Main-sequence progenitor configurations of the NN Ser candidate circumbinary planetary system are dynamically unstable

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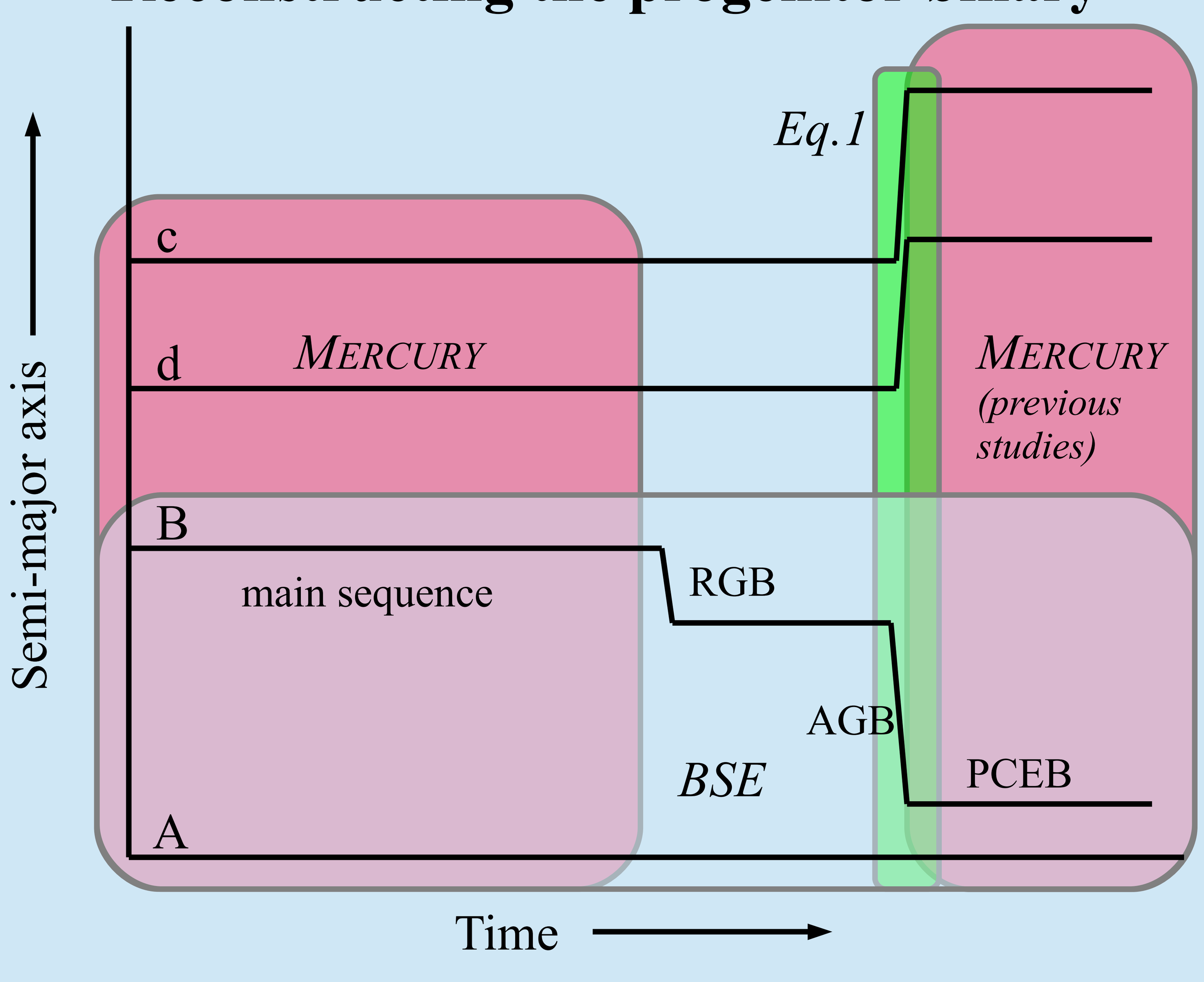
Recent observations of the NN Serpentis post-common envelope binary system have revealed eclipse timing variations that have been attributed to the presence of two Jovian-mass exo-planets. Under the assumption that these planets are real and survived from the binary's Main-Sequence state, we reconstruct initial binaries that give rise to the present NN Ser configuration and test the dynamical stability of the original system. Under standard assumptions regarding binary evolution, we find that survival of the planets through the entire Main-Sequence life-time is very unlikely. Hence, we conclude that the planets are not survivors from before the Common Envelope phase, implying that either they formed recently out of material ejected from the primary, or that the observed signals are of non-planetary origin.

