MICHIGAN ENGINEERING
UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

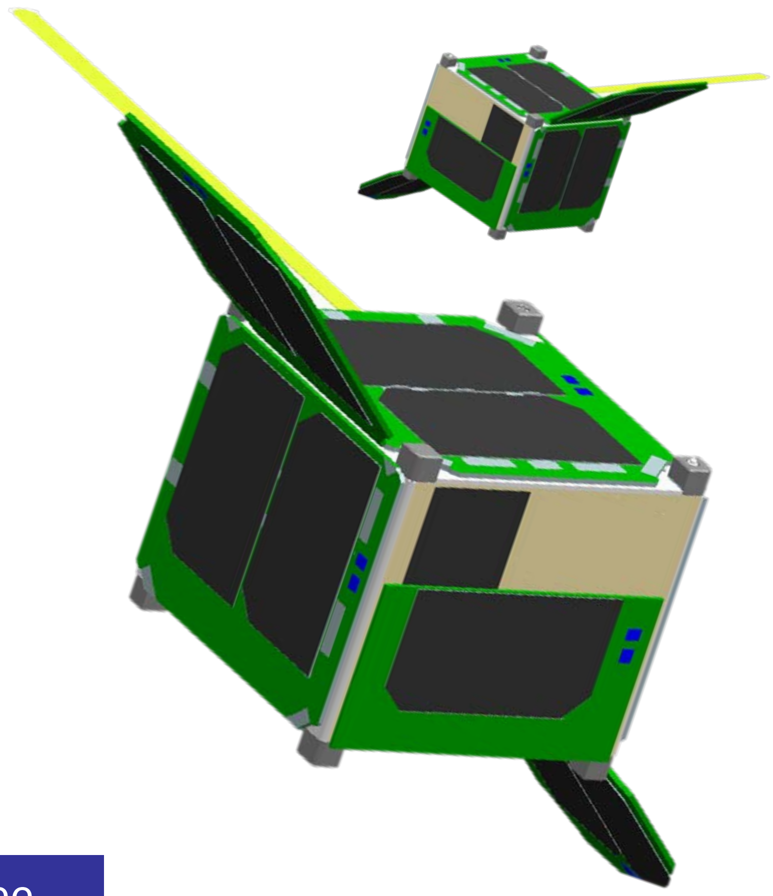
Simulation Results of Alternative Methods for Formation Separation Control

Thomas Heine, Charles Bussy-Virat, Mark Moldwin, Aaron Ridley
Department of Climate and Space Sciences and Engineering
University of Michigan

SCION: SCintillation and Ionospheric Occultation Nanosats

MICHIGAN ENGINEERING
UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

A CubeSat–based mission designed to make **multipoint**, GPS TEC and scintillation observations of the ionosphere on the **~1 km spatial scales** associated with communication and navigation system degradation.



Radio scintillation leading to:
20 dB signal fade in GNSS (GPS), loss-of-lock, dropped data packets, or total inoperability

[Basu and Groves, 2001; Ledvina et al., 2002; Seo et al., 2011 Datta-Barua et al., 2003; Doherty et al., 2004]

When, where, and why can we expect to see scintillation causing irregularities form?

Spacecraft overview

MICHIGAN ENGINEERING
UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

Space Segment:
2 x 1U CubeSats – same orbital track (pearls-on-a-string)

