Origin of an S-type retrograde planet in the evolved binary star system ν Octantis

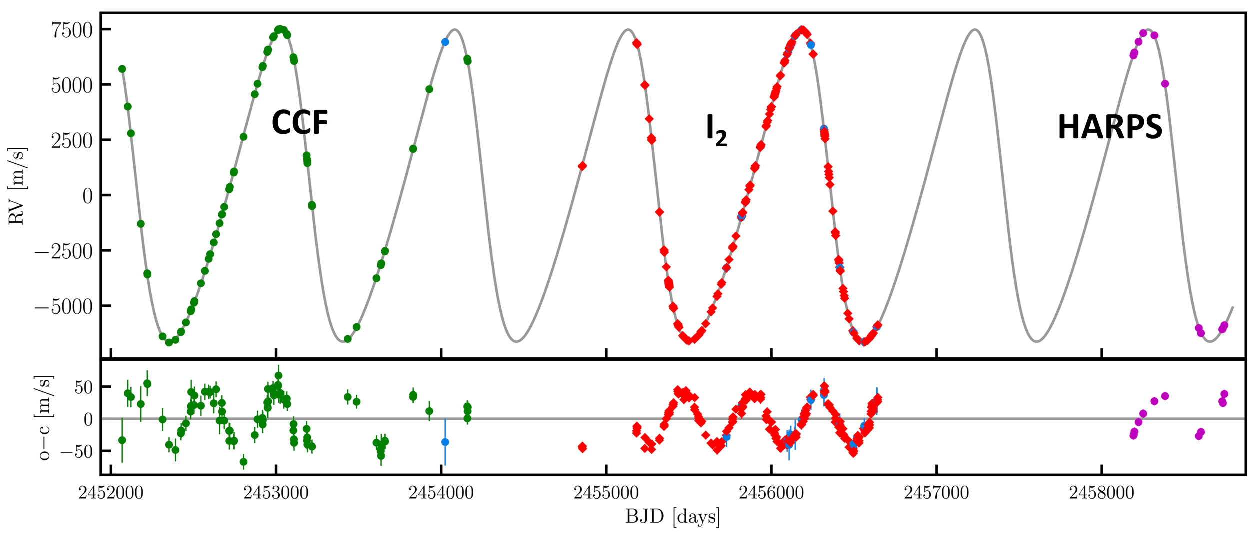
Ho Wan Cheng[1], Man Hoi Lee[1], Trifon Trifonov[2]

[1]The University of Hong Kong, Hong Kong

[2]Max Planck Institute for Astronomy, Germany

Background and Motivation

- The occurrence rate of S-type (either circum-primary or circum-secondary) planets in binary star systems is suppressed due to gravitational perturbation of close stellar companions.
- For binary separation less than 10 AU, the occurrence rate of S-type planets is just 15% of that for single-star systems or wide binaries (Moe & Kratter 2021).
- The existence of an S-type planet with a 1.25 AU wide retrograde orbit has been suggested for ν Octantis, in which the binary orbit is characterised by a semimajor axis of merely 2.6 AU.



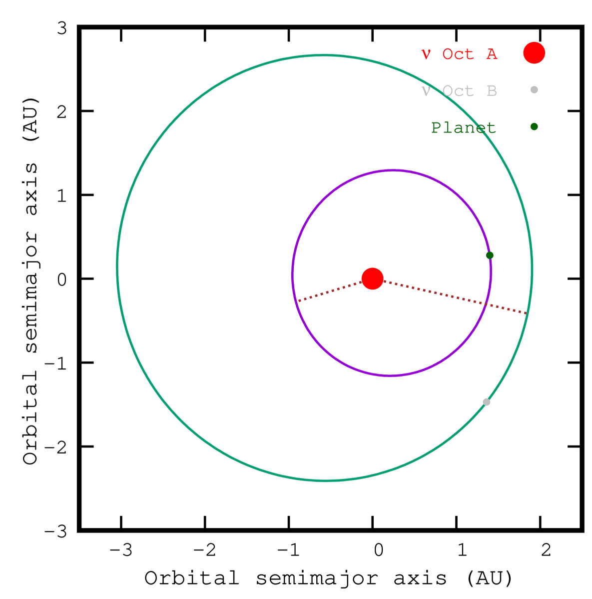
Precise RV measurements of ν Octantis spanning across nearly 20 years.

