IGSO De-orbit Way

and

GEO Protected Region

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ICG

(International Committee on GNSS)

Contents

1. Introduction

In ICG 2018, we showed the current possible issues of IGSO de-orbit in accordance with the disposal rule and proposed to start a discussion to seek the appropriate solutions of IGSO disposal way.

After that, we searched other organization's activities similar to our work to discuss the appropriate solution with them.

Fortunately, we heard CNR (National Research Council) activities and they kindly accepted to cooperate for this subject.

As the result, in the activity of ISO WG3 & 7, we introduced the possibility of the alternative disposal method of inclined GEO satellite (IGSO) in stead of the current GEO disposal guideline.

2. Current possible issues between GEO protected region and IGSO disposal

2.1 MELCO analysis (reported in ICG 2018)

MELCO introduced the IGSO disposal issues by the simulations of QZSS, BeiDou, and NAVIC. The detailed results are shown in Table 2 and the following figure -2, -3, and -4.

- i<30 degrees:

NAVIC, i=29 degrees, can avoid a significant eccentricity growth over 200 years, simply following the current disposal guideline.

- i>30 degrees:

QZSS, i=36~47 degrees, are being planned to be disposed to 3,600 km higher than GEO and that assures to avoid a significant eccentricity growth over 200 years. BeiDou, i=54 degrees, with simulated initial condition leads to a considerable eccentricity growth and interferes the GEO protected region.

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2. Current possible issues between GEO protected region and IGSO disposal

Table 2 Interference Summary

Figure	IGSO	De-orbit height [km]	RAAN [deg]	Inclination [deg]	Interference in			
					protected region	Operation region		
					GSO	BeiDou	NAVIC	QZSS
1-7 1-8	QZSS-QZO QZSS-GEO	3600 1920	0-360	36-47 0.05	No	No	No	No
1-9	BeiDou	350	189	54	Yes	Yes	Yes	Yes
1-10		350	69	54	Yes	Yes	Yes	Yes
1-11		350	309	54	Yes	Yes	Yes	Yes
1-12		1000	69	54	Yes	Yes	Yes	Yes
1-13	NAVIC	350	70	29	No	No	No	Yes
1-14		350	190	29	No	No	No	Yes
1-15		350	310	29	No	No	No	Yes
1-16		2000	310	29	No	No	No	Yes

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2. Current possible issues between GEO protected region and IGSO disposal

