A super-Earth planet orbiting an early-M dwarf

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&

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On behalf of CARMENES consortium

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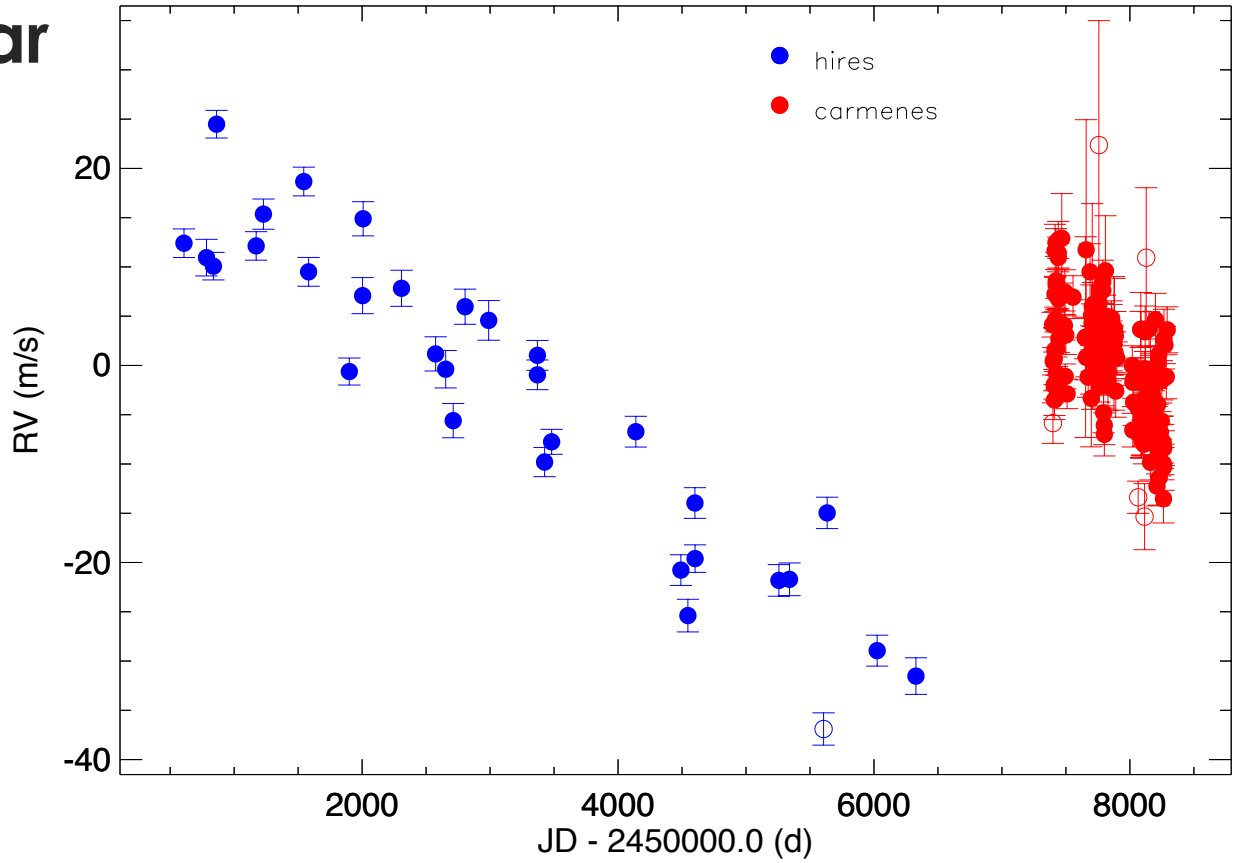
RV data

- **159** RVs from **CARMENES**:

  $\Delta t = 2.06$ a
- **32** RVs from **HIRES** (Tal-Or et al. 2018):

  $\Delta t = 20.65$ a
- **3-4 HIRES RVs per year**

Trend —> orbital motion around the center of mass of the stellar binary



Stellar binary: Orbital solution

- **551** astrometric measurements (WDS, Mason et al. 2001) available, time interval: 1821-2017 (**195.78 a**)

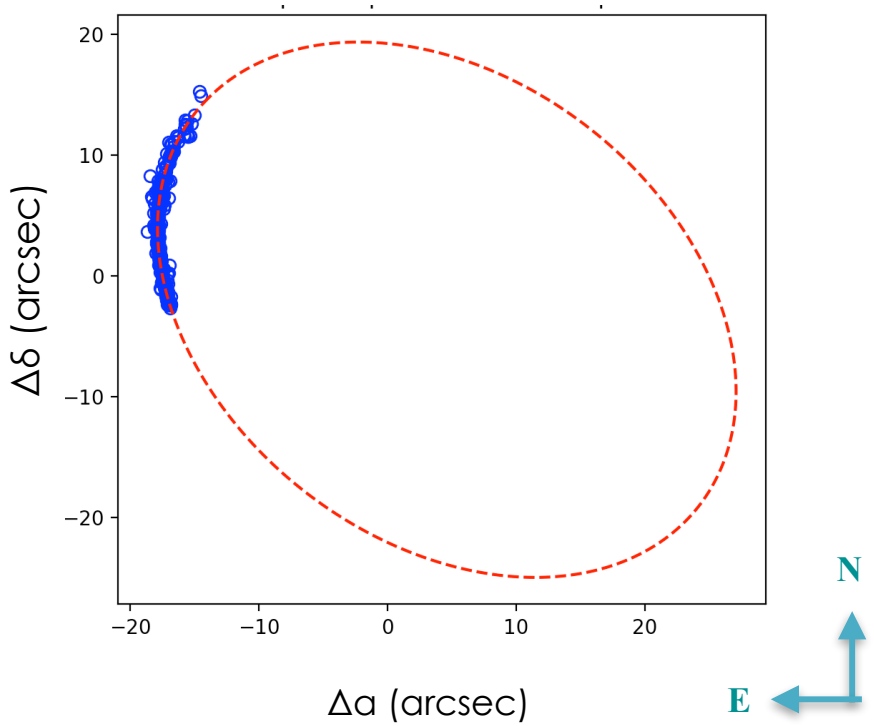
- **32** HIRES's RVs over a period of **20 a** (Tal-Or et al. 2018) —> absolute RVs calibrated (Nidever et al. 2002)

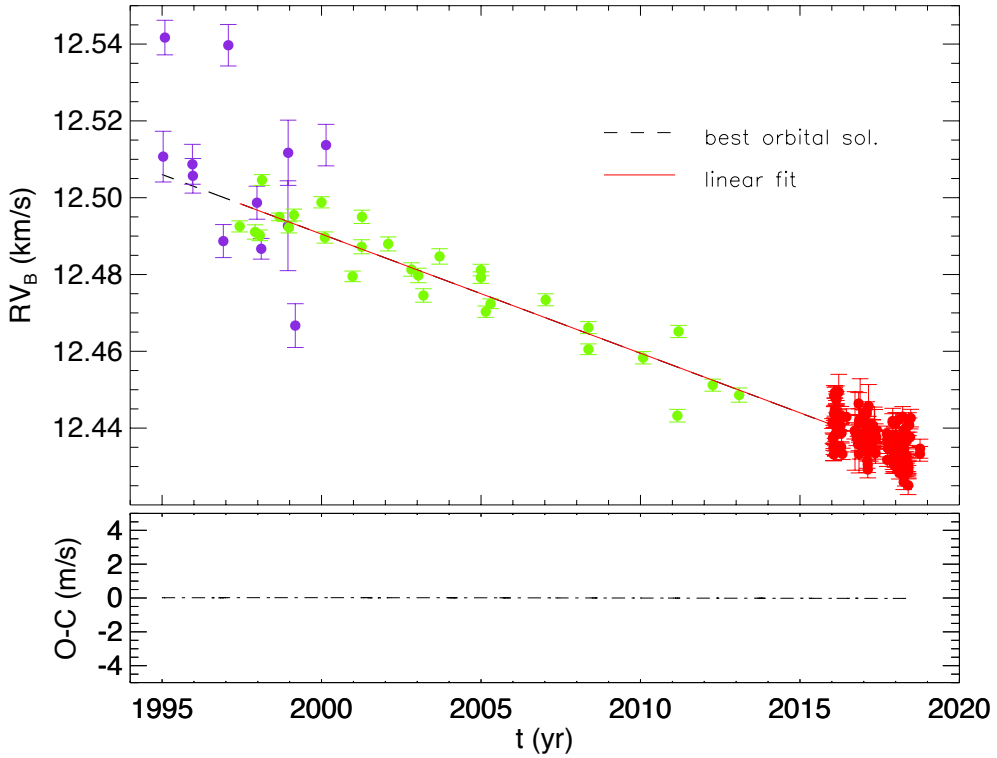
  Results: Evaluating and fitting model using MCMC

- q ~ 1 —> Teff, Lbol and SpT similar
- Total mass ± error
- a ≥ ρ gaia
- Orbital solution —> slope HIRES
- Ellipse —> reproduce astrometric data

