ON STATISTICS OF CHANGES IN RATES OF DRIFT AMONG UNCONTROLLED GEOSTATIONARY OBJECTS

Alla S. Sochilina(1), **Konstantin V. Grigoriev**(1), **Andrei N. Vershkov**(1), **Rolan I. Kiladze**(2),
Felix R. Hoots(3), **Richard France**(4)

(1)Pulkovo Observatory, 65/1, Pulkovskoye chaussee,196140, St-Petersburg, Russia, E-mail: aver@av8240.spb.edu
(2)Abastumani Astrophysical Obs., 52, k.17, q.6, Vaja Pshavela Av., 380086, Tbilisi, Georgia, E-mail: roki31@usa.net
(3) GRC International, 1900 Gallows Road, Vienna, VA 22182, 703-506-5931, E-mail: fhoots@grci.com
(4) GRC International, 985 Space Center Drive, Suite 310, Colorado Springs, CO 80915, (719) 596-6139,
E-mail: rfrance@grci.com

ABSTRACT

The comparison of the geostationary uncontrolled object long-term orbital evolution with NASA Two-Line-Elements of US Space Commands has been shown, that many of them have significant systematic discrepancies in longitudes. These discrepancies can be explained by sharp changes of satellite rate of drifts on some moments of time. At present there are more than a hundred of such objects, some of them have repeated changes. For instance, the objects 68050J Transtage 12, 79035E Raduga 5, apogee motor and exploded satellites (67066G Transtage 11 and 77092A Ekran 2) have no less than 3-5 changes. The values of the changes are in the limits 0.0002-0.01 °/day. The studies of changes with other orbital data and even with the optical observations confirmed this phenomenon. For explanation of it the statistic of all these changes for long time interval is necessary. The preliminary hypothesis, which could explain these changes, is a collision of satellite with space debris or its micro explosion, as soon as usual explosion of satellite calls the similar changes of rate close to 0.2-1.0 °/day only. For the beginning of statistic accumulation the studies of long-term evolution for all uncontrolled geostationary objects are fulfilled over the time interval 1993 – 2000 years. As the result of this work is a list of objects with their orbital data and the values of changes of their rate on corresponding time moments.

1. INTRODUCTION

On preparing of the geostationary satellite catalog [5] it was noticed that for several objects the representation of orbital elements (Observations) by evolution of improved orbits (Calculations) contained systematic errors in their longitudes. It is turned out that the shape of $(O - C)_\lambda$ curves depends on the motion regime of geostationary satellites (GS). For GS moving in the circular regime these discrepancies look as parabola (Fig. 1), but for librating ones $(O - C)_\lambda$ have a shape of sinusoid with constant or variable amplitudes. Their periods coincide with the periods of libration (Fig. 2).

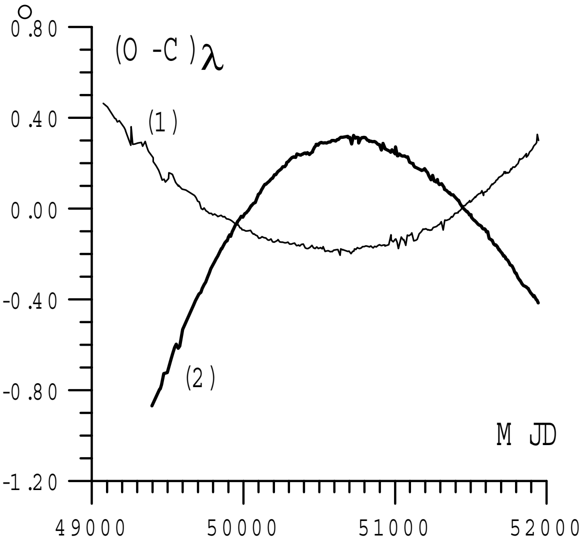

Fig. 1. GS 67066F (1) and GS 67066G (2): The improvement over the span equal to 2800 days

