Detecting the closest Earth-mass planets with ESPRESSO

João Faria

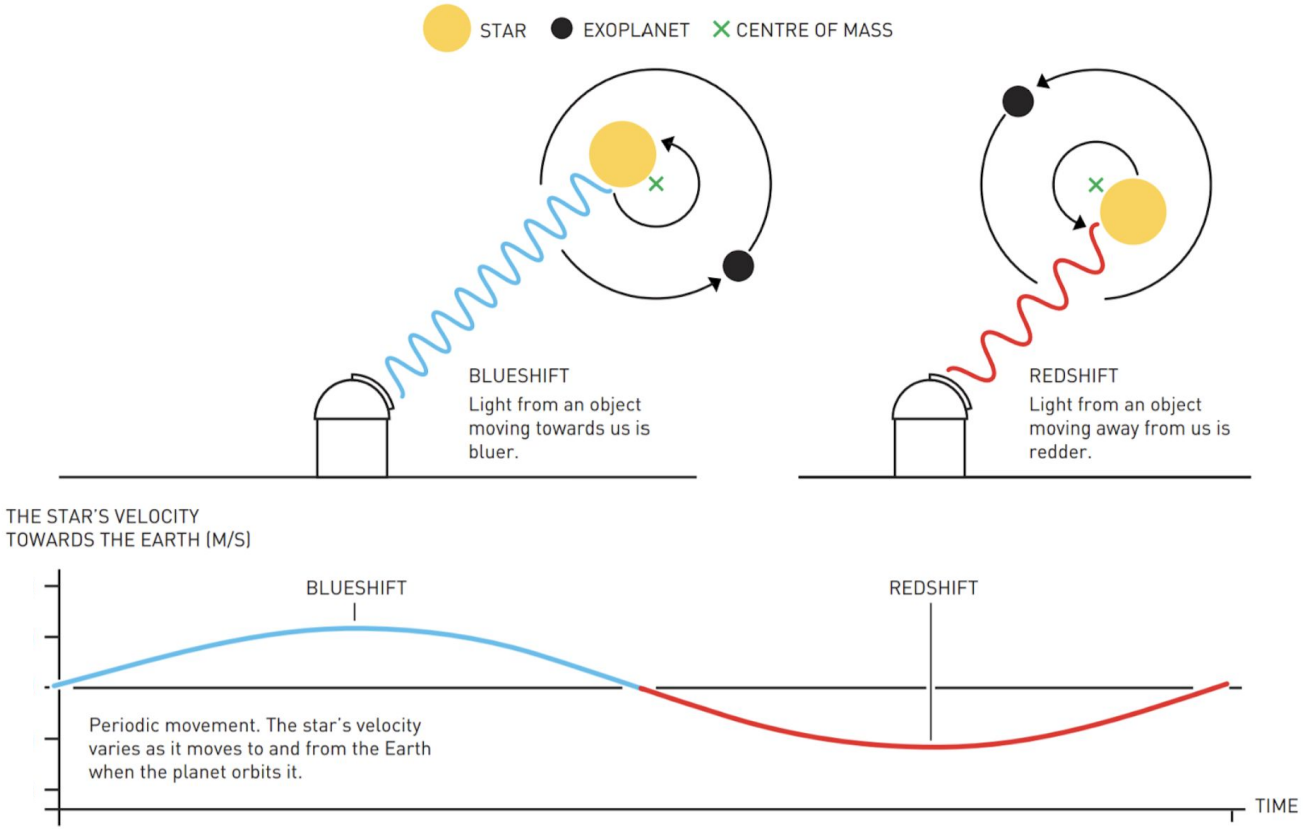
ia instituto de astrofísica e ciências do espaço

fct Fundação para a Ciência e a Tecnologia

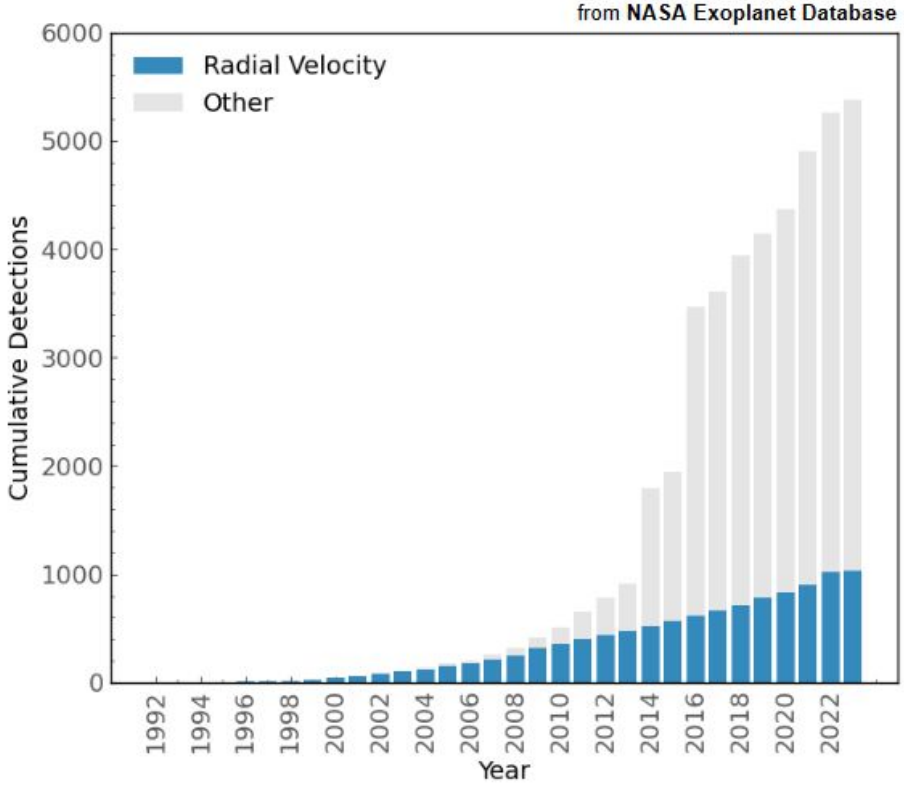
erc

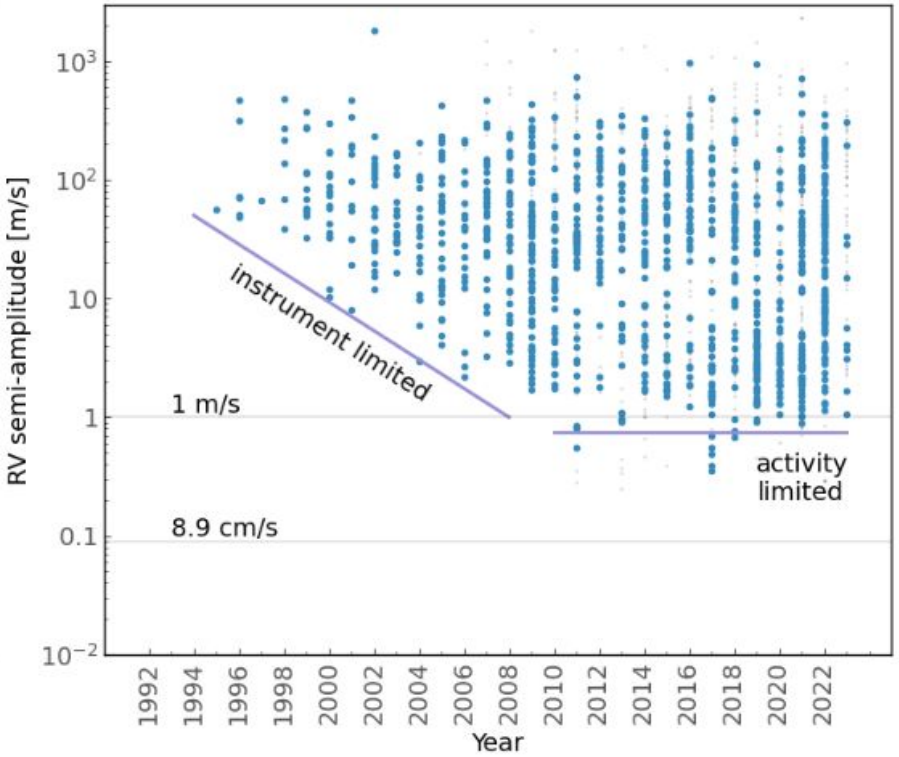
The Alpha Centauri System
Towards new worlds
Nice, 27 June 2023

radial velocities

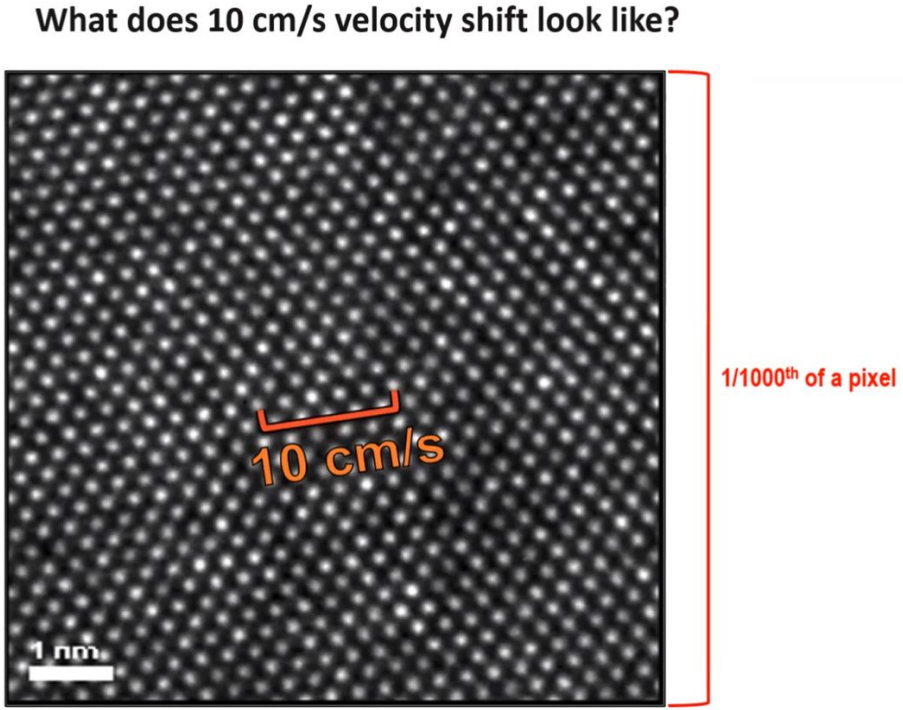


smaller RV amplitudes
lower planet masses





extreme precision radial velocities



credit: Suvrath Mahadevan (EPRV5)

