Critical Needs and Areas of Research for Space Situational Awareness and Space Traffic Management

Moriba Jah, Ph.D.

Director, Space Object Behavioral Sciences

London UK, Dec 07, 2016

The University of Arizona

Who am I?

Spacecraft Navigator for the NASA/Jet Propulsion Laboratory from 1999 to 2006

- MGS, Mars Odyssey, Mars Express, MER, Stardust, Hayabusa, MRO

Led Space Situational Awareness and Space Surveillance research programs for AFRL since 2007, was SSA Mission Lead for AFRL/RV

Directed the Air Force's Advanced Sciences and Technology Research Institute for Astronautics for 8 years (academic consortium)

- Lead NATO SSA Task Group (SCI-279-TG)
- AIAA Rep to US Delegation to UN COPUOS
- Fellow: AAS, AFRL, IAASS, RAS
- Committees: AIAA Astrodynamics, AAS Space Surveillance, IAA Space Debris, IAF Astrodynamics, SERC Research Management, AIAA UN COPUOS WG
- Consultant to the FAA, OSTP, IDA/STPI, DoD, NASA, DARPA, and International Entities

Traditional Reasons for Exploiting Space

1. Communications
   - TV, telephone, education, banking, business transactions, etc.
2. Position, Navigation, and Timing (PNT)
3. Military/Government
   - Intelligence, surveillance, and reconnaissance (ISR), communications, treaty monitoring, etc.
4. Land Stewardship
5. Earth Science (including climate and environment monitoring) and Space Science

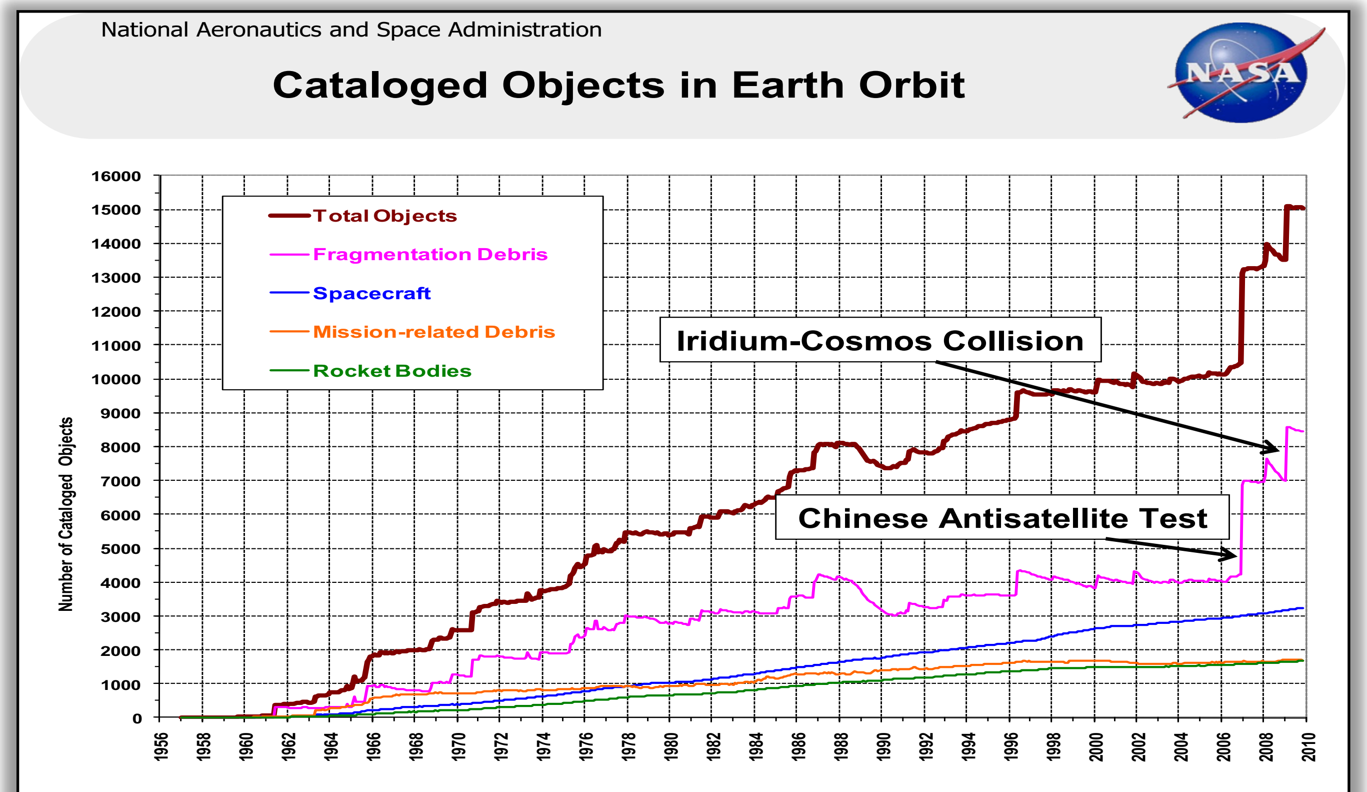
Fact: None of These Space Services and Capabilities Are Protected!

