The CARMENES search for exoplanets around M dwarfs:

Discovery of two super-Earth candidates in the inner edge of the habitable zone.

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IV IPARCOS Congress - 10 /12 /2025

Brief introduction

An exoplanet is any planet that orbits a star other than the Sun

M stars

- Habitable zone (HZ) near the star.
- Easier detection of Earth-like planets.

<u>Inconvenients</u>:

- High activity.
- Stellar rotation periods comparable to habitable-zone orbital periods.

Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical echelle Spectrographs

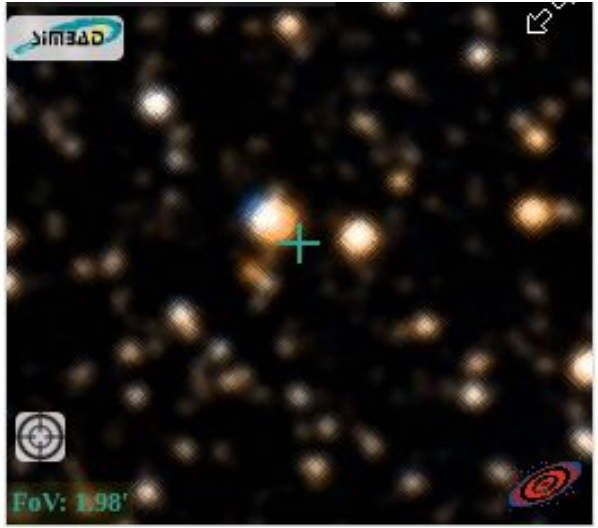
CARMENES

- We analyze the RVs of two targets obtained by the CARMENES consortium.

GJ XX

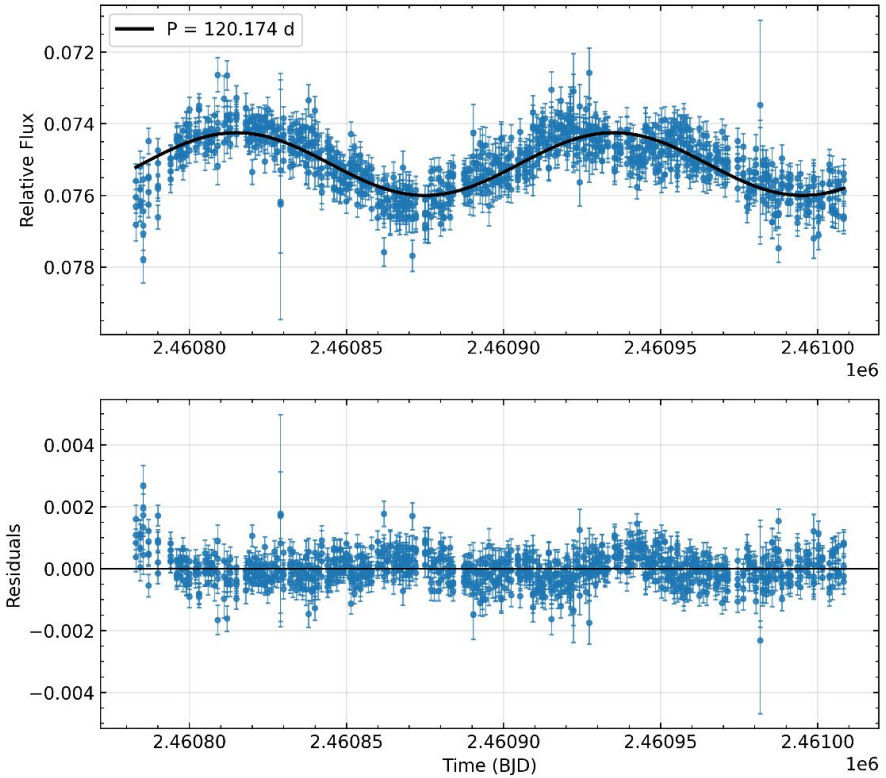
- GJ XX : M4.5 V
- d ≈10 pc

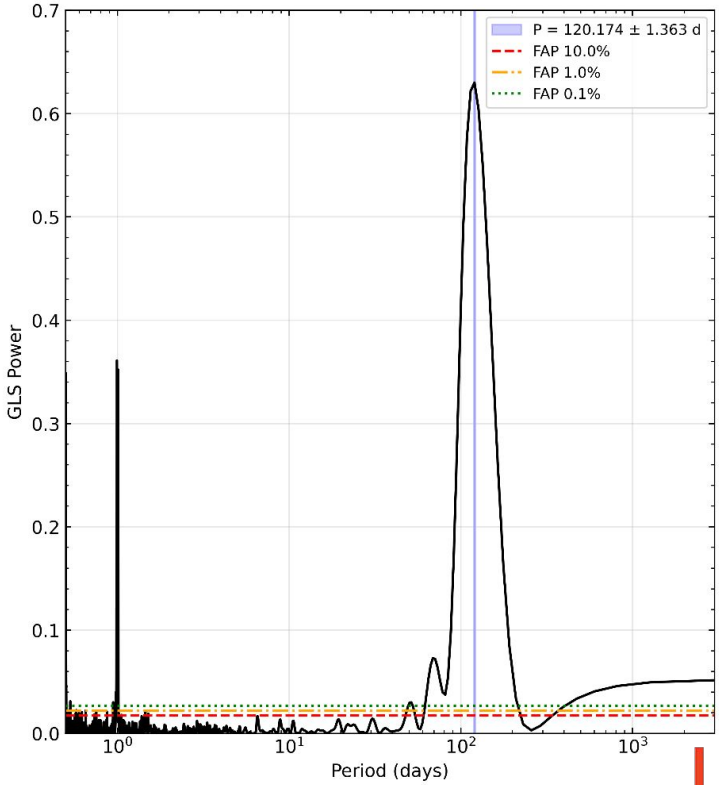
- $M = 0.18777 \pm 0.00943\ M_{\odot}$
- $T_{eff} = 3277 \pm 34$ K
- $\log g = 4.93 \pm 0.13$
- $[Fe/H] = -0.14 \pm 0.16$
- $v \sin i < 2$ km/s



Photometric analysis (LCO)

