A New Approach to Space Domain Awareness at the University of Arizona

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ABSTRACT

As the spacefaring community is well aware, the increasingly rapid proliferation of man-made objects in space, whether active satellites or debris, threatens the safe and secure operation of spacecraft and requires that we change the way we conduct business in space. The introduction of appropriate protocols and procedures to regulate the use of space is predicated on the availability of quantifiable and timely information regarding the behavior of resident space objects (RSO): the basis of space domain awareness (SDA). Yet despite five decades of space operations, and a growing global dependence on the services provided by space-based platforms, the population of Earth orbiting space objects is still neither rigorously nor comprehensively quantified, and the behaviors of these objects, whether directed by human agency or governed by interaction with the space environment, are inadequately characterized.

In response to these challenges, the University of Arizona (UA) has recently established the Space Object Behavioral Sciences (SOBS) Division of its Defense and Security Research Institute (DSRI) with a mandate to carry out research, education, and operational support to spacecraft operators. The SOBS Division builds on UA's heritage as a world leader in space science. By way of examples, UA, with a total research portfolio exceeding $600M per year, operates more than 20 astronomical telescopes on two continents, leads NASA's $800M OSIRIS-REx asteroid sample return mission, and has been deeply engaged in every US mission to Mars without exception.

Key goals of the SOBS Division are to develop a capability to predict RSO behavior, extending SDA beyond its present paradigm of catalog maintenance and forensic analysis, and to arrive at a comprehensive physical understanding of non-gravitational forces that affect the motions of RSOs. Without seeking to provide a universal solution to global SDA needs, SOBS nonetheless concentrates resources to advance the state-of-the-art in astrodynamic research toward those ends. Solutions to these problems require multi-disciplinary engagement that combines space surveillance data with other information, including space object databases and space environmental data, to help decision-making processes predict, detect, and quantify threatening and hazardous space domain activity. To that end, the division engages and integrates talent and resources from across the UA, including the Colleges of Science, Engineering, Optical Sciences, and Agriculture & Life Sciences. As activity ramps up over approximately the next three years, the SOBS Division will directly support the creation of timely knowledge of the space environment by drawing on a world-wide network of sensors processed through existing UA cyberinfrastructure. In addition, the SOBS Division will also provide a real-world training ground for current and future workers in the field through certificate programs and post-graduate degrees.

1.0 INTRODUCTION

To date, SDA has lacked credible scientific and technical rigor to quantify, assess, and predict space domain threats and hazards. The current state-of-the-art suffers from a number of inadequacies: there are no standard definitions of elements in the space domain; descriptions of space objects and events are limited; no standard method of calibrating sensors and information sources has been developed; tasking is addressed to individual sensors for specific data rather than to a comprehensive system for information required to address needs and requirements; there exists no rigorous understanding of space environment effects and impacts on space objects; there is no framework that encourages and enables big data analysis, and supports an investigative "from data to discovery" paradigm; we lack a consistent method to understand all of the causes and effects relating space objects and events.

The need to address these concerns has never been greater. On-orbit collisions, natural or intentional, are a global concern that threatens the long-term sustainability of our space activities and environment, and worsens the impact of the space debris population growth in critical mission-dependent orbital regimes. It accounts for an increase in the useless space object population of about 1% annually (with isolated events contributing spikes upwards of 20% population growth) and jeopardizes the livelihoods of tens of millions of people who depend on critical space capabilities and services.

Traditionally, efforts to develop and maintain awareness of all trackable space objects have relied upon the USSTRATCOM's Space Surveillance Network. But these sensors are often prohibitively expensive for even the richest of nations, and the space domain is too vast for traditional space surveillance, ground or space based, to be truly effective by itself. Protecting important space assets, especially those that provide critical services and capabilities such as communication, weather, bank routing, position, navigation, and timing, requires a new approach encompassing 21st-century technology and a fundamental understanding of the processes governing the behavior of objects in space.

It is in this context that UA, through the SOBS Division, seeks to place the characterization and behavior of space objects on a rigorous scientific footing. Until now, the global approach to space operations has been largely reactive, following the latest commercial exigency or governmental demand signal of the day. By contrast, the fundamental work being carried out at UA will lead to new ways to understand, measure and predict behavior in space. In turn, that work will underpin the development of best practices in space traffic management, and inform efforts to improve mission assurance and mitigate the effects of space debris hazards.

2.0 SOBS GOALS AND OBJECTIVES

The long-term goals of the SOBS Division are in three categories: R&D, training, and space operations support. The intent of the operational component is to predict RSO behavior with quantified uncertainty in order to provide decision makers with timely warnings of specific hazards and threats. To achieve these ends, the UA has instituted partnerships with the US Air Force Research Laboratory, private industry including Applied Defense Solutions, Pacific Defense Solutions, and Intelsat, and academia including the University of Minnesota, the University of Texas at Austin, and Georgia Tech.

Behavior prediction must take into account the behavior of other RSOs, physics, and indirect information gleaned from non-standard sources. The means to do so are now being implemented in a system architecture comprising four main blocks: sensors and other data sources; computational infrastructure; data processing algorithms; data product customers. The overall flow of information is illustrated in Figure 1.

