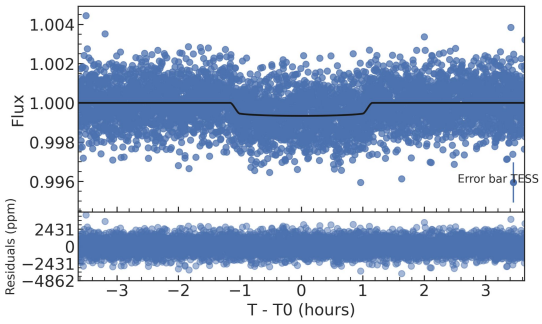

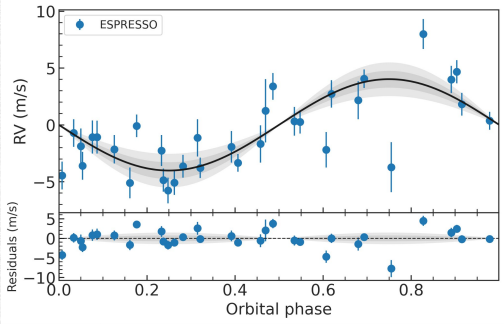

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Compatible with, but more precise than, juliet results

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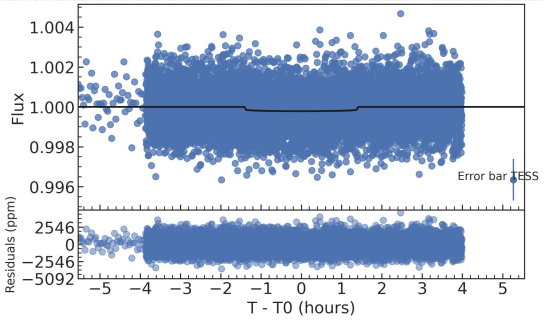

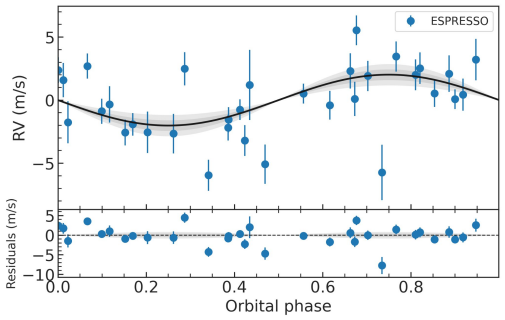

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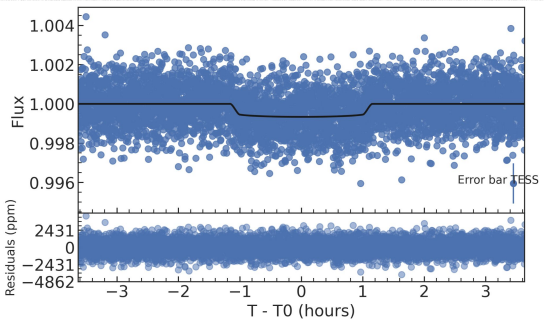

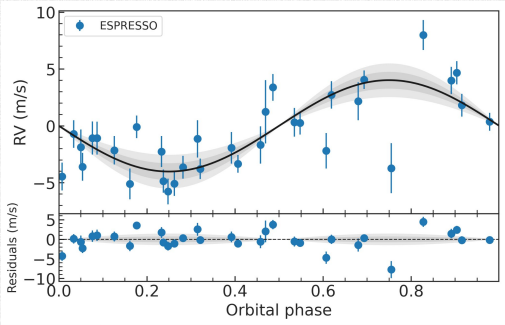

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4-5σ K measurements → masses, not upper limits

Conclusions and future work

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- Future work: Monitor these targets over longer time scales and with nIR spectroscopy
- An open question: why are these planets at the rotation period?
- An open question: how many similar planets are we missing in RV-only data?

Thank you!
Questions?