TECHNICAL MEANS FOR MONITORING SPACE AGREEMENTS

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OBJECTIVE

- **To demonstrate that existing technology enables sufficient monitoring of space treaties, Codes of Conduct, and agreements.**

Considerations

- Increasing dependence on satellite systems.
- Reemergence of Earth and space-based weapons programs directed against space assets,
- The growing number of actors in space, contributing to congestion and proliferation in debris
- The expected availability of lower cost launches that will greatly increase the number of spacecraft launched and strain already overtaxed mechanisms for monitoring.
- The use of very small systems in space that go below the current threshold of space surveillance systems.

MONITORING AND VERIFICATION

- No agreement can be verified unequivocally.
  - Multilateral treaties generally include no verification mechanism
    - Many parties are unable to verify anything on their own.
    - The consequences of violation are sufficiently harsh that explicit verification is not necessary.
- One must determine what is sufficient for the purpose.
  - Almost all nations are capable of contributing to achieve sufficiency

APPROACH

- Conjecture likely provisions
- Identify the observables of violation
- Determine technical capability to perceive those observables and act on them.
- Examine capabilities parametrically to develop alternatives with varying degrees of confidence.
- Focus on civil and commercial “Persistent Technical Means.”

Examples in Each Mission Phase

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LAUNCH

Treaty Provision	Possible Violation	Observables	Perception Mechanisms	Mitigation Measures
Freedom of Access	Interference with launch communication and control	EMI/RFI	Local Terrestrial, air, or space Sensors	Emission control
	Positioning satellites improperly during launch windows	Radar, EO	Radar and Optical Sensors	NOTAMS and closures
Debris Mitigation	Unnecessary release of launch related objects	Multiple, unanticipated objects	Radar and EO/Space and Terrestrial	Best practices
	Conjunction with resident spacecraft	Trajectory	Radar and EO/Space and Terrestrial	SSA
ON ORBIT				
Freedom of Movement	Interference with telemetry, commanding, or communications	EMI/RFI	Distributed receivers	Emission control
Debris Mitigation	Conjunction with resident spacecraft	Trajectory	Radar and EO/Space and Terrestrial	SSA
DISPOSAL OR REENTRY				
Passivation	Failure to deplete energy	Lack of observable propellant expulsion or momentum dump	Space surveillance	Sanction

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Collaborative Possibilities

- Perceiving satellite maneuvers
  - Planned Maneuvers
  - Unintentional Trajectory Modification
  - Intentional, Unannounced Modification
- Determining satellite orbits independently and uncooperatively

