Air Force Research Laboratory

Integrity ★ Service ★ Excellence

US Keynote Address:

Current Problems in SSA and Required Areas of Research

07/19/12

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Research Rationale

- **Improve space object (SO) orbit determination and prediction, and characterization**
  - Enhance orbital safety of operations
  - Exploit traditional and non-traditional data to maximize information (minimize ambiguity)
- **Improved accuracy, better timeliness, and uncertainty (precision) realism are needed**
  - SOs do collide with each other
  - SOs get lost or confused with others
  - SOs experience unknown dynamic effects (non-gravitational forces)
- **Formed a consortium of astrodynamics expertise to solve these problems (ASTRIA)**
  - AFRL/Space Vehicles Directorate
  - Thirteen universities, USAFA, AFIT, and NPS
  - Leveraging SBIR/STTR, SMART Fellowship, NDSEG Fellowship, NRC PostDoc Research Associateship, RD/RV Scholar, Air Force Summer Faculty Fellowship, Educational Partnership Agreements, AOARD/EOARD Grants

Advanced Sciences and Technology Research Institute for Astrodynamics*

Charter: Research entity combining government in-house and contractor expertise in astrodynamics with a consortium of universities performing research in relevant areas of interest to the U.S. Air Force Research Laboratory and Department of Defense.

Research Topics:
- *Data Association and Tracking*
- *Initial Orbit Determination*
- *Maneuver Detection and Reconstruction*
- *Satellite Characterization*
- *Data/Sensor Fusion for SSA*
- *Orbital Debris Tracking and Characterization*
- *Astrodynamics Applications to High Performance Computing*

*Dr. Moriba Jah, Director

Astrodynamics Tools:
- *General Mission Analysis Tool (GMAT)*
- *Satellite Tool Kit (STK)*
- *Orbit Determination Tool Kit (ODTK)*
- *Goddard Trajectory Determination System (GTDS)*
- *MATLAB (various analysis models and algorithms)*

Current Academic Members:
- *Purdue University*
- *University of Colorado, Boulder*
- *Texas A&M*
- *University of Texas , Austin*
- *State University of New York, Buffalo*
- *Utah State University*
- *Embry-Riddle Aeronautical University*
- *Missouri University of Science & Technology*
- *Penn State University*
- *Georgia Tech*
- *New Mexico State Univ.*
- *University of New Mexico*
- *Cal Poly SLO*
- *Rensselaer Polytechnic Institute*
- *Air Force Institute of Technology*
- *US Air Force Academy*
- *Naval Postgraduate School*

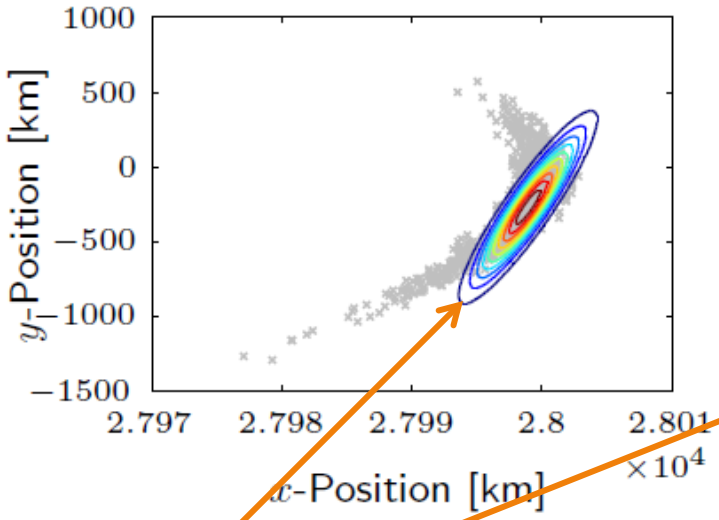
AFRL

What Hinders Our Ability To Do Better?

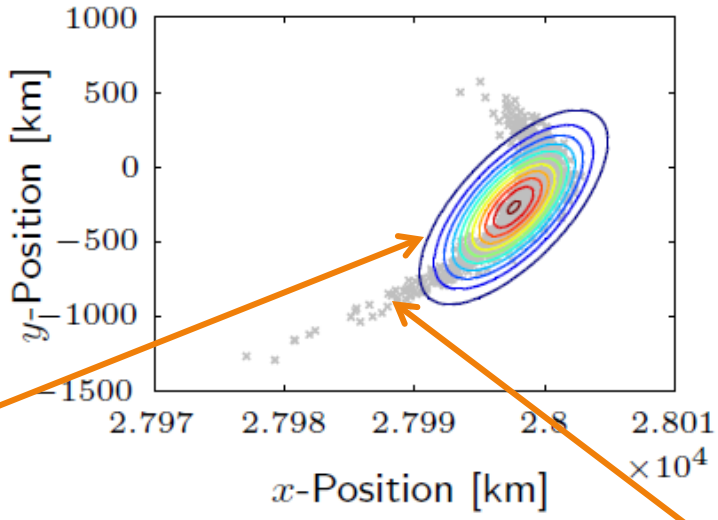
- State Vector
  - Sparse observations and no *a priori* information
  - Poor choice of coordinate-frame definition
  - Poor/unrealistic representation of associated uncertainty
- Space Environment
  - Lack of refinement (accuracy) in physics-based models given sparse observations and/or poor data assimilation/exploitation techniques
  - Empirical/heuristic models have limited applicability and provide little-to-no physical insight
- Space Object Dynamics
  - Lack of space object characteristics to properly model external force/torque behavior
    - Size, shape, material properties, inertia parameters, orientation, body rates
- Space Object Measurements
  - Poor characterization/understanding of errors including biases
  - No realistic/exhaustive quantification of data information content as it relates to observed objects
  - Robust and accurate data association to unique objects

