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First stars that can significantly perturb comet motion are finally found

Rita Wysoczańska (1), Piotr A. Dybczyński (1), Małgorzata Królikowska (2)
(1) Astronomical Observatory Institute, Faculty of Physics, A. Mickiewicz University, Słoneczna 36, 60-286 Poznań, Poland (rita.wysoczanska@amu.edu.pl)
(2) Space Research Centre of the Polish Academy of Sciences, Bartycka 18A, 00-716 Warsaw, Poland (mkr@cbk.waw.pl)

Abstract

Since 1950 when Oort published his paper on the origin of comets a continuous search for the stars which are able to perturb cometary motion has been conducted. We present our results based not on simulations but on the data obtained from Gaia DR2 mission (5) which for the first time show that such perturbations which significantly change a cometary orbit are possible and with high probability occurred in the recent past.

1. Introduction

It was proposed by Oort (10) that passing stars are responsible for making observable some of a great number of long period comets (LPCs) residing in the postulated cometary reservoir – the Oort Cloud. Many simulations were carried out to confirm Oort's theory that stellar encounters are indispensable for an injection of comets into the observable region, see for example (4). While there exists a widely accepted opinion, that close stellar passages near the Sun do occur regularly no one could point to a particular star that has perturbed the motion of any observed comet in a significant manner.

2. New stellar encounters

In April 2018 the second data release (DR2) (5) from the Gaia mission (6) has been made available to the public. It allowed us to prepare a new and exhaustive, as never before, list of stars that once in the future or past could be found in a close vicinity of the Sun. The search for close stellar encounters is limited to stars with known right ascension α, declination δ, radial velocity v_r, parallax π and proper motions μ_{α^*}, μ_δ. Until now identifications of the closest stellar encounters were performed by many authors, the newest published paper on this topic is by Bailer-Jones (1). Our attempt differs from this recent paper in that we did not exclude stars that do not have known radial velocity in Gaia DR2 if there is another source of that value. We also took into account that some stars pointed to be close stellar encounters are actually a part of more complex binary or multiple systems and therefore we calculated center of mass parameters of that systems and then used them instead of using those stars separately. In addition we used more recent Galaxy potential model (7). The first list of potential stellar perturbers was obtained using a linear motion approximation (see for example (2)). For obtaining more reliable parameters of the stellar passages we numerically integrated every star motion in a two body problem (the Sun-star) in a galactic potential. The integration was performed backwards or forwards for 50 Myr depending on the sign of the star radial velocity or alternatively until the star heliocentric distance reached 3000 pc. By this approach we obtained the list of over 800 objects consisting of single stars and multiple systems which in the past or in the future could approach the Sun and as a consequence perturb some LPCs orbits.

3. Influence on a cometary motion

Because we are mainly interested in finding any traces of a stellar action in the past dynamics of the observed LPCs we decided to start with the 50 closest encounters that happened in the past. To be able to integrate three body problem (the Sun-comet-perturbing star) we augmented our list of the stars with their masses found in the literature or estimated by us on the basis of available data. All stars from that list were integrated backwards with over 200 of LPCs which orbital elements were calculated and published by Królikowska (9) (8) with several additional new orbits (Dybczyński & Królikowska, in preparation). Each comet was integrated with each star from our list until it reached it previous perihelion or escaped the Solar system, thus its heliocentric distance was larger than 1 pc. Integration was done twice. First we integrated three body problem (the Sun-comet-star) in a galactic potential, second integration was done without the star to be able to spot the difference between motion of the comet when it does not undergo perturbation from the star. By such a calculation we were able to observe which orbital elements of which comet were significantly changed by stellar perturbations. We mainly look for changes in perihelion distances at a previous perihelion passage. Because two star-comet pairs showed promising results we decided to analyze these cases in detail. To this purpose we replaced the comet with swarm of its 5000 clones generated at the stage of obtaining the osculating orbit from positional observations, for a more detailed description see for example (3). We will present our findings that confirms that stellar perturbations can influence motion of particular comets by remarkably changing their perihelion distances and that the distance of closest approach between the star and the comet can happen to be significantly lower that 1000 au.

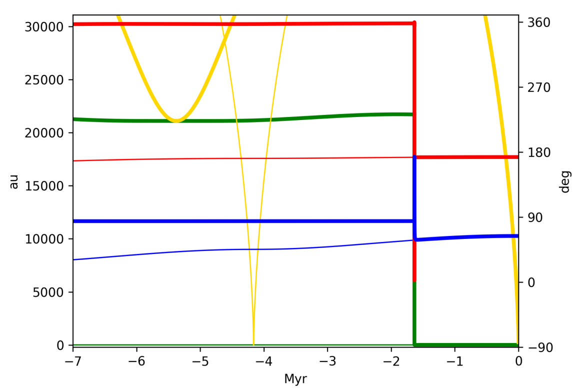

Figure 1: An example of the dynamical evolution of a nominal orbit of a comet under the strong influence of a star passing 1.7 Myr ago. Thick lines show the dynamics when a stellar action is taken into account while thin ones depict the osculating elements evolution under the galactic potential alone. Plotted are: the perihelion distance (green lines), the heliocentric distance (yellow lines), the inclination (blue lines) and the argument of perihelion (red lines). Angular elements are calculated with respect to the galactic plane.

4. Summary and Conclusions

We show for the first time two real perturbers of motion of the observed comets. However from our results it should be stressed that such events are rare and that significant perturbation happens only when the approach is very close and fulfill other requirements such as small relative velocity at the time of the encounter and preferably high mass of the star. Although our result are promising and can be treated as the confirmation of the proposed scenarios there is still plenty of doubt especially connected with still not satisfactory precision of some data presented in Gaia DR2. We will present a strong dependence of our result on the stellar data accuracy.

Acknowledgements

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