Towards Quantifiable Resident Space Object Activity and Behavior Prediction, Identification, Quantification, and Assessment

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The "What": Demand Signals from the White House

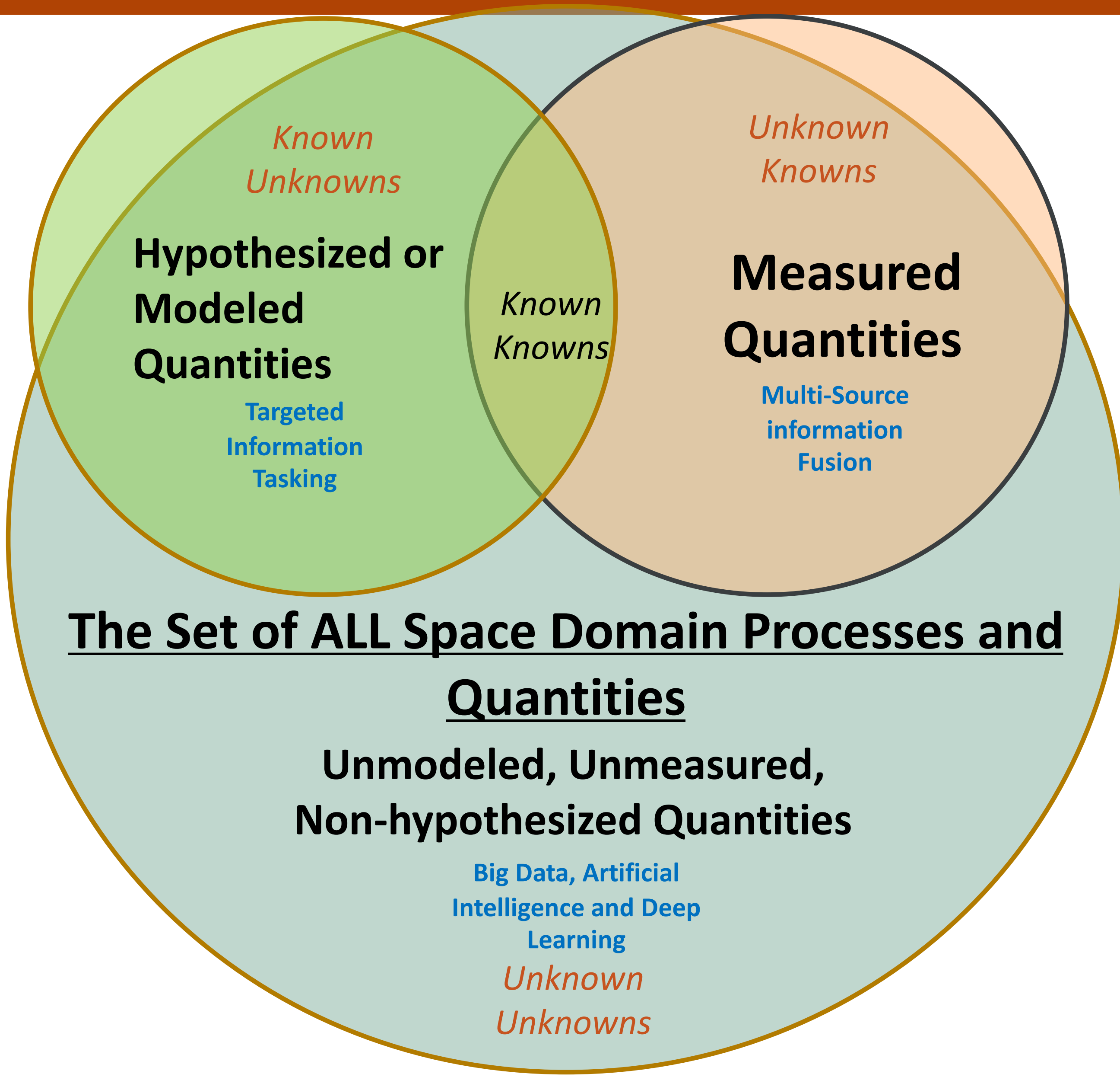
- **Safety, stability, and operational sustainability are foundational to space activities, including commercial, civil, and national security activities.** It is a shared interest and responsibility of all spacefaring nations to create the conditions for a safe, stable, and operationally sustainable space environment.
- **Timely and actionable SSA data and STM services are essential to space activities.** Consistent with national security constraints, basic U.S. Government-derived SSA data and basic STM services should be available free of direct user fees.
- **Orbital debris presents a growing threat to space operations.** Debris mitigation guidelines, standards, and policies should be revised periodically, enforced domestically, and adopted internationally to mitigate the operational effects of orbital debris.
- **A STM framework consisting of best practices, technical guidelines, safety standards, behavioral norms, pre-launch risk assessments, and on-orbit collision avoidance services is essential to preserve the space operational environment.**

The ability to predict, quantify, and assess the behavior of objects in space is foundational to all of these demands!