- RV data from HERCULES and astrometric data from *Hipparcos* enabled the binary's orbital inclination and hence the stellar masses to be derived (Ramm et al. 2009).
- Previous studies (Eberle & Cuntz 2010; Quarles et al. 2012; Goździewski et al. 2013; Ramm et al. 2016) and our dynamical analysis ruled out any possibility for a stable prograde planetary orbit.
- Our new high-resolution HARPS RVs consolidate the planet's reality. In addition, our new VLT/SPHERE-SAM observations suggest the companion star ν Oct B is a white dwarf (WD), implying that the orbital configuration of the system has significantly evolved.

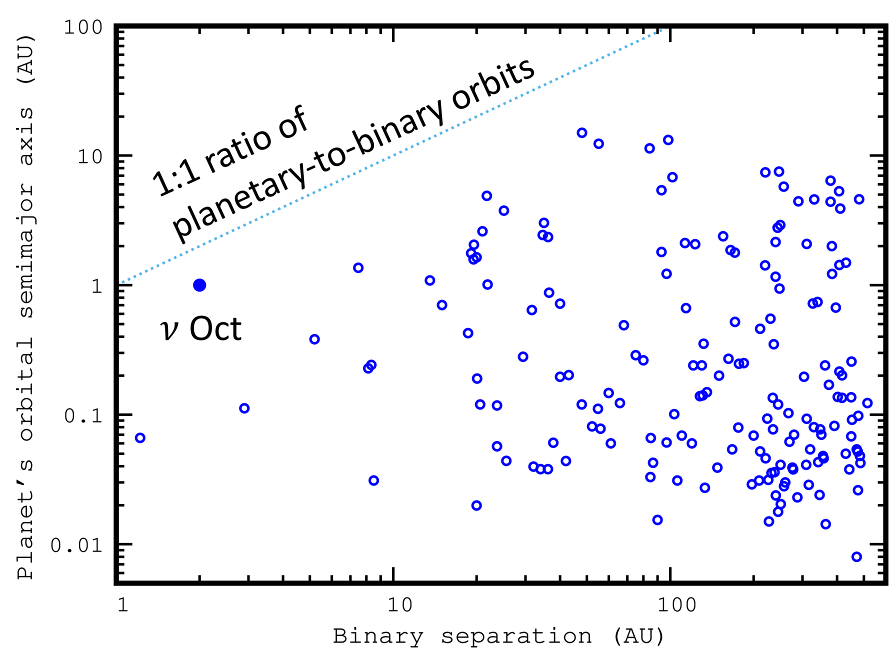
Primary questions:

What was the primordial configuration of the binary orbit?

How did the planet end up in a retrograde S-type orbit in such a tight binary star system?

