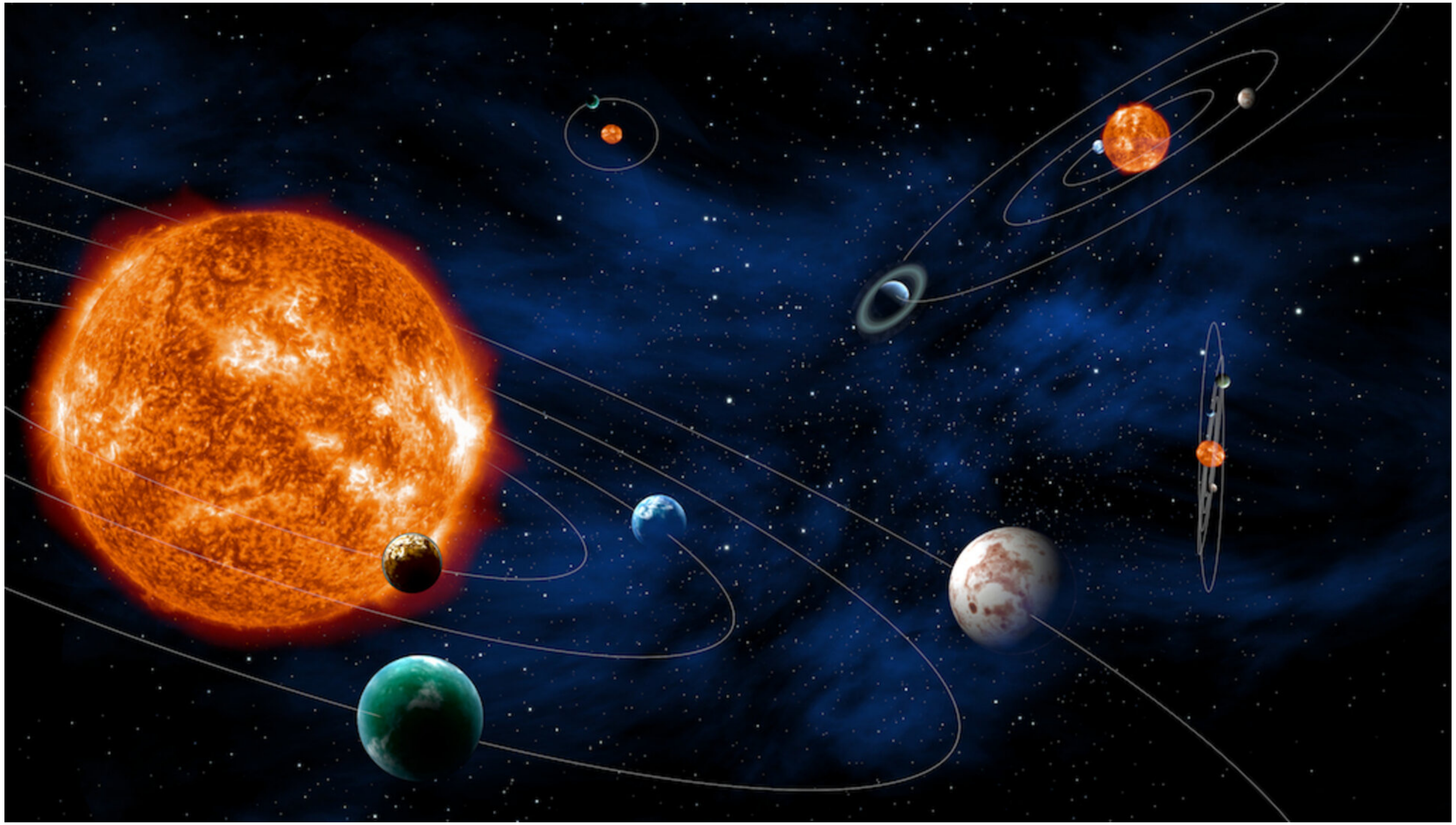
Exoplanets around M dwarfs



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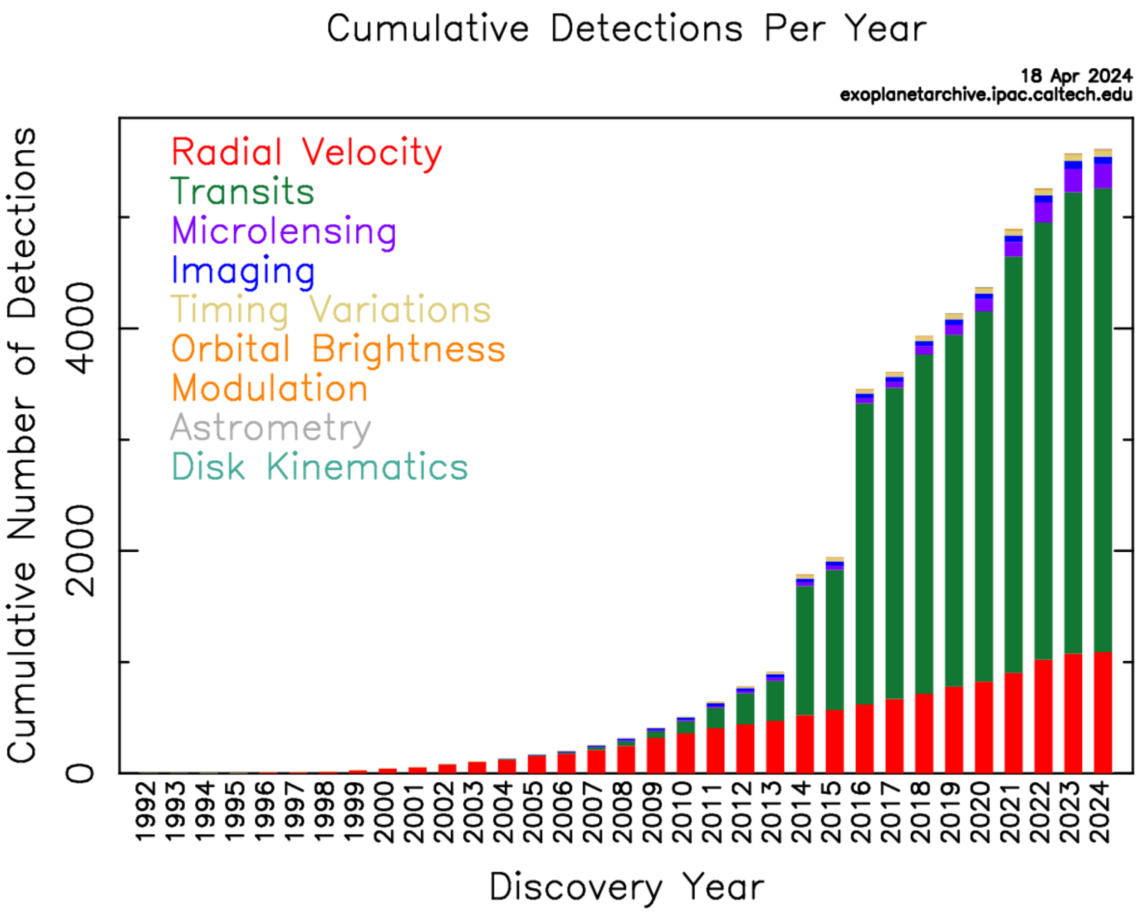
