On-orbit Satellite Collision Debris Analysis Based on Hypervelocity Impact Simulation

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Outline

This presentation will show you some preliminary work of using hypervelocity impact simulation technique to analyze on-orbit satellite breakup problem to obtain the small debris information which is beyond the space surveillance limit.

1. **Introduction to space debris and HVI simulation**
2. **Satellite collision simulation and debris analysis**

1. Introduction

I. **Threaten of space debris**

II. **Hypervelocity impact simulation**

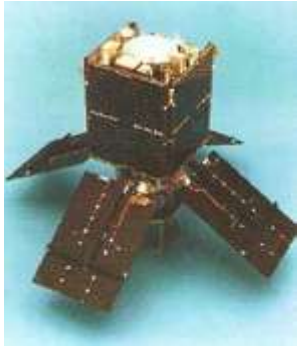
III. **Main idea of this research**

Threatening of space debris (1)

- **Space debris:**

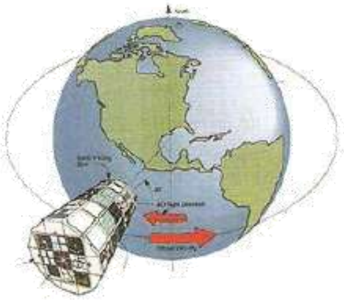
  Human space activities created lots of disused objects left in the orbit. These objects and the fragments created by the secondary impact of them are called space debris.

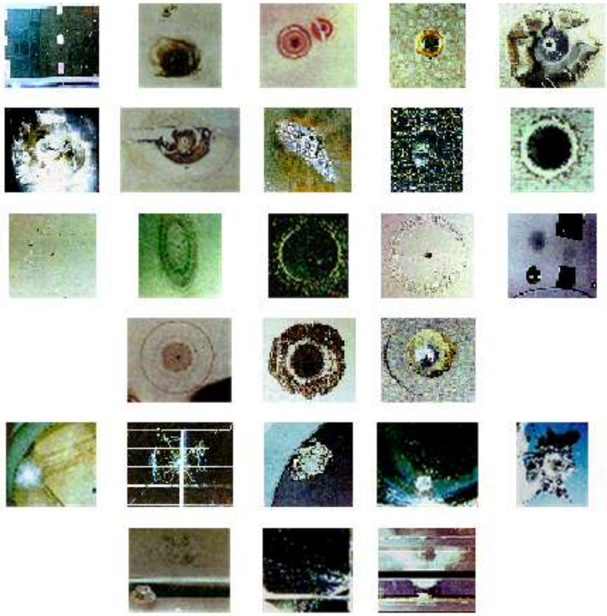
- **Catastrophic impact events (generated a large amount of space debris):**
  - **1991, Russian satellite COSMOS1934 and COSMOS926 hit each other**
  - **1996, Arianne rocket remains hit the gravity gradient pole of French satellite CERISE**
  - **2009, Russian satellite COSMOS2251 and American IRIDIUM33 collision**



Threatening of space debris (2)

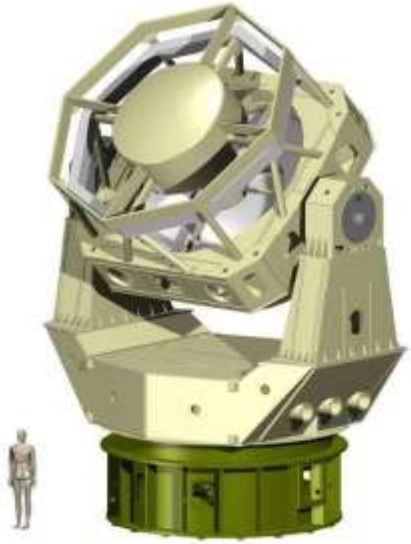
- **Space shuttles of the USA have replaced the windows over 80 times .**
- **Hubble space telescope has encountered over 5000 times impact , 150 holes on in the solar array**
- **Long Duration Exposure Facility (LDEF)**





Different solutions for large/small debris

- **Debris larger than 10cm (LEO) can be observed and tracked ——choosing launch window and initiative evading**
- **1cm debris is enough for perforating the body of satellite——covering important parts of the satellite with shield**

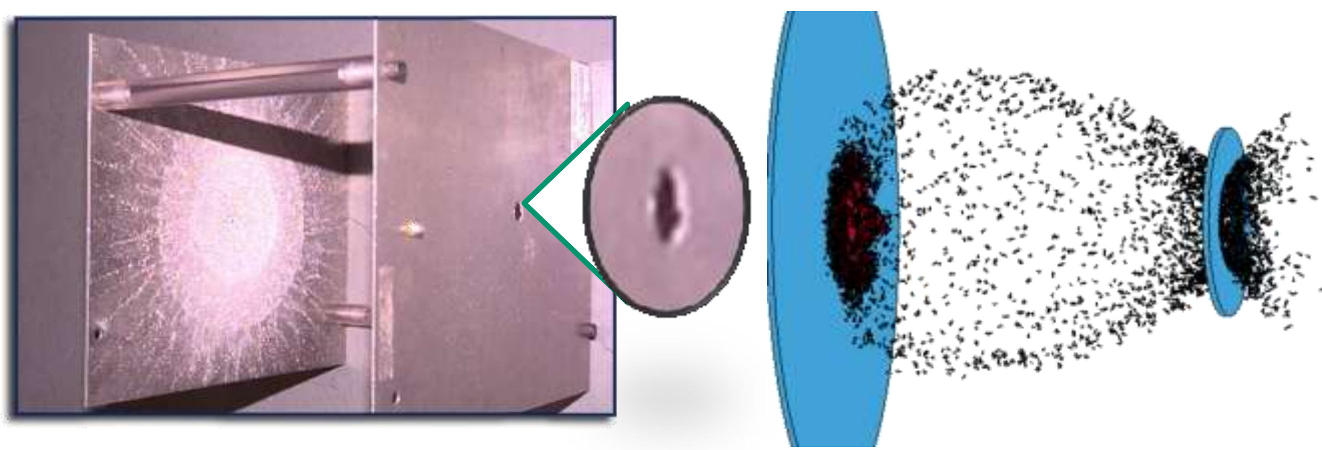


Hypervelocity impact simulation

- **Hyper velocity impact (HVI) simulation:**

  A numerical simulation technique of impact under hyper velocity (v>5km/s) which can show out the whole deformation and fracture process of the impact quantitatively.

