ON THE MODELLING OF SATELLITE FRAGMENTATIONS IN THE GEOSTATIONARY RING: SPATIAL MOTION AREA, STRATEGY AND RESULTS OF OPTICAL OBSERVATIONS

K. Grigoriev

Central Astronomical Observatory at Pulkovo,
65/1, Pulkovskoye chaussee, 196140 Saint-Petersburg, RUSSIA
Email: kgrig@mail.ru

ABSTRACT

International observation campaigns organized by the Inter-Agency Space Debris Coordination Committee (IADC) show substantial population of small objects in and near the geostationary ring and raise a problem of their identification, tracking, cataloguing and defining the sources of origin. Studies of the orbital evolution of model fragments, which could be created by destructions of a geostationary satellite are an important contribution to the solution of these tasks.

The paper presents the results of studies of the evolution of spatial motion area and orbital parameters of fragments of satellite destructions in GEO. Some models and approaches are being discussed. The examples for known and supposed breakups and comparison with the results of observations are given. A "barrier" strategy of searching fragments is proposed on the basis of probable trajectory density of model objects. The results can be used for the detection of sub-meter debris.

1. MODELLING

We use the spherical isotropical model of distribution of ejection velocities for numerous fragments (from several hundreds to thousands). Such approach allows to estimate the certain limits of motion area (in which the fragments of an exploded object move) and the probable trajectory density of model fragments. The trajectory density is determined as the probability of presence in element of volume or in field of view (ratio of the traversing time to period).

We used this model for the events with reliable-a-priori information about destruction moment (Pensa et al., 1996; Johnson, 2001), for the probable events (Kiladze, Sochilina, 2003; Agapov, 2003) and for simulated different ones.

In the previous works (Kiladze, Sochilina et al., 1997) the orbital evolution of the geostationary objects and prediction accuracy was investigated. We had an opportunity to use and test a program complex MCSO (Yurasov, 1998), as well.

Calculated for the various moments of time the orbital elements of model fragments allow to analyze their motion area – where the fragments of an exploded object move.

The orbital evolution of fragments is considered in different coordinate systems:

- in orbital parameters ("inclination i – right ascensions of the ascending node Ω" space, etc.),
- in the right ascension - declination space (RA-Decl),
- in the density of trajectory streams.

2. RESULTS

We have given more detailed analysis of the dependence between initial conditions and orbital parameters, and motion area of fragments. Some examples are given in Fig. 1-3, which show maximal ejection velocity ΔV to have the strongest influence, and special character for orbits with small inclinations.

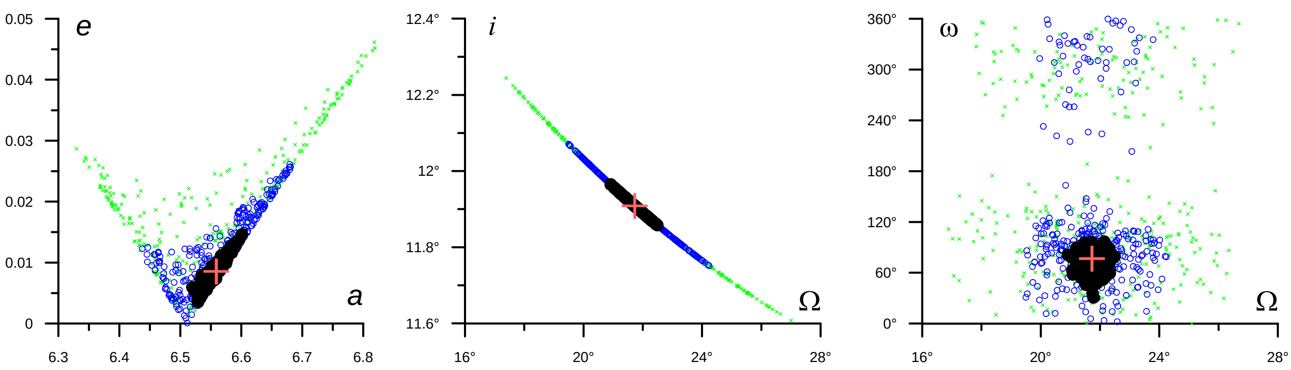

Figure 1. The orbital parameters of satellite 68081E (+) and of its model fragments at the moment of destruction for the different maximal ejection velocities ΔV: less then 10 m/sec (●), 30 m/sec (○), 60 m/sec (×)

Proceedings of the Fourth European Conference on Space Debris, Darmstadt, Germany, 18-20 April 2005
(ESA SP-587, August 2005)