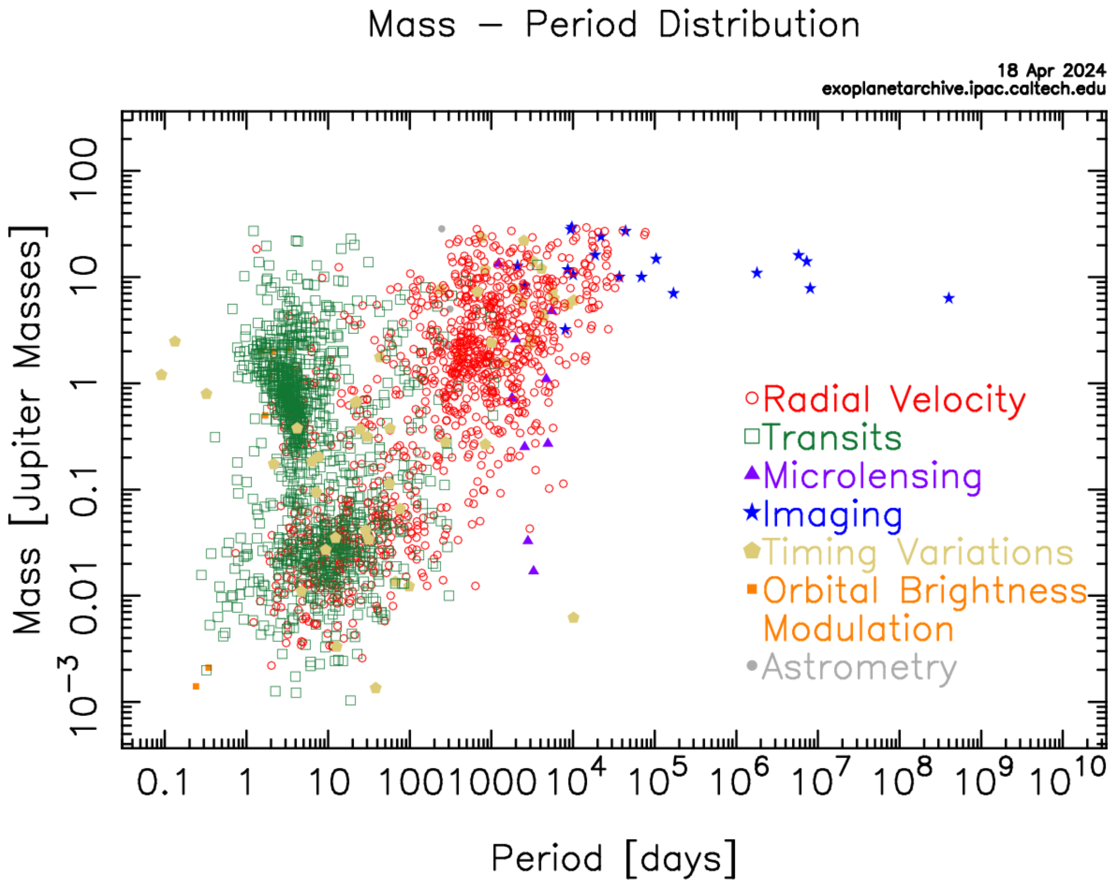
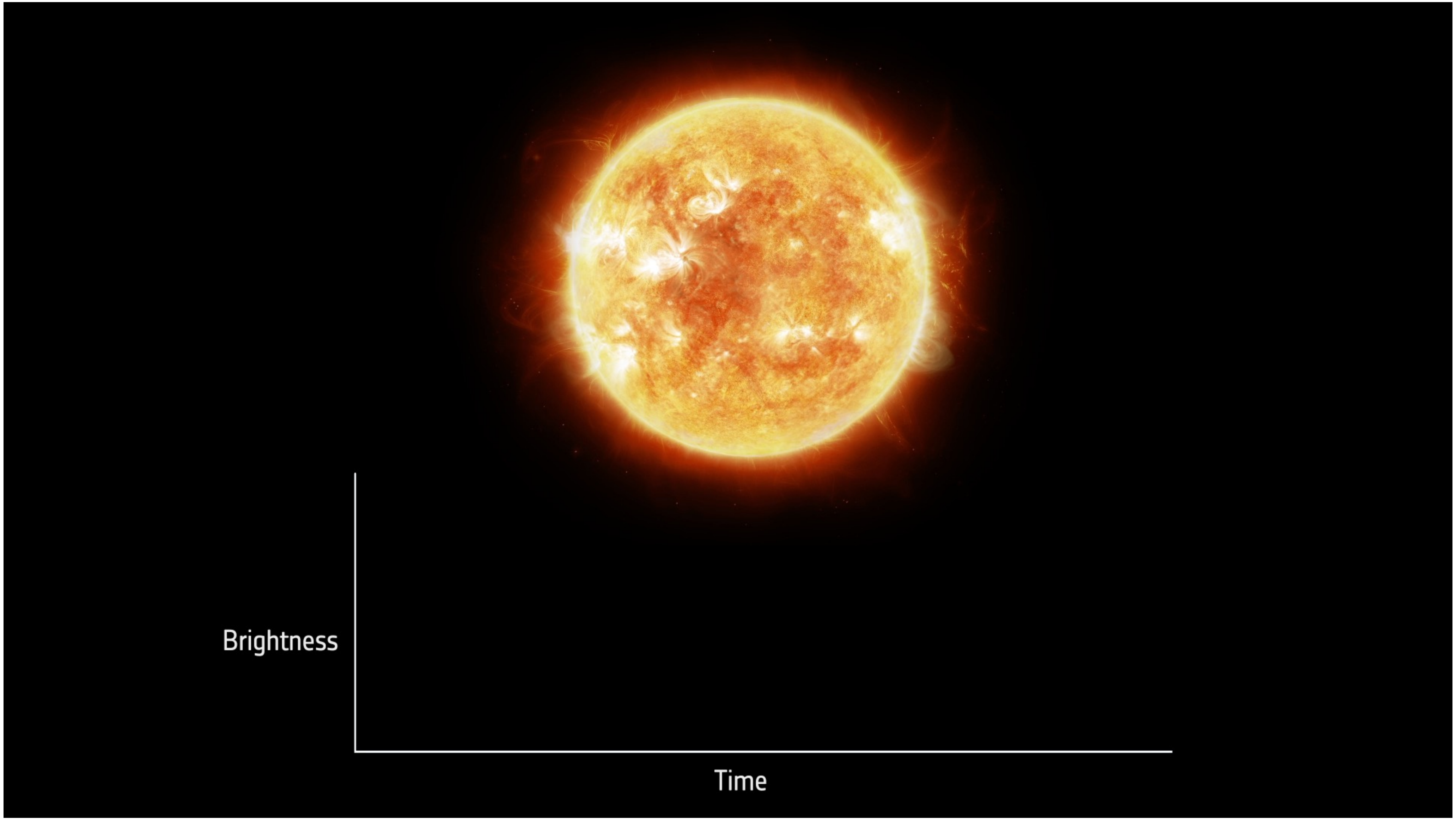
Exoplanets detection methods

5612 confirmed planets (18/04/2024)





Transit method



RV method (Doppler shift)

