Space Object Behavioral Sciences

Applications and Challenges to Space Domain Awareness, Space Protection, and Space Traffic Management

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Space Object Behavior: The Demand Signals (Our Goals to Deliver)

- Protection against the loss, degradation, and/or interruption of space capabilities and services
  - Threat/Hazard Warning and Assessment
- Long-term Preservation and Sustainability of Space Environment and Space Activities
  - Free and unhindered access to and use of space
- Launch/Orbital Safety of Operations and Re-Entry Risk Assessments
- Monitoring and Assessment of Space Laws, Policies, Guidelines, Recommendations, etc.
  - Space Traffic Management

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

Inputs into Space Object Behavior

- Natural
  - Space environment interactions with space objects
    - Gravity (Earth, Moon, Sun, and other), solar radiation pressure, thermal emissions, passive electrostatic charging, Earth albedo and radiation, atmospheric drag, etc.
  - Unintentional collisions between space objects (pseudo man-made)
- Man-made
  - Actively controlled space objects (propulsive maneuvers)
    - Driven by technical, profit-oriented, and/or political/cultural reasons
  - Policies, Guidelines, and Recommendations
    - Orbital debris mitigation and safety of operations

Space Object Behavioral Sciences: Motivation

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Space Hazard
"A Harsh Environment"

The space environment is hostile and hazardous

- Electronics upset
- Materials age
- Radio waves degrade

The space environment affects the dynamic behavior of objects

The environment needs to be understood and managed

Space Hazards
"The Safety of Flight"

There are many space objects—many dead, some not

- Paths only approximately known
- Space is more crowded today

Space objects are hazardous to each other

- The probability is low, but the consequences are very high!

Traffic control of space congestion needs to assure safe operations

Space Threats
"The Adversary"

Space is contested by adversaries today

- The required methods to address the threat are new
- The methods cross many phenomenologies and disciplines
- As long as we do not fully understand and measure the space domain, there will be places to hide and an ability for us to be deceived!!!

The threat is real, and growing

- We must be able to attribute cause of behavior: intentional vs unintentional

The threat must be detected, understood, and addressed

Hazards from the Space Environment

Space Environment Impacts to Systems and Services are Complex

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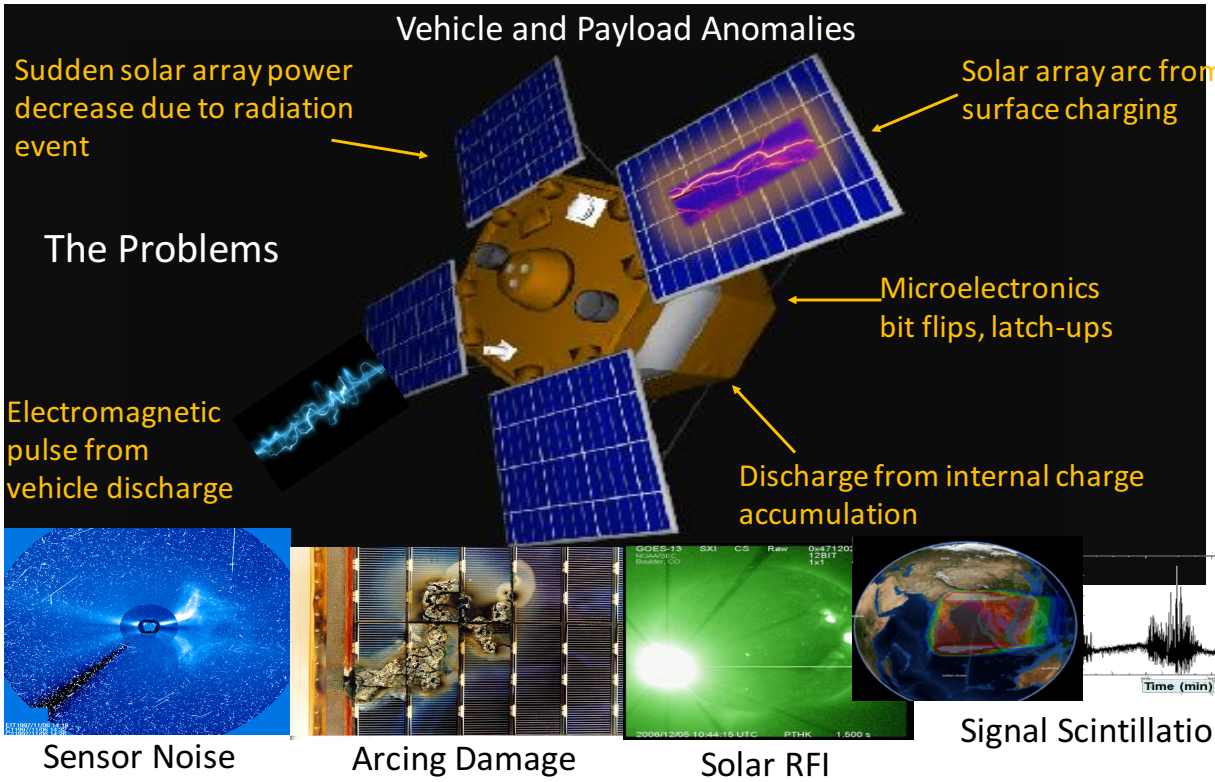
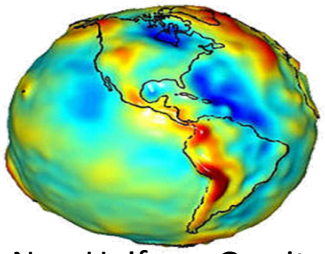


