Revealing Nearby Earth-Mass and sub-Earth Mass Planets with ESPRESSO

Jonay I. González Hernández and the ESPRESSO consortium

Instituto de Astrofísica de Canarias

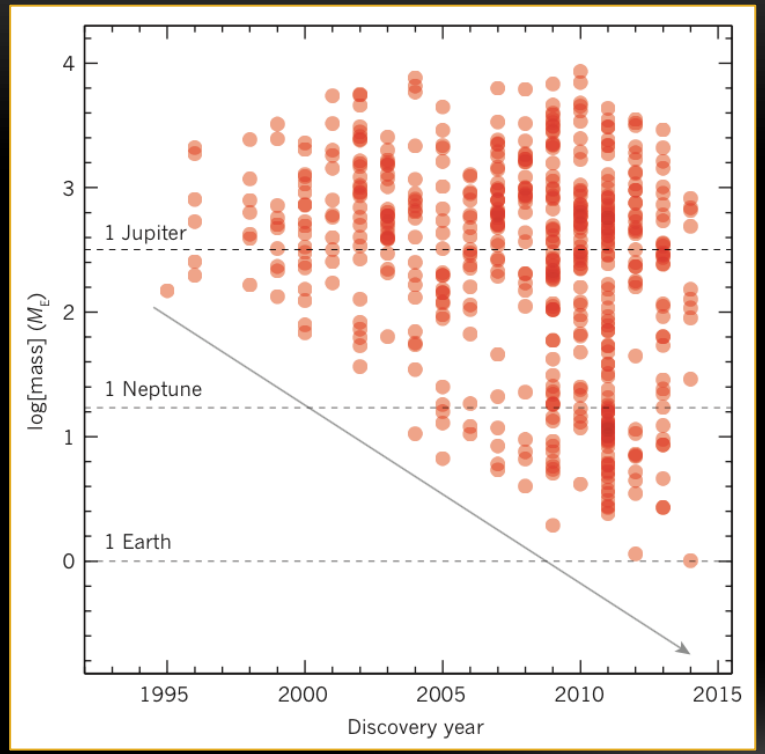
The XXXVIII Trobades de la Mediterrània:

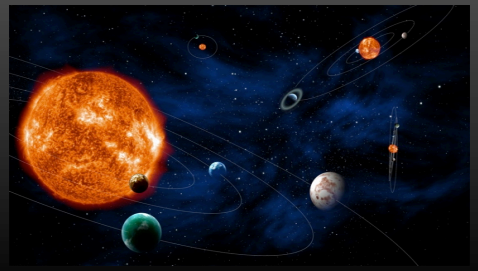
Life in the Universe, formation and evolution of the Solar System, and exoplanets

Institut Menorquí d'Estudis

Maó, Minorca, November 6, 2023

RV Detected Exoplanets

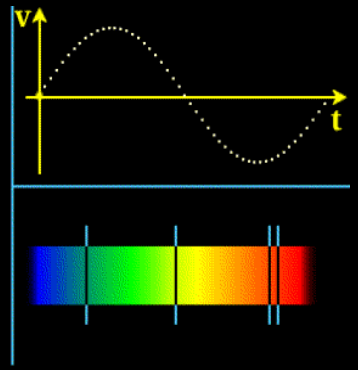




- RV precision from 15m/s in the 80s to 1m/s with HARPS from 2003
- With HARPS and HARPSN < 1 m/s
- With ESPRESSO

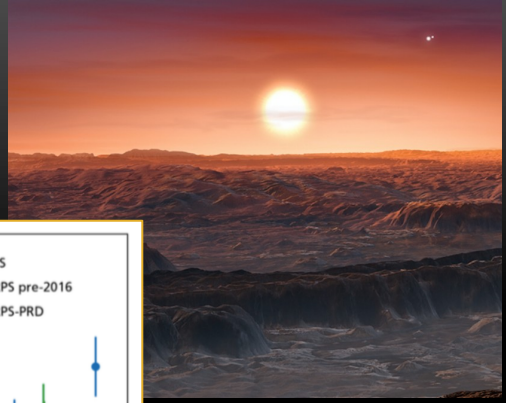
~ 10 cm/s

(~9cm/s 1yr Earth on Sun)

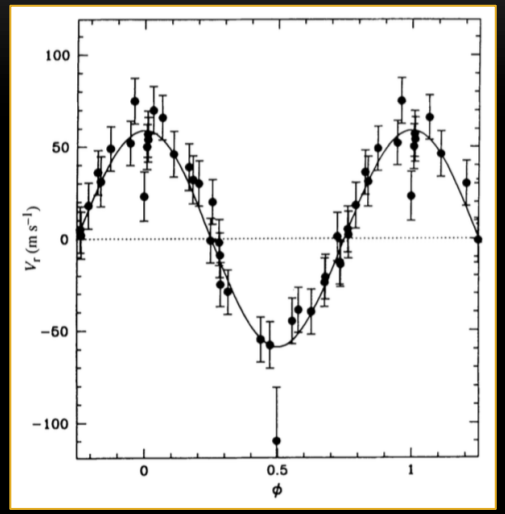


Mayor et al. (2014, Nature)

Search of Exo-Earths Orbiting Solar-Type Stars

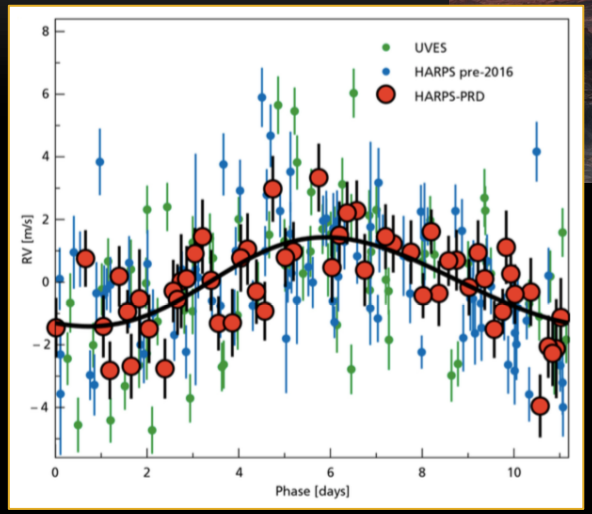


1995



RV Elodie@1.93m-OHP:
K~59 m/s P~4.2d $m_P$sini ~ 0.5 $M_{JUPITER}$
Mayor & Queloz (1995, Nature)

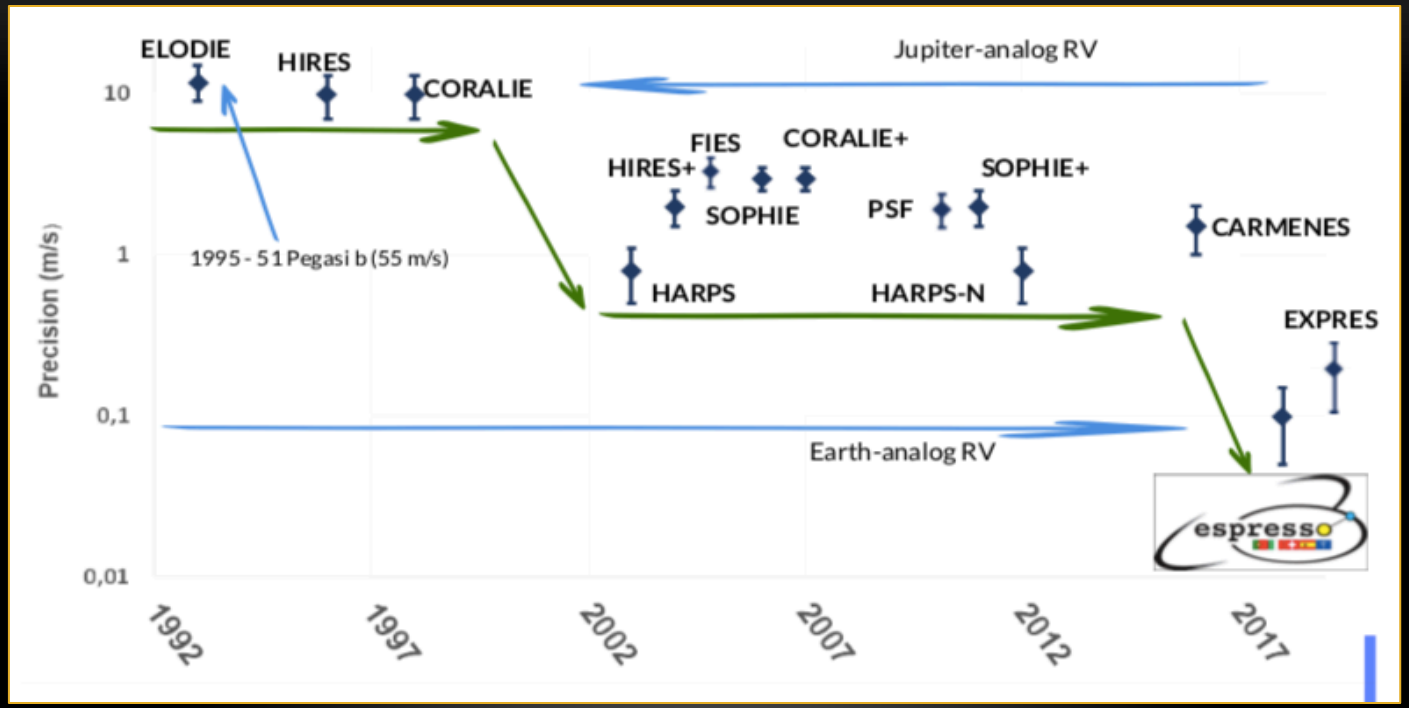
2016



RV HARPS@3.6m-ESO:
K~1.4 m/s P~11.2d $m_P$sini ~ 1.3 M_{EARTH}
Anglada-Escudé et al. (2016, Nature)

Nobel Prize in Physics 2019: Michel Mayor & Didier Queloz
"for the discovery of an exoplanet orbiting a solar type star"

Search for Exoplanets Orbiting Solar-Type Stars



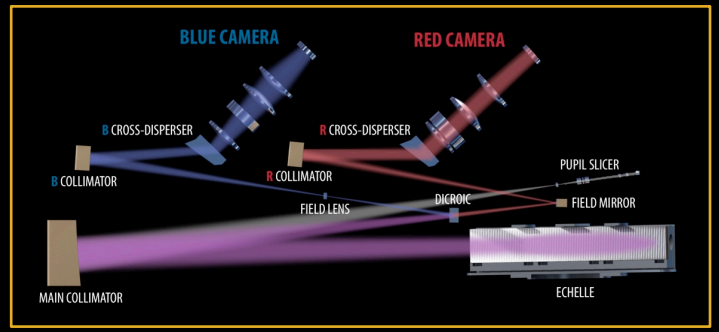
Funding + Engineering + Observing Facilities + Data Analysis Tools