Payload:
Novatel OEM V6 Dual-frequency GPS Rx

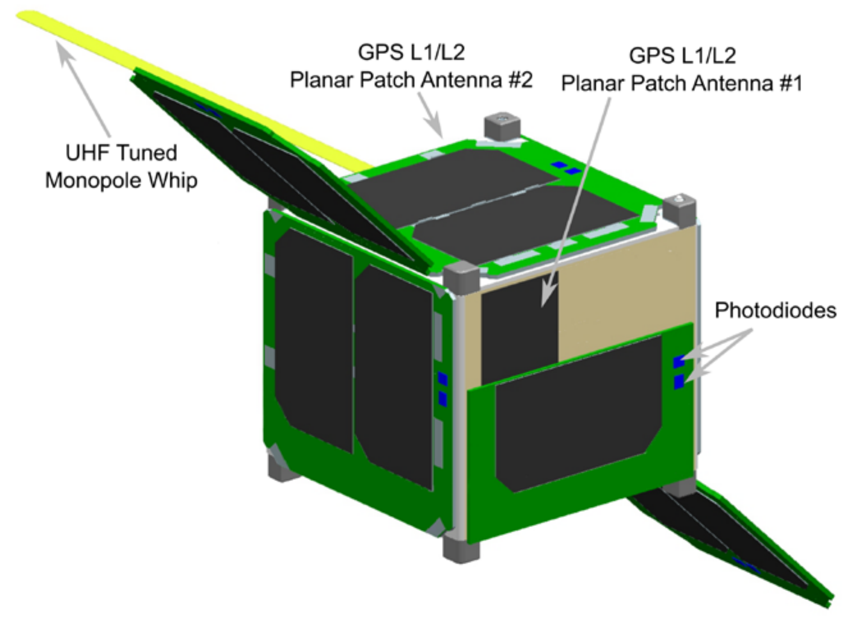
Communication:
UHF communication to ground

ADCS:
Coarse attitude determination and *control?*

Orbit:
600 km altitude, 55 deg inclination

Lifetime:
6-mo minimum

Resolution:
Minimum 50% of observations < 5 km at 90 days



Measurements

GPS telemetry up to 50 Hz including:

Code and carrier phase

Carrier C/N_0

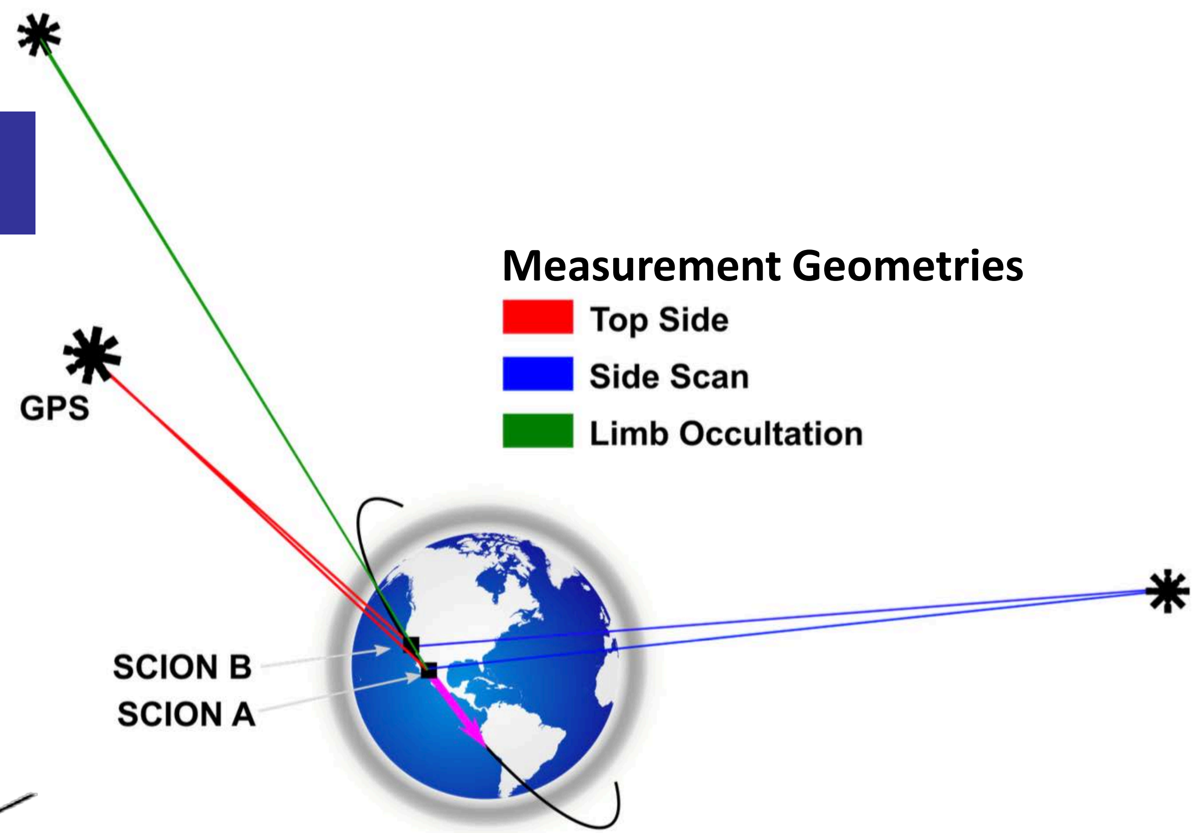
This allows calculation of GPS TEC, signal fade, and scintillation indices