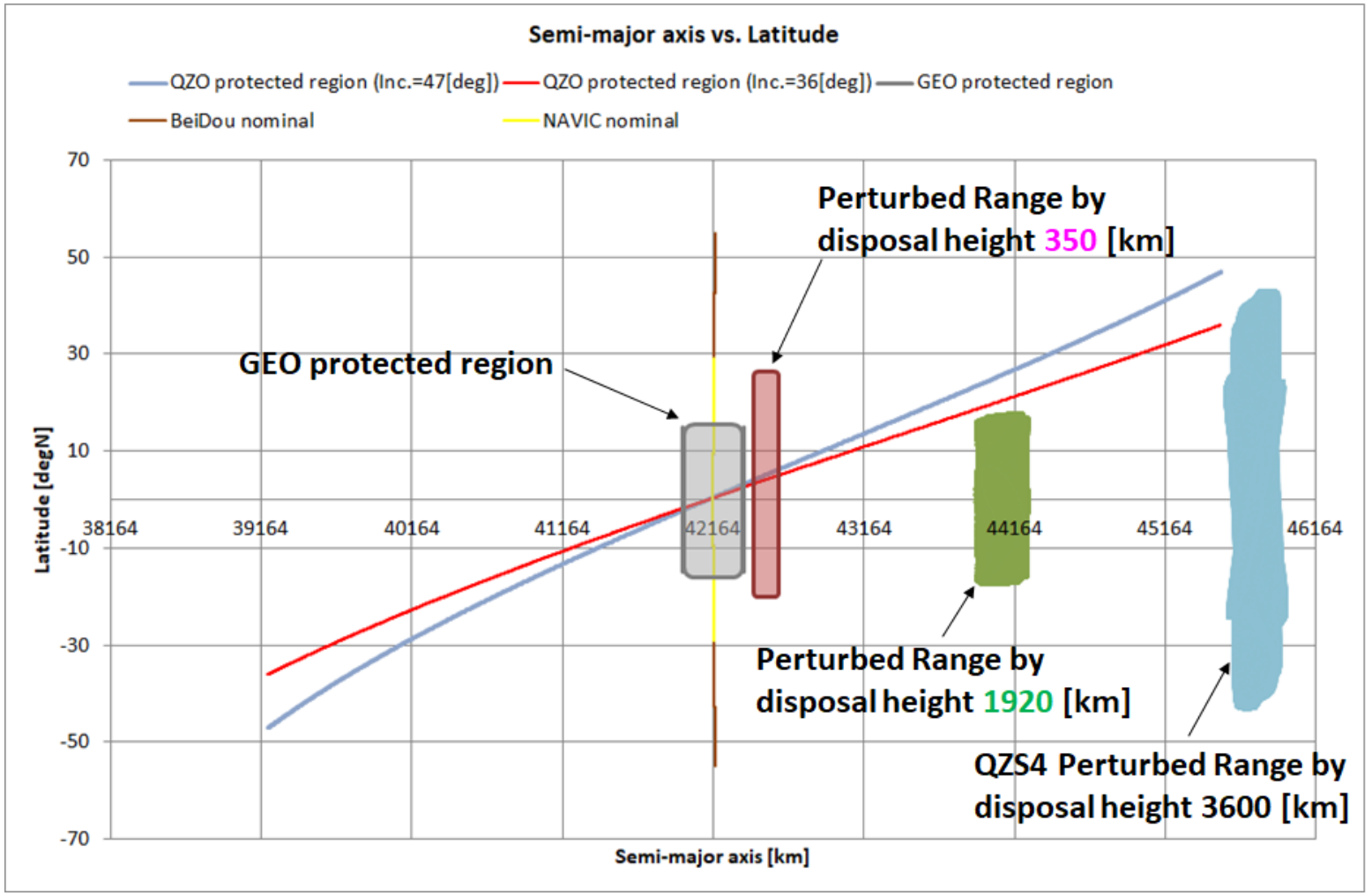

Fig 2 (=Fig.1-7 in Table 2) QZS4 Disposal Orbit Height 3600km and Perturbed Range during 100 years

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2. Current possible issues between GEO protected region and IGSO disposal

