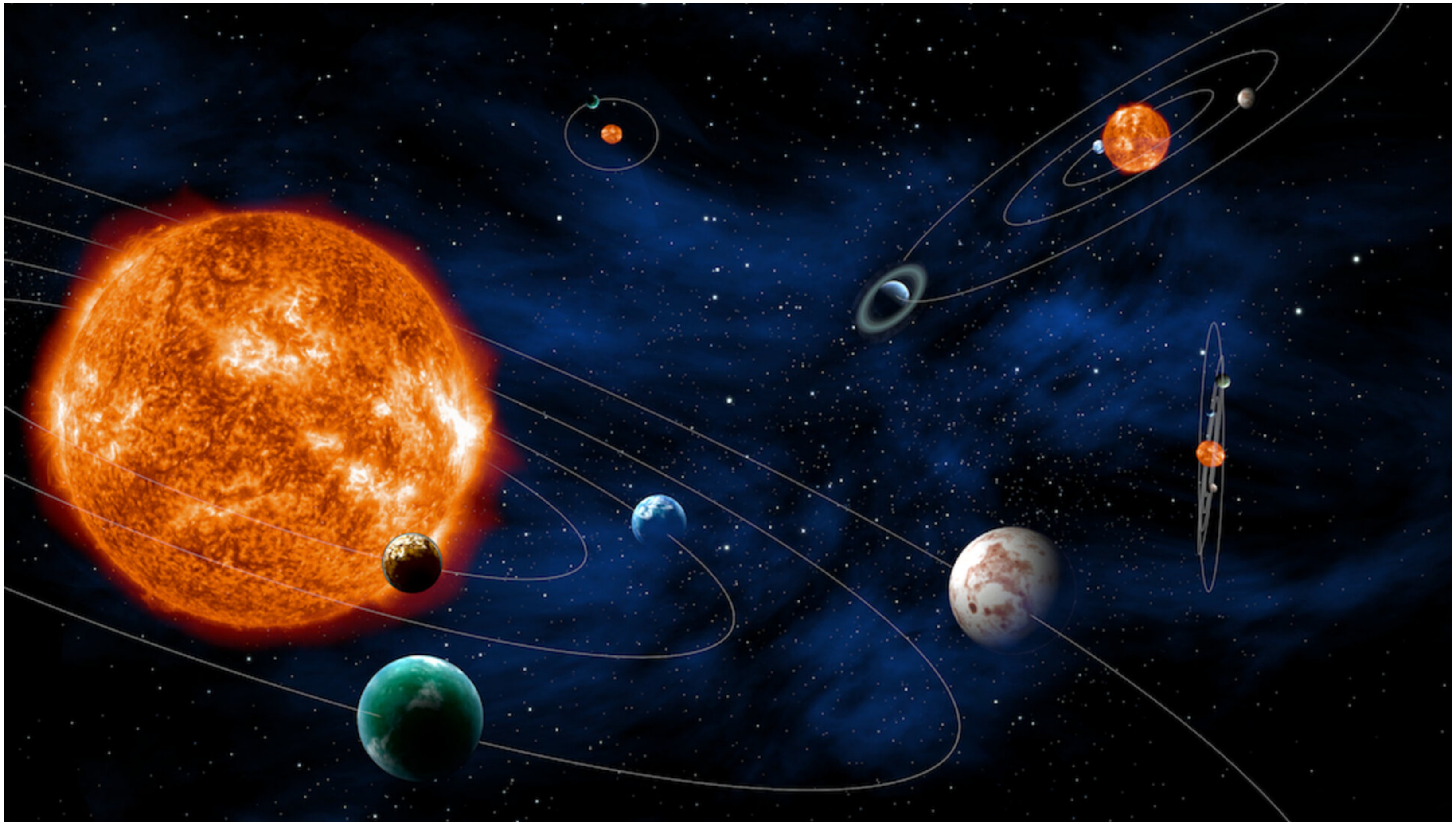
Exoplanets around M dwarfs



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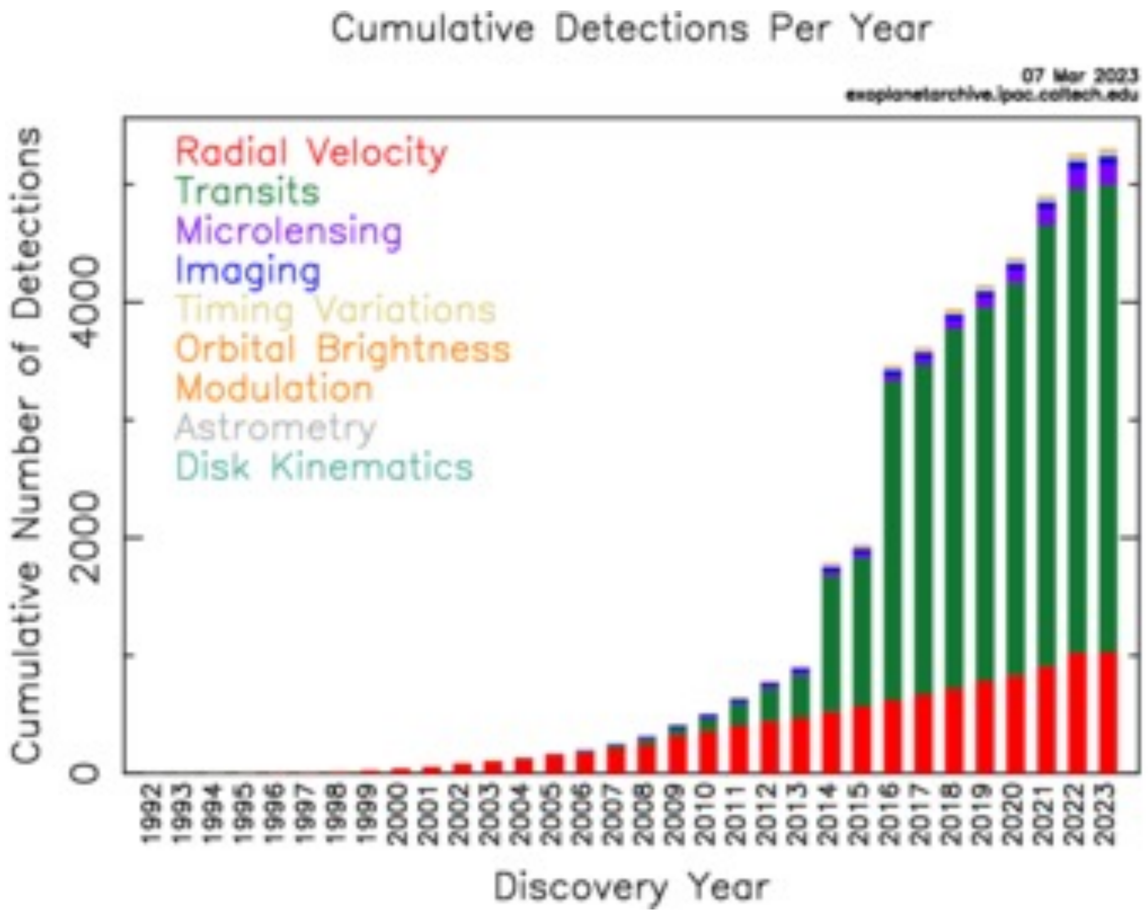
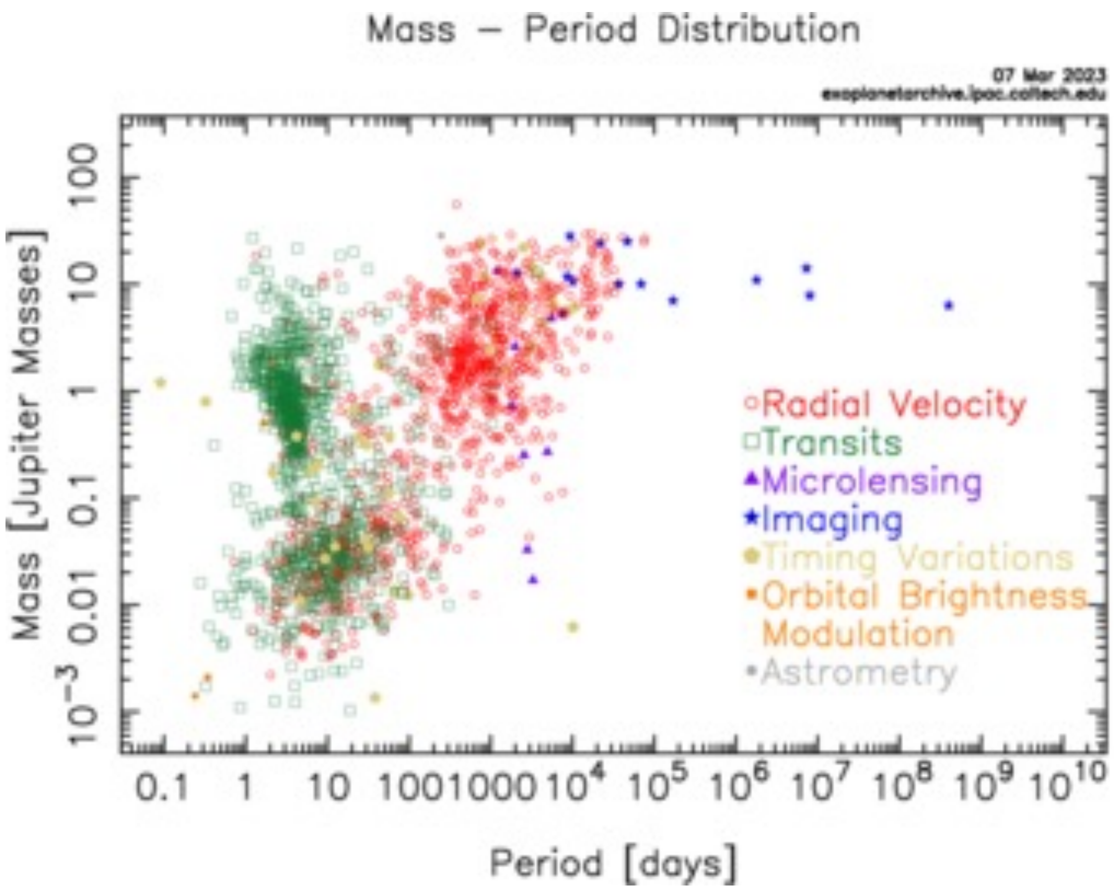
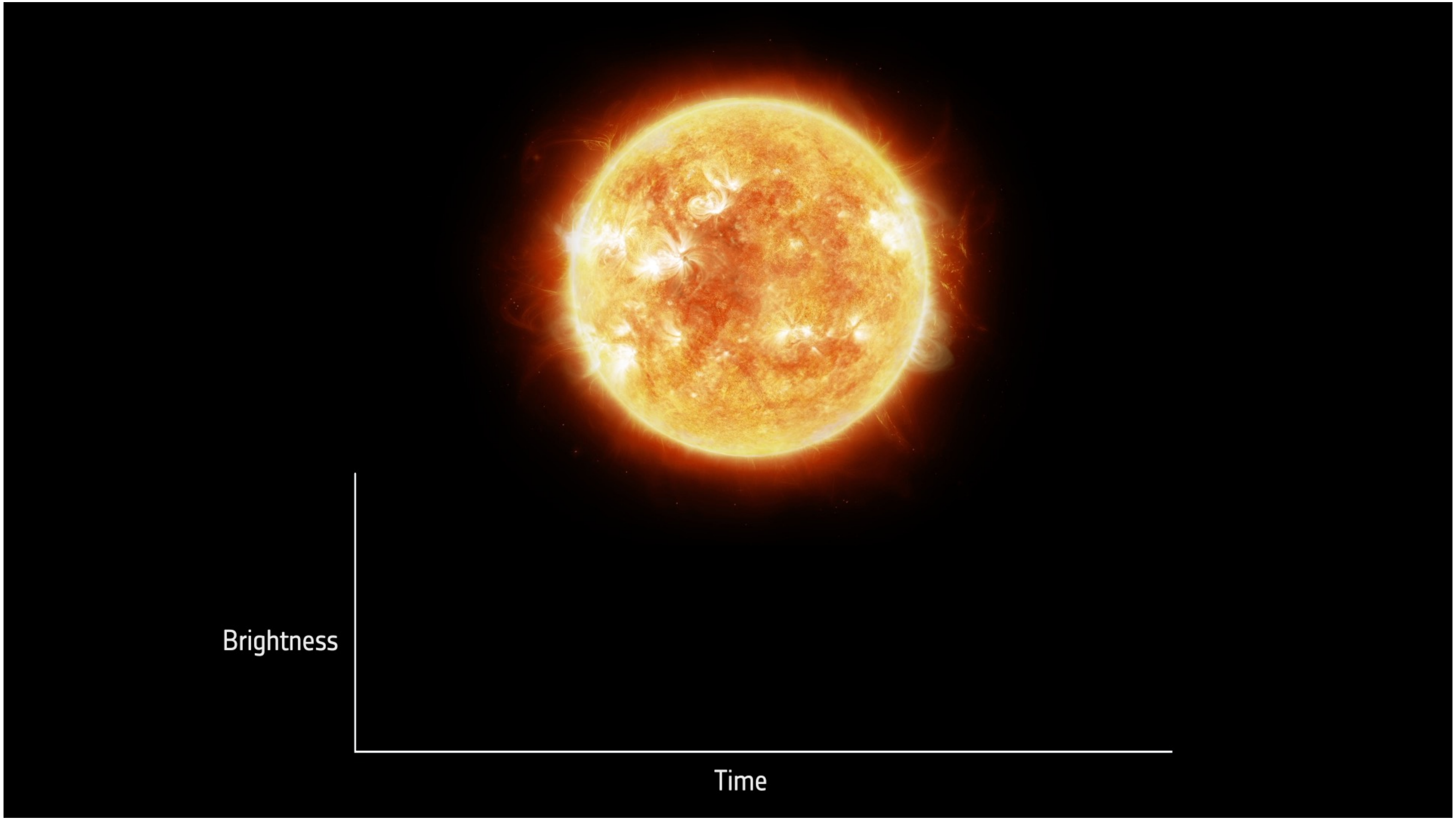
Exoplanets detection methods