- Photometric data: 957 data
- Timespan: 225 d

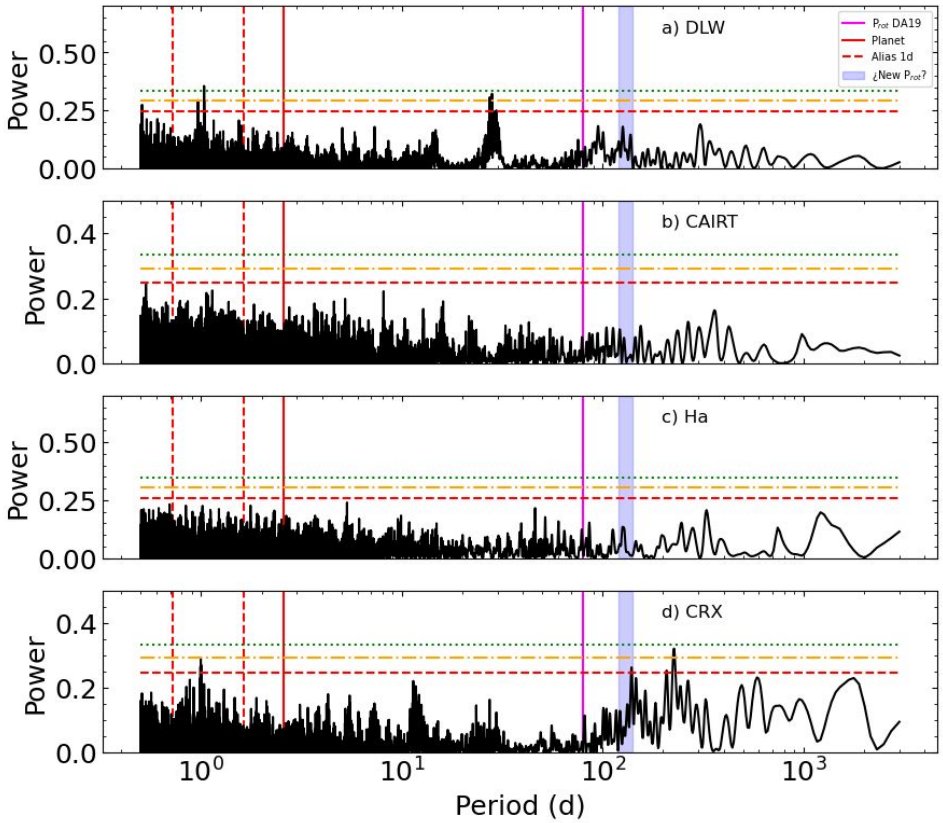




P_{rot} = 120.17 ± 1.36 d

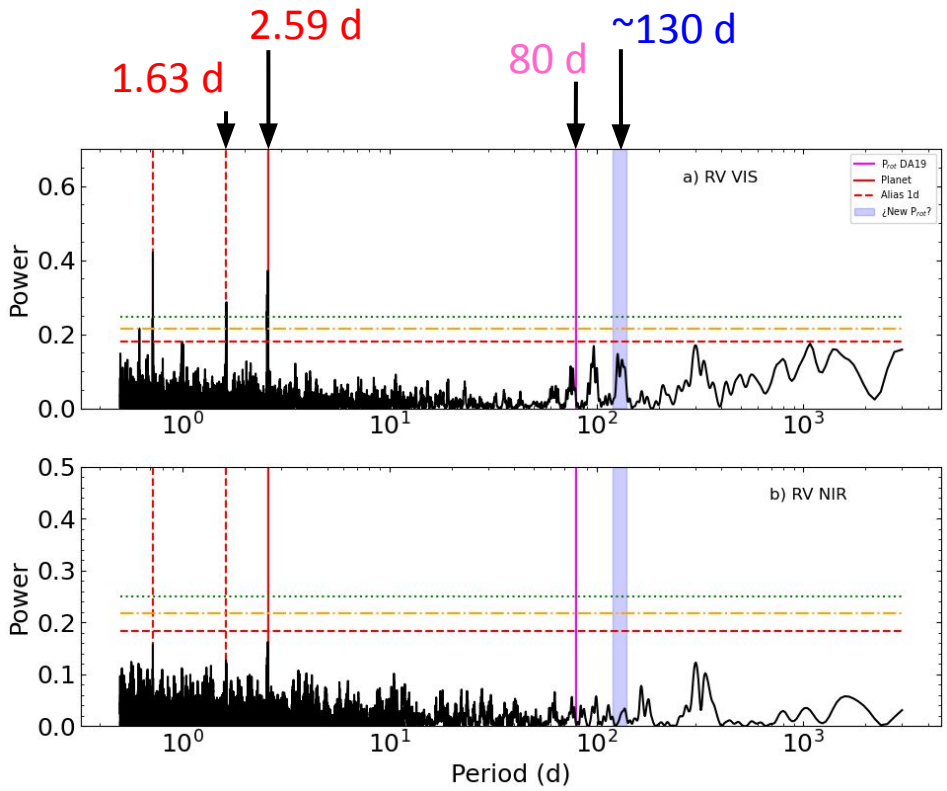
GJ XX : CARMENES data

- Activity indicators



RV VIS+NIR

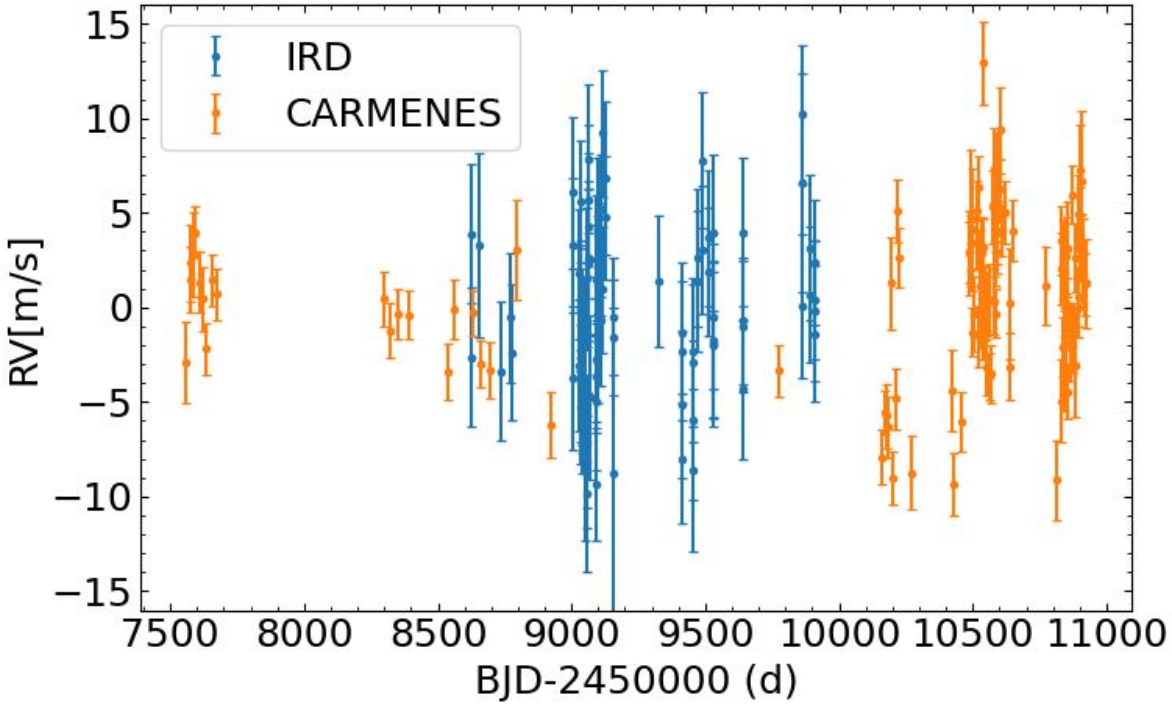
- CARMENES data: 115 data
- Timespan: 3378 d



