COE CST First Annual Technical Meeting:

Space Situational Awareness

D.J. Scheeres

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Federal Aviation Administration

Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Next Steps
- Contact Information

SSA Team Members

Direct Support from the FAA COE

- Dan Scheeres, CU Professor, PI
- George Born, CU Professor, Co-I
- Bob Culp, CU Professor Emeritus, Co-I
- Brandon Jones, CU Research Scientist
- Kohei Fujimoto, CU PhD Candidate

Related Research from Fellowship Students

- Aaron Rosengren, CU Graduate Student
- Antonella Albuja, CU Graduate Student
- Ddard Ko, CU Graduate Student

Government and Industry Partners

- AFRL Kirtland and Maui
- NASA Orbit Debris Program Office
- Analytical Graphics, Incorporated
- Orbital Sciences Corporation

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Purpose of Task

- ***Space Situational Awareness***

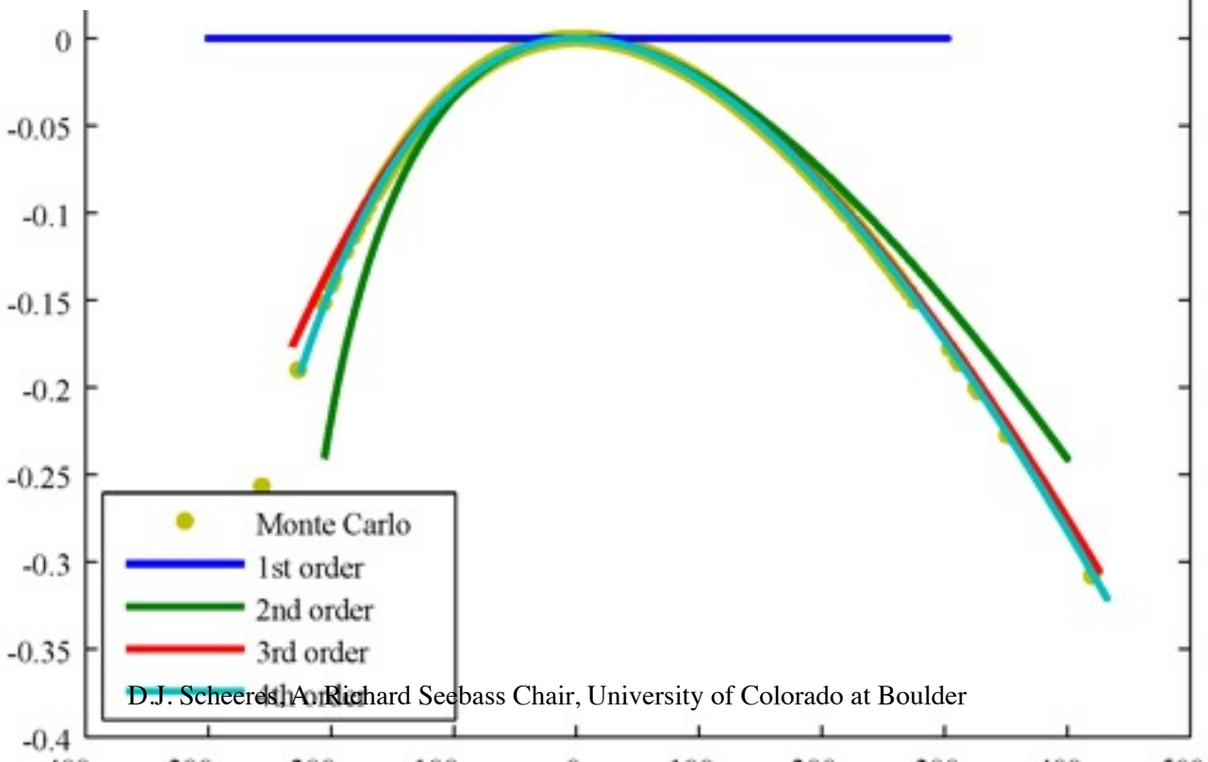
  SSA = Cognizance of Resident Space Objects (RSO) and activities in orbital regions of interest, both now and in the short and long-range future.

