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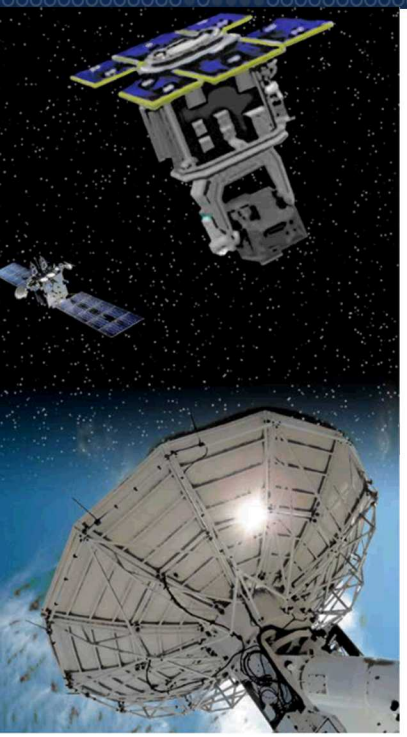

The Conjunction Problem: A Study of SSA Architectures to Monitor Orbital Maneuvers and Conjunctions

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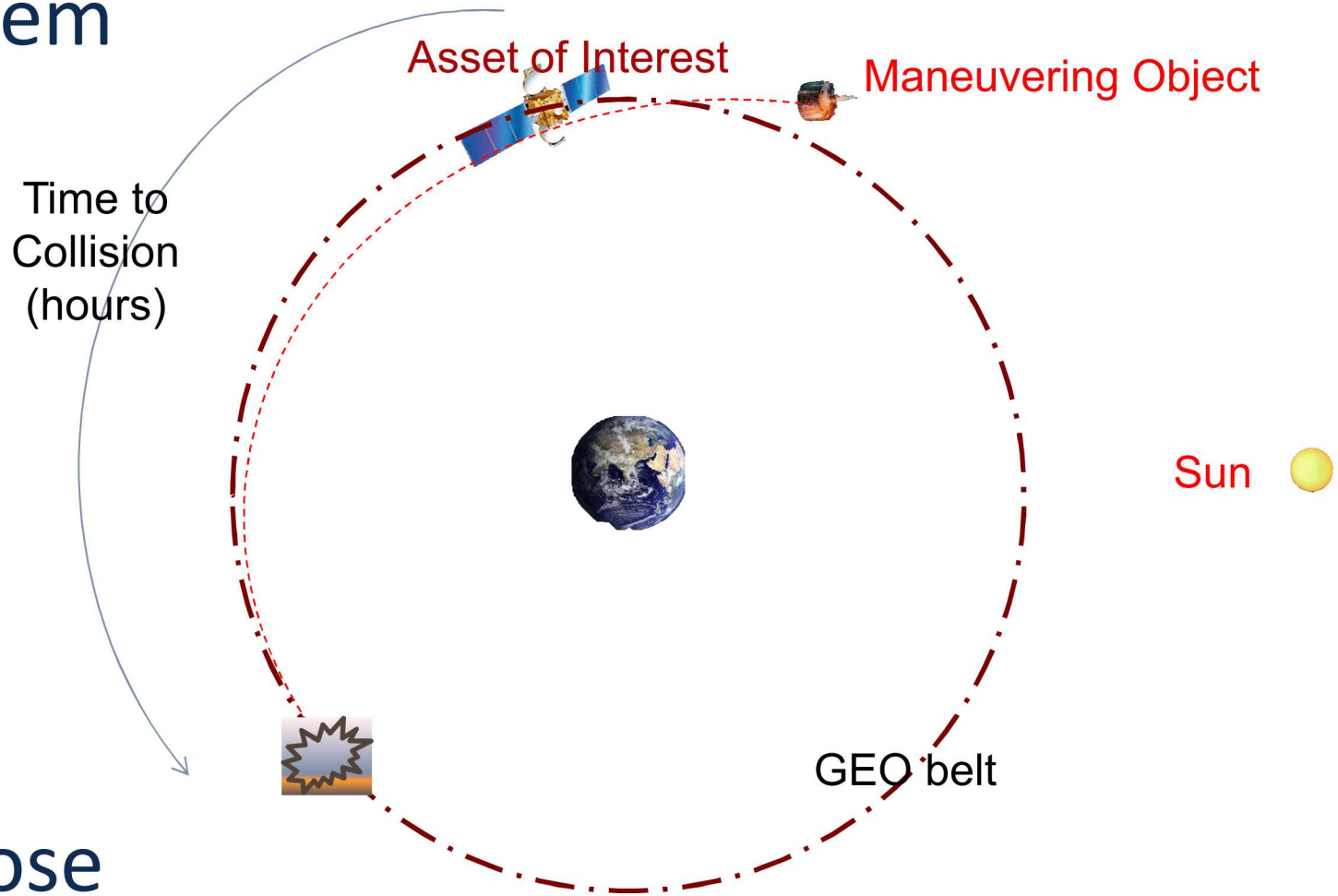
Problem



