SSA Capabilities and Policies
Academia/Scientific

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Example Roles in SSA

- **Operators** – Maintain and advance the state of practice
- **Industry** –Transition state of the art into practice
- **Academia** – Advance the state of the art
  - Academics must ***actively promote*** advancements to operators and industry to remain relevant!
  - Academia is better suited to the exchange of new ideas and impartial comparison between algorithms and methods

Role of Academia in SSA

- Advance understanding and state of the art

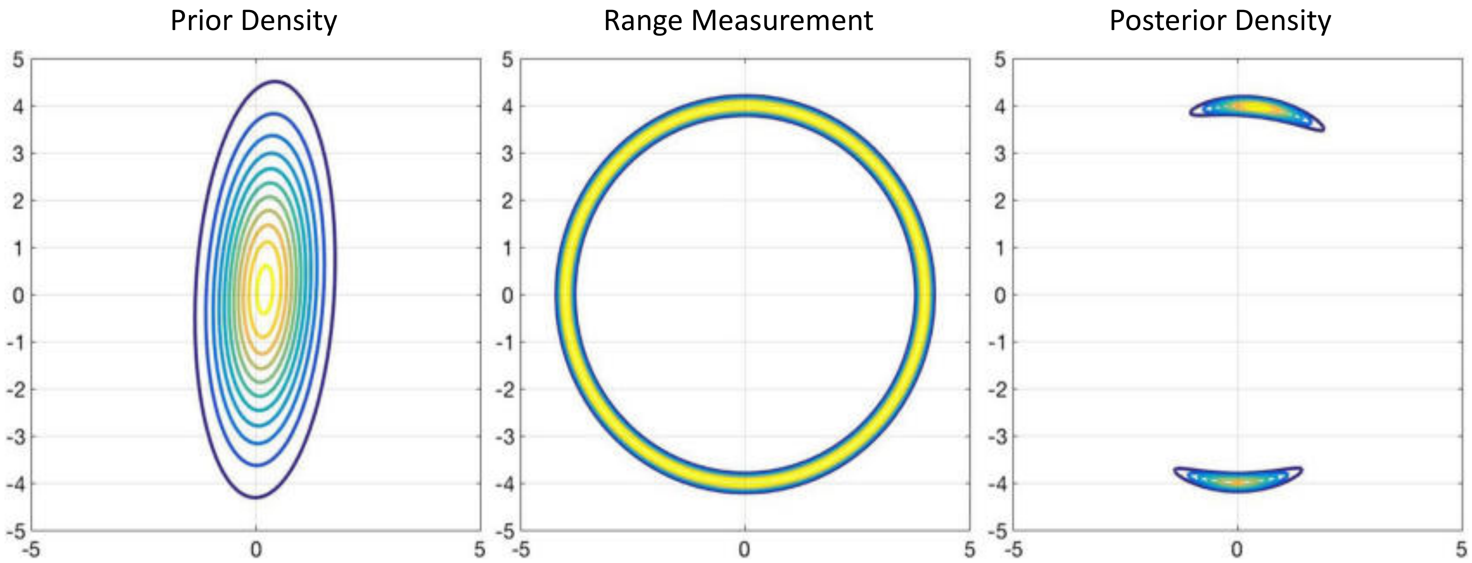


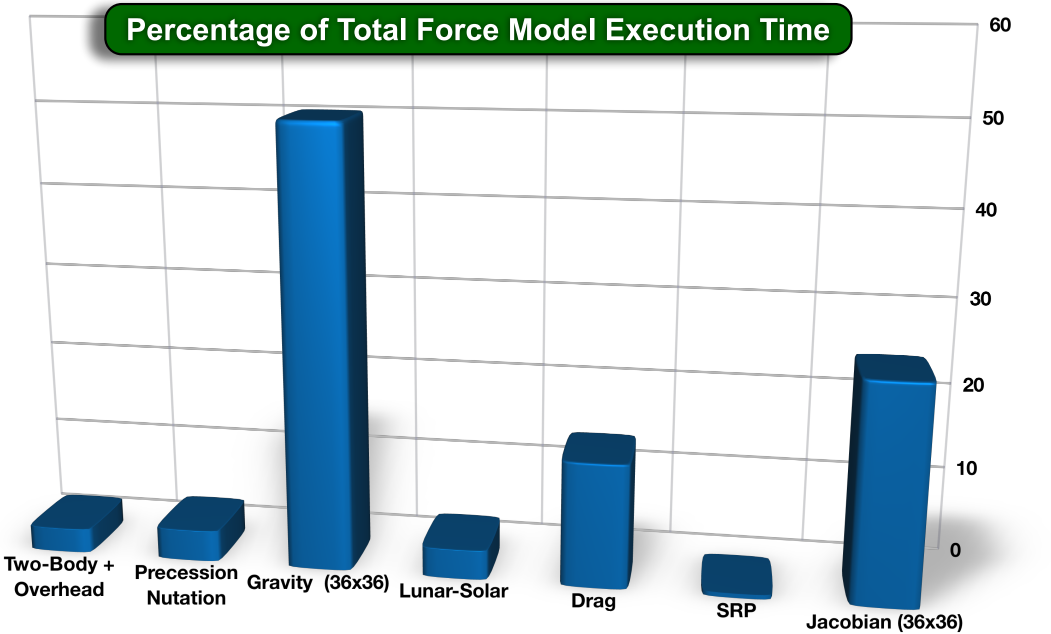
Image: Tuggle and Zanetti, 2018

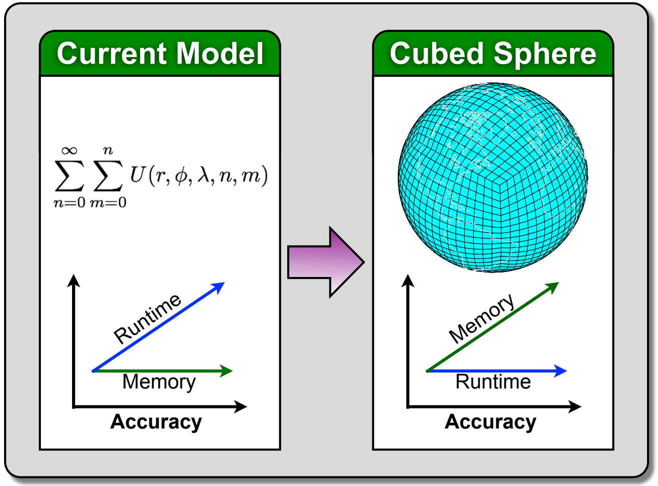
Role of Academia in SSA

- SSA estimation problems are fundamentally nonlinear.
- Academia has led the advancement of Bayesian inference for nonlinear systems
- Description on figure from previous slide:
  - Left Figure – A prior distribution for a 2-D estimated state vector
  - Middle Figure - A single measurement of distance from the origin (Gaussian noise/error)
  - Right Figure – Posterior distribution given prior and measurement
- In this scenario, classical methods such as the Kalman filter, extended Kalman filter, and the unscented Kalman filter fail.

Role of Academia in SSA

- Consider high-risk, high-reward ideas for SSA





Role of Academia in SSA

- Accuracy of propagators in SSA classically limited by computation resources
- Computational expense of gravity model limits accuracy for propagation of low-Earth objects.
- Jacobian also relies on gravity model
- Research in leveraging modern computers makes gravity model runtimes constant with an increase in memory requirements
- Gravity model runtimes can be greatly reduced.

Role of Academia in SSA

- Question assumptions that are considered fact

TLEs classically considered incompatible with special perturbation methods.