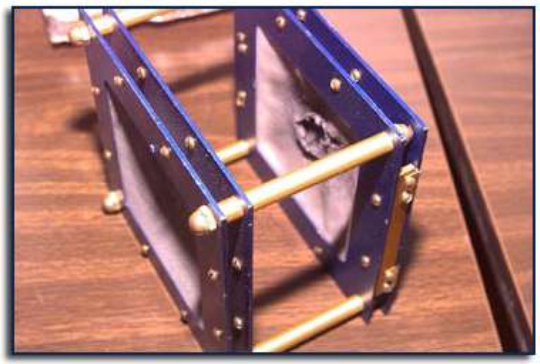
- **This technique is used to evaluate the protection ability of specific shield**

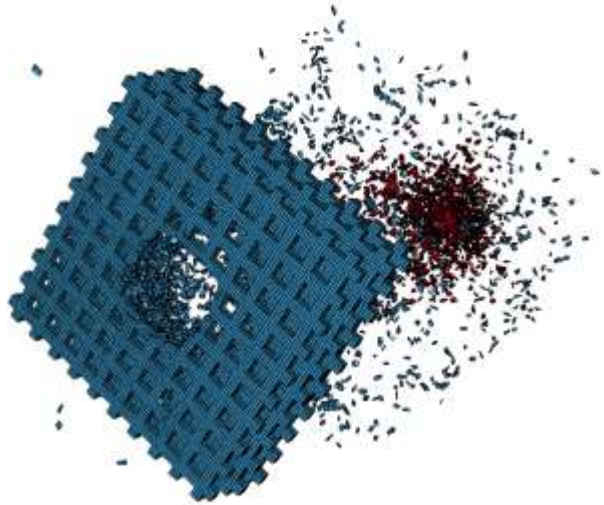


Whipple shield

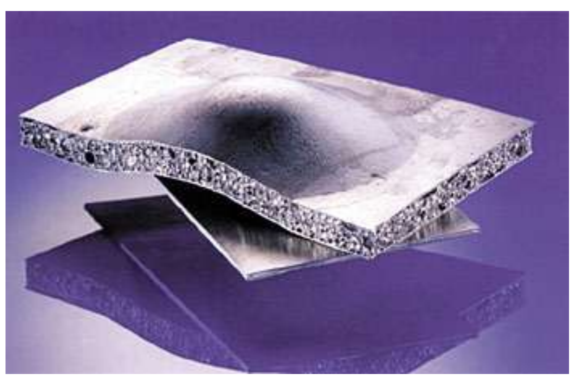
New concept shield

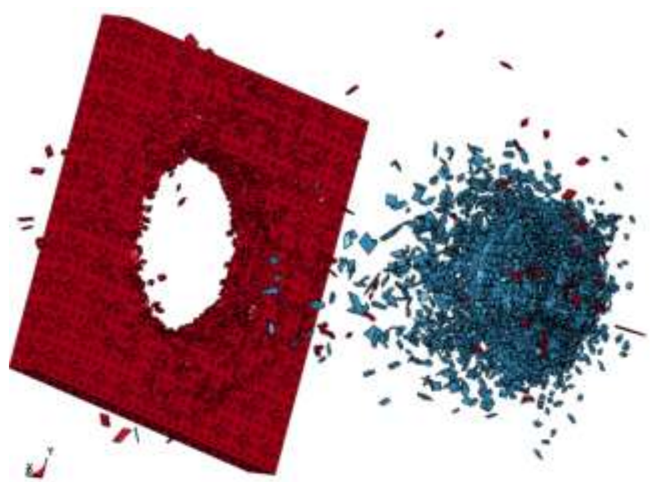
Multi-layer Aluminum net



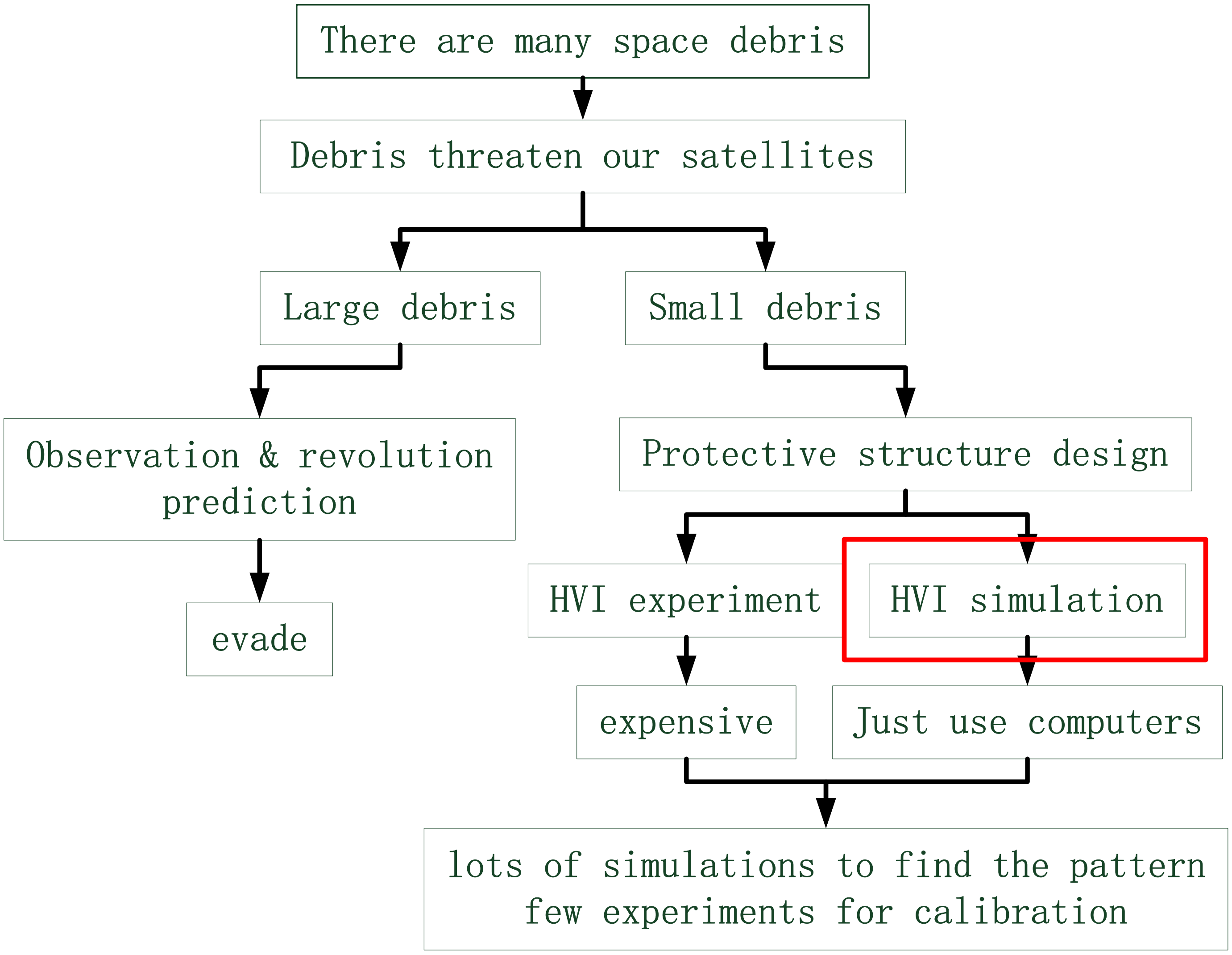


Aluminum foam





Summary

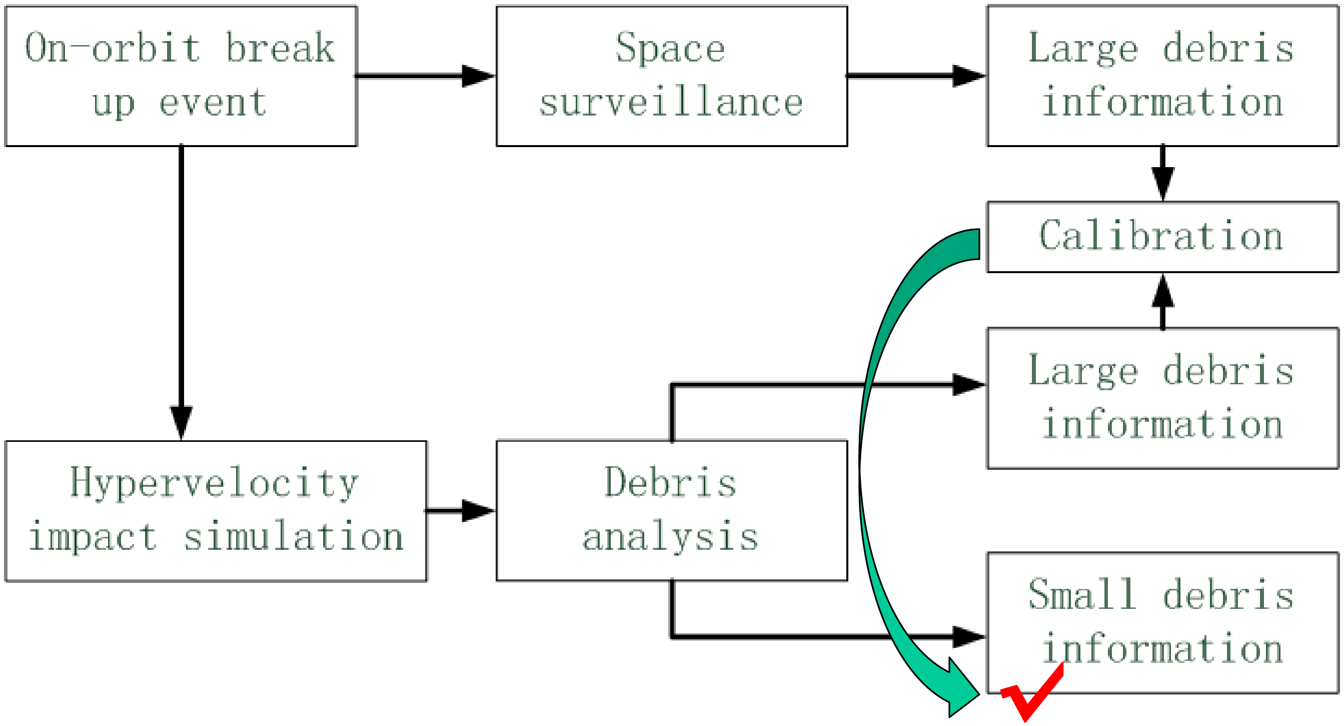


There are many space debris
Debris threaten our satellites
Large debris
Small debris
Observation & revolution prediction
Protective structure design
evade
HVI experiment
HVI simulation
expensive
Just use computers
lots of simulations to find the pattern
few experiments for calibration

Breakup model

- As more than half of the orbit debris are generated by collision and explosion.
- NASA presented a standard breakup model for the debris analysis generated by on-orbit collision or explosion.
- Since the main data source of creating NASA model is the space surveillance data, NASA model has much lower precision for small debris than that for large debris.

Main idea of this research



