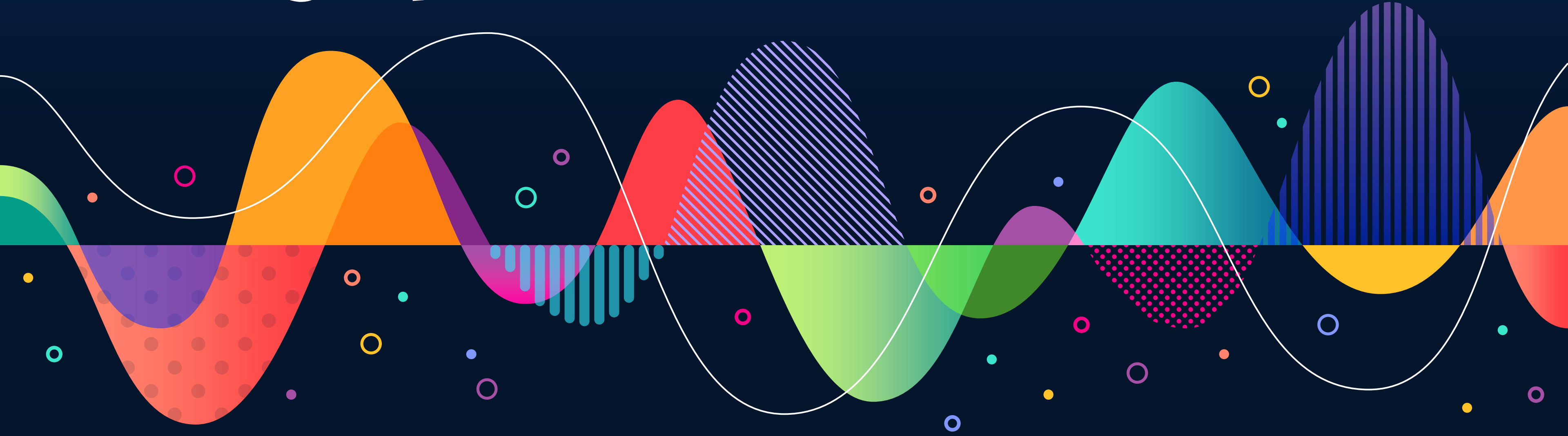
A. Suárez Mascareño

Detection of exoplanets with high-precision radial velocities



About me

My Career

BsC – University of Oviedo (2004 - 2011)

MsC – University of La Laguna (2012 - 2014)

PhD – University of La Laguna (2012 - 2016)

Post-Doc – University of Geneva (2016 - 2019)

Post-Doc – Instituto de Astrofísica de Canarias (2019 -2020)

Juan de la Cierva Fellow – Instituto de Astrofísica de Canarias (2020 - ...)

My Projects

HADES: Rocky planets orbiting nearby M-dwarfs with HARPS-N.

RoPES: Rocky planets orbiting GK-type dwarfs with HARPS and HARPS-N

ESPRESSO GTO: Earth-mass planets orbiting nearby Stars with ESPRESSO

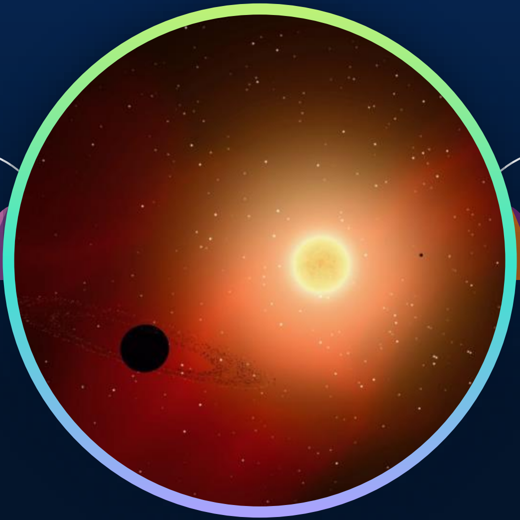
NIRPS GTO: Rocky planets orbiting nearby M-dwarfs with NIRPS

THE: Earth-mass planets in the HZ of nearby GK-type dwarfs with HARPS-3

IACSAT-1: The first Space observatory of the IAC

ANDES: High-resolution spectrograph for the ELT

Exoplanets



Planets orbiting stars other than the Sun

5044

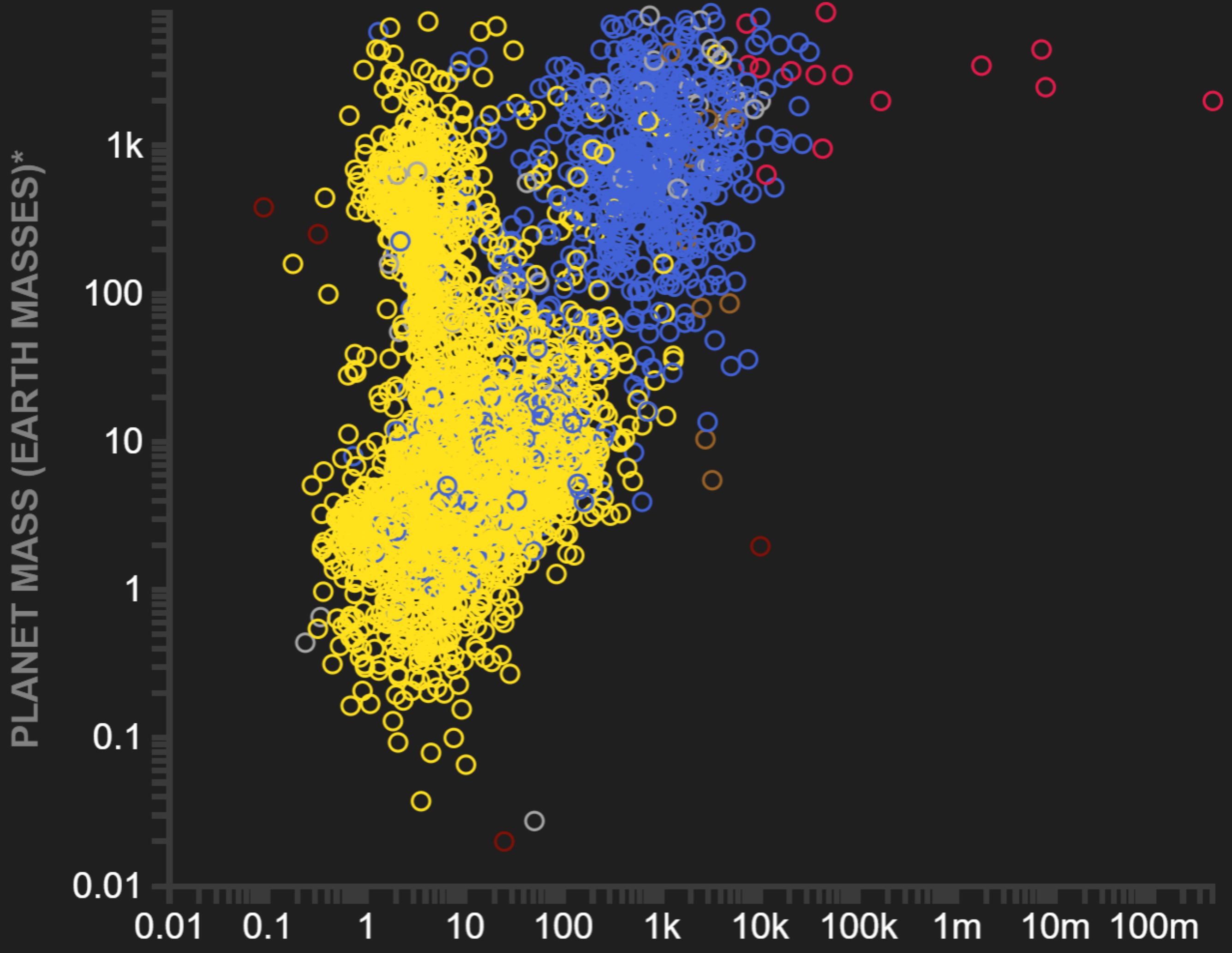
Known exoplanets

3781

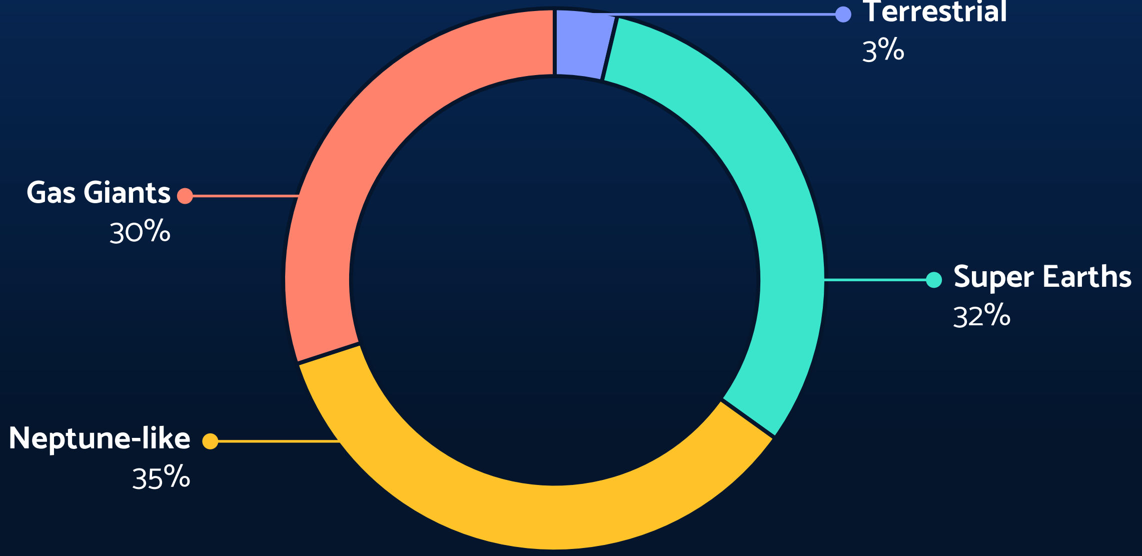
Planetary systems

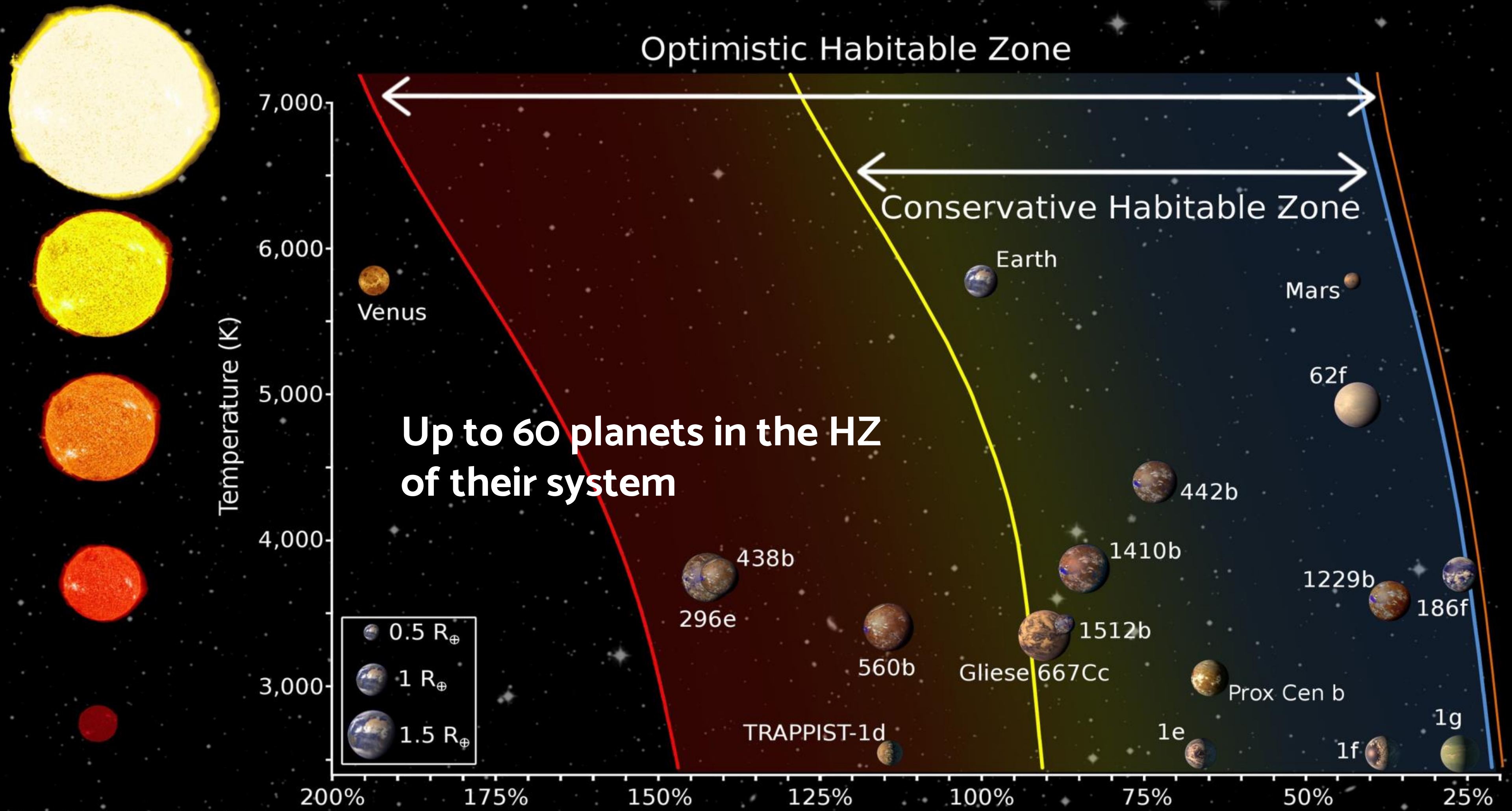
> 9000

Candidates


PLANET MASS (EARTH MASSES)*
1k
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1k
10k
100k
1m
10m
100m

Basic demographics





Up to 60 planets in the HZ of their system

Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/JPL

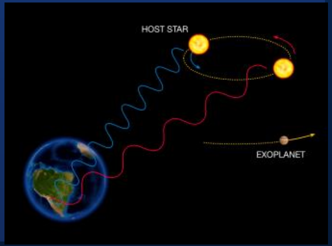
So many exoplanets...