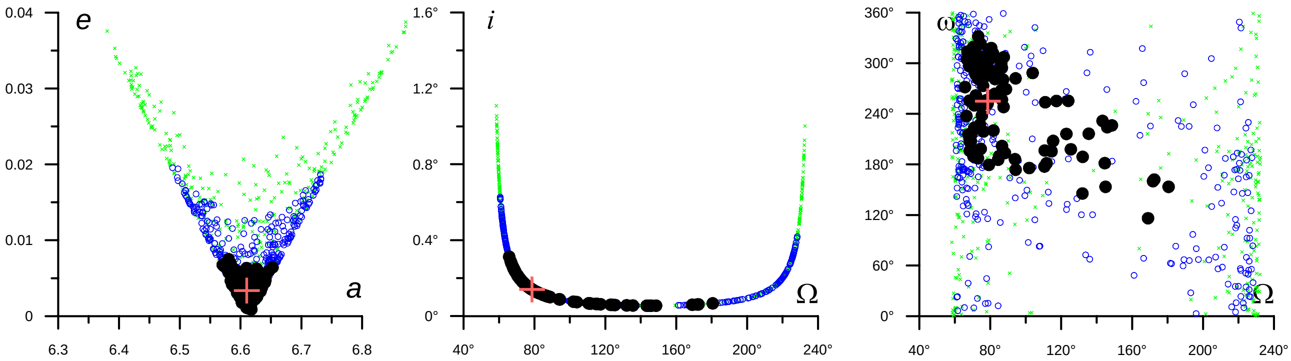

Figure 2. The orbital parameters of satellite 77092A (+) and of its model fragments at the moment of destruction for the different maximal ejection velocities ΔV: less then 10 m/sec (●), 30 m/sec (○), 60 m/sec (×).

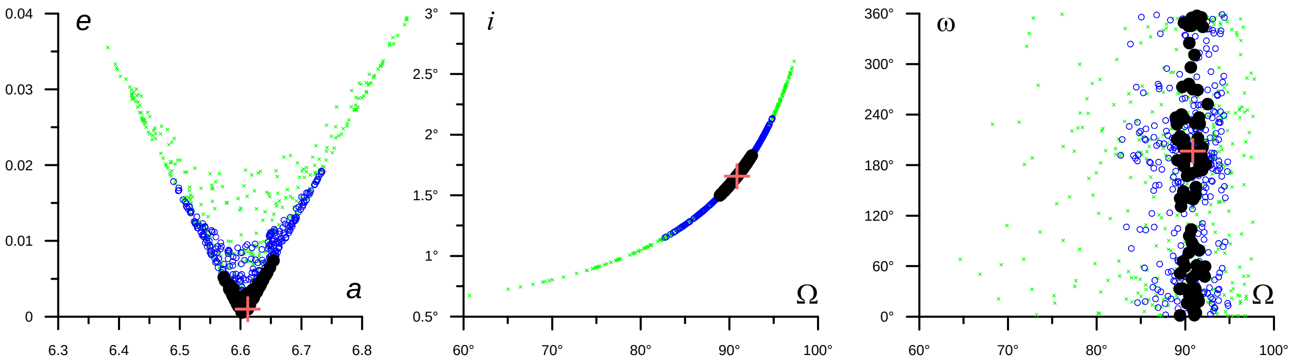

Figure 3. The orbital parameters of satellite 79087A (+) and of its model fragments at the moment of destruction for the different maximal ejection velocities ΔV: less then 10 m/sec (●), 30 m/sec (○), 60 m/sec (×).

However, the orbital position of object at the moment of destruction is the most essential and determines the shape of the orbital parameters and their long-term evolution. In Fig. 4, the destructions, received in the very definite moment destructions and in the assumption of the later moment is given area of parameters of model fragments of object 68081E. In ten years or more it is essential, as determines the area of orbital parameters. In Fig. 5, the orbital parameters clusters for those mentioned moments of destruction (true and false) to demonstrate distinctions of evolution of the shape are shown.

The results of modelling demonstrate good conformity with works (Pardini, Anselmo, 2004; Kuznetsov, 2003), in which other models of destruction and prediction were used.

Comparison with ESA campaigns data reveals a close correlation. In the (i – Ω) space the model destruction "clouds" by the sizes and forms coincide with the separate clusters of “uncorrelated” objects (Shildknecht et al, 2003). Especially it is appreciable in the result of 2002, when the choice of survey fields allowed to detect such fragments regularly.

