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A Polar Circumbinary Companion Orbiting a Pair of Young Brown Dwarfs

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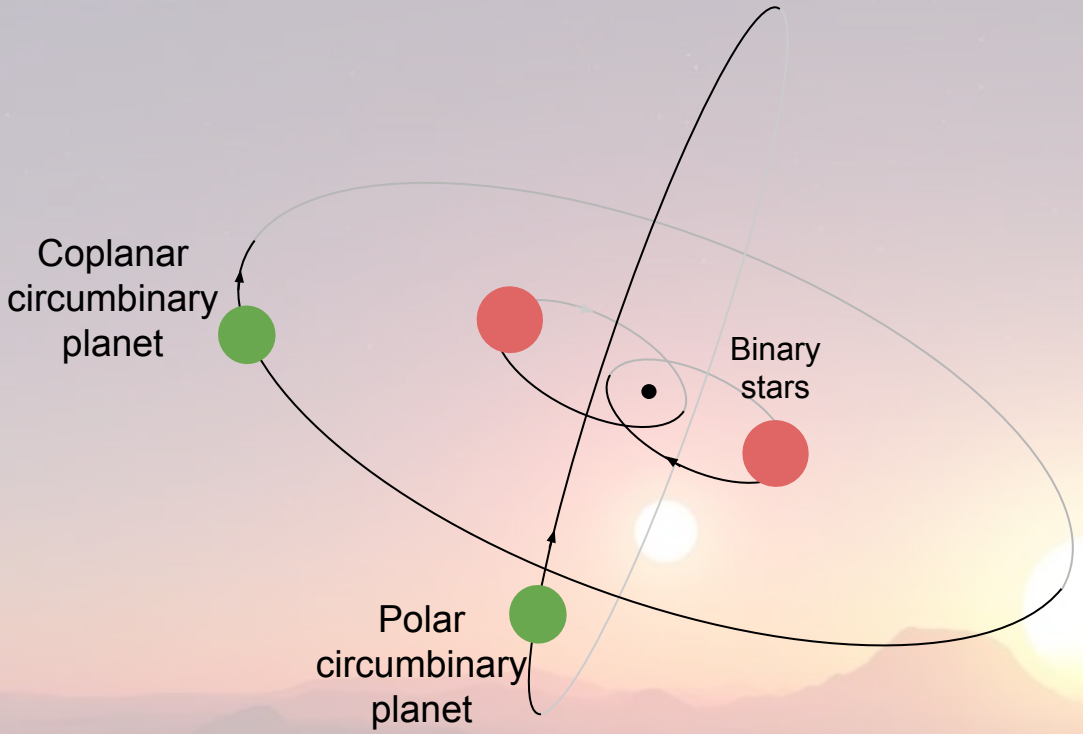
Polar circumbinary orbits

