COE CST Fourth Annual Technical Meeting

Task 187: Space Situational Awareness

Scheeres / Park
University of Colorado

October 29-30, 2014
Washington, DC

Center of Excellence for Commercial Space Transportation

Agenda

- Team Members
- Task Description
- Research Methodology
- Research Results
- Next Steps
- Conclusions and Future Work

Team Members

Direct Current / Past 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 Assistant Research Professor
- Jay McMahon, CU Assistant Research Professor
- Kohei Fujimoto, CU PhD Student (graduated May 2013)
- In-Kwan Park, CU PhD Student (current support)

Related Research from Fellowship Students

- Aaron Rosengren, CU Graduate Student, NSF Fellow (graduated March 2014)
- Antonella Albuja, CU Graduate Student, NSF Fellow
- Daniel Lubey, CU Graduate Student, NSTRF Fellow

Government and Industry Partners

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

Task Description

- ***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.

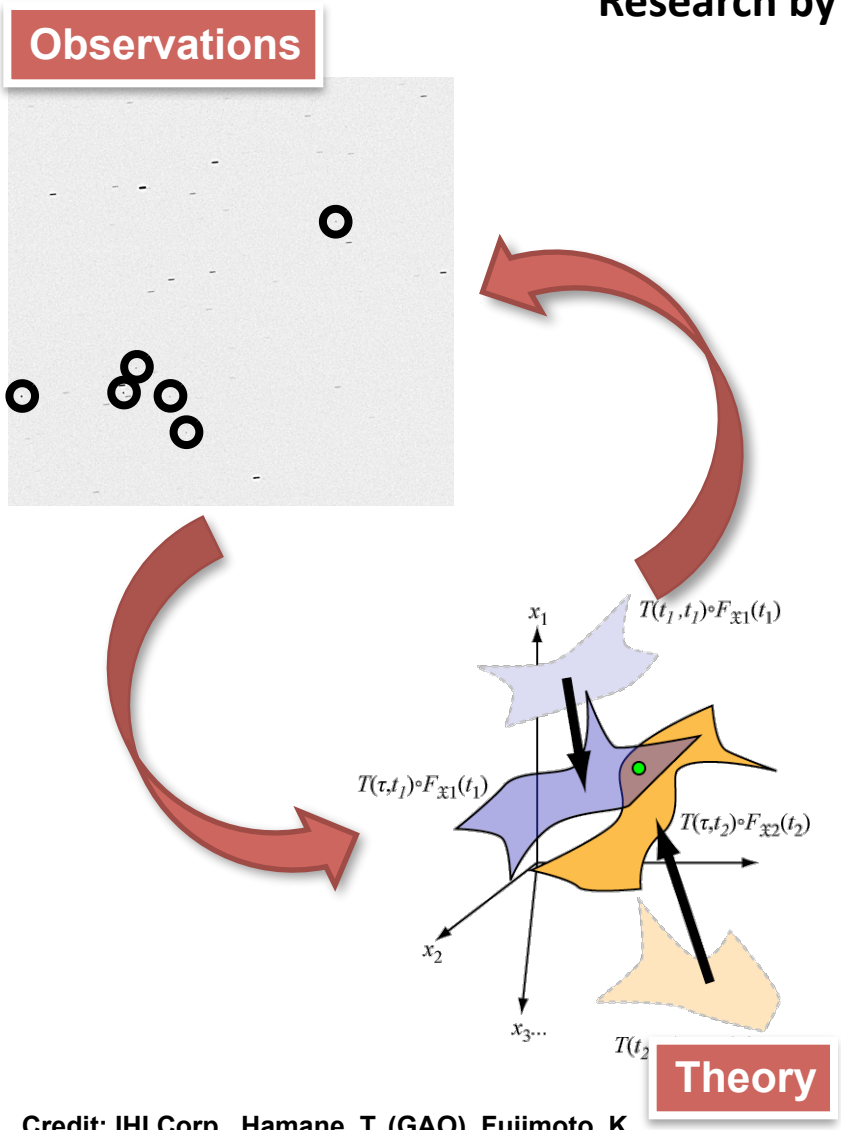
- **Objectives**: Improve SSA abilities in regions of interest to the FAA for space-based activities.
- **Current regions of focus**: LEO-*down* and GEO-*up*
- **Goals are to improve**: uncertainty modeling and propagation, precision long-term debris orbit and attitude propagation, non-gravitational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