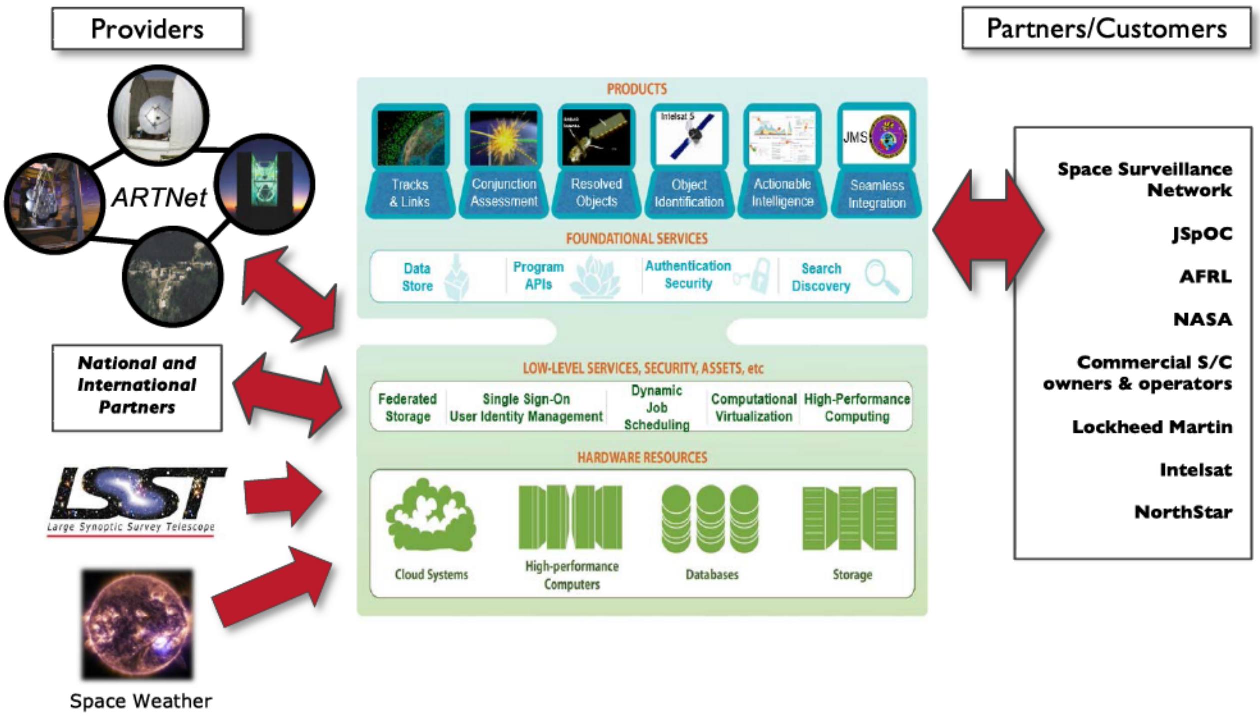

Figure 1: The structure of the operational component of the SOBS Division: data from a heterogeneous collection of sensors is processed and the results passed to customers who may also be partners with UA.

In addition to the technical activities, SOBS will concentrate and formalize SDA-related education programs—to include creating new courses and advanced degrees through a Graduate Inter-Disciplinary Program, as well as establishing certification programs and apprenticeships for military, civil, and private sector space researchers and operators. SOBS is already hosting visiting scholars, and is providing student internships and exchange programs in partnership with US government agencies. Both the educational and R&D components of SOBS are being strengthened through the hiring of a cluster of new faculty, authorized by UA, focused specifically on SDA and distributed across the relevant colleges and departments.

3.0 TECHNICAL APPROACH

3.1 Space Object Ontology

Our approach is to treat the space domain as a holistic ecosystem to understand and predict the evolution of the artificial RSO population. Currently a one-size-fits-all methodology is used to track RSOs. The result of this approach, however, is that most of the objects we detect cannot be tracked with any confidence. Artificial RSOs behave differently depending on their habitat (orbital regime) and makeup (size, shape, material properties, etc.). A flawed assumption made by most tracking algorithms is that the position and velocity of any two RSOs are completely uncorrelated; however, the local environment is common to both and does correlate their behavior. The question is, are there species (classes) of RSOs that can be characterized by similar behavior or common responses to space environmental and geophysical processes?

To address this question we are developing an ontology-based Space Domain Awareness Data Management System (SDA-DMS) to organize and study the different classes that make up the population based on their