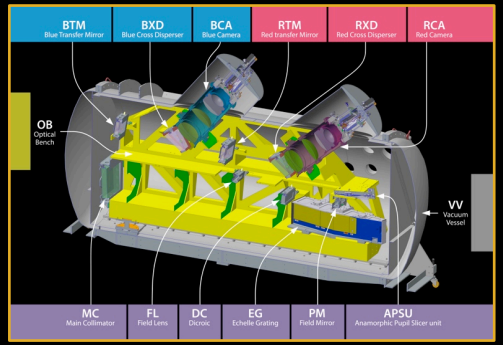
INSTRUMENTATION

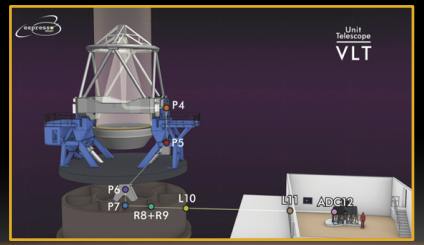
ESPRESSO @ 8.2m-VLT :

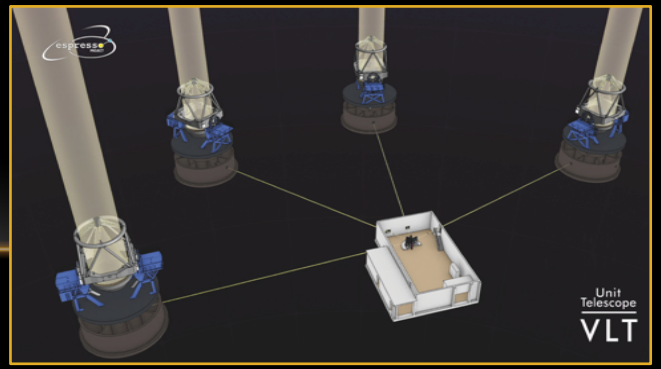
Ultra-Stable Spectrograph (0.38 – 0.78 μm)

IAC: Optical Bench, fiber link, optical elements and mounts







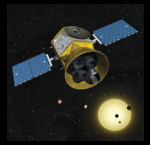


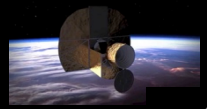
Pepe et al. (2014, AN); Pepe et al. (2021, A&A)

González Hernández et al. (2018, Handbook of Exoplanets)

Exo-Earths Orbiting GKM-type Stars

- Next space missions will produce many exoplanet transit candidates
  - JWST (2021)
  - TESS (2018)
  - CHEOPS (2019)
  - PLATO (2027?)





- These missions will only obtain unique results if complemented with ground-based facilities such as ESPRESSO, CARMENES, NIRPS, HARPS, HARPSN, HARPS3, ANDES, …

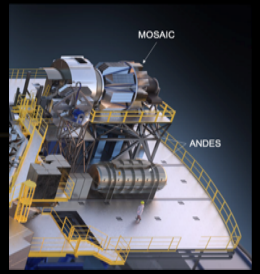
We need to concentrate efforts to search exo-Earths orbiting nearby bright dwarf stars of type GKM (10 pc / 33 ly)

INSTRUMENTATION : IAC PARTICIPATION IN ULTRA-STABLE HIGH-RESOLUTION SPECTROGRAPHS

- CARMENES @ 3.5m-CAHA (2015)
- ESPRESSO @ 8.2m-VLT (2018)

- NIRPS @ 3.6m-ESO (2023)
- HARPS3 @ 2.5m-INT (2025?)

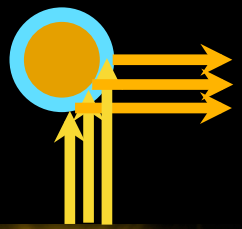
- CHORUS @ 10.4m-GTC (2028?)



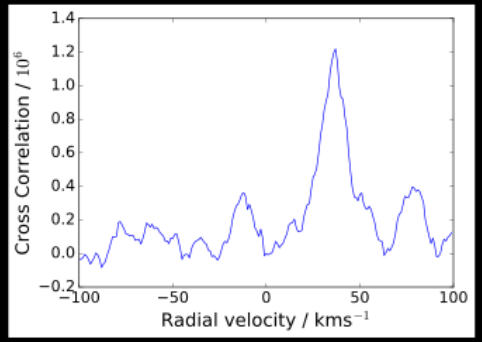
- ANDES @ 39m-ELT (2031?)

Exo-Earths Atmospheres : signatures of life

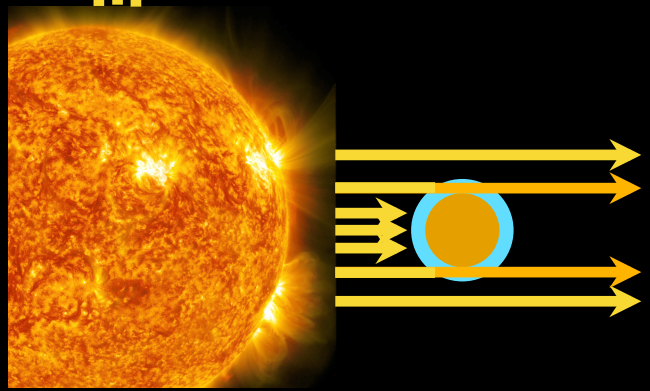
- Use high-resolution spectroscopy to disentangle the planetary and stellar spectra by comparing the combined spectrum to a star-only reference spectrum aided by the radial velocity offset (e.g. Snellen+15, Lovis et al. 2017)



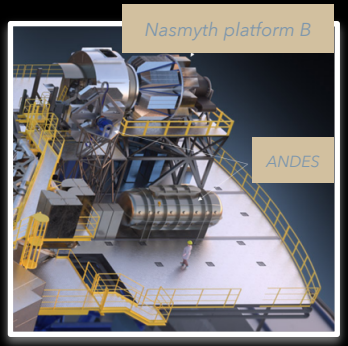
* In reflected light
Example: Proxima b
ANDES can detect planet in 7 nights at 8 sigma level



CCF with the detection of Proxima b in O_2 in 70h
Hawker & Parry (2019)



* In transmitted light
Example: Trappist 1 planets:
ANDES can detect:
- H_2O (1.3-1.7 μm) in 2 transits
- H_2O (0.9-1.1 μm) in 4 transits
- CO_2 in 4 transits
- O_2 in 25 transits

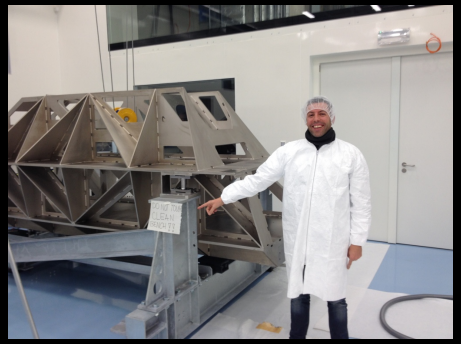


Marconi et al. (2021, The Messenger; 2022, SPIE)

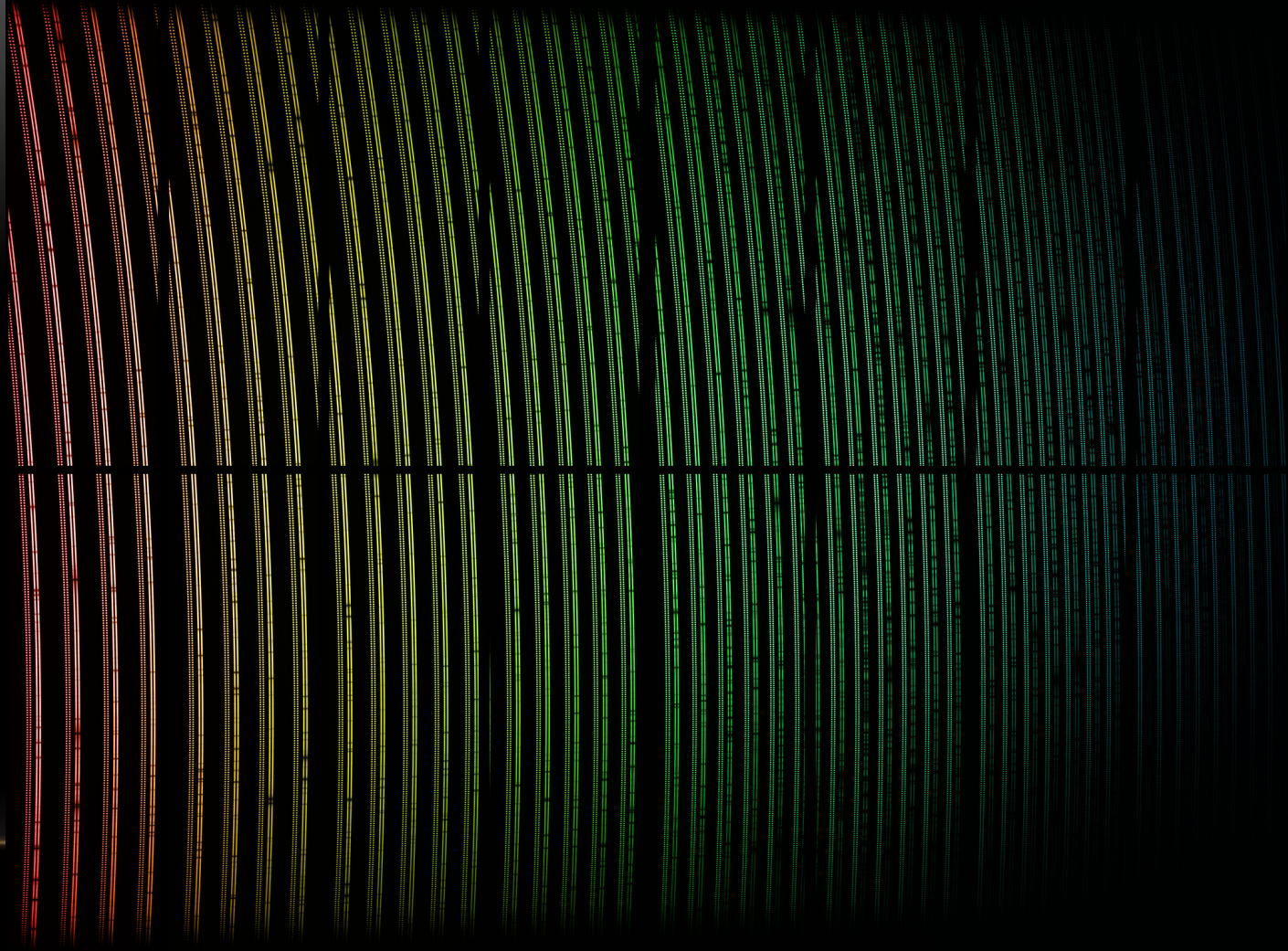
https://elt.eso.org/instrument/ANDES/

ESPRESSO

(**E**chelle **SP**ectrograph for **R**ocky **E**xoplanets and **S**table **S**pectroscopic **O**bservations)