State Vector Error Representation

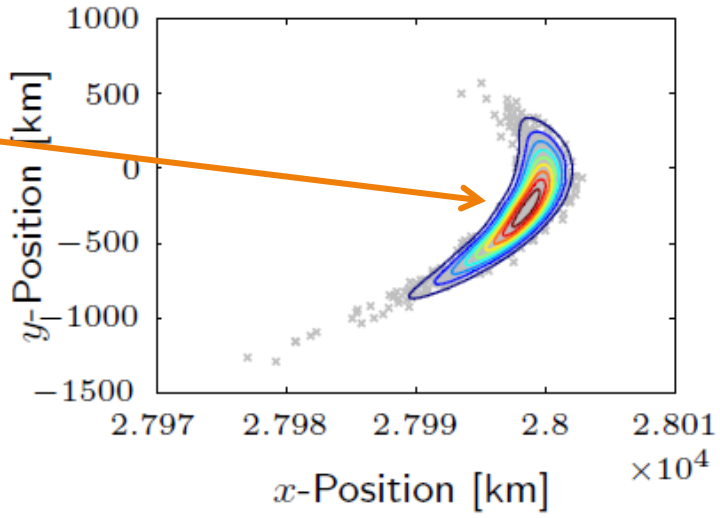
EKF



UKF



Estimated Knowledge Contours



AEGIS

True Error Gray Dots

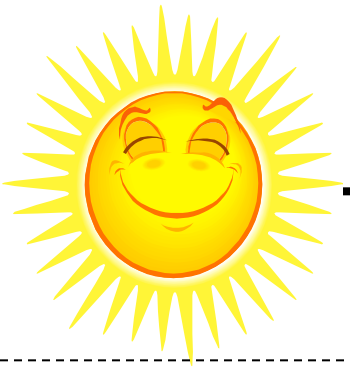
Space Environment Interactions

We have little-to-no understanding of how the integrated effect of space environment drives the behavior of inactive space objects

- Solar Radiation Flux
  - Reflection
    - Specular and Diffuse
  - Absorption
  - Heat Transfer (thermal re-radiation via emissivity)
- Earth Radiation Flux
  - Significant for LEO objects
- Charged Particle Environment
  - Passive surface (including differential) charging interaction with magnetic field
- Material Aging/Degradation
- 3rd-Body Gravitational Effects
  - Jupiter's influence for long-term predictions of deep space objects
- Relativistic Effects

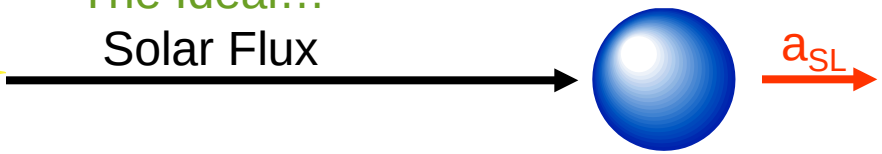
Space Object Dynamics

Size, Shape, Orientation, Material Properties…they matter!



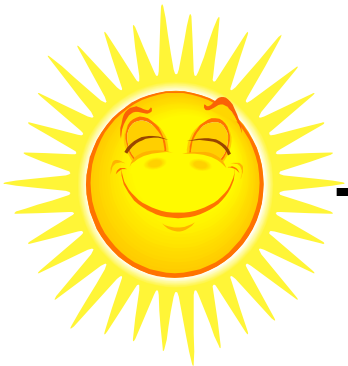
The Ideal…

Solar Flux



a_{SL}

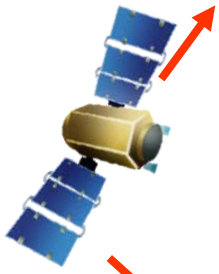
- SRP acceleration is purely along sun line
- No shape/attitude
- Uniform materials



