ON THE EVOLUTION OF FRAGMENTS OF THE GEOSTATIONARY OBJECTS

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From time to time in the scientific press information appears about catastrophes happening with the artificial Earth satellites, including objects moving in the neighborhood of the geostationary orbit [1,2].

Independent of the cause of such phenomenon (the explosion of remnants of fuel, collision with great body, etc) great quantities of different-size fragments always are created with large or small velocities ejected from the place of the event.

Because of the smallness of the majority of the fragments their observations are connected with the great difficulties. For this reason, as a rule, we don't succeed in surely establishing what happened with the geostationary satellites (GS). Indirect evidence of a catastrophe may be a significant growth of light after the event.

As a rule, we get to know about such event significantly later by discovering the sudden, strong (some m/s) change of GS velocity or orbital elements. We name such events, for short, as "explosion", in contrast to small (about mm/s) velocity changes, which we name as "collision" (meaning the collision with small cosmic debris) [3,4].

The method of determining the moment and place of an event, as well as the velocity and direction of ejection of fragments, is by means of its orbital elements, before and after "explosion", which is elaborated by the authors [5,6].

Today, there are 11 known cases of such "exclusions" on geostationary orbit; they are listed in Table 1. The information about 10 of them is in [6].

In Table 1 the number of GS, the moment of "explosion" T_o, orbital elements of GS e, i, Ω, ω, λ and drift, dλ/dt before and after "explosion", as well as the change of drift Δ(dλ/dt) are given.

In this work the behavior of 32 fragments of GS, ejected with equal initial rates into different directions, are situated on tops and sides of Ikasider (polyhedron with 20 tops).

The evolution of the GS orbital plane can approximately be represented as precession across the Laplace plane a with period of 53 years. During this time interval the pole of the GS orbit circulates around the pole of the Laplace plane.

Table 1. Orbital elements of exploded satellites before and after event

NN	T_0 (MJD)	e	i	Ω	ω	λ	$d\lambda/dt$ (^{o}/day)	$\Delta(d\lambda/dt)$ (^{o}/day)
66053J	47071.688587	0.010312	11.^{o}5253	9.^{o}4976	281.^{o}7312	288.^{o}3453	22.^{o}53757	0.^{o}67682
	03/10/1987	.016240	11.5321	9.5757	281.2806	288.9544	23.21439	
67066G	49397.408163	.005317	11.6745	25.3957	25.8977	6.2241	32.02443	-0.93796

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	14/02/1994	.008096	11.6578	25.4061	5.6721	6.6536	31.08647	
68081E	48673.397616	.008545	11.9100	21.7275	76.5843	196.7101	4.27995	0.20669
	21/02/1992	.008862	11.9100	21.7541	71.3055	196.8043	4.48664	
73040B	44671.200700	.004358	5.8669	62.8461	19.1543	145.2013	-2.32077	-0.21648
	08/03/1981	.002713	5.8728	62.8123	328.2317	144.8817	-2.53725	
73100D	48718.887352	.027538	13.3263	45.5479	165.4079	215.9878	-18.79458	-0.19387
	06/04/1992	.026787	13.3121	45.4283	163.3701	216.0936	-18.98845	
76023F	43060.207900	.013845	25.3482	10.9980	215.4257	226.6138	-7.22838	*
76023J	09/10/1976	.014202	25.2918	10.6278	215.9062	226.5970	-7.25248	
77092A	43680.632778	.003366	0.1407	77.3145	256.1496	98.8366	0.04767	-0.13279
	21/06/1978	.000195	0.1356	74.7306	-50.7829	98.5127	-0.08512	
78113D	50744.547145	.028236	14.1715	38.2444	177.1164	163.1494	-22.90318	-0.55491
	23/10/1997	.027325	14.1604	38.1593	166.2476	163.8886	-23.45809	
79087A	45121.755000	.000987	1.6575	90.9652	196.5378	52.5730	0.07580	-0.08803
	01/06/1982	.000451	1.6578	92.3283	83.5444	52.5333	-0.01223	
82019B	45960.349103	.000518	0.3705	143.1092	301.5961	201.9020	3.06907	0.47435
	17/09/1984	.001376	0.3440	138.3305	35.1682	201.7803	3.54342	
84129B	50074.650093	.000938	5.9226	57.9216	294.3247	359.9551	-4.06615	-0.80244
87095A	23/12/1995	.005996	5.8441	55.5646	203.3469	359.6639	-4.86859	

(*) Orbital elements of GS 76023F and its fragment 76023J.