5300 confirmed planets (27/02/2023)





Transit method



RV method (Doppler shift)

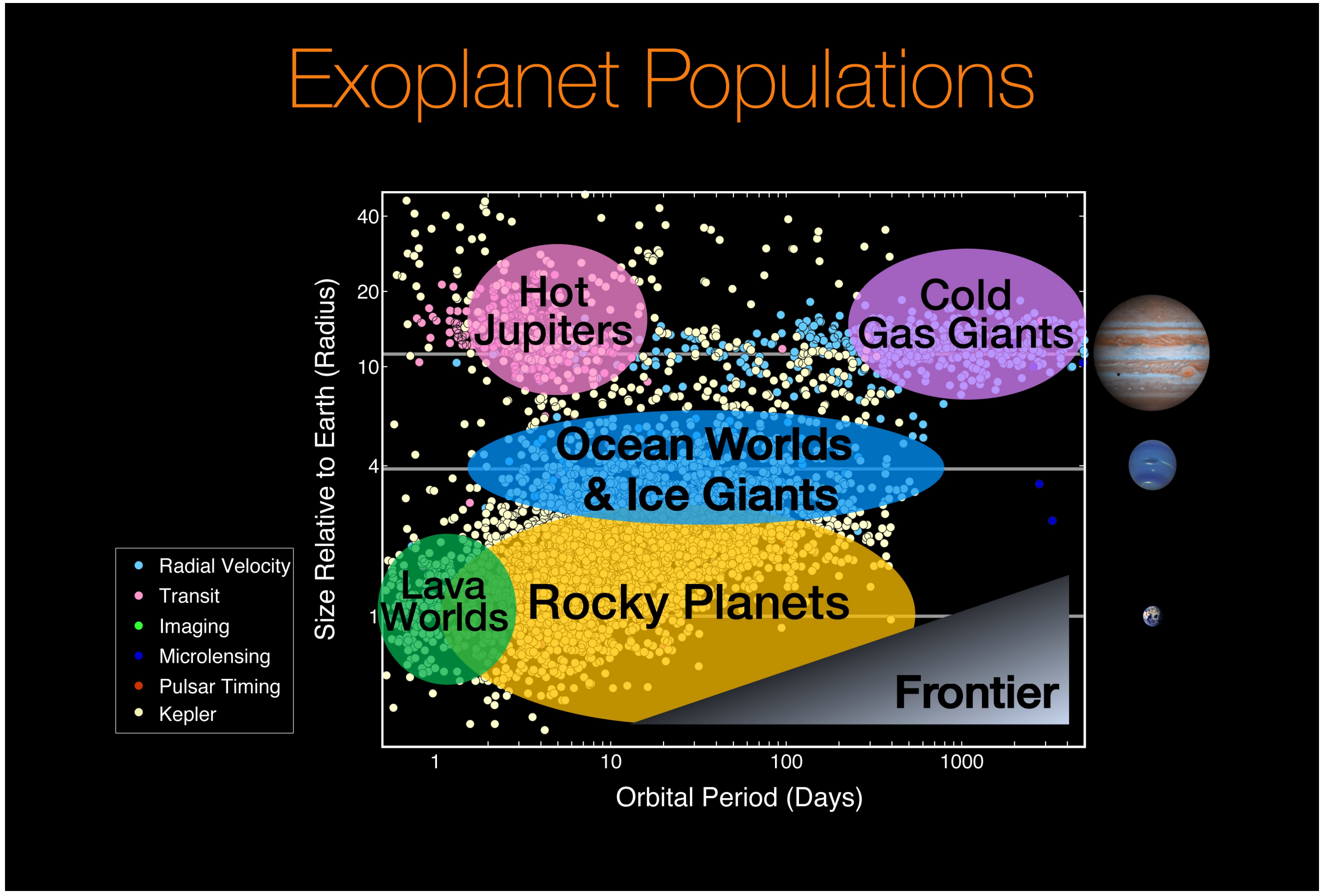
Exoplanet populations

MAIN GOAL: Find small rocky planets (Earth-size) in the habitable zone

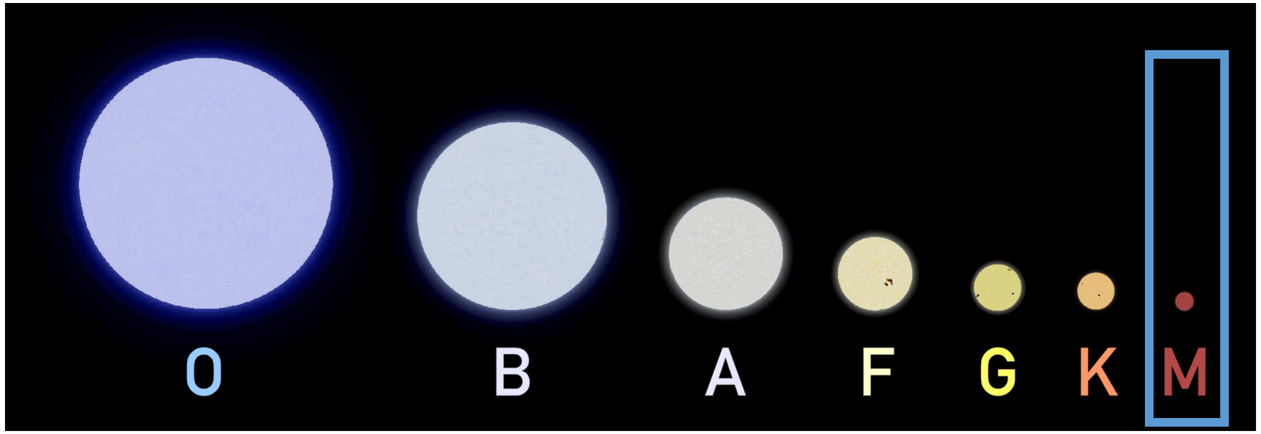
With more than 5000 exoplanets discovered, we found a huge diversity

Far from understanding:

- how planetary systems form
- how their architecture changes with the mass of the central star



M dwarfs, why?



- The Doppler shift depends on: the mass, the period → distance of the planet
- Massive and close-in planets, easier to detect

Mass = 0.6 – 0.08 Msun

ADVANTAGES

- ~ 75% of the stars within 10 pc
- Contrast planet-star is more favorable
- Earth-mass planet in the HZ: 1 m s−1
- Around of solar-like star: ~ 10 cm s−1

DISADVANTAGES

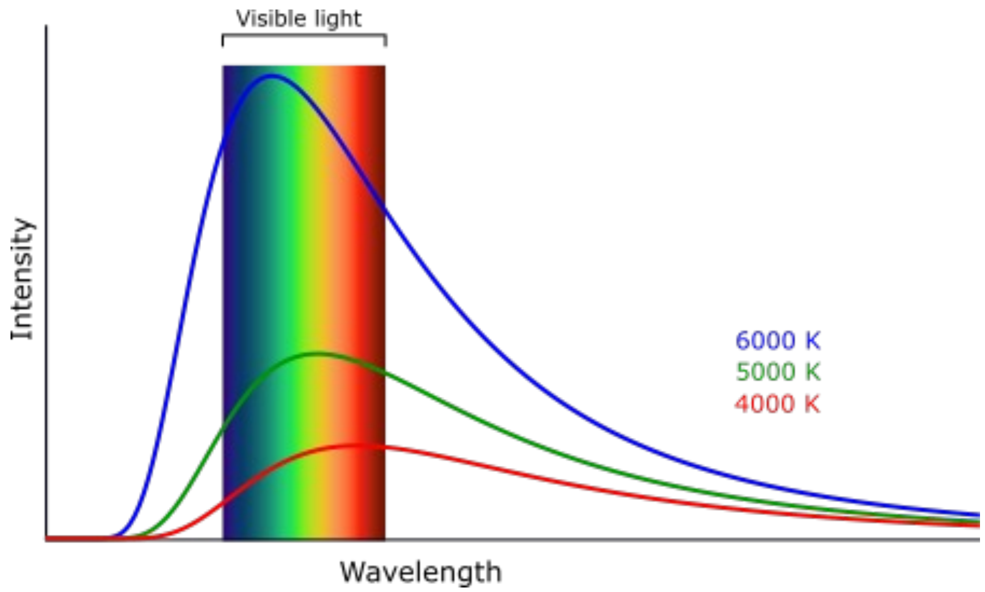
- On average more active than Solar-like stars
- Activity affects the shape of spectral lines inducing line profile distortion affecting the measured RV.

