Planet X and the Extended Scattered Disk

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Abstract. The effects that a hypothetical trans-Plutonian planet would produce on the orbital distribution of the Classical Edgeworth-Kuiper-Belt, has been surveyed for different physical and orbital parameters of the hypothetical body in Melita et al. (2003a). The best fits were obtained by a moderately eccentric and inclined Earth-sized object with a semimajor axis of $\sim 70AU$. However the history of some objects in the 'Extended Scattered disk' still represent a puzzle. One possibility is that they can be 'extracted' from the Scattered disk by the planetoid. In this work we confirm that such an hypothesis would not explain the present orbit of 2000 CR105, given the conditions for a gap as observed to be formed in the Classical EKB.

Keywords: TRANS-NEPTUNIAN OBJECTS: PLANETARY DYNAMICS: ORBITS: ORIGIN, SOLAR SYSTEM

1. Introduction

Since the discovery of the first Edgeworth-Kuiper-Belt object (EKBO, Jewitt & Luu 1993) the trans-Neptunian region has proven to be full of unexpected features. One is that there apperas to be an *edge* to the Classical Edgeworth-Kuiper Belt (Trujillo and Brown 2001). A possible explanation for both the edge of the belt and its highly excited state is the existence of some external agent, which operated -or operates- in the region, the most obvious being either a close stellar passage or an undiscovered planet.

The stellar passage scenario may explain such an edge, and has been discussed by Ida *et. al* (2000) and by Melita et al. (2003b). It has also been suggested that a Mars-sized body orbiting at ~60AU at a moderately eccentric and inclined orbit could provide the necessary perturbation to create the observed edge (Brunini & Melita 2002). This hypothesis has been analyzed more deeply in Melita et al. (2003b). With the parameters that were used for the hypothetical Planet X, the evolution to their present of objects such as 2000 CR105 remain unexplained. It has been suggested (Gladman 2002), that the trans-Plutonian planet perturbations can increase the perihelion distances of the Scattered disk objects (SDOs), thus decoupling them from the control of Neptune. In this work we study the diffusion of the perihelia of the SDOs induced by the presence of Planet X, to estimate the maximum values that their perihelia can achieve for given orbital parameters of Planet X.

2. The model

Each of our simulations involves the numerical integration of the equations of motion of 200 massless particles, taken to represent the primordial Scattered Kuiper Belt, in the gravity field of the Sun, Neptune (present mass and orbit) and a planetoid of terrestrial size with different initial values of semimajor axis, a_P, eccentricity e_P, inclination i_P and mass m_P. All the simulations have been run for a simulated time of $1Gyr$.

The orbital distribution of the SDOs is uniform in the range $30AU < q < 35AU$, $50AU < a < 200AU$, $0.0^o < i < 25.0^o$ where q are the perihelion distances, a are the semimajor axes and i the inclinations of the particles.

The numerical integrator used is an hybrid symplectic second order method previously used in Brunini and Melita (2002), which treats close encounters using a Burlish and Stoer integrator with the strategy developed by Chambers (1999).

2.1. Results

The semimajor axis a_P, eccentricity, e_P, inclination, i_P and mass of the planetoid for each simulation are given in table I. Also in table I the maximum values of the perihelion distance achieved by any of the test particles in the last 10^8 yr of the simulation, q_{max}, and its corresponding semimajor axis, $a_{max} = a(q_{max})$, are given. In figure 1 the instantaneous positions of the last 10^8 yr of the simulations at 10^6 yr intervals are shown.

Objects in the observed Extended Scattered disk have perihelia between ∼35 AU and ∼38 AU. With the exception of 2000 CR105, which has a very extended orbit with $q \approx 45AU$ and $a \approx 250AU$. In our simulations, the extension of the Extended Scattered disk is much larger than observed in the cases of runs 3 and 4 (see figure 1) and no object with an orbit as extended as the one as 2000 CR105 is obtained.

It should be noticed that $105AU$ and $110AU$ correspond to the 7/1 and 13/2 mean-motion resonance with Neptune respectively. The eccentricity librates at these locations, reaching quite small values, but the perihelion distances of the rest of the simulated SDOs remain much smaller.

Table I. Initial orbital parameters and masses of the planetoid for each simulation. The maximum perihelion distance achieved, q_{max} and the corresponding a_{max} are given. Run '0' corresponds to a simulation where Neptune is the only perturber present.

