Automated, Collaborative Applications to Close Kill-chain Gaps

Greg Furlich, Angie Crews
Center for National Security Initiatives, University of Colorado Boulder

Jack McGuigan
True Anomaly

Tim McLauglin, Chris Burns
InTrack Radar Technologies

Pace Balster, Gabrielle Jones, Gavin Hofer
Katalyst Space Technologies

Ian Stuart Bartlett, Lakitha Hettiarachchi
HEO

Lt. Haley Spolar, Major Sean P. Allen
SDA Tools, Applications, Processing Lab, SSC, USSF

ABSTRACT

To accelerate delivery of battle management software, the SDA Tools, Applications, and Processing (TAP) Lab was stood up in Colorado Springs, Colorado in 2023. The SDA TAP Lab stimulates partnership among industry, academia, and across the government to solve SDA gaps and rapidly transition solutions into operations. The motivation for the SDA TAP Lab is the lack of automation along the analysis chain; the burdens placed on operators; the reliance on large, stovepipe systems; and the ever-increasing activity in the space domain.

In the Fall of 2023, a cohort of organizations from industry, academia, federally funded research and development centers, and US government entities were selected to address five specific kill-chains provided by the United States Space Force (USSF). The inaugural cohort comprised of members from Katalyst Space Technologies, InTrack Radar Technologies, True Anomaly, HEO, the University of Colorado Boulder, and others. The cohort worked together to accelerate the research and development of technologies and capabilities to detect, track, and characterize hostile events such as direct ascent anti-satellite and co-orbital anti-satellite threats from the start of the engagement and beyond. Cohort members developed capabilities for prelaunch characterization, launch detection, launch re-acquisition, and payload characterization to create indicators which analyzed threat validity and intent. These applications were developed to defeat operational surprise through camouflage, concealment, deception, and maneuver (CCDM). These applications were then integrated into a common mission data processing infrastructure developed between cohort members and SDA TAP Lab staff. The completed pipeline demonstrated end-to-end capabilities integrated into a microservice architecture. Effective collaboration in the SDA TAP Lab tech accelerator cohort one led to significant accomplishments in 49 business days. This collaborative spirit has carried into further cohorts that are continuing to develop resilient and redundant applications that close threat gaps to ensure responsible action in space.

1. INTRODUCTION

The SDA Tools, Applications, and Processing (TAP) Lab opened to performers in Fall 2023. The organizations contributing to this paper were among the inaugural cohort working on the unclassified problem statements released through the SDA TAP Lab. These problem statements cover unclassified threats to the USSF's ability to maintain space superiority in a contested space environment[1, 2]. To enable a fast-paced developmental environment, the SDA TAP Lab provides a collaborative space and information infrastructure where cohort members work together to close these kill-chains using commercial or open source data and capabilities.

As space becomes more contested, time is of the essence to ensure and preserve a domain with free action for all and deter future hostility in space by publicly demonstrating the full ability to counter such actions. By establishing strong ties with US allies and partners through a coalition of the willing in the SDA TAP Lab, the cohort demonstrates the utility for a system connecting disparate information to close on adversarial threats. The inaugural cohort started strong with inclusion of an international partner with HEO, academic faculty members from University of Colorado Boulder, small businesses contributing rapid development to maturing and innovating critical technologies to the mission, such as Katalyst Space Technologies and InTrack Radar Technologies (IRT) and mission experts from Federally Funded Research and Development Centers (FFRDCs) and the USSF.

2. SPACE DOMAIN AWARENESS TOOLS, APPLICATIONS, AND PROCESSING LAB

The SDA TAP Lab was stood up under the USSF's Space Systems Command (SSC) in Colorado Springs at the Innovation Hub hosted by Virginia Tech Applied Research Cooperation. The mission of the SDA TAP Lab is to accelerate delivery of battle management software to defeat operational surprise in the space domain that manifests in hostile intent under camouflage, concealment, deception, and maneuver (CCDM). This thesis is based in General Saltzman's, Chief of Space Operations (CSO), theory of success through competitive endurance in great power competition in space[3, 4]. To endure and outlast in space, success and advantage are maintained through defeating and deterring operational surprise via detecting and correctly interpreting that a hostile engagement has begun and verifying which assets are threatened.