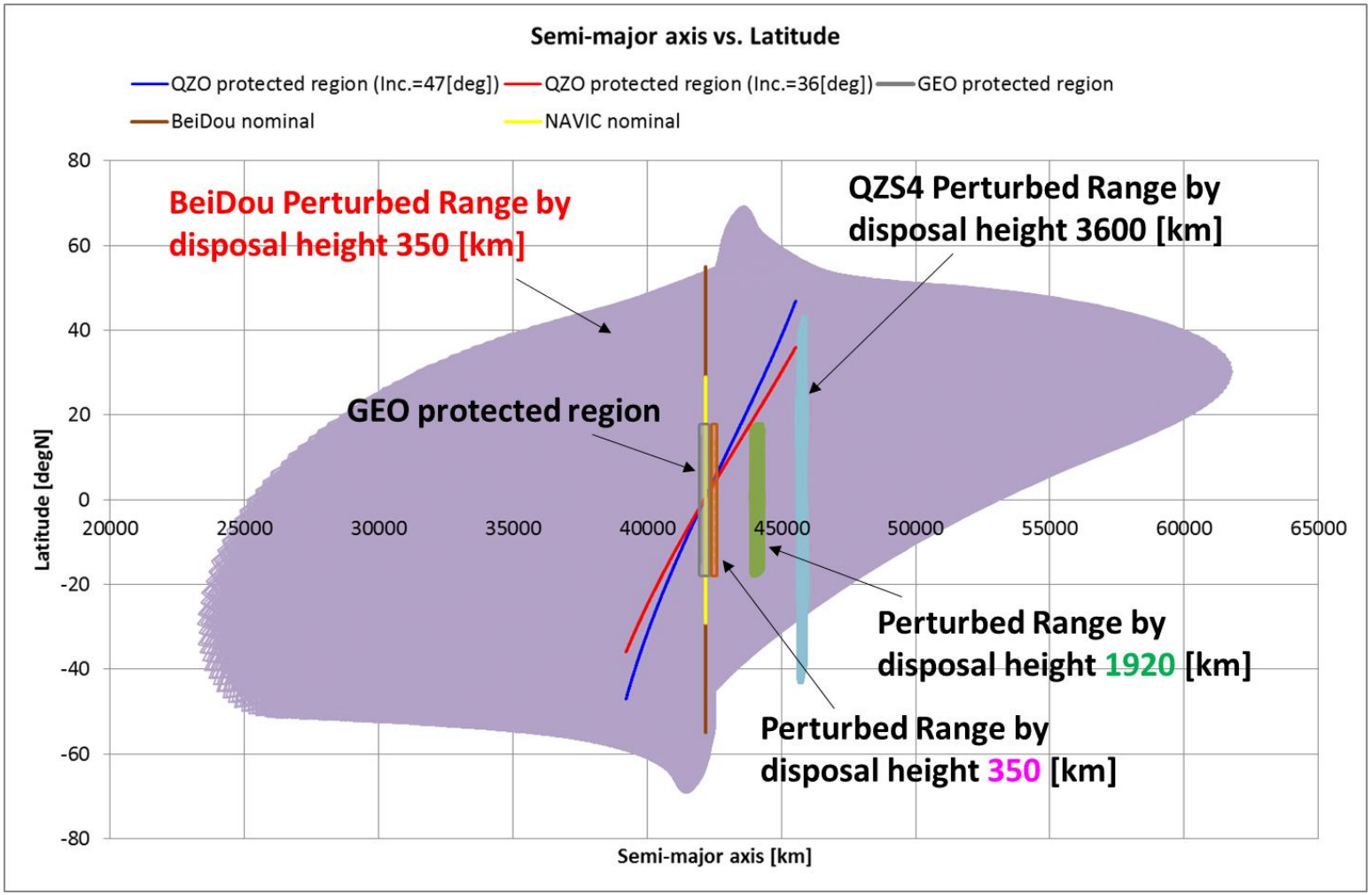

Fig.3 (=Fig.1-9 in Table 2) BeiDou Disposal Orbit Height 350km and Perturbed Range during 100 years

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2. Current possible issues between GEO protected region and IGSO disposal