Advancements in “hard” and “soft” information fusion demonstrate otherwise

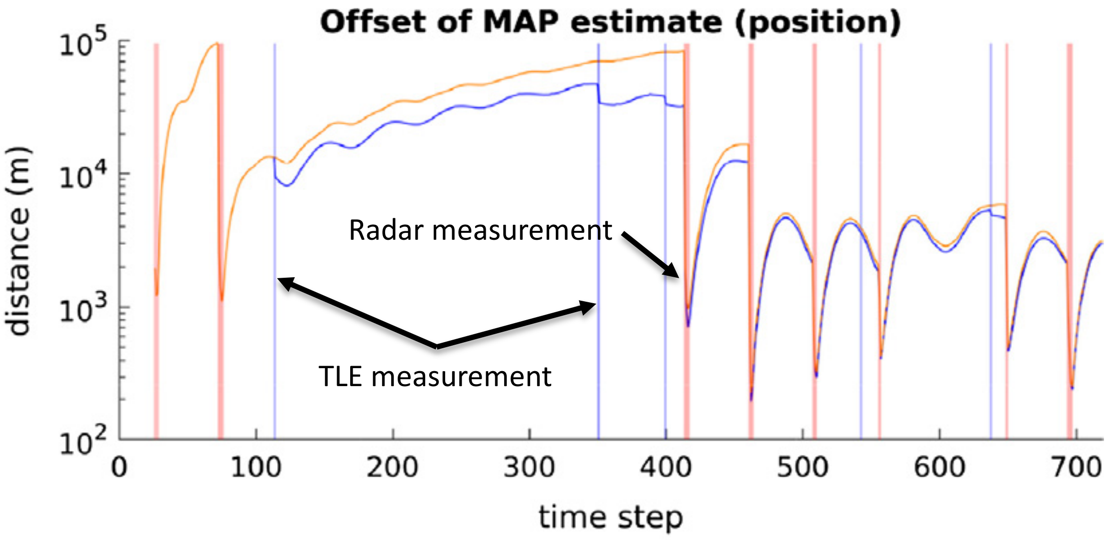


Image: Delande, et al., 2018

Role of Academia in SSA

- Combining Two-Line Elements (TLEs) and special perturbations methods of orbit determination/propagation have traditionally been infeasible
- Combining methods of “hard measurements” (quantifiable measurements with known uncertainty) with “soft measurements” (not quantifiable or measurements with unknown uncertainty) enable improved estimation performance
- New methods of hard/soft information fusion allow for maximizing information gained from data
- Image description:
  - Blue vertical bars are times where a new TLE is available
  - Vertical orange bars are time with a new range measurement
  - Including the TLE as soft information improves accuracy until a sufficient number of hard measurements are available.

Role of Academia in SSA

- Train the future researchers and operators in SSA

Image: US. Air Force

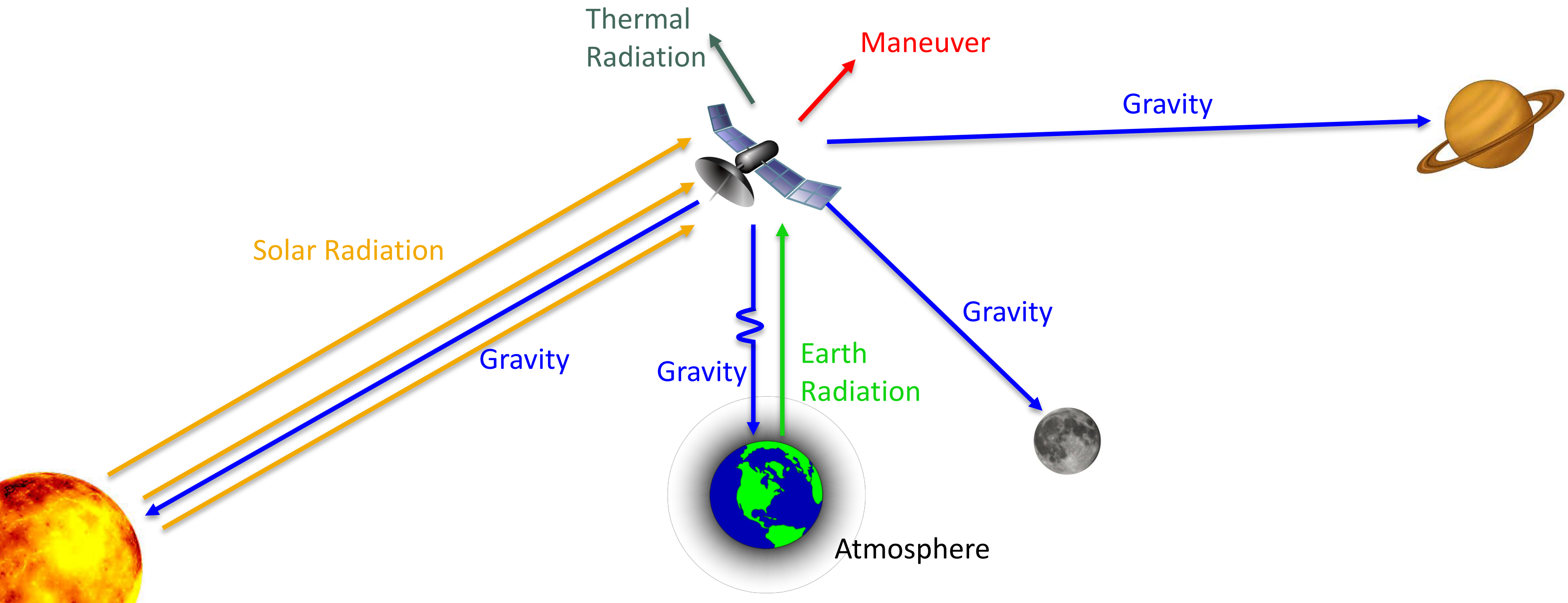
Image: ESA

Image: DARPA

SSA – A Multi-disciplinary Problem

- Applied Mathematics
- Astronautics
- Astronomy
- Computer Science
- Engineering Mechanics
- Information Fusion
- Material Science
- Psychology
- Policy
- Remote Sensing
- Space Weather
- Others…

