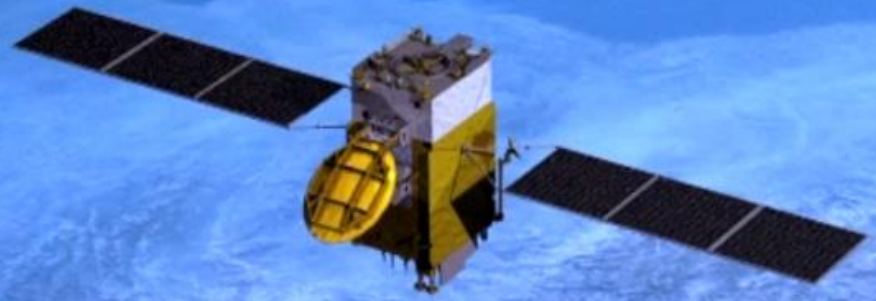
Update of Study on Disposal Options of BDS EOL Satellites



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China Academy of Space Technology
17-Oct-2023

I. Study process of the space debris mitigation issues in WG-S

- **June 2023 WG-S Subgroup Meeting**

As for the action item ‘MEO/IGSO satellite disposal status and plan' which was proposed in ICG-16 meeting, the meaning of the action item and the process of the table filling were introduced, and all the system providers were recommended to complete the table.

- **Aug 2023 WG-S Intersessional Meeting**

As for the action item ‘MEO/IGSO satellite disposal status and plan' , the current options, planned options, description and restrictions for disposal options were introduced by GPS, GLONASS and BDS, and the current options of Galileo was also introduced in the meeting.

II. Action Item: MEO/IGSO satellite disposal status and plan

GNSS /RNSS	Orbit	Current Disposal Options					Planned Disposal Options					Description for disposal options	Restrictions for disposal options	Remarks
		passivation in the operational orbit	manoeuver to stable disposal orbit	manoeuver to unstable disposal orbit	directed de-orbit	other option	passivation in the operational orbit	manoeuver to stable disposal orbit	manoeuver to unstable disposal orbit		directed de-orbit			
GPS	MEO	○	•	○	○	○	○	•	○	○	○	Boost 100km above operational orbit to disposal orbit and then conduct passivation		GPS disposal must be 2019 ODMSP compliant
GLONASS	MEO	•	○	○	○	○	• (GLONASS-K2)	○	○	○	○	No maneuver to clear the operational orbit at the end of the mission phase is required. Low collision risk. No need for additional fuel and related risks.	No direct restrictions. Regular monitoring and analysis is required to prevent the significant increase of space debris density and collision risk. A new disposal strategy may be required in the long-term amid increasing debris density and possible deployment of new/additional MEO constellations(GNSS/non-GNSS)	
	IGSO (as planned)	Full deployment is planned after 2030					N/A at the moment TBD during the development							
BDS	MEO	○	•	○	○	○	○	•	○	○	○	1.Perigee 300km above MEO. 2.e<0.001.3.argument of perigee selected for stability.	Safety to the MEO constellations & propellant limitation.	
	GEO	○	•	○	○	○	○	•	○	○	○	Apply the IADC/UN orbital debris mitigation guideline.	Safety to the GEO protected area & propellant limitation.	
	IGSO	○	○	○	○	○	○	○	•	○	○	1.Perigee 300km above GEO. 2.eccentricity & argument of perigee selected for instability.	Safety to the GEO protected area & propellant limitation.	
Galileo	MEO	○	•	○	○	○	○	•	○	○	○	1. Raising orbit to as minimum 300km above the Galileo orbit. 2. target small eccentricity and optimum argument of perigee to minimize eccentricity growth.		Based on ESA report in ICG-13 'Application of IADC and UN orbital debris mitigation guideline to Galileo '
Navic	GEO	○	○	○	○	○	○	○	○	○	○			
	IGSO	○	○	○	○	○	○	○	○	○	○			
QZSS	GEO	○	○	○	○	○	○	○	○	○	○			