The SDA TAP Lab proceeds after these threats through openly inviting organizations from industry, academia, FFRDCs, and government groups to participate in a technology acceleration sprint named Project Apollo. Organizations apply through the SDA TAP Lab website and are selected if proposed capabilities help the SDA TAP Lab cohort achieve its mission. Each cohort is organized into a sprint of three months where performers iterate on their technology and integrate their capabilities into the SDA TAP Lab mission system. Organizations that are selected do not receive funding from the SDA TAP Lab for their participation. However, throughout the cohort sprint, performers are provided beneficial participation in invited expert talks, USSF SDA operator engagement, and briefings to VIP tours of the lab. The SDA TAP Lab also provides many digital resources and infrastructure to cohort members to make collaboration efficient such as community chat functions, code hosting repositories, and virtual machine infrastructure amongst many others.

(a) Cohort 1 (b) Cohort 2 (c) Cohort 3

Fig. 1: Cohort banners with the logo of each organization that participated in cohorts 1 - 3. Image Credit: Major Sean Allen, SDA TAP Lab Chief.

Fig. 2: Group photo of the inaugural cohort members at the kickoff meeting. Image Credit: Major Sean Allen, SDA TAP Lab Chief.

The SDA TAP Lab started with 14 organizations in the inaugural cohort in Fall 2023. Organization participants of the first three cohorts are shown in Figure 1. As of Summer 2024, the SDA TAP Lab has started its fourth cohort with around 60 organizations. A group photo from the inaugural cohort kickoff is shown in Figure 2. The large number of collaborators reflect the corporate need and momentum of the Lab. A democratized system has greater impact through redundancy and resiliency capabilities. More about the SDA TAP Lab can be referenced from [5].

3. UNCLASSIFIED KILL-CHAINS

The SDA TAP Lab has publicly released problem statements focusing on five unclassified kill-chains. These kill-chains are informed by key USSF SDA stakeholders that are cleared for public distribution. Releasing these problem statements publicly provide cohort members insight into the needs of the customer and allows for rapid prototyping and development without the restrictions of a classified environment. This allows for the SDA TAP Lab to evaluate the use of commercial data and capabilities against these threats, as previously advised by the Government Accountability Office (GAO)[6]. The five kill-chains publicly released are:

1. Geosynchronous Earth Orbit Direct Ascent Anti-Satellite Threats
2. Geosynchronous Earth Orbit Co-orbital Anti-Satellite Threats
3. Low Earth Orbit Direct Ascent Anti-Satellite Threats
4. Low Earth Orbit Co-orbital Anti-Satellite Threats
5. Defensive Cyber Operations

These five kill-chains and the possible modes of CCDM a threat can exhibit are illustrated in Figure 3.