Space Object Interaction with Environment



Space Environment

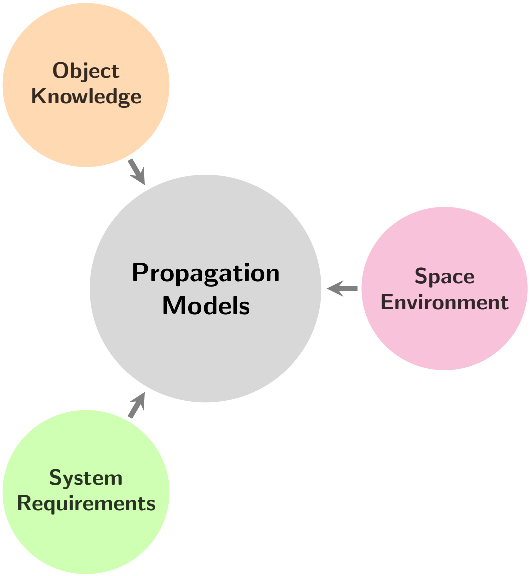
- To maintain SSA, must understand the spacecraft's interaction with its environment

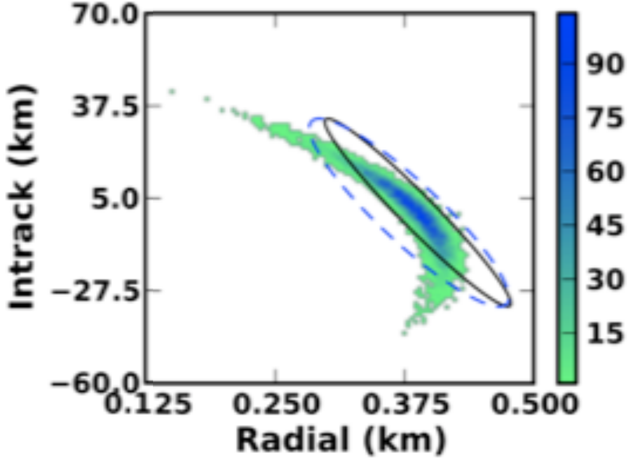
> *You must measure it to know it; you must predict it to understand it.* - Moriba Jah, UT-Austin

- Conservative forces
  - Gravity (Earth and other bodies)
  - Aspherical gravity and its temporal variations
  - Relativistic forces
- Non-Conservative forces
  - Solar radiation pressure
  - Earth radiation pressure
  - Thermal radiation
  - Maneuvers
  - Electrostatic charging
  - Outgassing