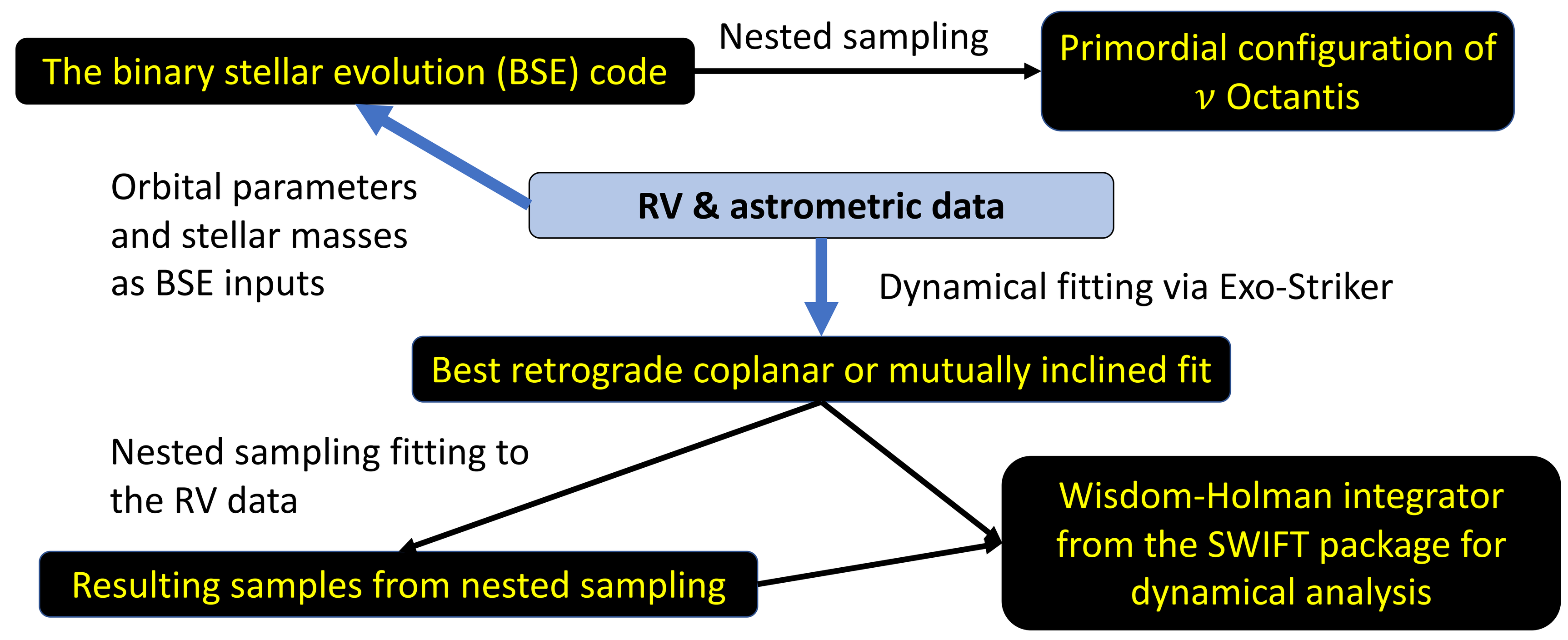


Face-on view of the orbits of the S-type planet and WD companion ($M_2 = 0.57M_{\odot}$) around the K1 IV subgiant star ($M_1 = 1.57M_{\odot}$) in ν Octantis.



