# Advanced Sciences and Technology Research Institute for Astrodynamics (ASTRIA)

February 2009

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377ABW-2009-1155

# Astrodynamics?

- **Astrodynamics is the science that studies the spatial and temporal behavior of artificial and natural objects in space. Any cause that affects both translation and/or rotation of an object in space is of concern to astrodynamics.**
- **Knowing where an object *was* can be difficult, but requires little to no knowledge of the object's characteristics:**
  - **The Orbit Determination process**
- **Knowing where an object *will be* can be nearly impossible and is enabled via characterization:**
  - **The Trajectory Prediction process**



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# What affects our dynamics?

- **The trajectory is determined by a number of forces acting on the spacecraft:**
  - **Gravitational forces**
    - **Dominant body force (dominant body is treated as spherically symmetric; produces pure Keplerian motion)**
    - **Non-dominant body forces (third body forces)**
    - **Dominant body gravity field asymmetries**
    - **General relativistic effects**
  - **Non-gravitational forces**
    - **Thruster activity**
      - **Trajectory Correction Maneuvers or Orbit Trim Manuevers**
      - **Attitude Control System**
      - **Angular Momentum Desaturations (AMDs)**
    - **Solar Radiation Pressure and Earth Albedo**
    - **Thermal radiation**
    - **Aerodynamic effects (Drag)**
    - **Gas leaks (real or compensative)**
      - **Propulsion system**
      - **Outgassing**
      - **Unknown/unmodeled accelerations**



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# Motivation

- Although Astrodynamics capabilities have been continually improved to meet operational needs and challenges, new improvements are needed to satisfy evolving operational needs.

- Space situational awareness and space control problems require novel and innovative approaches and techniques (scientific revolution versus evolution). The best opportunity to achieve this is by accessing our nation's brightest minds across academic institutions.



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# The ASTRIA Mission and Vision

**The Mission of ASTRIA is to assemble America's top astrodynamics research and development talent and focus it to solve defense-related space control problems.**

**The Vision of ASTRIA is to imagine, identify, develop and deliver new space control capabilities; make expertise on space control available to all branches of government; and help guarantee America's space superiority through excellence, innovation and practicality in astrodynamics and related fields.**

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# What is the Advanced Sciences and Technology Research Institute for Astrodynamics?

- **ASTRIA is a research entity that combines government in-house and contractor expertise in Astrodynamics with a consortium of universities performing research (6.1, 6.2, and 6.3) in areas of astrodynamics of interest to the Air Force Research Laboratory and the Department of Defense, providing an avenue for innovative solutions to address current and future problems.**

- **ASTRIA fosters collaborative research among and between the academic members and the Air Force Research Laboratory.**

- **ASTRIA has a Board of Advisors (BOA) comprised of key government staff that are in the appropriate positions to make recommendations on and give guidance to the research activities of ASTRIA in order to provide a successful path of technology transition and always insure relevance of the research to the warfighter's needs.**



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# ASTRIA Government Team

**Advanced Sciences and Technology Research Institute for Astrodynamics**

*Dr. Moriba Jah
Dr. Chris Sabol
Dr. Paul Schumacher
Dr. Kim Luu
Dr. L. Robbie Robertson
Dr. Frank Chavez
Dr. T. Alan Lovell
Mr. Robert Howard
Mr. Nathan Stastny
Dr. Chin Lin

* = Director



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# Current ASTRIA Membership

- Purdue University (already signed)
- University of Colorado [CU] (Boulder) (already signed)
- Texas A&M (already signed)
- University of Texas [UT] (Austin) (already signed)
- State University of New York [SUNY] (Buffalo) (already signed)
- Utah State University (already signed)
- Embry-Riddle Aeronautical University (already signed)
- Missouri University of Science & Technology (already signed)
- Penn State (in progress)
- Georgia Tech (in progress)
- US Air Force Academy (USAFA)
- Naval Postgraduate School (NPS)
- University of Hawaii [UH] (in progress)