How do we find them?

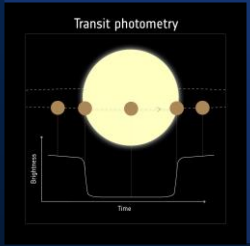
Different techniques

Radial Velocity

Measure the gravitational pull of the planet based on the doppler movement of the spectrum

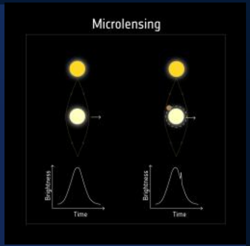


Transit photometry

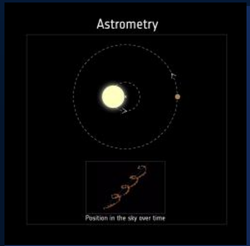


Drop in brightness as a planet eclipses

“Small” lensing effect caused by a planet during a lensing event



Microlensing

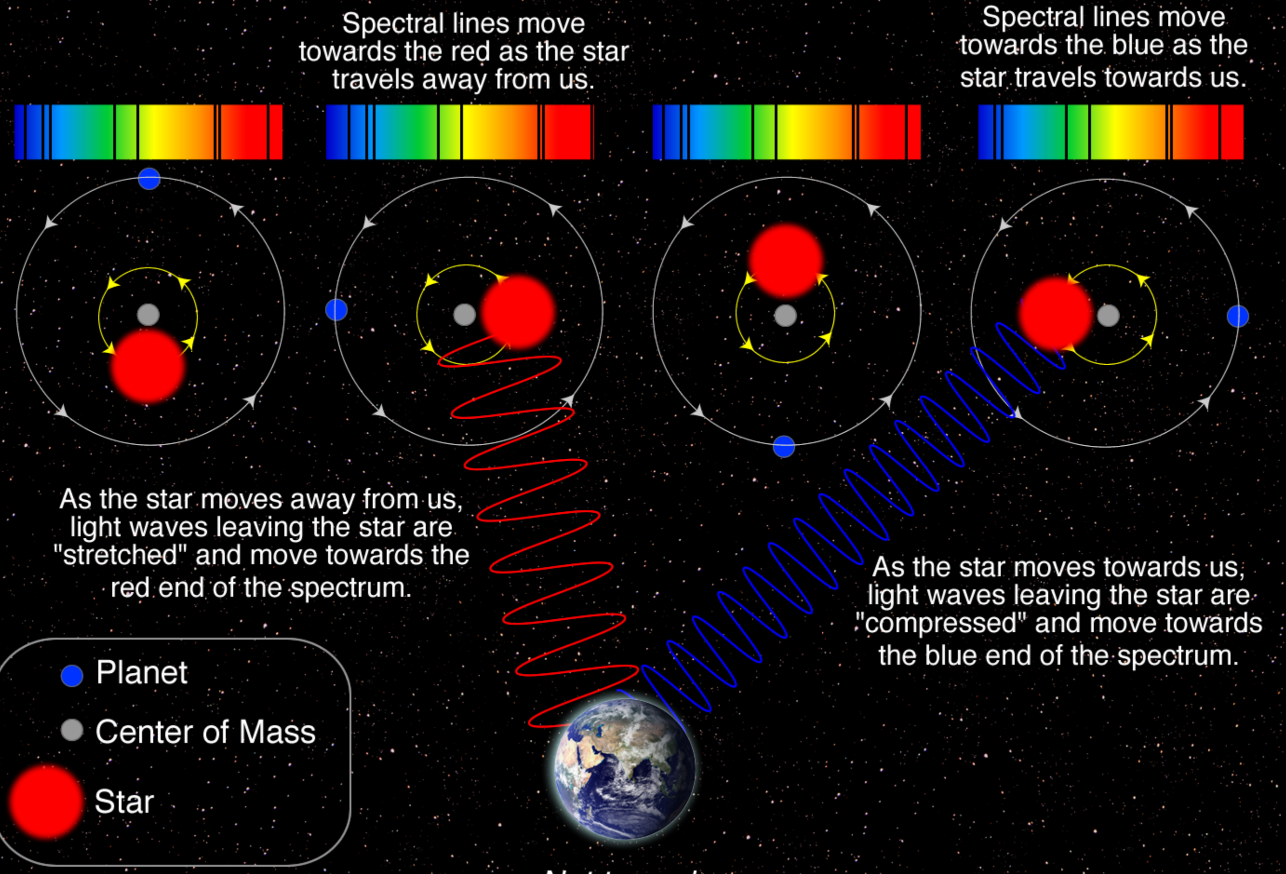


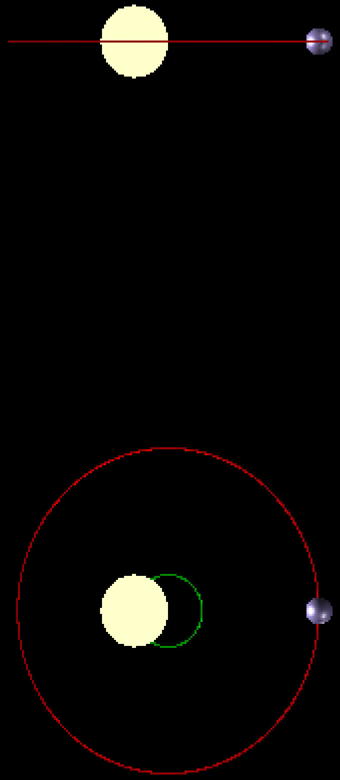
Measure the gravitational pull of the planet based on the change of the position in the sky over time

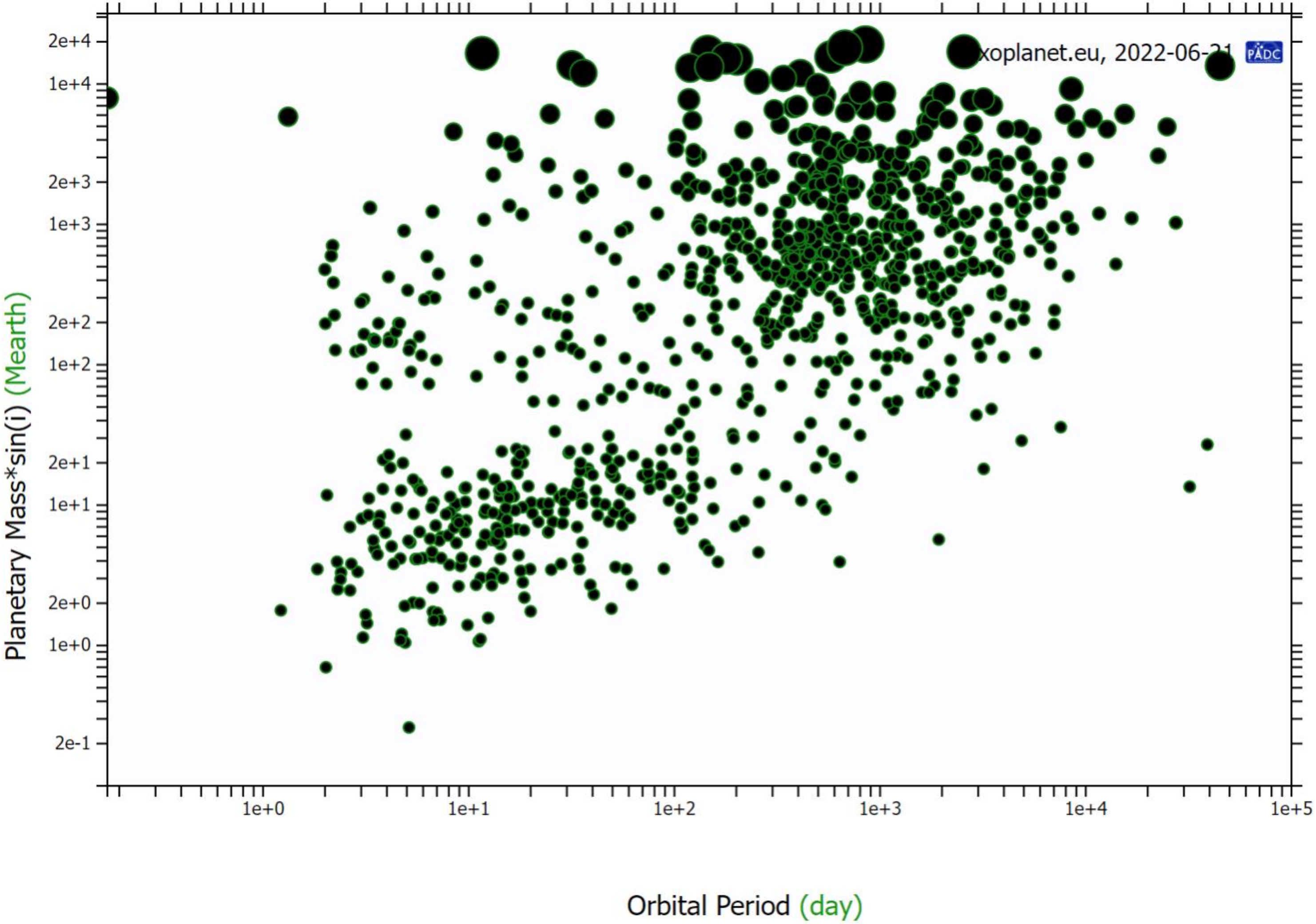
Astrometry

Radial Velocity Method

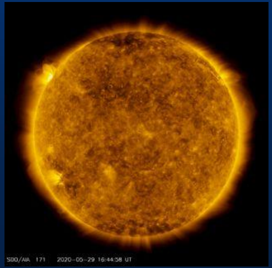
The star and planet orbit their common center of mass.

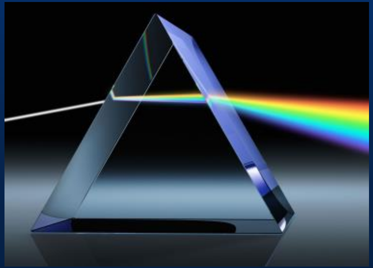


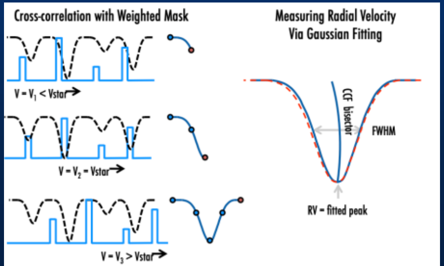


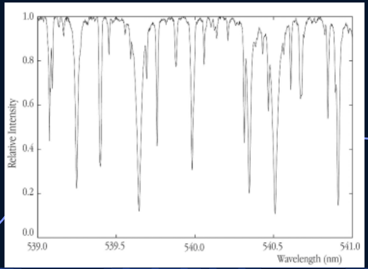


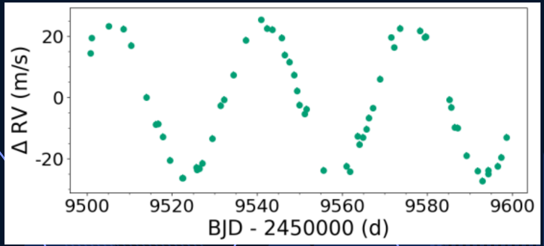
exoplanet.eu, 2022-06-21
PADC
Planetary Mass*sin(i) (Mearth)
2e+4
1e+4
2e+3
1e+3
2e+2
1e+2
2e+1
1e+1
2e+0
1e+0
2e-1
1e+0
1e+1
1e+2
1e+3
1e+4
1e+5
Orbital Period (day)


SDO/AIA 171 2020-05-29 16:44:58 UT

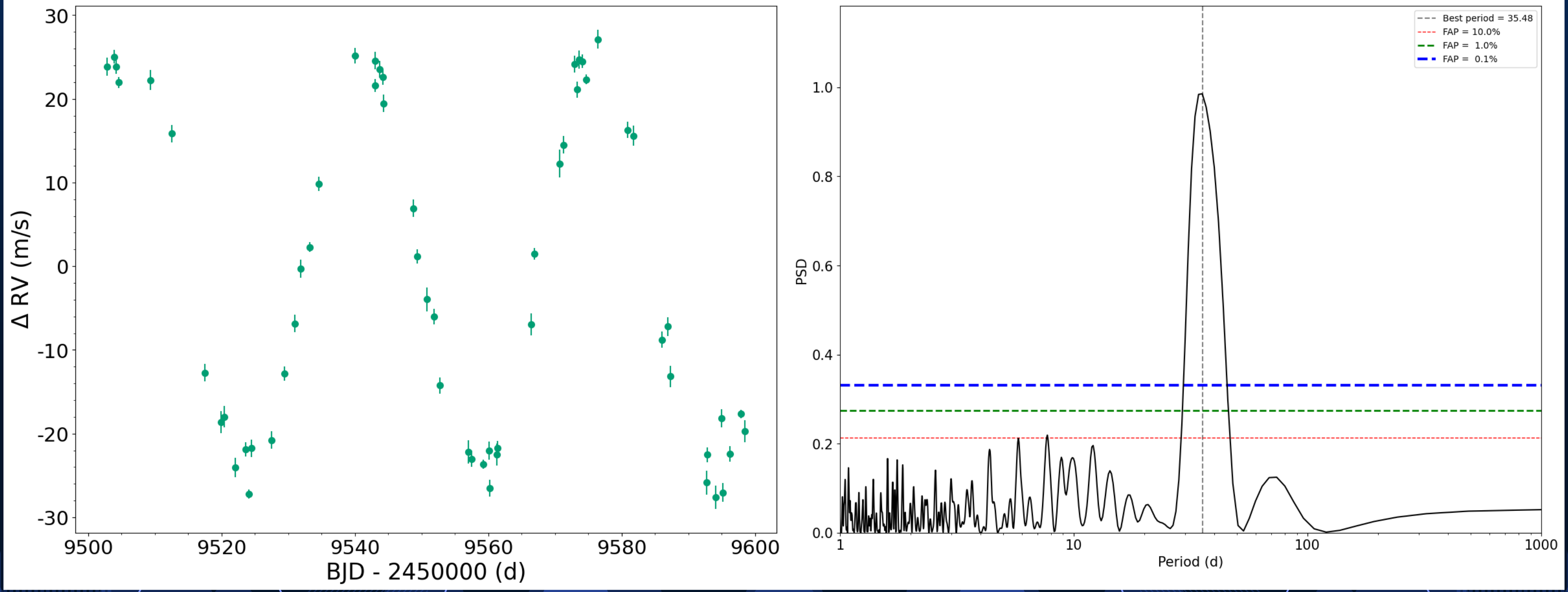



Cross-correlation with Weighted Mask
V = V_1 < Vstar
V = V_2 = Vstar
V = V_3 > Vstar
Measuring Radial Velocity Via Gaussian Fitting
CCF bisector
FWHM
RV = fitted peak