To correctly remove the Keplerian trend due to the binary system

Stellar binary: Orbital solution





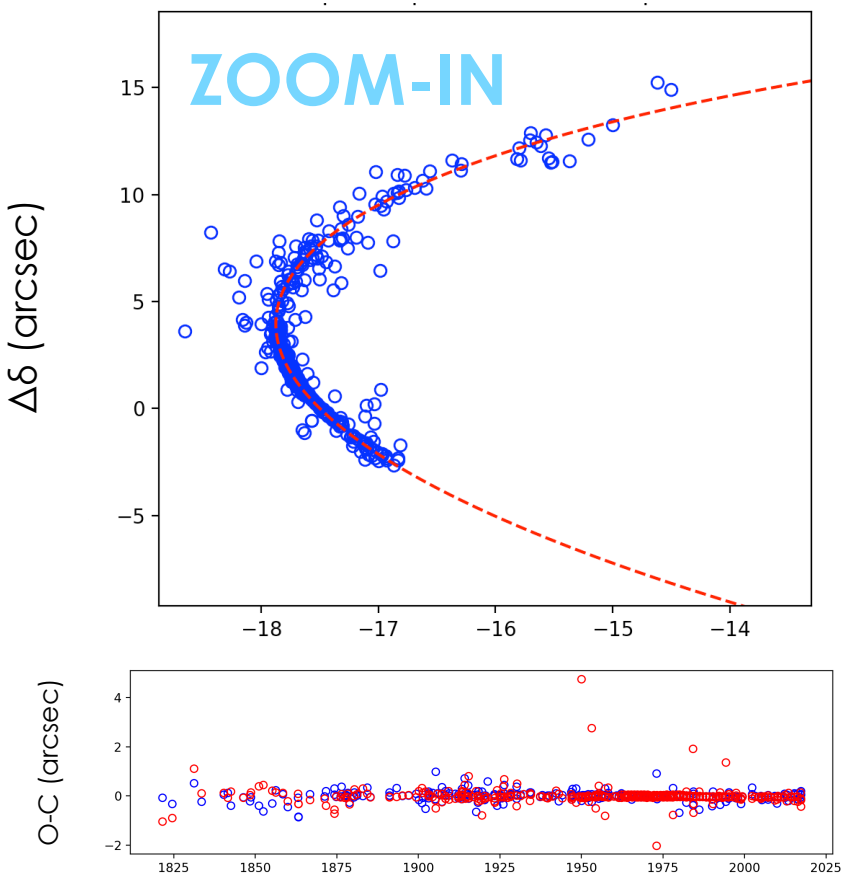
- Astrometric data far for covering the entire orbit (20%)
- Very few RVs data (2%)

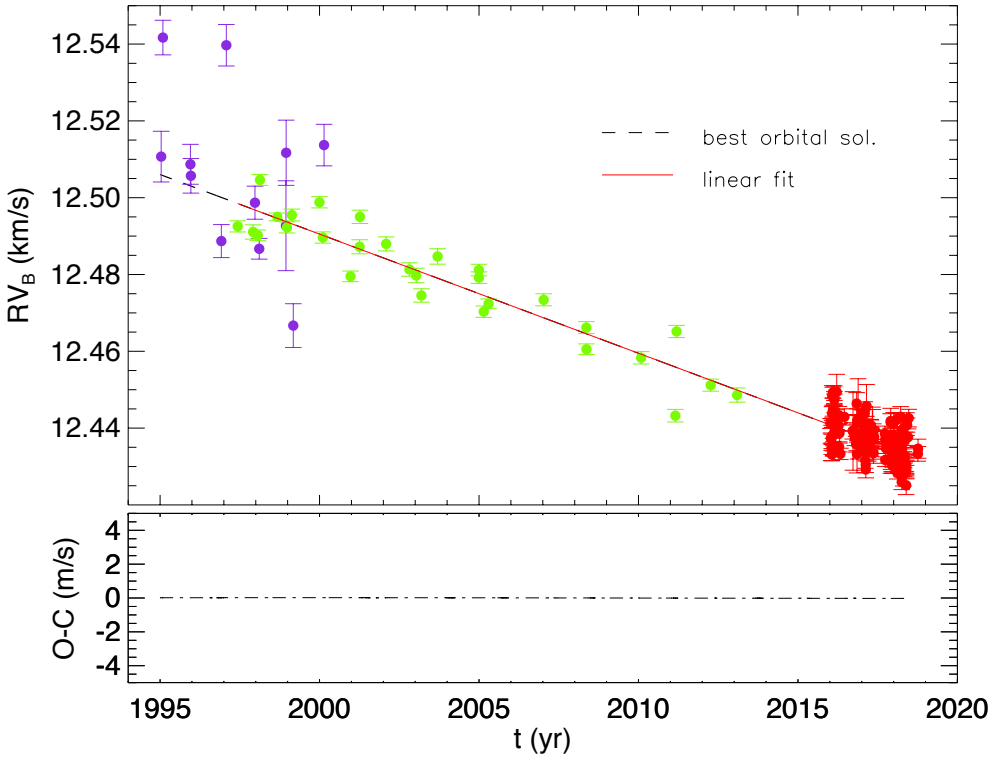
P: 1810 ± 186 a
e: 0.22 ± 0.02
a: 116 ± 3 au
i: 61.7 ± 9.8 deg

- Diff. between orb. solution and linear fit less than rms of data & **orb.sol. differs to straight line** in **less** than **1%** of CARMENES and HIRES **error bars**
- Error in zero point correction ~ 0.15 km/s (Nidever,+02)

Linear fit removed in the analysis.

Stellar binary: Orbital solution





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RV data

- **159** RVs from **CARMENES**:

  Δt = 2.06 a
- **32** RVs from **HIRES** (Tal-Or et al. 2018):

  Δt = 20.65 a
- **3-4 HIRES RVs per year**
- After detrended and 2σ-clipping rejection:

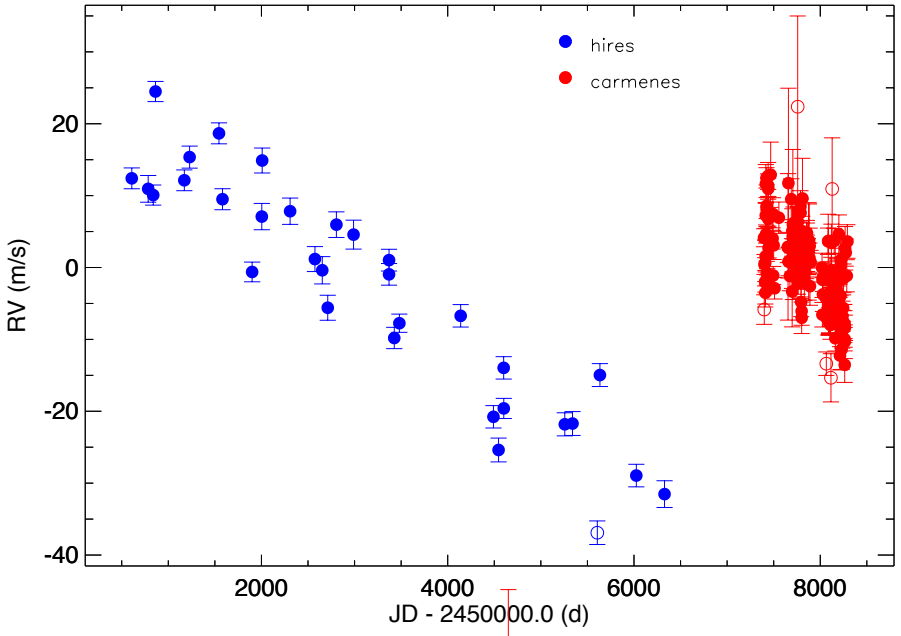
  $stddev_{CARM}$= 4.19 m/s

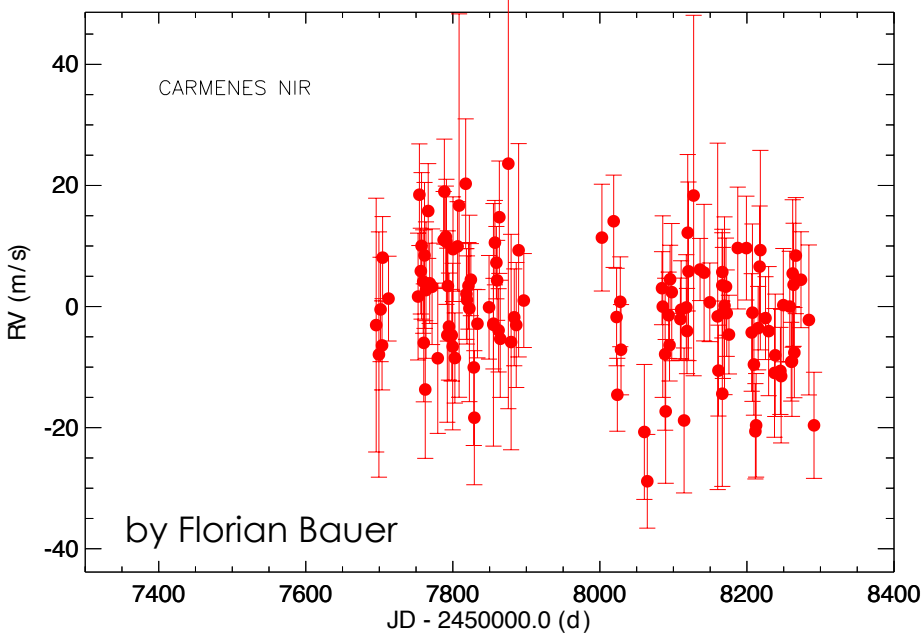
  mean e_{CARM} = 2.31 m/s

  $stddev_{HIRES}$ = 5.23 m/s

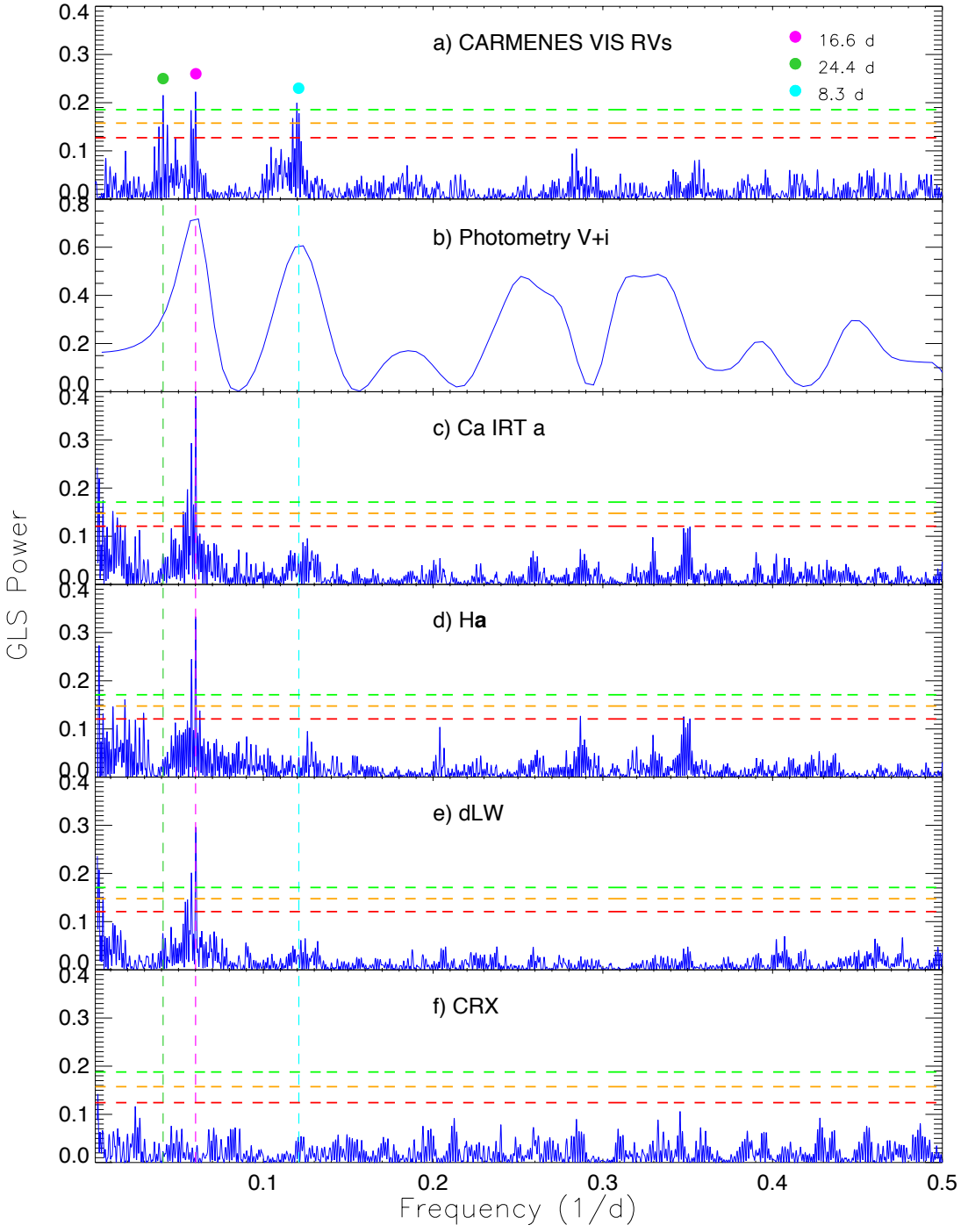
  $stddev_{CARM-NIR}$= 9.23 m/s

  mean $e_{CARM-NIR}$ = 10.0 m/s





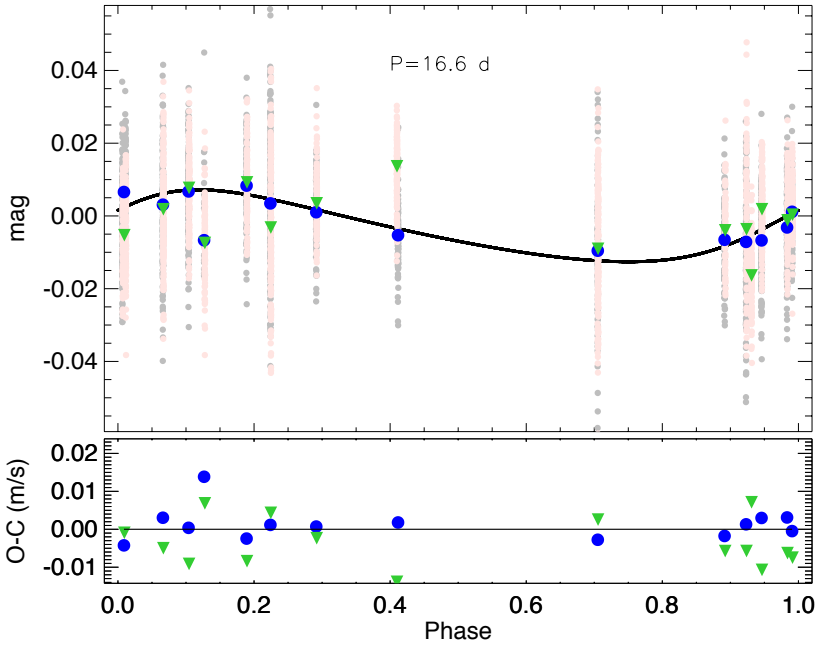
Activity



- RV: peaks at 8.3, 16.6 and 24.4 d
- Activity indicators:

P_{rot}=16.61±0.04 d

Photometry LCO (Las Cumbres)



by Victor Béjar

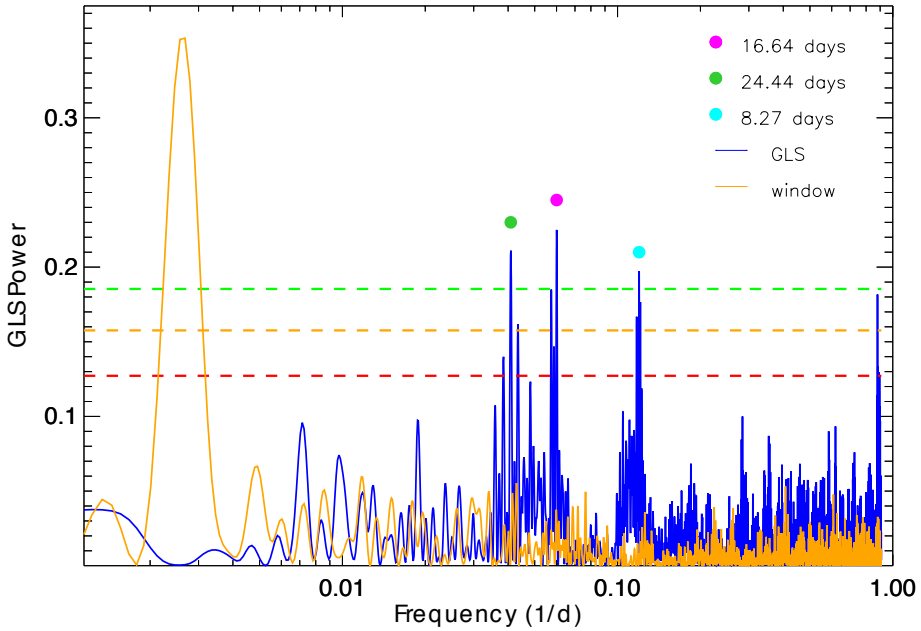
Alias phenomena

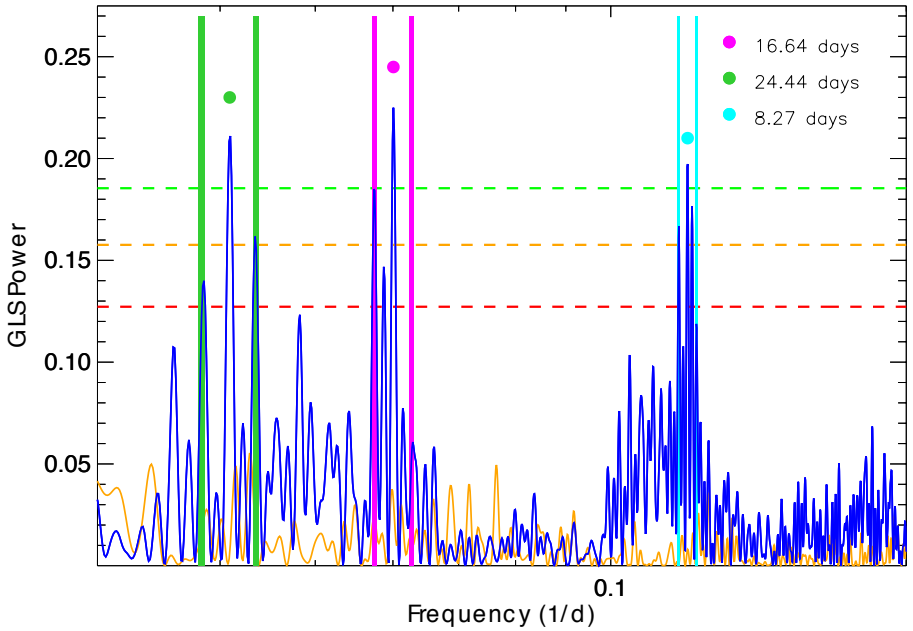
False generated frequencies

Observations are a discrete sample —> gap produces alias (Dawson & Fabrycky 2010)