At the moment of "explosion" every fragment forms a new orbit, the plane of which intersects the orbital planes of other fragments, including the orbital plane of the primary object, at the point of "explosion". The inclination of the fragment's orbit to the initial one is as follow:

$$\Delta i = \frac{V_p}{V_\tau}, \tag{1}$$

where Δi is expressed in radians, V_p – the polar component of fragment's motion, and V_τ - tangential velocity of GS.

Simultaneously, the initial poles of all the fragments are disposed on the great circle at 90^o on the celestial sphere from the point of "explosion" (Fig. 1).

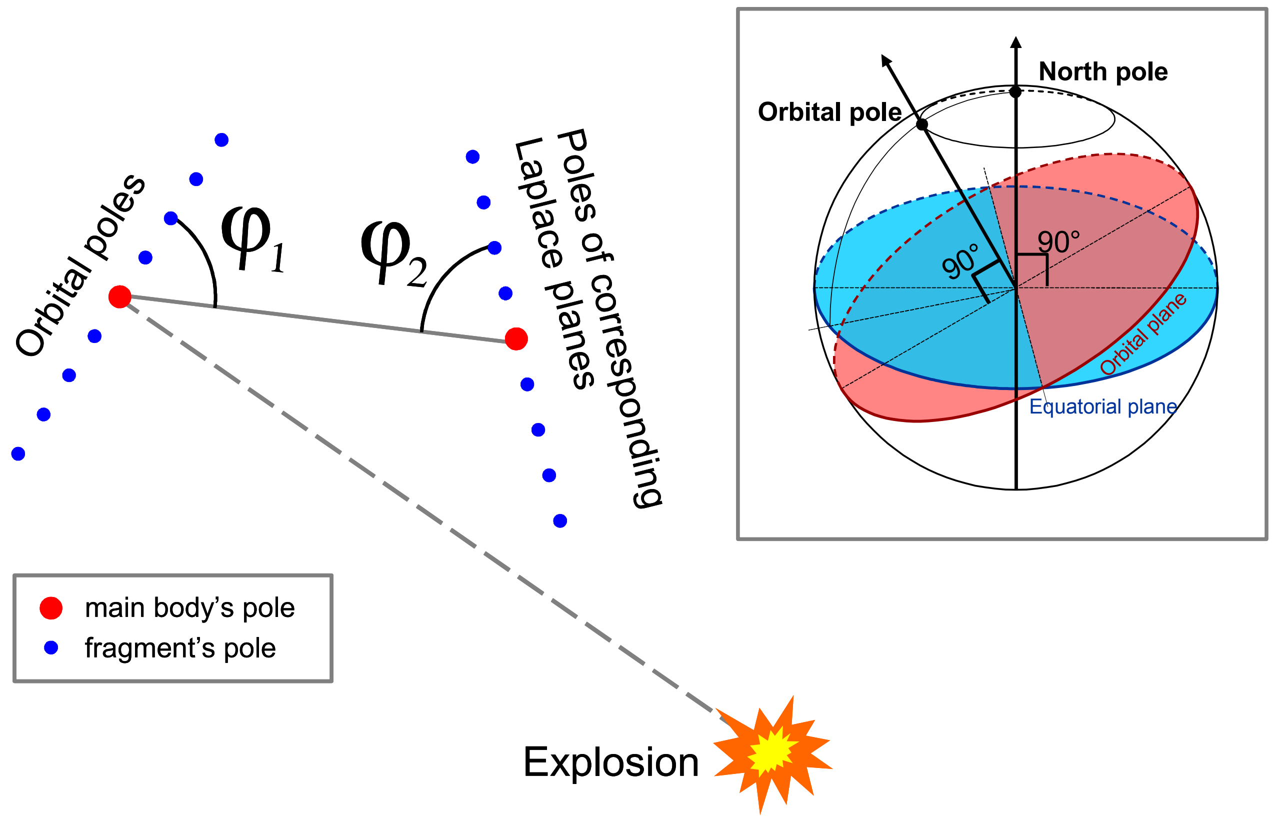

Fig. 1. Poles of the fragments' orbital planes and the poles of their Laplace planes at the moment of explosion.