Use the observation large debris data to calibrate simulation large debris data, then the small debris data is closed to the reality.

2. Satellites collision simulation and debris analysis

I. Iridium33 and Cosmos2251 collision background

II. Simulation model

III. Debris analysis

I. Qualitative analysis

II. Quantitative analysis

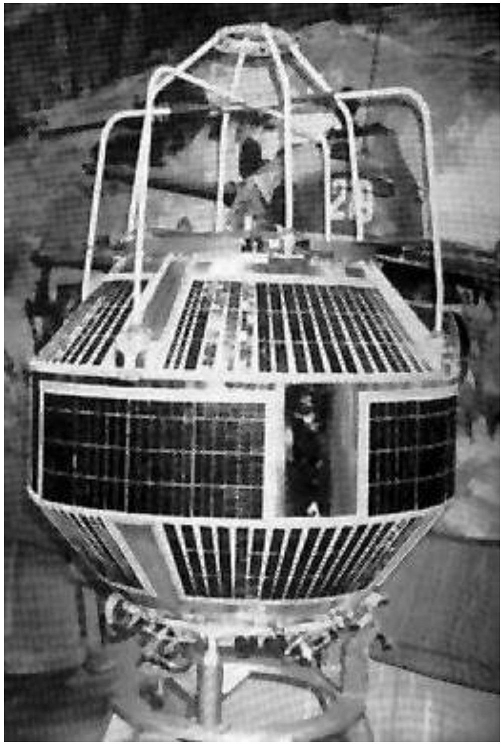
I. Fragment amount analysis

II. Fragment mass analysis

III. Fragment scattering angle analysis

IV. Conclusion

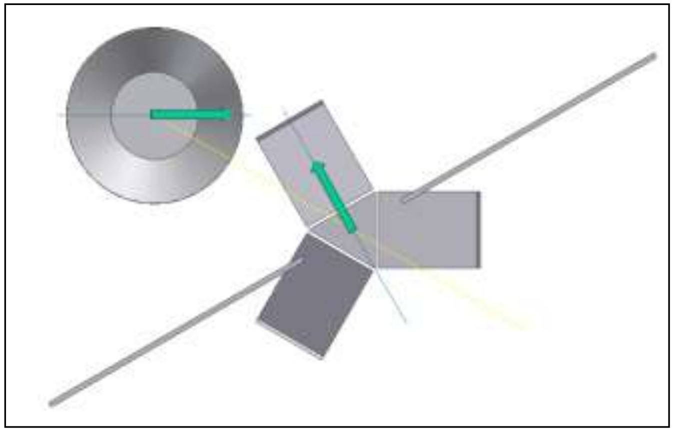
Collision of Iridium33 & Cosmos2251

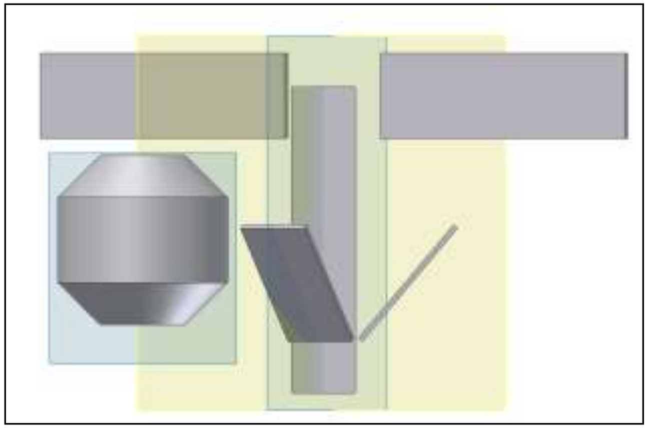


- **In an unprecedented space collision, a commercial communications satellite (IRIDIUM 33) and a defunct Russian satellite (COSMOS 2251) impacted each other on February 9th, 2009 above Northern Siberia, creating a cloud of debris.**
- **Till now, over 1719 large fragments have been observed.**

Satellite property

- Iridium 33 —— LM 700A (Lockheed Martin)
- Overall length: 3.6m   weight: 600kg
- Cosmos 2251 —— Strela-2M
- Height: 3m   diameter: 2m   weight: 900kg
- Absolute velocity of the two satellites are both 7.9km/s
- Angle of two orbit plane is about 105 degree.