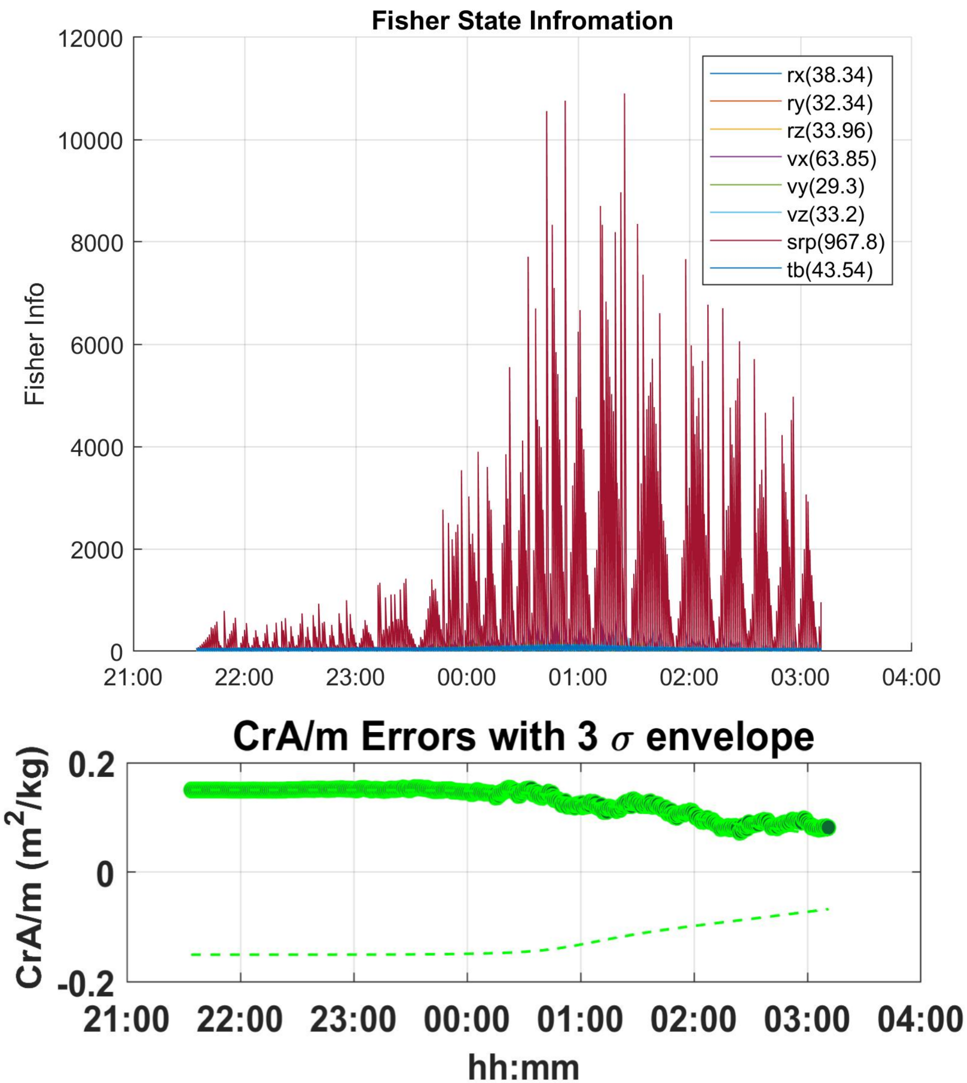
Can't Manage What You Don't Know; Don't Know What You Don't Measure

- Absence of knowing what "normal" behavior is in space
- Anomalies are difficult if not impossible to attribute a cause to
- No true persistent monitoring
  - A sensor working does not imply a sensor detecting!
- Lack of Transparency in space operations
- "Debris or not debris…that is the question…"