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# Planned ASTRIA Programs

- Education Partnership projects
- Extended, on-site research at AMOS, Kirtland AFB, Hanscom AFB
  - Sabbatical leave appointments
  - Graduate/Post-Doctoral Fellowships
    - National Research Council (NRC) Research Associate program (via AFOSR)
    - National Defense Science and Engineering Graduate Fellowship (NDSEG) program
    - National Science Foundation Graduate Research Fellowship Program (NSF-GRFP)
    - Sciences, Mathematics, and Research for Transformation Defense Scholarship for Service (SMART) program
  - Summer Fellowships
    - Air Force Summer Faculty Fellowship Program (AF-SFFP)
    - Visiting Student Research Program (RD and RV Scholars)
    - Air Force Academy Visiting Cadet program
- Workshops, Seminars, and Lectures
- ASTRIA Research Program soliciting research via: SBIR/STTR and BAA



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# SBIR/STTR/NRC

- http://www.dodsbir.net/topics/Default.asp
- SBIR: AF093-012 (August 24, 2009 - September 23, 2009)
  - Advanced Estimation and Data Fusion Strategies for Space Surveillance/Reconnaissance
- STTR: AF09-BT11 (August 24, 2009 - September 23, 2009)
  - Realistic State and Measurement Error Uncertainty Computation and Propagation for Space Surveillance and Reconnaissance
- http://sites.nationalacademies.org/pga/rap/
- RO#13.10.04.B7278 (August 1, 2009)
  - Advanced Estimation Concepts for Astrodynamics-Based Space Situational Awareness and Reconnaissance



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# Benefits of ASTRIA

## Benefits to AFRL

- Access to the very best and brightest
- Intellectual diversity
- Help us stay abreast of new technology trends
- Enhance the AFRL workforce
- Help foster a collegial environment for research
- Serve as mentors for staff enrichment
- Serve as a clearing house and broker for collaborative research opportunities

## Benefits to Academia

- Relevant and challenging problems
- Opportunities for collaborative research
- Employment opportunities for students
- Sabbatical leave appointments
- Financial support for research
- Aid in the transition of technology to customers
- Connection to research opportunities with AFOSR



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# Some Recent Publications & Conference Presentations

Kelecy, T., Jah, M., (2009). *Analysis of Orbital Prediction Accuracy Improvements Using High Fidelity Physical Solar Radiation Pressure Models for Tracking High Area-to-Mass Ratio Objects*. 5th European Space Debris Conference, Darmstadt, Germany, March 30 – April 2.

DeMars, K., Jah, M., (2009). *Passive Multi-Target Tracking With Application To Orbit Determination For Geosynchronous Objects*. 19th AAS/AIAA Space Flight Mechanics Meeting, Savannah, Georgia, February.

Wetterer, C., Jah, M., (2009). *Attitude Determination From Light Curves Via Unscented Kalman Filtering*. 19th AAS/AIAA Space Flight Mechanics Meeting, Savannah, Georgia, February. **Accepted in AIAA Journal of Guidance, Control, and Dynamics (April 2009)**

Jah, M., Kelecy, T., DeMars, K., (2008). *Orbit Determination Strategies Addressing The Search, Acquisition, And Characterization Of Geosynchronous Space Debris Objects*. 59th International Astronautical Congress, Glasgow, Scotland, September 29 – October 3.

Kelecy, T., Jah, M., (2008). *Maneuver Detection and Orbit Determination Of A Low Earth Orbiting Satellite Executing Low Thrust Finite Burn Maneuvers*. 59th International Astronautical Congress, Glasgow, Scotland, September 29 – October 3. **Accepted IAF Journal Acta Astronautica (August 2009)**



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# Some Academic Members' Work of Particular Interest to AFRL

- Terry Alfriend and Dan Scheeres-- Uncorrelated Track Association (funded by AFOSR)

- Jill Tombasco (student) & Penina Axelrad (advisor)-- Relative Satellite State Estimation (funded by NDSEG)

- Lt. Col. Jack Wetterer -- Attitude Determination via Sigma-Point Filtering of Temporal Photometry (funded by HSAI – sabbatical leave from USAFA)



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# Some RD Scholars' Work of Particular Interest to AFRL

- **Frank Centinello – 6 Degree of Freedom Trajectory Reconstruction Via Astrometric and Photometric Data Reduction in A Sigma-Point Filter (SUNY, Buffalo)**
  - **Advisor: Prof. John Crassidis**

- **Kyle DeMars – Interactive Multiple Model Probabilistic Data Association Sigma-Point Filter (Univ. of Texas, Austin)**
  - **Advisor: Prof. Robert Bishop**