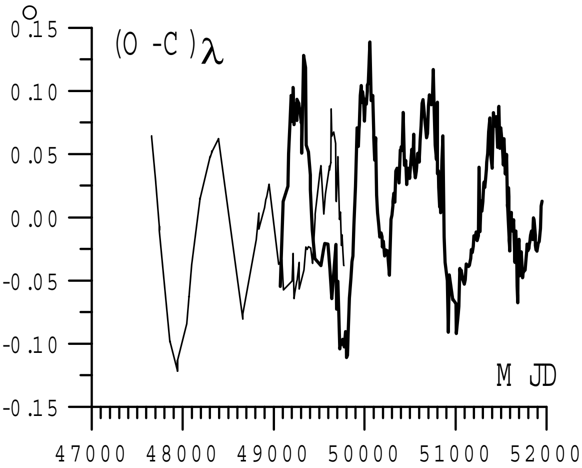

Fig. 2. GS 85102A and GS 81061A: $(O - C)_\lambda$ obtained from the comparison of OLI (left) and TLE (right) evolutions with the available osculating orbits

Analysis of $(O - C)_\lambda$ during the time interval 1993 – 1996 for all uncontrolled GS has revealed more than 50 objects (from 350 ones).

Proceedings of the 3rd European Conference on Space Debris, ESOC, Darmstadt, Germany, 19 - 21 March 2001
(ESA SP-473, August 2001)

For explanation of this phenomenon R. Kiladze suggested the hypothesis of sudden change of rate of drift [2], which could happen as a result of collision with small debris or micro explosion on GS. Therefore, such change of velocity we shall call "collision".

At present from treatment of the NASA Two-Line-Elements (TLE) data and of Long-time Interval Orbits (OLI) determined in period 1993 – 2000 in the former USSR with the help of photographic and electro-optical observations over long time interval, showed that a number of "collided" GS increased twice. Moreover, the number of GS with multi-collisions also had been increased.

One of a possible source of small-size debris may be explosions of GS. The generated fragments periodically intersect the orbit of the primary body and the orbits of neighboring GS. So, for the final solution of the question it must be not only treat the whole existing orbital data for uncontrolled GS, but also continue the treatment of precise observations of these objects. The observations of small fragments of GS and investigation of their origin and behavior represent the peculiar interest.

2. EXPLOSIONS IN THE REGION OF GEOSTATIONARY ORBIT

One of exploded objects 68081E was observed in a half hour after the event [6]. Its rate of drift changed by 0.2 °/day. The change of the rate of drift for GS 77092A was a little less than this value but this GS is moving in regime of libration and the explosion happened in the point of reverse. Therefore, its orbit was strongly deformed and the ratio of cross-section to the mass increased four times as much. The velocity of GS 78113D has been significantly changed thrice. It is not clear now if there were two explosions of small forces or two collisions with fragments. At last, the most strong explosion happened with GS 67066G which changed its rate of drift almost by 1 °/day and the eccentricity – by 0.003. At present the 5 GS explosions are proved. The whole quantity of cosmic debris generated by means of these explosions consists of several tons.

In Table 1 the orbital elements of these objects before and after explosion are given. The behavior of $(O - C)_\lambda$ for these GS is shown in Fig. 3 and 4. For comparison behavior of $(O - C)_\lambda$ for the rest of (unexploded) Transtages is shown in Fig. 5.

Table 1. The orbital elements of GS before and after explosion

No	T_0	e	i	Ω	ω	λ	$d\lambda/dt$ (°/day)
67066G	15/02/94	0.00533300	11.°6752	25.°3856	26.°2737	24.°6764	32.02549
	49397.9842	0.00813759	11.6582	25.4189	7.4957	24.5373	31.08763
68081E	21/02/92	0.00948600	11.8870	21.7440	75.8400	197.3026	4.25456
	48673.3967	0.00948600	11.9055	21.7657	71.4630	197.6250	4.48587
73100D	10/04/92	0.02787504	13.3334	45.3622	165.1831	165.4818	-18.7902
	48721.5580	0.02677380	13.3194	45.4035	164.5238	165.4544	-18.98583
77092A	22/06/78	0.00019520	0.1342	74.9752	305.3183	98.5211	-0.08520
	43680.6328	0.00336200	0.1408	77.3252	256.6817	98.8011	0.04911
78113D	16/10/97	0.02801989	14.1626	38.3146	176.8359	319.9890	-22.90412
	50737.70062	0.02861278	14.1588	38.2535	177.2404	320.0928	-23.41754
78113D	21/01/98	0.02857873	14.2870	37.2780	179.7116	221.2659	-23.41908
	50834.15537	0.02829205	14.2822	37.2763	174.6639	221.2402	-23.43684
78113D	19/02/98	0.02808147	14.3202	37.0032	175.6434	266.3758	-23.43815
	50862.9506	0.02732296	14.3173	36.9838	169.8091	266.1826	-23.46149