Purpose

Explore space situational awareness (SSA) architectures for detection of space object maneuvers and conjunction events

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Model Parameters

Sensor onboard Asset of Interest	Satellite location: • GEO belt • zero inclination	On-board sensor parameters • Staring sensor • Aperture size: 0.025-0.1m • Integration time: 1-5 s
Ground-based optical telescope network	Network size and locations • 3 GEODSS + SST OR • 13 site: proposed	Ground sensor parameters • Integration time: 1-5 s • All 1 m diameter (including SST, for convenience)
Notional co-orbital sensor constellation	Satellite constellation size • 3-6 platforms • zero inclination GEO	Space sensor parameters • VMF Tracking • Aperture size: 0.3-0.5m • Integration time: 1-5 s
Other space-based sensor constellation	Satellite constellation and orbit • 3-6 Notional Near GEO • 1-2 LEO sensors (SBSS-like, or ORS-5-like)	Space sensor parameters • VMF tracking • Aperture size: 0.3-0.5m • Integration time: 1-5 s

Other Parameters, Assumptions and Constraints

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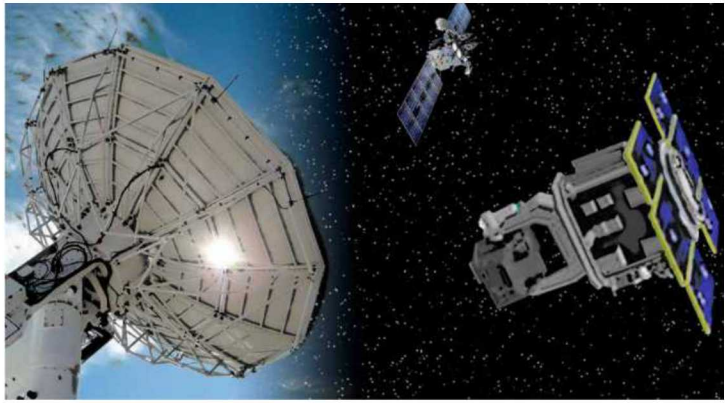
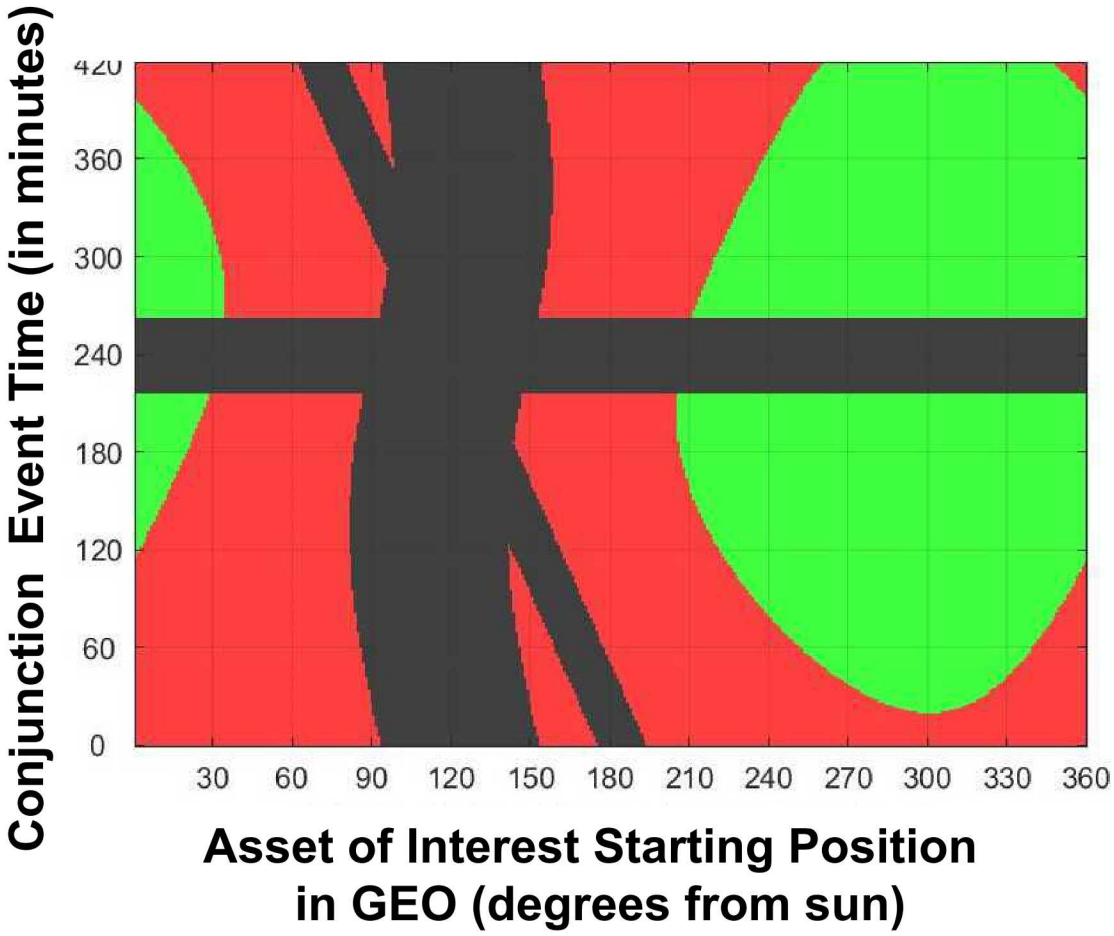
- Maneuvering Object
  - Diameter (0.25, 0.5, 1.0 m)
  - Diffuse aluminum sphere
    - 18% reflective
  - Starting position
    - Within the vicinity of the Asset of Interest
  - Forward movement only