On the other side, the semi-major axis of the fragment's orbit will differ from the semi-major axis of initial orbit by the quantity:

$$\Delta a = \frac{2a}{V_o} V_\tau, \qquad (2)$$

where Δa denotes the change of the semi-major axis of fragment.

Accordingly, every fragment after the "explosion" gets its own Laplace plane. Their poles are located on the great circle passing through the poles of the Earth and of the initial Laplace plane (Fig. 1).

From the moment of "explosion" the poles of the orbits of each fragment begin to move around their own poles of the Laplace planes, with slightly different velocities.

The behavior of the populations of 32 fragments was studied on basis of GS motion theory [7 – 12], for all 11 events, represented in Table 1. The velocity of fragment ejection has been adopted to be 75 m/sec. For several GS the influence of velocities of ejection (250, 20 and 10 m/sec) were also studied. But their values don't essentially change the character of the fragments' behavior: the configuration of Figures 1 – 6 is invariant to change of the ejection velocity and only the scales of the Figures change proportionally to it.

The evolution of the fragments' orbits was retraced during 30 000 days, i. e. about 80 years.

In this case significantly different pictures are shown by different GS.

The behavior of fragments of GS 68081E after every 2 000 days is shown on the Fig. 2.

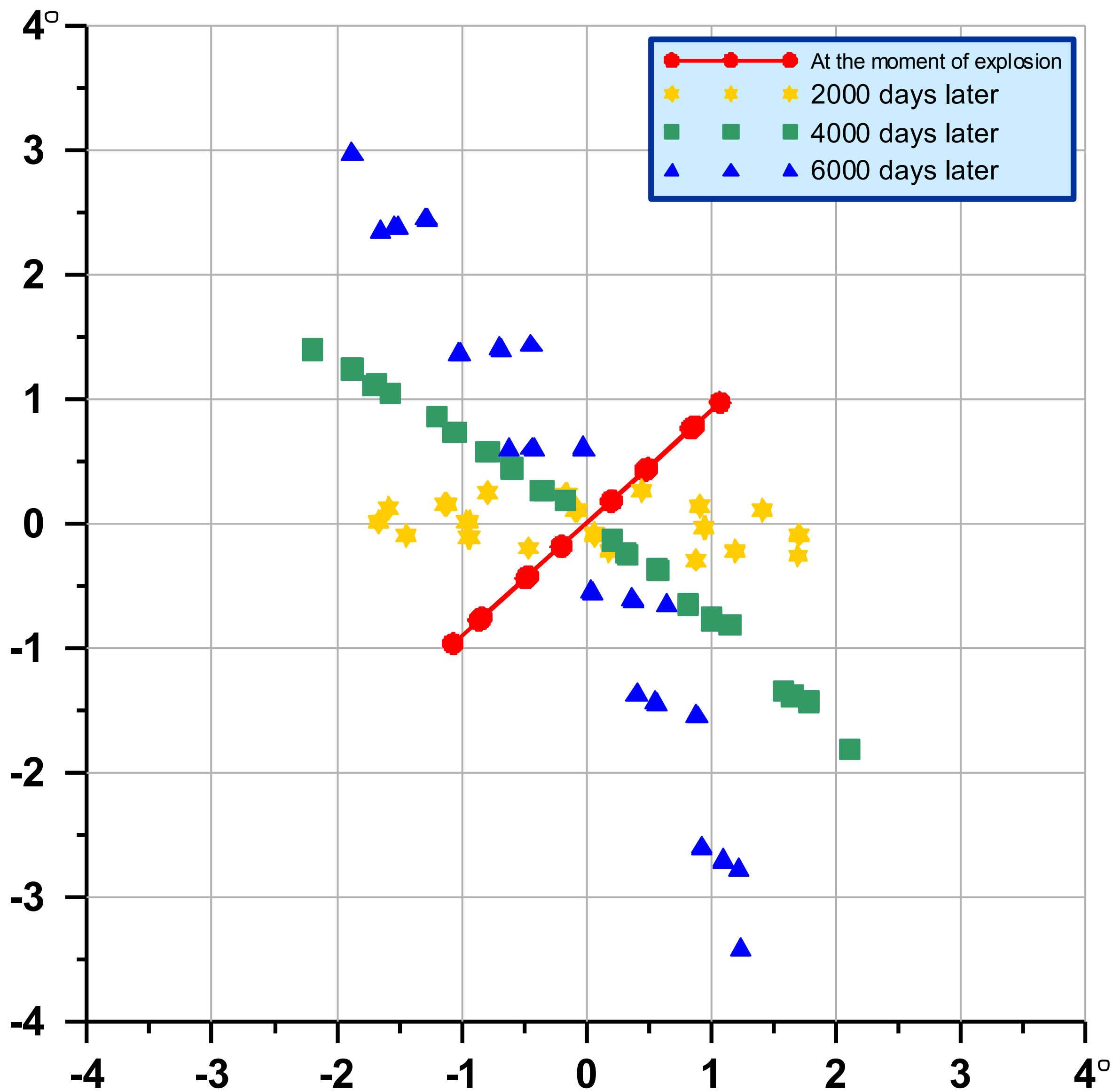

Fig. 2. The evolution of the poles of GS 68081E fragments' orbits with 2 000 days intervals.

In Fig. 2. it is shown that in 2 000 days after the "explosion" the poles of the fragments' orbits occupied enough space on the sky, but after 4 000 (more exactly 3 900) days they can line up. In the end of the evolution they again begin to occupy greater and greater space. Most of the investigated GS have similar behavior (but with another characteristic times).

For example, in the Fig. 3 the evolution of the poles of GS 73040B fragments' orbits is shown with 3 000 days intervals. In this case the minimum of dispersion comes 9 500 days after the "explosion".