Research Methodology

- Directly funded FAA research on initial orbit determination, object correlation, uncertainty mapping and conjunction analysis
- Leverage other student support models to perform research of relevance to the overall goals of the FAA COE CST
  - Long-term orbit and physical dynamics of space debris, and their implications
  - Current student support from NSF and NASA through fellowships
- Previous research output and results
  - Presented 26 papers at 14 international conferences
  - Published 7 papers in peer-reviewed journals
  - Submitted additional 4 papers to journals

Association of Optical Observations

Research by Kohei Fujimoto

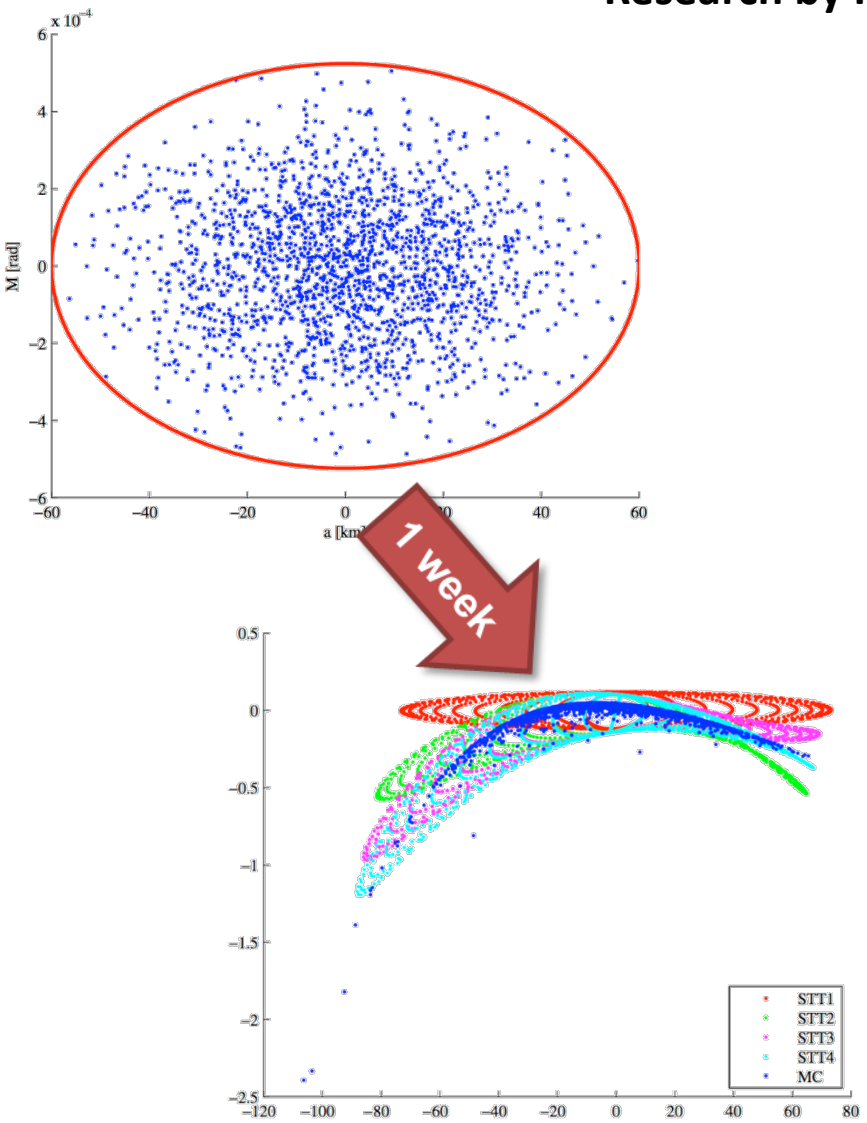


Credit: IHI Corp., Hamane, T. (GAO), Fujimoto, K.