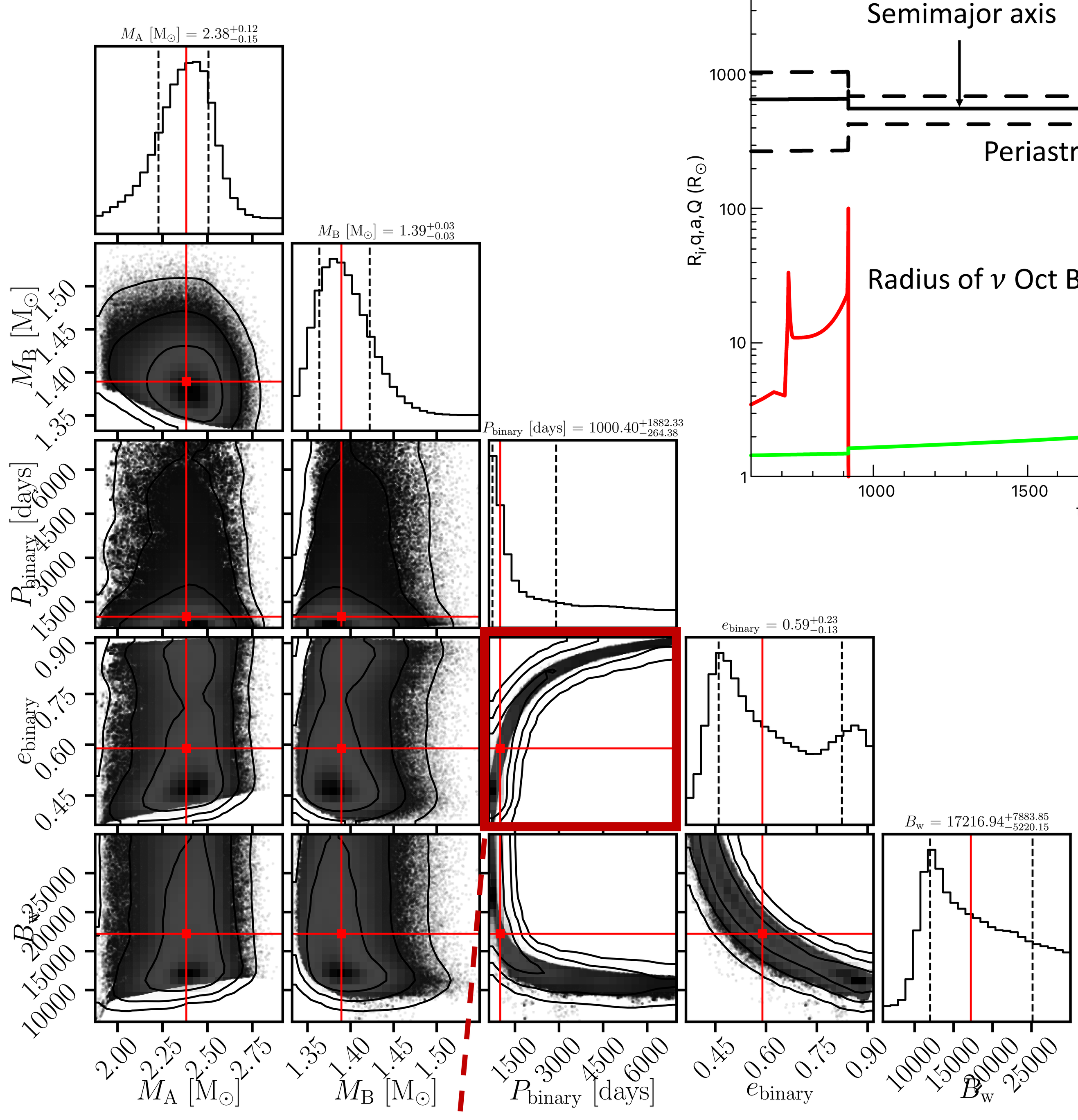
Comparison of ν Octantis with other systems hosting S-type planets. ν Oct is characterised by a relatively wide S-type planetary orbit under tight binary separation.

Methods



Plausible primordial orbital settings of the binary star

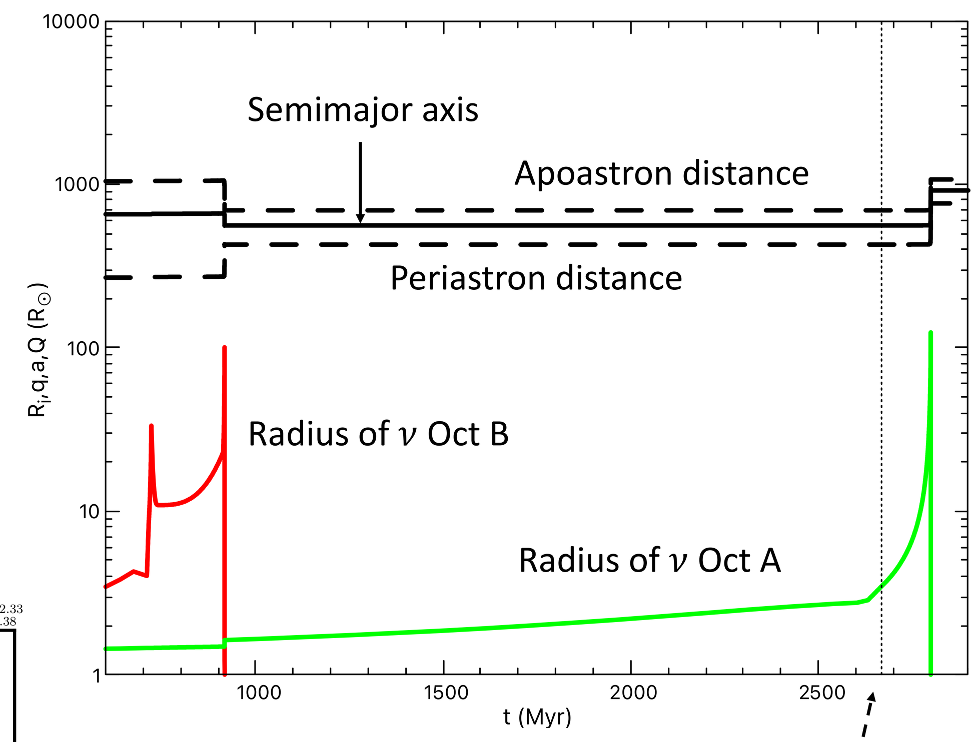
Nested sampling coupled with the BSE code for exploring plausible primordial orbital configurations.