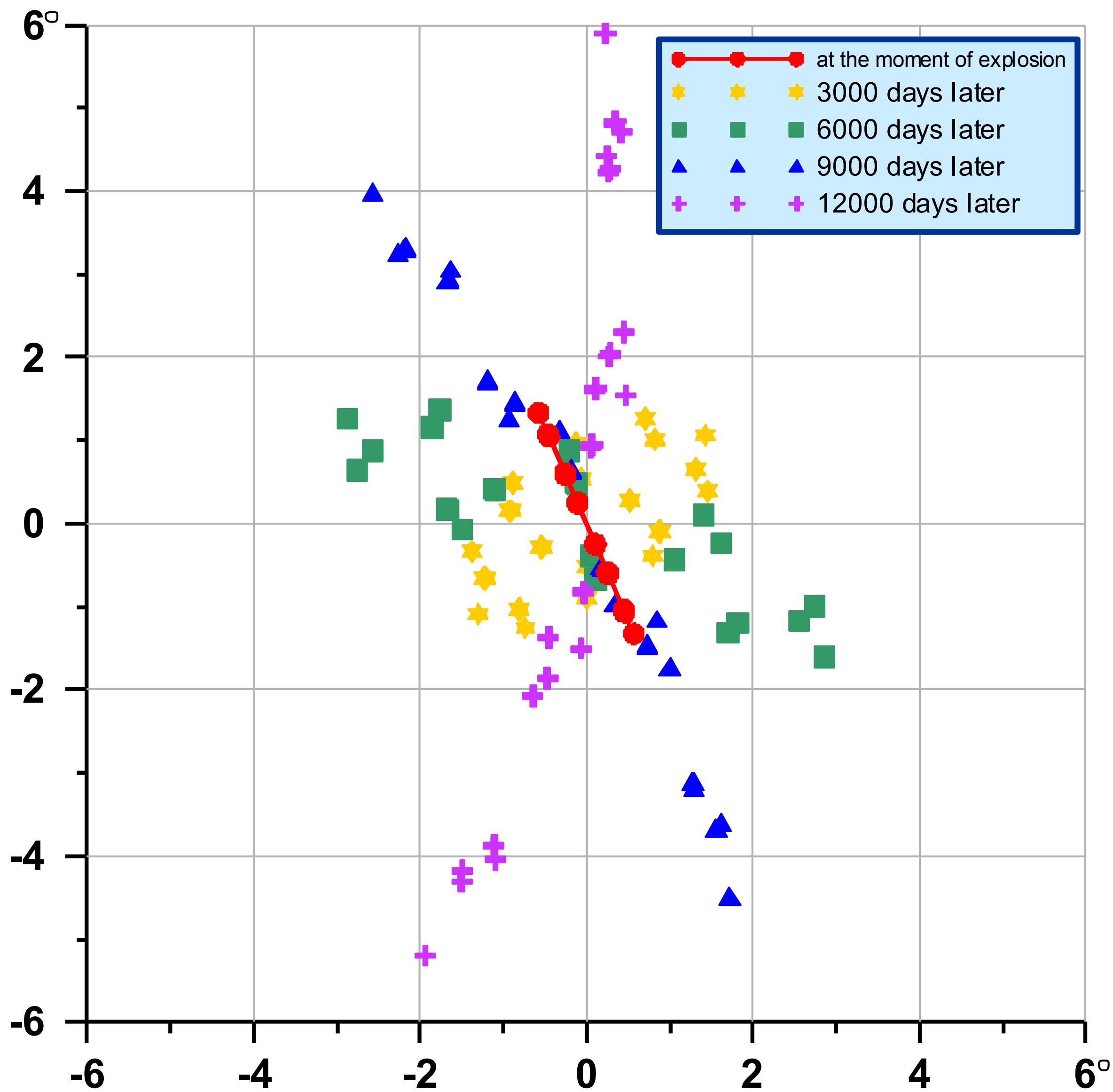

Fig. 3. The evolution of the poles of GS 73040B fragments' orbits with 3 000 days intervals.

In Fig. 4 and 5 the evolutions of the poles of GS 82019B and 84129B fragments' orbits with 1 000 days intervals are shown. In both these cases the minimum of the dispersion comes 2400 days after the"explosion".

