How Important is Rotational Fission in the Trans-Neptunian Region?. J. L. Ortiz[1] , A. Campo Bagatin[2], A. Thirouin[1], R. Duffard[1], J. Licandro[3], D. C. Richardson[4], P. Santos-Sanz[1], N. Morales[1], P. G. Benavide[2]. [1]Instituto de Astrofísica de Andalucía - CSIC (Spain) (ortiz@iaa.es), [2]Universidad de Alicante (Spain) (acb@ua.es), [3]Instituto de Astrofisica de Canarias - CSIC (Spain), and [4]Department of Astronomy, University of Maryland (USA).

We present a number of evidences to support the idea that rotational fission is a possible mechanism in the formation of systems of large Trans-Neptunian Objects (TNOs). That may include binary systems, complex systems (like the case of Haumea) and TNO pairs (pairs of bodies sharing very similar orbital elements, but not bound together) yet be confirmed.

We also present N-body simulations of rotational fissions which show that this process is feasible and may generate satellites and --in some cases-- even create a ``family'' of bodies orbitally associated to the primary.

Introduction A wealth of knowledge on the trans-neptunian region has been accumulating since the discovery of the first TNO in 1992. A particularly interesting topic in TNO science is the study of binary and multiple systems. TNO binaries appear to be quite common ([1]) and a few examples of multiple systems have been observed (Pluto, Haumea).

Several mechanisms of binary formation have been proposed for TNOs ([1]). However, rotational fission has not been particularly investigated in the case of TNOs at the moment, while it is considered to be an important source of binaries in the Near Earth Asteroid population, whose sizes and compositions are apparently very different from currently observed TNOs'.

Are there rotationally fissioned TNOs? By studying the rotational parameters of several TNOs, [2] pointed out that --for several cases-- the tensile strengths of TNOs had to be low so that they would not withstand shear fracture and they might be structurally damaged objects. At least some TNOs might be able to breakup easily due to rotation. Large TNOs gravity dominated would overcome rigid body forces and be approximately in hydrostatic equilibrium and adopt nearly equilibrium figures due to their rotations. In [3] we show that around 20\% of large objects would have fissioned due to rotation. Furthermore, evidence of a spin barrier around 4 hr has been found in the observational data (e.g. [4]), below which no TNOs are found, possibly indicating that the bodies predicted in the maxwellian distribution below that limit already broke up.

After fission, part of the ejected material can form a satellite, as in the case of asteroids. Binary or multiple systems might then have been common within the early trans-neptunian region and part of them have been probably destroyed by dynamical interactions along several Gyrs.

Haumea is an excellent candidate for this study. Its very fast rotation could perhaps make it a typical case of a rotational fission, and the existence of small satellites would also argue in favour of it being the remnant of a rotational fission process.

Another potentially interesting case may be Orcus' system. The specific total angular momentum of the system is very close to that of an object with the same total mass and density but spinning near the critical spin rate ([5]).

The case of Haumea Haumea is a dwarf planet with a 3-axial shape (2000 x 1500 x 1000 km), a mass of 4.006X 10^{21} kg ([6]) and a short spin period of 3.92 hr. Two satellites, Hi'iaka and Namaka, are orbiting Haumea. A group of TNOs has been dynamically associated to this system and frequently called the Haumea's ``family''.

Three main theories have been proposed to date for the genesis of the Haumea system, namely: a) A catastrophic collision would have spun--up the body and created its two satellites and the family ([7]); b) A grazing collision ([8]) has been hypotesized so that part of the ejecta would have formed the satellites and the family, and part of it would have been gravitationally re-captured by the primary. Finally, c) [9] proposed the formation of a large satellite in a first collision at sub-sonic speed. The satellite would subsequently be destroyed by means of a second collision that would form the current two satellites together with the family itself.

Considerations based on physical ([10] and [11]) and statistical ([12]) arguments weaken the reliabiliy of such models and lead us to look for a more likely formation mechanism. We consider the rotational fission as a possible explanation for the existence of this system.

Our alternative scenario is based on the following assumptions:

1) The proto-Haumea was in hydrostatic equilibrium, regardless if its core was fluid or formed by multiple components, and it approximately adopted a figure of equilibrium that may be modelled as a gravitational aggregate altogether. The mantle of the proto-haumea could be pre-shattered ([13]). [14] showed that N collisions of energy Q^*_S/N, that is 1/N-th the threshold specific energy for fragmentation of the target, cause the same amount of structural damage into the target than a single collision at Q^*_S\$. So, N sub-catastrophic collisions may be able to finally shatter a

large target producing a cohesionless structure. [12] calculated a probability larger than 20\% of having groups of sub-catastrophic collisions shattering an object the size of the proto-Haumea in this way in the first Gyr of the outer Solar System evolution.

Probability rises close to 1 if only the mantle should be shattered by the same process.

2) The proto-Haumea was already rotating fast: a likely assumption supported by observational evidence.

3) It suffered a rotational fission that created its satellites and provided the mass of Haumea's ``family''.

In order to cause the spin up of an isolated rotating system, additional angular momentum must be provided by an external cause.

In the Near Earth Asteroids case, the spin up is caused by the YORP effect. Rotational fission in the TNO region may be likely induced by subcatastrophic collisions providing enough angular momentum on an already fast spinning object to trigger the process.

The specific angular momentum of the systems formed respectively by Haumea + Namaka and Haumea + Hiiaka are both around 0.3, while the scaled spin rate is around 0.6. Such values fall into the ``high size ratio binaries'' ([15]) which are supposed to come from rotational fissions or mass sheddings.

Numerical simulations of rotational fissions With the aim of studying the possibility of forming binary systems by rotationally fissioning large TNOs, we performed numerical simulations of the processes using PKDGRAV N-body code ([16])

A fast spinning object --close to breakup limit-- with a total mass 10\% larger than the current mass of Haumea was synthetically generated. Its 1000 particles are gravitationally held together, may collide with each other in a partially elastic way and simulate the assumed pre-shattered proto-Haumea.

A final angular momentum increase to trigger fission is performed by A) A sub-catastrophic collision; B) An artifical spin--up. We also performed C) A more energetic collision, providing more angular momentum than that barely needed for fission.

As a result, fission easily drives either to the formation of a bound system (A and B) with similarities with the Haumea system (secondary/primary mass ratio, primary mass and spin), either to the formation of a pair of objects with positive total energy (C).

Discussion Even if the details of the formation of complex systems like Haumea's are to be fixed, the main mechanism for the formation of binary systems or even pairs by rotational fission in the trans-neptunian region has been set and numerically tested. Further work is needed to refine this model.

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