- Direct Bayesian approach to observation association
  - Exploits sparseness of the estimation problem
  - Robust with little tuning
  - Presented at IAC 2012
- Experimentation with real-world observations
  - Collaboration with IHI Corp., University of Bern
  - Developed techniques to take into account measurement error
  - Presented at ISTS 2013
- "Closing the loop" on the too-short-arc problem
  - Papers describing our research advances published in Journal ASR

Analytic Propagation of Uncertainty

Research by Kohei Fujimoto

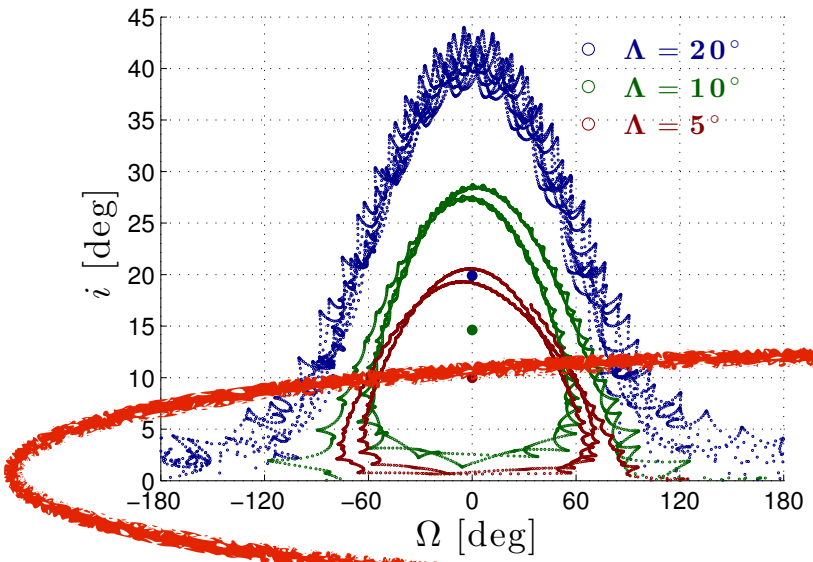


- Rapid non-linear uncertainty propagation
  - Special soln. to the Fokker-Planck eqn. for deterministic systems
  - State transition tensor description of the solution flow
- Added effects due to atm. drag
  - Classical results (King-Hele) applied to a modern problem
- Developed new approach to conjunction analysis
  - Mixes the use of analytical theories and GMMs
  - Currently submitted to JGCD for publication

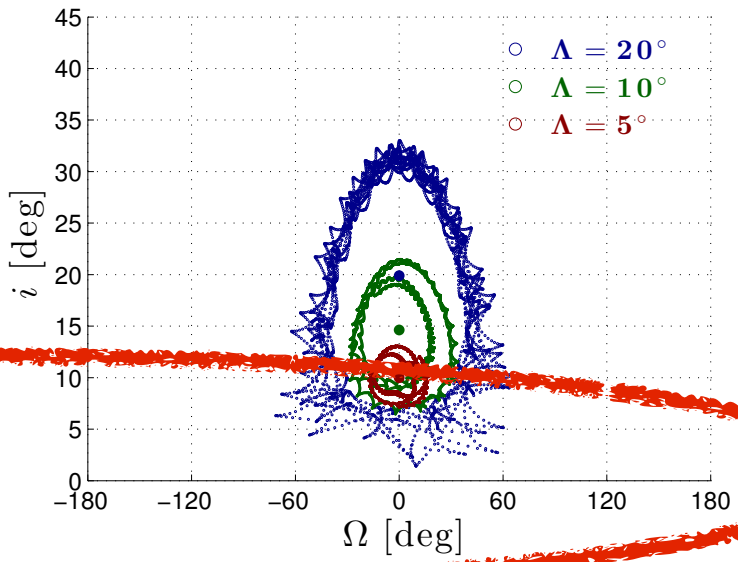
Long-Term GEO Disposal Orbits

- Research by Aaron Rosengren:
  - Current GEO "disposal" orbits are boosted to higher altitudes, but stay in the same plane. Debris shed from these defunct satellites can – and will – cross into the GEO belt
  - Transferring satellites into the Laplace Plane for disposal will minimize future risk of orbit debris at GEO, maintaining this natural resource for future generations
  - Published in ASR