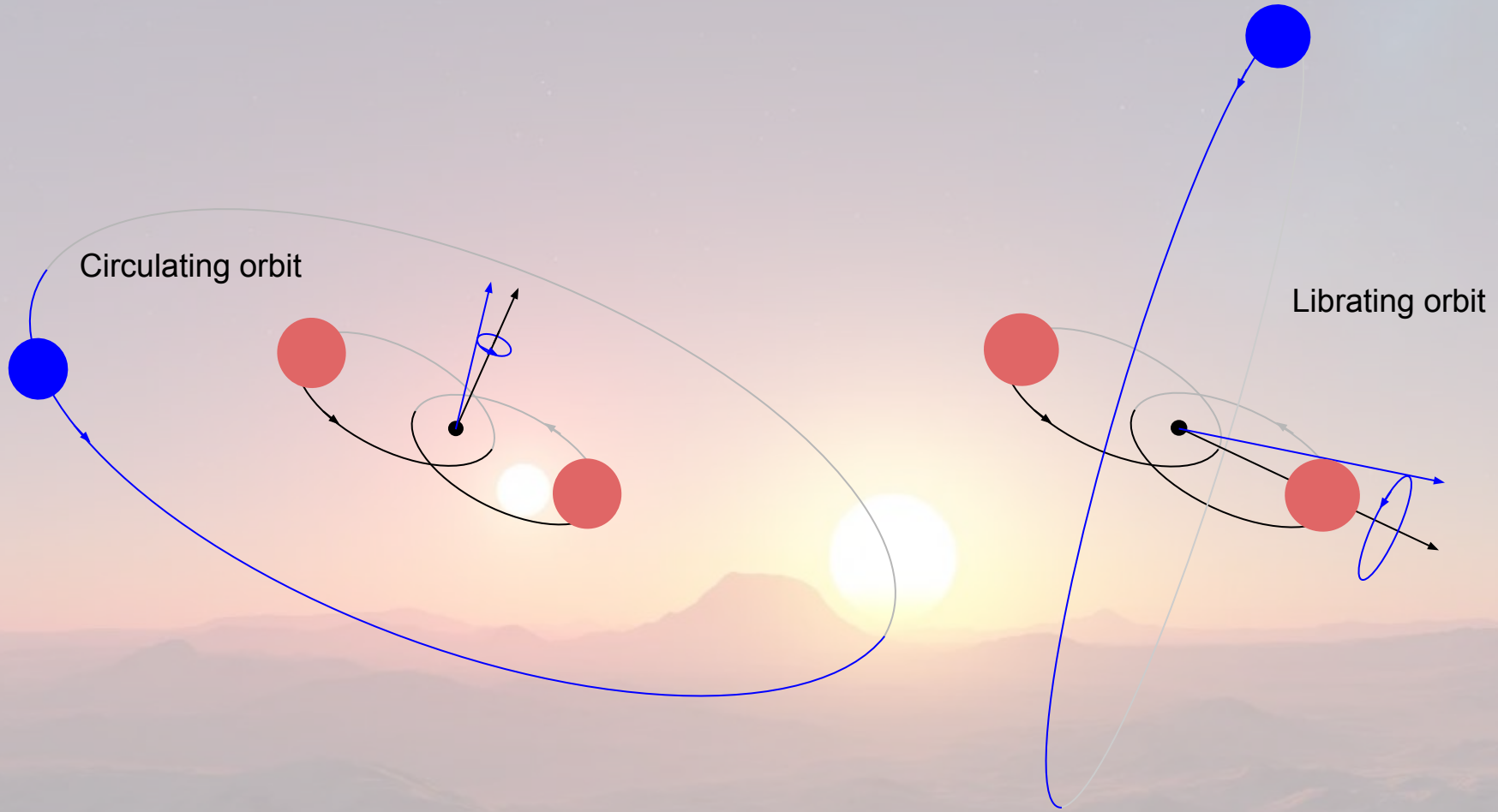


Two most stable configurations of circumbinary planet: Coplanar and Polar

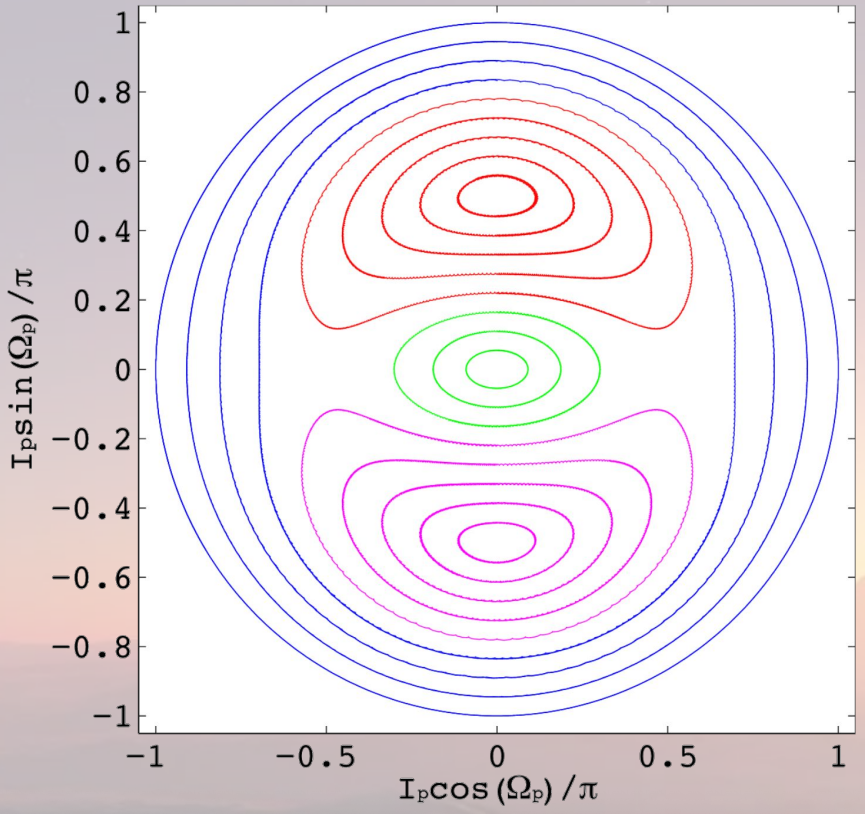
Polar is most stable around more eccentric binaries

Correspond to two dynamical states in which the circumbinary orbit can be in: Circulating and Librating