Relative Intensity
1.0
0.8
0.6
0.4
0.2
0.0
539.0
539.5
540.0
540.5
541.0
Wavelength (nm)


Δ RV (m/s)
20
0
-20
9500
9520
9540
9560
9580
9600
BJD - 2450000 (d)

Search for periodic signals



Fit the data

Measure

Orbital period

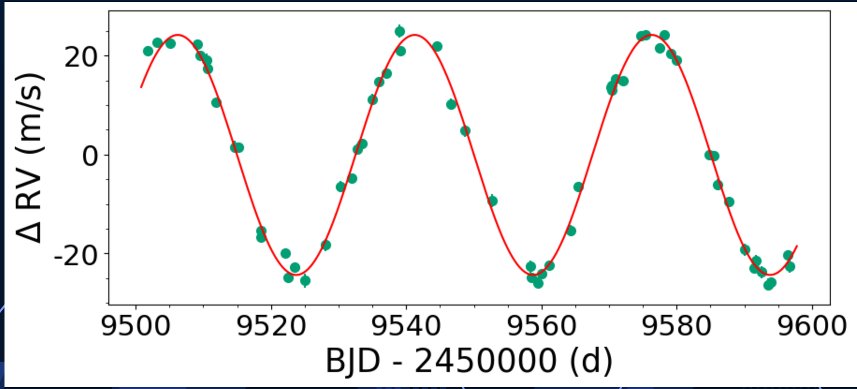
Orbital phase

RV amplitude

Derive

Orbital distance

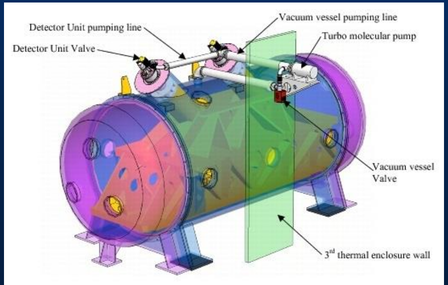
Planet (minimum) mass



Actually not so easy

About astrophysical instrumentation and stellar activity

The instruments



Fibre-fed

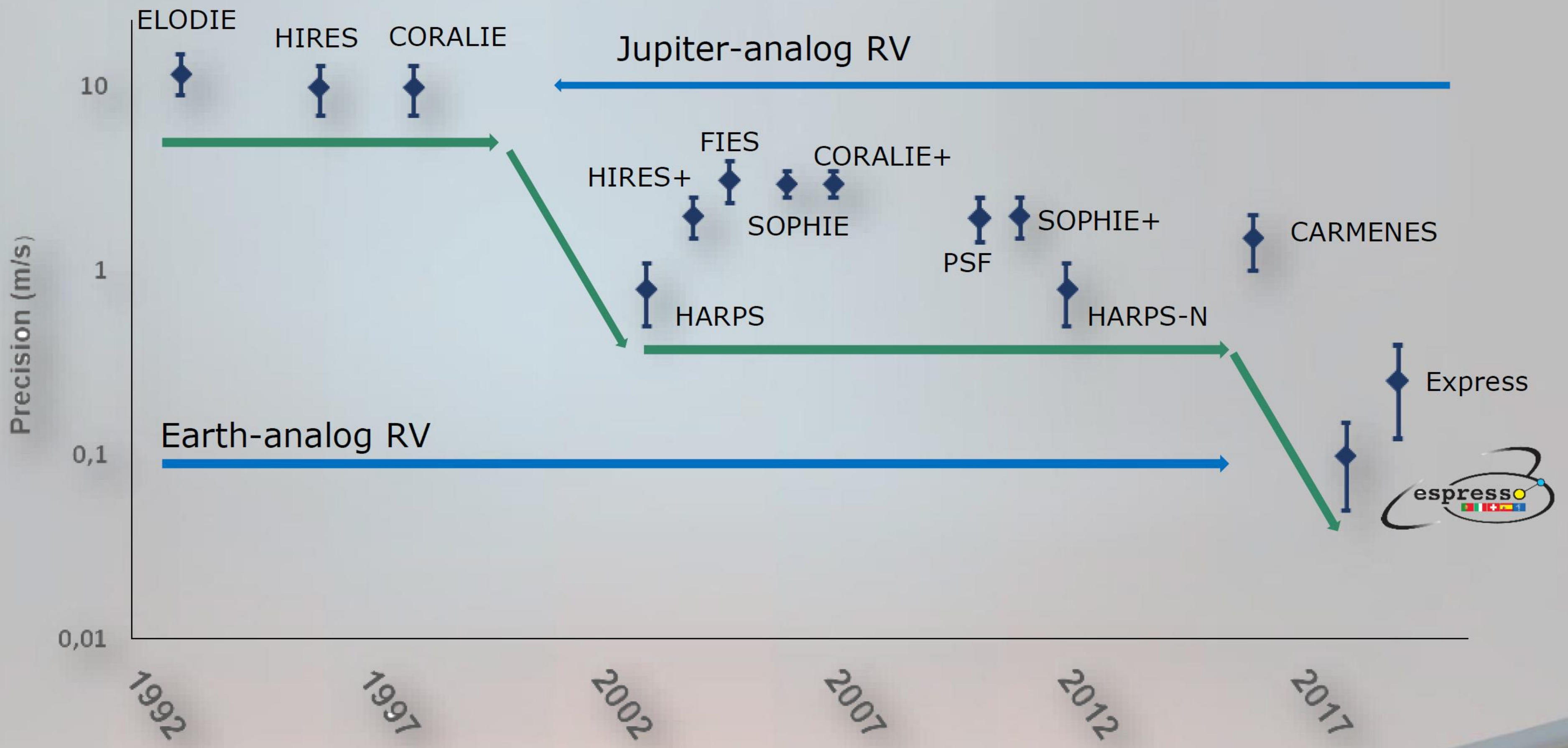
High resolution – R > 80 000

Ultra-stable – Temperature, pressure and stress isolated

Accurate wavelength calibration (ThAr, Laser Comb)

Simultaneous calibration (ThAr, Laser Comb, Fabry Perot)

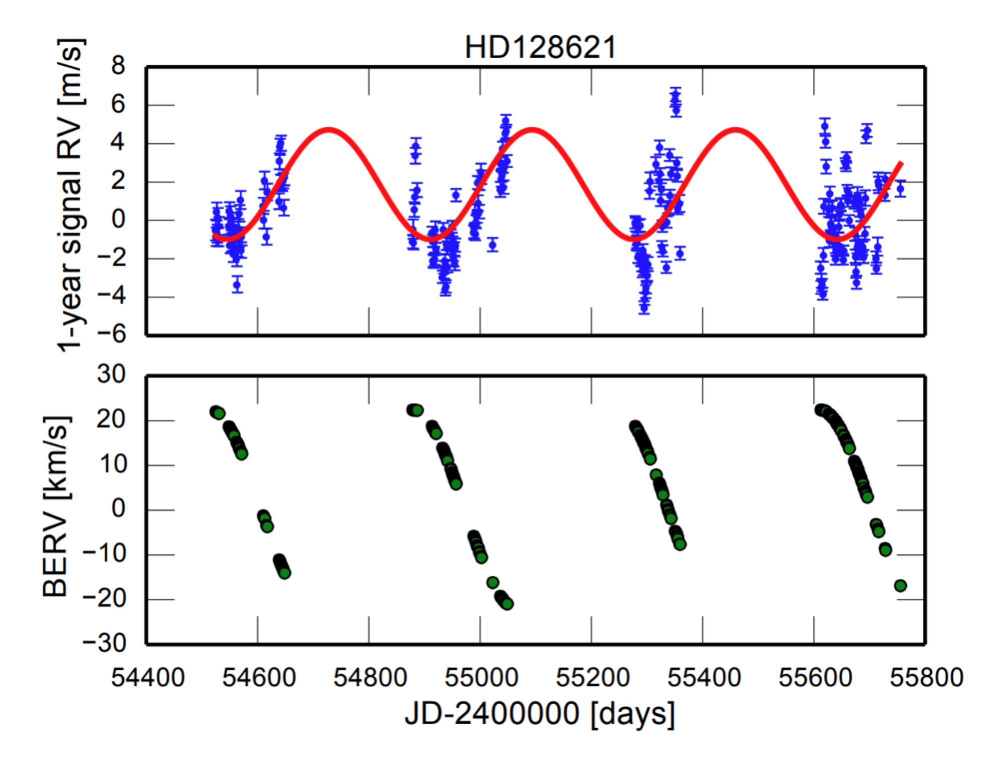
Designed specifically to obtain precise radial velocities (< 1-2 m/s)


ELODIE
HIRES
CORALIE
Jupiter-analog RV
10
FIES
CORALIE+
HIRES+
SOPHIE
SOPHIE+
CARMENES
PSF
1
HARPS
HARPS-N
Precision (m/s)
Express
Earth-analog RV
0,1
espresso
0,01
1992
1997
2002
2007
2012
2017

The instruments are not perfect

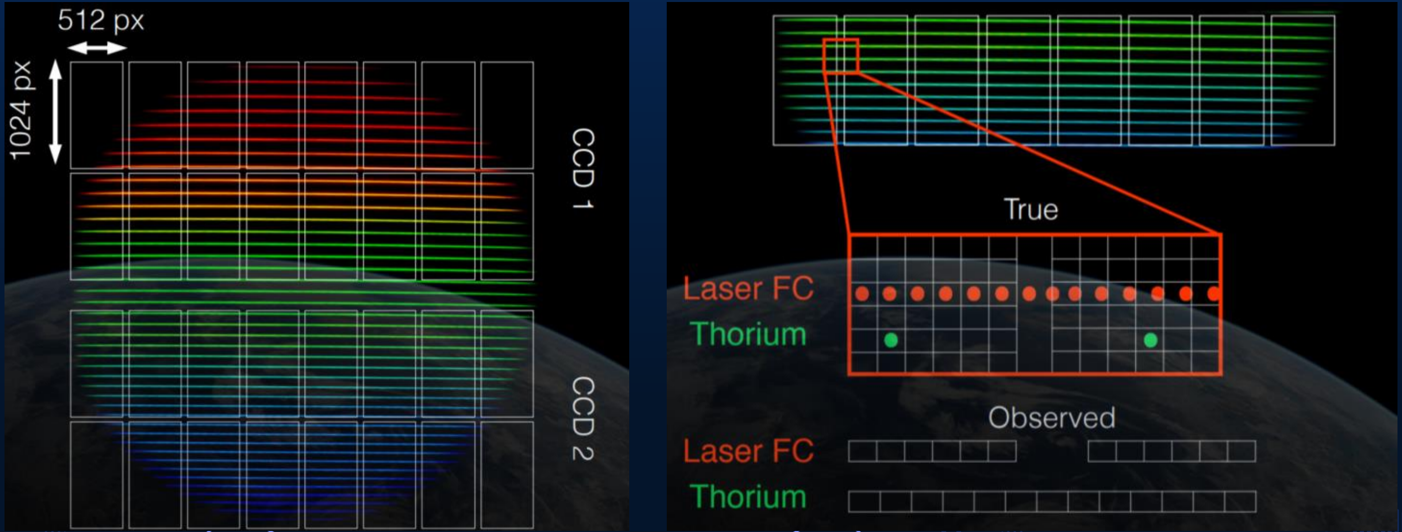
- Parasitic signals
  - Temperature changes
  - Pressure changes
  - CCD irregularities
  - Imperfect wavelength solution
  - Poor fiber illumination
  - Modal noise
  - Telluric contamination
  - Imperfect barycentric correction

Parasitic signals



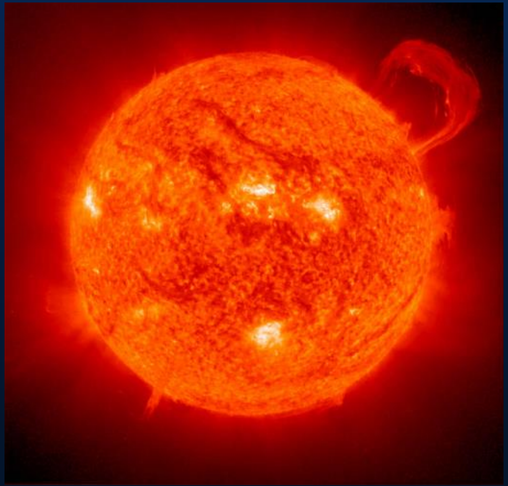
Dumusque et al. 2015

Parasitic signals



Dumusque et al. 2015

The stars - precision in RV



We need bright stars

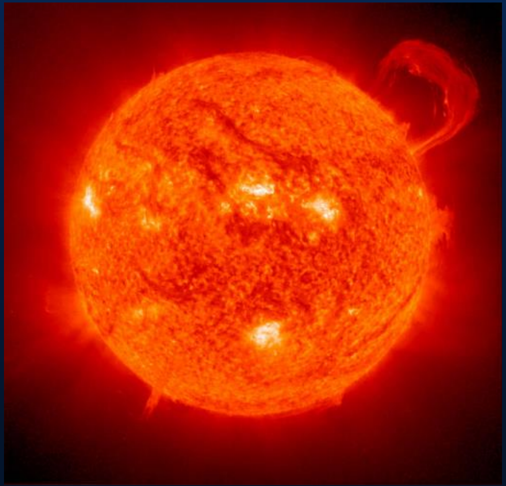
We need star with many lines in their spectrum (FGKM)