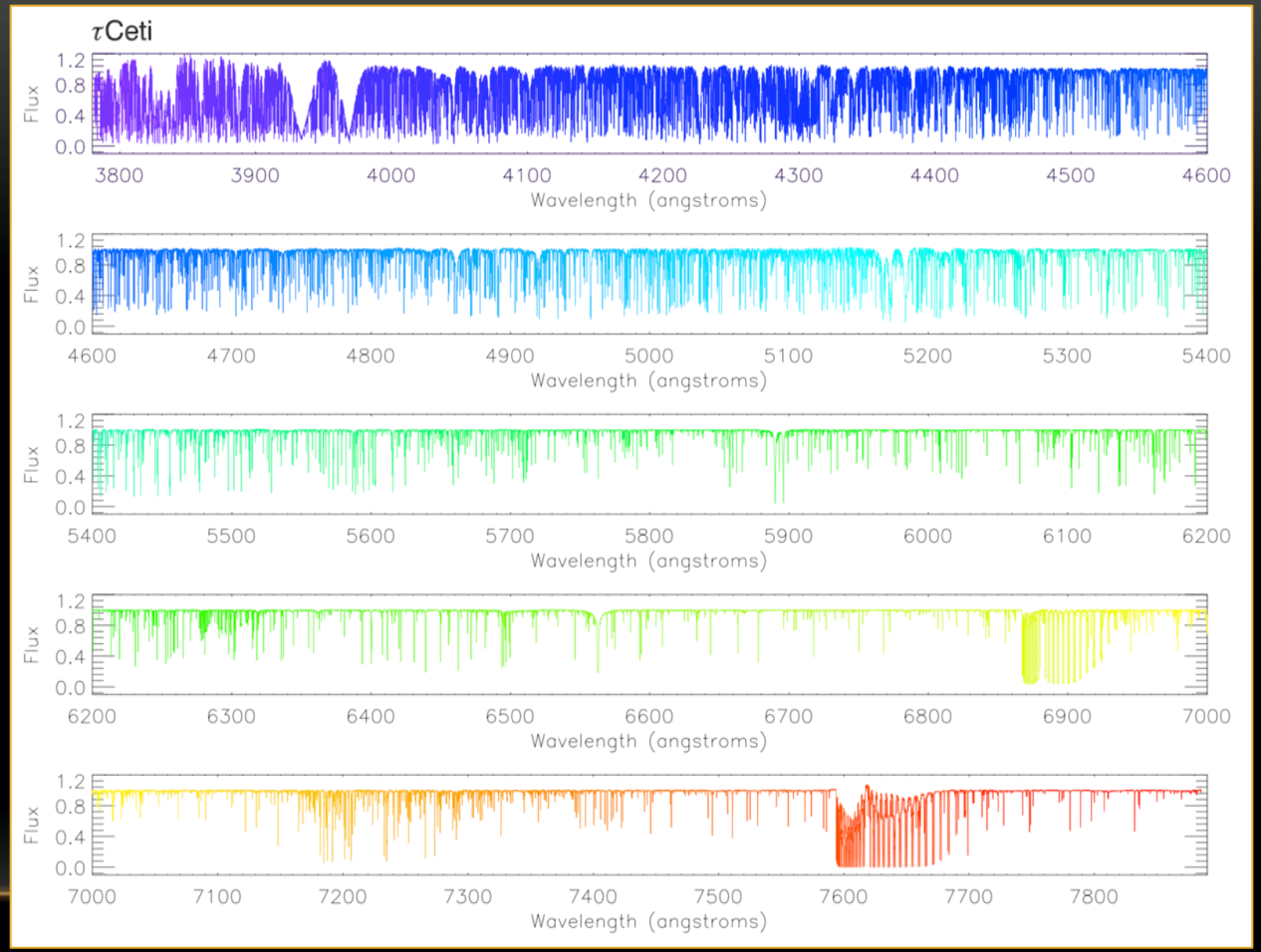
January 2016



ESPRESSO

(**E**chelle **SP**ectrograph for **R**ocky **E**xoplanets and **S**table **S**pectroscopic **O**bservations)

July 2016



DRS + DAS

Pepe et al. (2021, A&A)

ESPRESSO

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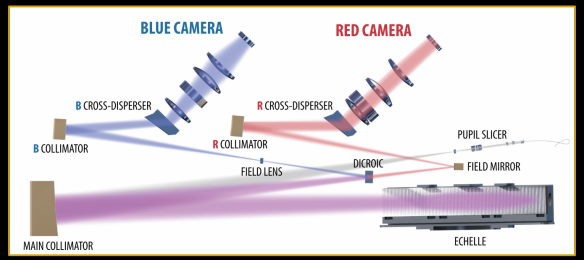

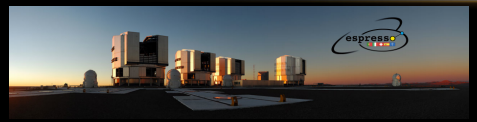

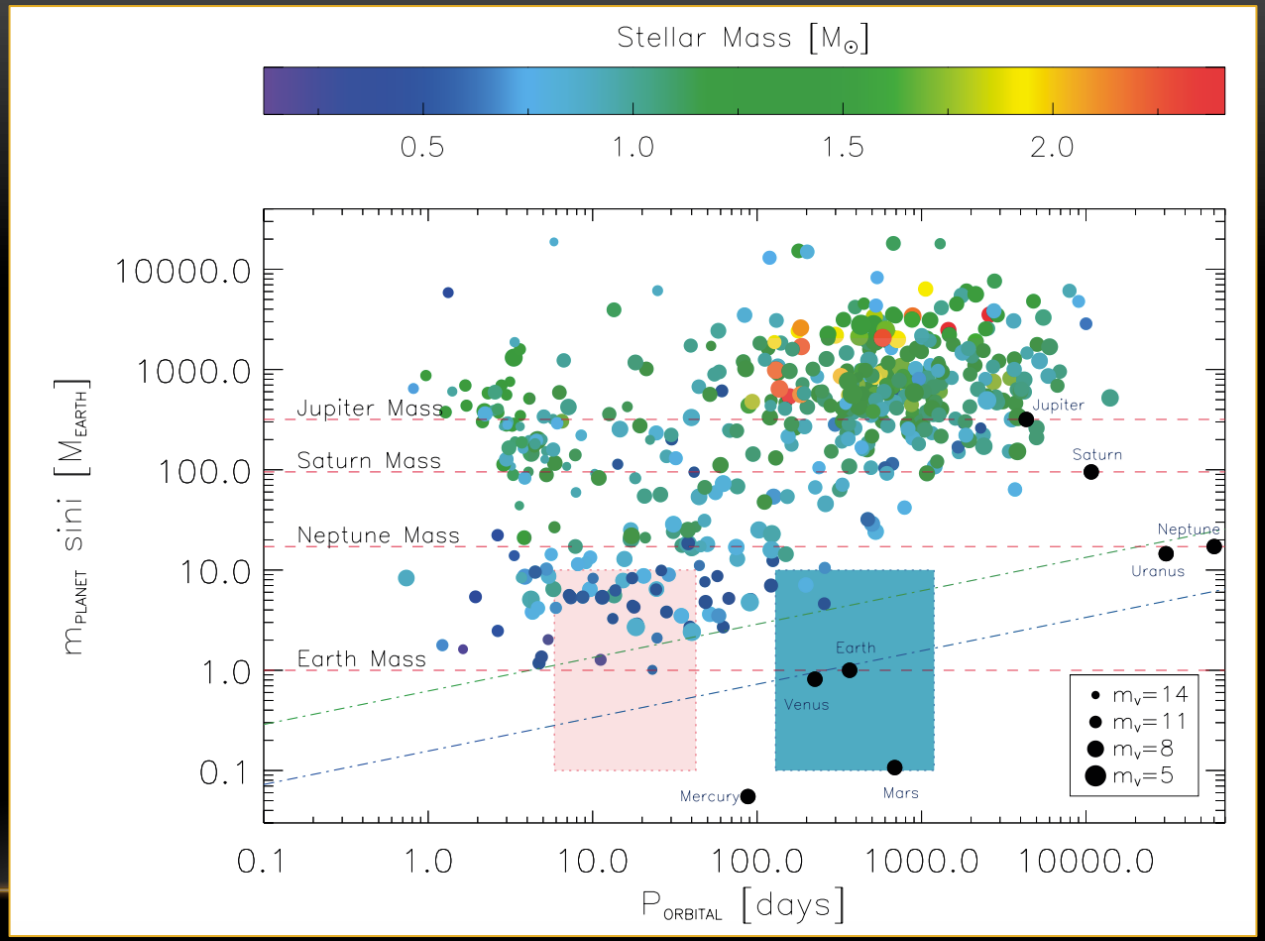

González Hernández et al. (2018, Handbook of Exoplanets)

Density of super-earths in solar-type star : K2-38b,c

ESPRESSO

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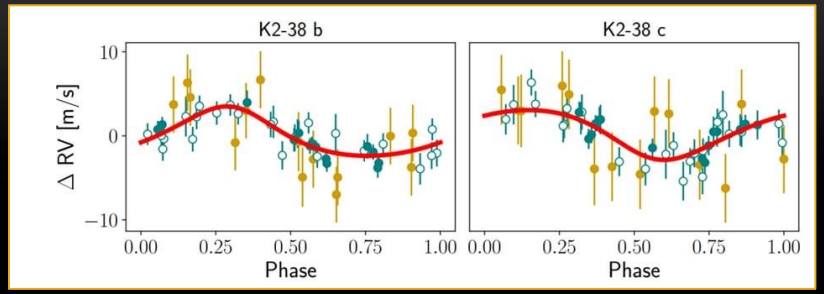
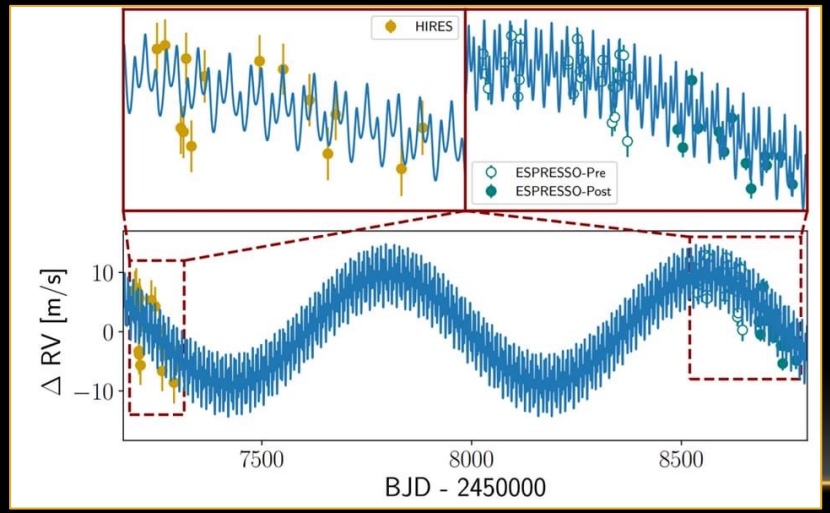
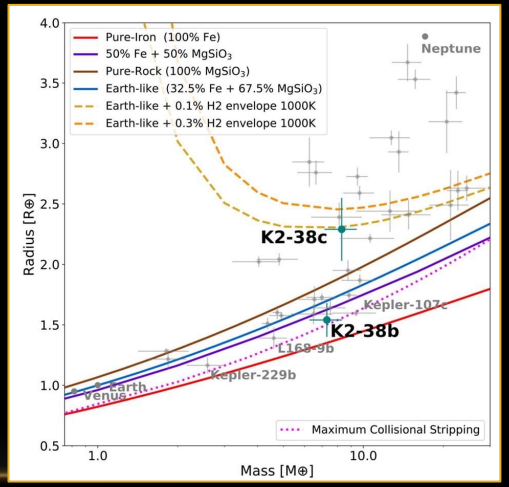