ESPRESSO

installed at the VLT

stabilised
high-resolution
cross-dispersed

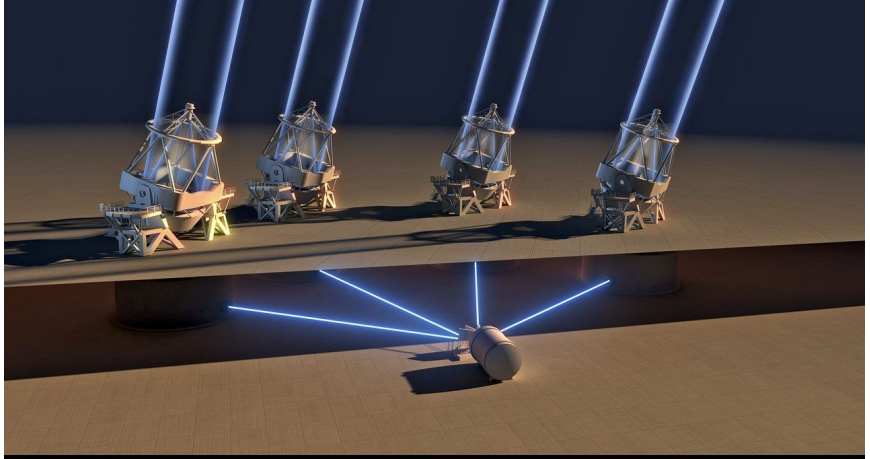
designed for ultra-high
RV precision and
extreme spectral fidelity

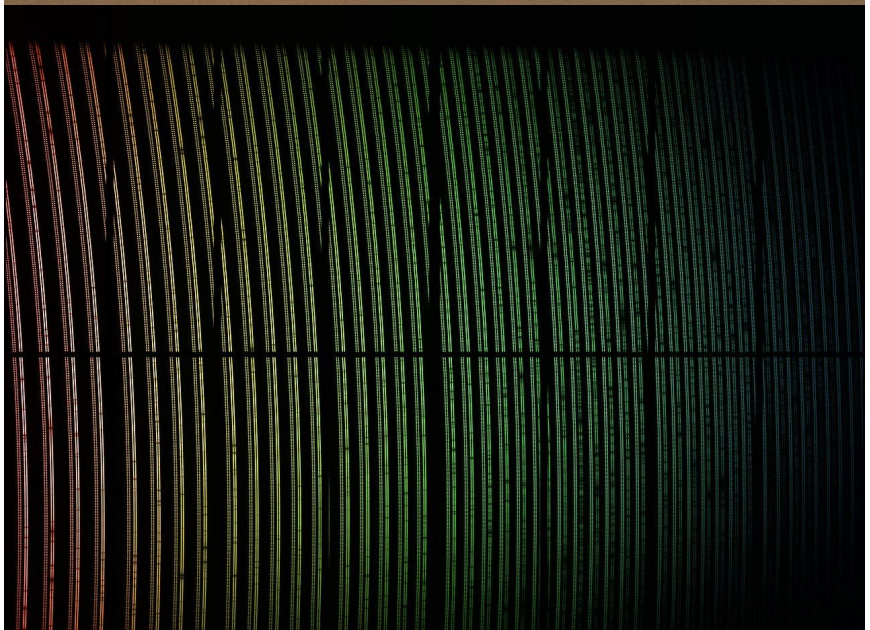
R = 140 000 (HR mode)

wavelength coverage
378 - 788 nm

in operation since 2018

can use any of the 4 UTs
or the 4 simultaneously





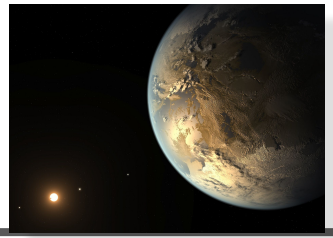
the **E**chelle **SP**ectrograph for
Rocky **E**xoplanets and **S**table
Spectroscopic **O**bservations

Pepe *et al.* (2021)

searching for planets with ESPRESSO

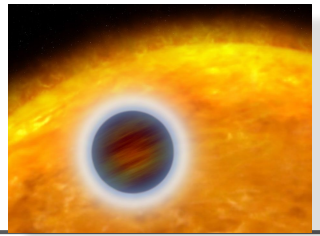
WG1

detection and characterization of Earth-mass planets in the habitable zone around GKM dwarfs



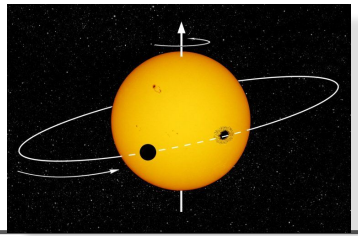
WG2

characterization of planetary atmospheres



WG3

RV follow-up of transiting planets

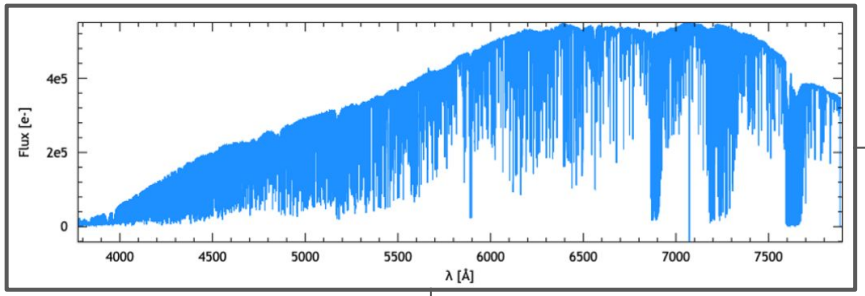


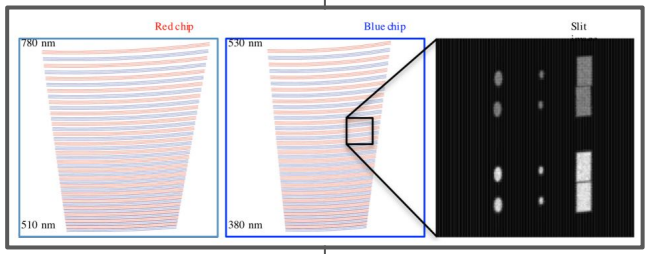
WG4

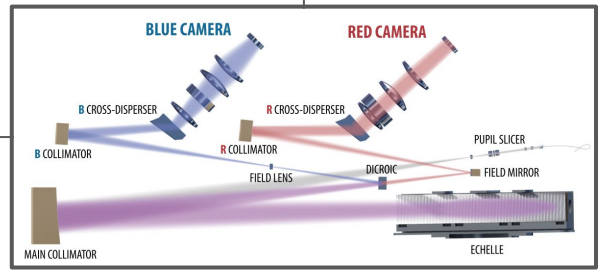
fundamental cosmology

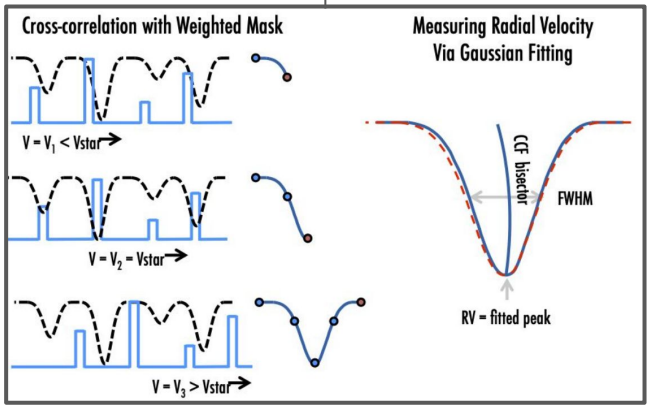
Pepe *et al.* (2021)

