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Analysis of Close Approaches Between Small Satellites and Catalog Objects

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Presentation at

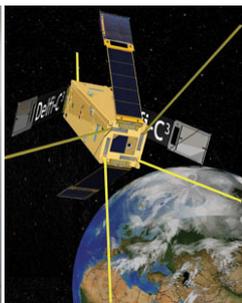
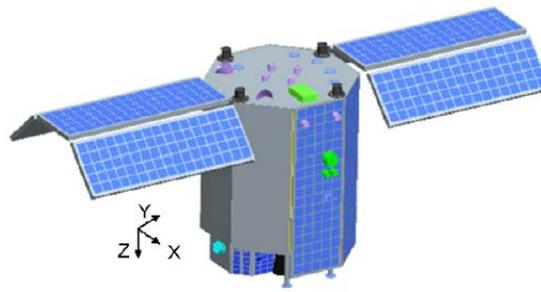
The 2011 Beijing Space Sustainability Conference,
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Outline

- 1. Introduction**
- 2. Spatial distribution of current ULM satellites**
- 3. Close approaches Analysis**
- 4. Collision probability estimation**
- 5. Conclusions**

1. Introduction

- Small satellites have been widely applied in many aspects of space activities.
- It can be anticipated that a large number of Ultra Low Mass (ULM) satellites (<15kg) will be launched to space in the next few decades, and these will become a potential source of orbital debris for lack of de-orbit capabilities.
- Collisions with debris larger than 10cm can seriously damage or destroy a satellite, which will then create large amount of fragments. The additional particles further increase the collision probability in the region, which leads a slow-motion chain reaction that could make some orbital regions unstable. The situation is called the **Kessler syndrome**.



1. Introduction(cont)

- To better preserve the near-Earth environment for future space generations, remediation measures, such as **space traffic management** and **active debris removal**, have been considered besides **space debris mitigation guidelines** by United Nations and national space agencies.
- Conjunction assessment could provide technical basis for potential small satellite traffic management solutions.
- With the growth in the number of small satellites, the **close approaches** and **collision rate** resulting from the increasing numbers of small satellites should be estimated.

