Planets around the eclipsing binary UZ Fornacis

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Introduction

Evidence has been accumulating that planets around eclipsing compact binaries exist. Here we look at UZ Fornacis, a binary containing a white dwarf primary star and a lower mass red dwarf secondary star. The small size of the white dwarf allows accurate timing of its eclipses. These show that the time from one mid-eclipse to the next is not constant. Here we investigate if these light-travel time (LTT) variations are due to circumbinary planets.

Searching for planets

The timing of eclipses in an unperturbed binary can be described by a linear ephemeris:

$$T = T_0 + P_{orb} \cdot E$$

Here T_0 is a reference epoch, P_{orb} the binary's orbital period and E the binary cycle number which is zero at T_0.

Periodic differences between the observed and calculated mid-eclipse times can be fitted by the periodic influence of circumbinary planets. Due to the high dimensionality we use the Markov Chain Monte Carlo (MCMC) technique.

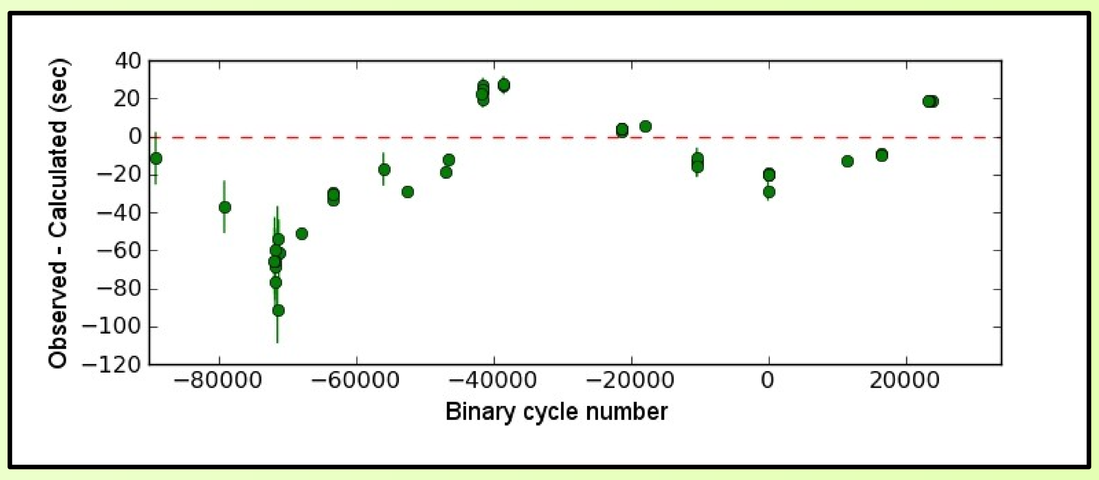

Figure 1: Observed minus calculated (O-C) diagram for UZ Fornacis mid-eclipse times. The green dots are datapoints. The red dashed line shows a linear ephemeris.

UZ Fornacis

Primary star: 0.7M$_\odot$ white dwarf.
Secondary star: 0.14M$_\odot$ red dwarf secondary.
Orbital period: 2.1 hours.
Other features: cataclysmic variable of AM Her type.

The observed data for UZ Fornacis spans roughly 27 years (Potter et al. 2011 and references therein).
From figure 1 above it is clear that there are deviations from a linear ephemeris. A good fit can be attained with two planets on eccentric orbits, as is shown in figure 2. Following the Packed Planetary Systems hypothesis (Barnes & Raymond 2004) we also consider three planets on circular orbits, leading to an excellent fit as can be seen in figure 3.

