Physical properties and long-term evolution of the debris clouds produced by two catastrophic collisions in Earth orbit

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After two decades of slightly declining growth rate, the population of cataloged orbital debris increased by more than 40% in just a couple of years, from January 2007 to February 2009, due to two collisions in space involving the catastrophic destruction of three intact satellites in high inclination orbits

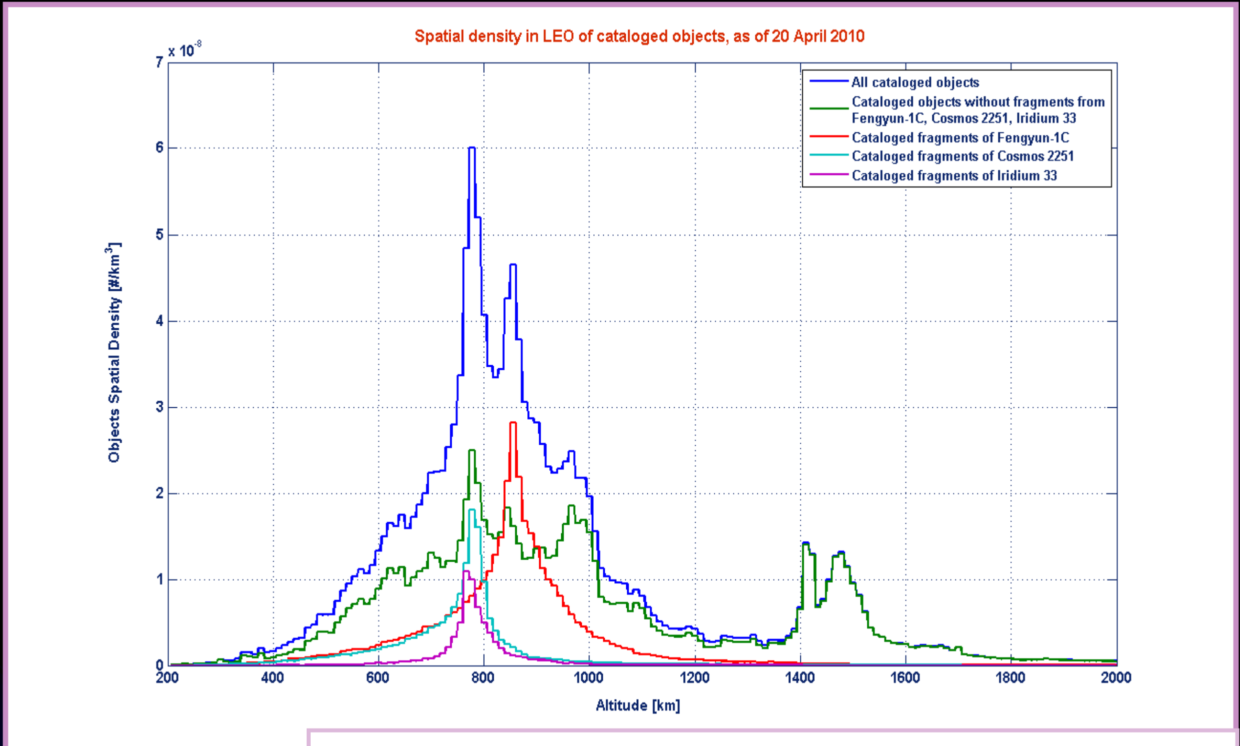
- **Fengyun-1C**

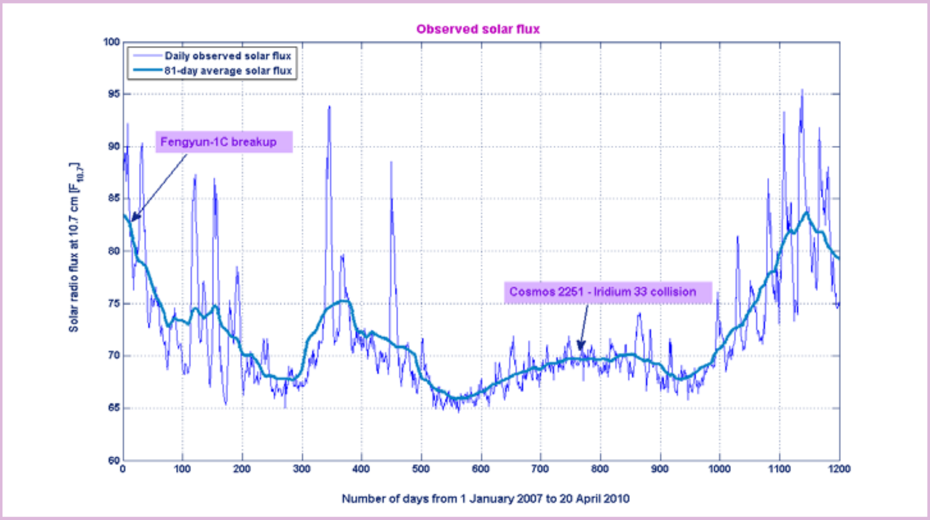
  On 11 January 2007, the defunct polar weather satellite Fengyun-1C, orbiting at an altitude of about 863 km, was destroyed as a results of the first successful Chinese anti-satellite weapon test

- **Cosmos 2251 and Iridium 33**

  On 10 February 2009, Cosmos 2251 and Iridium 33 collided in orbit at an altitude of about 790 km. This was the first accidental catastrophic collision between two intact objects

Both events produced a huge amount of debris in one of the orbital regimes already most affected by past launch activity and fragmentation events





Observed solar flux

As of 20 April 2010

2841 fragments of Fengyun-1C

1228 fragments of Cosmos 2251

512 fragments of Iridium 33

had been cataloged (*Space Track*)

of these:

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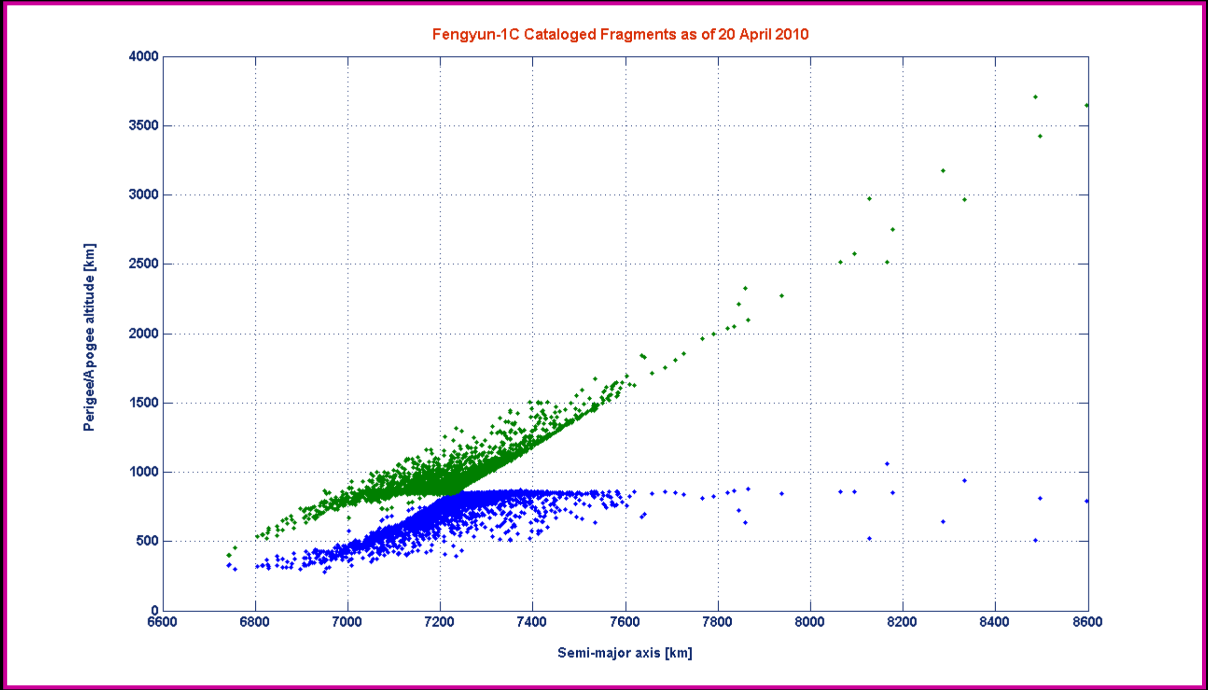
85 (~3%) debris of Fengyun-1C

