2004 MN_4 keyholes

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(99942) Apophis (a.k.a. 2004 MN_4)

In late December 2004 impact monitoring robots found that NEA 2004 MN_4 would have an extremely close approach to the Earth on 13 April 2029, with a probability of hitting our planet that rose up to 2.6% on 27 December.

On that date, precovery optical observations made on 15 March were found in the archives of Spacewatch; as a result, the impact probability dropped to 0.

Radar observations made from Arecibo on 27, 29 and 30 January further improved the orbit, so much that adding optical astrometry right now is not very useful.

2004 MN_4 in 2029

The current orbital uncertainty translates into an along-track displacement in 2029 of about half an Earth radius per unit of σ.

The asteroid orbit will suffer a very large perturbation, and the range of post-encounter orbital periods currently allowed by the available astrometry encompasses a number of mean motion resonances.

2004 MN_4 in 2029

This opens the door to the possibility of resonant returns, with both the asteroid and the Earth making an integer number of heliocentric revolutions, and coming back to collision, or near collision, within a few years.

In the b-plane (centred on the Earth and normal to the geocentric velocity “at infinity” of 2004 MN_4), the small regions through which the NEA has to pass in order to end up impacting the Earth at a resonant return are called keyholes (Chodas 1999).

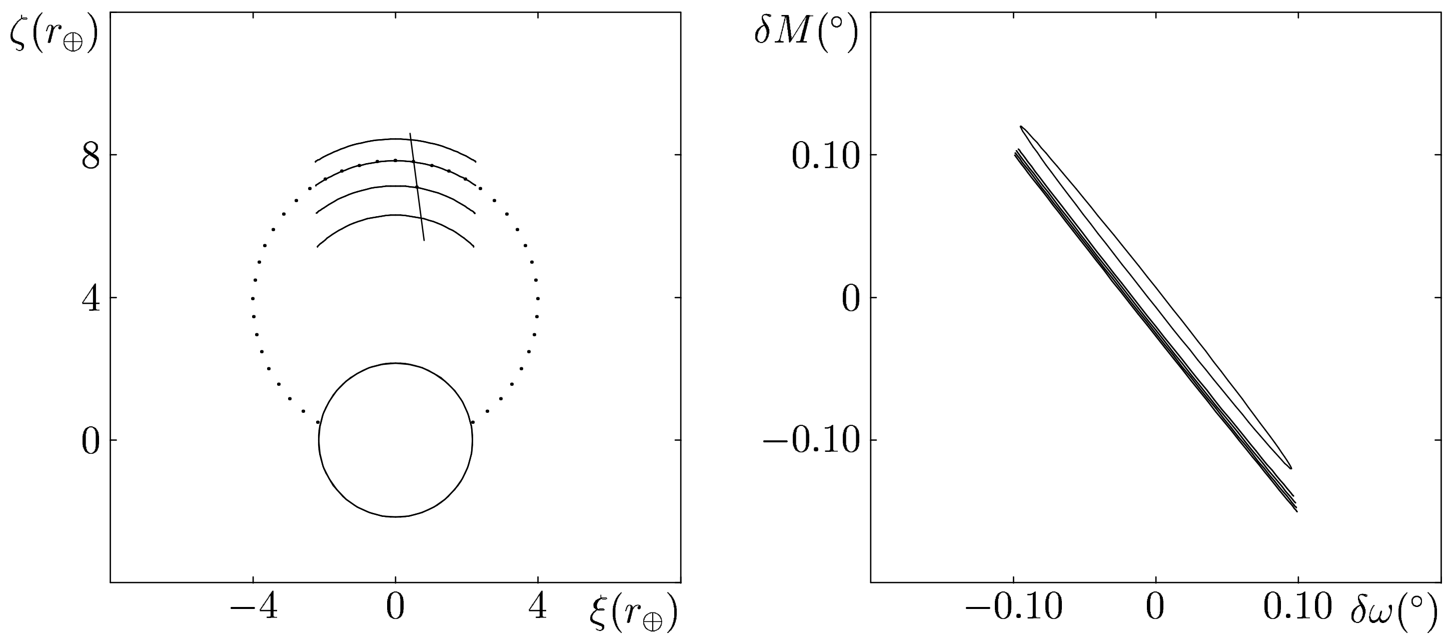
Some theoretical results

The analytical theory of resonant returns (Valsecchi, Milani, Gronchi and Chesley 2003) shows that, on the b-plane, the angle between the uncertainty region of 2004 MN_4 and each keyhole is not small.

