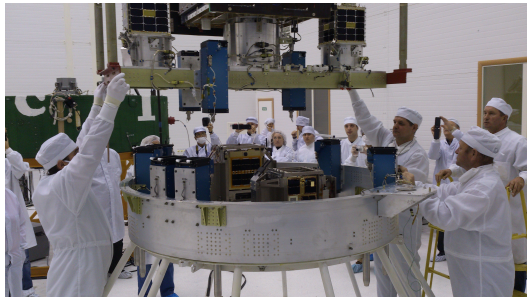
Long-term performance analysis of NORAD Two-Line Elements for CubeSats and PocketQubes

S. Speretta, P. Sundaramoorthy, E. Gill

ISC Kosmotras



Content

- Miniaturization and space debris
- Real case analysis
- Small satellite tracking performances
- Conclusions

Ready, steady, go!

Introduction

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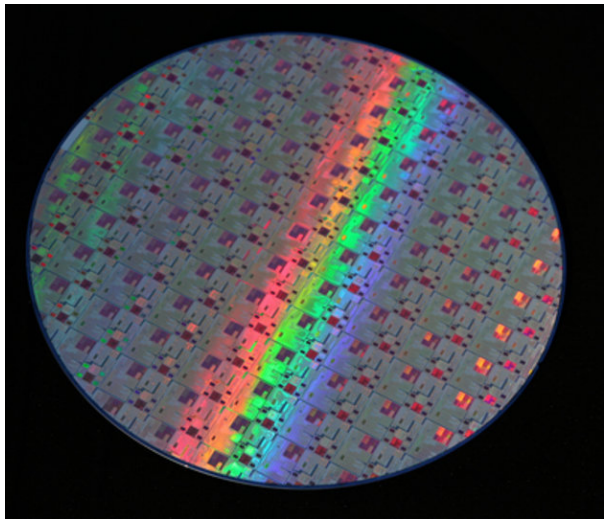
- Spacecraft Miniaturization
  - CubeSats came ~20 years ago!
  - What is the minimum size for something useful?
  - 10 cm is the smallest trackable object!
- Is it still all true now?
  - Smaller form factors have been suggested
  - Micro-electronics progressed tremendously
  - What about objects tracking?



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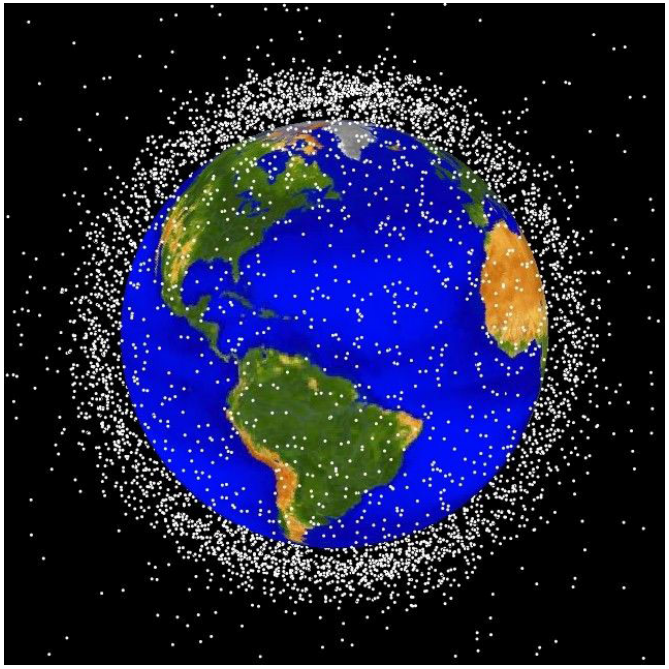
Introduction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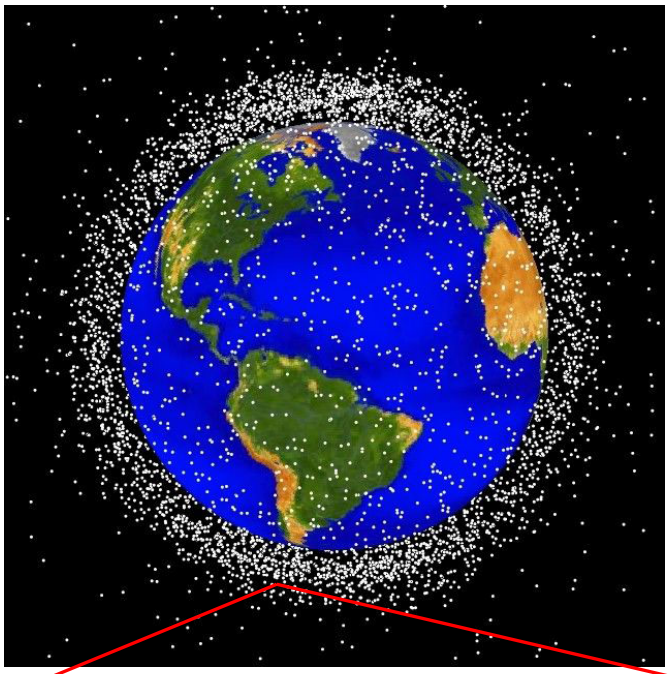
- Space debris is a big problem
  - 29k - for sizes larger than 10 cm
  - 670k - for sizes larger than 1 cm
  - >170M - for sizes larger than 1 mm

Estimation!

- What is the impact that satellites have in there?

Introduction

- Space debris is a big problem
- What is the impact that satellites have in there?
  - Is miniaturization a problem?
  - Mega-constellations?



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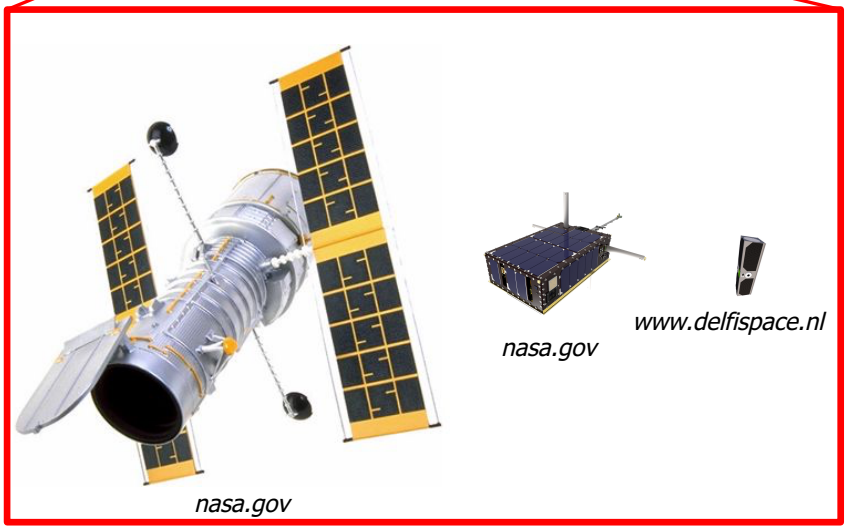

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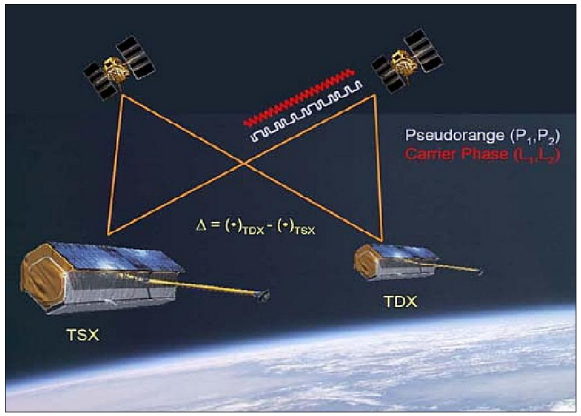
Spacecraft orbit determination

1-way ranging



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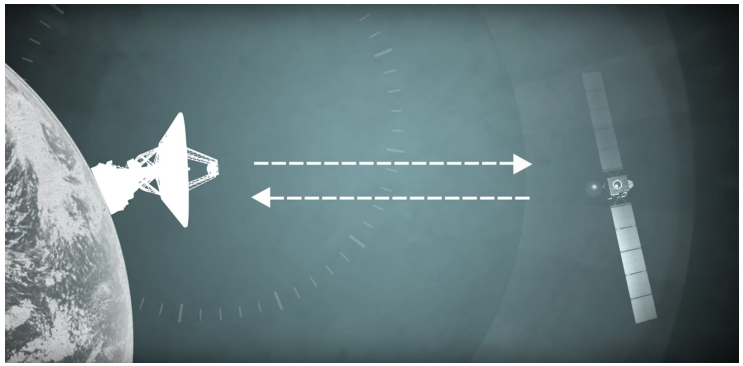
Radar