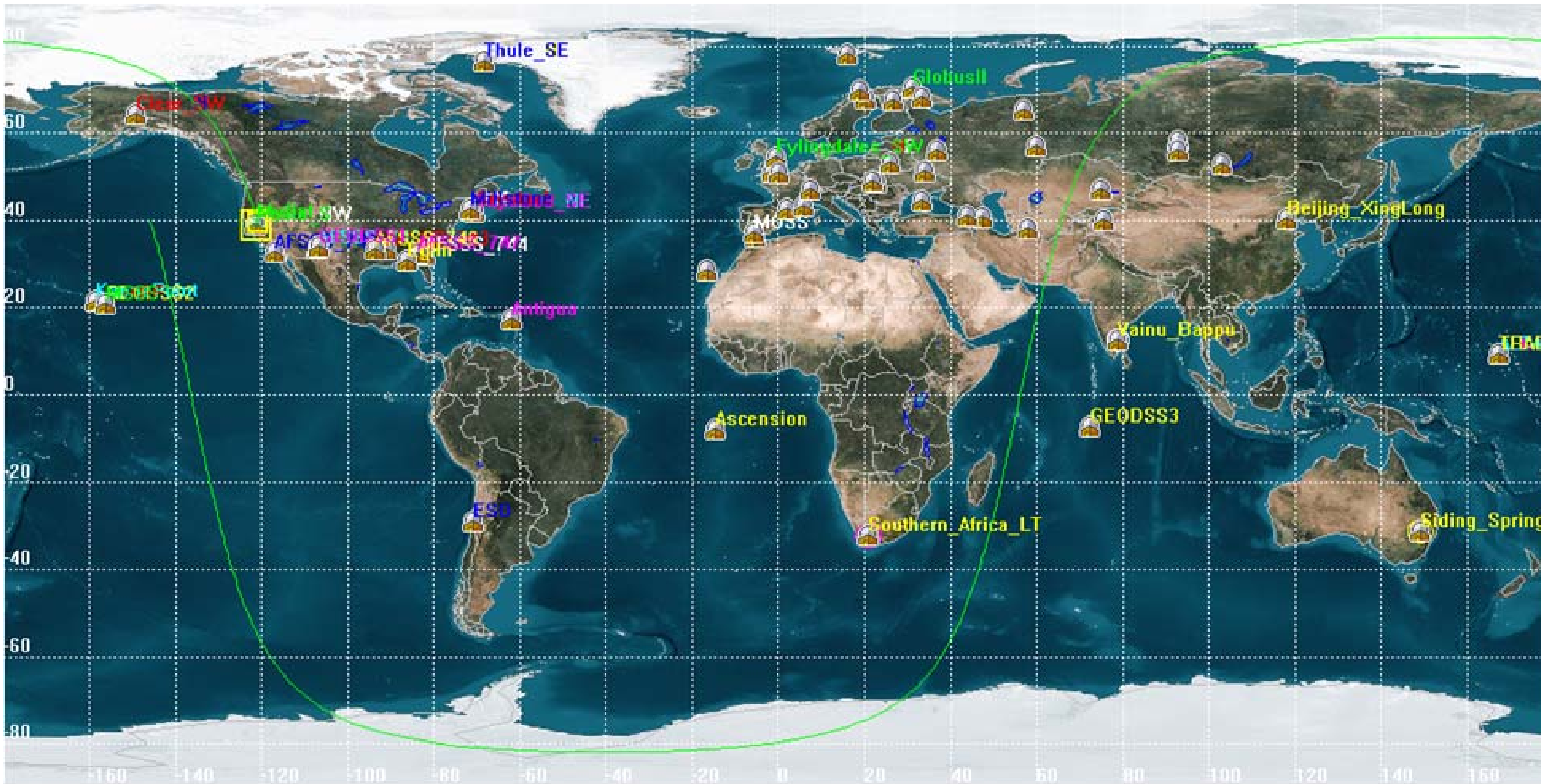
Representative Analyses

- Satellite Maneuver in the Southern Hemisphere
- Maneuver of a Geostationary Satellite over the Indian Ocean

Analysis Approach

- Synthesize observations of the trajectory
  - Samples at regular or irregular intervals
  - Add measurement imprecision (noise)
- Determine observation opportunities
- Consume observations for orbit determination using modern mathematical techniques.
- Develop new orbit