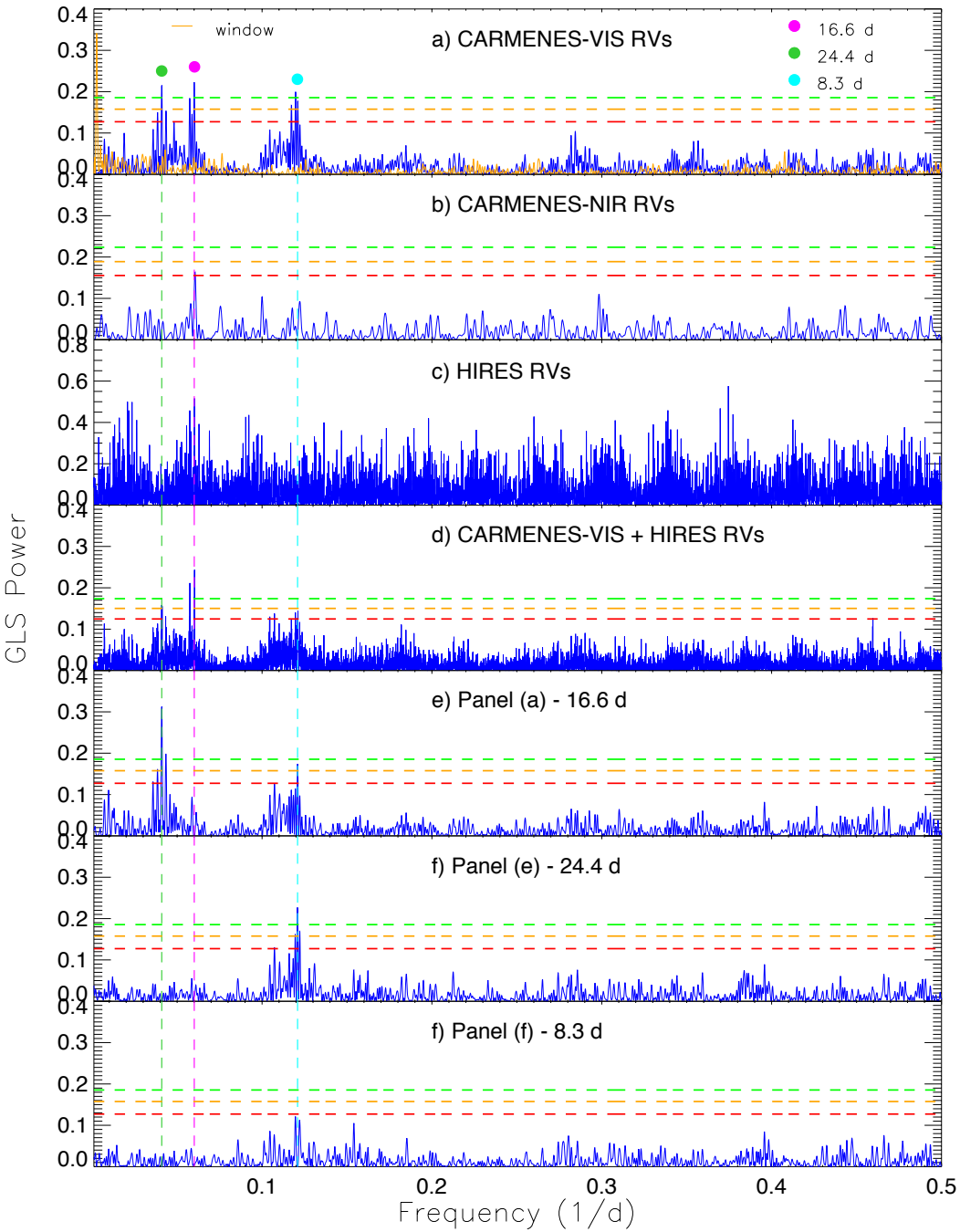
One peak in spectral window —> 1 yr

24.4, 16.6 and 8.3 days are not related or are aliases of obs. window





GLS periodograms of radial velocities



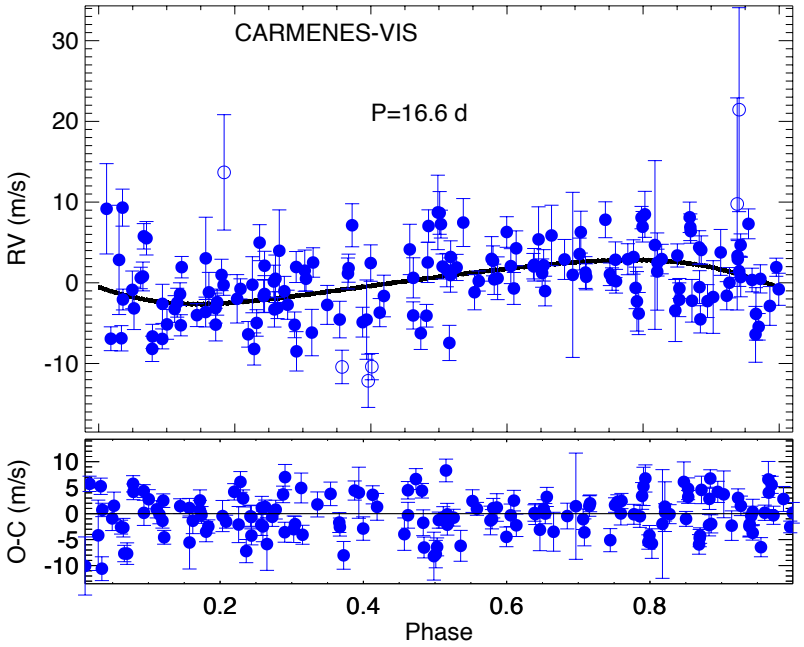
- CARMENES-VIS —> 24.4, 16.6 and 8.3 d
- CARMENES-NIR —> 16.6 d
- HIRES —> nothing (not adequate cadence)
- CARMENES-VIS+HIRES —> as support: idem results

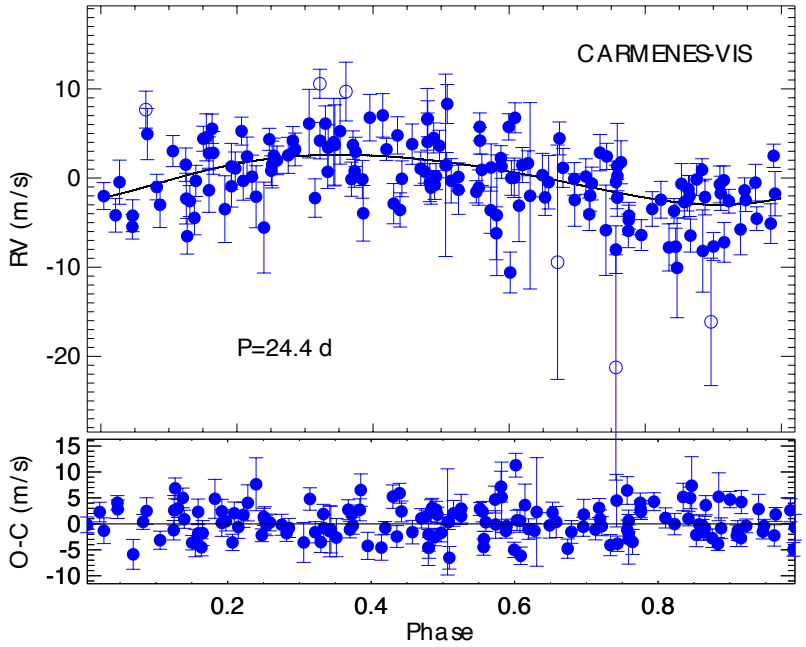
24.4 d —> PLANET

8.3 d —> ??