SSA Venn Diagram



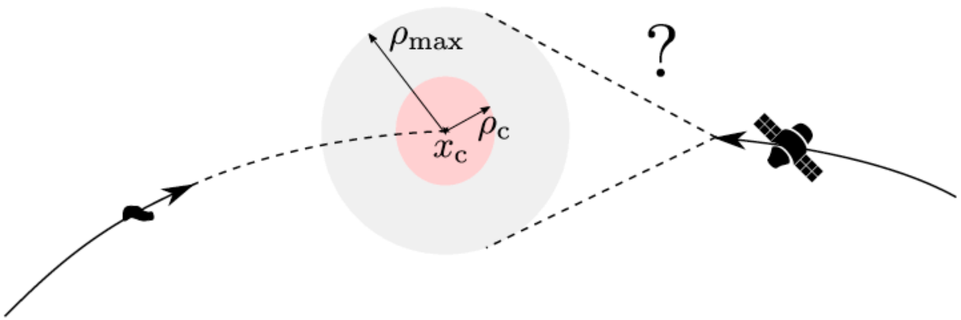
Data vs Information



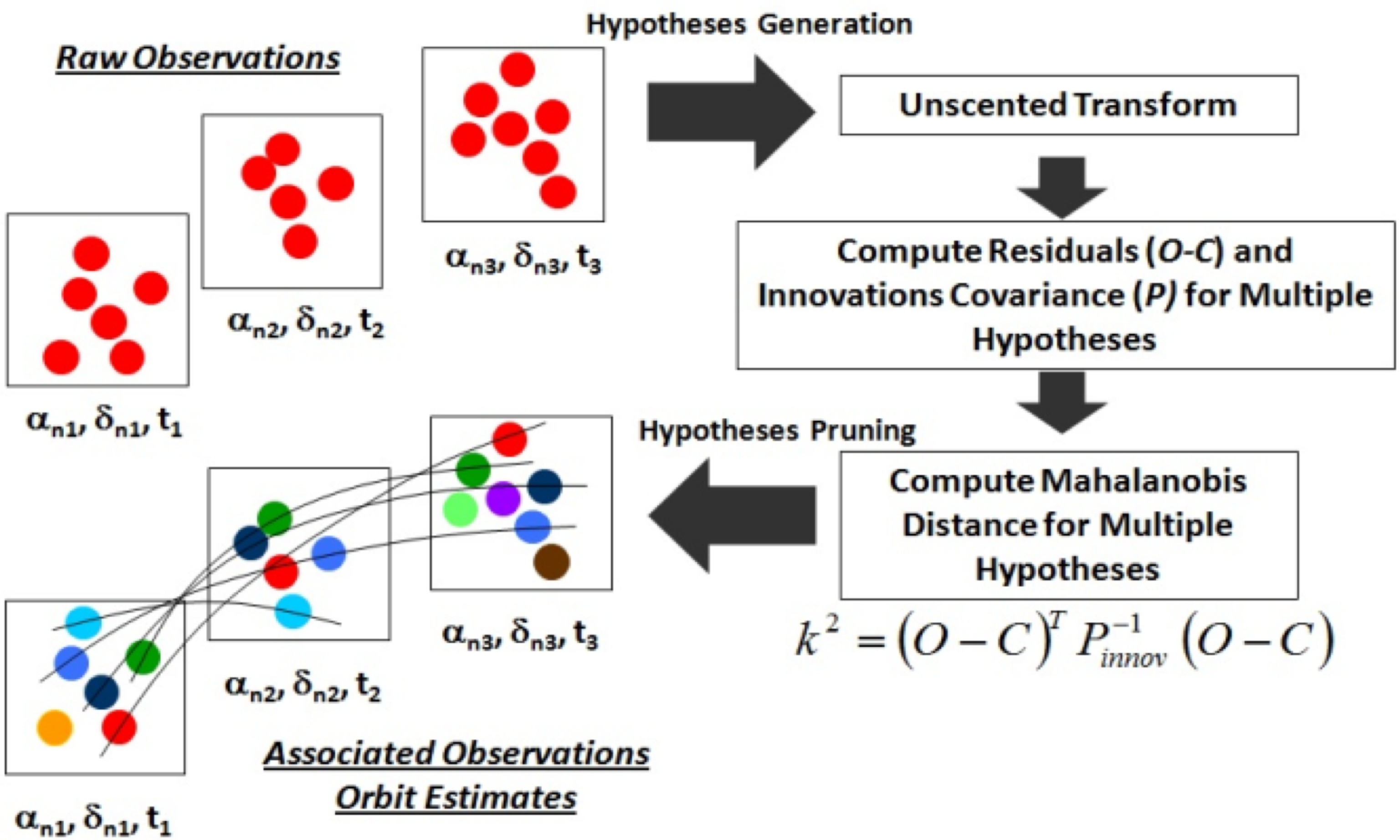
Probability of Collision: Subjective

- ***Ignorance and Uncertainty are not the same thing!***
- Depends uniquely on the evidence used in supporting the hypothesis
- Given the same evidence to multiple analysts, the answers are likely to all be different
  - Driven by underlying assumptions AND algorithms
- Does not provide measure of confidence to support decision-making
  - e.g. How do you know you have the world's most accurate clock? You have about 300 of them!
  - How many ***independent sources*** of information were used to derive any given collision probability?
- What is the single most important thing to make collision warnings decrease?
  - Add Data/Information specifically collected and exploited to remove ambiguity from the "system"
  - Focus on ambiguity removal instead of state estimation

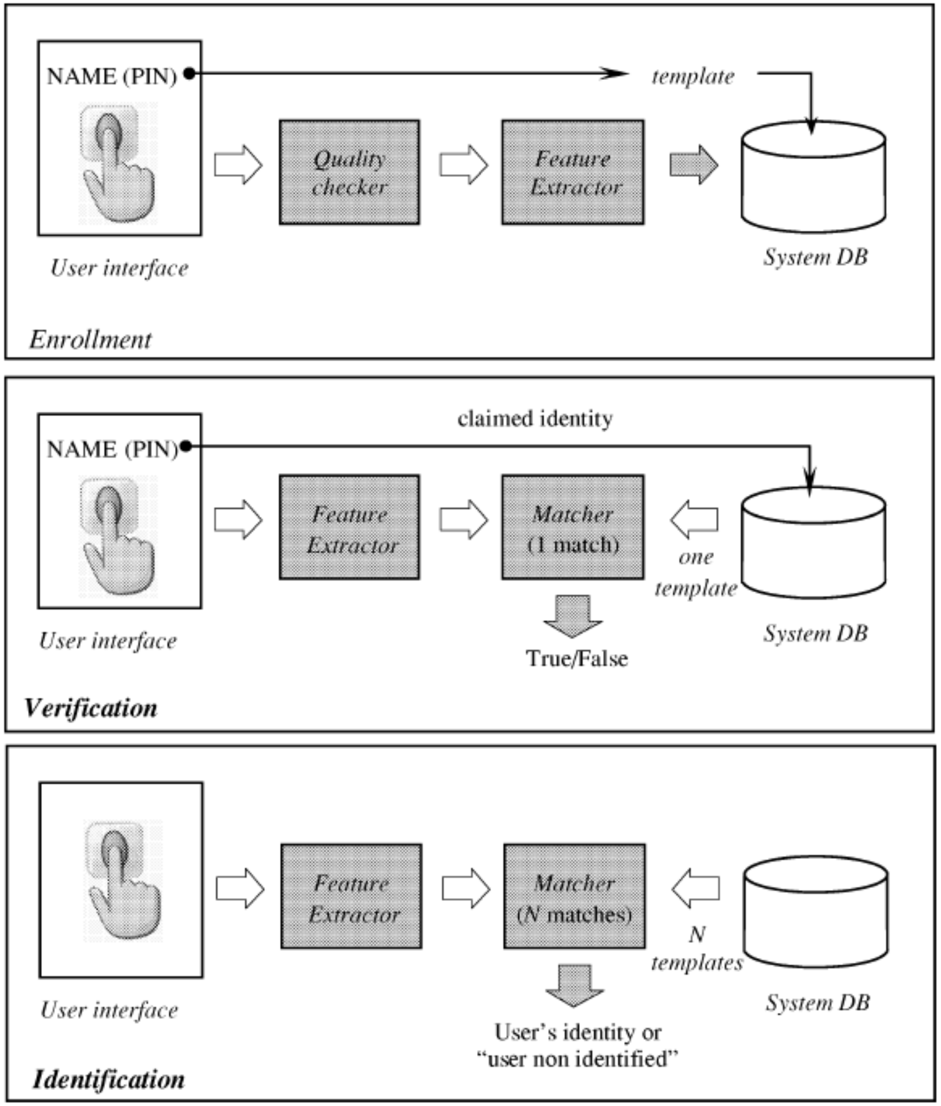
Delande, E., Houssineau, J., Jah, M., (2018) Physics and Human-Based Information Fusion for Improved Resident Space Object Tracking. *Elsevier Advances in Space Research*, Vol. 62, Issue 7, pp 1800-1812. https://doi.org/10.1016/j.asr.2018.06.033



