New approach on the study of stability regions of the classical KB

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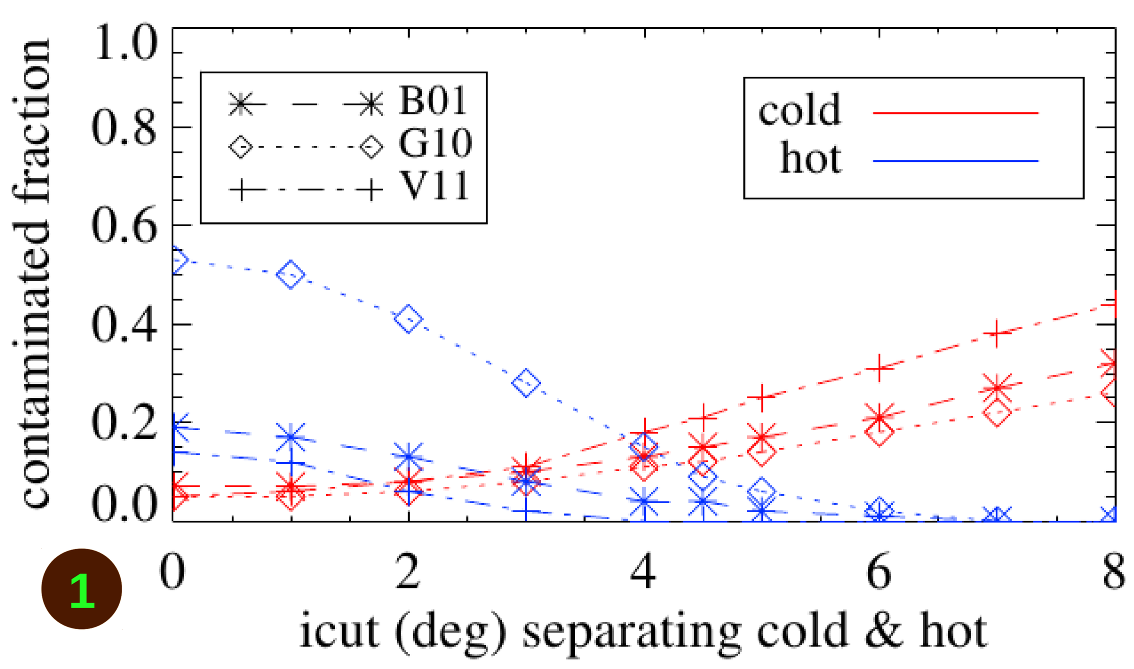
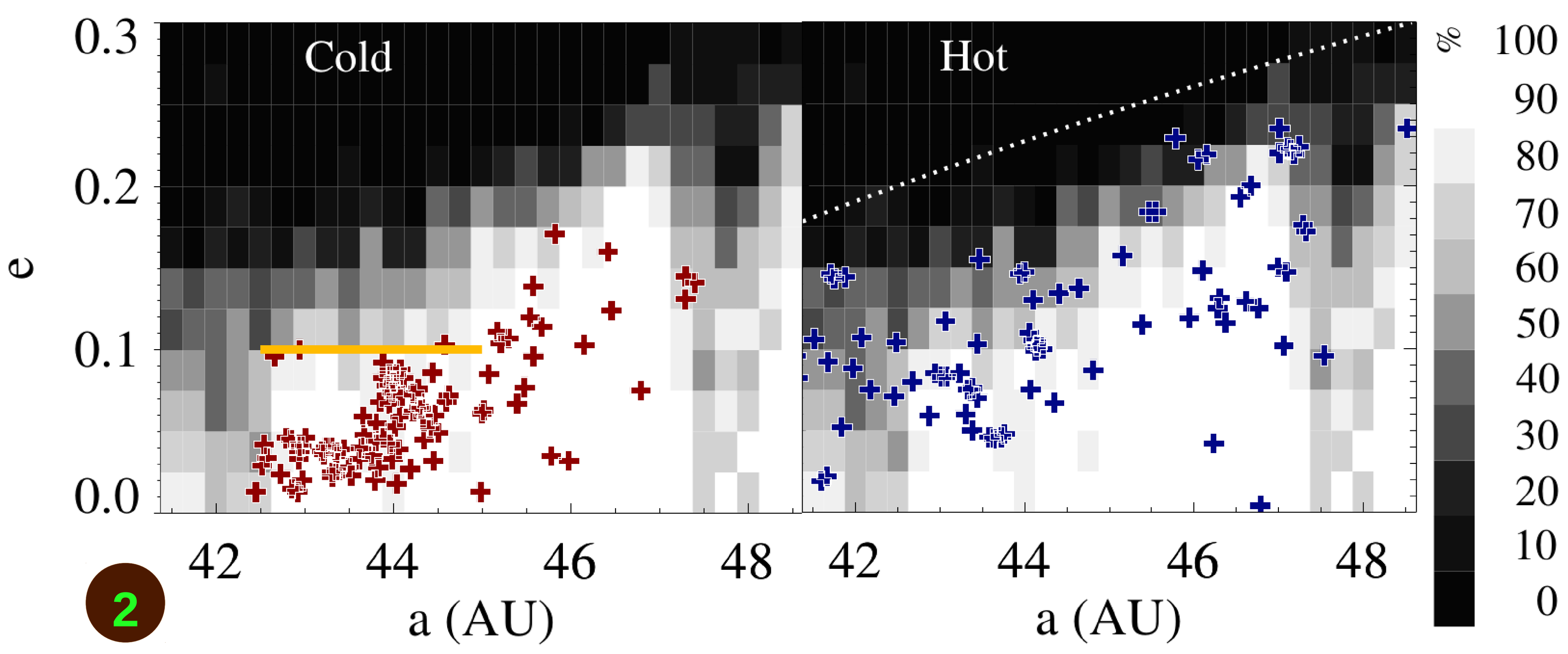
Many studies have been dedicated to explain the complex dynamical structure of the Kuiper Belt (e.g. Levison et al. 2008). Dawson & Murray-Clay (2012) proposed a model in which the cold classical population formed in-situ between 42-47 AU (see also Batygin et al., 2011). They compared the eccentricity distribution of the cold classical KBOs to the dynamical stability map of Lykawka & Mukay (2005) and showed that they do not fill the whole stable region. However, the Lykawka & Mukay map was computed for a wide range of inclinations while the cold classical KBOs have very low inclinations. We calculate a new 4-Gyr orbital stability map but as a function of *proper* orbital elements (semimajor axis, eccentricity and inclination). By superimposing the cold classical KBOs over the low-inclination portion of the survival map, we find out that cold classical KBOs have eccentricities nearly ranging up to the stability limit. The small gap between their orbital distribution and the stability boundary, if real, has ambiguous implications.

