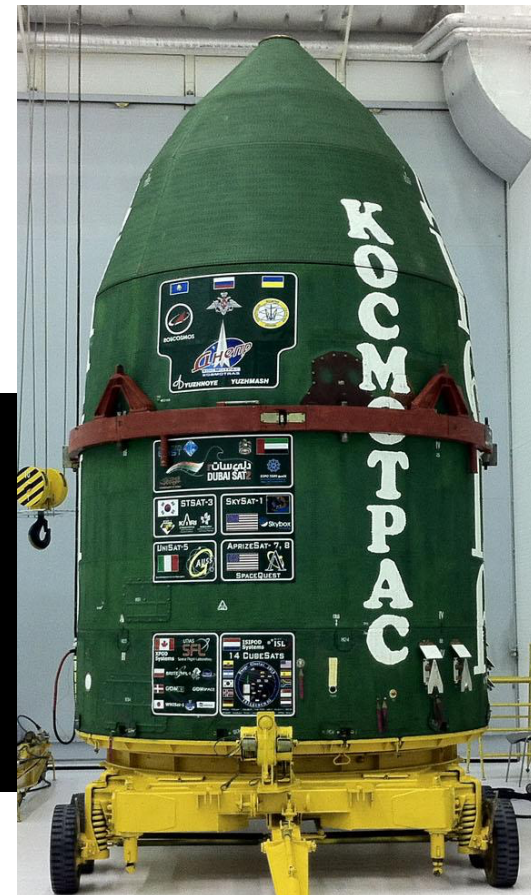
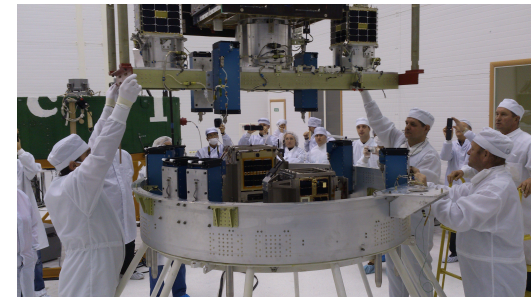


# Long-term performance analysis of NORAD Two-Line Elements for CubeSats and PocketQubes

S. Speretta, P. Sundaramoorthy, E. Gill



*ISC Kosmotras*



# Content

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



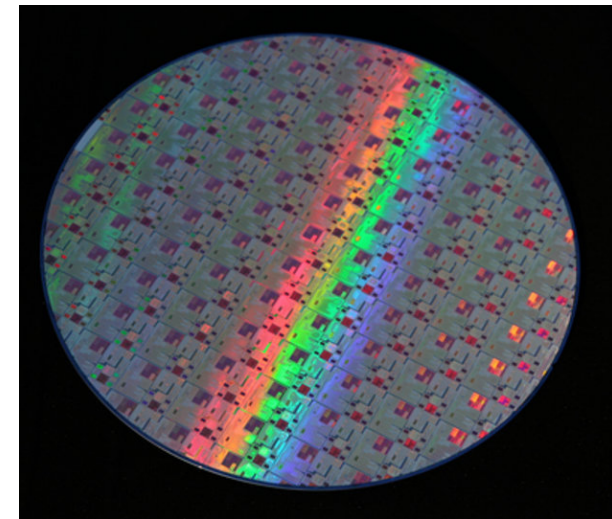
Ready, steady, go!

# Introduction

- 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?



*Calpoly.edu*



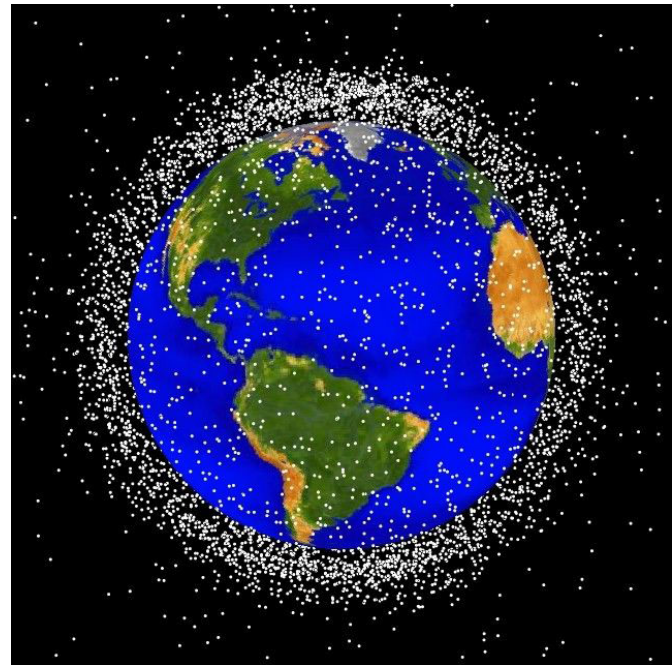
*esa.int*

# Introduction

- 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!

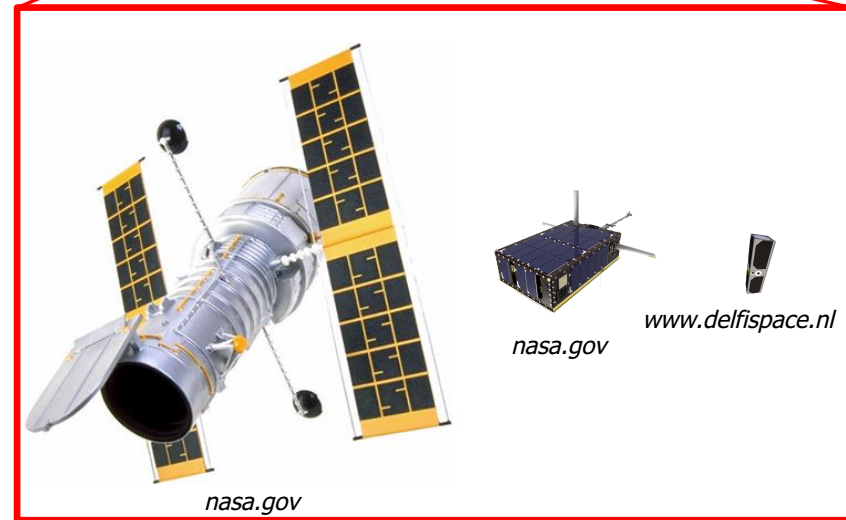
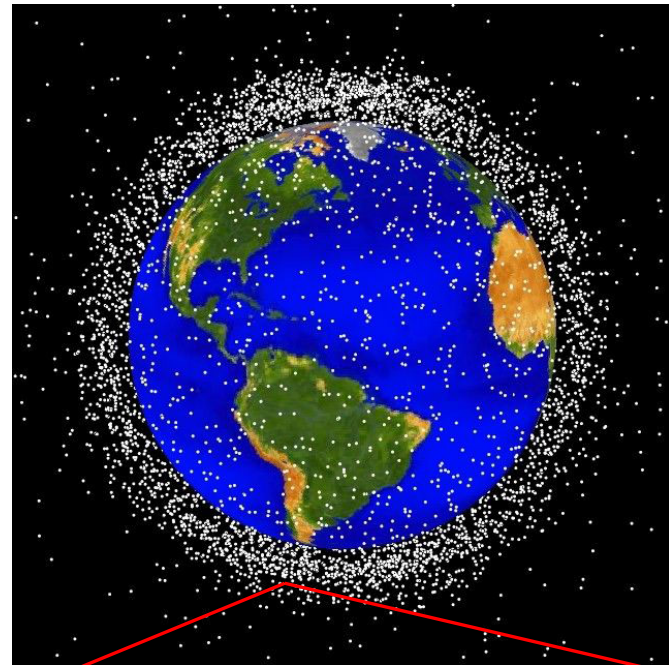
- What is the impact that satellites have in there?