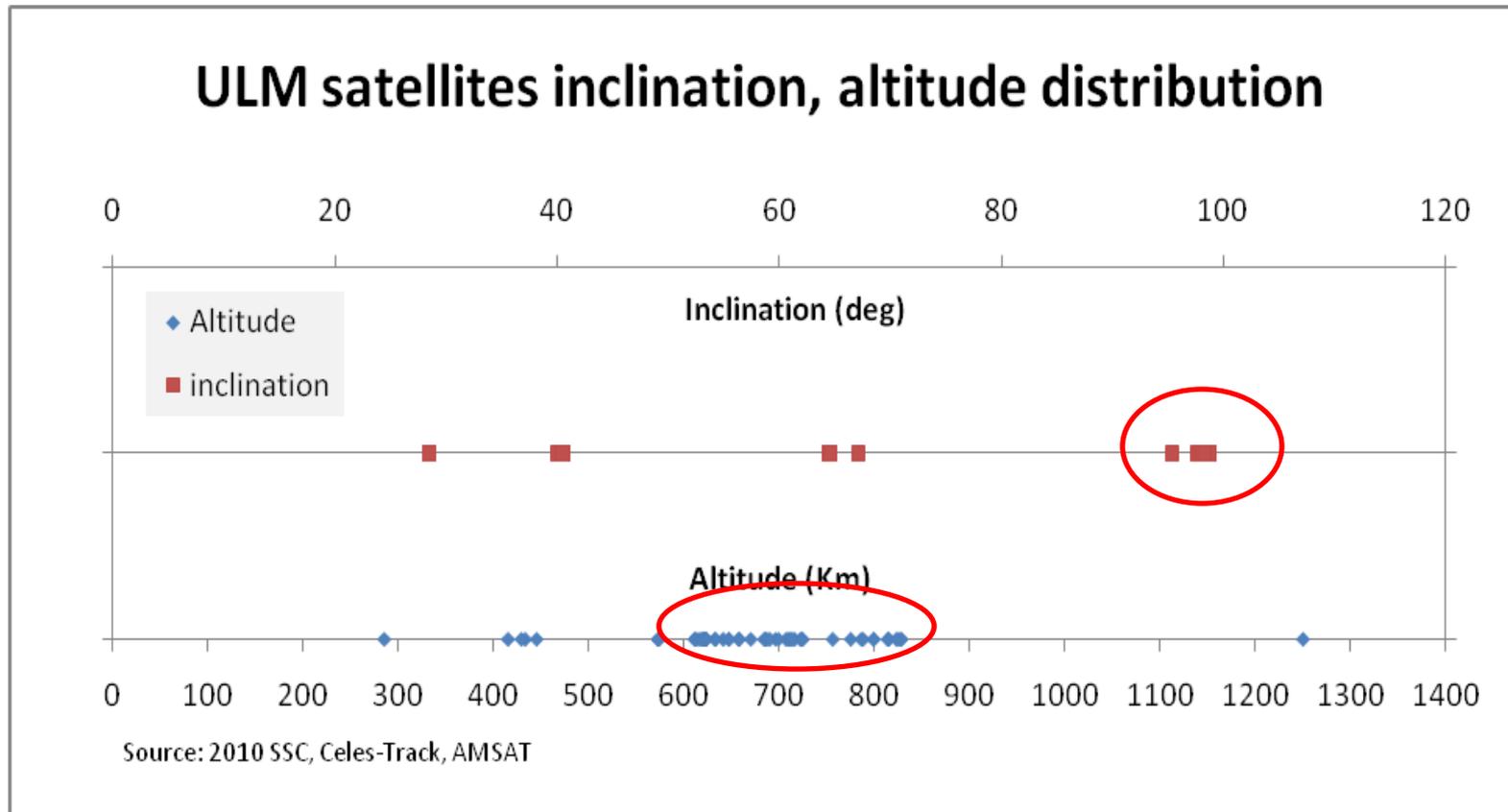


2.Spatial distribution of current ULM satellites

Class	Wet mass	Number of satellites	Orbit
Large satellite	> 1000 kg	553	384 in GEO
Medium sized satellite	500 – 1000 kg	127	119 in LEO (22 in SSO), 3 in GEO, 3 in MEO, 2 in Elliptical
Mini-sat	100 – 500 kg	147	137 in LEO (26 in SSO), 8 in Elliptical, 2 in GEO,
Micro-sat	15 – 100 kg	66	All in LEO (23 in SSO)
Ultra-low mass satellite	<15kg	38	All in LEO (32 in SSO)