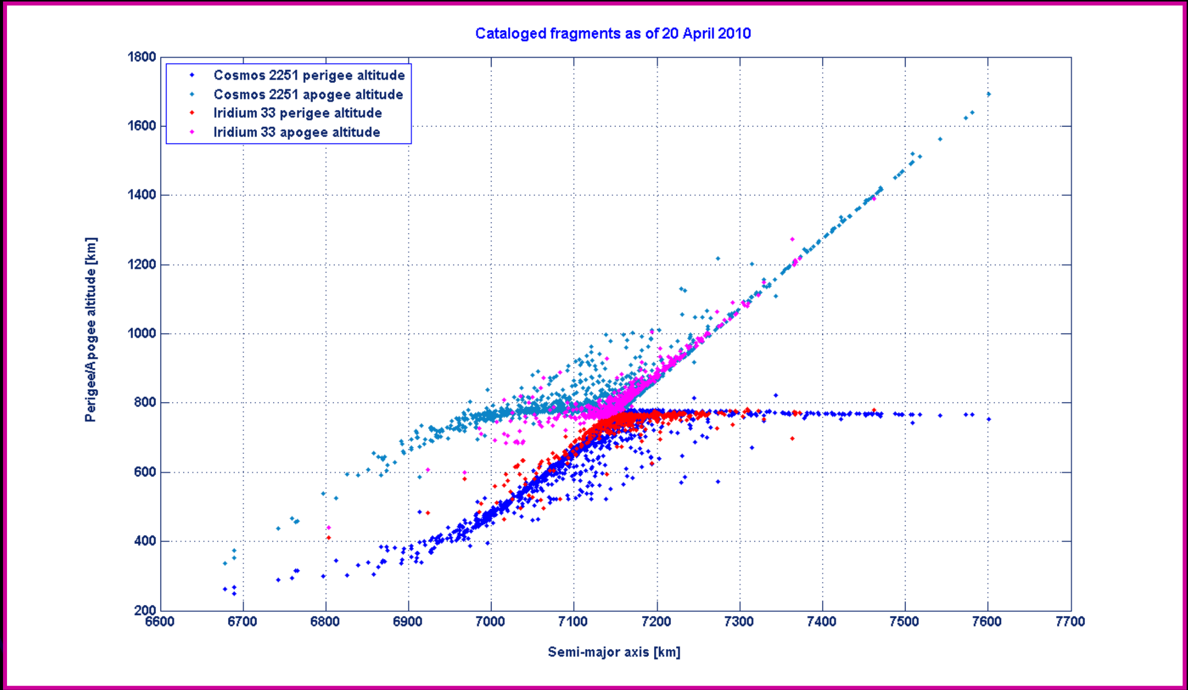
50 (~4.1%) debris of Cosmos 2251

22 (~4.3%) debris of Iridium 33

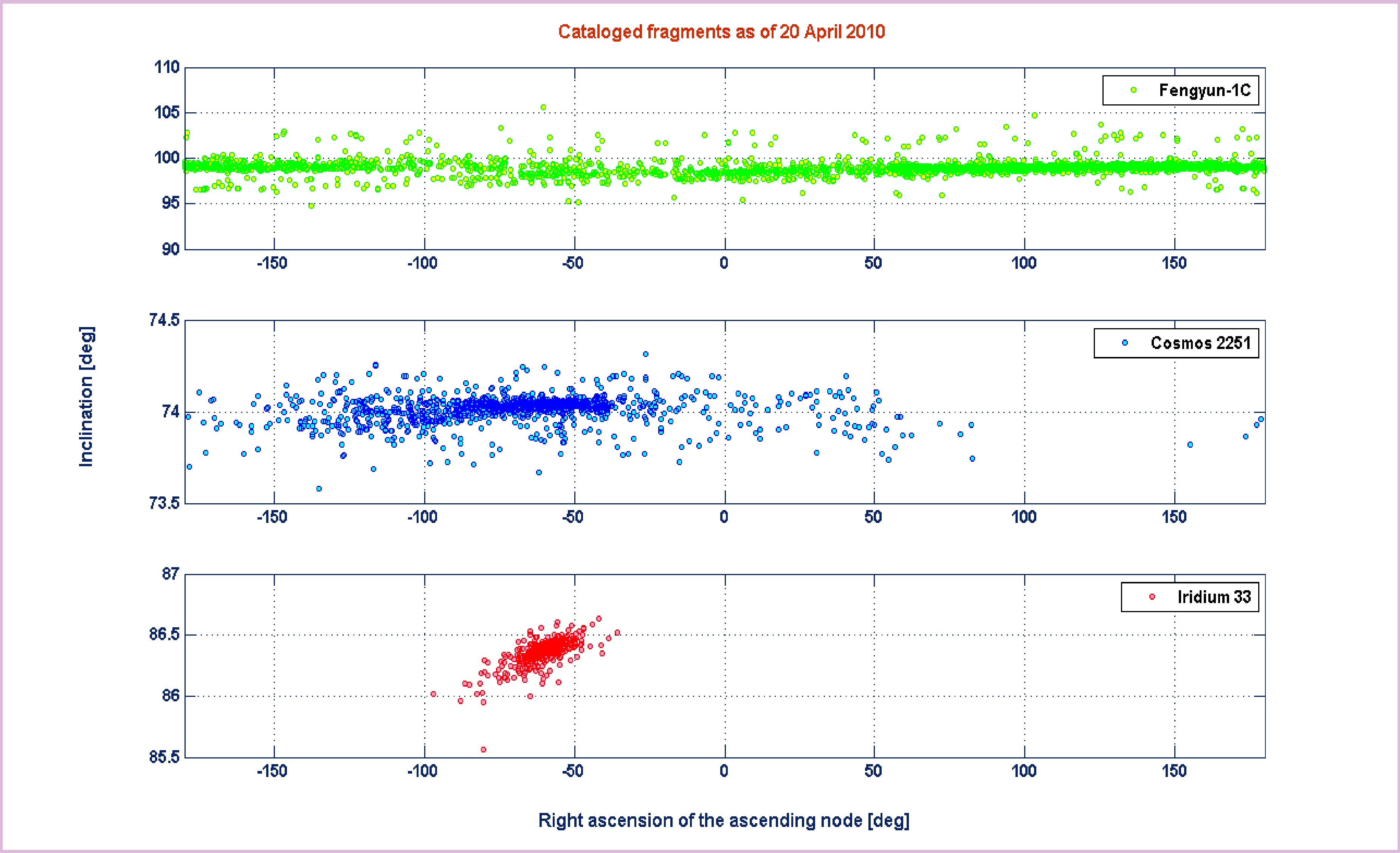
had already reentered in the atmosphere

GABBARD DIAGRAMS

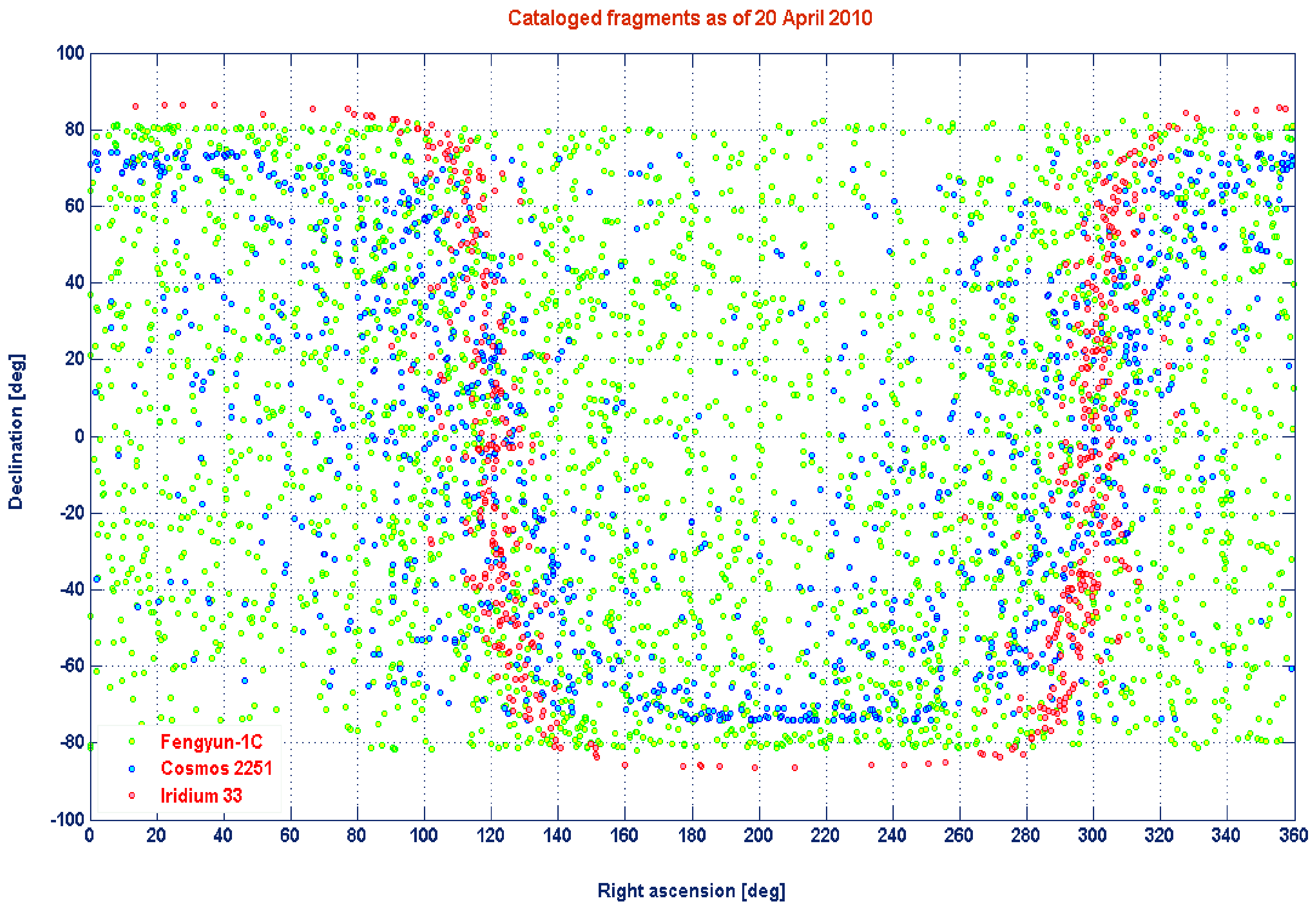




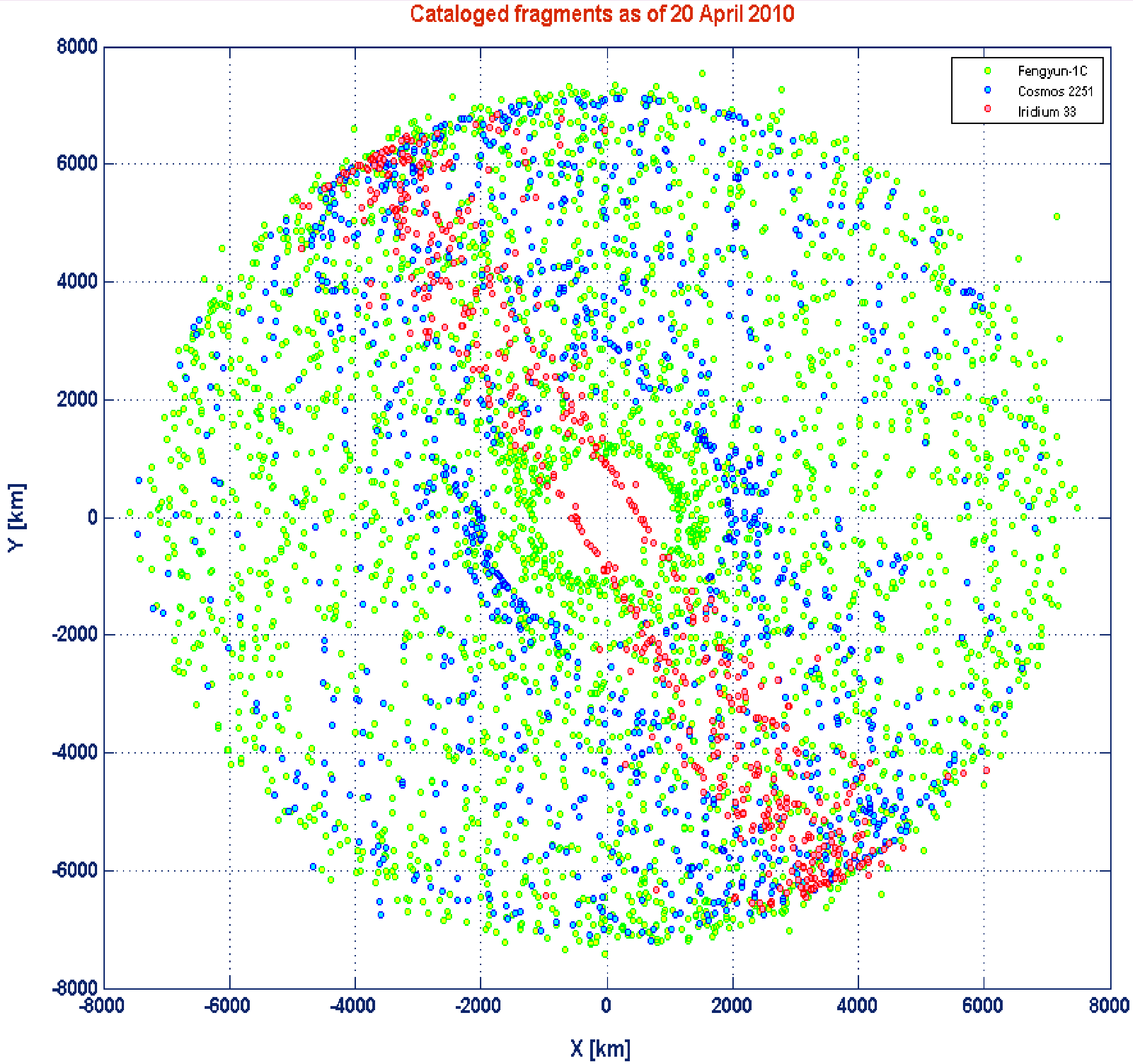
Distribution of debris inclination vs. right ascension of the ascending node



Snapshot of cataloged debris right ascension and declination



Snapshot of the inertial x-y components of the cataloged debris position vectors



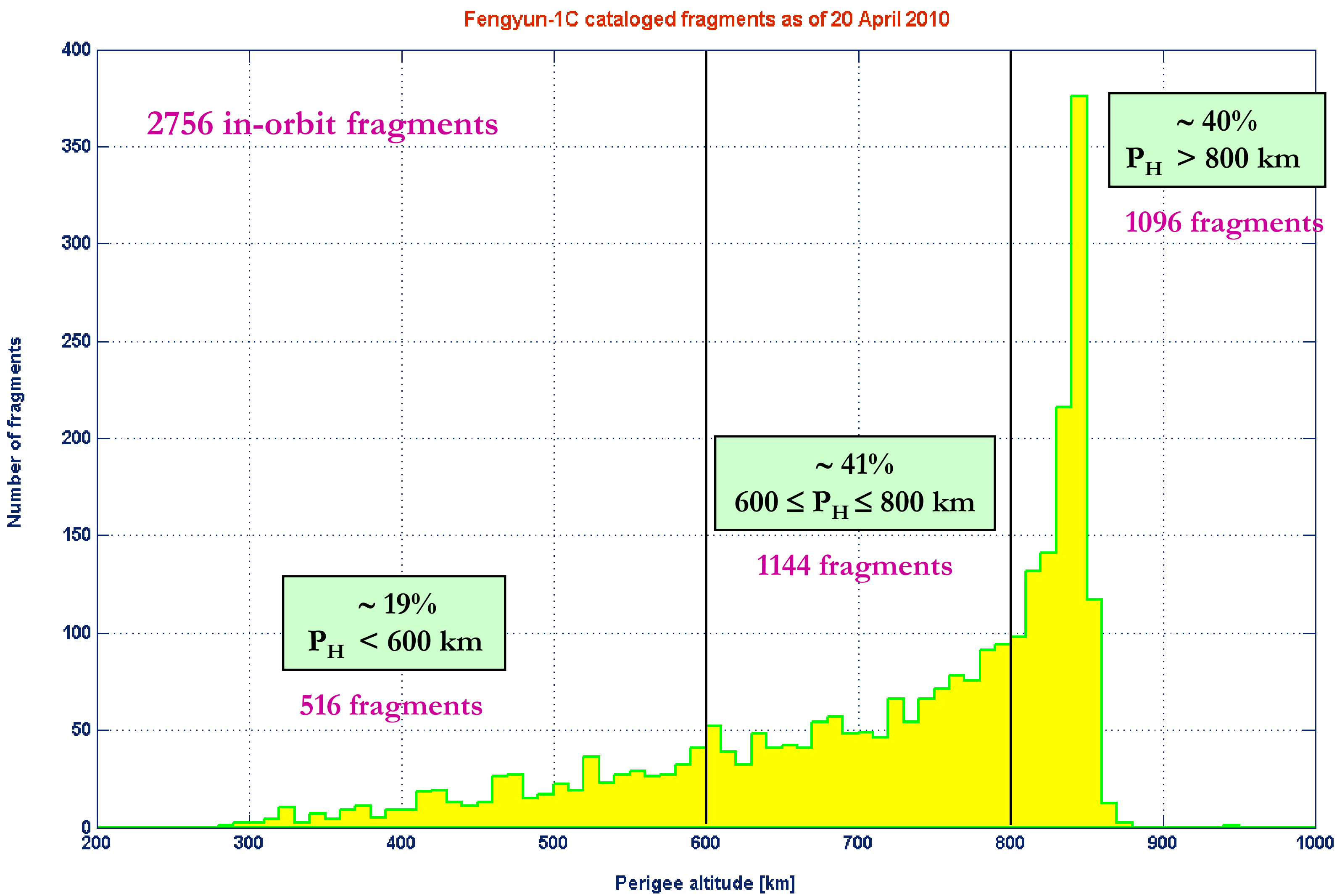
In order to investigate the long-term consequences of the collisions on the orbital debris environment