- **Objectives**: Improve SSA abilities in regions of interest to the FAA for space-based activities.
- **Current regions of focus**: LEO-*down* and GEO-*up*
- **Goals are to improve**: uncertainty modeling and propagation, precision long-term orbit propagation, non-gravitational model prediction and estimation, orbit estimation techniques.

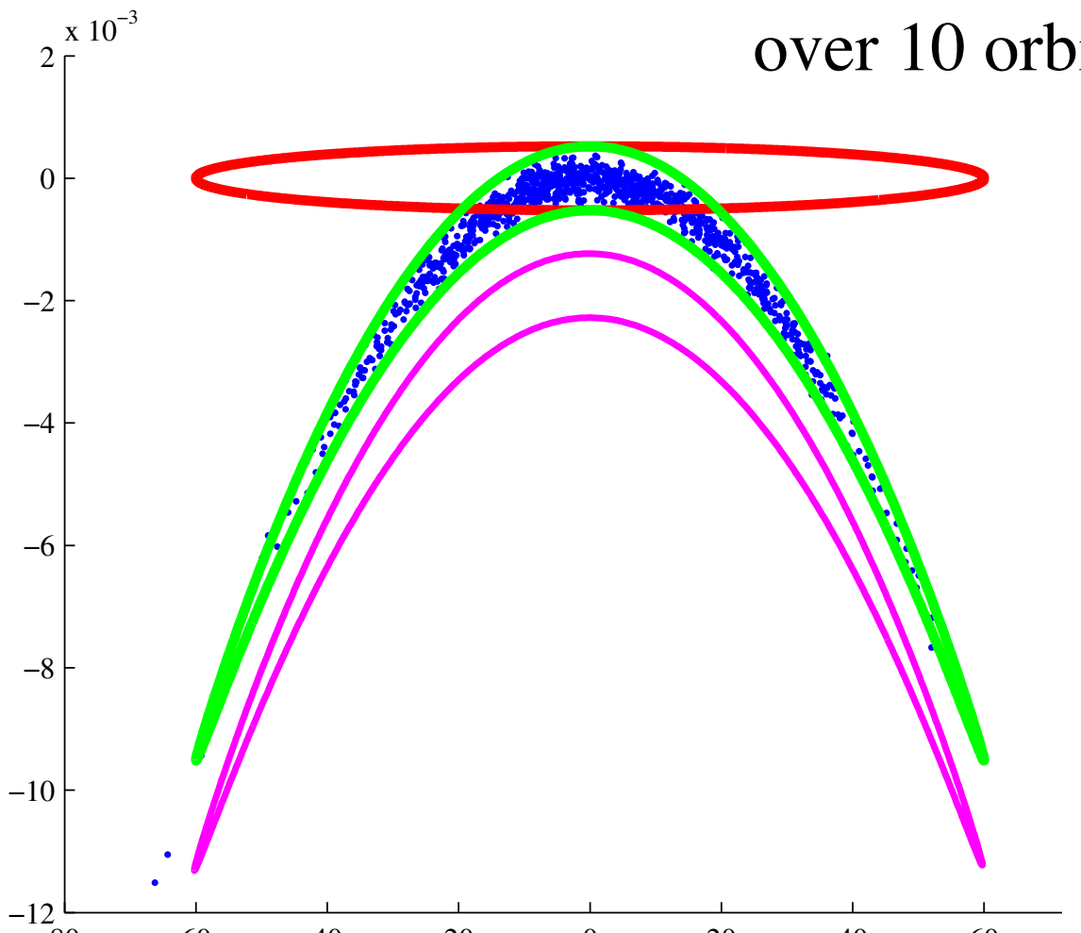
Long-Term Probability Density Function Propagation

- Developing novel semi-analytical solutions for propagation
  - Enables rapid and accurate uncertainty propagation
  - Leverages decades of research in analytical celestial mechanics research
  - Is being extended to perturbations and non-conservative forces
  - Serves as an enabling and foundational framework for other advances in estimation, dynamic modeling, and conjunction analysis