Orbital period increases with eccentricity. At periastron, the primordial stars were always separated by around 1.3 AU, which would be too close to the semimajor axis of the current planetary orbit for dynamical stability.

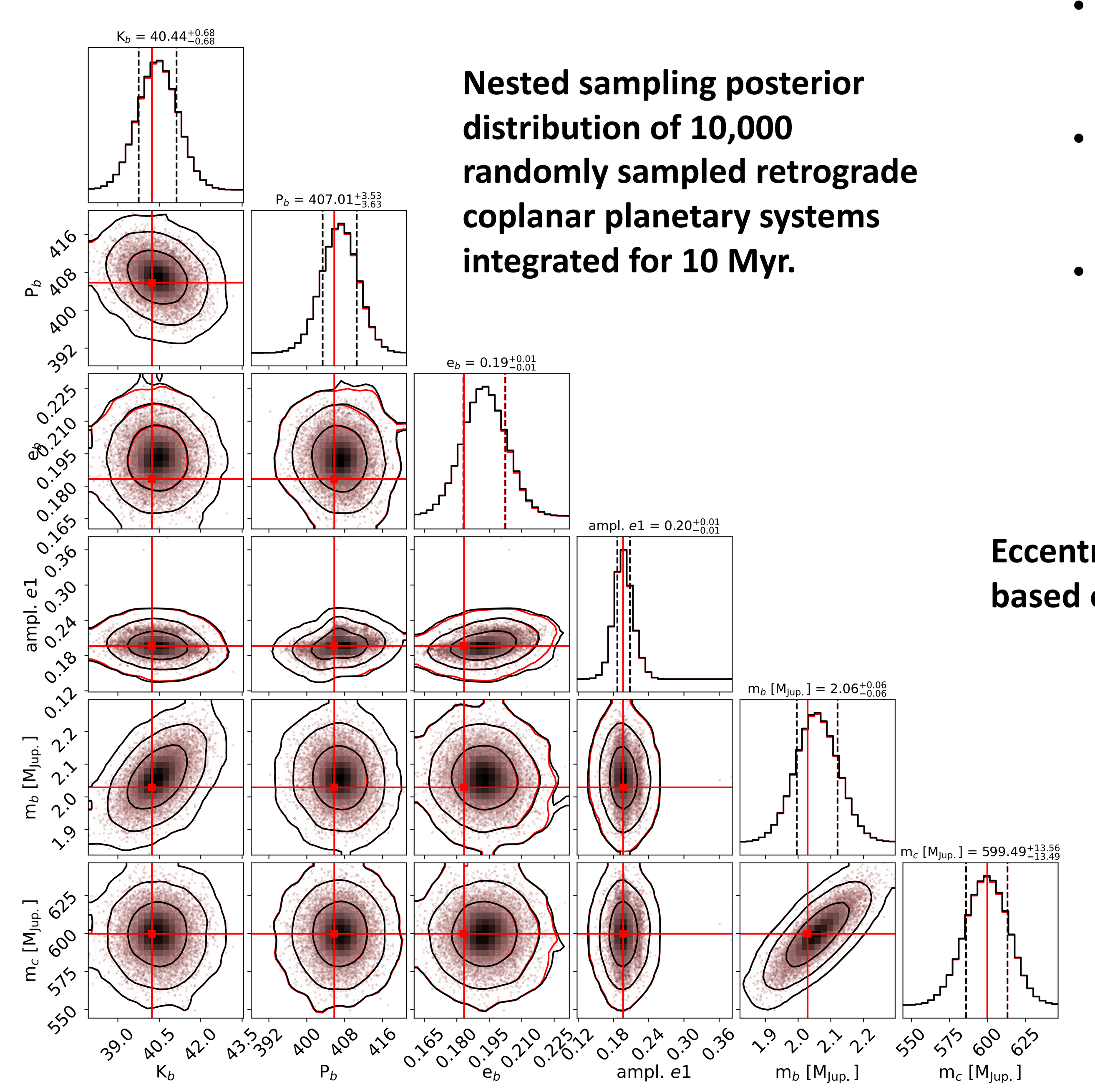
B_w is a poorly constrained parameter that describes tidally enhanced mass loss.

