Review report on PhD thesis

The doctoral thesis titled “Distribution functions of asteroid physical properties” by Helena Cibulková presents a statistical approach to determination of asteroid spin and shape parameters, and investigations to explain found distributions of these.

The first two chapters of the thesis bring the general description of asteroid physical properties and the methods that are being used to derive their spin states and shape models. Chapters 3 and 4 contain actual new results obtained within this work. Unlike previous studies in this field, that concentrated on determination of spin and shape properties of particular asteroids, this work presents a novel, statistical approach based on two simplified models applied to sparse data for thousands of targets from Lowell Observatory database (Chapter 3) and Pan-STARRS1 survey (Chapter 4). The first of these models (except for its mathematical background) has been largely developed, tested and applied by the candidate, while in case of the second model, the method developed by other researchers (still, with the participation of the candidate) has been tested and applied here on data from a new source. The last chapter summarizes the main findings in asteroid parameter distributions and conclusions from the methods testing. The bibliography list contains a comprehensive range of proper references. The thesis is organized carefully and neatly, and the text is written in clear and concise manner with very few typing or language errors.

Attached to the thesis there are two scientific papers published in high-rank journals, with the candidate being their first author. The first paper presents a new collisional model of the main asteroid belt, created in an attempt to reproduce currently observed size-frequency distribution of asteroids in various parts of the main belt, using a modified version of the Boulder code. Surprisingly, a much better match with observations is obtained with the assumption of monolithic bodies, instead of those of rubble-pile structure. It also points further directions to verify this result and to make the simulations more realistic. The second of the papers summarizes analysis and results of population-wide spin and shape modelling described in Chapter 3. It is worth mentioning, that the results described in Chapter 4 are the basis for another publication, currently submitted to Astronomy & Astrophysics, which will be a third paper with the candidate as a first author. The publication list contains two more published papers with candidate’s co-authorship. This sums up to five scientific papers, which is a very good achievement.

Among the the main results of the thesis there is a confirmation of previously discovered anisotropy in distribution of asteroid spin axis longitudes (λ), and finding correlations of this distribution with some of their physical and dynamical properties. Specific results also contain determining the shape elongations of asteroid of various sizes, periods and origin, with a few discoveries among asteroid groups and families, like stronger elongation of small asteroids (D≤25 km) compared to larger ones; or less elongation of both fast (P<4h) and slow (P>8h) rotators, compared to those of intermediate periods. Also, the thorough tests of both methods of determining spin and shape properties of large asteroid populations using various sample sizes are a worthwile result, revealing both their strengths and weaknesses, like a relatively good ability of model 1 to reproduce distributions of spin axis longitudes (λ) with shape elongations, and an inability to correctly reproduce distribution of spin axis latitudes (β). On the contrary, model 2 can be used for finding general distribution of spin latitudes and shape elongations, however is unable to determine the sense of rotation, or correctly determine the rotation period (at least not on the used dataset from Pan-STARRS survey). The minimum number of objects for obtaining stable results has been found. Future studies utilizing these models will greatly benefit from this work, actually it has already been cited in two papers.

The thesis presents a broad approach to the subject, proving that the author successfully joins knowledge and abilities from various fields and research areas (celestial mechanics, numerical simulations, photometric data analysis, asteroid spin and shape modelling) coupled with sound knowledge of statistical analysis tools. It is impressive and rarely met among early stage scientists, and definitely proves that the author is able to conduct creative scientific work.

Although the research done within this work failed to fully explain the anisotropy of asteroid pole longitude distribution, it explored many paths and resulted in finding a few notable correlations of this distribution (with orbit inclination, longitude of the ascending node, asteroid rotation period, and shape elongation) providing valuable clues for further investigations.

The findings of the thesis will also be important for the interpretation of future results from Gaia mission, where also the ellipsoidal shape approximation will be used. This approximation was shown here to overestimate shape elongations and to perform worse in spin latitude (β) determinations of asteroids with high orbital inclination.

Among few weak sides of the thesis I would mention the following:

- Contrary to the methodology, simulations, and results comprehensive description in Chapter 3, the one in Chapter 4 is rather limited, making it hard to understand without prior knowledge of the paper by Nortunen et al. (2017, A&A 601, A139). For example there is no explanation of the $D_{b/a}(L^{1-\infty})$ symbols presented in Table 4.1, or the meaning of colour scale in plots in Fig. 4.3. The reference to the paper is given, however in my opinion more details and explanations should be provided in the thesis, so that every chapter is self-contained, and the presented results are easy to interpret.

- Also, the uncommon notion of "inverse amplitude" (after: Nortunen et al., 2017), is confusingly called in the thesis "lightcurve amplitude" and used in equations 3.15, 4.1, and 4.3, what is inconsistent with Figure 4.11 presenting commonly used peak-to-peak lightcurve amplitudes. Obviously it does not affect the model or the results, it is just a lack of proper description.

- The caption of Fig. 3.24 suggests that both distributions of pole latitudes have been divided by synthetic distribution presented in Fig. 3.4. However asteroid models in DAMIT were mostly created using a different method (convex inversion on dense lightcurves, or with their addition) thus debiasing based on simplified model used in this work should not be applied there. The difference would pertain e.g. to targets with asymmetric lightcurves or those with uneven number of extrema that are present in DAMIT, but not possible here, with the assumption of ellipsoidal shapes.

Questions to the author:

- The distributions of pole latitudes in Fig. 3.4 look notably different from the corresponding plots in the paper (Fig. 2 in Cibulková et al. 2016, A&A 596, A57). Please explain why, and also justify the choice for the bins number and sizes in Figure 2.
- Since the described model has been shown to badly reproduce rotation periods, then how were the rotation periods from Pan-STARRS1 data determined (Fig. 4.5)? Or is the histogram for Pan-STARRS database only a rescaled plot of a chosen subsample of LCDB periods?

Summing up, the above mentioned issues, small omissions (like 90° instead of 50° in the Figure 3.29 caption, or the inconsistence of legend and caption of Fig. 4.8), and minor language issues do not change overall very good grade that the thesis deserves.

In my opinion both the form and the contents of the thesis fulfill all requirements posed on theses aimed for obtaining a PhD degree and I recommend this work for the defense in front of the respective commitee.

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