Knowledge of Orbit State

- Orbit state *and* uncertainty propagation



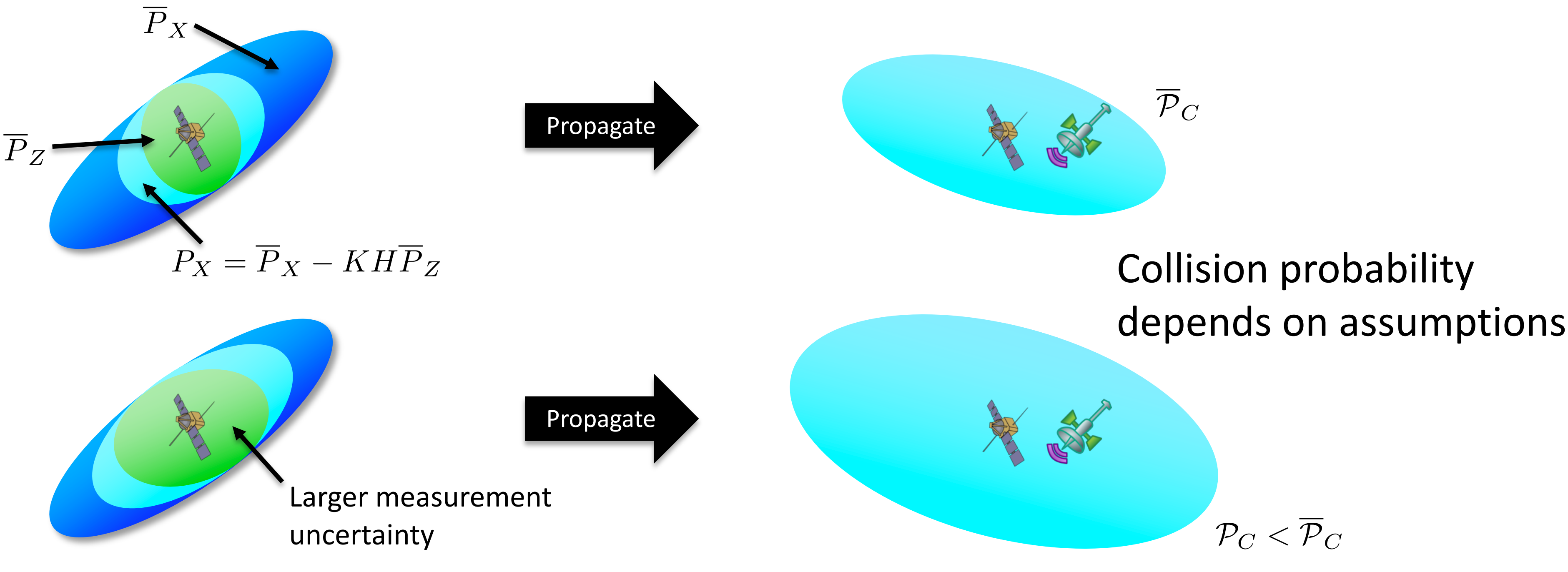


Knowledge of Orbit State

- Knowledge of orbit state is a function of many elements
  - Knowledge of the spacecraft
  - Knowledge of the environment
  - System requirements
  - Computational resources

- How do we translate knowledge of a spacecraft into predicted knowledge of the state?
  - Sensitive to what is known about the spacecraft
  - How do we accurately account for systematic and random errors?
  - How do we represent such uncertainties?
  - How do we do it tractably?
  - What are the impacts of truncating information?

Conjunction Assessment

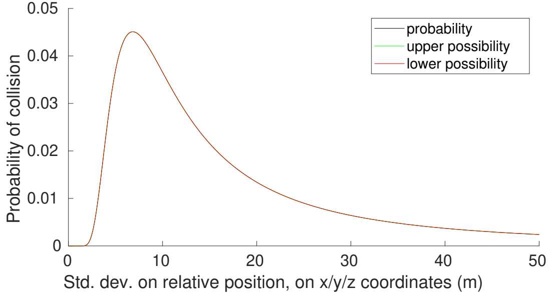


Conjunction Assessment

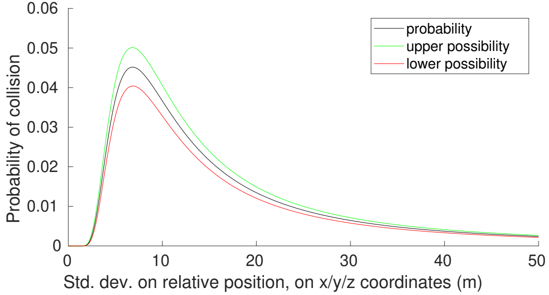
- The commonly used metric for collision risk is the probability of collision - P_c
- This value is fundamentally flawed, but it is the best that we currently have.
- For example: Using measurements with more noise yields a smaller probability of collision.
  - The larger data noise produces a larger posterior density, which becomes larger after propagation.
  - Hence, the probability that a spacecraft is in a given region of space is reduced.
  - This reduces the probability of collision with another object!
  - This is a fundamental flaw because it should give us less confidence in our knowledge of if there is a collision
- What improvements can be made to assess risk to spacecraft?

Conjunction Assessment

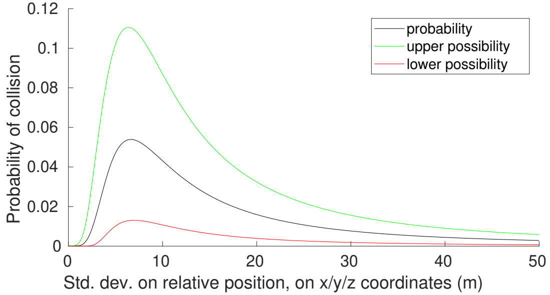
- Risk indicators must provide information on ignorance
- Risk indicators must be concrete and clear



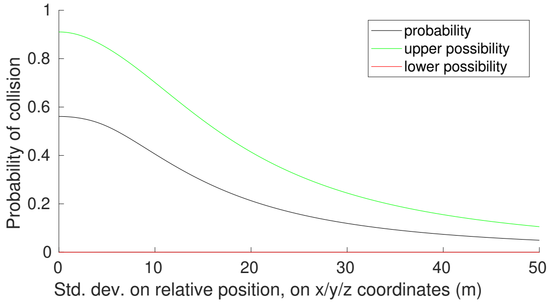
(a) Collision radius: mean 3.5 m, std. dev. 0 m