We need stars with narrow lines in their spectrum (slow rotation)

We favor low mass stars (bc. planet/star ratio)

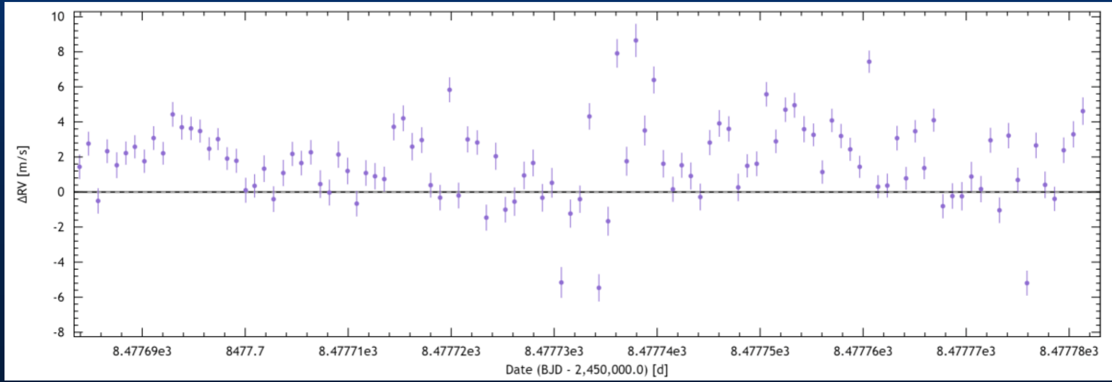
The more we deviate, the worse we do

The stars – stellar activity

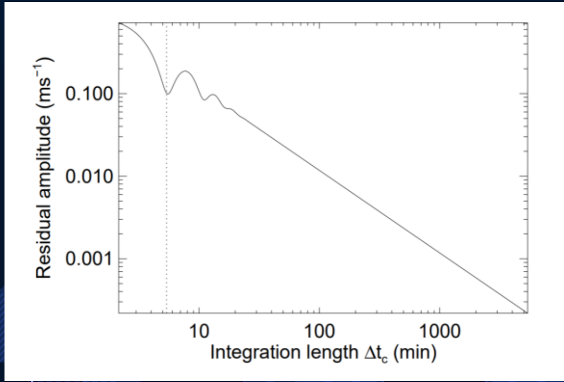


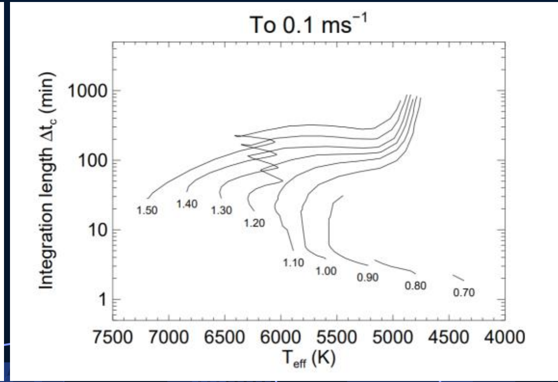
Oscillations	• Minutes • < 3 m/s
Granulation	• < 2 days • < 3 m/s
Rotation	• < 1 day to > 100 days • < 1 m/s to > 1 km/s
Cycles	• > 1 year • < 1 m/s to > 10 m/s

Oscillations



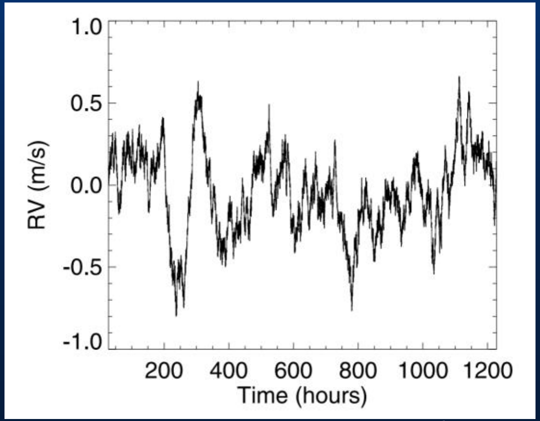
Pepe et al. 2021



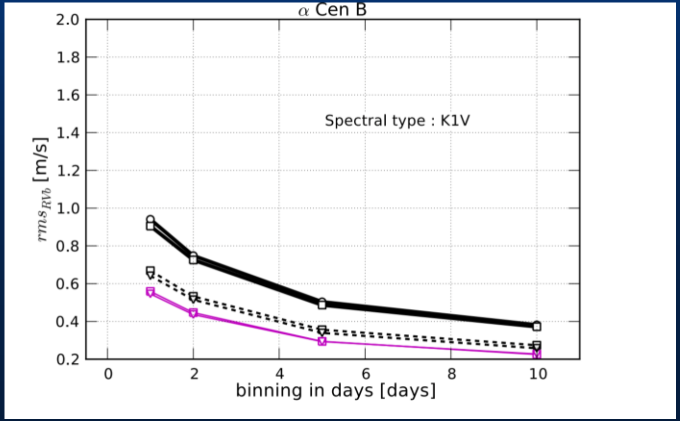


Chaplin et al. 2019

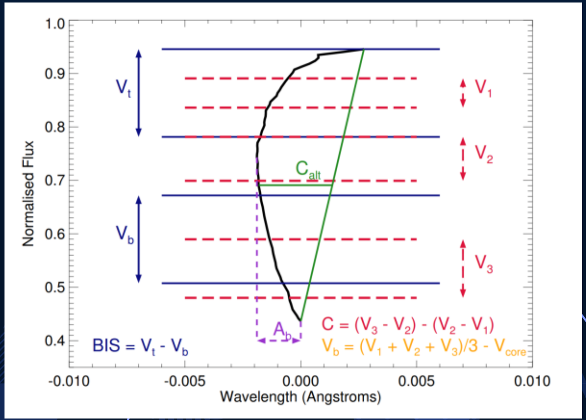
Granulation

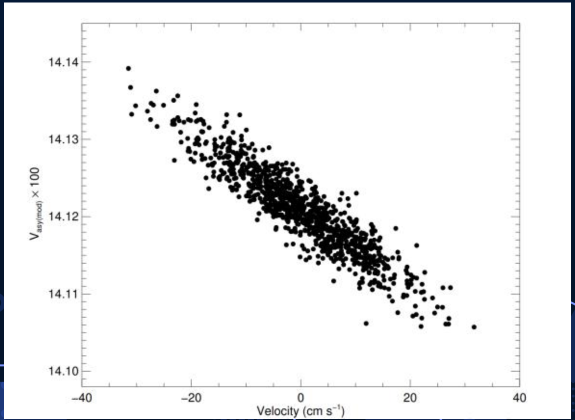


Meunier et al. 2015



Dumusque et al. 2011





Cegla et al. 2019

Rotation

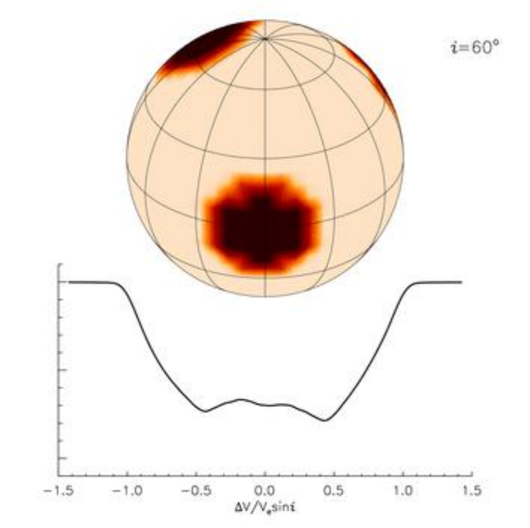
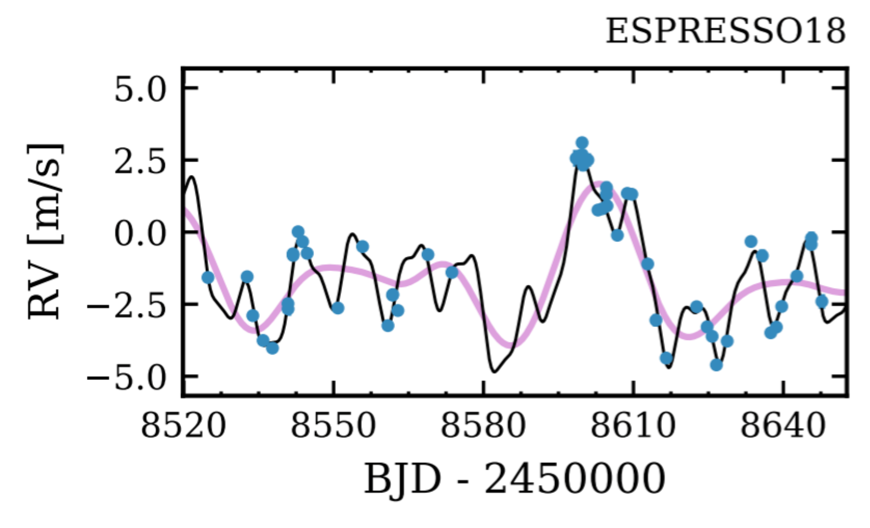
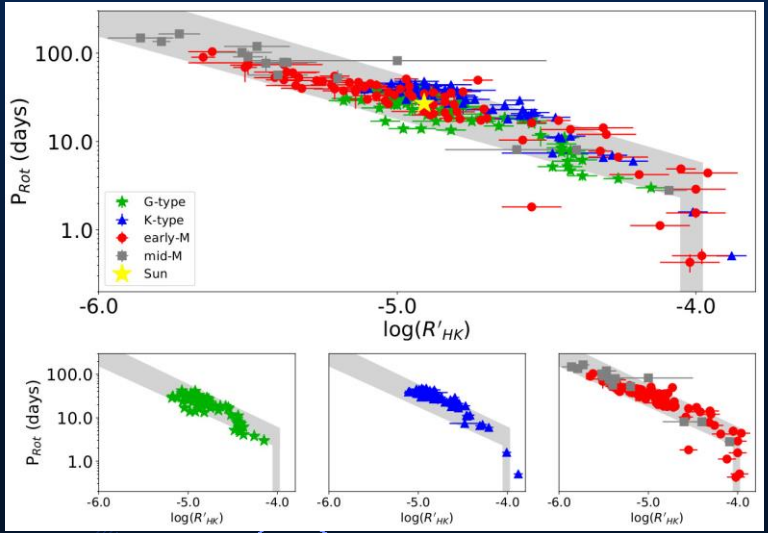


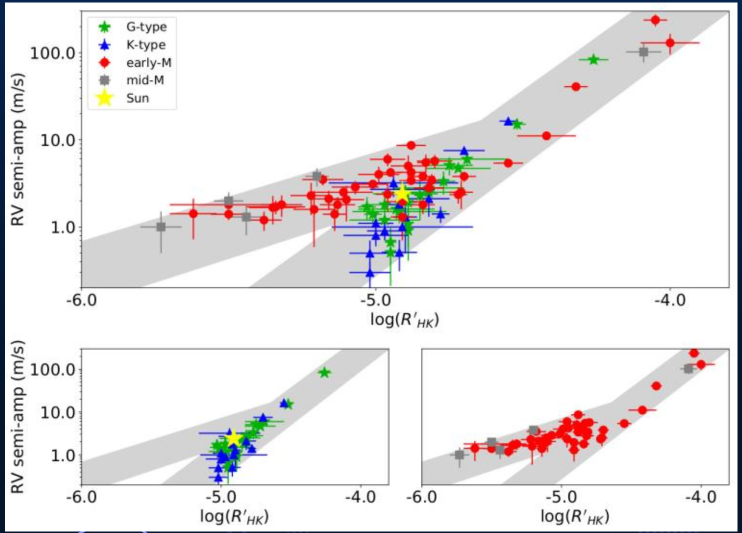
Image from University of Uppsala
Idea from Dravins et al. 1985



