COE CST Fifth Annual Technical Meeting

Task 187: Space Situational Awareness

PI: Dan Scheeres
Student: In-Kwan Park
University of Colorado

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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, graduating this Fall)

Related Research from Fellowship Students

- Aaron Rosengren, CU Graduate Student, NSF Fellow (graduated March 2014)
- Antonella Albuja, CU Graduate Student, NSF Fellow (graduated October 2015)
- Daniel Lubey, CU Graduate Student, NSTRF Fellow (graduated October 2015)

Government and Industry Partners

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

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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.

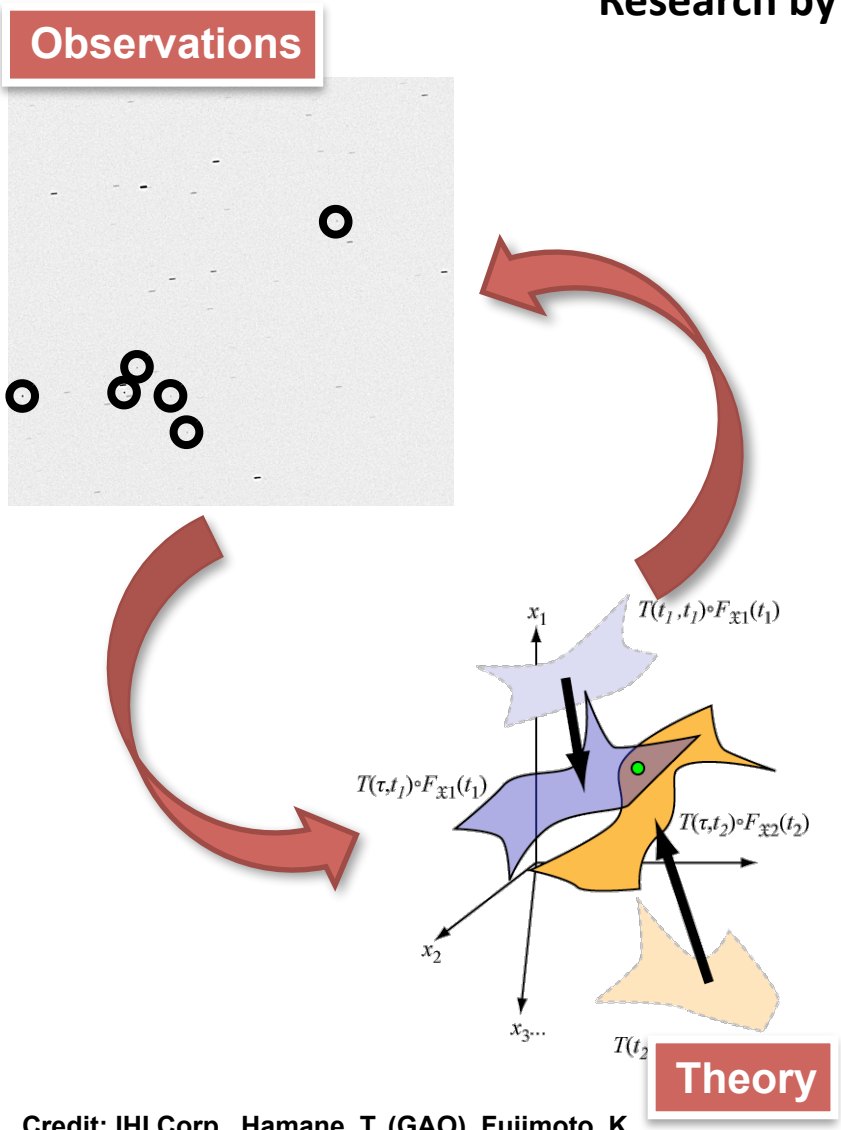
- **Objectives**: Improve SSA abilities in regions of interest to the FAA for space-based activities.
- **Current regions of focus**: LEO-*down* and GEO-*up*
- **Goals are to improve**: uncertainty modeling and propagation, precision long-term debris orbit and attitude propagation, non-gravitational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