MOTIVATION



1 Fraction of cold/hot population "contaminated" by the hot/cold population by Dawnson & Murray-Clay (2012). B01=(Brown, 2001), G10=(Gulbis et al., 2010) and V11=(Volk & Malhotra, 2011).

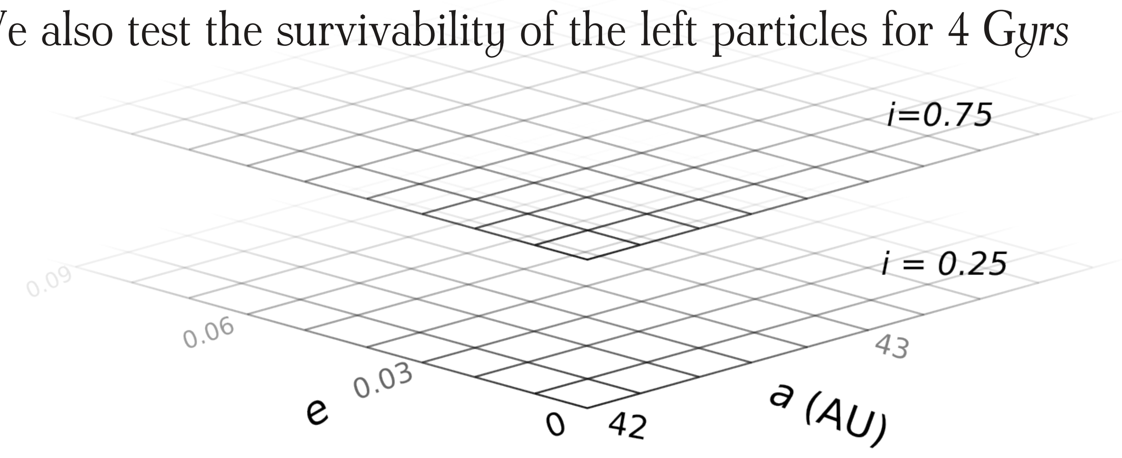


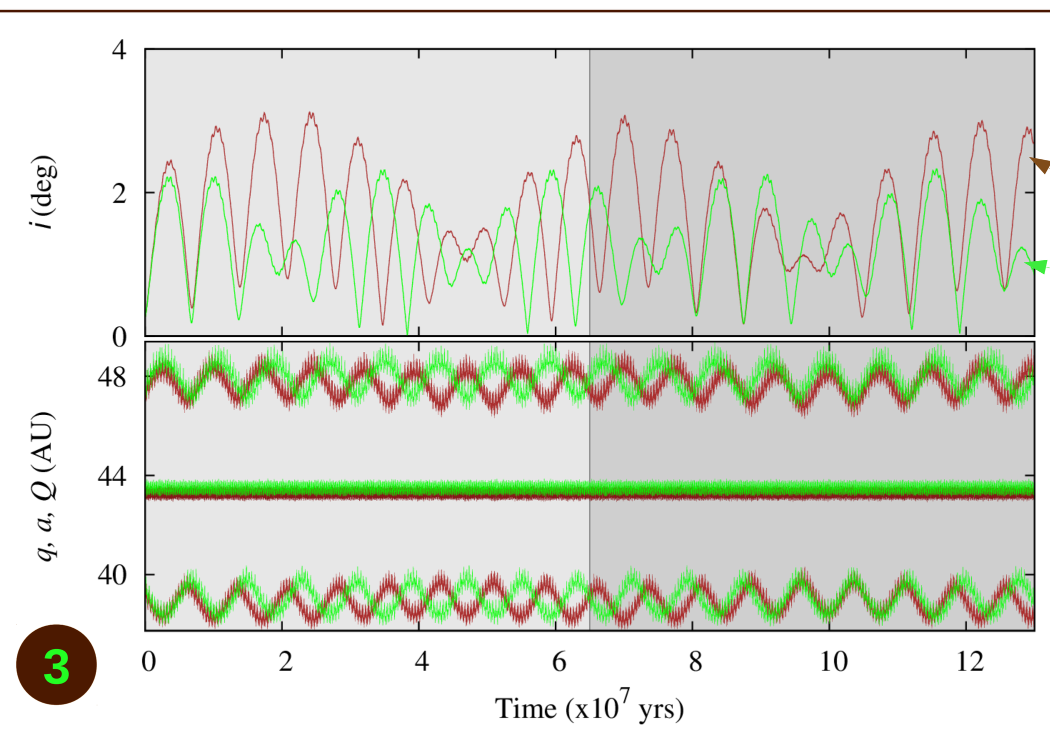
2 By Dawson & Murray-Clay (2012), eccentricity distribution of cold and hot KBOs superposed over the background survival map by Lykawka & Mukai (2005). The cells are bins of survival particles with initial inclination ranging from 0 to 30 *deg*.