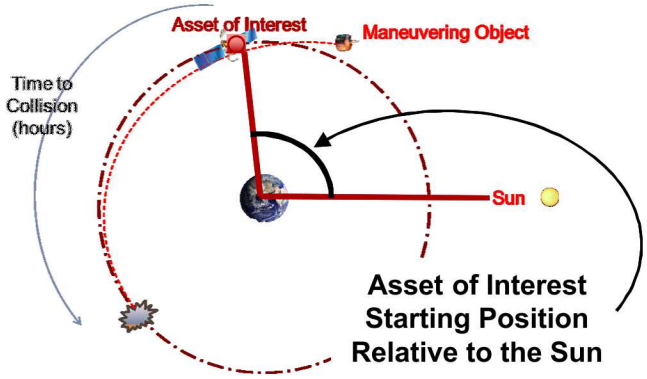


- Conjunction Event
  - Only considered co-orbital in plane
  - Time to Conjunction (7 and 15 hours)
- Other Factors
  - Day of year, time of day
  - Terrestrial weather not included
  - Cost to be considered in future study
- Sensitivity Calculations Based on
  - Electro-optical sensor parameters
  - Optical telescope parameters
  - Relative motion of sensor and object
  - Velocity-matched filter processing

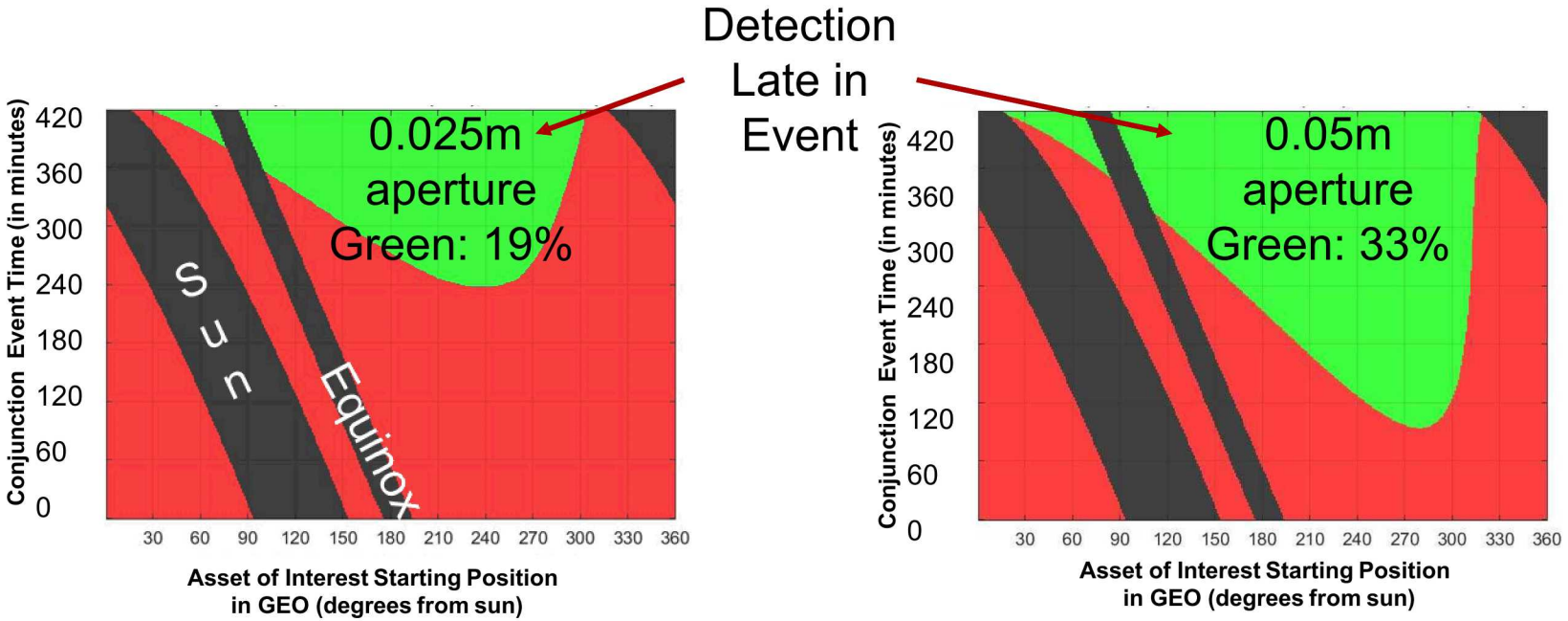
Understanding the Plots: Look for the Green



- **GREEN**