- Planet ?
- 3:1 resonance
- Activity ? (1° harmonic)

CARMENES-VIS phase folded





- The residual rms is 3.86 m/s

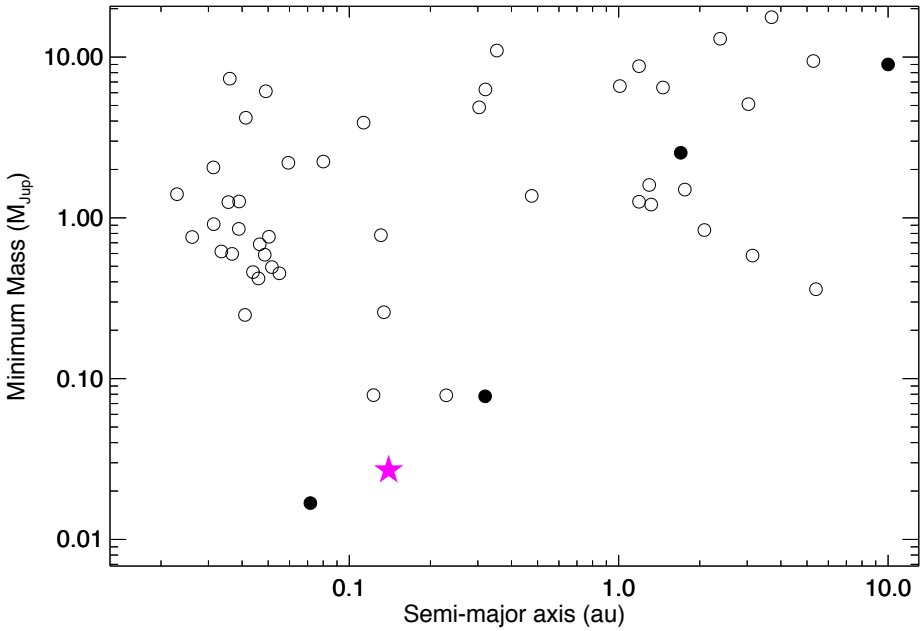
- Semi-amplitude of 2.8 m/s.
- The residual rms is 3.3 m/s

ACTIVITY

PLANET

Conclusions

- Prot at 16.61 ± 0.04 d by photometry, NIR and spectroscopic activity indicators
- Keplerian signal at 24.4 d, inner edge of HZ (0.15-0.29 au), with a minimum mass of 8.68 M_{earth} and e = 0.13
- Result supported by adding HIRES radial velocities
- The signal around 8.3 d —> Not enough arguments in favor of two planets



Exoplanets in a binary system in S-type configuration:

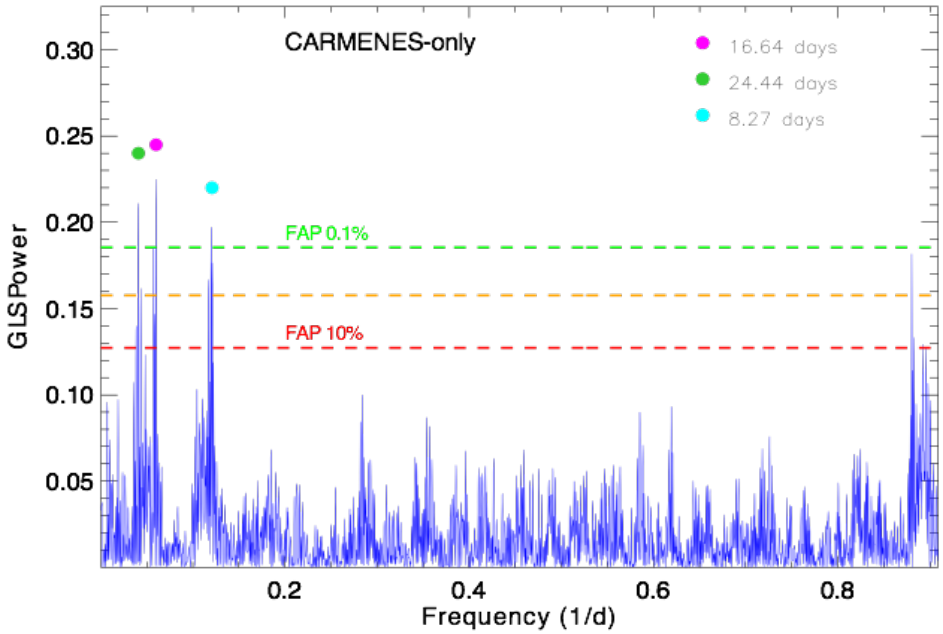
One of the closest and least massive discovered to date.

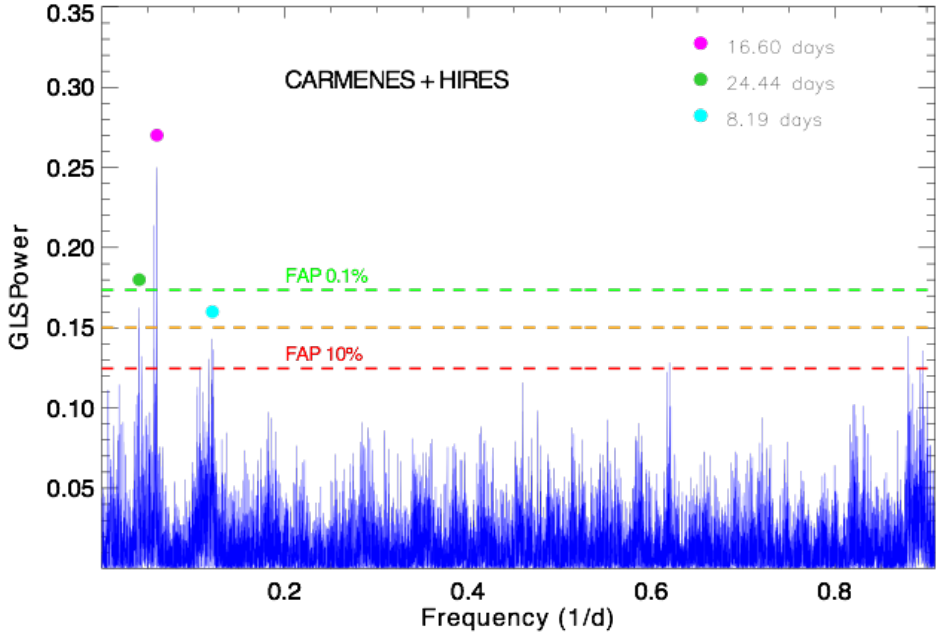
Thank you !!!!

GLS periodogram

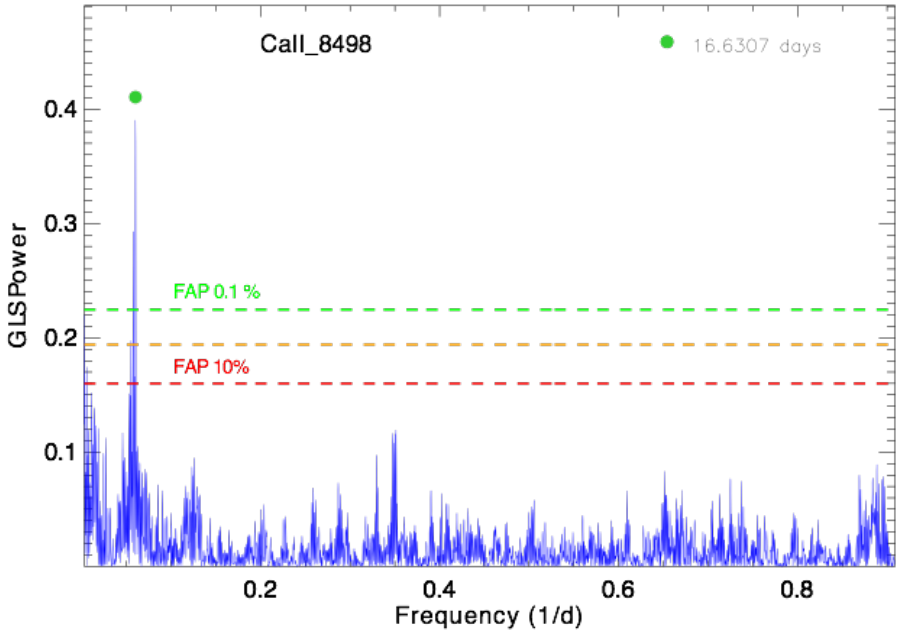
- Peaks: 8.27, 16.64 and 24.44
- Higher than FAP=0.1% (green)