(b) Collision radius: mean 3.5 m, std. dev. 0.15 m



(c) Collision radius: mean 3.5 m, std. dev. 1.5 m



(d) Collision radius: mean 3.5 m, std. dev. 15 m

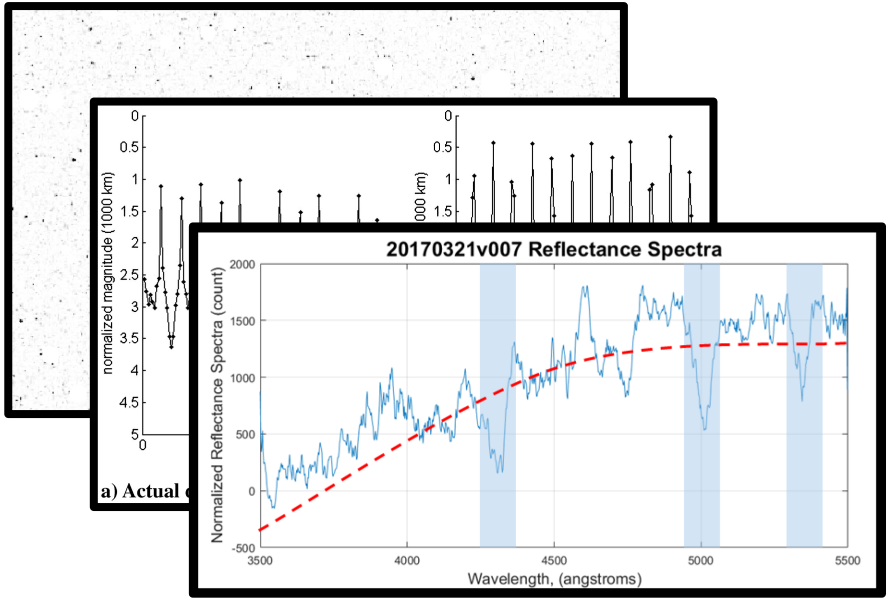
Image: Delande et al., 2019

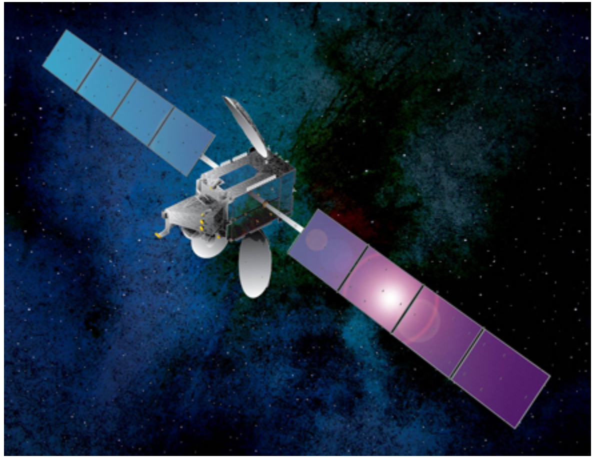
Conjunction Assessment

- We have two kinds of uncertainty:
  - Systematic (lack of knowledge)
  - Random (irreducible)
- How do we accurately reflect systematic uncertainty in the conjunction assessment process?
- How do we provide operators with the data necessary to assess risk?
- Image description:
  - The charts on the previous slide depict results from a new method of risk assessment that takes systematic uncertainty into consideration
  - This produces upper and lower bounds on P_c
  - With this approach, the separation between the bounds increases with reduced measurement quality, thereby reflecting systematic error

Information Fusion

- How do we transform measurements into knowledge?





Information Fusion

- How do we go from measurements to knowledge of a space object?
  - In general, data association is non-trivial
  - Optical images provide limited information on location and brightness
  - Brightness provides some data on angular rates, but is ambiguous
  - Spectroscopy can provide information on materials, but is sensitive to observing conditions

- We need new measurement types and improved algorithms for information extraction that help identify spacecraft!

Tracking Dim Objects

- How do we track small (i.e., dim) objects with low signal-to-noise?
- How do we handle the joint detection and tracking problem?