Demand Signals from the Global Space Community

- Warning, protection, and attribution of loss, degradation, or interruption of space services, capabilities, or activities
- Warning and protection against humanity-ending events from space
- Unhindered, low-cost, easy, and long-term access and use of the space environment
  - Implications for good stewardship of the space environment

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

Alive and Dead Objects: A growing problem in all regions of space!



~1400 "Live" objects

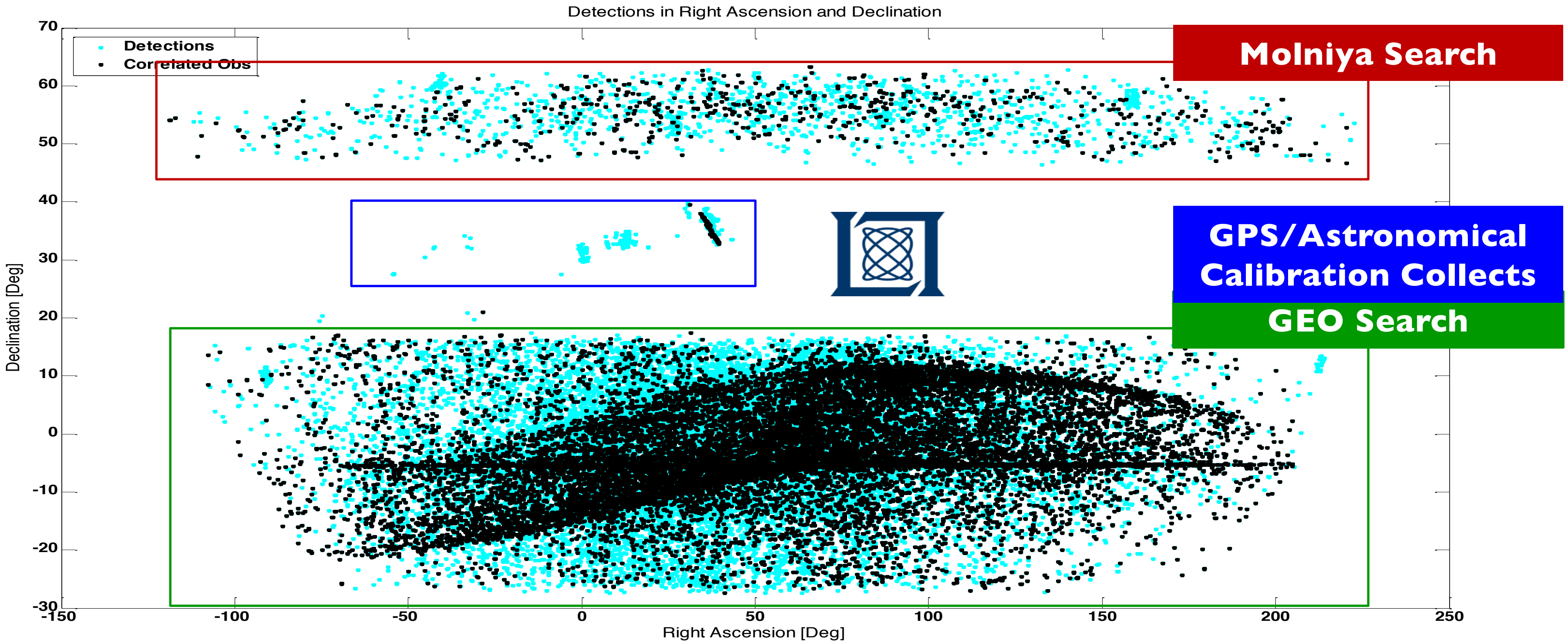
~22,000 objects >10cm

~3-600,000 objects >1cm

Space participants are proliferating – over 60 countries today

Sources	Sinks
• New Live objects/satellites • All space object weathering leads to flaking, chipping, erosion • Mission/deployment related debris • Gravity fatigue and torqueing self destruction • Dead objects/debris and explosions • Fretting fatigue causing structural failure	**De-orbiting objects:** Space environment and/or gravitationally induced perturbations about ***1-3 per day***

Space Surveillance Telescope Synoptic Search Data (Cyan = Uncorrelated)



Synoptic search produces > 10k observations on 1000's of targets nightly

What Hinders Our Ability to "Tag" and Track (i.e. Uniquely Identify and Keep "Custody" of Objects in Space)

- We seek to have a Big Data problem in the Space Domain
  - Need to amass large amounts of DISPARATE sources of information
  - Need to do Data Management: how to properly organize, store, access, store, manipulate, represent, and exploit data (not a database or flat file!)