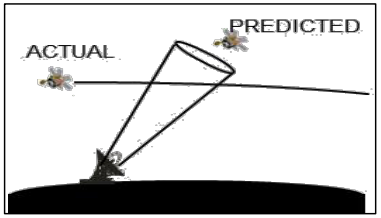
Sensor Noise

Arcing Damage

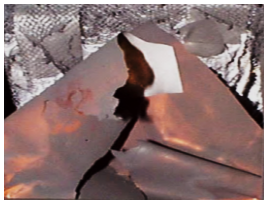
Solar RFI

Signal Scintillation


Non-Uniform Gravity



Atmospheric Drag


Material Aging & Damage

The Space Environment imposes:
- Design constraints
- Performance limitations
- Knowledge uncertainties

We apply time and effort to operate through the space environment impacts. They are a background noise that could conceal real threats.

Hazards From Space Objects

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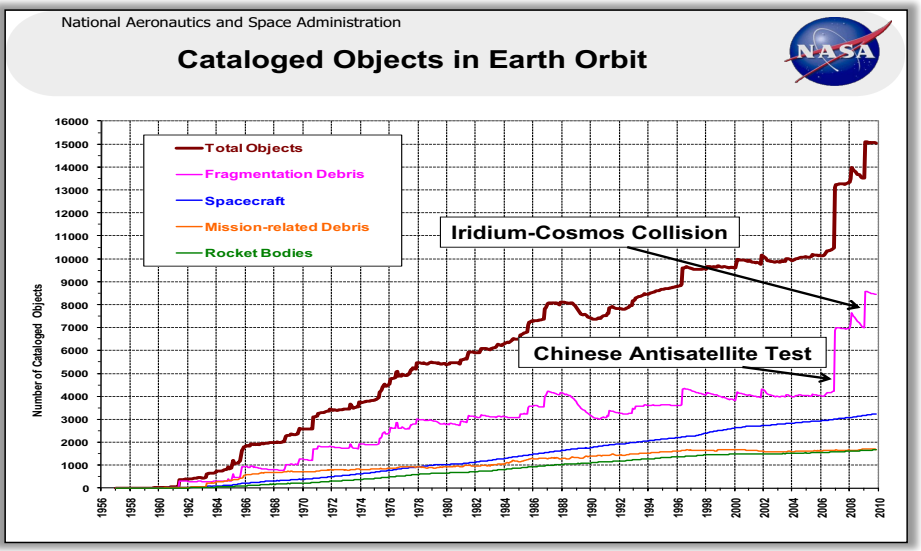
Alive and Dead Objects: A growing problem in all regions of space!

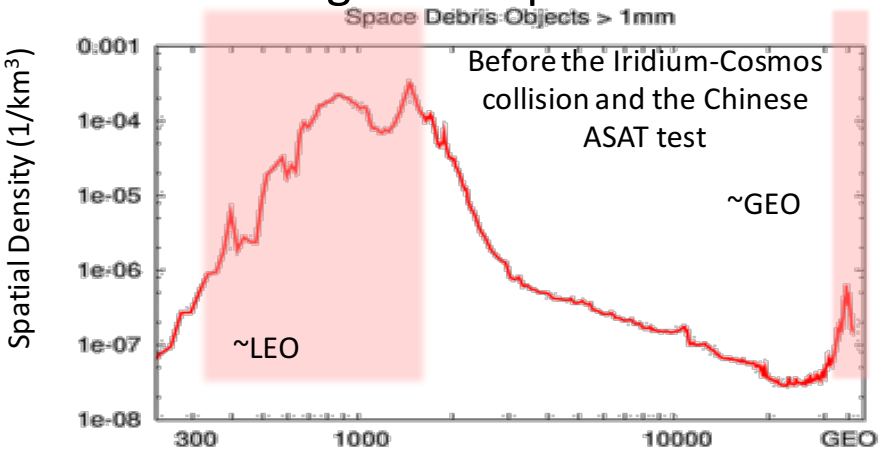


~1200 "Live" objects

~20,000 objects >10cm

~3-600,000 objects >1cm

Space participants are proliferating – 43 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***

Example: SST Synoptic Search Data (Blue = Uncorrelated)