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# Examples of Recent Research



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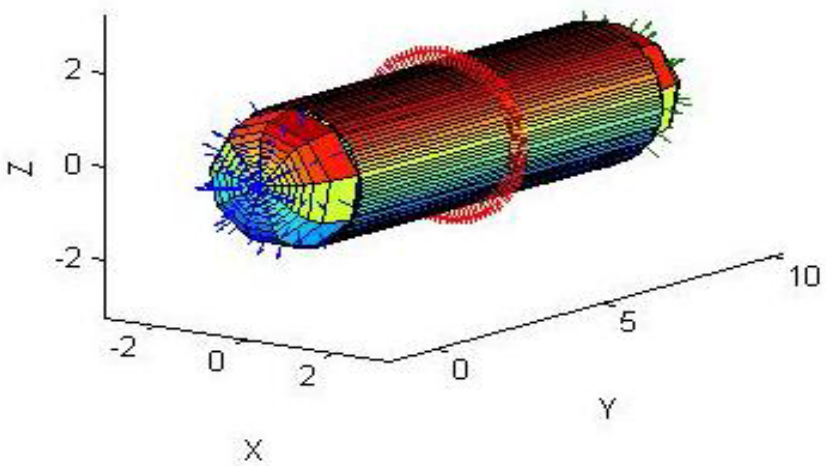
# Light Curve Attitude Estimation

(a) Photo of Atlas Centaur II Upper Stage

(b) Model of Rocket Body



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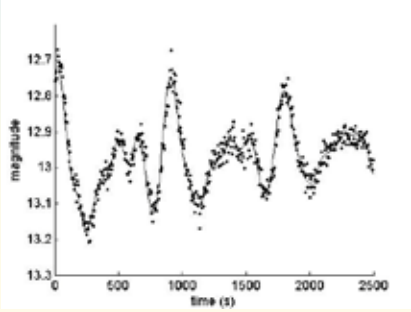
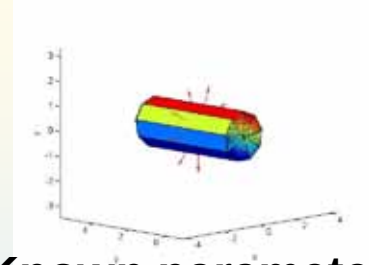
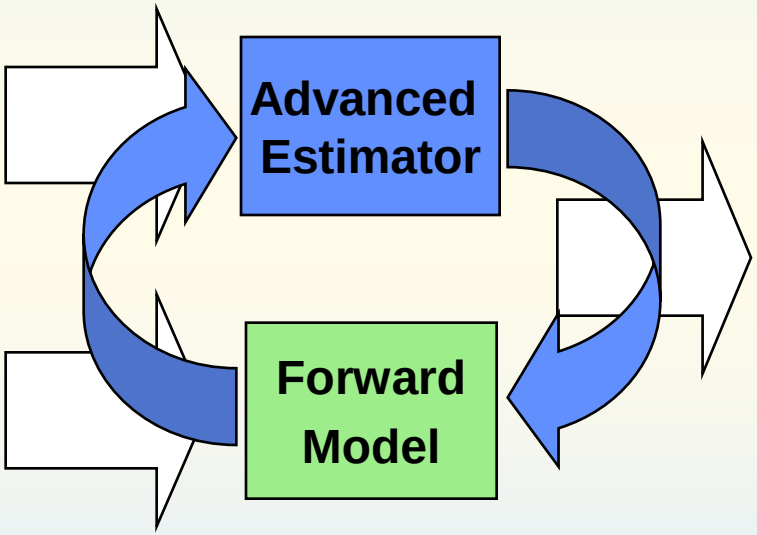
# Estimation-Based Satellite Characterization