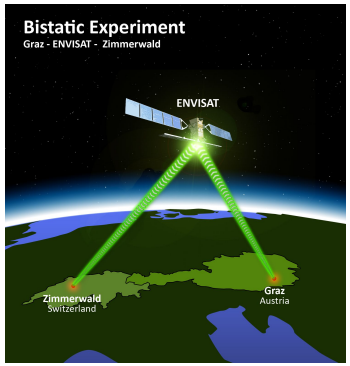
USAF - NORAD

2-way ranging



Islam Alyafawi

Laser



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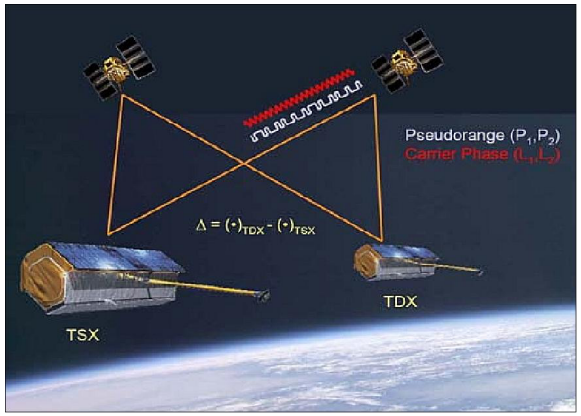
What about pico-/femto-satellites?

1-way ranging ?



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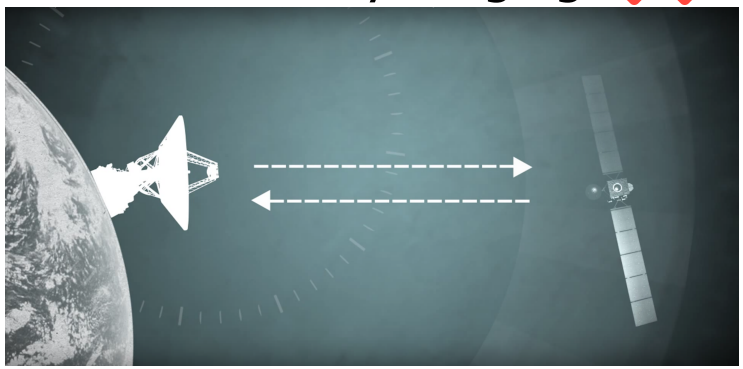
Radar ✓

USAF - NORAD

2-way ranging ✗



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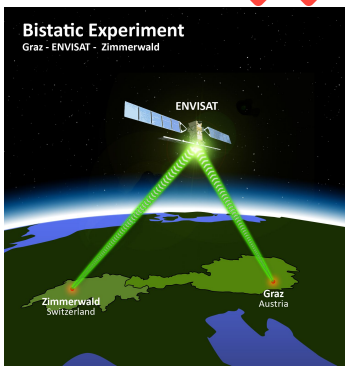

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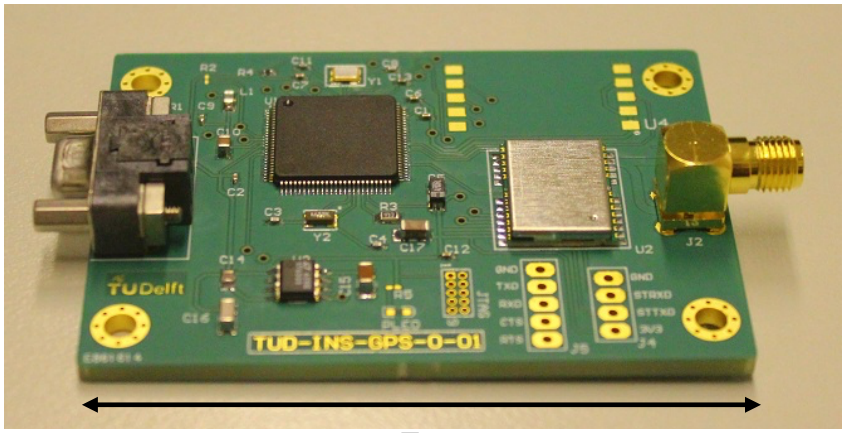
What about pico-/femto-satellites?



7 cm

- TLEs are the main way
  - Very practical
  - Low accuracy (> 1km)
  - **Is accuracy dependent on satellite size / radar cross-section?**
  - **Is update rate dependent on satellite size / radar cross-section?**
- 1-way and 2-way ranging demonstrated on CubeSats
  - ~ 0.5 km accuracy (2-way)
  - GPS for femto-sats available, no flight heritage
- Laser ranging
  - Not demonstrated yet

Data set

- Dnepr-19 launch (Nov 21st 2013)
  - 590 x 760 km, ~98°
  - 30 satellites deployed
  - 4 PocketQubes
    (from 5x5x5 cm to 5x5x12.5 cm, 1P to 2.5P)
  - 18 CubeSats
    (1U to 3U)
  - 1 small satellite
    (1.5x1.5x1.95 m)
- Only launch to date with PocketQubes
- Perfect test case for size comparisons

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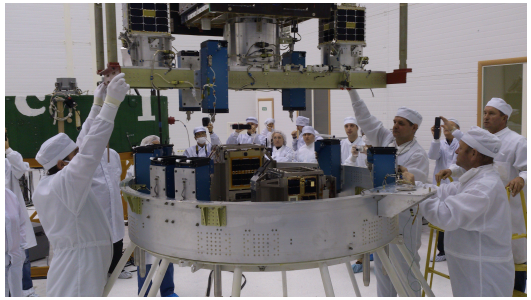
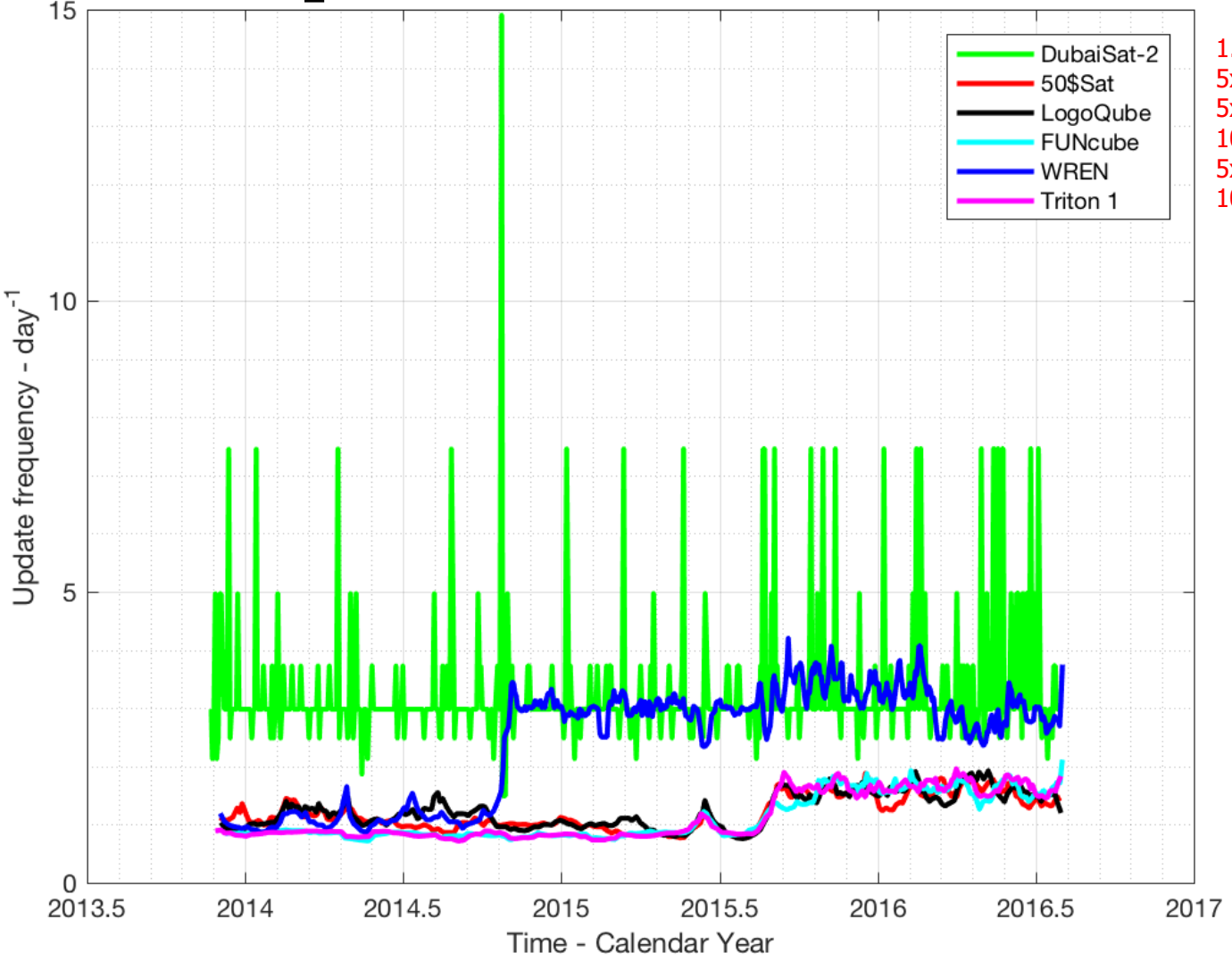