The physical characteristics of the three clouds of fragments, in terms of ballistic parameter and area-to-mass distribution, were derived from a decay analysis of representative samples of cataloged objects

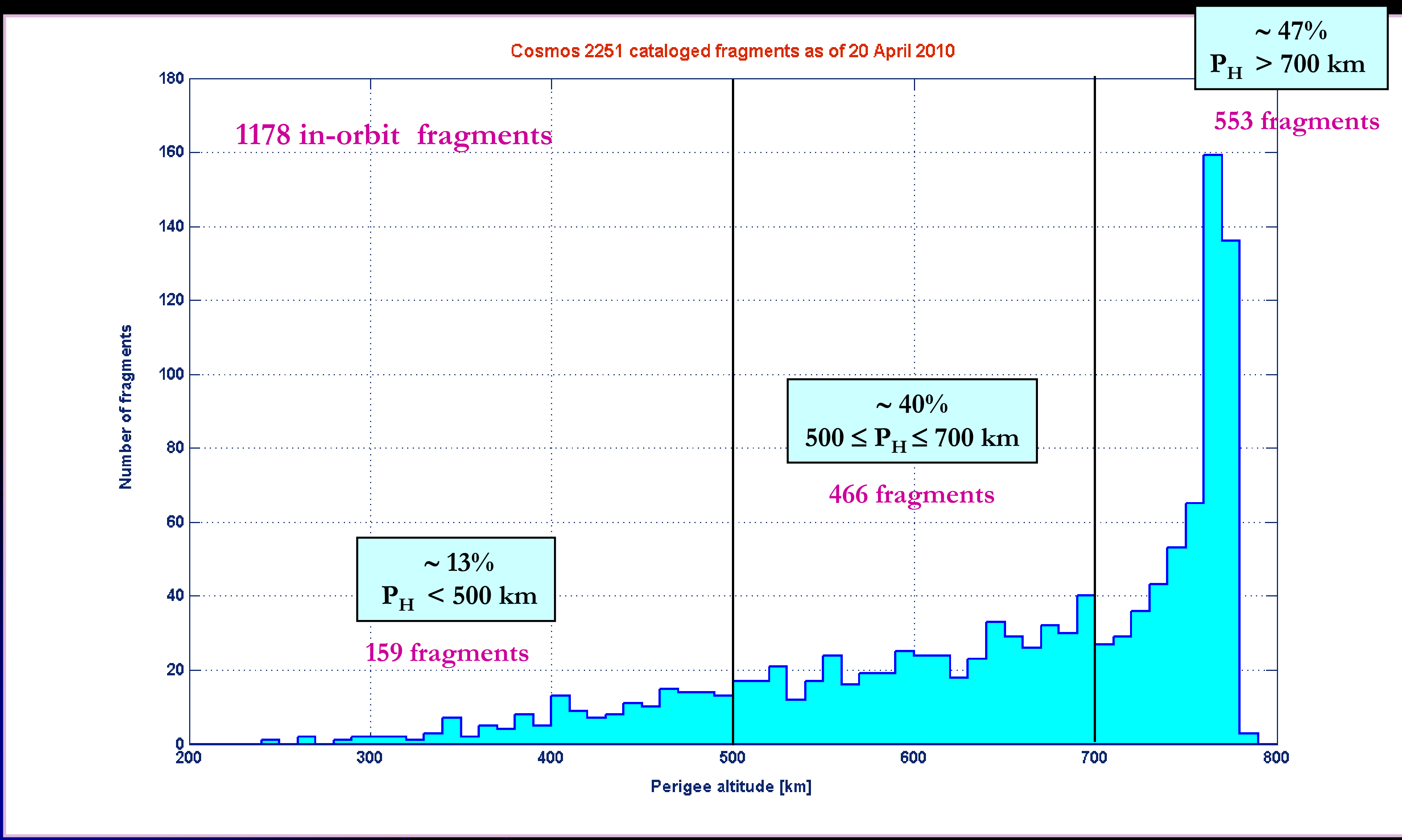
Such information was then used to realistically estimate the debris lifetime and the long-term contribution of the three clouds to the circumterrestrial environment

How to choose representative samples?

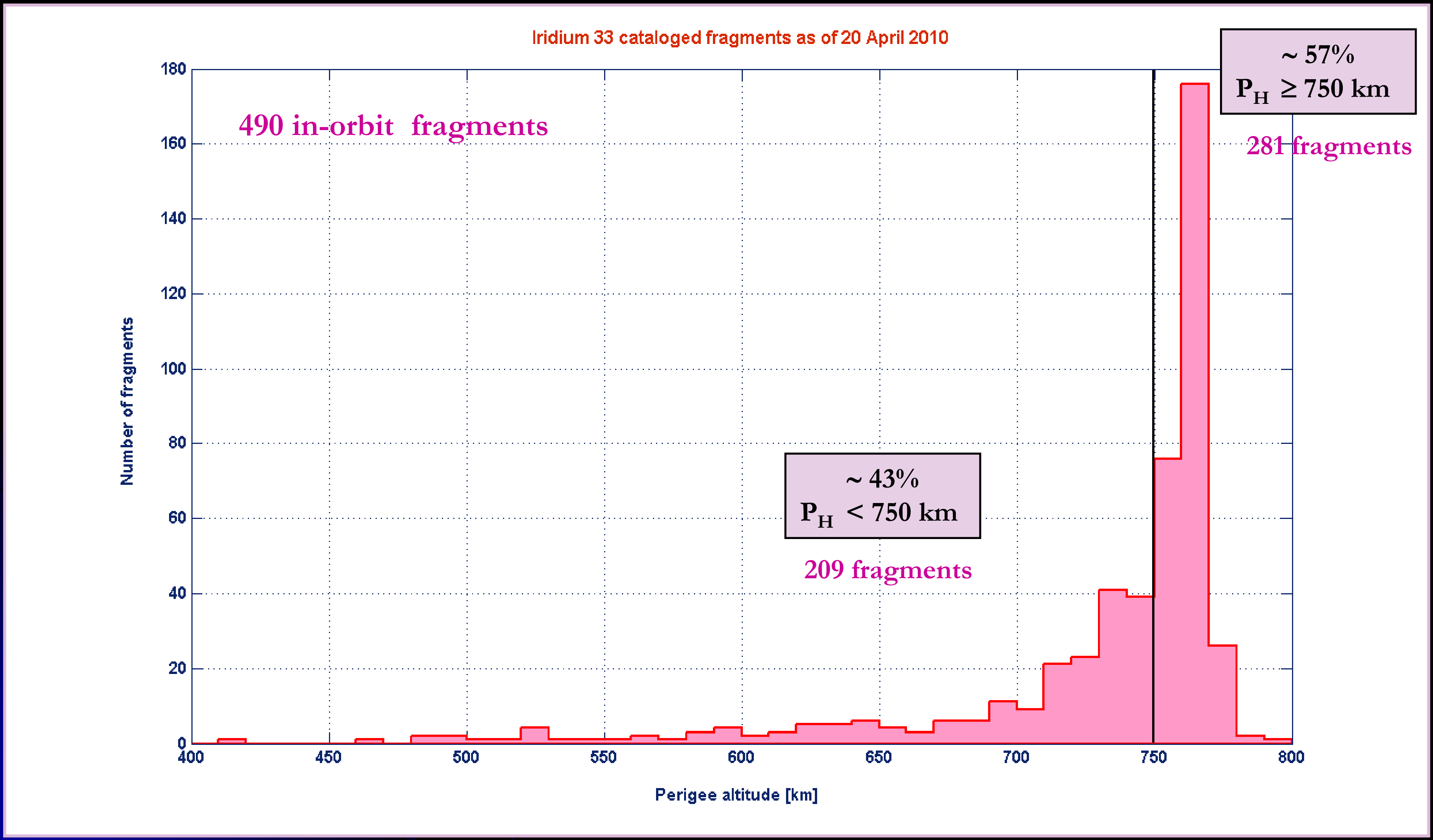
Perigee altitude distribution of the Fengyun-1C cataloged fragments



Perigee altitude distribution of the Cosmos 2251 cataloged fragments



Perigee altitude distribution of the Iridium 33 cataloged fragments



Representative samples

For each cloud, nearly 10% of the fragments were randomly selected in each perigee altitude region

For each selected fragment

- The ballistic parameter was determined by fitting, in a least squares sense, the semi-major axis decay inferred from the historical TLEs
- A scaling factor was computed by comparing the fitted ballistic parameter with the ballistic parameter obtained from the average B^* (arithmetic mean of the values of B^* over the same time interval used for the fit)

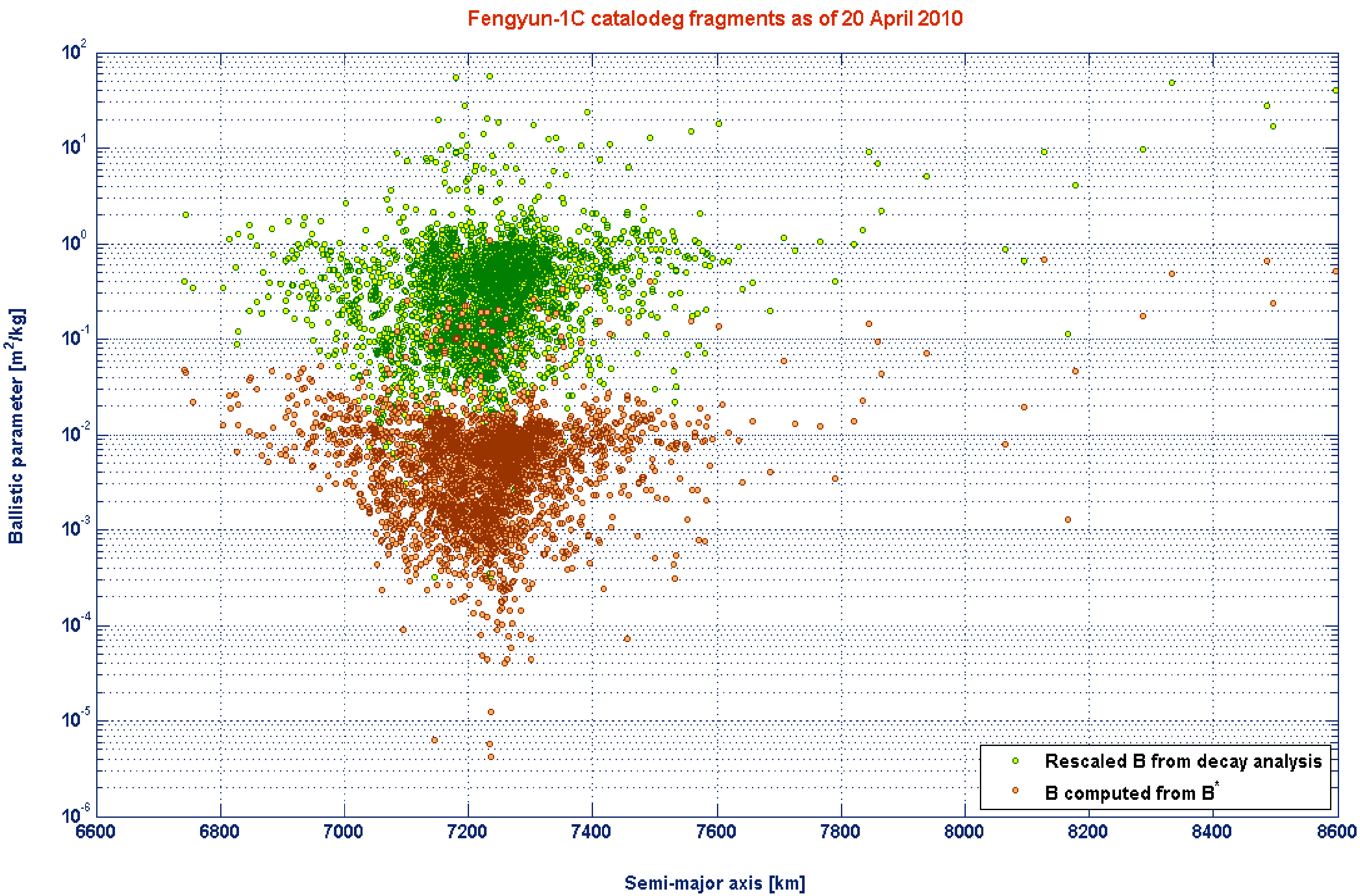
For each sample

- A mean scaling factor and its standard deviation were computed
- Assuming a Gaussian distribution, with the mean and standard deviation thus found, randomly generated B scaling factors were applied to all the fragments with perigee altitude in the range represented by the sample itself