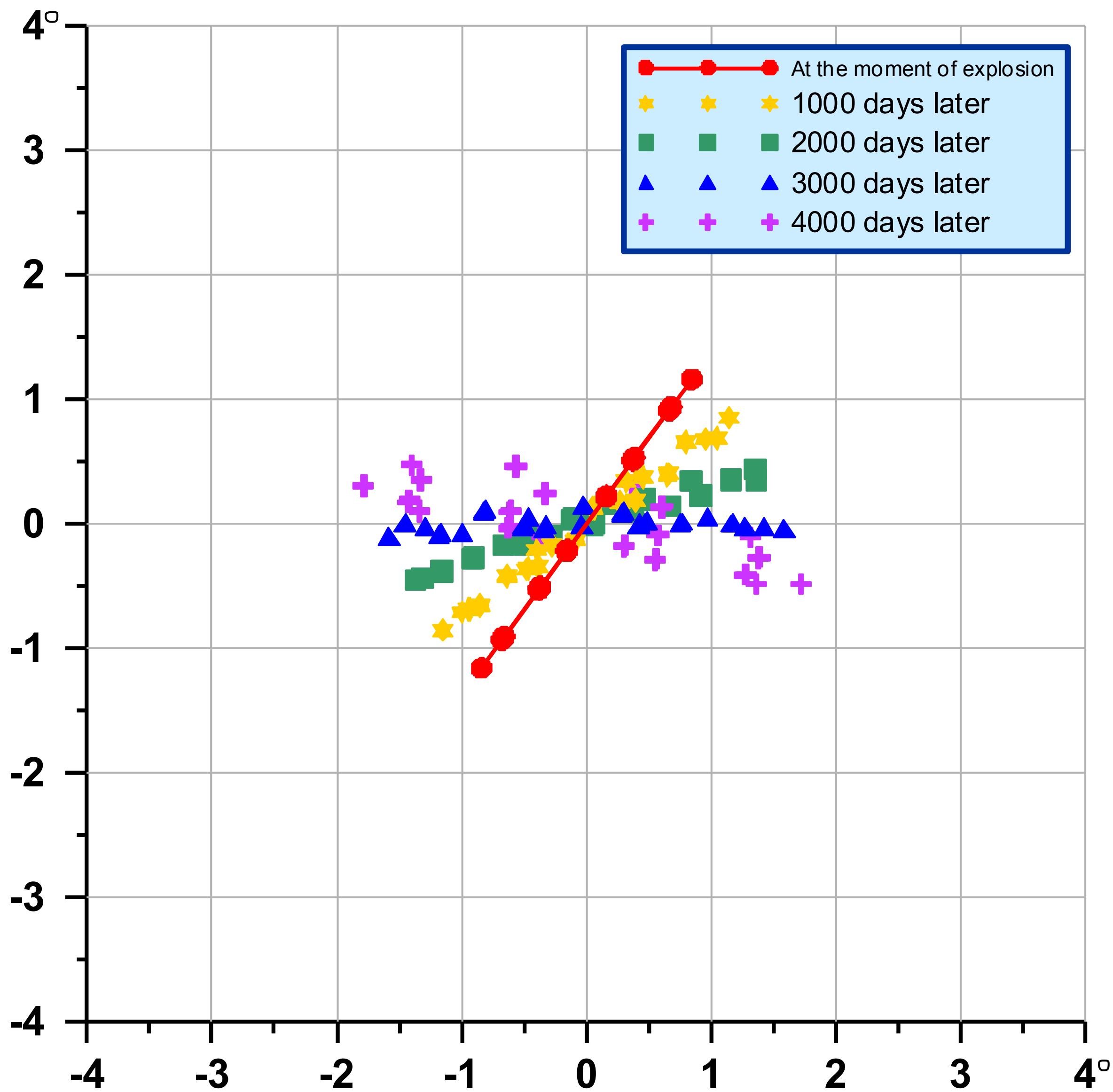

Fig. 4. The evolution of the poles of GS 82019B fragments' orbits with 1 000 days intervals.

