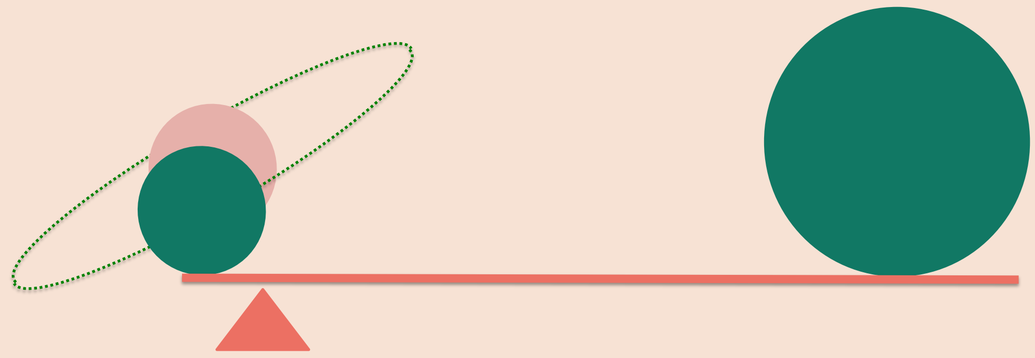
Detecting Distant Outer Planets Around White Dwarfs from Transit Timing Variations



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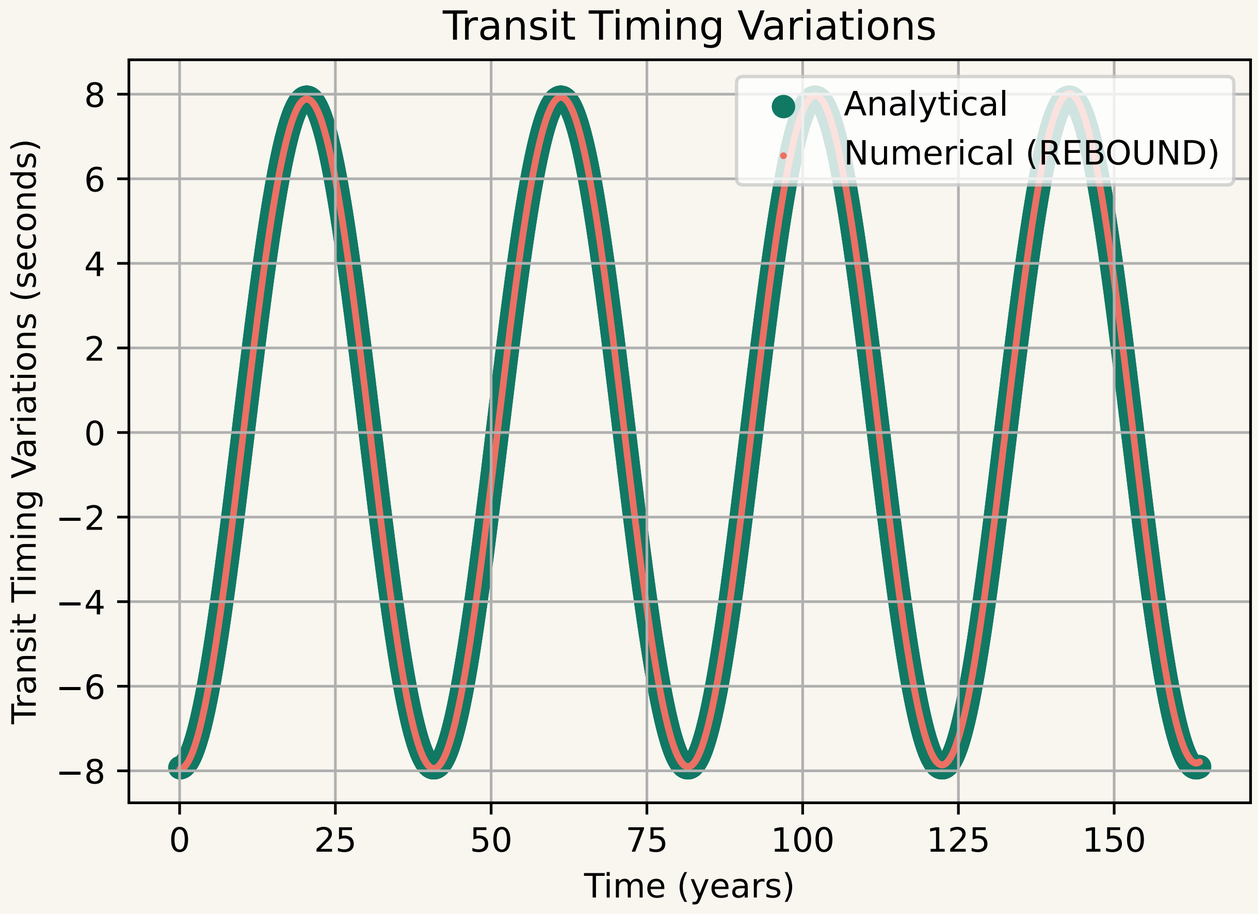
Motivation

White dwarfs (WDs) are small, making transits of orbiting planets geometrically unlikely. Only planets in very close orbits are expected to transit [1]. However, WDs likely host more distant planets [2]. Detecting these distant planets poses a challenge. One promising method involves using Transit Timing Variations (TTVs) of an inner planet. The gravitational influence of a distant planet can cause reflex motion, leading to detectable variations in the transit times of the inner planet.