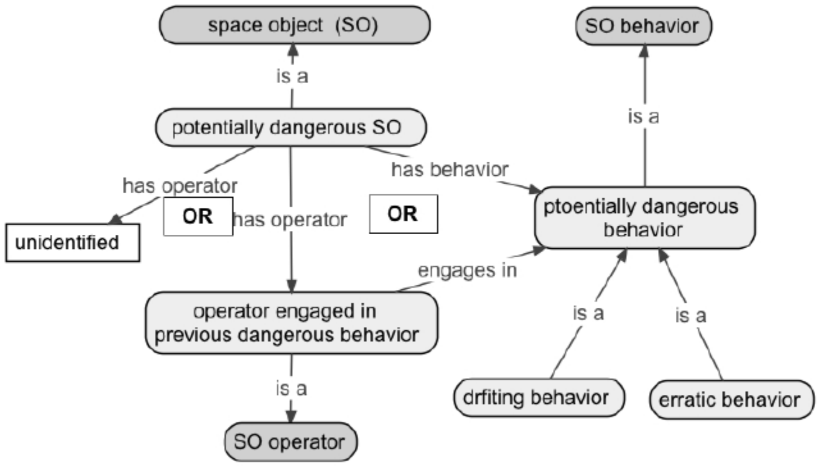

Figure 2: Ontology-based inference of new knowledge.

behavior with the goal of determining the future evolution of the population. An example ontology, illustrated in greatly simplified form in Figure 2, defines a potentially dangerous SO as one that engages in potentially dangerous behaviors *or* has an operator who is unidentified *or* has previously engaged in a potentially dangerous behavior such as erratic or drifting motion. From this logical definition, a reasoner can infer if a specific SO is potentially dangerous and add that information to the SDA-DMS, so researchers can query for threats. In the actual ontology, relationships are substantially more complex. For example, break-up events due to collisions, explosions, and material aging can be understood with an ontological description of the population. Indeed, ontologies have been used in other domains to quickly and efficiently link together disparate sources of information, enabling a "from data to discovery" paradigm that evinces correlations amongst the disparate information sources given a specific questions posed to the combined data-set. We seek to have a big data problem where we can bring data science and analytics solutions to our scientific pursuits.

3.1 Natural Language Exploitation

In addition to 'hard' data from sensors, SDA-DMS will ingest data from 'soft' sources such as United Nations guidelines, European Union codes of conduct, country-specific doctrine and cultural beliefs, press announcements, as well as other open source literature such as news reports and amateur blogs. This work builds on UA's demonstrated strength in natural-language processing which has recently been employed to scan biomedical literature describing research into cancer signaling pathways. After digesting 55,000 papers, far more than any single human could hope to process, the software has been able to discern clinically significant pathways that have eluded physicians and contributed to the lack of efficacy of anti-cancer drugs.[1,2]

The same processing will be applied to natural language multi-media sources to assist in RSO track correlation and object identification. Furthermore, similar techniques applied to patterns of RSO behavior across tens of thousands of objects will identify connections that would be very difficult to uncover otherwise. For example, open sources often discuss the details of a satellite's design and mission. Sometimes these reports are accurate, sometimes mistaken, and sometimes deliberately misleading. In the context of threat identification, the latter category is crucial because it may indicate a potential threat masquerading as a benign event. Misleading reports will be identified by comparing them against reports from citizen scientists, who monitor the sky with telescopes to track known and unknown objects, and who often report their findings on social media such as Jonathon's Space Report.[3]

4.0 UNIVERSITY OF ARIZONA ASSETS APPLIED TO SOBS

The SOBS Division builds on very substantial investments made by UA in infrastructure, facilities, and technical staff to support a diverse range of scientific research that is unrelated to SDA. These include, amongst others, astronomical telescopes spanning the spectrum from radio frequencies to the ultraviolet, automated detection and tracking of potentially hazardous natural bodies in near-Earth orbit, massively parallel simulations of self-gravitating cosmological systems, cyber-tools to facilitate research in the life sciences, and natural-language research that has identified hidden protein pathways in cancer development. We illustrate with some examples below how these assets are now being exploited in support of the SOBS program.

4.1 Sensor Network Development

Theoretical and analytic work pursued under the SOBS program is anchored by real data collected from a worldwide network of professional astronomical telescopes. UA is the only university anywhere which designs, builds, and operates its own telescopes, as well as the instruments that exploit them. These include the twin 8.4 m Large Binocular Telescope (LBT) in Arizona,[4] shown in Figure 3, presently the largest EO/IR telescope in the world. The primary mirrors are two of the seven largest single-piece mirrors ever made, all fabricated at the Steward Observatory Mirror Laboratory on the UA campus. In addition to the LBT, UA manages more than 20 other astronomical telescopes in north and south America. In the slightly longer term, the 8 m Large Synoptic Survey Telescope (LSST), coming on line in 2022, will scan the entire observable sky every four nights, producing 30 TByte of data per night.[5] LSST, Figure 4, is an international partnership with UA as a full member. UA was again responsible for the main mirrors, now completed, and more importantly from the SDA perspective will also host the LSST data processing center. LSST is explicitly designed to look for changes that occur in the sky; the algorithms now being designed to signal astronomical event detections are immediately adaptable to SDA requirements. Furthermore, the high bandwidth of the data flow coming off the telescope has led to the requirement that events be flagged in no more than 37 s.

Figure 3: The Large Binocular Telescope on Mt. Graham, AZ combines light from two 8.4 m primary mirrors.

UA's own telescope network is being further extended, with even broader geographic reach, by inclusion of partners at sister astronomical and educational institutions around the world. The locations of telescopes presently in the network are shown in Figure 5. Additional assets, also shown, are being integrated now, and we will continue to expand the SOBS network.