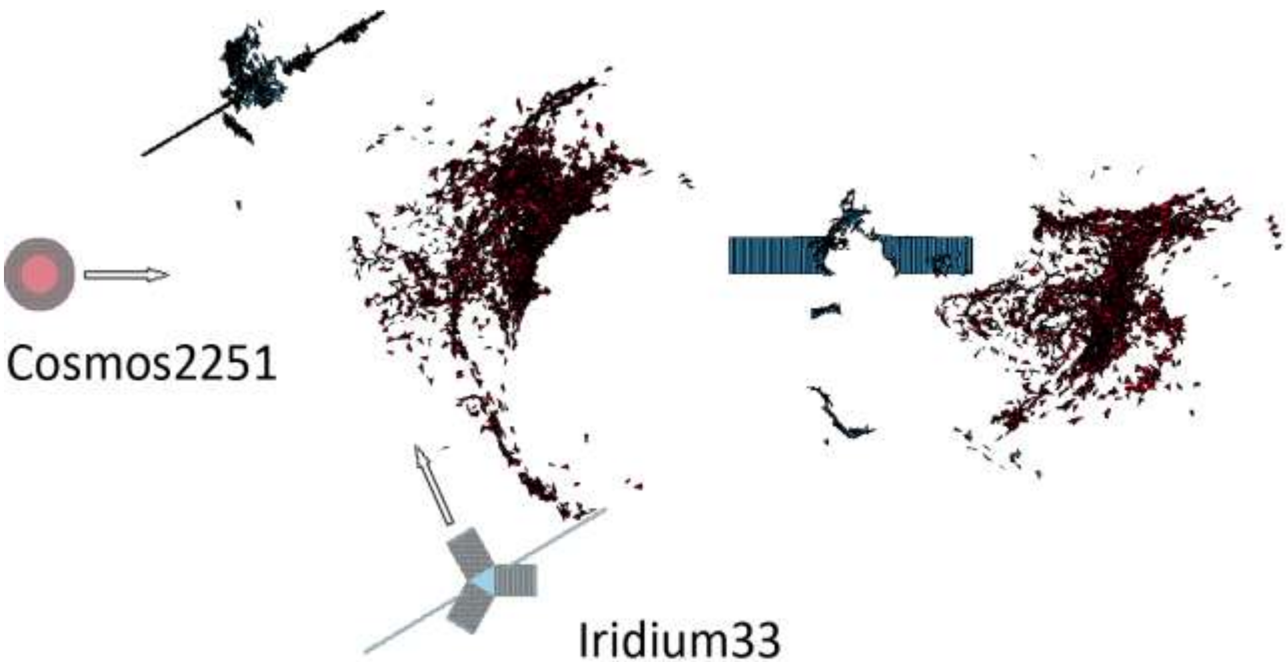
Simulation algorithm

- A mixed algorithm of finite element method (FEM) and smoothed particle hydrodynamics (SPH) method is used to simulate the collision process. Debris analysis method is applied based on that.
- You can find more details of the simulation and debris analysis method in this paper

  Xiaotian Zhang, Guanghui Jia, Hai Huang. Fragments Identification and Statistics Method of Hypervelocity Impact SPH Simulation[J]. Chinese journal of Aeronautics.
- We cannot actually observe the collision process on orbit. The way that we know the collision event is deferring from the suddenly increase of the debris population.

Qualitative analysis

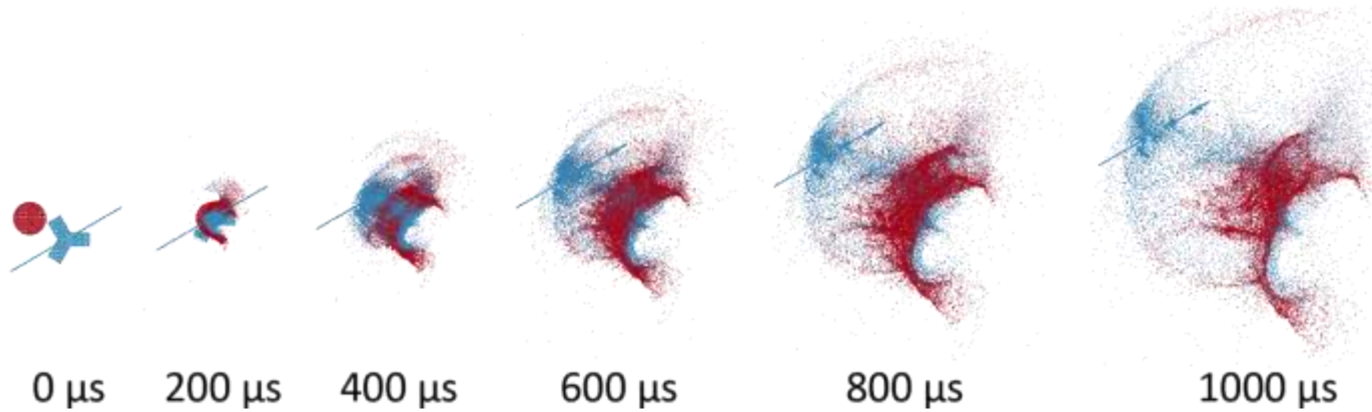
Since the impact location is unknown. Firstly we just assume that the satellites hit each other's centroid.



Large fragment view at 1ms after the impact

Most material of Iridium33 is converted into small debris while the large ones are mostly from cosmos2251.

Central impact simulation result (2)



small fragment view at 0-1ms after the impact

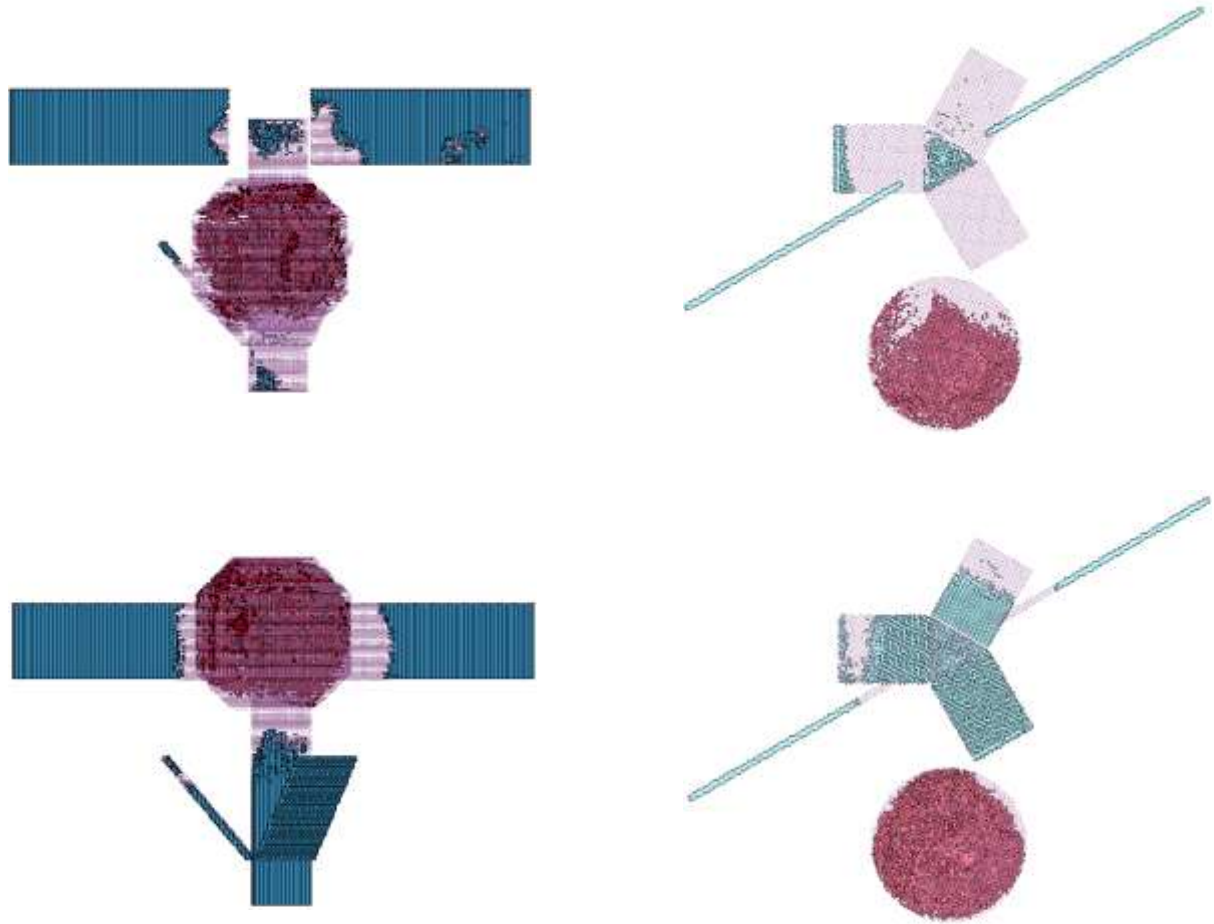
The amount of small debris is much more than large ones. The material flows over a large region, metal behaves like liquid in the process.