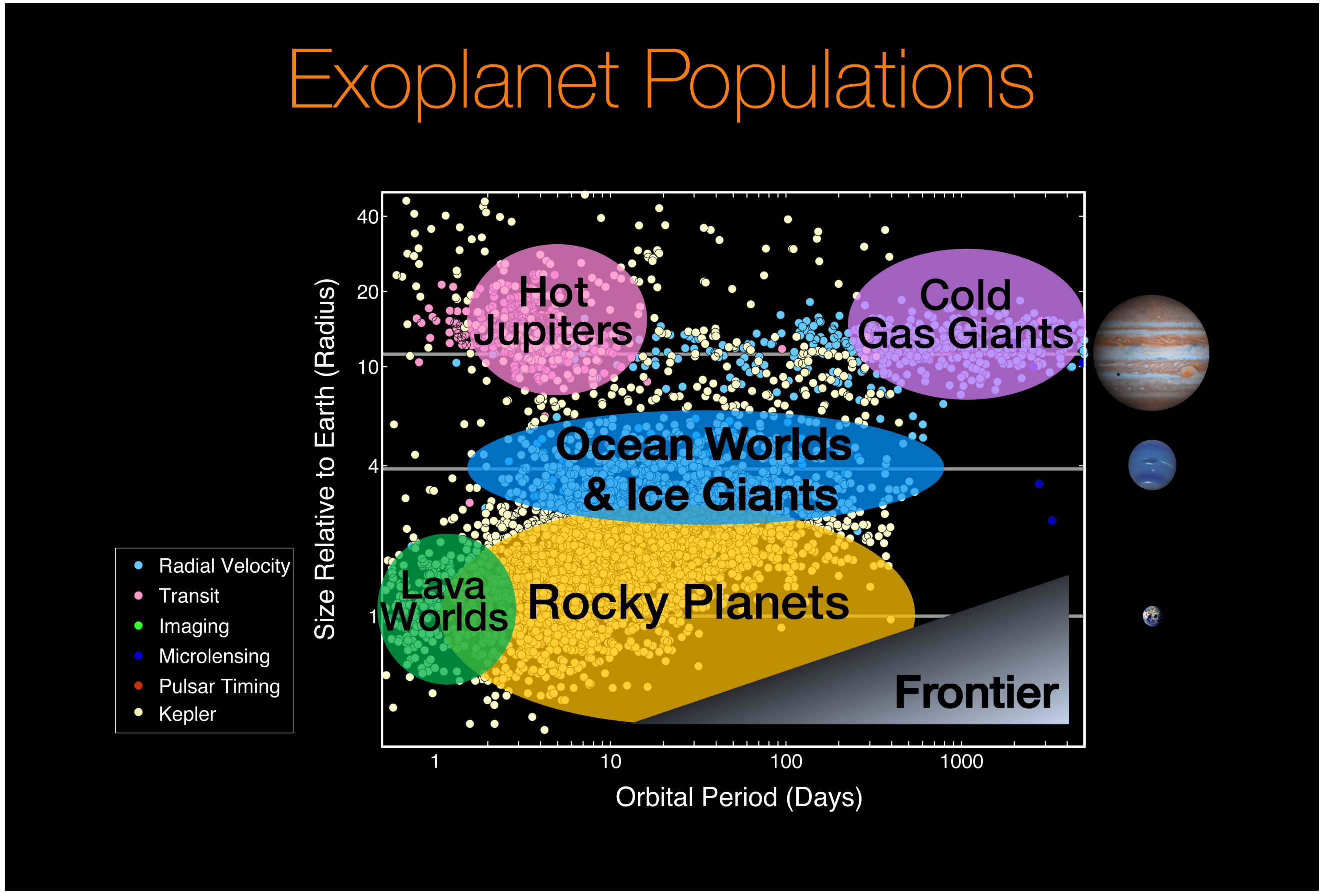
Exoplanet populations

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

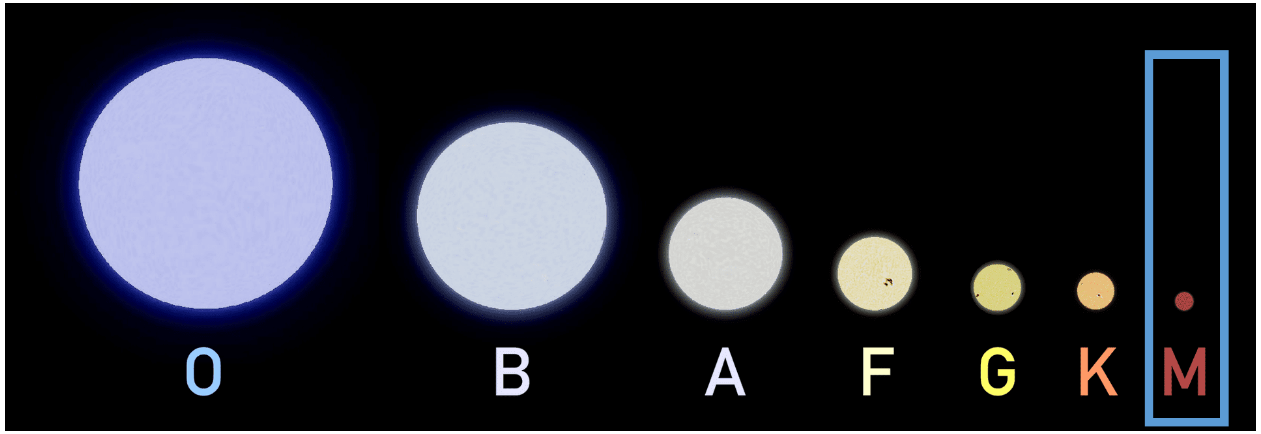
With more than 5600 exoplanets discovered, we found a huge diversity

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

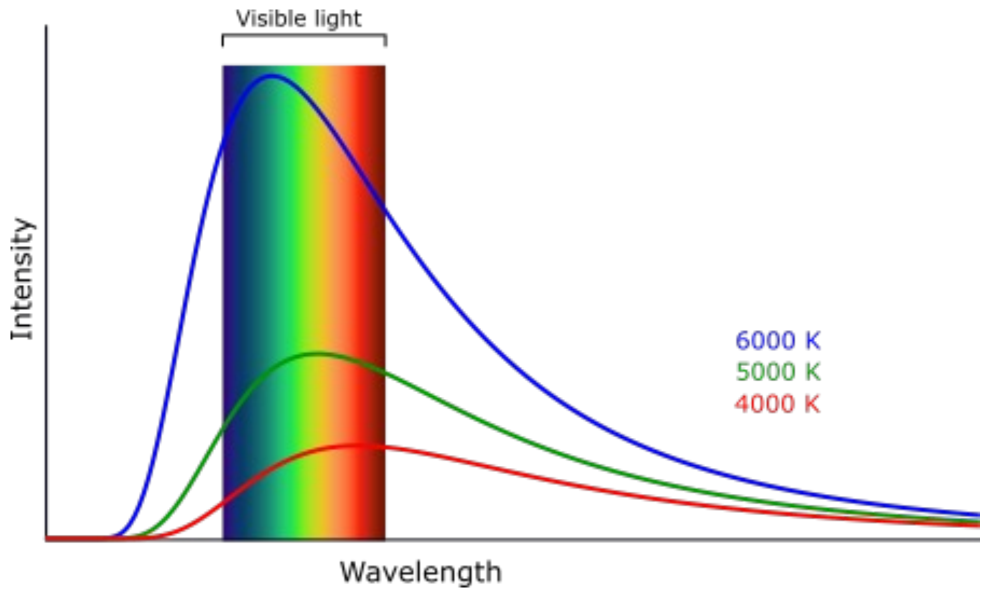
- On average more active than Solar-like stars
- Activity affects the shape of spectral lines inducing line profile distortion affecting the measured RV.