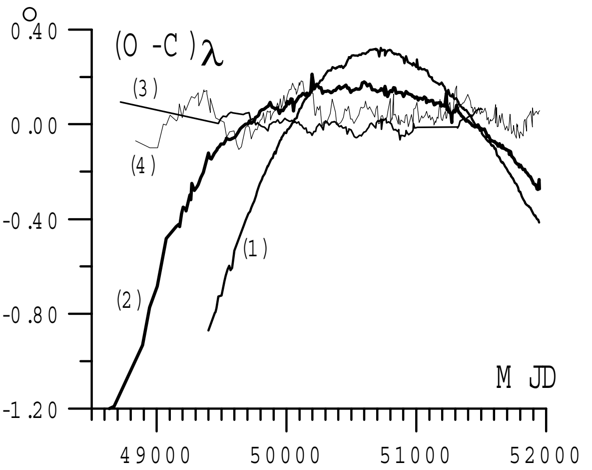

Fig. 3. Behavior of (O – C)$_\lambda$ for exploded GS 67066G (1), 68081E (2), 73100D (3) and 77092A (4) after the event

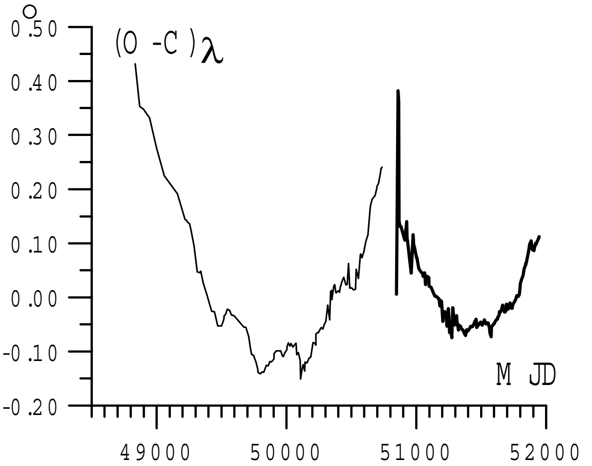

Fig. 4. Behavior of (O – C)$_\lambda$ for GS 78113D before and after explosion

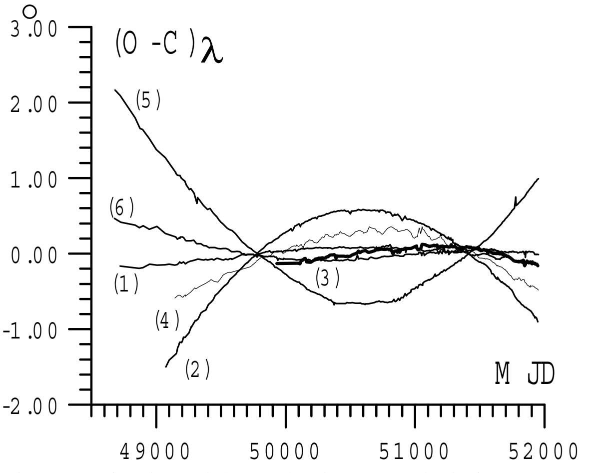

Fig. 5. Behavior of (O – C)$_\lambda$ for unexploded Transtages 66053J (1), 68050J (2), 69013B (3), 74039C (4), 76023F (5) and 77034C (6)

In Fig. 6 the behavior of (O – C)$_\lambda$ for the "family" of GS (among which one of them was exploded) is shown.

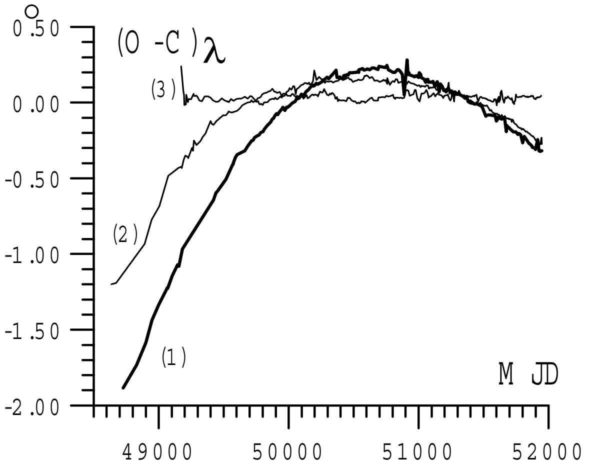

Fig. 6. Behavior of the "family" 68081A (1), 68081E (2) and 68081D (3)

In Table 2 the data and the values of changes in rates of drift for exploded GS, according to existing orbital elements, are given. The moments for supposed explosions are given with three figures after the point.