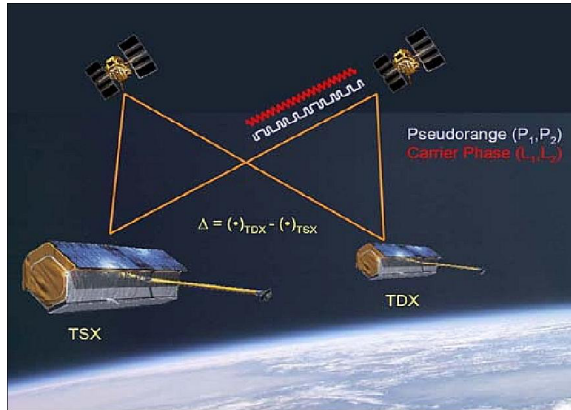
# Introduction

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



# Spacecraft orbit determination

## 1-way ranging



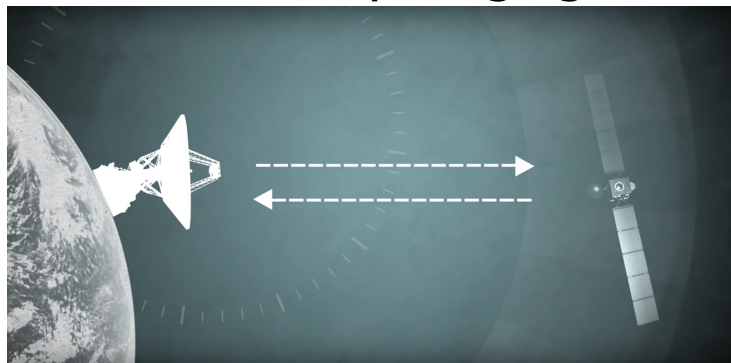
*dlr.de*

## Radar



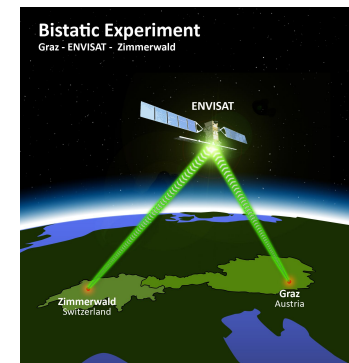
*USAF - NORAD*

## 2-way ranging



*Islam Alyafawi*

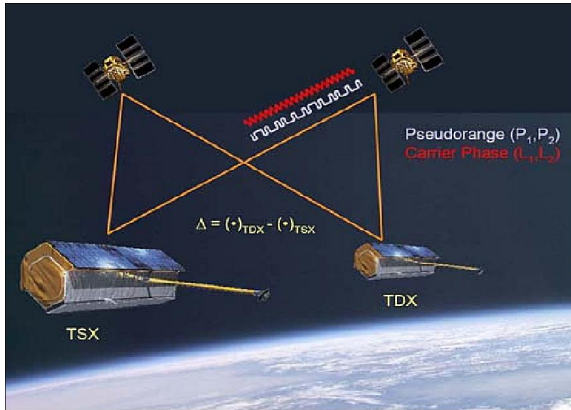
## Laser



*University of Gratz*

# What about pico-/femto-satellites?

1-way ranging ?



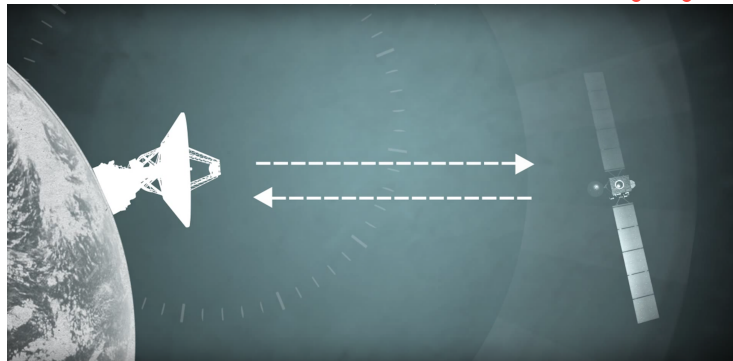
dlr.de

Radar ✓



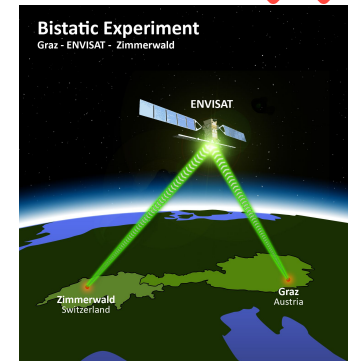
USAF - NORAD

2-way ranging ✗



Islam Alyafawi

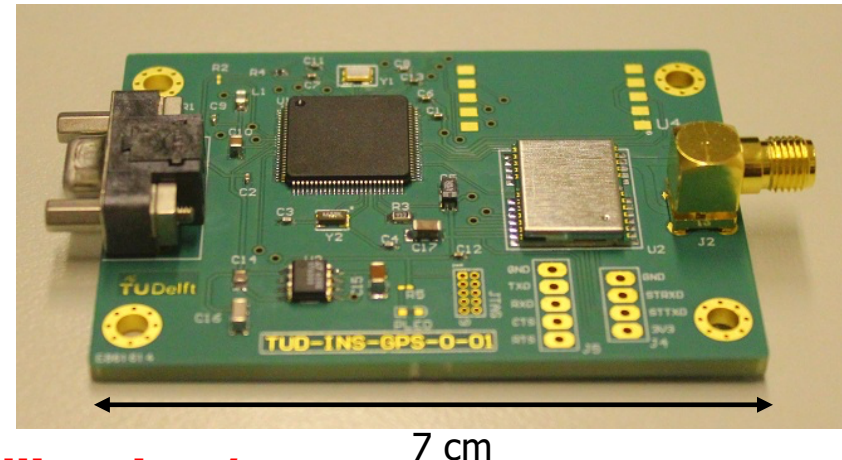
Laser ✗



University of Gratz

# What about pico-/femto-satellites?

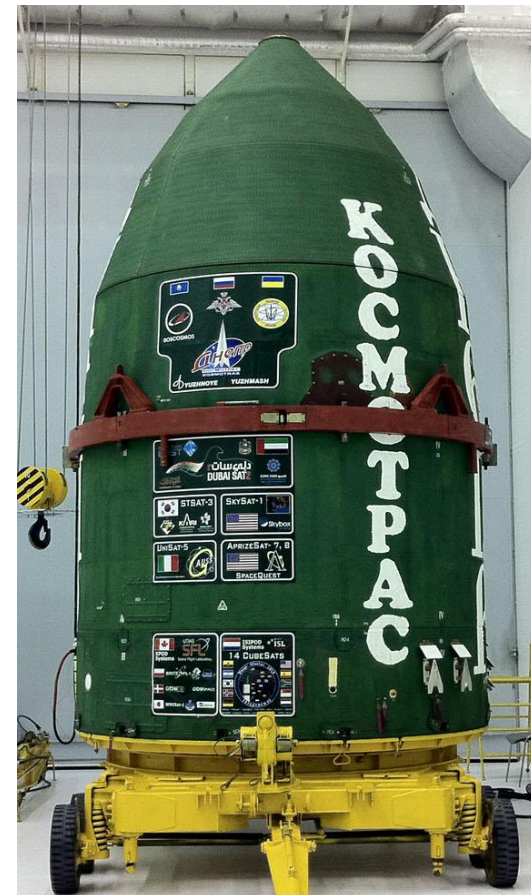
- TLEs are the main way
  - Very practical
  - Low accuracy (> 1km)
  - **Is accuracy dependent on satellite size / radar cross-section?**
  - **Is update rate dependent on satellite size / radar cross-section?**
- 1-way and 2-way ranging demonstrated on CubeSats
  - ~ 0.5 km accuracy (2-way)
  - GPS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



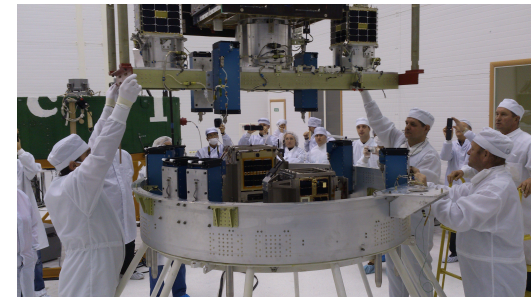


# Data set

- Dnepr-19 launch (Nov 21<sup>st</sup> 2013)
  - 590 x 760 km,  $\sim 98^\circ$
  - 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