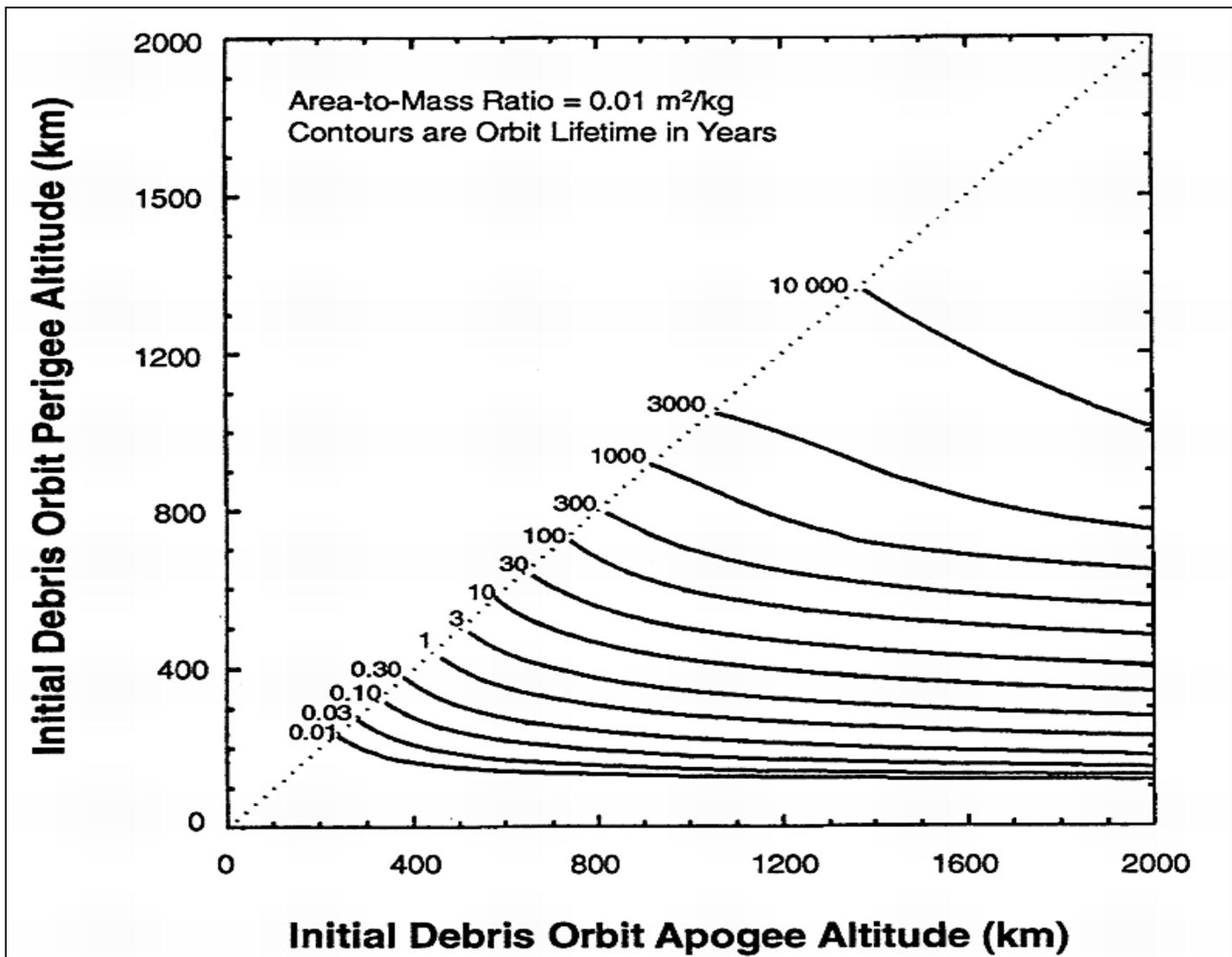
http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/ucs-satellite-database.html

2.Spatial distribution of current ULM satellites



Ultra-low mass satellites inclination, altitude distribution

<http://swfound.org/media/23310/weeden%20%20smallsat%20space%20traffic%20management.pdf>



Orbital lifetime as a function of altitude

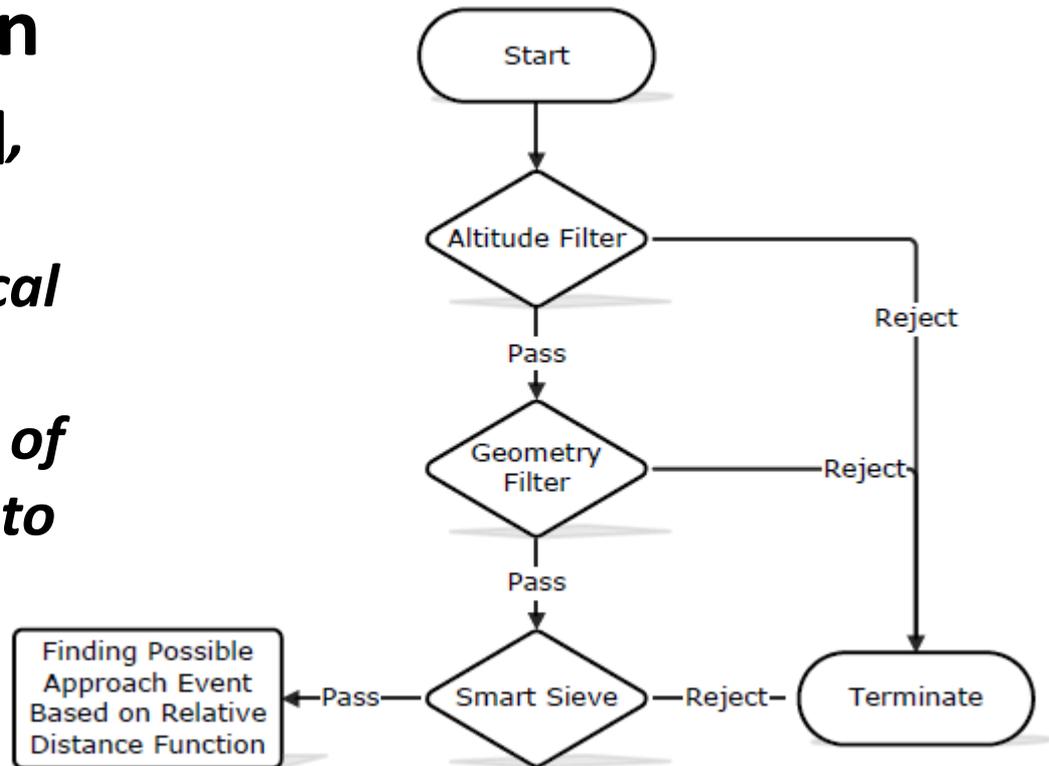
Jehn, R., 2007, 'The Space Debris Problem', Lecture at International Space University Summer Session, Beijing, China, 2007.