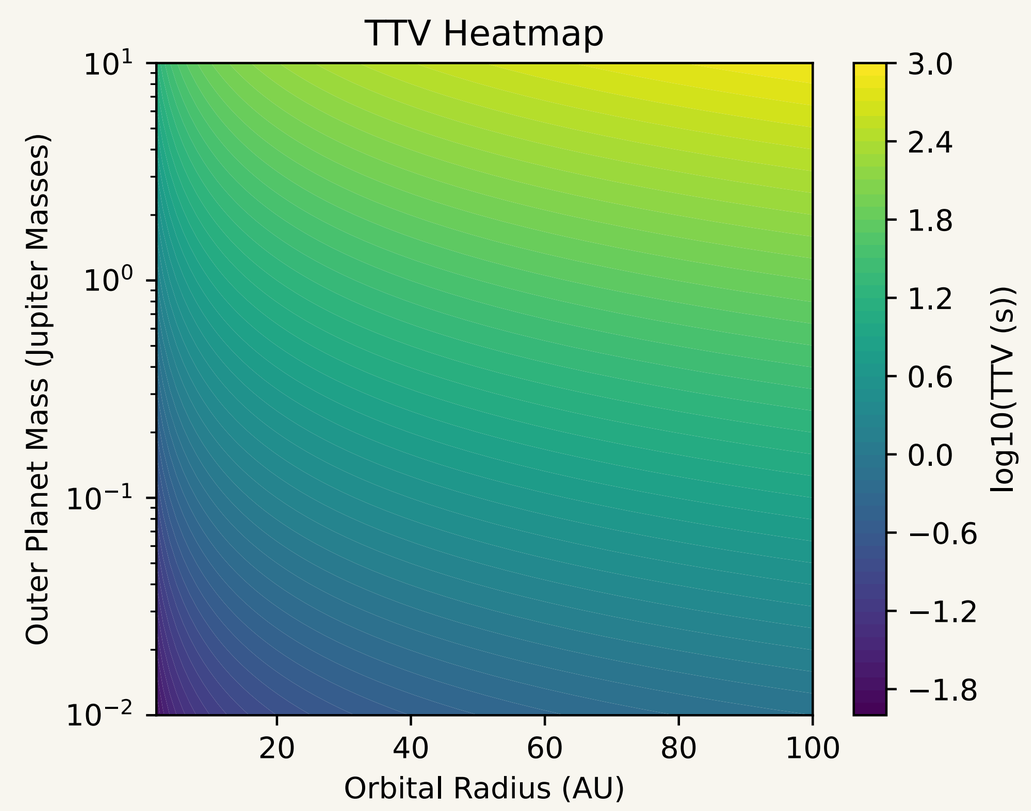
Simulating TTVs



In order to transit, an inner planet must be so much closer to the WD than the outer planet, that TTVs can be well approximated by treating the inner planet and the WD as a single point mass.
The figure above shows results for the 3-body problem numerically with REBOUND [3], which matches the analytical result for a 2-body system from Kepler's third law.

The outer planet has the mass of Jupiter and is at 10 AU, causing variations of inner planet transit times with a semi-amplitude of 8 seconds.

Detectability of Distant Planets from TTVs



The graph shows the calculated reflex motion of a 0.6 solar mass WD caused by outer planets with different masses and distances.

Large planets at large distances can cause large TTVs that could be detectable in ground-based monitoring of deep inner-planet transits.

Conclusion

Distant planets orbiting WDs discovered through TTVs may be the ideal targets for direct imaging. The TTVs tell us where the planet is in its orbit, and deep transits can block most of the starlight during direct imaging observations.

As WDs are increasingly observed by time domain surveys, more transiting close-in planets will be discovered, and long-term monitoring of transit times may reveal targets for direct imaging.

References:
[1] Vanderburg, A., Rappaport, S.A., Xu, S., et al. 2020
[2] Andryushin, A. S., & Popov, S. B. 2021, Astronomy Reports, 65, 246
[3] Rein, H. & Liu, S.-F. 2012, aap, 537, A128,