Cases comparison of different impact location

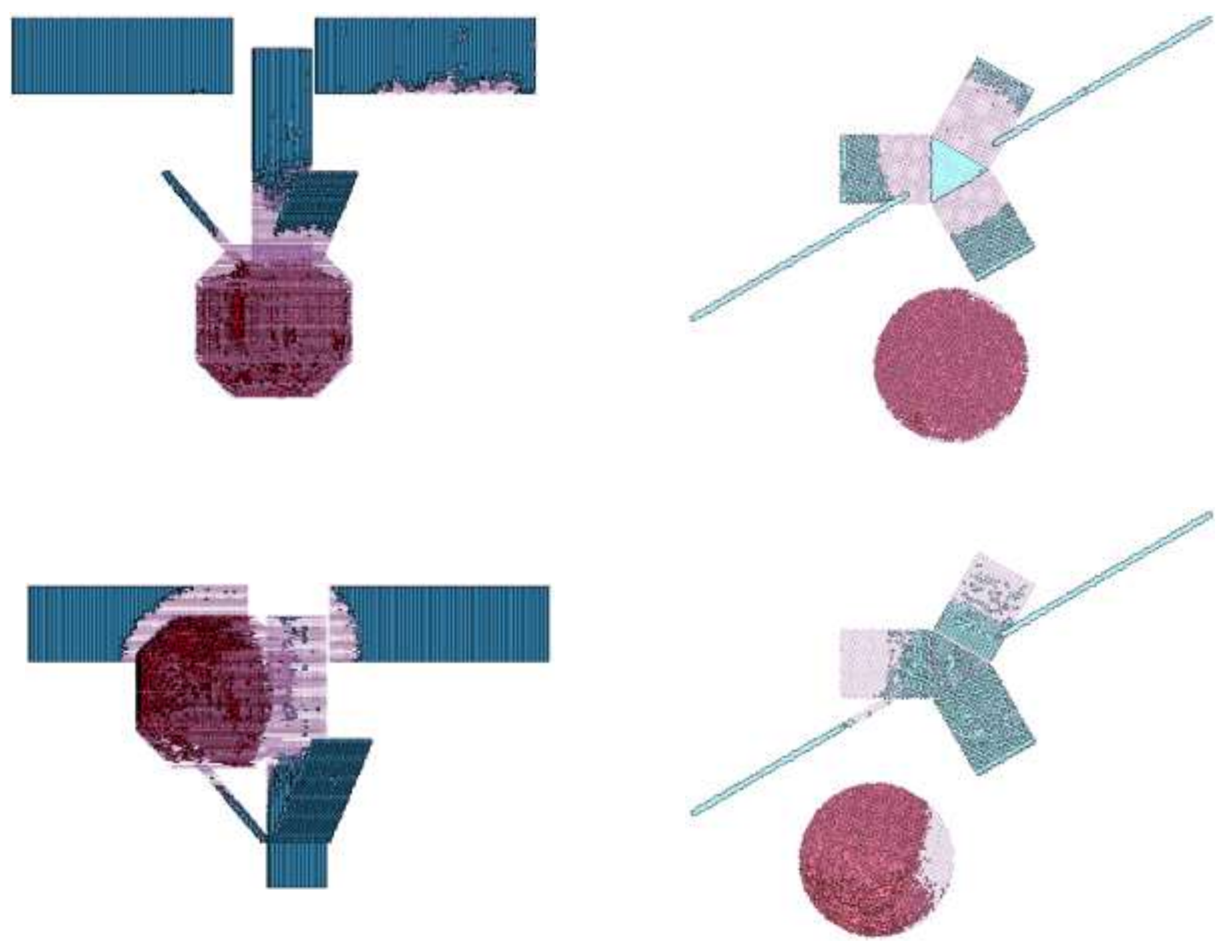
- 5 typical impact locations are compared
- Backward-graph is used to show the spall region of the satellites
- Backward-graph:

  Substitute the node coordinates in the large fragment view of the result with the original coordinates before the impact.

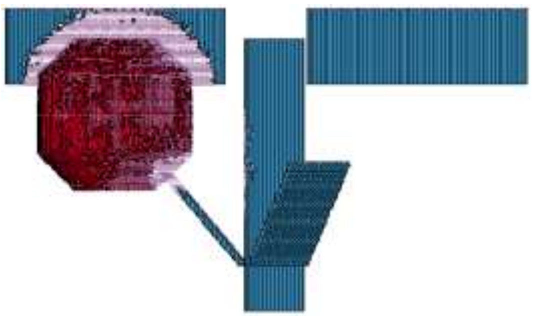
Backward-graph



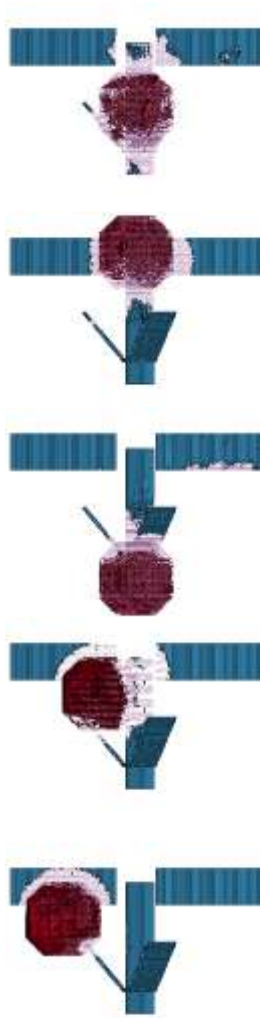
Backward-graph



Backward-graph



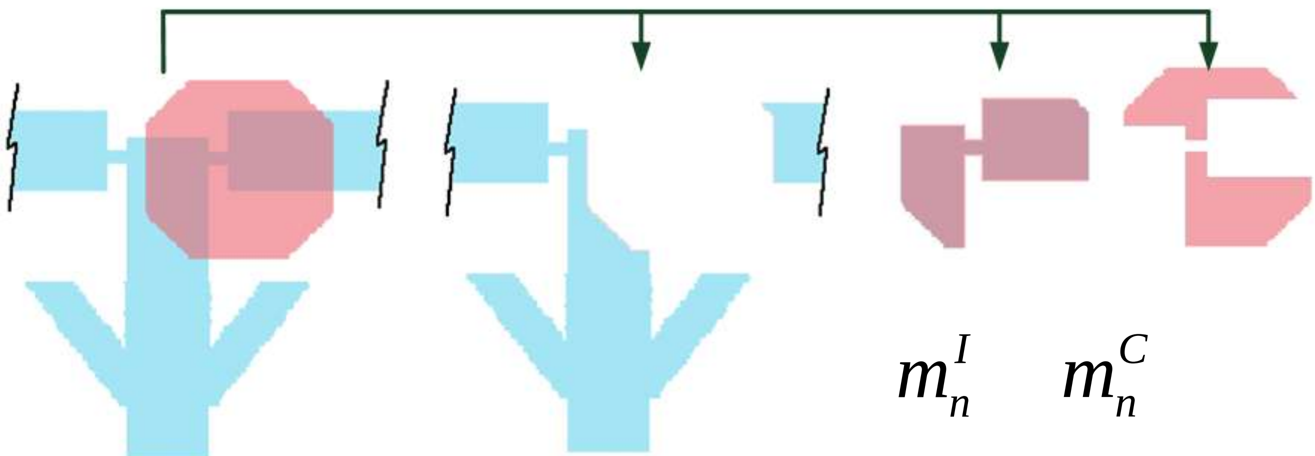
Cases comparison



- Comparing the 5 pictures left, material in the normal impact region mostly transforms into small fragments by impact; while large fragments consist of material not in the region.