Potential Space Surveillance Resources



Sun Synchronous Satellite Maneuver over the Indian Ocean

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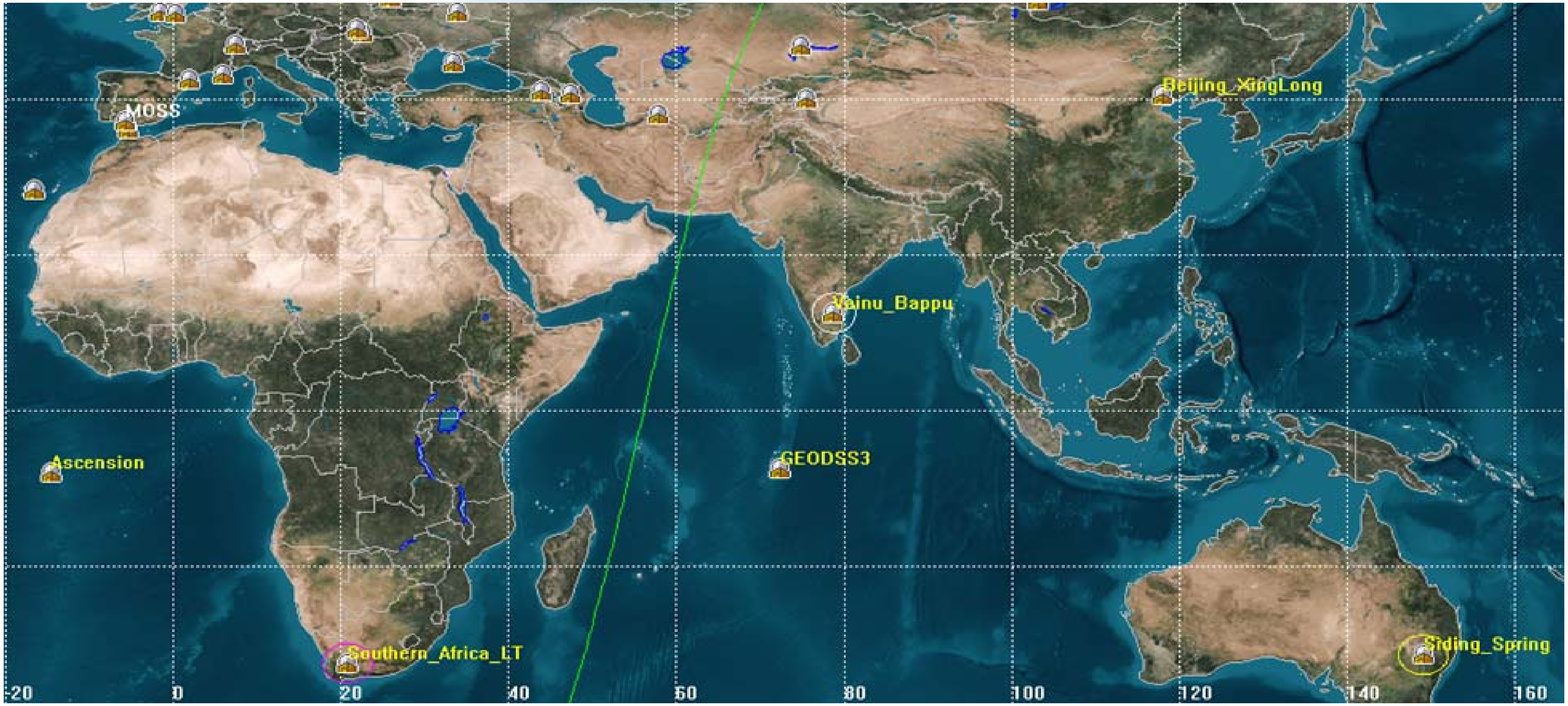
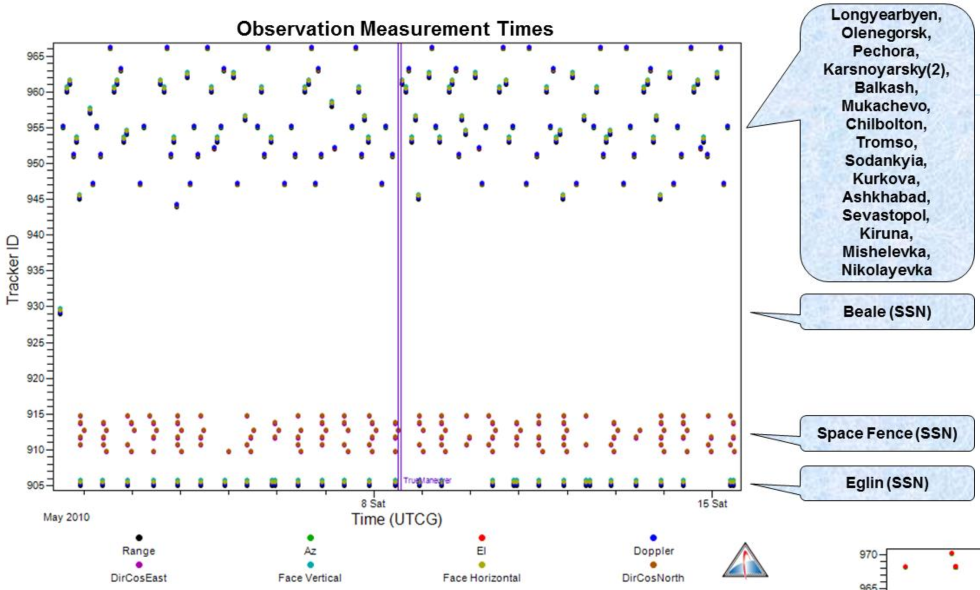