4.2 Catalina Sky Survey

UA also operates the Catalina Sky Survey (CSS), a NASA-funded program whose primary mission is to identify and catalog near-Earth asteroids larger than 140 m in size that may pose a threat of impact with the Earth.[6] Since its inception in 1998, the CSS has discovered over half of all such known objects using three telescopes near Tucson, AZ that feed a fully automated data pipeline. Data from the CSS have been used to identify previously lost and unknown satellites.

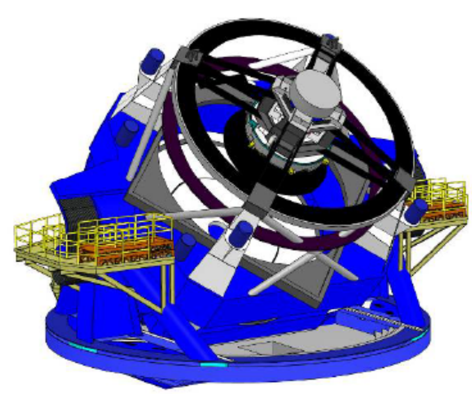

Figure 4: Solid model of the LSST which will provide 30 TB of publicly available data per night.

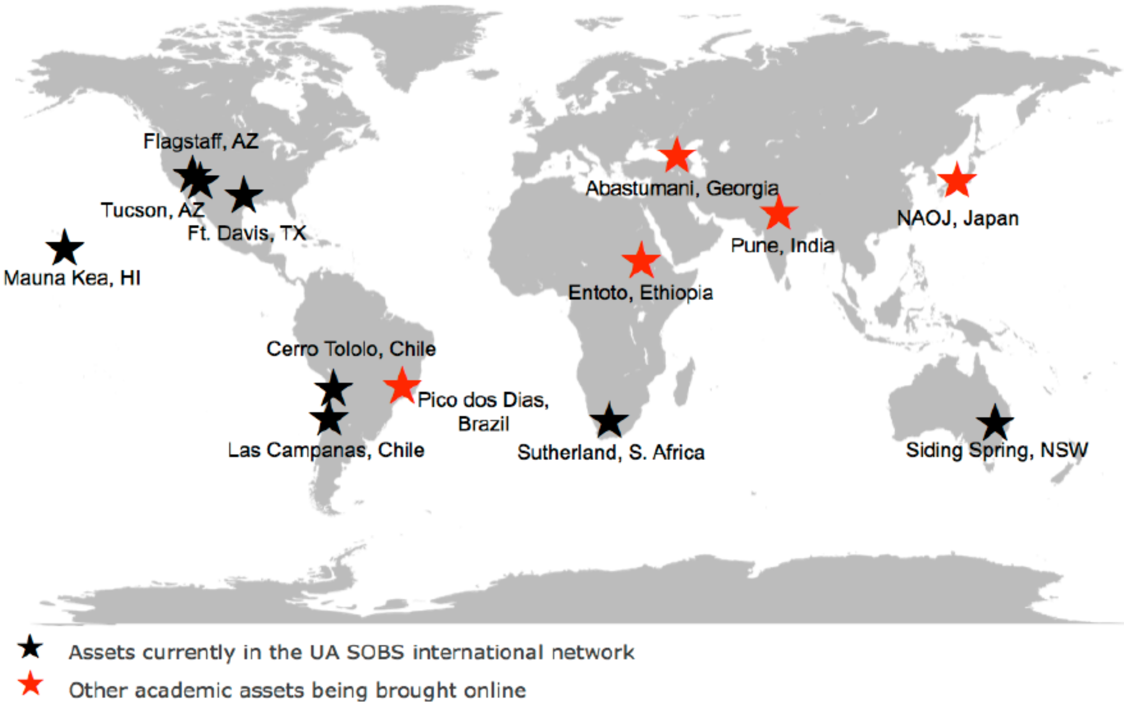

Figure 5: Sites of telescopes in the UA's SOBS international network.

On 2015 March 13 at 02:44 UTC, NASA launched the Magnetospheric Multiscale (MMS) mission from Cape Canaveral, FL. The launch vehicle was an Atlas V. MMS comprises four identical spacecraft instrumented to study plasma physics in the earth's magnetosphere. The 0.7-m Schmidt telescope of the CSS on Mt. Bigelow, AZ, was tasked to collect data two hours after launch, around the time when the four satellites were expected to separate from their Centaur upper stage, and the Centaur's Contamination and Collision Avoidance Maneuver (CCAM) was expected. Distance to the objects was approximately 10^7 m. The Schmidt telescope captures images on a 4k × 4k unfiltered CCD with a FOV of 8.12 deg^2 (2.85 × 2.85 deg).

In-frame photometric calibration used stars seen in the detection images, two of which are shown in Figure 6. Although shown saturated, the data are not. The brightest object is the Centaur itself and the four unresolved MMS satellites; together, they have a visual magnitude of V=6.8. Five objects appear in the frame in addition to these at magnitudes ranging from V of 15.3 to 16.6. Yet another object appears trailing the rest of the cluster, also at about V=16.5.