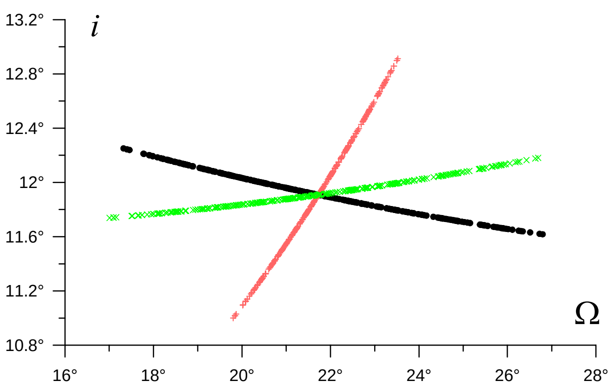

Figure 4. The orbital parameters of model fragments in different initial position: u=22˚ (+); 78˚ (×); 108˚ (●).

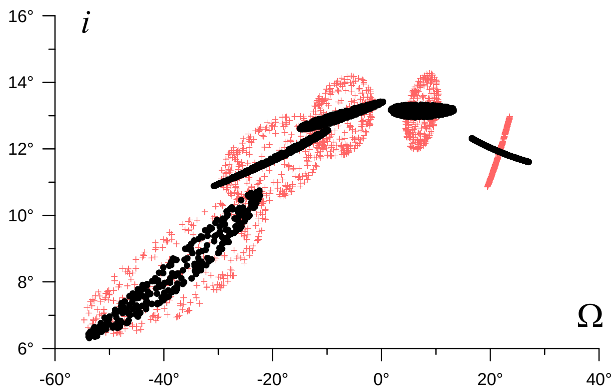

Figure 5. The evolution of orbits for true and simulated destruction with a step 4 year for 68081E.

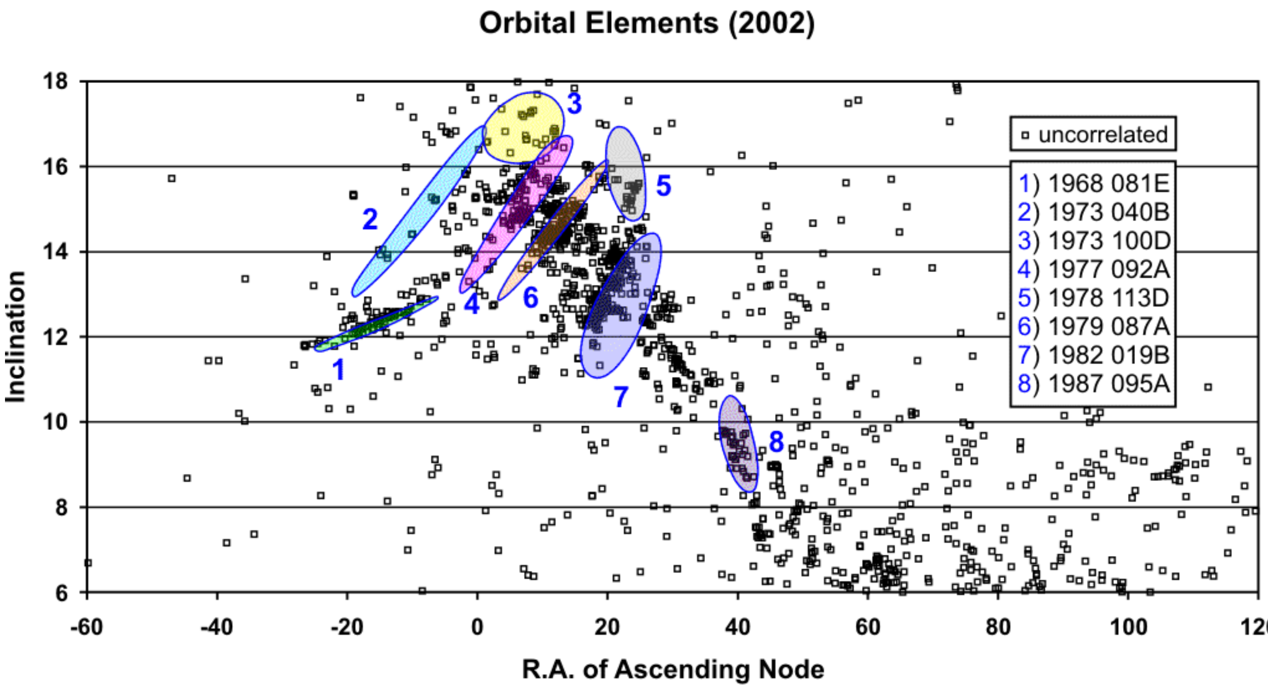

Figure 6. The orbital parameters of uncorrelated objects (□) and of model fragments of some objects.