In fact, a keyhole can be quite extended in a direction transversal to that of the uncertainty region footprint (LoV) on the b-plane.

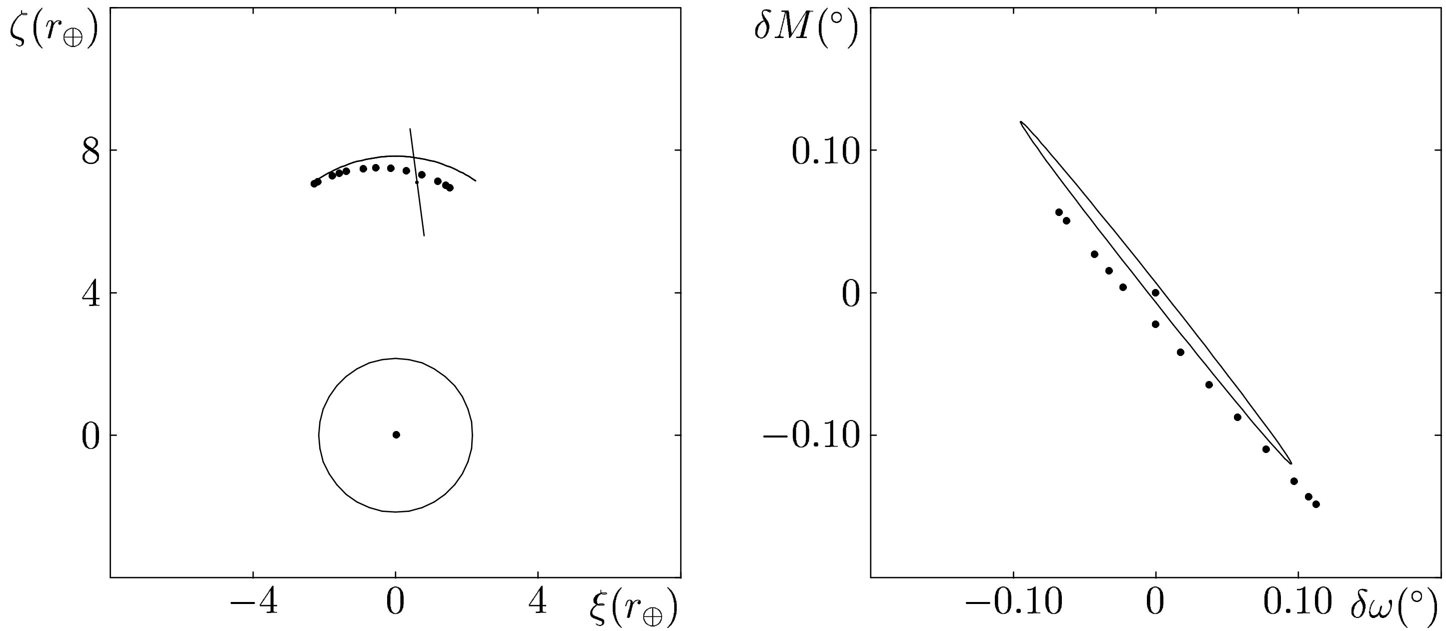
Using the algorithms presented by Valsecchi, Rossi, Milani and Chesley at IAUS 197 (2005), it is possible to compute the shape of a keyhole in the plane of any pair of orbital elements, assuming given values for the other four.