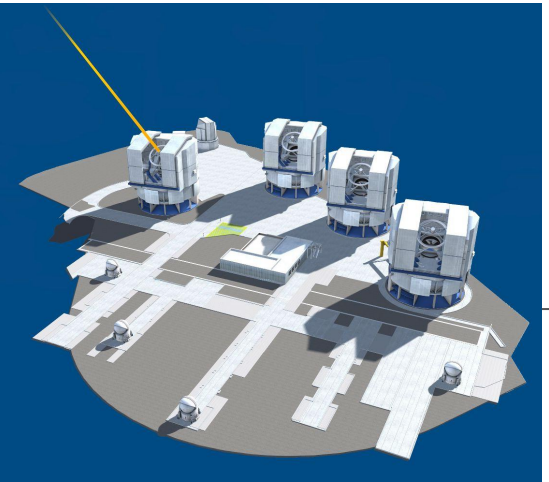
searching for planets with ESPRESSO





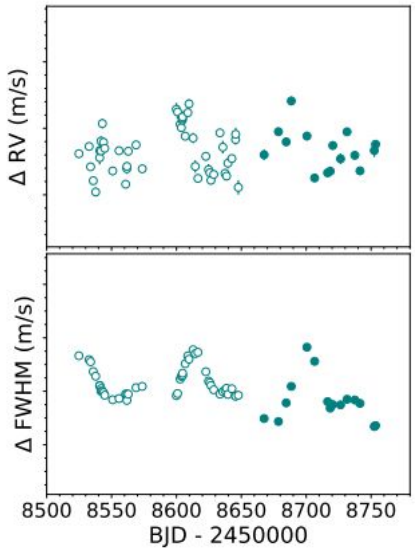






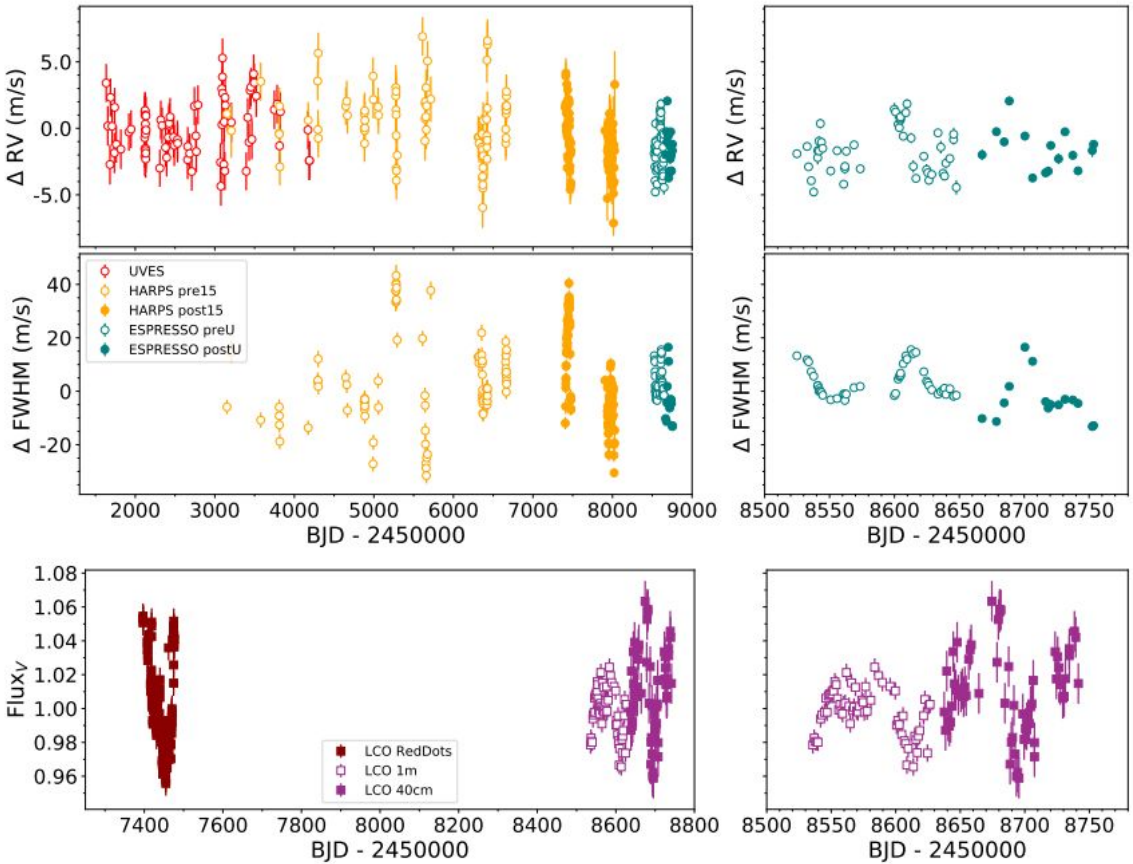
Pepe *et al.* (2021)

detecting Proxima *b* and dealing with stellar activity



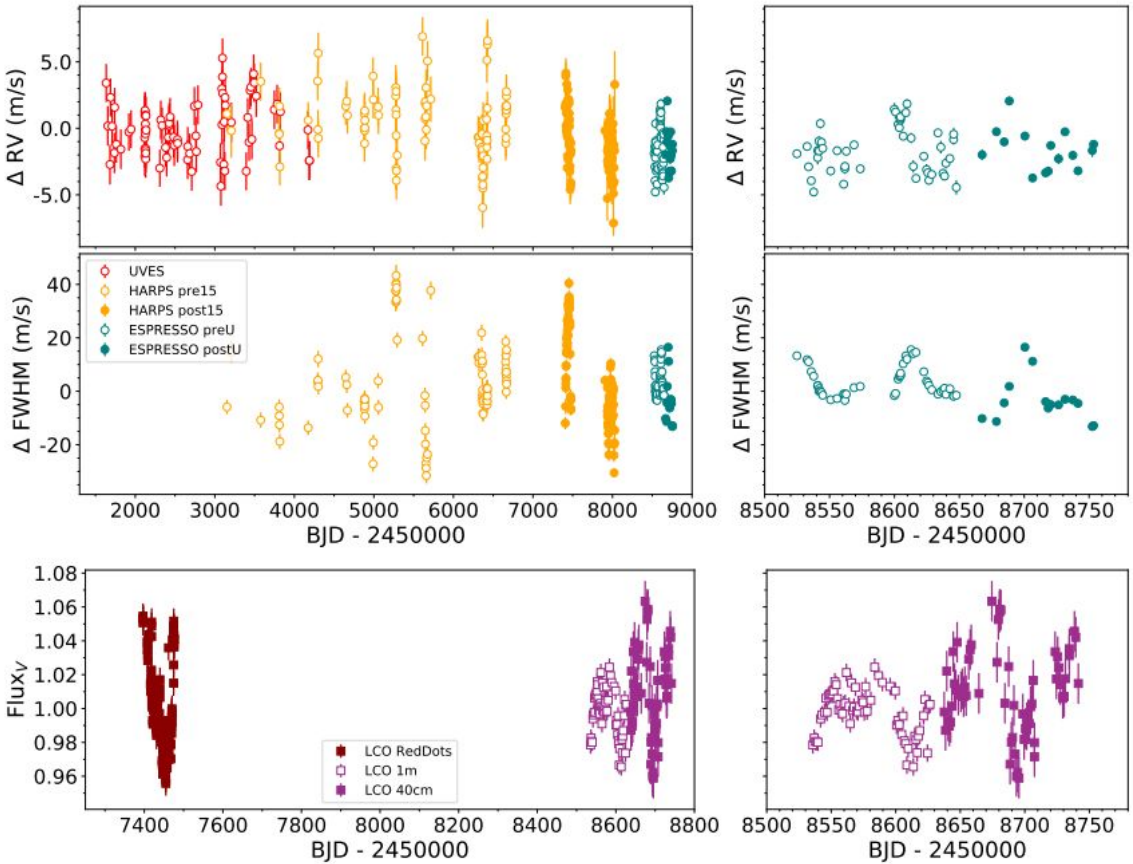
Suárez-Mascareño *et al.* (2020)

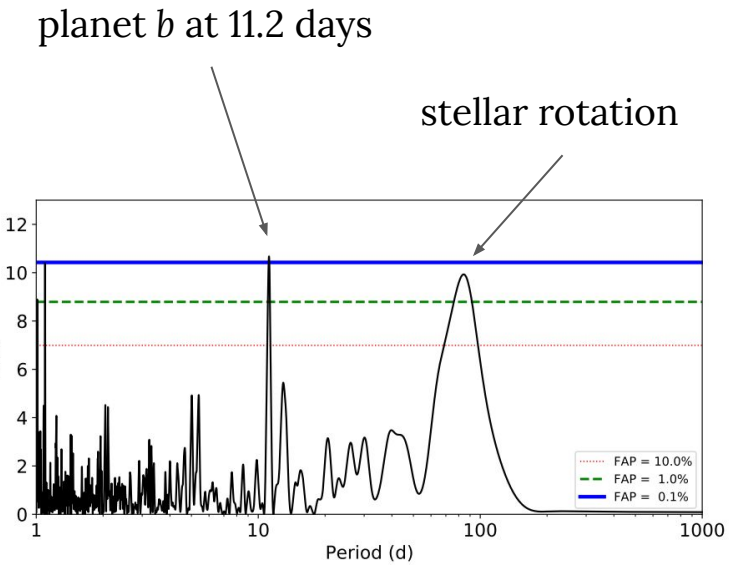
detecting Proxima *b* and dealing with stellar activity



Suárez-Mascareño *et al.* (2020)

detecting Proxima *b* and dealing with stellar activity



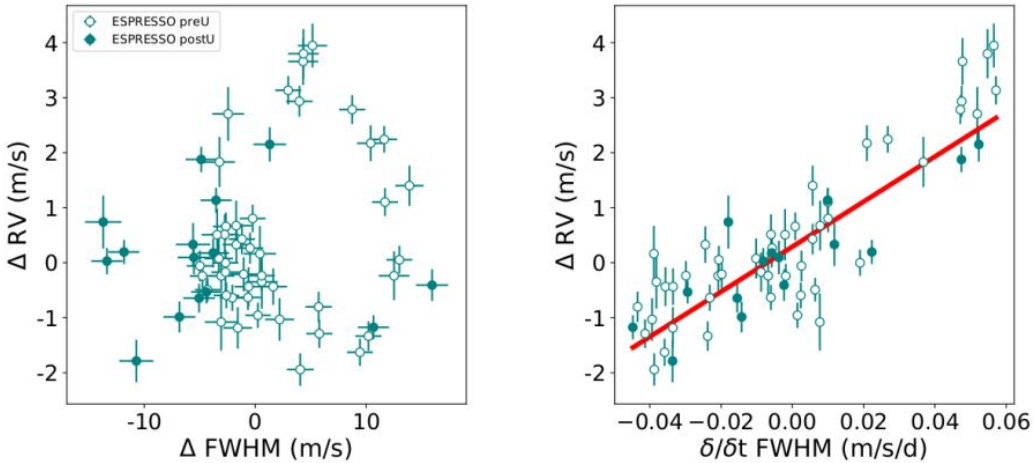


Suárez-Mascareño *et al.* (2020)

detecting Proxima *b*
and dealing with stellar activity

the CCF FWHM is an excellent activity indicator

(but) RVs correlate better with the FWHM derivative



Suárez-Mascareño *et al.* (2020)