Unique Resident Space Object Identification (URSOI)



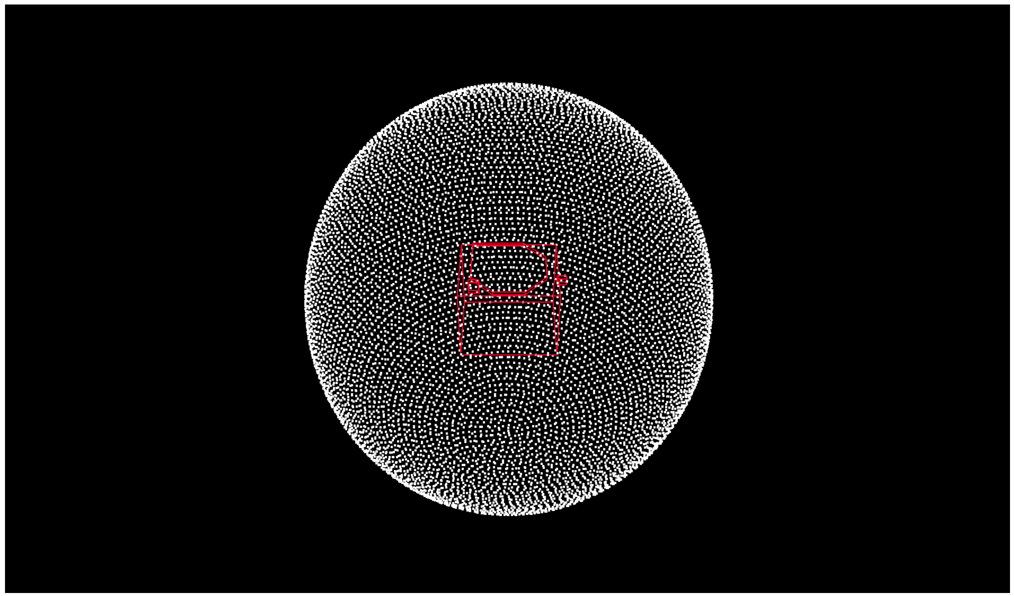
Development and Implementation of RSO Biometrics for URSOI

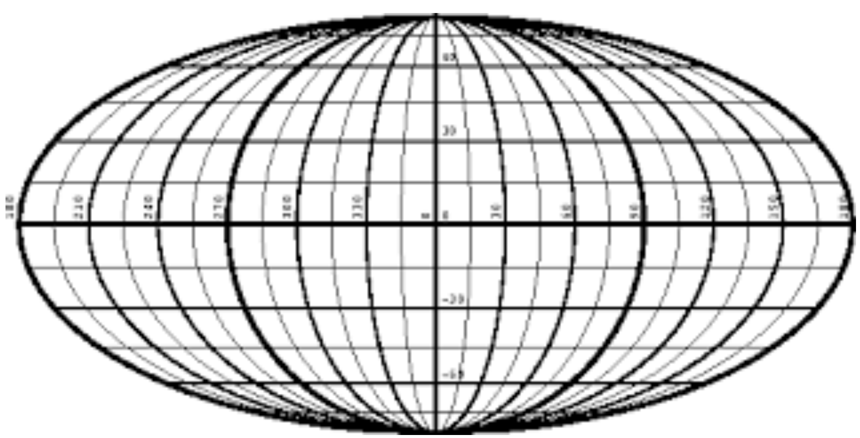


An Introduction to Biometric Recognition

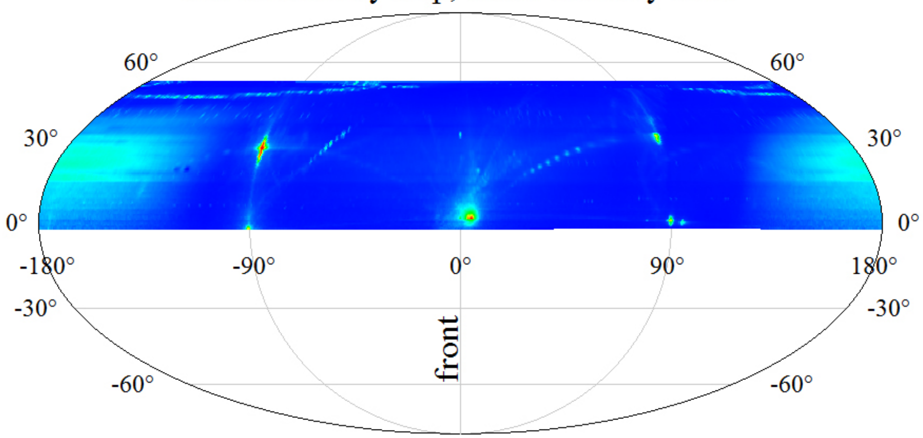
Anil K. Jain, *Fellow, IEEE*, Arun Ross, *Member, IEEE*, and Salil Prabhakar, *Member, IEEE*