Three look directions:

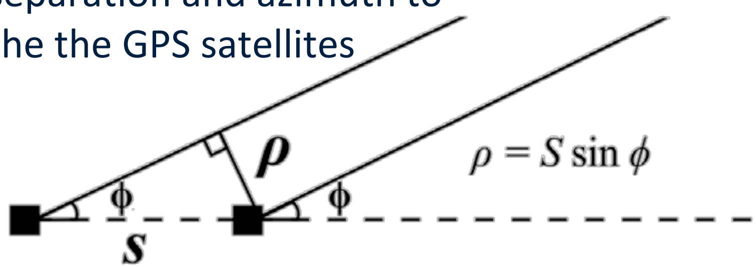
Top-side

Side-Scanning (or cross-track)

Rearward Limb Occultation



Measurement resolution is a function of spacecraft separation and azimuth to the the GPS satellites

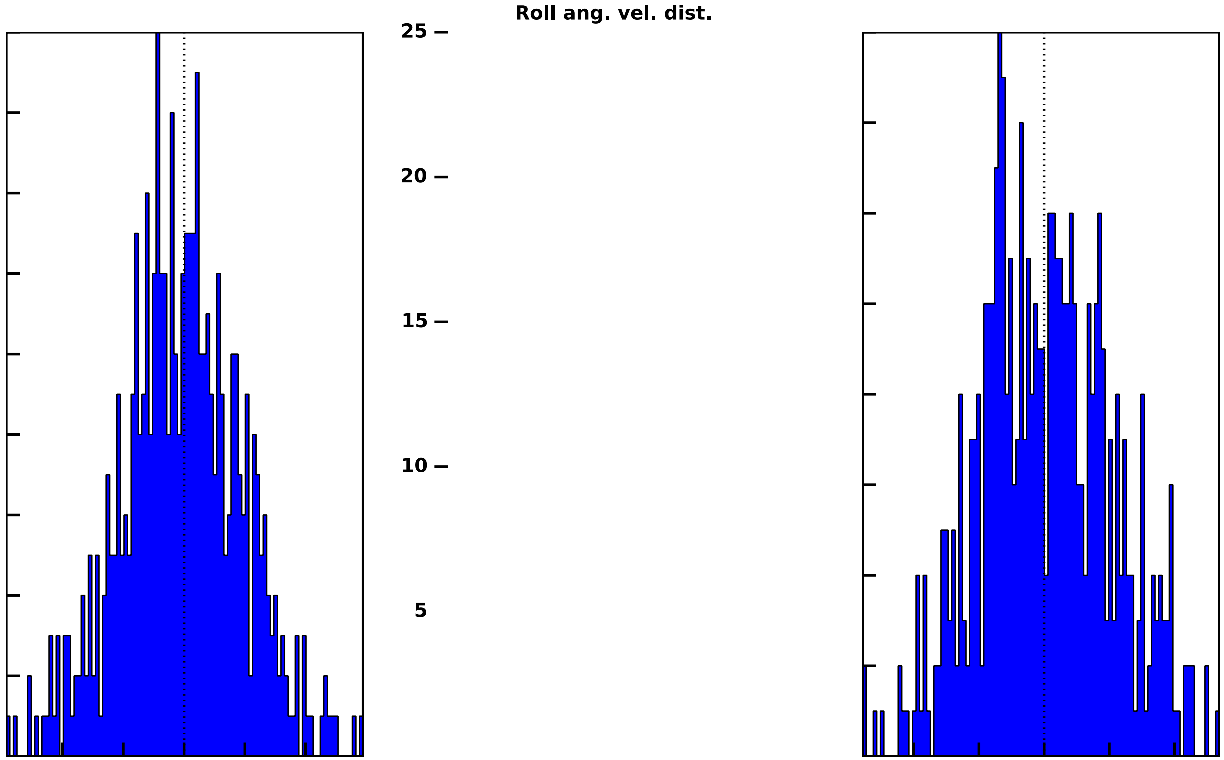


Example:

6 km spacecraft separation corresponds to 1 km multipoint resolution ~30% of the time (based on relative position to GPS satellites)

Modelling uncontrolled attitude at deployment