  - Need both Physics and Human Based inputs and connect/link via a PHYSICALLY and SEMANTICALLY CONSISTENT framework (Models, NLP, Ontologies, Common Language)
- We must be able to learn from our data and based upon its information content, develop and refine characteristics-based models of space object behavior (e.g. improved astrodynamics)
  - Need to go beyond representing everything as a sphere
- We must develop a scientific and standard taxonomy of space objects and events
  - Species, Habitat, Interaction with the Environment, Birth/Death process, etc.
  - Optimal sensor and data collection strategies to maximize identification
- We must be able to better quantify, predict, understand, manage, and fuse various types and representations of uncertainty
  - "Rosetta Stone" of Uncertianty

SOBS Dedicated Cyberinfrastructure (SOBS-CI)

- Designed using mature and well established, scalable computational infrastructure components.
- Widely utilized in multiple community oriented projects e.g. CyVerse, LIGO etc. which support diverse (global) research communities
- SOBS Dedicated infrastructure that is based on CyVerse technology stack, with additional considerations and safe guards for meeting regulatory compliance (ITAR, CUI etc.)
- Provides federation of data, computation and identity with public instance of CyVerse (allowing SOBS CI to connect with public instances on "as needed basis" to obtain public data)
- Extensible to support novel data types and computation