The results of comparison with ESA GEO surveys are given in Fig. 6. It is necessary to notice, that the observation conditions did not allow to detect fragments of our others candidates.

Next our purpose was the creation of an effective strategy for space debris detection by telescopes with small field-of-view and limited sensitivity of sensors.
Therefore we have selected the most reliable events – the explosions of the satellites Ekran 2 (1977-092A, 21/06/1978), Titan IIIC Transtage (1968-081E, 21/02/1992).

A "barrier" strategy (fixed point) was chosen because of uncertain number of fragments and their positions in the orbit, and also due to the limited motion area of fragments in RA-Decl space (Fig. 7).

The coordinates are selected on the condition of sufficient time of continuous observations (some hours) and of maximal trajectory density of model fragments (of one or several "parental" objects), as in Fig.8.
Such technique allows to detect the fragments of the known origin and can facilitate a task of their identification and tracking.
The initial identification of objects is carried out on the bases of angular velocities analysis.

The ephemerides of those two objects were calculated for the first experimental observations of space debris in CrAO (Oct.2004) and Sajan Observatory (2003-2004).
In inclination-node space Fig. 9 shows all catalogued GEO objects, model fragments of 68081E and area in which there are objects which could traverse the selected field ($\alpha=3^h$, $\delta=+10.5^\circ$).

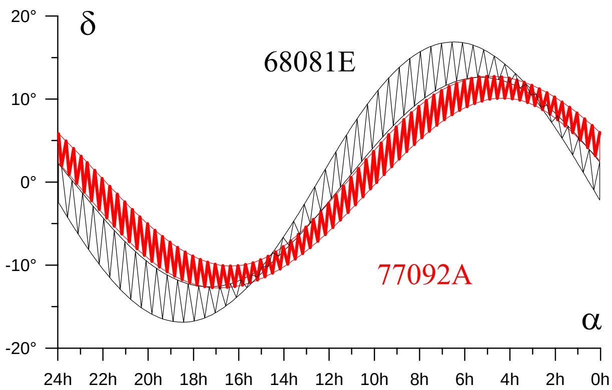

Figure 7. The motion area of model fragments in October 2004.

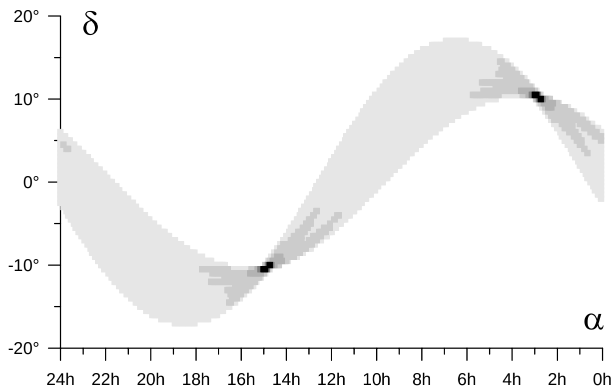

Figure 8. The trajectory density of model fragments in October 2004.

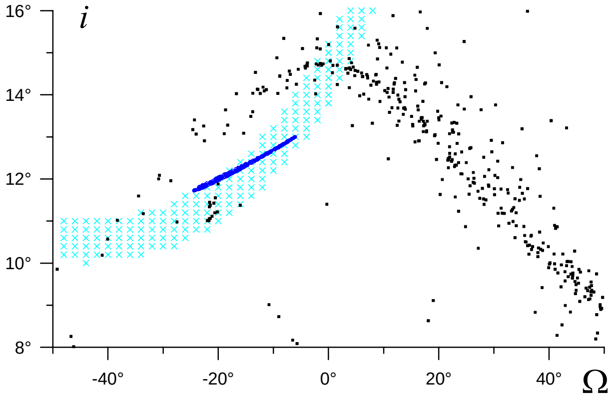

Figure 9. The orbital parameters of catalogued satellites (■), of model fragments of 68081E (●) and ones traversing the selected field in Oct.2004.

3. CONCLUSIONS

1. The constructed model allows to analyze the motion area of fragments in its longtime evolution.
The initial orbital position causes strong perturbations not only on distribution orbit planes of fragments but in particular, on the character of *i*-Ω clusters evolution and shape of motion area, that is very important for identification or/and planning.
2. The results of modelling for the known and some probable destruction show a close correlation with the observations of space debris in GEO.
3. There is a possibility of search of known destructions fragments with the purpose of their tracking and cataloguing. We are planning to continue our research and experimental observations and we are ready for cooperation (Fig.10).