  - Detection above threshold
- **RED**
  - Sub-threshold - no Detection
- **BLACK**
  - Blocked by earth
  - Within solar exclusion region
  - Object in shadow (near equinox)



Findings: Sensors Onboard Asset of Interest

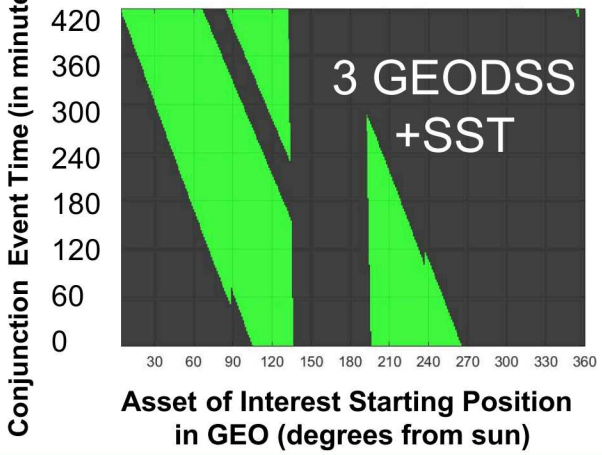


Sensor onboard Asset of Interest can provide limited detection late in the conjunction event

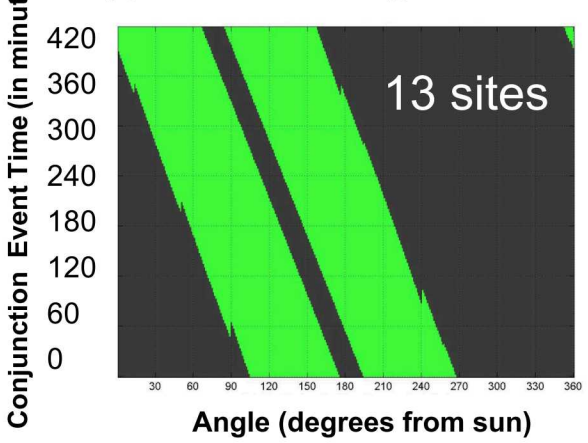
%Coverage	Maneuvering Object Diameter (m)		
Aperture Diameter (m)	**0.25**	**0.50**	**1.00**
0.025	16.5%	49.9%	69.1%
0.05	29.6%	61.8%	73.9%
0.1	49.9%	69.1%	78.0%