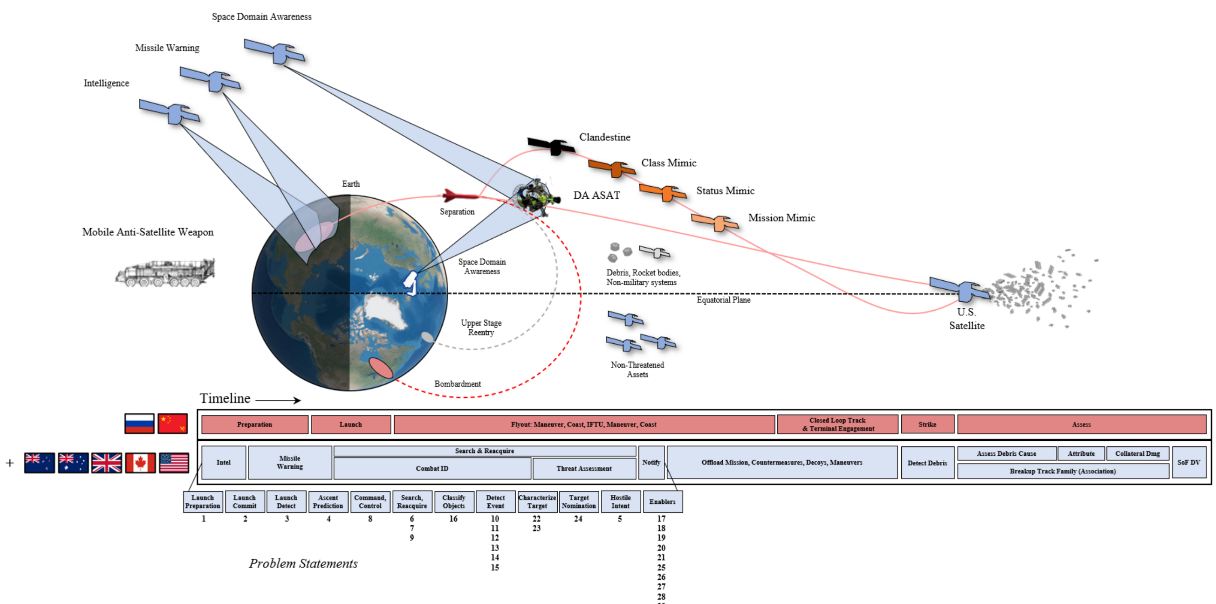


Fig. 3: Graphic Representation of the SDA TAP Lab kill-chains. Image Credit: Major Sean Allen, SDA TAP Lab Chief.

4. AUTOMATED, COLLABORATIVE KILL-CHAIN APPLICATIONS

To close the kill-chain in an automated fashion, members of the cohort contributed custom applications that decomposed pieces of the kill-chains into addressable problems. This allowed each organization to contribute their strengths and developed products into services that work together and make the sum greater than the whole.

Each of the sections and the capabilities highlighted are contributed by the following technical points of contact:

Section 4.1: Prelaunch Indicators, Dr. Angie Crews (angie.crews@colorado.edu), University of Colorado Boulder

Section 4.2: Unclassified Launch Detection, Dr. Greg Furlich (greg.furlich@colorado.edu), University of Colorado Boulder & Lt. Haley Spolar, USSF

Section 4.3: Launch Nominals, Chris Burns (chris.burns@intrackradar.com) and Tim McLauglin (tim.mclaughlin@intrackradar.com), IRT

Section 4.4: Tasking, Search, and Re-acquisition, Jack McGuigan (Jack.McGuigan@Trueanomaly.space), True Anomaly

Section 4.5: Commercial Non-Earth Imaging for Resolved Asset Assessment, Stuart Bartlett (stuart@heospace.com), HEO

Section 4.6: Hostility Assessment, Pace Balster (pace.balster@katalystspace.com), Gabrielle Jones (gabrielle.jones@katalystspace.com), and Gavin Hofer (gavin.hofer@katalystspace.com), Katalyst Space Technologies

4.1 Prelaunch Indicators

Activities prior to launch can provide indications of upcoming events that can be used to tip and cue launch detection systems. For this use case in support of the SDA TAP Lab, we desired to utilize unclassified, publicly available imagery to find activity at launch sites that may indicate future space launches. By automating an approach to identify launch site activity, additional decision space is provided to the operators to counter the DA-ASAT threat.

As part of Cohort 1, publicly available imagery was analyzed from NASA, the European Space Agency (ESA), and the National Geospatial-Intelligence Agency (NGA). NASA data was accessed through the EarthData database [7]. Although numerous datasets were available for analysis, it was determined that the NASA imagery did not have the resolution necessary to find indications of activity at launch sites. For instance, the highest resolution imagery available was from Landsat, which has a resolution of 30-meters [8]. ESA imagery was accessed through the Earth online portal [9]. As a U.S. citizen, access to the ESA datasets on the Earth Online portal was limited and the datasets that were available were sparse. Commercial imagery was accessed via the NGA sponsored Global Enhanced GEOINT Delivery (G-EGD) database managed by Maxar [10]. The commercial imagery from providers such as Maxar, Planet, and Blacksky Global had high resolutions (sub 1-meter), but the images were accessed through a user Graphical User Interface (GUI) that was not conducive to automation.