Polar circumbinary orbits



Polar circumbinary orbits



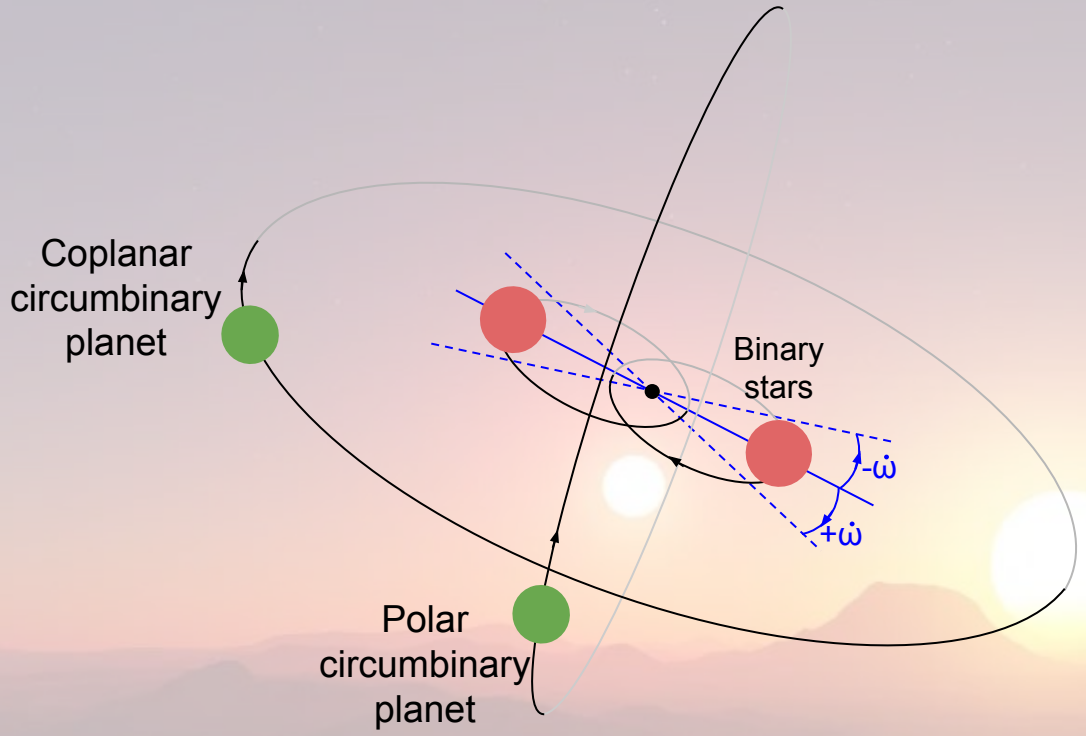
Martin and Triaud (2014)

Circulating regions are in green and blue.

Librating regions are in red and pink.

Energy levels of the Hamiltonian show distinct regions *(Farago and Laskar 2010)*

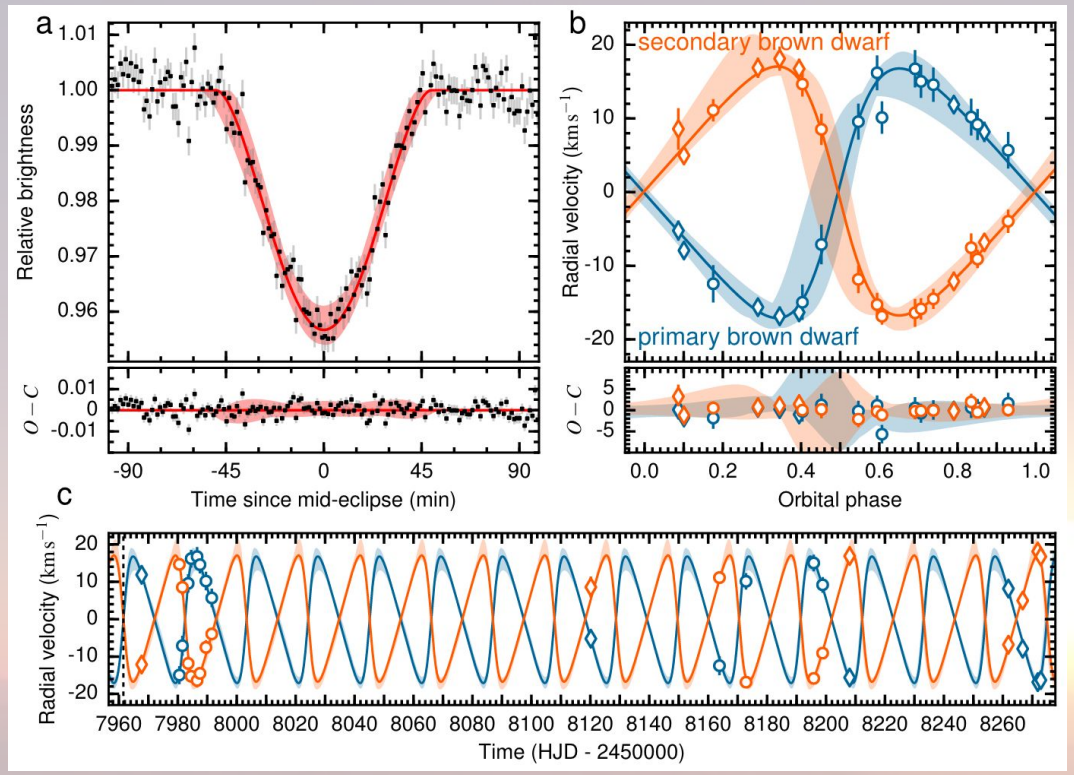
Polar circumbinary orbits



The two states can be distinguished.

Coplanar circumbinary companions induce a prograde apsidal precession, whereas Polar companions induce retrograde apsidal precession, e.g. *Zhang and Fabrycky (2019)*.

2M1510



Triaud et al. (2020)

2MASS J15104786-2818174 (2M1510) a Brown dwarf system.

Eclipsing binary detected by Speculoos, radial velocities from UVES:

P ≈ 20.9 days
M1 ≈ M2 ≈ 0.033 $M_{\odot}$
Age ≈ 45 Myr

Almost identical tertiary brown dwarf at projected separation 250AU

One of 2 known young eclipsing BD binaries.

Radial velocities and Analysis

Initial radial velocities taken in 2017-2019. New points were taken in 2023 also with UVES giving 6 year baseline.

Using DOLBY-SD double-lined binary reduction code *(Sairam et al 2024)* improved radial velocity precision to ≈ 40 m/s.