TLE update rate



1.5x1.5x1.95 m
5x5x7.5 cm (1.5P PocketQube)
5x5x12.5 cm (2.5P PocketQube)
10x10x11.4 cm (1U CubeSat)
5x5x5 cm (1P PocketQube)
10x10x34.2 cm (3U CubeSat)

TLE update rate

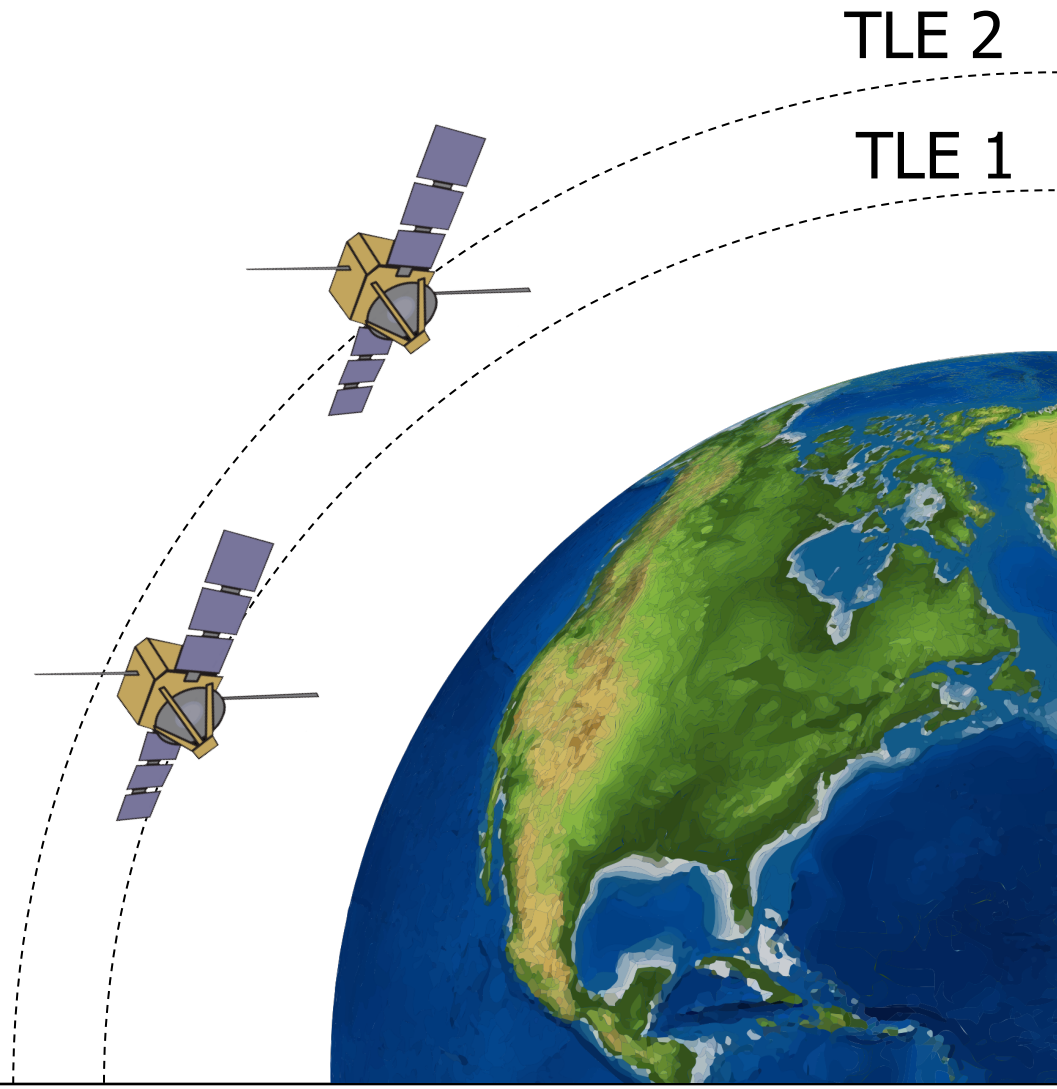
- "New element sets are generated by NORAD on an as-needed basis rather than according to an established timetable" (Celestrak)
- 10 cm side considered by many the smallest detectable by NORAD
- **All objects (even smaller than 10 cm) get 1-3 TLE / day**
- TLE update rate **cannot** be considered a problem for very small objects

TLE self-consistency

- Established technique to provide a variance estimate of TLE error
  - Useful when no reference measurement is available (GPS, ranging, etc…)
  - Only looks at the position difference between multiple orbital elements sets
- The error depends on
  - Propagation errors (larger for low update rates)
  - Position errors (depends on RADAR accuracy)