CARMENES & IRD GJ XX

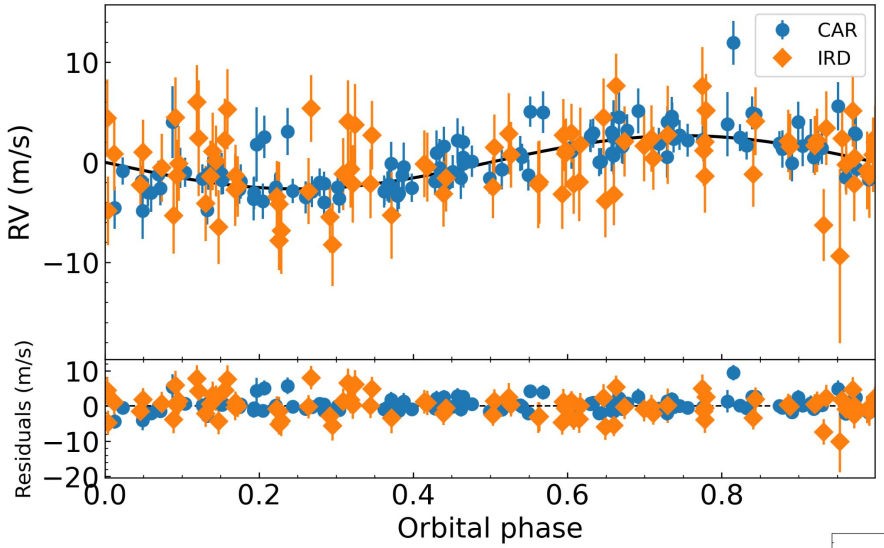
- CARMENES data: 115 data
- Timespan: 3378 d

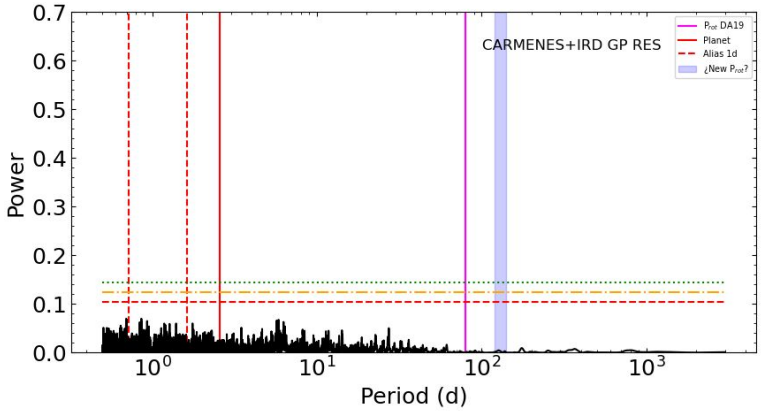
- IRD data: 89 data
- Timespan: 1283 d



CARMENES+IRD GJ XX

- RV+Gaussian Process (GP) analysis





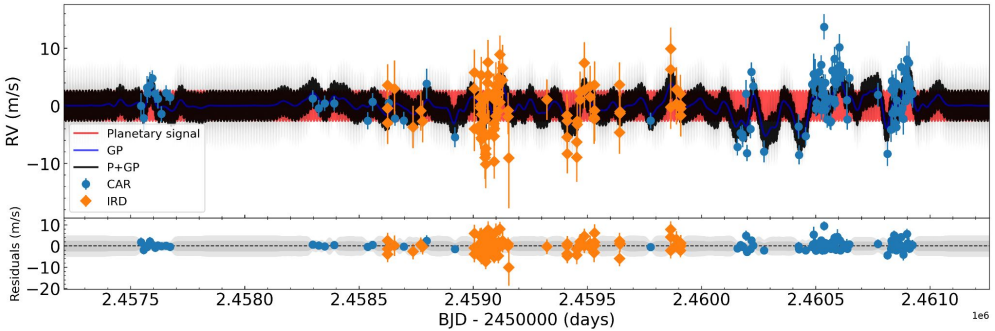
P_{pl}= 2.5862 ±0.0001 d BIC=-1712.0725

K_b = 2.65± 0.25 m/s

Msini = 2.94 ± 0.18 $M_\oplus$

P_{rot}= 135 ± 33 d

ln likelihood = 879.9678



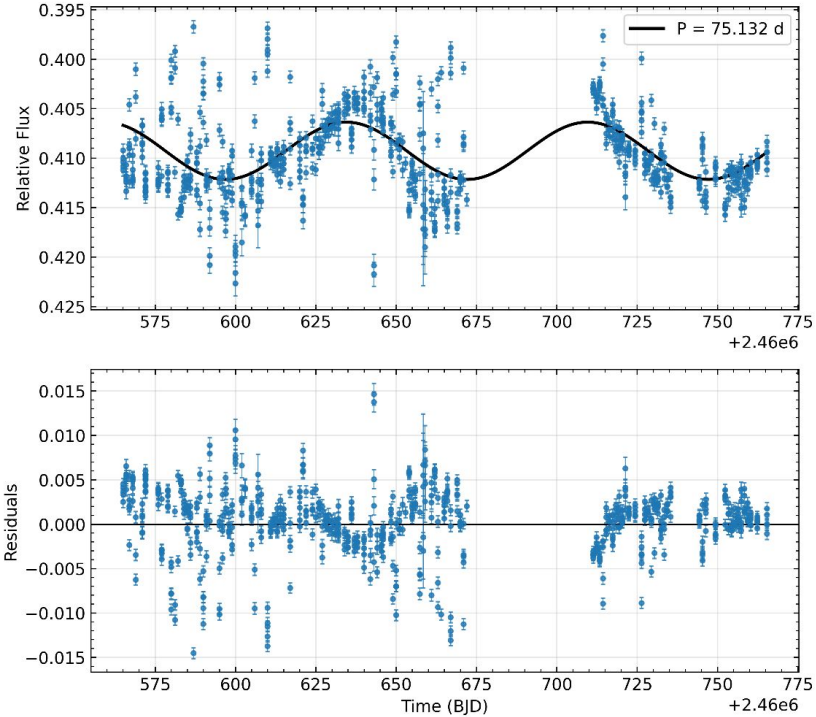
Ross XX

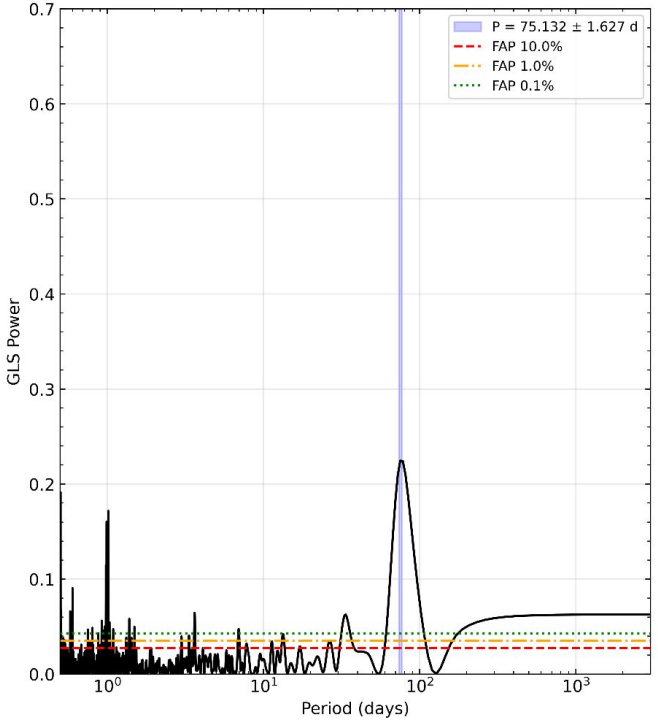
- Ross XX : M3.0 V
- d ≃12 pc

- M = 0.3484 ± 0.0109 $M_{\odot}$
- T_{eff} = 3501 ± 23 K
- log g = 5.04 ± 0.11
- [Fe/H] = -0.19 ± 0.1
- vsin i < 2 km/s