4. ACKNOWLEDGMENTS

Author would like to thank Prof. W.Flury and Dr. P.Papushev for their interest and support of this work, Prof. R.Kiladze and Dr. A.Sochilina for critical remarks and discussions, as well as, V.Rumyantsev for provided observations.

5. REFERENCES

Pensa A. F., Powell G.E., Pork E.W. and Sridharan R., Debris in geosynchronous orbits, *Space Forum*, Vol. 1, pp. 23–37, 1996.

Johnson N. L., Evidence for historical satellite fragmentations in and near the geosynchronous regime, *Proc. Third European Conference on Space Debris*, ESA SP-473, pp.355–359, 2001.

Kiladze R.I., Sochilina A.S. On the evolution of fragments of the geostationary objects, *Proc. Fifth US-Russian Space Surveillance Workshop*, 24-27 September 2003, Pulkovo, St.Petersburg, Russia, pp.325-334, 2003.

Agapov V. et al. Experience of formation of the GEO orbital information archive based on different data sources, *Proc. Fifth US-Russian Space Surveillance Workshop*, 24-27 September 2003, Pulkovo, St.Petersburg, Russia, pp.34-45, 2003.

Kiladze R.I., Sochilina A.S., Grigoriev K.V. and Vershkov A.N., On Investigation of Long-term Orbital Evolution of Geostationary Satellites. *Proc. The Second European Conference on Space Debris*, ESA SP-403, pp.53-57, 1997.

Yurasov V.S. Long-term Prediction of Space Object Motion in GEO. *Proc. Third US/Russian Space Surveillance Workshop*. 20-23 October 1998, Naval Observatory, Washington, pp.119-130, 1998.

C.Pardini, L.Anselmo, Dynamical Evolution of Debris Clouds in Geosynchronous Orbit, *35th COSPAR Scientific Assembly*, Paris, France, 18-25 July 2004.

Kuznetsov E.D. The long-term evolution of geostationary satellite fragments after explosion, *Proc. Fifth US-Russian Space Surveillance Workshop*, 24-27 September 2003, Pulkovo, St.Petersburg, Russia, pp.340-349, 2003.

T.Shildknecht et al., An optical search for small-size debris in GEO and GTO. *Proc. Fifth US-Russian Space Surveillance Workshop*, 24-27 September 2003, St.Petersburg, Russia, pp.244-258, 2003.

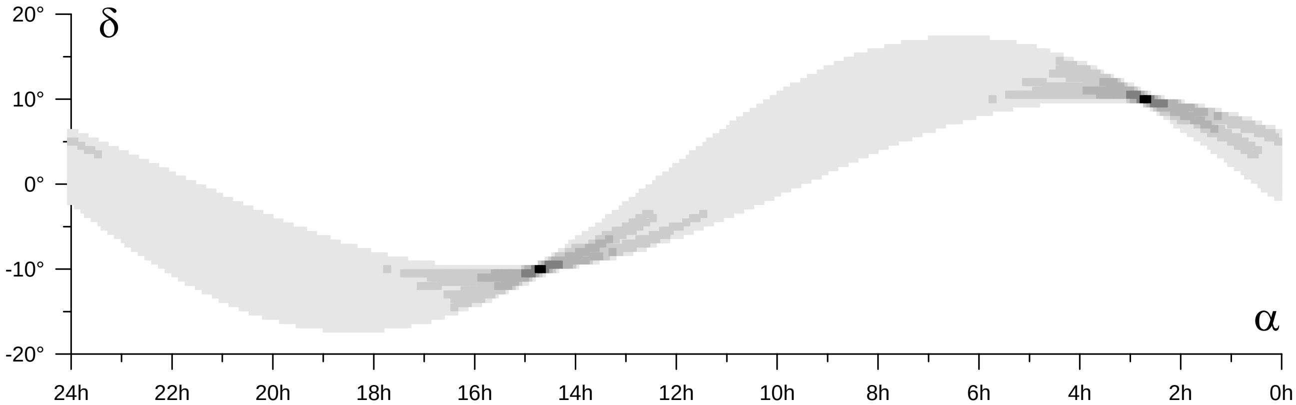

Figure 10. The trajectory density of model fragments in May 2005 ($\alpha=14^h40^m$; $\delta=-10°$).