Perform two radial velocity analyses

Initial analysis:

kima *(Faria et al. 2018, Baycroft et al. 2023)*

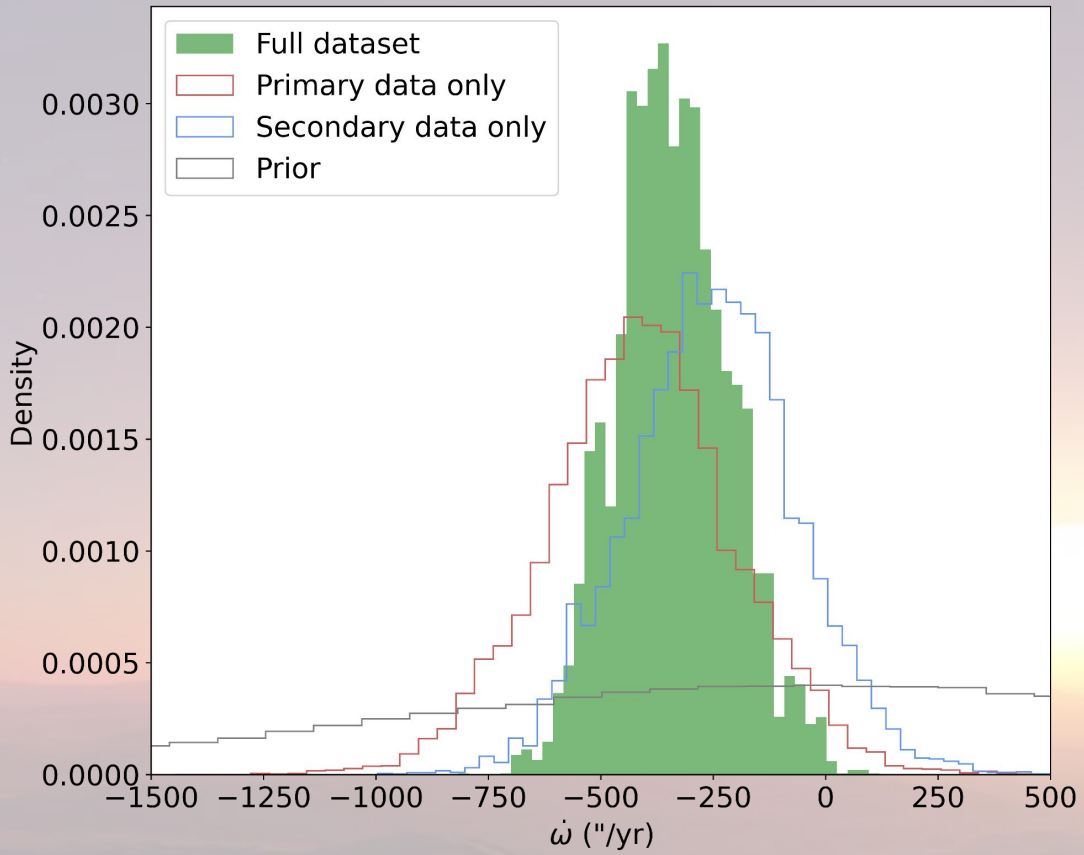
Keplerian radial velocity fit of double-lined binary including apsidal precession

Second analysis:

rebound *(Rein and Liu 2012)*
+ emcee *(Foreman-mackey et al 2013)*

N-body radial velocity fit of double-lined binary

2M1510



Baycroft et al. (2025)

From *kima* analysis binary parameters improved and retrograde apsidal precession detected:

dω/dt = -343 ± 126 arcsec/yr

Retrograde precession favoured from analyses of the radial velocities from both primary and secondary stars individually.

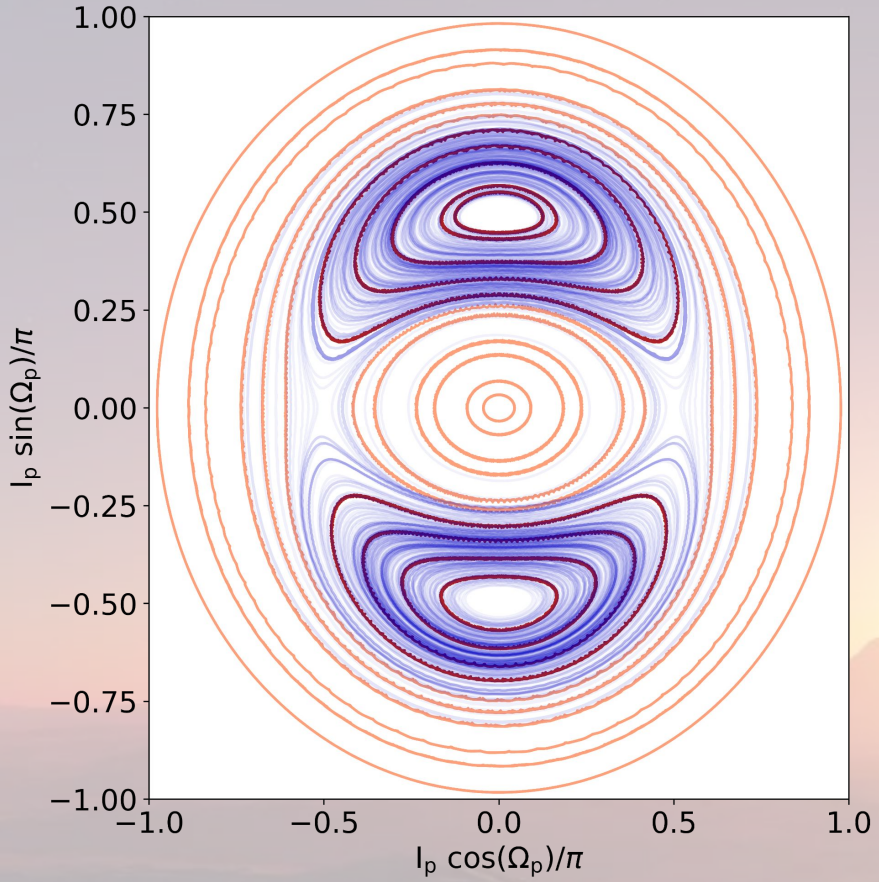
One possible cause is a polar circumbinary planet