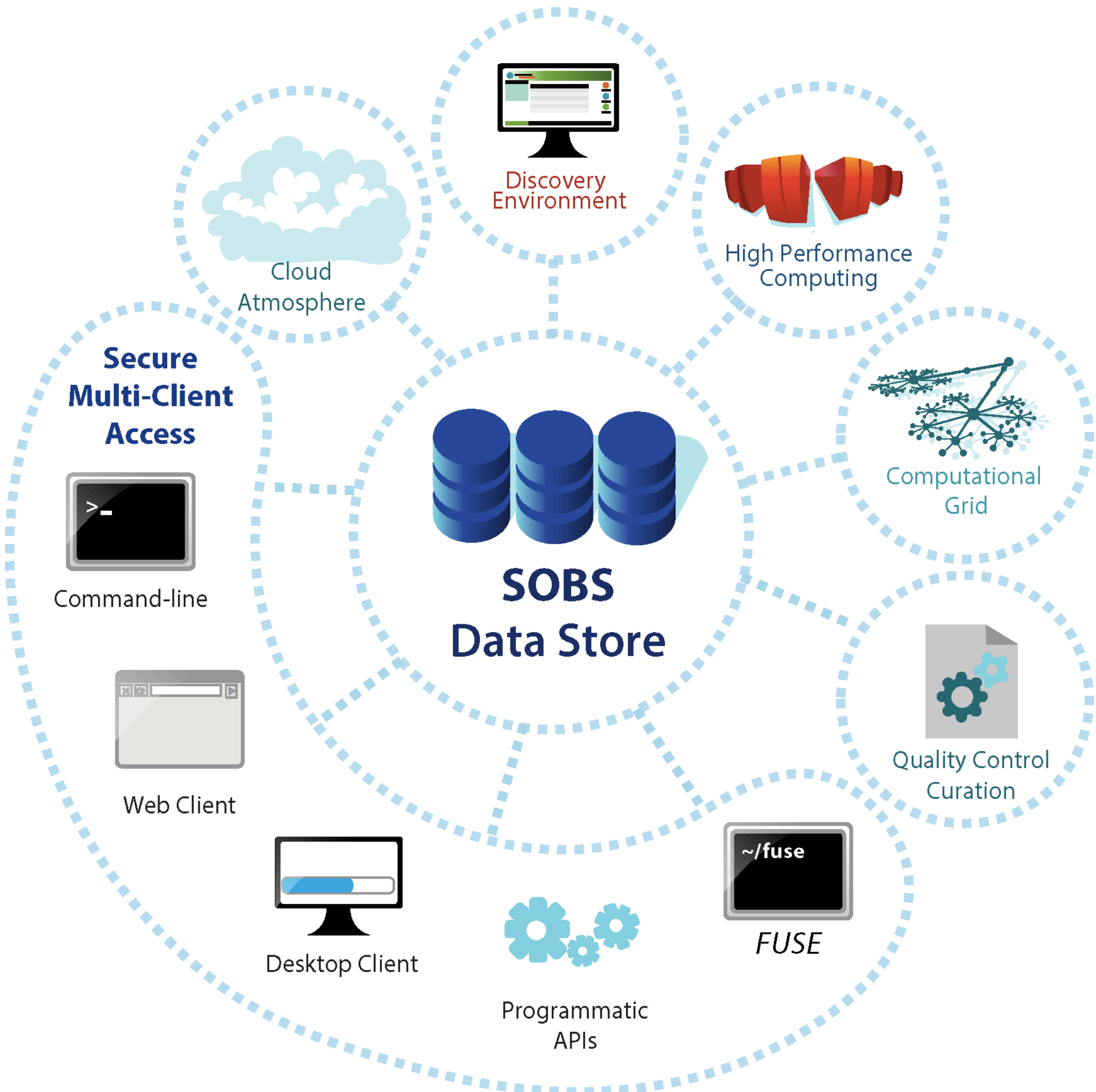
How will it be used ?

- Directly **use** applications (DE) to launch analysis and manage data and meta data assets
- Providing **reproducibility and validation** capabilities for all analysis
- **Consume** specific components (a la carte, Data Store, Atmosphere)
- Design and **build** their own systems (powered by CyVerse components) but controlled by designated community (and share within community)
- Custom design analysis **appliances** (Atmosphere)
- **Publish and Share** their findings and data in a **secure** manner
- **Advocate** use of best practices and building **"your" community CI**
- Create new **learning material** and courses, special topics workshops with real scale data and analysis