Movie: Courtesy of Shahzad Virani and Marcus Holzinger, Georgia Tech

Influence of *New Space* on SSA

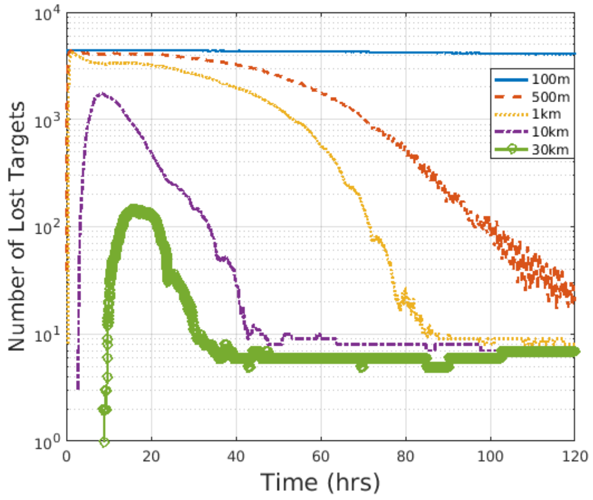


Image: Ravago et al., 2018

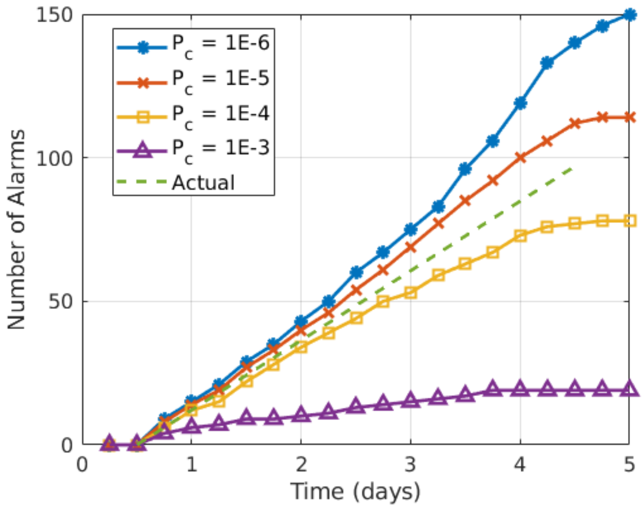
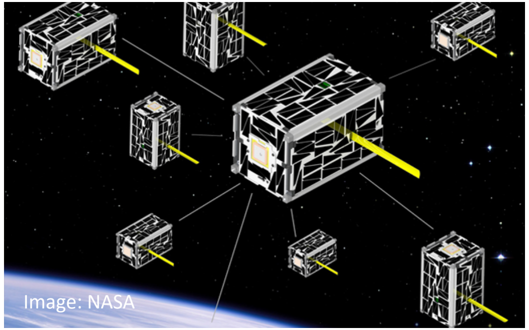
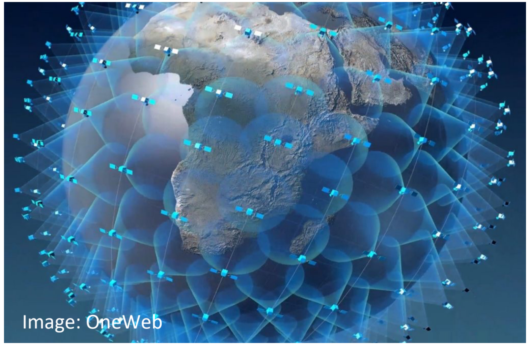


Image: Ravago and Jones, 2018





Influence of *New Space*

- Many advancements will be driven by the *New Space* industry
  - Getting into space is increasingly inexpensive
  - Vehicle launches are getting cheaper
  - Kilo-constellations (1,000s of spacecraft)
  - Proliferation of cube-/small-sats
- This yields a discrete jump in the number of trackable space objects
  - How do we adjust to such changes in the near future?
  - What are the operational impacts?
  - What are the recommended practices for new space operators?
  - What level of cooperation is require to be successful?
- What are the impacts to existing practices and methods?
  - Example: Common $P_c = 10^{-4}$ no longer a feasible risk threshold!

Resource Utilization

- How do we use sensor resources for SSA?