Run	m_P (10^{-6} $M_{\odot}$)	a_P(AU)	e_P	i_P (deg)	a_{max} (AU)	q_{max} (AU)
0	–	–	–	–	110.2	99.1
1	0.34	56.	0.1	10.	104.8	51.64
2	0.34	62.	0.15	10.	62.6	53.6
3	3.38	62.	0.15	10.	82.6	71.9
4	5.0	70.	0.25	10.	110.1	99.1

3. Discussion

Our results suggest that an Earth-size planet with a perihelion distance of $\sim 50AU$ in a moderately eccentric orbit would produce a noticeable effect on the Scattered disk population, creating many more high perihelion objects than are observed (see figure 1). A smaller Mars-sized planet with a similar perihelion distance but a smaller eccentricity can also decouple a substantial number of SDO's from the control of Neptune, in numbers that reassemble better the observed orbital distribution. Thus, its existence, may explain the origin of some of the Extended Scattered disk objects, with perihelia in the range $37 \leq q \leq 40AU$. However none of these models would explain the orbital origin of 2000 CR105 ($q \sim 45AU$, Gladman *et. al* 2001), if this is related to existence of a trans-Plutonian planet, this should be located at 100 AU's, because the planet can only increase the perihelion distances of objects with semimajor axes close to its own, while the semimajor axis of 2000 CR105 is at ~250 AU. However, the perihelion of this object may have been decoupled from the control of Neptune by the dynamical friction interaction with the primordial EKB (Melita et al. 2003a).

Thus, the Planet X hypothesis does not answer fully the question of the origin of the Extended Scattered disk. Other arguments about the likelihood of the existence of a Planet X in the trans-Neptunian region are discussed in the following section.

3.1. The likelihood of the existence of Planet X

A constraint for the maximum luminosity that Planet X can have is given by IRAS observations, since its brightness in the IR-band must