Table 2. The data and the changes in rates of drift for exploded GS

No	T (MJD) (day)	dλ/dt (°/day)
67066G	49209.	-0.00090
	49397.984	-0.93786
	49985.	-0.00069
	50343.	-0.00056
	50700.	-0.00052
	51189.	-0.00045
68081E	48637.397	-0.23131
	49399.	-0.00052
	49703.	-0.00037
	50405.	-0.00052
	51504.	-0.00031
73100D	48721.558	-0.19580
	50623.	0.00012
77092A	43680.630	0.12300
	49631.	0.00119
	50085.	0.00058
	50801.	0.00074
	51135.	0.00097
	51351.	0.00038
	51769.	0.00077
78113D	49811.	0.00054
	50140.	0.00047
	50737.701	-0.51342
	50834.155	-0.01776
	50862.951	-0.02334
	51251.	0.00066

Table 3. The list of the strong changes in velocities of GS

No	Date of event (MJD)	change of drift rate (°/day)	Longitude of event	No	Date of event (MJD)	change of drift rate (°/day)	Longitude of event
68050J	49340(20.12.93)	-0.00071	201°	80016A	49294(03.11.93)	-0.04684	104
	49625(01.10.94)	-0.00064	263	80081D	49196(49196.00)	0.00829	288
	50022(01.11.95)	-0.00071	299	80104A	49468(26.04.94)	-0.01654	60
	50745(25.10.97)	-0.00103	129	82110B	50020(31.10.95)	-0.00379	103
	51374(15.07.99)	-0.00083	303		50159(18.02.96)	0.00372	295
68081A	49604(10.09.94)	-0.00096	259		50399(12.11.96)	-0.00534	6
	50363(07.10.96)	-0.00079	171		50592(24.05.97)	0.00434	134
68081D	49196(28.07.93)	0.00856	290		50745(24.10.97)	-0.00263	310
	49811(05.04.95)	0.00079	245		50820(07.01.98)	-0.00280	218
74039A	49924(27.07.95)	0.00053	145		51000(06.07.98)	0.00344	0
74039C	50786(04.12.96)	-0.00073	202		51191(13.01.99)	-0.00636	131
76023F	49415(04.03.94)	0.00062	275		51356(28.06.99)	0.00595	291
	50206(03.05.96)	0.00067	305		51541(30.12.99)	-0.00711	66
	50612(13.06.97)	0.00068	305		51748(24.07.00)	0.00685	175
	50846(02.02.98)	0.00119	245	85016A	50344(18.09.96)	-0.00115	191
76107A	50220(17.05.96)	0.00124	73		50372(17.10.96)	-0.00092	188
78039A	50155(13.03.96)	-0.00200	87		50825(12.01.98)	-0.00064	270

In Table 3 the strong (more than 0.0005 °/day) changes of rate of drifts of GS are given.

3. THE ACCURACY OF USED ORBITAL DATA

The multiplicity of the occasions of collisions made us to control carefully and subsequent development of GS motion theory. At present a new intermediate orbit for GS is constructed, which gives the possibility not only increase the accuracy of $(O-C)_\lambda$, but also increase the effectiveness of software.

The new software allows to calculate the evolution even such difficult for investigation objects, as GS 67026A, which was moving in the regime of libration near the point L2 (105° W) and from 1997, – after two-year staying in the vicinity of unstable point 12° W, – beginning moving around two stable points. It must be mentioned that the present course of events was predicted by authors [3]. At present the evolution of this GS is constructed on the time interval of 2700 days with the middle error of 0.°043 (Fig. 7). It seems that the maximal discrepancy $(O-C)_\lambda$, reaching 0.°1 at the moment of passing of unstable point, is because of accidental errors of TLE, which are determined over the short time spans and possible errors in parameters of geopotential. For this reason the next object of discussion is the accuracy of TLE orbits.