Photometric analysis (LCO)

- Photometric data: 595 data
- Timespan: 200 d

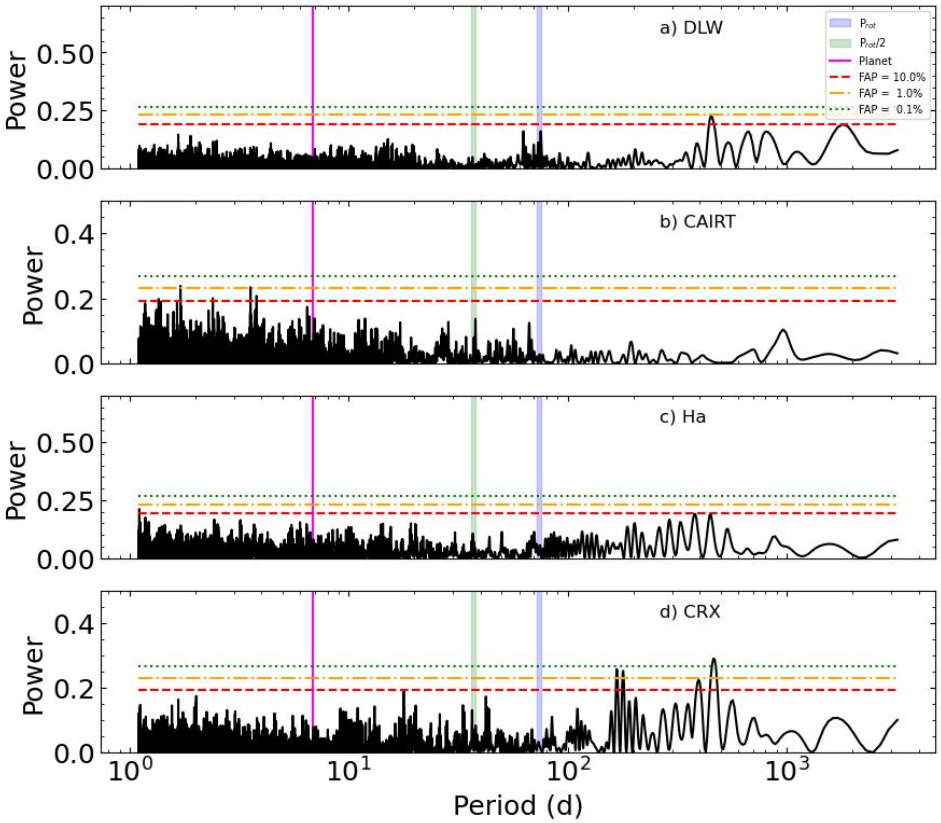




P_{rot} = 75.13 ± 1.62 d

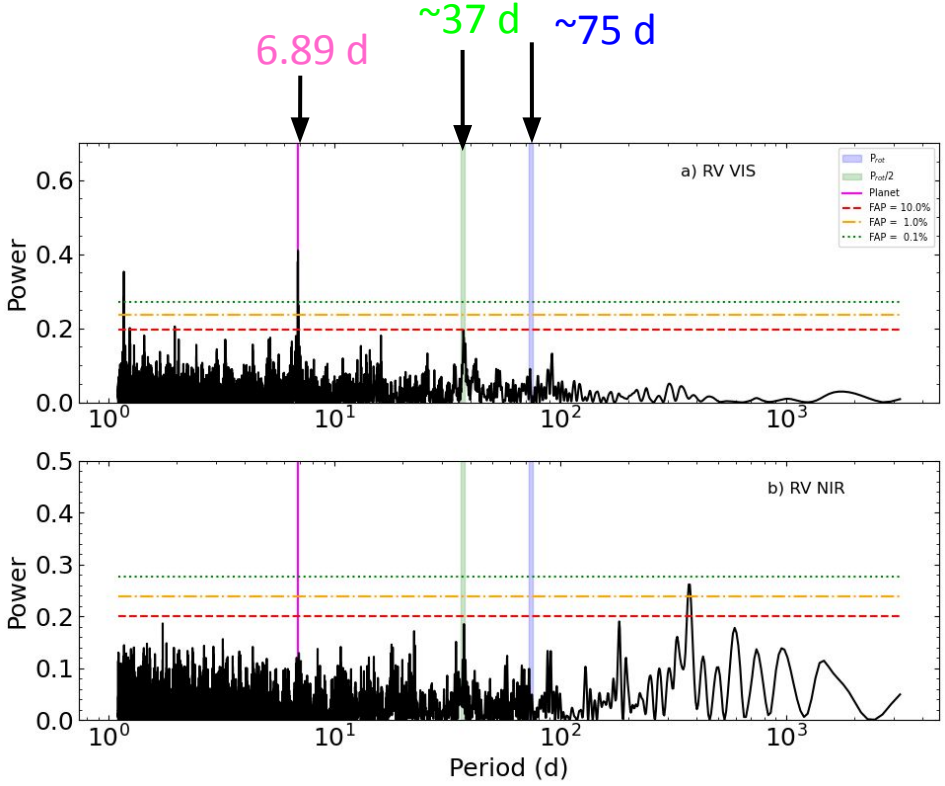
Ross XX : CARMENES data

- Activity indicators



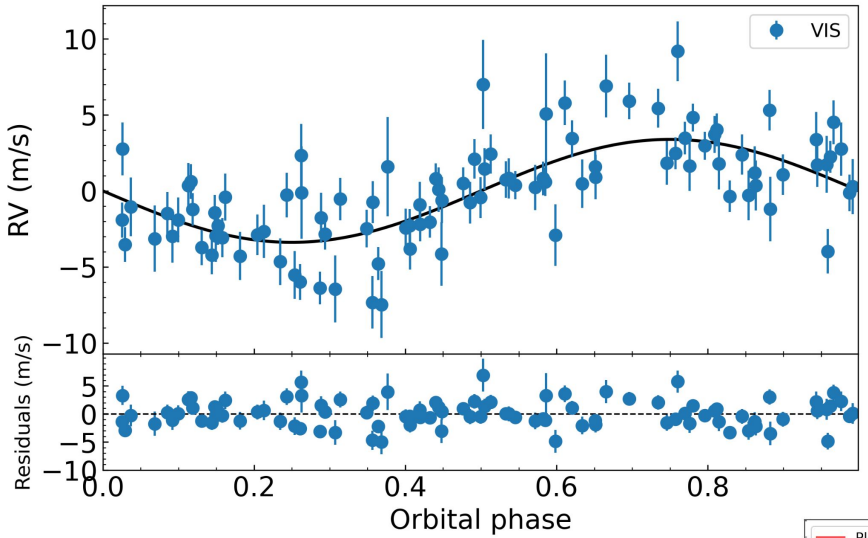
RV VIS & NIR

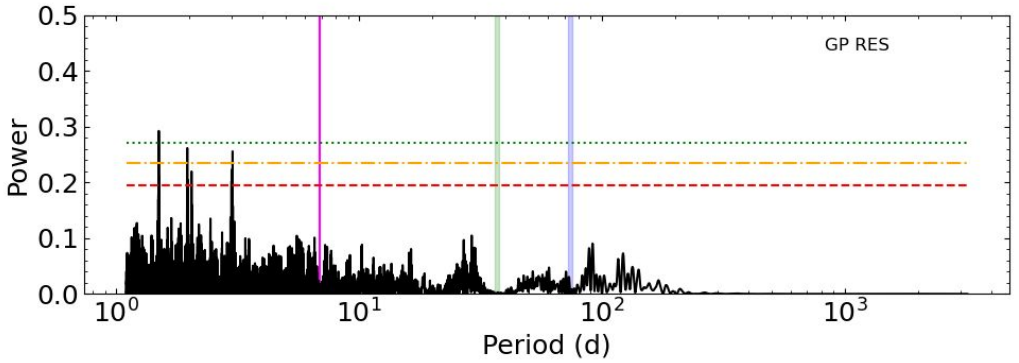
- CARMENES data: 98 data
- Timespan: 3524 d