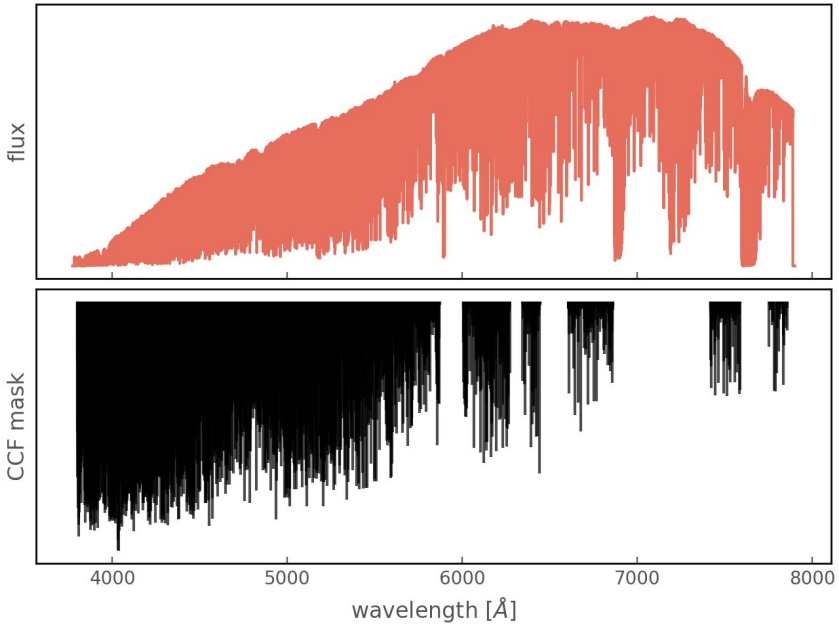
chasing a short-period signal

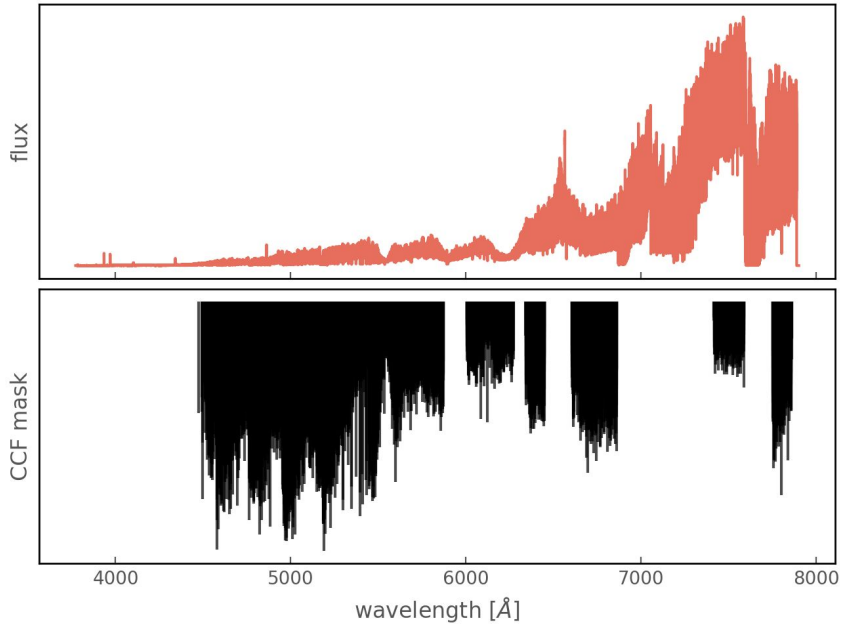
"We find evidence for a second short period signal with a period of 5.15 days and a semi-amplitude of 0.4 m/s"

see https://twitter.com/espresso_astro/status/1359510829679394817

the candidate Proxima *d*
(and dealing with stellar activity, again)

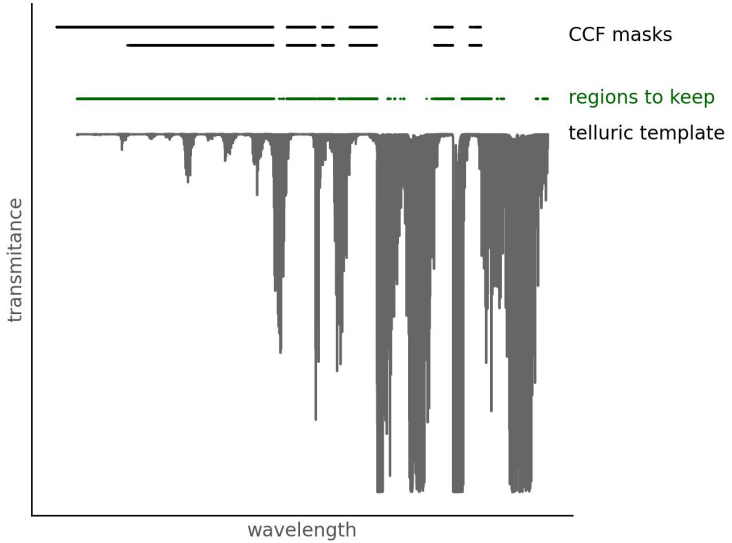
first step was to derive RVs
with the template-matching technique





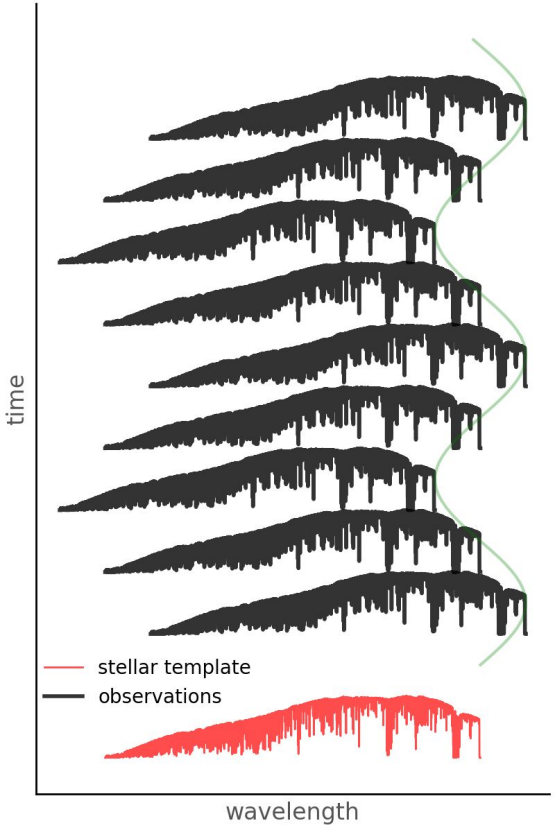
the candidate Proxima *d*
(and dealing with stellar activity, again)

first step was to derive RVs
with the template-matching technique



1. Compute telluric template (TAPAS / TelFit)
   and mask out affected regions

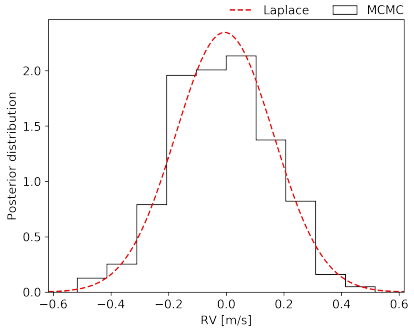
2. Compute stellar template
   combining all available observations



3. Compute RVs by aligning individual
   spectra with stellar template

4. Assume one RV shift common
   to all spectral orders
   (continuum fit is marginalised out)

5. Estimate the posterior distribution
   for the RV shift, either through
   MCMC or Laplace approximation

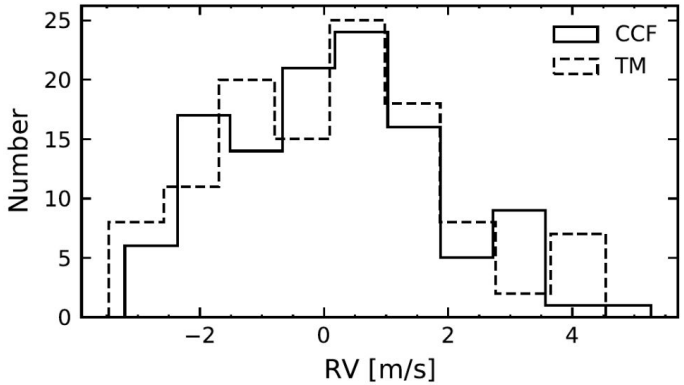


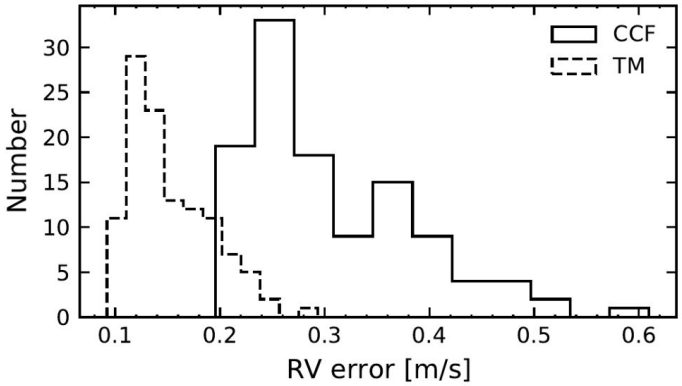
Silva *et al.* (2022)

the candidate Proxima *d*
(and dealing with stellar activity, again)

first step was to derive RVs
with the template-matching technique

for Proxima, we obtain
- very similar rms
- significantly lower uncertainties
when compared with CCF RVs