Observations



Known parameters associated with object




Estimates of the unknown parameters associated with object and uncertainties



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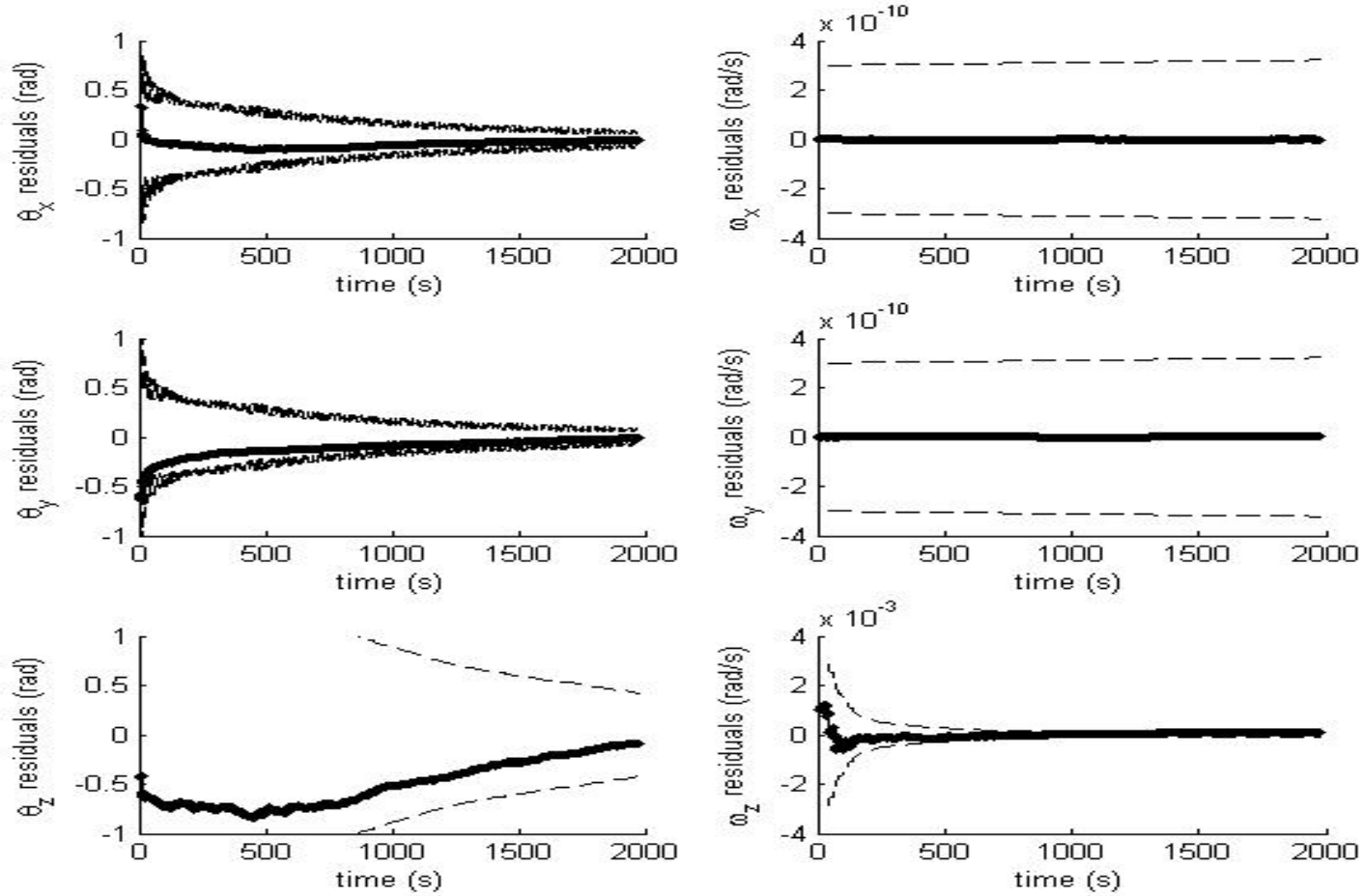
# Light Curve Attitude Estimation