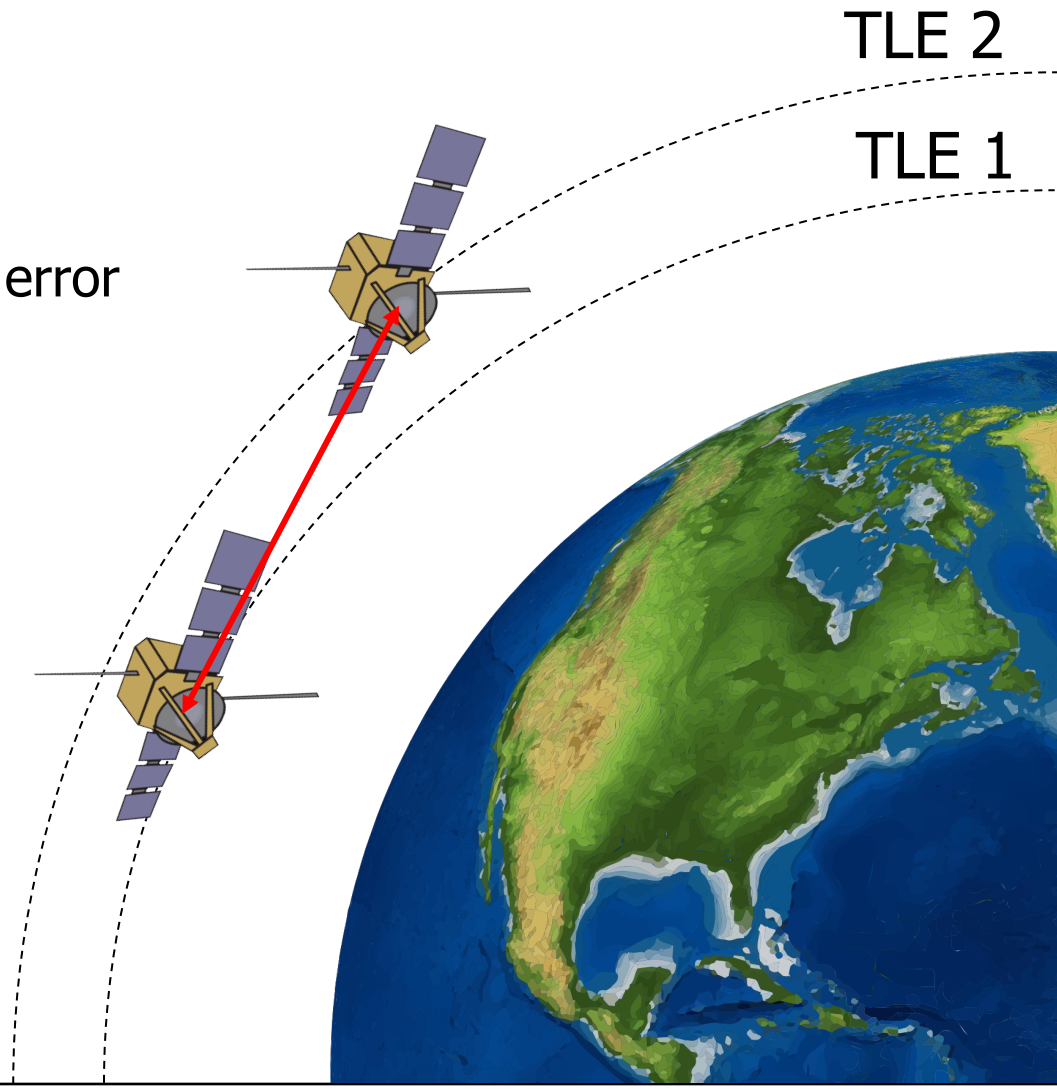
TLE self-consistency

- Time = T_0



TLE self-consistency

- Time = T_0
- Distance is considered the error



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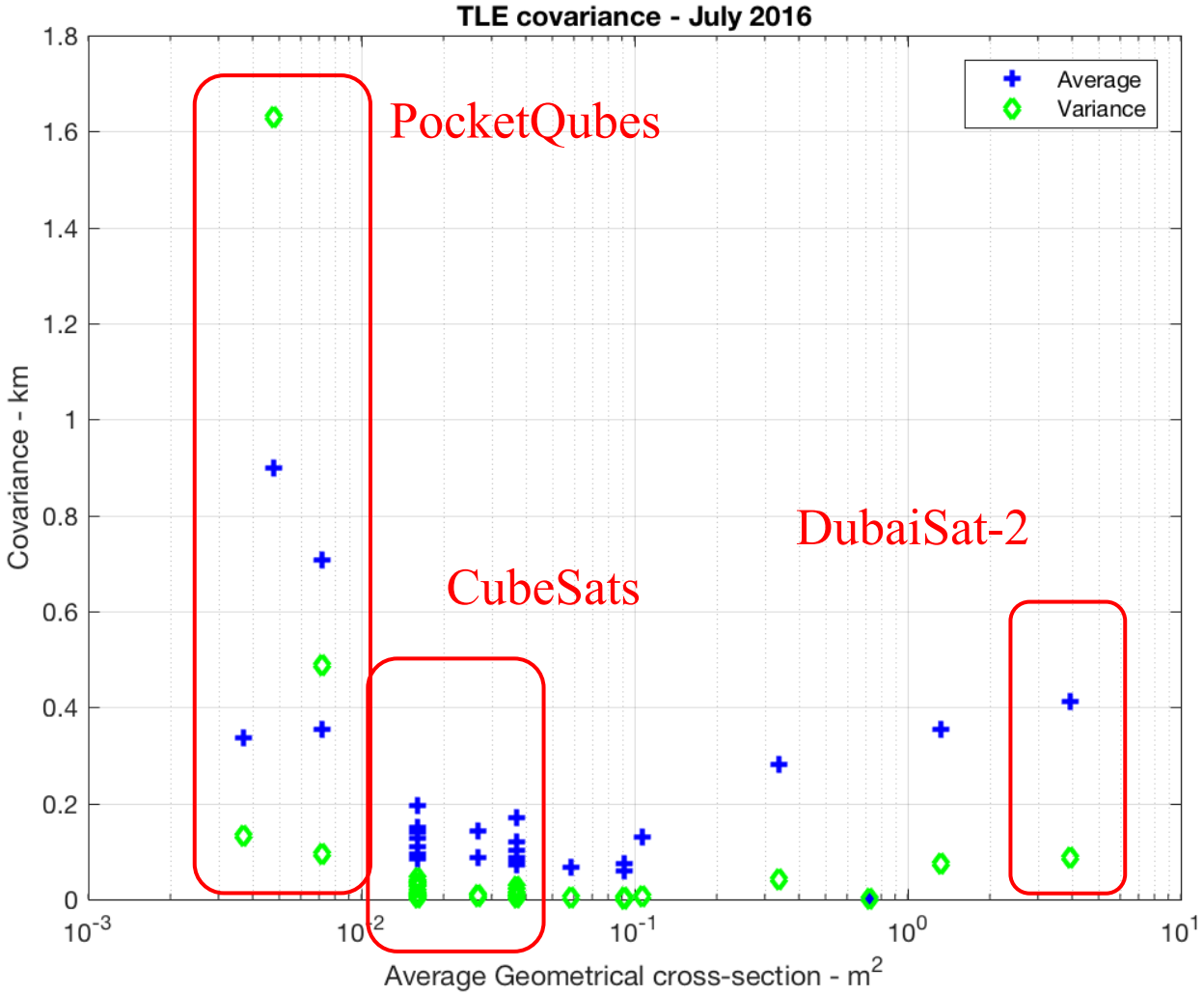

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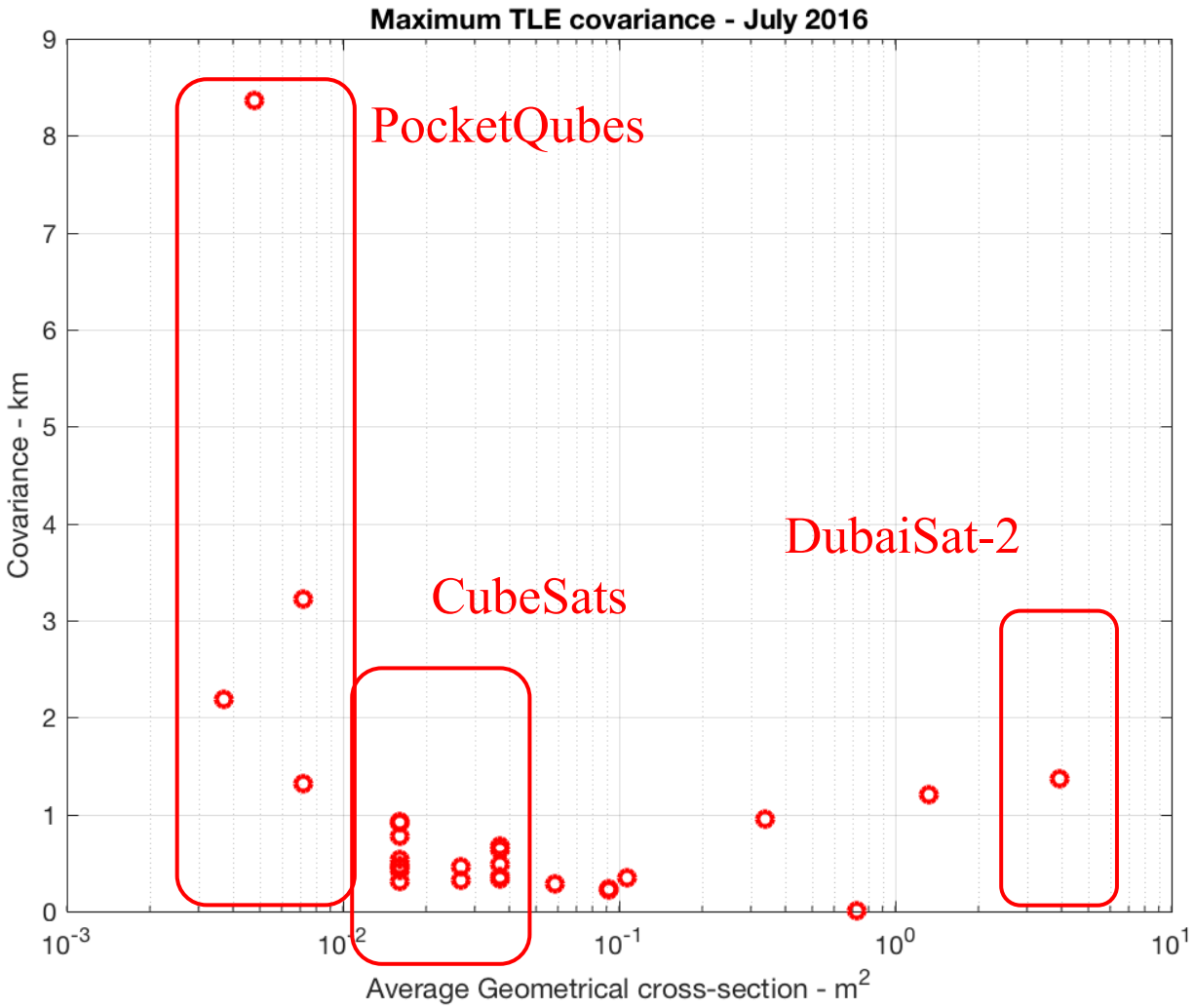
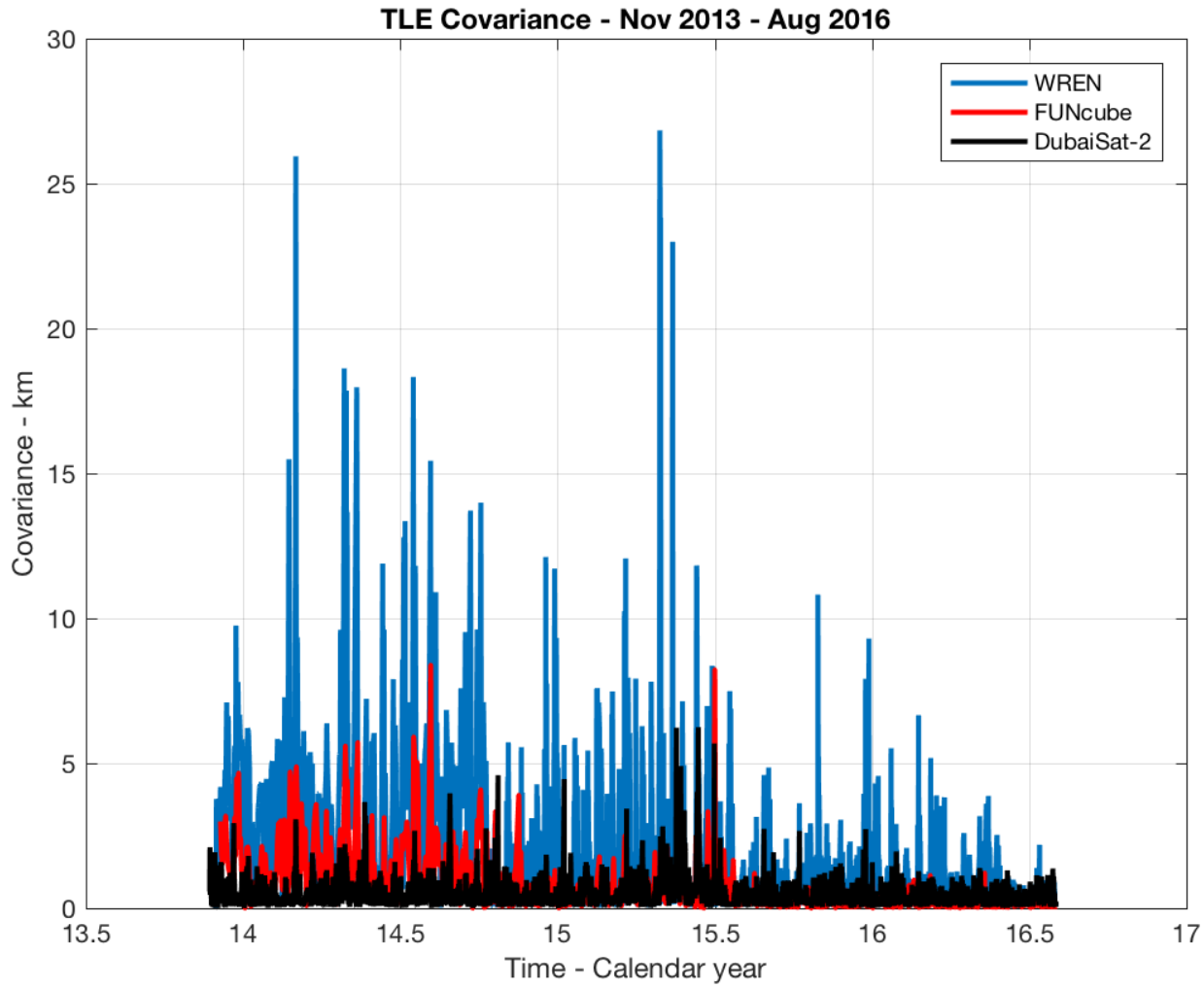