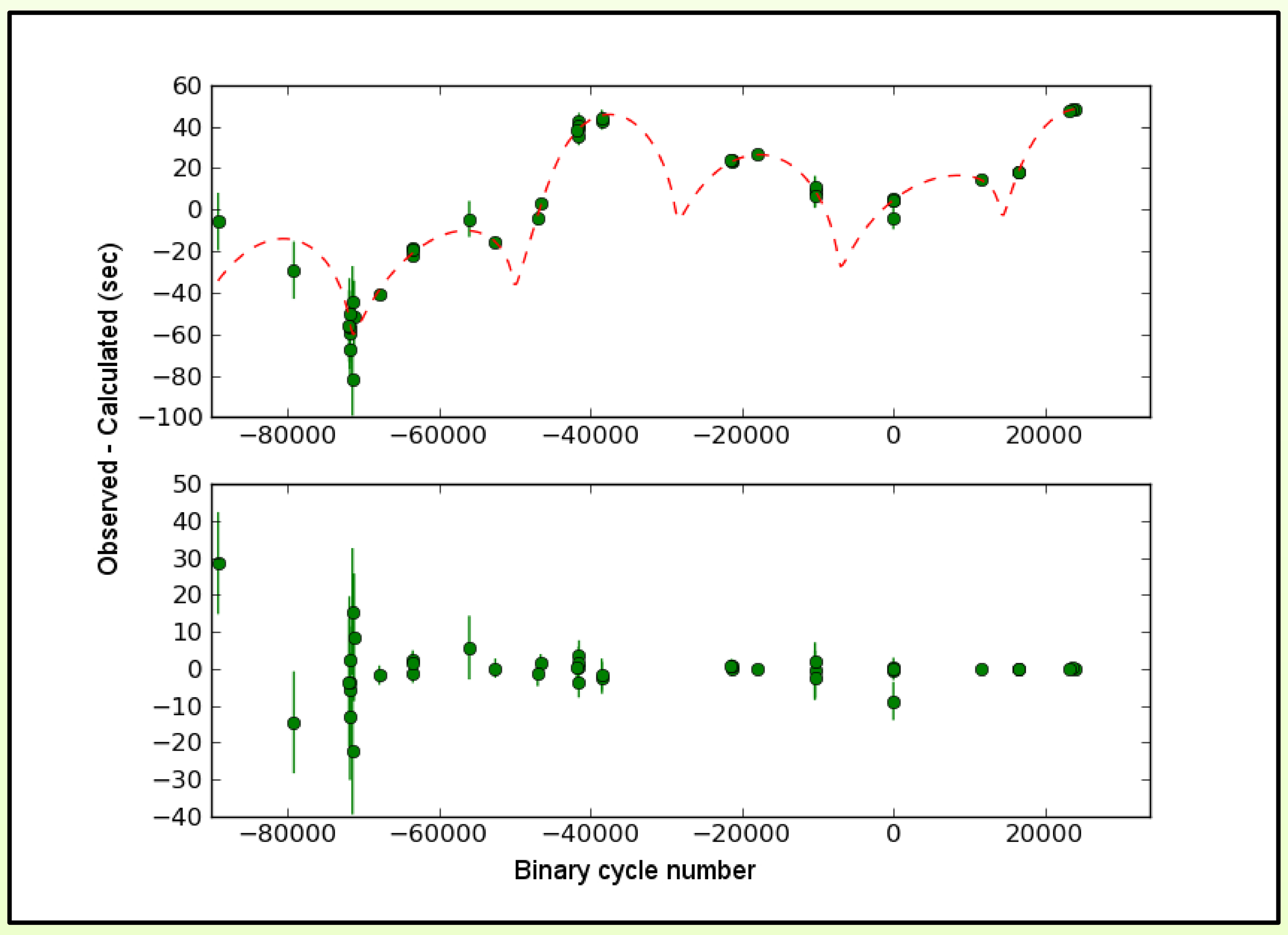

Figure 2: O-C diagram for UZ Fornacis. The red dashed line shows a fit with 2 planets on eccentric orbits. The bottom panel shows the residuals between data and fit.