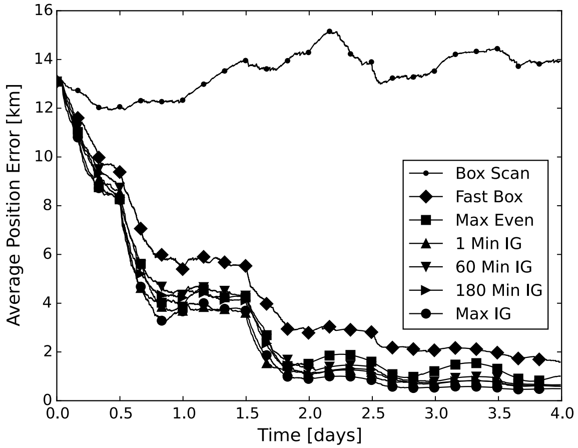


Image: Gehly et al., 2018a

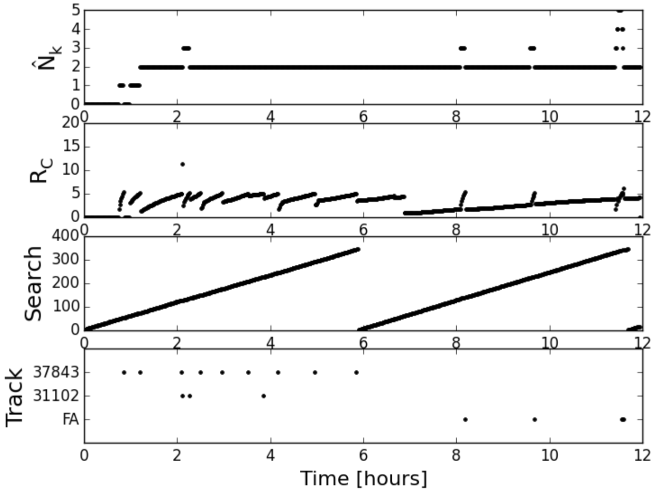


Image: Gehly et al., 2018b

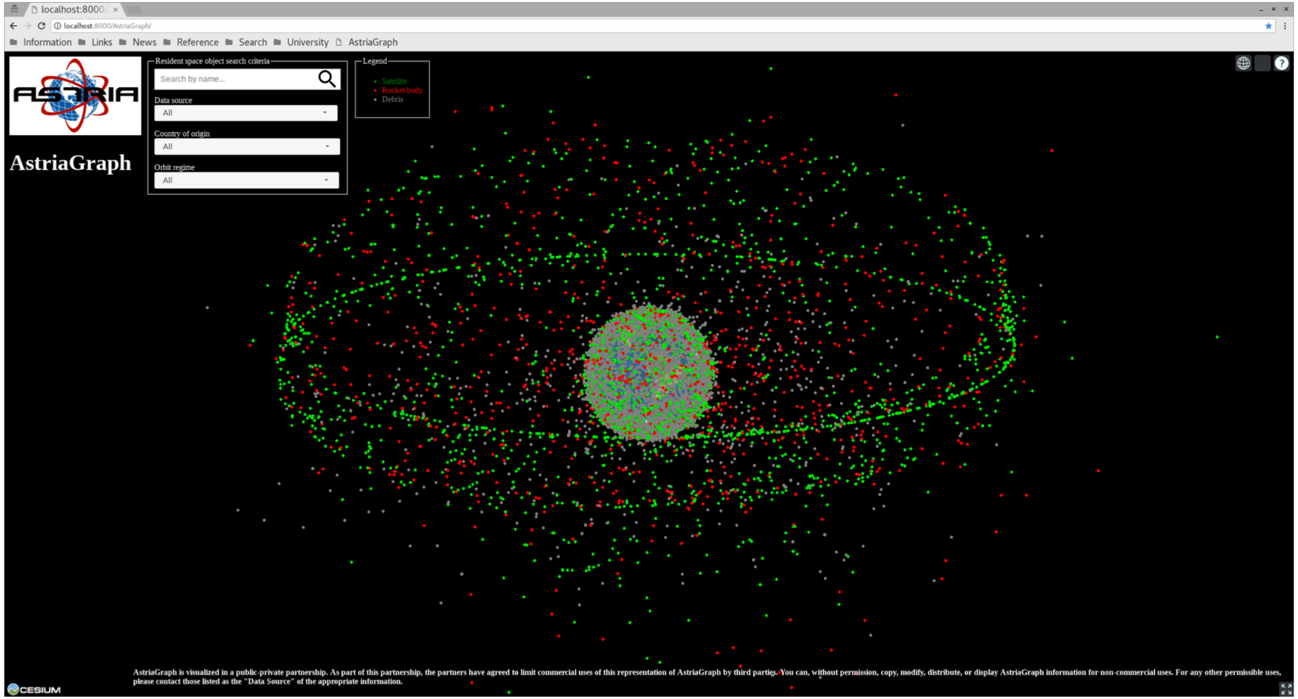
- What is the utility of data available?
- Example: Do we need 1M observations of the International Space Station?

Resource Utilization

- Data is becoming increasingly common
  - Multiple universities produce SSA data
  - Multiple companies produce volumes of SSA data
- With so much data, what is its *utility*?
  - How much data is sufficient?
  - How much should data cost?
- What modes of operation are appropriate?
  - Custody maintenance versus precise orbit determination
  - Searching versus tracking of space objects

ASTRIAGraph: Knowledge Graph for Space Domain Awareness

ASTRIAGraph



A Tried and Trusted Research Institution

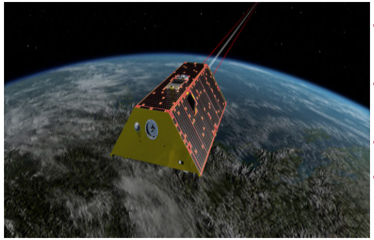
- Extensive computational modeling
- Existing HPC visualization
- Haptic Interfaces
- Networked together

- Robust, extensible, modular, secure cyberinfrastructure
- Dynamic interaction with information sources
- Delivering actionable data products

Unrivaled environment for workforce development

UT's has, and creates, SSA expertise and infrastructure

- Advanced degrees
- Certifications
- Apprenticeships
- Visiting scholars program



- Interdisciplinary research
- World-class spaceflight expertise
- Astrodynamics
- Algorithm design and V&V

Delivering Future Capability

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