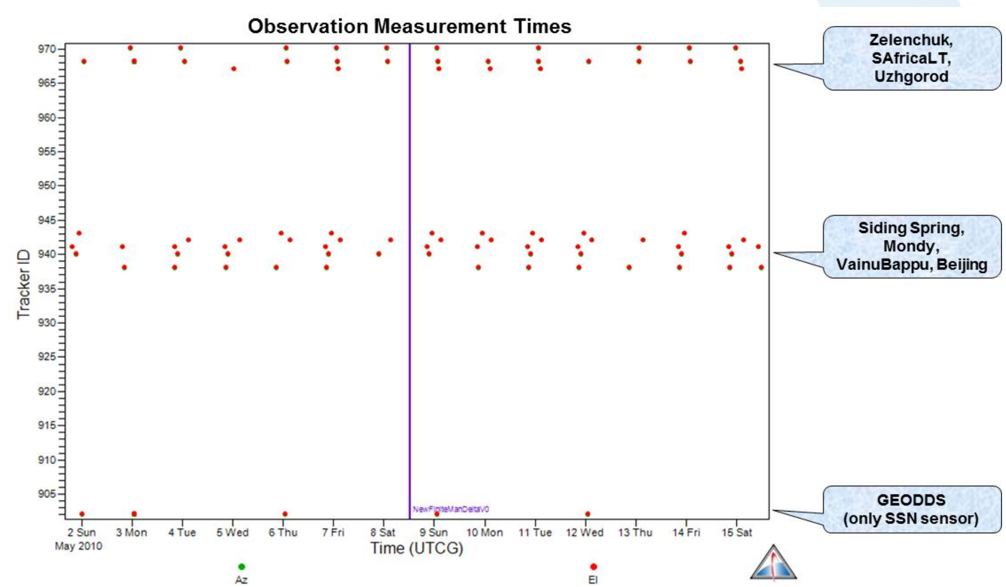
One kilometer per second delta V in track