M dwarfs, activity effects

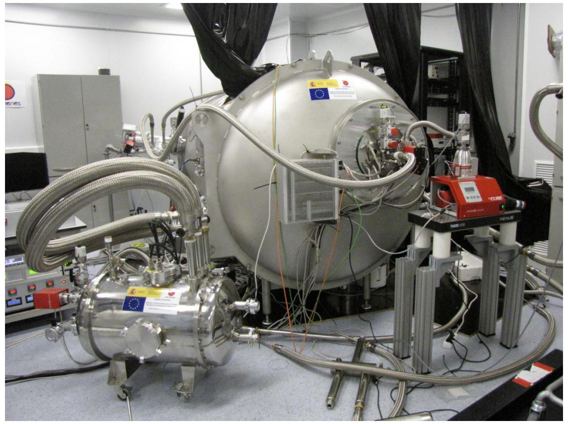
Rotational periods of M dwarfs often coincide with the orbital periods of planets in the expected habitable zone of these stars.

↓

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

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

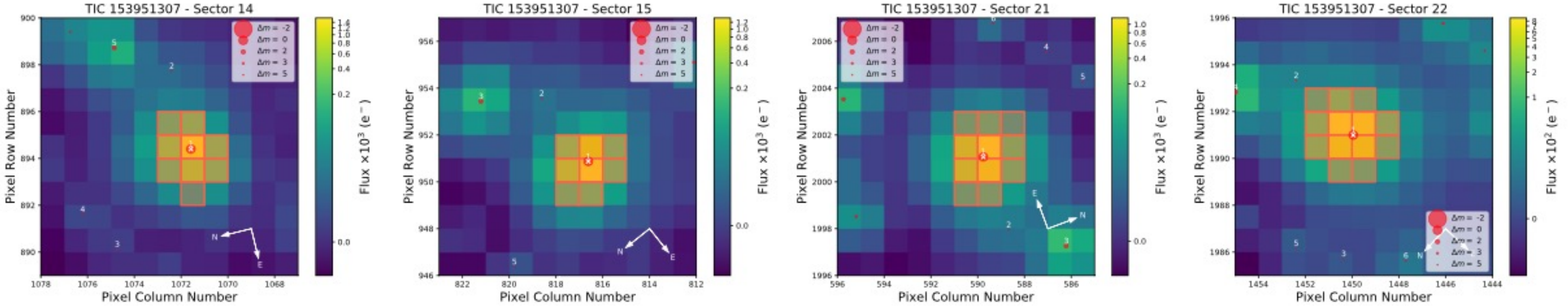
From 1 January 2016 to 31 Dicember 2020, CARMENES conducted a 750-night exoplanet survey targeting ~300 M dwarfs, including *TESS* targets, during Guaranteed Time Observations

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

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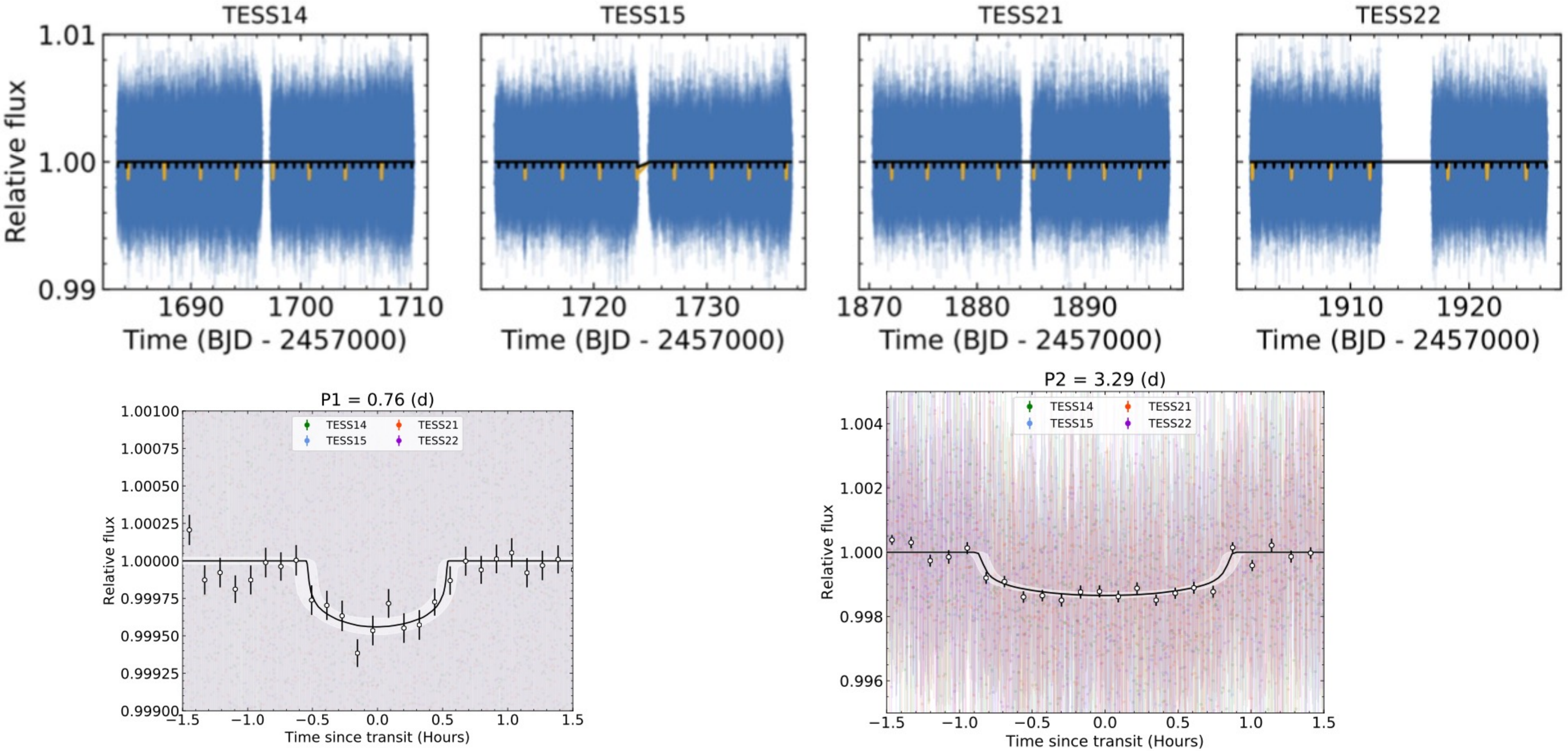
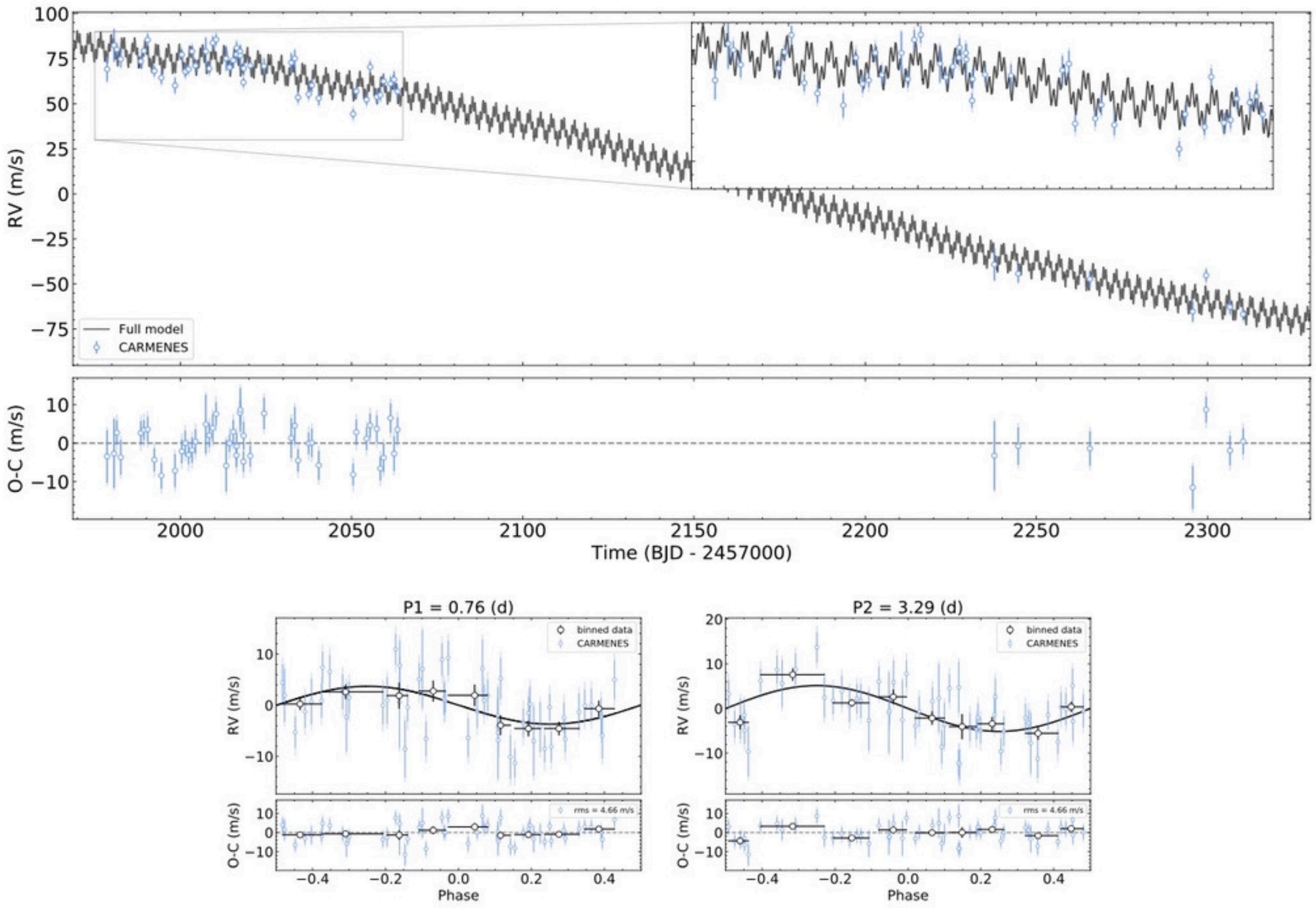
TOI-1238: Joint analysis *TESS* + CARMENES data