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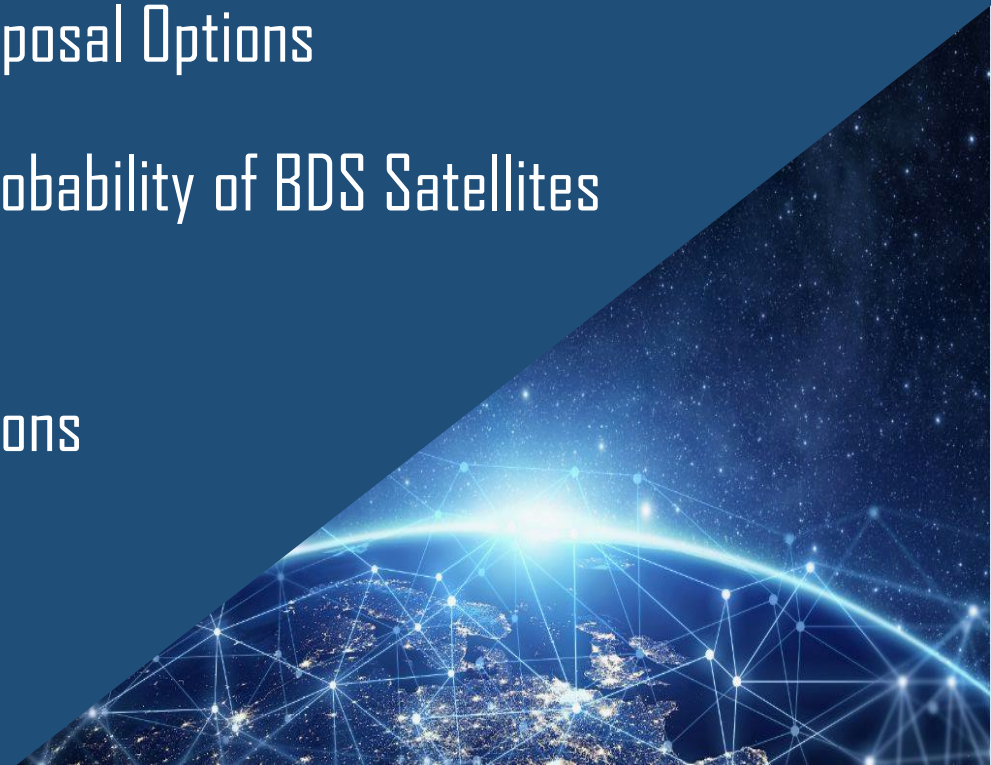
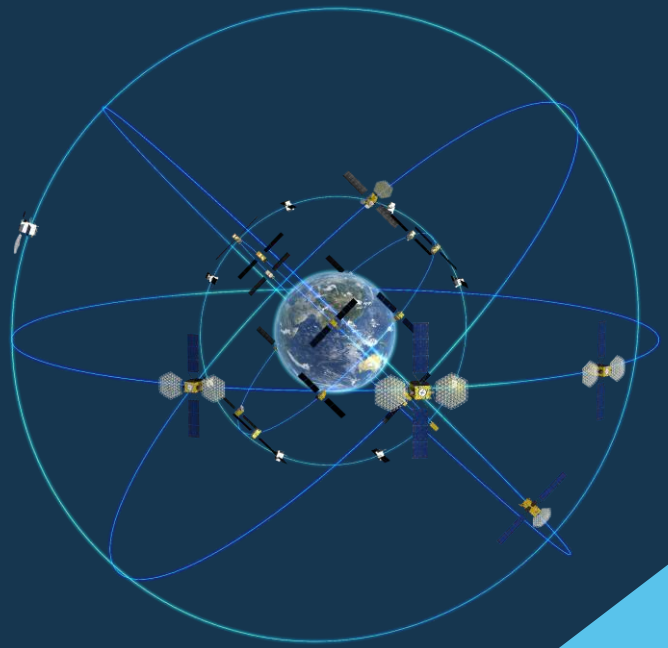




GNSS Space Debris Status Update and International Guidelines

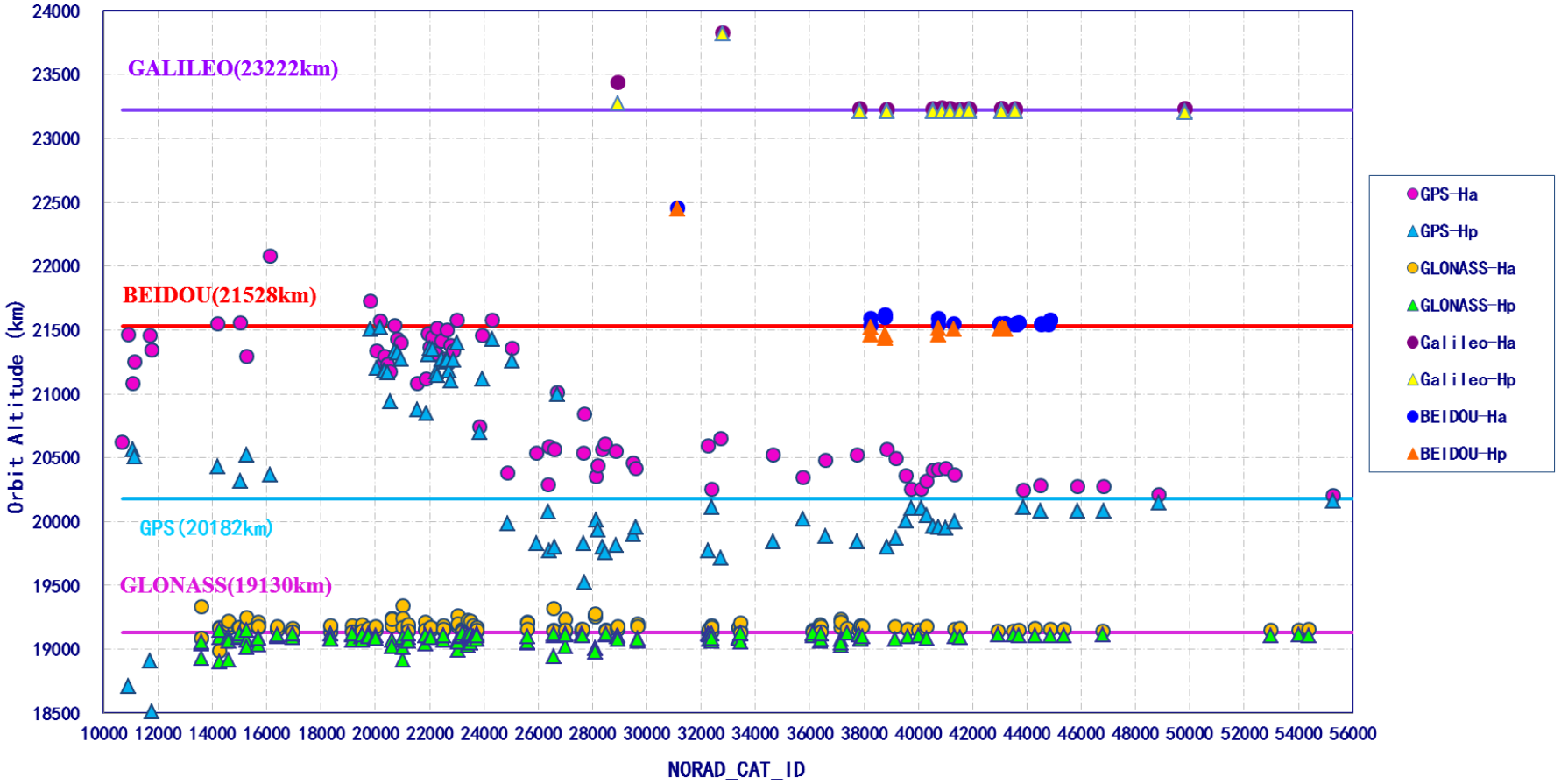
01

I. GNSS/RNSS Satellites in Orbit Update

Constellation	Nation/Area	Number of SVs *			
		GEO	IGSO	MEO	Total
GPS	USA	0	0	82	82
GLONASS	Russia	0	0	141	141
Galileo	Europe	0	0	30	30
BDS	China	16	12	32	60
QZSS	Japan	1	4	0	5
NAVIC	India	3	6	0	9