Faria et al. 2022

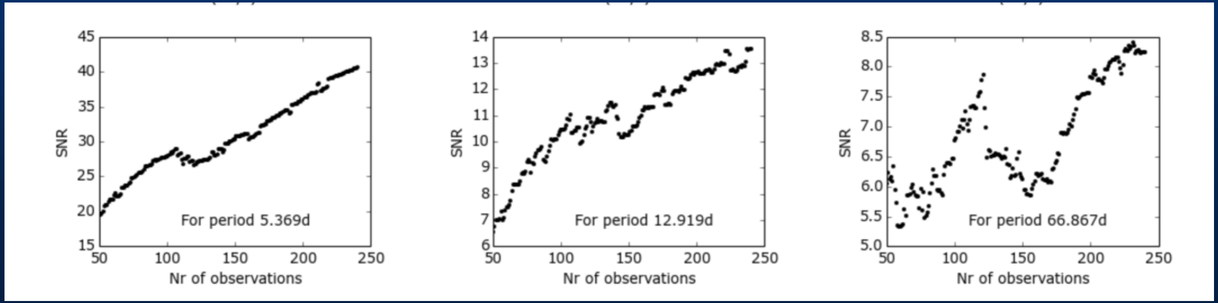
Rotation



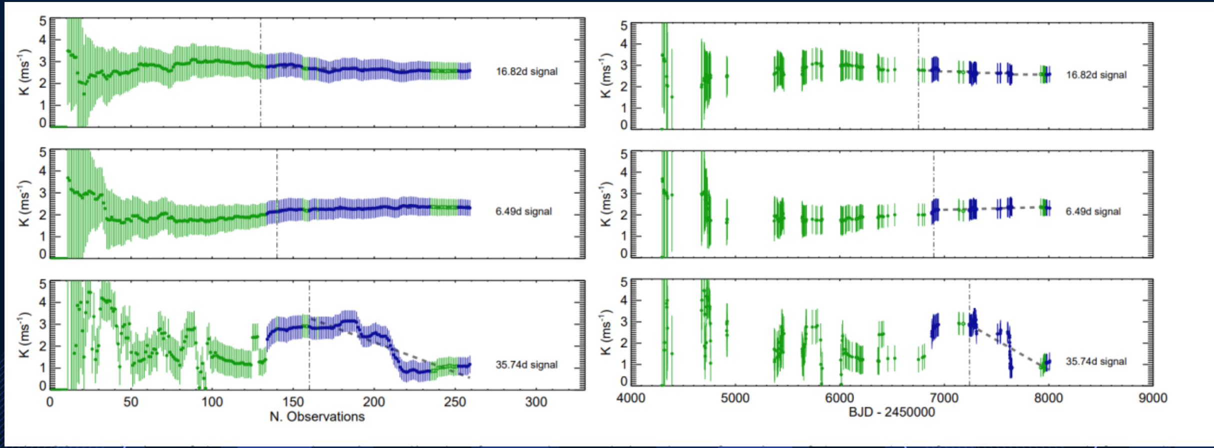


Suárez Mascareño et al. 2015, 2016, 2017, 2018

Rotation

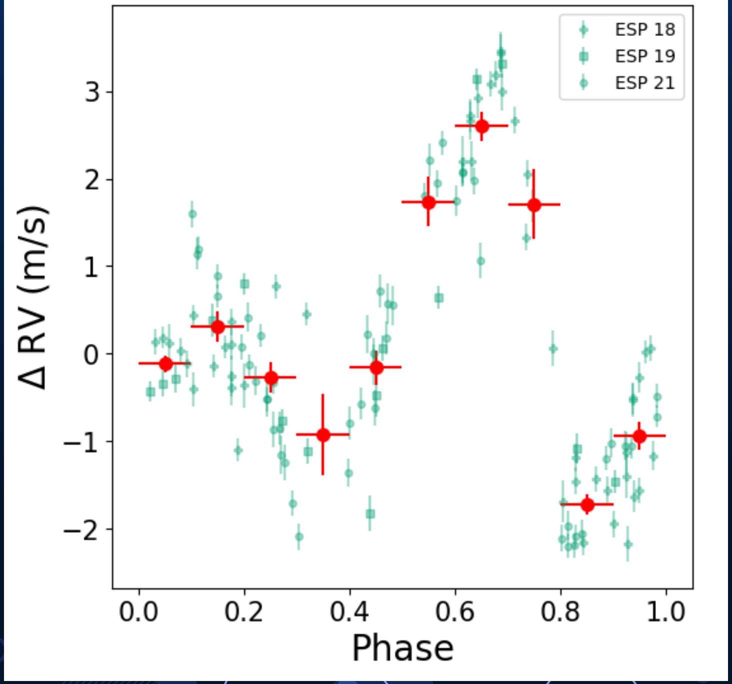


Mortier et al. 2017

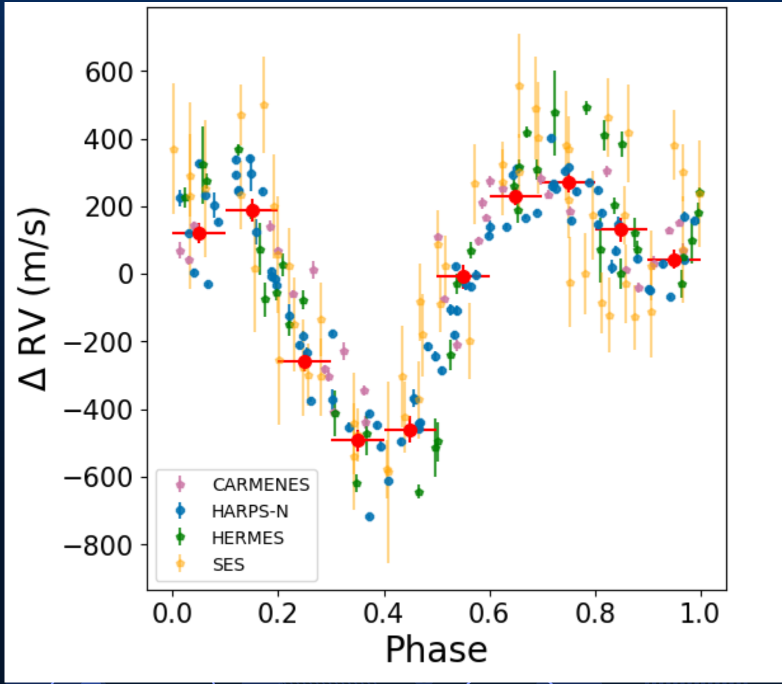


Suárez Mascareño et al. 2018b

Rotation

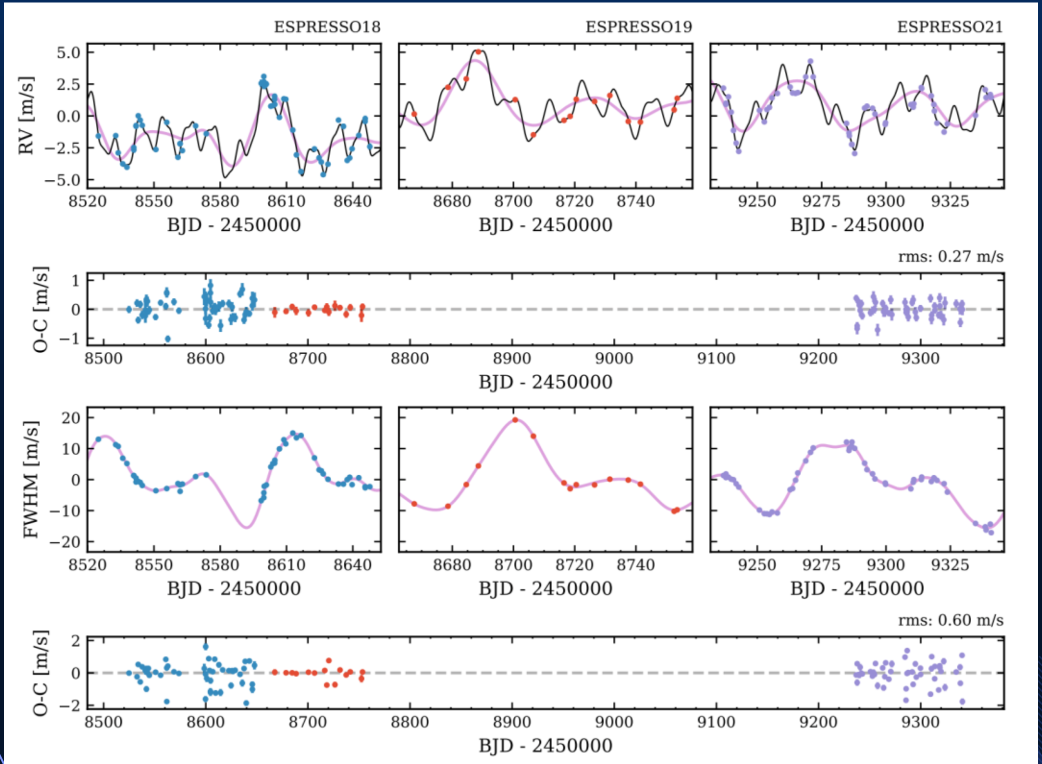


Data from Faria et al. 2022



Data from Suárez Mascareño et al. 2021

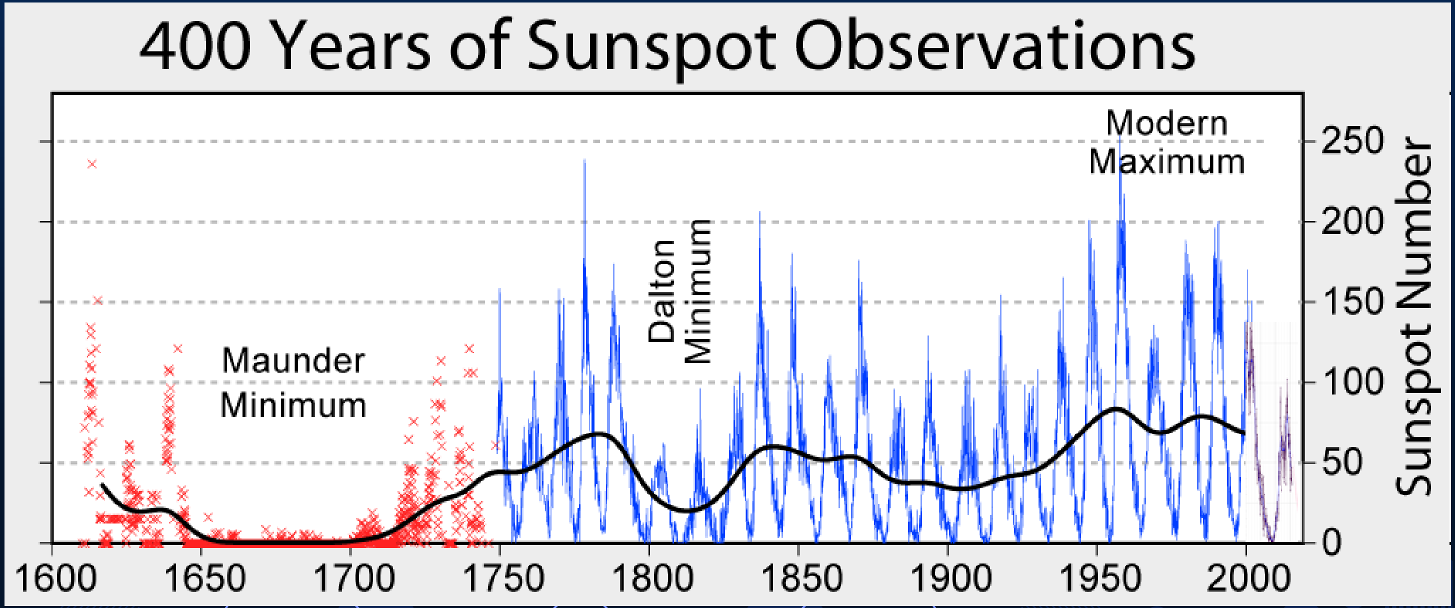
Rotation



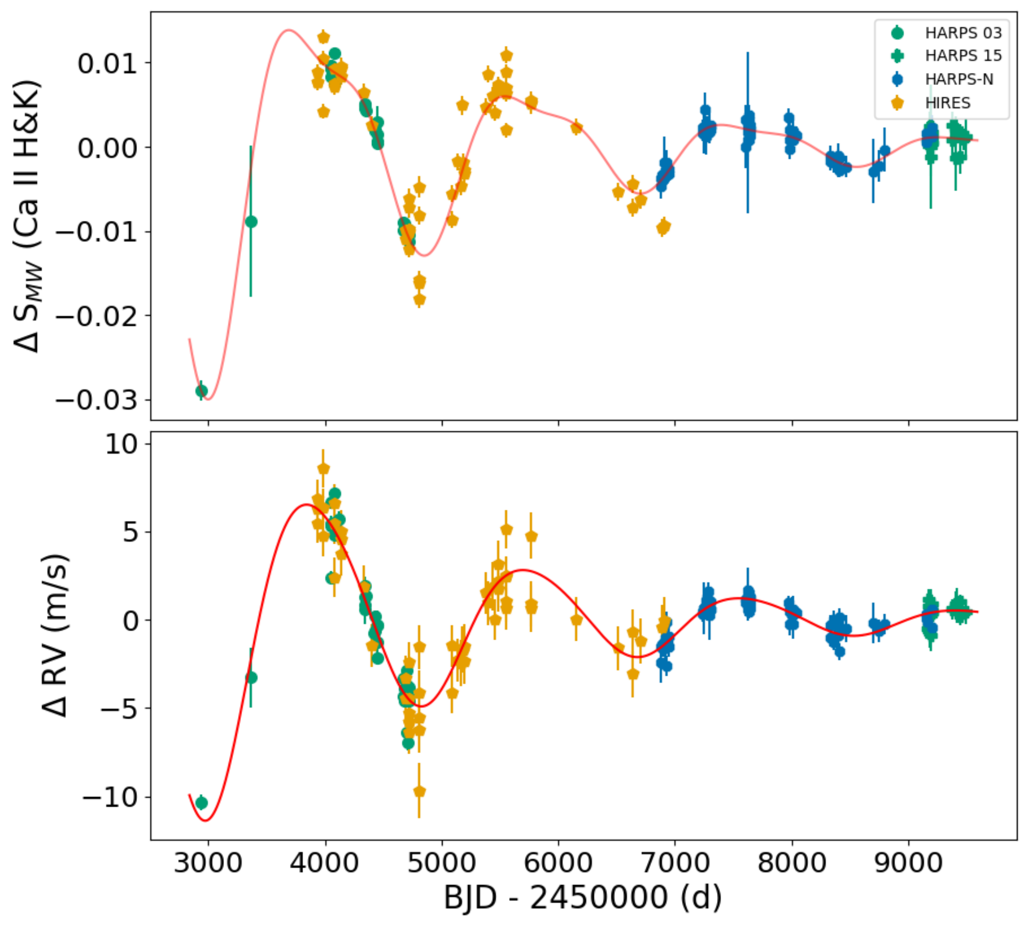
Faria et al. 2022

Haywood PhD thesis
Haywood et al. 2014
Rajpaul et al. 2015
Suárez Mascareño et al. 2020
Barragán et al. 2022
Delisle et al. 2022

Cycles


400 Years of Sunspot Observations
Modern Maximum
Dalton Minimum
Maunder Minimum
Sunspot Number
250
200
150
100
50
0
1600
1650
1700
1750
1800
1850
1900
1950
2000

Cycles



Suárez Mascareño et al. *hopefully soon*

Cycles

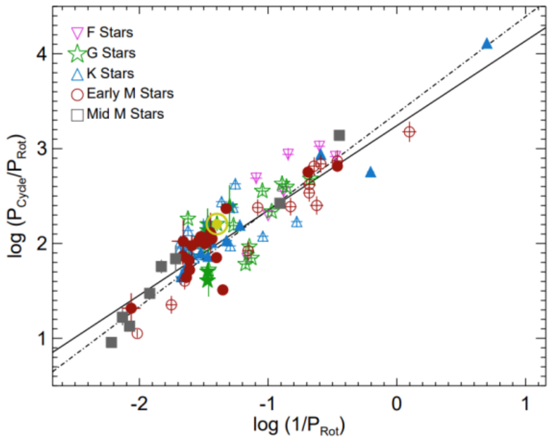


Fig. 20: P_{cyc}/P_{rot} versus $1/P_{rot}$ in log-log scale. Filled dots represent main-sequence stars while empty circles stand for pre-main-sequence stars. The dashed line shows the fit to the full dataset. The solid line shows the fit to the main-sequence stars with radiative core.