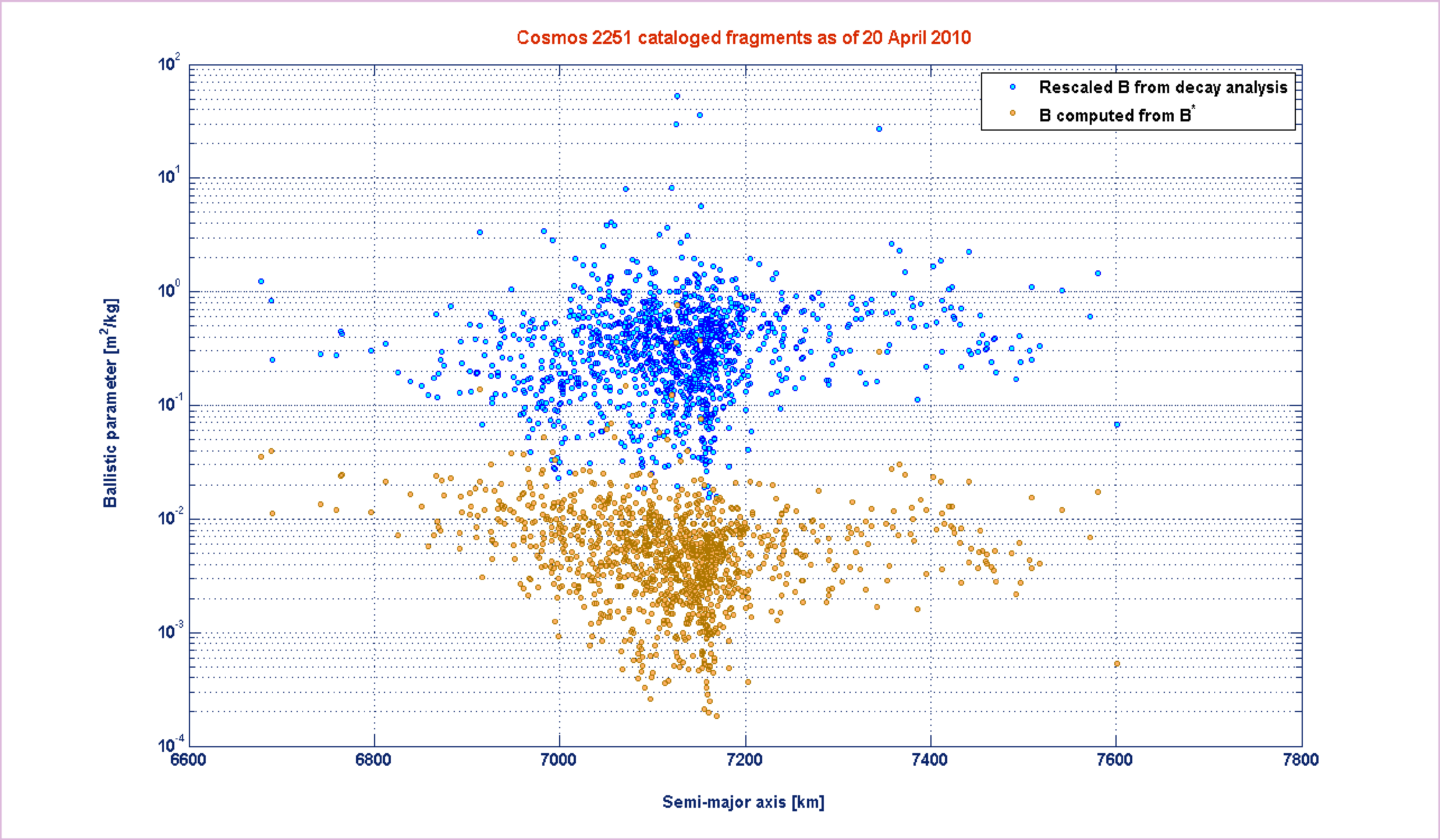
For each debris cloud

- The rescaled ballistic parameter distribution was obtained by merging the resulting populations, classified in terms of perigee altitude

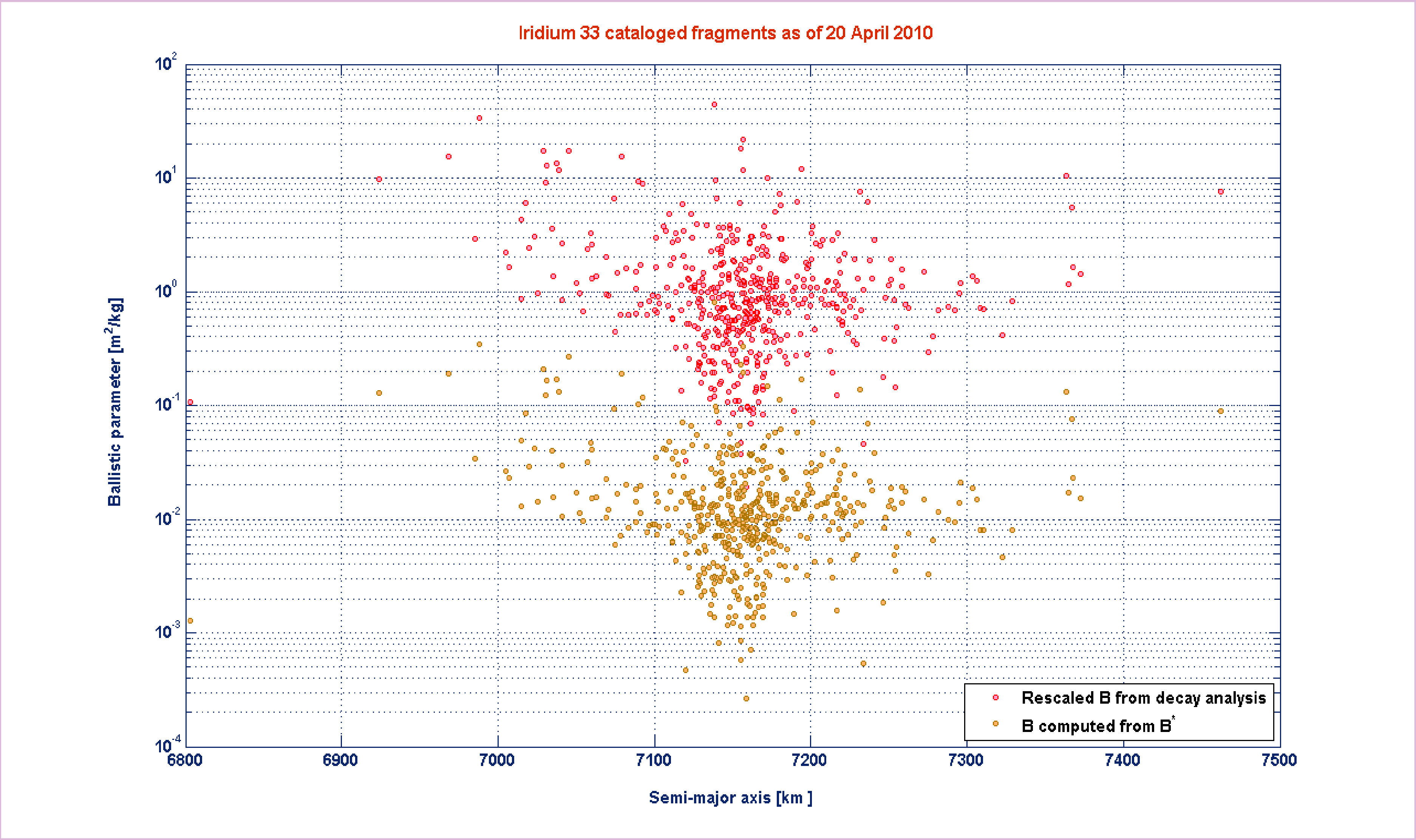
Fengyun-1C debris: ballistic parameter rescaling based on decay analysis



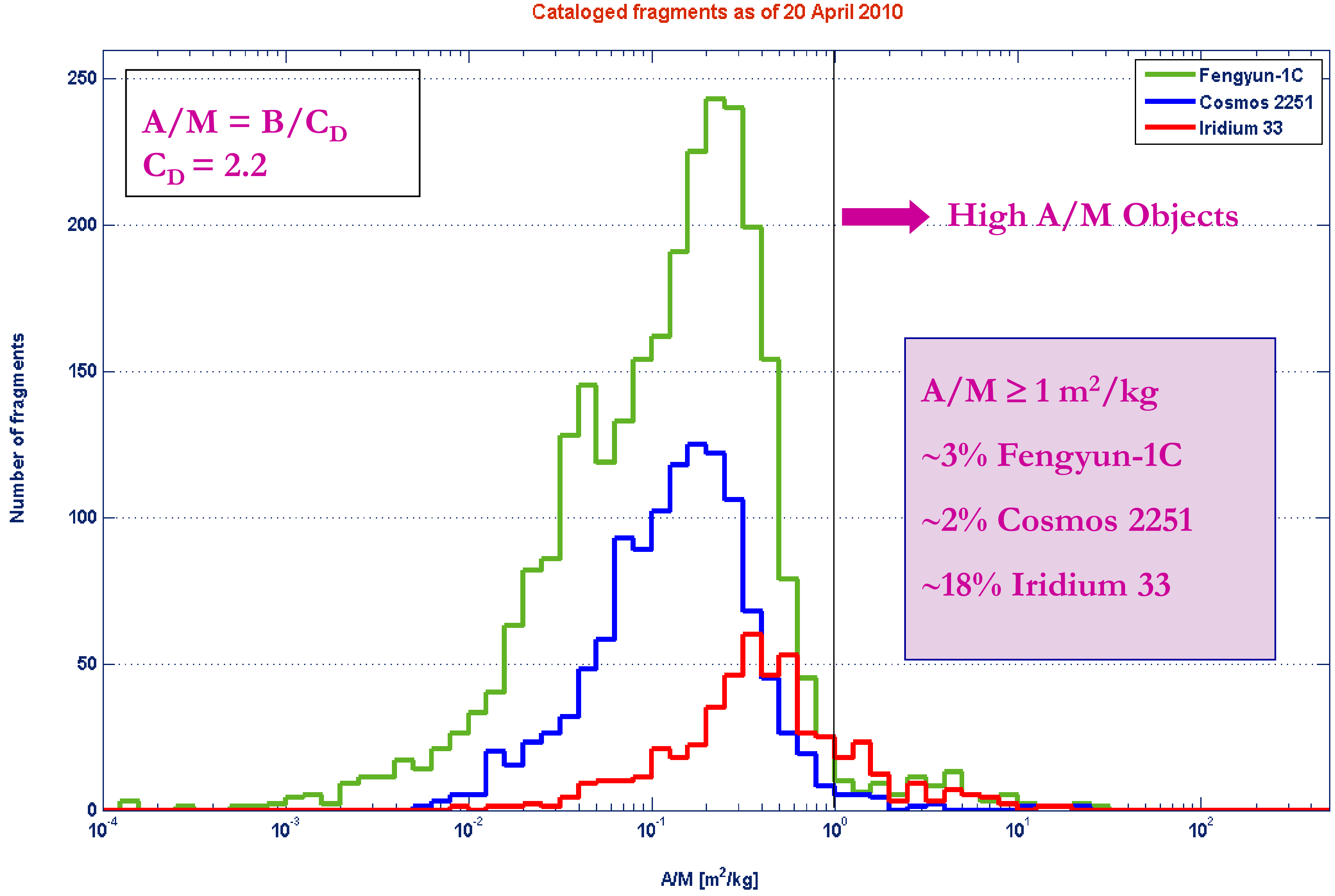
Cosmos 2251 debris: ballistic parameter rescaling based on decay analysis