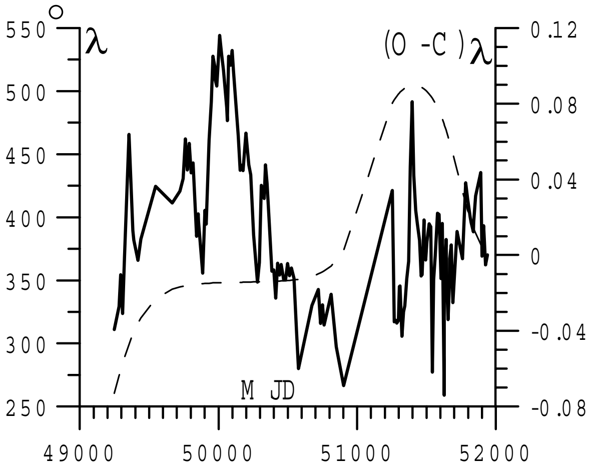

Fig. 7. Longitude λ and $(O-C)_\lambda$ for GS 67026A (λ – dashed line)

The comparison of TLE orbits with evolution ones for several GS shows that their $(O-C)_\lambda$ have, as a rule, the form of sinusoids with the period of 1 year and amplitude 0.°04 – 0.°05. At the same time, OLI doesn't consist such periodic component (Fig. 8) [4].

The principal causes of these oscillations are in the use of different motion theories and the different time spans on which the orbits are defined [1]. But these annual oscillations are of no importance in an investigation of the long period evolution of longitudes, because on time intervals more than 1000 days their influence does not exceed 1×10^{-4} °/day. At the same time the observed changes are essentially larger.

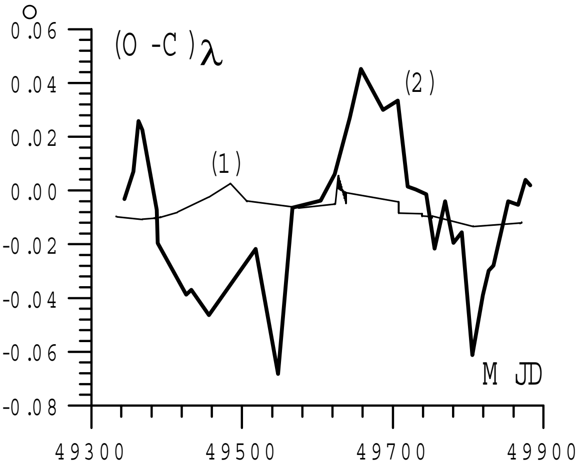

Fig. 8. GS 84016A: (O-C)$_\lambda$, improvement over span equal to 540 days for the orbits OLI (1) and TLE (2), separately

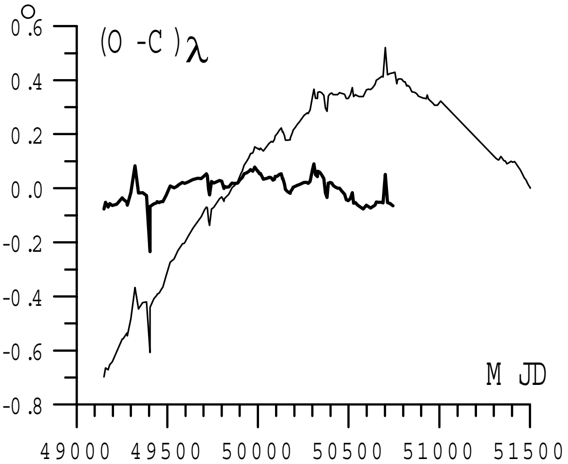

Fig. 9. GS 81061F: (O-C)$_\lambda$, caused by the "collision" of satellite moving in circulating regime

The modeling of collisions and the impossibility of representation of the observations before and after the collision by the same orbital evolution, prove the reality of phenomenon.

Because of variety of the types of systematical discrepancies, the most characteristic events of behavior of (O – C)$_\lambda$ will be given in the next part.

4. THE CHANGE OF RATE OF DRIFT AND ITS MODELING

As it is shown in Fig. 5 in representation of (O – C)$_\lambda$ for circulating GS there are many various cases. Depending on a number of collisions the curve (O – C)$_\lambda$ can be strongly deformed. From the Fig. 9 it is clear that these moments can be defined between intervals, where (O – C)$_\lambda$ are represented by straight lines.