Exploring Alternatives

Distant tertiary inducing precession	$\lvert d\omega/dt \rvert \lesssim 0.001$ arcsec/yr
Proper-motion changing the viewing angle	$\lvert d\omega/dt \rvert \lesssim 0.13$ arcsec/yr
Binary spin-orbit misalignment	$\lvert d\omega/dt \rvert \lesssim 2.5$ arcsec/yr
Polar Disc	Likely too old for protoplanetary disc. No detected infrared excess

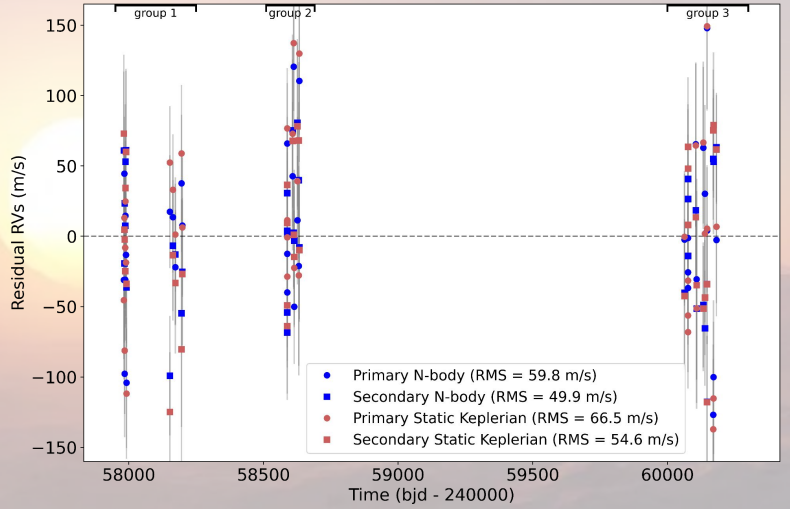
The only viable alternative is a circumbinary companion. Due to no extra sets of lines in the spectra and the RV jitter being low, likely a planetary companion with at $M \lesssim 20\ M_{Jup}$

2M1510



N-body fit gives posterior distribution most of which is in the Librating configuration.

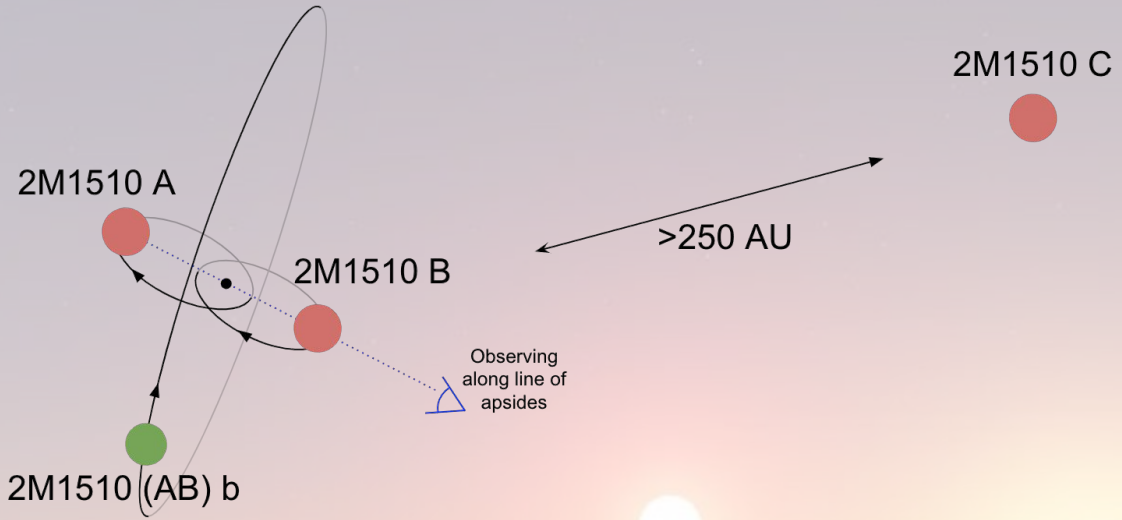
Fit improves between
Static Keplerian→Precessing Keplerian →Nbody