M dwarfs, activity effects

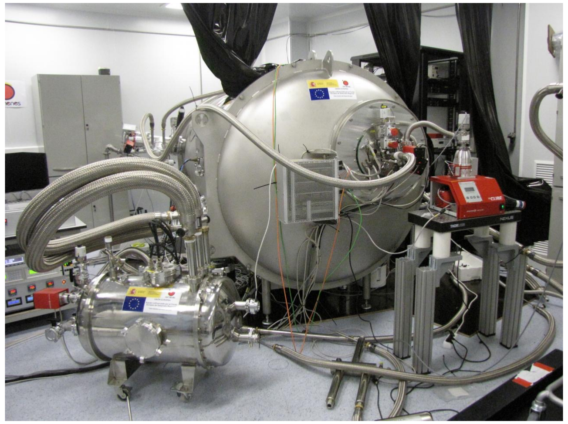
Rotational periods of M dwarfs often coincide with the orbital periods of planets in the expected habitable zone of these stars.

↓

An observational challenge



carmenes



Calar Alto Observatory in Almeria, Spain

GIANO

@ TNG telescope, Roque de Los Muchachos Observatory in the Canarian Island, Spain

M dwarfs, CARMENES

Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Échelle Spectrographs is an instrument built for the 3.5m telescope at the Calar Alto Observatory by a consortium of German and Spanish institutions

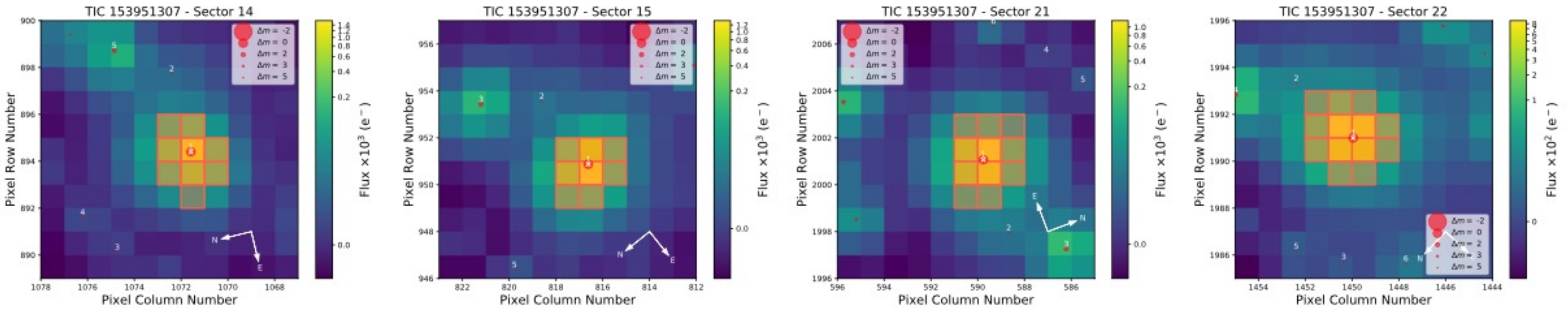
From 1 January 2016 to 31 Dicember 2020, CARMENES conducted a 750-night exoplanet survey targeting ~300 M dwarfs, including *TESS* targets, during Guaranteed Time Observations

In 2021 started the new CARMENES survey (CARMENES Legacy+) with 300 additional nights for the corsortium

The main scientific objective of CARMENES is to carry out a survey of late-type main sequence stars with the goal of detecting low-mass planets in their habitable zones.

M dwarfs, TOI-1238 a multiplanetary system

Parameters	Value	Ref.[(a)]
TIC	153951307	Stas18
Karm	J13255+688	Cab16
2MASS	J13253177+6850106	2MASS
α (hh:mm:ss)	13:25:31.76	*Gaia* EDR3
δ (dd:mm:ss)	+68:50:09.8	*Gaia* EDR3
V (mag)	12.79 ± 0.0005	Stas18
G (mag)	12.2139 ± 0.0003	*Gaia* EDR3
J (mag)	10.039 ± 0.020	2MASS
H (mag)	9.348 ± 0.019	2MASS
K_s (mag)	9.184 ± 0.014	2MASS
$W1$ (mag)	9.106 ± 0.023	AllWISE
$W2$ (mag)	9.037 ± 0.020	AllWISE
$W3$ (mag)	9.037 ± 0.027	AllWISE
$W4$ (mag)	>9.0	AllWISE
π (mas)	14.1558 ± 0.0123	*Gaia* EDR3
d (pc)	70.6424 ± 0.0614	
$\mu_\alpha \cos\delta$ (mas yr^{-1})	−4.887 ± 0.016	*Gaia* EDR3
μ_δ (mas yr^{-1})	−45.886 ± 0.015	*Gaia* EDR3
RV (km s^{-1})	−17.49 ± 0.85	*Gaia* DR2
U (km s^{-1})	12.30 ± 0.27	This work
V (km s^{-1})	−19.65 ± 0.50	This work
W (km s^{-1})	−2.70 ± 0.63	This work
Spectral type	K7–M0	This work
$T_{\rm eff}$ (K)	4089 ± 54	This work
$\log g$ (cgs)	4.63 ± 0.06	This work
[Fe/H] (dex)	+0.31 ± 0.19	This work
M ($M_\odot$)	0.59 ± 0.02	This work
R ($R_\odot$)	0.58 ± 0.02	This work
L ($L_\odot$)	0.0827 ± 0.002	This work
$v \sin i$ (km s^{-1})	≤2	This work
$P_{\rm rot}$ (d)	40 ± 5	This work
Age (Gyr)	>0.8	This work



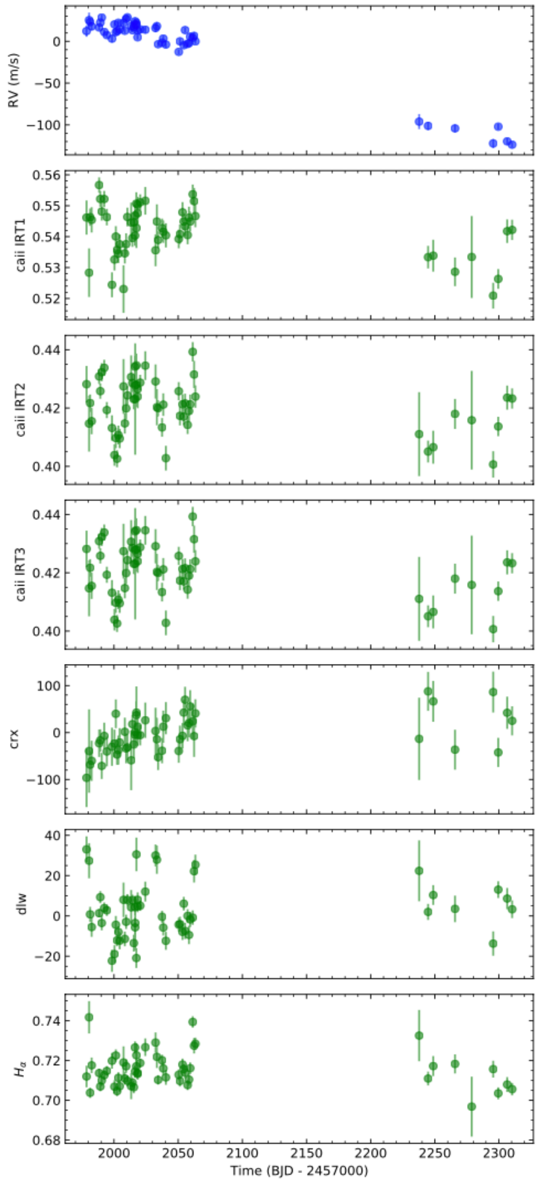
<u>Two planet</u> candidates via *TESS* data alert website:

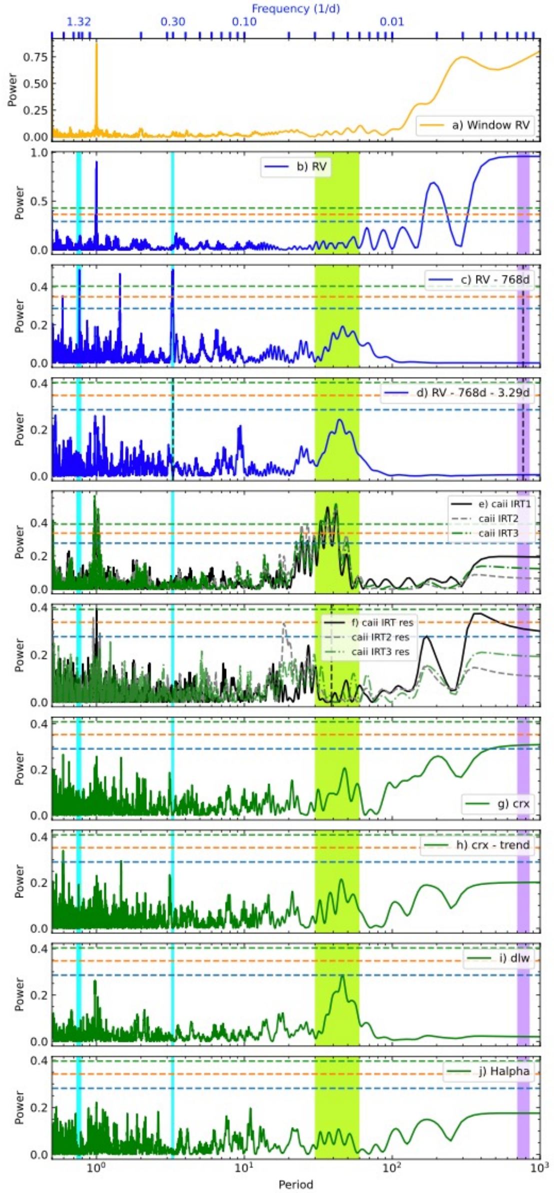
P1 = **3.29d** P2 = **0.76d**

Follow up with CARMENES spectrograph

González-Álvarez et al. 2022

TOI-1238: CARMENES data

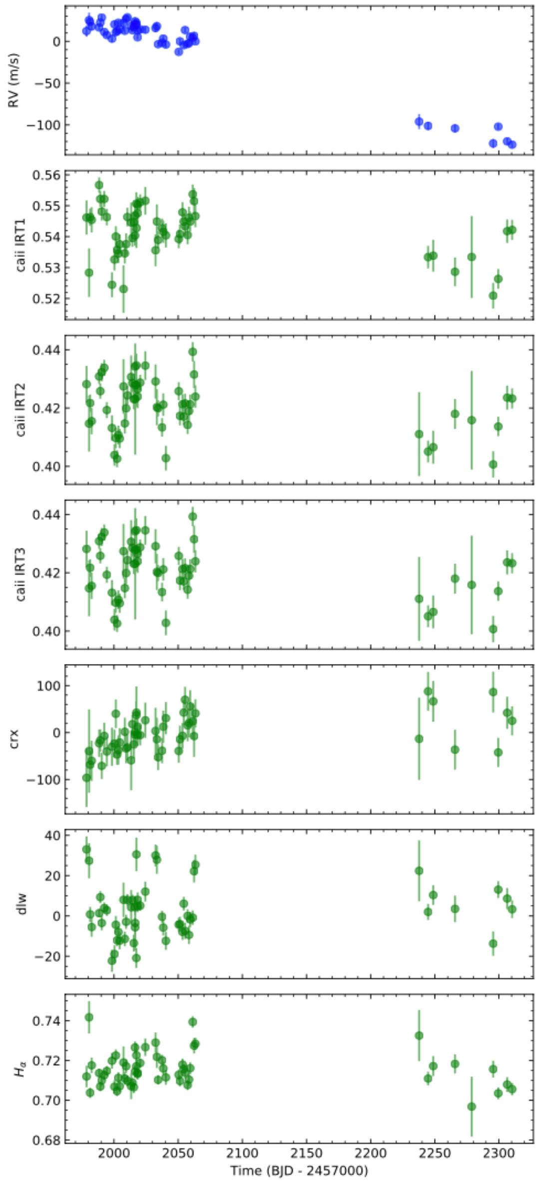


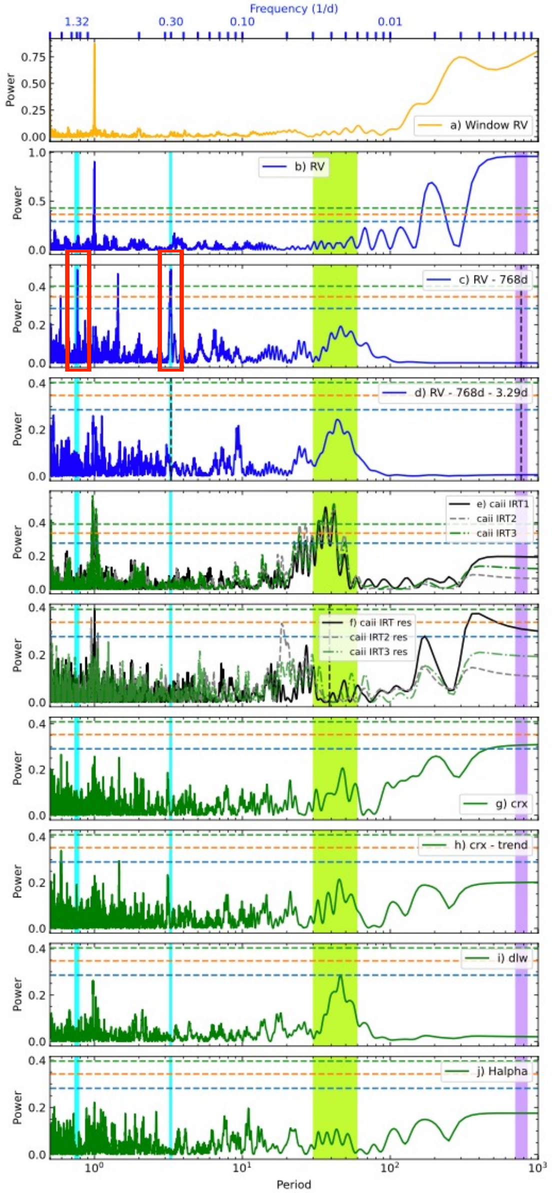


Long term signal

Stellar Prot = 40 ± 5 d

TOI-1238: CARMENES data



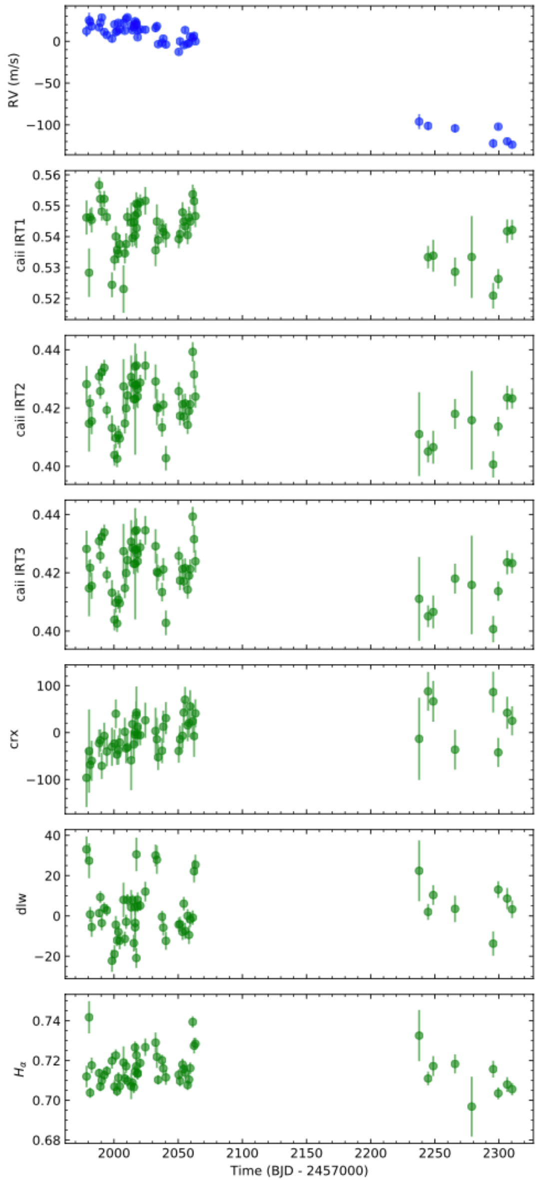


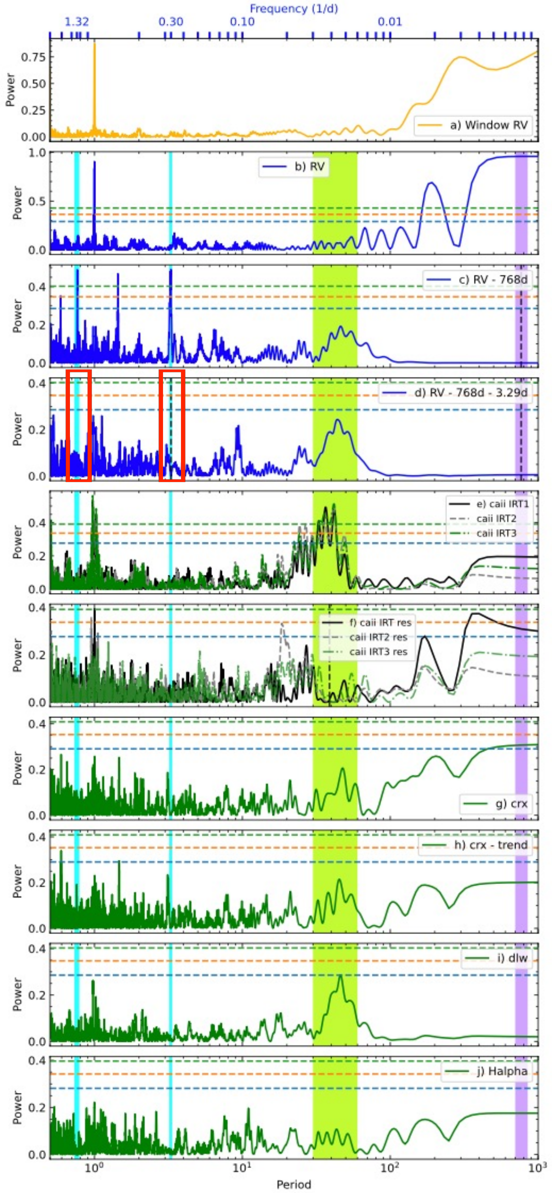
Long term signal

Planetary signals appear

Stellar Prot = 40 ± 5 d

TOI-1238: CARMENES data





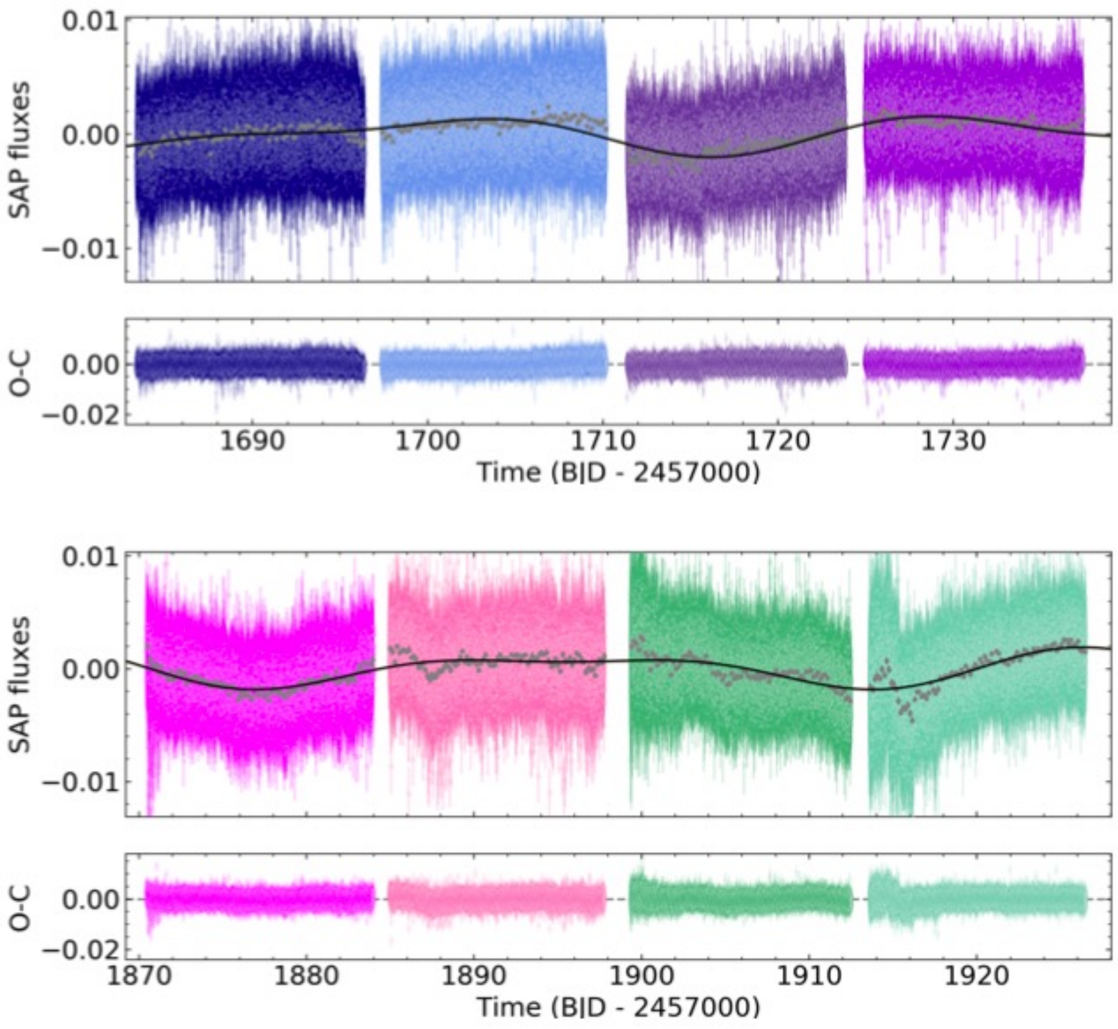
Long term signal

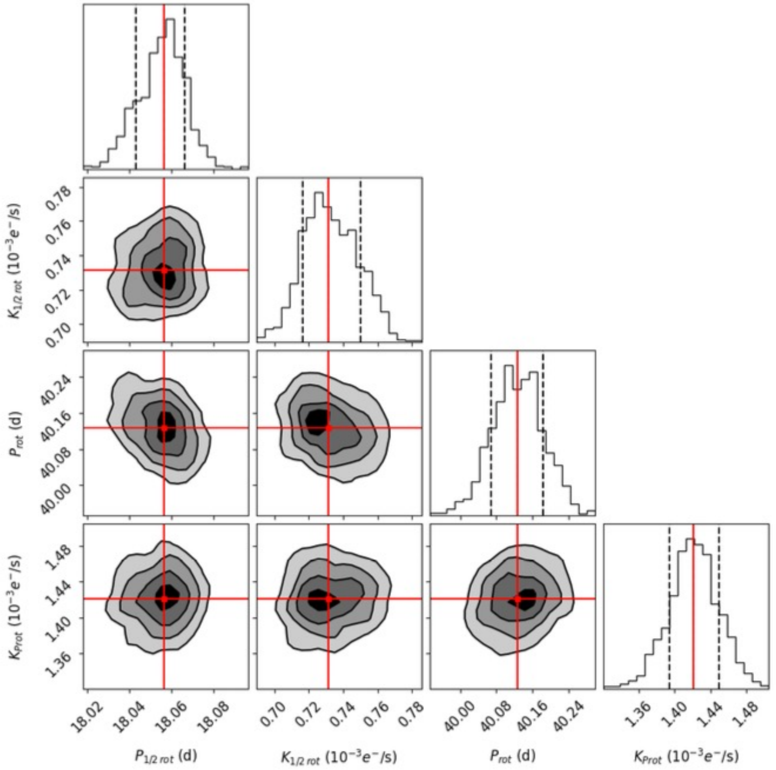
Planetary signals appear

Stellar activity signal

Stellar Prot = 40 ± 5 d

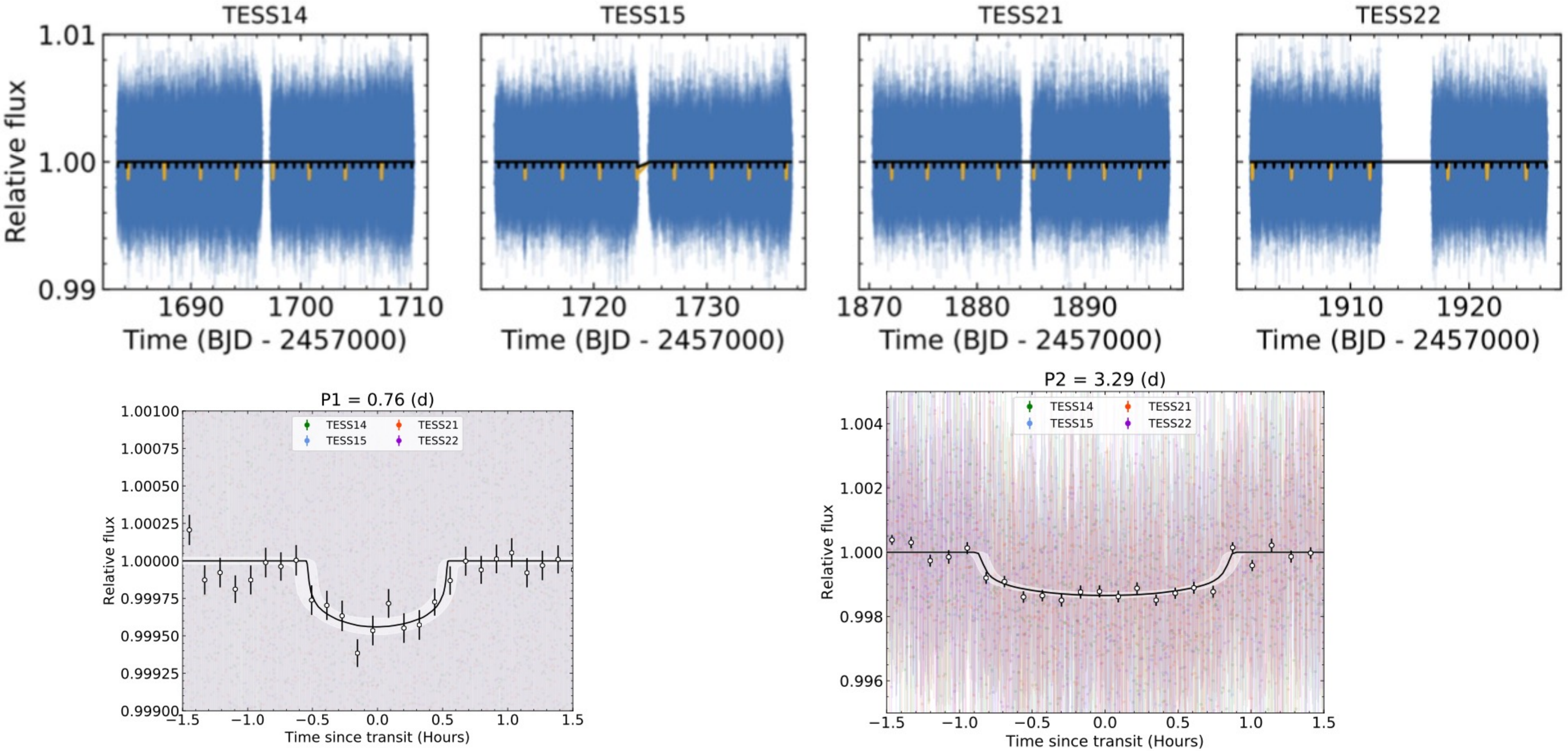
TOI-1238: *TESS* data → Stellar Prot





Stellar Prot also confirmed by TESS LCs analysis