CARMENES Ross XX VIS

- RV+Gaussian Process (GP) analysis at $P_{rot}/2$





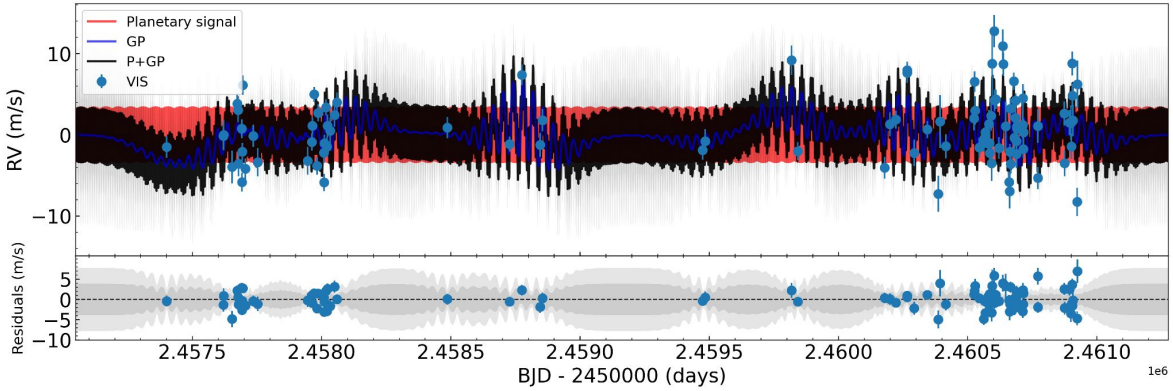
P_{pl}= 6.8877 ±0.0003 d BIC= -726.4042

K_b = 3.38 ± 0.27 m/s

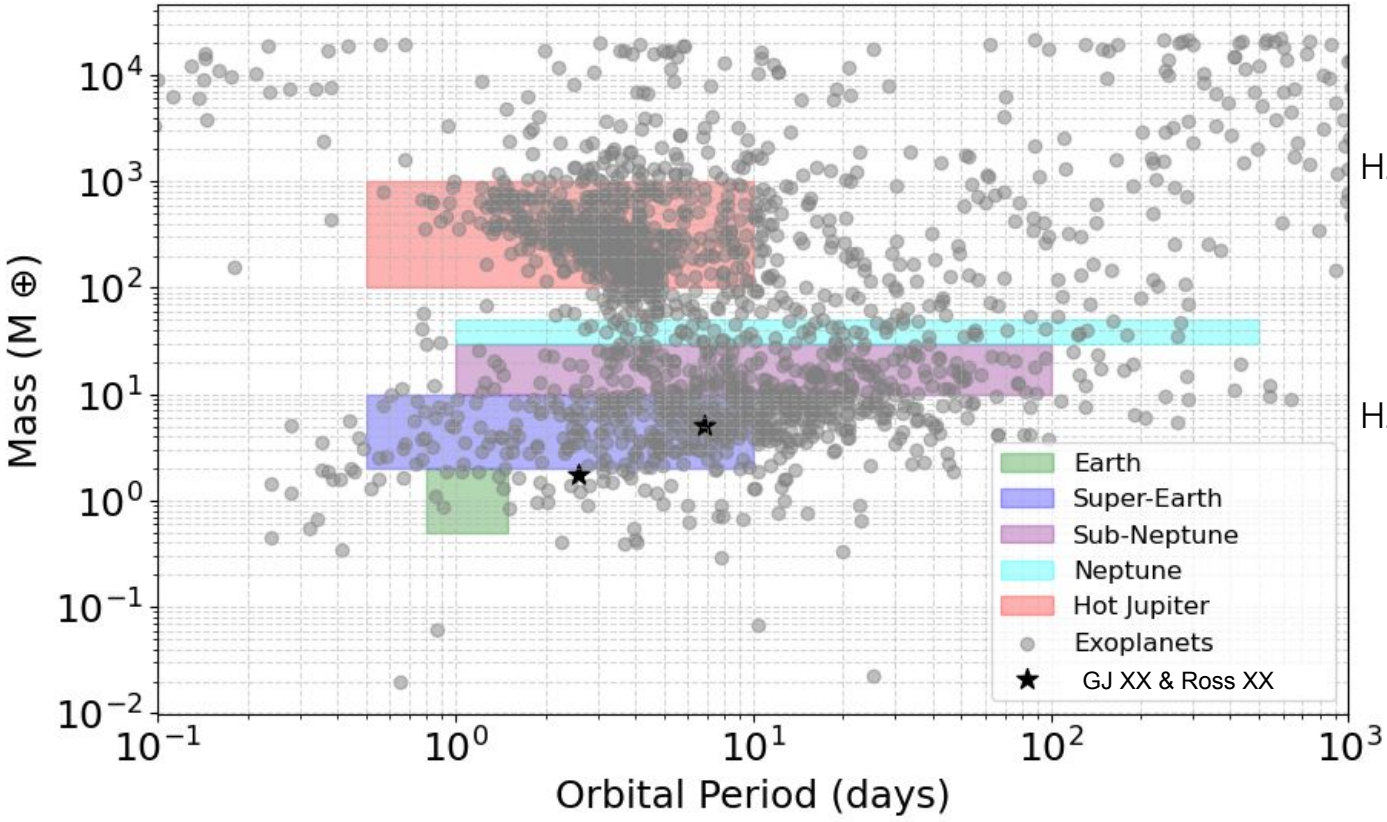
Msini = 5.07 ± 0.40 $M_\oplus$

$P_{rot}/2$= 38.35 ± 0.80 d

ln likelihood = 381.5420



Mass-Period of GJ XX & Ross XX



HZ of GJ XX: 10.7 —> 45.5 d

HZ of Ross XX: 21.9 —> 91.5 d

Conclusions

- We determined both rotational period of the stars
- For both GJ XX and Ross XX, the best model is 1pl+GP.
- There is no counterpart of the candidate planetary signals in any activity indicator.
- We found two super-Earths at the inner edge of their star’s HZ.