Quantitative analysis

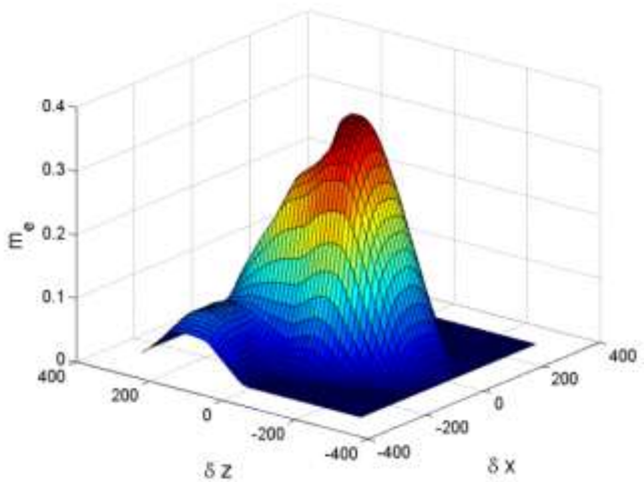
- Normal Impact Mass (NIM)

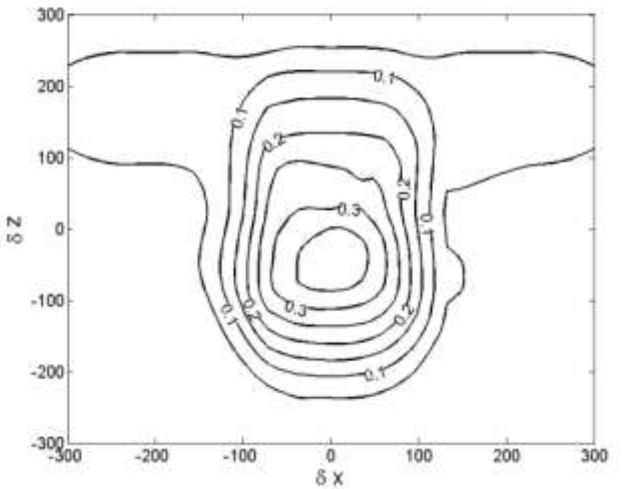


- Dimensionless Equivalent Normal Impact Mass (DENIM)

$$m_e = \frac{2\min\left(m_n^C, m_n^I\right)}{m^C + m^I}$$

DENIM distribution





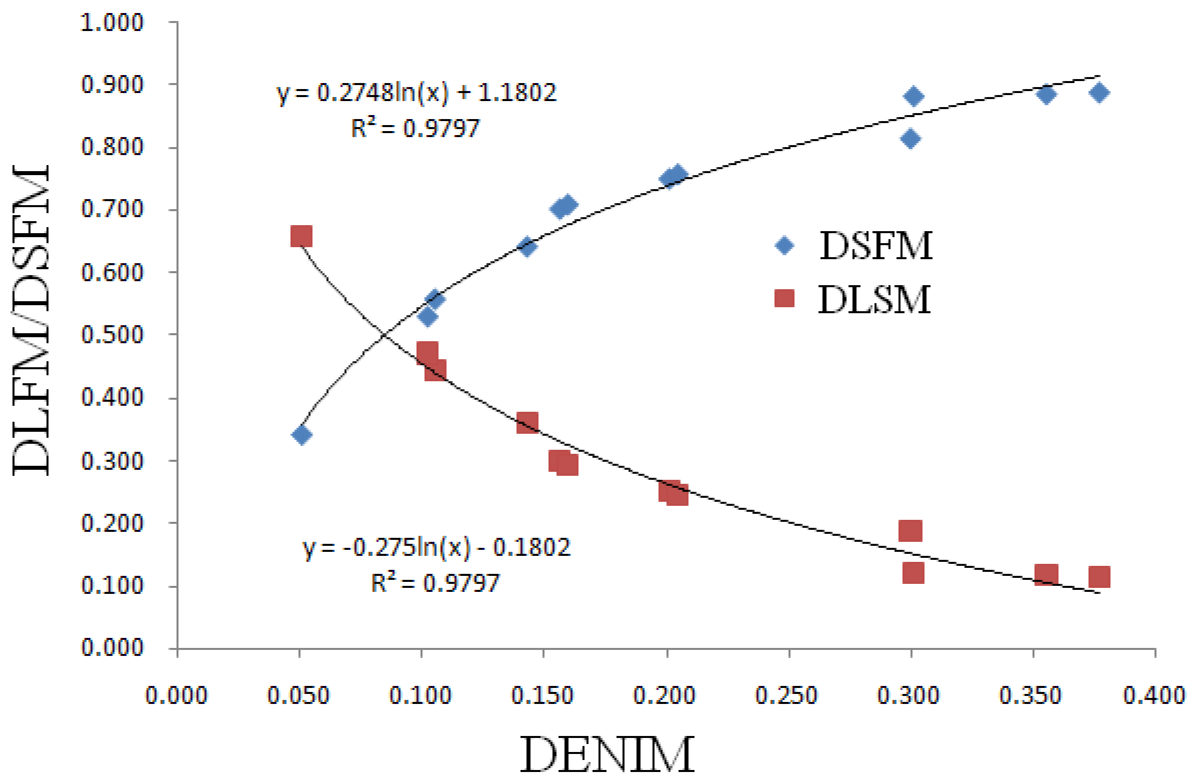
- Fixing the position of Iridium33 and change the impact location of Cosmos2251 we can get the DENIM distribution.
- The maximum number is 0.38.