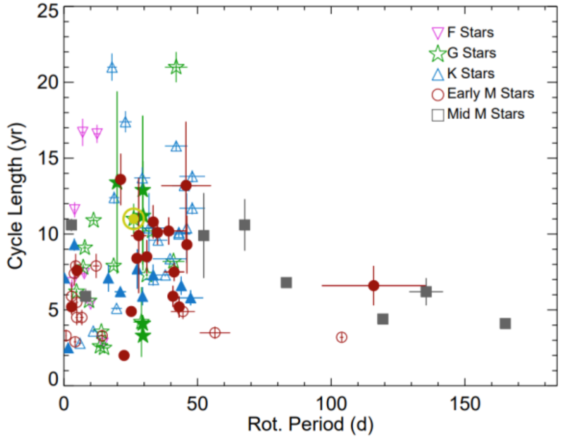


Fig. 21: Cycle length versus rotation periods. Filled symbols show the stars analysed in this work.

Suárez Mascareño et al. 2016

Cycles

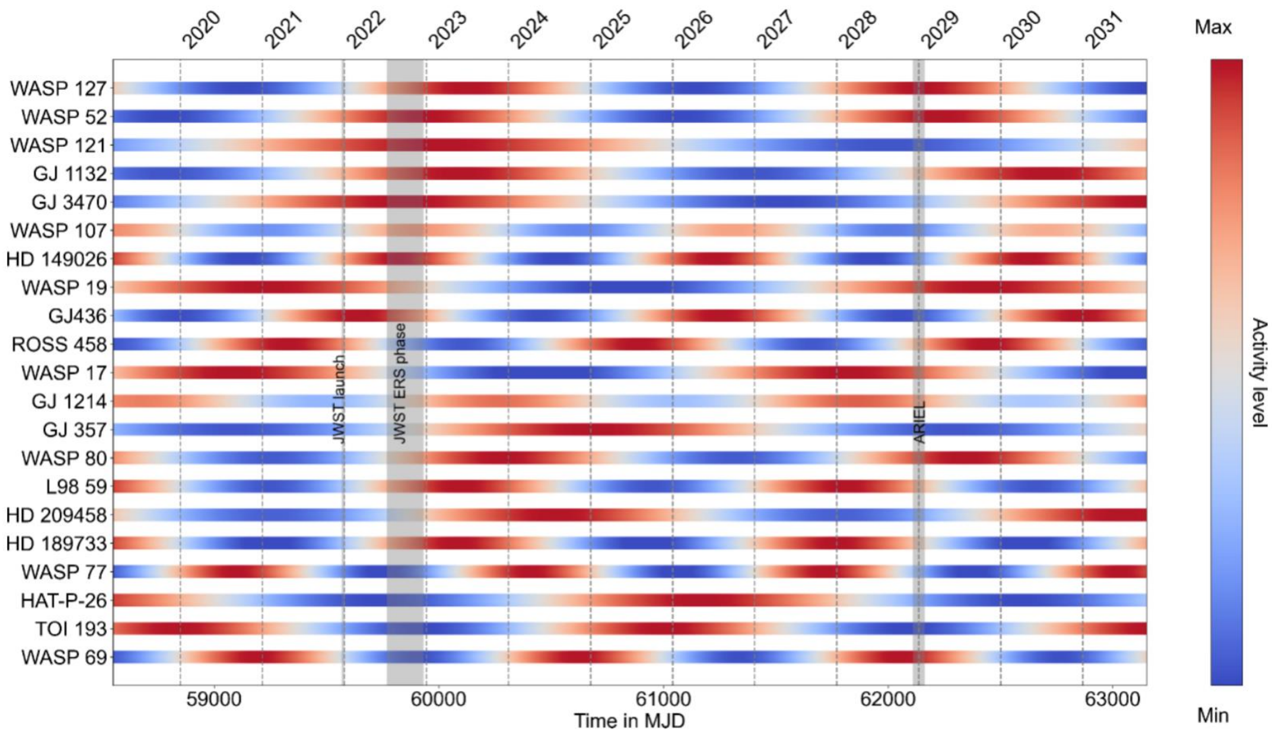
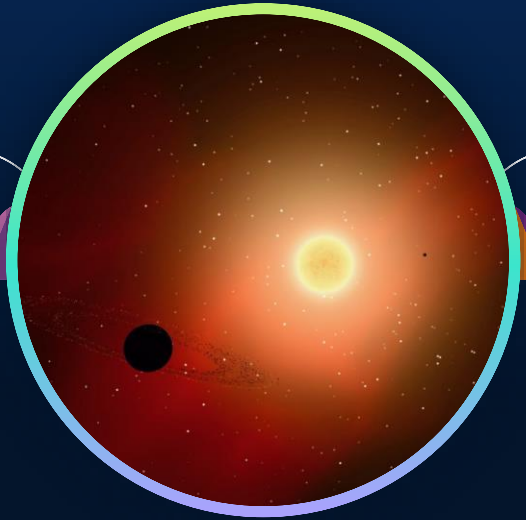


Figure 9. Forecast for optimal observations of *JWST*'s guaranteed time objects for the next 10 yr. The red and blue regions indicate the duration of activity maxima and minima, respectively. Depicted in grey from left to right are the launch of *JWST*, ERS phase and planned launch of ARIEL, respectively.

Sairam et al. 2022

Where are the planets?



Let's talk Proxima Centauri

Revisiting Proxima with ESPRESSO★,★★,★★★

A. Suárez Mascareño[1,7], J. P. Faria[2,14], P. Figueira[17,2], C. Lovis[10], M. Damasso[11], J. I. González Hernández[1,7], R. Rebolo[1,7,16], S. Cristiani[9], F. Pepe[10], N. C. Santos[2,14], M. R. Zapatero Osorio[12], V. Adibekyan[2,14], S. Hojjatpanah[2,14], A. Sozzetti[11], F. Murgas[1,7], M. Abreu[3,20], M. Affolter[4], Y. Alibert[5], M. Aliverti[6], R. Allart[10], C. Allende Prieto[1,7], D. Alves[3,20], M. Amate[1], G. Avila[8], V. Baldini[9], T. Bandi[4], S. C. C. Barros[2], A. Bianco[6], W. Benz[4], F. Bouchy[10], C. Broeng[4], A. Cabral[3,20], G. Calderone[9], R. Cirami[9], J. Coelho[3,20], P. Conconi[6], I. Coretti[9], C. Cumani[8], G. Cupani[9], V. D'Odorico[9,18], S. Deiries[8], B. Delabre[8], P. Di Marcantonio[9], X. Dumusque[10], D. Ehrenreich[10], A. Fragoso[1], L. Genolet[10], M. Genoni[6], R. Génova Santos[1,7], I. Hughes[10], O. Iwert[8], F. Kerber[8], J. Knusdstrup[8], M. Landoni[6], B. Lavie[10], J. Lillo-Box[12], J. Lizon[8], G. Lo Curto[8], C. Maire[10], A. Manescau[8], C. J. A. P. Martins[2,19], D. Mégevand[10], A. Mehner[8], G. Micela[13], A. Modigliani[8], P. Molaro[9,15], M. A. Monteiro[2], M. J. P. F. G. Monteiro[2,14], M. Moschetti[6], E. Mueller[8], N. J. Nunes[3,20], L. Oggioni[6], A. Oliveira[3,20], E. Pallé[1,7], G. Pariani[3], L. Pasquini[8], E. Poretti[6,15], J. L. Rasilla[1], E. Redaelli[6], M. Riva[6], S. Santana Tschudi[1], P. Santin[9], P. Santos[3,20], A. Segovia[10], D. Sosnowska[10], S. Sousa[2], P. Spanò[6], F. Tenegi[1], S. Udry[10], A. Zanutta[6], and F. Zerbi[6]

A candidate short-period sub-Earth orbiting Proxima Centauri★

J. P. Faria[1,2], A. Suárez Mascareño[3,4], P. Figueira[5,1], A. M. Silva[1,2], M. Damasso[6], O. Demangeon[1,2], F. Pepe[7], N. C. Santos[1,2], R. Rebolo[8,4,3], S. Cristiani[9], V. Adibekyan[1], Y. Alibert[10], R. Allart[11,7], S. C. C. Barros[1,2], A. Cabral[12,13], V. D'Odorico[9,14,15], P. Di Marcantonio[9], X. Dumusque[7], D. Ehrenreich[7], J. I. González Hernández[4,3], N. Hara[7], J. Lillo-Box[16], G. Lo Curto[17,5], C. Lovis[7], C. J. A. P. Martins[1,18], D. Mégevand[7], A. Mehner[5], G. Micela[19], P. Molaro[9,14], N. J. Nunes[12], E. Pallé[3,4], E. Poretti[20], S. G. Sousa[1,2], A. Sozzetti[6], H. Tabernero[21], S. Udry[7], and M. R. Zapatero Osorio[21]

FRIENDLY NEIGHBOUR PROXIMA

Sp. Type: M5.5V

Eff. Temperature: 2900 K

Mass: 0.12 M_{sun}

Radius: 0.15 R_{sun}

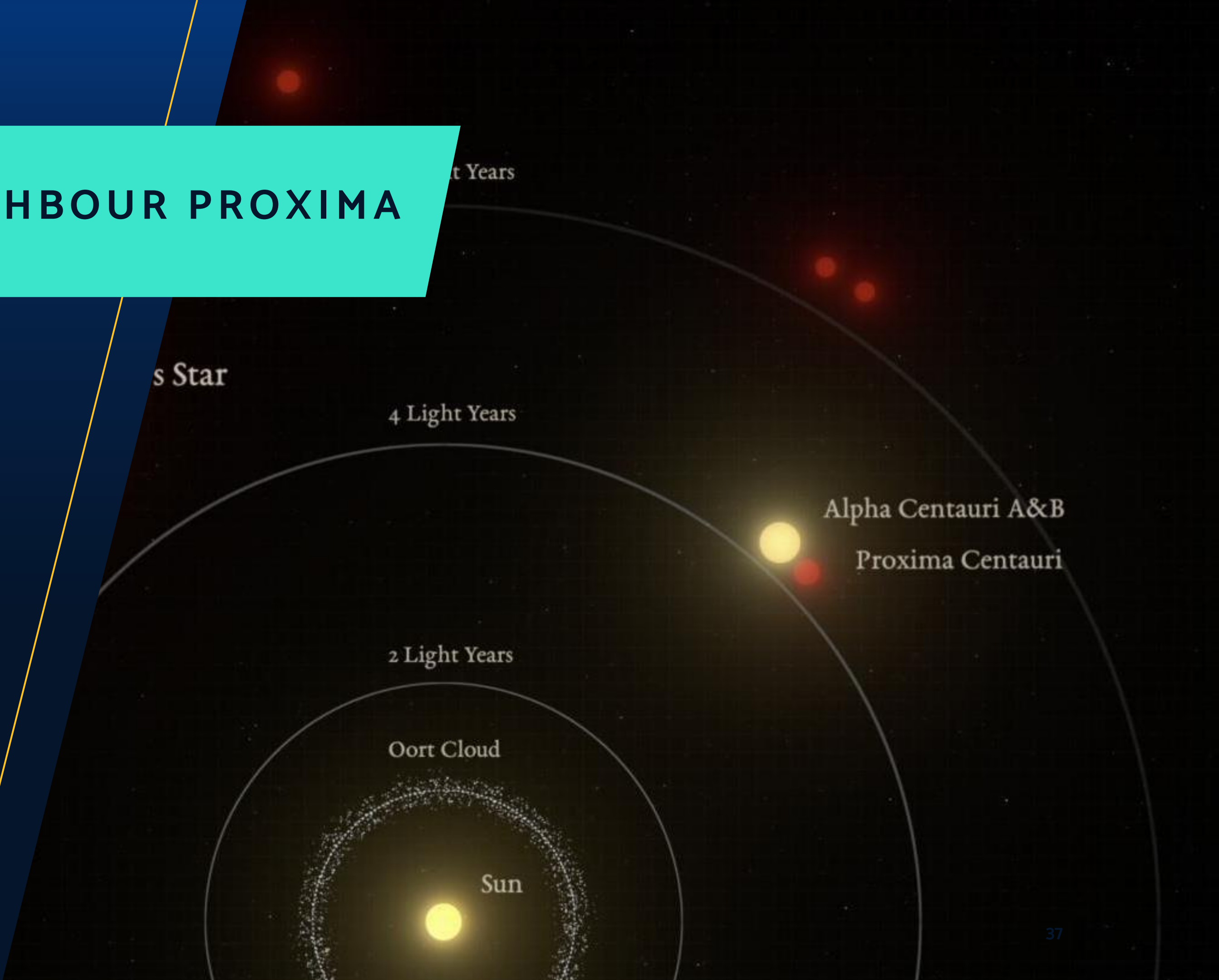
Age: 4.9 Gyr

Visual magnitude: 11.1

Rotation ~83 days

Cycle ~7 years

Habitable zone 7 - 130 days



Almost best case scenario

- Very low mass → Large planet/star ratio for all masses
- Very low mass → Undetectable oscillations/granulation
- Low-temperature → Lots of lines
- Small radius → Low projected rotation velocity
- Slow rotation → Narrow lines
- Slow rotation (II) → Low amplitude activity signal
- Slow rotation (III) → Rotation signal at longer period than (part of the) Habitable zone
- Slow rotation (IV) → Rotation signal easy to sample
- Low amplitude cycle → No need to model it

