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Did a stellar fly-by shape the outer solar system?

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Abstract

In contrast to the planets, the transneptunian objects (TNOs) mostly move on inclined, eccentric orbits. This implies that some process restructured the outer solar system after its formation. As some TNOs move outside the zone of influence of the planets, external processes might have played an important part in structuring the outer solar system. Here we show that a close fly-by of a neighbouring star can simultaneously produce not only many of the TNO features but also the family of Sednoids, which are otherwise difficult to explain. In the past it was estimated that such close fly-bys are rare during the relevant development stage. However, our computer simulations show that such a scenario might be much more likely than previously assumed.

1. Introduction

There are several features of the solar system that seem at odds with the simple picture of forming from a smooth disc surrounding the young Sun and staying that way afterwards. First, the surface density of the solar system drops by a factor of more than 1000 outside Neptune's orbit at 30 AU. Second, most TNOs move on eccentric, inclined orbits ($i > 4°$) relative to the planetary plane. Third, such objects exist even outside the range of influence of the planets. All three points strongly indicate that the outer reaches of the solar system must have been considerably modified by some process(es) that took place after its formation.

Here we suggest that the Sednoids would have been excited to their current orbits by the close fly-by of a star. However, in contrast to the sometimes invoked capture scenario [4, 5, 1], here the Sednoids would originate from the Sun's own once more extended disc.

2. Fly-by parameter range

We simulate the Sun as being surrounded by a disc of test particles. This disc could represent either a protoplanetary or a debris disc, the inner part might even contain the already formed planets. We modelled fly-bys with perturber masses of 0.3, 0.5, 1.0, 2.0 5.0, 10. 20, 50 M_{sun} at periastron distances of r_{peri}= 30, 50, 100, 150 200, 300, 500, and 1000 AU. The parameter space in orbital inclination was covered in steps of 10° and the angle of periastron in steps of 30°.

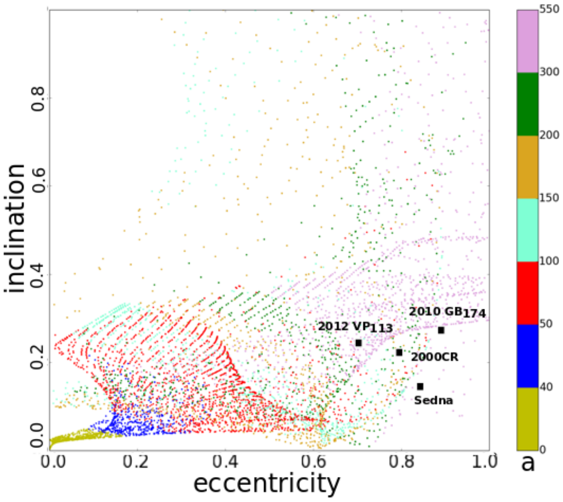

Figure 1: Inclination vs. eccentricity of all test particles in a fly-by with m_p=0.5 M_{sun} on an inclined orbit (60°) with an angle of periastron of 90° passing the Sun at 100 AU. The colours are representative for a.

Of all these parameter combinations the best match to the observed properties is found for the fly-by of a star of mass m_p=0.5 M_{sun} on an inclined orbit (60°) with an angle of periastron of 90° passing the Sun at 100 AU, that was initially surrounded by a 150 AU-sized disc. There have been previous simulations [2, 6] with similar parameters which found neither a cold Kuiper belt population nor Sedna-like objects. The reason is probably too low resolution in the outskirts of the disc and a too small initial disc size.

A fly-by with the parameters in this parameter range reproduces many of the features of the outer solar system all in one go. Not only does it reproduce the hot and cold Kuiper belt population and the Sednoids, but also the new family of TNOs which have relatively large periastra but low eccentricities [7] and gives an explanation for Neptune being more massive than Uranus. Thus this model fulfils two demands on a new theory - it agrees largely with the available data and it is simpler than existing models. The question is now: Is it also likely that such an event has actually taken place?