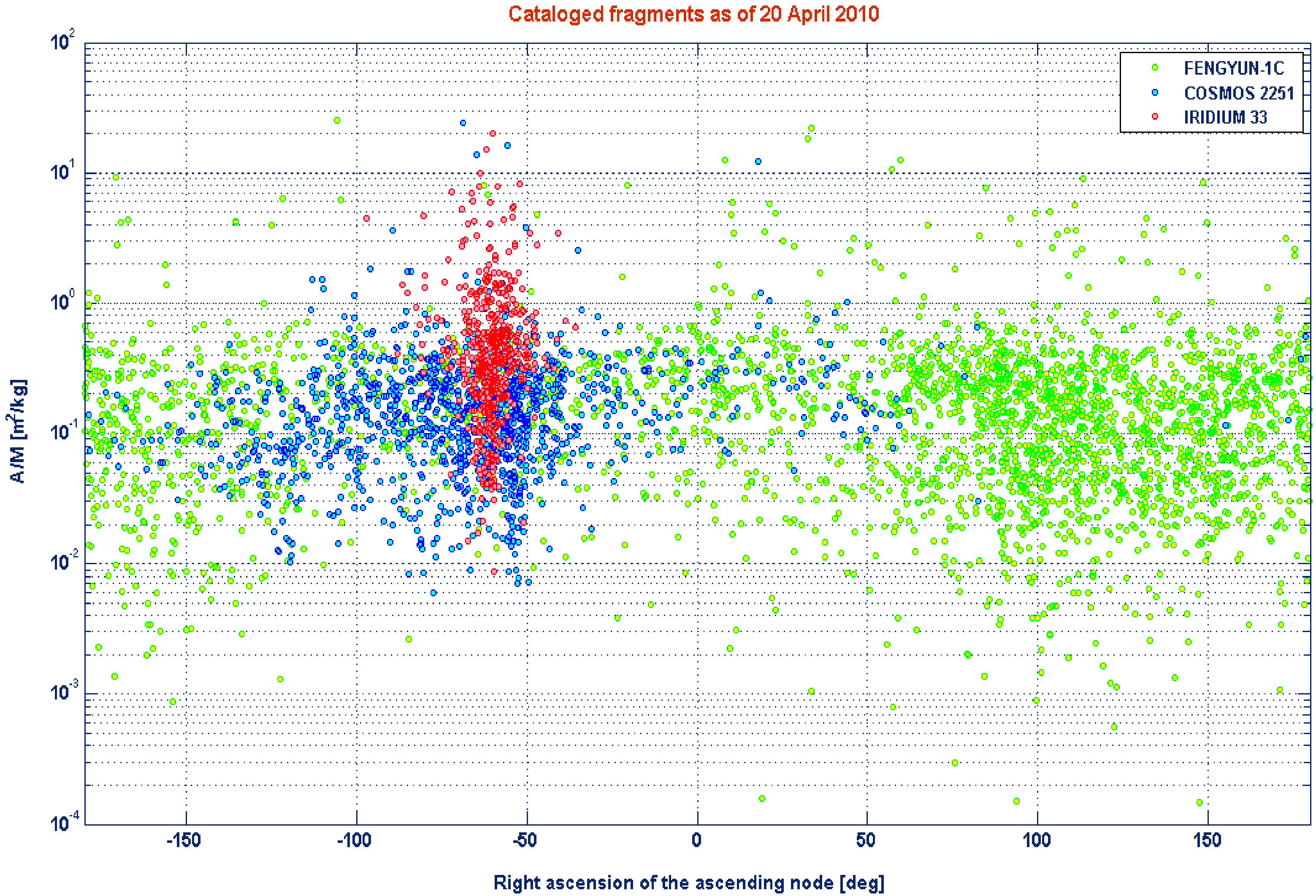
Iridium 33 debris: ballistic parameter rescaling based on decay analysis



A/M distribution of the cataloged fragments deduced from decay analysis



Fragments distribution in terms of area-to-mass vs. right ascension of the ascending node



Debris clouds evolution

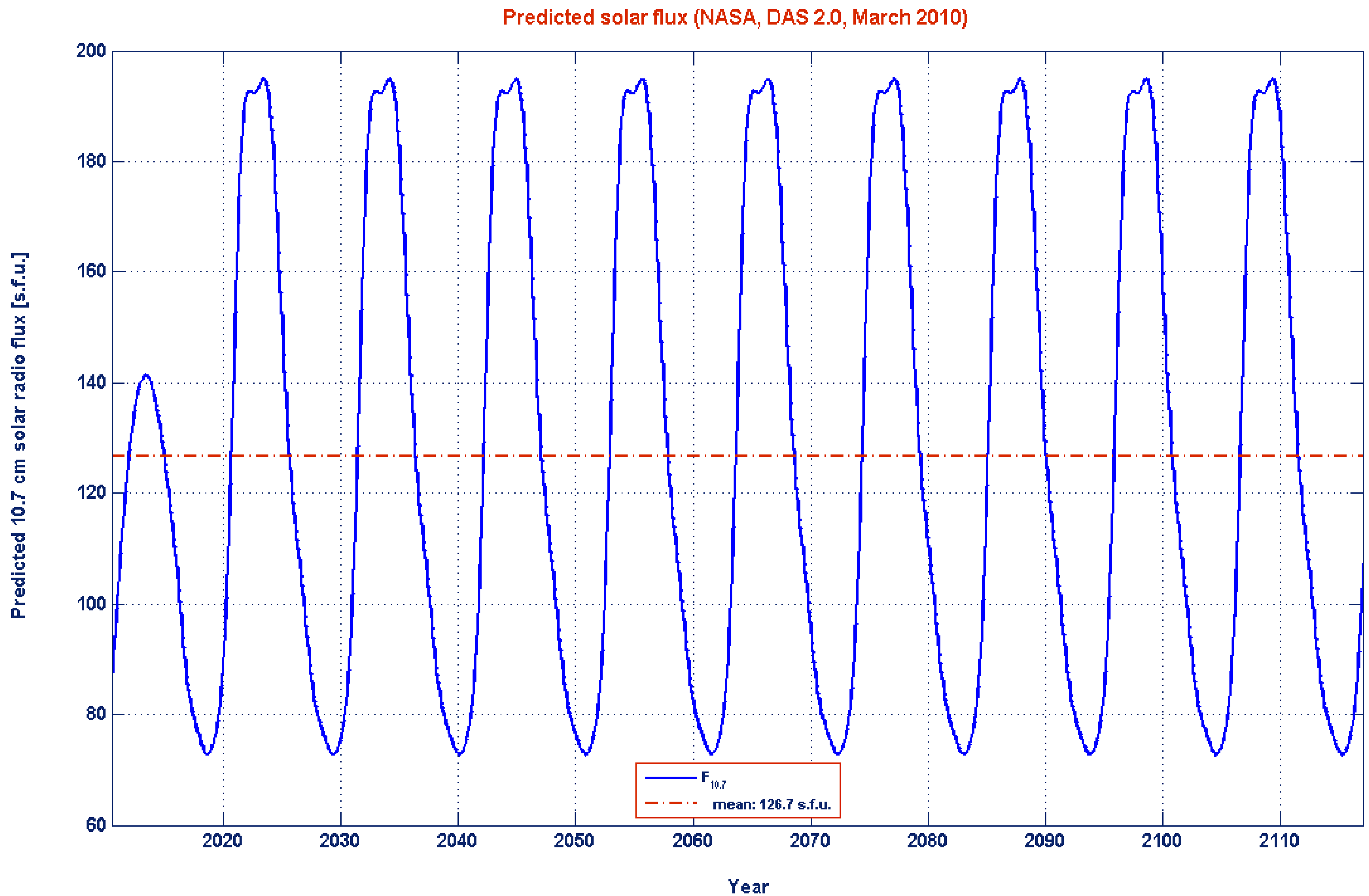
- The cataloged fragments of Fengyun-1C, Cosmos 2251 and Iridium 33 were individually propagated for 100 years, taking into account all the relevant perturbations

- To estimate the effects of air drag, the Jacchia-Roberts 1971 density model was adopted

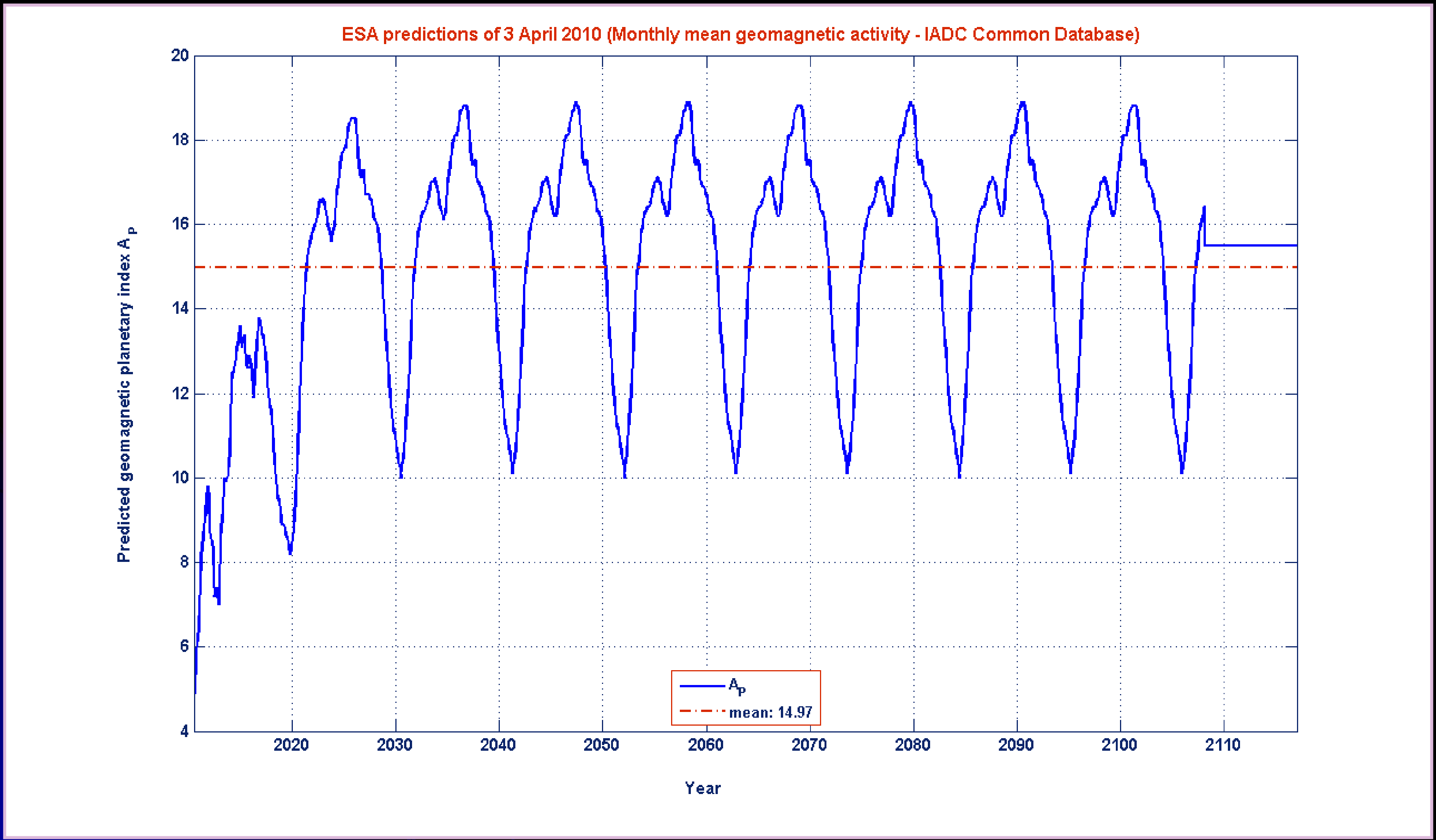
- The predicted $F_{10.7}$ solar radio flux was that recommended for use with the NASA DAS 2.0.1 software tool since 1 March 2010 (NASA)

- The predicted geomagnetic planetary index A_P was that available in the IADC Common Database on 3 April 2010 (ESA)