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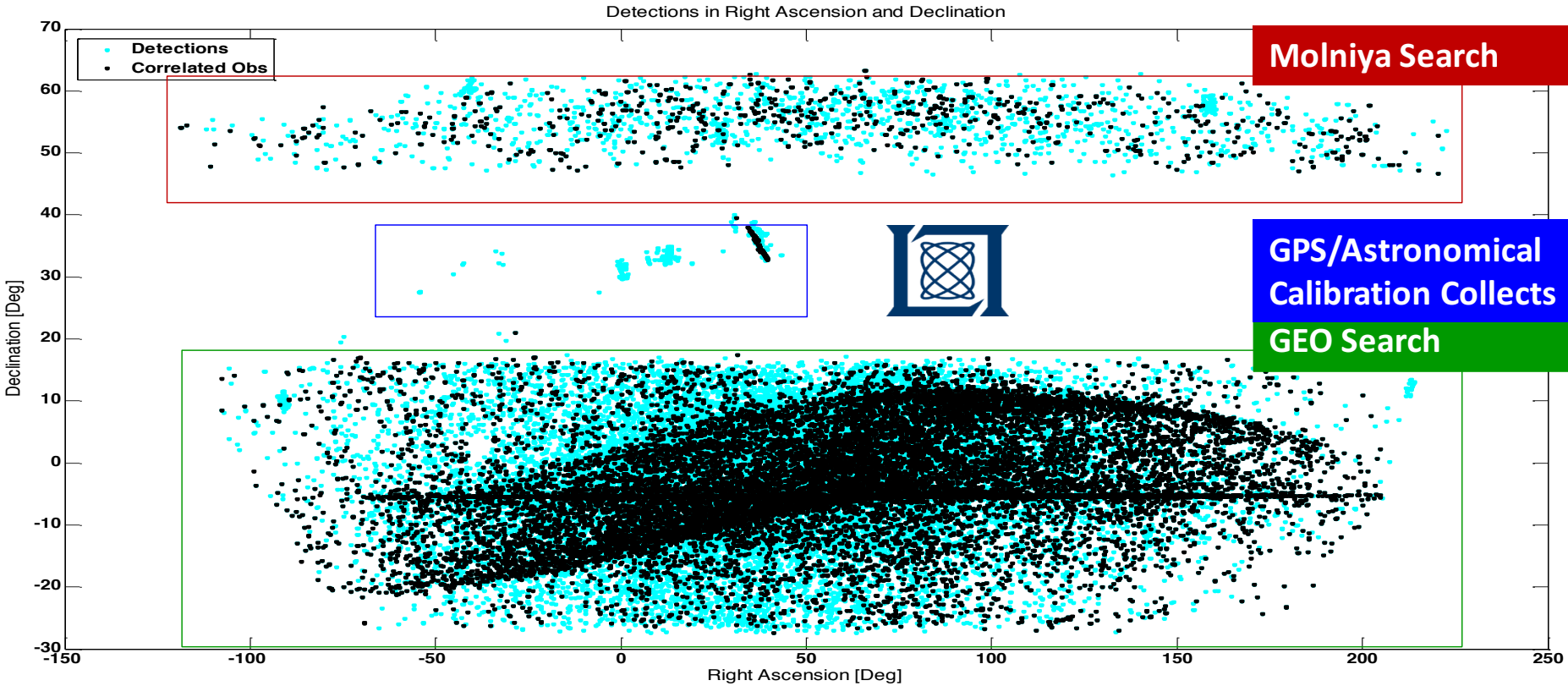

Many Objects Detected But Not Tracked: No Idea What They Are!

Space Object ID and Classification via Data Fusion

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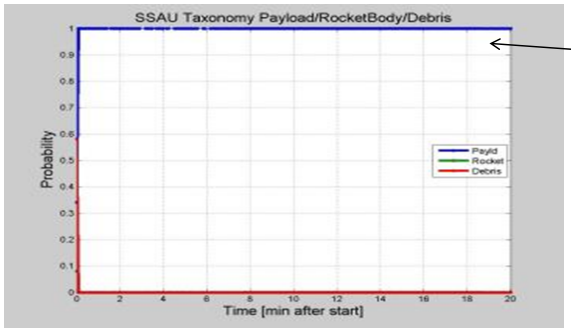
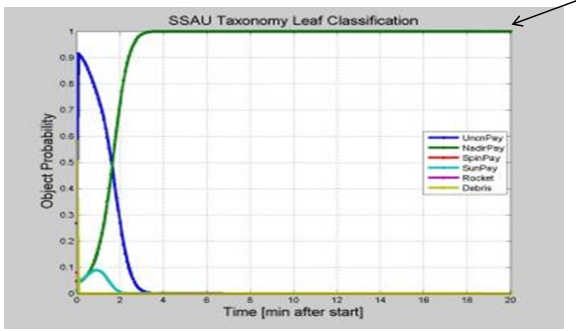
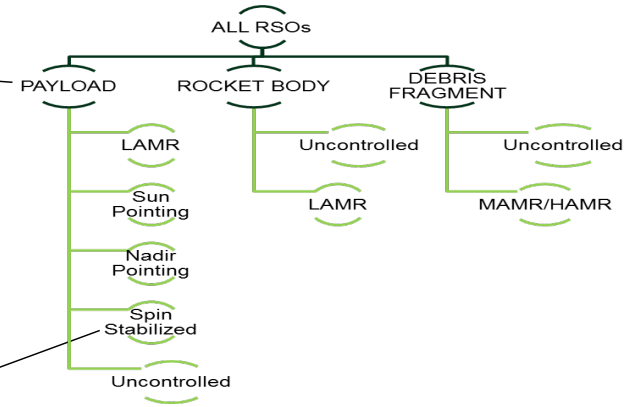
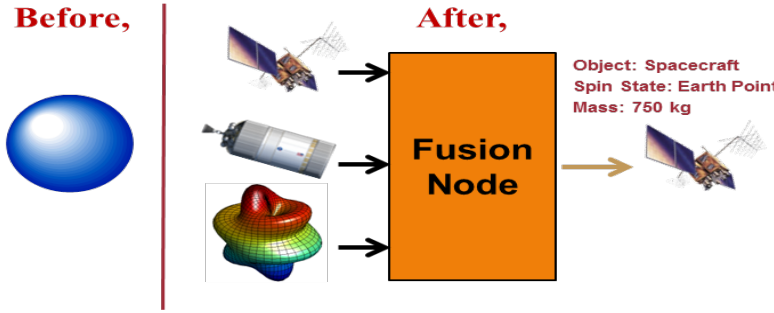
Data Fusion Means Exploiting Mutual Information!