Introduction

Several short-period eclipsing post-common envelope binaries have been discovered to show eclipse timing variations[1], which are often attributed to one or more giant planets. In many cases the multi-planet orbital solutions are highly unstable, and a non-planetary interpretation of the signals is to be preferred[2].

NN Ser is an eclipsing post-common envelope binary comprising a C/O White Dwarf of 0.535 $M_\odot$ and an M dwarf of 0.111 $M_\odot$ on a 0.13 day orbit[3]. Eclipse timing variations have been interpreted as evidence for two giant planets, orbiting at 5.4 and 3.4 au, in or close to a 2:1 resonance[4,5]. The system is stable in its current state[4,5,6], and so a planetary interpretation of the timing variations is not immediately ruled out. Such planets may be either "first generation", surviving from the main sequence, or "second generation", formed after the ejection of the primary's envelope. We investigate the plausibility of the existence of planets that have survived from the binary's main sequence stage by reconstructing the binary's original configuration and studying the dynamical stability of the original four-body system.

Reconstructing the progenitor binary



We break the evolution of the NN Ser system into several parts, outlined above. Previous works have studied the stability of the current system[4,5,6]. We reconstruct the original binary system using the binary evolution code BSE[7]. We calculate the original orbits of the planets, before the binary loses mass, on the assumption that their orbits expanded adiabatically during the mass loss from the primary:

$$\frac{\text{initial orbital radius}}{\text{present orbital radius}} = \frac{\text{present binary mass}}{\text{initial binary mass}} \qquad (1)$$

We then study the stability of the initial configuration with N-body integrations using MERCURY[8].