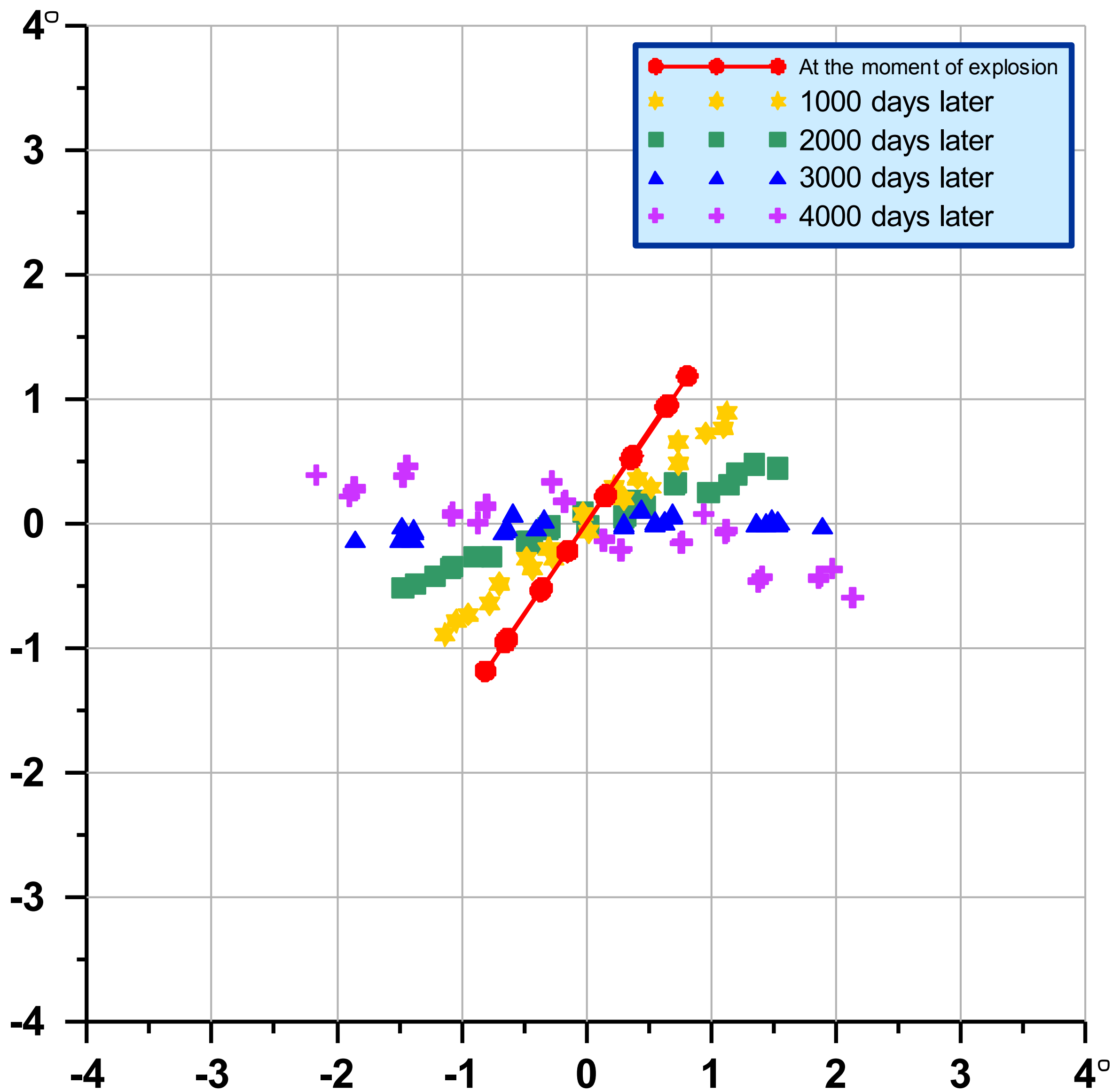

Fig. 5. The evolution of the poles of GS 84129B fragments' orbits with 1 000 days intervals.

Placing the fragments' orbital poles across the great circle on the celestial sphere (across the straight line in the Figures) means that the planes of all orbits intersect each another on the line perpendicular to this circle. Consequently, during the period of such regularization of fragments' orbits (it lasts several years) two points – antipodes arrive on the celestial sphere. For the geocentric observer every fragment created by the "explosion" will pass them during a day.

This circumstance significantly lightens searching for fragments of the supposed explosion by means of barrier constructing at the proper points.

It should be noted, that the ideal disposition of orbital poles across the great circle is a rarity: practically always some dispersion is present. Due to the dispersion the situation ariseswhen instead of two points – antipodes in the same place - two small areas arise through which the fragments pass. Their sizes (radii) are equal to the above mentioned dispersion.