3. Close approaches Analysis

A. Modeling tool

Problem description

At a given time span $[t_B, t_E]$, whether two objects are within some specified critical distance D . If they are, the minimal distance and time of close approach is required to be calculated.



Calculation process (Presented by Ting W.)

3. Close approaches Analysis

B. Conjunctions of current debris environment

Case 1: conjunctions of current SSN catalog against itself.

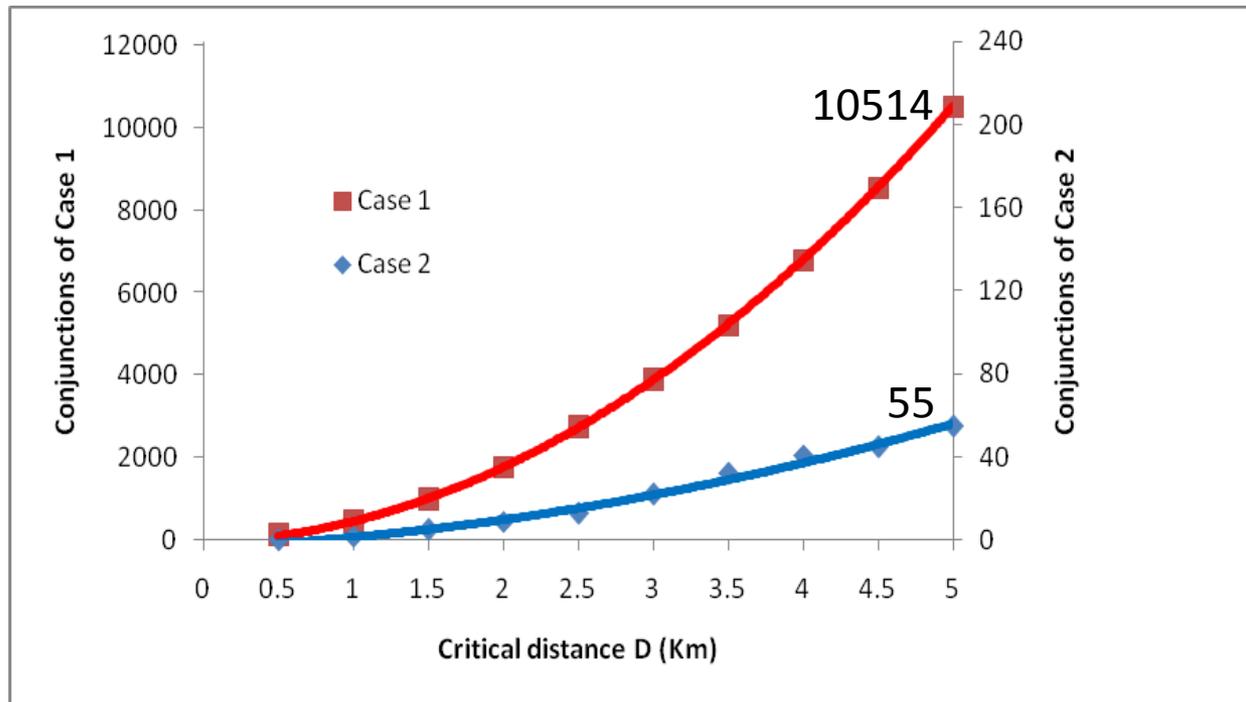
Case 2: operational ULM satellites against the catalog

Time: from 0:00, July 7, 2011 to 0:00, July 8, 2011

Catalog: unclassified historical NORAD TLEs, which have more than 14000 space objects.