A MATLAB script was written to allow users to define inputs and then automate the downloading and plotting of imagery from the sensor data files. The Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on NOAA-20 was chosen as a representative NASA dataset. After the user selected a launch site, spacecraft, and date/time, the script loaded TLEs and propagated the spacecraft orbit to find access windows, as shown in Figure 4. The script then downloaded VIIRS near-real time sensor data files based on the access windows. The sensor data files were filtered based on a user-selected radius around the launch sites and VIIRS images were then plotted over the launch site location. The MATLAB script then displayed the G-EGD commercial imagery of the chosen launch site that was closest in date and time to the user's selection.

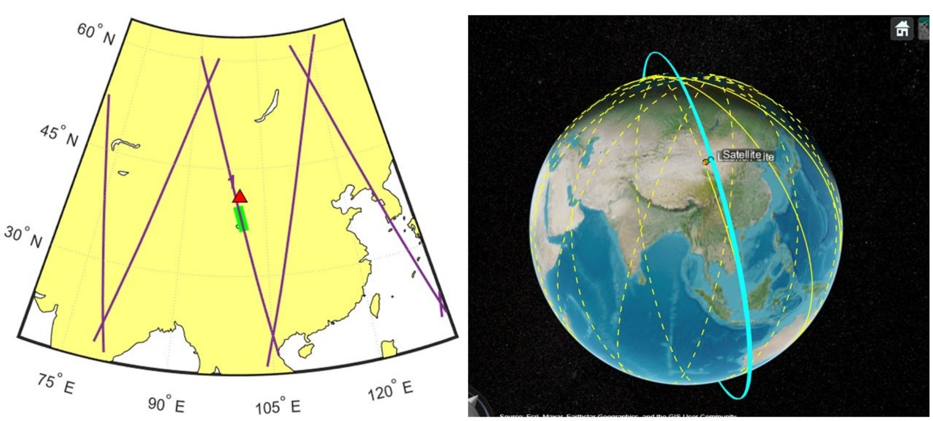


Fig. 4: 2D and 3D NOAA-20 VIIRS access windows plotted over the Jiauqan Launch Site Facility in China.

The Cohort 1 analysis demonstrated that commercial imagery from G-EGD would be the best option to pursue for future analysis due to the availability of high resolution imagery products. Later work demonstrated automating as a microservice the ingestion of G-EGD imagery into the SDA TAP Lab's automated Node Red workflow. Additionally, AI/ML models were incorporated to find features in the launch site images, such as rockets on launch pads, that may indicate an impending launch.

4.2 Unclassified Launch Detection

The USSF has many exquisite launch detection systems for missile warning and missile tracking. However, these systems exist at a classified level where the information is not publicly distributed. To enable the emulation of the whole kill-chain and provide a launch alert message at an unclassified level, the University of Colorado Boulder, led by Dr. Furlich, developed capabilities for automated launch detection using publicly available weather satellite data. This detection capability uses the NOAA Geostationary Operational Environmental Satellite (GOES) Advanced Baseline Imagery (ABI) in the Mesoscale Domain Sectors (MDS) scan mode [11–13]. The MDS provides imagery every 60 or 30 seconds for requested areas of interest. Typically these MDS cover areas of interested related to severe weather patterns such as hurricanes or fires, however when covering US launch complexes such as Cape Canaveral, launches can be observed [14, 15].

These capabilities consist of methods to pull the GOES publicly available data[16] in near real-time, process the imagery for detecting launch signatures, and generating a launch alert messages. This code base is integrated into a API endpoint for a user to query the new imagery from both GOES East or West every 30 seconds when a new image is released. These capabilities can be run in real-time to continuously monitor and generate launch alerts using GOES East and West data in the SDA TAP Lab's Node-RED Flow (Section 5). This application can also be ran in a playback mode using historic data to test on previous launches.