- By Dawson & Murray-Clay (2012):
  - **Cold** objects inclination < 2 *deg*
  - **Hot** objects inclination > 6 *deg*
- By superposing the cold objects over survival map of Lykawka & Mukai (2005), an empty survival region becomes evident. Cold objects within the semimajor axis range ~ 42.5-44 *AU* are confined to $e < 0.1$.
- It suggests that the cold objects formed in-situ and had their eccentricities excited moderately up to 0.1.
- Such feature imposes constraints on Neptune's dynamic history.

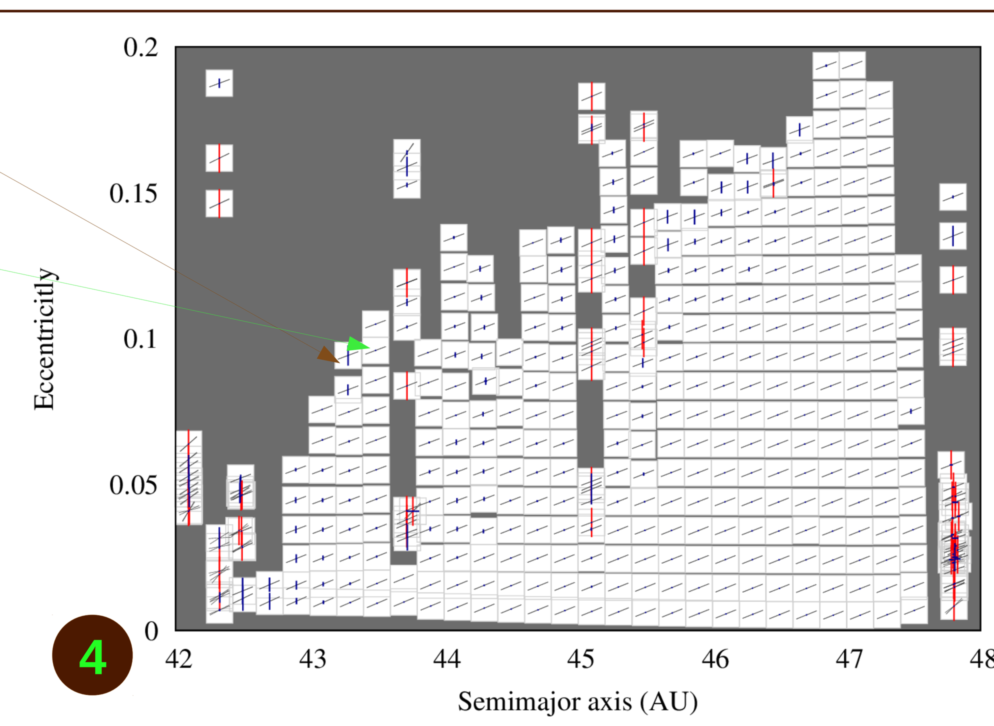
APPROACH

- We distribute massless particles all over the initial $a \times e \times i$ space:
  - $42\ AU < a < 48\ AU$, every 0.2 *AU*
  - $0 < e < 0.2$, every 0.01
  - $0 < i < 10\ deg$, every 0.5 *deg*
- Particles evolve under the scenario Sun + giant planets for 10^8 *yrs*
- We calculate the proper elements of the left particles
- We also test the survivability of the left particles for 4 G*yrs*

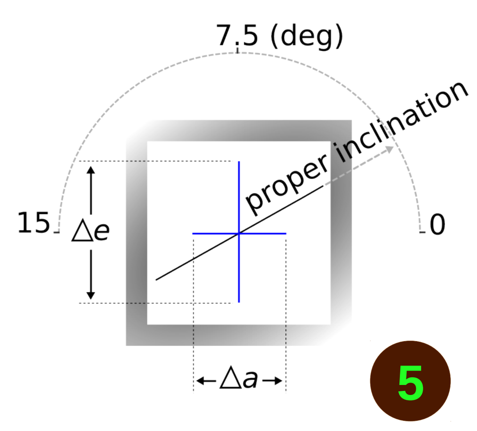




3 To determine the accuracy on proper element calculations, we split the whole evolution into two halves. Proper elements calculated for the first and second halves are used to determine the precision.