The Reality…

Solar Flux

a_X



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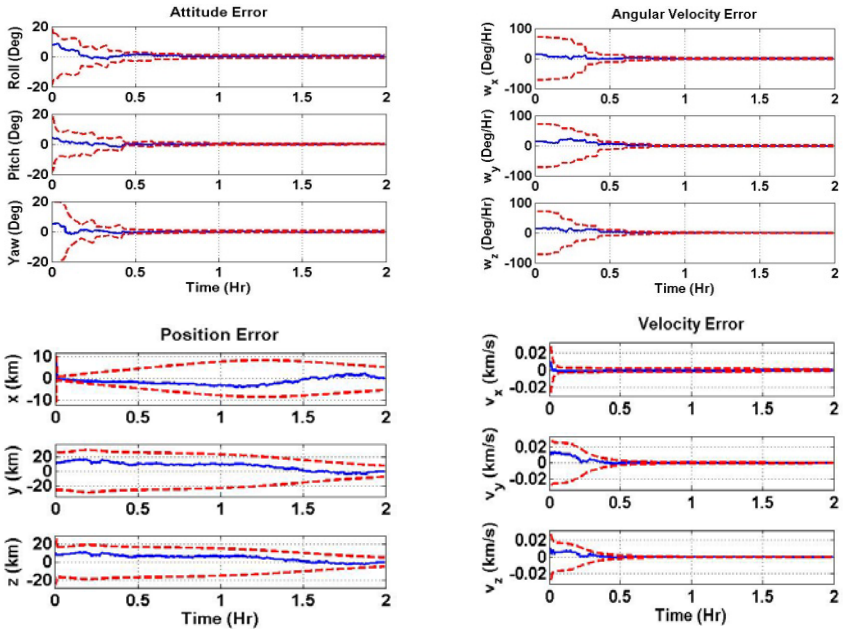
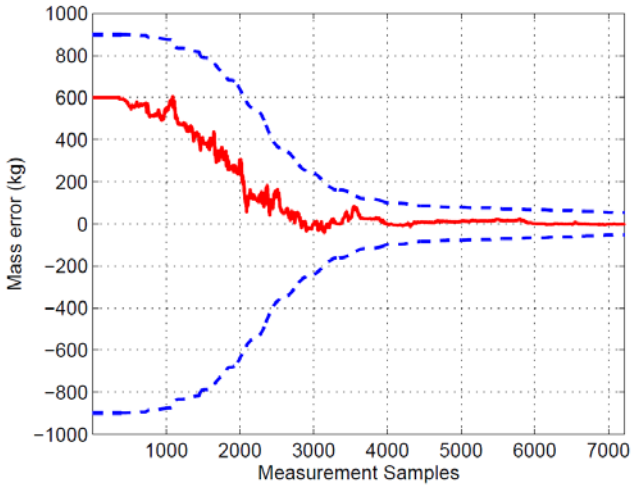
- SRP acceleration likely in non-sun line direction thermal emissions, attitude changes
- Size, shape and attitude may or may not be known as a function of time
- Materials likely unknown, and/or aging effects a factor

Imprecise Modeling Increases Error in Reconstruction & Prediction

Space Object Observation Exploitation

- Example with Astrometric and Photometric Data Fusion
  - Astrometric angles data are very sensitive to the SO trajectory (translational dynamics) but fairly insensitive to SO characteristics (e.g. mass, orientation, materials, etc.) over short time spans
  - Photometric light curve data are very sensitive to SO characteristics but fairly insensitive to SO trajectory
  - These data types are complementary and orthogonal





Data Association

- Fixed-Gate vs Probabilistic
  - Fixed-Gate is simpler to implement but may lead to higher false associations
  - Probabilistic is only as good as how representative the uncertainty is of the true pdf, and for non-Gaussian pdfs where is the threshold?
- Kinematic-Only vs Feature-Aided
  - Each object is unique (different) in some way. Can we collect data that infers these differences with quantified ambiguity (e.g. brightness, multi-wavelength, optical cross-section, etc)?
- Effects of Stochastic (Residual) Biases
  - Aliasing of state vector; optimistic uncertainty can lead to solution divergence and mistags
- Effects of Sparse Observations
  - Unrealsitic and/or too large of an uncertainty
  - Insufficient information content to resolve ambiguity
- Relative Multi-Sensor Data Weighting
  - The information content in discrete sensor data is not the same as the combined/fused content
- Probability of Detection < 1
  - Sensor noise, effects of media, space object dependence

Areas of Recommended Research

- **Dynamical interaction and modeling of objects with the space environment**
  - coupling between translational and rotational motion
  - full (high-fidelity and physics-based) effect of the natural environment on inactive space objects
- **Advances in Space Object State and Parameter Inference**
  - improved and problem-specific data collection/assimilation/exploitation techniques
  - investigation of applying information-theoretic and information fusion approaches
  - development and implementation of advanced space object identification and discrimination techniques based upon multiple hypothesis testing
- **Accurate and Realistic Prediction of Conjunctions/Collisions**
  - Development of realistic and quantifiable measures of space object ambiguity (uncertainty)
  - Accurate and precise long-term 6+DOF trajectory propagations
- **Advanced Computational and Visualization Methods**
  - Exploitation of multiple processors and high performance computing
  - Fast and accurate methods of numerical integration

Realistic International Collaborative Opportunities (Examples)

- **United Nations Committee On Peaceful Utilization of Outer Space (UN-COPUOS)**

- **Multi-lateral Agreements and Treaties**
  - **Trilateral Technology R&D Program (TTRDP)**
    - **USA, UK, Canada**
  - **NATO Panels**
  - **US – Australia Bilateral agreements**

- **Air Force Office of Scientific Research**
  - **AOARD (Tokyo), EOARD (London), SOARD (Chile)**
  - **http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=9487**