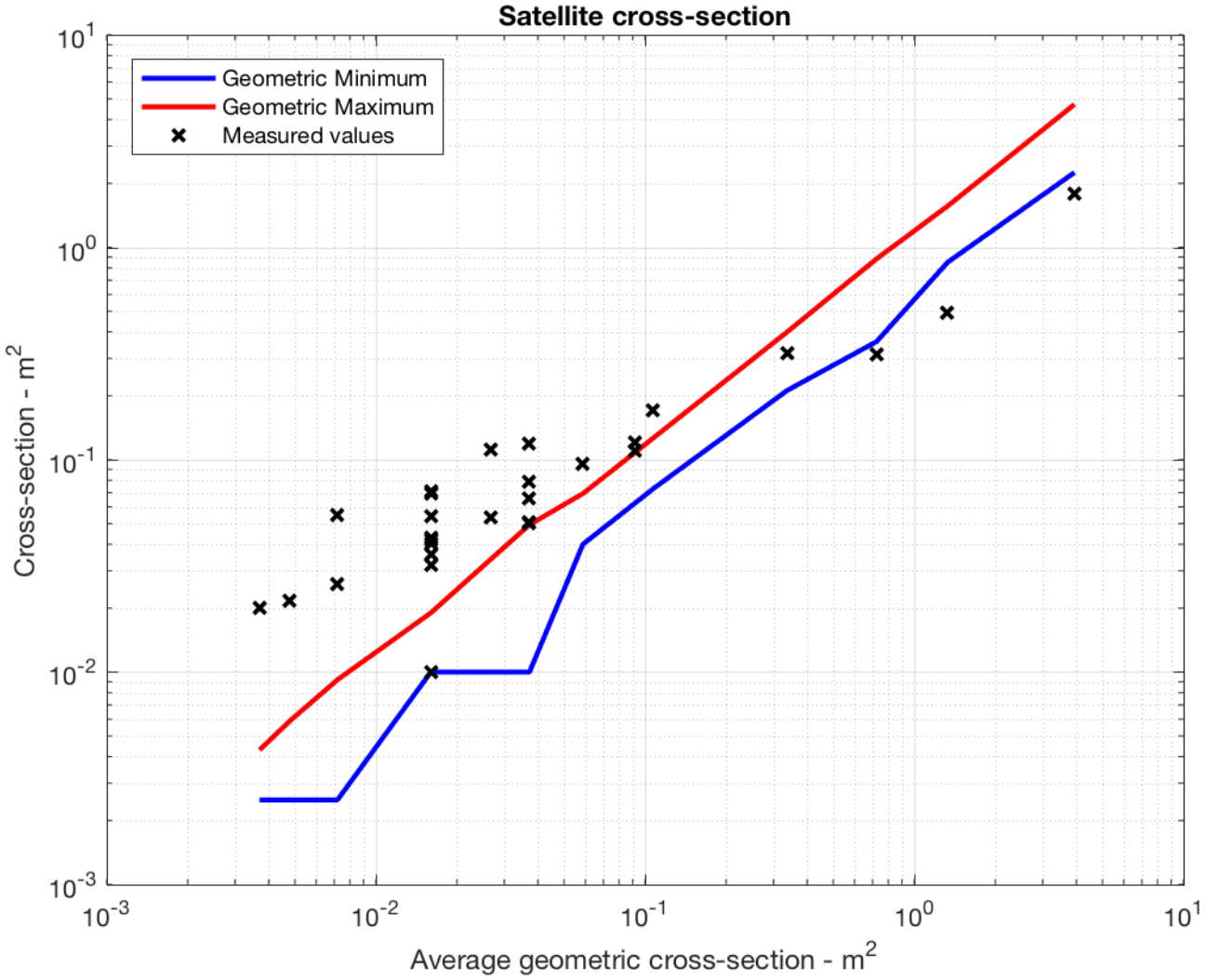
TLE self-consistency



TLE self-consistency

- Average error increases for satellites smaller than 10 cm:
  - Average between 300 m and 900 m
  - Between 200m and 400 m for satellites > 10 cm
- Variance gets up to 1.6 km for satellites < 10 cm
- Maximum error up to 8 km for satellites < 10 cm
- Very small objects are trackable
  - Performances start to degrade
  - Tracking performances need to be kept into consideration