Objective: Improve ability to ID/discriminate and enable threat triggers based on space object class/species habitat and behavior. Fused information content is key!

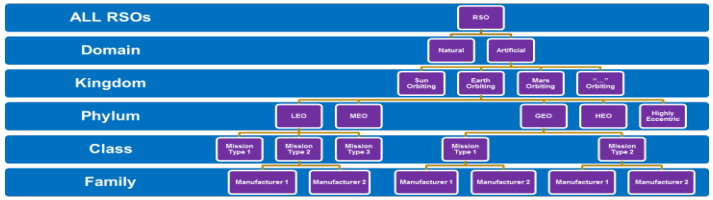


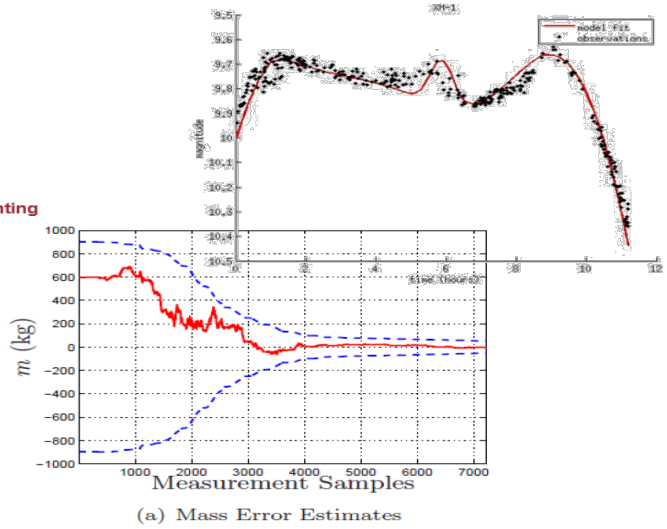






Artificial Space Object Taxonomy





The Space Domain Information Fusion Model

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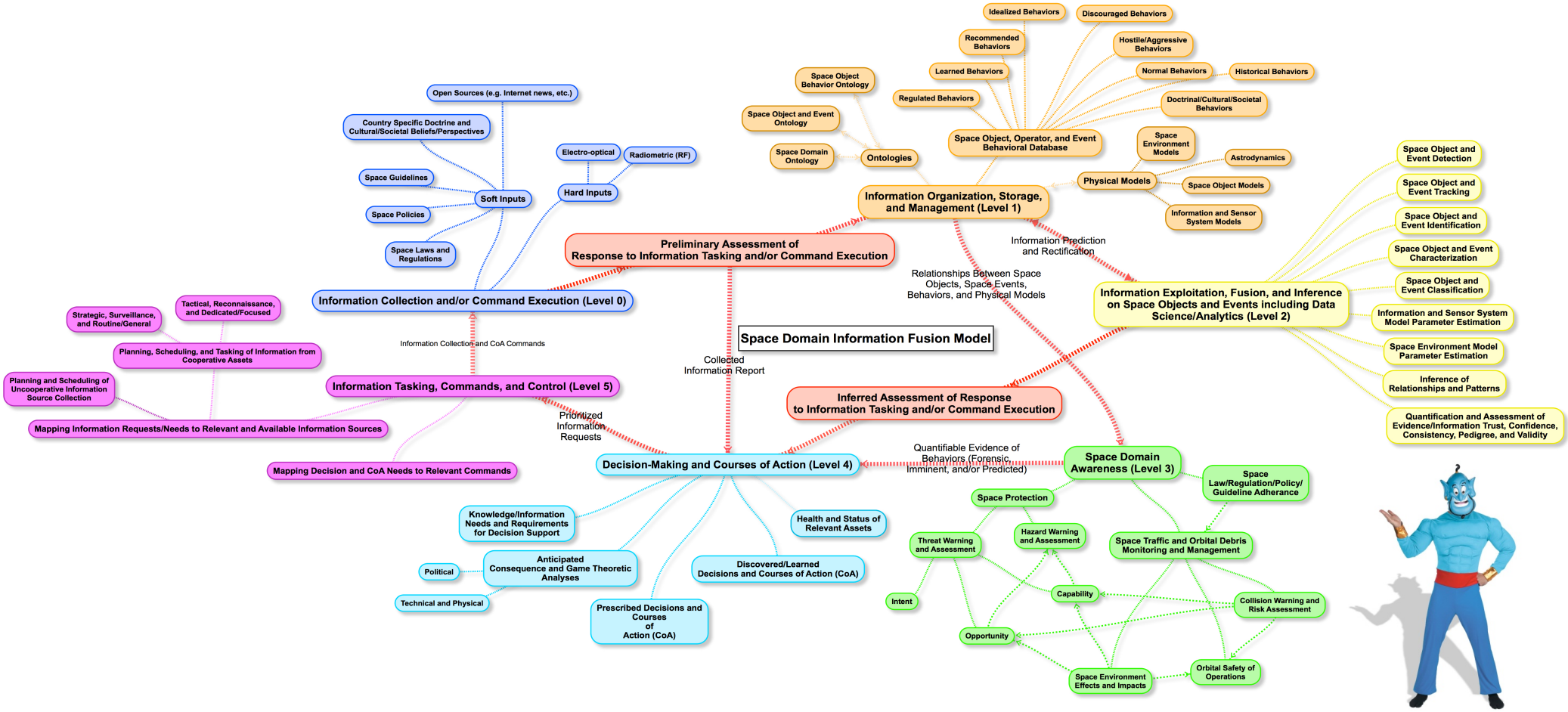

We Need a Space Object Classification System: Taxonomy