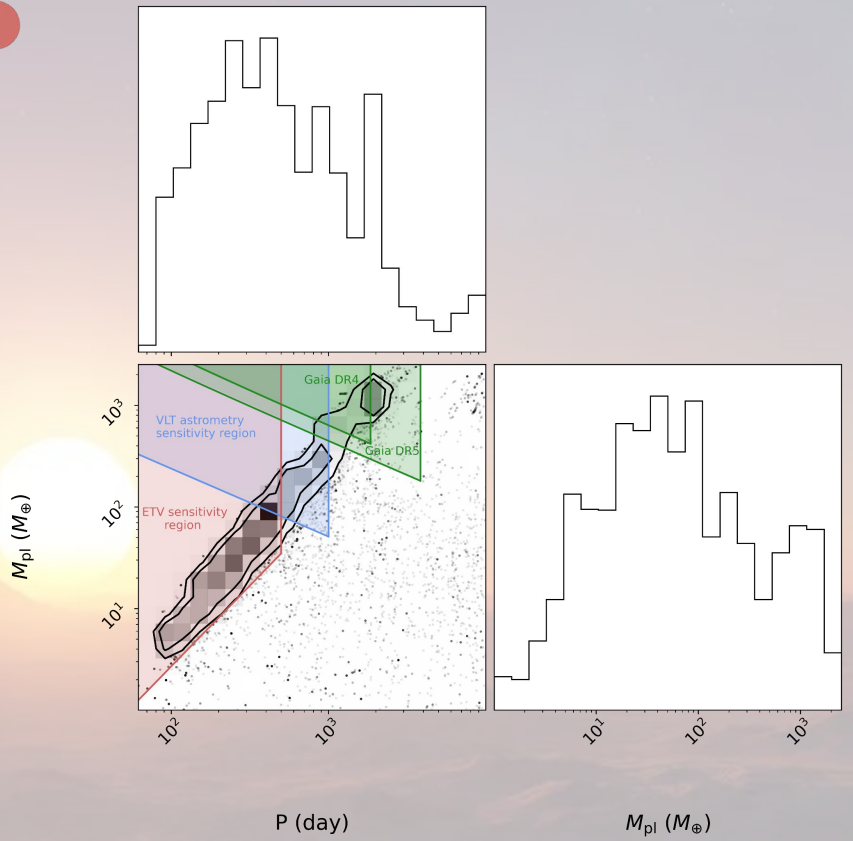


Baycroft et al. (2025)

2M1510

Baycroft et al. (2025)

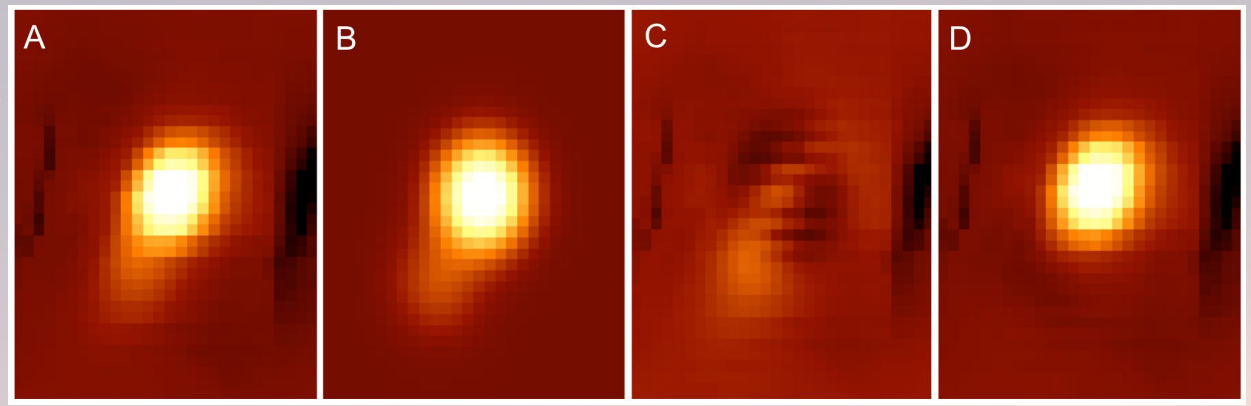




Degeneracy in Mass-Period space. Various follow-up possible.

Since observing along the apsides, the orbit of the polar companion would be face-on

2M1510



Calissendorff et al. (2019)

Calissendorff et al. 2019 observed with SINFONI on the VLT (Imaging)