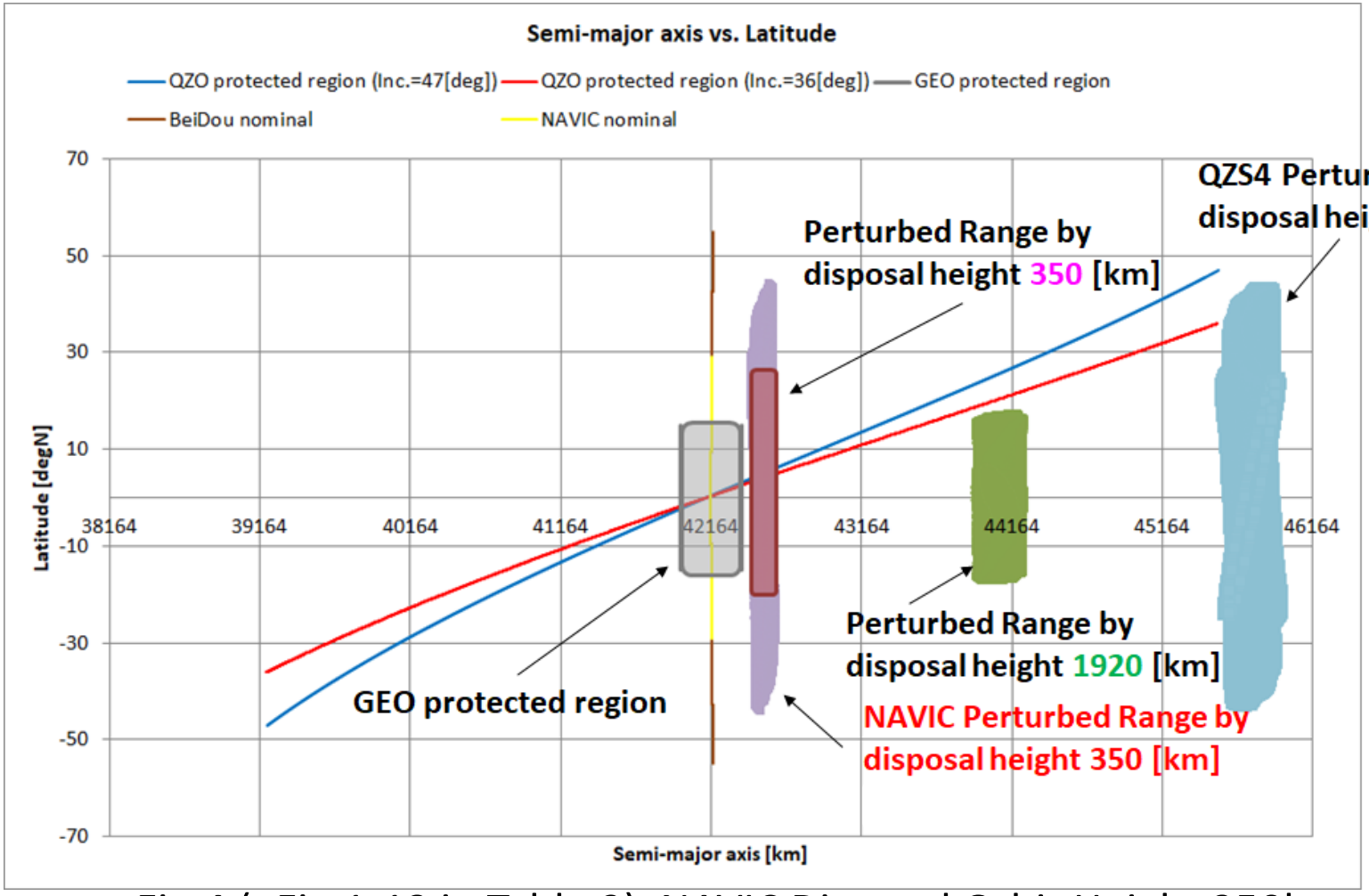

Fig.4 (=Fig.1-13 in Table 2) NAVIC Disposal Orbit Height 350km and Perturbed Range during 100 years

2. Current possible issues between GEO protected region and IGSO disposal

2.2 CNR analysis

CNR analysis shows the disposal issues of inclined GEO satellites (IGSO) relating to the inclination.

When i<30 degrees, it is always possible to avoid a significant eccentricity growth over 200 years, irrespective of the other initial conditions (i.e. epoch, right ascension of the ascending node and argument of perigee).

The current disposal guideline might be practical up to i=30 degrees, with a maximum delta velocity penalty of 11.5 m/s.

2. Current possible issues between GEO protected region and IGSO disposal

2.2 CNR analysis

Table 1 (*1) shows the initial disposal inclination (i0) and height (h0) to ensure no further interference with the GEO protected region over 200 years by following the current disposal guidelines. Figure 1 (*1) shows the additional delta-velocity as a function of height.

(*1: On the end-of-life disposal of spacecraft and orbital stages operating in inclined geosynchronous orbits Luciano Anselmo, Carmen Pardini)

Table 1

h_0 (km)	i_0
235	≤ 2°
285	≤ 18°
300	≤ 20°
350	≤ 26°
400	≤ 28°
500	≤ 29°
550	≤ 30°

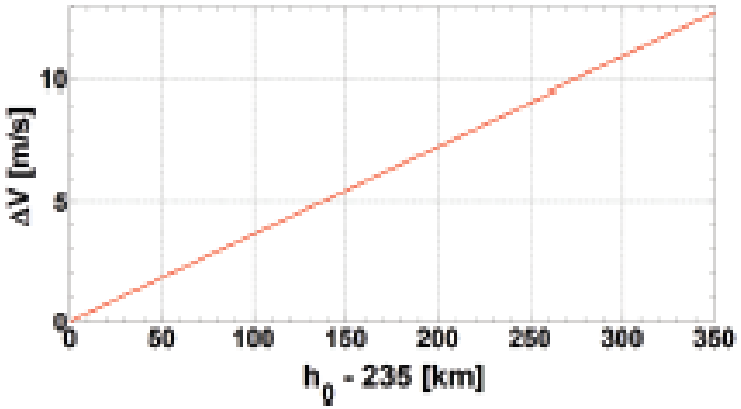

Figure 1

2. Current possible issues between GEO protected region and IGSO disposal

2.2 CNR analysis

However, when i>30 degrees, it is not possible to define end-of-life disposal strategies and which are also simple, universal and inexpensive at the same time. Reducing the initial inclination and/or changing the initial right ascension of the ascending node of the disposal orbit would of course be far too expensive and unfeasible.