*Data collected from www.space-track.org by Sep 15th 2023

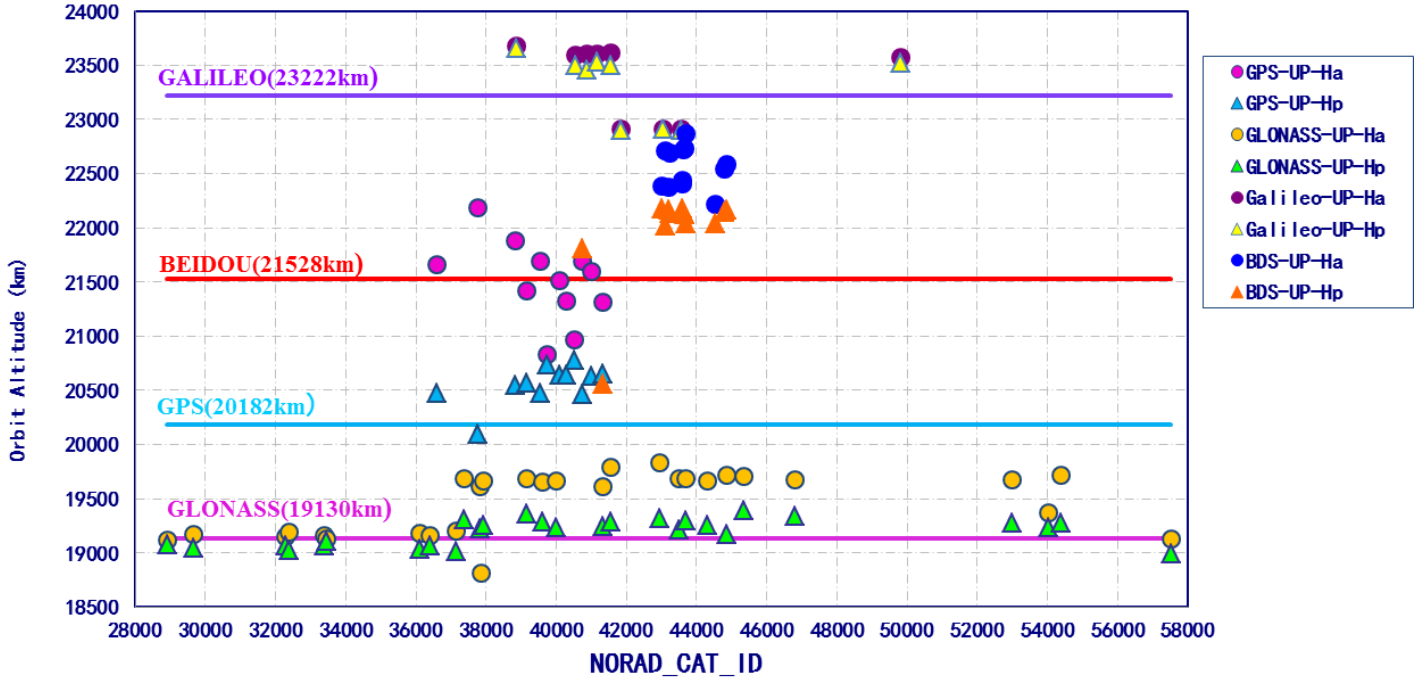
II. GNSS Satellites Orbit Altitude Update



- The data show that more than 30 GPS EOL satellites have crossed the BDS operational orbit, and it would have a collision risk.
- We appreciate and recommend that GPS satellite will adopt the disposal option to boost 100km above operational orbit to disposal orbit.

Data collected from www.space-track.org by Sep 15th 2023

III. Upper-stage of GNSS Orbit Altitude Update



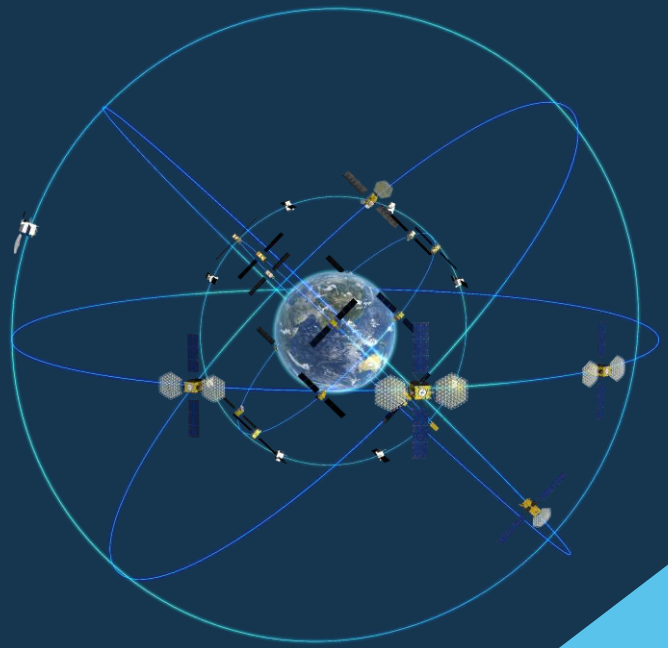
- The maximum increase in apogee altitude of GPS Upper-stage is nearly 1900km, and all the Upper-stage of GPS have crossed the BDS operational orbit.
- One of the Upper-stage of Galileo is very close to the Upper-stage of BDS and we should pay more attention to the safety of the Upper-stage.