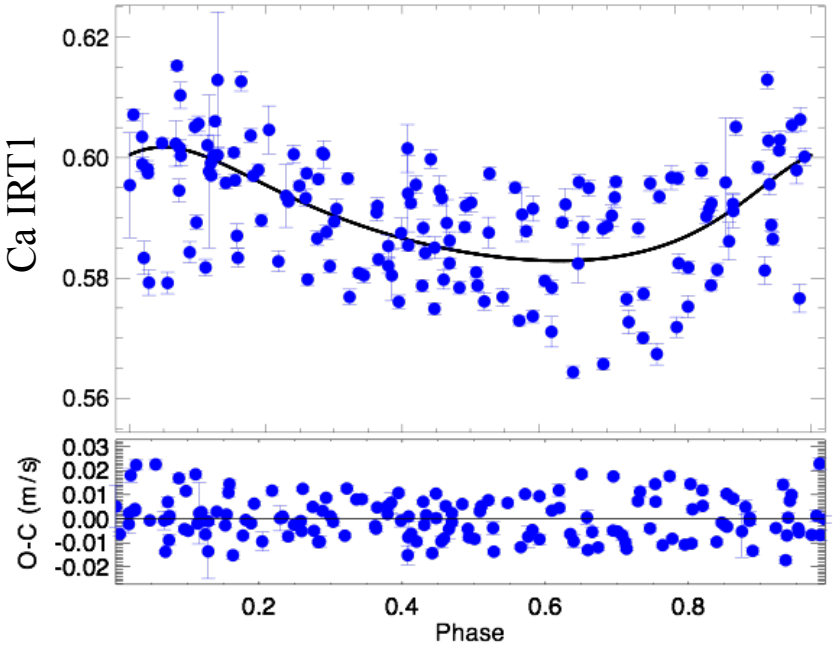
- Addition of HIRES → less power at 8.27 and 24.44 days (cadence not adequate for short periods)