Radar cross-section analysis



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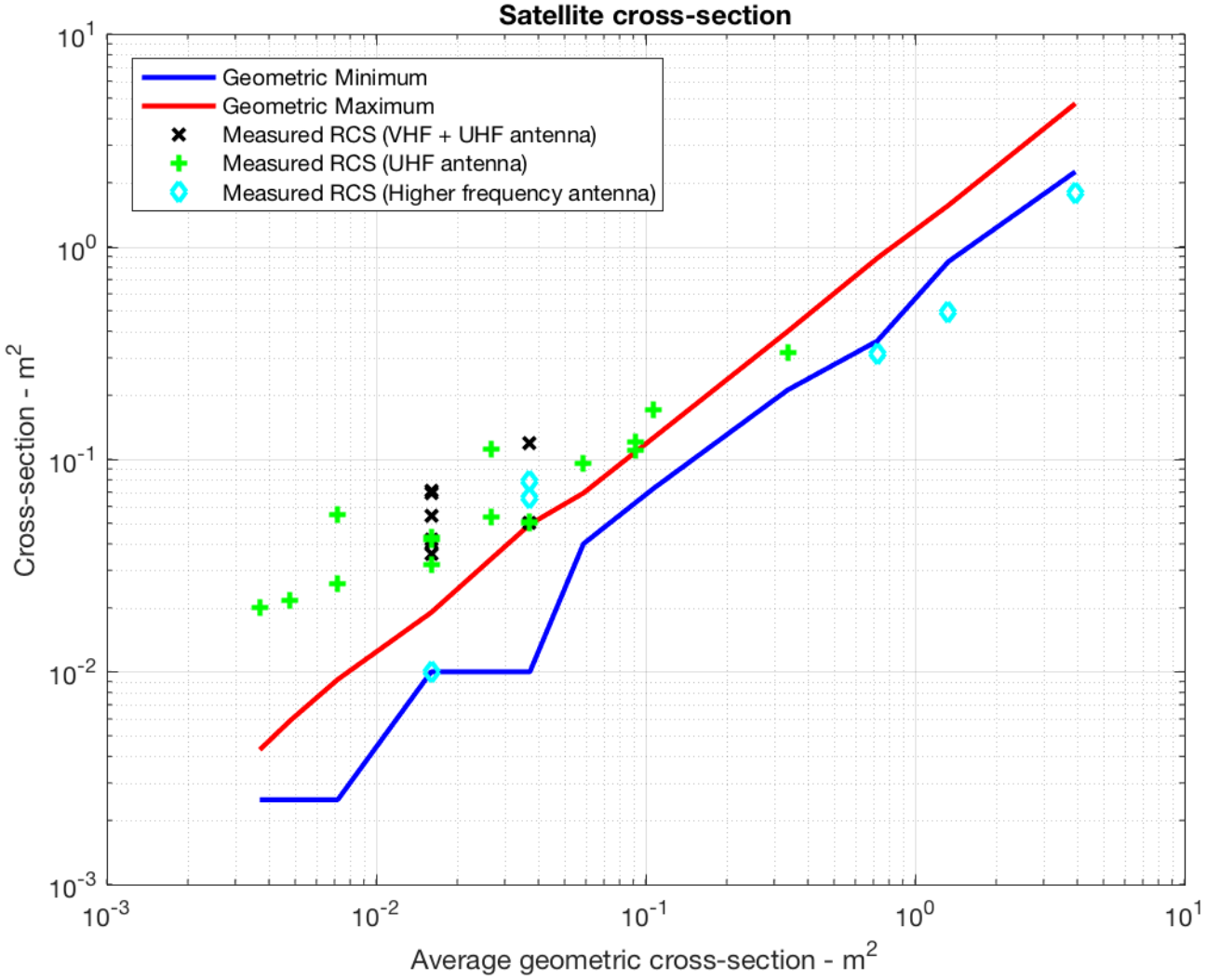

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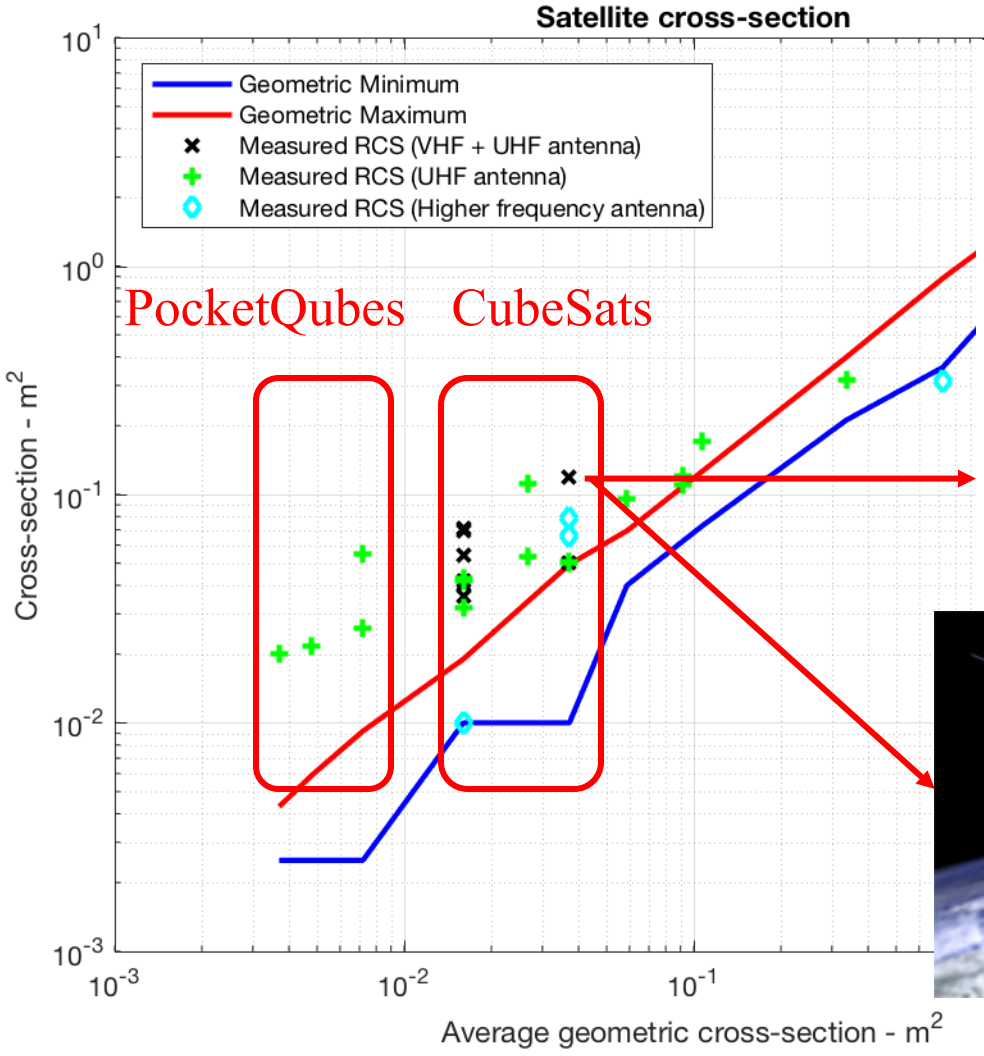