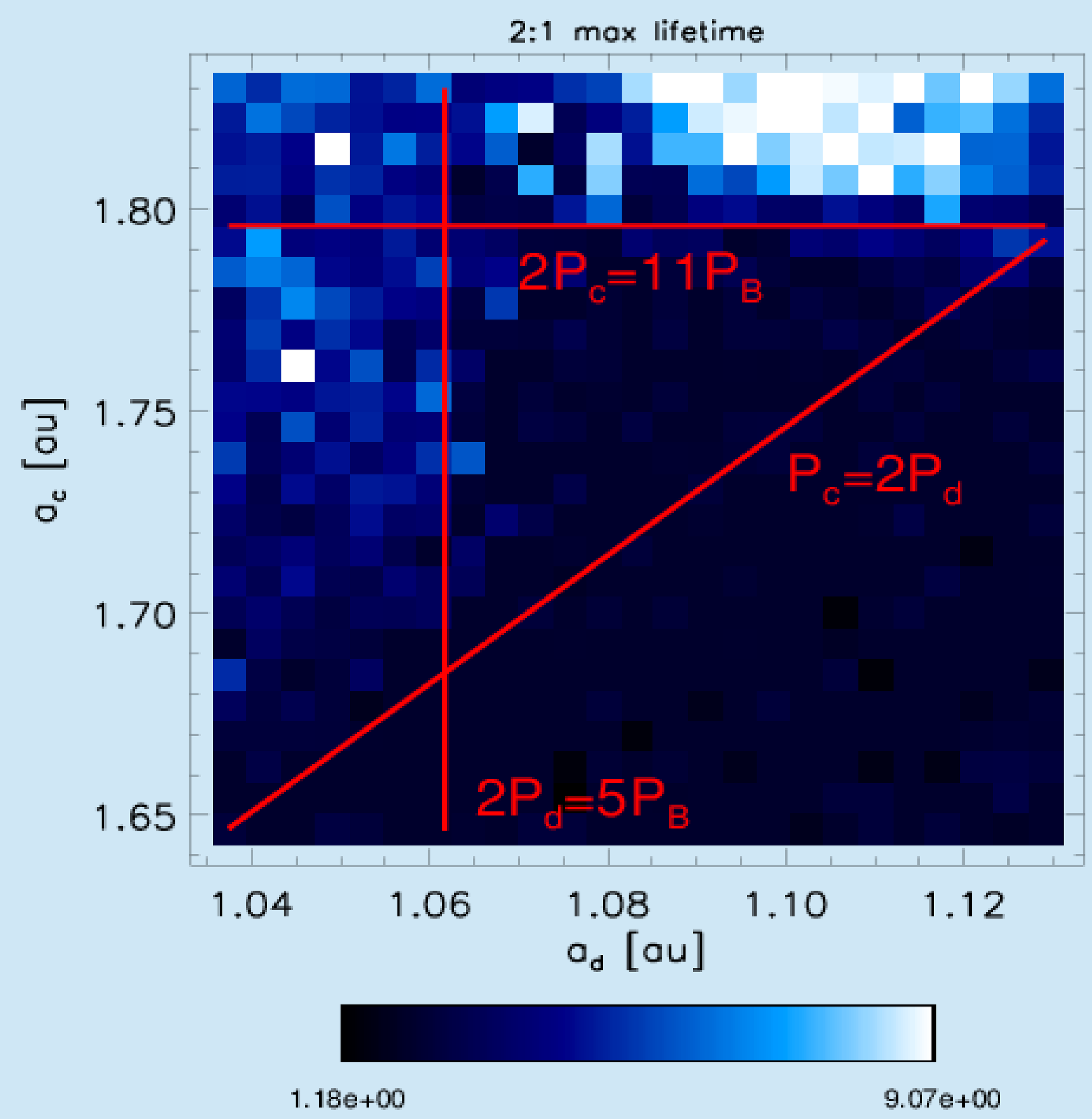
We vary the initial mass of the primary, the parameters governing common envelope evolution, and the initial binary separation. Progenitor binaries that give rise to systems similar to NN Ser all have a primary mass of around 2 $M_\odot$ and initial separations of 0.5 to 1 au. As the initial location of the inner planet would have been just beyond 1 au, the stability of the progenitor system may be poor.

Dynamical Stability

Having determined the parameters of the progenitor binary systems, we studied the stability of their planetary systems. First we took all successful progenitor binaries and integrated these systems with the planets on their (contracted) nominal orbits. All were highly unstable, typically on time-scales of centuries. Next we placed the planets on wider orbits, up to 3σ greater than the nominal values, and again tested all the binaries. With the inner planet's orbit enlarged by 2σ and the outer's by 3σ, we found a few systems (16 of 3740) that were stable for 10 Myr.

We then fixed the binary parameters at the values in these stable systems and performed long-term integrations (1.16 Gyr, the MS lifetime of the primary). We varied the planets' orbital radii from the nominal values to nominal values +3σ. The lifetimes of these systems are shown below (log scale, in years). Locations of some mean motion resonances between different bodies are marked in red. An island of stability exists at the top of the plot, rather removed from the nominal values of the planets' semi-major axes, but even so only 16 of the 6250 systems integrated in this grid remained stable for the MS lifetime of the primary.

A complementary grid, exploring the effects of reducing the planets' masses while holding their semi-major axes fixed, resulted in no systems stable over the MS lifetime.



Conclusions

Survival of planets from the MS in the NN Ser system to yield a configuration similar to that observed today is almost impossible under our assumptions. While more detailed consideration of effects such as the CE phase and its impact on the planets' orbits may turn up some routes to survival, we believe that the survival of planets from the MS is highly unlikely.

If the eclipse timing variations in NN Ser are due to planets, they must therefore be of second-generation origin. When one considers that in other similar systems a planetary origin for the variations has been ruled out, a non-planetary origin may also be considered the more likely explanation in NN Ser.

Acknowledgements

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References

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