Report of “Identification methods of genetically related asteroids” by Petr Fatka

1. Which of the contained results can be considered a new scientifc result?

Original work produced by the candidate is contained within four papers published in the refereed literature, specifically in the journal *Icarus*. I summarise the main results below, broken down by publication:

- Paper I (Pravec et al, 2018) investigates tight orbital clusters of asteroids. The authors show that cluster properties satisfy a relationship between rotational period and mass ratio expected on theoretical grounds if the secondaries were derived by YORP-induced rotational fission of a parent asteroid. The relationship was shown to hold previously for pairs of asteroids (Pravec et al, 2010); the present work shows the rotational fission mechanism to be also responsible for forming clusters.

- Paper II (Pravec et al, 2019) follows up on Pravec et al 2010 work, on asteroid pairs focusing on pairs with rotational state information to further constrain the formation mechanism. A byproduct of the research is a census of binary asteroids within the sample. It is observed that those parent asteroids which are binary systems tend to rotate faster than non-binary parents.

- Paper III (Moskovitz et al, 2019) searches for pairs among the Near-Earth Asteroids (NEAs) and identifies two strong candidates based on orbit similarity and past dynamical evolution. Spectroscopy is used to obtain the taxonomy of these asteroids. The obtained spectra are consistent with a common taxonomy between the pair components . For one of the pairs, the case for genetic relationship is significantly strengthened by finding a taxonomy that is generally rare among NEAs. One of the pairs is identified independently in the work by de la Fuente Marcos & de la Fuente Marcos (MNRAS Letters, published 02/19) which the present thesis does not mention.

- Paper IV (Fatka et al, 2020) focuses on the formation times of clusters, finding evidence for multiple rotational fission episodes creating different generations of secondaries. It tests a simple model whereby YORP spins up the parent asteroid to the critical rotational limit by YORP following each fission episode.

2. What is the importance for the work in the area and possible applications to neighbouring areas?

Planetary scientists study asteroids to understand how the solar system formed and evolved; and the processes that control its evolution now and in the past. Collisions dominate the evolution of larger asteroids, creating the so-called asteroid families. For asteroids smaller than a few tens of km, the principal agents of orbital and physical change are solar-radiation-driven effects: Yarkovsky and YORP. These have important implications for studies of asteroid families, near-Earth & binary asteroids and meteorite delivery to Earth. The range of applications is not confined to the solar system, as planetary systems are thought (and observed) to originate and co-habitate with debris disks. The candidate’s research group has led the work showing that YORP drives asteroid evolution for small asteroids with rotational fission now recognised by the community as one of a very few

mechanisms capabe of creating new asteroids. The work contributed by the candidate allows us to calibrate our understanding of these processes in the real solar system. Apart from the applciations listed above, the new knowledge will also inform studies of the millions of new Main Belt and Near-Earth asteroids soon to be discovered by the Large Synoptic Survey Telescope (LSST).

3. Form of the thesis & author's ability for creative scientifc work

Material in the thesis is presented in a logical way. The first section provides key definitions, the scientific context and aims & objectives, followed by a generic section of Methods (Section 2) and their application to the study of asteroid groups (Section 3). In some cases, it has been appropriate to explore and apply alternative methods; I found these to be also adequately explained and justified. The English level is also above average.

The candidate is clearly able to form and test hypotheses, then use available evidence and experimental outcomes to draw reasonable conclusions. This is particularly evident in Paper IV where fission theory is adapted to test the hypothesis of repeated fission episodes in asteroid clusters and finds that only two of the four cluster studied agree with theory, it is concluded therefore that fission cannot not be solely responsible for producing the clusters. He also appears to be aware of the respective strengths and limitations of his methods and uses that knowledge to adapt his approach to the circumstances, for instance resorting to the MOID as opposed to encounter statistics to establish relationships between NEAs (Paper III).

Based on the material at my disposal, I believe the candidate fulfls the criteria for a PhD.

Questions for the candidate:

Question 1: The relationships in Section 1.4 used to test consistency of the observed asteroid groups with fission theory depend on a number of assumptions, some of which are listed on p16. A caveat in the analysis of pairs comes from the condition that energy and angular momentum are conserved, for example it is assumed that YORP has not significantly spun up (or down) the primary after secondary separation. On the other hand, it is shown in Paper IV that, in the case of one cluster, YORP can respin the primary up to fission limit in ~10^5 yr (Section 3.4) and some of the pairs are significantly older than this. The implication is that the present spin state may not represent the epoch when the secondary was ejected. How would the violation of this condition be manifested in Figs 1.8 and 3.5 and how do you test for it?

Question 2: Can one of the two largest asteroids in the Hobson & Mandragora clusters be interlopers? How can you test this observationally?

Minor Remarks: There are more recent and better-populated versions of Fig 1.5 in the literature. The candidate may also create its own using, for instance, data in the MPC's LCDB online facility.