2-Body Propagation over 100 orbits



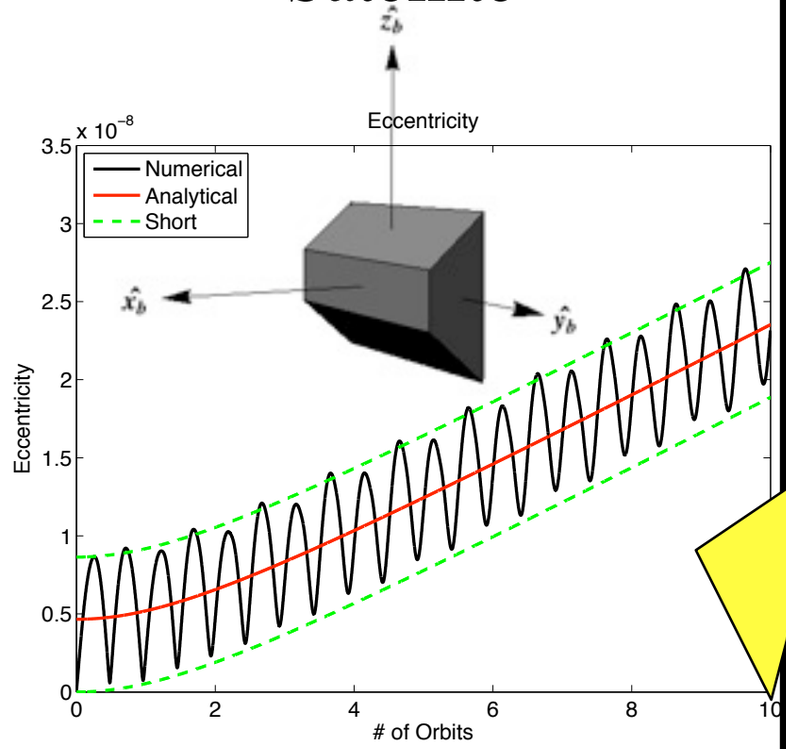
2-Body + *Drag* over 10 orbits



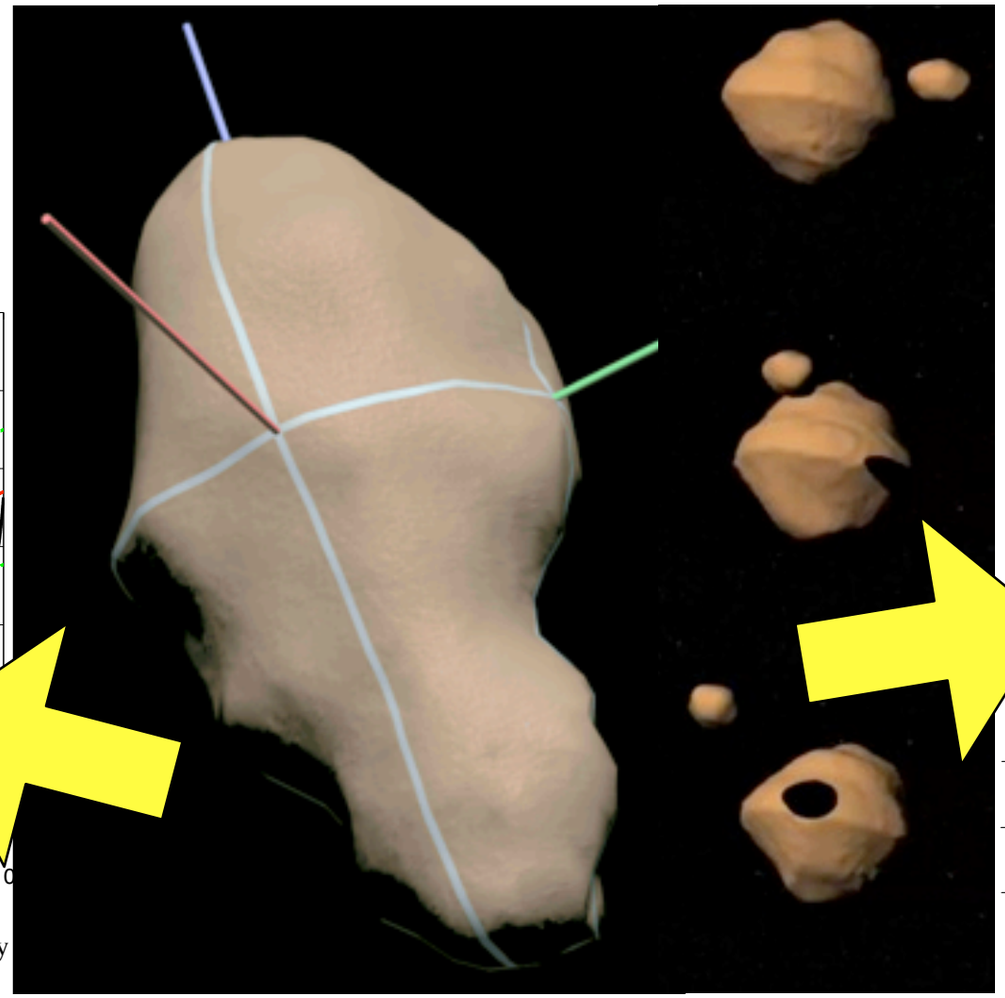
Non-Gravitational Modeling & Dynamics

- Solar Radiation Pressure non-grav models developed for asteroids can be directly applied to RSO dynamics and models
  - Time scale of interest for asteroids, ~ 1E4 -> 1E6 years
  - Equivalent time scale of interest for RSO ~2 -> 200 years for LEO to GEO
  - Current focus on High Area to Mass Ratio object dynamics in GEO, rotational dynamics of debris, estimation of non-grav models (drag and solar radiation)