Fragments statistics

No	δz (cm)	δx (cm)	Cosmos2251 NIM （kg）	Iridium33 NIM （kg）	DENIM	DSFM	DLFM	Fragment amount
1	0	0	589	266	0.36	0.88	0.12	1280
2	0	180	444	117	0.16	0.70	0.30	1288
3	0	-180	261	119	0.16	0.71	0.29	1204
4	-100	80	281	107	0.14	0.64	0.36	759
5	-200	80	238	38	0.05	0.34	0.66	379
6	-12	-36	586	283	0.38	0.89	0.11	1329
7	120	-96	170	79	0.10	0.56	0.44	428
8	84	204	437	76	0.10	0.53	0.47	706
9	48	132	568	151	0.20	0.75	0.25	1403
10	96	-72	331	153	0.20	0.76	0.24	749
11	-48	12	389	226	0.30	0.88	0.12	1537
12	-60	-84	337	225	0.30	0.81	0.19	1330

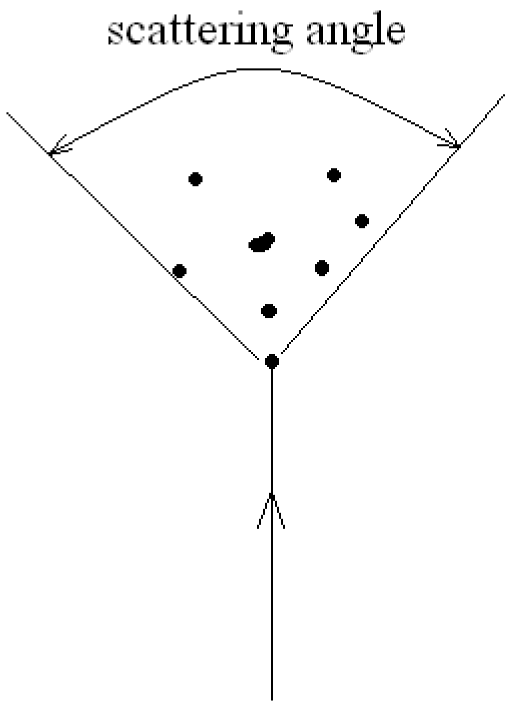
DENIM Dimensionless Equivalent Normal Impact Mass
DLFM Dimensionless Large Fragment Mass
DSFM Dimensionless Small Fragment Mass

DENIM determines DLFM and DSFM

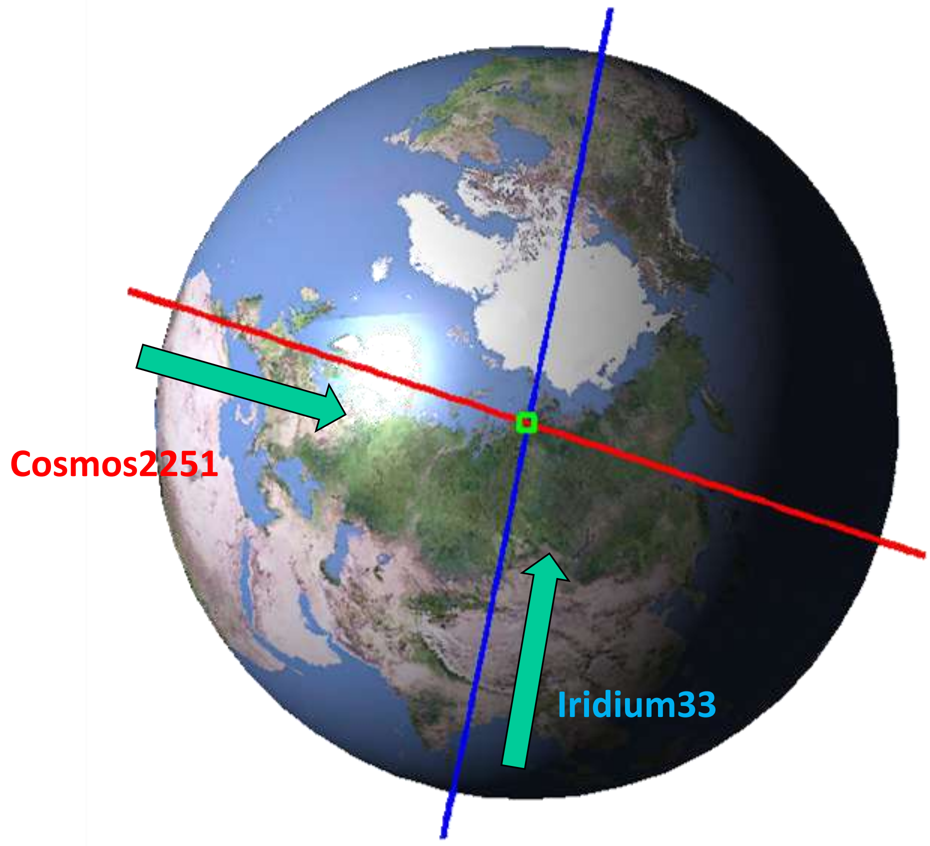


DENIM	Dimensionless Equivalent Normal Impact Mass
DLFM	Dimensionless Large Fragment Mass
DSFM	Dimensionless Small Fragment Mass

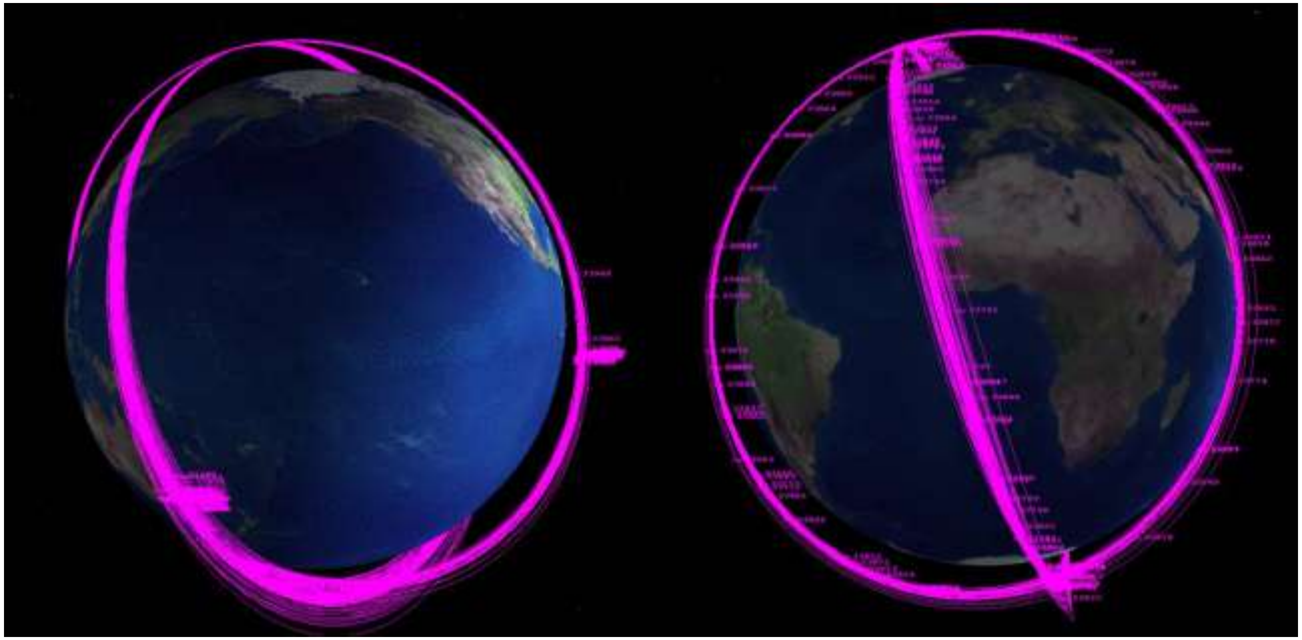
Scattering angle



Collision orbits



Large debris (>10cm) orbits



30 min   10 day

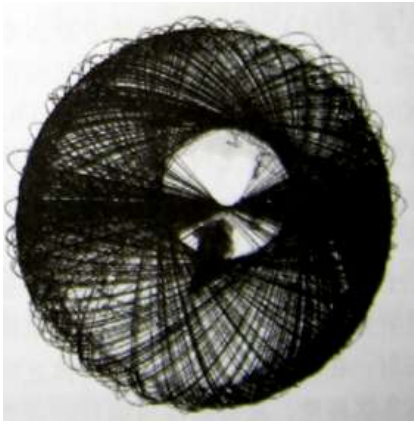
Dr. Geoffrey Forden
http://forden.armscontrolwonk.com/archive/2194/212-and-counting