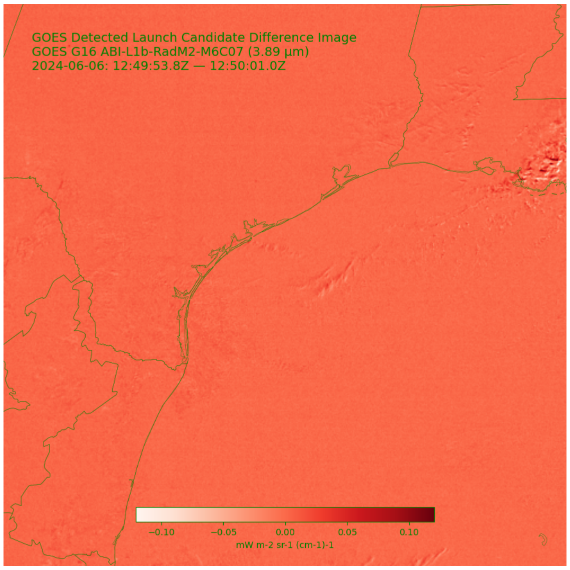
This automated launch detection capability has been successfully demonstrated on three civilian launches. Further information on these launches is provided in Table 1. Example imagery of the detection of Starship IFT 4 is shown in Figure 5 and a portion of the example launch alert message generated from the Starship IFT 4 launch is shown in Table 2.

Launch Name	Launch Location	Estimated Launch Datetime (UTC)	GOES Observer
Starliner Boe-CFT	Kennedy Space Center FL, USA	2024-06-05T14:52:23.7Z	GOES East
Starship IFT 4	Space X Starbase Boca Chica, TX, USA	2024-06-06T12:50:53.8Z	GOES East
GOES U	Kennedy Space Center FL, USA	2024-06-25T21:26:55.1Z	GOES East and West

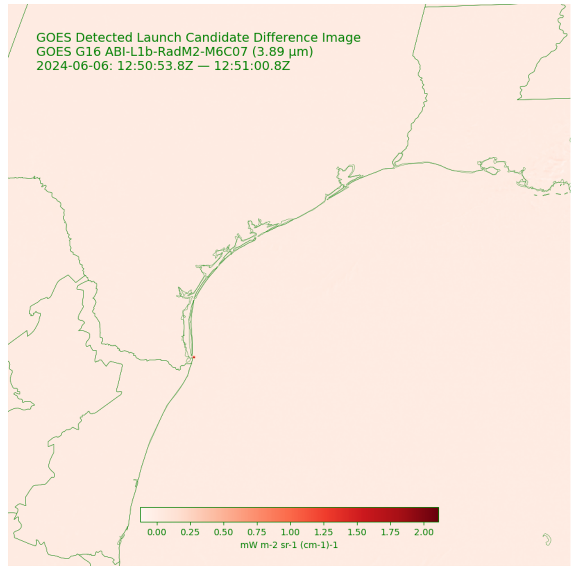
Table 1: Successful launch detections from this unclassified launch detection method using weather satellite data with launch name, location, estimated launch datetime, and GOES satellites that observed the launch.


```
{
    ...
    "launch":true,
    "type":"imagery",
    "source":"GOES G16 ABI-L1b-RadM2-M6C07",
    "latitude":26.03114605265303,
    "longitude":-97.19476287222237,
    "liftoffAt":"2024-06-06T12:50:53.8Z",
    "launchSite":"SpaceX Orbital Launch Pad 1 (Boca Chica)",
    ...
}
```

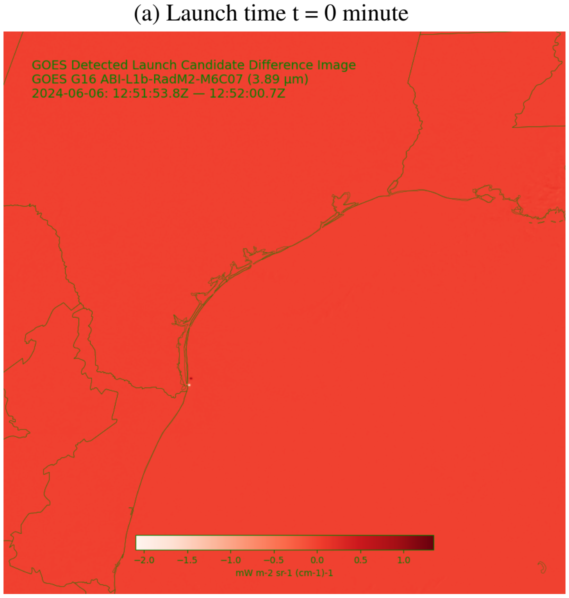

Table 2: Snippet of an example launch alert message from the Space X Starship IFT 4 launch detection.



