# Near Earth Asteroid 2002 AA29

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## Abstract

Asteroid 2002 AA29 is one of three known examples of horseshoe orbit behaviour. The asteroid is co-orbital with Earth; the only substantial difference in orbital parameters being a $10.7°$ inclination. From time to time, 2002 AA29 leaves the horseshoe behaviour and enters a quasi-satellite relationship with Earth (Connors et al. [1]), the next instance being approximately 2580 AD. Using the SWIFT simulation suite running on the Swinburne supercomputer this project investigates the orbital behaviour of 2002 AA29, in particular the quasi-satellite phase. The investigations confirm the presence of quasi-satellite behaviour and discount the possibility of resonances with Jupiter causing the transition.

## Horseshoe Orbit

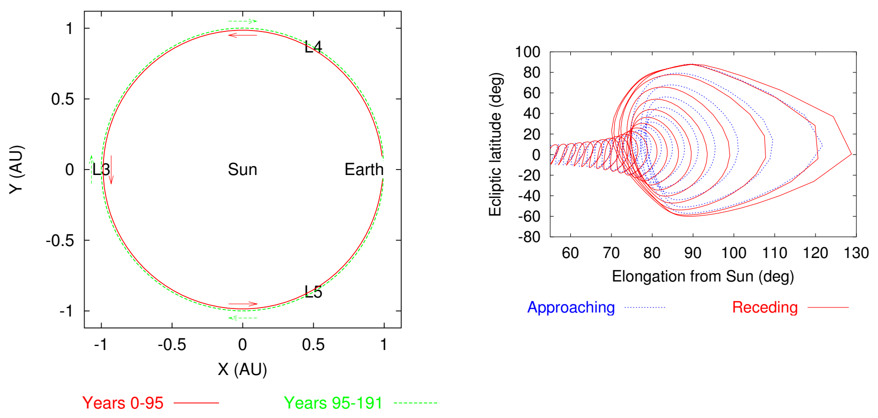


**Figure 1: 2002 AA29 annual average position over 192 years in co-rotating frame (left), and close approach near 2190 AD as seen in the morning sky (right).**

The equations of motion for gravitational systems with three or more bodies are not generally analytically integrable. A number of tractable three-body restricted cases exist for which motions have been determined analytically. Examination of such systems in a frame that co-rotates with the planet led to the derivation of Lagrangian equilibrium points (L1–L5) at which a light object may be dynamically stable. The object may be seen as trapped in a horseshoe shaped gravitational well along the planet's orbit, bounded by high walls near the planet. 2002 AA29 oscillates about the potential well generated by the Earth-Sun system over a period of 190 years (Fig. 1). Annual motion appears as a spiral about the Earth's orbit.

## Quasi-satellite Phase

2002 AA29, from time to time, enters into an Earth quasi-satellite state in which it stays within 0.2 AU of Earth for several decades. During the quasi-satellite phase the asteroid occupies the region normally excluded by its horseshoe motion. Fig. 2 shows consecutive close approaches to Earth; one resulting in several quasi-satellite orbits.

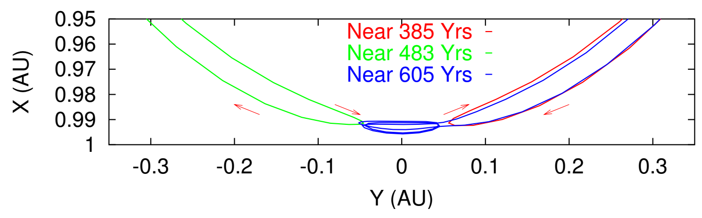


**Figure 2: Three consecutive close approaches, the third leading to quasi-satellite behaviour.**

To get out of the horseshoe pattern, 2002 AA29 must gain enough energy to climb the potential barrier near Earth. To investigate possible sources of that boost the following checks were done:

- Alignment of Jupiter at Earth-asteroid close approaches. No consistent alignment was found at the onset or termination of quasi-satellite phases.
- Resonance between Jupiter and oscillation in semi-major axis during quasi-satellite phase (Fig. 3). Subsequent phases showed varied oscillation periods; 13 to 16.8 years. No convincing resonance was found.
- Sensitivity to position of 2002 AA29's nodes (potential close approaches). Changing the asteroid orbit orientation slightly changes the onset of quasi-satellite phase.

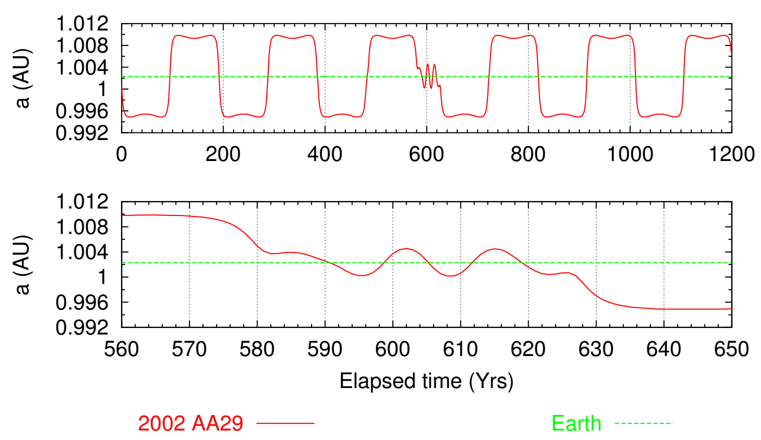


**Figure 3: 2002 AA29 semi-major axis vs. time for simulation (top) and quasi-satellite period (bottom).**

The most likely cause of the quasi-satellite behaviour is interaction with Earth, and this is very sensitive to alignment near the nodes.

## Simulation Stability

Tests of simulation stability were performed to ensure that results are reliable. Shorter integration time steps, 0.00027 vs. 0.001 years, produced grossly different results beyond approximately 5000 years elapsed. An alternate, commonly-used solar system starting state (Standish et al. [2] vs. JPL HORIZONS) lead to behavioural changes within the first 500 years. Simulation without the outer planets rapidly diverges from the base behaviour indicating that their distant effect is significant. The simulations are clearly very sensitive to starting state, and less so to simulation time step. The primary simulation is sufficiently stable over the 1200 years analysed in detail.

## Conclusions

The orbital dynamics of 2002 AA29 are interesting as an example of horseshoe interaction with Earth. The quasi-satellite behaviour is unique among known examples of horseshoe orbits. Jupiter, and the outer planets, play a part in the evolution of the inner solar system but do not appear to be the trigger for entry or exit to the quasi-satellite stage. The asteroid's oscillatory motion about Earth seems to be purely the result of interactions with Earth near the asteroid's nodes.

Future work on the nature of the quasi-satellite phase could look in more detail at the nature of nodal interactions between Earth and 2002 AA29.

## References

[1] M. Connors, P. Chodas, S. Mikkola, P. Wiegert, C. Veillet, and K. Innanen. Discovery of an asteroid and quasi-satellite in an Earth-like horseshoe orbit. *Meteoritics and Planetary Science*, 37:1435–1441, October 2002.

[2] E. M. Standish, X. X. Newhall, J. G. Williams, and D. K. Yeomans. *Explanatory Supplement to the Astronomical Almanac*, chapter Orbital ephemerides of the Sun, Moon and planets. University Science Books, Mill Valley, CA, 1992.