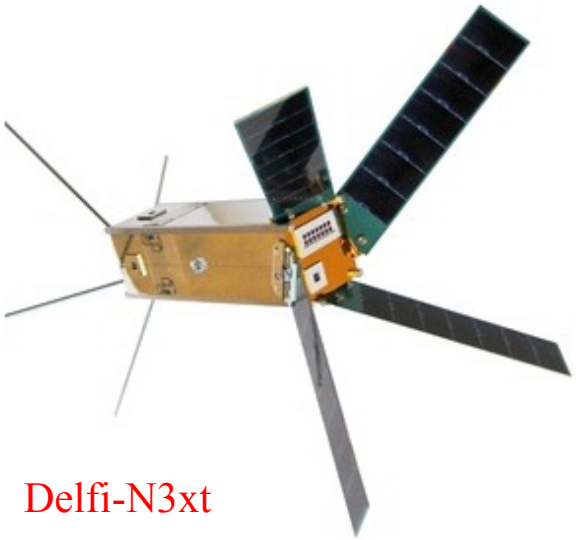

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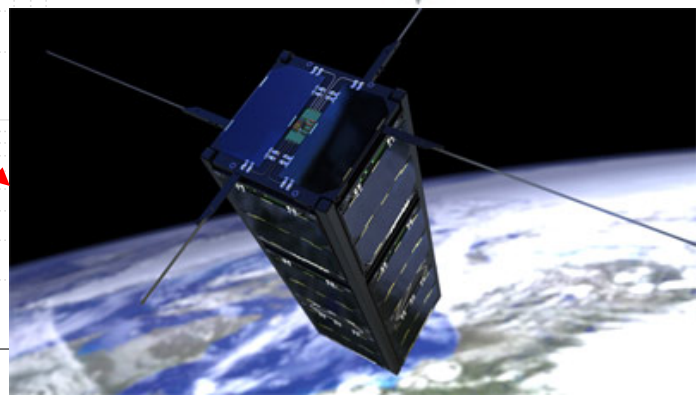
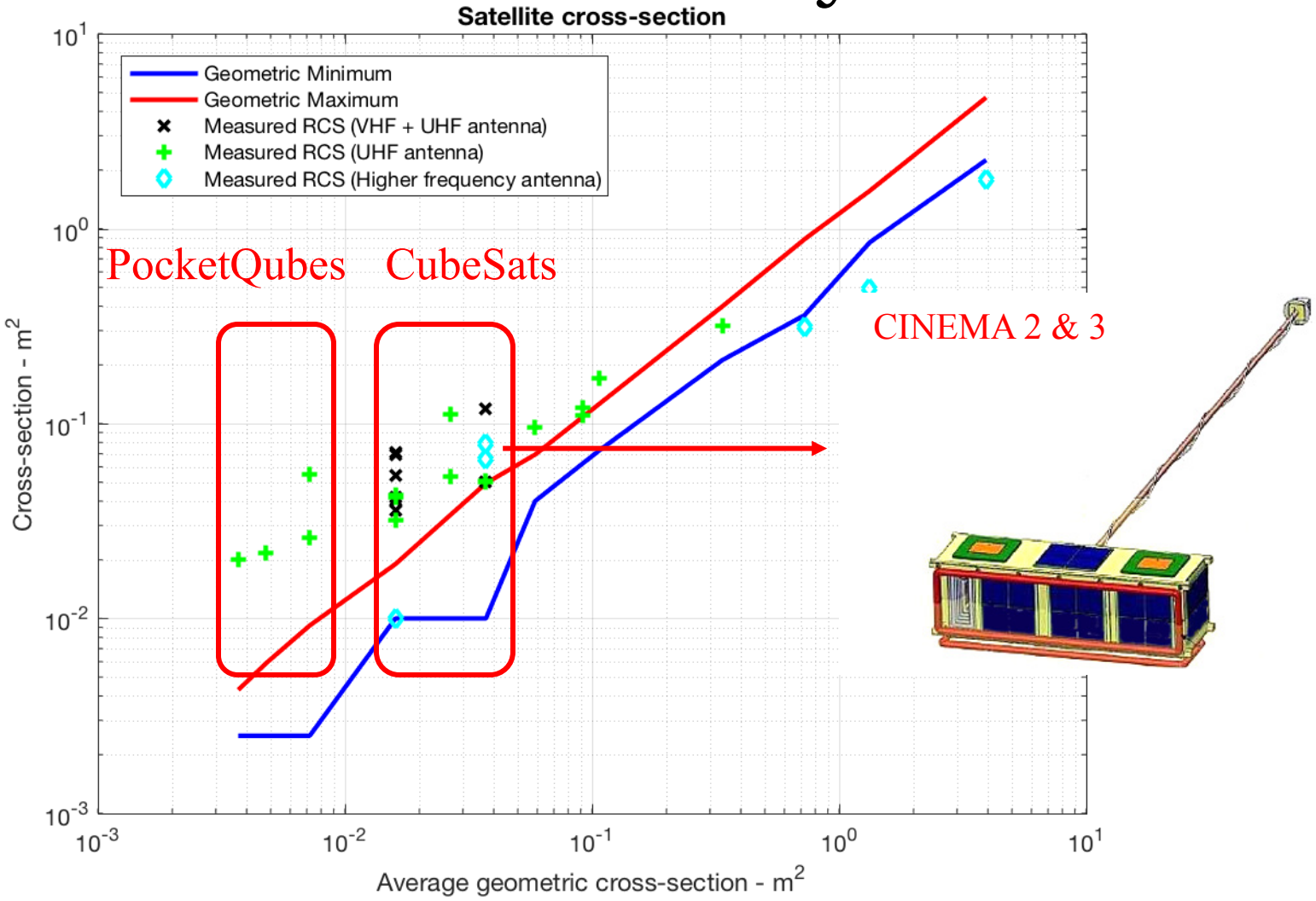
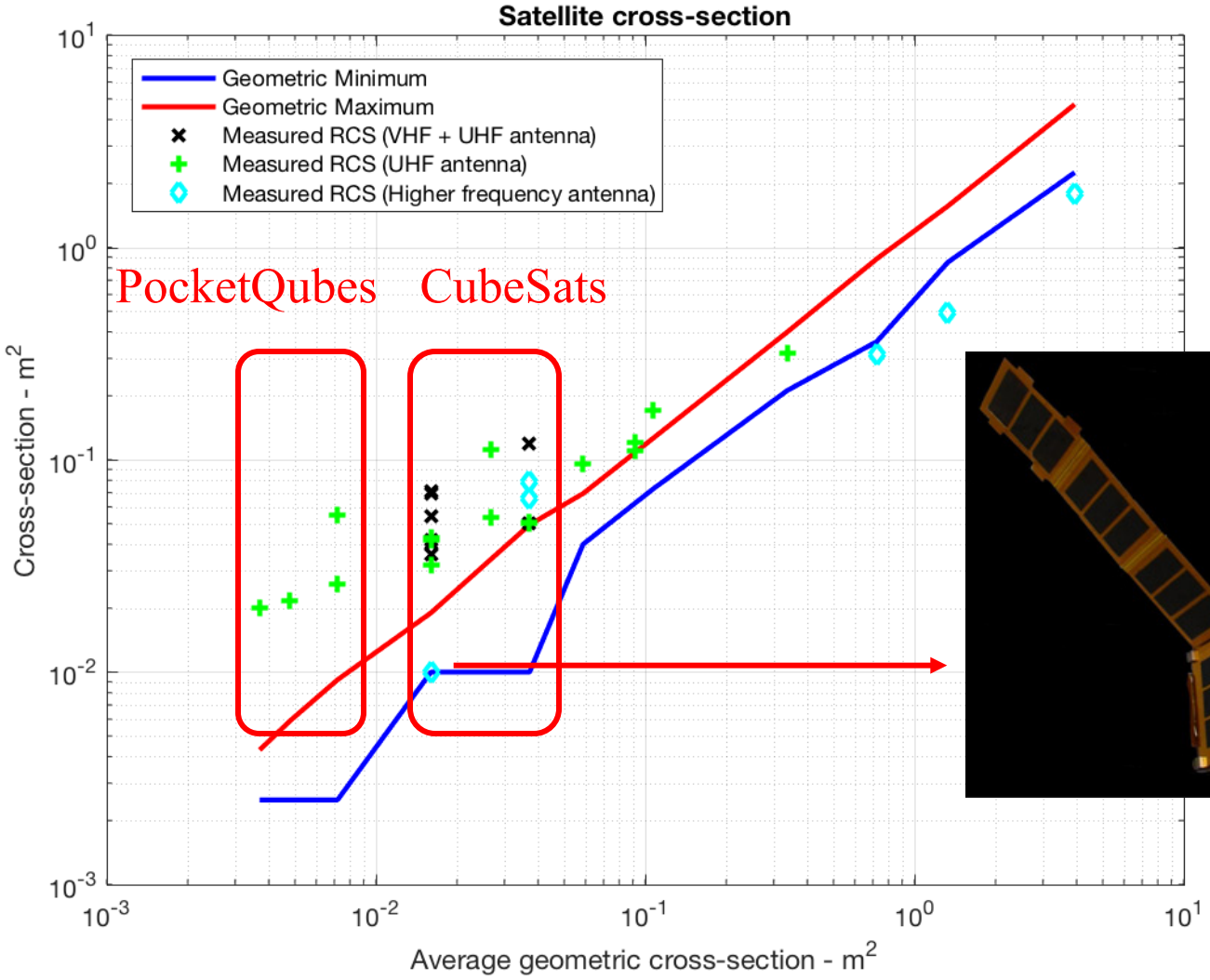


Triton-1

Radar cross-section analysis



Radar cross-section analysis



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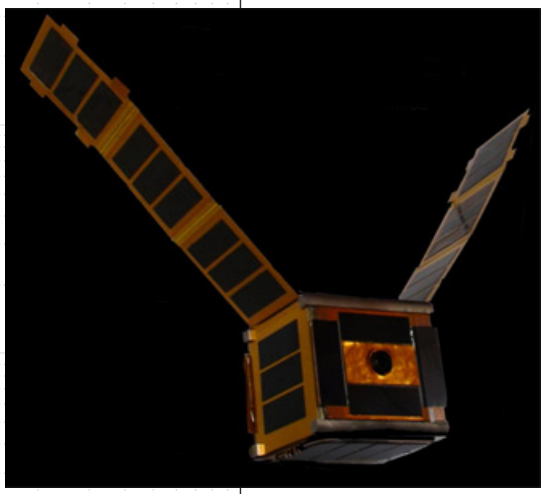