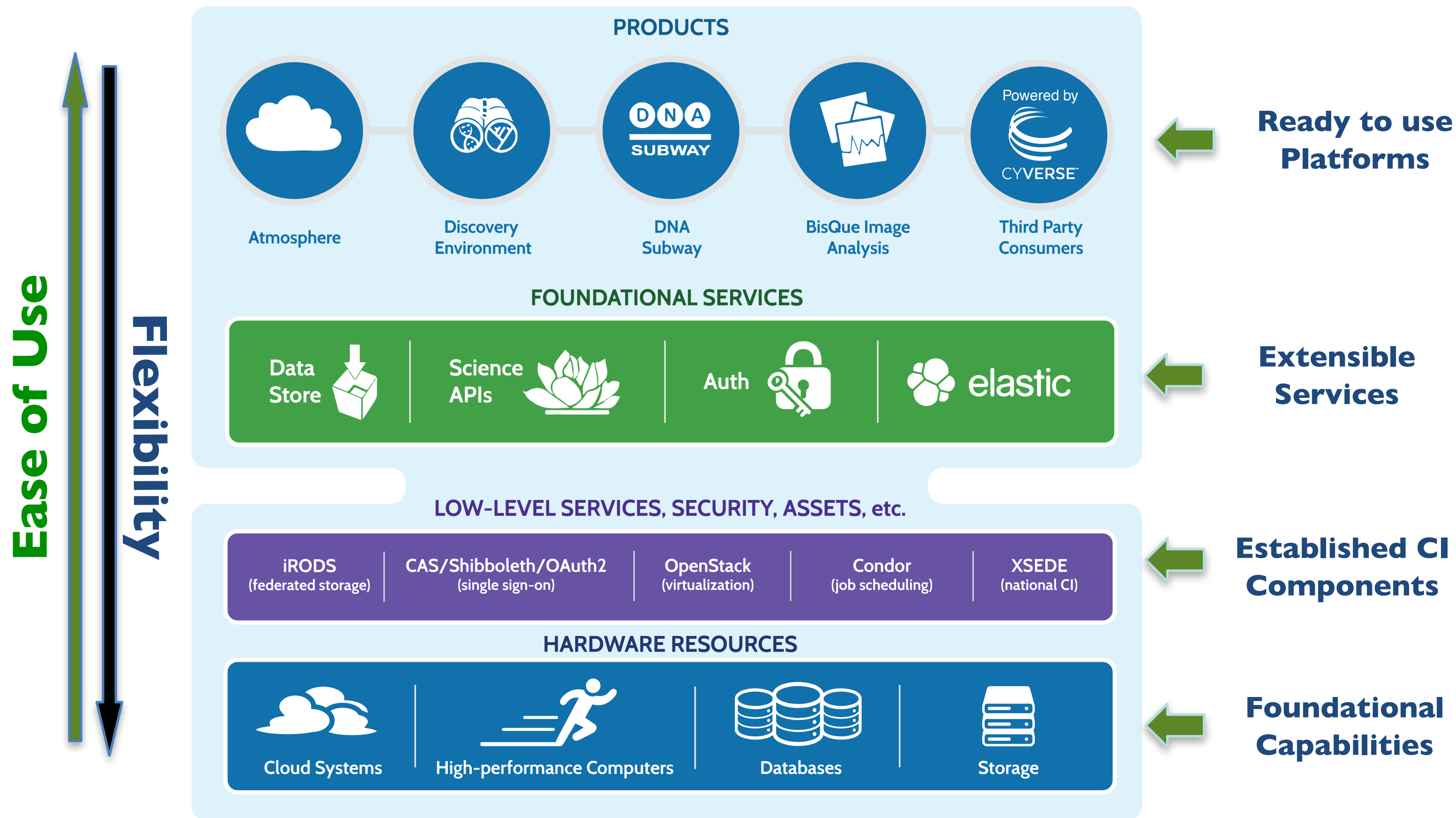
SOBS CI: Scalability, Usability & Security

- Supports scalable analysis in ITAR compliant environment (end to end), burst capacity for HPC (High Performance Computing) at partner site at UT Austin, Texas Advanced Computing Center (TACC)
- Federation of data and ability to utilize multiple computational platforms (UA, TACC, AWS-gov etc.) directly from within SOBS-CI
- Access to contemporary tools (curation, metadata management) and search platforms already integrated into the data store for enabling data expeditions and knowledge repositories e.g. Elastic Search, with ability to add more to the same platform
- Ability to set alerts, monitors on data at rest or streams