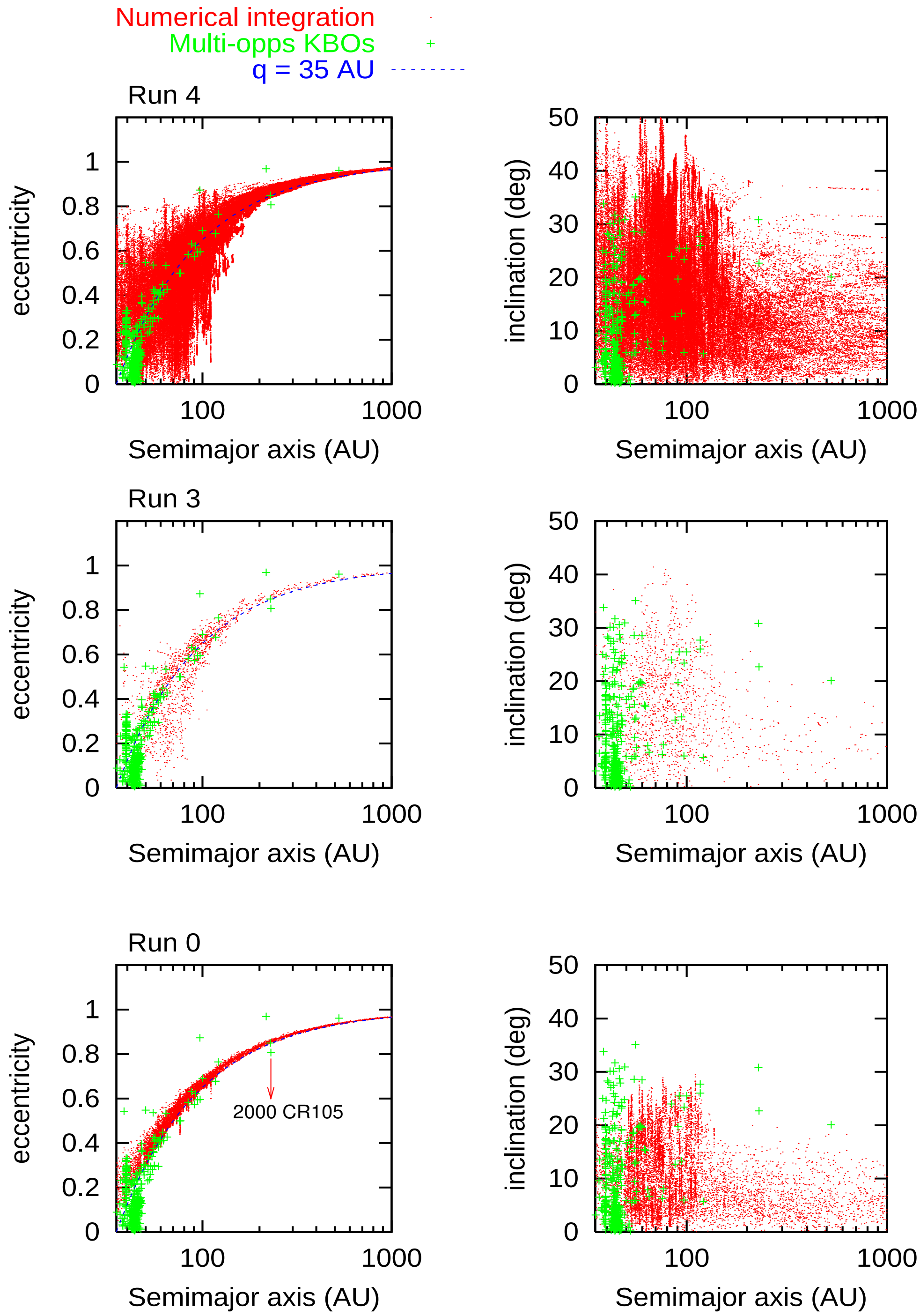

Figure 1. a-e and a-i plots for runs 0, 3 and 4. The location of 2000 CR_105 is indicated.

be below the limiting magnitude of that survey (unless it was located in the galactic plane at the time of the observation). The relationship between luminosity and size or mass depends on an uncertain value of the albedo, but according to Hogg *et. al* (1991), the maximum mass at $\sim 60AU$ could be set at $\sim 1\ M_{\oplus}$. The perturbation on the EKB is directly proportional to the mass of the planetoid. Since a substantial fraction of the Plutinos and some 1 % of the Classical EKBOs are to remain close to their primordial formation sites (Stern and Colwell 1997, Davis & Farinella 1997, Kenyon and Luu 1999), this also sets an upper limit for the mass and orbit of Planet X. Melita et al. (2003a) have found that an Earth-mass planetoid at $55AU$ and $e_P = 0.1$ would clear completely the EKB. A Mars-size object at $55AU$ and $e_P = 0.2$ would clear the Plutino population and would not create a gap either. A 1/3 $M\oplus$ object at $60AU$, $e_P = 0.15$ may conserve the Plutinos but leaves a great deal of leftovers at large perihelia. The best fit can be obtained for $m_P = 1.5\ M_{\oplus}$ at $70AU$ and $e_P = 0.25$. However in this case the fraction of plutinos lost is considerable.

The hypotheses about Planet X's origin can be sorted into three logical classes. The object formed *in-situ* or it came from an *inner* or an *outer* region, with respect to its present location. There seems to be little support for the first possibility due to the large formation timescales involved (Stern & Colwell 1997). On the other hand, Melita et al. (2003a) concluded that a transport from the inner region is possible if the disk is wide and cold enough. Indeed, a putative correlation between size and orbital excitation in the presently observed sample (Levison & Stern 2001) has given support to the idea that bigger and more excited EKBOs -the *hot population*- actually originated in the Uranus-Neptune region, which would explain not only the orbital excitation but also correlations with physical properties of the EKBOs (Gomes 2003, Morbidelli & Levison 2003). Planet X would only be, then, one of the biggest members of this hot population, which has been 'trapped' in the disk. One may even argue that the 'Jumping planets' scenario, put forward to explain the origin if Uranus and Neptune, may have occurred in cascade.

On the other hand, the possibility that Planet X is an exceptionally big planetesimal on its way back from the Oort cloud, is a problem that remains to be assessed. Such an hypothesis implies that it has made its way out in the past. We have shown that planetary-size objects have a considerable probability of being captured by an extended disk while leaving the planetary region (Melita et al. 2003a). But if the disk is smaller ($\sim 60AU$), and/or it is orbitally excited, then its ability to capture embryos is greatly reduced. The interactions with Neptune rapidly excite the $40AU - 50AU$ region, and the disk there, is no longer able to absorb torque. So, if the disk extends only up to $\sim 60AU$, then the portion able to absorb torque is very small. So a returning 'big planetesimal' would be consistent with a small and hot primordial disk.