3. Close approaches Analysis

B. Conjunctions of current debris environment



Cumulative distribution of conjunctions as function of critical distance

$$N_o = \left(\frac{D_o}{D_1}\right)^2 N_1$$

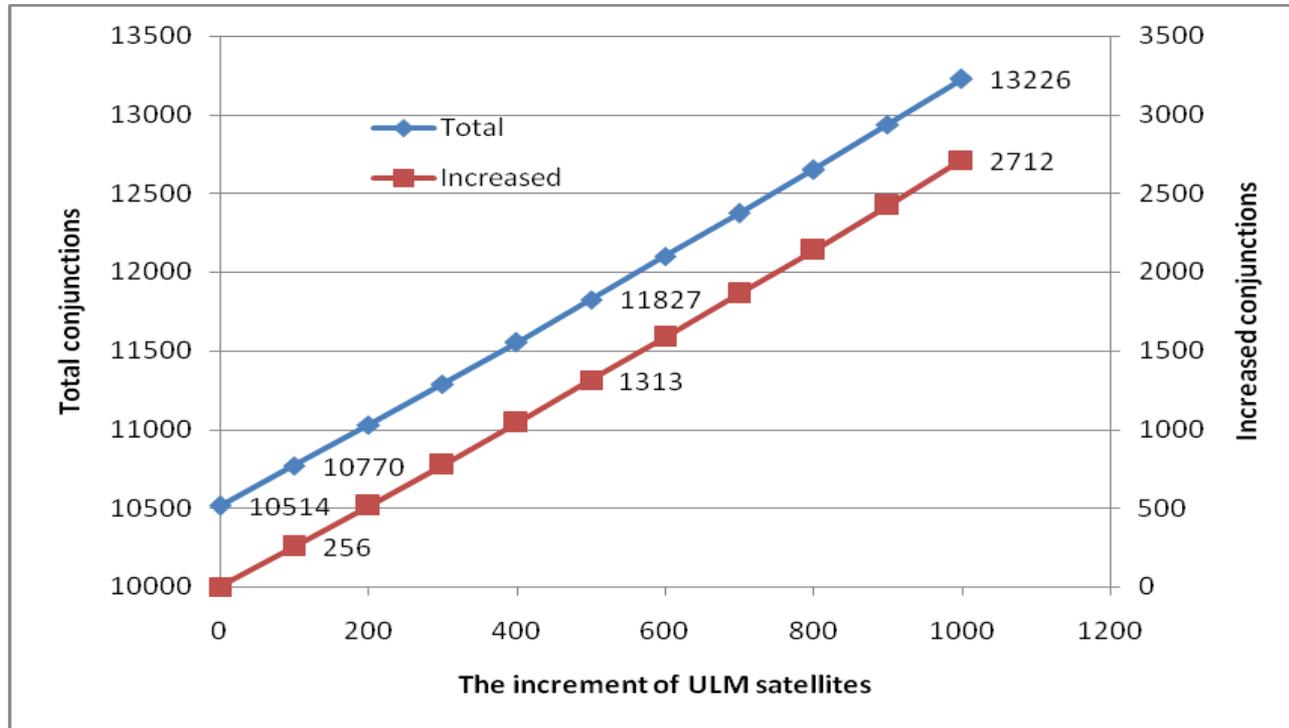
How this situation changes with a future increase in the ULM population in this region?