Thank you all for your time!
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Gaussian process (GP)

GP approach —> Quasic-Periodic Kernel:

$$\gamma_{QP}(t_i, t_j) = A^2 \exp\left\{ -\frac{\sin^2[\pi(t_i - t_j)/P_{GP}]}{2\lambda_p^2} - \frac{(t_i - t_j)^2}{2\lambda_e^2} \right\}$$

- P_{GP} (Stelar rotational period)
- λ_e (Lifespan of the active regions)
- λ_p (Active region distribution)

RV+GP analysis (planet+rotation) ⟶ $\mathrm{RV} = A_0 G(t) + A_1 \dot{G}(t)$

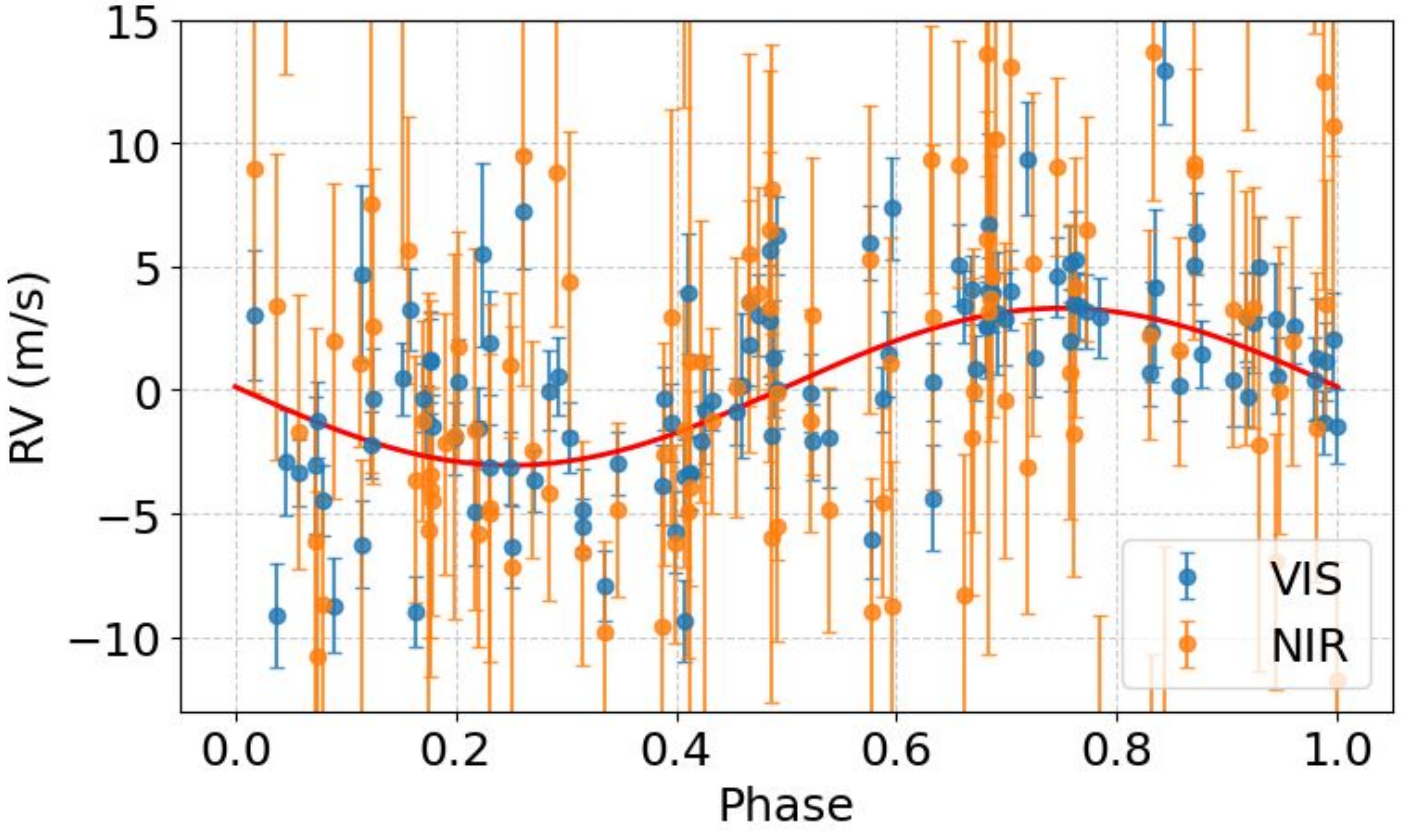
Multi-GP approach —> Quasic-Periodic Kernel:

Simultaneous fit RV + activity ⟶

$$\mathrm{RV} = A_0 G(t) + A_1 \dot{G}(t)$$
$$\mathrm{H}_\alpha = A_2 G(t) + A_3 \dot{G}(t)$$