Only specific initial conditions would be able to guarantee a relative stability of the eccentricity.

Certain combinations of the initial conditions (inclination, semi-major axis and eccentricity) lead to a considerable eccentricity growth.

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3. Possible resolution

CNR analysis shows the possibility of IGSO disposal way in accordance with the initial inclination.

Table 3

Initial inclination (degrees)	Solution
< 40	**Graveyard:** The stability remains in any initial disposal condition with normal height.
40<60	**Re-entry:** Delta-velocity>200 m/s **Graveyard:** The stability varies depending on the perigee orientation.
60<	**Re-entry:** Delta-velocity can go from 1 up to 200 m/s. The 17-year re-entry can be found with some initial condition.

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3. Possible resolution

Fig.5 (*2) by CNR show that only specific initial conditions of inclination, semi-major axis and eccentricity would be able to guarantee a relative stability of the eccentricity.

(*2: Towards a sustainable exploitation of the geosynchronous orbital region
Loannis Gkolias, Camilla Colombo, Martin Lara, Alessandro Rossi, IADC, Rome, May 2019)

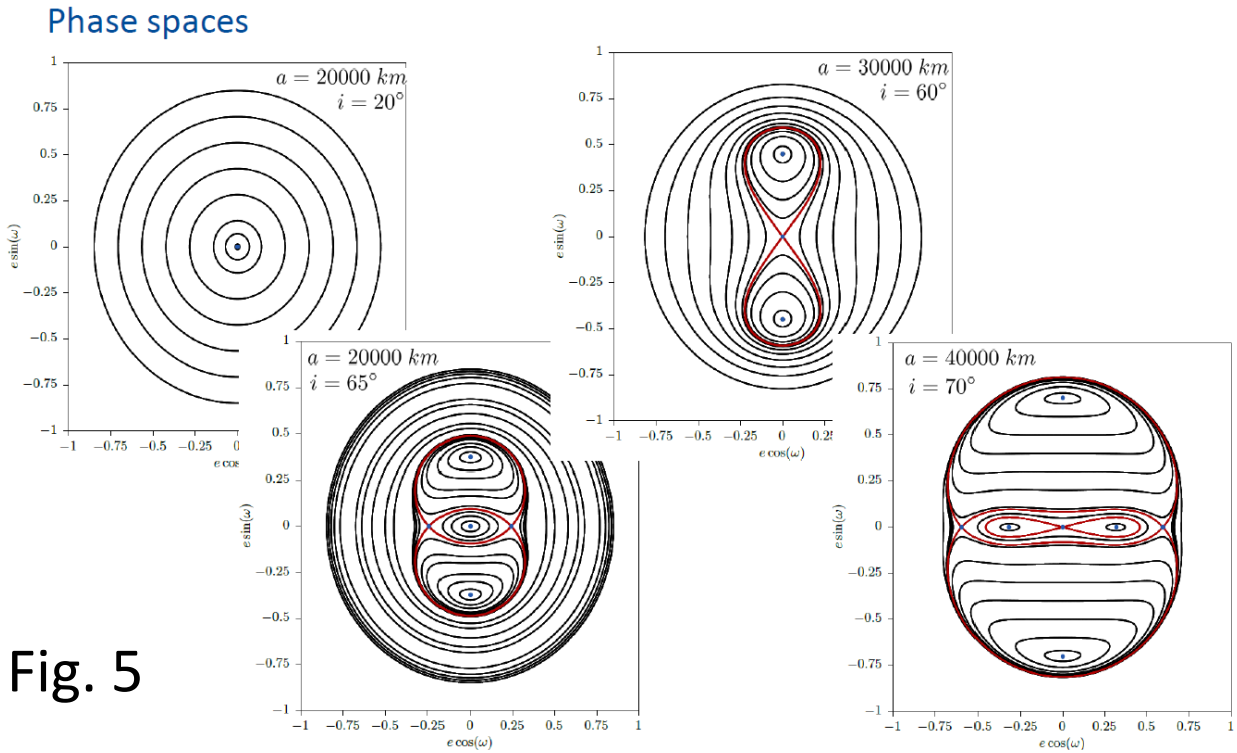

Fig. 5

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3. Possible resolution

Fig.6 (*2) by CNR summarizes the possibility of IGSO disposal way in accordance with the initial inclination, semi-major axis and eccentricity. Fig.6 is consistent with the explanation of Table 3.

