1. カイパーベルト天体の衝突と数十億年間の軌道進化
2. 巨大微惑星の存在による太陽系小天体と巨大惑星の軌道進化

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I have performed computer simulations on two different research projects during the fiscal year Heisei 20 (numbered 1 and 2 in this document). Worth noting, these research topics represent a new and pioneer work on the Kuiper belt and the early solar system. In this way, the various results from both projects will likely render a number of publications in international refereed journals and conferences. More details on the importance, current status and preliminary results are shown below for both projects.

1 – Collisional families in the Kuiper belt and their long-term dynamical evolution

I aim to understand the effects of collisions in the Kuiper belt. For example, how the orbital distributions of collisional families change with time in the belt and how such families evolve within the distinct populations of trans-Neptunian objects in this region. Furthermore, I aim to investigate the fraction of fragments that acquire unstable orbits, thus providing a source of Centaurs and likewise an influx of small bodies in the inner solar system (e.g., short period comets). In this project I chose to investigate the long-term dynamical evolution of Haumea's (formerly 2003 EL61) collisional family. Finally, by implementing a method for this investigation, I also aim to establish a standard model to investigate systematically other families, such as Pluto's.

I performed 15 main simulations of the Haumea's family using 1600 particles under the gravitational influence of the four giant planets in each of runs. I also varied some key parameters (e.g. low/high initial ejection velocities, inclusion of gravitational influence of the largest fragments, etc). In all simulations the systems evolved over 4 Gyr.

Although the simulations are completed, I have just started analyzing the output data. Thus, the preliminary results are:

- Even considering simulations with distinct initial conditions for the Haumea's family, we can reproduce its orbital distribution in the Kuiper belt very well
- The obtained Haumea's families in the simulations cover a wide range of orbital elements (a, e, i), so we can make observational predictions for the existence of new family members
- The orbital spread of the family fragments over Gyr is quite small. Therefore, the currently observed orbital distribution can be used as a proxy to infer about the collision properties that originate the Haumea's family, presumably ~4 Gyr ago
- Several fragments are able to acquire unstable orbits and also be captured in mean motion resonances with Neptune (a fraction of the latter can also survive for 4 Gyr)
- According to the results above, the existence of other collisional families in the Kuiper belt implies they must have spread over wide areas in element space (a, e, i), thus playing an important role in defining the orbital structure of the belt

Finally, a paper is currently under preparation:

Lykawka P. S., Nakamura A. M., Horner J. A., Jones B. W. and Mukai T. 2009. *Long-term dynamical evolution of Haumea (formely 2003 EL61) collisional family*. In preparation.

2 – Dynamical Evolution of Giant Planets and Solar System Small Bodies with the Presence of Embedded Massive Planetesimals

I aim to investigate the dynamical outcomes of the four giant planets during the early solar system, right after the break up of their mutual orbital resonant configurations. In addition to this particular investigation, I also consider the role of the past existence of a system of massive planetesimals in the solar system, their typical outcomes and the influence on the orbital evolution of giant planets and small body reservoirs, such as the asteroid and Kuiper belts. In particular, this is very unique, because all past models have neglected the role of such massive bodies in the solar system history.

In this project, I chose to investigate systems with massive disks including either only the four giant planets or the giant planets plus one massive planetesimal (a planetoid) located beyond the last giant planet. To provide statistically meaningful results, I decided to perform 10 simulations of each specific initial configuration, accounting for the stochastic behaviour of these systems. Unfortunately the vast number of initial conditions and the limited amount of computer power for the given period (around 1 year) did not allow me to cover all possibilities, so that only planetoids with 3 ME (ME = Earth's mass) were considered (I included in the original plan, masses of 1 ME and 5 ME), and systems of more than one planetoid were not taken into account this time (a simple system of 3-equal mass planetoids was planned, but not included in the calculations executed during the Heisei 20 year).

I performed 480 main simulations of systems with only the giant planets, and further 720 main simulations for systems including a planetoid with 3 ME. These simulations covered four distinct total masses for the planetesimal disk (0.3, 1, 2, and 3 minimum mass solar nebula - MMSN), which were composed of 10000 bodies, and 30 distinct initial planetary configurations in total for each considered disk mass. In all simulations the systems evolved over 100 Myr.

Because the simulations were completed recently, I have not started analyzing the output data yet. Thus, unfortunately I am unable to show the preliminary results at the moment. However, considering the volume of data obtained from the comprehensive simulations described in this project, I anticipate that at least one paper (but likely two or more) will be written over the course of 2009/2010:

Lykawka P. S. and Mukai T. 2009. *Formation of solar systems with the presence of embedded planetoids in a massive planetesimal disk*. In planning.