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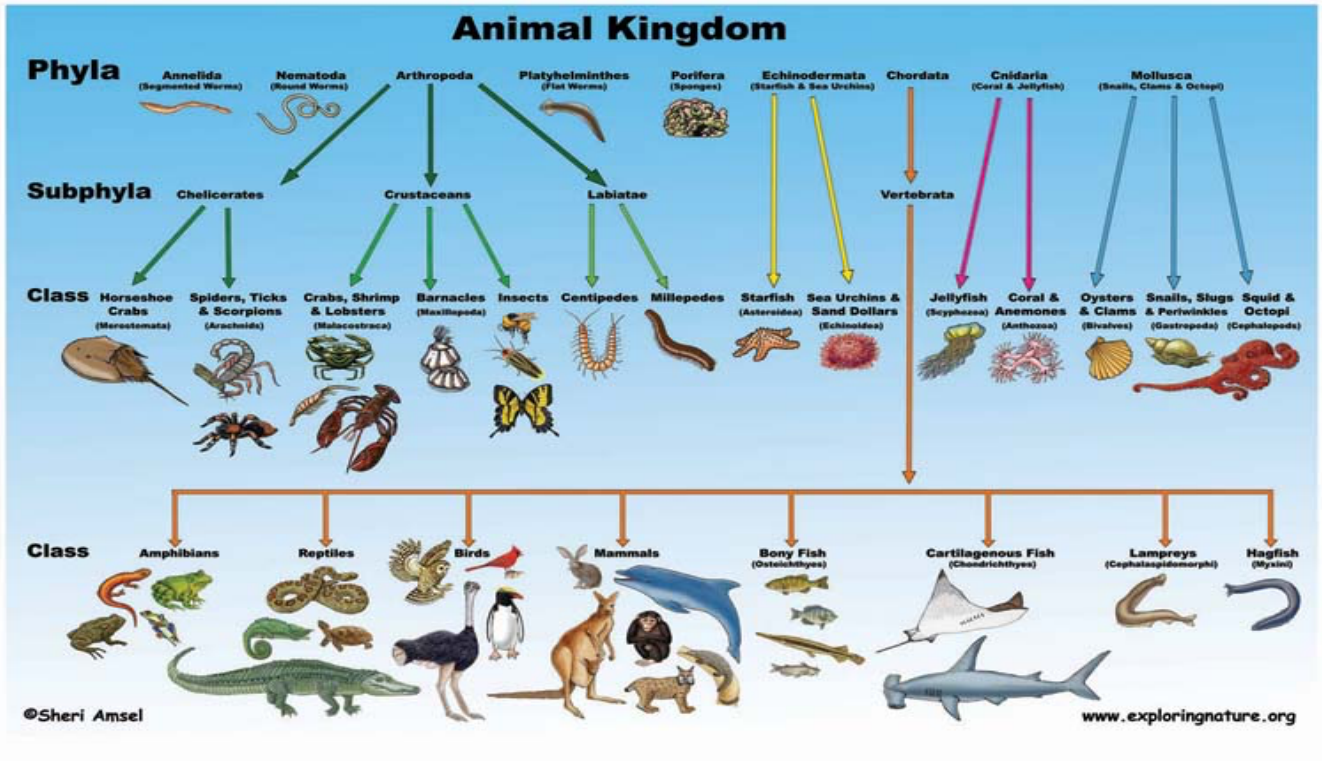
- People use a one-size-fits all method of space object population tracking and assessment
- All space objects are not created equal nor do they all behave in the same way
- We should be able to optimize our data collection and exploitation strategy for the population that is "species" dependent
- We will discover that certain space object species are more or less susceptible to different inputs, some from the space environment



Why pursue Ontologies for the Space Domain?