Bifurcation diagram

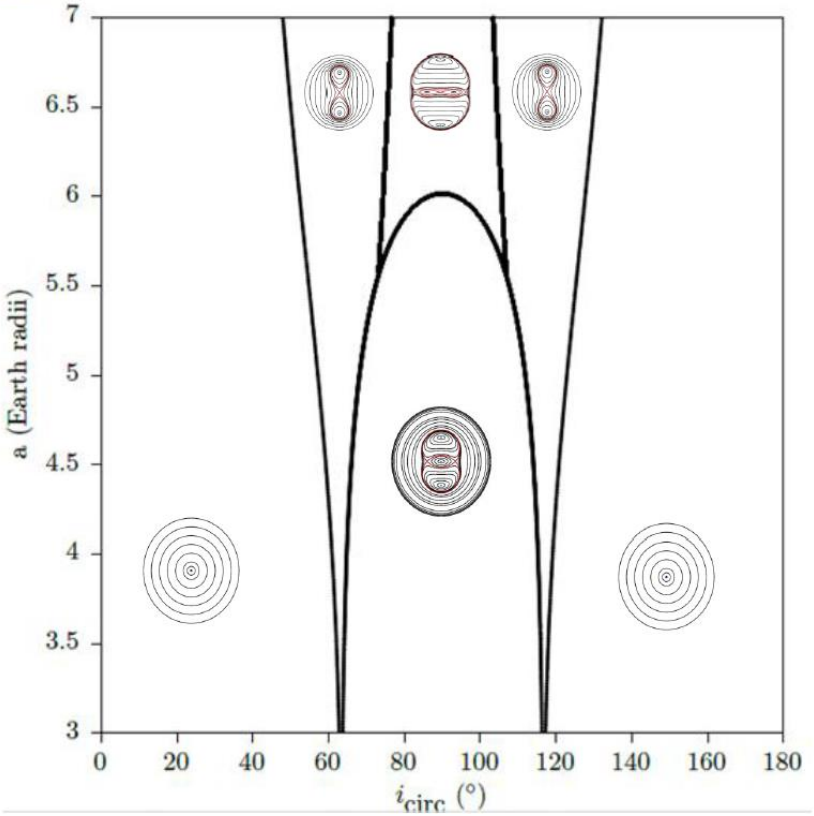

Fig. 6

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3. Possible resolution

Fig.7 (*2) by CNR is one example of fast re-entering orbit.