Research Methodology and Results

- 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
  - Current student support from NSF and NASA through fellowships
- Previous research output and results of relevance to our FAA CST COE research goals from combined team (since 2010)
  - Presented 34 papers at 20 conferences
  - Published 12+ papers in peer-reviewed journals
  - Submitted additional papers to journals
- Graduate students associated with these activities
  - 5 PhDs with some connection to FAA activities graduated in SSA
  - 1 Assistant Profs / 2 post-docs / 2 in Industry

Association of Optical Observations

Research by Kohei Fujimoto

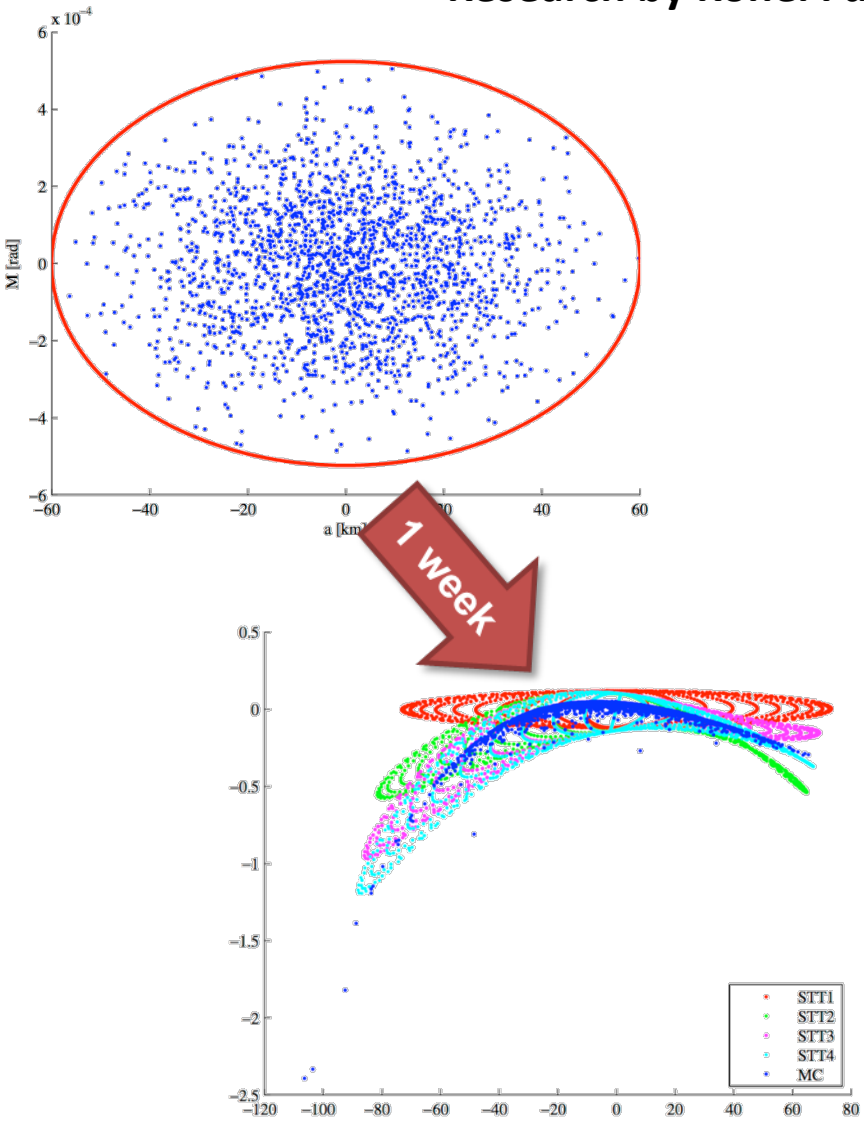


Credit: IHI Corp., Hamane, T. (GAO), Fujimoto, K.