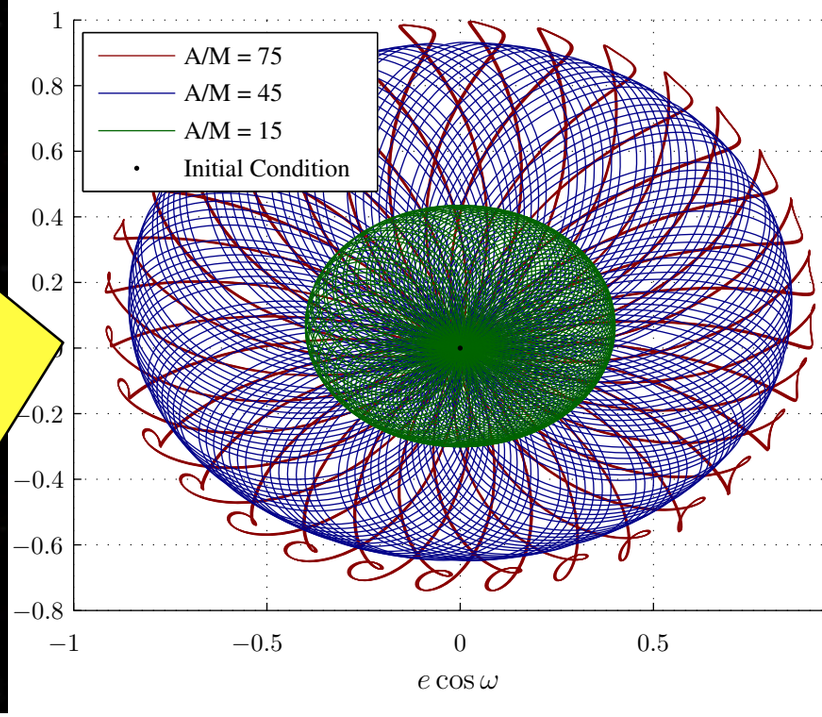
Eccentricity of the Grace Satellite



D.J. Scheeres, A. Richard Seebass Chair, University

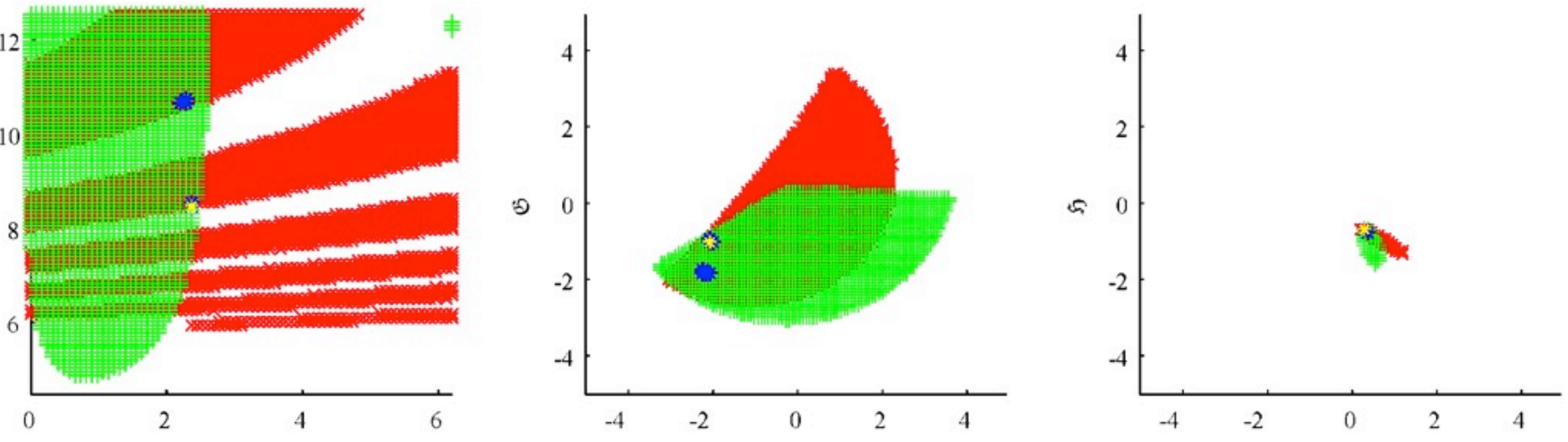


Eccentricity Vector of HAMR Objects



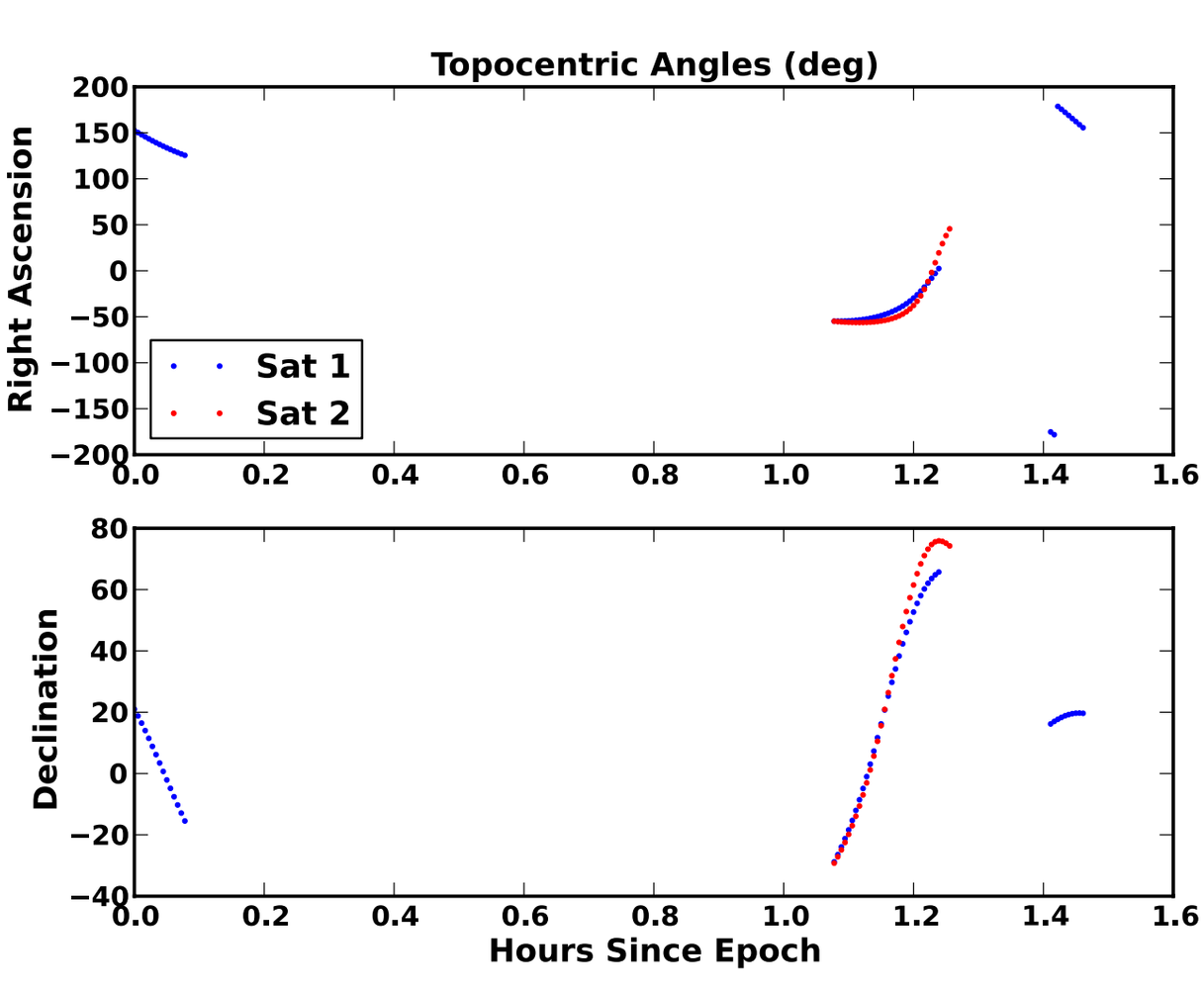
Short-Arc RSO Correlation

