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SATELLITES OF URANUS DURING THE PLANETARY MIGRATION

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1. THE PROBLEM

Nowadays it is well accepted that the migration process as described in [1] caused a lot of significant changes in the original architecture of our solar system. Before the era Nice model, some different migration scenarios were presented, however it seems that this model can best explain several features of our current solar system ([2], [3], [4], etc). In our race to understand some parts of the evolutionary history of the system, the population of the satellites occupies a major position. According to many authors, it is well believed that the distant satellites (called irregular) are captured objects, while those close to the planets (regular) are primordial and they were immune to the migration phenomena. This kind of conclusion for regular satellites is mentioned in some papers but it seems that a clear proof with direct integration, including planetary close encounters has not yet been shown. The capture of irregular satellites as a consequence of the migration was studied in [4]. The basic mechanism that governs these captures is dictated by the several close approaches between the planets. However, while this mechanism is quite efficient, if a planet does not suffer any encounter or only a few number occurs, this mechanism may not work. This is the case of Jupiter, where the number of encounters is very few compared to Saturn, Uranus and Neptune. Also in [4], the captured satellites were considered massless objects and the presence of the regular satellites was not considered.

In this work, following Nice model, we study the stability of the regular satellites as well as their limit-distance of the stability during the migration. In particular, attention is devoted to possible satellites beyond Oberon. This is the farthest regular object of Uranus' and we examine the survivability of those more distant than Oberon. A similar study can be done for Callisto and Jupiter's satellites, although close encounters are very rare in this case.

2. METODOLOGY

Basically we use Gomes' code ([2]). Initially we ran several examples of migration, and we selected five cases which successfully reproduced the current solar system.

A naive way to investigate the dynamics of the satellites during the migration is to add some target satellites to a planet of a successful migration and try to re-run the integration. However, as the system is chaotic and due to its high sensitivity, a previous successful integration can fail and end up in a completely different solar system. Moreover, this kind of integration becomes very expensive in terms of cpu-time. Here we have to study the dynamics of the satellites when the planets migrate successfully to the current configuration.

To do that, our strategy is to record the planets evolution during each one of the five successful migrations: at each seven years, the orbital elements of the planets are stored in a file. Once the integration is finished, for each three points (14 years), a second degree interpolating polynomial is created for each orbital element, so that the whole evolution of each migration is available at any time through these polynomials.

During the migration we have to account for the close encounters between planetesimals and the target satellites. Then we consider the strategy adopted in [5] and [6]: during the evolution, whenever a planetesimal approaches within $100R_U$ (or $300R_U$) to Uranus, its planetocentric position and velocity are archived in a file. As expected, most of these encounters occurs when Jupiter and Saturn approaches the $2S : 1J$ resonance. Finally we have to define the mass of each planetesimal that approaches to Uranus. To do that we consider a power law distribution, but we take into account the current observed values of the irregular satellites. Moreover we allow the existence of some Pluto-sized planetesimals as seen today in the Kuiper belt. To increase the statistics of the encounters, each original planetesimal with mass m_0 is cloned to 500 new objects, keeping unaltered, of course, the original mass of the parent body m_0.

3. INTEGRATION & RESULTS

For Uranus we considered the main regular satellites: Miranda, Ariel, Umbriel, Titania and Oberon, with their current masses and coordinates. Several fictitious objects beyond Oberon s_i were included with inclination $I = 1^0$ (with respect to the equator), and eccentricity $e = 0.001$. The semi-major axes were distributed in the range $a = [27.5R_U, 68.40R_U]$. Therefore all these satellites are integrated together the 4 planets, which are available at any time through the interpolating polynomials described in section 2. To compute the planetesimal-satellite close encounter, we inject in the integration, in a random way, one by one, those objects previously stored as mentioned in section 2([7],[6]. The frequency of the injection of these planetesimals is done according to the number of the encounters per time registered during the previous integration.

Fig.1 shows the final configuration (thick dot) of these satellites. Note that the objects beyond Oberon usually are ejected or eliminated by collisions, while the regular ones always survive. Sometimes some non negligible variations occur , especially for those with small mass. As a by product of the whole process, those planetesimals that approach under certain conditions can be captured by the planet. Note that this kind of capture does not need any planetary close approach, that is, differently than the method of Nesvorný et al, it also works in the Jupiter's case. On the other hand, since our planetesimals do have mass, it is clear the importance of the presence of the current regular satellites. Moreover if the regular satellites were not considered, intruder planetesimals could be captured as regular satellites. Fig.2 shows the captured satellites (thick dots) and red triangles are the real satellites.

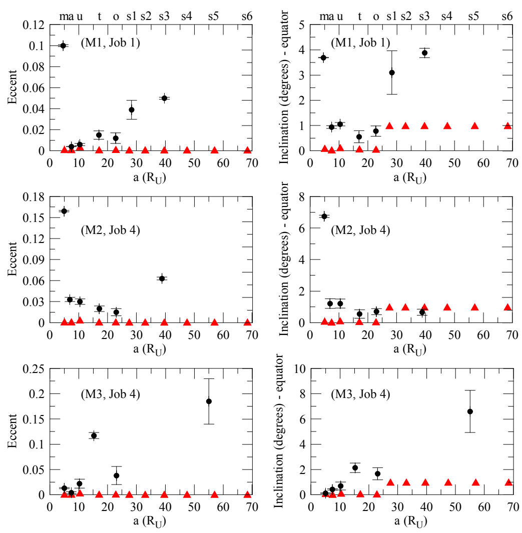

Figure 1 – Initial (red triangles) and final (thick circles) elements for a 5 Myrs integration time. Real regular satellites remain stable while fictitious are eliminated

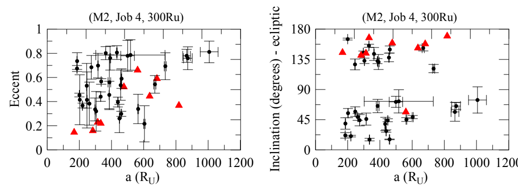

Figure 2 – Captured satellites (thick dots) and real irregular satellites of Uranus (red triangles). Bars are standard deviations

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