ESPRESSO@VLT

Installed at the VLT array (4x8.2 meter telescopes)

R ~140 000

Wavelength 390-780 nm

Ultra-stabilized

Simultaneous calibration (FP, Laser Comb)

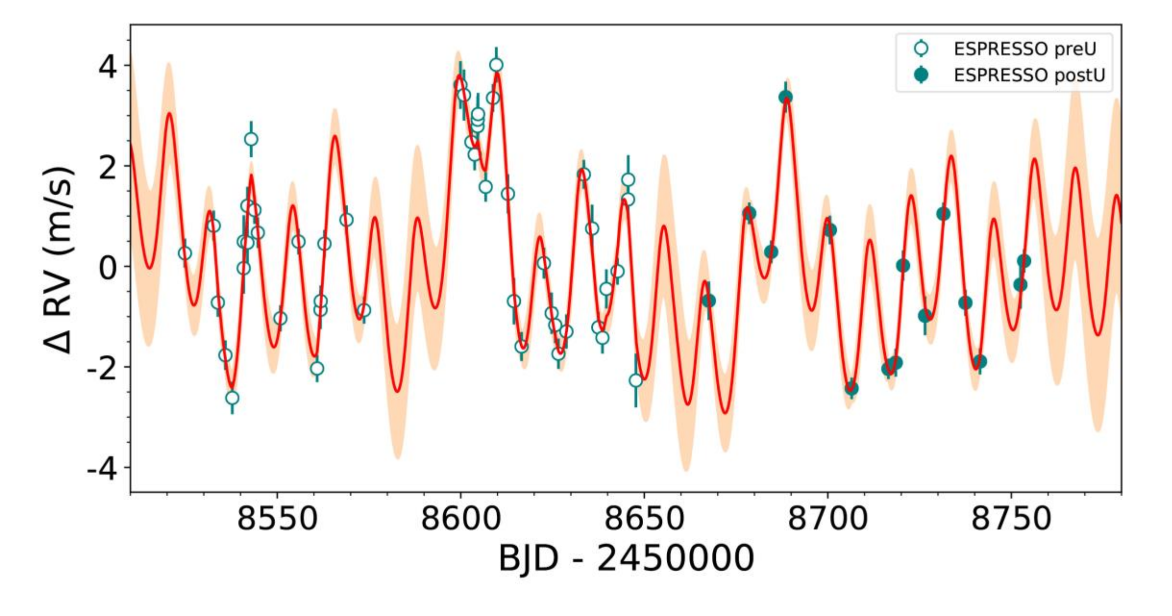
Designed to obtain RV precisión of 10 cm/s

REVISITING PROXIMA WITH ESPRESSO

Proxima b

- Period 11.186 d
- Semi-Amplitude 1.38 m/s
- Minimum mass 1.27 M
- Equilibrium temperatura 234 K

(Anglada Escudé et al. 2016, Suárez Mascareño et al. 2020)

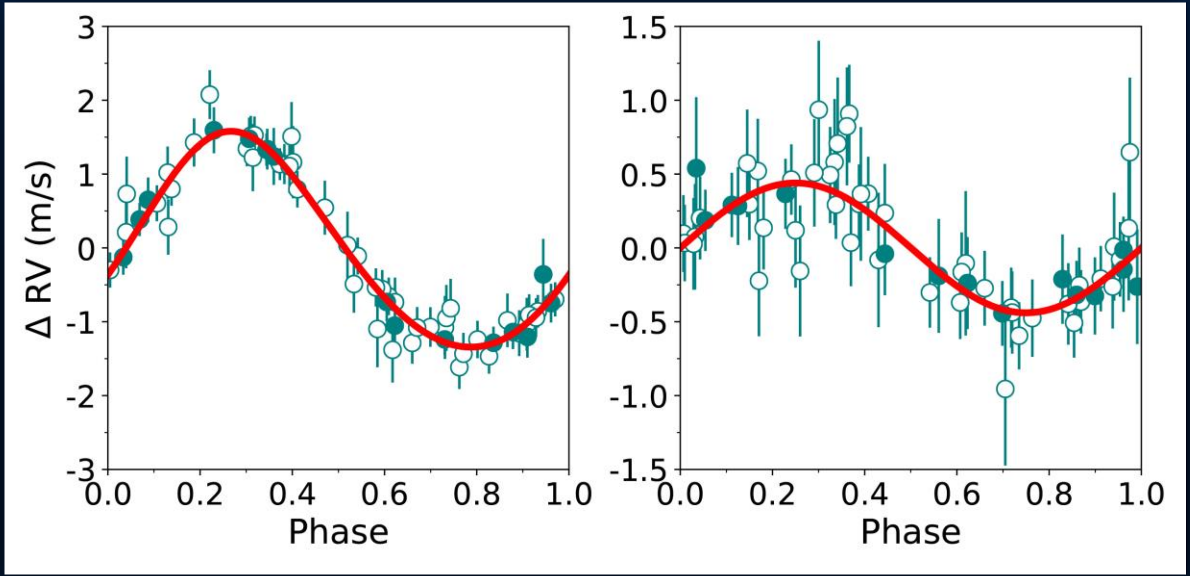


ANOTHER PLANET?

Candidate signal

- Period 5.1 d
- Semi-Amplitude 44 cm/s
- Minimum mass 0.3 M
- Equilibrium temperatura 500 K

(Suárez Mascareño et al. 2020)



THE HUNT FOR THE 5 DAYS PLANET

52 new observations

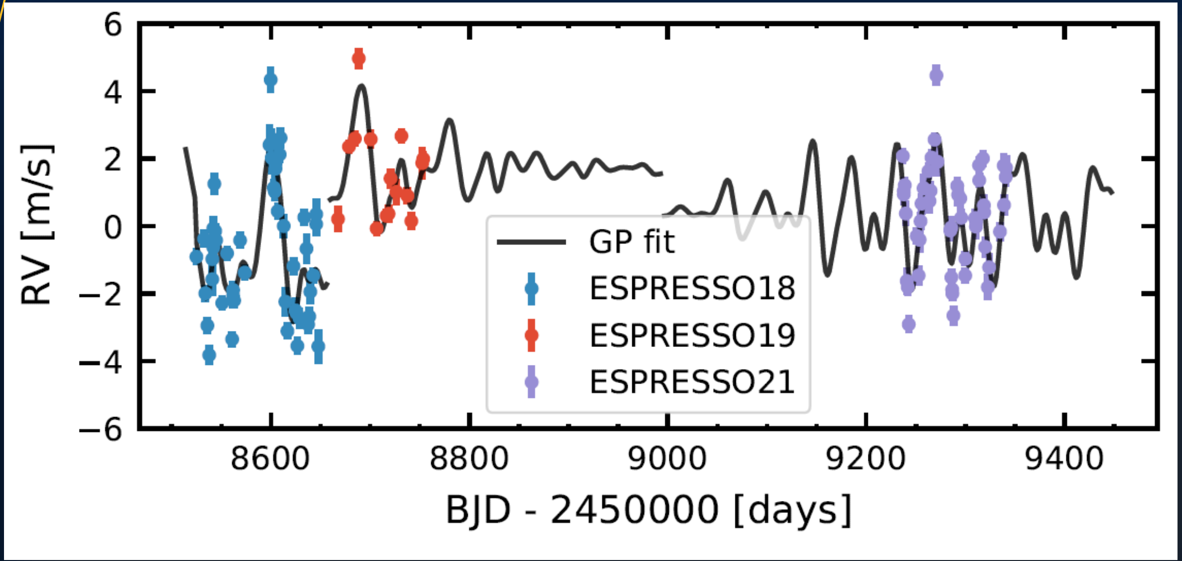
117 ESPRESSO obs (total)

99 individual nights

RMS RV 2.1 m/s

sigRV 17 cm/s

(Faria et al. 2022)

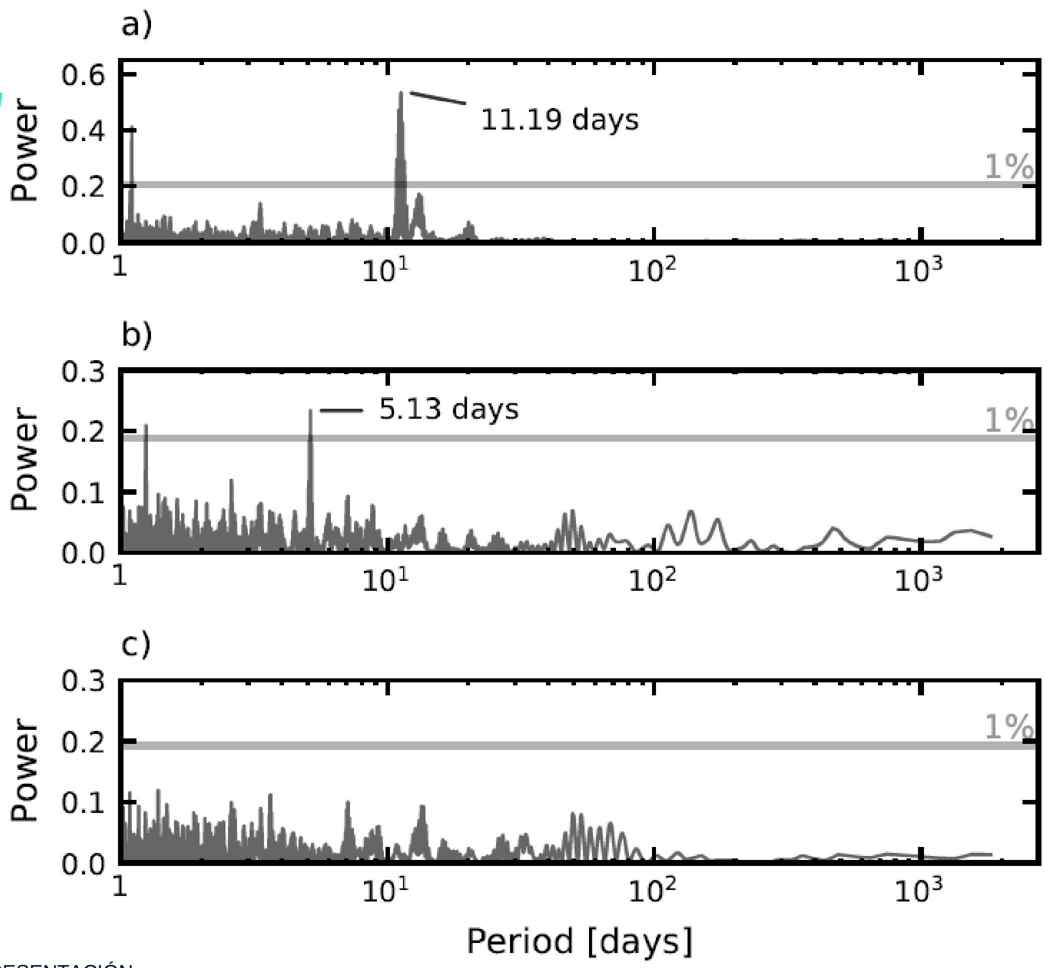


PRE-WHITENING

11.19 d signal significant after subtracting activity

5.13 d signal significant after subtracting 11.19 d signal.

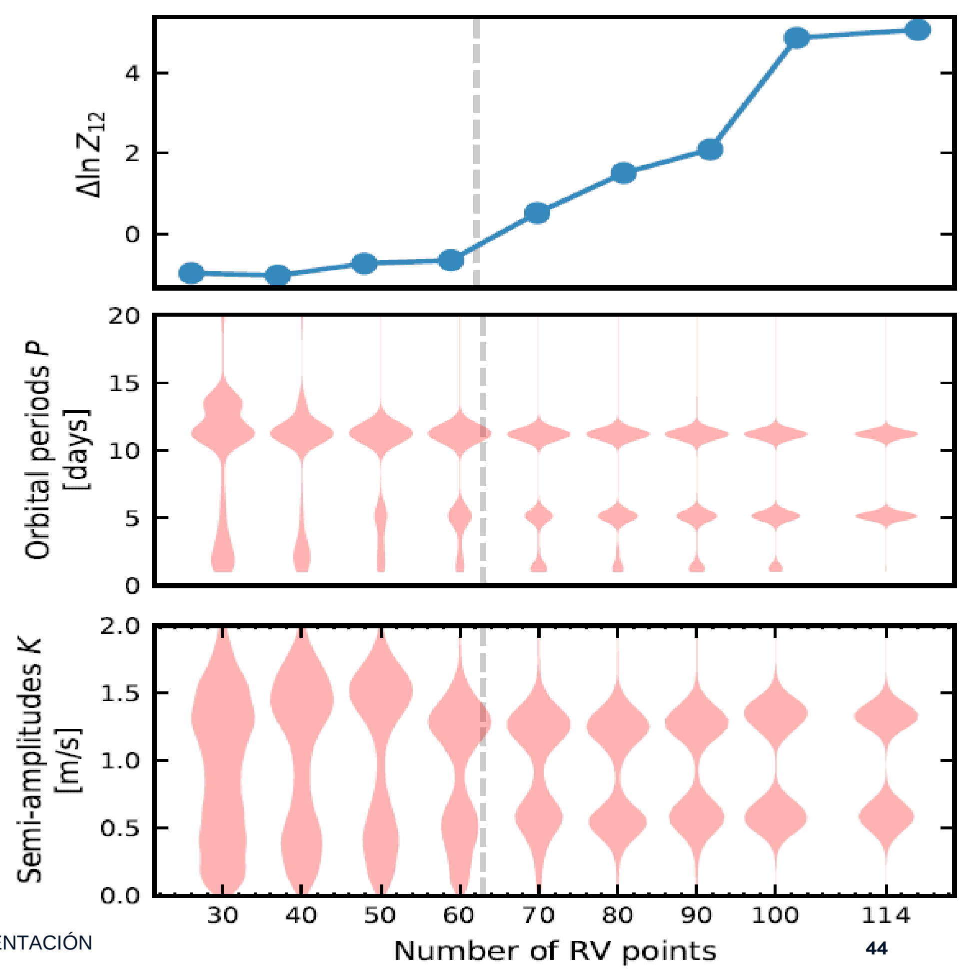
No significant signals in the residuals.