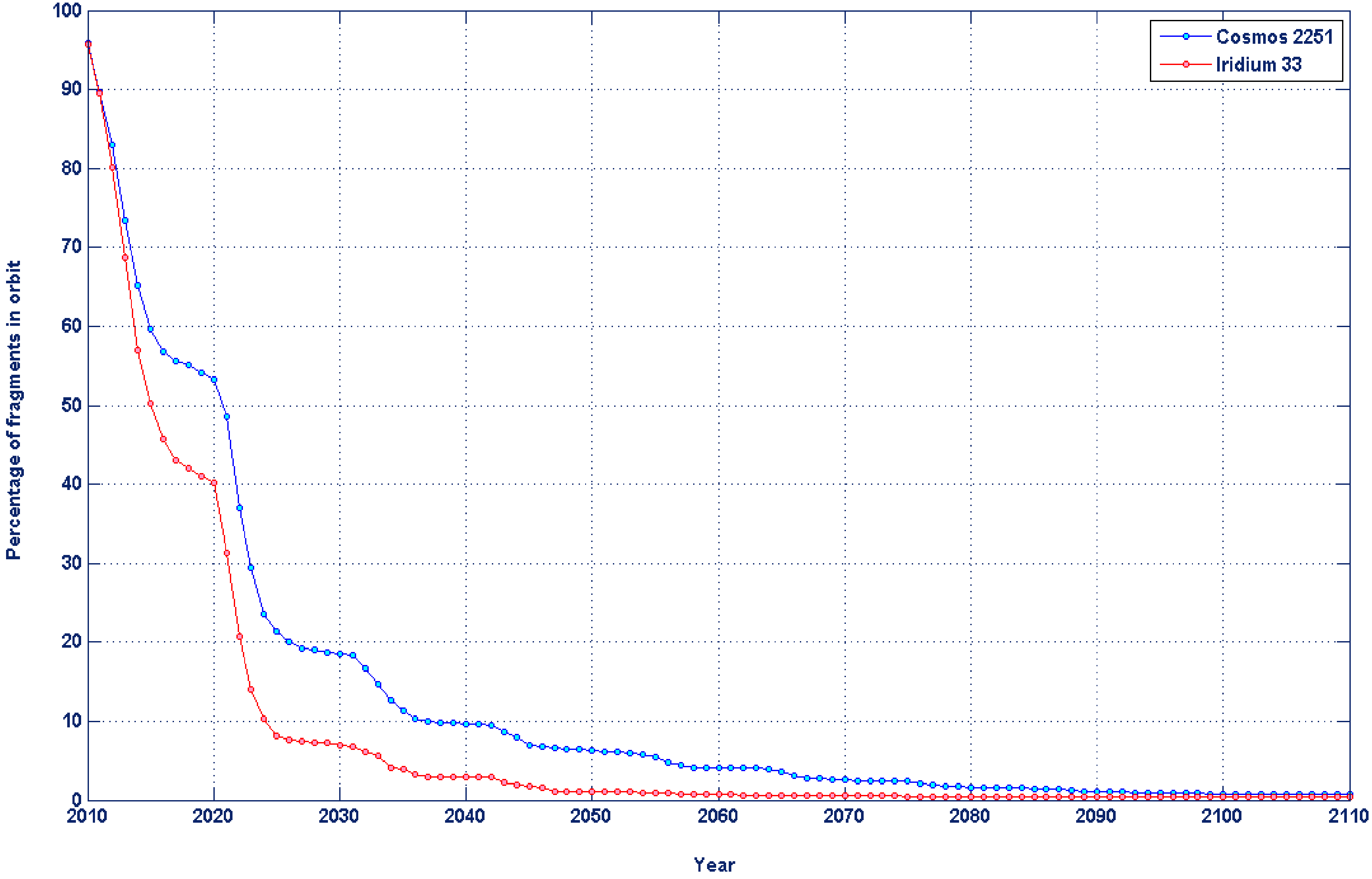
Solar flux predictions



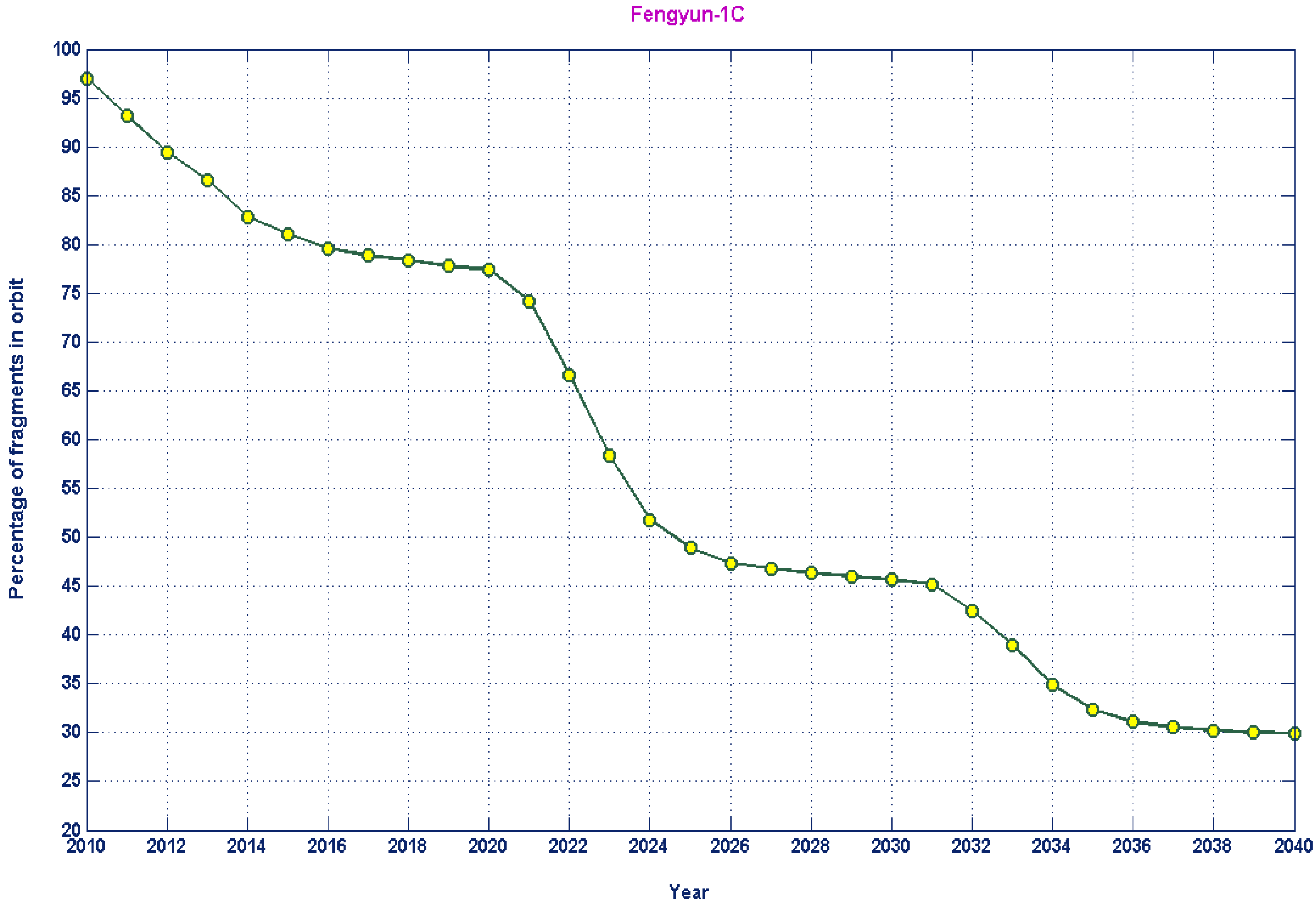
Planetary geomagnetic index predictions



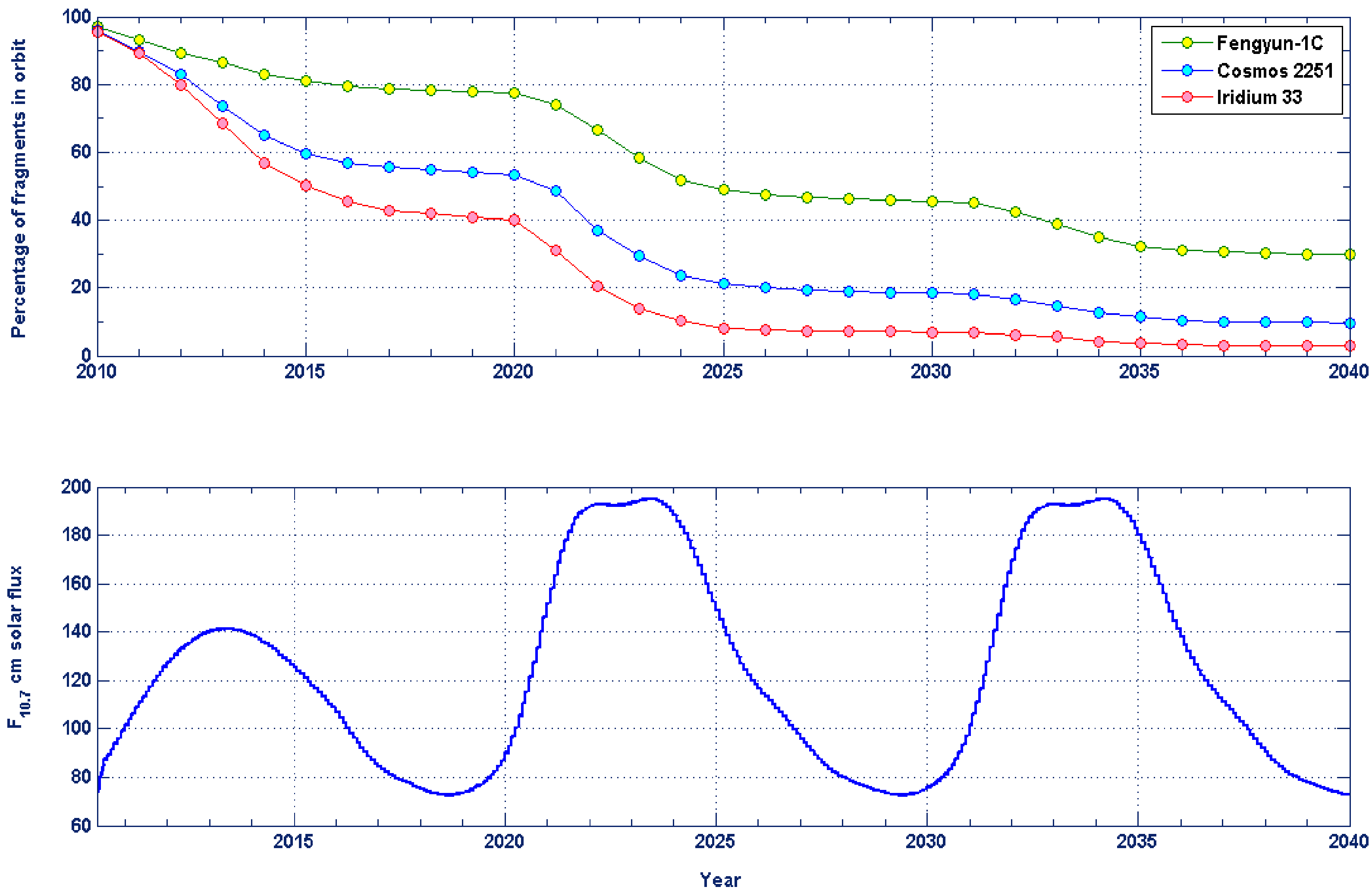
Cosmos 2251 and Iridium 33 fragments evolution over one century