- If there is no attitude control on the two spacecraft, they will randomly drift after deployment
- Since we can not predict at which rate they will drift, we ran hundreds of satellites with random initial angular velocities. (Realistic values for the drift are a few degrees/s)
- The distributions on the pitch, roll, and yaw angular velocities are shown below



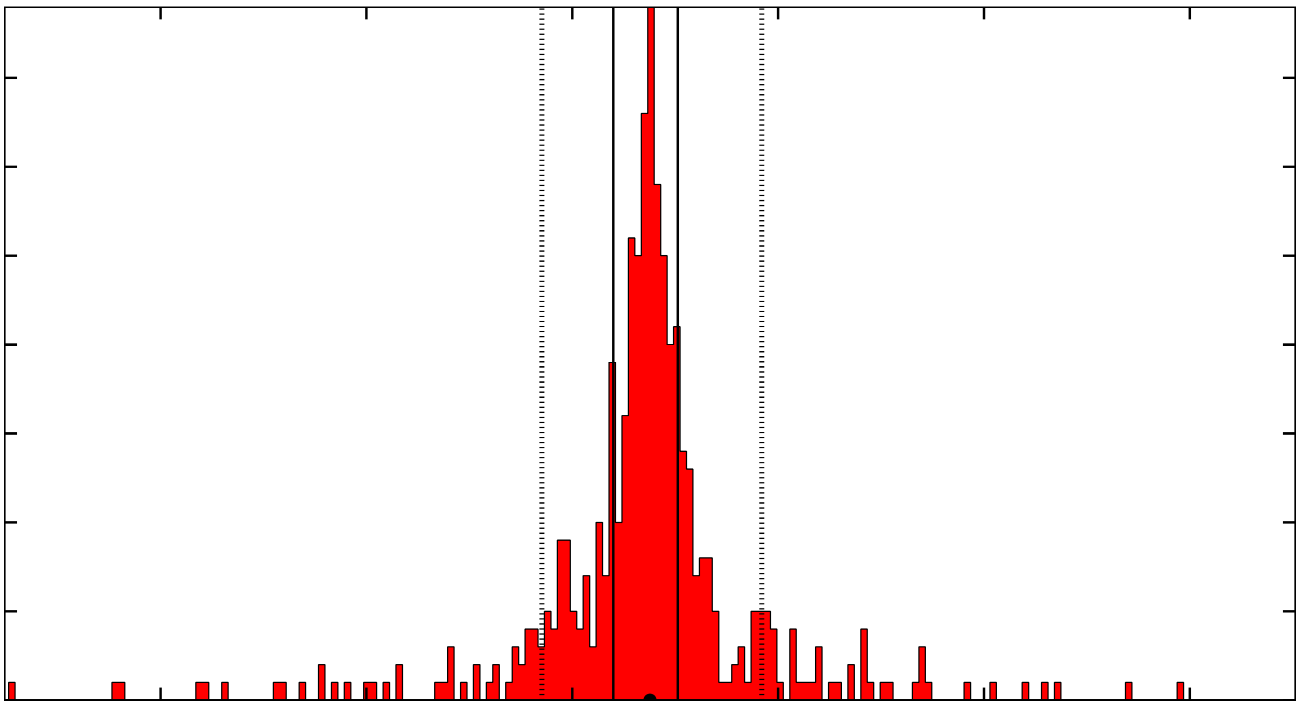
- We then propagate the 500 hundred satellites and look at their relative positions as a function time