Findings: Ground-Based Telescope Networks

Variable coverage ~ 27-40%



Typical coverage ~40%



Ground-based telescopes limited to <45% coverage of potential conjunction events

Performance against 0.25 m diameter object

Aperture Size (m)	Integration Time (s)	Percent Coverage	Network
1.0	5s	40%	13 sites
1.0	1s	21%	13 sites

Larger apertures and longer integration times improve coverage especially against smallest (0.25 m) object size

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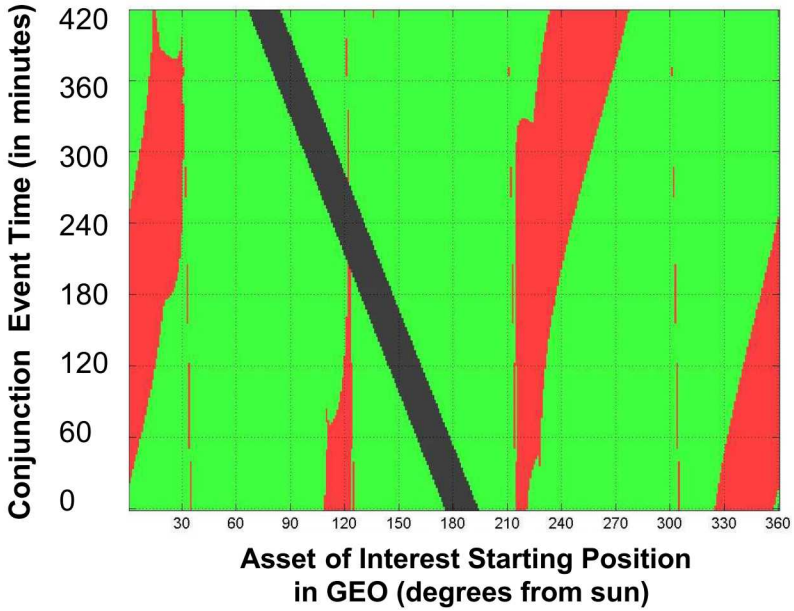
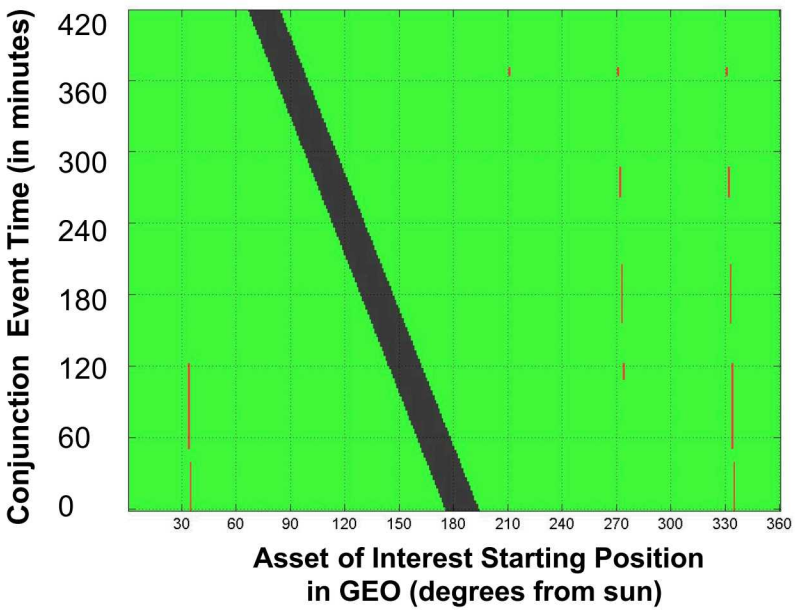
Findings: Notional GEO Constellation Size Matters