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

Analytic Propagation of Uncertainty

Research by Kohei Fujimoto & In-Kwan Park



- 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
  - Papers published in JGCD

Necessary Accuracy for Uncertainty

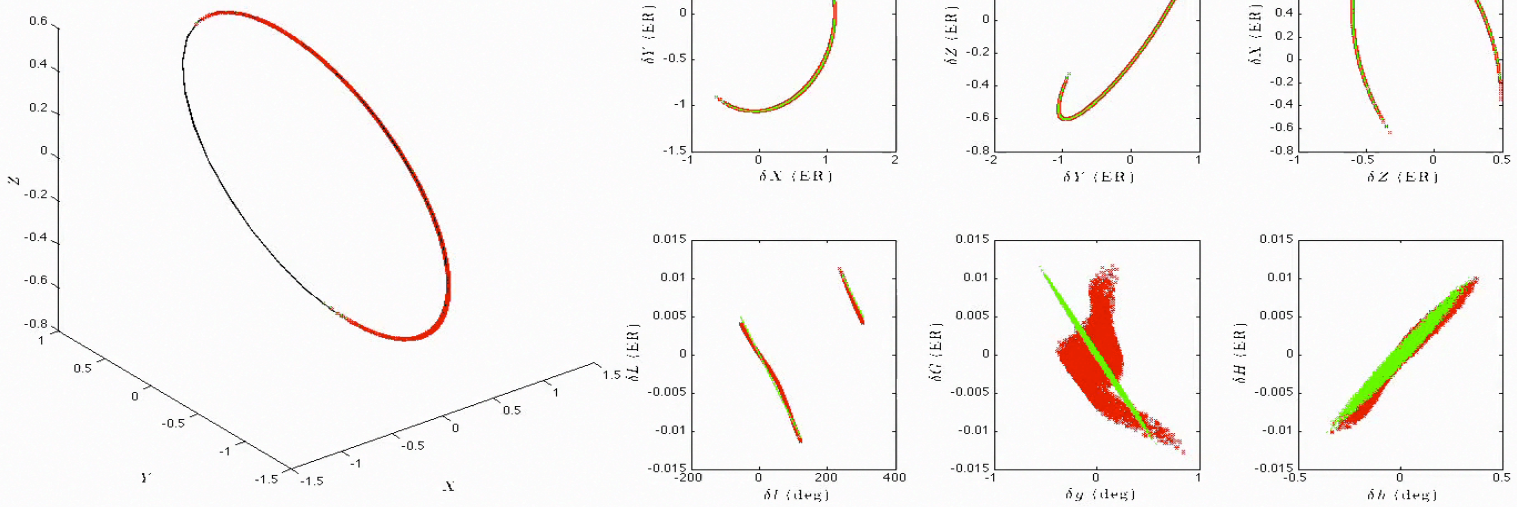
- Research by In-Kwan Park: Focus on a fundamental question –

"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 rapid computation of conjunction analysis