Large debris (>10cm) orbits

1 week

3 month

1 year

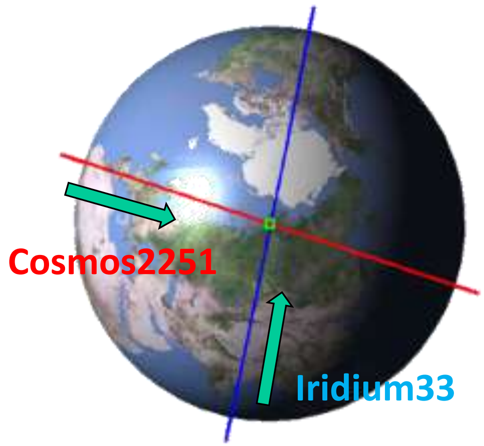


3 year

Dr. WANG Ting

Preliminary analysis on the collision event between Russian and American satellites[J]. Space Debris Research and Application. 2009,vol 9.

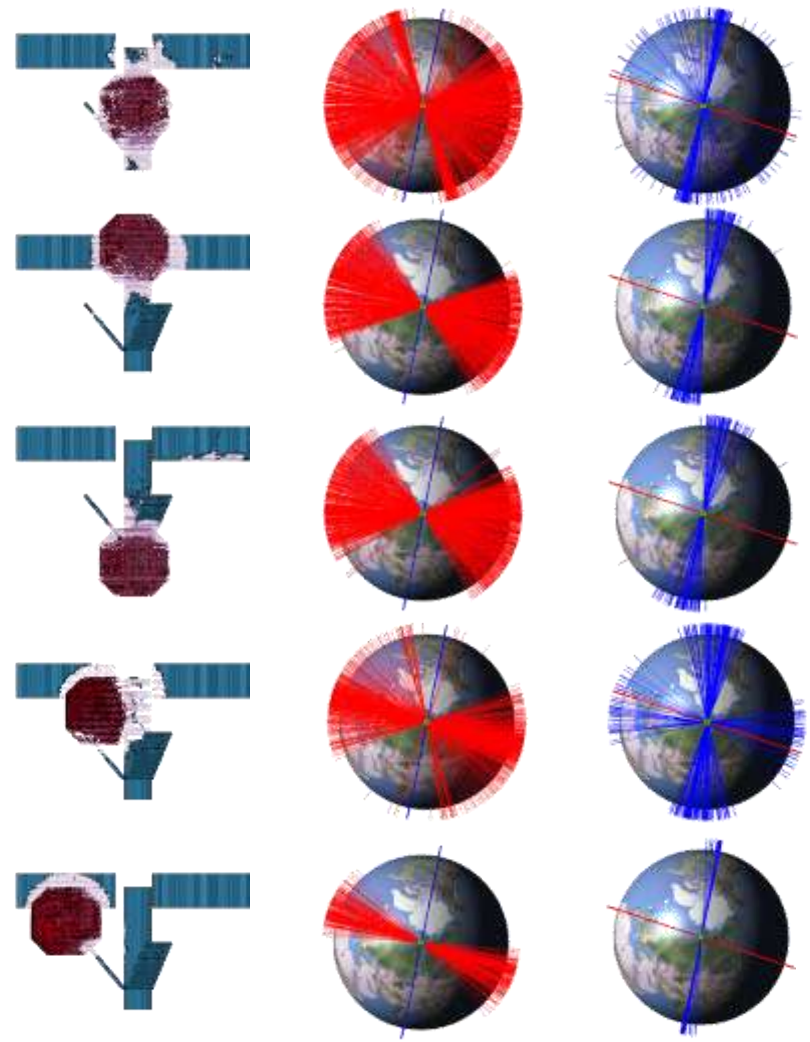
Debris orbits considering both large ones and small ones



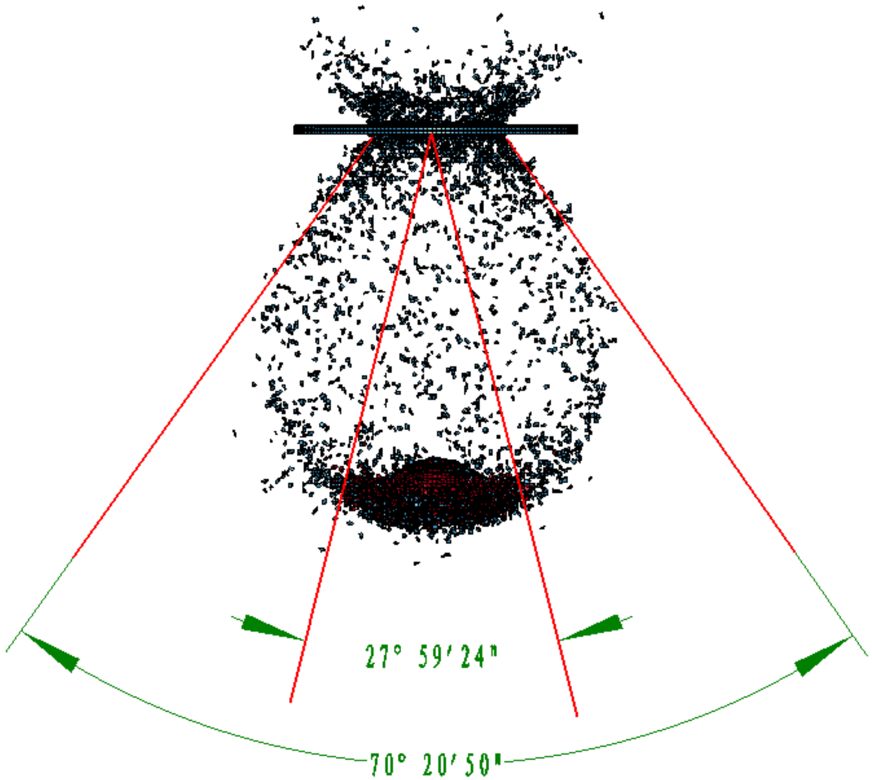
Debris orbits 1 hour after the collision including debris > 1cm.

It does not need 1-3 years.
Several hours are enough for the debris to spread over all LEOs.

Impact location | **Cosmos debris** | **Iridium debris**



Different scattering angle for large and small debris



The projectile hits the bumper at the speed of 6km/s.
The scattering angle for small debris is about 70 degree while that for large debris is about 28 degree.

Conclusion (1)

- ## Qualitative analysis

1. **Most material of Iridium is converted into small debris while the large fragments are mostly from Cosmos.**
2. **The amount of small debris is much more than large ones.**
3. **The material in the normal impact region mostly transforms into small fragments while large fragments are from the material far from that region.**

Conclusion (2)

• Quantitative analysis

- **Debris amount analysis**
  1. The amount from the simulation is close to the surveillance data.
  2. The amount of different impact location is not far from one another.
- **Debris mass analysis**
  1. The total mass of either large fragments or small fragments is determined by DENIM despite impact location.

Conclusion (3)

- **Quantitative analysis**
  - **Debris scattering angle analysis**
    1. Considering the small debris, scattering angle is much larger than that only considering large debris.
    2. Scattering angle is also related to DENIM and mainly determined by DENIM.
    3. Only several hours after the impact the debris will spread over all LEOs.

Thank you！