None of these six pieces of debris were anticipated ahead of launch. Furthermore, four of them were automatically detected in follow-up observations conducted four days later by the CSS 1.5-m telescope on Mt. Lemmon, AZ, confirming that they are neither chunks of ice shed from the rocket on launch, nor high area-to-mass ratio (HAMR) objects. The debris pieces are therefore likely in the range of 20–30 cm in size, based on their photometry.

4.3 Resolved Imagery with Large Aperture

Beyond simple metric track observations, the 6.5 m MMT, another telescope near Tucson operated by UA, has been used to acquire resolved images of objects in geostationary Earth orbit (GEO) using high-order adaptive optics (AO) to correct for atmospheric blurring.[7] The value of such observations lies both in the ability to

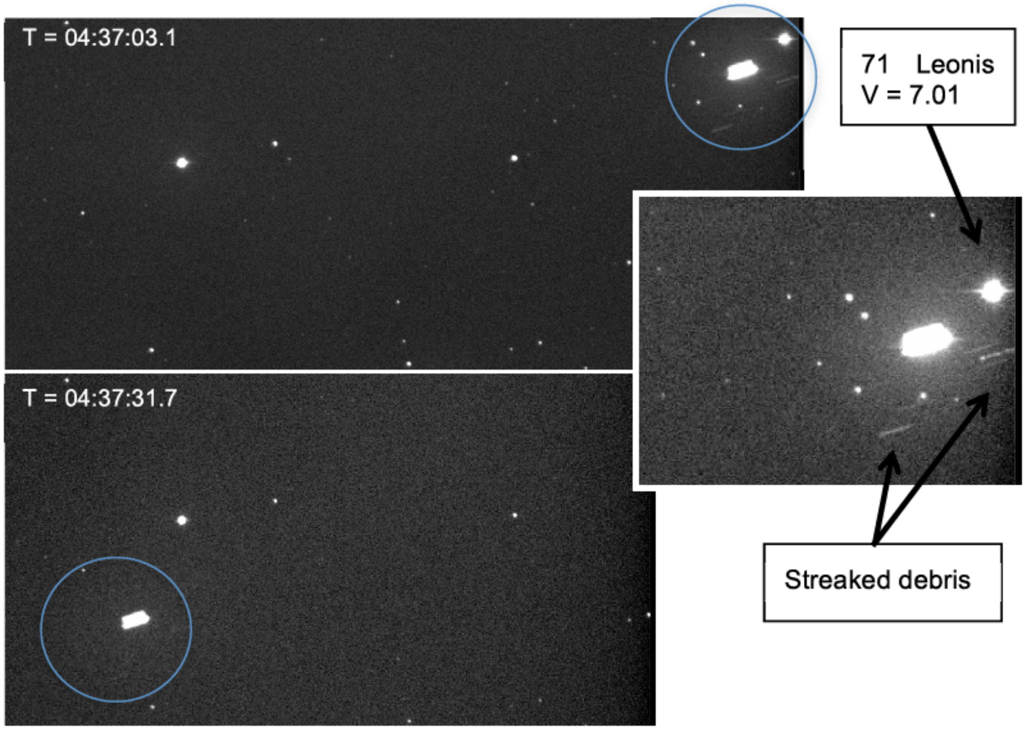

Figure 6: Two 1 s images, recorded 28 s apart, of the MMS satellites separating from their upper stage two hours after launch. The long dimension of the top panel is 0.6 degrees. The zoomed panel shows the Centaur with at least five additional object trails, and star 71 Leonis. Images courtesy of Catalina Sky Survey. Photometry courtesy HartSCI LLC. Acquisition information courtesy SMC, Aerospace Corporation, and United Launch Alliance.

distinguish major components of large GEO satellites and in the greatly improved sensitivity to closely-spaced objects at small separations, since AO not only improves image resolution by directing the energy back where it should go, but enhances contrast by moving energy away from places in the image where it should *not* be. This is illustrated in Figure 7 which plots the diameter of the smallest microsatellite that could be detected as a function of separation from a large bright GEO object when imaged in the 2.2 μm atmospheric window. The detection limit out to about 100 m separation is set by the halo of scattered light from the main satellite, which in turn is determined by the degree of correction of the AO. The results are calculated assuming a faint unresolved spherical object with the same albedo as the bright satellite and are scaled to assumed total integration times on the detector of 2 minutes and 10 minutes. The lower limit of detectable brightness is taken to be 5× the local rms noise computed from recent resolved observations at the MMT of Anik F2, a telecom satellite built around a Boeing 702 bus with solar panels spanning 48 m.

In one case observed with the MMT, a GEO satellite was imaged in the three IR bands at 1.2, 1.6 and 2.2 μm. The object was expected to be unresolved except at the longest wavelength, where the solar panels should be highly reflective. This was indeed the case, as illustrated in Figure 8 which shows 30 s exposures in each color after Richardson-Lucy restoration using stellar PSFs recorded in the corresponding bands at around the same time. However, surprisingly, the overall span of the spacecraft was found to be substantially larger than published data led us to expect. Where we anticipated a marginally resolved image in the red band suggestive of a 12 m span, the K_s band image shows a clearly resolved object with an estimated length of 24 m.