Faria *et al.* (2022)

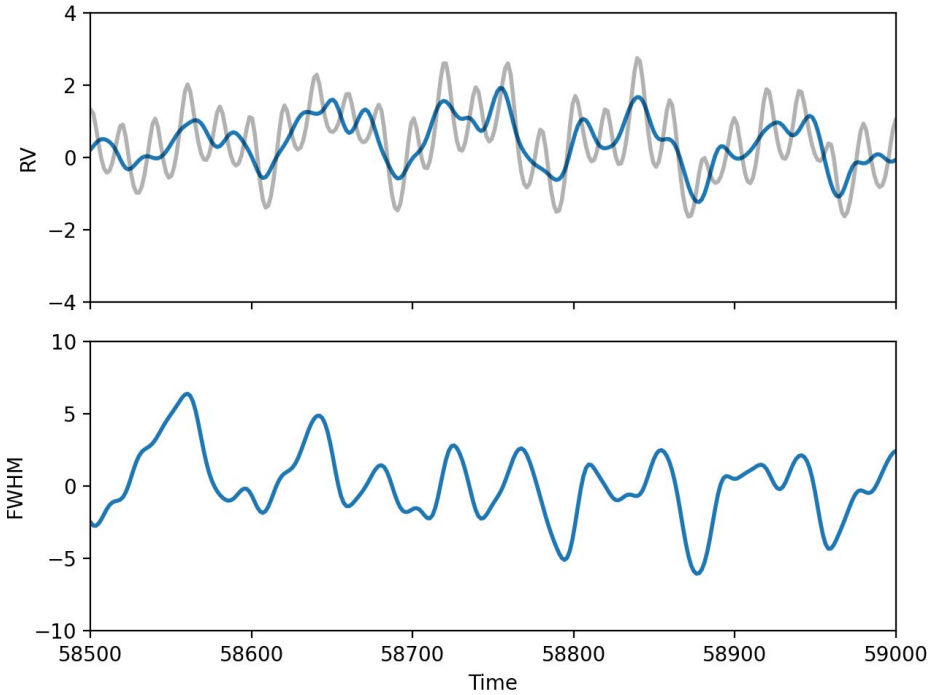
the candidate Proxima *d*
(and dealing with stellar activity, again)

then we simultaneously model
the RVs and the CCF FWHM

the FWHM is an excellent proxy for
stellar activity variations

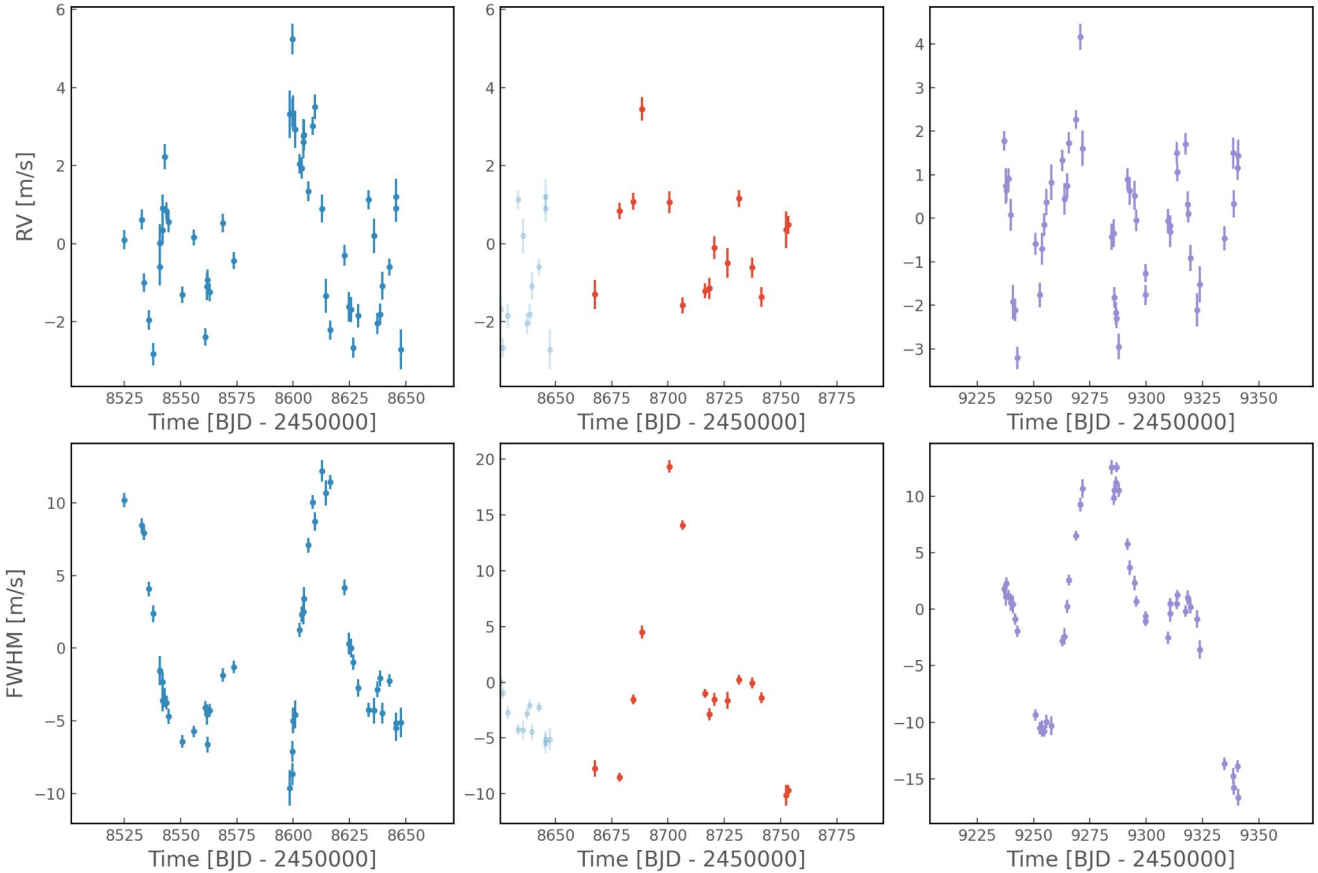
two quasi-periodic GP
with shared hyperparameters

$$\mathcal{K}_{\rm QP}(\tau) = \eta_1^2 \exp\left[-\frac{\tau^2}{2\eta_2^2} - \frac{2\sin^2\left(\frac{\pi\tau}{\eta_3}\right)}{\eta_4^2}\right]$$



Faria *et al.* (2022)

the candidate Proxima *d* (and dealing with stellar activity, again)

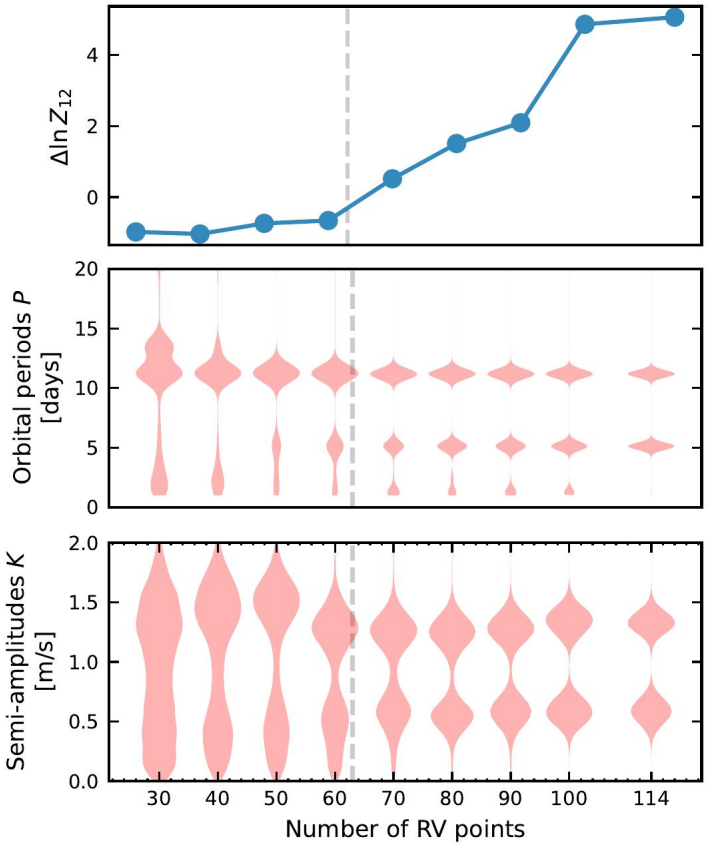


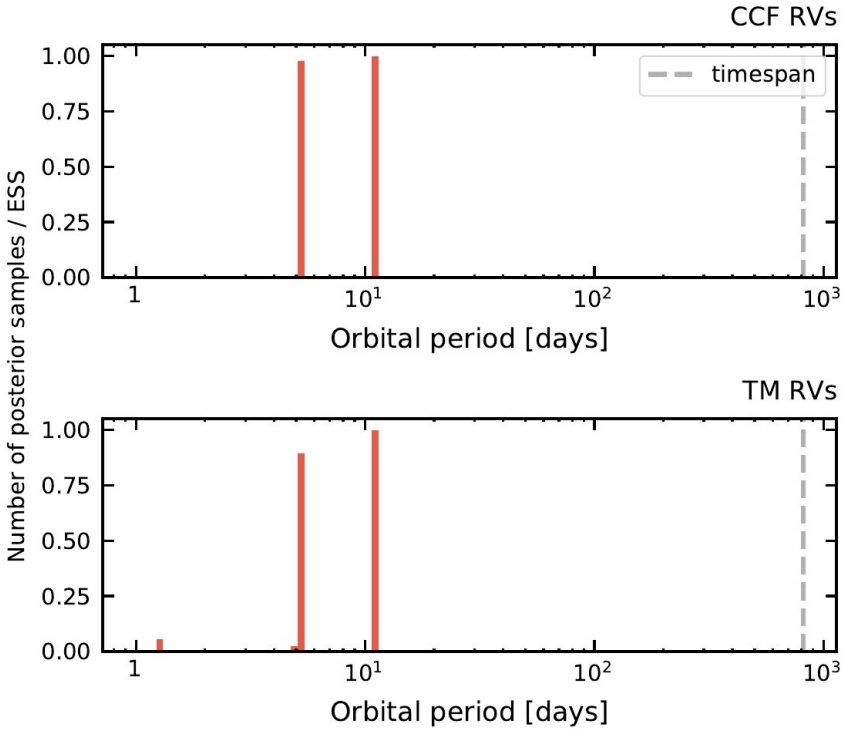
114 observations
spanning 2.2 years

RV rms: 1.6 m/s
mean σRV: 30 cm/s

Faria *et al.* (2022)