Data collected from www.space-track.org by Sep 15th 2023

IV. MEO Disposal Requirements of IADC

Disposal Action	MEO Navigation Satellite Orbit
25-year decay	Not recommended due to large ΔV required
Disposal orbit	TBC: 1.Minimum long term perigee of 2000km,apogee below MEO 2.Perigee 500km above MEO or nearby operational region and e≤0.003; RAAN and argument of perigee selected for stability
Direct Reentry	Not recommended due to large ΔV required

Requirements from IADC-04-06‘Support to the IADC Space Debris Guidelines’ in Dec 2019



02

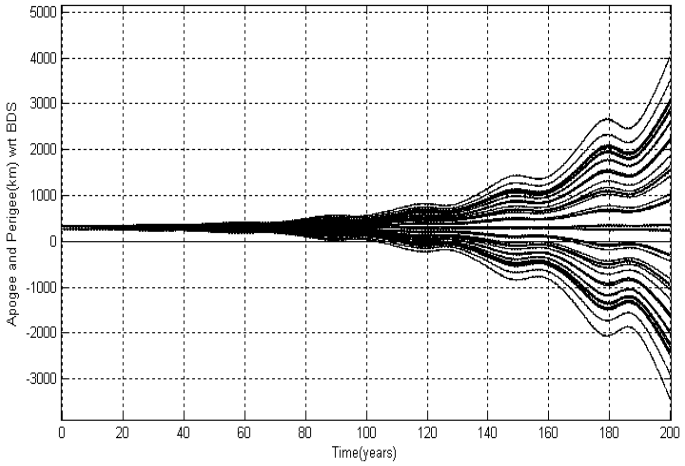
Long-term Evolution of BDS Satellites with Different Disposal Options

I. Disposal Safety Restrictions for BDS satellites

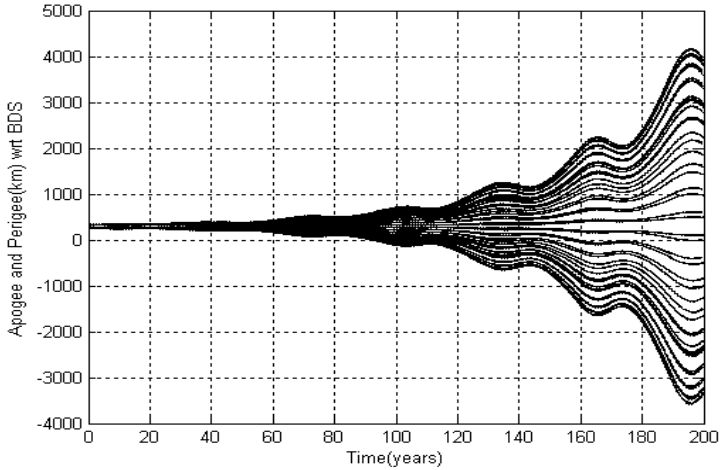
- Based on research of NASA and other organizations, disposal for BDS EOL satellites should ensure low collision risk with operational orbit and nearby constellations within 200 years.
- Considering propellant limitation and isolation from nearby satellite orbits, the increase in altitude of BDS EOL satellites should be more than 300km.
- The variation of altitude after disposal should be minimized over 200 years, or the disposal orbit should decay as early as possible.

II. Evolution of BDS MEO Satellites

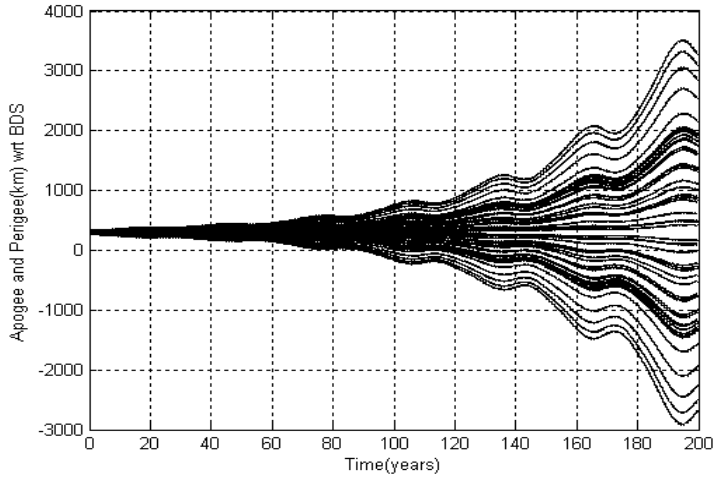
- Minimum eccentricity growth strategy (stable disposal strategy): ω0=190/320/240 deg, the disposal orbit is very stable (emax=0.006 & perigee remains above BDS constellation within 200 years)
- High eccentricity growth strategy (unstable disposal strategy): ω0=290/70/350 deg, the disposal orbit eccentricity grows significantly (emax=0.016 & perigee crosses the BDS constellation but does not reach GEO within 200 years)