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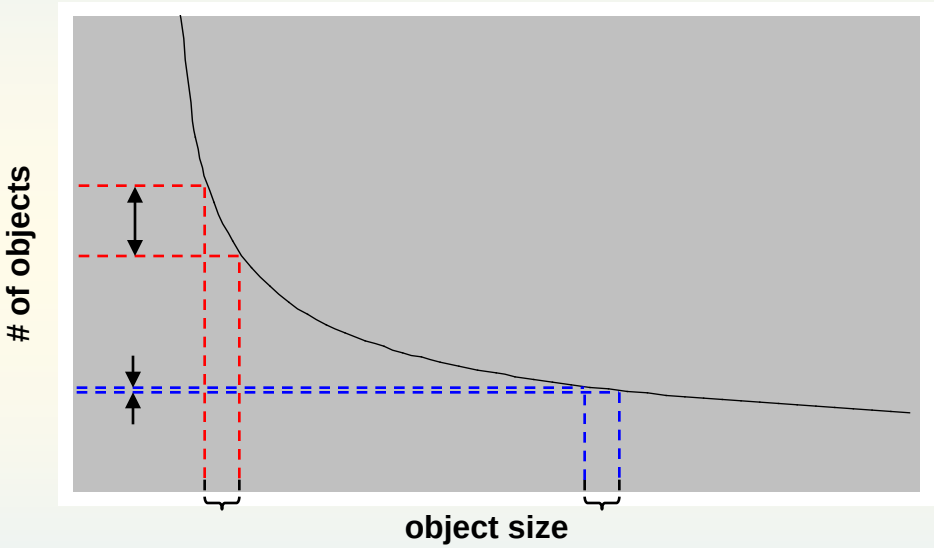
# Implications of Seeing Dim/New Objects

## Building Self-Consistent Database Given Many Marginally Detectable Objects




- Both number of targets and proportion of marginally detectable targets increase exponentially as target size decreases
- Requires realistic and sufficiently small covariances for successful covariance-based track association (possibly the use of Multiple Hypothesis Tracking [MHT] methods)



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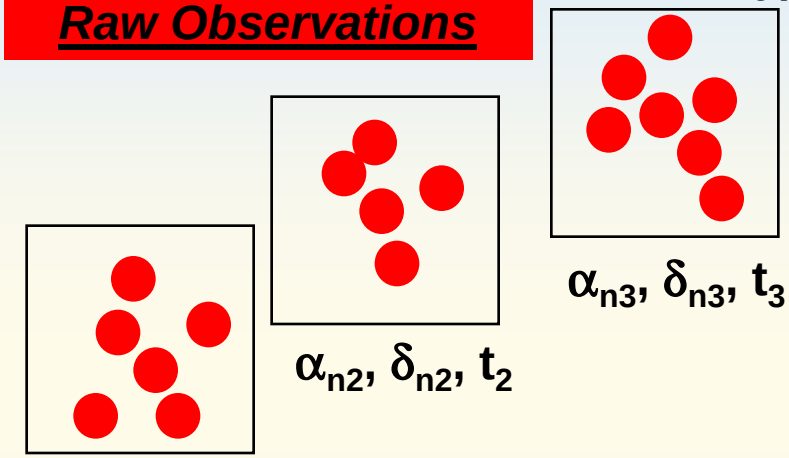
# Interactive Multiple Model Probabilistic Data Association Filter