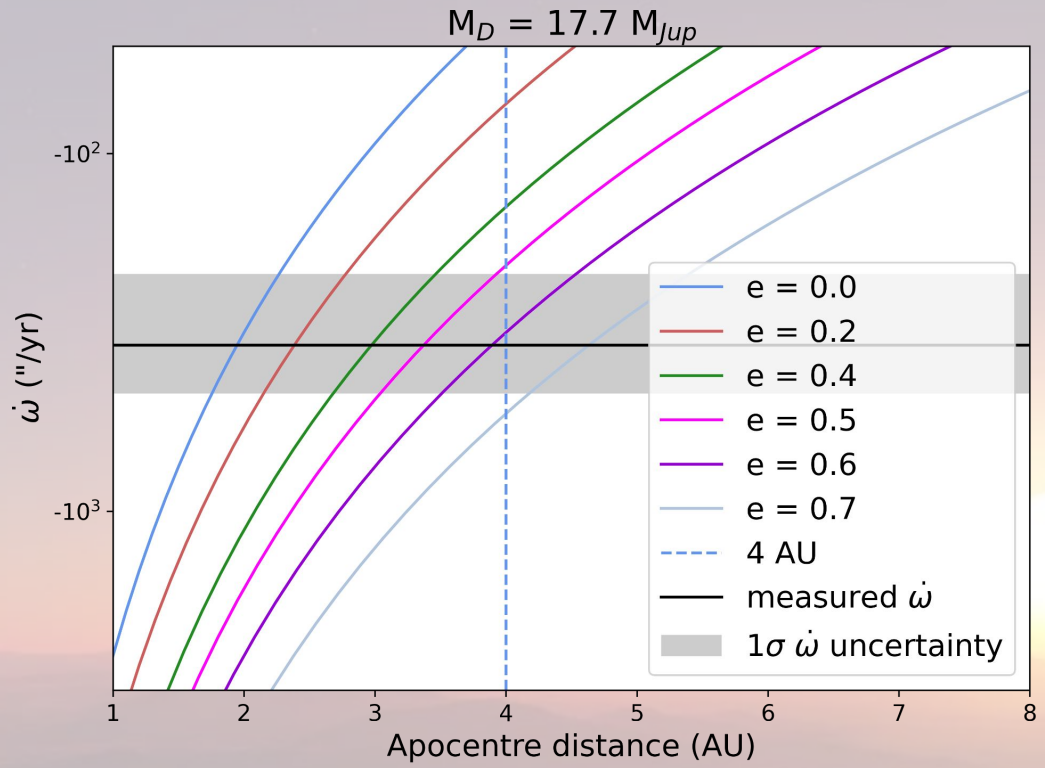
PSF asymmetry yields a companion with projected separation 4AU and mass $17.68^{+4.20}_{-2.10}$ M_{Jup}

Unsure how reliable the mass measurement is.

For such a companion to cause measured retrograde precession a < 2AU.

Tension exists between two tenuous measurements

2M1510

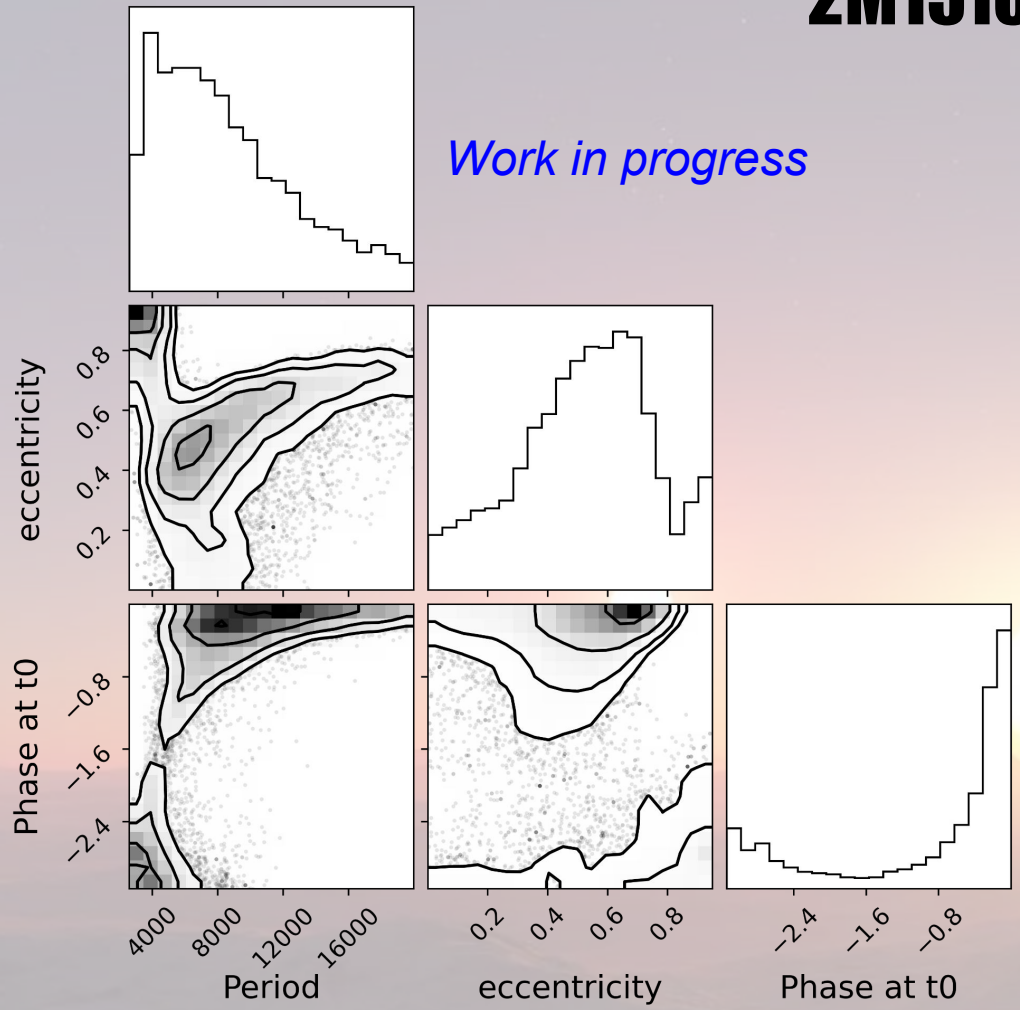


Both can be explained with an eccentric orbit.