2004 MN_4 keyholes: theory



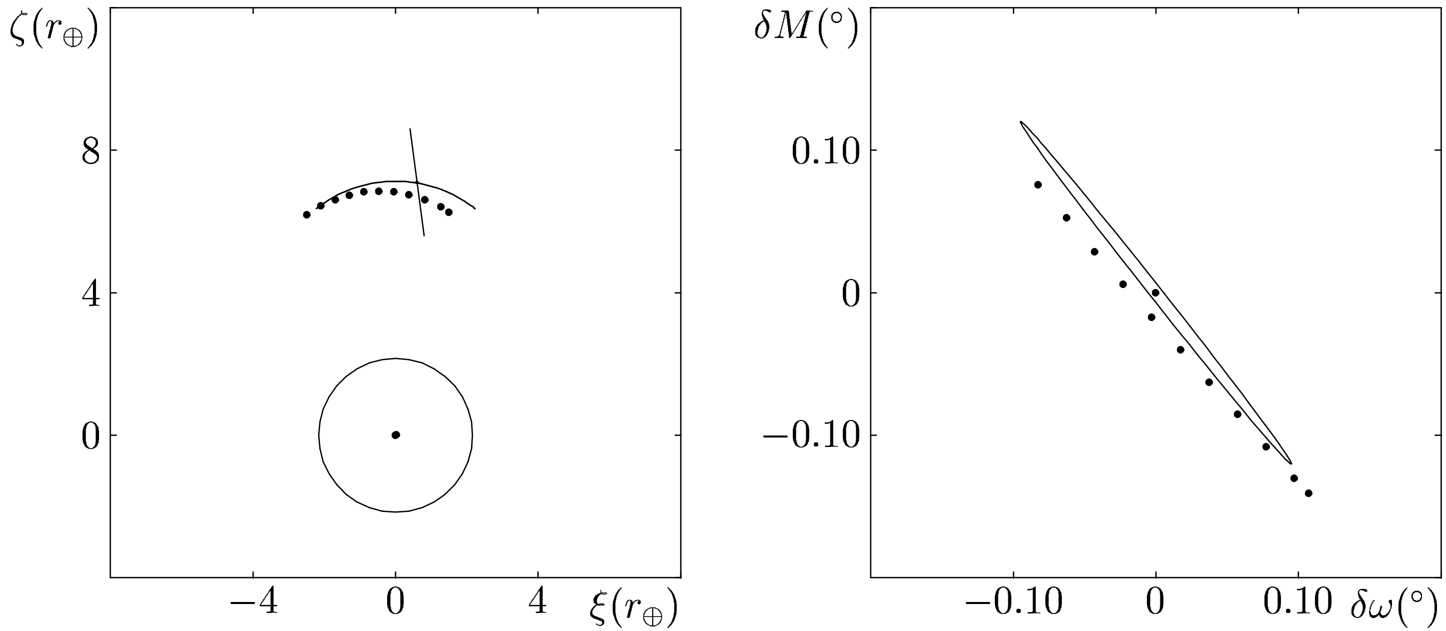
Left: LoV and theoretical keyholes for impacts in 2034, 2035, 2036, 2037 on the 2029 b-plane; Earth radius includes focussing, dots show the 6/7 resonance. Right: same keyholes, and pre-image of the Earth, in the $\delta\omega$-δM plane; the origin is a “central” 2029 collision.

2004 MN_4 2036 keyhole: practice



Left: LoV and 2036 theoretical keyhole, together with dots showing numerically found impact solutions; one of them is a "central" collision, the others are inside the "real" 2036 keyhole. Right: same impact solutions in the $\delta\omega$-δM plane.

2004 MN_4 2035 keyhole: practice



Left: LoV and 2035 theoretical keyhole, together with dots showing numerically found impact solutions; one of them is a "central" collision, the others are inside the "real" 2035 keyhole. Right: same impact solutions in the $\delta\omega$-δM plane.