4x co-orbital GEO satellites
78% Green

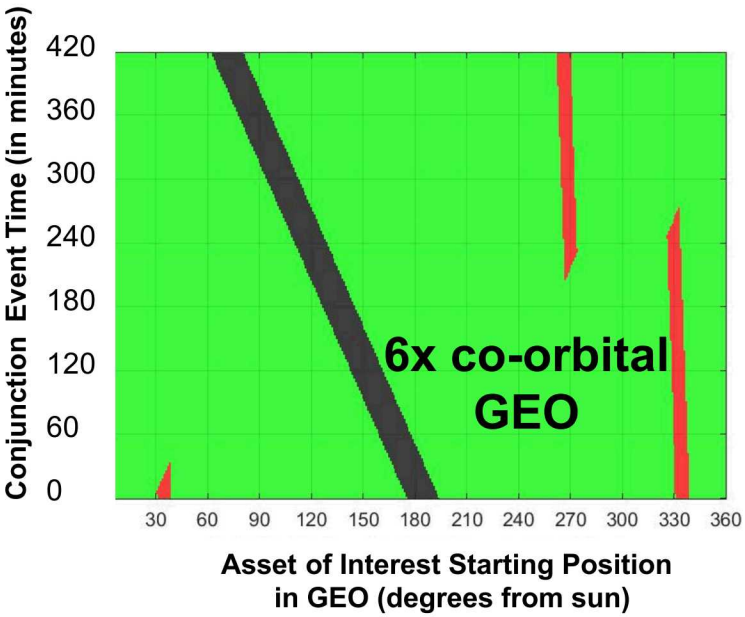


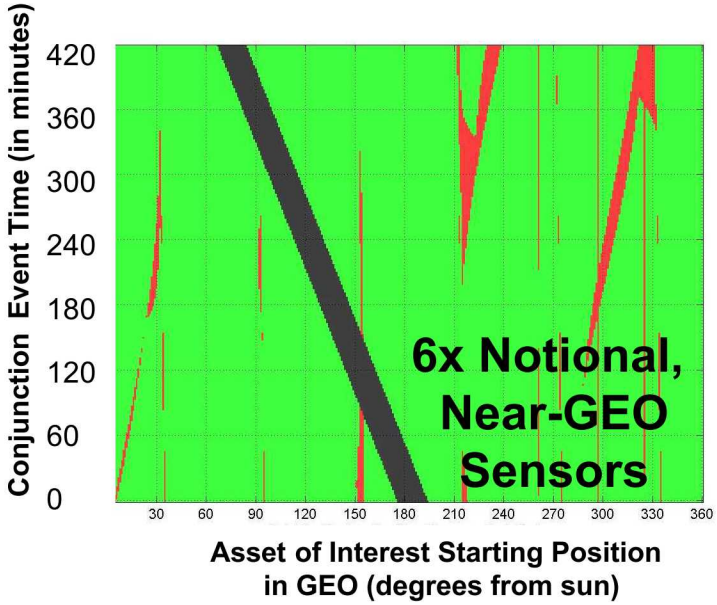
6x co-orbital GEO satellites
94% Green

0.5m aperture
3s integration time
0.25m maneuvering object

High detection capability achieved with dedicated constellations of sensors with velocity matched filters (synthetic tracking)

Findings: Notional Near-GEO Sensor Constellations





High spatial-temporal coverage of 0.25 m maneuvering object conjunction event can be achieved with a constellation of sensors

Satellites in Constellation	Sensor Aperture (m)	Integration Time (s)	Coverage
4	0.3	5	58.3%
4	0.5	5	83.6%
6	0.3	5	82.7%
6	0.5	5	93.6%
6	0.5	2	87.2%

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Summary of Findings

- Small-aperture sensors on Asset of Interest
  - Not sufficient by themselves
  - Cannot monitor entire maneuver/conjunction event
  - Mostly useful late in conjunction event
- Ground-based telescope networks
  - Not sufficient by themselves – daylight/solar outage limits coverage
  - Can provide best combination of sensitivity and search rate
  - 1m diameter or larger apertures required to detect 0.25m objects
  - Relatively low-cost, easily maintained back-up for space-based sensors
- Near-GEO sensor constellation
  - 6 satellite constellations are sufficient by themselves
  - 0.5m aperture required for highest sensitivity
  - Dedicated co-orbital GEO or Near-GEO sensors work best

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Conclusions and Recommendations

- Methodology for modeling SSA architecture for orbital maneuvers and conjunctions events demonstrated

- Academic study useful for exploring sensor trade space—findings help to
  - Limit consideration of low performing options
  - Encourage further study of high performing options

- Potential follow-on studies:
  - Analyze more combinations of event times and maneuvering object size
  - Study effect of search rate on architecture and detection/tracking
  - Include cost analyses as part of architecture trade space