CARMENES GJ XX VIS & NIR

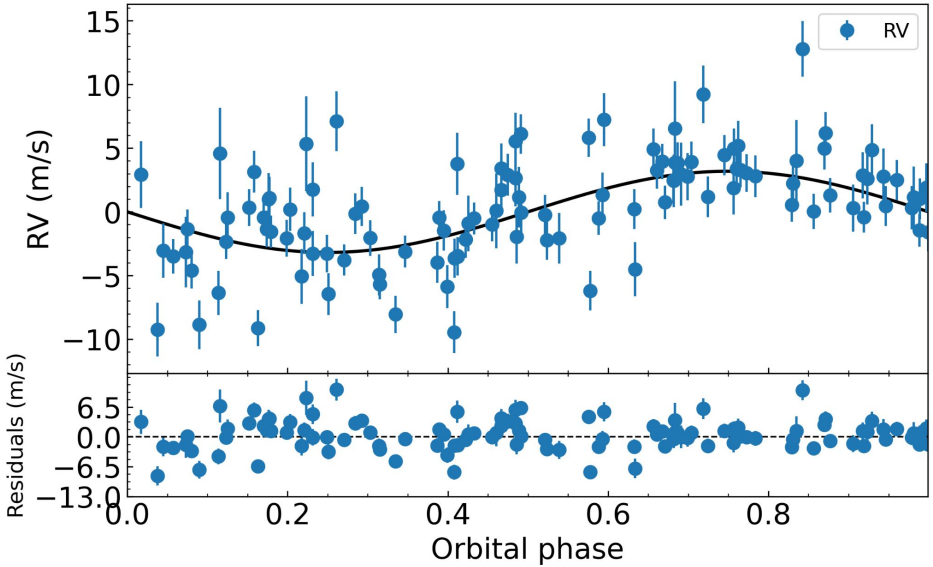
- CARMENES VIS & NIR RVs in 2.58d phase

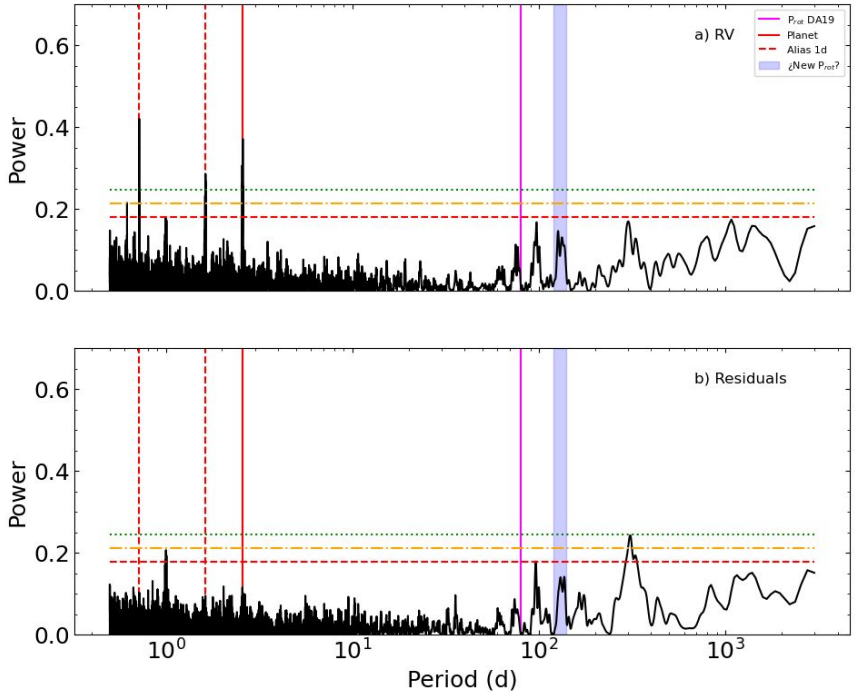


K=3.2 m/s

CARMENES GJ XX VIS

- Classic Keplerian fit e=0





P_{pl}= 2.5863 ±0.0008 d

K_b = 3.18 ± 0.21 m/s

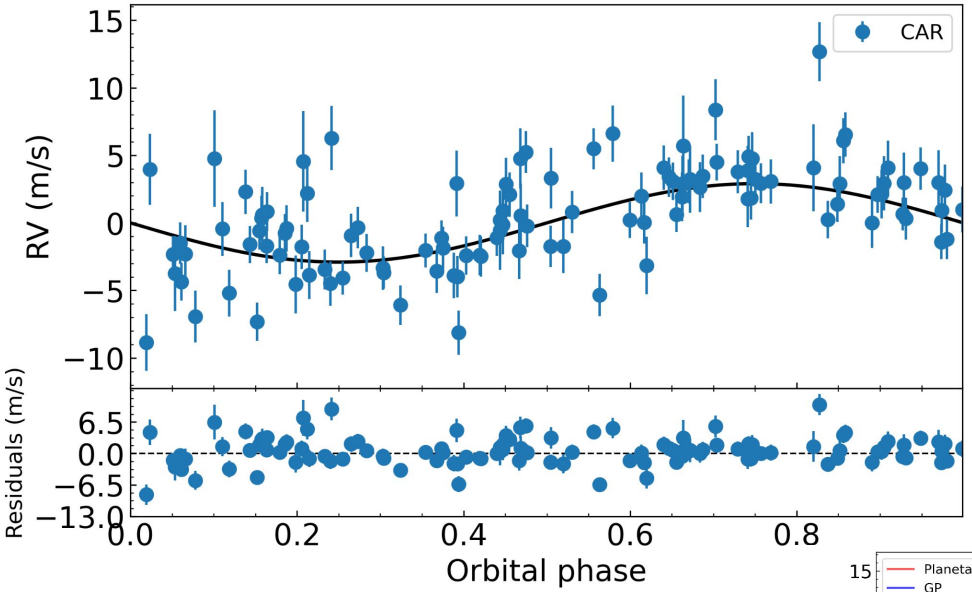
Msini = 2.32 ± 0.16 $M_\oplus$

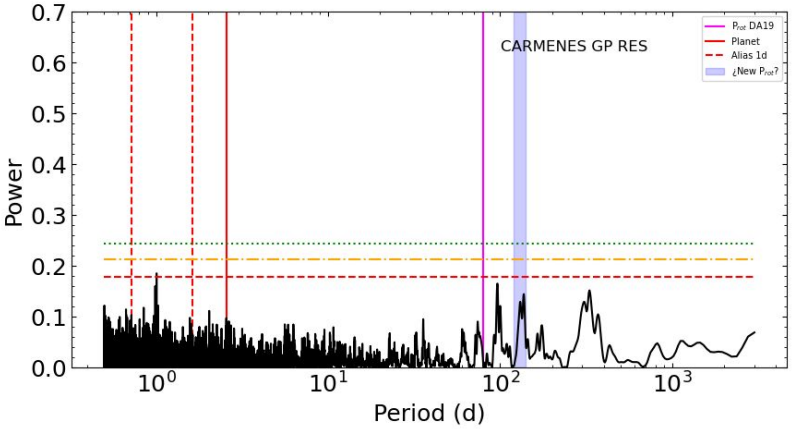
ln likelihood = 436.5513

BIC=-854.1228

CARMENES GJ XX VIS

- Classic GP fit CARMENES VIS RVs





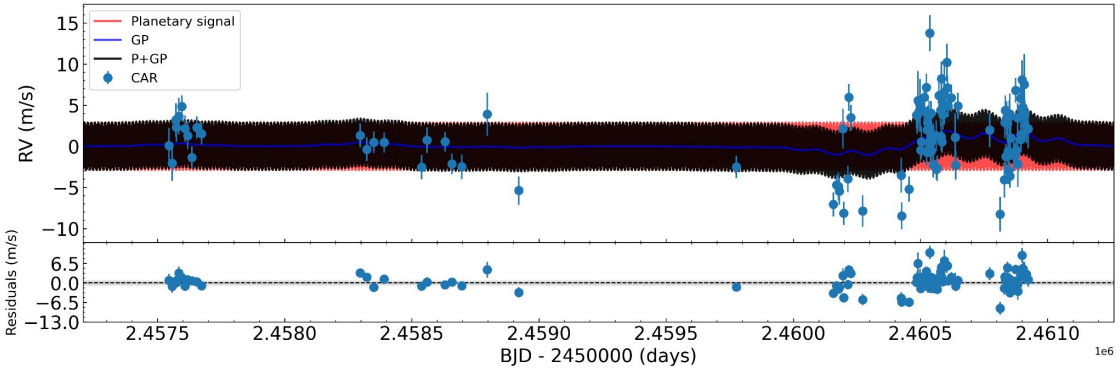
P_{pl}= 2.5863 ±0.0001 d BIC=-872.9293