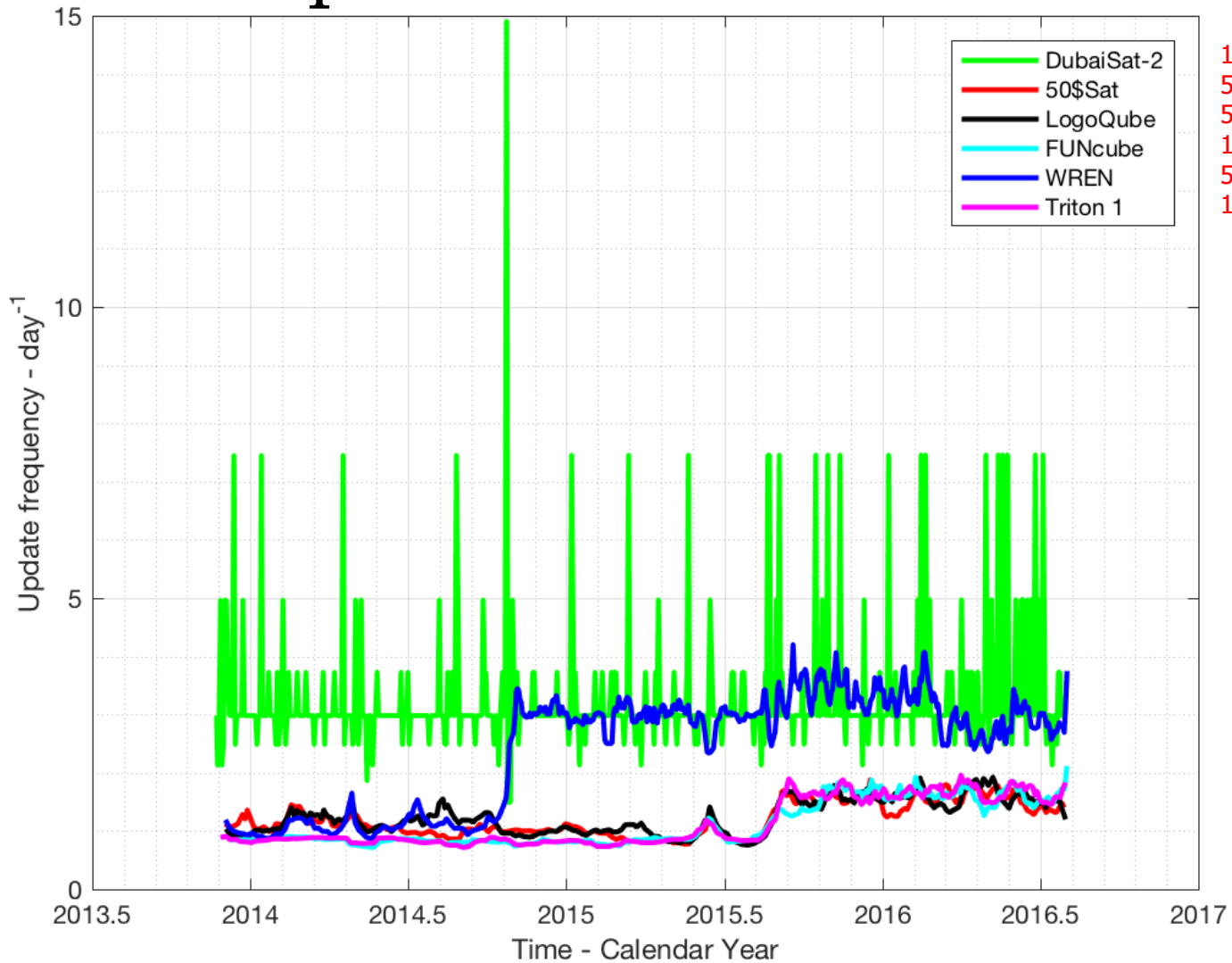


*ISC Kosmotras*





# 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

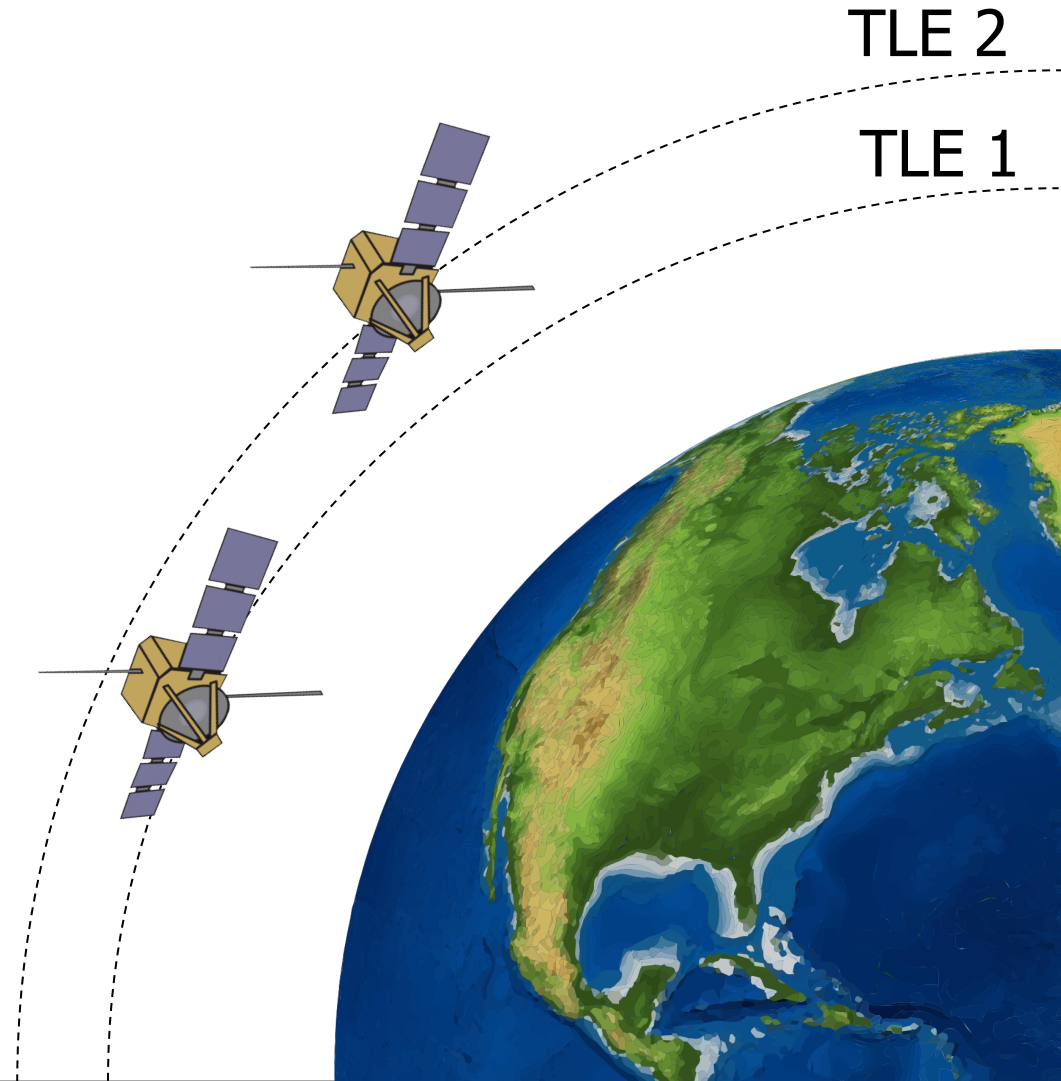
- “New element sets are generated by NORAD on an as-needed basis rather than according to an established timetable” (Celestrak)
- 10 cm side considered by many the smallest detectable by NORAD
- **All objects (even smaller than 10 cm) get 1-3 TLE / day**
- TLE update rate **cannot** be considered a problem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

