ON THE POSSIBLE RELATIONSHIP BETWEEN SMALL SOLAR SYSTEM BODIES AND THE PLANET XWAVES

A. Guliyev**, *R. Guliyev**

[a] *Shamakhy Astrophysical Observatory named after Nasireddin Tusi of the Azerbaijan National Academy of Sciences*

To test the possible link of such a massive body and long-period comets as well as other objects, a model Solar System that includes only the Jovian planets and the putative perturber was integrated for 1 million years, assuming that the mass of the highly inclined perturber is about 10 Earth masses. Besides that, we have explored the orbital evolution of 54 comets and 44 with extreme centaurs up to 1 million years, taking into account the gravitational influence of the unknown planet. We discovered that different variations of true anomaly obtain close encounters (<5AU) between the planet and numerous small bodies of the Solar System.

Keywords: mcomets–celestial mechanics–numerical simulations–Planet X

1. INTRODUCTION

In [7] we largely focused on an examination of the assumption about concentration of the LPCs perihelion positions around some point or plane (great circle on the celestial sphere) with the following parameters:

$$i_p = 86.18^\circ,\ \Omega_p = 271.74^\circ \tag{1}$$

Any evidence on the existence of one of these planes may lead to reject the hypothesis of a chaotic perihelia distribution. The results obtained here suggest that two such planes on the celestial sphere may exist, i.e. locations around which concentration of comet perihelia as well as clustering of comet aphelia take place. One of these areas is close to the ecliptic plane and it has not been studied here. The second one, which appears to be more crowded with comet perihelia,

* E-mail: quliyevayyub@gmail.com
** E-mail: rustamdb@gmail.com

is however relevant to our investigation. Considering the impact of observational bias, it might be argued that the uncovered area may have a significantly higher probability to be observed than the one close to the ecliptic plane. Thus, its existence may be considered as one of the specific features of the LPCs system. The central plane of this area is almost perpendicular to the ecliptic. Focusing on the analysis of this area instead of the region surrounding the ecliptic plane, we can see clear patterns in the distribution of certain angular parameters. The presence of such an area might be explained as the result of the existence of a peculiar family of comets injected by an unseen massive planet on the distant periphery of the Solar System having the orbital elements:

$$a = 339\,\mathrm{AU},\ e = 0.16,\ \omega = 57^\circ,\ \Omega = 272.7^\circ,\ i = 86^\circ \tag{2}$$

If the planet moves along a retrograde orbit it has a set of elements:

$$a = 339\,\mathrm{AU},\ e = 0.16,\ \omega = 303^\circ,\ \Omega = 87.3^\circ,\ i = 94^\circ \tag{3}$$

A putative highly-inclined trans-Neptunian planet could generate two types of comets: some comets having aphelia in the zone of planet motion, others having their distant nodes in the same region as the one traversed by the hypothetical trans-Neptunian planet. We have focused on the search for such groups of comets within the framework of our study. It turned out that there is in fact an excess of distant nodes of comet orbits in the area (1) as well as in the range 250-400 AU, and the same can be said about the aphelia of a considerable number of comets. We calculated two optimal ellipses considering aphelion positions and distant nodes of the corresponding comets. As a result, the angle between the directions of the semi-major axes of these ellipses is about 27°, which we interpret as an indication of the location of the orbital plane of the putative trans-Neptunian massive perturber and can hardly be attributed to a coincidence. Similar hypotheses have been developed in recent years by e.g. [1]

In our work we have been able to provide approximate values for five orbital elements of the prospective trans-Neptunian planet. However, our approach has not yet been able to provide neither a precise value of its mass nor the exact location in its orbit of the hypothesized trans-Neptunian massive perturber. Numerical integrations show that the orbit of such a planet should be sufficiently stable, although it is likely that the origin of such an object does not fit within the framework of modern cosmogonic theories of the Solar System formation, i.e. within an eight-planets-only Solar System.

Table 1. List of close encounters between comets and the planet (< 5 AU) regarding to (2)

MA(deg)	Comet	T(yr)	r(AU)	MA(deg)	Comet	T(yr)	r(AU)
0	C/1911 O1	−948	2.4	170	C/1822 N1	−88003	3.7
0	C/1822 N1	−104450	4.1	170	C/2012 L1	−283705	1.7
0	C/1920 X1	−106854	2.8	180	C/2012 L1	−339502	1.7
0	C/1881 K1	−142109	3.0	200	C/1914 S1	−9080	4.4
0	C/1881 K1	−154605	1.1	200	C/2012 L1	−11137	4.9
10	C/1911 O1	−1128	3.6	210	C/1911 O1	−16961	2.3
10	C/2006 CK10	−32472	3.7	220	C/1881 K1	−175708	3.7
50	C/1846 B1	−163766	3.5	220	C/2016 M1	−455423	3.0
70	C/1822 N1	−5694	3.0	240	C/2012 L1	−73831	1.3
70	C/1807 R1	−74163	4.6	260	C/2012 L1	−18373	1.2
70	C/2017 A3	−383182	7.2	260	C/1881 K1	−232493	1.5
80	C/2011 C1	−17897	3.8	280	C/1914 S1	−128579	4.7
80	C/1914 S1	−169179	0.9	290	C/2012 L1	−367108	3.6
90	C/1807 R1	−105571	3.4	290	C/2004 G1	−510385	2.0
110	C/2012 L1	−687599	4.9	290	C/2012 L1	−597158	4.4
120	C/1911 O1	−3014	1.9	300	C/2005 N1	−530	4.6
120	C/1881 K1	−68691	0.9	300	C/1920 X1	−5831	3.0
130	C/2012 L1	−90664	4.8	310	C/1807 R1	−84451	4.4
130	C/2004 G1	−364429	4.6	310	C/1920 X1	−105598	4.1
130	C/2016 M1	−442323	3.0	320	C/2012 L1	−25465	3.0
140	C/2011 C1	−56157	0.4	320	C/1881 K1	−159729	3.0
150	C/1807 R1	−75243	4.8	330	C/1822 N1	−28894	4.7
160	C/2006 CK10	−3761	2.9	330	C/1822 N1	−47599	4.7
				340	C/2007 M3	-9977	4.0