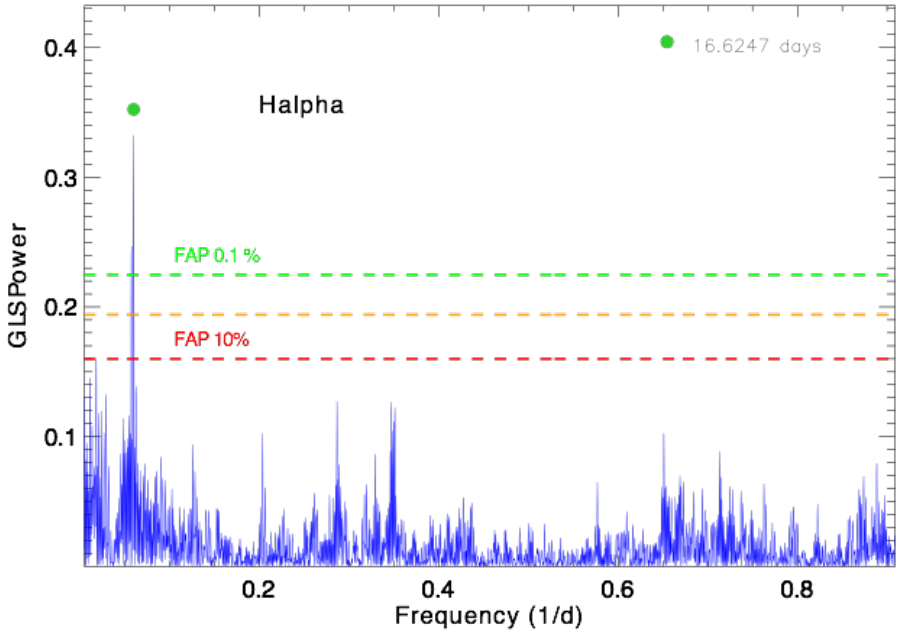


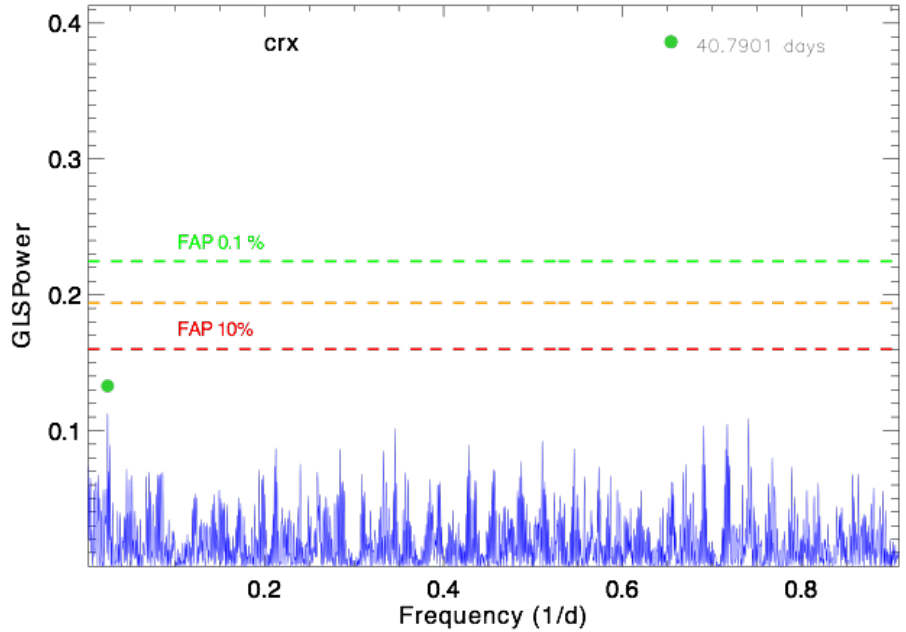


Activity indicators → P_{rot}=16.6d

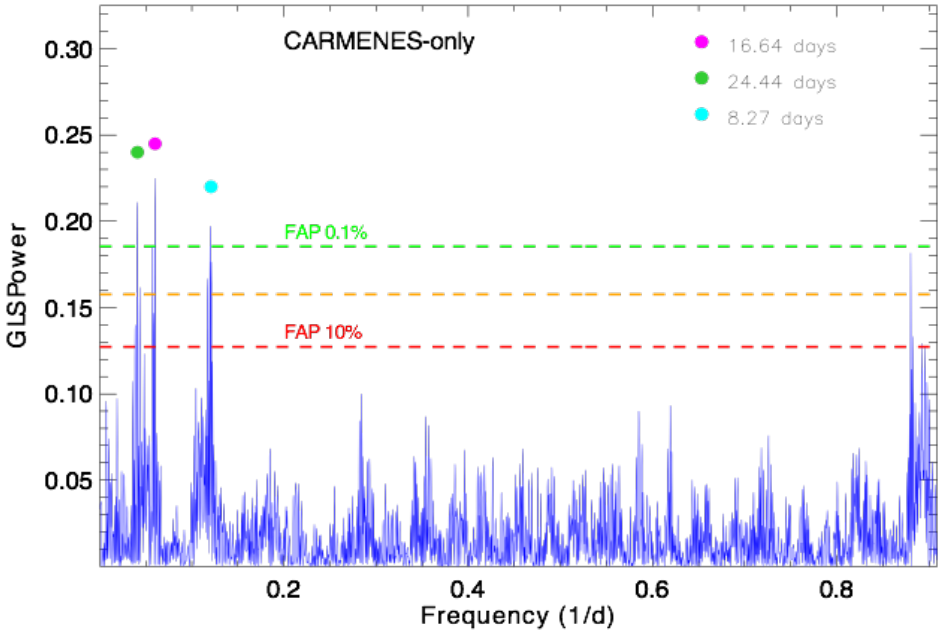


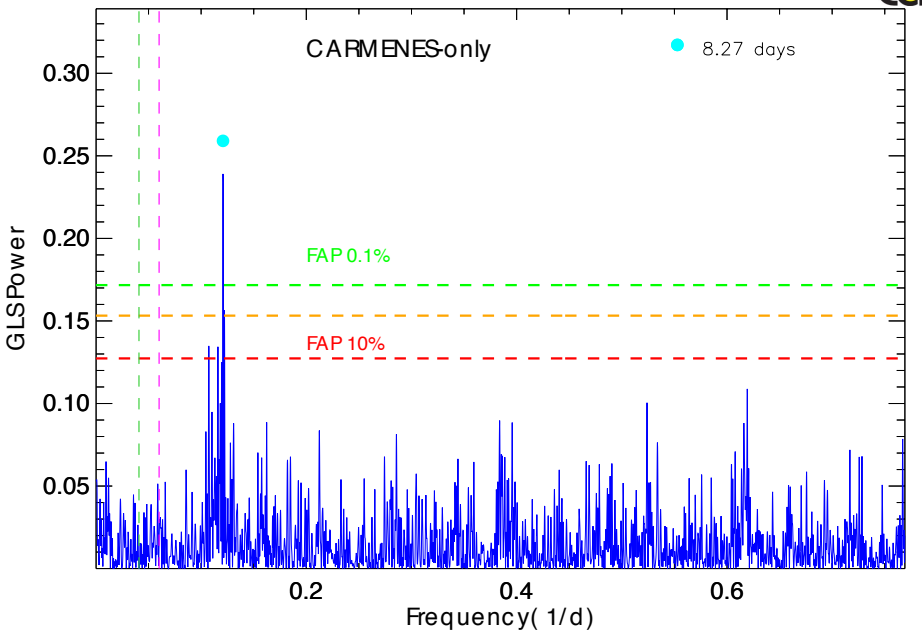






RV analysis


CARMENES-only
16.64 days
24.44 days
8.27 days
FAP 0.1%
FAP 10%
GLSPower
Frequency (1/d)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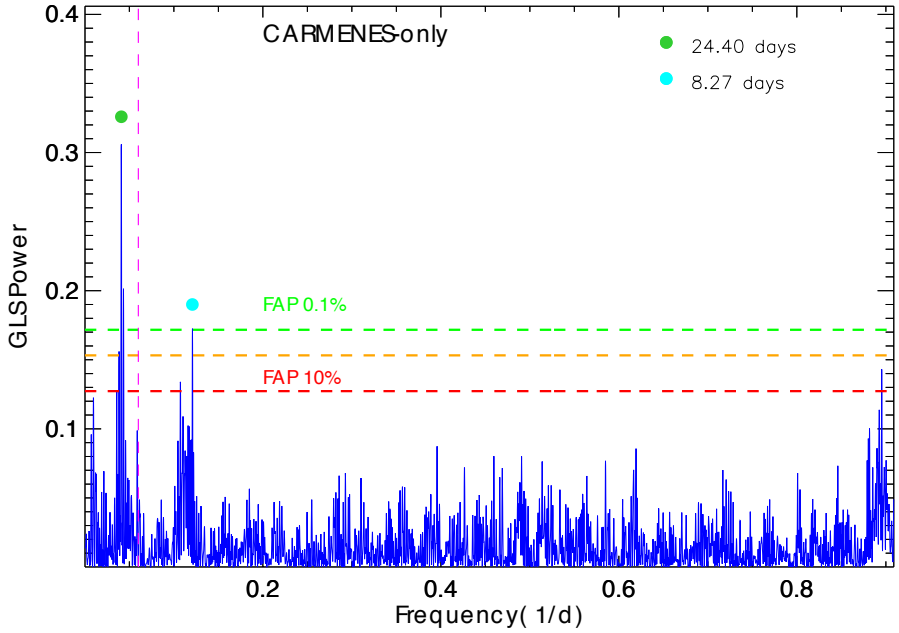
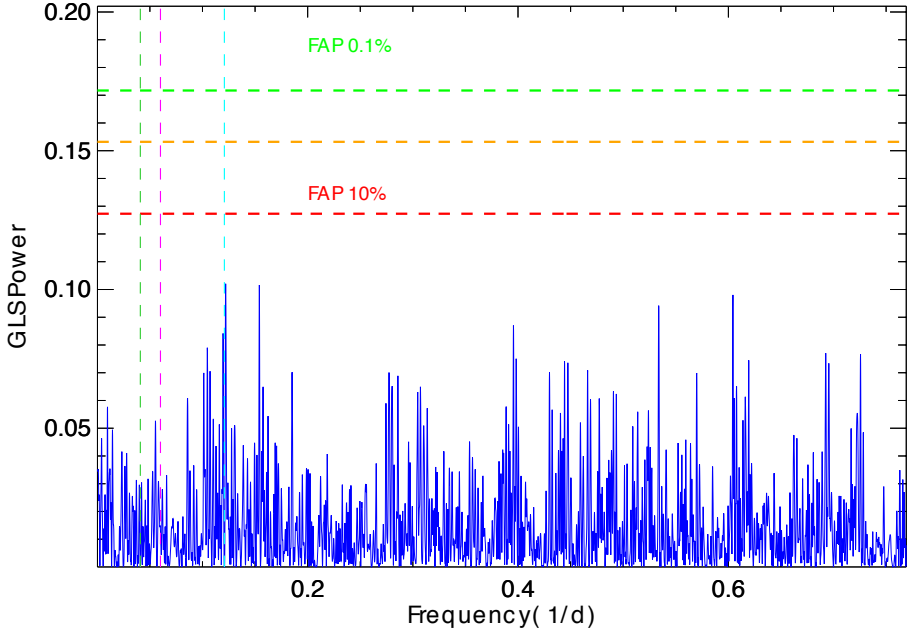

CARMENES-only
24.40 days
8.27 days
FAP 0.1%
FAP 10%
GLSPower
Frequency(1/d)


FAP 0.1%
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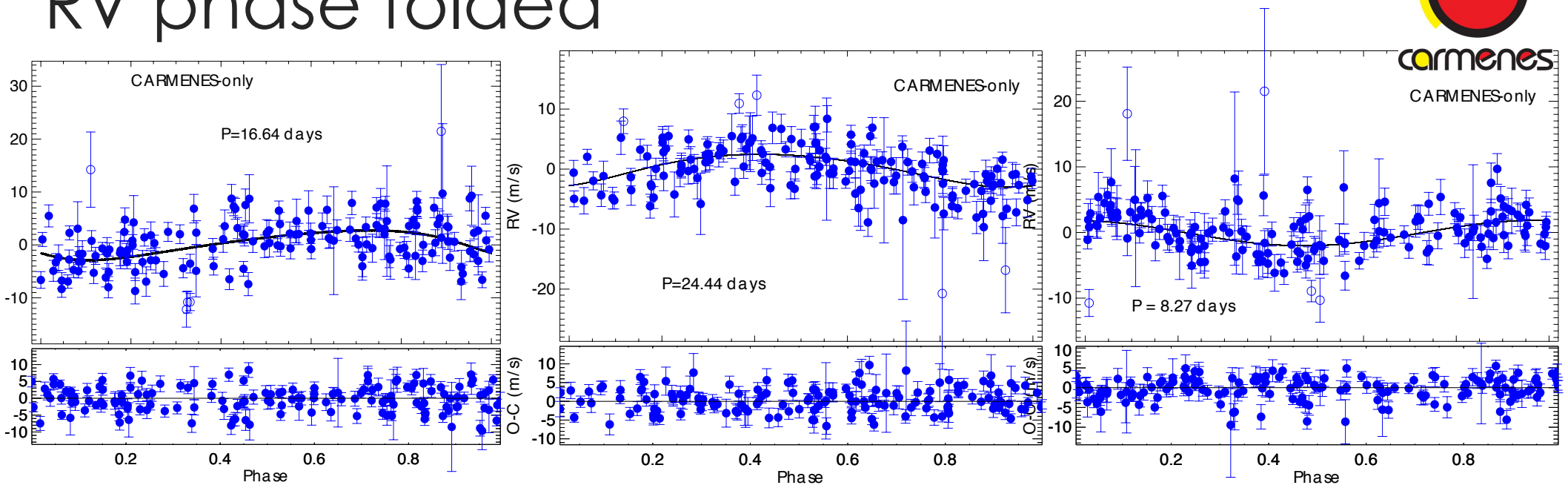
Frequency(1/d)