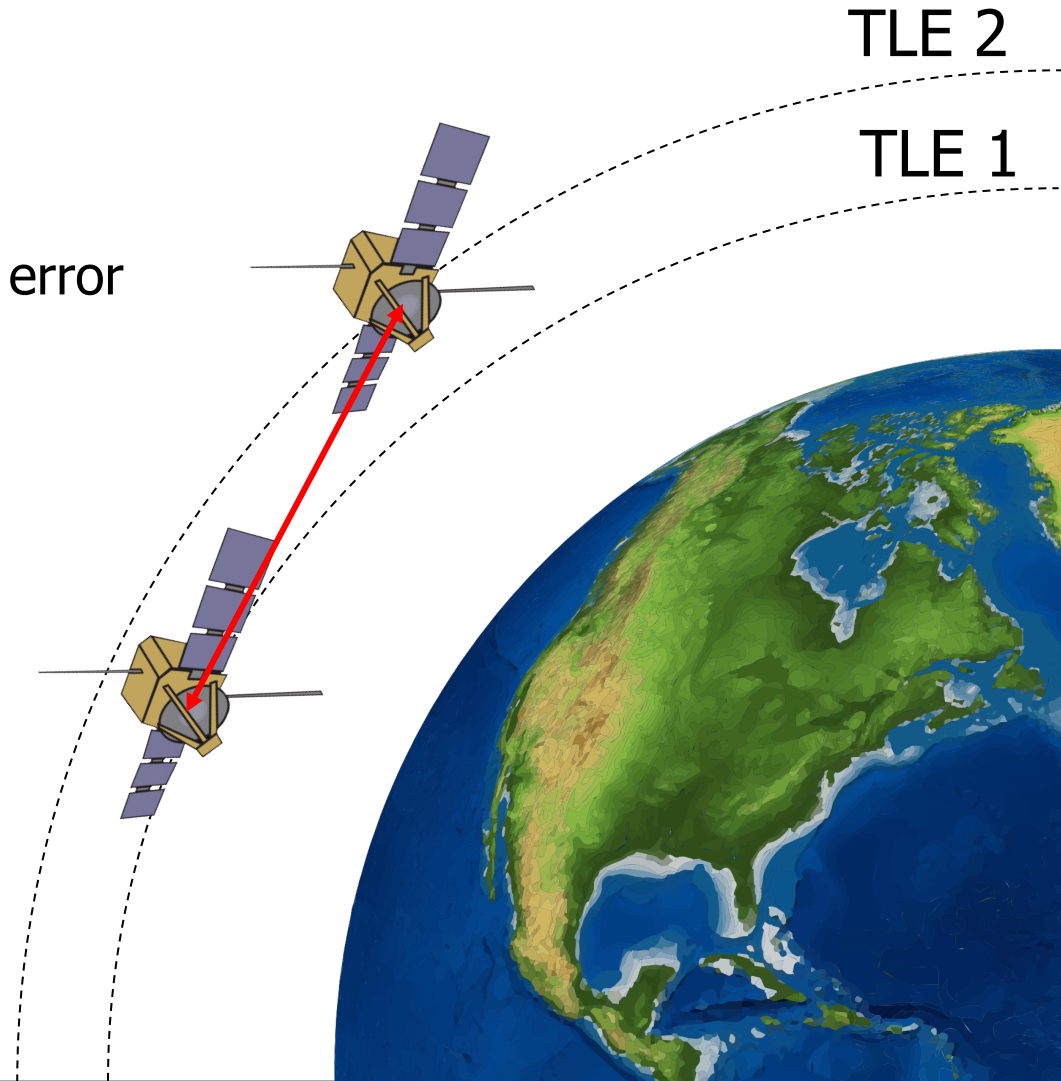
# TLE self-consistency

- Time =  $T_0$



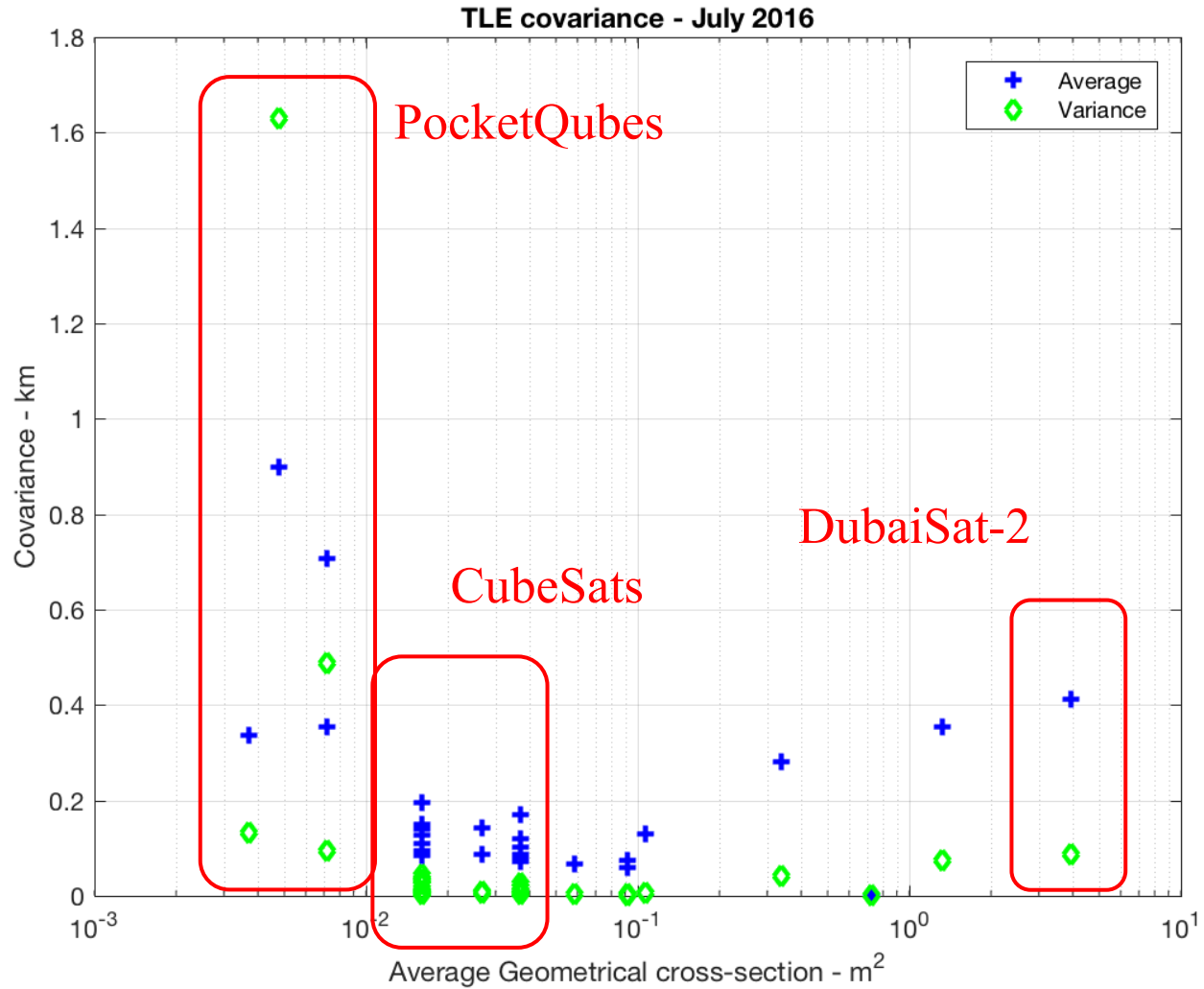
# TLE self-consistency

- Time =  $T_0$
- Distance is considered the error

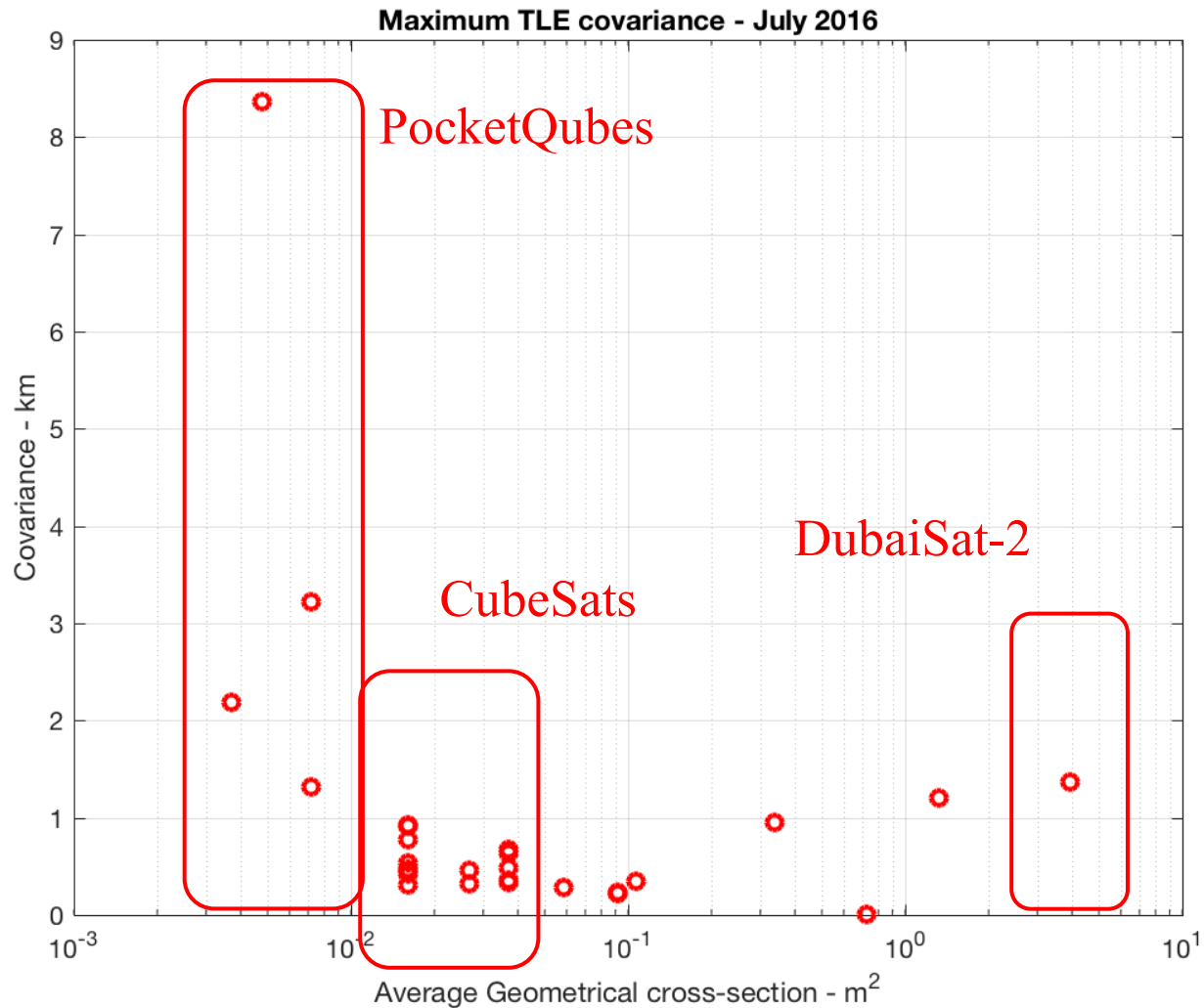




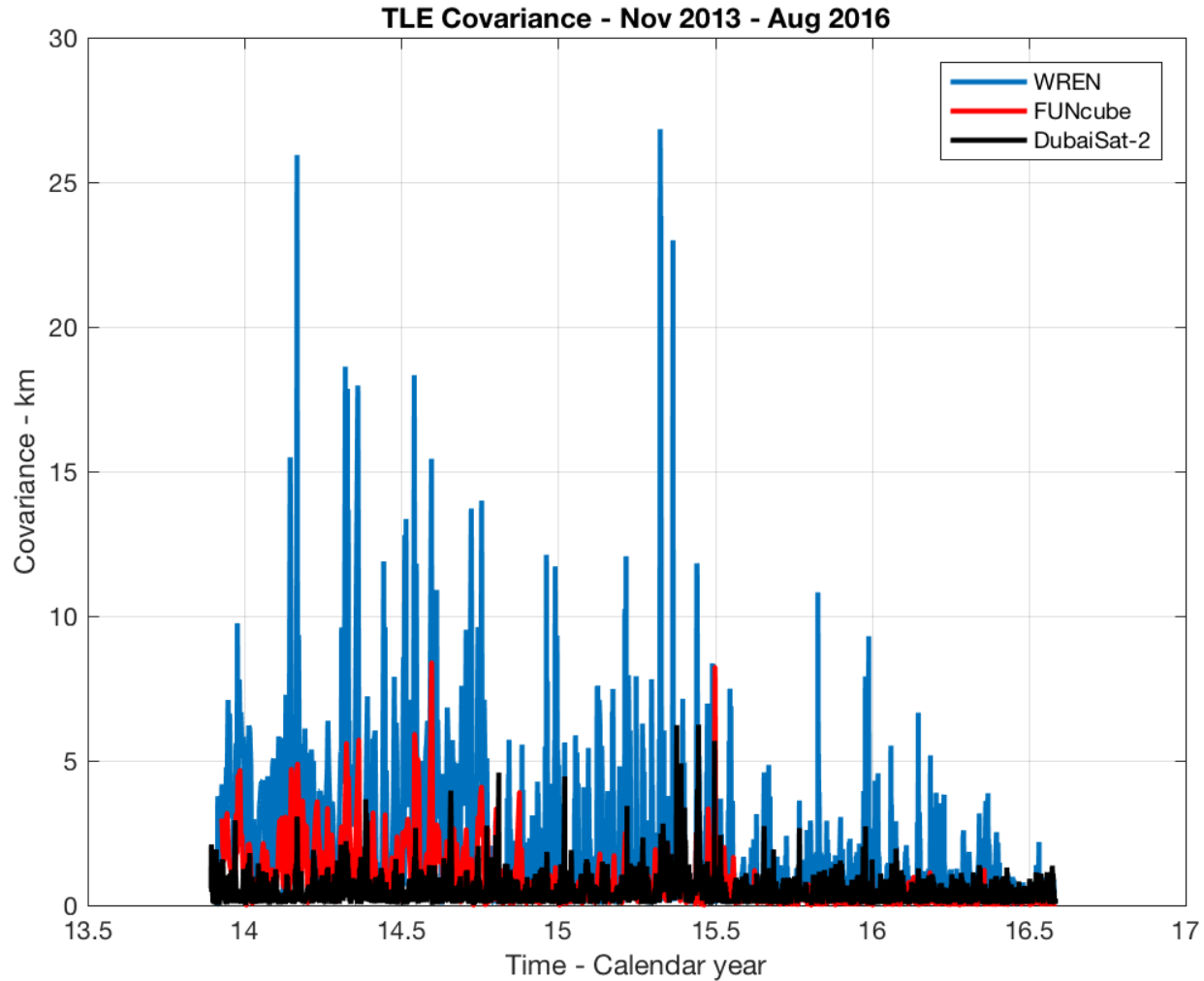