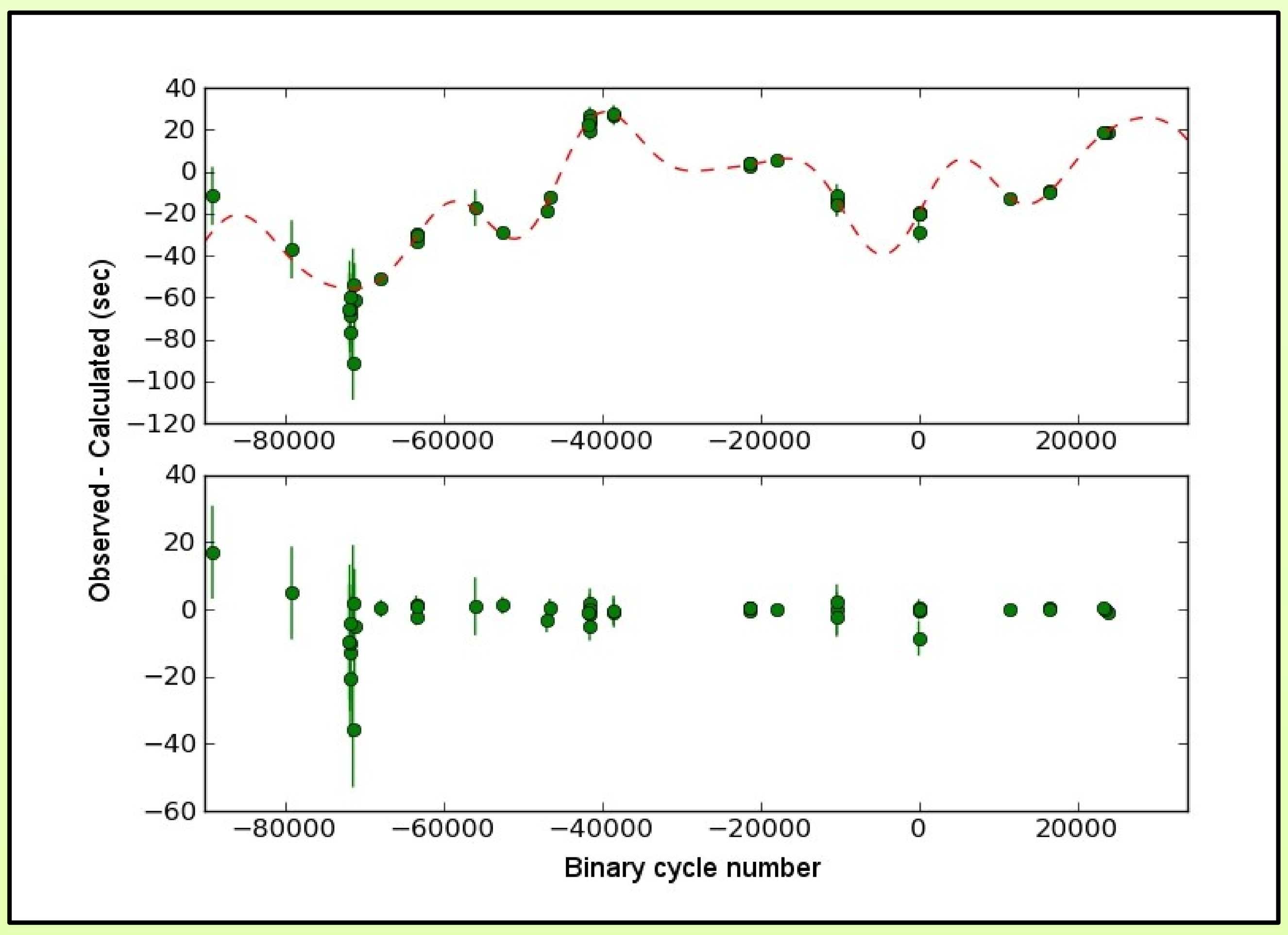

Figure 3: O-C diagram for UZ Fornacis. The red dashed line shows a fit with 3 planets on circular orbits. The bottom panel shows the residuals between data and fit.

Orbital stability of planetary systems

A second crucial step is examination of the orbital stability of proposed planetary systems. Previous fits to O-C data have been proven to be unstable on dynamical timescales (Horner et al. 2011).

Not only the mutual gravitational forces of the binary and the planets are important, but also the influence of multiple planets on each other. In future work we will additionally include the influence on the individual binary components.

All UZ Fornacis' planetary systems, with either two or three planets, seem to be unstable on evolutionary short timescales of $t < 10^4$ years. Figure 4 shows an example of the evolution of the binary and two planets on eccentric orbits. In the three planet system, where the eccentricities are less extreme, the small period ratio causes the system to be unstable.