$m_c \sim 8.3\ M_{EARTH}$
$R_c \sim 2.3\ R_{EARTH}$
$\rho_c \sim 0.69\ \rho_{EARTH}$

$m_b \sim 7.3\ M_{EARTH}$
$R_b \sim 1.5\ R_{EARTH}$
$\rho_b \sim 2.0\ \rho_{EARTH}$

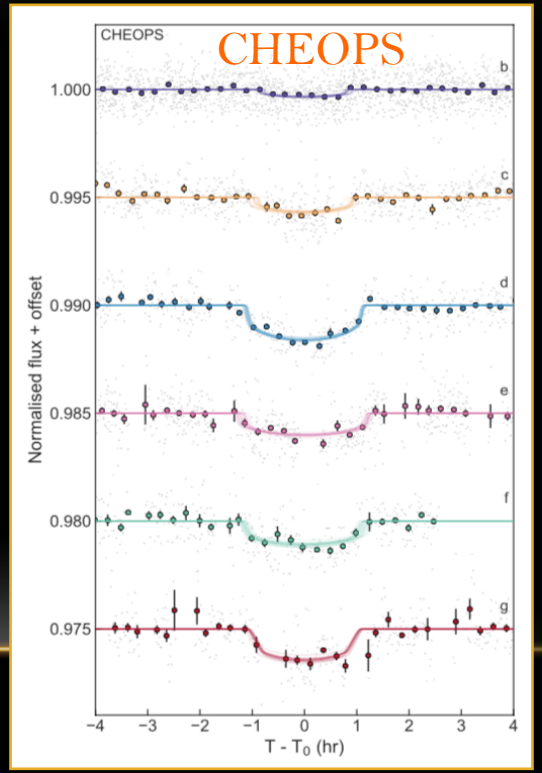


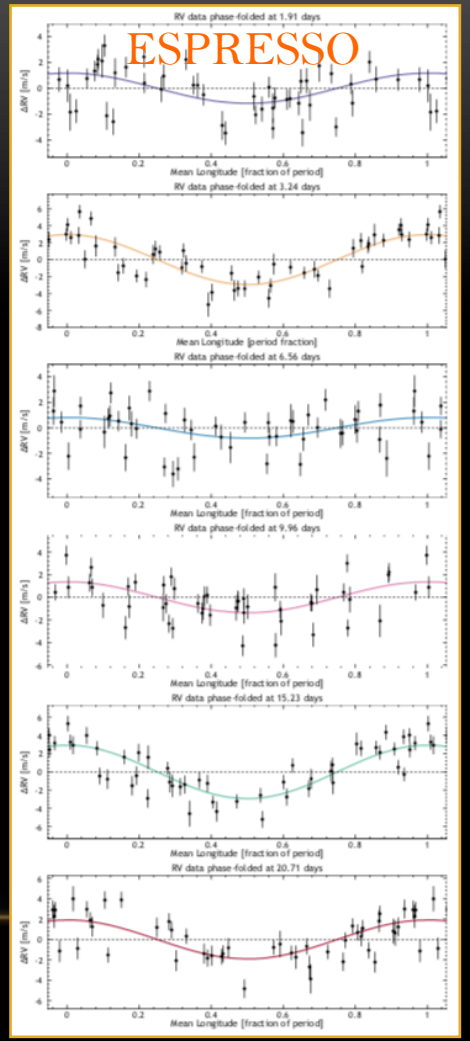
$\rho_{EARTH} \sim 5.5\ g\ cm^{-3}$

Toledo-Padrón et al. (2020, A&A)

Planetary Systems Orbiting GKM-type Stars

- TOI-178 planetary system : TESS+CHEOPS+ESPRESSO



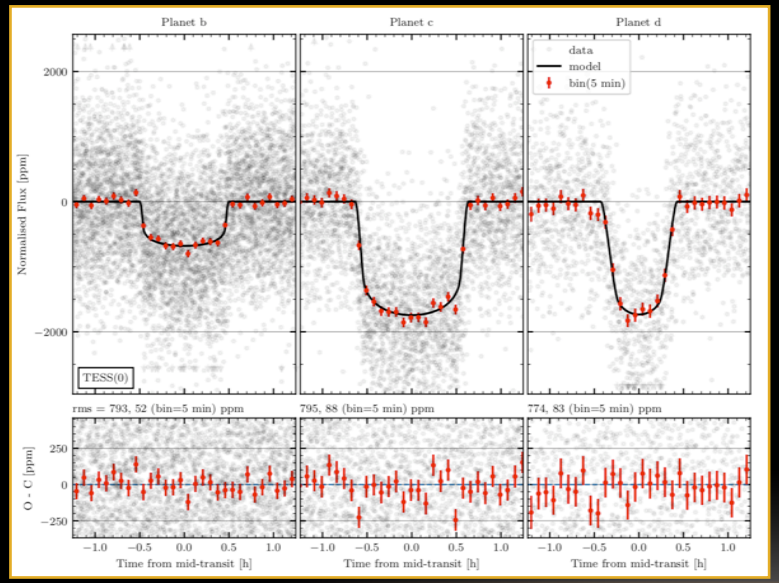


Leleu et al. (2021, A&A)

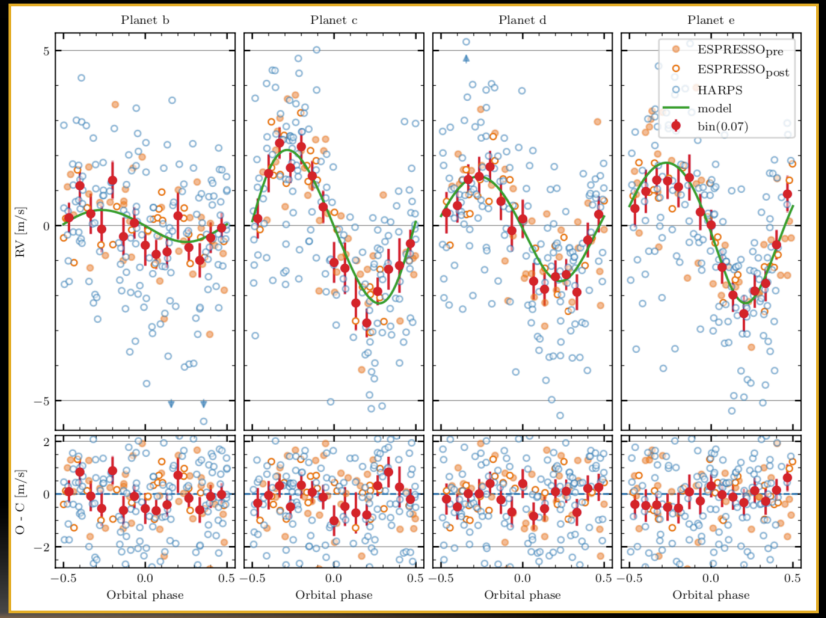
Planetary Systems Orbiting GKM-type Stars

- L98-59 (TOI-175) planetary system : TESS+ESPRESSO

TESS



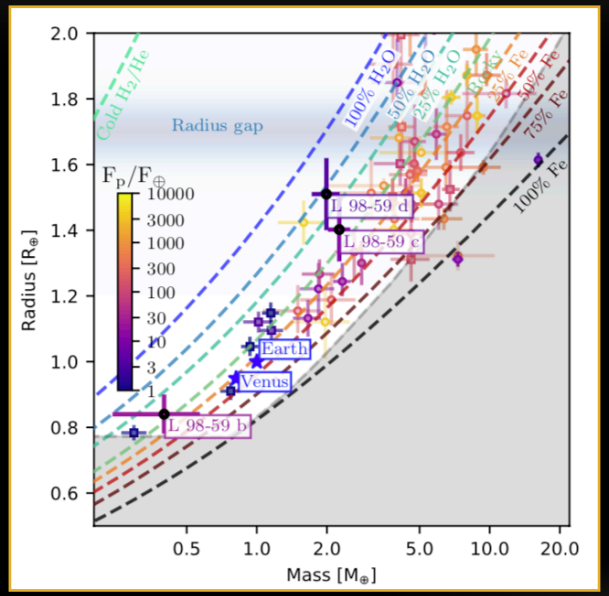
ESPRESSO



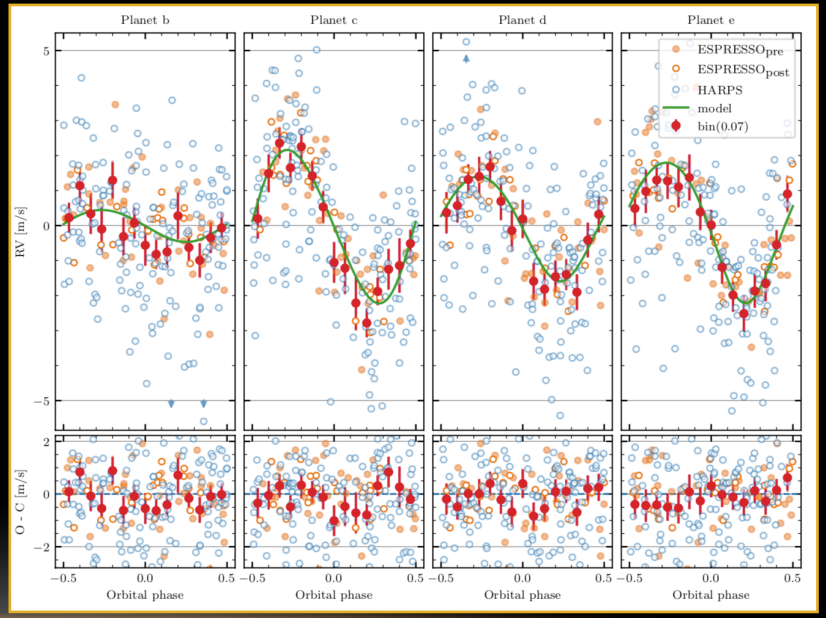
Demangeon et al. (2021, A&A)