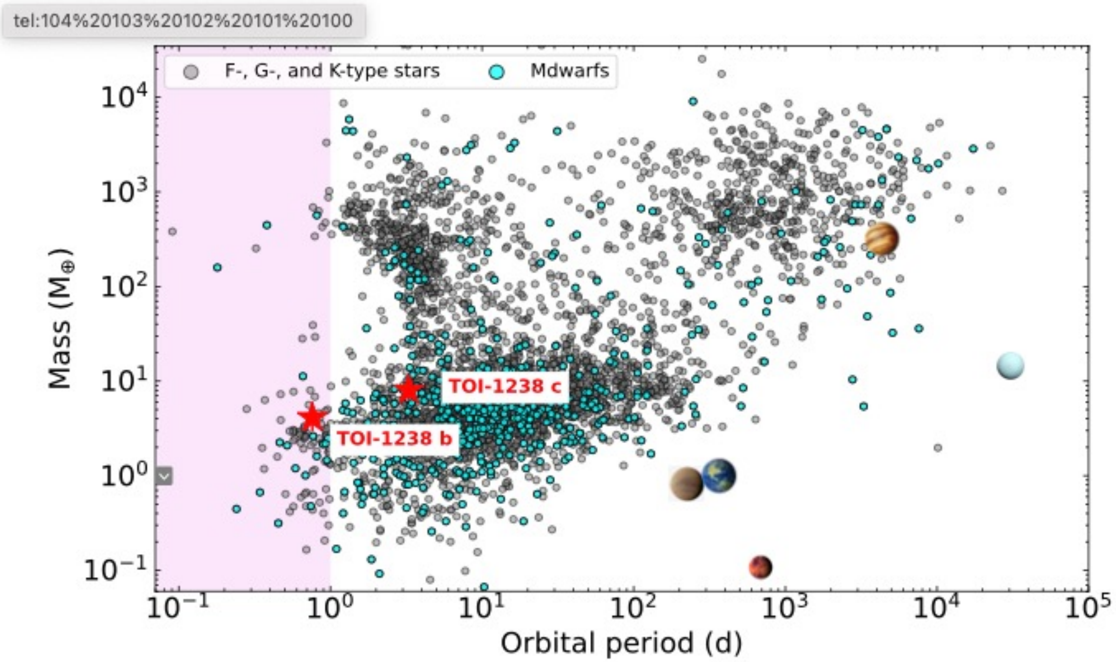


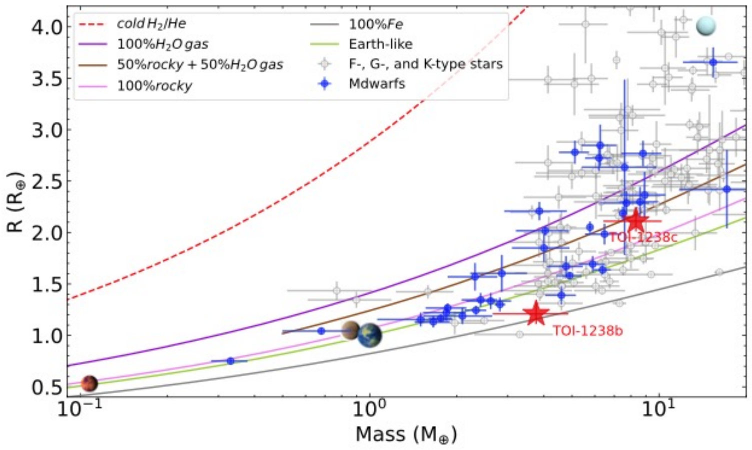
TOI-1238: Joint analysis *TESS* + CARMENES data