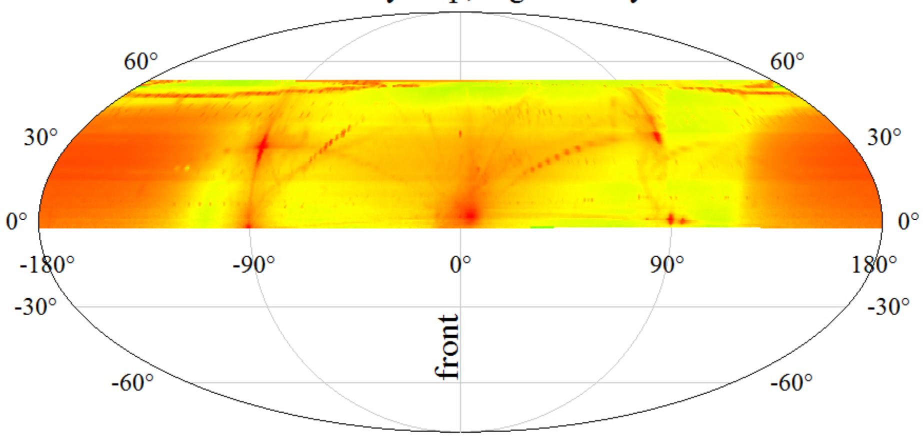
Space Object Centered Celestial Sphere and Mollweide Projection





Topex: Photometric "Fingerprint"





Topex "Fingerprint" based upon 100 Hz Photometric Data collected by the Graz SLR station.

Kucharski, D., Bennett, J.C, Kirchner, G., Jah, M.K., Webb, J.G. "High Sampling Rate Photometry of Spinning Satellites for Nano-Perturbation Detection". AMOS Conference. (2018).

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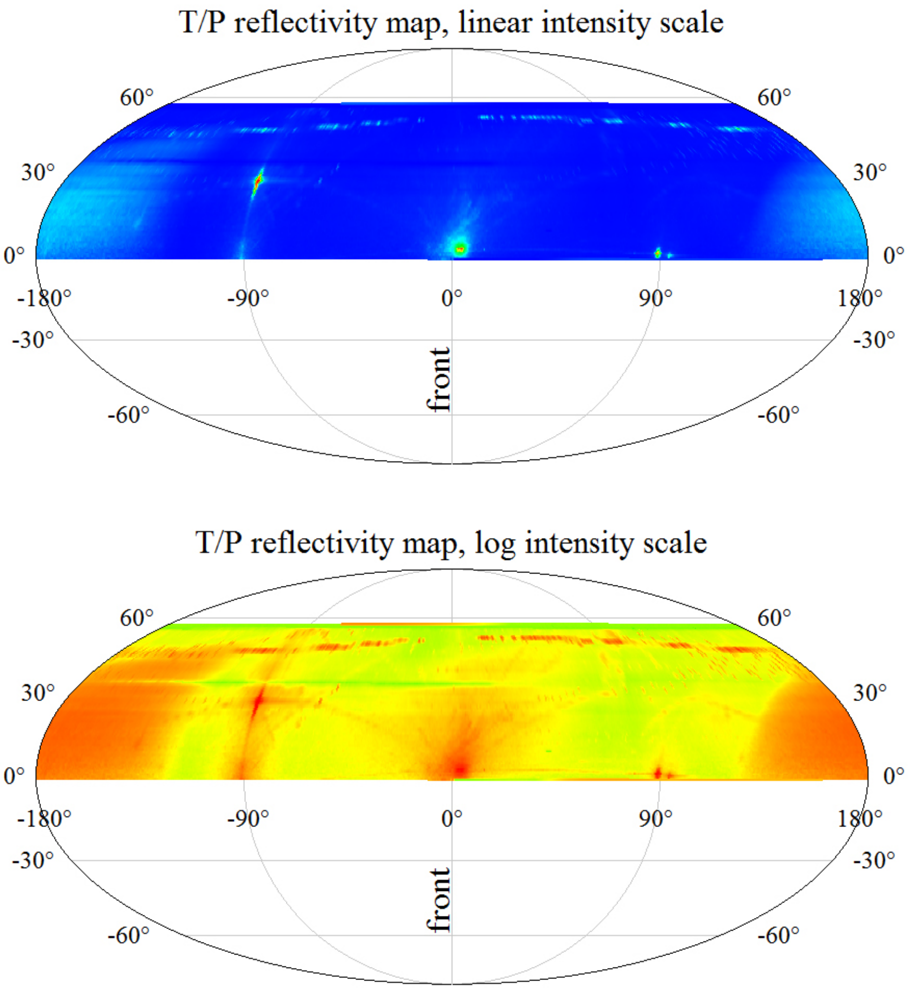