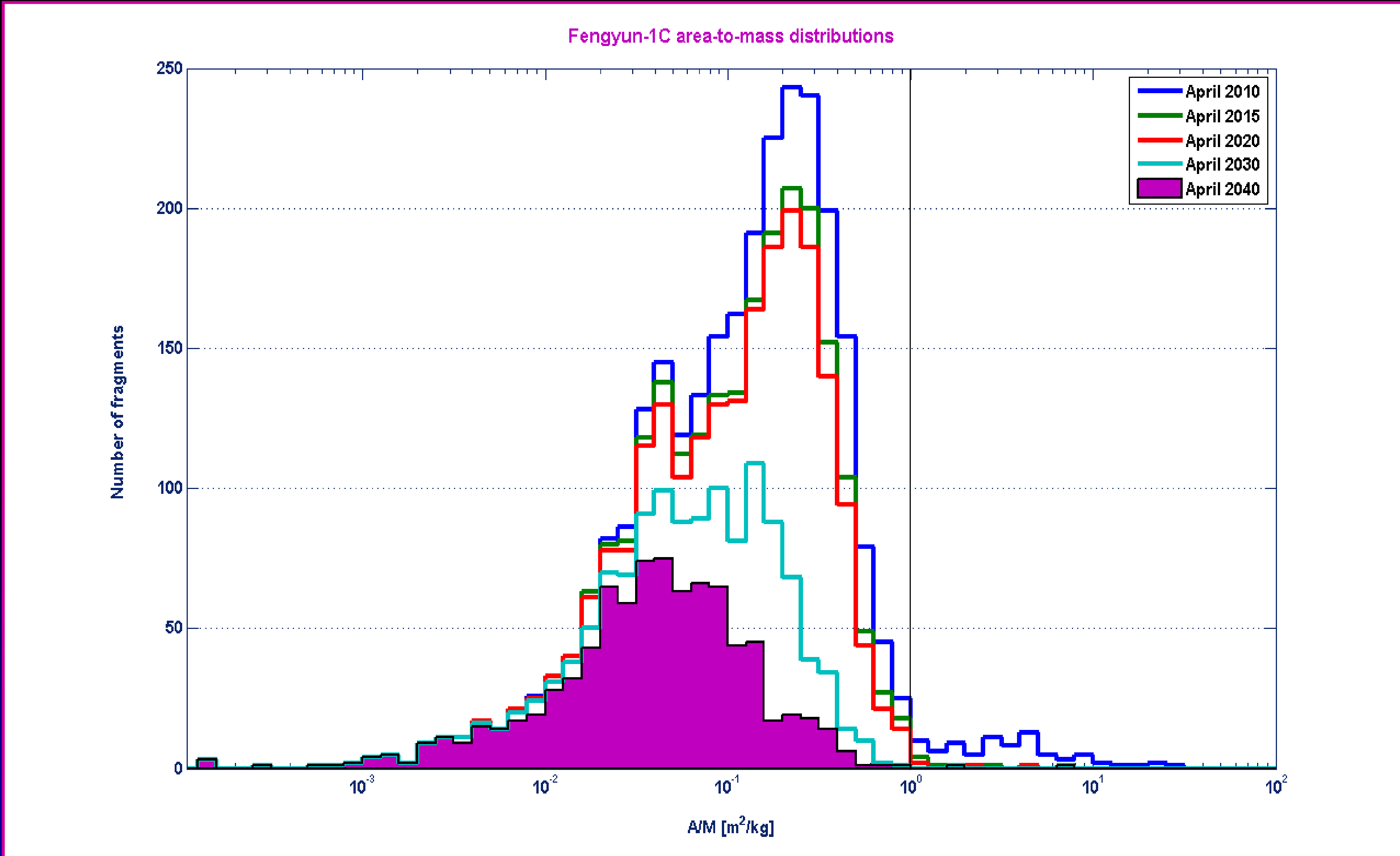
Fengyun-1C fragments evolution over the first 30 years



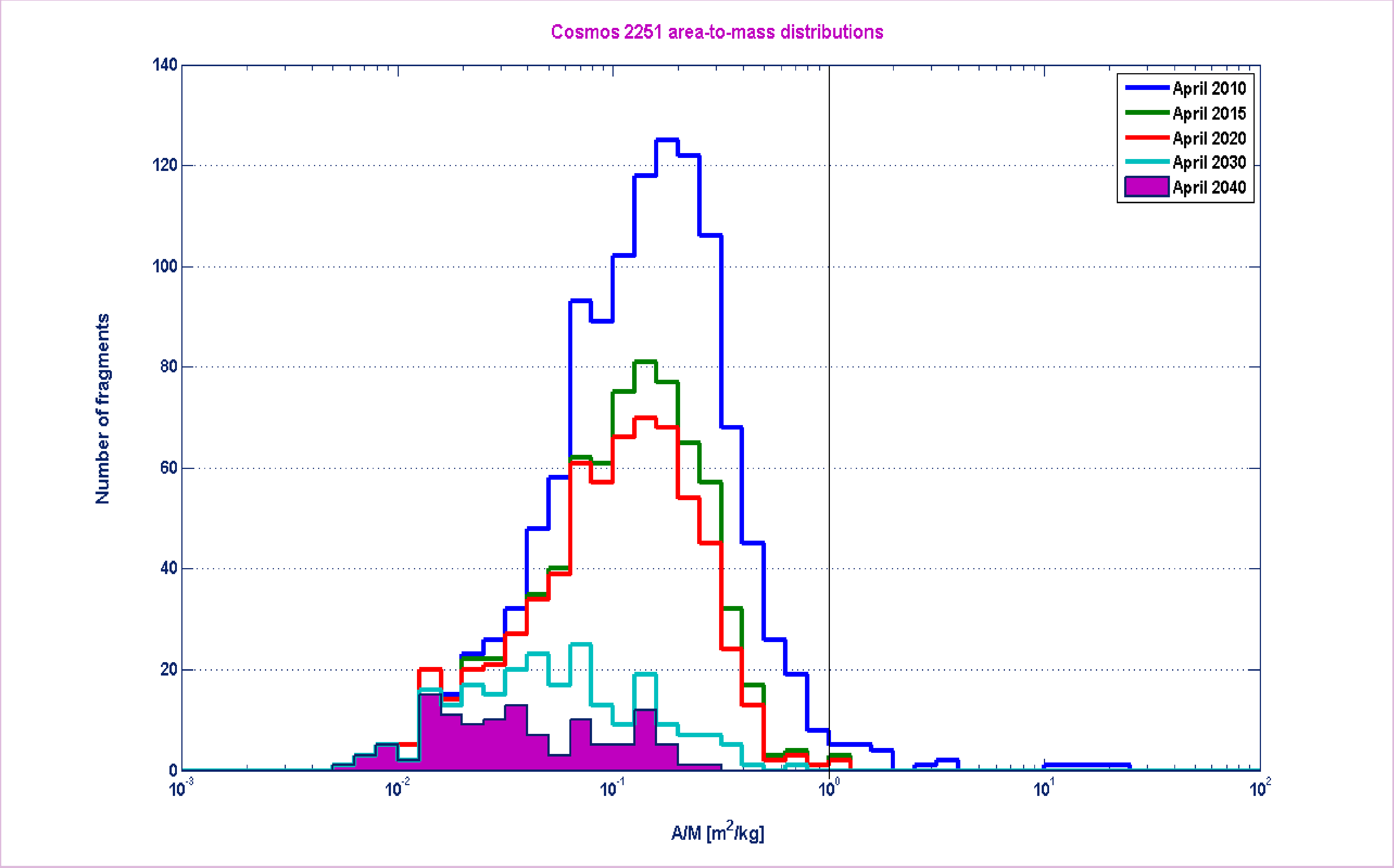
Fengyun-1C, Cosmos 2251 and Iridium 33 fragments evolution over the first 30 years



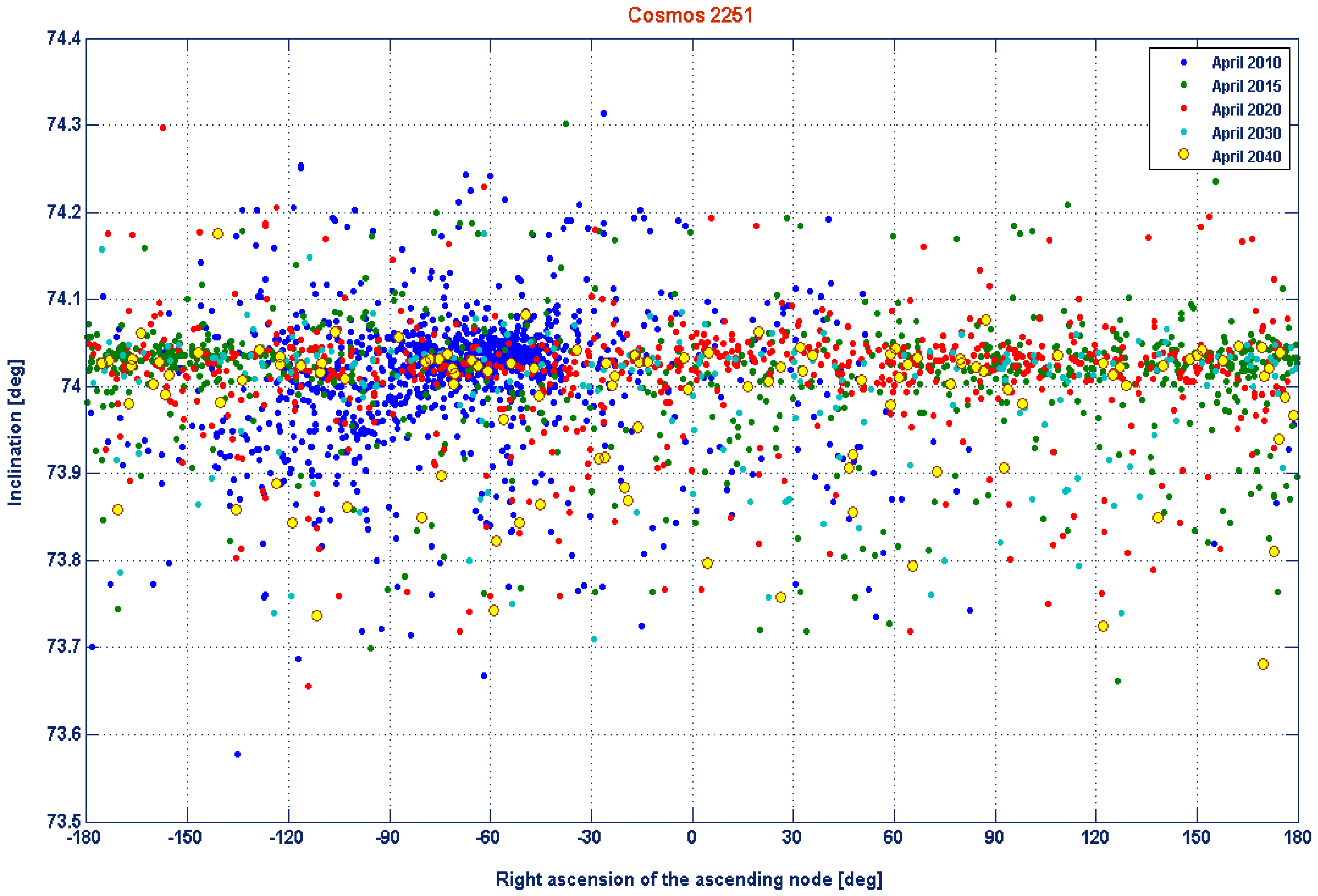
Time evolution of the Fengyun-1C A/M distribution



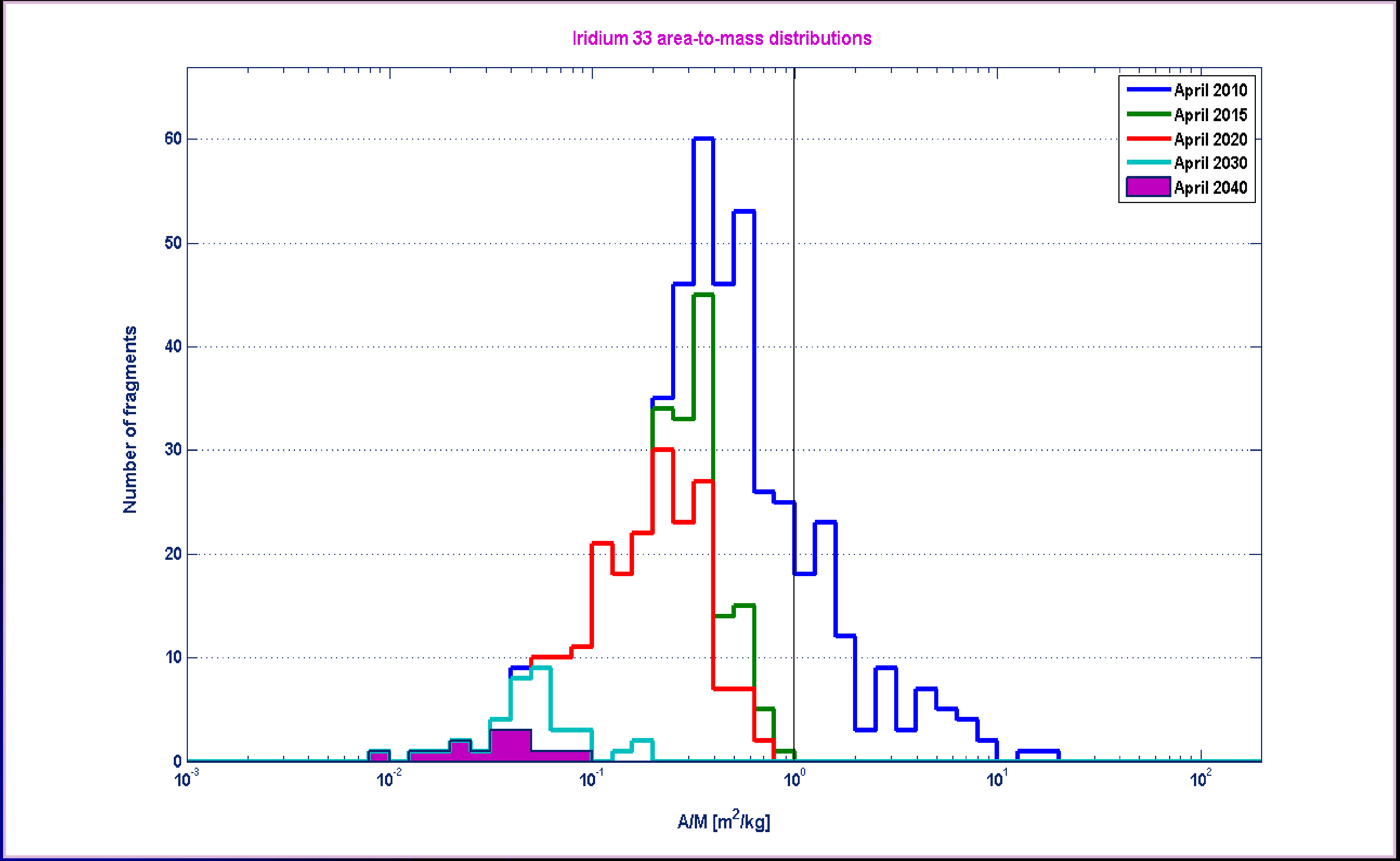
Time evolution of the Cosmos 2251 A/M distribution