TOI-1238: Joint analysis *TESS* + CARMENES data



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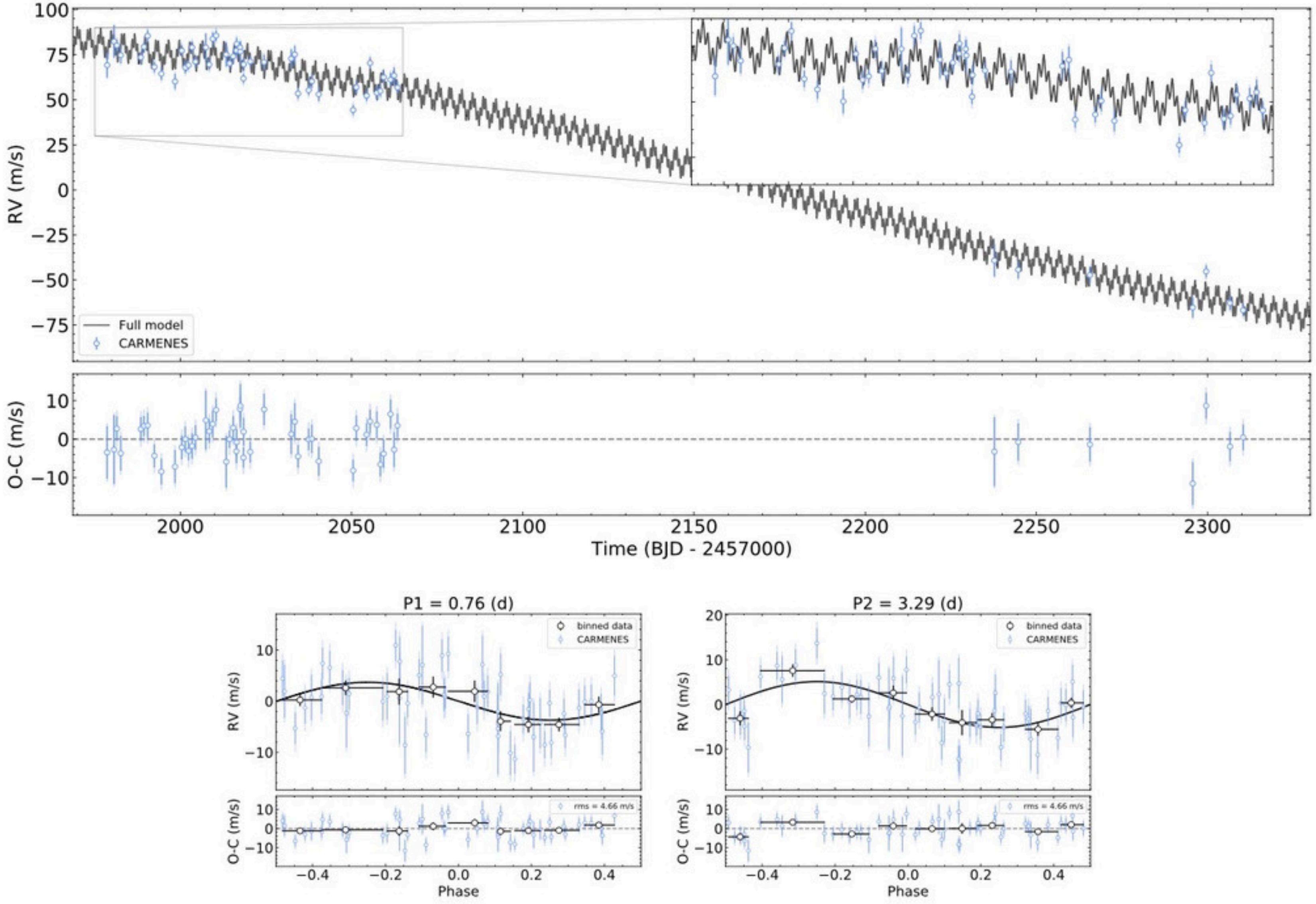
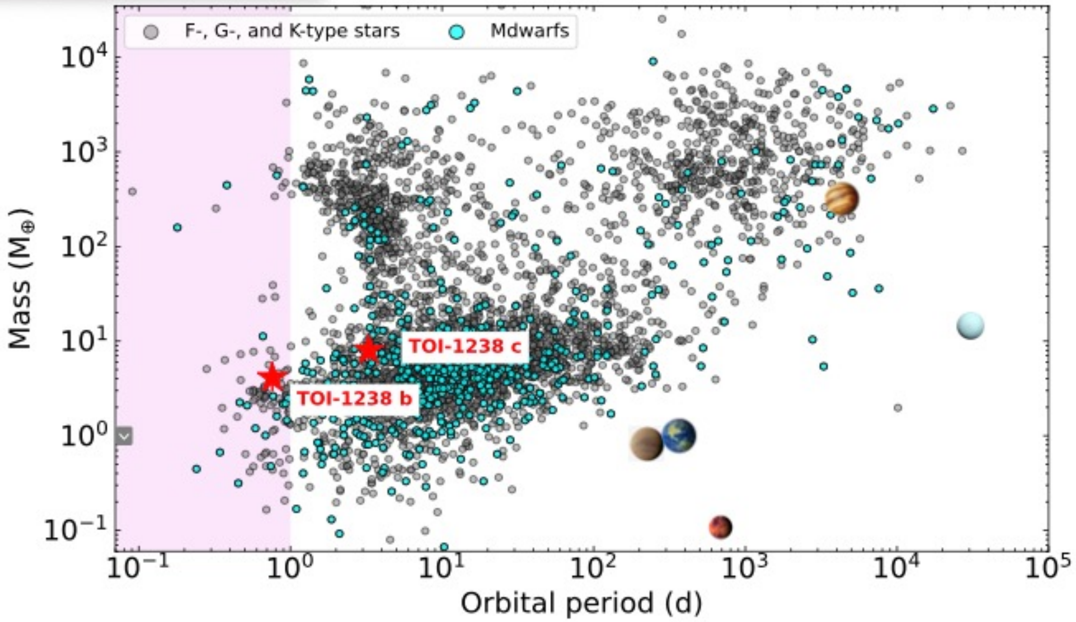
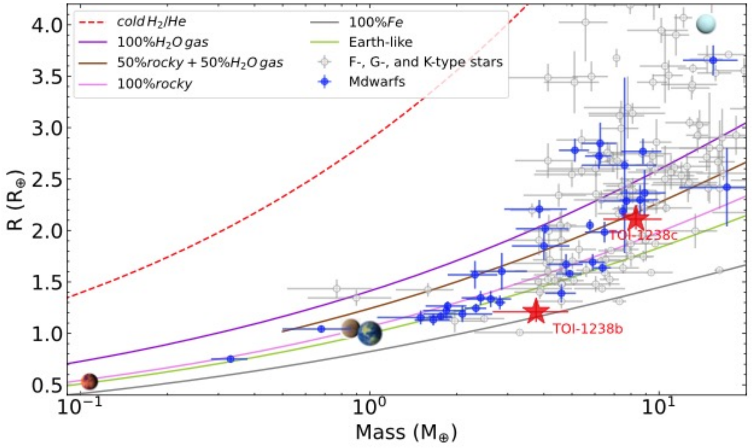


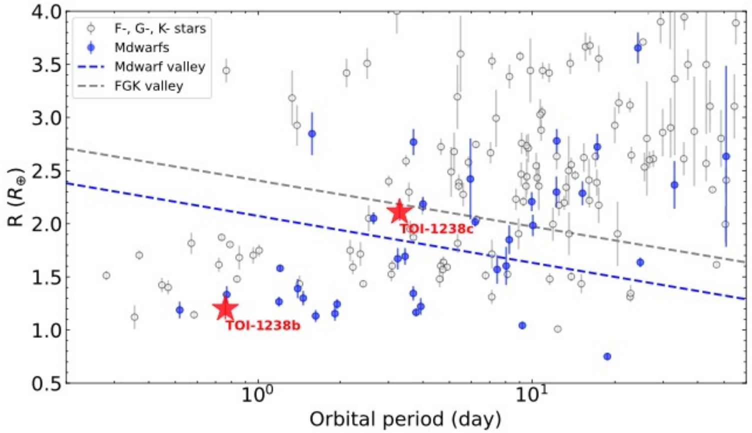
TOI-1238: Planetary parameters

Parameter	TOI-1238 b	TOI-1238 c	Ext. companion
	Fitted planet parameters		
P (d)	$0.764597^{+0.000013}_{-0.000011}$	$3.294736^{+0.000034}_{-0.000036}$	≥ 600
t_0 (1)	$1684.102^{+0.002}_{-0.003}$	$1707.352^{+0.002}_{-0.001}$	
e	≤ 0.25	≤ 0.15	
K (m s^{-1})	$3.74^{+1.03}_{-0.99}$	$5.10^{+1.02}_{-1.06}$	≥ 70
r_1	$0.45^{+0.14}_{-0.15}$	$0.51^{+0.07}_{-0.11}$	
r_2	$0.04^{+0.002}_{-0.002}$	$0.07^{+0.002}_{-0.003}$	
	Derived planet parameters		
$R_p/R_\star$	$0.019^{+0.001}_{-0.001}$	$0.033^{+0.001}_{-0.001}$	