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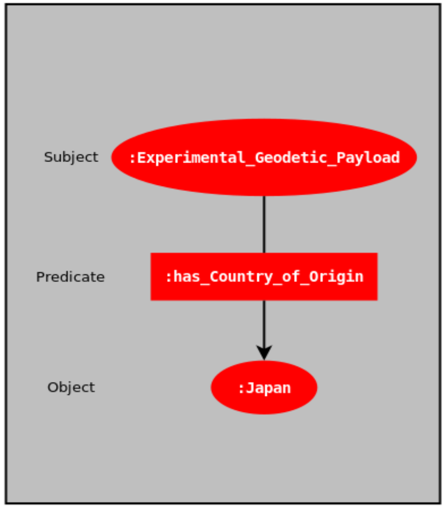
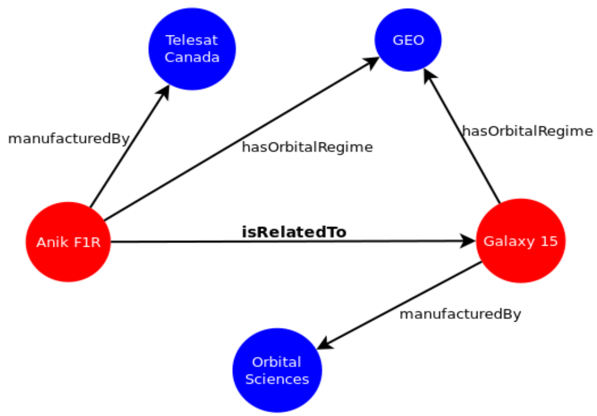
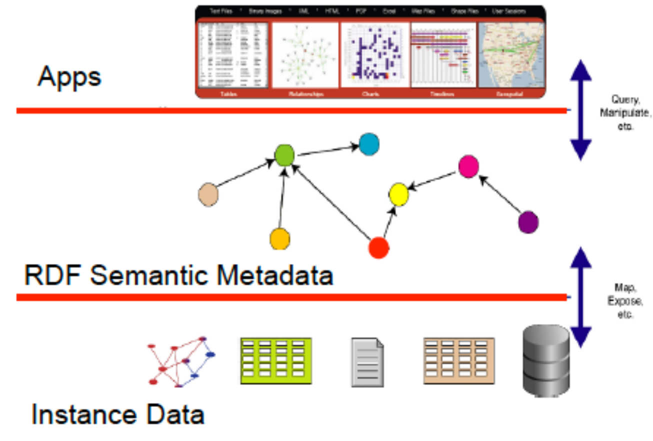
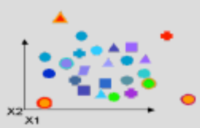
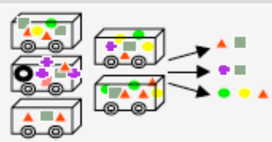
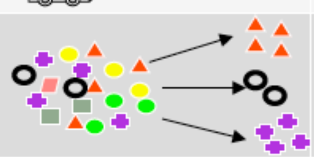
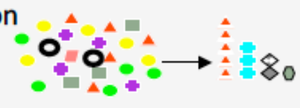
Data Engineering, Modeling, Science, and Analytics







Problem Classification	Sample Problem
Anomaly Detection 	Given demographic data about a set of customers, identify customer purchasing behavior that is significantly different from the norm
Association Rules 	Find the items that tend to be purchased together and specify their relationship – market basket analysis
Clustering 	Segment demographic data into clusters and rank the probability that an individual will belong to a given cluster
Feature Extraction 	Given demographic data about a set of customers, group the attributes into general characteristics of the customers

Images from Oracle

From Data to Identification and Classification

Measureables
Non-resolved Radiometry
Angles
Range
Range Rate
Passive Imagery
Active Imagery
Vibrometry
RF Signals
Radar Cross Section
Polarimetry
Gravitmetry
EM Fields
Particulates
Other

⬌

Physical Properties
Shape
Mass
Inertia Tensor
Materials Composition
Orientation / Stability
Temperature
Internal Components
External Components
Age
Surface Properties
Size
Age
Other

⬌

Functional Properties
Communications
Thrusters / Stationkeeping
Attitude Control
Mechanical
Passive Imagery
Sensing Functions
Guidance Navigation

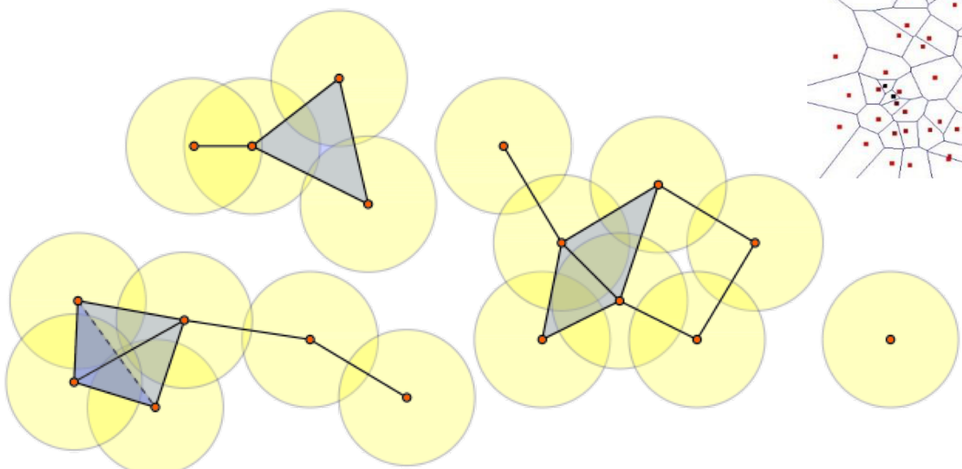
Operational Properties
Ownership
Mission
Operational Modes

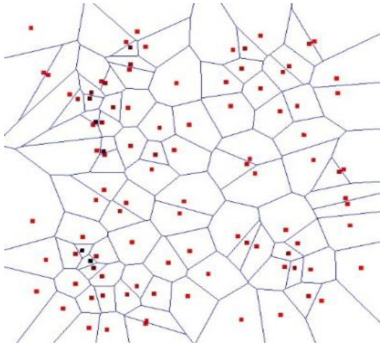
Category	Mass Range (kg)
Large satellite	> 1000
Medium-sized satellite	500-1000
Minisatellite	100-500
Microsatellite	10-100
Nanosatellite	1-10
Picosatellite	0.1-1
Femtosatellite	< 0.1

To Know it, you MUST Measure it; to Understand it, you MUST Predict it!