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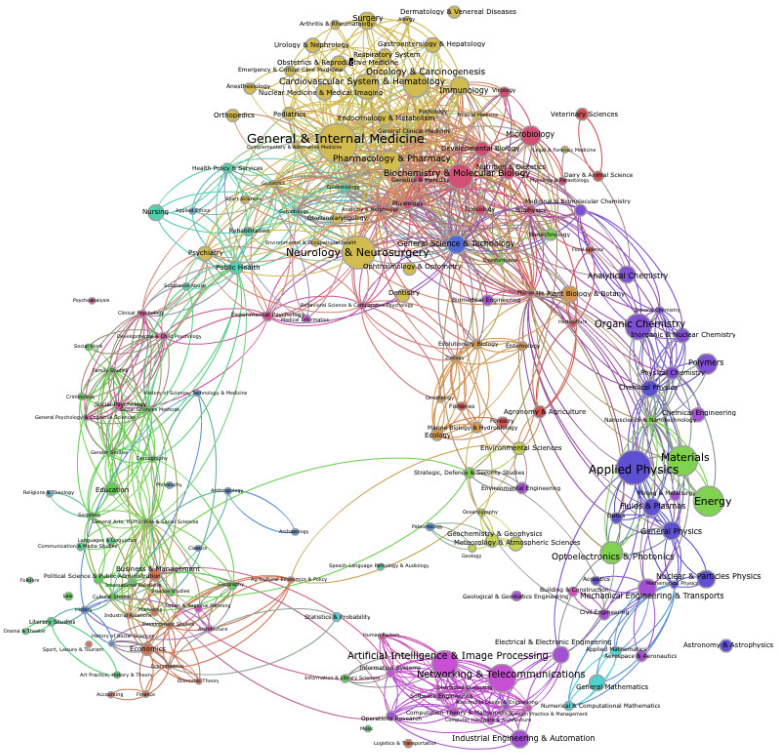
- Ontologies are used to describe a domain and their importance are in the inter-relationships
- Enable a “from data to discovery” paradigm
- Identify “patterns of life” in the space object population
- Easily link disparate sources of information together, ask specific questions of the linked data, and identify correlations that would otherwise remain hidden
  - Which objects behave similarly?
  - When a given object moves, do any other objects in the population move also and if so, with what latency?
  - Are there any individual space objects in a species that behave abnormally?



Critical Areas for Research

- Use of ontologies and taxonomies that facilitate space object behavior quantification, assessment, and prediction
- Space environment effects and impacts on space objects and events
  - Material aging and degradation
    - Sloughing and break-ups, optical properties, etc.
  - 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!
    - Continuous/low-thrust space object detection and track custody

Critical Areas for Research

- Space environment effects and impacts on space objects and events (cont)
  - N-degree-of-freedom motion
    - Stiff ODE problem
    - Semi-analytical theories
  - Improving space environment models via direct observation and indirectly via big data science and analytics
- Probability density function inference, quantification, prediction, and exploitation
  - Taxonomy/classification of PDFs
  - Using PDFs in data/track association, object ID, threat warning and assessment, information tasking, etc.

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?
  - How do we know when we are done?
    - Cramer-Rao Lower Bound equivalent
    - Channel saturation
  - How does this inform multi-modal sensing and sensor development?
    - Hyperspectral, hypertemporal, spectroscopy, polarimetry, RF, etc.
  - How do we create/enhance information content?
    - Enhancing or creating measurable change and differences as a basis of information
- Hard/Soft Information Fusion
  - Combining and fusing semantics, sensor data, and opinions
- Big Data storage and management, and exploitation
  - Data Science and Analytics for exploitation
  - 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…

Essential Elements for Space Object Behavioral Sciences

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Scientifically rigorous modeling and simulation (M&S) environment

- Integrated Space Environment Models
- Comprehensive Space Object Models
- Realistic Sensor Models (e.g., noise, biases, slewing)
- Doctrinal, cultural, and political perspectives
- Space Policies and Laws

Holistic and *physically consistent* approach to space object detection, tracking, identification, characterization, classification, and threat/hazard warning and assessment

- Finite Set Statistics (FISST)
- The Space Domain Information Fusion Model
- Scientifically Driven Artificial Space Object Taxonomy

Framework that enables rapid and straightforward linking/correlation/fusion of multiple and disparate sources of information (hard and soft inputs)