Example of the BSE evolution showing changes in the binary orbit and stellar radii.



Estimated age of the current system.

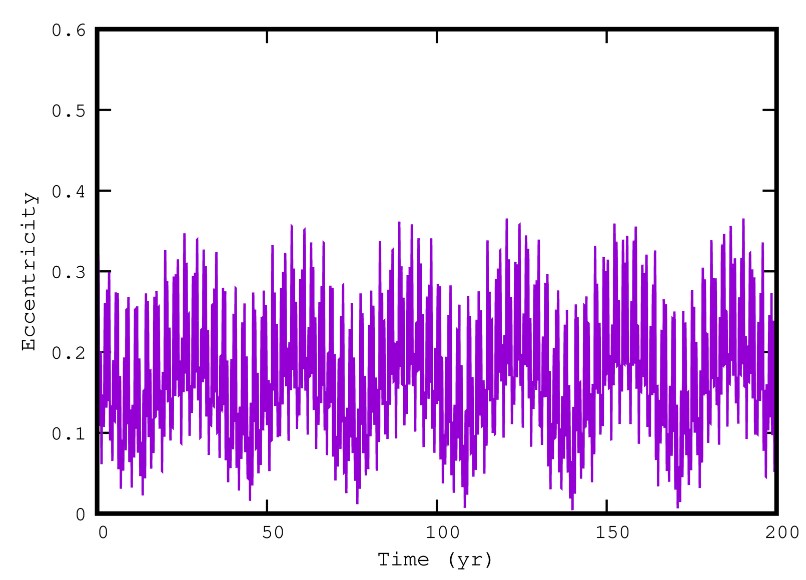
Planet's stability under present-day orbital configuration



Nested sampling posterior distribution of 10,000 randomly sampled retrograde coplanar planetary systems integrated for 10 Myr.

- The mutually inclined fits were found to have mutual inclination of about 154°.
- Only 2 out of 100,000 (0.02%) mutually inclined fits can survive over 0.2 Myr.
- In contrast, 86% of retrograde coplanar fits remain stable for at least 10 Myr. And the best-fit parameters guarantee dynamically stability for 2870 Myr, which is the age of the system.

Eccentricity variation of the planet on centennial timescales based on the best retrograde coplanar fit.



Conclusions

- The ν Oct planet must be retrograde and nearly coplanar for long-term dynamical stability.
- B_w greater than 10^4 is required for "reasonable" primordial configurations of the binary orbit.
- The initial binary orbit was too close to the current planetary orbit at periastron, ruling out early in-situ planet formation.
- An assumption that the S-type planet in between the two massive stellar progenitors has maintained dynamical stability, survived through stellar evolution and somehow evolved to its current location with a retrograde orbit will be examined.
- A scattering-induced tidal capture mechanism (Gong & Ji 2018) that transforms circumbinary planetary orbits into S-type will be applied in attempt to explain the origin of the ν Oct planet.
- Results from the two scenarios above will shed light on whether the ν Oct planet is 2nd generation originated from the ejected stellar envelope of ν Oct B.

Acknowledgements

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