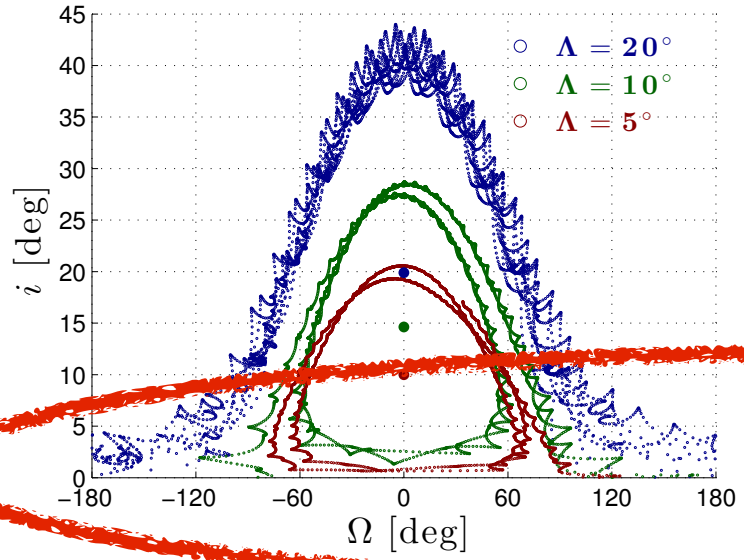
– Papers published in JGCD



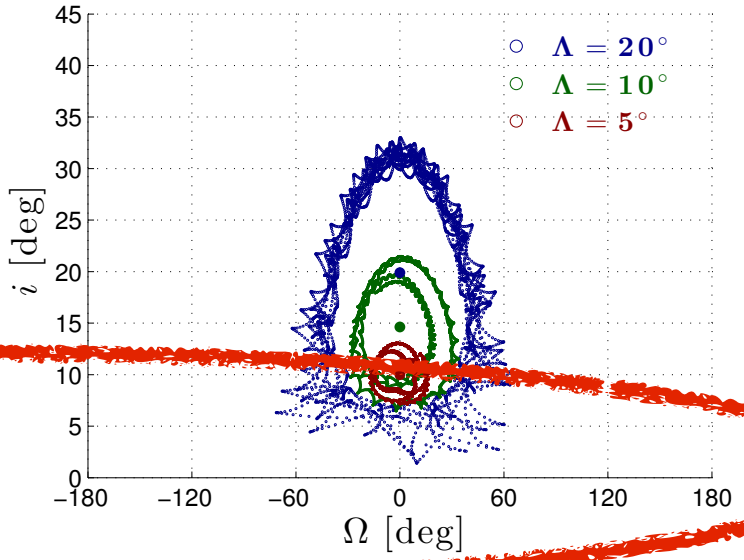
Long-Term GEO Disposal Orbits

- 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

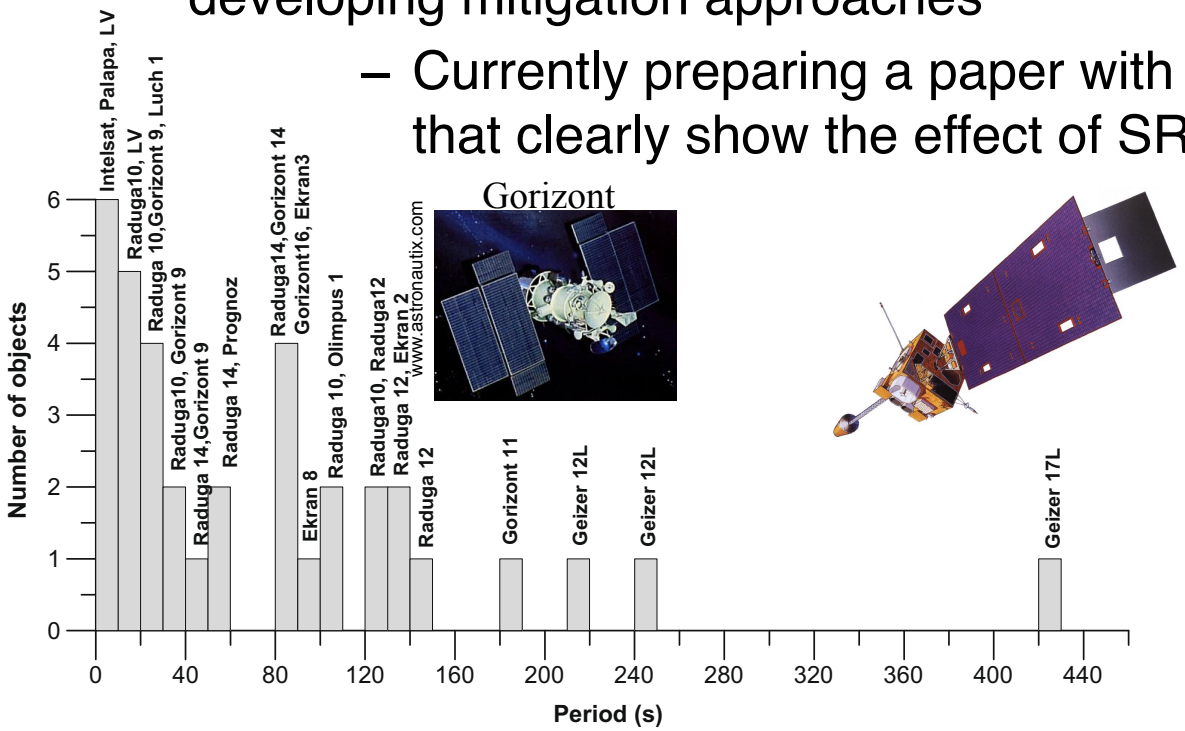


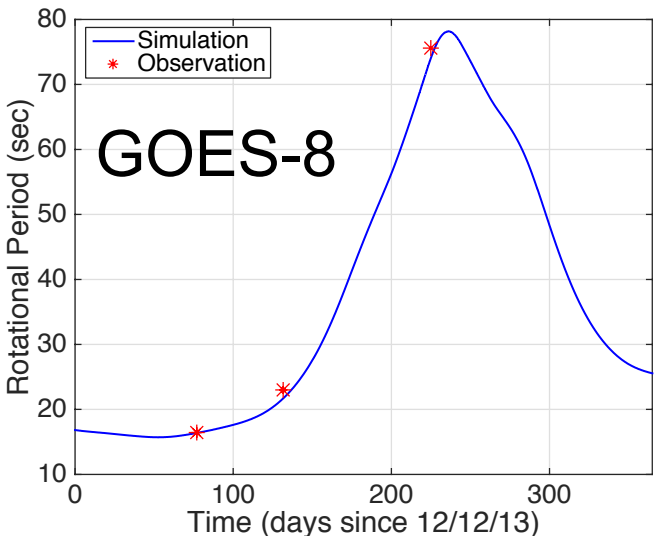
Laplace plane disposal orbit



Evolution of Defunct Satellites

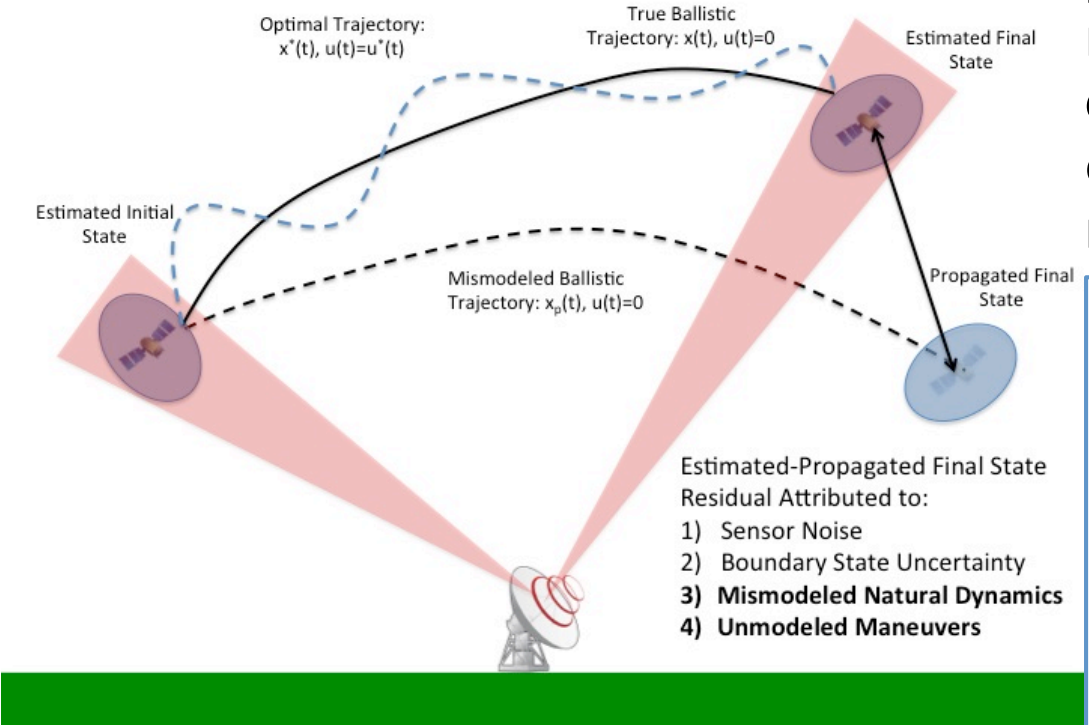
- Research by Antonella Albuja:
  - Observations of defunct GEO satellites shows that their rotation periods change over time, and that many of them rotate rapidly
  - Such evolutionary changes can occur due to environmental perturbations — especially due to solar radiation pressure torques
  - Understanding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