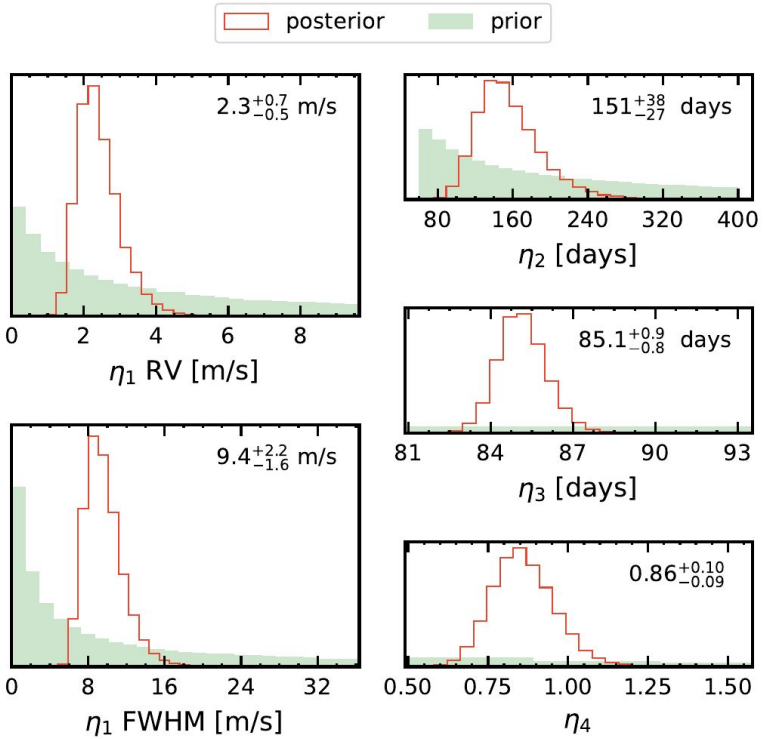
the candidate Proxima *d* (and dealing with stellar activity, again)

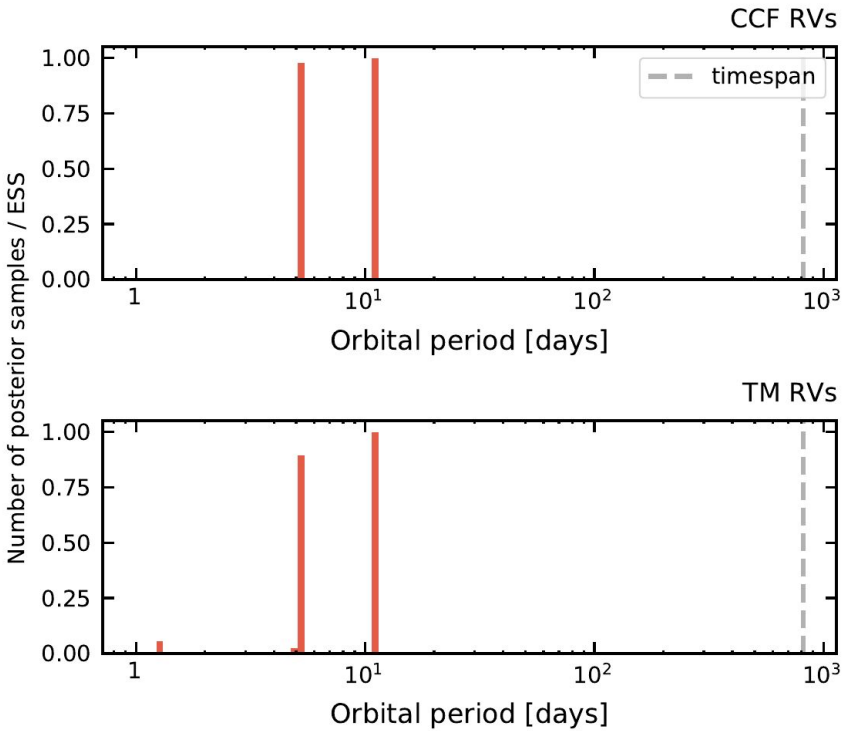




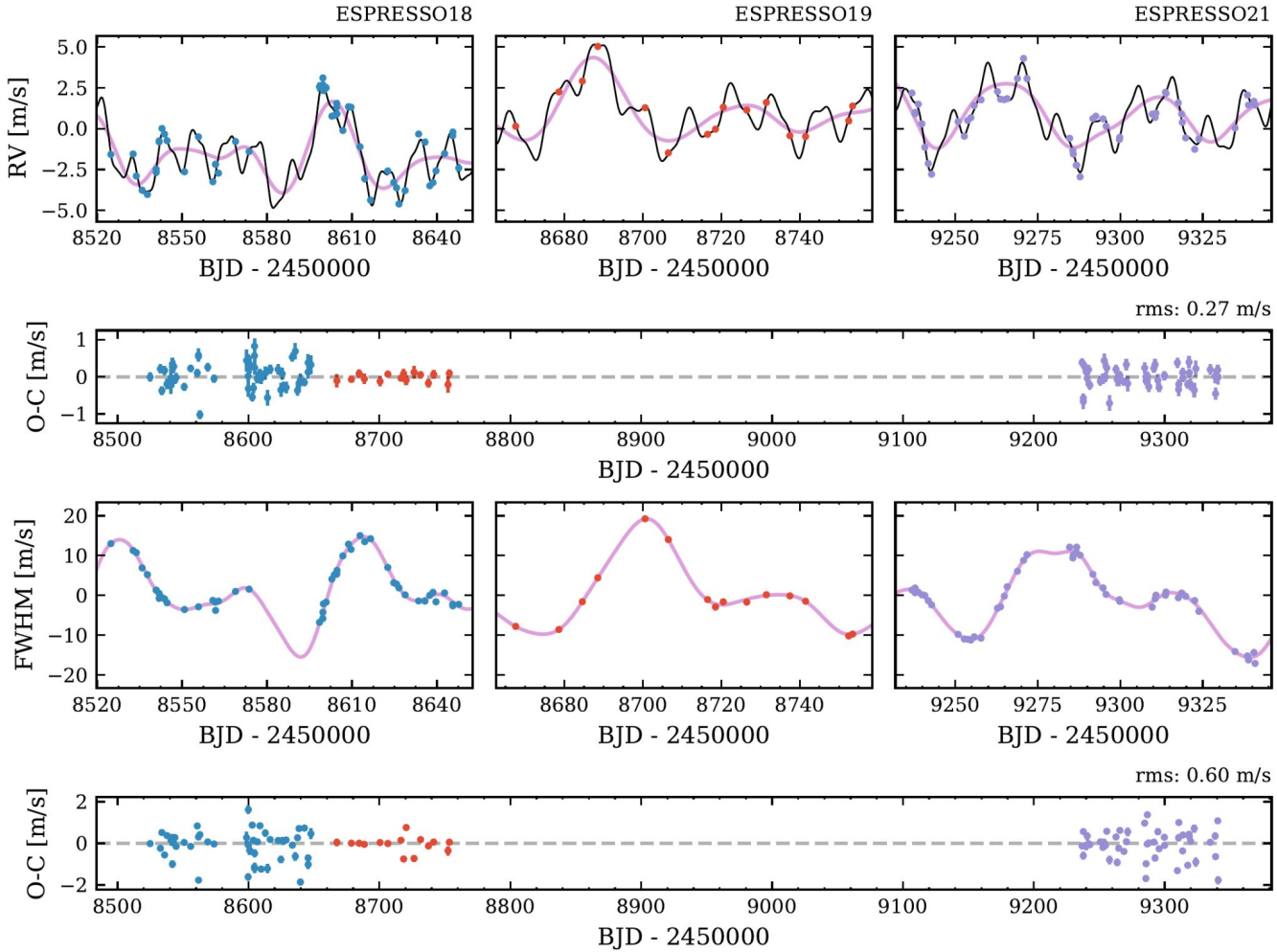
Faria *et al.* (2022)

the candidate Proxima *d* (and dealing with stellar activity, again)