Data are the currency



A Blueprint for Cyberinfrastructure Design

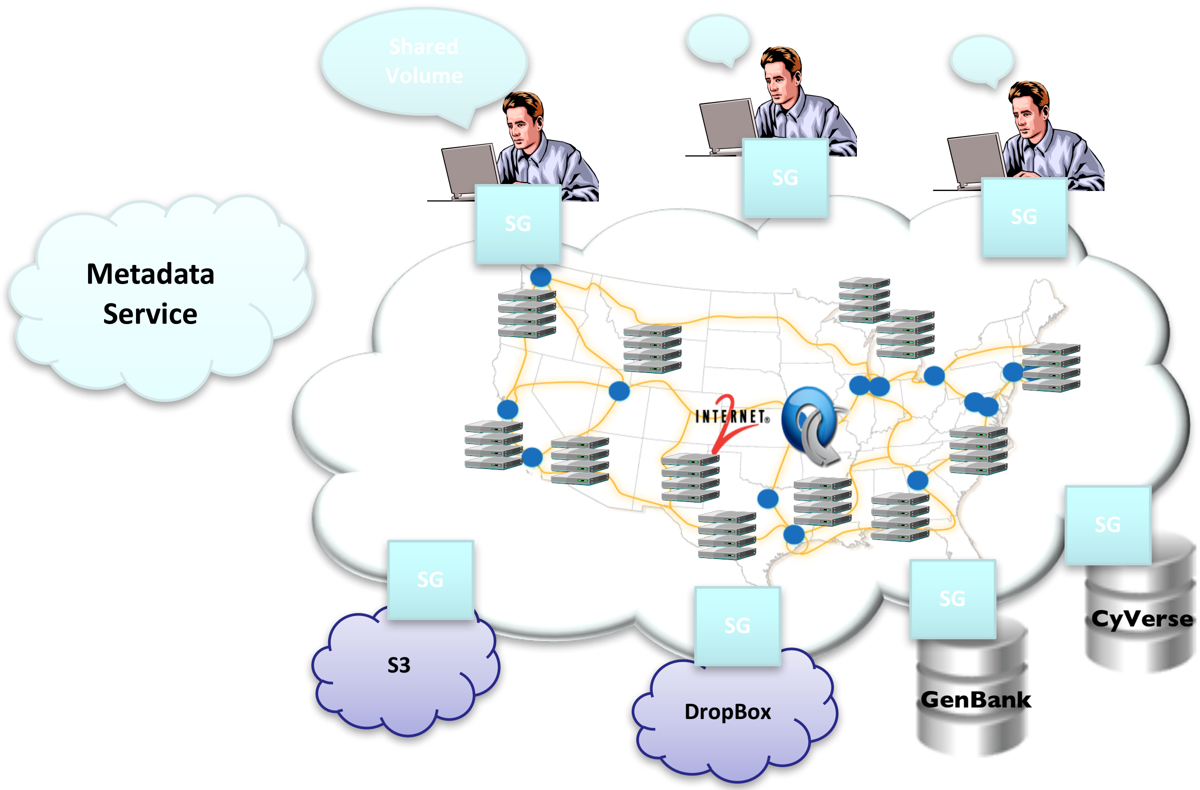


http://www.cyverse.org

Getting Started

Feature	Public SOBS-CI	Private SOBS-CI
Obtaining Account	http://user.cyverse.org (no cost)	By invitation
System Access	Open access	Dedicated VPN end point for teams, with institutional sanctioned end points for sensor data/streams
Storage	100GB no cost for user, 1 TB for open projects. 1+ TB you need to provide support	Private installation with directional federation to public SOBCI data store (no upper limits, defined by contract)
Compute	4 concurrent jobs, limited HPC and cloud	Limits based on SLA (service level agreement) per project. Burst capacity to UT/TACC (10,000+ cores)
Collaboration tools	Fine grain data and app sharing, Wiki, slack IM, app sharing	Same as public SOBS but in protected space
Security, Audit	Basic scans, app and data usage logs	Detailed provenance for data and applications at project level

Syndicate: Using modified CDN (Content Delivery Networks) for supporting Edge Computing and global teams