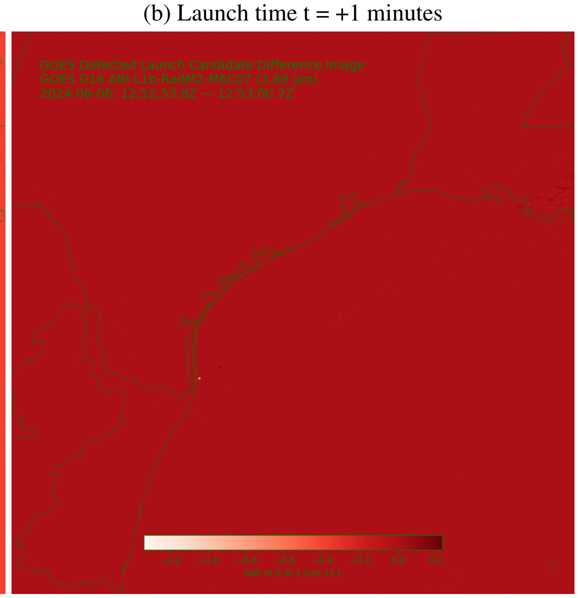
(a) Launch time t = 0 minute



(b) Launch time t = +1 minutes



(c) Launch time t = +2 minutes



(d) Launch time t = +3 minutes

Fig. 5: Imagery of the Starship IFT 4 launch observed by GOES 16 ABI Channel 7 radiance imagery. A differenced image was generated using the previous image against the the current to make the launch signal more apparent.

4.3 Launch Nominals

Once a launch is detected, it is necessary to cue sensors with collection requests. A launch nominal is helpful when predicting where the launch vehicle and its payloads are headed to. InTrack Radar Technologies has experience building launch nominals and through participation in the SDA TAP Lab was able to package this experience and the associated algorithms into a service.

An operator uses the service to generate a nominal prior to launch to understand potential sensor access windows. Alternatively, a nominal can be generated once a launch is detected as part of an automated workflow. Using the launch location and time along with the intended altitude and inclination of the target, the service is able to generate a nominal. These parameters may be provided by an operator, a launch detection or a combination of the two. Historical data may be used for any missing parameters.

An example launch nominal message after processing a GOES-U launch detection is indicated in the Table 3.


```
{
    "tle": [
        "0 PAYLOAD",
        "1 98001U 00000      24177.89369444 -.00000037  00000+0  00000+0 0   9995",
        "2 98001   10.3912   91.9941 4888438 179.7326    1.3149   1.84003300     04"
    ],
    "tle0": [
        "0 PAYLOAD",
        "1 98001U 00000      24001.00000000 -.00000037  00000+0  00000+0 0   9994",
        "2 98001   10.3912  315.9168 4888438 179.7326    1.3149   1.84003300     04"
    ],
    ...
}
```


Table 3: Example launch nominal message from GOES-U launch. This corresponds to the GOES detected launch time in Table 1.

4.4 Tasking, Search, and Re-acquisition

Rapid follow-up collections on a target after launch or large maneuvers are essential to assessing the potential hostility of actions on orbit. To this end, True Anomaly developed an algorithm to generate search patterns to improve the ability of SDA sensors to locate or reacquire a target.

For new launches, a launch nominal may be provided from a user or an external automated service, suzh as IRT's method. In the case where neither is available, a maximum-likelihood estimate of orbital elements can be produced using the distribution of historical launches and expected time of launch.