4 Survivability map in terms of proper elements. White blocks stand for survival cells and contain a set of information as summarized in the sketch of Fig 5. Red bars indicate the error on a proper element determination failed, i.e., surpassed the cell respective dimension.



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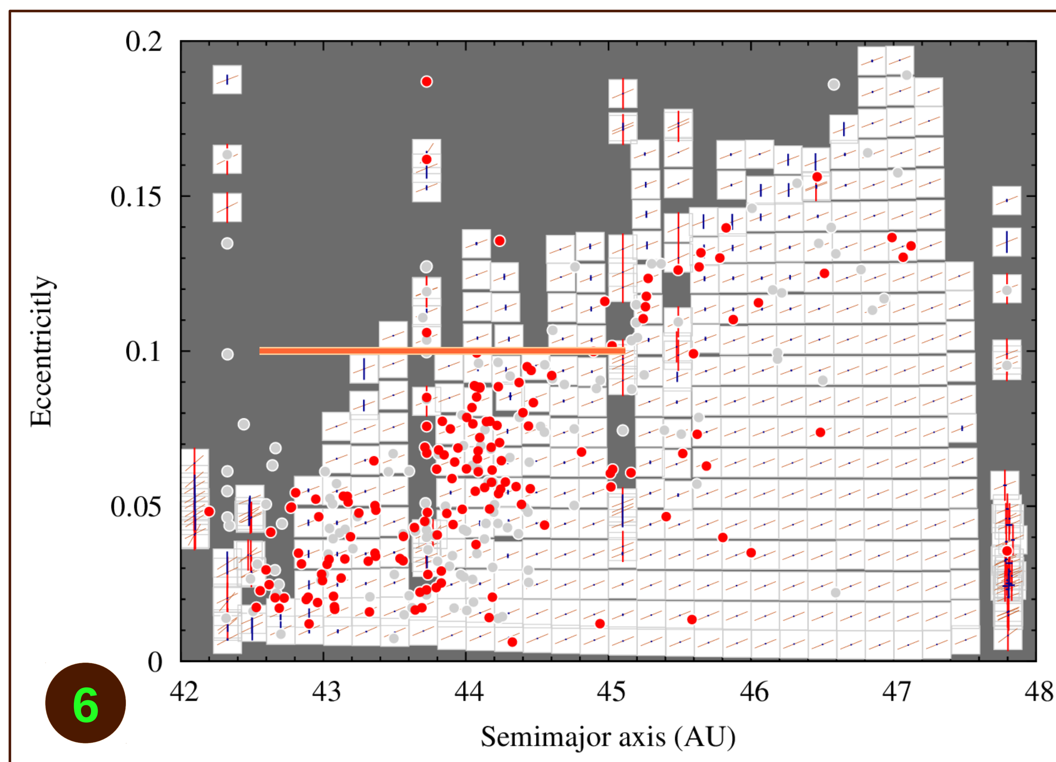
RESULTS