- Object Based Production / Ontologies

Access to a very large and diverse set of cultural, political, geometric, modal, temporal, and type of data and information

- *We want to have a Big Data problem!*

UA Space Object Behavioral Sciences Way Forward

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What is UA doing internally related to
Space Object Behavioral Sciences, and
What resources are being brought to bear?

iSOBS: Dynamic Data Exchange

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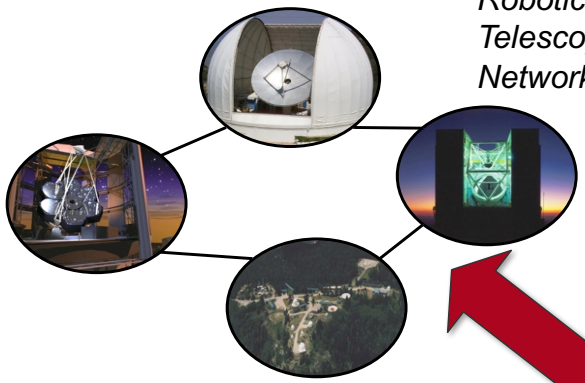
Providers

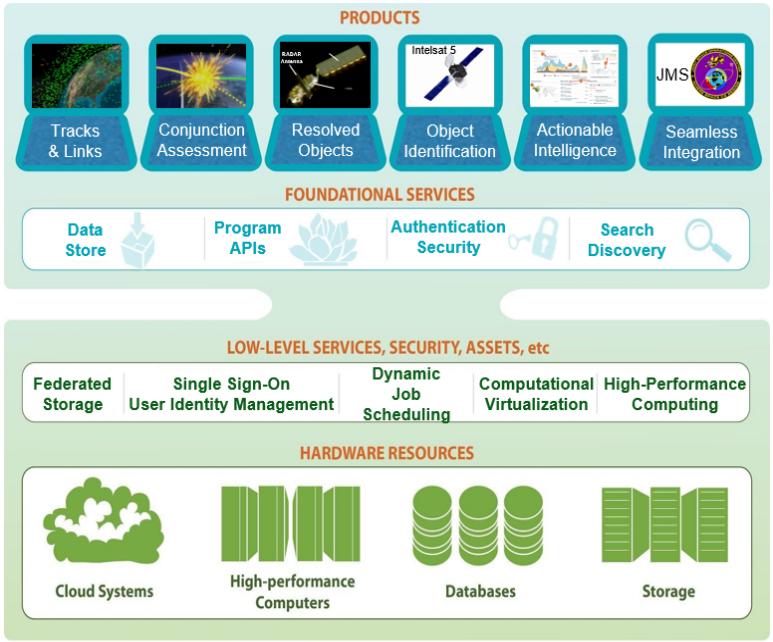
Arizona Robotic Telescope Network



National and International Partners

LSST
Large Synoptic Survey Telescope

Space Weather



Partners / Customers

- Space Surveillance Network
- JSpOC
- AFRL
- NASA
- FAA
- International Partners
- Commercial S/C owners & operators
- Lockheed Martin
- Intelsat

The Space Object Behavioral Sciences Initiative

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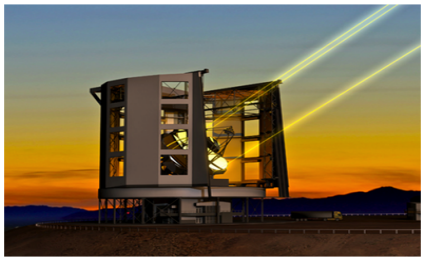
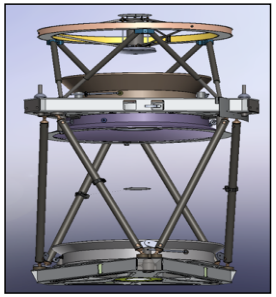
A Trusted Non-Traditional Data Source

- Extensive operational experience
- Existing optical, IR, radio telescopes
- Coverage in both hemispheres
- Networked together



Unrivaled environment for workforce development



- Advanced degrees
- Certifications
- Apprenticeships
- Visiting scholars program

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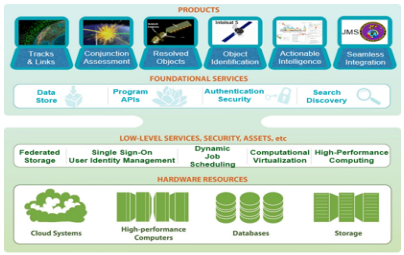
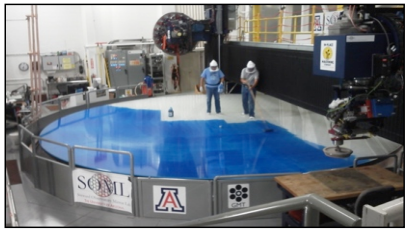


- Robust, extensible, modular, secure cyberinfrastructure
- Dynamic interaction with automated sensors
- Delivering actionable data products

UA has, and creates, Space Object Behavioral Science expertise and infrastructure



- Interdisciplinary research
- World-class optics and instrumentation
- Astrodynamics
- Algorithm design and V&V