A target that has executed a large maneuver may initially appear as a UCT or be completely missed by SDA sensors. The uncertainty introduced by a maneuver is modeled by increasing the covariance on the target's state vector proportional to the expected maximum maneuver magnitude. Since this covariance is 3-dimensional, it is first reduced to a marginal 2D distribution in the plane orthogonal to the observer vector. A search pattern is then generated by mapping a simple function (i.e. a spiral) of the resulting statistical manifold to the coordinate frame of the sensor (i.e. right ascension & declination).

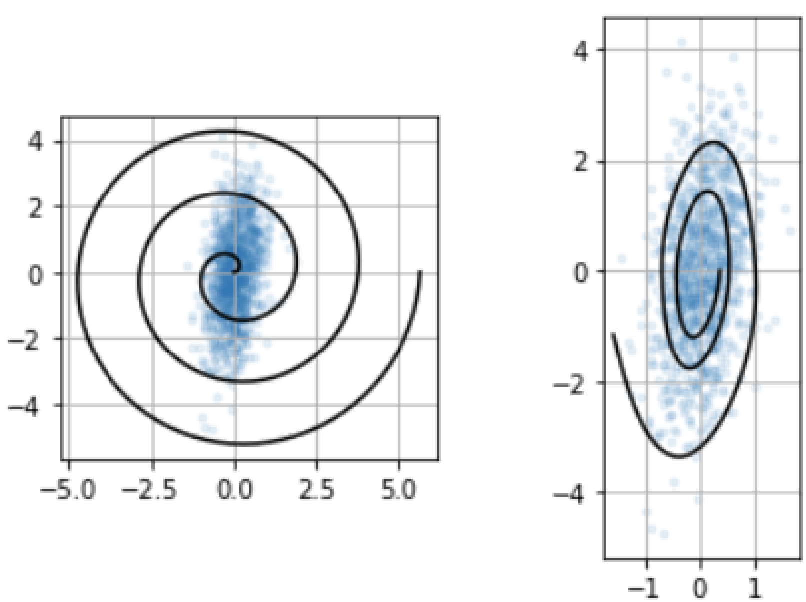
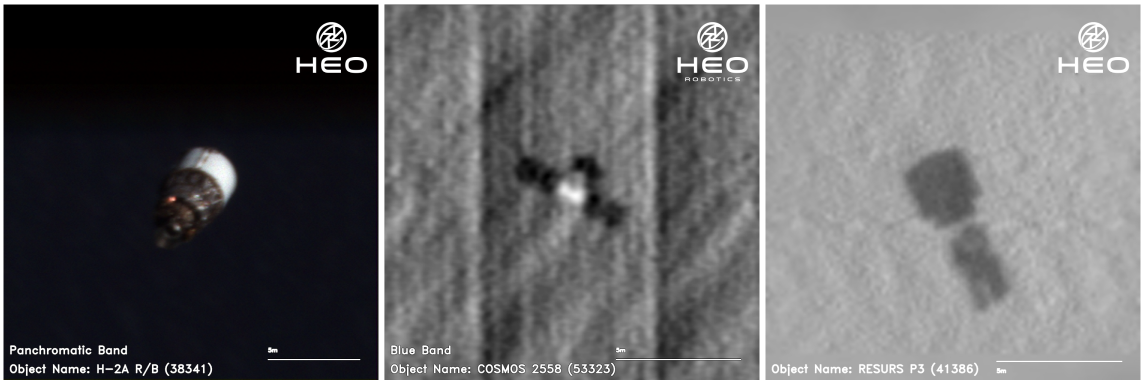


Fig. 6: Constant-Expansion Spiral of Statistical Manifold

Figure 6 shows a constant-expansion spiral search pattern in the search coordinates (left) and in the statistical manifold of the target's state distribution mapped to the search coordinates (right). The modified pattern spends time dwelling near the center of the distribution before more rapidly expanding. This function is well-suited for RF groundstations with steerable dish antennas. For EO sensors, the function must be discretized into separate exposures and a path generated between them. In this case, a nearest-neighbor travelling salesman algorithm is used, starting from the centermost point.