Baycroft et al. (in prep)

2M1510

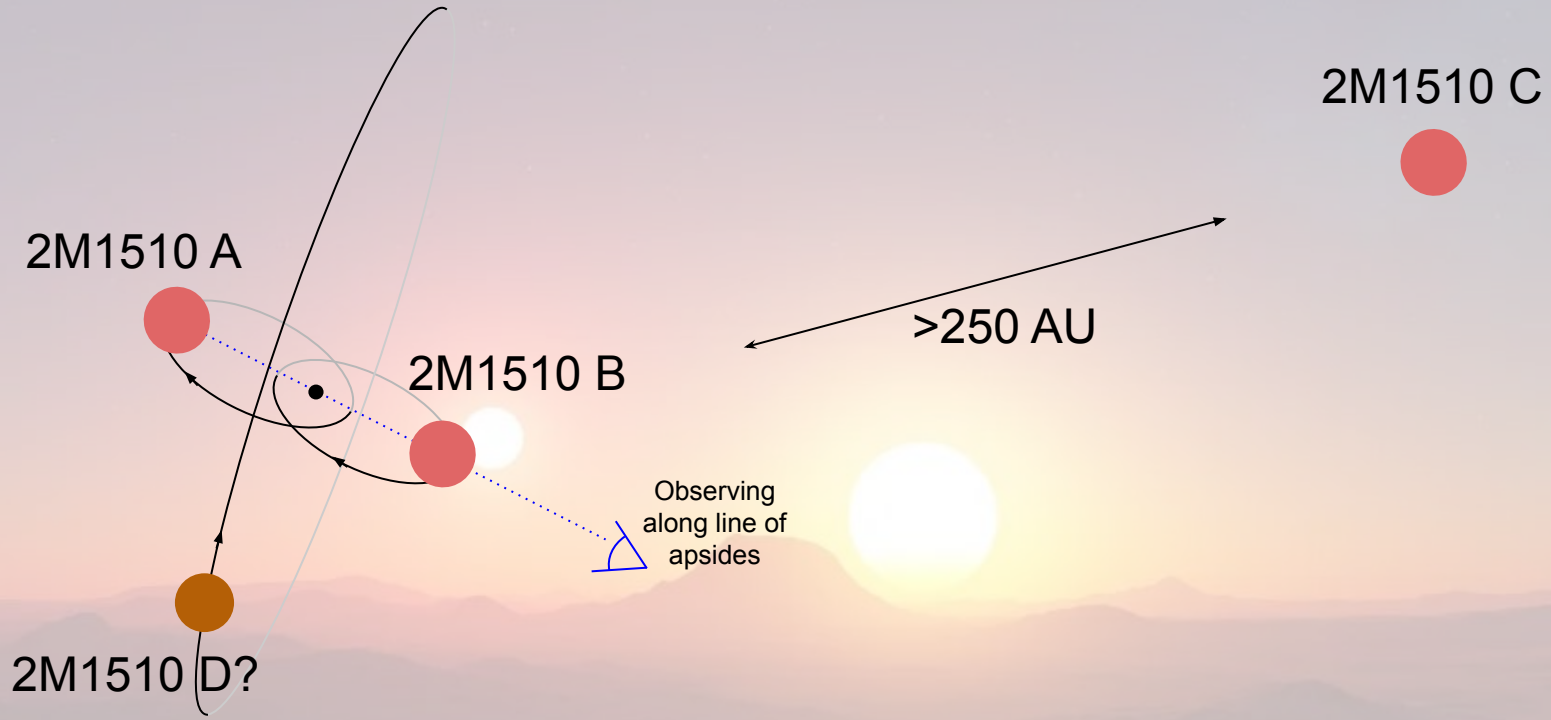
Work in progress



Including the mass and separation constraints from the direct imaging constrains eccentricity-Period.

Period ≈ 6000 days (or 4000)
eccentricity ≈ 0.5 (or >0.9)
Mass ≈ 17 M_{Jup}
I_{mut} ≈ 90°

2M1510


2M1510 C
2M1510 A
>250 AU
2M1510 B
Observing
along line of
apsides
2M1510 D?

Follow-up of 2M1510

1. More radial velocities to confirm apsidal precession measurement and refine precision

2. New epochs of Direct Imaging to confirm detection and track/constrain the orbit

3. Recover eclipses to search for timing and/or depth variations, improve radius constraints

4. Search in Gaia astrometry at DR4

5. Study atmospheres of each brown dwarf (Ground based/JWST?)

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Conclusions

- Apsidal precession is an important way to detect polar circumbinary orbits, as well as investigate circumbinary planets in general (See talk by Benjamin Montet)
- Apsidal precession of binaries can be measured from radial velocity timeseries (use of *kima* encouraged)
- 2M1510 is a great example of this in action
- Intriguing system with 3 identical brown dwarfs, and then a polar companion that could be a smaller brown dwarf