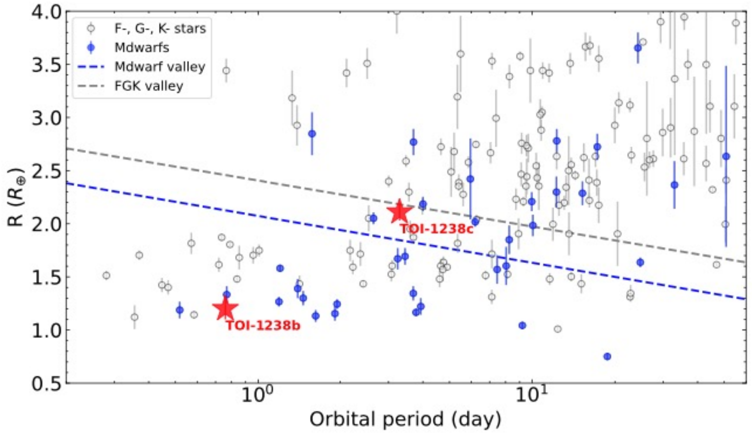


TOI-1238: Planetary parameters

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}	







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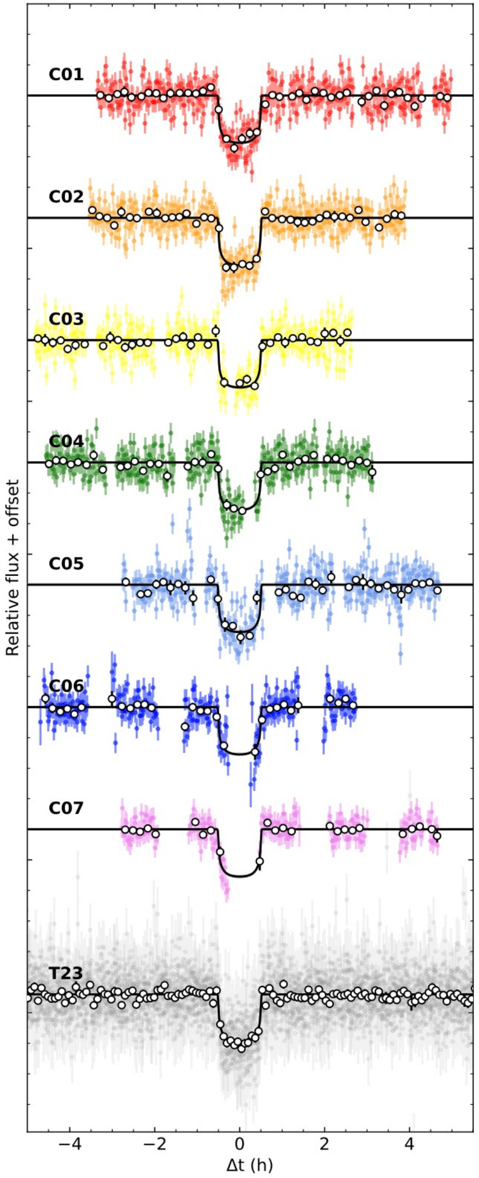
TOI-1238: Conclusions

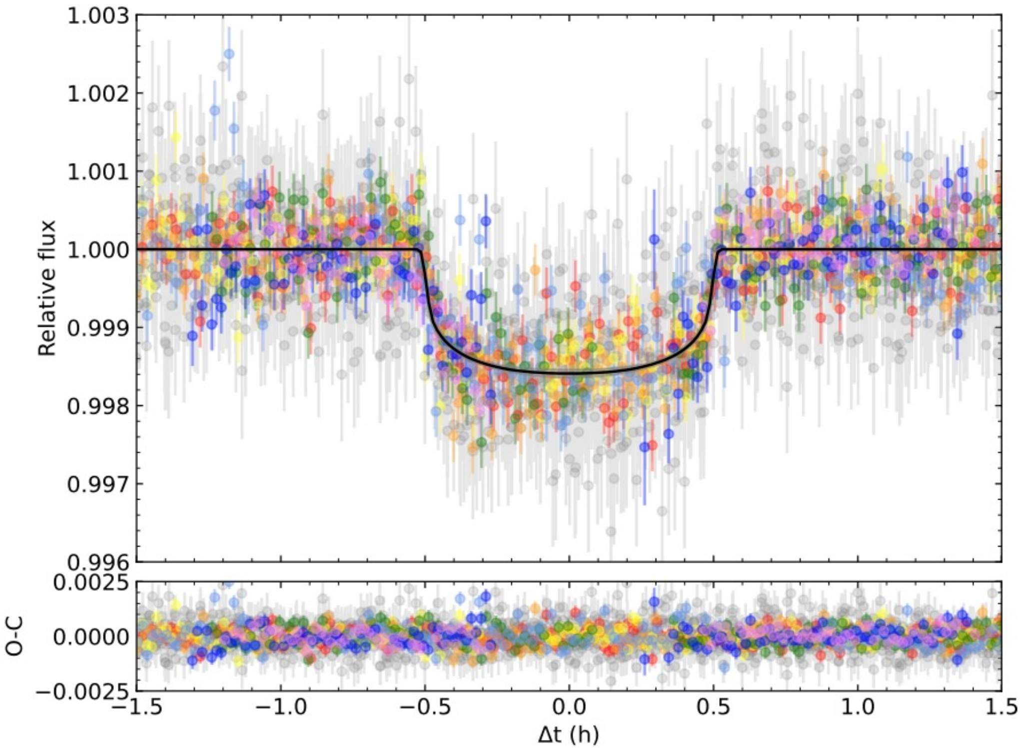
- Very interesting system to test innovative models for explaining theories of planet formation and evolution

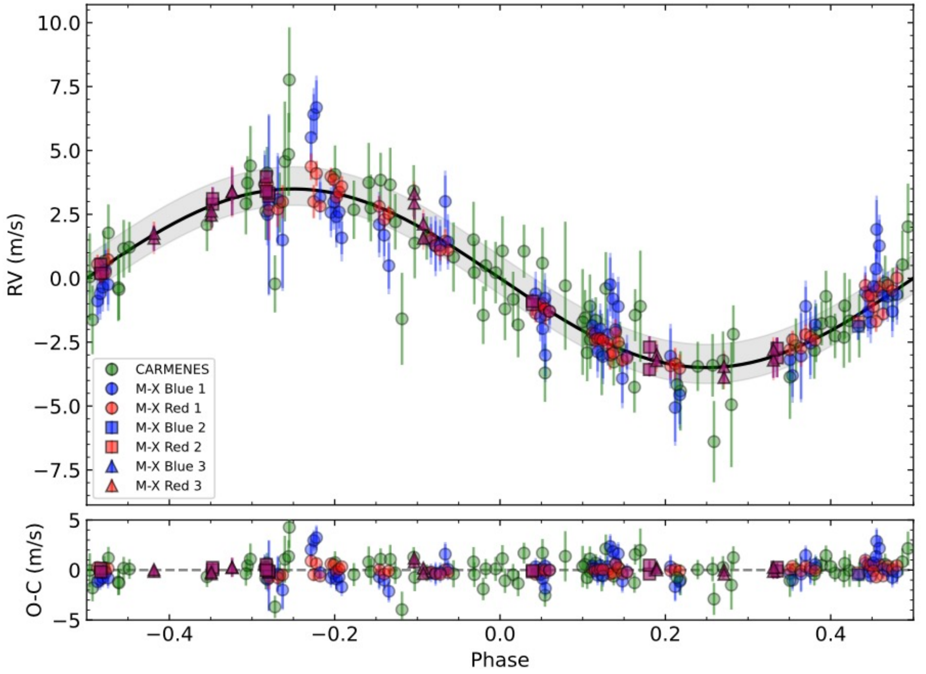
- System: M dwarf star with two transiting planets + a brown dwarf → not very abundant

- 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)

M dwarf, GJ 486 b (Trifonov et al. 2021)







- Nearby M3.5 V star (8 pc)
- Warm transiting rocky planet of about 1.3 $R_\oplus$ and 3.0 $M_\oplus$
- Ideal for both transmission and emission spectroscopy and for testing interior models of telluric planets.