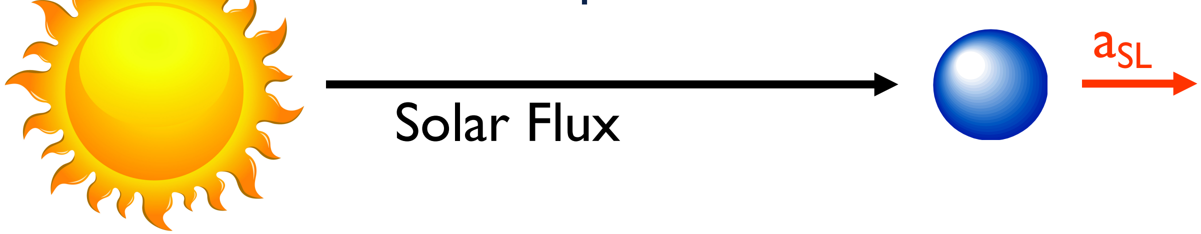
What Affects Space Object Motion?
The Four "Field" with Self Effects

- Gravitational
  - Central body, non-sphericity, tides, relativistic
- Radiative
  - Solar Radiation Pressure
  - Planetary Albedo
  - Planetary Radiation Pressure
  - Thermal Emissions
  - Communications
- Particulates
  - Atmospheric Drag
  - Chemical/Ion Propulsion
  - Outgassing
- Planeto-Magnetic
  - Lorentz
  - Coulomb

What's in Orbit? Why don't we Know?

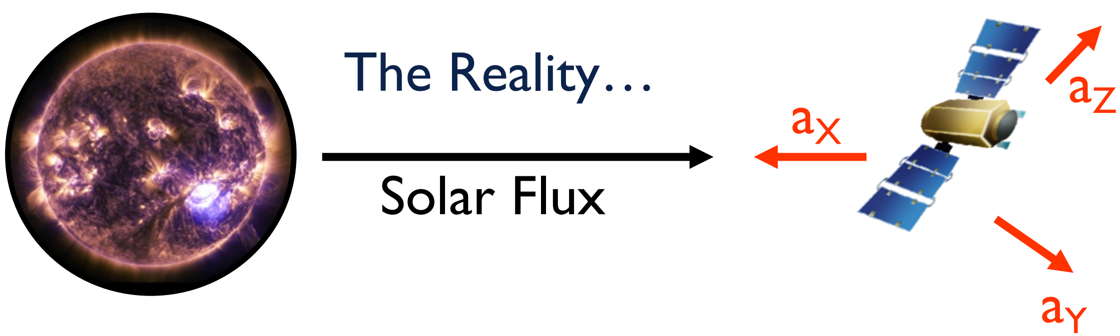
Imprecise modeling increases error in reconstruction *and* prediction

The Assumption…



- SRP acceleration is purely along sun line
- No shape/attitude
- Materials are uniform

The Reality…



- 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

A Few Interesting Issues

- Information Content
  - Difference and Rates of Change
  - If a tree falls in the forest with nothing to hear it, does it make a sound?
- We digitize signals all of the time
  - FM, AM, Fiber Optics
- An Arctic core sample reveals a history of climate changes
- A space object trajectory is a signal rich in information
  - How do we separate causes from effects?
  - How about effects buried in the noise
  - Abductive/Inductive Reasoning can be helpful

Critical Areas for Research

- Space environment effects and impacts on space objects and events
  - Material aging and degradation (Space Object Environmental Gerontology)
    - Sloughing, delamination, and break-ups, optical properties, etc.
  - Physically connect observed albedo with thermal emissions and solar/Earth radiation pressure albedo (analytically)
  - New methods of space object and event detection, tracking, and classification
    - Photoacoustic signatures, stroboscopic effects, vectorized energy and momentum states and parameters, etc.
  - Non-gravitational forces and torques
    - Solar pressure, Earth albedo, Earth radiation, charging effects, magnetic field interactions, etc.
    - Intra/er model physics consistency tied to observed phenomenologies
    - Continuous/low-thrust space object detection and track custody

- Use of ontologies and taxonomies that facilitate space object behavior quantification, assessment, and prediction
  - Classify not only space objects and events but also their PDFs!