MICHIGAN ENGINEERING

UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

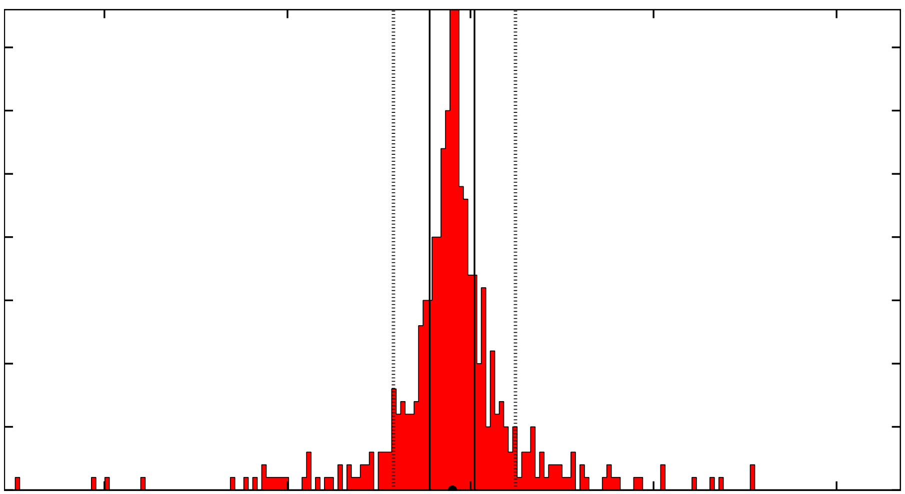
- The spacecraft are distributed along the orbit 90 days after deployment as shown below
- 50% of the satellites are clustered in a 1.72 km bin size, 80% in a 5.88 km bin size
- In other words, there is a 80% chance that the 2 SCION satellites will be separated by less than 5.88 km after 90 days

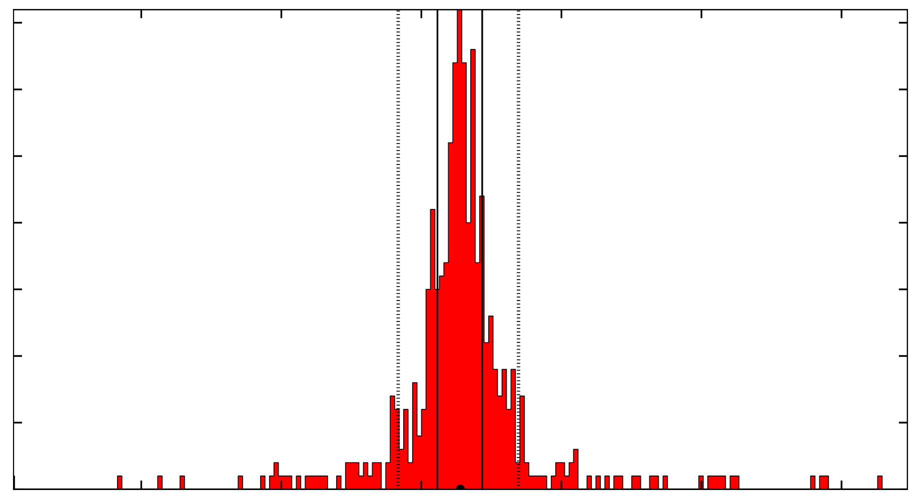
cecraft distribution along the orbit 90 days after deployment



Influence of the solar activity

- The previous slide was considering a strong solar activity (F10.7 = 200 and Ap = 80). This is a worst case scenario
- These figures show the same distributions as before but with quiet solar activity (F10.7 = 90 and Ap = 7) and moderate solar activity (F10.7 = 120 and Ap = 15)
- After 90 days, there is a 80% probability that the satellites will be:
    - 370 m apart from each other for quiet solar activity (left)
    - 940 m apart from each other for moderate solar activity (right)
    - 5.88 km apart from each other for strong solar activity (previous slide)