K_b = 2.90 ± 0.27 m/s

Msini = 2.11 ± 0.20 $M_\oplus$

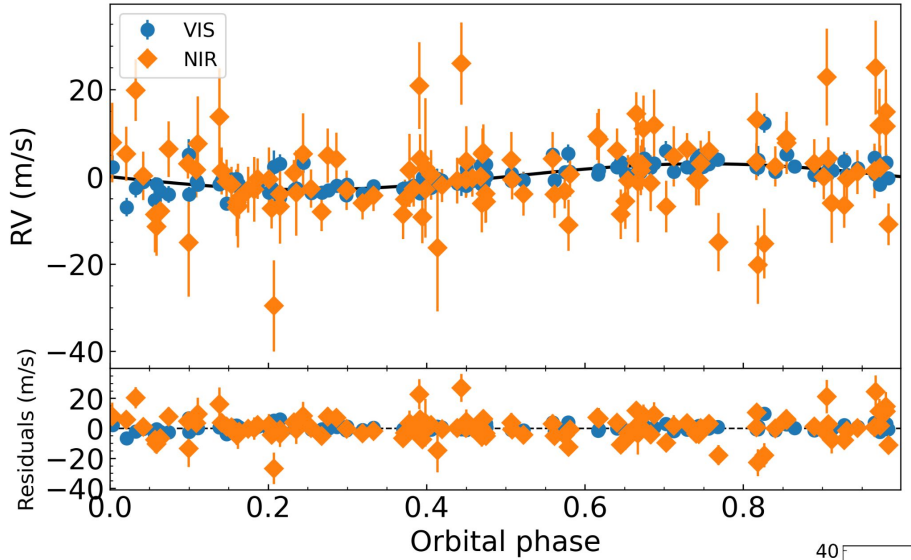
P_{rot}= 154 ± 33 d

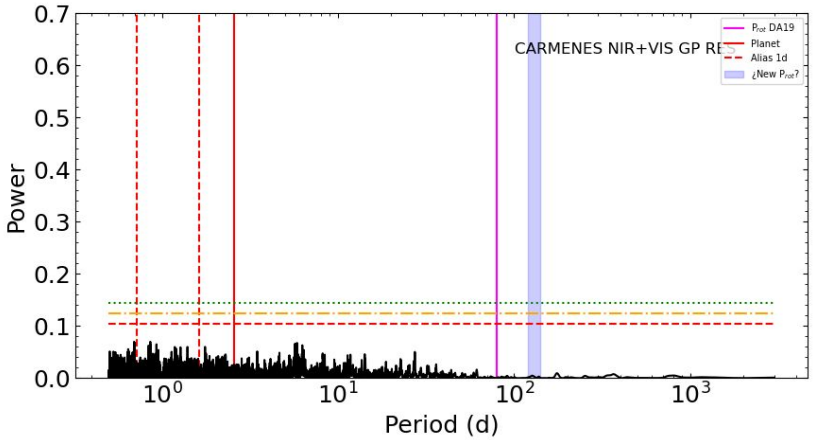
ln likelihood = 457.8168



CARMENES GJ XX VIS & NIR

- Classic GP fit CARMENES VIS & NIR RVs





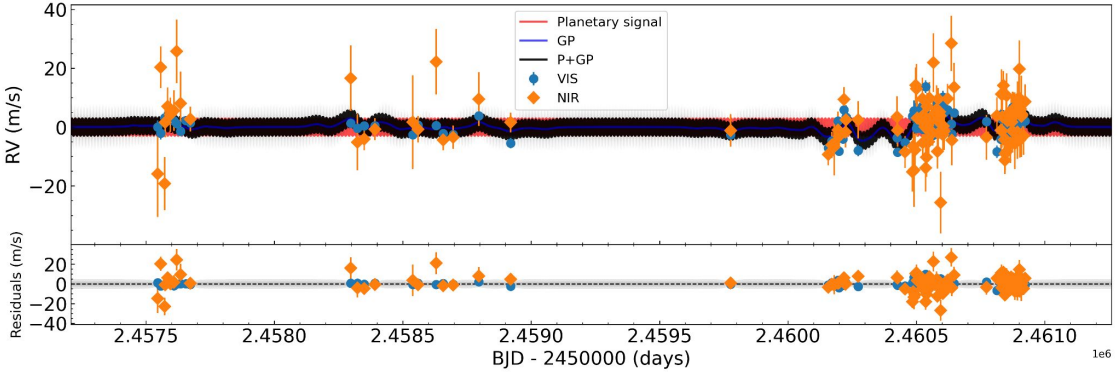
P_{pl}= 2.5862 ±0.0001 d

K_b = 2.96 ± 0.25 m/s

Msini = 2.16 ± 0.19 $M_\oplus$

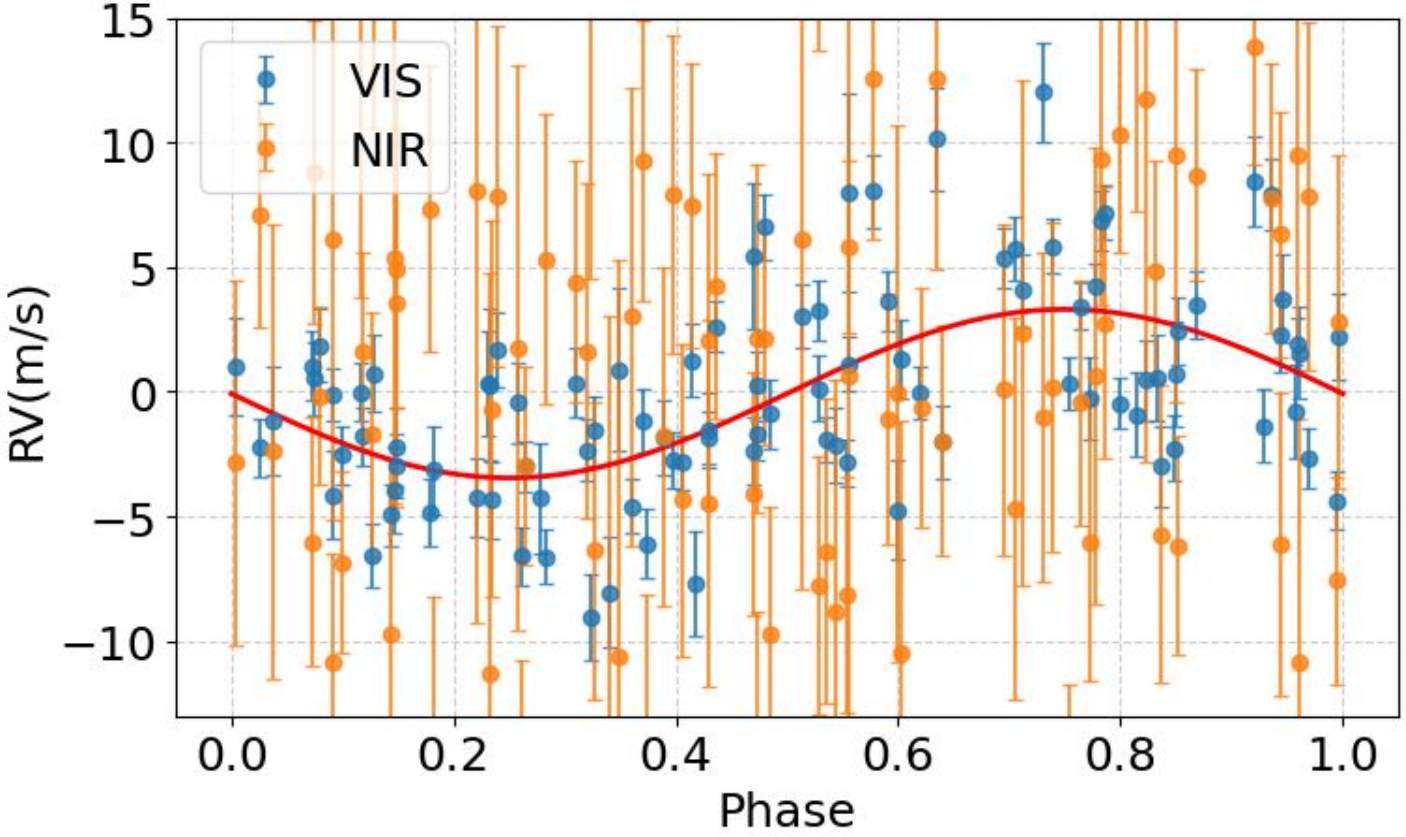
P_{rot}= 146 ± 28 d

ln likelihood = 911.1401



CARMENES Ross XX VIS & NIR

- CARMENES VIS & NIR RVs in 6.89d phase



K=3.81 m/s