Planetary Systems Orbiting GKM-type Stars

- L98-59 (TOI-175) planetary system : TESS+ESPRESSO



ESPRESSO



$m_b \sim 0.40\ M_{EARTH}$

$R_b \sim 0.85\ R_{EARTH}$

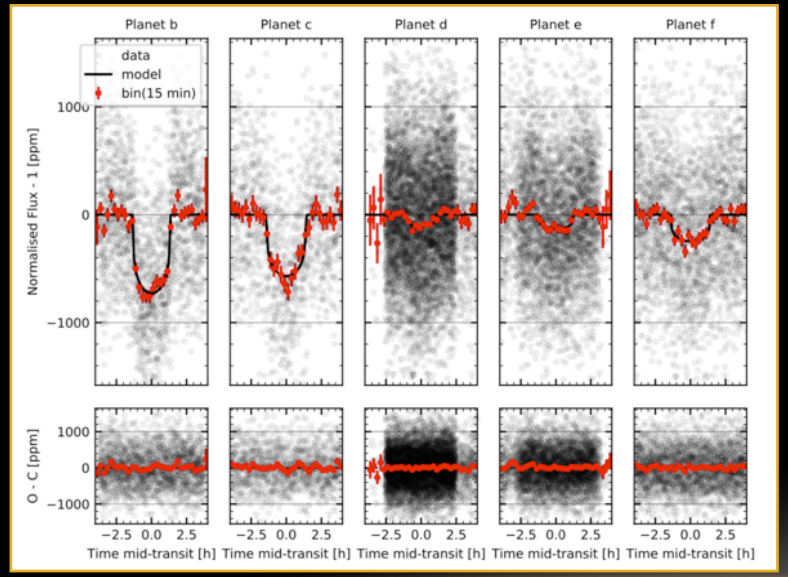
$\rho_b \sim 0.65\ \rho_{EARTH}$

Demangeon et al. (2021, A&A)

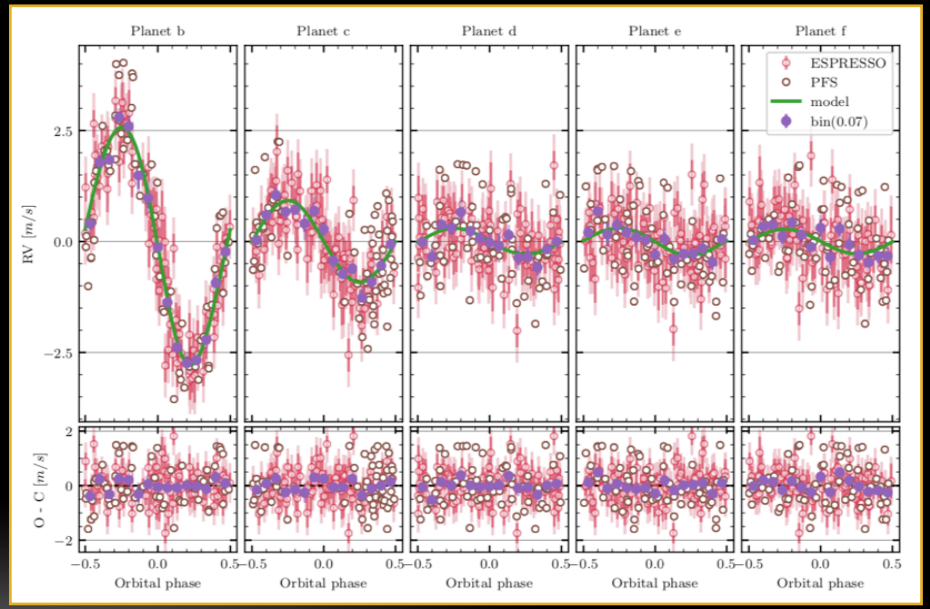
Planetary Systems Orbiting GKM-type Stars

- HD23472 (TOI-174) planetary system : TESS+ESPRESSO

TESS



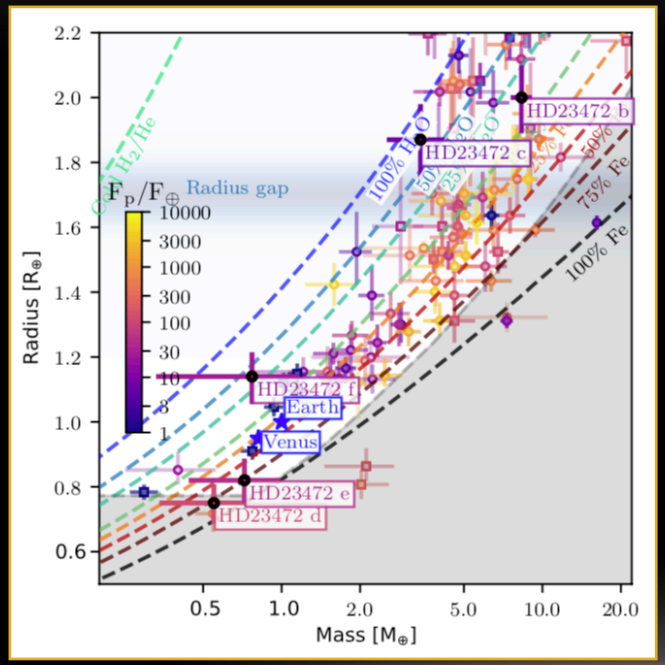
ESPRESSO



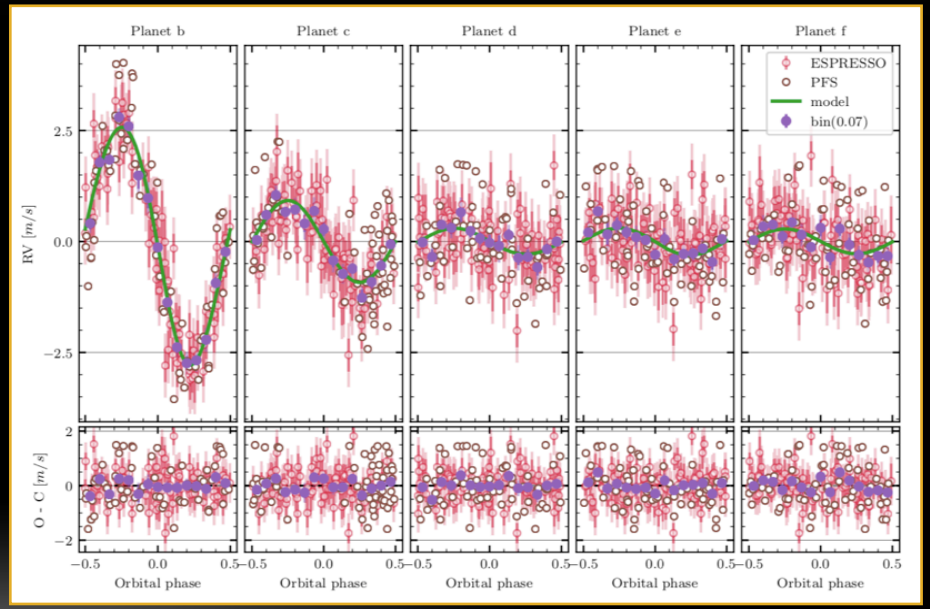
Barros et al. (2022, A&A)

Planetary Systems Orbiting GKM-type Stars

- HD23472 (TOI-174) planetary system : TESS+ESPRESSO



ESPRESSO



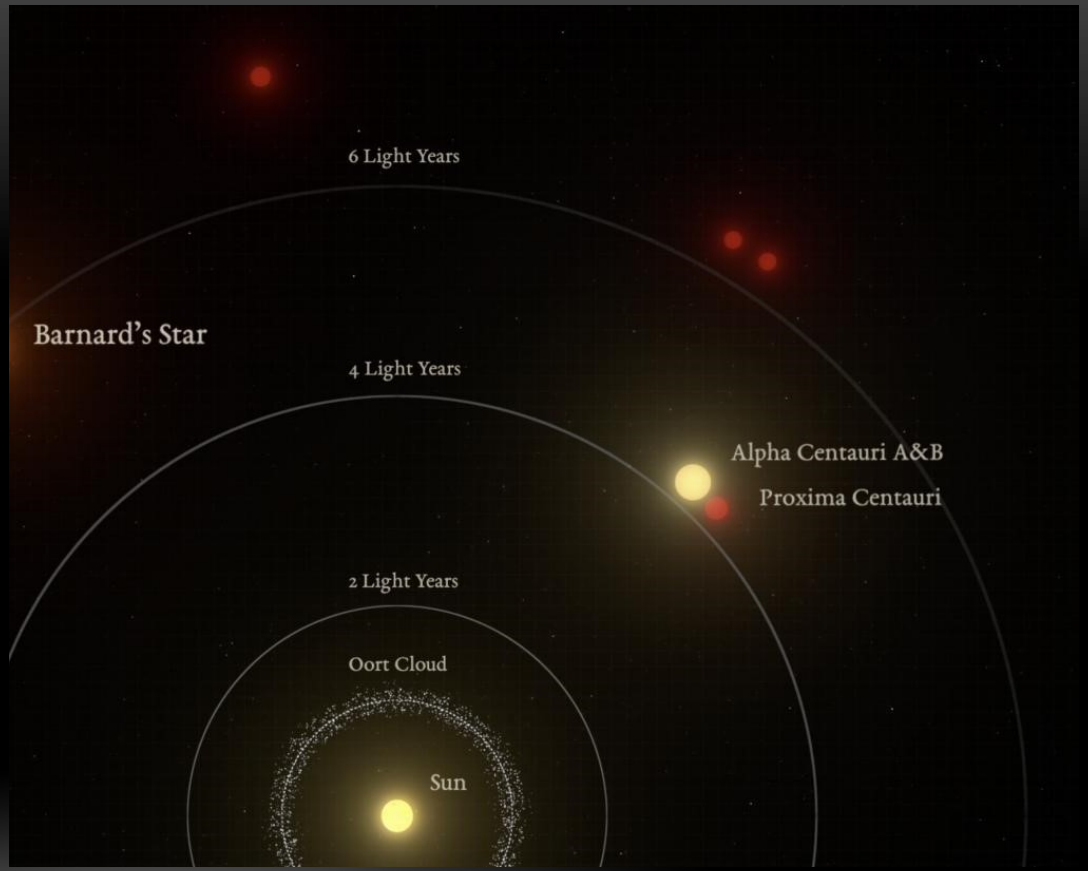
Planets b,c,f : super-Earths $\rho_{b,c,f} \sim 1.12, 0.54, 0.56\ \rho_{EARTH}$

Planets d,e : super-Mercuries $\rho_{d,e} \sim 1.36\ \rho_{EARTH}$

Barros et al. (2022, A&A)