Ω=30°,e=0.001,ω=0~360



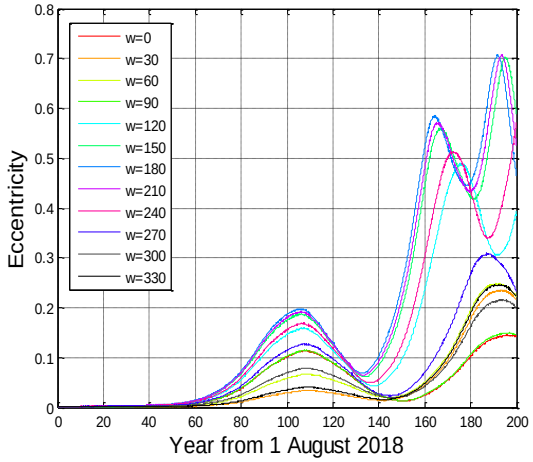
Ω=150°,e=0.001,ω=0~360°



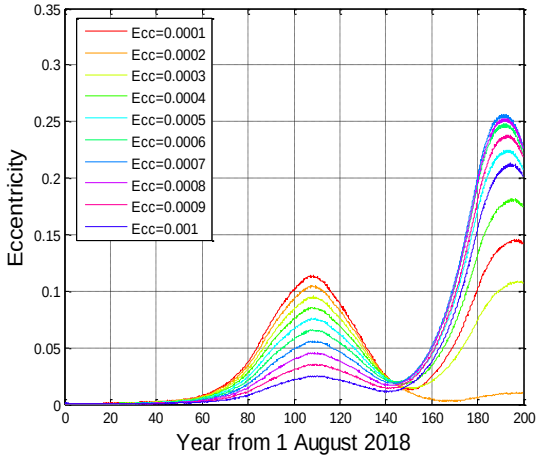
Ω=270°,e=0.001,ω=0~360°

III. Evolution of BDS IGSO Satellites

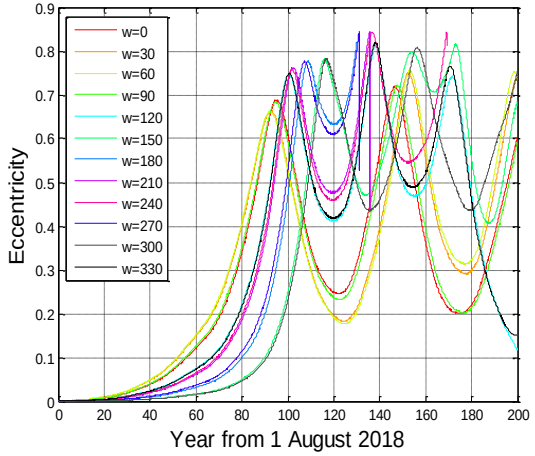
- Minimum eccentricity growth strategy: ω0=0/0/120deg, the disposal orbit is very stable (emax=0.72 & perigee reaches GEO or MEO within 200 years)
- High eccentricity growth strategy: ω0=180/270/270deg, the disposal orbit eccentricity grows significantly (emax=0.82 & perigee reaches MEO or has a reentry within 200 years)



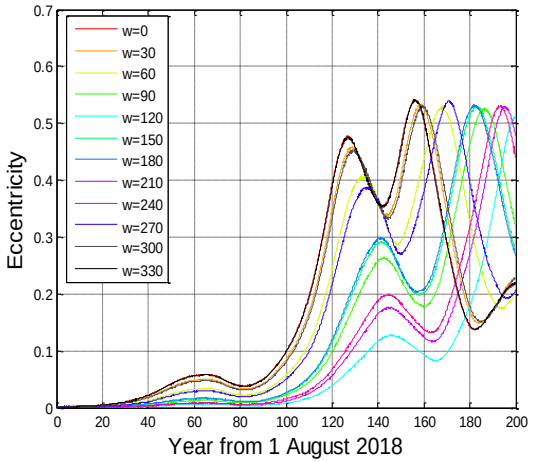
Ω=70°,e=0.001,ω=0~360



Ω=70°, ω=0 ,e=0.0001~0.001



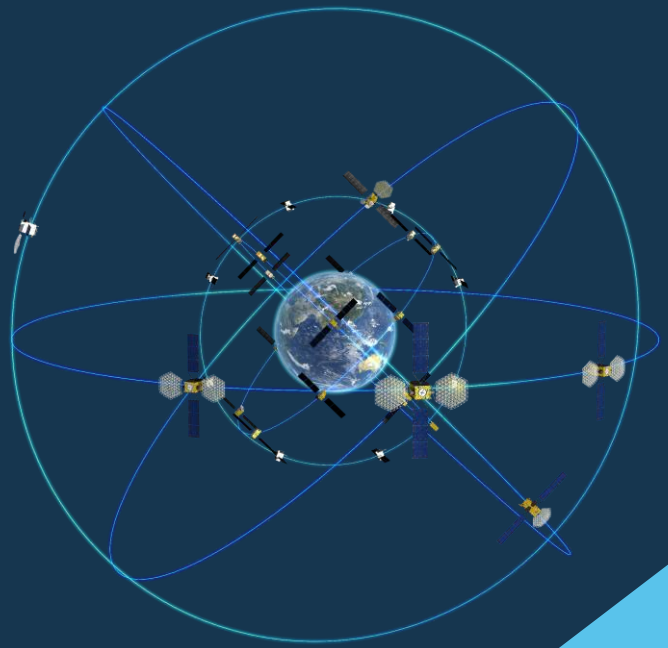
Ω=190°,e=0.001,ω=0~360°



Ω=310°,e=0.001,ω=0~360°

IV. Recommendation for the disposal orbit of BDS EDL Satellites

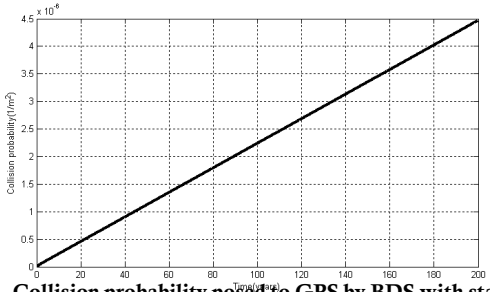
ORBIT	RAAN	Increase in orbit altitude/km	Eccentricity	Stable disposal strategy		Unstable disposal strategy	
				ω_0 / deg	Max Eccentricity in 200 years	ω_0 / deg	Max Eccentricity in 200 years
MEO	30	300	0.001	190	0.002	290	0.16
	150	300	0.001	320	0.006	70	0.14
	270	300	0.001	240	0.004	350	0.11
IGSO	70	300	0.0002	0	0.01	180	0.71
	190	300	0.001	0	0.72	270	0.82(decay in 130 years)
	310	300	0.001	120	0.52	270	0.55