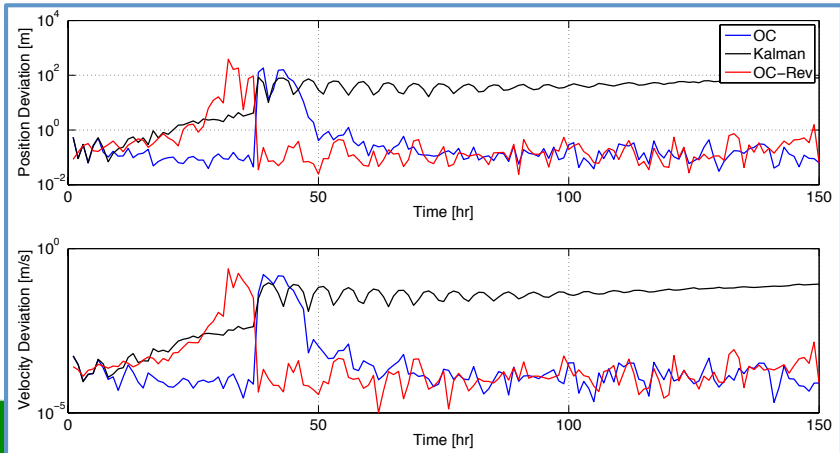


Orbit Debris Model Estimation

- 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



Current Status

- Current designated PhD student Park will defend in December, start post-doc in January
- Allotted funds through FY15 have been spent
- White paper proposal for continued support submitted March 2015
  - Proposal to combine previous work on conjunctions analysis into a computational tool for rapid and accurate “impact forecasting” for space vehicles traversing orbit regimes

Conclusions and Future Work

- Since 2011 using FAA support and leveraging AFOSR, NSF and NASA support
  - Have published extensively in SSA topics of interest to the COE
  - Have produced PhDs who hold SSA-related positions in industry, research and academia
- Spent allocated funds through May 2015
- Proposed future work to integrate past research into conjunction analysis forecasting tool

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)

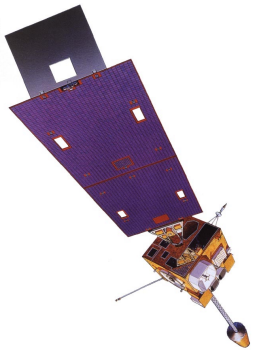
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

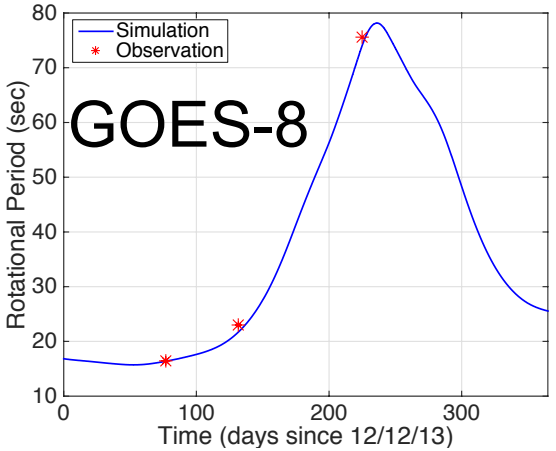
- Orbit debris remains a fundamental issue for all aspects of space utilization. Specific challenges remain in performing long-term forecasts for specific pieces of orbit debris. While the population of debris is relatively well understood — research advances continue to open new windows on this population.

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.

Large Fluctuations of Spin Period in Defunct GOES-8 Satellite can be accurately fit by modeling Solar Radiation Pressure Effects





STATUS

- Graduated two FAA-funded PhD students: Kohei Fujimoto, May 2013 & In-Kwan Park Fall 2015
- Have a large combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 34 distinct papers at 20 conferences
- Over 12 papers published with more in peer review

FUTURE WORK

- Next proposed 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