3. Fly-by probability

Given that 90% of the Milky way clusters largely dissolve within 10 Myr [3] , it is often assumed that basically no close fly-bys happen afterwards. This is the main reason why previous suggestions of fly-bys possibly being responsible for the properties of the outer solar system have received not much attention. We model the frequency of clusters similar to the Orion Nebula cluster (ONC) throughout the different clusters phases - embedded, gas-expulsion, expansion and new semi-equilibrium phase. Fig. 2 shows that although the fly-by frequency that leads to the solar system features are highest in the initial 1-2 Myr, afterwards fly-bys do happen also at a much lower rate. Thus we find that such type of fly-bys are probable not only during the early phases but also on Gyr time scales, with a 5-7% probability during the first 10 Myr and a 20-30% chance in the next Gyr.

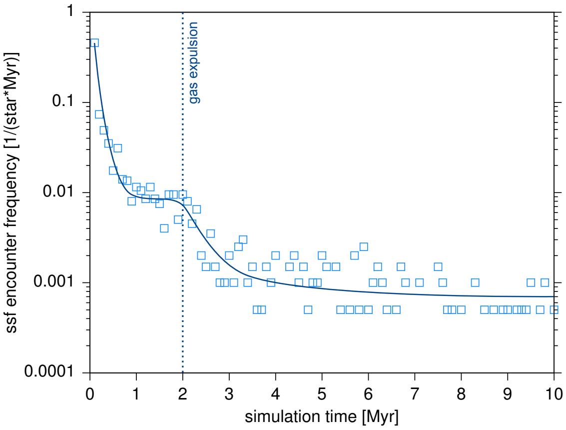

Figure 2: Frequency of fly-bys with the parameters of Fig.1 as a function of time since cluster formation for an ONC-like cluster.

It is often argued that in the outer regions of the solar system objects would require well over 10 Myr to grow to their current size and at that time fly-bys would be extremely rare. However, newly available high-resolution images of discs around stars younger than 10 Myr show prominent ring structures at several 10s to 100s AU and beyond. Many authors interpret these as signatures of already formed or currently forming planets. If gas giants can form at such distances from their host star in such a short time span, it can no longer be excluded that TNO-sized objects can also form on time scales < 10 Myr. This means that a solar system forming fly-by could have happened either during the first 10 Myr or afterwards.

4. Summary and Conclusions

We found that fly-bys of stars with masses in the range 03.-1.0 M_{sun} at perihelion distances of between 50 and 150 AU inclined between 50 to 70 degree and tilted between 60 to 120 degree are the most promising candidates for shaping the outer solar system. Such fly-bys lead to Sednoids, a hot and cold Kuiper belt population and various other properties characteristic for the outer solar system. What distinguishes this model from others, is that only a single event is necessary to create all this features. Thus the beauty of this model lies in its simplicity. We find that such type of fly-bys are probable not only during the early phases but also on Gyr time scales, with a 5-7% during the first 10 Myr and a 20-30% chance in the next Gyr. This probability of such an event is competitive to that of other models for origin of the outer solar system features. The strength of this hypothesis lies in its simplicity by explaining several of the outer solar system features by one single mechanism.

References

[1] Jílková, L., Portegies Zwart, S., Pijloo, T., & Hammer, M. 2015, , 453, 3157

[2] Kobayashi, H., Ida, S., Tanaka, H. 2005, Icarus 177, 246-255

[3] Lada, C. J., & Lada, E. A. 2003, , 41, 57

[4] Morbidelli, A., Levison, H. F. 2004, 128, 2564-2576.

[5] Kenyon, S. J., Bromley, B. C. 2004, Nature 432, 598-602

[6] Punzo, D., Capuzzo-Dolcetta, R., Portegies Zwart, S. 2014, 444, 2808-2819

[7] Sheppard, S. S., Trujillo, C., & Tholen, D. J. 2016, , 825, L13