R_p ($R_\oplus$)	$1.21^{+0.11}_{-0.10}$	$2.11^{+0.14}_{-0.14}$	
$a/R_\star$	$5.19^{+0.16}_{-0.17}$	$13.73^{+0.43}_{-0.47}$	
a (au)	$0.0139^{+0.0008}_{-0.0008}$	$0.037^{+0.002}_{-0.002}$	≥ 1.1
$b = (a/R_\star)\cos i$	$0.32^{+0.17}_{-0.19}$	$0.39^{+0.10}_{-0.13}$	
i (deg)	$86.51^{+2.11}_{-1.98}$	$88.38^{+0.57}_{-0.47}$	
t_{14} (h)	$1.09^{+0.05}_{-0.08}$	$1.75^{+0.06}_{-0.06}$	
$t_{\rm depth}$ (ppm)	$366.34^{+44.64}_{-40.73}$	$1113.42^{+83.63}_{-86.58}$	
$M_p \sin i$ ($M_\oplus$)	$3.75^{+1.14}_{-1.06}$	$8.32^{+1.90}_{-1.88}$	$\geq 2\sqrt{1-e^2}\,M_{\rm Jup}$
M_p ($M_\oplus$)	$3.76^{+1.15}_{-1.07}$	$8.32^{+1.90}_{-1.88}$	
ρ_p (g cm^{-3})	$11.7^{+4.2}_{-3.4}$	$4.9^{+2.5}_{-1.8}$	
$T_{\rm eq}$ (K)(2)	965–1300 K	590–800 K	
S ($S_\oplus$)	442^{+39}_{-35}	63^{+6}_{-5}	