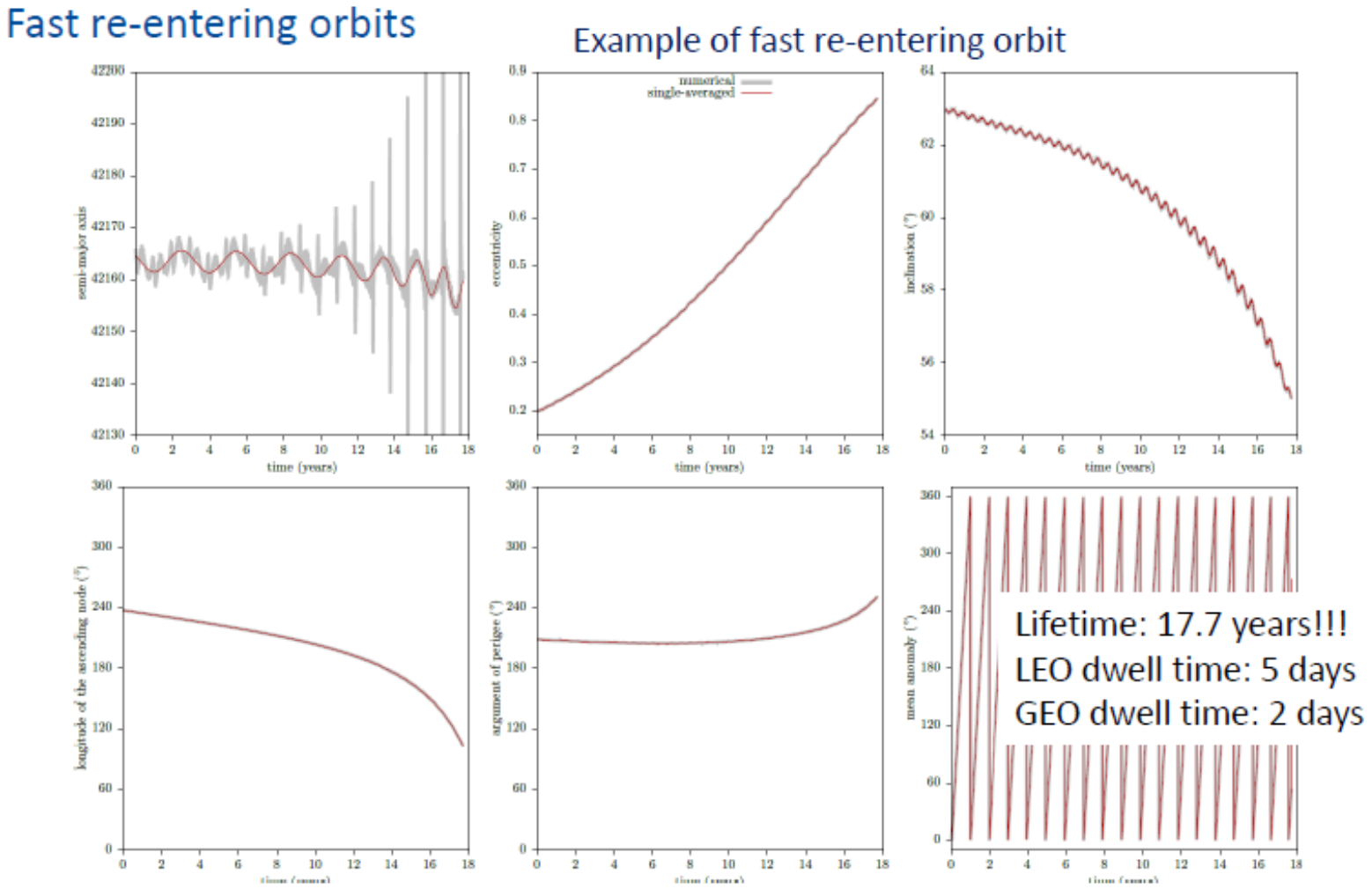

Fig. 7

4. Alternative disposal method of inclined GEO

In 2020, as the result, we proposed to modify the de-orbit guideline of ISO 24113 to add the re-entry option from inclined GEO, as the alternative way of IGSO de-orbit. Next page shows the proposed modification of ISO 24113, 6.3.2.2. The updated rule will allow the interference with the protected region during re-entry.

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4. Alternative disposal method of inclined GEO

<Proposed update of the GEO disposal ISO 24113 or 23312>

6.3.2.2 A spacecraft operating in the GEO protected region with a continuous presence shall be disposed of in such a way that its orbital state, after disposal manoeuvres, satisfies at least one of the following conditions:

a) the orbit has an initial eccentricity less than 0,003 and a minimum perigee altitude ΔH (in km) above the geostationary altitude, in accordance with Formula (1):

$$H=235+(1000 \times CR \times A/m) \quad \ldots (1)$$

b) the orbit has a perigee altitude sufficiently above the geostationary altitude that long-term perturbation forces do not cause the spacecraft to enter the GEO protected region within 100 years after its end of life.

NOTE Formula (1) was derived to ensure that long-term perturbations will not cause a spacecraft to re-enter a protected zone of geostationary altitude plus 200 km.

c) In the case of inclined GEO satellites, re-entry option will be possible with feasible velocity increase depending on the specific initial combination of inclination, eccentricity and ascending node. If the orbital lifetime and dwell time passing through the protective orbital regions are acceptable considering the contents of this standard, it can be taken as a disposal option.

(Detailed methodology can be attached to 24113 as informative Annex, if needed.)

6.3.2.3 A spacecraft operating in the GEO protected region with a periodic presence shall be disposed of in such a way that long-term perturbation forces do not cause it to enter the GEO protected region within 100 years after its end of life.

5. Conclusion

There are increasing the use of inclined GEO orbit (for example, BaiDou, NAVIC and QZSS).

However, for high inclination orbit satellites, it is difficult to define the feasible disposal strategies by only using the current disposal guideline.

In this case, please consider the natural re-entry solutions for the inclined GEO satellite exist. Because the satellite design to complete the successful disposal will be necessary to keep the sustainable space activities.

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Thank you for your attention.