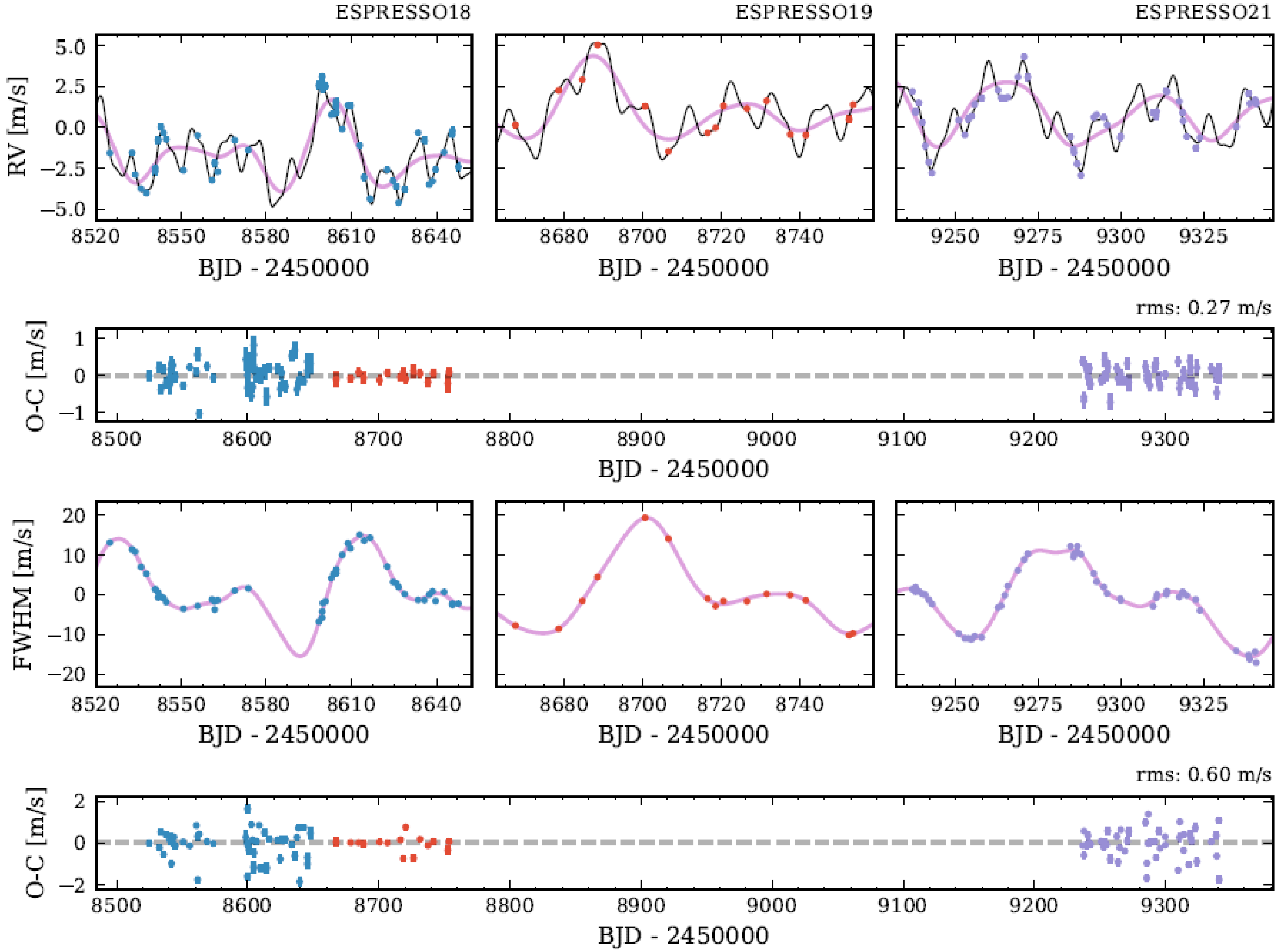
STABLE WITH THE NUMBER OF MEASUREMENTS

Planetary signals are expected to be stable with time.

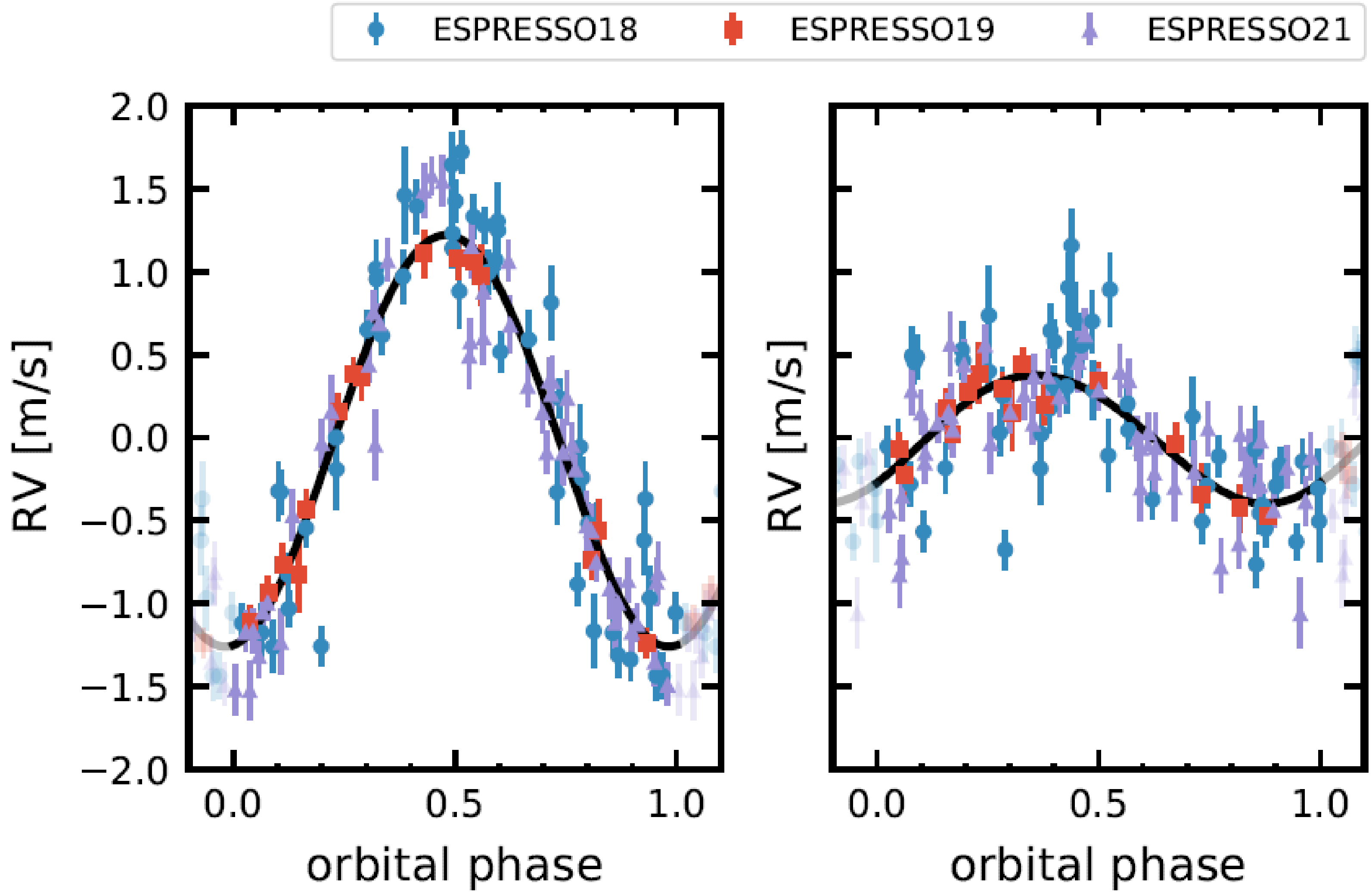
Activity signals are usually not stable with time.



ENTACIÓN

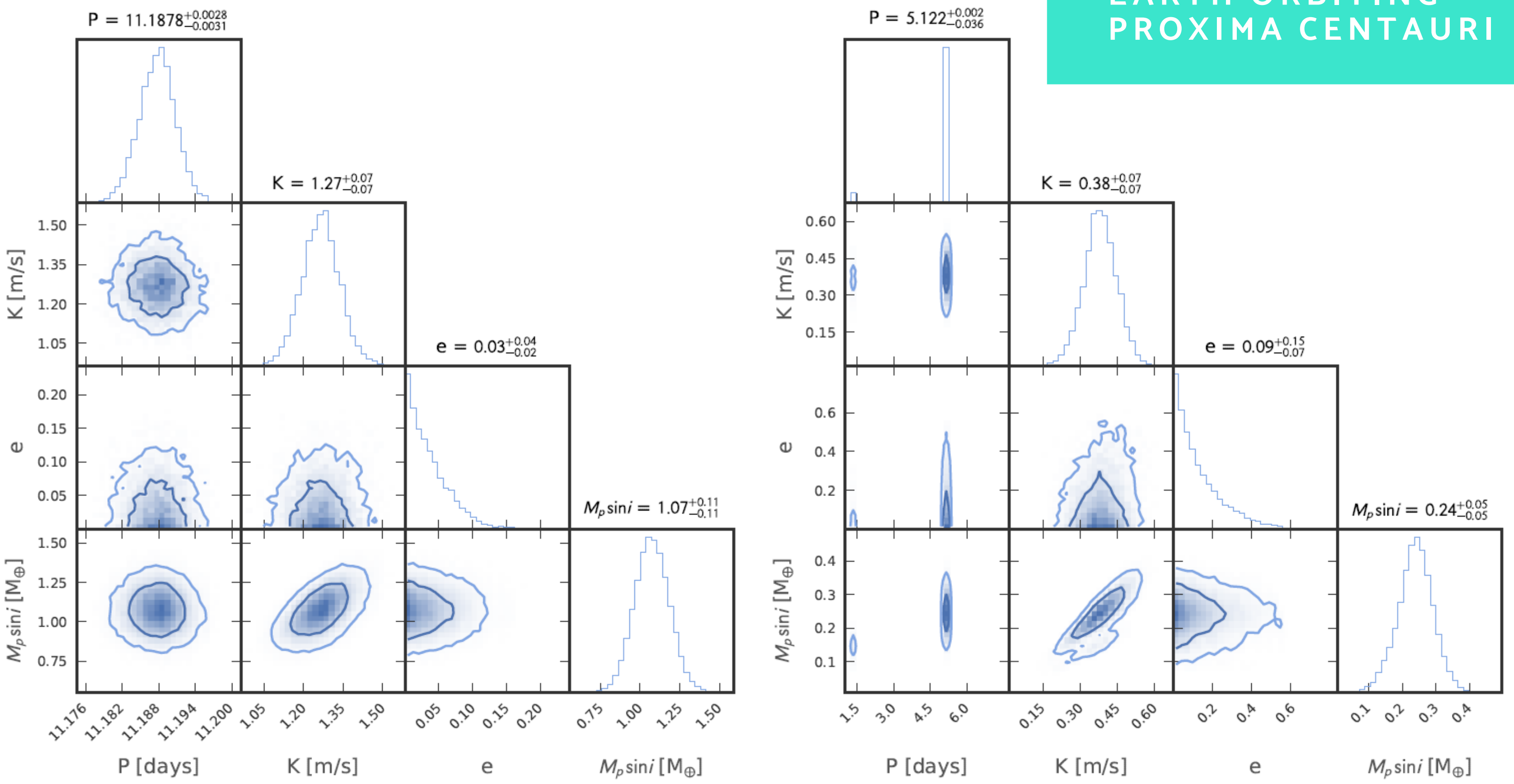


ESPRESSO18
ESPRESSO19
ESPRESSO21
RV [m/s]
BJD - 2450000
rms: 0.27 m/s
O-C [m/s]
FWHM [m/s]
rms: 0.60 m/s



ESPRESSO18
ESPRESSO19
ESPRESSO21
RV [m/s]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0.0
0.5
1.0
orbital phase
RV [m/s]
0.0
0.5
1.0
orbital phase

A SHORT-PERIOD SUB-EARTH ORBITING PROXIMA CENTAURI



SUMMARY

Radial velocities

The RV technique is fairly straightforward to understand, but complicated to execute (for low mass planets)

Instrumentation

Obtaining precise RVs demands extreme instrumentation and exquisite knowledge of all their quirks and issues.

Stellar activity

Many stellar effects create RV variations which could lead to false positive detections (when mistaken for planets) or prevent detections (by increasing noise levels)

Proxima

The closest star to the sun ticks almost all the boxes for an ideal RV target. Activity is very nicely reproduced via GPs using the FWHM of the CCF as activity proxy.

Proxima d

Proxima d is a sub-Earth planet orbiting at a distance of 0.029 AU with a minimum mass of 1/4 of the mass of the Earth.

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