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To whom it may concern

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Review of the doctoral thesis:

Asteroid Models from Sparse Photometry

By Mr. Joseph Hanus

The manuscript by J. Hanus addresses an outstanding problem in current Solar System science: the exploitation of sparse photometric data of asteroids. The interest of this topic is clear, as explained in the text: the forthcoming wealth of asteroid-related data coming from surveys such as PanSTARRS, Gaia, LSST... deserves specific methods to be appropriately exploited. Since such surveys were not designed to provide dense sampling of complete light curves, the sparse sampling is thus a critical issue to explore.

In the first part, the text describes the inversion methods with an appropriate number of relevant references to previous works. The first original part of the doctoral work analyses the accuracy of currently available sparse data.

The physical interpretation of the results strongly depends upon largely unknown bias introduced by the inversion process and possible systematic effects in the observations. A considerable part of the work is thus devoted to explore these aspects in order to consolidate the interpretation of the results. In Chapter 4 several tests are presented. I think that this section has a specific importance. Although scientific results are not the main aim here, it is an excellent (and certainly very time-consuming) exploration assessing the quality of the results.

Also, reasonable criteria for selecting reliable models are presented.
After the presentation of the “catalogue” of the obtained physical models (Chapter 5), the physical interpretation of the results that follows (Chapter 6) is crucial. Here, the advantage of having a richer sample of objects, and thus better statistics, is outstanding.

The statistical distribution of the pole latitudes is particularly well represented, with a clear depletion of ecliptic latitudes for “small” asteroids (here <30 km). This finding was already described in literature (such as in the cited Kryszczynska et al. 2007) but with poor statistics, while here it appears very solid and more detailed. Such polarization of the spin axis and the mechanisms that produced it put important constraints in the evolution of both the Main Belt and Near-Earth population.

As a consequence, it is very welcome that the author attempts a “global” modelling of the evolution of spin properties by building a model based on few fundamental mechanisms: the torque due to thermal emission (“YORP”); non-catastrophic collisions; gravitational torques and spin-orbit resonances; mass shedding at limit speed - with some simplifications. The goal is to reproduce the observed distribution of spin axis directions (latitudes) by computing the effect of the above mechanisms on shapes derived from observations.

The most critical free parameter is the one modulating the intensity of the YORP effect. Its determination seems to provide values consistent with predictions and other physical constraints.

However, as it always happens when exploring new domains, some caveats apply on some of the adopted simplifications. The main one, in my opinion, is that YORP appears to be extremely sensitive to shape. Although this is stated in the text, the model is not fully consistent when considering shapes. In fact, for fragmented, cohesionless asteroids (which should dominate for sizes <50 km) overall reshaping can occur during the lifetime of the object, for relaxing the internal stresses created by changes in the spin axis. The model does not account for this process, which in turn affects YORP intensity. It could well be that the statistic behaviour of the YORP would not change, and thus the model properties – but this is not proven. The only shape modification is introduced when a mass shedding occurs, but still the details of its implementation are not described. Also, the mass shedding criterion that is used applies to spherical bodies, but asymmetries and flattening can significantly alter the threshold.

The above suggests that an interesting link could exist between the intimate nature of a body (fragmented or monolith) and the evolution of its spin, deserving further investigations. If taking into account a complex reshaping (with many unknowns) was probably beyond the scope of this work, new perspectives are thus open thanks to the thorough, new analysis that it presents.

The study of the distribution of pole latitudes in proximity of resonances and inside dynamical families highlights some interesting properties, but here the statistics appears a little poor for drawing firm conclusions and going beyond some expected features. In this part, Mr. Hanus shows that he masters the complex issues related to the identification of family members. Also, some interesting, previously unknown situations are discussed. This is the case, for example, of some candidate members of the Koronis family, which do not exhibit the expected polarization (“Slivan state”) of the spin axis. Interestingly, in the case of 832 Karin, intra-family
collisions, which have changed its rotation state, are mentioned. Such collisions could also be relevant when modelling the overall evolution of the spin population, since they introduce substantial "local" deviations from the average statistics of collisions in the belt.

Eventually, the manuscript describes the coupling of the shape models to Adaptive Optics observations and stellar occultation results. Sizes derived from thermal modelling are also presented. This section appears as a useful assessment of the diameters accuracies that can be reached with different methods.

I conclude my review by stressing some points that appear relevant.

The illustrated inversion procedure is now a solid approach whose properties have been well explored. However, as shown for example in the last chapter, a fraction of the shapes are not consistent with those derived by other observational techniques. It is difficult to say where the origin of the problem is, however a systematic study on a purely synthetic sequence of photometric data (starting from known shapes) could help to better isolate the problematic cases (especially with the sparse sampling).

By the same approach, the role of noise could be verified. Signal-to-noise ratio of the observations is an important factor in the success of the modelling, and the future surveys (which motivated this study) are probably affected by noise properties different (lower?) from currently available data (in particular in the case of observations from space).

The above limitations cannot be said to be flaws in the thesis work, conversely I consider them as suggestions for further investigations.

In fact, as a reader I was impressed by the huge amount of original results and the variety of approaches, which clearly demonstrate the capacities of Mr. Hanus as a researcher.

In conclusion, I have to say that this is a thorough and original exploration of the multi-parametric light curve inversion process (especially of sparsely sampled light curves), enriched by a number of very interesting exploitations of the results.

The thesis exposes with clarity and completeness original results, and in my opinion it is also a fertile ground for future developments. I thus consider that the objectives of the scientific work were fully satisfied and that this manuscript should be accepted as PhD thesis.

Best regards

Paolo Tanga