% of sc)

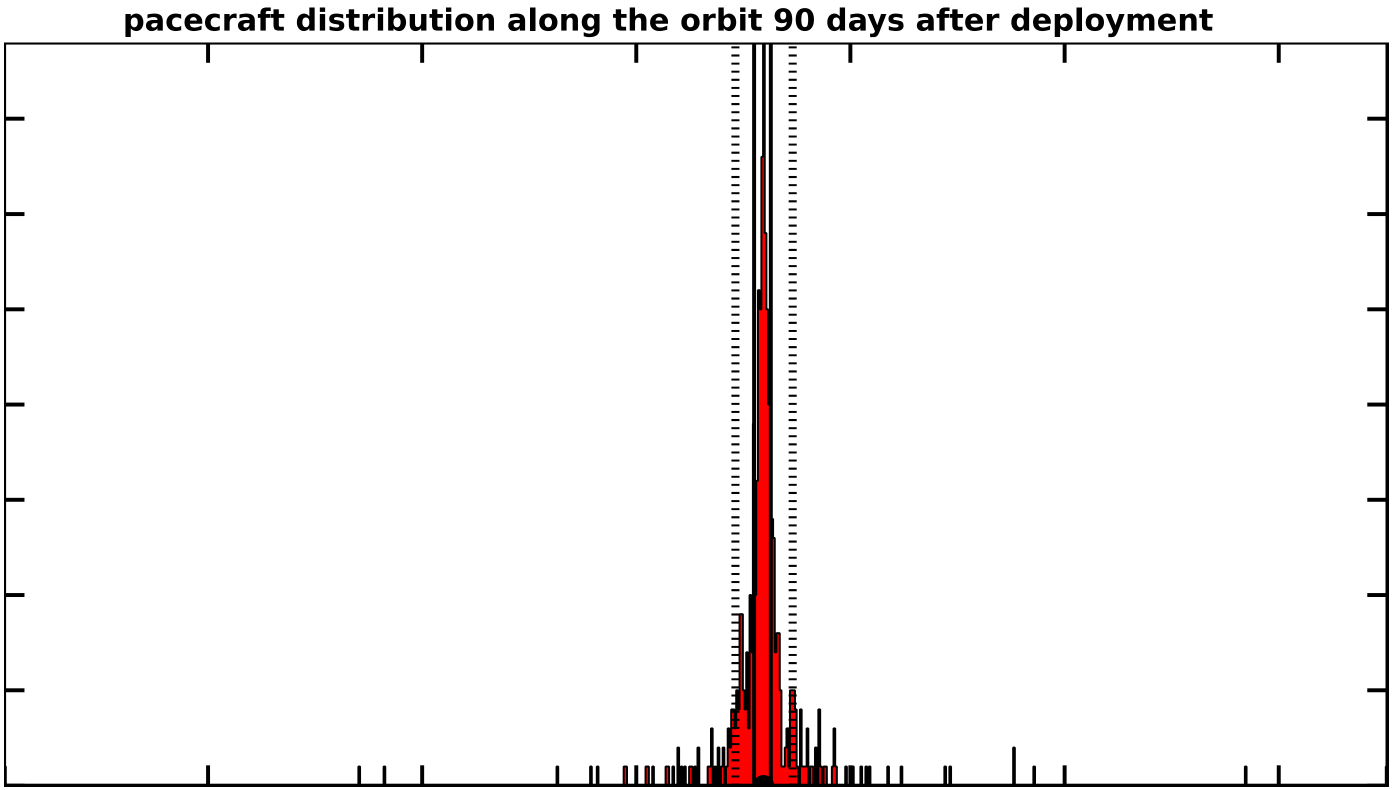
Conclusion

- This analysis shows that without attitude control, the distance between the two SCION satellites will likely be smaller than 10 km, even with a strong solar activity.