# TLE self-consistency



# TLE self-consistency



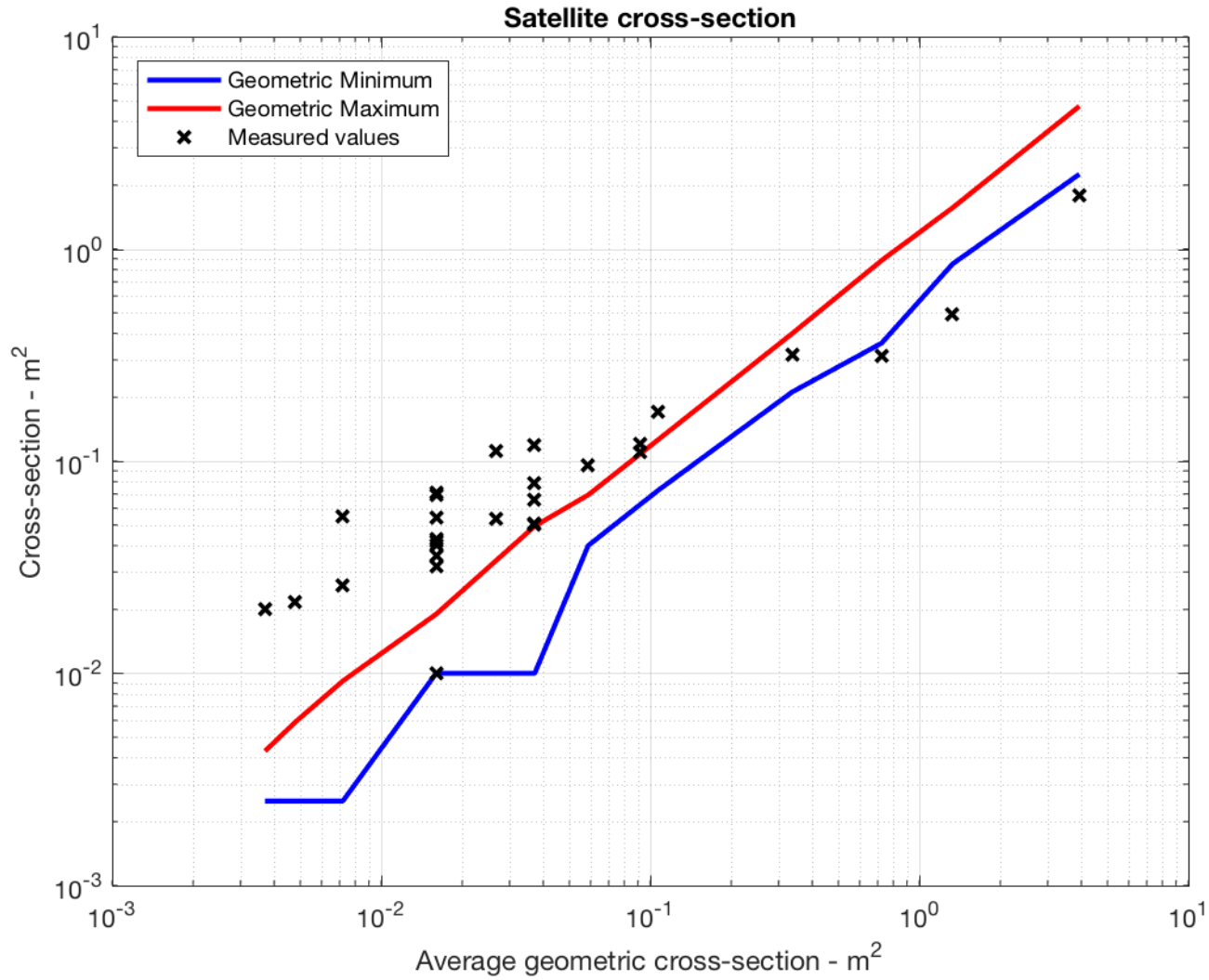
# TLE self-consistency



# TLE self-consistency

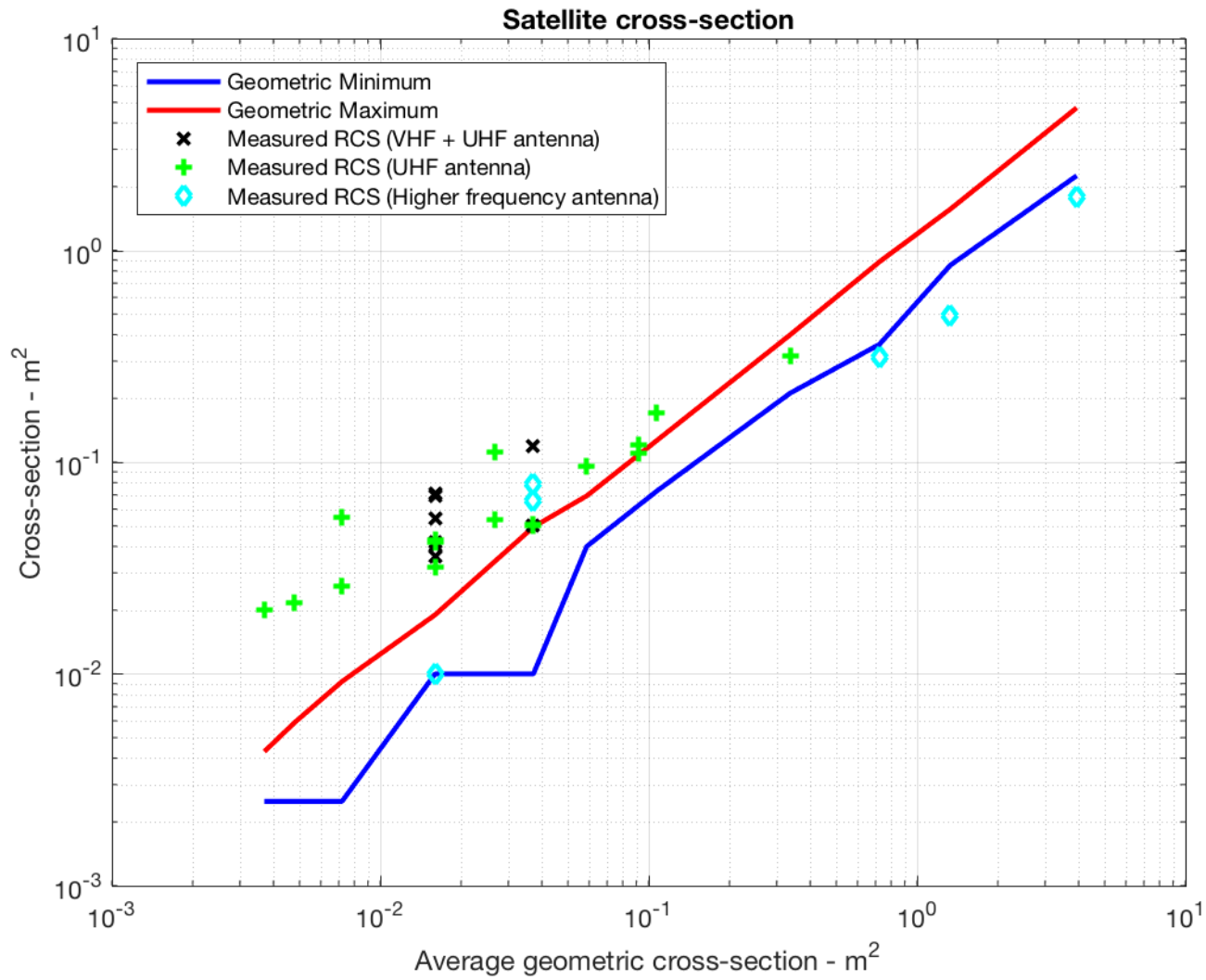
- Average error increases for satellites smaller than 10 cm:
  - Average between 300 m and 900 m
  - Between 200m and 400 m for satellites  $> 10$  cm
- Variance gets up to 1.6 km for satellites  $< 10$  cm
- Maximum error up to 8 km for satellites  $< 10$  cm
- Very small objects are trackable
  - Performances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