Proxima Centauri

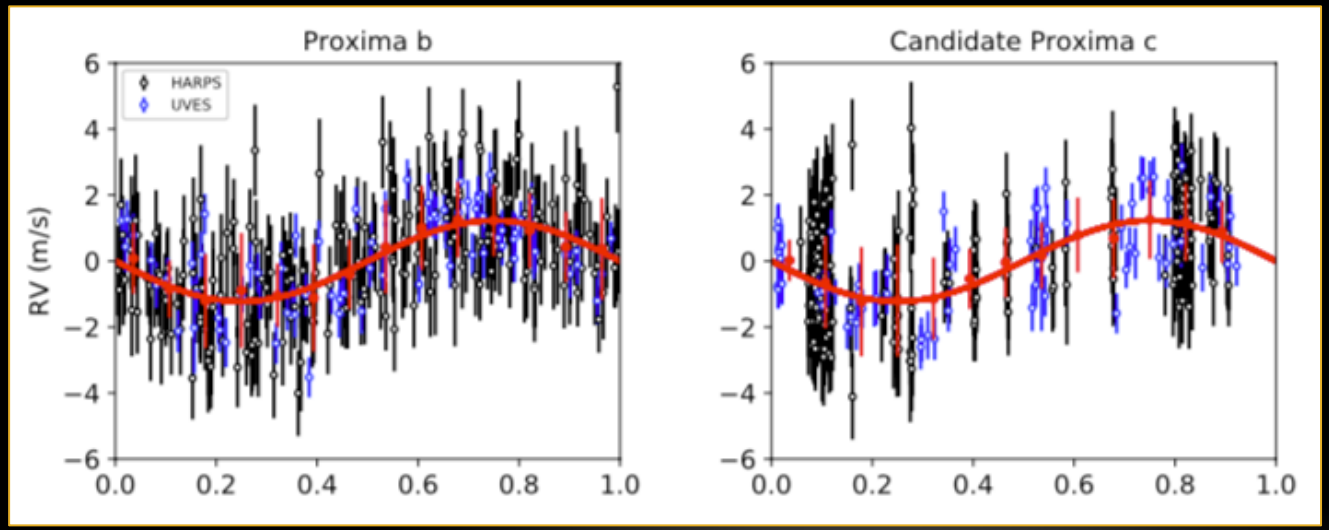
- Sp. Type: M5.5V
- Eff. Temperature: 2900 K
- Mass: 0.12 M_{Sun}
- Radius: 0.15 R_{Sun}
- Age: 4.9 Gyr
- Visual magnitude: 11.1
- Rotation ~83 days
- Cycle ~7 years

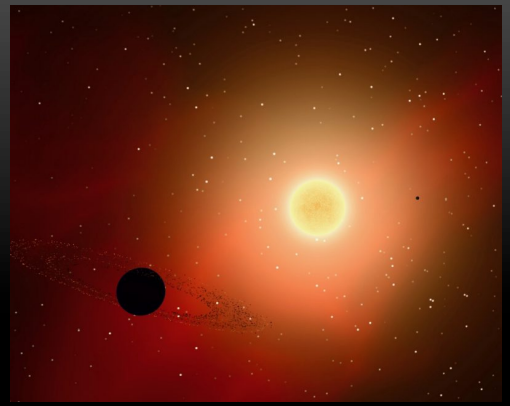


Proxima c

- 17 yr of HARPS + UVES data

5.2 yr period super-Earth candidate of ~6 M_{EARTH}



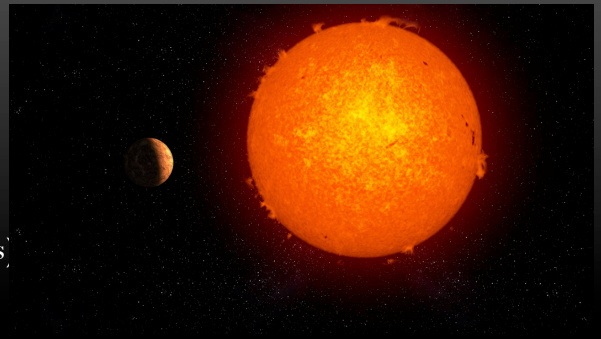


m_{Pc}~ 1.2 M_{EARTH}
P_{Pc}~ 11.2 d
a_{Pc}~ 0.05 AU
$T_{eq,Pc}$ ~ 234 K

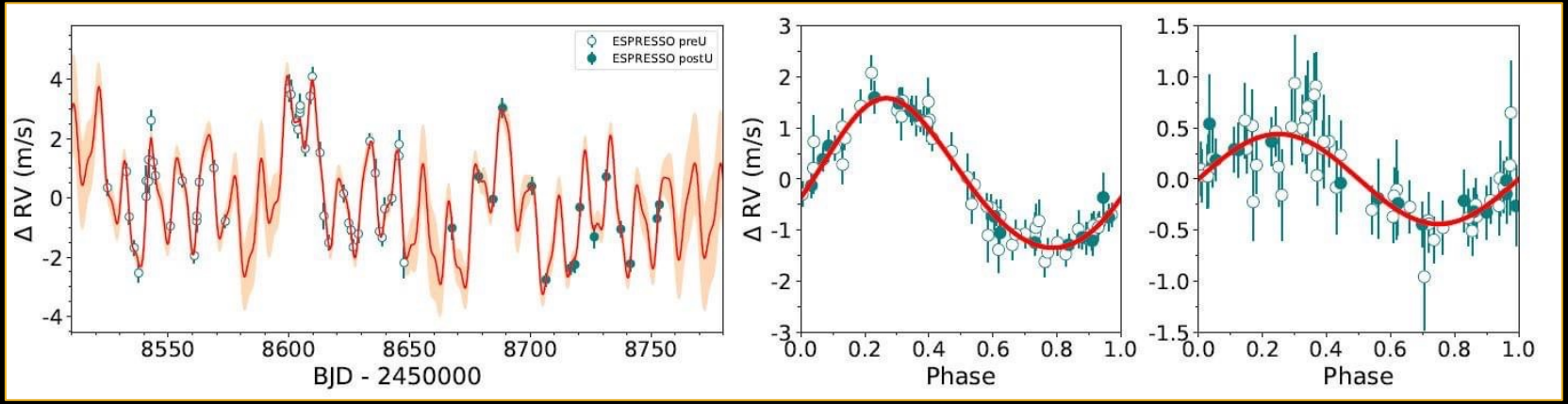
Damasso et al. (2020, Science)

PROXIMA b,d

ESPRESSO (**E**chelle **SP**ectrograph for **R**ocky **E**xoplanets and **S**table **S**pectroscopic **O**bservations)



11.2d period Exo-Earth of 1.1 M_{EARTH}



P_{ROT}~ 87.5 d
RMS_res ~ 0.27 m/s

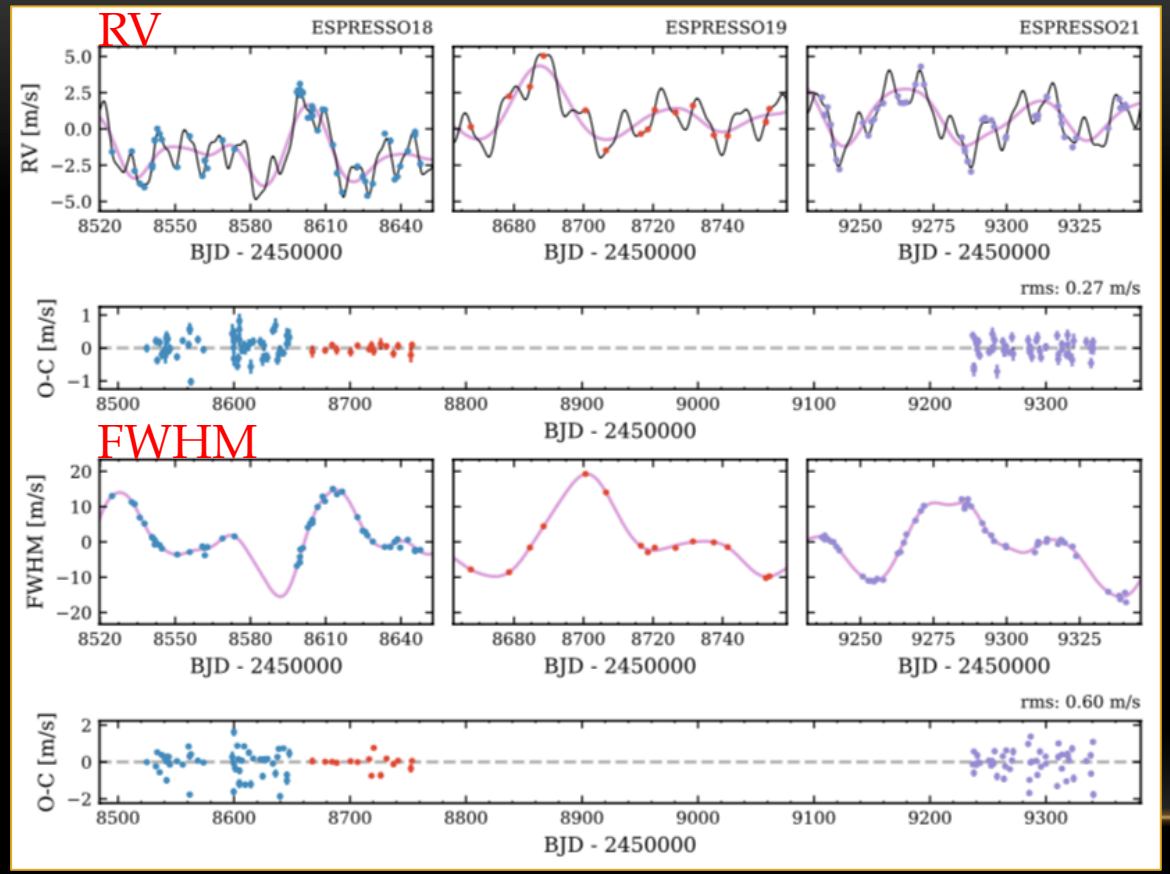
K_b ~ 1.37 m/s
K_c ~ 0.35 m/s

m_b~ 1.2 M_{EARTH}
P_b~ 11.2 d
a_b~ 0.05 AU
$T_{eq,b}$ ~ 234 K

m_d~ 0.4 M_{EARTH}
P_d~ 5.1 d
a_d~ 0.03 AU
$T_{eq,d}$ ~ 330 K

Suárez Mascareño et al. (2020, A&A)

Proxima b & Proxima d

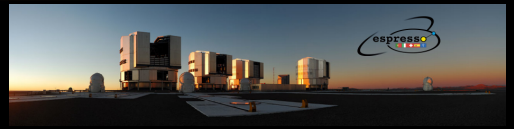


- A few months (114 RV epochs) of ESPRESSO observations over 2 yr

- Two planet model + activity model (GP):