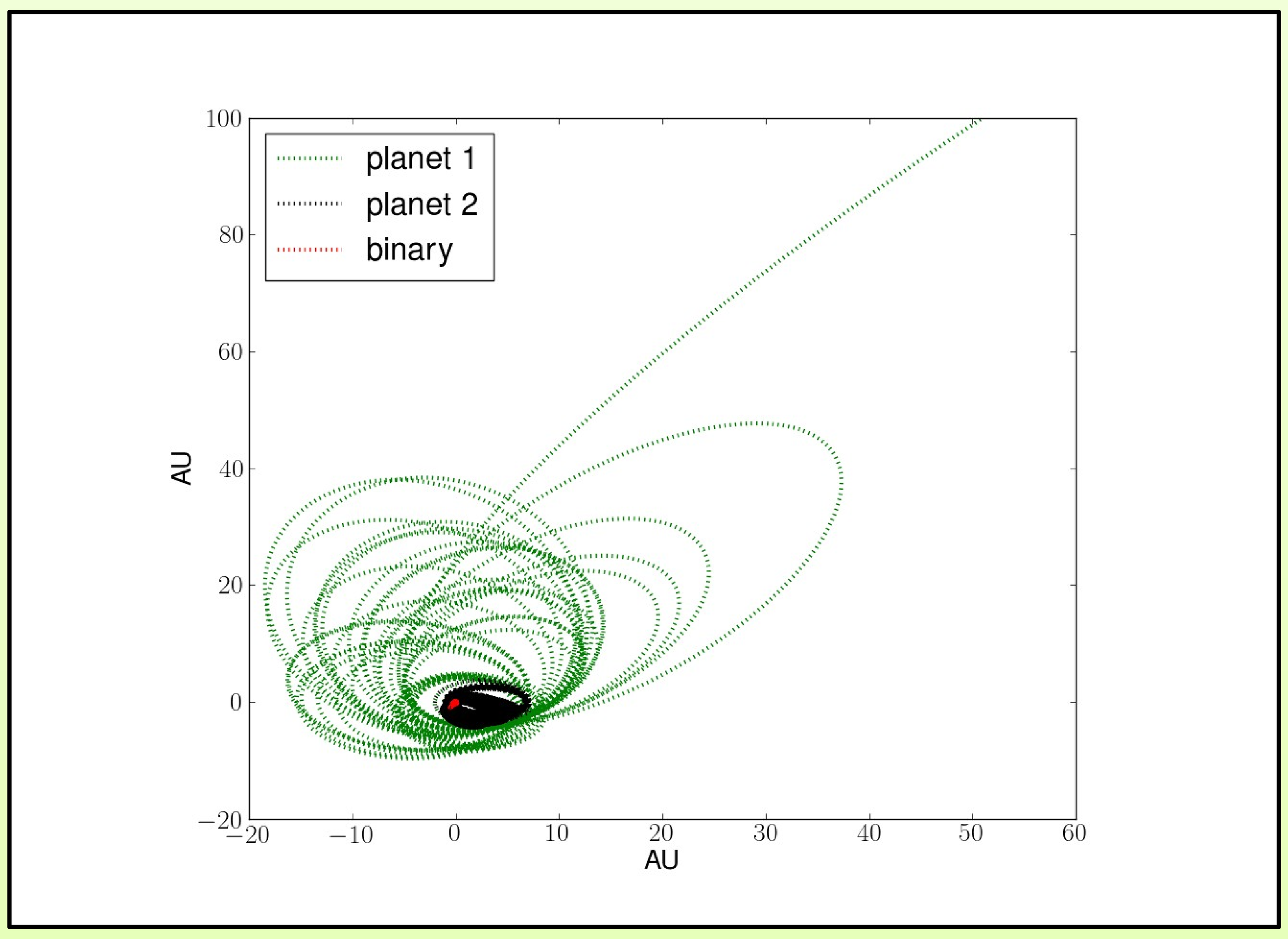

Figure 4: Orbits of two eccentric planets around the cataclysmic variable star UZ Fornacis. Both planets start off on eccentric orbits. The system is integrated using a variable step Bulirsch-Stoer integrator.

Discussion and conclusion

Circumbinary planets may be the cause of observed light-travel time variations. Some binaries showing O-C variations, can be fitted beautifully with a planetary system. However, subsequent analysis of the orbital stability of such a system is crucial, as this can rule out certain scenarios due to dynamical instability.

Other causes for LTT variations, such as apsidal motion, interacting magnetic fields or the impact of mass transfer within the binary, may also be considered.

References

Potter et al. 2011 MNRAS 416 --- Barnes & Raymond 2004 ApJ 617
Horner et al. 2011 MNRAS L416