# Radar cross-section analysis

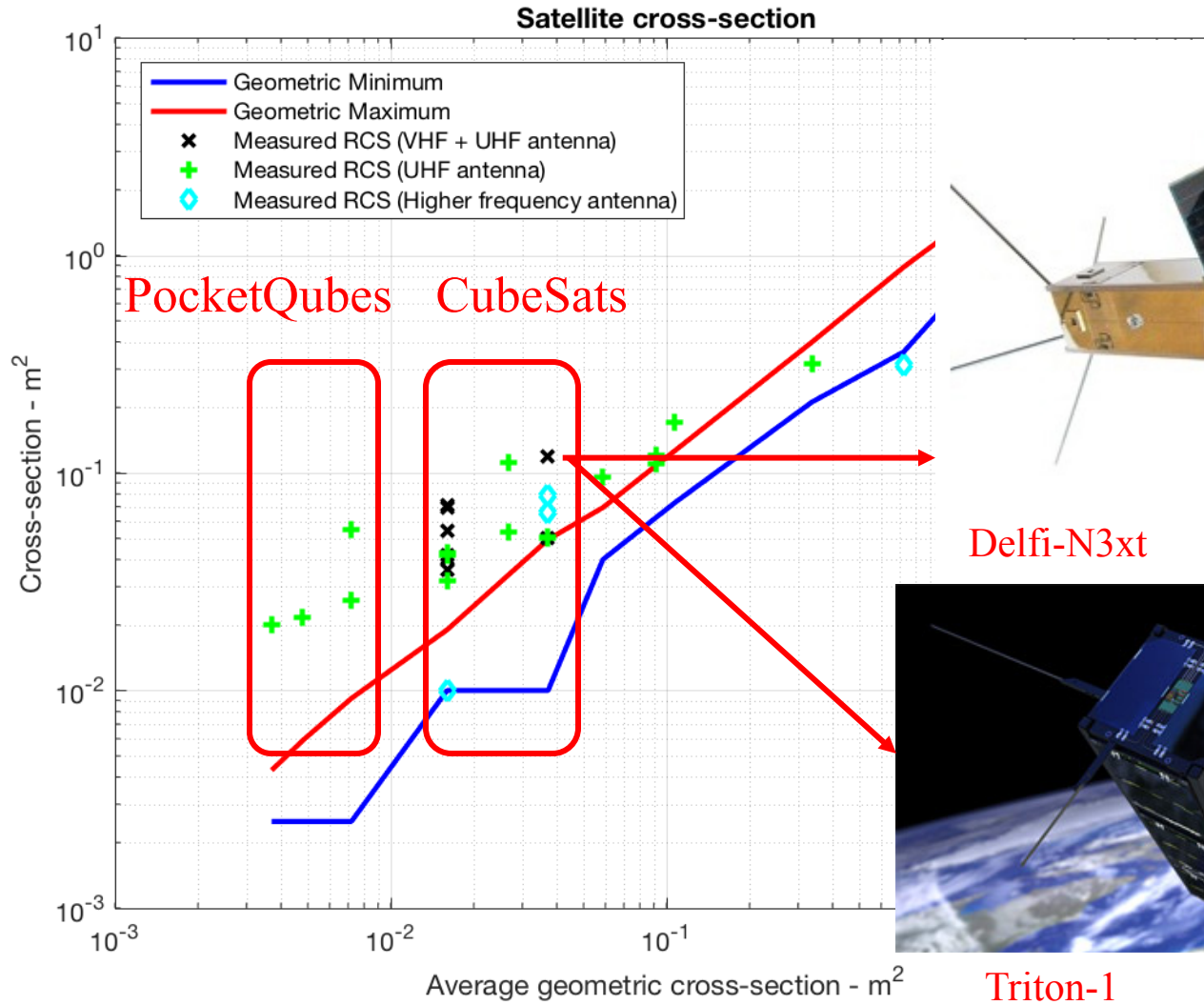




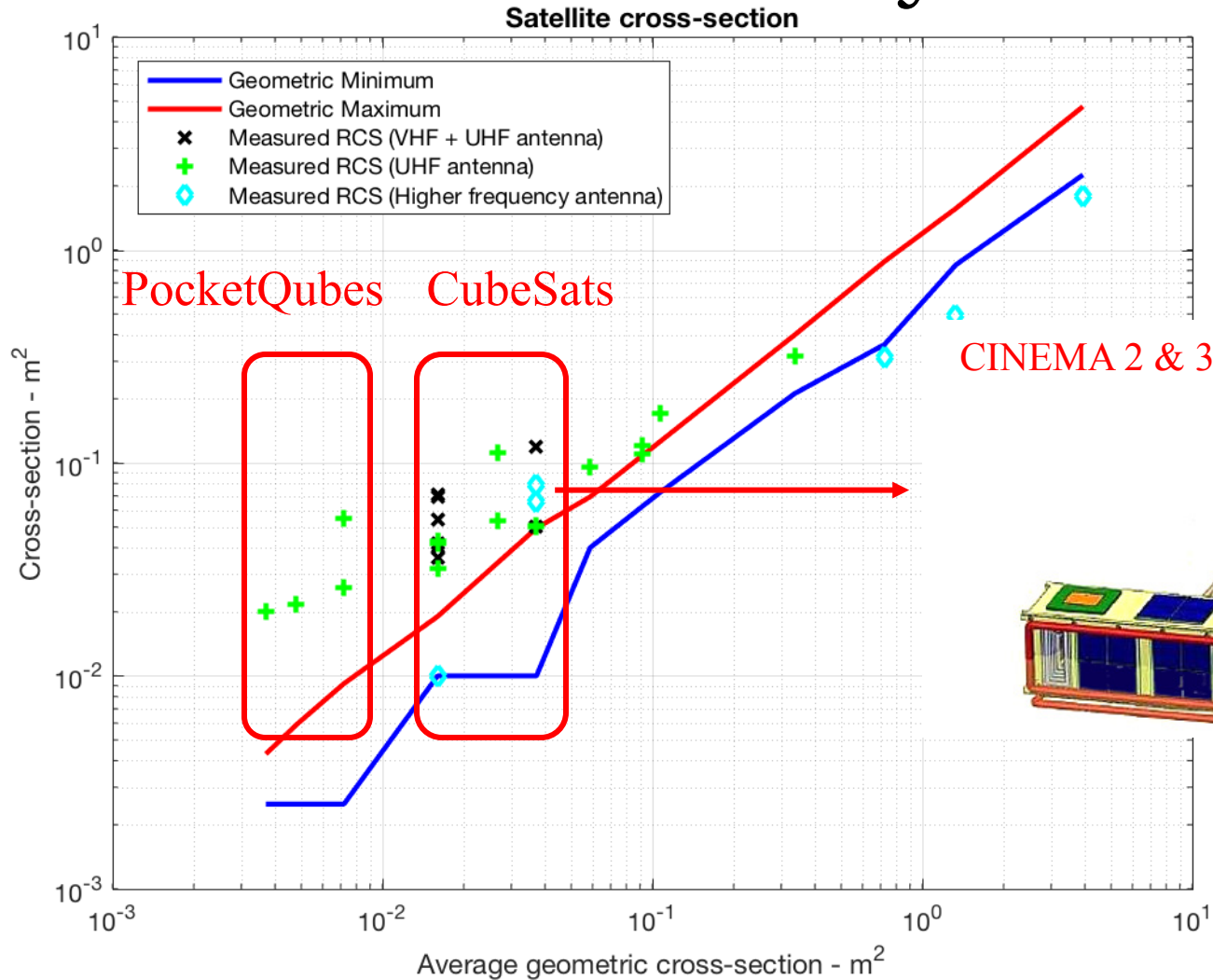
# Radar cross-section analysis



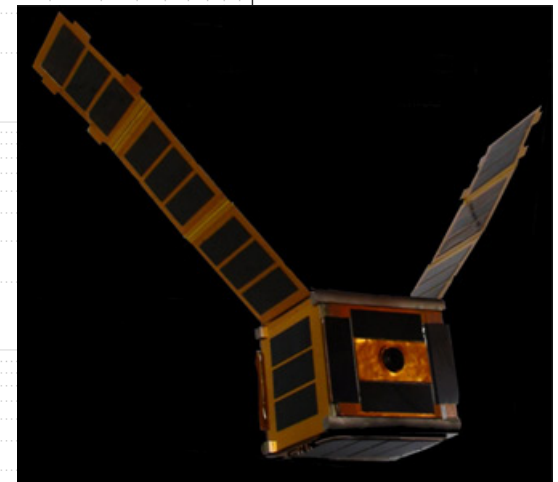
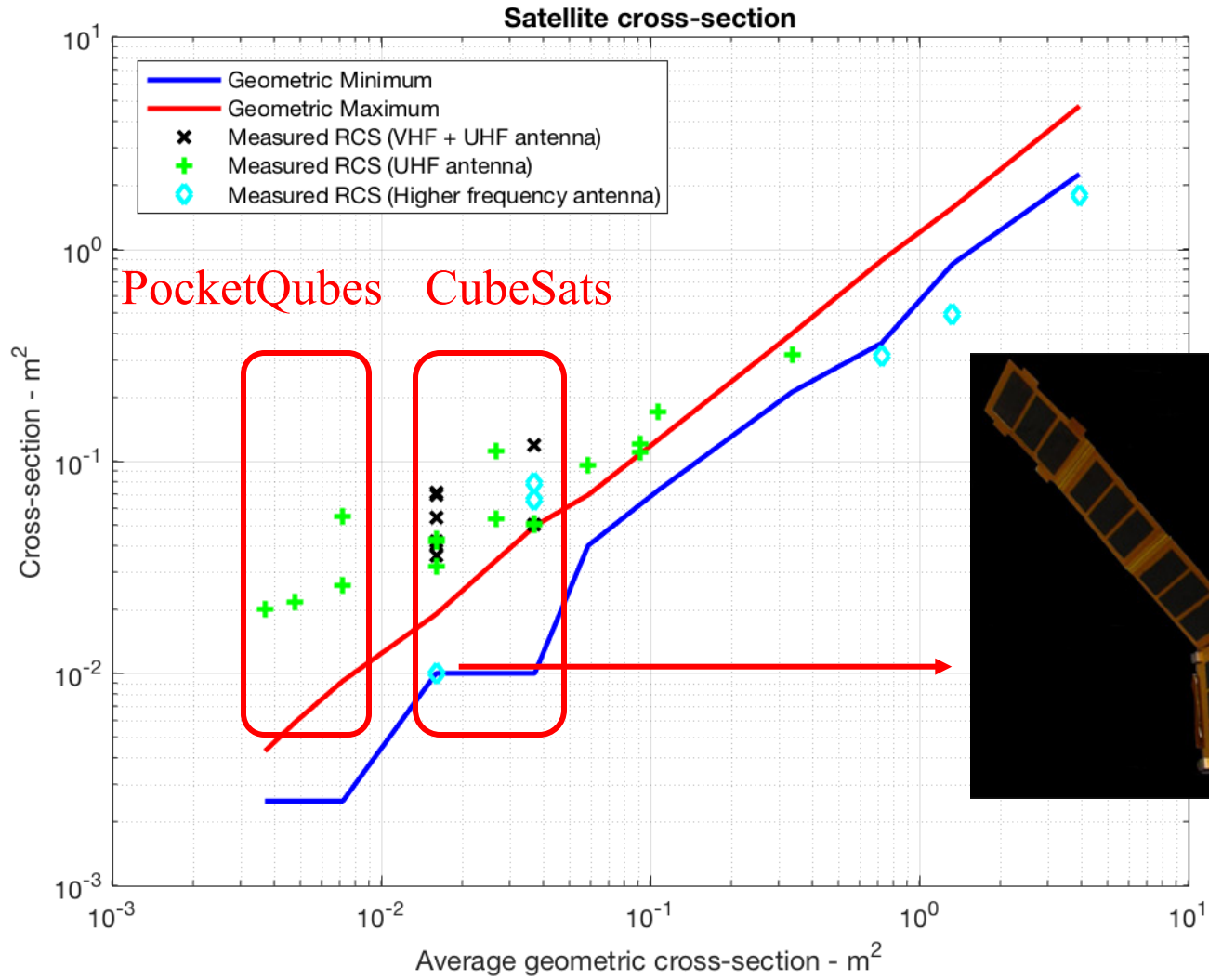
# Radar cross-section analysis