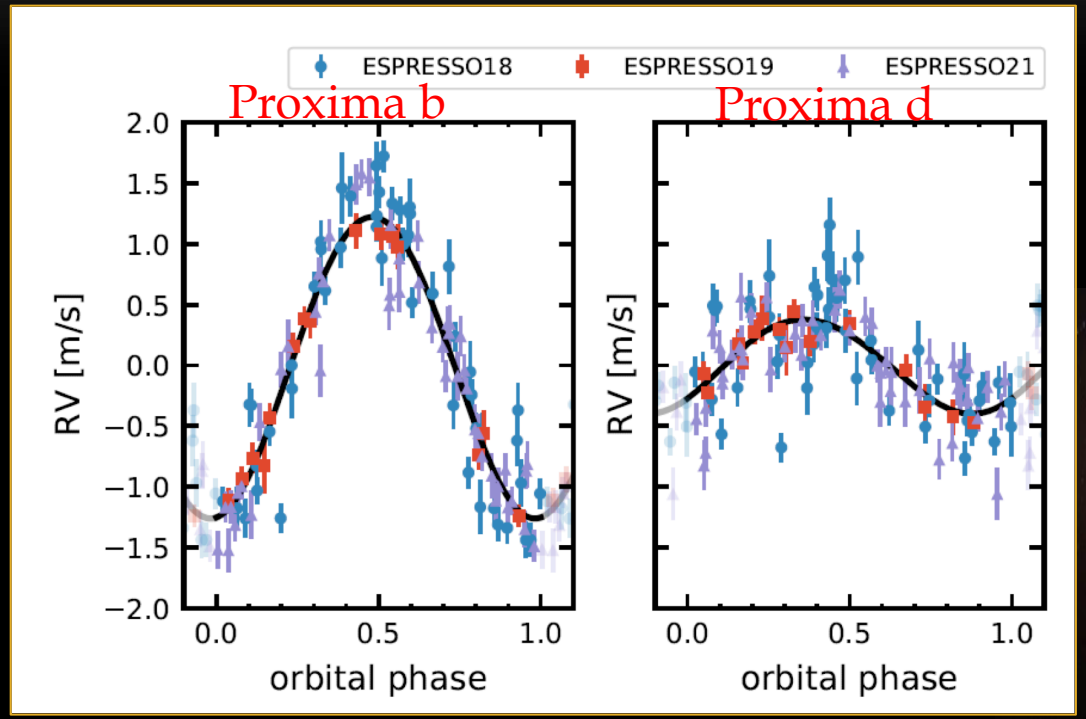
RVs + FWHM

- 11.2d Exo-Earth of 1.1 M_{EARTH}
- 5.1d sub-Earth of 0.26 M_{EARTH}



Faria et al. (2022, A&A)

Proxima b & Proxima d

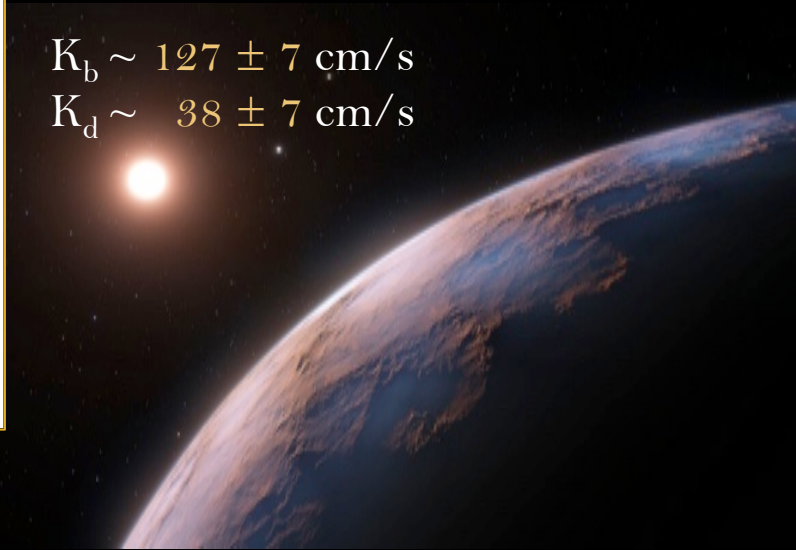


- 11.2d Exo-Earth of 1.1 M_{EARTH}
- 5.1d sub-Earth of 0.26 M_{EARTH}

The lightest exoplanet ever discovered with the RV technique

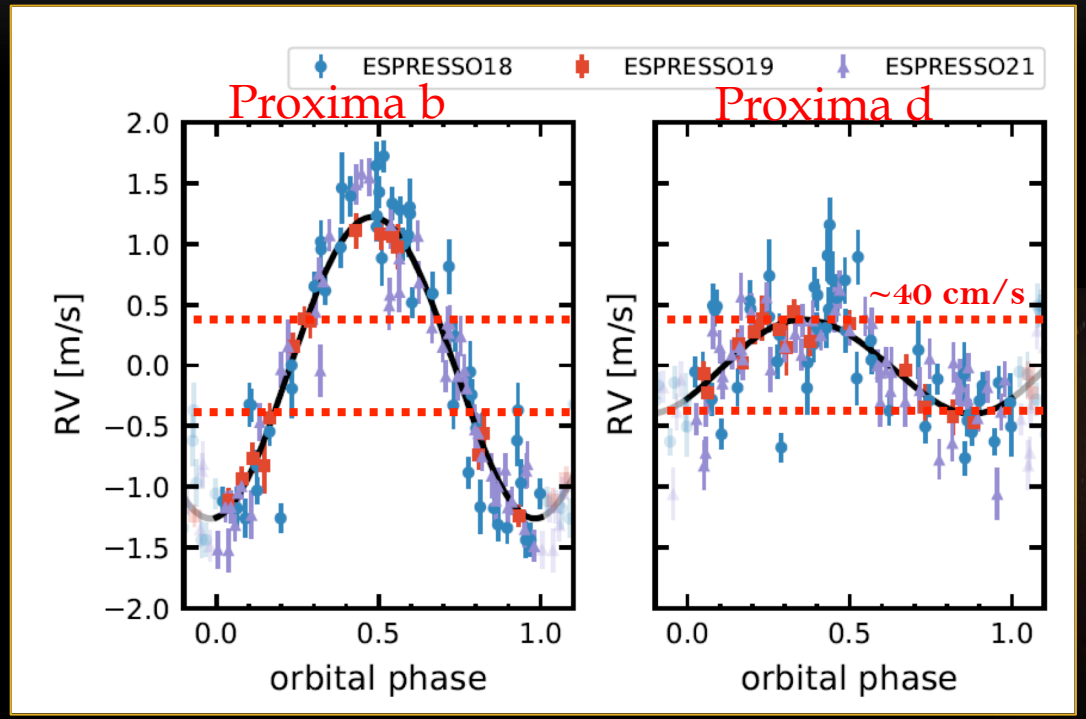
$K_b \sim 127 \pm 7$ cm/s

$K_d \sim 38 \pm 7$ cm/s



Faria et al. (2022, A&A)

Proxima b & Proxima d



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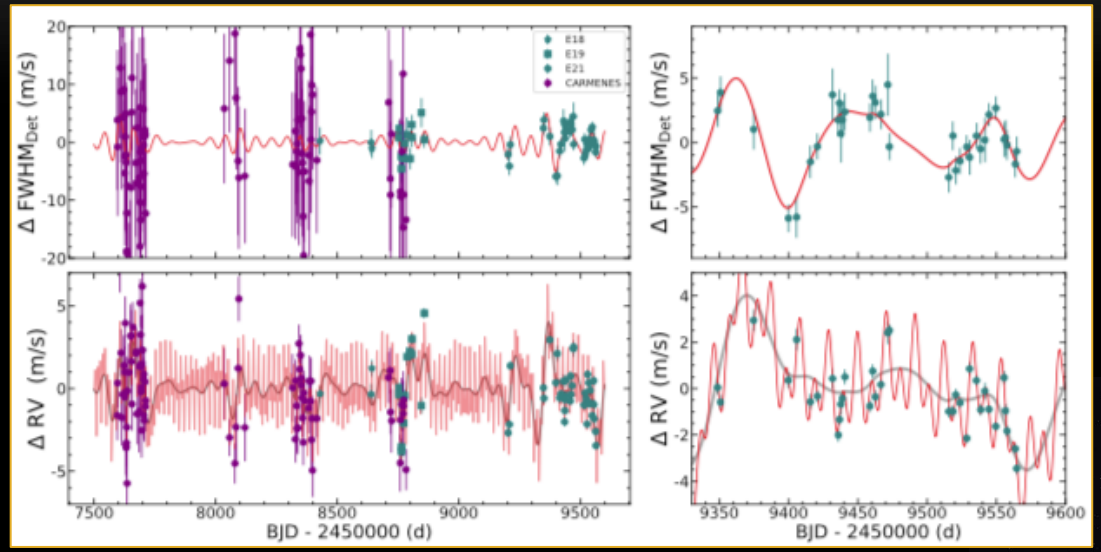
Faria et al. (2022, A&A)

GJ1002 b & GJ1002 c



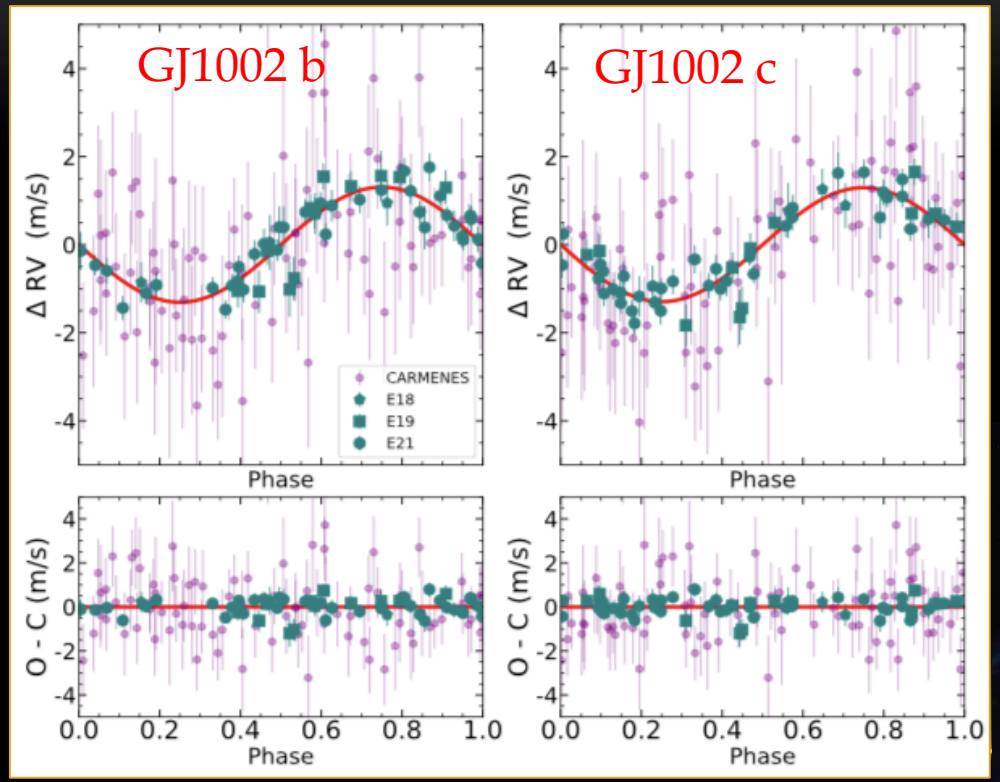
$P_b \sim 10.3$ d
$K_b \sim 1.31$ m/s
$m_b \sim 1.08\ M_{EARTH}$