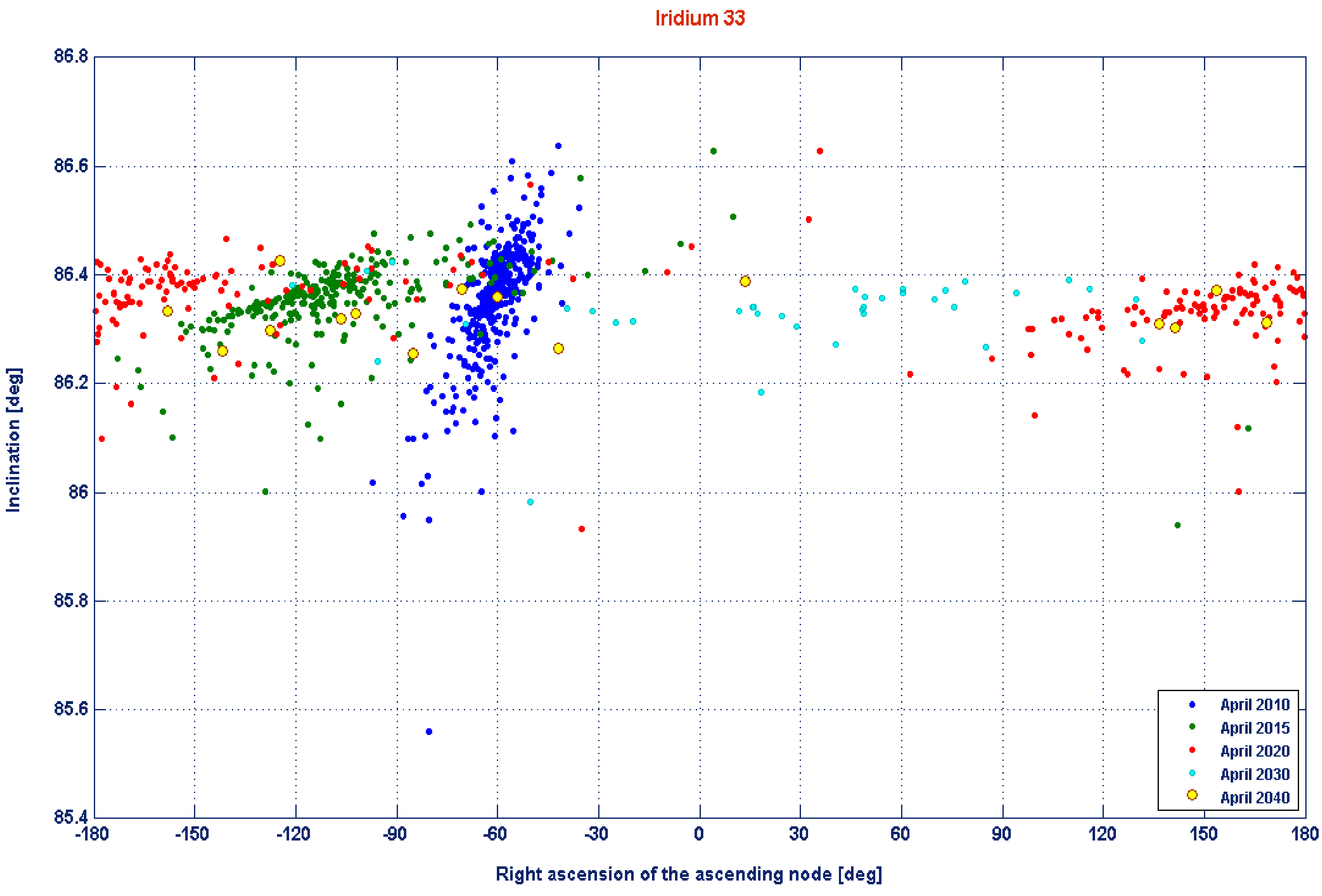
Time evolution of the Cosmos 2251 fragments distribution in terms of inclination vs. right ascension of the ascending node



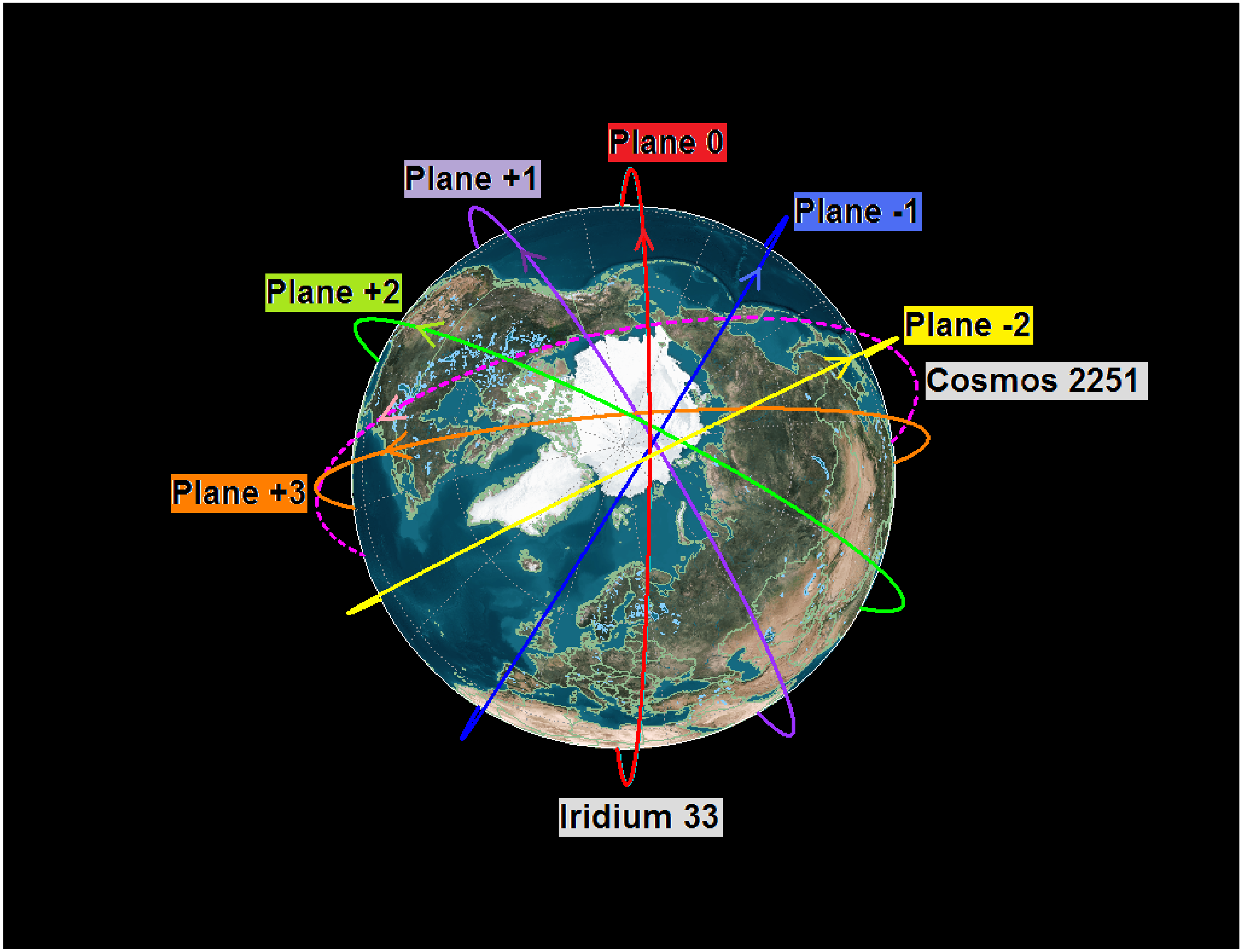
Time evolution of the Iridium 33 A/M distribution



Time evolution of the Iridium 33 fragments distribution in terms of inclination vs. right ascension of the ascending node



Impact risk assessment for the Iridium constellation



Flux of cataloged objects on the Iridium constellation planes on 20 April 2010

Cataloged objects including the Fengyun-1C, Cosmos 2251 and Iridium 33 debris			
Iridium plane	Cross-sectional area flux [m^{-2} yr^{-1}]	Average relative velocity [km/s]	Average collision velocity [km/s]
-2	1.25×10^{-5} [+80%]	9.09	11.64
-1	1.46×10^{-5} [+70%]	8.64	12.07
0	1.87×10^{-5} [+80%]	5.67	12.32
+1	1.67×10^{-5} [+138%]	8.98	12.34
+2	1.44×10^{-5} [+127%]	9.62	12.04
+3	1.23×10^{-5} [+143%]	9.69	12.01

Cataloged objects without the Fengyun-1C, Cosmos 2251 and Iridium 33 debris			
Iridium plane	Cross-sectional area flux [m^{-2} yr^{-1}]	Average relative velocity [km/s]	Average collision velocity [km/s]
-2	6.96×10^{-6}	9.69	12.69
-1	8.59×10^{-6}	10.77	13.33
0	1.04×10^{-5}	11.24	13.53
+1	7.01×10^{-6}	9.08	12.70
+2	6.35×10^{-6}	9.04	12.36
+3	5.06×10^{-6}	8.14	11.60

Iridium plane	Cross-sectional area flux [m^{-2} yr^{-1}]	Average relative velocity [km/s]	Average collision velocity [km/s]
Fengyun-1C cataloged debris			
-2	3.27×10^{-6}	9.23	12.26
-1	4.02×10^{-6}	12.13	13.49
0	6.03×10^{-6}	12.65	14.01
+1	7.58×10^{-6}	13.35	14.24
+2	5.49×10^{-6}	12.28	13.84
+3	4.07×10^{-6}	12.03	13.39
Cosmos 2251 cataloged debris			
-2	1.64×10^{-6}	6.93	7.98
-1	1.45×10^{-6}	3.79	4.74
0	1.56×10^{-6}	2.39	3.58
+1	1.50×10^{-6}	4.11	4.99
+2	1.95×10^{-6}	7.52	8.16
+3	2.11×10^{-6}	9.91	10.96
Iridium 33 cataloged debris			
-2	8.84×10^{-7}	7.58	7.65
-1	7.76×10^{-7}	3.68	3.90
0	7.95×10^{-7}	0.63	0.84
+1	8.90×10^{-7}	4.15	4.26
+2	1.08×10^{-6}	7.98	8.04
+3	1.33×10^{-6}	11.07	11.09

Conclusions

- An updated and more accurate estimation of the ballistic parameter and A/M distributions of the three orbiting debris clouds produced by the breakups of Fengyun-1C, Cosmos 2251 and Iridium 33 was completed
- Considering the fragments still in orbit on 20 April 2010, the fraction of those with $A/M \geq 1\ m^2/kg$ was 3% for the Fengyun-1C cloud, 2% for the Cosmos 2251 cloud and 18% for the Iridium 33 cloud
- The Iridium 33 cloud will be the most fast to decay, with 90% of the cataloged debris removed from orbit in 15-25 years
- For the Cosmos 2251 cloud, the natural perturbations will need about 30-40 years, depending on solar activity, to reach the same result
- The Fengyun-1C cloud will exhibit a significantly longer lifetime
- Due to the initial orbit inclination (86.4°) and to the relatively limited debris spread in semi-major axis, the orbit planes of most of the Iridium 33 fragments will continue to present a modest node dispersion for several years
- The two breakup events increased by a factor 2 the collision probability with cataloged debris of the Iridium constellation
- At present, the additional flux is dominated by the Fengyun-1C debris, significantly higher than those of Cosmos 2251 and Iridium 33 combined