***Raw Observations***




**Hypotheses Generation**

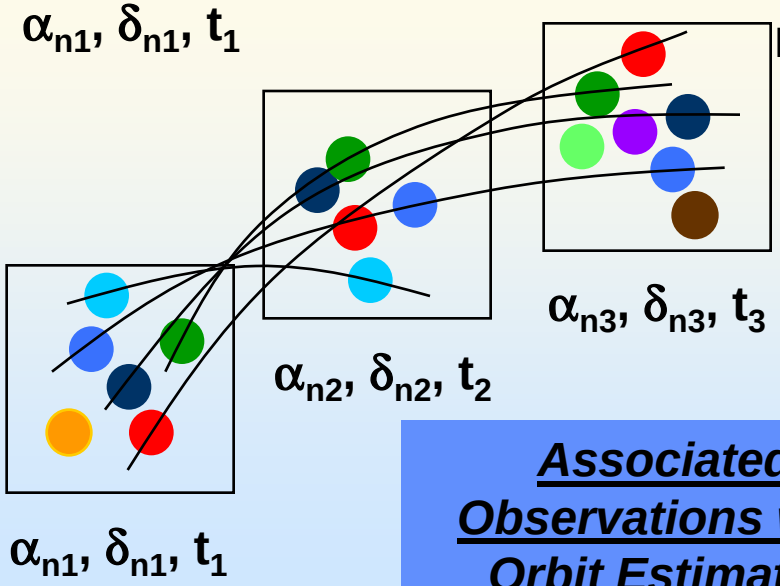
**Unscented Transform**

**Compute Residuals (*O-C*) and Innovations Covariance (*P*) for Multiple Hypotheses**

**Hypotheses Pruning**

**Compute Mahalanobis Distance for Multiple Hypotheses**

$$k^2 = (O-C)^T P_{inov}^{-1} (O-C)$$




***Associated Observations with Orbit Estimates***

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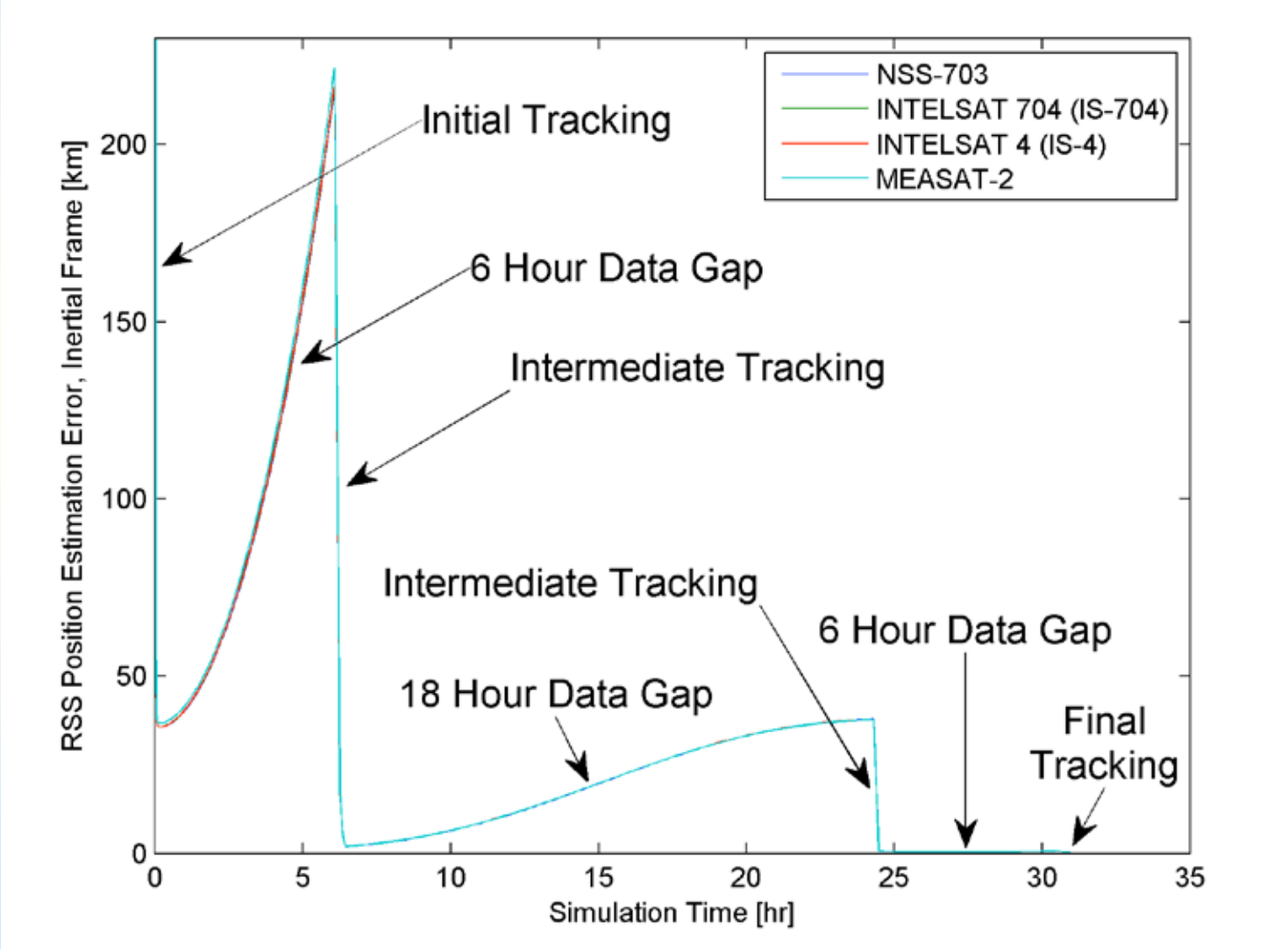
# Interactive Multiple Model Probabilistic Data Association Filter