Caballero et al. 2022

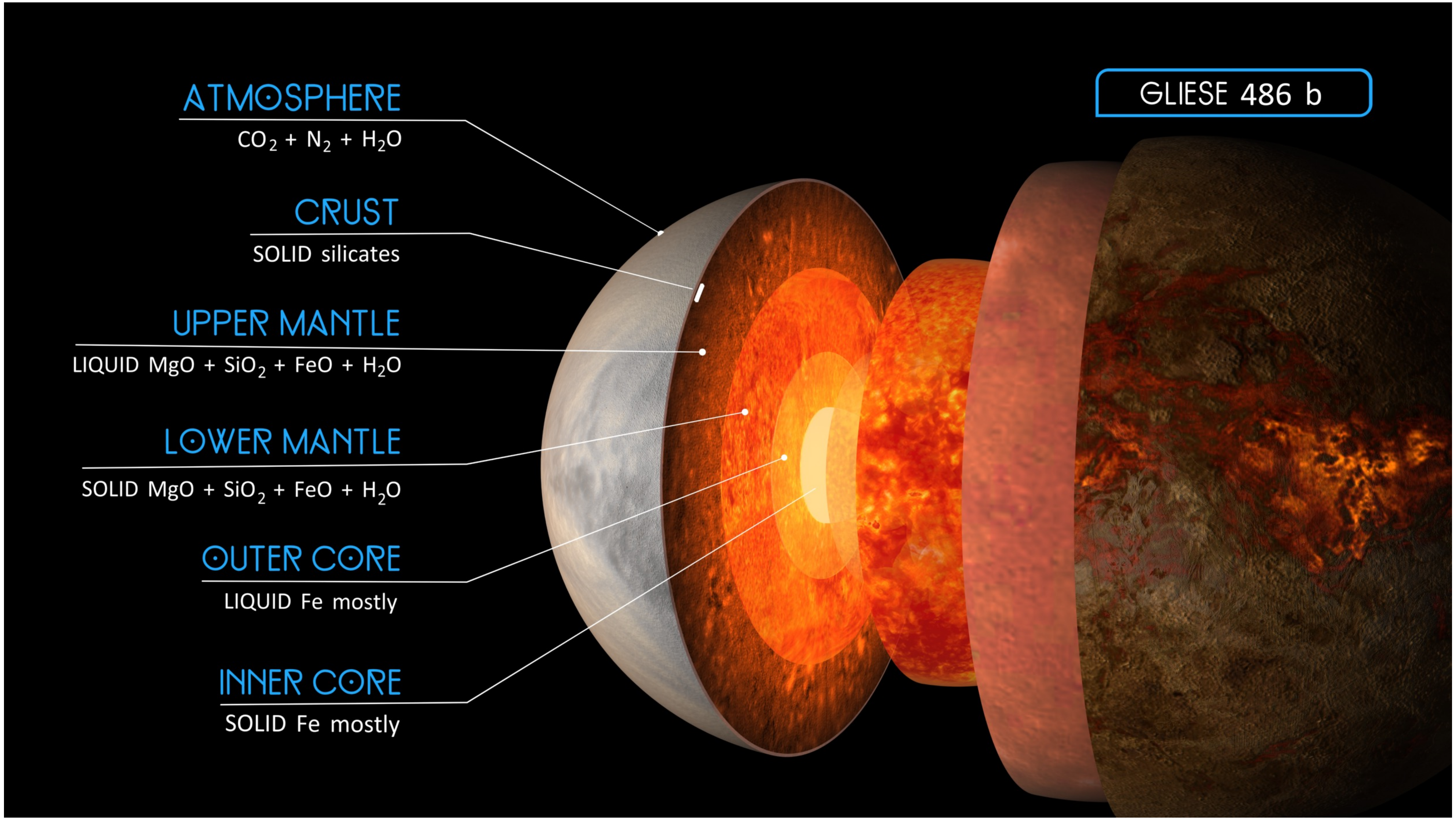
M dwarf, GJ 486 b

From accurate planet parameter (errors in M and R of 4%) and stellar parameters (R measured from interferometry)

↓

planet internal structure and composition:

- relatively small metallic core with respect to the Earth
- a deep silicate mantle
- a thin volatile upper layer



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M dwarfs, TOI-1470 a multiplanetary system