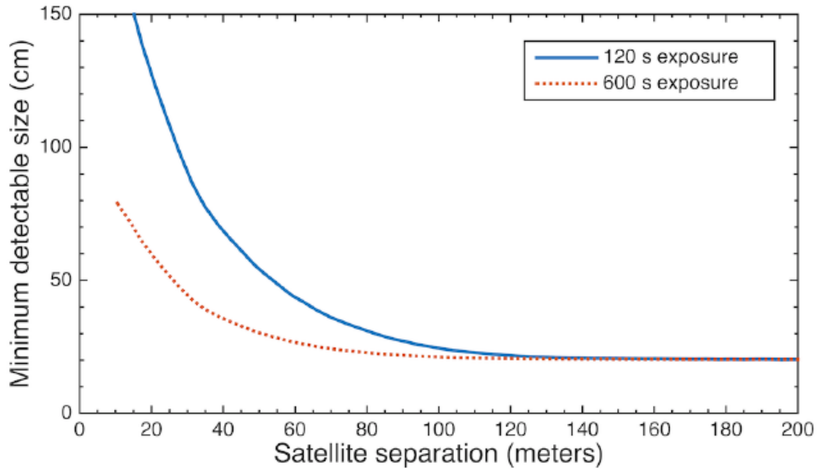

Figure 7: Quantitative detectability of microsatellites in 2 minute and 10 minute exposures at 2.2 μm wavelength.

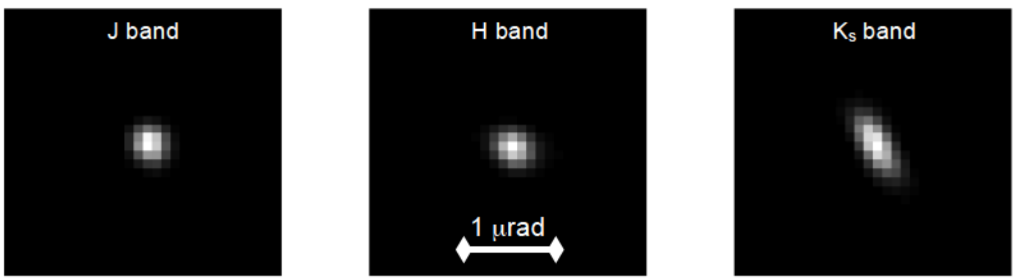

Figure 8: Images of a GEO satellite in the three IR wavebands *J*, *H*, and K_s (1.2, 1.6 and 2.2 μm center wavelengths). Note that the solar panels are resolved only at the reddest wavelength.

We note that although the spacecraft is unambiguously resolved at 2.2 μm, the angular extent is only twice the diffraction-limited resolution element of the 6.5 m aperture at that wavelength. It is immediately clear that the size of the solar panels could not be directly established with any ground-based telescope in the 3-4 m class: the panels are invisible at shorter wavelengths, below the optical stack cut-off, and diffraction by the smaller aperture would obscure the size at any wavelength long enough that the panels could be seen, either in reflection or in self emission. Even from space, to detect the anomaly a telescope would have to be placed at a substantially smaller stand-off distance.

4.4 The CyVerse Cyberinfrastructure

Data developed by the sensors is fed to a processing center built on the infrastructure of UA's CyVerse Collaborative.[8] CyVerse is a 10-year Engineering Research Center set up by the US National Science Foundation, now in its seventh year of operation. It is a $100M program to create cyberinfrastructure, initially for plant sciences, and now extended to all of life science. The CyVerse paradigm offers scalable and distributed data management across federated storage centers to manage massive data sets in an intelligent way. Key details are given in the table below. The system provides scalable and distributed high-performance computing in an environment that is intuitive for users and hides all the mechanics of the actual data storage and computation. Extensive documentation is available, as well as training and assistance in translating scientific needs into functioning software tools.

CyVerse by the Numbers

Users

- 33,000 users across all systems

Computing

- 75,000 analytical jobs run
- 22,000 on-demand cloud instances launched
- 4,000,000 CPU hours used in 2015

Data Storage

- 1.4 PB in storage
- Growing by 1.5 TB per day
- 89 M data objects
- 50% in use by 2 or more people
- 7 PB of data moves last quarter

The ability to securely manage user identities and to handle data and results at multiple classification levels is essential to the work of the SOBS Division. The CyVerse system is equipped for this already; much of the data stored, though not classified, is either proprietary to a commercial company or personally identifies clinical patients, and is strongly safeguarded against inappropriate disclosure to other users as well as the technical staff managing the systems. In addition, UA is moving aggressively to enable classified work to be performed under its purview.