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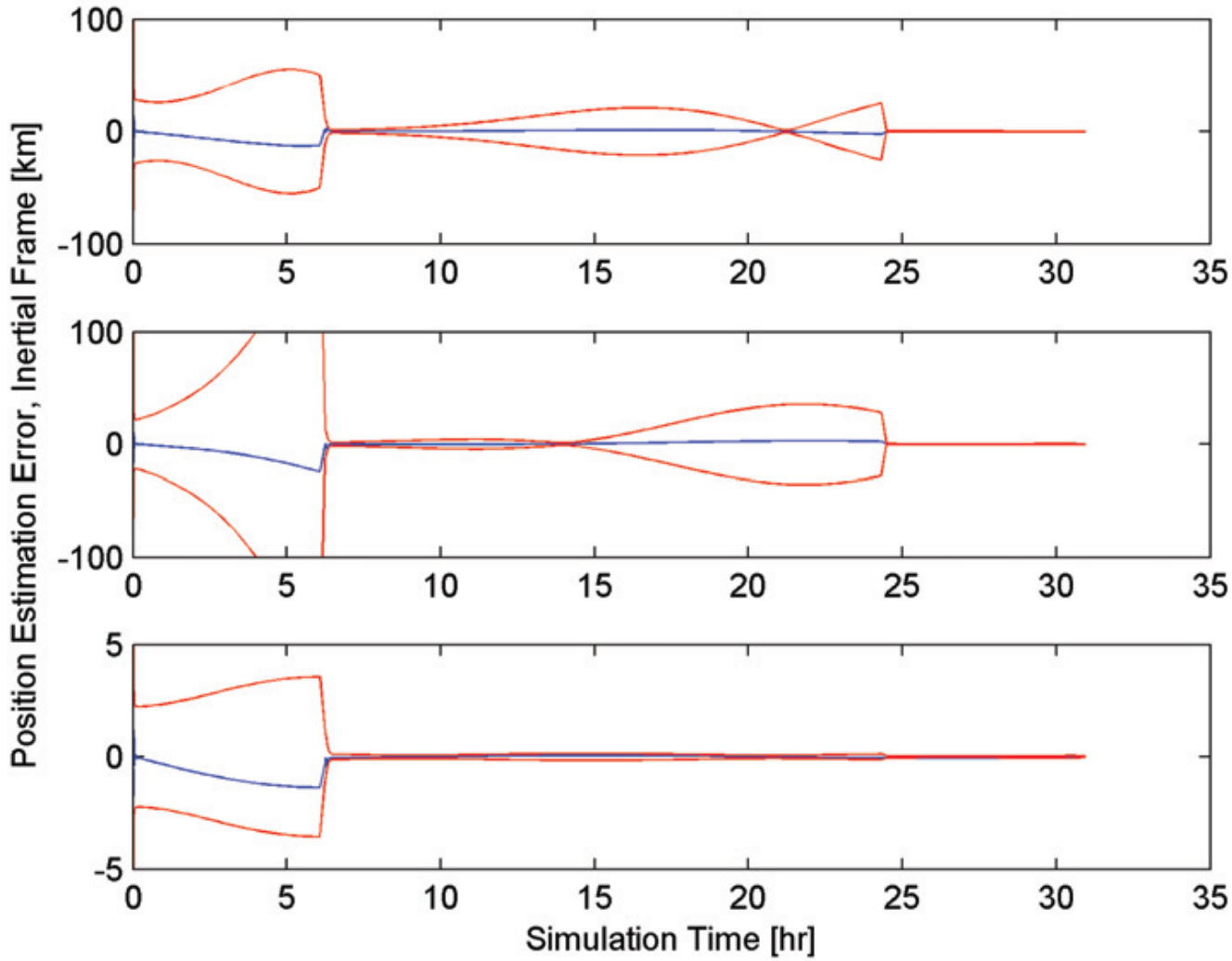
# Interactive Multiple Model Probabilistic Data Association Filter