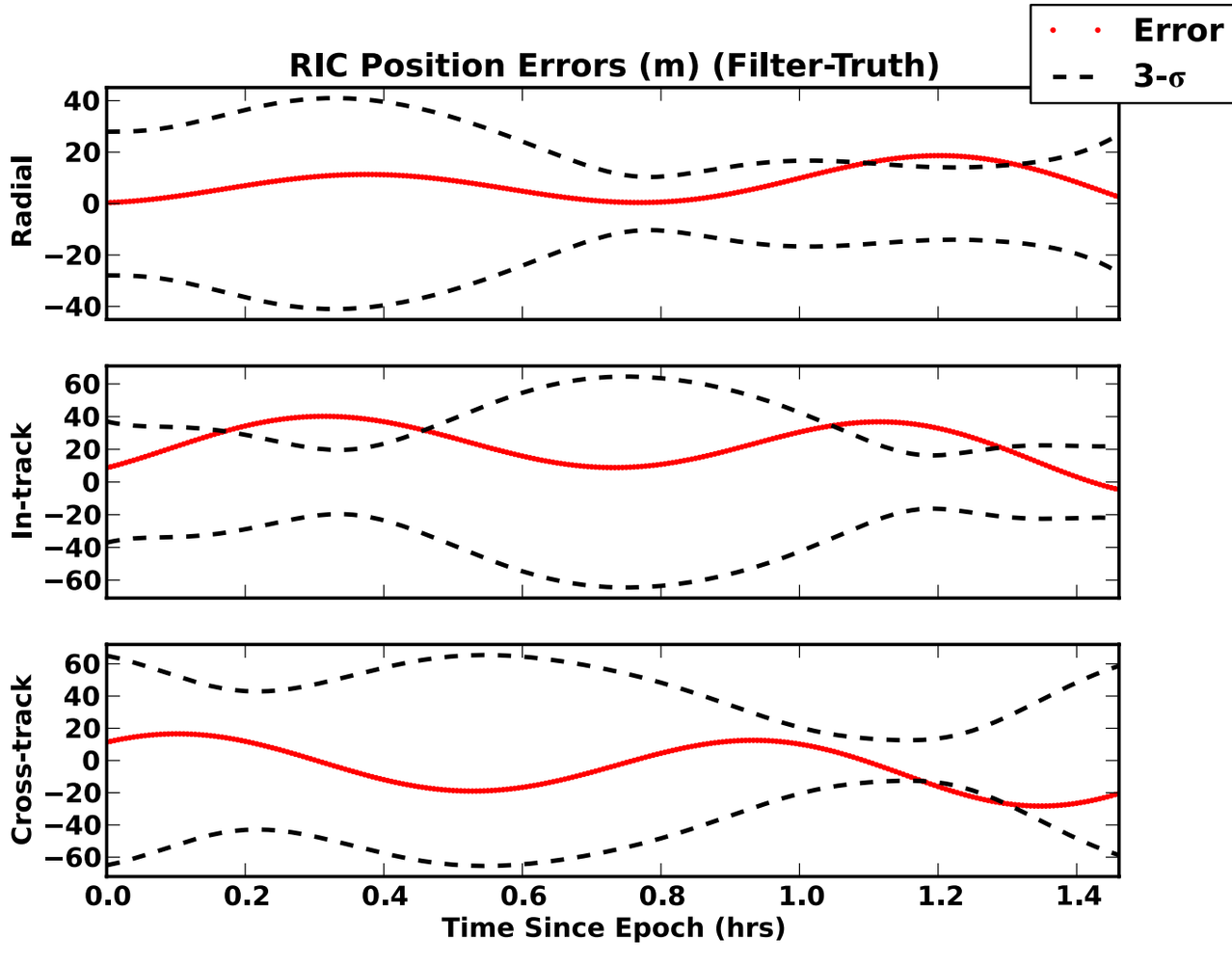
- Given two observations of RSO separated in time, can we determine if these are the same object?
- If they are, can we achieve an initial orbit determination estimate?
- A new approach to initial orbit determination and correlation has been developed – "Best Paper of Conference" in 2010.
  - Hypothesis-free correlation testing – fundamental improvement of process
  - Robust and rigorous approach to combining sparse track observations
  - Method based on the topology of probability density functions in 6-D space