3. Close approaches Analysis

ULM satellite population growth scenarios

- We assumed that there will be a rapid growth of ULM satellites in LEO. Varying numbers of ULM satellites are deployed into LEO, which are all in **SSO** with zero eccentricity. The altitudes of them range between **600km** and **900km**. The right ascension of the ascending node, argument of perigee and mean motion are randomly generated.
- **No other launches and no future breakups.**
- Using the SSN catalog of July 7, 2011, we calculated conjunctions of updated databases against themselves during one day, with the increment of ULM satellites from **100** to **1000**. Each scenario included 100 runs.

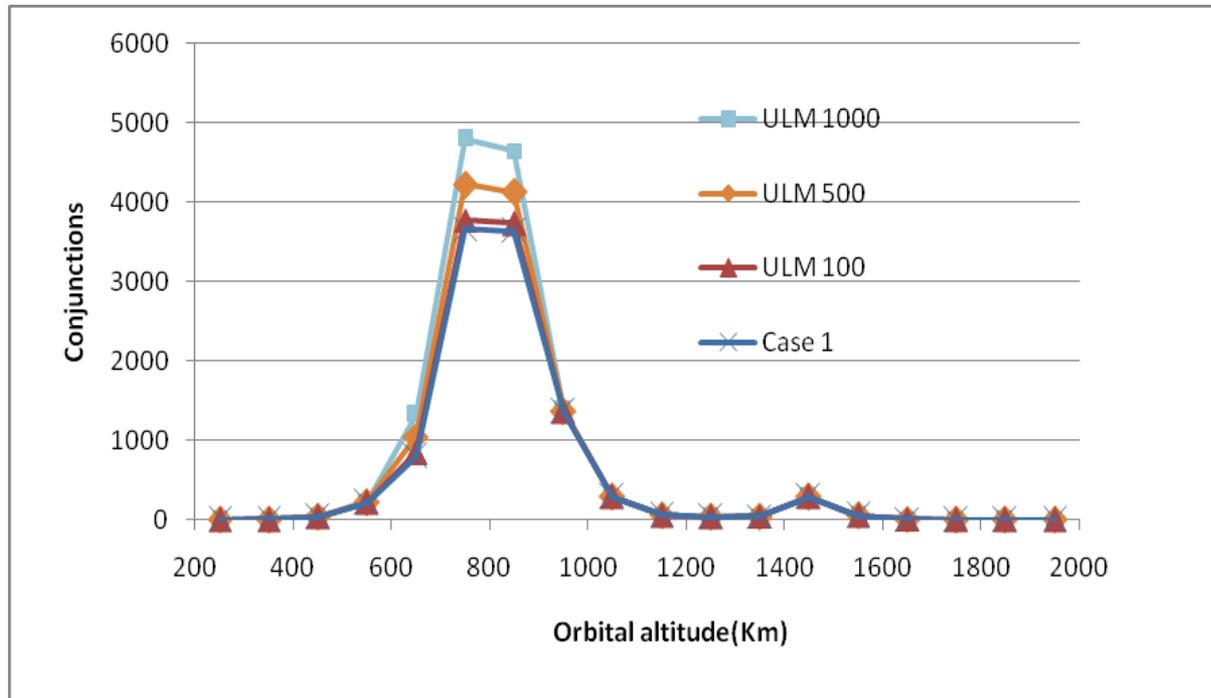
3. Close approaches Analysis



D=5Km

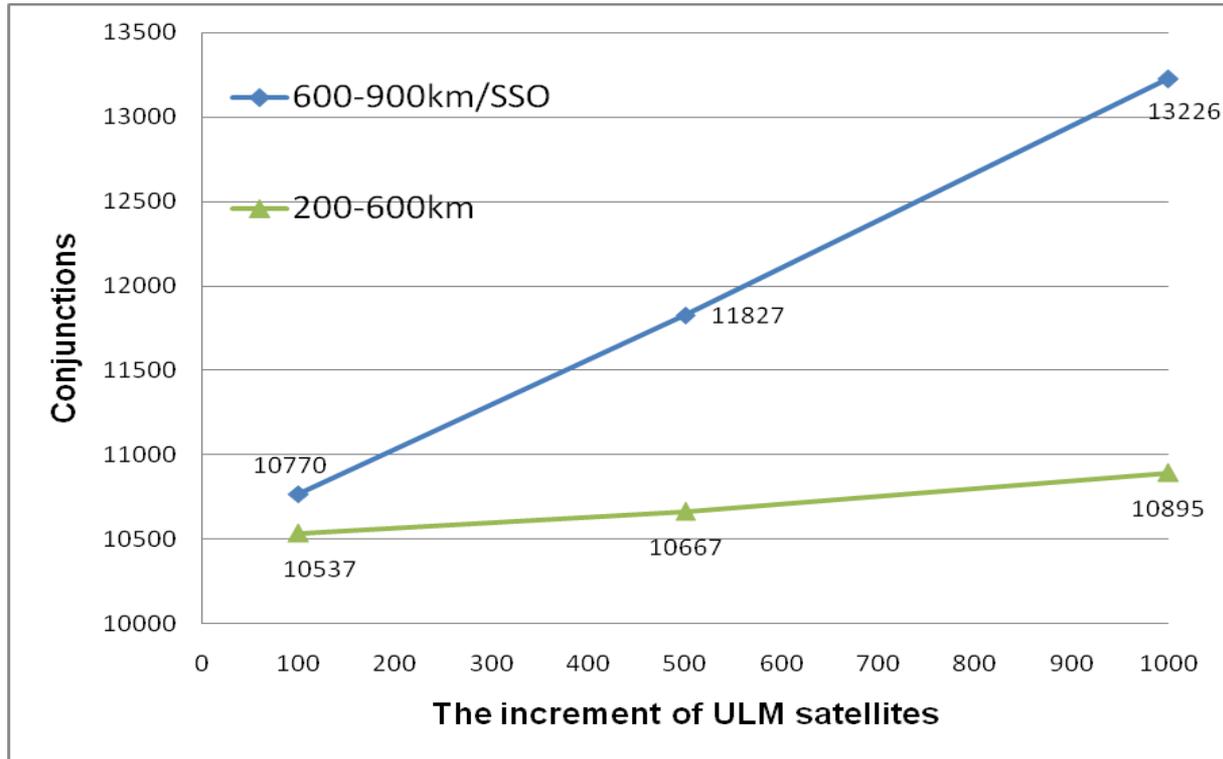
Conjunction numbers with growth of ULM satellites

3. Close approaches Analysis



**Comparison of altitude distributions of four different scenarios.
From top to bottom: 1000 ULM satellites growth, 500 ULM satellites growth, 100
ULM satellites growth, case 1.**

3. Close approaches Analysis



Comparison of ULM satellites growth in different altitude bands

4. Collision Probability Estimation

- ***Estimation method***

The method is based on two assumptions:

- ◆ Collision flux f around each object is same;

(Note: f , is defined as the number of debris which pass $1m^2$ impact cross section and time span of interest is one year)

- ◆ An object will only be impacted by objects that among close approaches.

4. Collision Probability Estimation

$$N_o = \left(\frac{D_o}{D_1}\right)^2 N_1$$

Mean collision number between all LEO catalog objects

$$C_{LEO} = f_{LEO} S_{mean} t$$

$$S_{mean} = \pi d_{mean}^2$$

Collision flux of LEO

Mean distance of all LEO objects

$$f_{LEO} = N_{D,LEO,\Delta t} / (\pi D^2 \Delta t)$$

$$D_{mean} = \sqrt{\frac{\sum_{k=1}^K (r_i + r_j)^2}{K}}$$

r_i, r_j : the size of objects.