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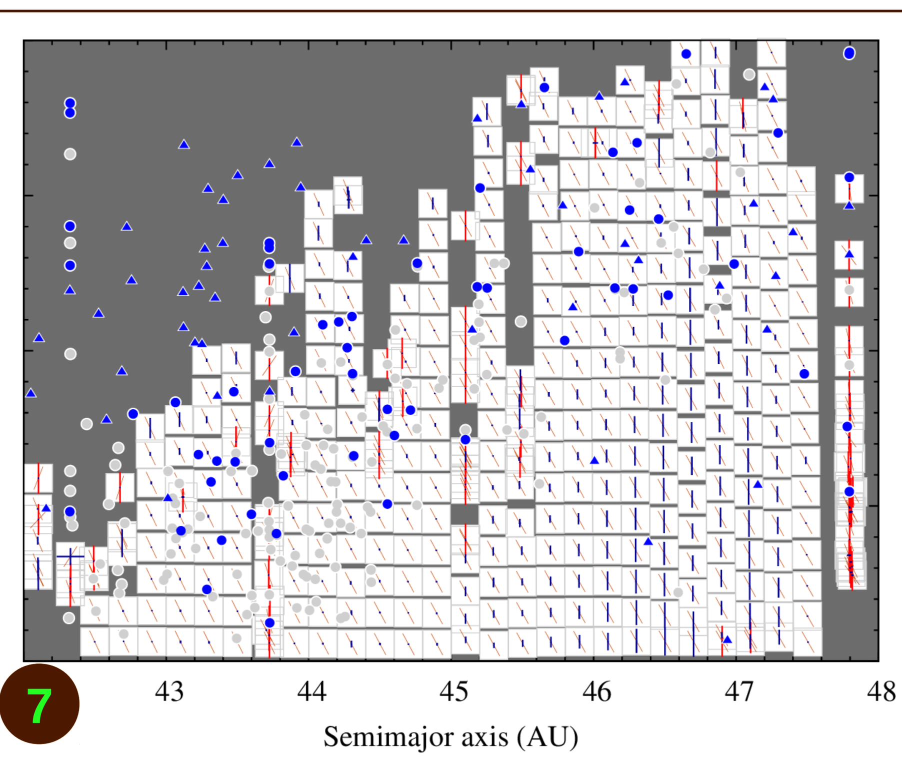

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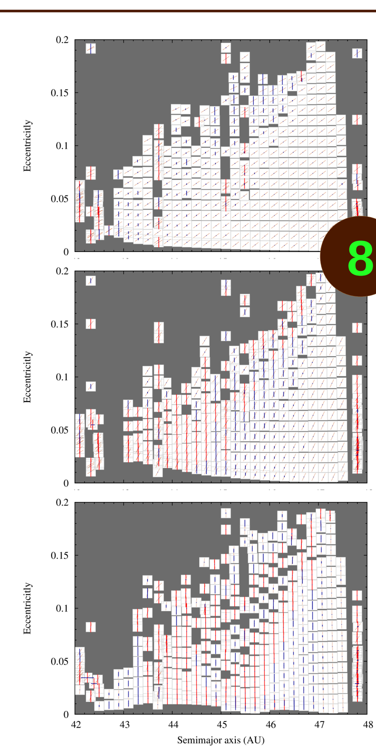

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Red and blue circles stand for cold and hot classicals KBOs , respectively. Light grey circles are the ambiguous mixed population of hot and classical KBOs. Blue triangles stand for hot classical KBOs whose inclinations are higher than 14 *deg*. Background average inclinations are 2 and 9, respectively.

$\langle i \rangle = 3.13$ *deg*
$\langle i \rangle = 5.05$ *deg*
$\langle i \rangle = 7.28$ *deg*

Conclusions

- Survivability and stability[1] in proper $a \times e$ space are highly dependent on the inclination (figs 6-8).
- Objects confronted with background stability maps must always agree on inclinations. Indeed, as one note in Fig. 7, objects with inclinations higher than 14 degrees seem to occupy a "dead" zone when plotted over a background map with proper inclination about 9 degrees.
- In Fig. 6, the cold KBOs are reasonably uniformly distributed along the semi-major axis range 42.5:45 AU. It suggests that such objects were likely excited up to a limit in eccentricity dictated by the background stability/survivability.
- Cold KBOs were possibly formed in-situ and had eccentricities excited differing from Hot KBOs origin.

[1] Stability is constrained to the accuracy of proper elements determination.

LITERATURE

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