For GS with a small rate of drift and, consequently, with a rather large influence of resonant perturbations the additional oscillations in (O – C)$_\lambda$ take place. It is seen in Fig. 10 that GS 79035E over time interval 47000 – 51000 MJD has two collisions. For this satellite a motion model has been constructed with following changes of velocity: 0.00048 °/day (48368 MJD) and 0.00083 °/day (49393 MJD). It has to notice that any extra change of velocity increases the amplitude of oscillations.

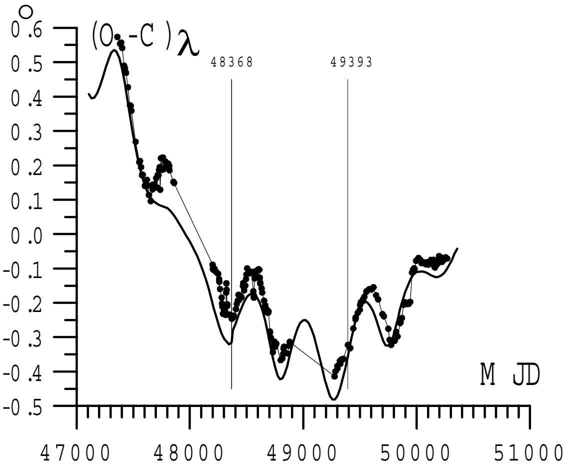

Fig. 10. GS 79035E: the model of (O-C)$_\lambda$ for satellite moving in the circular regime with two collisions

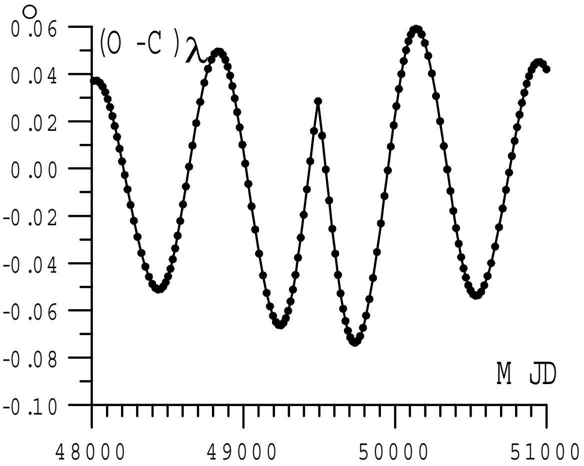

Fig. 11. (O-C)$_\lambda$ for a fictions GS with the change of the rate of drift on -0.001 °/day at the point of turn

In Fig. 11 an example of (O – C)$_\lambda$ for fictive librating GS is given, when the change of rate of drift, equal to –0.001 °/day, takes place at the point of reverse. We have the analogical situation with GS 85102A (Fig. 12), which over the time interval 47600 – 50000 MJD has been collided twice, near the point of turn ($\lambda = 94°$). In Fig. 13 for GS 81061A the representations of (O – C)$_\lambda$ with the model of three collisions are also shown.

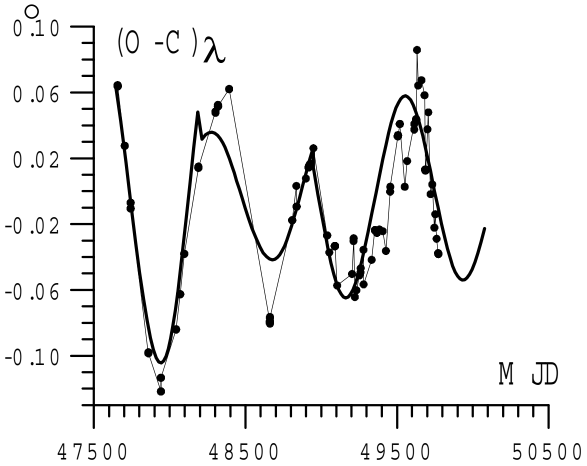

Fig. 12. GS 85102A: $(O\text{-}C)_\lambda$ of the librating satellite with two collisions and its modeling