Long-term Collision Probability of BDS satellites

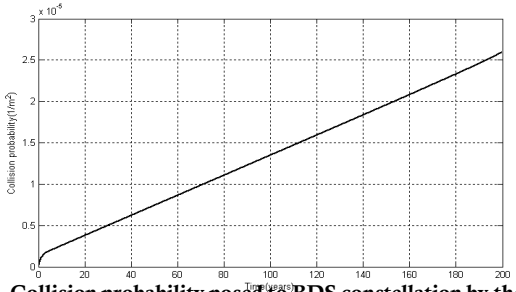
03

I. Collision probability posed to GPS, Galileo and BDS and graveyard orbit by BDS MEO with stable/unstable disposal orbit

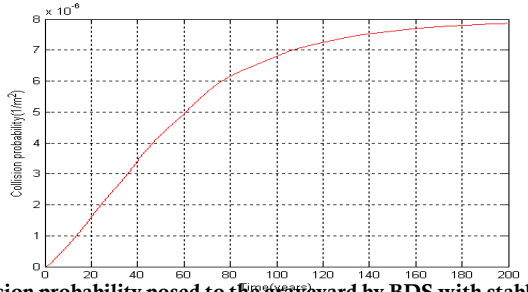


Collision probability posed to GPS by BDS with stable disposal orbit

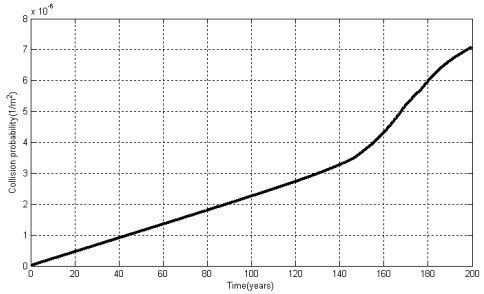
Collision probability posed to Galileo by BDS with stable disposal orbit



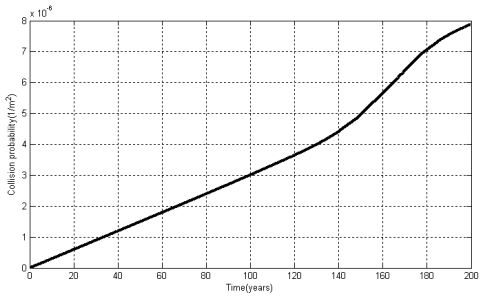
Collision probability posed to BDS constellation by the stable disposal orbit



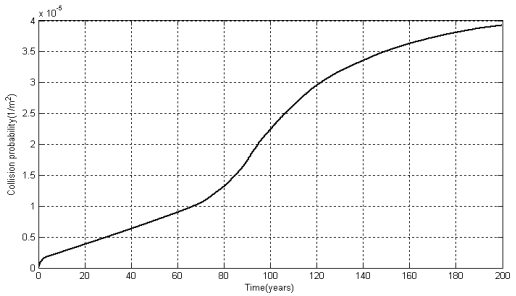
Collision probability posed to the graveyard by BDS with stable disposal orbit



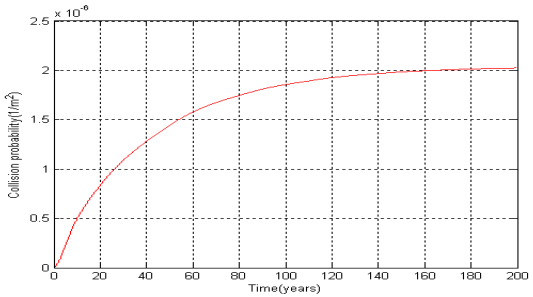
Collision probability posed to GPS by BDS with unstable disposal orbit



Collision probability posed to Galileo by BDS with unstable disposal orbit



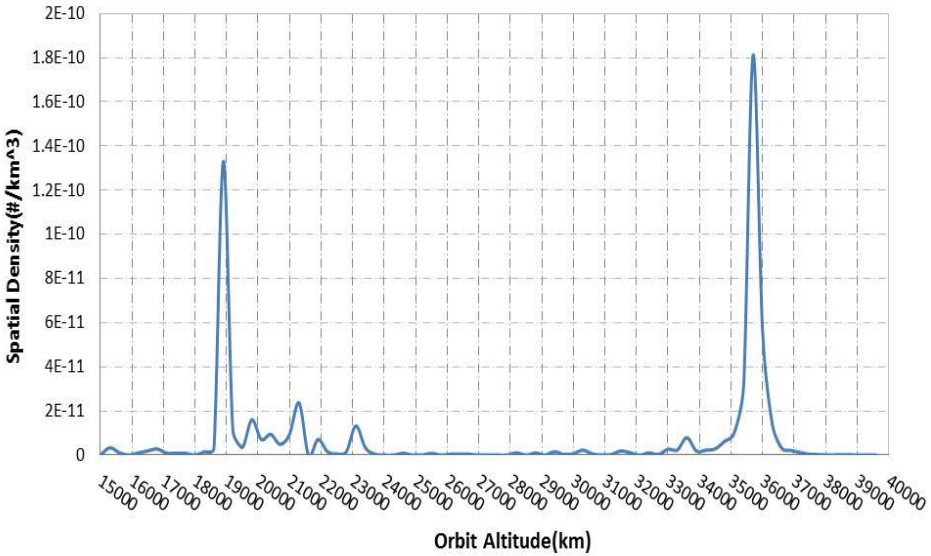
Collision probability posed to BDS by unstable disposal orbit