Collaborative Persistent Capabilities Contribute Many Observation Opportunities



Maneuvering Sun Synchronous Satellite

Maneuvering Geostationary Satellite



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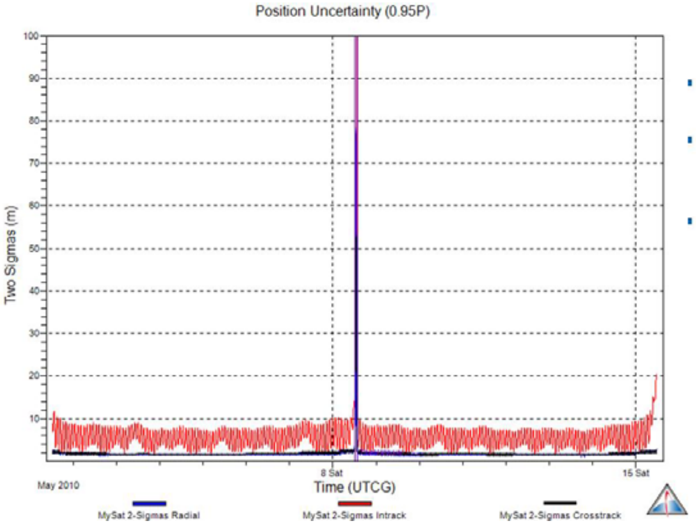
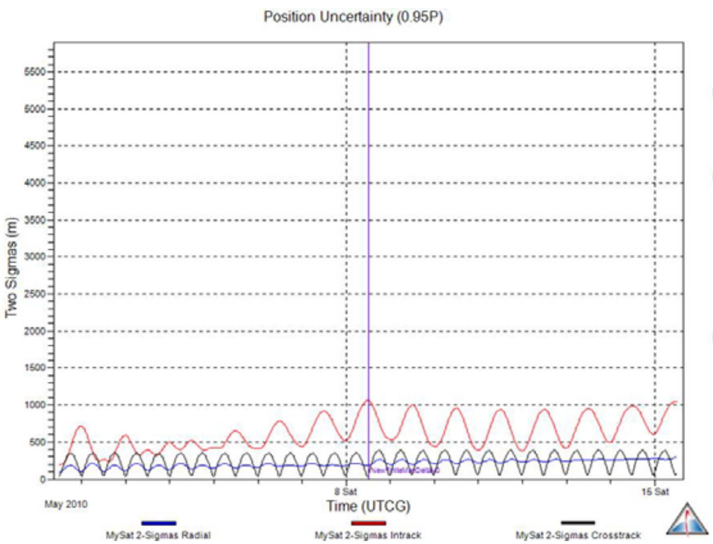
Collaborative Technical Means Achieve Exceptional Orbit Estimates



- 5m position uncertainty
- Near perfect maneuver recovery
- Up to 5x more intrack accuracy

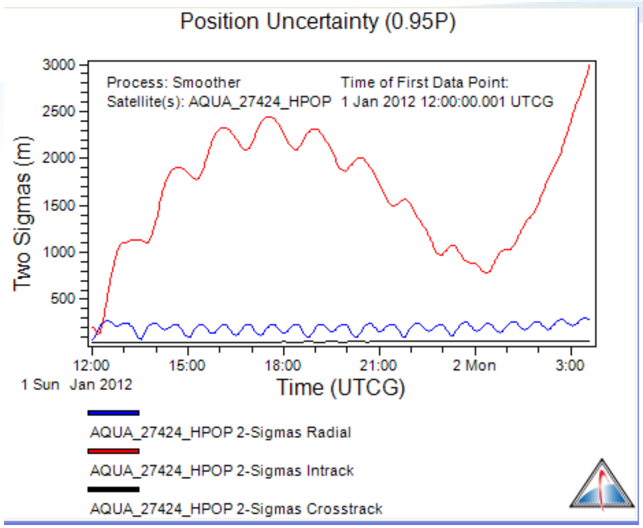
Maneuvering Sun Synchronous Satellite

Maneuvering Geostationary Satellite

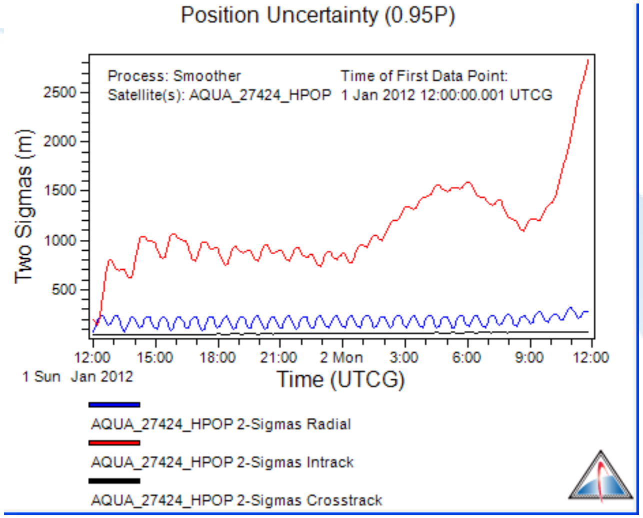


- 0.4-0.7 km position uncertainty
- More dense, angles-only measurements increase intrack SSA accuracy
- Up to 7.8x more intrack accuracy

