# Spin axes and shape models of asteroid pairs: Fingerprints of YORP and a path to the density of rubble piles

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**Introduction:** An asteroid pair consists of two unbound objects with almost identical heliocentric orbital elements that were formed when a single "rubble pile" asteroid failed to remain bound against an increasing rotation rate [1,2]. Models suggest that the pairs' progenitors gained the fast rotation due to the YORP effect. Since it was shown that the spin axis vector could be aligned by the YORP effect [3,4], a coherent alignment should be seen on asteroid pairs, if they were indeed formed by the described mechanism. Alternatively, if the pairs were formed by a collision, the spin axes should have a random direction and the secondary body might have a tumbling rotation.

**Method:** Here I use the lightcurve inversion method [5,6,7,8] in order to derive the rotation axis vectors and shape models of asteroid pairs that were observed on multiple apparitions: *2110*, *3749*, *5026*, *6070*, *7343* and *44612*. All observations were conducted at the Wise Observatory in Israel during 2007 to 2014.

**Results:** Three asteroid pairs were found with aligned spin axes and three objects with ambiguous results. In addition, the secondary member *44612* presents the same sense of rotation as its primary member *2110*, and its spin is not tumbling. Finally, I use a rotational fission model [9,2], based on the assumption of angular momentum conservation, and match it to measured spin, shape, and mass ratio parameters in order to constrain the density of the primary members in the pairs. Using this novel method, low-density values that are expected from a rubble pile are derived. All these results lead to the conclusion that the disruption of these asteroid pairs was most likely the outcome of the YORP effect that spun-up rubble pile asteroids.

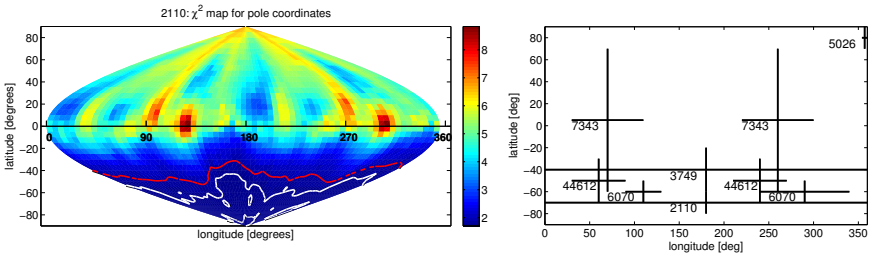


**Figure: Left:** An example for the $\chi^2$ values for all spin axis solutions on a longitude-latitude plane for (2110) Moore-Sitterly. The uncertainty of the fit corresponding to $1\sigma$ (white solid line) and $3\sigma$ (red line) above the global minimum clearly demonstrates the retrograde sense of rotation of *2110*. **Right:** Distribution of longitude and latitude of the spin axis vectors of the six observed asteroid pairs. Three asteroids resulted with polar-directed spin axes and not equatorial-directed spin axes and the three others with ambiguous results. This supports the notion of a spin-up and fission due to the YORP effect.

**Acknowledgements:** I am grateful to the AXA research fund for their generous postdoctoral fellowship.

**References:** [1] Vokrouhlický and Nesvorný 2008, AJ 136, 280–290. [2] Pravec et al. 2010, Nature 466, 1085–1088. [3] Slivan 2002, Nature 419, 49–51. [4] Vokrouhlický et al. 2003, Nature 425, 147–151. [5] Kaasalainen and Torppa 2001, Icarus 153, 24–36. [6] Kaasalainen et al. 2001, Icarus 153, 37–51. [7] Durech et al. 2010, A&A 513, A46. [8] Hanus et al. 2011, A&A 530, A134. [9] Pravec and Harris 2007, Icarus 190, 250–259.