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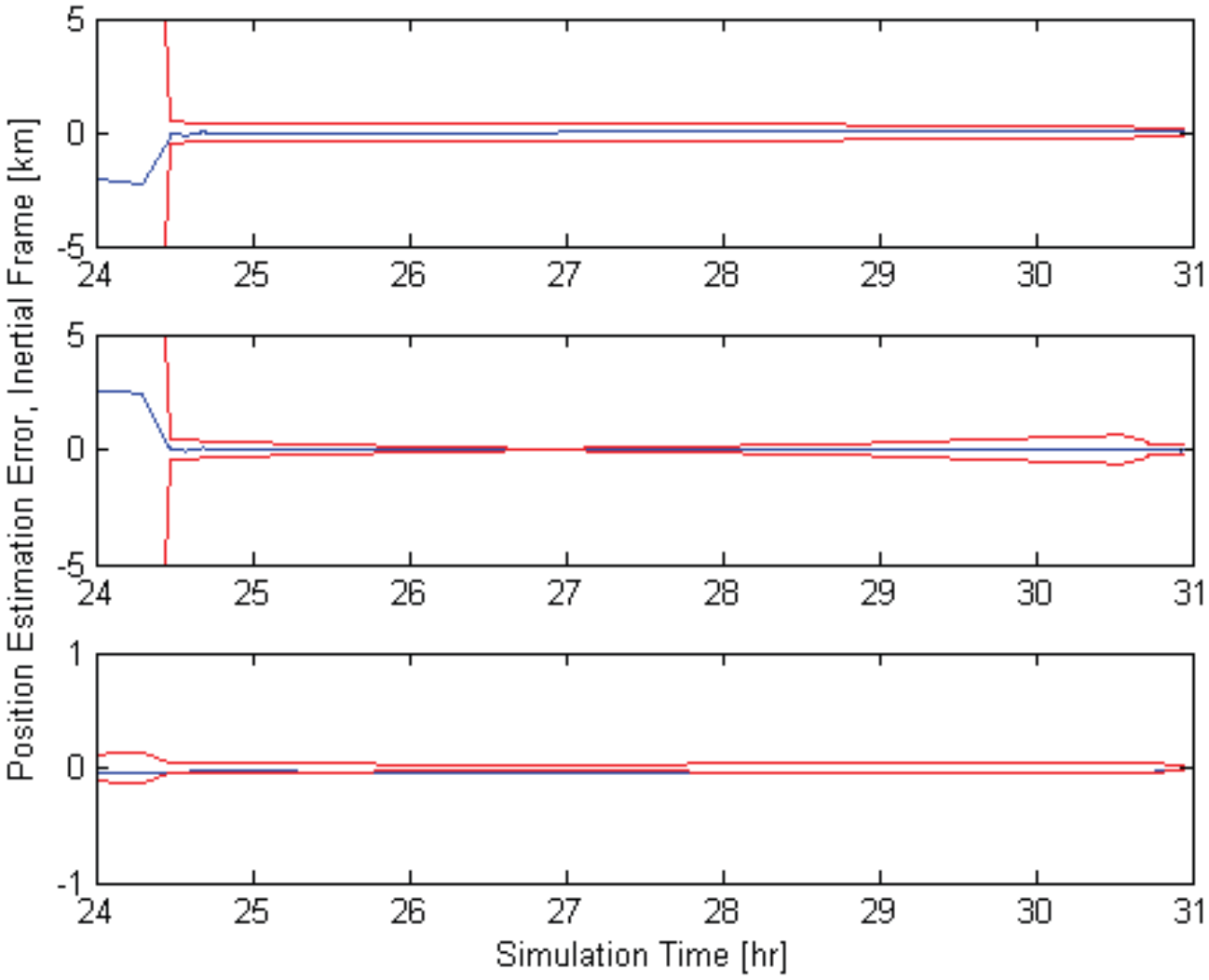




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# Summary

- The Advanced Sciences and Technology Research Institute for Astrodynamics is the sole mechanism that combines all of the nation's Astrodynamics R&D talent and focuses it uniquely upon defense related problems.
- ASTRIA's core will be a strong research partnership between academia and AFRL
- ASTRIA's value to the warfighter will always be high, given the relevant input and guidance from a Board of Advisors comprised of key government staff representing (and with a stake in) the warfighter's changing and challenging needs.
- ASTRIA's research portfolio will insure diversity, innovation, and a consistent path from conceptual design and development through technology transfer and transition to operationally relevant environments



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