- However, there are limits to this approach:
  - There is a small chance that the satellites end up being outliers of the previous distributions: in other words, end up being separated by higher distances (20-100 km)
  - The SCION satellites' rotation rate cannot be more than a few degrees/s to maintain GPS tracking

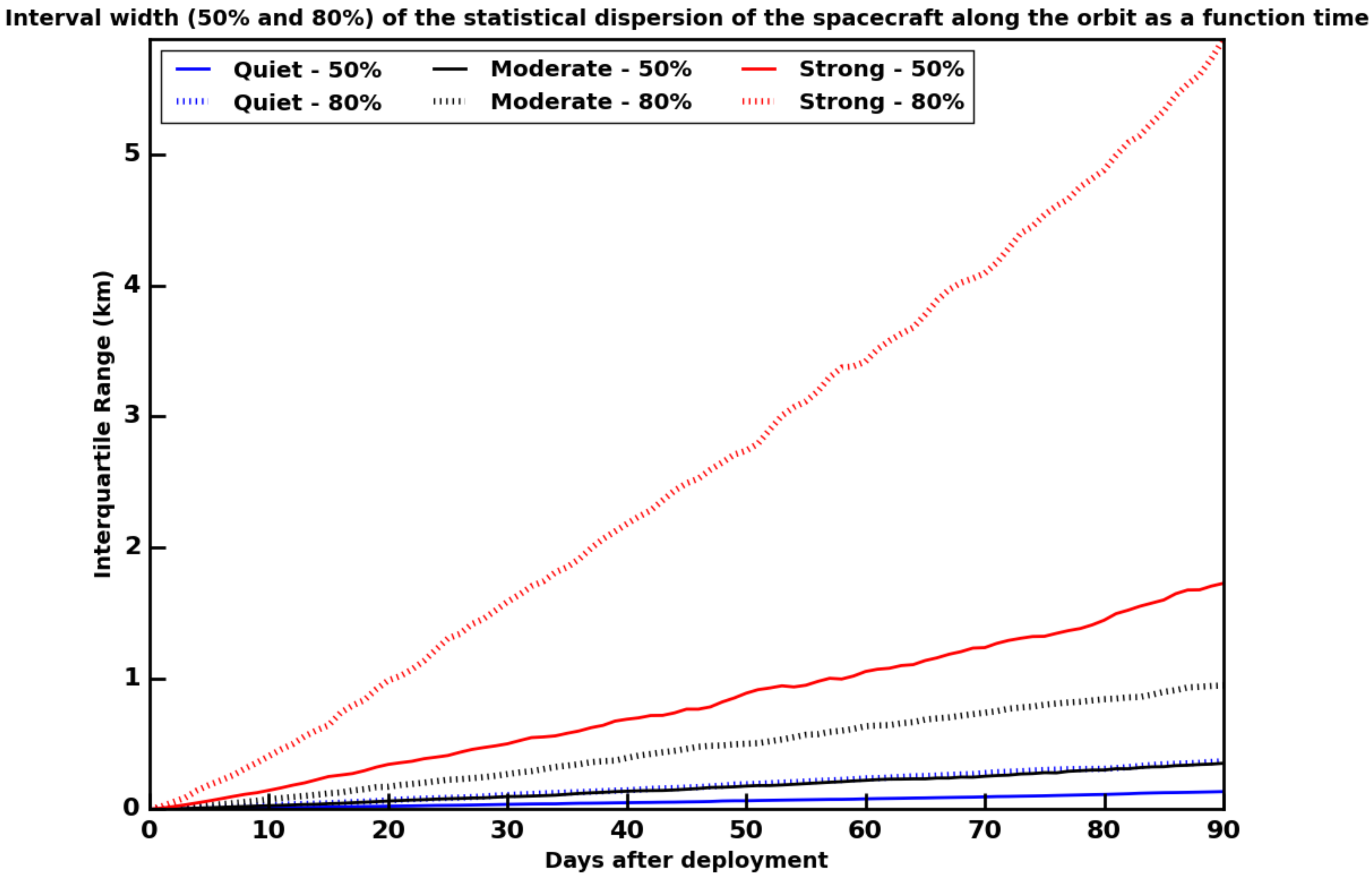
BACKUP SLIDES

Outliers (backup slide)



Influence of solar activity (backup slide)

