EPSC Abstracts
Vol. 16, EPSC2022-873, 2022, updated on 08 Nov 2022
https://doi.org/10.5194/epsc2022-873
Europlanet Science Congress 2022

Early collisional evolution of TNOs

Paula Benavidez, **Adriano Campo Bagatin**, Álvaro Álvarez-Candal, and Jean-Baptiste Vincent
Universidad de Alicante, Física Ingeniería de Sistemas y Teoría de la Señal, Alicante, Spain (paula.benavidez@ua.es)

1. Introduction

The currently accepted scenario states that the primordial transneptunian belt (TB) extended from about 22 AU to 30 AU from the Sun, with a sharp edge. During the dynamical instability, this disk was strongly depleted by the influence of Neptune, and some bodies were implanted in the plutinos region, and others would end up as hot classicals (HC). The presence of some initial mass beyond 30 AU is under discussion yet compatible with a distribution of mass in which the Cold Classical (CC) belt would have formed. Most recent literature suggests two different size distributions for the primordial disk population informed by streaming instability models [1, 2] (hereafter NV16 and NV19), contrasting with the traditionally assumed broken power-laws (BPL). On the other hand, there is no consensus on the strength parameters that govern the response to collisions in the TB.

The main purpose of this work is to systematically study how the size frequency distributions (SFDs) proposed in the literature respond to dynamical and collisional evolution in the framework of early evolution. Therefore, we have modified our ALICANDEP code to include the characteristics of the new proposed evolution scenarios. Equipped with ALICANDEP-22, we have performed about 56 numerical simulations exploring different scaling laws and varying the onset time of dynamical instability (t_i).

To select the best scenarios, we compare our results with the following observable constraints: number of bodies larger than 100 km, number of dwarf planets, lack of large bodies in the cold population, and estimated SFD slope for HC and CC objects.

2. Methodology

Here we updated the model (to ALICANDEP-22), and we adopted a simple scheme to include the possibility of considering an early dynamical excitation scenario under the current framework. This model includes statistical elimination and implantation of bodies from an inner disk to current TB regions, modelling dynamical effects present in the Nice model ([3], CBB12) and its current interpretation. Initially, most mass is concentrated in an inner disk ranging from just outside Neptune's initial orbit from about 22 AU to 30 AU and a small amount of mass is initially located between 42 to 47 AU, to simulate the in-situ formation of the cold classical disk. The inner disk evolves not only collisionally but also dynamically.

Such an inner disk undergoes collisional evolution and simultaneous dynamical excitation and depletion in an initially cold massive disk. Dynamical excitation during the instability of the giant planet triggers a smooth dynamical elimination of mass during the pre-instability phase, which is handled statistically. Lastly, further elimination and implantation of planetesimals to the outer region take place. Such region is modelled as three zones, accounting for the plutinos, the CC and HC populations.

The fragmentation algorithm is based on the fragmentation and re-accumulation model by [4] including improvements based on later available experimental data, numerical and theoretical studies. We assumed four scaling law to perform our simulations. These correspond to SL1: [5] for ice bodies; SL2: same as SL1 but scaled down by a factor 0.1; SL3: Same than SL1 but scaling Q* down by a factor 0.06 and shifting the minimum to 30 m; SL4: Scaling law by [6] and [7].

3. Results

We performed a large set of numerical simulations, exploring the parameter space to illustrate the consequence of the different evolution scenarios.

We identified sets of boundary conditions for the collisional and dynamical evolution of the primordial outer disk for which ALICANDEP-22 matches main current observables.

From our results, we may summarize that collisional evolution is relatively soft when the dynamical instability starts early, before 30 My, in a primordial disk of 20-30 Earth mass. In this case, the only change to the initial shape of the distribution regards the slope of the SFD for bodies D<10 km. This result implies that:

- The amount of primordial bodies with D<10 km largely defines the shape of the eroded SFD in 30 m to a few km.
- The initial shape (not the absolute number of bodies!) of the SFD for large bodies (D>10 km) is not significantly affected by the collisional evolution. Thus, the population of bodies D>10 km is only reduced according to dynamical depletion without modifying its primordial shape.
- Initially rounded populations around D=100 km, followed by a shallow slope at the largest bodies (Pluto-size bodies) end (such as NV16 and NV19) are more likely to end the evolution with the required number of dwarf planets observed in the plutino and HC populations, compared to a primordial BPL.
- The SFD of the implanted populations (plutinos and HC) recalls the shape of the SFD of the observed population of Jupiter Trojans (in the comparable size range). Among the distributions studied in this work, the NV16 SFD is the one that achieves a better agreement with that population in a greater size range (4-100 km), compared to NV19.
- The results of this work rule out the possibility that a BPL gives the SFD of the primordial population. That is due to the difficulty of this type of SFD to simultaneously reproduce the expected number of bodies with D>100 km and the dwarf planets observed in the population of plutinos and HC. In addition, the collisional evolution is essentially stopped once the dynamical instability phase begins, preventing a gradual change of the SFD around 100 km, which is instead present in the population of Jupiter's Trojans.

4. References:

[1] Nesvorný D., Vokrouhlický D., 2016, ApJ, 825, 94.
[2] Nesvorný D., Vokrouhlický D., 2019, Icarus 331, 49.
[3] Campo Bagatin A., Benavidez P. G., 2012, MNRAS, 423, 1254.
[4] Petit J.-M., Farinella P., 1993, CeMDA, 57, 1.
[5] Benz W., Asphaug E., 1999, Icarus, 142, 5.
[6] Leinhardt Z. M., Stewart S. T., 2009, Icarus 199, 542
[7] Leinhardt Z. M., Stewart S. T., 2012, ApJ, 745, 79.

Acknowledgements

PGB and ACB acknowledge funding by the Spanish Ministerio de Investigación, Ciencia e Innovación through project RTI2018-099464-B-I00 ``Retos de la Sociedad'' (2018 call).