2. NUMERICAL SIMULATIONS

In order to check for a possible dynamical connection between the LPCs and the hypothetical Planet X, we have selected 54 comets based on their orbital characteristics (mainly their aphelion distances (Q), inclinations (i') and perihelion latitudes (B')). For this purpose we have used the Bulirsch-Stoer algorithm which is included in the MERCURY package In our numerical explorations we have considered a model Solar System that includes the gravitational forces of the Sun, the four Giant planets and the hypothetical trans-Neptunian highly-inclined planet or Planet X, assuming that its mass is $\sim 10M_{\oplus}$. The B–S code of theMERCURY 6 package may handle close encounters of minor bodies with a putative massive body, thereby we have exploited this feature tracking the motion of any

Table 2. List of close encounters between comets and the planet (< 5 AU) regarding to (3)

MA(deg)	Comet	T(yr)	r(AU)	MA(deg)	Comet	T(yr)	r(AU)
0	C/2003 L2	−850	2.0	170	C/2013 F3	−330989	4.2
10	C/2003 L2	−1004	3.4	180	C/1999 K3	−70400	1.0
10	C/1999 K3	−124467	4.1	180	C/2017 A3	−288983	2.3
10	C/2013 F3	−268806	4.4	180	C/2003 L2	−481254	3.5
10	C/1999 K3	−800292	4.5	190	C/2003 L2	−97275	2.2
20	C/2003 L2	−1155	1.3	200	C/2006 CK	−197216	2.4
20	C/2007 M3	−18566	4.9	200	C/1999 K3	−232099	2.3
20	C/2003 L2	−45033	2.5	200	C/2013 F3	−338188	3.2
20	C/1980 E1	−49630	5.0	220	C/1999 K3	−58799	1.1
20	C/2003 L2	−182496	3.6	220	C/1847 N1	−140755	3.9
30	C/2002 K1	−84943	3.6	240	C/1999 K3	−28118	3.8
30	C/2003 L2	−194956	1.6	240	C/2013 F3	−159064	3.3
40	C/2003 L2	−82607	1.0	240	C/2013 F3	−208856	3.7
40	C/2003 L2	−45310	3.4	250	C/2013 F3	−252831	4.8
40	C/2003 L2	−82729	4.4	250	C/2013 F3	−445932	4.0
40	C/1999 K3	−118287	4.7	260	C/2013 F3	−16599	4.2
60	C/1999 K3	−236498	4.6	260	C/2013 F3	−128762	4.7
60	C/1999 K3	−292597	2.9	270	C/2013 F3	−60247	3.6
70	C/2003 L2	−14495	2.3	270	C/2007 M3	−103994	4.9
70	C/1822 N1	−373097	1.7	270	C/2013 F3	−241219	3.8
90	C/1999 K3	−174410	3.8	280	C/2013 F3	−254251	2.0
90	C/1999 K3	−323241	3.9	280	C/2013 F3	−266663	0.5
90	C/1999 K3	−708167	1.8	280	C/1999 K3	−391185	4.2
120	C/2003 L2	−2894	3.6	290	C/2003 L2	−137155	2.7
120	C/2003 L2	−52525	1.7	290	C/1999 K3	−480509	3.4
120	C/1999 K3	−193291	2.0	320	C/2006 CK	−520608	2.5
140	C/1999 K3	−162658	3.7	320	C/2013 F3	−625303	1.5
140	C/1822 N1	−658262	1.6	320	C/2003 L2	−655094	0.8
150	C/1999 K3	−379618	4.5	330	C/2003 L2	−6595	2.3
150	C/1999 K3	−404412	3.3	330	C/1847 N1	−43666	3.8
150	C/1999 K3	−484881	1.7	330	C/2003 L2	−44224	2.5
160	C/1999 K3	−14210	3.5	330	C/1999 K3	−412356	4.0
160	C/2005 N1	−226717	3.5	330	C/2013 F3	−438086	3.2
170	C/2003 L2	−16165	2.2	330	C/1999 K3	−600226	3.4

comet whose orbit led it to come within 1 Hill radius of the massive perturber. It is worth to note here that a celestial body whose mass would have a value like the one given above, and located at such heliocentric distance ($r > 300$ AU), would have a Hill sphere radius of ∼3–7 AU. The initial orbital elements of Jovian planets are obtained from the DE431 numerical theory provided by the JPL ephemeris service[1)]. Orbital elements of the minor bodies (integrated to the same reference epoch JD 2456594.5 or 2013-10-29) are drawn from the same source. The simulations were carried out for approximately 10^6 yr in the past; a formal accuracy parameter set to 10^{-12} was applied. The non-gravitational forces are not considered during the integrations.