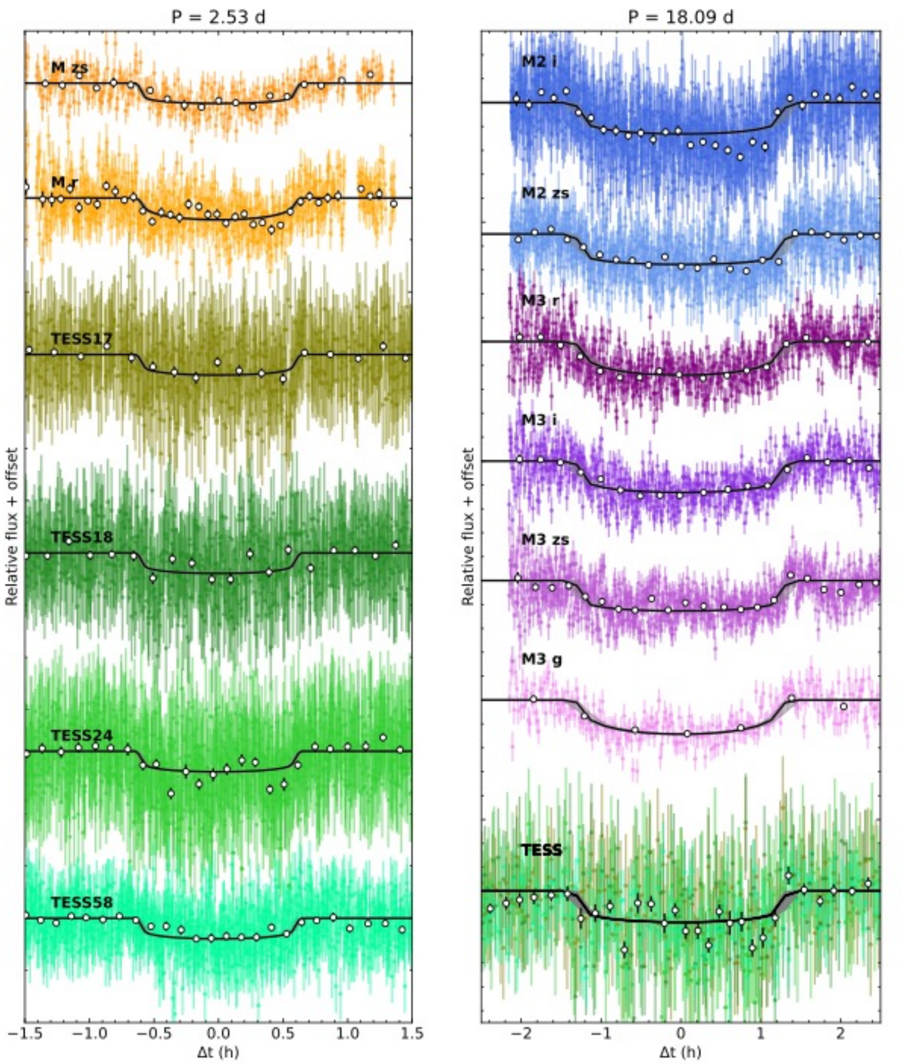
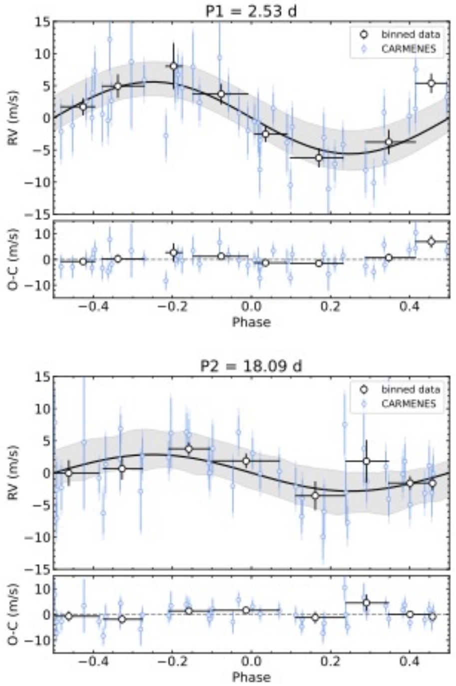
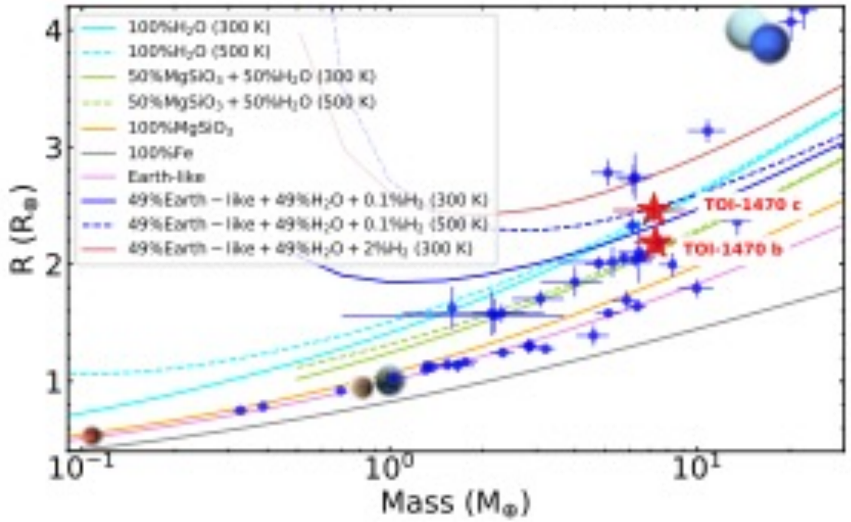


Fig. 13. Individual light curves folded in phase with the orbital periods of the transiting planets per filter or sector (colored points). The best joint fi is plotted as a black line. The white dots correspond to the binned photometric data. The *x*-axis represents the time computed from the mid-transi times as derived from the best joint fit.

<u>One planet</u> candidates via *TESS* data alert :
P1 = **2.53 d**

Follow up with CARMENES spectrograph





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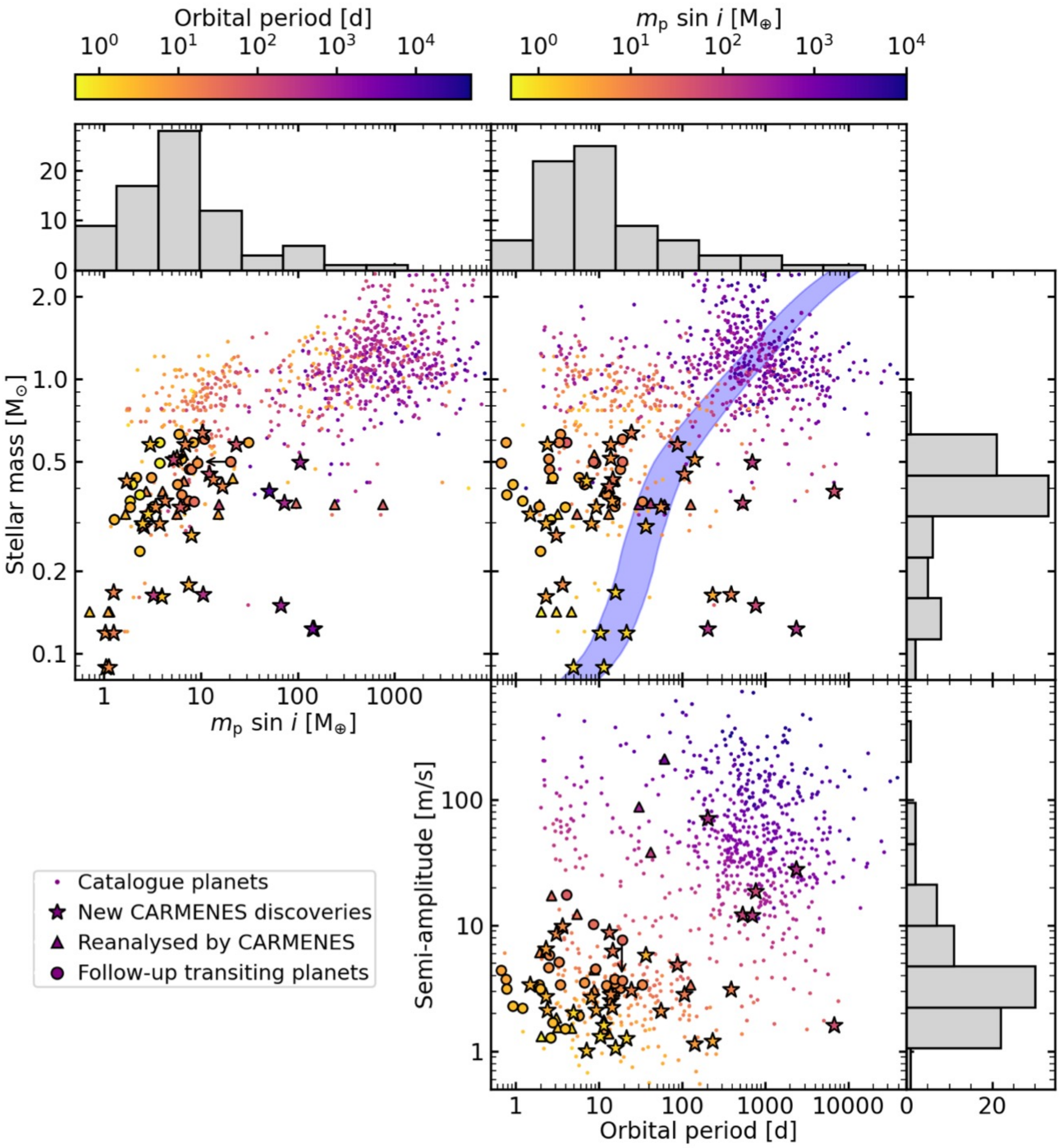
Summary: CARMENES DR1 exoplanet sample



- ▪ 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