RV phase folded

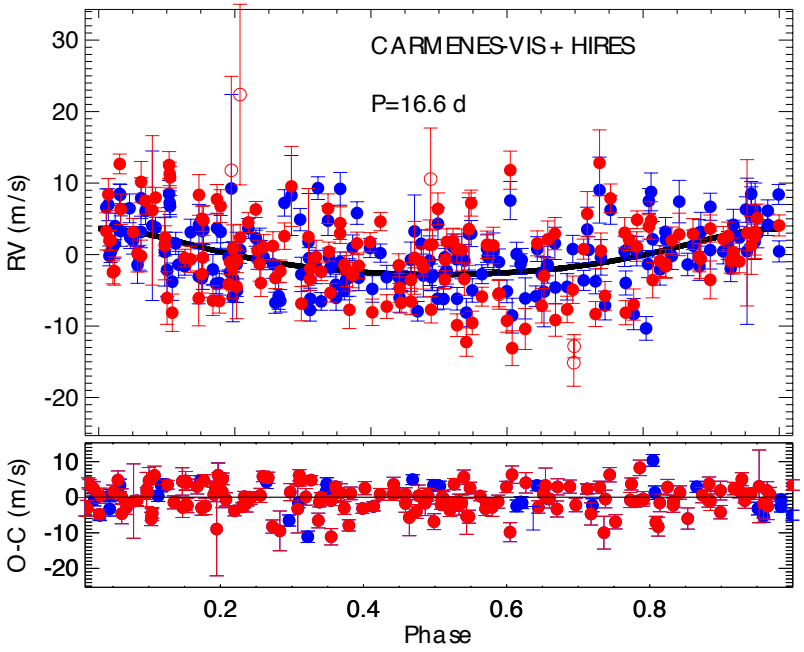


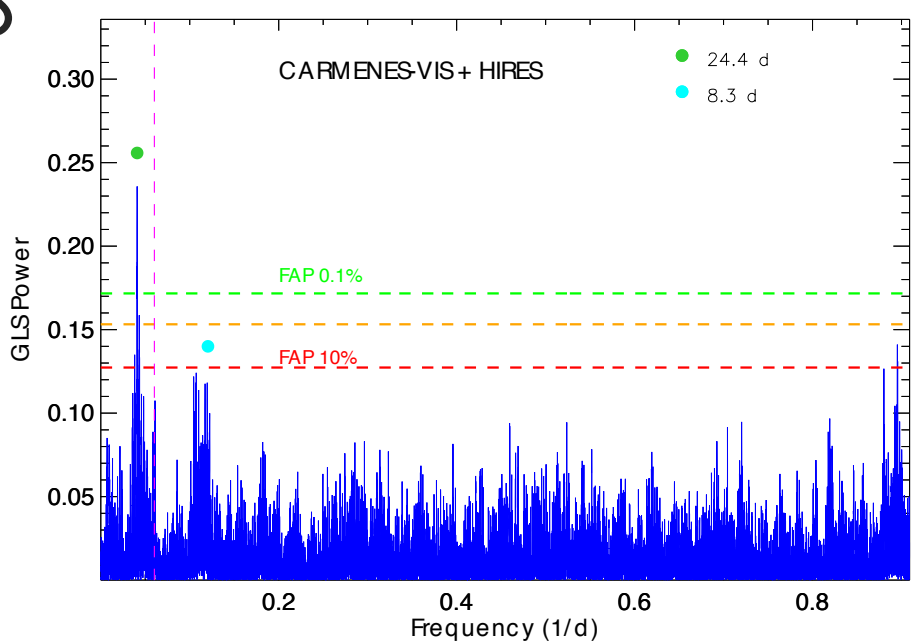
Planet *b*		
Parameter	Units	Value
P	Period (days)	24.44 ± 0.05
T_P	Periastron time (JD-2,400,000)	57835.6 ± 4.04
e	Eccentricity	0.13 ± 0.15
ω_*	Argument of periastron (deg) .	205.34 ± 59.22
K	RV semi-amplitude (m/s)	2.75 ± 0.41
γ	Systemic velocity (m/s)	0.04 ± 0.26
$M_P \sin i$ ..	Minimum mass (M_J)*	0.027 ± 0.004
$M_P \sin i$ ..	Minimum mass ($M_\oplus$)*	8.68 ± 1.15
a	Semi-major axis (AU)	0.138 ± 0.004

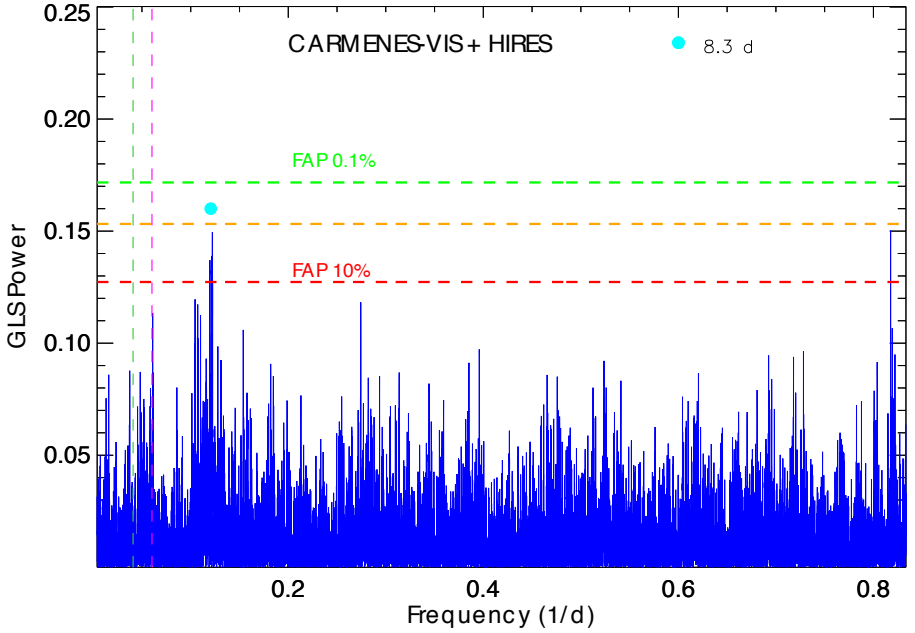
Planet *c* tentative!!		
Parameter	Units	Value
P	Period (days)	8.276 ± 0.008
T_P	Periastron time (JD-2,400,000)	57828.8 ± 6.50
e	Eccentricity	0.0 ± 0.2
ω_*	Argument of periastron (deg) .	10.29 ± 132.58
K	RV semi-amplitude (m/s)	1.93 ± 0.34
γ	Systemic velocity (m/s)	−0.09 ± 0.23
$M_P \sin i$ ..	Minimum mass (M_J)	0.014 ± 0.002
$M_P \sin i$ ..	Minimum mass ($M_\oplus$)	4.30 ± 0.60
a	Semi-major axis (AU)	0.067 ± 0.002

Same periodicities within errors found when using CARMENES+HIRES data

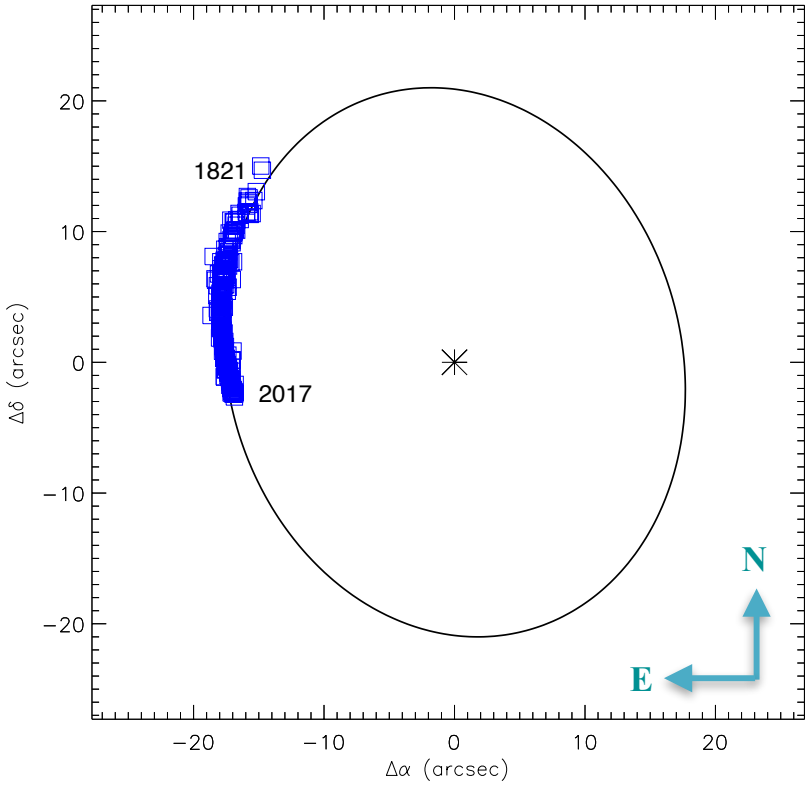
CARMENES-VIS + HIRES

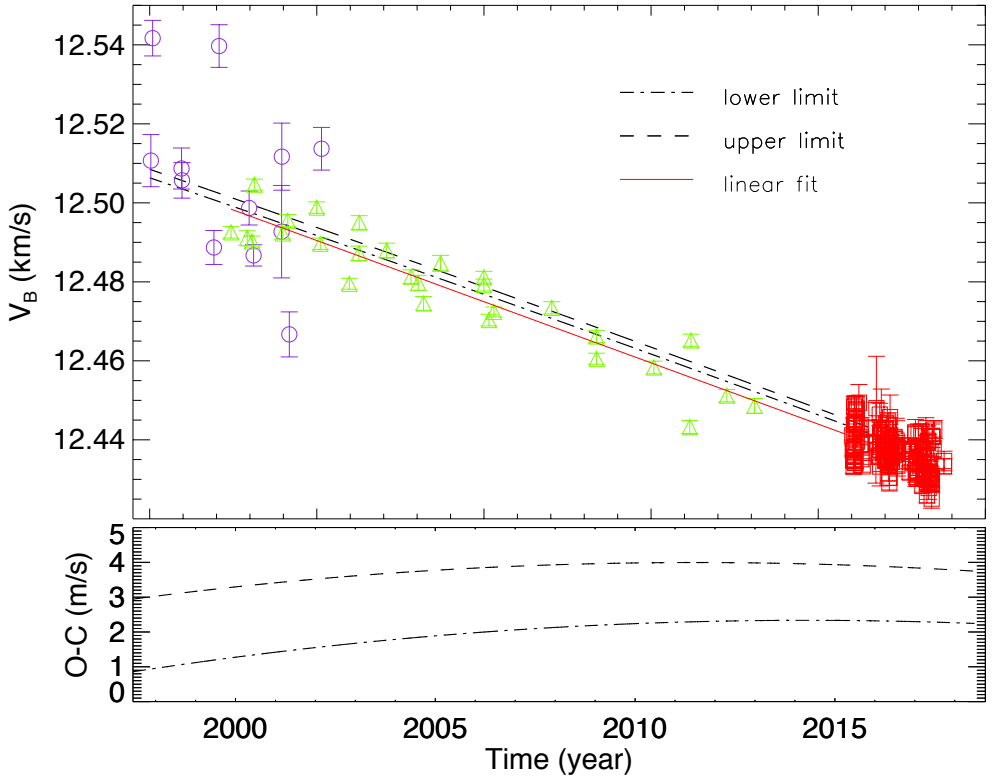






Stellar binary: Orbital solution





- Astrometric data far for covering the entire orbit
- Very few RVs data (%)

P: 1050 - 1550 a
e: 0.0 - 0.25
a: 110 - 135 au

- Degenerate solution
- Diff. between orb. solution and linear fit less than rms of data & **orb.sol. differs to straight line** in **0.2 m/s**
- Error in zero point correction ~ 0.15 km/s (Nidever,+02)

Linear fit removed in the analysis.