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To whom it may concern,

I report the thesis entitled "Simulations of asteroid collisions using a hybrid SPH/N-body approach" by Pavel Sevecek. In the thesis, the author explores collisions of asteroids via computational simulations. The author describes the numerical model for the simulations and shows validation tests of the simulation code. Using the validated simulation code, the author finds a collisional outcome model for 10km sized asteroids that is consistent with 100km-sized asteroids, the angular momentum transfer via collisions of rotating targets, the impact forming the Hygiea family. I below briefly summarize the contents in the thesis.

The author fully describes the methods of computational simulations in Chapter 2. The author uses the method of Smoothed Particle Hydrodynamics (SPH), which describes the dynamics of continuum materials using Lagransian particles. SPH is used for the impact of asteroids and the ejection of fragments. The ejected fragments can be reaccumulated onto large remnant bodies. This reaccumulation phase is calculated by additional N-body simulations. The authors mostly describes the details of these methods. The simulations are validated via some tests in Chapter 3. The code of the author reproduces analytical solutions for fluid problems (the problems for one dimensional shock tube, point source explosion, and Kelvin-Helmholtz instability), bouncing and rotation of elastic bodies (elastic bands, rotating rods) , and a cliff collapse of frictional bodies shown by a laboratory experiment.

The collisional property of 10km sized asteroid is investigated in Chapter 4. The author performs the impact simulations for more than 100 runs with different impact parameters. The size frequency distributions (SFD) of collisional outcomes are compared with those for 100km-sized asteroid collisions. Even if the outcome sizes are scaled by the factor given by the radio of targets, the SFDs are similar only for $Q \sim Q_D^*$, where Q is the specific impact energy and Q_D^* is the critical specific energy for catastrophic disruptions. For $Q < Q_D^*$ and $Q > Q_D^*$, the SFDs are quire different. The author modifies Q according to the consideration that the effective impact energy is limited for the cross-sectional area of the impact . The modified scaling reproduces the 10km- and 100km-sized targets' SFDs well. The result may allow us to understand the collisional physics independent of target sizes.

The collisional outcomes of spin rotating targets are investigated for 10km- and 100km-sized targets in Chapter 5. The resultant SFDs significantly depends on the initial spin angular momentum for 100km-sized targets, compared to the results for 10km-sized targets. The difference seems to be caused by the large spin angular momentum relative to the impact angular momentum for 100km-sized bodies. The author additionally investigates the variation of rotation. The variation is effective for small impact energies Q ($\ll Q_D^*$).

The author tackles the origin of Hygiea family via the collisional simulations in Chapter 6. Though collisional simulations, the collision that Hygiea experienced is likely to be of 428km-sized parent body with $Q \sim 0.25\ Q_D^*$. Such collisions have relatively low impact energies. However, the almost whole surfaces of targets can be mixed by the collision. In addition, Hygiea is a very spherical body, whose sphericity is similar to planets. The author finds the sphericity is achieved for the material friction coefficient on the surface of Hygiea.

These findings are very interesting and important to reveal the origin of the solar system. The author systematically investigates collisions of asteroids for various parameters though a lot of his efforts, which reveal collisional physics for main-belt asteroids. In addition, the code developed by the author is useful to reveal the collisional histories in the solar system. Therefore, I would like to recognize this thesis as “excellent” level.

I give some comments on the thesis below.

Yours sincerely,
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Comments

Chapter 3:

In the cliff collapse test shown in Fig. 3.7, the simulation by the author reproduces the experiment well. It looks almost no differences. However, I found small differences at the second and third panels (at t = 5 and 15s). In the second panel (at t = 5s), the simulation shows almost a square, while the experiment shows a slope at the bottom. In the third panel (at t = 15s), the slopes at the bottom are slightly different. I guess the simulation see the slightly earlier snap shots than those of the experiment. If so, the information is helpful for the improvement of the friction treatment in simulations.

Chapter 4:

This chapter is mainly clear to me. However, the comparison of SFDs for 10km- and 100km-sized targets mentioned at the second paragraph in Chapter 4.3 is difficult to understand, because there is no figures about the comparison in Chapter 4.3. It is kind to give a reference (Fig. 1 in Sevecek et al. 2017) around the description.

Chapter 5:

-) The treatment for merging is explained in Chapter 5.2.2. It is mainly clear for merging particles that satisfy with the conditions given in Eqs. (5.2) and (5.3) when collisions of particles occur for $r < r_i + r_j$. However, the treatment of the non-merging particles are not explained. The treatment such as passing (nothing happens) bouncing, or others should be mentioned.

-) The author shows the resolution test in Chapter 3. However, resultant angular momentums may be more sensitive to resolutions. Even small fragments can run away with huge angular momentums. Therefore, low energy impacts effectively change the angular momentums of targets, as the author shows. The issue should be discussed.

-) I am wondering collisional outcomes are explained by Q/QD^* and L_{imp} / L_{target}. If the scaling does not work, the author may mention it.

Chapter 6:

In Chapter 6.3.2, the author gives a constraint on the friction coefficient, which is expected to be very small. Such low friction may be achieved by melting. However, melting does not occurs for low energy collisions expected to produce the Hygiea family. The author claims an impact weaken the strength of materials on the surface of Hygiea. However, most Main-Belt asteroids suffer such collisions, but only Hygiea is specially spherical. Therefore, the author may want to give a constraint on the friction relative to the self-gravities of asteroids.

Minor Comments:

Page 43: In Eq. (43), “Q” is used. However, it is used for a different meaning in other chapters. The notation should be changed. λ is used for a different meaning in Chapter 3.3.

Page 46: The description about “Low discrepancy” is unclear to me. How does the author define box B? The boxes are the same as those in the tree method?

Page 92: “ratii $\log_{10} (m_{imp} / M_{pb})$” should be replaced with “ratios $\log_{10} (M_{pb} / m_{imp})$ ”.

Page 145: “$d_{lf} \sim 40$” should be revised as “$d_{lf} \sim 40$ km” .