Developing Orbits Independently in Due Course



Space Surveillance System



Space Surveillance System Plus India and South Africa

MITIGATING RADIO FREQUENCY INTERFERENCE

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- Communication and data transfer exploit extremely small regions of spectrum at extremely low power.
- Small satellite antennas lead to large beam spreads in space.
- There are thousands of unintentional and intentional interference incidents every week
- Several perceptions of the interference are necessary in order to locate the source
  - Either two or more collaborating satellites in relatively close proximity or several hits from one satellite that moves.

Principles of RFI Geolocation

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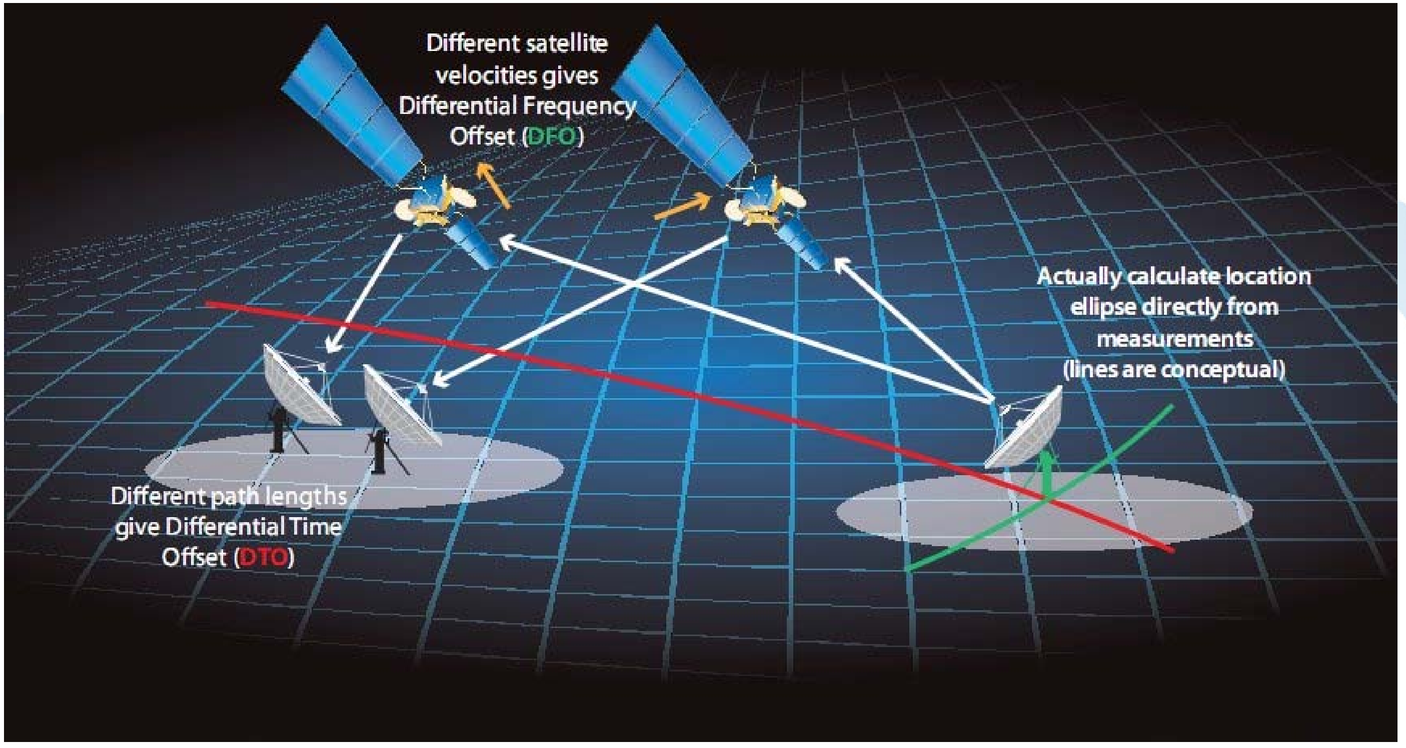
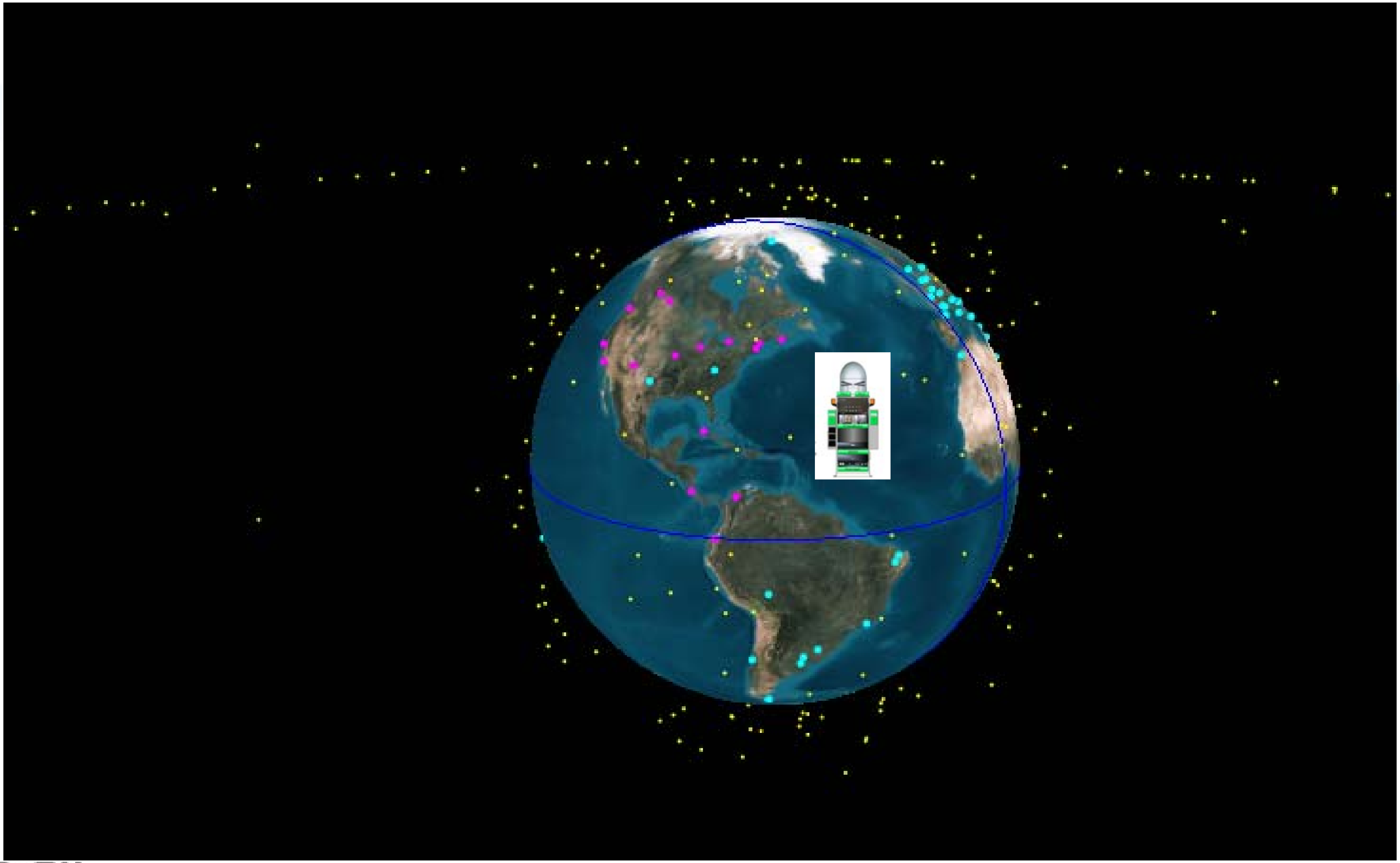