The CyVerse infrastructure serves as a platform for both SDA operations as well as research and development. Once again appealing to UA's very broad base of scientific research, algorithm development draws on ongoing work in Bayesian inference in the domain of temporal emotional reactions within personal relationships,[9] inferring intent from video,[10] using ontologies to discover similarity among thousands of plant mutant phenotypes across species,[11] and uncovering hidden mechanisms that drive cancer.[2]

5.0 SPACE DOMAIN INFORMATION FUSION

Data on the space environment and objects in it, imported into SDA-DMS, come from a disparate variety of sources and sensors. To maximally exploit the information we must in some sense fuse the data. In this context, the concept of 'data fusion', which is so often only vaguely defined, means that we seek quantitative answers to specific questions with the lowest uncertainty permitted by all the available data. For example, "Where will this object be next Tuesday at 3 o'clock?" or, "What is the likelihood that my on-orbit network capability will be disrupted by space debris within the next two years?" To address this challenge, SOBS has defined a Space Domain Information Fusion (SDIF) model, illustrated in Figure 9, which exploits the techniques of task-specific information (TSI).

TSI is a paradigm for the exploration/discovery of information-optimal solutions to quantifiable estimation and classification tasks. TSI emerges from a rigorous application of traditional Shannon information theory and produces a mathematical formalism capable of quantifying the fundamental limits on task-specific sensor system performance.[12,13] Of equal importance, the method also informs appropriate data collections and enables the design of sensor systems that optimize task performance in the presence of known device characteristics and system constraints. The key insight of the TSI approach is that task-specific performance is optimized by maximizing the mutual information between the data and the measurement outcome. Note that this is very different from a conventional data processing approach, which seeks to make the output (e.g. an image) "look like" the scene.

The SDIF model is designed to demonstrate a system of systems that accomplishes a series of tasks:

- Facilitate the gathering of information from a system, driven by the specific needs of a given user.
- Autonomously determine how to weigh, trust, and process new information and evidence into the system.
- Provide a rigorous and physically and semantically consistent picture of the space domain via hard and soft input information fusion.

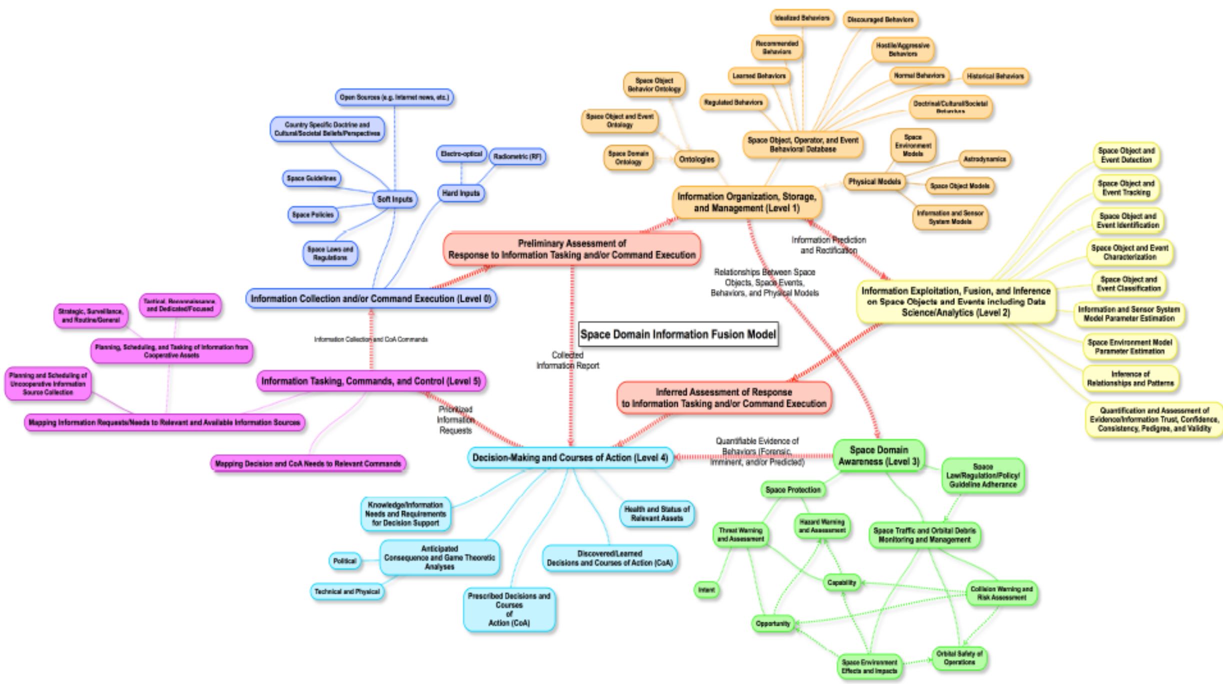

Figure 9: Overview of the Space Domain Information Fusion paradigm adopted by SOBS.

- Discover previously unknown elements of space objects and events via the leveraging of Object Based Production and ontological frameworks.
- Provide space object behavior and event predictive capabilities that are probabilistically quantifiable.
- Demonstrate the art of the possible in terms of decision-making processes and enabling command and control products and services.

The SDIF model provides a closed-loop information framework that can satisfy a variety of user needs, with a broad range of operational concerns, where the knowledge of the space domain is the same. The framework provides a common operating picture that is consistent for all users. The model consists of six main levels as shown in Figure 9 and described in summary as follows:

Level 0

Here, raw data enter the system. These data sources include hard inputs from a variety of sensors and historical surveys, as well as soft inputs such as United Nations guidelines, European Union codes of conduct, country-specific doctrine and cultural beliefs, press announcements, and other open source literature. Both are important in predicting, quantifying, and assessing space threats and hazards.