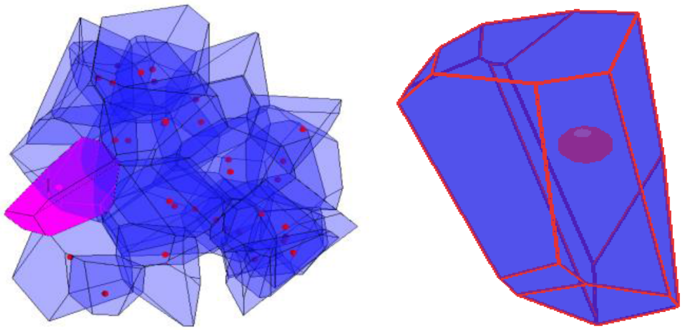
From Data to Discovery: Patterns in the Graph

- Discovering Unknown Knowns
- Our framework facilitates multi-source information curation and analytics to identify correlations
  - One must ask the right question (make the correct query)
- Find which correlations have causal relationships
- Link these data (e.g. Vietoris-Rips Complex, Voronoi Clustering)





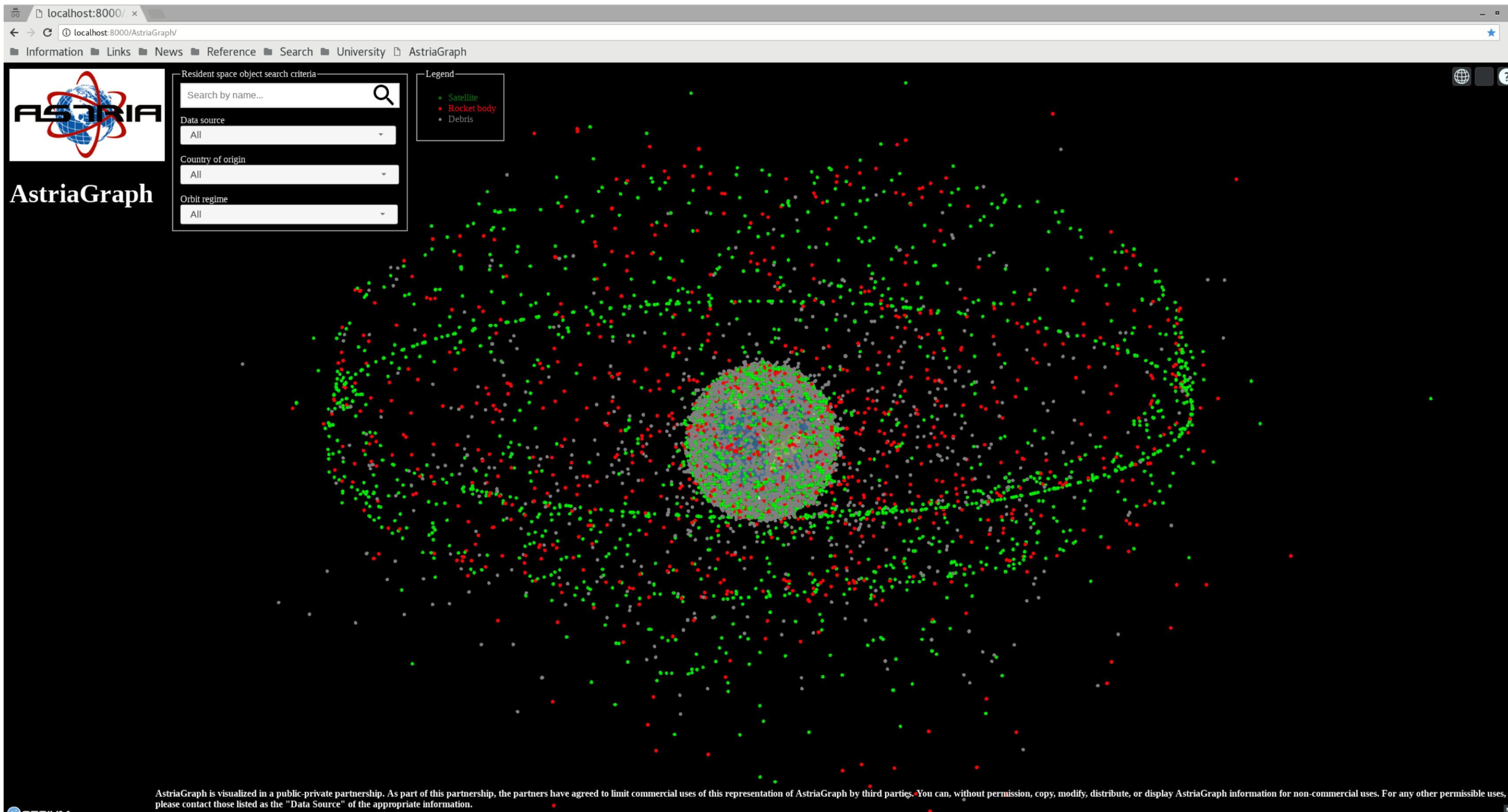
(a)



(b)