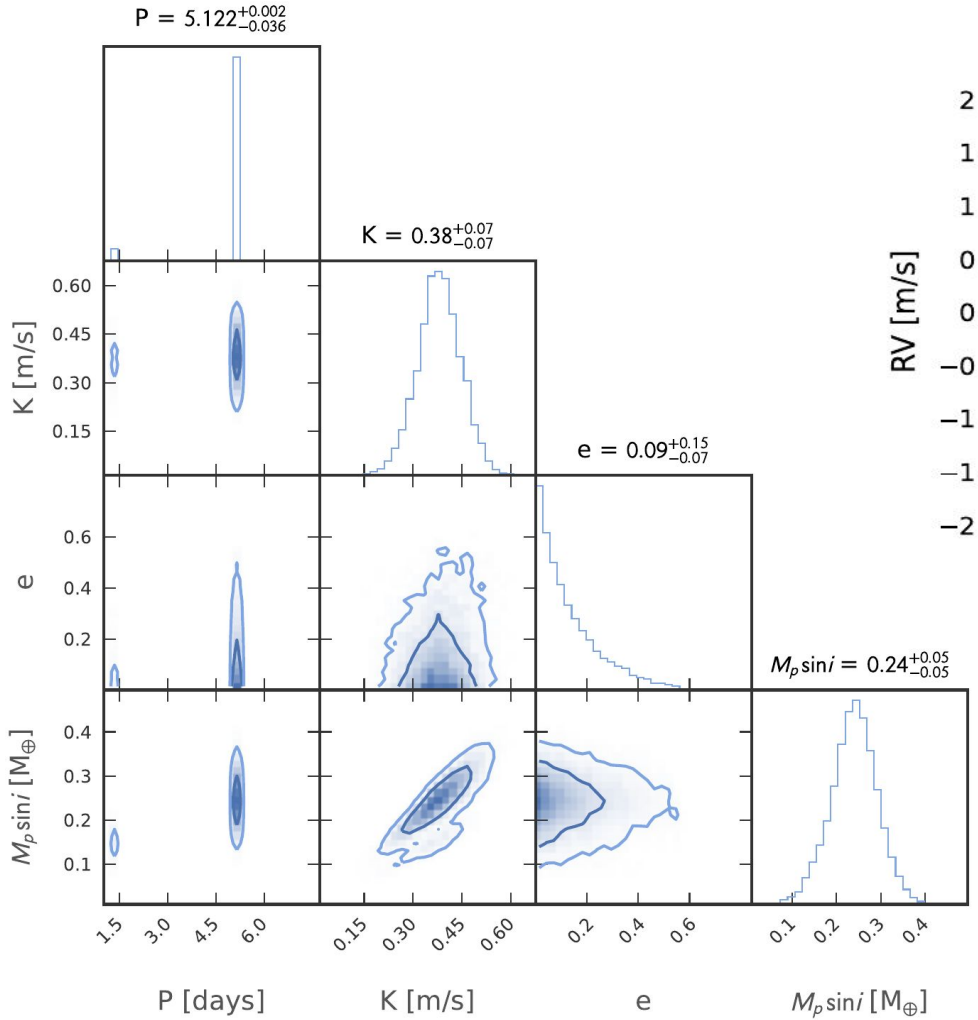


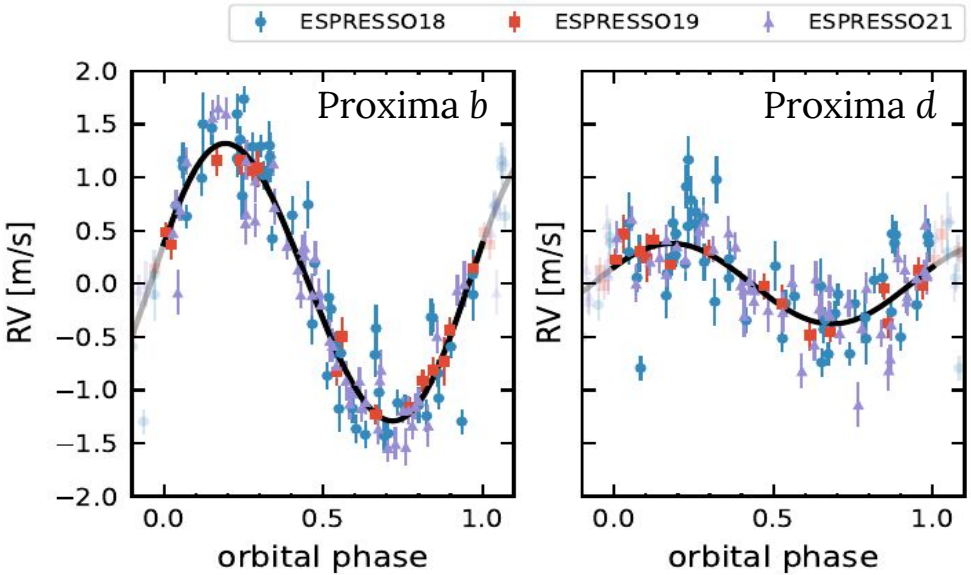
Faria *et al.* (2022)



residual RV rms, after subtracting stellar activity and two-planet model, compatible with photon-noise

Faria *et al.* (2022)





Faria *et al.* (2022)

the press coverage

eso2202 — Science Release

New planet detected around star closest to the Sun

10 February 2022

About the Release

Release No.: eso2202

Name: Proxima Centauri, Proxima d

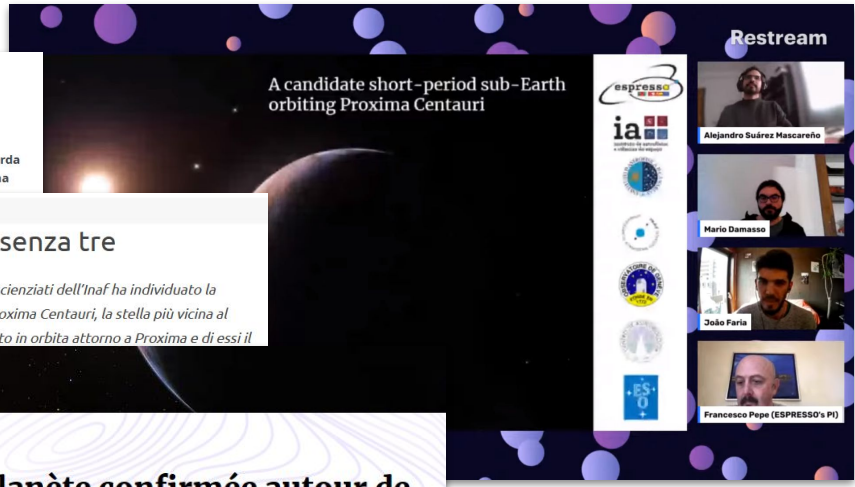
Type: Milky Way : Star : Circumstellar Material : Planetary System

Facility: Very Large

Detectan planeta que orbita la estrella más cercana al Sol

10/02/2022

Se estima que el planeta candidato Proxima d tiene apenas un 25% de la masa de la Tierra, tarda cinco días en completar su órbita alrededor de Próxima Centauri y lo hace, además, en la 'zona habitable' de la estrella.



LO STUDIO SU ASTRONOMY & ASTROPHYSICS

Proxima Centauri, non c'è due senza tre

Un gruppo internazionale di ricerca a cui partecipano anche scienziati dell'Inaf ha individuato la presenza di un nuovo, piccolo pianeta che orbita intorno a Proxima Centauri, la stella più vicina al Sistema solare. Questo candidato pianeta è il terzo a oggi noto in orbita attorno a Proxima e di essi il più leggero, con una massa minima

questo il suo nome – è uno tra gli es

Ufficio stampa Inaf 10/02/20

«Il pianeta che abbiamo appena scop

chiamato Proxima d, orbita intorno a

Proxima Centauri a una distanza di c

quattro milioni di chilometri, meno d

WIKIPEDIA The Free Encyclopedia

Proxima Centauri d

Create account

Proxima Centauri d

13 languages

Article Talk Read Edit View history

From Wikipedia, the free encyclopedia

Coordinates: 14h 29m 42.9487s, −62° 40′ 46.141″

Proxima Centauri d (also called **Proxima d**) is a candidate exoplanet orbiting the red dwarf star Proxima Centauri, the closest star to the Sun and part of the Alpha Centauri triple star system. Together with two other planets in the Proxima Centauri system, it is the closest known exoplanet to the Solar System, located approximately 4.2 light-years (1.3 parsecs; 40 trillion kilometres; 25 trillion miles) away in the constellation of Centaurus. The first signs of the exoplanet emerged as a weak 5.15-day signal in radial velocity data taken from the Very Large Telescope during a 2020 study on Proxima b's mass. This signal was formally proposed to be a candidate exoplanet by Faria et al. in a follow-up paper published in February 2022.[2][1]

Proxima d is a sub-Earth at least one-quarter of the mass of Earth (or twice the mass of Mars), orbiting at roughly 0.029 AU (4.3 million km; 2.7 million mi) every 5.1 days.[2] It is the least massive and innermost known planet of the Proxima Centauri system. It is the least massive exoplanet detected with the radial velocity method as of 2022. Proxima d orbits too close to its star to be habitable, and receives about 190% of Earth's irradiation—assuming an Earth-like reflectivity, its equilibrium temperature may reach 360 K (87 °C; 188 °F).[1]

Proxima Centauri d

Artistic depiction of Proxima Centauri d, with Proxima Centauri and Alpha Centauri A & B visible in the background

Discovery[1]	
Discovery site	VLT-ESPRESSO
Discovery date	2020
Detection method	Radial velocity
Orbital characteristics[1]	
Semi-major axis	0.028 85 $^{+0.000\ 19}_{-0.000\ 22}$ AU
Eccentricity	0.04 $^{+0.15}_{-0.04}$
Orbital period (sidereal)	5.122 $^{+0.002}_{-0.0036}$ d
Semi-amplitude	0.39 ±0.07 m/s
Star	Proxima Centauri
Physical characteristics[1]	
Mean radius	≤0.81 ±0.05 $R_\oplus$
Mass	≥0.26 ±0.05 $M_\oplus$
Temperature	360 K (87 °C; 188 °F)

See also [edit]

- List of nearest exoplanets

References [edit]

1. ^ a b c d e Faria, J. P.; Suárez Mascareño, A.; et al. (January 4, 2022). "A candidate short-period sub-Earth orbiting Proxima Centauri" (PDF). *Astronomy & Astrophysics*. European Southern Observatory. **658**: 17. arXiv:2202.05188. Bibcode:2022A&A...658A.115F. doi:10.1051/0004-6361/202142337.
2. ^ a b Suárez Mascareño, A.; Faria, J. P.; et al. (11 May 2020). "Revisiting Proxima with ESPRESSO". *Astronomy & Astrophysics*. **639**: 24. arXiv:2005.12114. Bibcode:2020A&A...639A..77S. doi:10.1051/0004-6361/202037745. ISSN 0004-6361.