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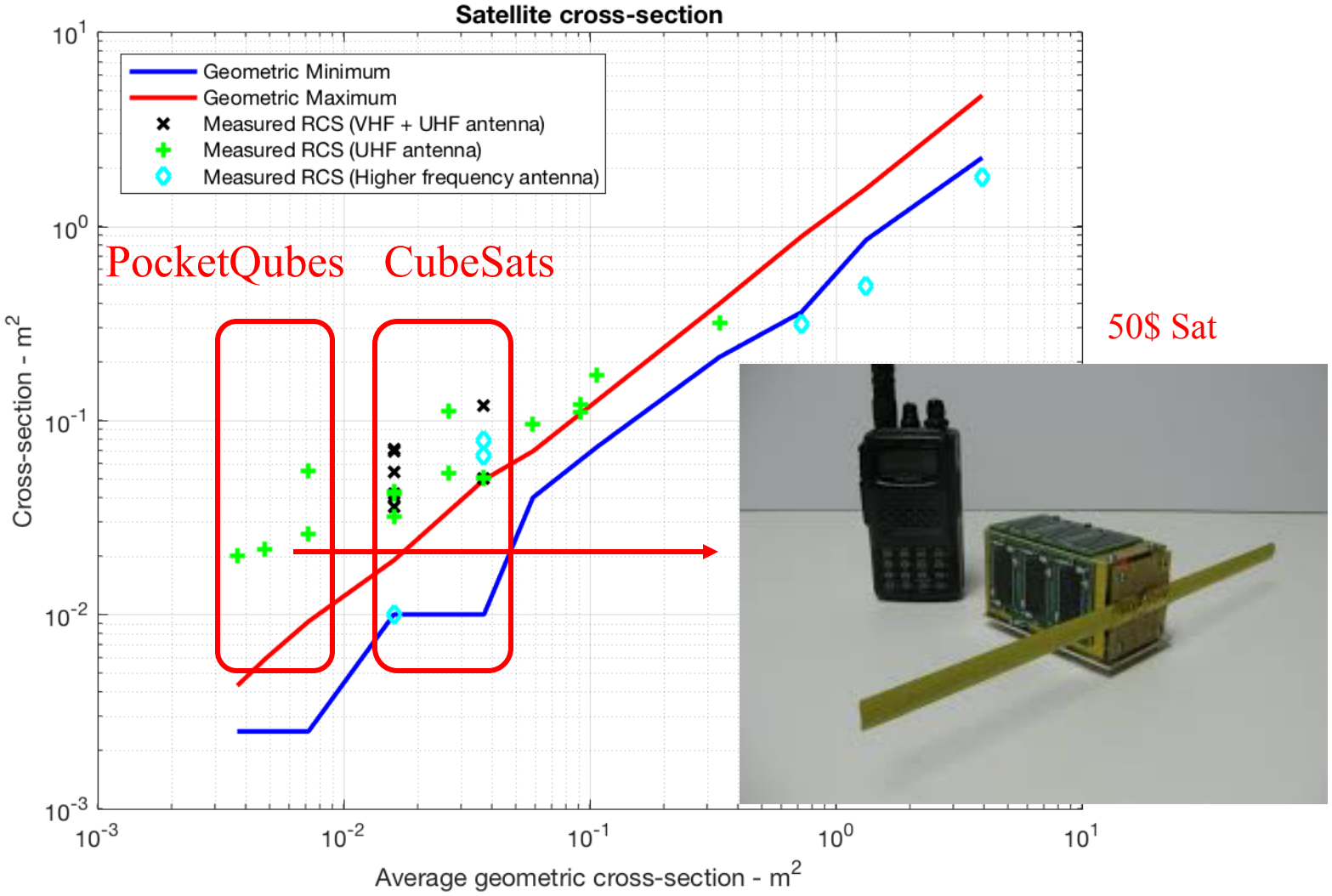

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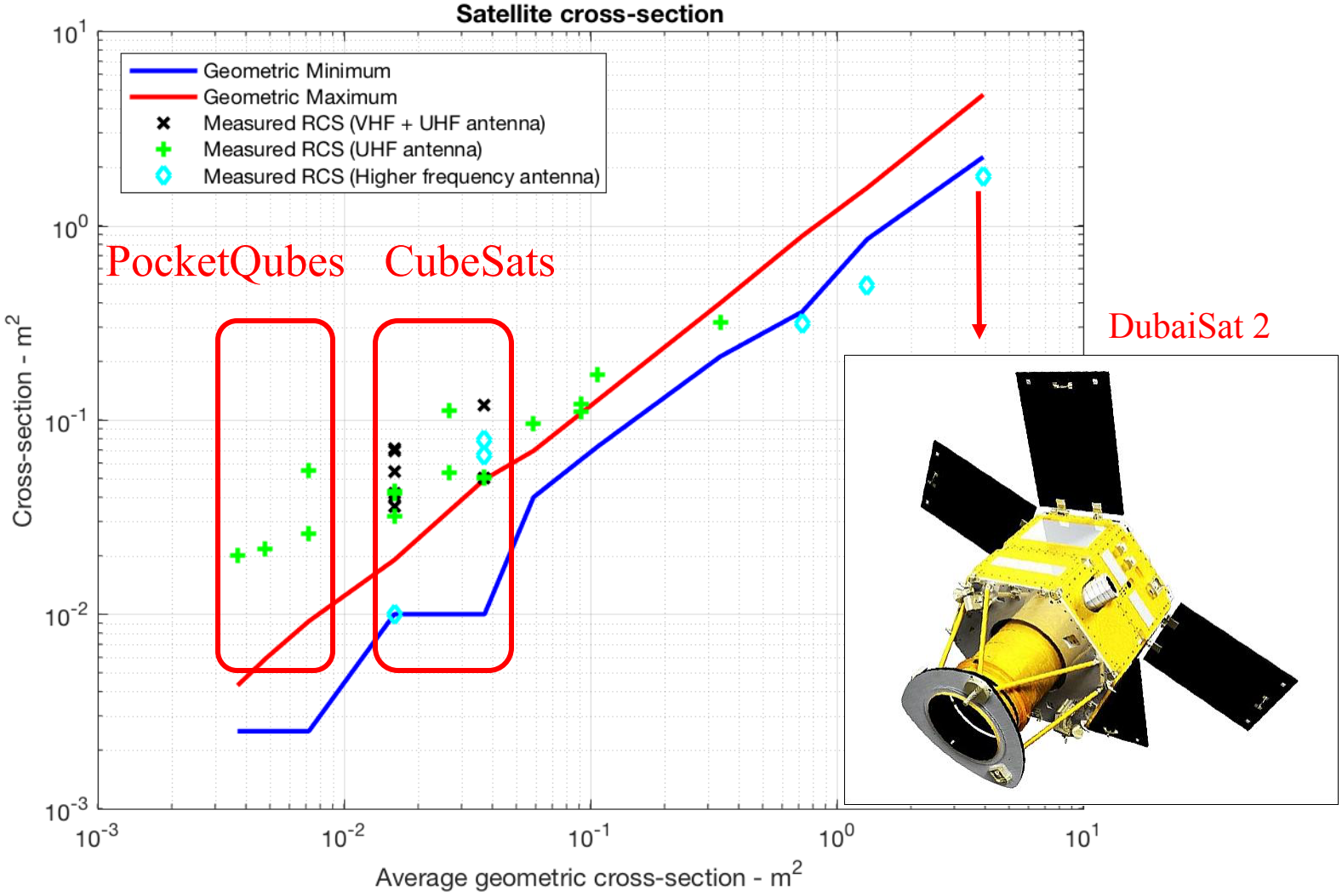

Radar cross-section analysis

- Consistent over-estimation of satellite size for small objects
  - Seems coherent with antenna size
  - Not always coherent with deployed solar panels
- Depends on current generation of NORAD sensors (AN/FPS-85)
  - What will happen with newer versions (Space Fence)?

Conclusions

- Objects smaller than 10 cm are trackable in LEO below 600 km
- TLE update rate is comparable with bigger objects
- Position errors start to increase below 10 cm in size
- Proper measures can be taken to increase radar cross-section
- Can something else be also done?
  - Enforce active ephemeris determination?
  - Enforce ephemeris sharing?

Questions?

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