An alternative scenario that can be considered is that the solid phase of the primordial circumsolar disk (PCD) was sharp-edged itself, with an outer boundary at $\sim 60AU$. Some circumstellar disk observations would support this hypothesis (McCaugheran *et. al* 1998). In that case the leftovers at high perihelia and semimajor axes would have never existed in the first place. Nevertheless, the high orbital excitation in the disk would still need to be explained (Morbidelli and Brown 2003). In this case it is difficult to decide which scenario, stellar encounter (Melita et al. 2003b) or Planet X provides a better fit to the observations, being both good. But to decouple a planetary embryo from Neptune at $a_P = 60AU$, the disk should have extended beyond so that the outer disk can absorb torque.

The eventual detection of Planet X would imply a greater primordial number of Plutinos. This would itself point towards resonance capture and outwards planetary migration (Malhotra 1995). But its existence remains to be confirmed. We estimate that future technical capabilities will give an answer quite soon. If Planet X were to be discarded, then the sharpness of the Classical EKB can be attributed to either of two extra causes. Namely, a sharp-edge PCD or stellar encounters with surrounding stars in the primordial environment gave shape to the EKB (Ida et al. 2001, Melita et al. 2003b).

References

Brunini A. & Melita M.D. 2002. The existence of a planet beyond 50 AU and the orbital distribution of the Classical Edgeworth-Kuiper-Belt Objects. *Icarus*, **160**, 32-43.

Chambers, J. E. 1999. A hybrid symplectic integrator that permits close encounters between massive bodies. *M.N.R.A.S.* **304**, 793-799.

Davis, D.R., Farinella, P. 1997. Collisional Evolution of Edgeworth-Kuiper Belt Objects. *Icarus*, **125**, 1, 50-60.

Gladman B. 2002. Personal comunication.

Gladman, B., Holman M., Grav, T., Kavelaars, J.J, Nicholson, P.D., Aksnes, K., Petit M.J. 2001. Evidence for an extended scattered disk. *Icarus*, **157**, 2, 269-279.

Gomes, R. 2003. The origin of the Kuiper Belt high-inclination population. *Icarus*. **161**, 404-418.

Hogg, D.W., Quinlan, G.D., Tremaine, S. 1991. Dynamical limits on dark mass in the outer solar system. *Astron. J.*, **101**, 2274-2286.

Ida, S., Larwood J. and Burkett A. 2000. Evidence for early stellar encounters in the orbital distribution of Edgeworth-Kuiper belt objects. *Astrophys. J.*. **528**, 531-536.
Kenyon, S.J. and Luu, J.X. 1999. Accretion in the Early Kuiper Belt. II. Fragmentation. *Astron. J.* **118**, 1101-1119.
Levison H. and Stern S. 2001. On the Size Dependence of the Inclination Distribution of the Main Kuiper Belt. *Astronom. J.*, **121**, 3, 1730-1735.
Malhotra R.. 1995. The origin of Pluto's orbit: implications for the Solar System beyond Neptune. *Astron. J.* **310**, 420-429.
McCaugheran, M.J., Chen H., Bally, J, Erickson, E. Thompson R, Rieke, M. 1998. High-resolution near-infrared imaging of the Orion 114-426 silhouette disk. *Astrophys. J.*, **492**, 157-161.
Melita M.D. and Brunini A. 2000. Comparative study of mean-motion resonances in the trans-Neptunian region. *Icarus* **147**, 231-245.
Melita M.D., Larwood J and I.P Williams. 2003b. The Edge Edgeworth-Kuiper Belt: The close stellar passage scenario. *Icarus*. Submitted.
Melita M.D., Williams, I.P., Collander-Brown, S. and Fitzsimmons A. 2003a. External dynamical sculpting of the Kuiper Belt: The Planet X scenario. *Icarus*. Submitted.
Morbidelli A. and Brown M.E. 2003. The Kuiper Belt and the pri-omordial evolution of the Solar System. *Comets II*. M.Festou *et. al* eds. University of Arizona Press. Tucson, AZ. *In press*.
Morbidelli A. and Levison H. 2003. Kuiper Belt interlopers. *Nature*. **422**. 30-31.
Stern S.A. and Colwell J.E. 1997. Accretion in the Edgeworth-Kuiper Belt: Forming 100-1000 KM Radius Bodies at 30 AU and Beyond. *Astron. J.* **11**, 841.
Trujillo, C.A. and Brown, E. 2001. The Radial Distribution of the Kuiper Belt *Astrophys. J.* **554**, 1, 95-98.

Acknowledgements

MDM would like to acknowledge PPARC for providing the funding that enabled this work to be carried out. We are grateful to B. Gladman for having suggested the hypothesis that originated this investigation.