In Table 2 the numbers of GS, moments and equatorial coordinates, α and δ, of one of compact intersection points of orbital planes, as well as the rate of dispersion of poles' coordinates, σ (in degrees), are given.

It should be noted that in a few cases (GS 66053J, 78113D) the process of regularization of orbits is slightly expressed.

Table 2. Moments and equatorial coordinates of the events of compact intersection of fragments' orbits

COSPAR	**MJD**	**Year**	**α**	**δ**	**ε**
66053J	56700	2014	$9^h\ 16.5^m$	0.76°	0.573
67066G	50700	1997	$5^h\ 56.9^m$	12.37	0.023
	65700	2038	$10^h\ 04.3^m$	8.00	0.703
68081E	52600	2002	$3^h\ 41.3^m$	11.52	0.070
	67000	2042	$9^h\ 42.3^m$	8.55	0.538
73040B	54200	2007	$1^h\ 29.0^m$	9.33	0.211
73100D	59800	2022	$11^h\ 11.8^m$	-7.50	0.307
76023J	50000	1995	$0^h\ 17.0^m$	16.41	0.340
77092A	54700	2008	$1^h\ 52.3^m$	9.18	0.192
78113D	63500	2032	$9^h\ 43.3^m$	-3.10	0.520
79087A	54400	2007	$2^h\ 37.3^m$	9.96	0.161
82019B	48400	1991	$6^h\ 39.0^m$	3.35	0.033
	62400	2029	$8^h\ 52.8^m$	-1.19	0.798
87095A	52500	2002	$6^h\ 41.0^m$	8.28	0.031