ASTRIAGraph: RDF-based Knowledge Graph for Space Domain Awareness

http://astria.tacc.utexas.edu/AstriaGraph



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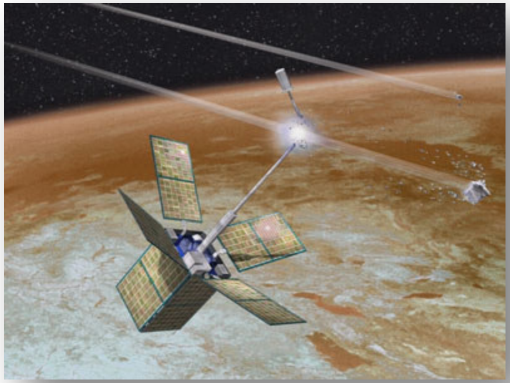
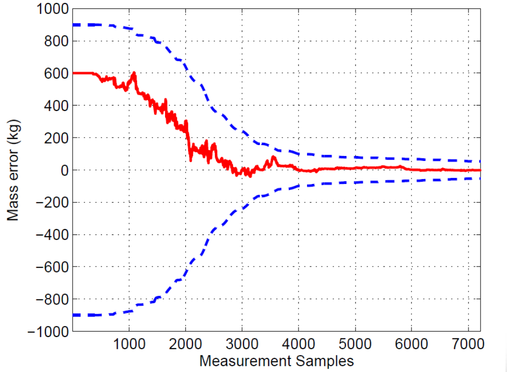
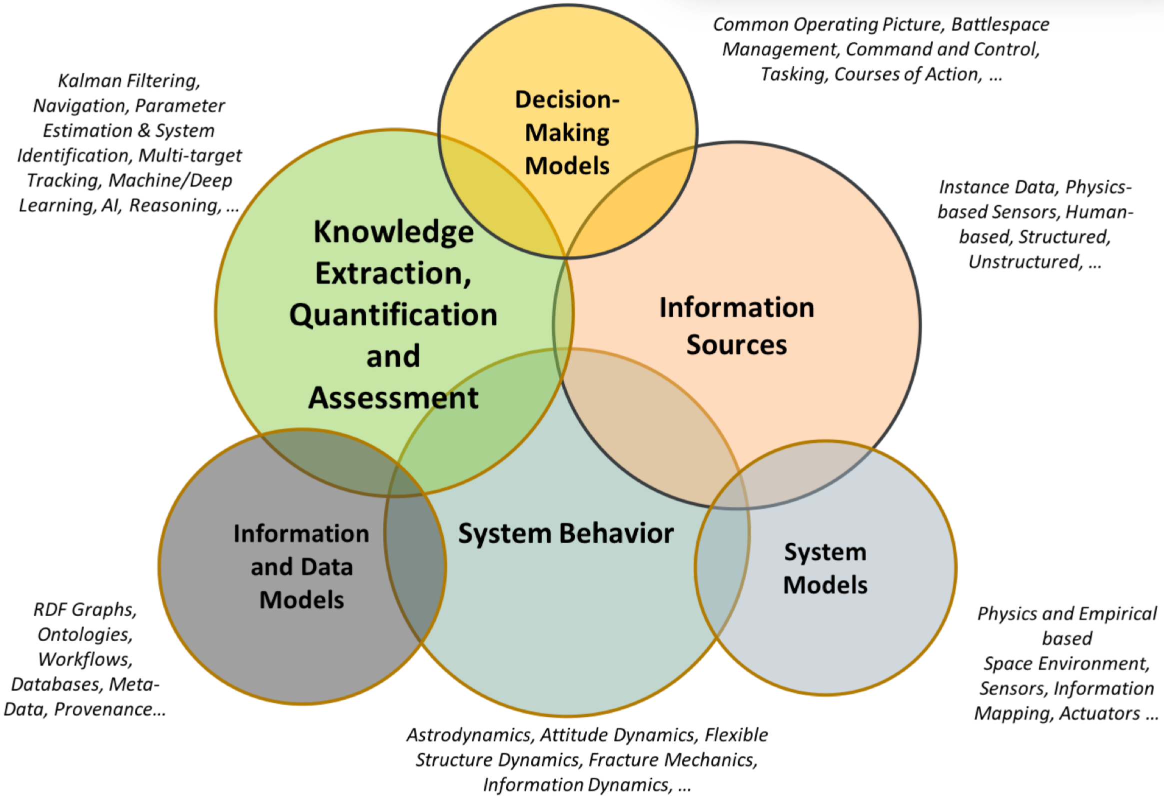
http://sites.utexas.edu/moriba







Way Ahead?

- Strive to make everything detectable = trackable
  - Multi-source Information Fusion leveraging Ontologies (enables big data science and analytics)
  - Develop man-made space object and event taxonomy/classification scheme supported by empirical data
  - Develop method for Unique Resident Space Object Identification (URSOI) based upon “biometrics”
- Monitor and assess the population including social/cultural context
  - identify correlations
  - infer causes
  - test hypotheses (i.e. use the Scientific Method)
- Derive orbital safety, space traffic, long-term sustainability products and policies/guidelines/rules informed by evidence-based information and science
  - Produce quantifiable and measureable risk factors!
  - Develop a Space Sustainability Rating
- Create an international partnership (e.g. public-private non-profit) with a common data lake, transparency, *lingua-franca* for fusing, managing, and exploiting space traffic data, etc.
- Insurance policies as a mechanism to regulate and manage risk
  - Do people with their own SSA, collision avoidance, and disposal/removal get discounts?

"The problem with the world is that the stupid are cocksure and the intelligent are full of doubt" ***Bertrand Russell***

Questions?

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ASTRIA: What Does Steady State Look Like?

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