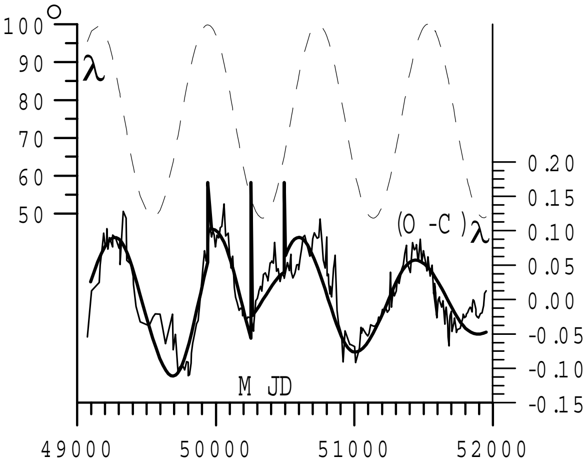

Fig. 13. GS 81061A: modeling of $(O - C)_\lambda$ for GS with two collisions (λ – dashed line), moments of collisions are marked by vertical lines

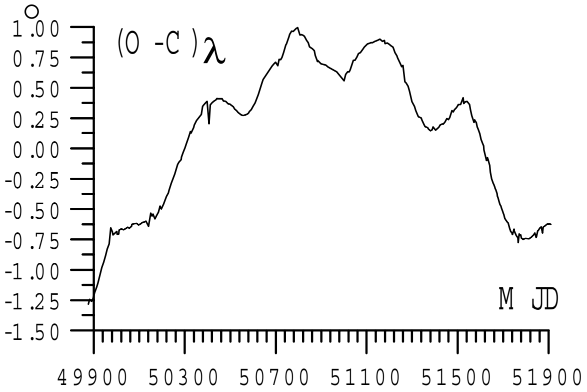

Fig. 14. GS 82110B: $(O - C)_\lambda$ for multi-collided GS

GS 82110B is an impressionable example of multi-collided satellite. There are 11 breaks on the $(O - C)_\lambda$ curve of this GS (Fig. 14). The correspondent values of impulses are given in Table 3. The multiplicity of motion changes of GS 82110B may be of artificial origin.

The masses of striking particles may be estimated in the following way.

The change of rate of drift of GS by 0.001 °/day correspondence to the change of speed by 2.84 mm/s [2]. If the relative speed of particle is 100 m/s and the mass of GS – 1 ton, then the mass of the particle must be equal to 28.4 gr. Hence, the noticeable change of GS motion may by provoked by particles with mass less than 50 gr.

More than 100 collided GS during the time interval 1993 – 2000 can be as arguments in favor of the strong pollution of the region of geostationary orbit.

It seems that it would be useful to have the catalog of collided GS because as a result of the straight collisions, some GS may be lost or false identified. For this reason in GAO Pulkovo of Russian Academy of Science preparing of such catalog has begun recently. The work may became joint, if to this work should add observers, having GS data. As soon as at present most of ground-based stations can not observe objects less than 1 m-size, it would be useful to joint the forces of different departments for patrol of GS region, using dynamical method.

5. REFERENCES

1. Grigoriev K.V., Hoots F.R. On Improvement of Orbits of Geostationary Satellite from Observations over the interval of time 150-200 days. *Forth US/Russian Space Surveillance Workshop* 23-28 oct., 2000. US Naval Obs. Washington, DC (In press).

2. Kiladze R.I., Sochilina A.S., Grigoriev K.V., Vershkov A.N. On investigation of long-term orbital evolution of geostationary satellite. Proceedings of 12th Symposium on "*Space Flight Dynamics*", ESOC, Darmstadt, Germany, 2-6 June 1997, pp.53-57.

3. Kiladze R.I., Sochilina A.S. On evolution of geostationary satellite orbits. *Advances in Space Research*, Vol.19, No 11, 1997, pp. 1685-1688.

4. Kiladze R.I., Sochilina A.S., Grigoriev K.V., Vershkov A.N. On Ways of Modernization of Geostationary Ring *Surveillance. Forth US/Russian Space Surveillance Workshop 23-28 oct., 2000.* US Naval Obs. Washington, DC (In press).

5. Sochilina A.S., Kiladze R.I., Grigoriev K.V., Vershkov A.N. *Catalog of Orbits of Geostationary Satellites*. St-P. 1996, 103p.

6. Pensa A.F., Powel G.E., Pork E.W. and Shridharan R. Debris in Geosynchronous orbits. *Space Forum*, vol.1, No 1-4 ISSN 1024-803X, 1996, pp. 23-37.