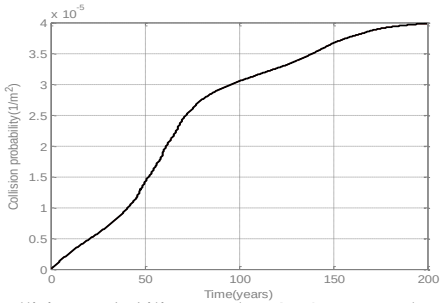
Collision probability posed to the graveyard by BDS with unstable disposal orbit

- The collision probability posed to operational orbit or graveyard orbit by BDS MEO Satellites is of a 10^{-5} ~10^{-6} order of magnitude.
- The unstable disposal strategy results in a lower collision probability (2×10^{-6}) to the BDS graveyard orbit than the stable disposal strategy (8×10^{-6}).
- The stable disposal strategy results in a lower collision probability (6×10^{-6}) to the nominal constellations of BDS, GPS and Galileo than the unstable disposal strategy (8×10^{-6}).

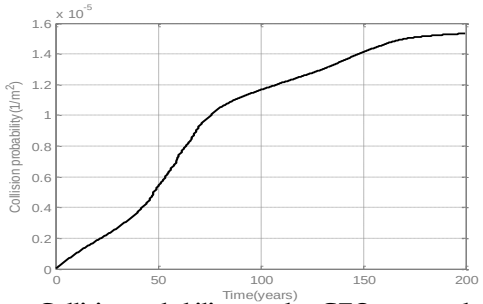
II. Collision probability posed to the GEO protected area by BDS IGSO with stable/unstable disposal orbit



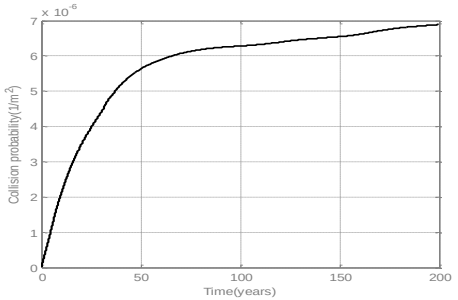
Spatial density of current space debris



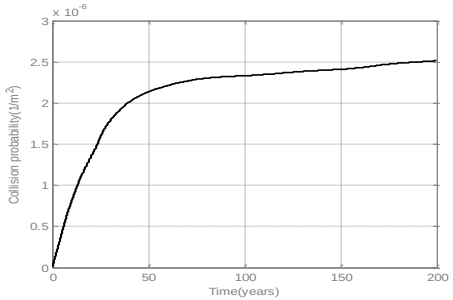
Collision probability posed to GEO protected area by BDS with stable disposal orbit



Collision probability posed to GEO graveyard by BDS with stable disposal orbit



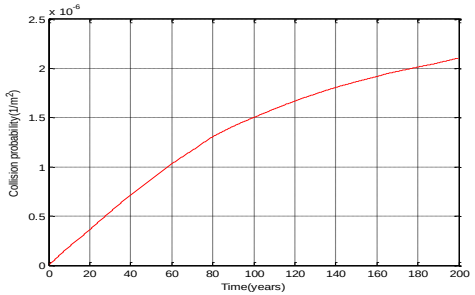
Collision probability posed to GEO protected area by BDS with unstable disposal orbit



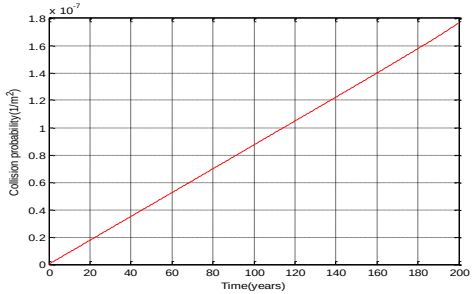
Collision probability posed to GEO graveyard by BDS with unstable disposal orbit

- The collision probability posed to operational orbit or graveyard orbit by BDS IGSO Satellites is of a 10^{-5} ~10^{-6} order of magnitude.
- The unstable disposal strategy results in a lower collision probability (7×10^{-6}) to the GEO graveyard orbit than the stable disposal strategy (4×10^{-5}).
- The unstable disposal strategy results in a lower collision probability (2.5×10^{-6}) to the GEO protected area than the stable disposal strategy (1.5×10^{-6}).

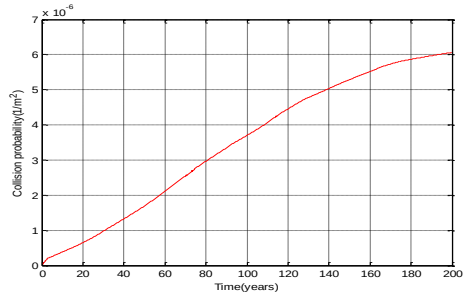
III. Collision probability posed to the nearby constellation/protected area by BDS MEO/IGSO with passivation in the operational orbit



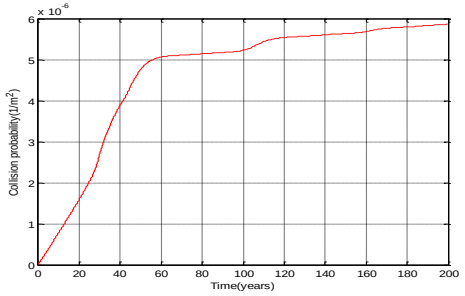
Collision probability posed to GPS by BDS MEO with passivation in the operational orbit



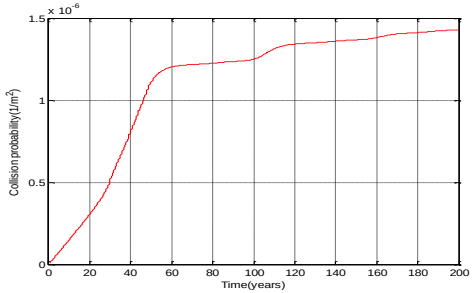
Collision probability posed to Galileo by BDS MEO with passivation in the operational orbit