tel:104%20103%20102%20101%20100







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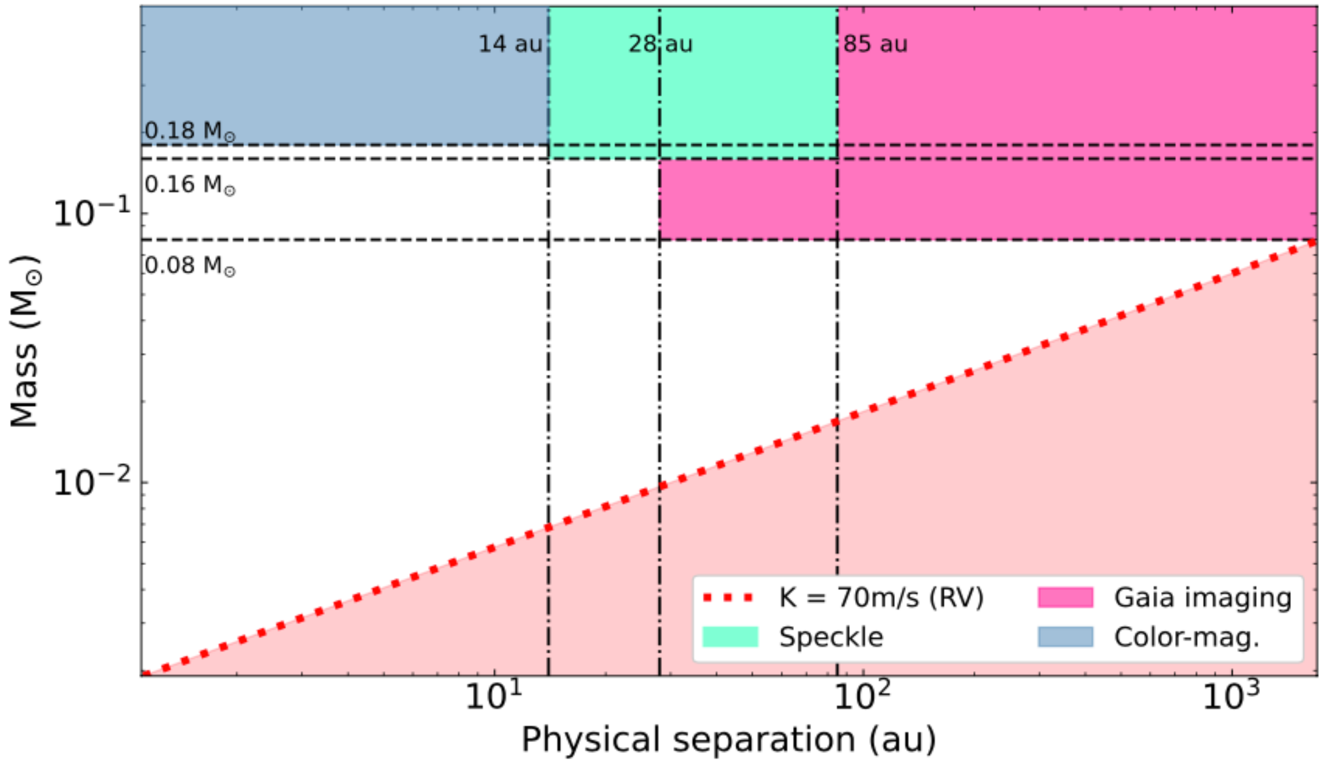
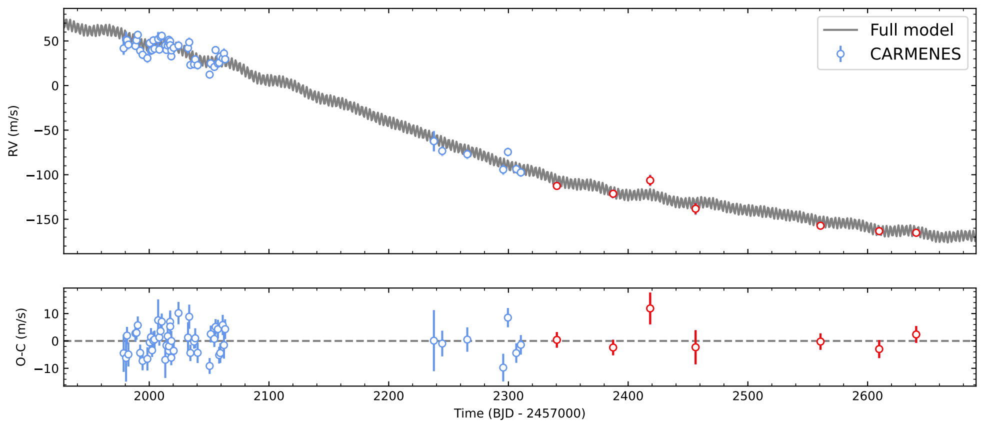
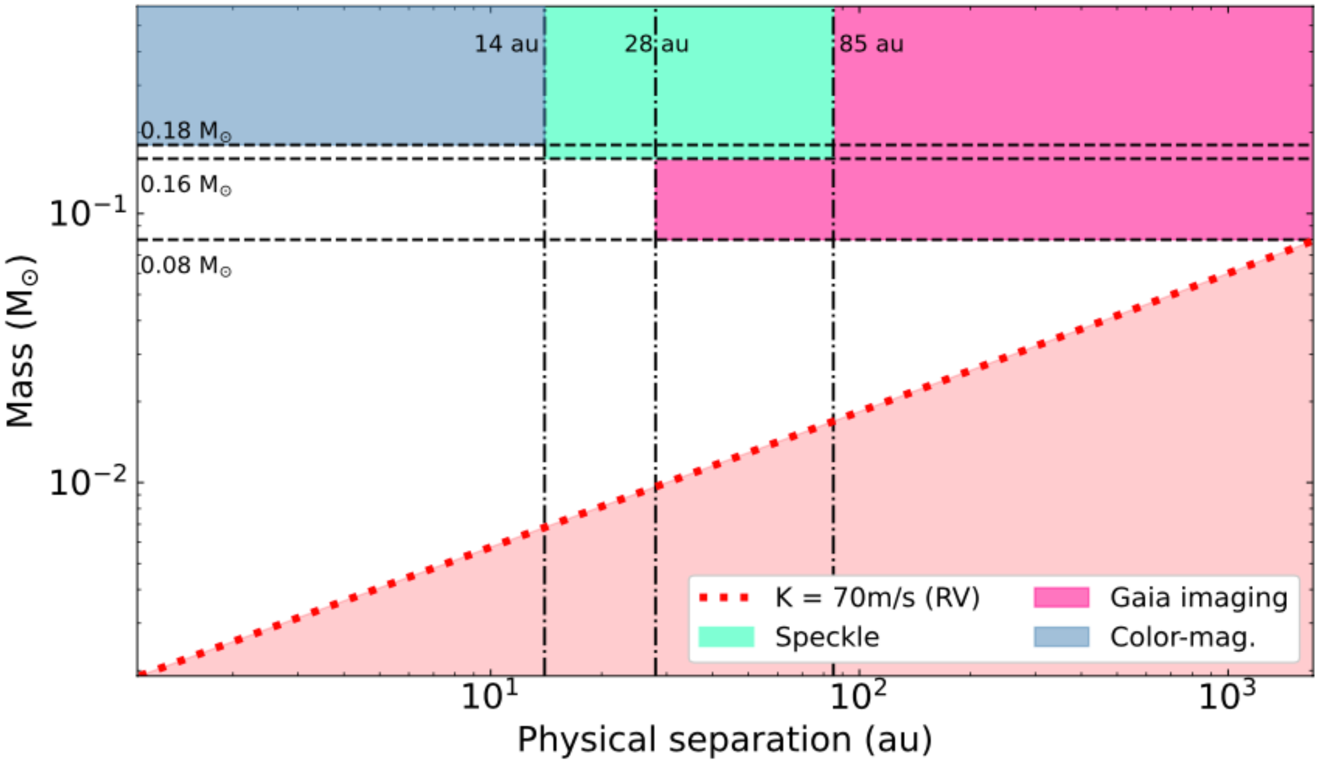


TOI-1238: CARMENES long term follow up

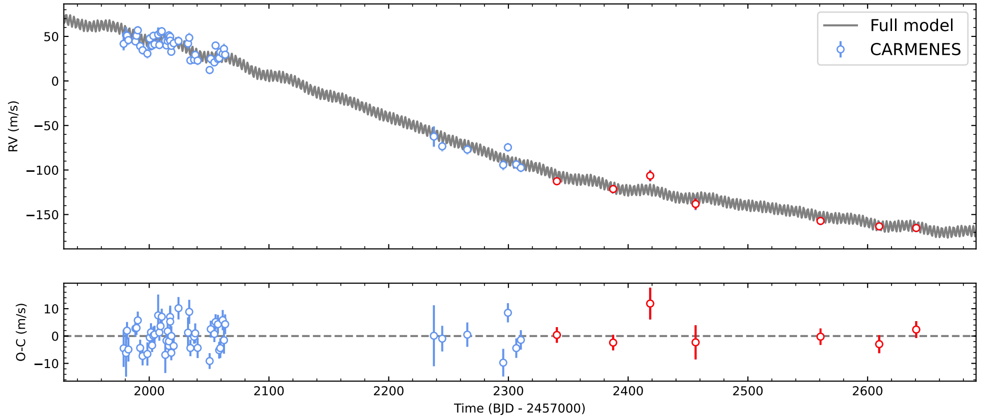


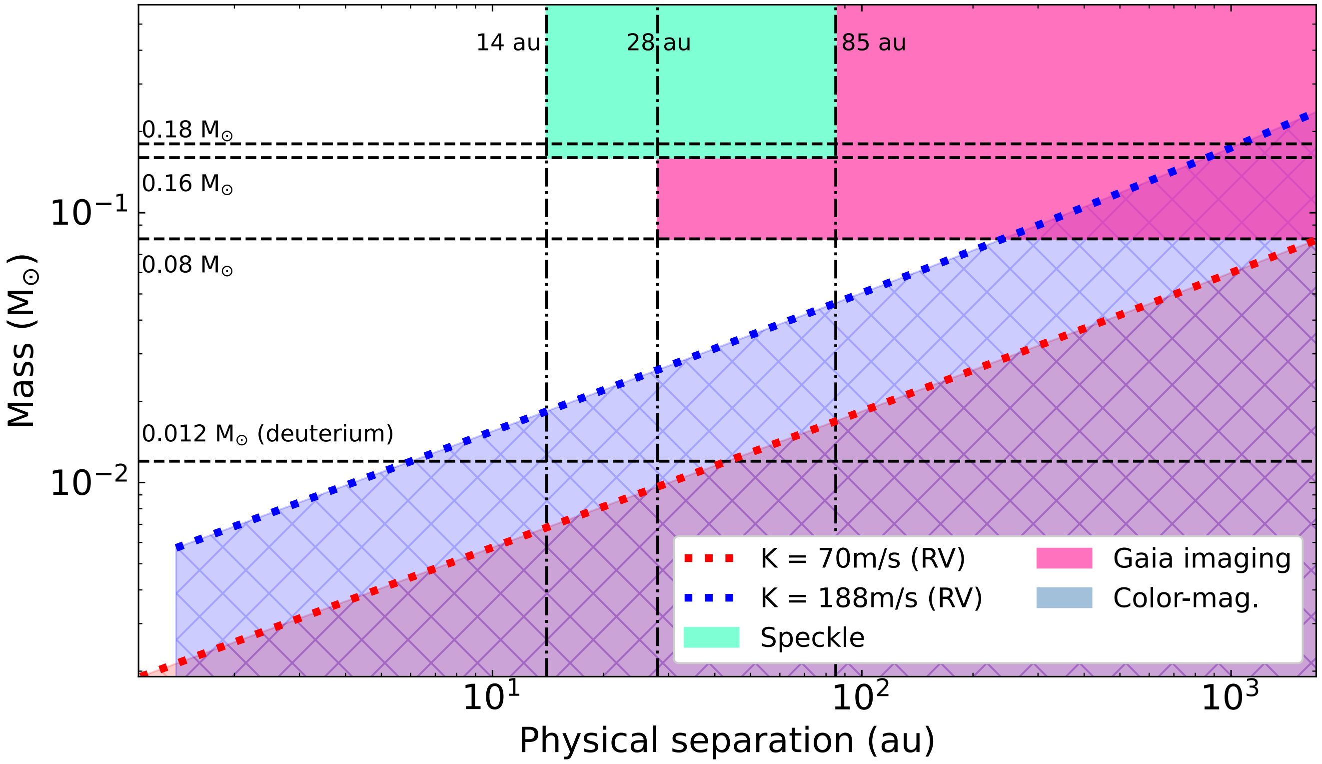


New limits:

K > 188 m/s
P > 1200 d
Mp min > 6 Mjup

TOI-1238: CARMENES long term follow up





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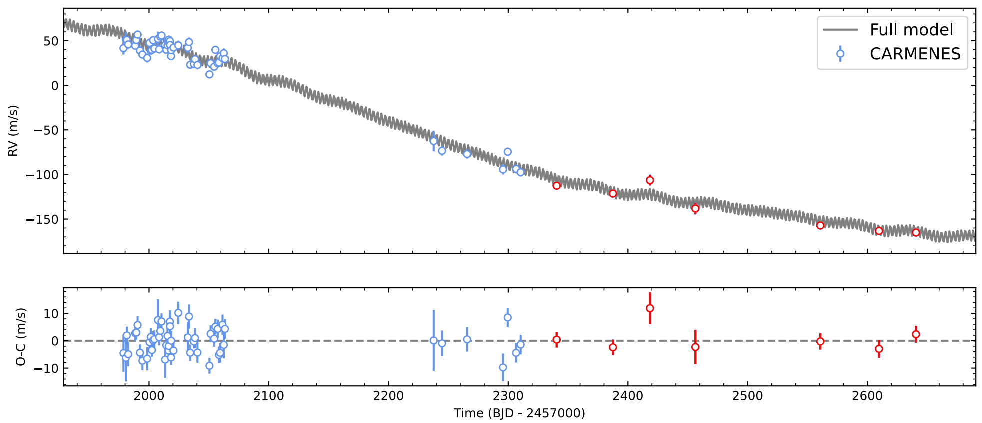

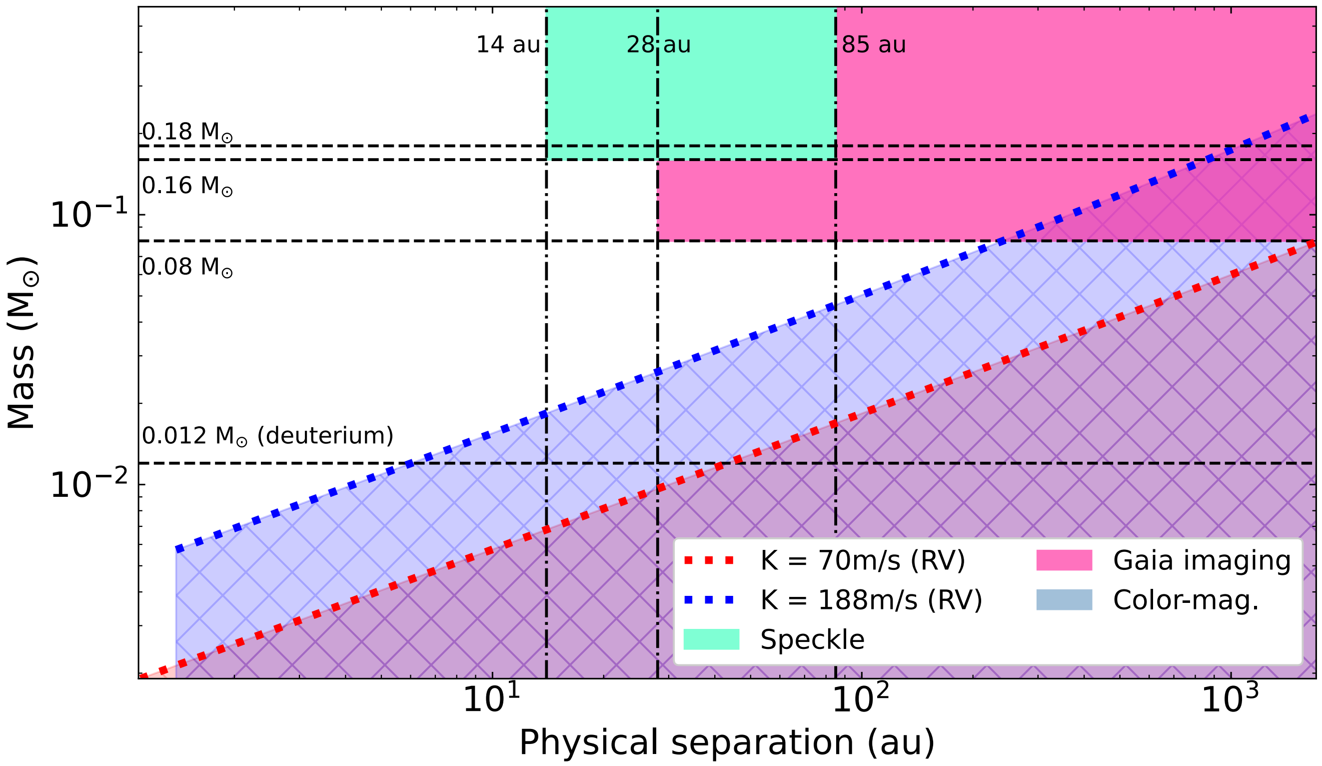

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More likely to be: a <u>brown dwarf or giant planet (planet - brown dwarf boundary)</u>

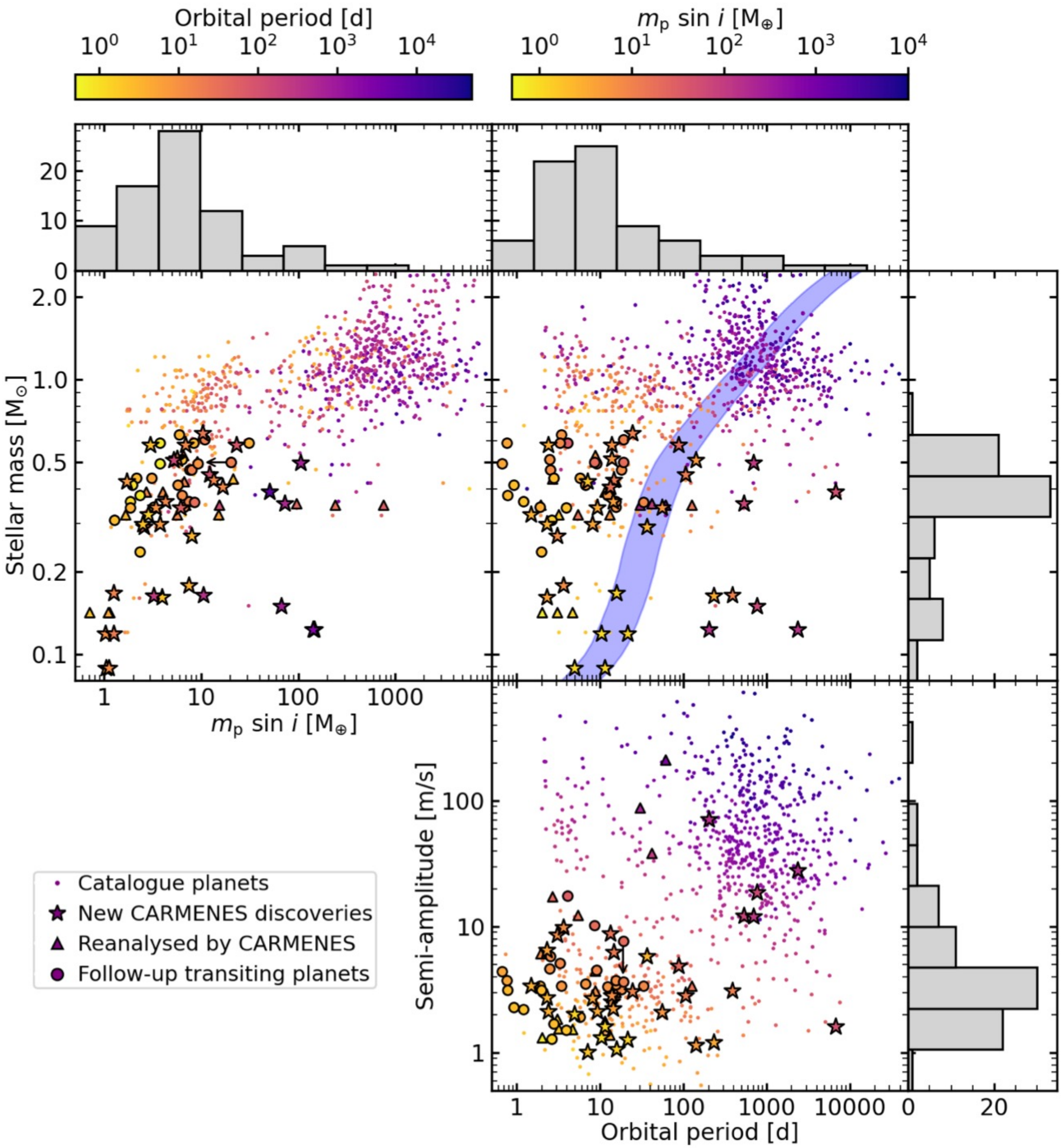
TOI-1238: Conclusions

- Very interesting system to test innovative models for explaining theories of planet formation and evolution

- System: M dwarf star with two transiting planets + a brown dwarf → not very abundant

- The best formation mechanisms for this system will be explained by the gravitational instability of the disk (Boss et al. 1997, Kratter and Lodato el at. 2016)

Summary: CARMENES DR1 exoplanet sample



- NASA Exoplanet Archive detected via RVs (903)

★ Planets newly detected from the CARMENES blind survey (33)

● Planets confirmed from transit follow-up (26)

▲ Known planets re-analysed with CARMENES data (17)

The new planets cover a broad region of the parameter space (stellar host and orbital period)

Remarkable: CARMENES has discovered the half of RV planets known to orbit star of mass below 0.25 Msun

References. Ama21: Amado et al. (2021); Bau20: Bauer et al. (2020); Bla22: Blanco-Pozo et al. (2023); Blu20: Bluhm et al. (2020); Blu21: Bluhm et al. (2021); Cal21: Cale et al. (2021); Cha22: Chaturvedi et al. (2022); Dam22: Damasso et al. (2022); Dre20: Dreizler et al. (2020); Esp22: Espinoza et al. (2022); GA20: González-Álvarez et al. (2020); GA22a: González-Álvarez et al. (2022); GA22b: González-Álvarez et al. (in prep.); GA22c: González-Álvarez et al. (in prep.); Kam18: Kaminski et al. (2018); Kem20: Kemmer et al. (2020); Kem22: Kemmer et al. (2022); Kos21: Kossakowski et al. (2021); Kos22b: Kossakowski et al. (2023); Lal19: Lalitha et al. (2019); Luq18: Luque et al. (2018); Luq19: Luque et al. (2019); Luq22: Luque et al. (2022); Mor19: Morales et al. (2019); Nag19: Nagel et al. (2019); Now20: Nowak et al. (2020); Pal22: Pallé et al. (2023); Per19: Perger et al. (2019); Qui22: Quirrenbach et al. (2022); Rei18a: Reiners et al. (2018a); Rib18: Ribas et al. (2018); Sar18: Sarkis et al. (2018); Sot21: Soto et al. (2021); Sto20a: Stock et al. (2020a); Sto20b: Stock et al. (2020b); SM22: Suárez Mascareño et al. (2023); TP21: Toledo-Padrón et al. (2021); Tri18: Trifonov et al. (2018); Tri20: Trifonov et al. (2020a); Tri21: Trifonov et al. (2021); Tri22: Trifonov et al. (in prep.); TW: This work; Zec19: Zechmeister et al. (2019).

Ribas et al. 2023