Time and Frequency difference of arrival of a signal at two or more collaborating satellites reveal distance (time of arrival) and velocity (frequency through Doppler shift) from which the source can be "triangulated" if one knows the trajectories of the satellites

International Collaboration

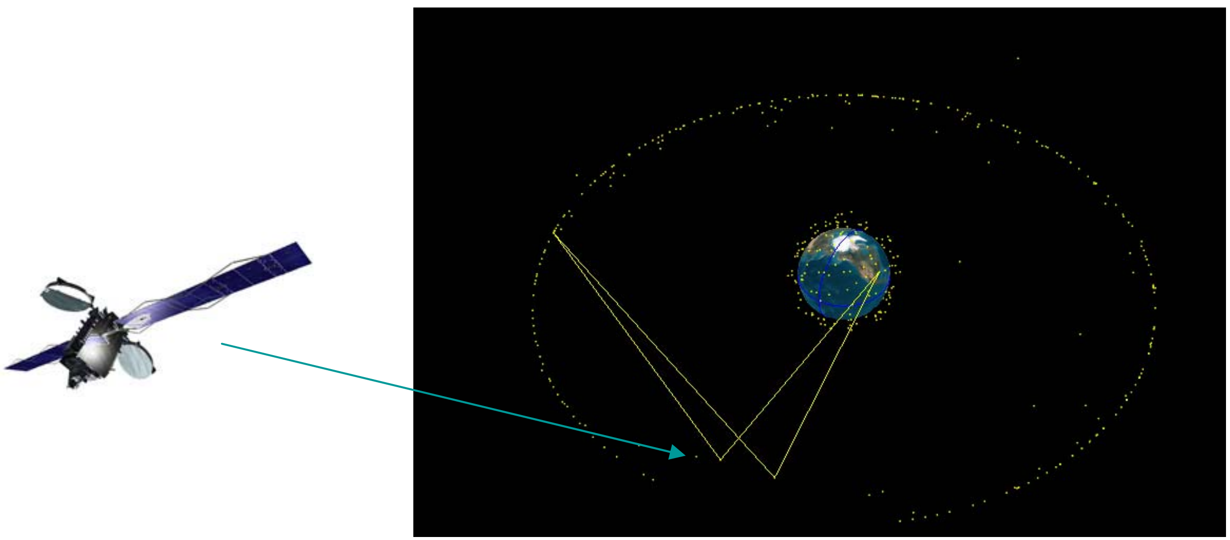
- Satellite orbits are generally not known with sufficient precision.
- Reference emitters on the ground enable more refined orbit estimates and provide fiducial points for calibrating geolocation.
  - Locate the emitter as though it were interference and then adjust to the known location of the emitter.

Potential World-Wide Reference Emitter System



Hosted Payloads

- Payloads augmented to satellites for other than the primary mission can accomplish much at modest cost.



Payloads on Geostationary Satellites enable observation of other satellites not otherwise visible while assuring transmission to the ground.

Conclusion

- Monitoring is a matter of degree.
  – What is sufficient to achieve diplomatic goals?
- Civil and commercial means can contribute to and, in some cases, completely fulfill monitoring or verification needs.
- This presentation suggests a taxonomy and a technical approach toward Persistent Technical Means
  – Demonstrated with concrete examples.