4. Collision Probability Estimation

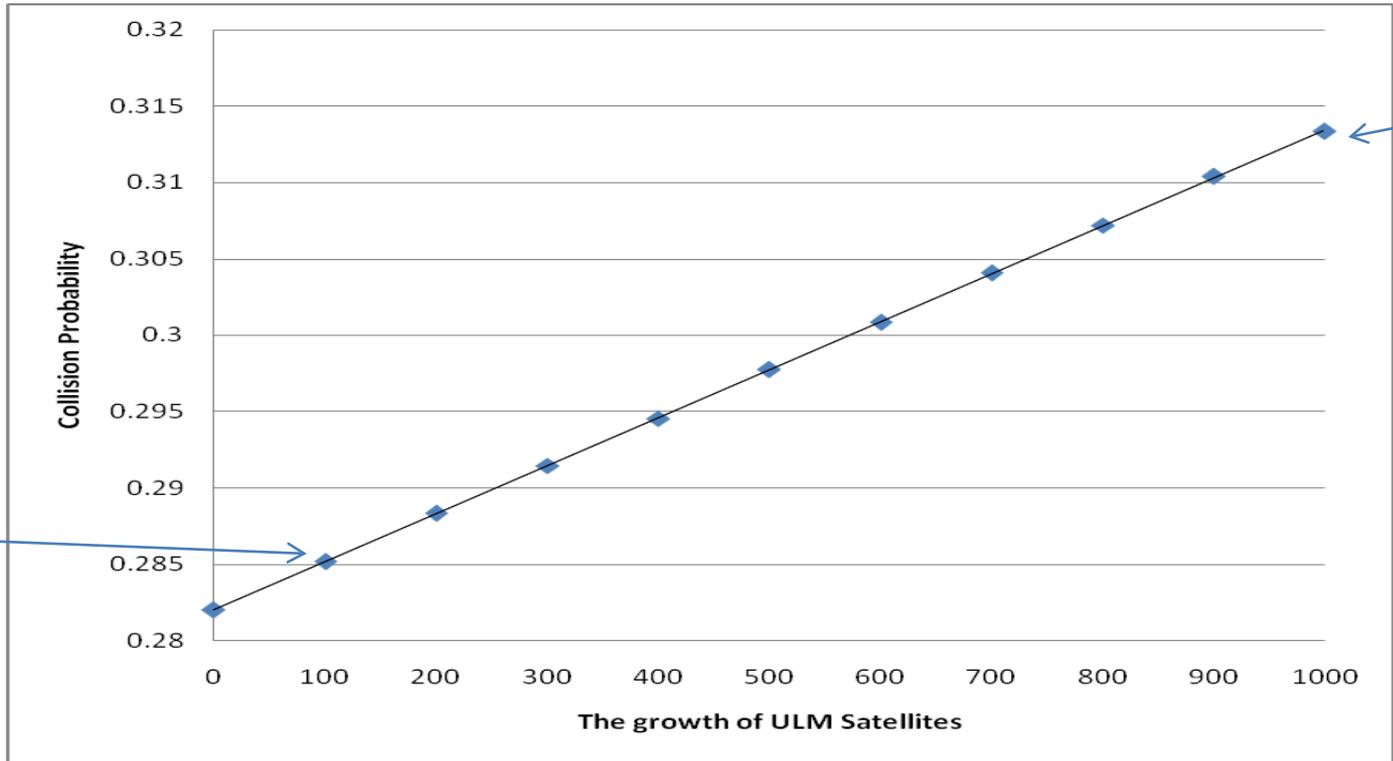
According to probability theory, the collision probabilities between catalog objects submit to Poisson distribution. The collision probabilities of a object impacted by k debris should be:

$$p_k \{X = k\} = \frac{e^{-\lambda} \lambda^k}{k!} \quad \text{where} \quad \lambda = c_{LEO}$$

When $k=0$, it means that the object is not impacted by other debris. Therefore, the collision probability of the object impacted by at least one debris is:

$$p_1 = 1 - e^{-\lambda}$$

4. Collision Probability Estimation



↑ 1.1%

From 0.282 to 0.285

← 11% ↑

Collision probabilities with growth of ULM satellites

5. Conclusions

- All current ULM satellites in orbit are deployed in LEO, and most of them are in Sun Synchronous Orbits (SSO), which are concentrated in altitude band from 600 to 900km.
- The increase in close approaches between the existing catalog and further ULM satellites populations is closely related with orbital altitude. It could be suggested to ULM satellites designers to avoiding 600~900Km orbit altitude, especially 700~900 Km.
- The collision probability will increase more than 10% if 1000 ULM satellites were deployed to heavily used LEO orbital altitude. It means that the number of future ULM satellites which orbits are designed as heavily used orbital band should be controlled to an appropriate level so as to suppression the collision probability.

Thank you!

Q & A