Super-synchronous disposal orbit

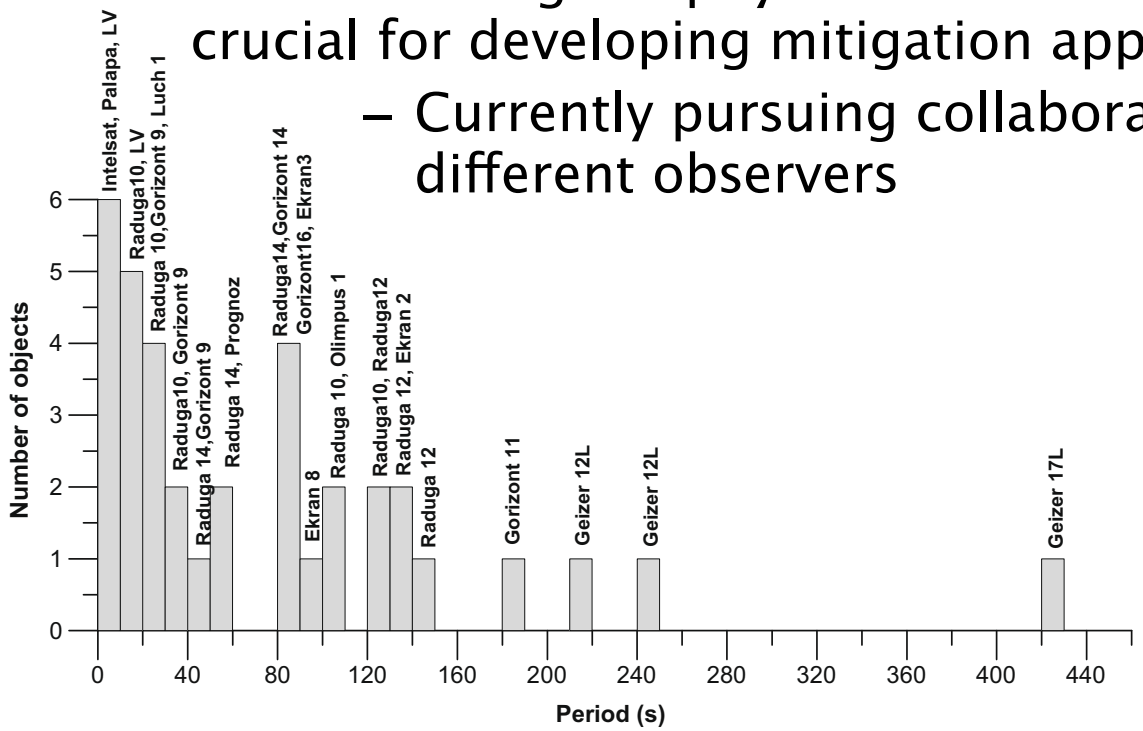


Laplace plane disposal orbit



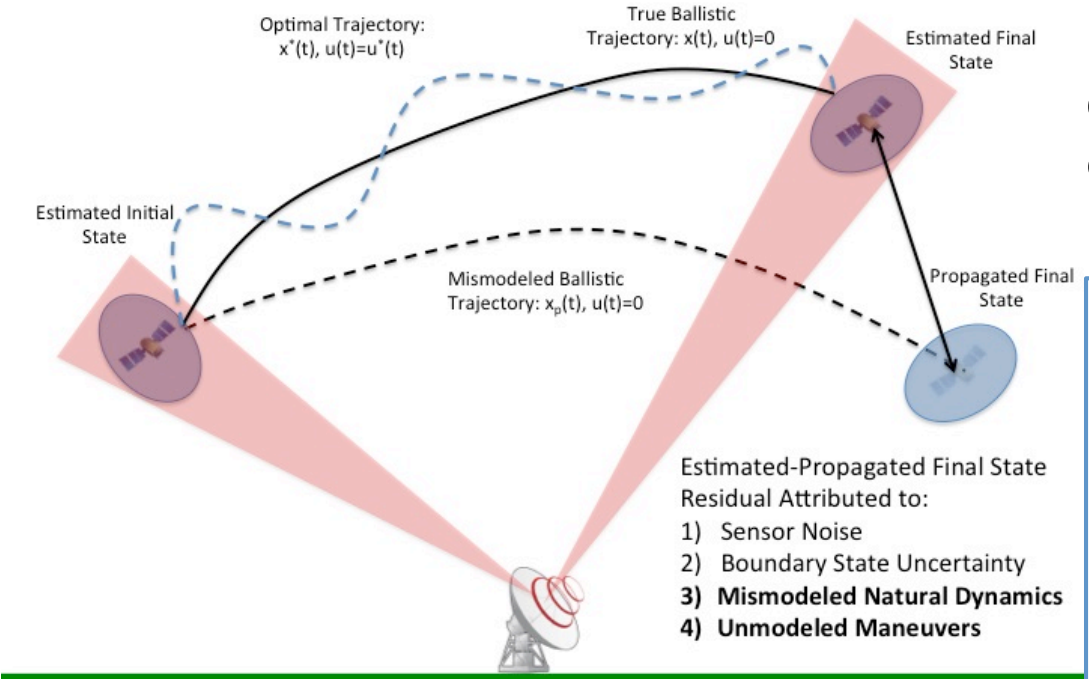
Evolution of Defunct Satellites

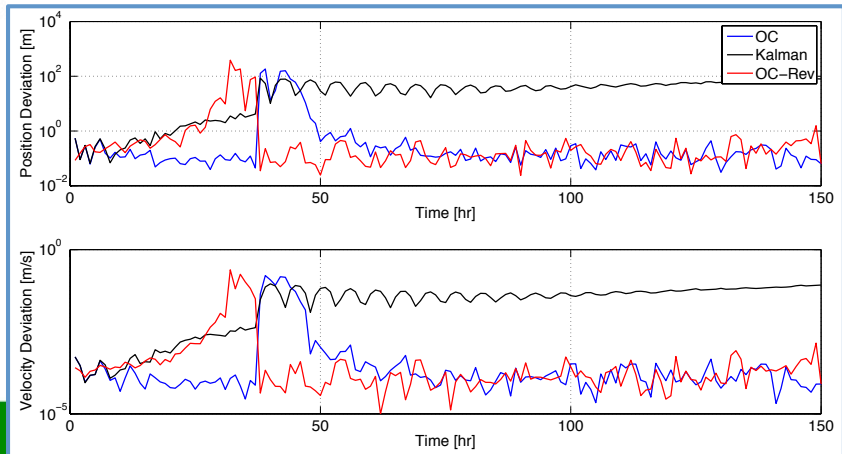
- Research by Antonella Albuja:
  - Observations of defunct GEO satellites shows that their rotation periods change over time, and that many of them rotate rapidly
  - Such evolutionary changes can occur due to environmental perturbations — especially due to solar radiation pressure torques
  - Understanding the physical evolution of defunct satellites is crucial for developing mitigation approaches
    - Currently pursuing collaborations with several different observers



Orbit Debris Model Estimation

- Research by Daniel Lubey:
  - Space debris orbit estimation is limited by non-gravitational effects
  - These are unique for each body, and must be modeled and estimated accurately for generating precise long-term predictions
  - Current research is leveraging previous AFOSR-sponsored research on optimal control to develop automatic methods for estimating non-gravitational models based on tracking data