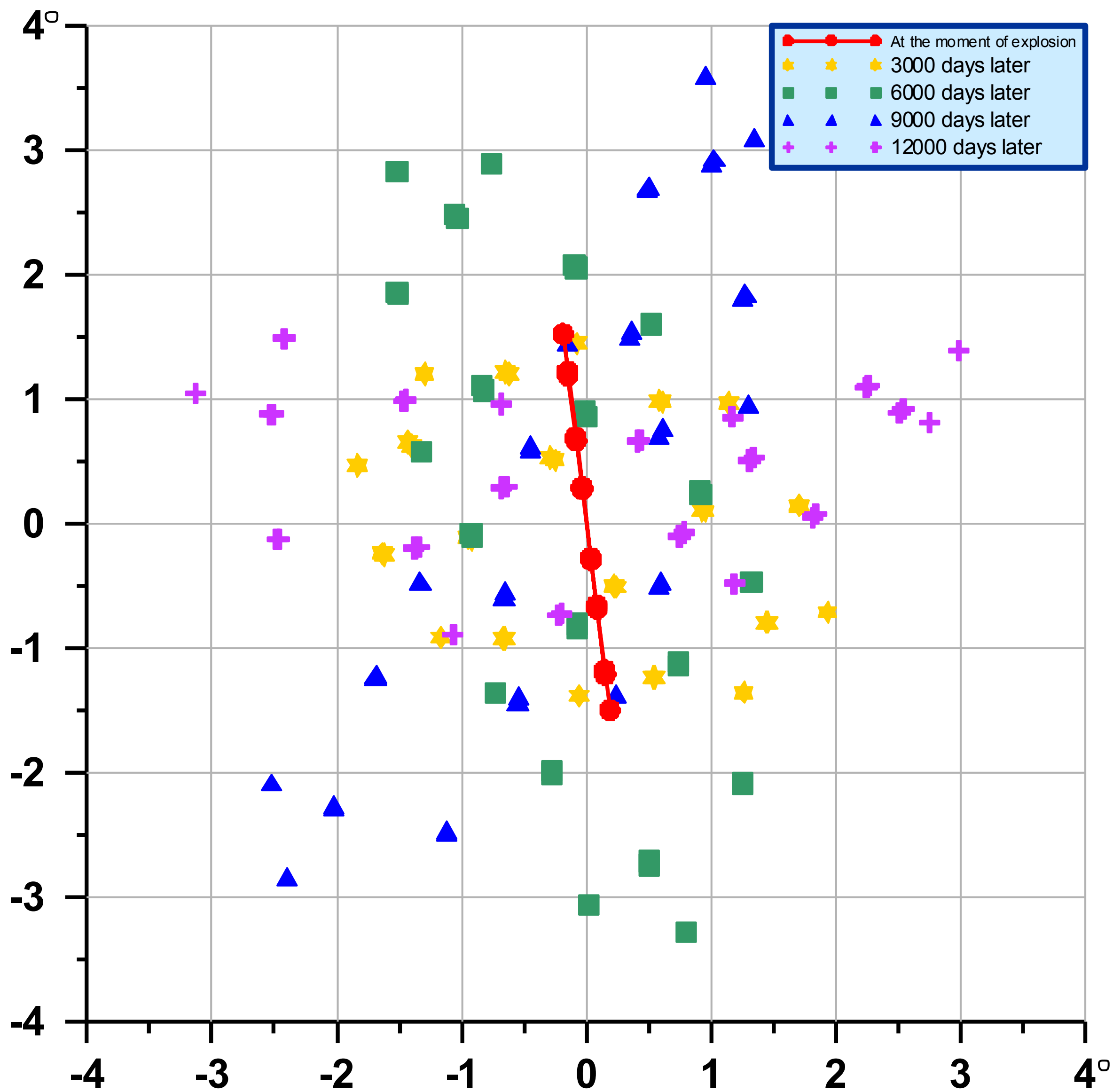

Fig. 6. The evolution of the poles of GS 66053J fragments' orbits with 3 000 days intervals.

As an example, in Fig. 6 the evolution of the orbits of GS 66053J fragments after every 3 000 days is shown. In this case the minimum dispersion happens 9 000 days after "explosion", but this minimum is so weak that Fig. 6 is slightly different from the picture of chaotic distribution of points.

Based on this material, one can conclude that the process of regularization of orbits in the first approximation depends on the place of the "explosion" in orbit: it is sharply expressed at the points a maximum distance from the intersection of the orbital plane with the Laplace plane (node).

A more exact investigation of the problem shows that the process of regularization generally depends on angles φ_1 and φ_2 represented on Fig. 1: angles between the great circle connecting the pole of the initial orbit with the pole of the Laplace plane, and great circles on which the poles of orbital fragments and the poles of their Laplace planes are disposed.

A detail analysis of this problem is the object of our future work.

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