L_p-norm Orbit Determination

- Orbit determination in LEO faces data association and quality challenges.
- Mis-tagged data or measurement outliers can force an orbit estimate to diverge or yield poor convergence that compromises the entire catalog maintenance activity.
  - To remedy this we are developing nonlinear, adaptive estimation capabilities that are independent of and insensitive to measurement error distribution
  - Current focus is on using *minimum L_1-norm orbit determination*, which provides robust estimation capabilities that are insensitive to data mis-tagging and outliers.
  - Tools are being developed to explore the applicability and use of this approach





Results since commencement of funding

- Journal Papers in press:

- K. Fujimoto and D.J. Scheeres. “Correlation of Optical Observations of Earth-Orbiting Objects and Initial Orbit Determination," **Journal of Guidance, Control and Dynamics**, in press, 2011.
- K. Fujimoto, D.J. Scheeres and K.T. Alfriend. “Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem," **Journal of Guidance, Control and Dynamics** , in press, 2011.

- Conference Papers:

- K. Fujimoto, D.J. Scheeres , and K.T. Alfriend. “Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem," paper presented at the 2011 **AAS/AIAA Spaceflight Mechanics Meeting**, New Orleans, February 2011. Paper AAS 11-202.
- A. Rosengren and D.J. Scheeres. “Averaged Dynamics of HAMR Objects: Effects of Attitude and Earth Oblateness,” paper presented at the 2011 **AAS/AIAA Astrodynamics Specialist Meeting**, Girdwood, Alaska, August 2011. Paper AAS 11-594.
- D.J. Scheeres and A. Rosengren. “Closed Form Solutions for the Averaged Dynamics of HAMR Objects,” paper presented at the **62nd International Astronautical Congress**, Cape Town, South Africa, October 2011.
- K. Fujimoto and D.J. Scheeres. “Non-Linear Propagation of Uncertainty With Non-Conservative Effects," paper submitted to the 2012 **AAS/AIAA Spaceflight Mechanics Meeting**, Charleston, SC, Jan/Feb 2012.
- S. Gehly, B. A. Jones, P. Axelrad, G. H. Born, "Minimum L1 Norm Orbit Determination Using a Sequential Processing Algorithm", paper submitted to the 2012 **AAS/AIAA Spaceflight Mechanics Meeting**, Charleston, SC, Jan/Feb 2012.

- Industry Interactions:

- Exchanges of simulated data with AFRL Maui research personnel.
- Interactions with NASA Orbit Debris Program Office and the Center for Space Standards & Innovation (AGI)
- Dissemination of orbit determination tools to Aerospace Corp. researchers for analysis and testing.

Next Steps

- Funding for Year 2 is now in-place.
- Mechanisms for matching funds have been identified and taken advantage of.
- Research progressing on all fronts identified.
- Dissemination of research into conference and journal literature is on-track.

Interested in collaborations with other COE-CST supported Research Tasks

Contact Information

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