SCIENCES › ACTUALITÉS

Une 3e planète confirmée autour de Proxima du Centaure, l'étoile la plus proche du Soleil !

EXOPLANÈTES EXOBIOLOGIE RELATIVITÉ GÉNÉRALE MÉTHODE

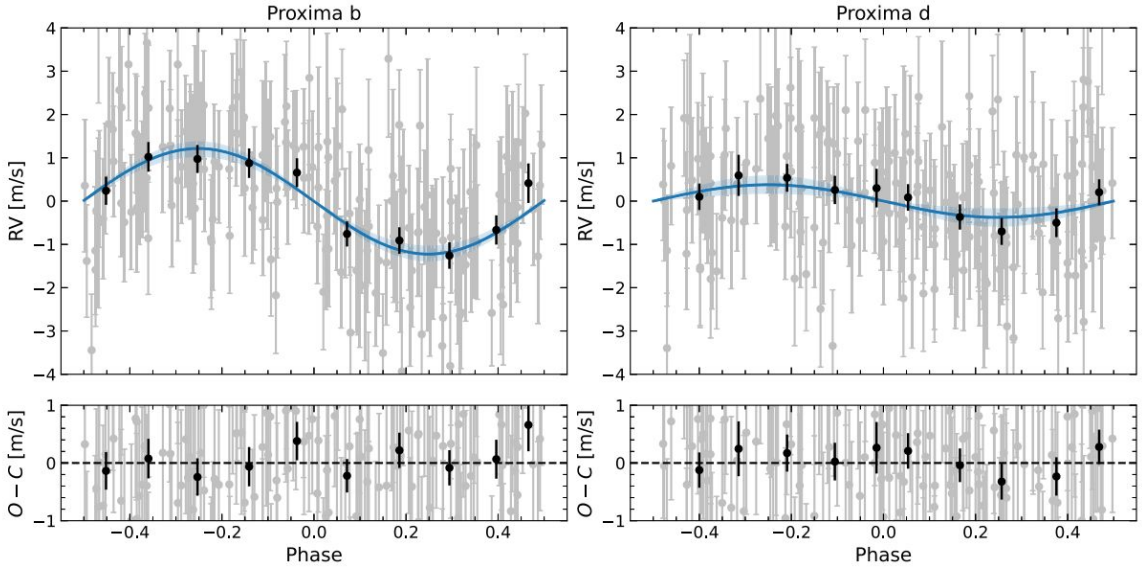
MUNDO

atualizado 10 Fevereiro 2022, 15:26

Descoberto novo planeta a orbitar a estrela mais próxima do Sol

por Nuno Patrício - RTP

“confirmation” with HARPS data



HARPS RVs rederived with
a line-by-line approach

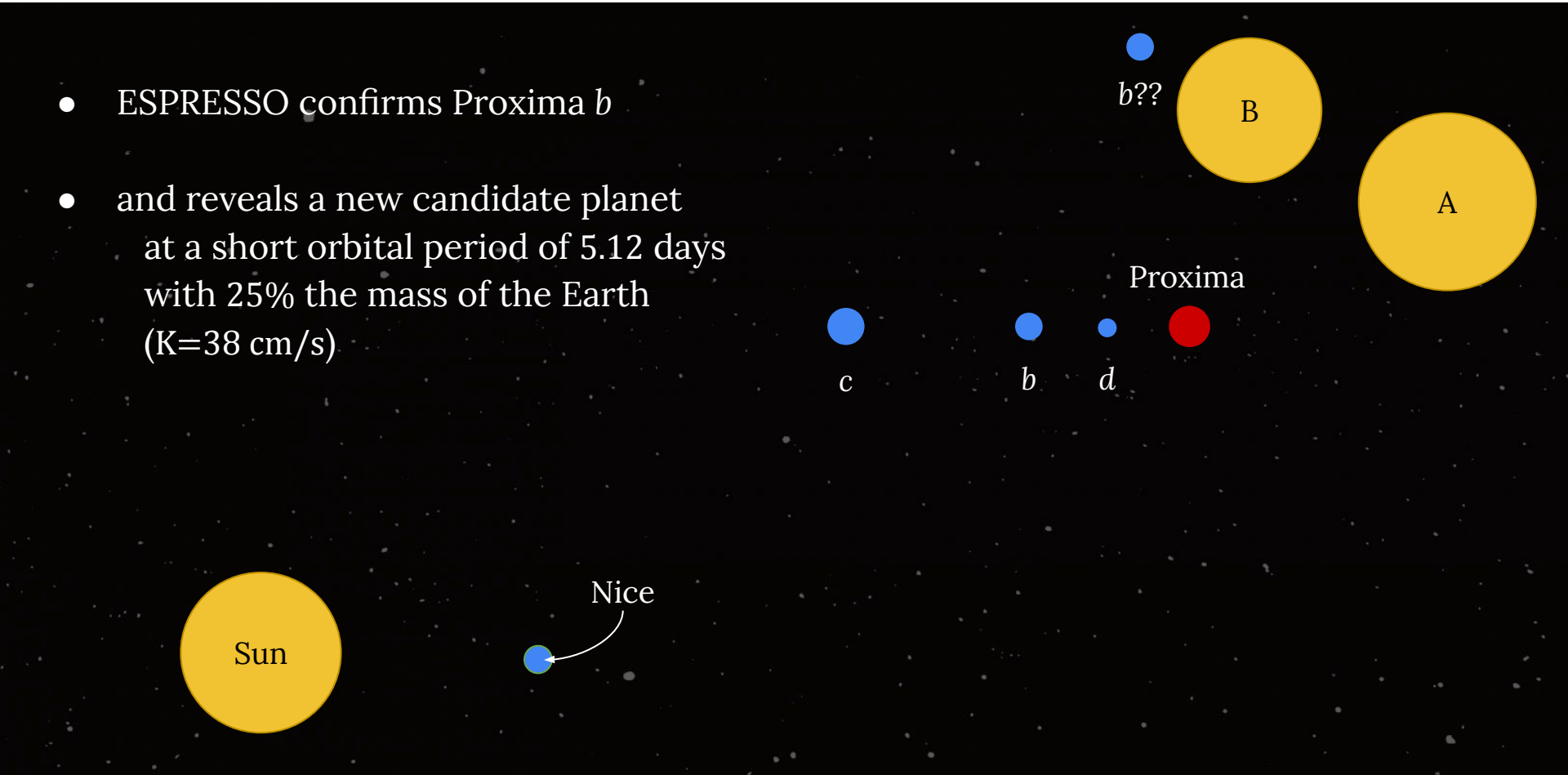
Artigau *et al* (2022)

Comparison Between The LBL Detection of Proxima b and d (Model $M_{\mathrm{bd+dLW}}$) with Published Literature Values

Parameter	Prior	[a]LBL	[b]SM2020	[c]Fa2022
P_{b} (days)	$\mathcal{U}$(**10.0**, **20.0**)	$11.1881^{+0.0061}_{-0.0058}$	11.1842 ± 0.0007	$11.1868^{+0.0029}_{-0.0031}$
K_{b} (m s^{-1})	$\mathcal{U}$(**0**, 5)	1.22 ± 0.17	1.37 ± 0.10	1.24 ± 0.07
P_{d} (days)	$\mathcal{U}$(**5.0**, **5.3**)	$5.167^{+0.047}_{-0.091}$	$5.168^{+0.051}_{-0.069}$	$5.122^{+0.002}_{-0.036}$
K_{d} (m s^{-1})	$\mathcal{U}$(**0**, 5)	$0.38^{+0.19}_{-0.20}$	$0.35^{+0.10}_{-0.11}$	0.39 ± 0.07

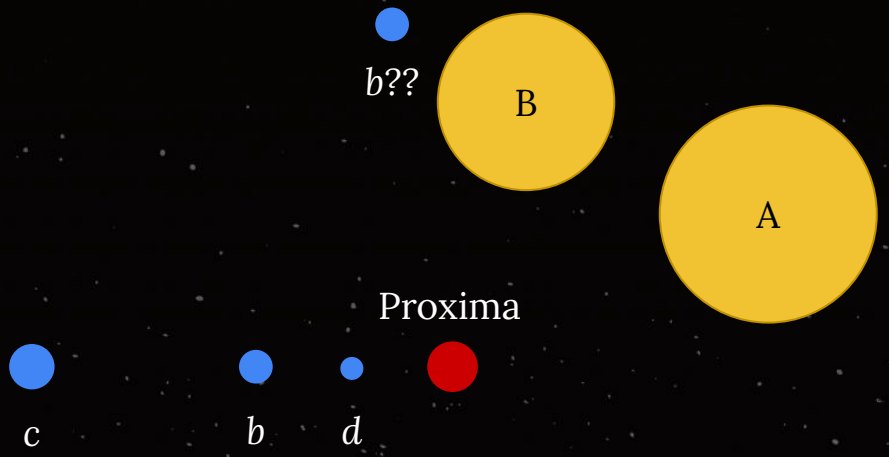
the closest Earth-mass planets

- ESPRESSO confirms Proxima *b*
- and reveals a new candidate planet at a short orbital period of 5.12 days with 25% the mass of the Earth (K=38 cm/s)



the closest Earth-mass planets

- ESPRESSO confirms Proxima *b*
- and reveals a new candidate planet
  at a short orbital period of 5.12 days
  with 25% the mass of the Earth
  (K=38 cm/s)



Thank you

ia instituto de astrofísica e ciências do espaço
fct Fundação para a Ciência e a Tecnologia
erc