Delivering Future Capability

UA's Cluster Hiring Program

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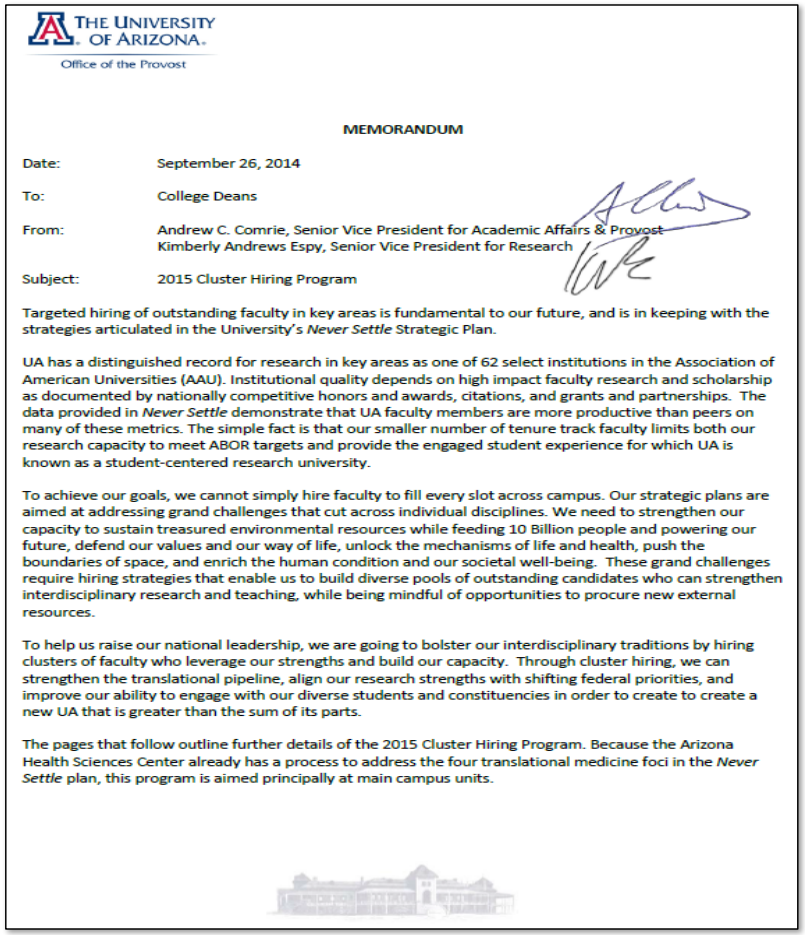
- Objective: targeted hiring of outstanding faculty in key areas
- Campus-wide call for whitepapers
- 6 were selected, including Space Object Behavioral Sciences (labeled SSA), Imaging, and Earth Dynamics Observatory
- Job descriptions formalized
  - Moving Object Detection and Identification
  - SSA Sensor System and Instrumentation Design
  - Astrodynamics
  - Complex Systems Integration / scheduling optimization



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Office of the Provost

MEMORANDUM

Date: September 26, 2014

To: College Deans

From: Andrew C. Comrie, Senior Vice President for Academic Affairs & Provost
Kimberly Andrews Espy, Senior Vice President for Research

Subject: 2015 Cluster Hiring Program

Targeted hiring of outstanding faculty in key areas is fundamental to our future, and is in keeping with the strategies articulated in the University's *Never Settle* Strategic Plan.

UA has a distinguished record for research in key areas as one of 62 select institutions in the Association of American Universities (AAU). Institutional quality depends on high impact faculty research and scholarship as documented by nationally competitive honors and awards, citations, and grants and partnerships. The data provided in *Never Settle* demonstrate that UA faculty members are more productive than peers on many of these metrics. The simple fact is that our smaller number of tenure track faculty limits both our research capacity to meet ABOR targets and provide the engaged student experience for which UA is known as a student-centered research university.

To achieve our goals, we cannot simply hire faculty to fill every slot across campus. Our strategic plans are aimed at addressing grand challenges that cut across individual disciplines. We need to strengthen our capacity to sustain treasured environmental resources while feeding 10 Billion people and powering our future, defend our values and our way of life, unlock the mechanisms of life and health, push the boundaries of space, and enrich the human condition and our societal well-being. These grand challenges require hiring strategies that enable us to build diverse pools of outstanding candidates who can strengthen interdisciplinary research and teaching, while being mindful of opportunities to procure new external resources.

To help us raise our national leadership, we are going to bolster our interdisciplinary traditions by hiring clusters of faculty who leverage our strengths and build our capacity. Through cluster hiring, we can strengthen the translational pipeline, align our research strengths with shifting federal priorities, and improve our ability to engage with our diverse students and constituencies in order to create to create a new UA that is greater than the sum of its parts.

The pages that follow outline further details of the 2015 Cluster Hiring Program. Because the Arizona Health Sciences Center already has a process to address the four translational medicine foci in the *Never Settle* plan, this program is aimed principally at main campus units.

Questions?