MICHIGAN ENGINEERING
UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

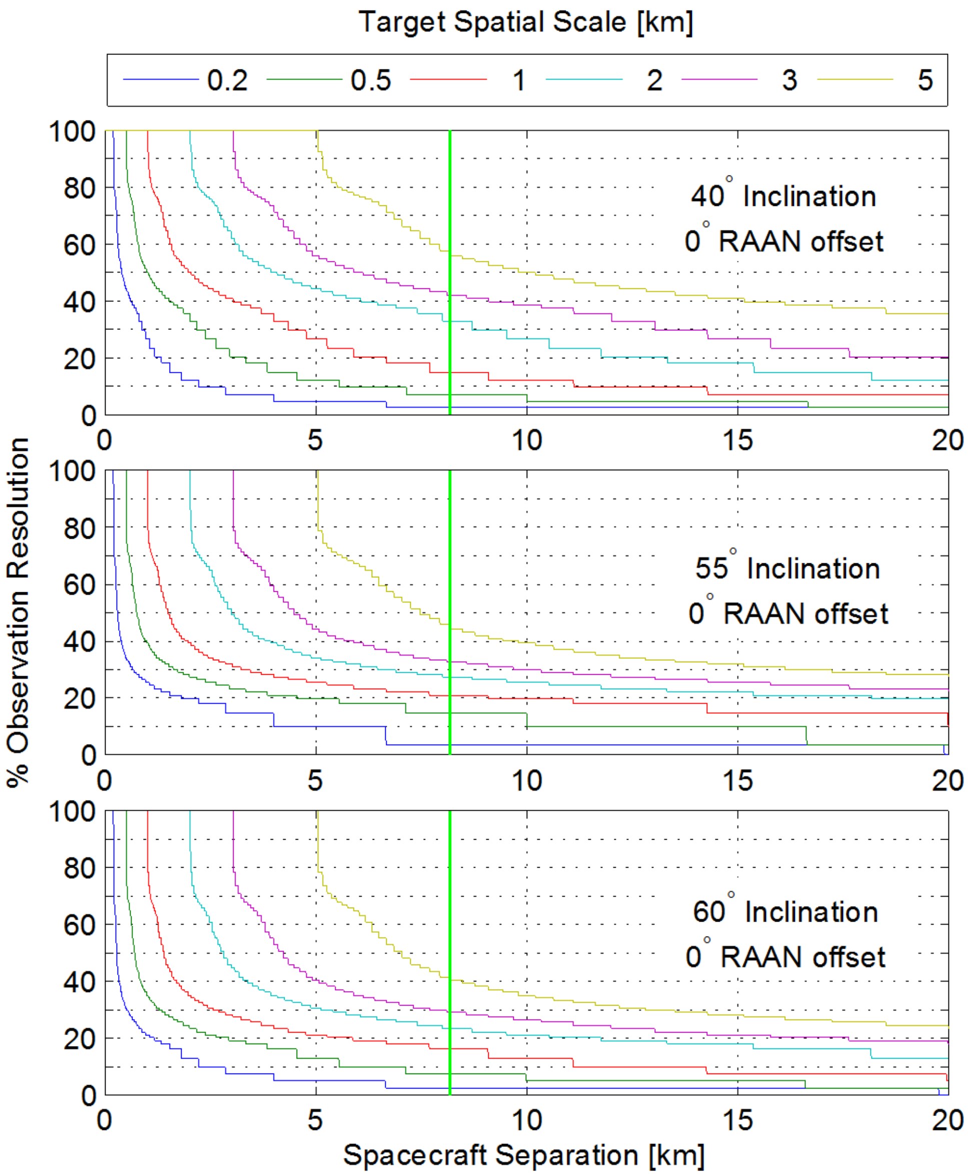


Measurement Resolution Opportunities with Spacecraft separation

10% S<10 km at F10.7 200

99% S<10 km at F10.7 120

99.9% S<10 km at F10.7 90



Passive Separation Control

Spinning the spacecraft averages differences in their drag profile

The spin rate is constrained by the GPS acquisition

This has been shown to extend the time the spacecraft can make kilometer scale observations by at least a factor of two