Since we do not know the current location of the hypothesized planet, we have decided to produce a series of simulations sampling its mean anomaly by 10°, thereby shifting its position in the orbit almost equidistantly. Thus, we got 36 simulations for given mass.

Our results show that such an orbit can indeed be sustainable despite the extreme inclination, at least for the period of integration. In addition, we have succeeded in detection of the number of close encounters between some comets and the planet. List of these comets will be given below.

Tables 1 and 2 show the encounters of the putative planet with the selected group of comets (54), where MA is the mean anomaly in degrees, T is the time of close encounter in years (from the start epoch), and r is the distance in AU.

Table 1 shows comet approaches to a putative highly-inclined planet having orbital elements given by (2), a total of 59 approaches. The comet C/1911 O1 is of particular importance. This comet had a probable encounter with the planet only 948–16 961 years before the integration start date.

In the case of a putative massive perturber having as orbital elements those given by (3), the number of close encounters is even greater—70 (Table 2). We consider the existence of this perturber as less probable, being the solution given by (2) the one that takes precedence. Nevertheless, it is interesting to note the abundance of encounters in the case of the comet C/2003 L2, which only 850 years from the simulation start epoch could be within the Hill sphere of the Planet X. These results might be of interest for predicting a more accurate location of the hypothetical planet at the present time.

In addition to LPCs, we thought it necessary also to include other objects in our research such as extreme TNOs ($a \geqslant 250$ AU, ETNOs) and extreme Centaurs. There were currently plenty of papers describing the gravitational interactions of an unseen massive perturber and Kuiper belt's objects ([1–3, 8, 9]). [6] and [2] have shown that dynamical effects of massive distant perturber may explain the existence of highly inclined, large semi-major axis Centaurs. The addition of these objects to our simulation was based on the following considerations – if these bod-

1) https://ssd.jpl.nasa.gov/

ies are ejected out of the Solar System in a relatively short time-scale as a result of the existence of the putative massive perturber, such a body cannot possibly exist.

3. SUMMARY

To providing an estimate for the orbital elements of the putative trans-Neptunian massive perturber, we have explored the orbital evolution of 54 comets, 44 ETNOs and centaurs up to 1 Myr backward in time, taking into account the gravitational influence of the unknown planet. In this case, we have considered its mass having a value of about $10M_{\oplus}$. In order to explore the whole range of mean anomaly for the hypothetical planet, we have carried out a series of simulations varying the mean anomaly of the trans-Neptunian massive perturber by 10°. It turned out that some comets could have had close encounters with the prospective planet shortly before their discovery. One weakness of our investigation is that the comets with very short arcs and very old data sets like C/1748 K1 are studied together with objects that have much more reliable orbit determinations.

Table 3. List of close encounters between ETNOs and the planet X (<5 AU) regarding to (2) and (3)

Regarding to (2)				Regarding to (3)			
MA(deg)	Object	T(yr)	r(AU)	MA(deg)	Object	T(yr)	r(AU)
10	2013 LU_{28}	−939183	4.8	10	2013 LU_{28}	−946951	1.0
20	2013 LU_{28}	−989420	3.3	20	2011 OR_{17}	−262291	4.4
50	2013 LU_{28}	−707737	4.6	30	2011 OR_{17}	−81061	2.0
160	2013 LU_{28}	−829486	2.7	70	2010 GW_{14}	−691235	4.8
160	2013 LU_{28}	−916442	4.3	70	2010 GW_{14}	−740927	4.1
180	2012 KA_{51}	−91928	2.8	170	2010 GW_{14}	−808636	3.0
190	2012 KA_{51}	−278237	1.7	190	2013 LU_{28}	−922707	4.1
290	2010 GW_{14}	−859885	3.5	230	2011 OR_{17}	−84151	2.3
320	2017 CW_{32}	−692077	3.0	260	2017 SN_{33}	−882247	2.0
320	2017 CW_{32}	−698318	3.0				
330	2017 CW_{32}	−711579	1.3				
340	2012 KA_{51}	−20347	4.2				

According to our calculations, a special place is occupied by the comet C/1911 O1, since several centuries before its discovery, it could have had a close approach with the hypothetical planet at a distance of 2–3 AU; also it is worth mentioning that comet C/2003 L2 would have a close encounter of the same kind with a putative highly-inclined massive perturber having as orbital elements those given by (3). Perhaps, this is the comet that could answer the question of where the planet is now.

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