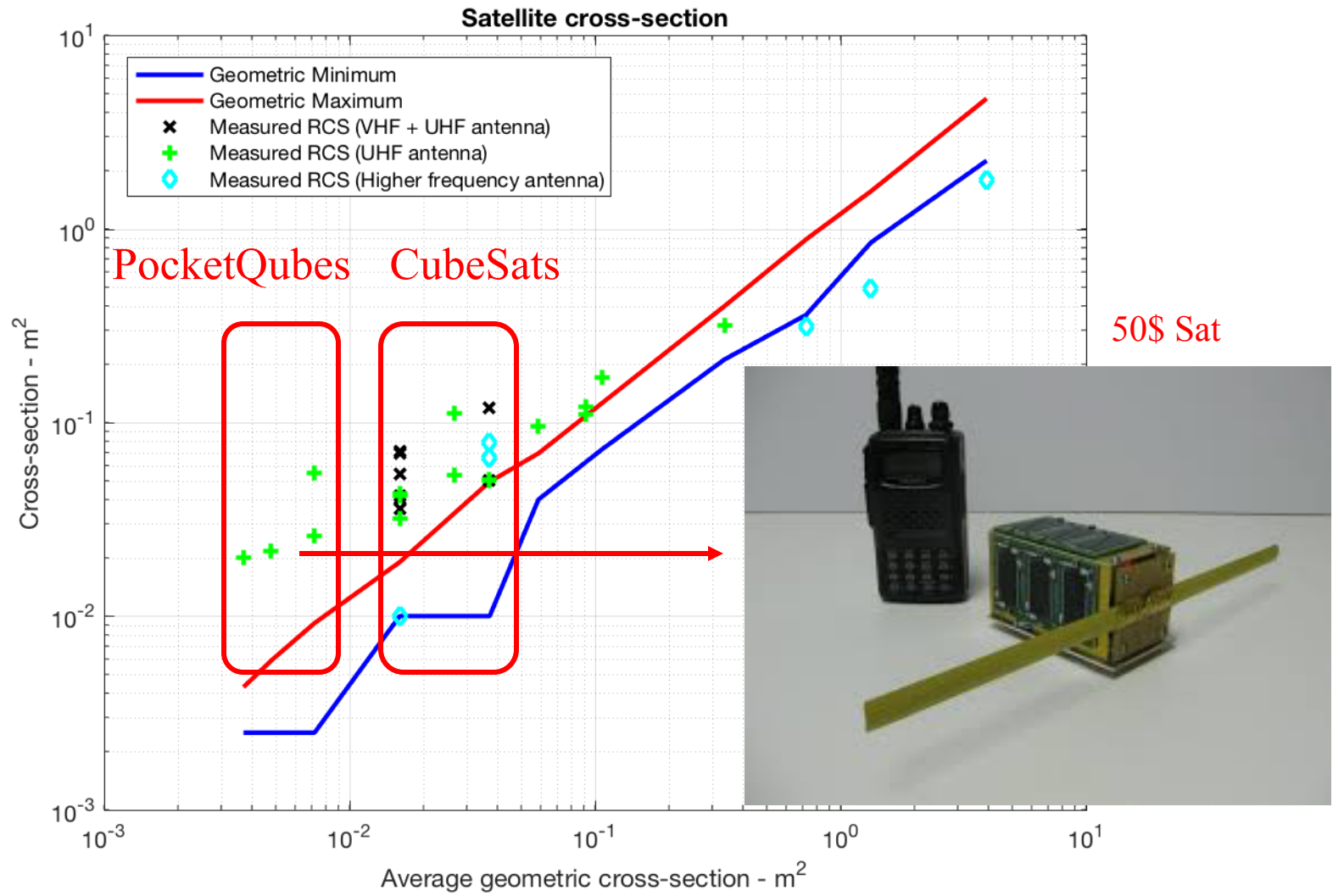
# Radar cross-section analysis



# Radar cross-section analysis

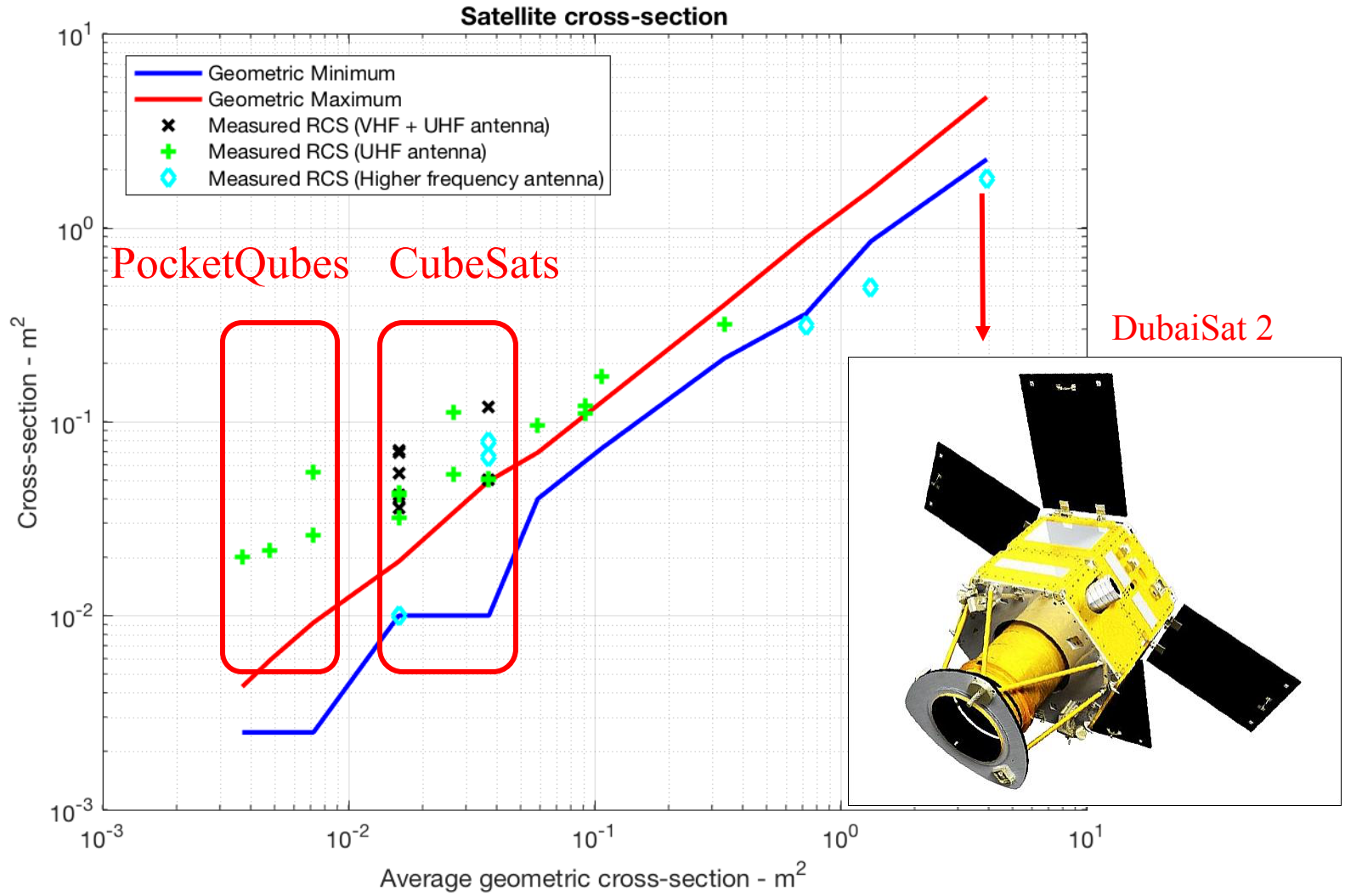


# Radar cross-section analysis





# Radar cross-section analysis



# 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?

[www.delfispace.nl](http://www.delfispace.nl)

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