Collision probability posed to BDS constellation by BDS MEO with passivation in the operational orbit



Collision probability posed to GEO protected area by BDS IGSO with passivation in the operational orbit

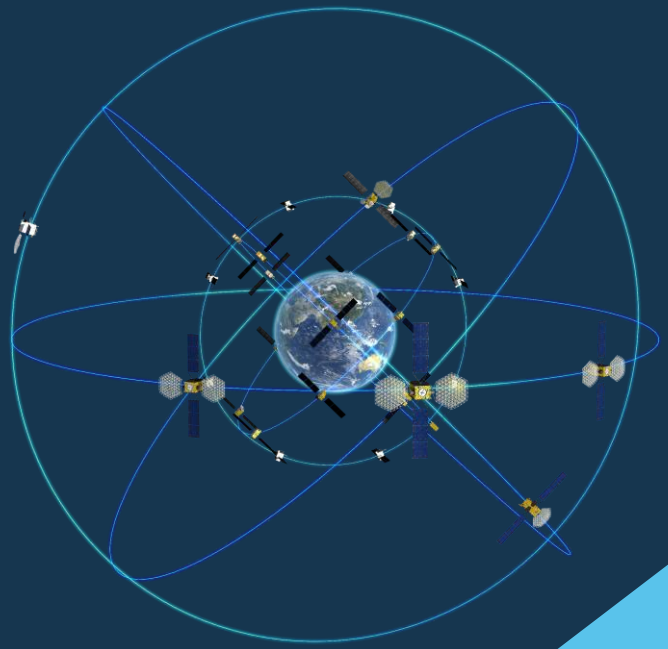


Collision probability posed to GEO graveyard area by BDS IGSO with passivation in the operational orbit

- If BDS MEO satellite is passivated in the operational orbit, the collision probability posed to operational orbit of BDS, GPS and Galileo is of a 10^{-6} order of magnitude.
- The strategy of passivation in the operational orbit of BDS MEO satellite will result in a lower collision probability to GPS and Galileo, but a higher collision probability to the BDS constellation.
- If BDS IGSO satellite is passivated in the operational orbit, the collision probability posed to GEO protected area and graveyard area is of a 10^{-6} order of magnitude.
- The strategy of passivation in the operational orbit of BDS IGSO satellite will result in a lower collision probability to graveyard area , but a higher collision probability to GEO protected area.

IV. Conclusions for the long-term collision probability

- The collision probability posed to operational orbit or graveyard orbit is of a 10-5 ~10-6 order of magnitude, which is less than the 0.001 threshold for LEO crossing objects.
- The stable disposal strategy could be adopted for BDS MEO EOL satellites, and the unstable disposal strategy could be adopted for BDS IGSO EOL satellites.
- To decrease the collision probability posed to operational orbit, the eccentricity and argument of perigee can be optimized for the option of passivation in the operational orbit.
- The option of directed de-orbit is not recommended for BDS satellites due to large propellant required.



Conclusions and Recommendations

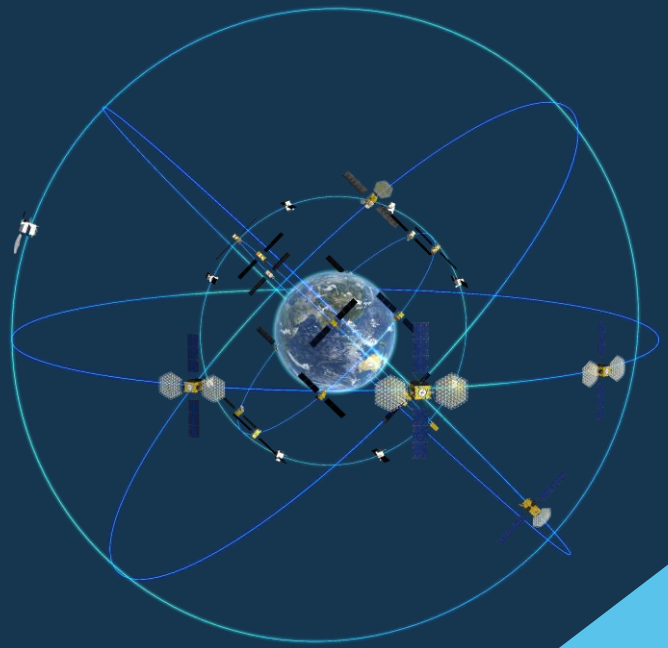
04

Conclusions and Recommendations

- There are no final guidelines for MEO/IGSO satellites post-mission disposal from international organizations (IADC), while post-mission disposal strategy and safety restrictions of GNSS EOL satellites are not exactly the same.
- Due to propellant limitation, the option of disposal orbit is adopted by BDS EOL satellites instead of directed de-orbit. The analysis showed that the collision probability posed to operational orbit or graveyard orbit by BDS MEO&IGSO EOL satellites within 200 yeas is of a 10^{-5} ~10^{-6} order of magnitude for both stable and unstable disposal strategy.
- The collision risk will increase as there are more GNSS/RNSS satellites deployed in the future. As a result, ICG members should continue to pay more attention to the safety of MEO and IGSO space debris. System providers should try to establish the GNSS/RNSS space debris guidelines together with IADC and continue to exchange information on their GNSS/RNSS satellites post-mission disposal plans and implements in WG-S.

Review action and next steps

N0.	Working content	Process	Next step	Remarks
1	Complete the draft template for the action item ‘MEO/IGSO satellite disposal status and plan'	Nearly complete	To recommend RNSS providers to complete the table	
2	Prepare a response to IADC with feedback on the report	In process	To prepare a draft response document which includes the feedback from all the system providers to WG-S cochairs	
3	Update the contact list of the space debris mitigation issue	In process	To recommend the system providers to provide the contact /participant list to WG-S cochairs	



Thanks for your attention!