Level 1

This forms the heart of the system: it is the foundational piece that must be correct. The space domain is described through Object Based Production with relationships between objects that reside in it as well as external influences described by a dynamic ontology. A behavioral database, models of the physics, and other information about the space domain 'universe' are at this level. This is where all incoming information and evidence is stored, before and after processing, and where past, current, and predicted knowledge and beliefs about our universe reside. The fundamental function of this level is to go from "data to discovery": it is designed to leverage big data science and analytic schemes.

Level 2

This is where our beliefs and knowledge in Level 1 are subjected to critical scrutiny. Here also we assess the degree to which any new evidence can be trusted, and if the evidence indicates that our beliefs should change, to what extent we allow that change to be made or our confidence in our belief to be adjusted. So far, no specific questions have been asked of the information; the intent is simply to update knowledge of the universe as described to the extent possible given the evidence provided. No judgments are made.

Once our beliefs have been rectified (confirmed, changed, or neither because any new evidence was unrelated) any changes are propagated back to Level 1 to bring our knowledge up to date. *This is important to note!*

Level 3

Here is where we ask specific questions about things in our universe and where the tools of TSI are brought to bear to make judgments about those things and their relationships. Users will supply their own questions and decision-making criteria. For example, to one user an object 1 km from a space asset may be threatening. Another may be comfortable with a separation as small as 100 m. Level 3 takes the knowledge from Level 1 and assesses it against user-defined criteria.

By keeping Levels 2 and 3 separate from Level 1, users can apply different evidence and judgments to the information without changing the core inputs. In this paradigm, the picture of the space domain is consistent regardless of the specific user.

Level 4

At Level 4, decisions are made by addressing questions such as, “Should I do something?”, “If I do this, what is the expected effect?”, “What other information do I need to decide between these three courses of action?” Some courses of action might be predetermined by the user, and others not. The user may simply be looking for a body of evidence of something occurring in the space domain that concerns them.

Level 5

Any output from Level 4 that leads to a requirement for further information passes to Level 5 where sensors and information sources are tasked to collect new information. Other non-information gathering actions may also be tasked. A prioritized list of actions is established and executed. The user has a lot of flexibility into what happens at this level.

6.0 BENEFITS OF THE SOBS APPROACH

The UA’s Space Object Behavioral Sciences Division offers efficient and cost-effective ways to solve problems related to space domain and traffic governance and monitoring. One important application is to inform the Space Object Situation Room (SOSR), a SOBS initiative now in development to help entities around the world protect space services and capabilities against natural and intentional interruption, disruption, loss and/or degradation. Analysts at the SOSR can monitor an orbital regime, such as the near-GEO region or a country’s exclusive GEO slot for space domain activity and other space object traffic. The system, as described above, cross-references multiple sources and types of satellite data, space surveillance and tracking, as well as international frequency allocations and foundational space environmental inputs such as solar and geomagnetic activity. Automatic alerts of hazardous or threatening activity are issued to system analysts or other authorized users if the system detects behaviors that, for example, indicate a space object may be maneuvering, that two or more space objects are in close proximity (a possible sign of intentionally uncooperative interaction or impending collision), that a space object has stopped transmitting, a space object that was presumed defunct has started transmitting, or that it has encroached upon another entity's orbital slot. Analysts will then investigate by reviewing a dossier with the object's history to determine whether it or its owners are associated with previous similar behavior; for instance, the object may be on a "watch list". The analysts cross-check the observed and quantified behavior against accepted international guidelines, best practices, or codes of conduct. Analysts then notify relevant entities and can provide a "case package" with evidence for review. The case package includes space domain "maps," orbital trajectories with the space object's last known position, its relevant tracking data, potential compliance issues, and other identifying information, including country of registration, owner, (if applicable and known) and known behavior.

The UA SOBS Division and its partners are working with interested stakeholders to develop an equitable cost-model that would allow all nations, regardless of national resources, to engage. In addition to the global spacefaring community, the system's inherent security features, rich datasets, and advanced analytical capabilities lend themselves to organizations interested in tracking and identifying the source of specific space object behaviors. For example, NASA could use the system to become better informed as to the sources and sinks of the space debris population which could lead to improved debris mitigation guidelines. This application could also provide a rigorous scientific basis for space insurance companies and create a market incentive for entities that operate in good faith and in accordance with international and national laws and guidelines.

Through the Space Object Behavioral Sciences Division of DSRI, UA is uniquely positioned to become a leader in SDA because of its long history of substantial investment in technical infrastructure, the unrivalled environment it offers to train current and future industry and government employees in space operations, and the great breadth of scientific research in adjacent fields that can be brought to bear. However, UA recognizes that SDA has a long history of its own in the government, academic, and commercial sectors, and is now actively seeking partners to strengthen its capabilities. UA already collaborates with a wide range of organizations within the space community, both government and commercial, to understand and focus on long-term missions, needs, and challenges. Nevertheless, we seek new partners to ensure that the work remains at the forefront of state-of-the-art processes and technologies, as well as areas of new research.

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