$P_c \sim 21.2$ d
$K_c \sim 1.30$ m/s
$m_c \sim 1.36\ M_{EARTH}$

GJ 1002: faint M5.5V star (V~13.8, J~8.3)

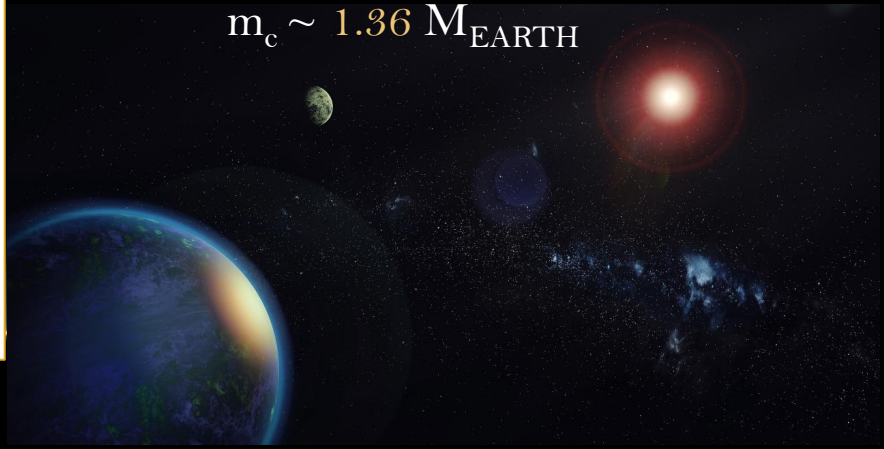
Suárez Mascareño et al. (2023, A&A)

GJ1002 b & GJ1002 c



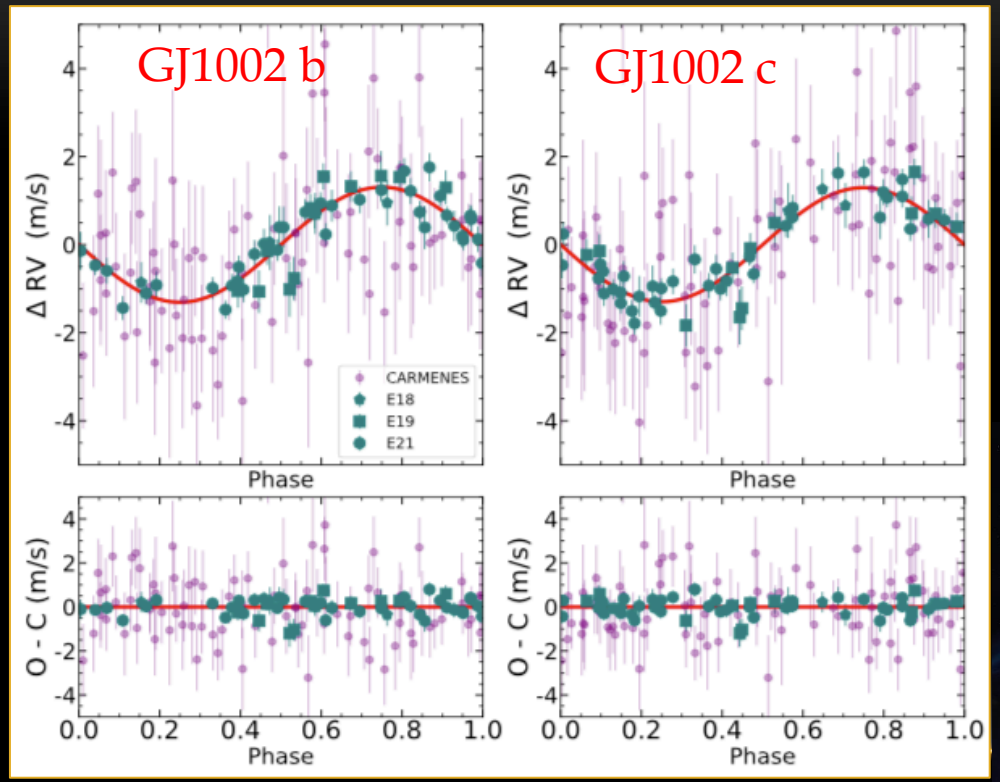
$P_b \sim 10.3$ d
$K_b \sim 1.31$ m/s
$m_b \sim 1.08\ M_{EARTH}$

$P_c \sim 21.2$ d
$K_c \sim 1.30$ m/s
$m_c \sim 1.36\ M_{EARTH}$



Suárez Mascareño et al. (2023, A&A)

GJ1002 b & GJ1002 c

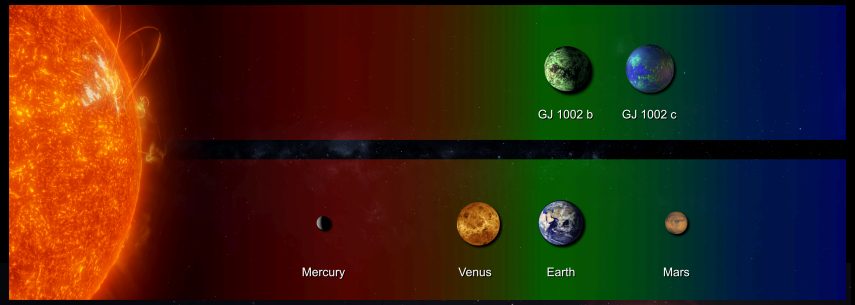


$T_{eq,b} \sim 231$ K

$m_b \sim 1.08\ M_{EARTH}$

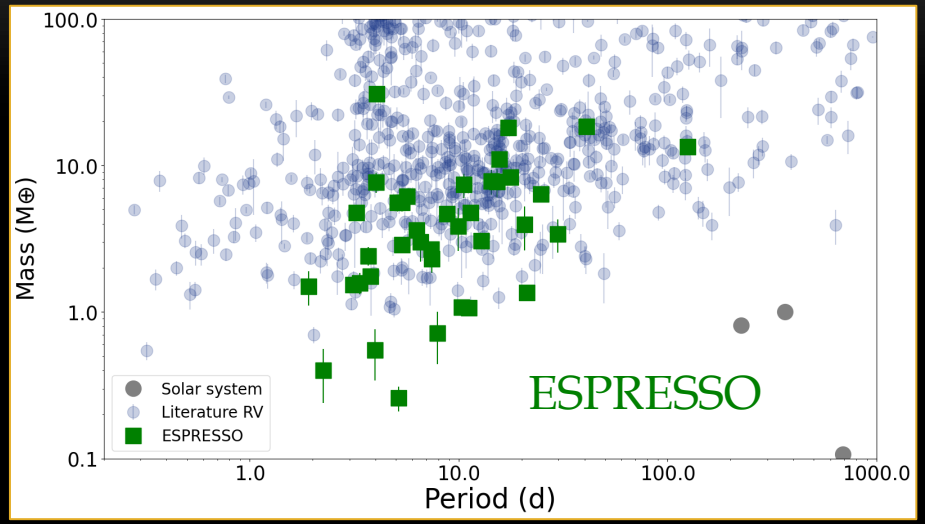
$T_{eq,c} \sim 182$ K

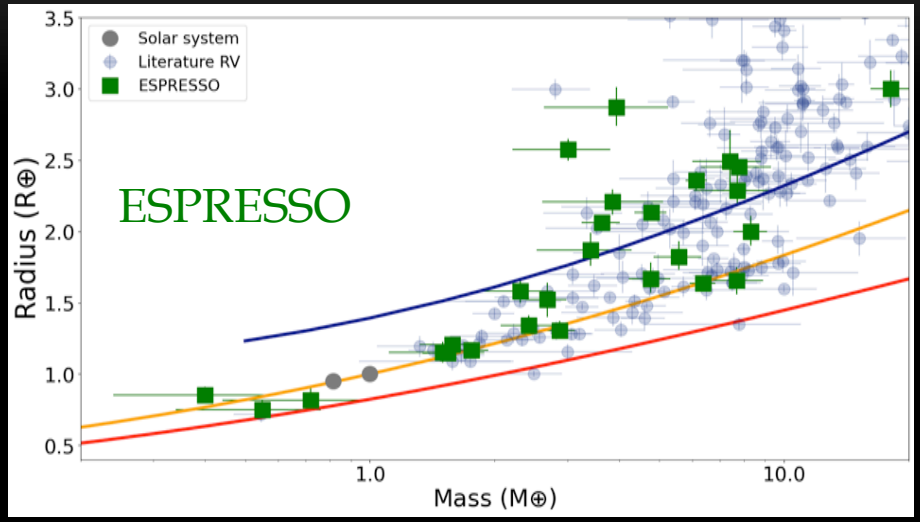
$m_c \sim 1.36\ M_{EARTH}$

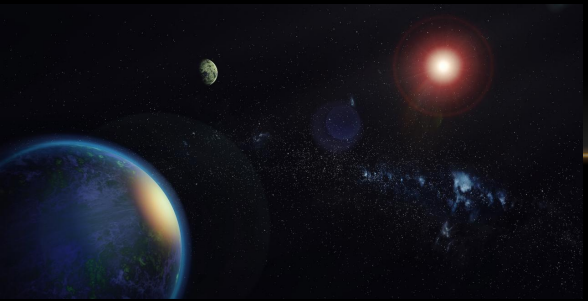


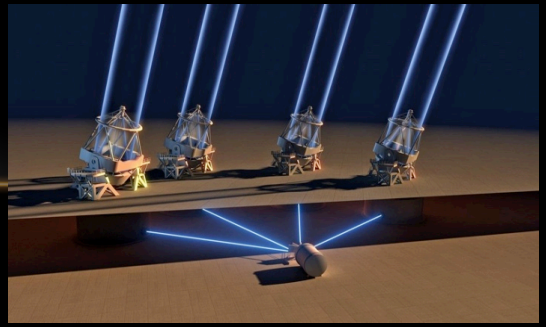
Suárez Mascareño et al. (2023, A&A)

ESPRESSO Results









CHORUS @ 10.4M-GTC

- Ultra-stable spectrograph for the GTC
  - UVS spectrograph (R~25k – 0.31 – 0.42 μm)
  - VIS spectrograph (R~100k – 0.42 – 0.78 μm)
  - Science cases:
    - Earth-like planets in the HZ of nearby star
    - Fundamental constants
    - Chemical evolution in the MW, and nearby Galaxies

P.I. : Jifeng Liu

First light 2028?

Credit: Pablo Bonet / IAC

Zhang et al. (2020, SPIE)

Revealing Nearby Earth-Mass and sub-Earth Mass Planets with ESPRESSO

Jonay I. González Hernández and the ESPRESSO consortium

Instituto de Astrofísica de Canarias

The XXXVIII Trobades de la Mediterrània:

Life in the Universe, formation and evolution of the Solar System, and exoplanets

Institut Menorquí d'Estudis

Maó, Minorca, November 6, 2023