Critical Areas for Research

- Information Theoretic methods for Space Objects and Events
  - Quantifying the required information content in the context of specific problems to be addressed
    - Can we map information needs to required bits and get the bits from "the network" instead of being specific-sensor driven?
    - Channel Saturation and the Cramer-Rao Lower Bound (CRLB)
  - How does this inform multi-modal sensing and sensor development?
    - Multi/Hyperspectral, hypertemporal, spectroscopy, polarimetry, RF, etc.

- Uncertainty Quantification and Realism
  - Develop a "Rosetta Stone" for ambiguity/opinion/uncertainty
  - How do I combine a Bayesian input with a Dempster-Shafer input with someone's opinion, etc.?
  - Which measure of uncertainty can or should I use and when?

- Hard/Soft Information Fusion and Out-of-Sequence Measurements
  - Combining and fusing semantics, sensor data, and opinions

- Big Data storage and management, and exploitation
  - Data Science and Analytics for exploitation (From Data to Discovery)
    - Space Object Behavior as a Sensor of Space Environment, Geophysical and Climatological Processes, and Human-Based Activity
  - Linked Data via Ontologies and Object Based Production
  - Development and use of the Space Domain Information Fusion Model

Critical Areas for Research

- Behavioral Science
  - Cultural and societal perspectives and beliefs and their influence on space objects and events
  - Predicting intent!
- Space Policy/Law/Guidelines
  - Scientifically informing policies to support a variety of community needs
- Human Factors
  - Representing data and information
  - Visualization and interaction for decision-making
- Many others…

Moriba Jah, Ph.D.

Director, Space Object Behavioral Sciences

moribajah@email.arizona.edu

+1 520 621 2040

http://sobs.arizona.edu

THE UNIVERSITY OF ARIZONA

Major Challenges As Hypotheses

- It is possible to formulate a new general theorem for fusing data from any sources to improve reasoning about the entities, and prove rigorously that this works for any data types.
  - Think Hard (physics-based) and Soft (human-based) information fusion

- It is possible to develop techniques that allow mapping of one information source's state space to another while coping with the uncertainty present in each.
  - Think hybrid states (e.g. discrete and continuous)

- It is possible to develop methods for determining an appropriate augmented state for the inherent information space.
  - Develop an Information Theoretic "Message" depending upon the "Question"

- It is possible to determine how observations with different types of associated uncertainty can be combined:
  - So that uncertainty is suitably assigned numerically to evidence and/or prior information.
  - So that the level of trust in or reliance on a given data source or piece of data is adequately represented

Major Challenges As Hypotheses

- It is possible to develop methods of estimating and predicting the augmented state of an entity and the relationship between entities, which allow for the incorporation of human-based observations from novel and underexploited data sources (correlation discovery from linking disparate data).

- It is possible to characterize the trade space for an augmented state, identifying the appropriate fusion levels, given a set of physics-based and human-based sources and a desired accuracy or efficiency requirement.

- It is possible to capture and represent contextual information and use it to perform the tasks of (a) data association, (b) data fusion, (c) the verification of data sources, and (d) the scheduling of resources, for both physics-based and human-based sources.

- It is possible to understand a changing context and develop fusion algorithms that are robust to it.

Major Challenges As Hypotheses

- It is possible to develop methods to accommodate unmatched data rates and latencies which derive from physics-based and human-based sources without having to reprocess all of the data thereafter again.

- It is possible to form a pattern of life and detect anomalies using data from both physics-based and human-based sources.

- It is possible to develop universal sensor management principles that could equally apply to physics-based and human-based sources and demonstrate how these could be used for optimization of control, cueing and decision support.

- It is possible to develop techniques for control in a distributed network of sources for the purpose of estimating the augmented state

- It is possible to develop novel distributed fusion methods to operate over asymmetric computing and networking resources that can accommodate both physics-based and human-based sources.