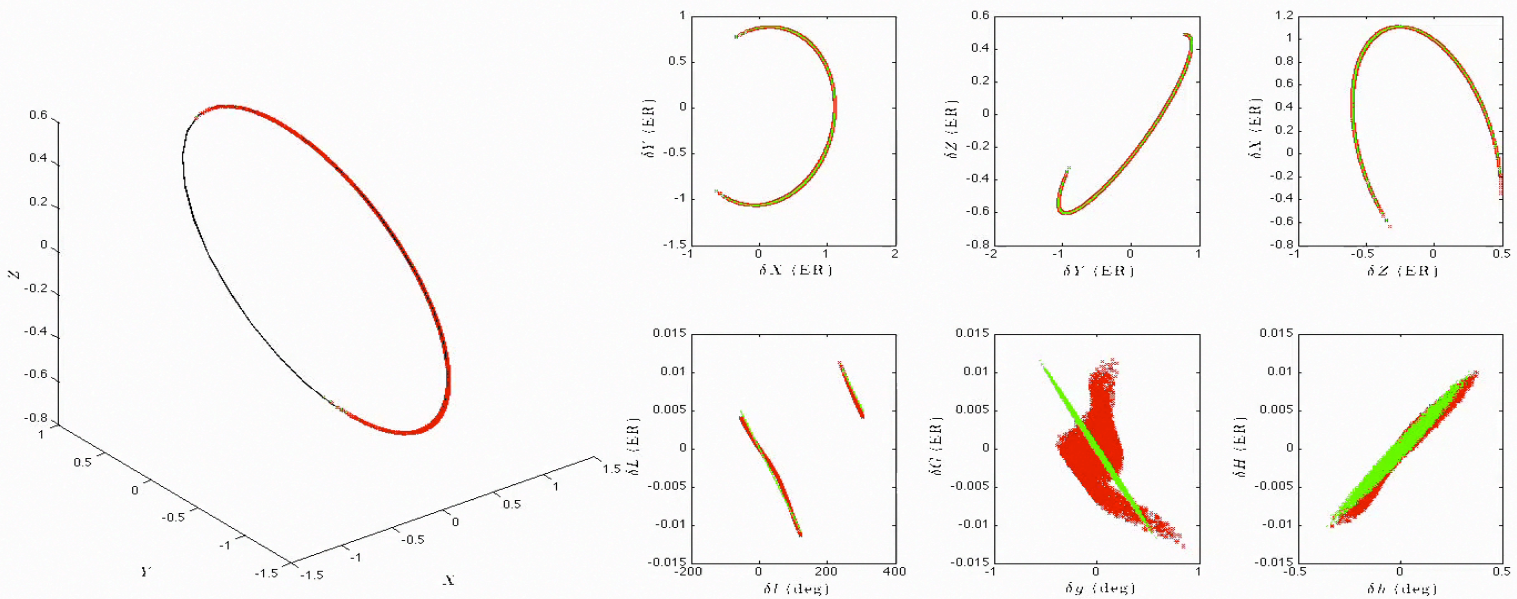
Necessary Accuracy for Uncertainty

- Research by In-Kwan Park: Focus on a fundamental question –

"How much precision is needed in describing the dynamical motion of a spacecraft to ensure an accurate determination of propagated orbit uncertainty?"

– Answer: Secular dynamics approximations can fully capture the first few moments of a statistical PDF distribution

– Implications: Computationally fast theories can capture debris uncertainty, motivating new approaches to conjunction analysis



Next Steps

- Combe recent research by Fujimoto and Park to explore methods for rapidly and accurately propagating orbit uncertainty distributions and performing conjunction analyses
  - Will use secular equations to propagate orbit uncertainty distributions
  - Will use State Transition Tensors and GMMs to analytically compute conjunction probabilities
  - Can achieve orders of magnitude increase in computational efficiency

Conclusions and Future Work

- Spent allocated funds through May 2014
  - New funds for research support through May 2015 just allocated
- Next stage of FAA directly-funded research:
  - Plan to integrate previous research on uncertainty propagation, model estimation and conjunction analysis to develop a tool for rapid, long-term assessment of debris impact hazard and risk

TASK 187. Space Situational Awareness

- **PROJECT AT-A-GLANCE**
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHER: Mr. In-Kwan Park (PhD)

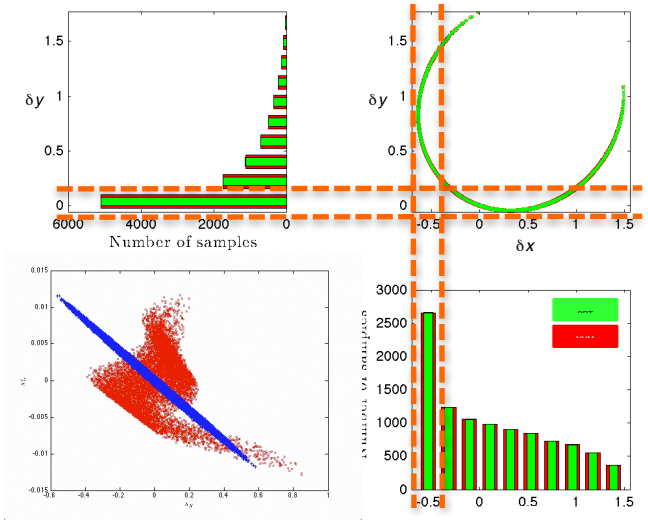
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Orbit debris remains a fundamental issue for all aspects of space utilization. Specific challenges remain in performing long-term forecasts for specific pieces of orbit debris. While the population of debris is relatively well understood — research advances continue to open new windows on this population.

STATEMENT OF WORK

- Effective space situational awareness faces the challenge of bringing together observations from disparate sensors and sources, developing computationally efficient dynamic propagation schemes for orbits and their uncertainty distributions, and formulating accurate estimation methods for the purpose of quantifying and qualifying space-based activities.
  - Maximize the information extracted from usual sources of SSA data (minimize uncertainty)
  - Identify how data should be collected to maximize information content (maximize efficiency)
  - Recover and predict the space domain with more accuracy
  - Timely estimation of the space-based environment to create actionable information.

Analytical vs Numerical Uncertinaty Propagation



STATUS

- Graduated one funded PhD student: Kohei Fujimoto, May 2013
- Combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 26 distinct papers at 14 conferences
- 7 papers published, 4 more in peer review at journal

FUTURE WORK

- Next stage of direct FAA funded research will focus on developing a rapid asset/debris conjunction analysis tool
- Non-directly funded research will focus on:
  - Long-term space debris dynamics (orbit and attitude)
  - Modeling and estimation of debris non-gravitational forces