4.5 Commercial Non-Earth Imaging for Resolved Asset Assessment



(a) NEI of H-2A rocket body with structural features and subsystems clearly visible.

(b) Russian Cosmos 2558 inspector satellite, with satellites and payload body visible.

(c) Russian RESURS-P3 communication satellite. Failed solar panel deployment clearly visible.

Ground-based space situational awareness sensor observations can capture precise information about the position and velocity of RSOs. However, they cannot necessarily answer other questions about an object's properties, state, or identity. Is a UCT a satellite, or a debris object? Is a satellite oriented such that its payload is oriented toward a particular location on the ground? Is a subsystem, like a solar panel, or antenna, properly deployed?

One approach that can provide this information is resolved imagery, where we capture sufficient pixels to see specific features on the RSO. HEO captures resolved imagery through flyby non-Earth imaging (NEI). HEO operates a distributed network of cameras throughout LEO, both directly and by contracting existing Earth imaging assets. To image an RSO, our software automatically identifies opportunities where the RSO will pass close to one of these cameras. When the opportunity arises, we turn our imaging asset off-nadir, and capture an image of the object as it passes at ranges of 25-100 km. This approach allows us to capture resolved images without needing to expend propellant on the imaging satellite. The resulting imagery and analytics are then provided through HEO's web platform, HEO Inspect, and the accompanying API.

This capability becomes especially important in the face of CCDM. UCTs and known objects that are unidentified, miscatalogued, or presumed to be debris can provide cover for adversary action. To accomplish their missions, however, these concealed spacecraft still need the same onboard systems as any other spacecraft, possibly including PV panels, communications antennas, and optical/RF payloads. These features can be observed through resolved imagery.

As part of TAP Lab Cohort 1, HEO's automated systems were integrated into the TAP Lab's system of boolean indicators. HEO conducts ongoing imaging campaigns to observe unidentified RSOs, producing a back catalogue of analytics and classifications. As objects were considered through the Node-RED flow, these classifications were automatically queried, and compared with public catalogue data and other partner analytics. If, for example, an object catalogued as a debris or rocket body object displays these features, it immediately merits further investigation. By using a simple binary truth table over features, this analysis can be done in real time.

This integration also provided access to the HEO tasking API. If an object is deemed high-priority and current imagery is inadequate, a tasking campaign can automatically be initiated. This can serve to clarify an ambiguous classification, or obtain more information about an object flagged as suspicious by another system, such as light curve detection or launch analysis. Once this tasking is completed, the data automatically becomes available through the API, for integration down the chain in hostility analysis. This functionality was available during Cohort 1, but not activated. More about HEO's NEI is provided in [17].

4.6 Hostility Assessment

General Saltzman's theory of success involves avoiding operational surprise. Since we assume surprise may come from camouflage, concealment, deception or maneuver (CCDM), we must interrogate targets for evidence of CCDM. Current capabilities for object classification and characterization are done manually by analyzing light curve data or orbital elements plots for anomalous features. This process can take hours to days to complete for objects of interest or known threats, leaving us vulnerable to potential unknown threats that are hiding in the excess of unexamined data. Additionally, observation association algorithms rely upon kinematic correlation algorithms that generally only consider the position and velocity of objects, leaving out important information such as the visual magnitude. This information is important for positive identification of objects and uncorrelated tracks (UCTs) to confirm we are tracking what's expected. There needs to be an automated process to detect indications of CCDM and nominate targets for follow-up inspection. In addition, there needs to be a UCT processing workflow that can incorporate kinematic and non-kinematic information to improve the confidence of correlations [18].

No one system, process or phenomenology can tackle the full problem space. We need multiple indications, analyses and data sources in an automated framework to detect signs of CCDM. With this in mind, Katalyst has created an automated workflow (shown in Figure 8) in collaboration with HEO Robotics and InTrack Radar Technologies that is able to detect signs of camouflage and deception through combinations of independent indicators to nominate class violators within cataloged rocket bodies, debris, apogee kick motors and uncharacterized objects.

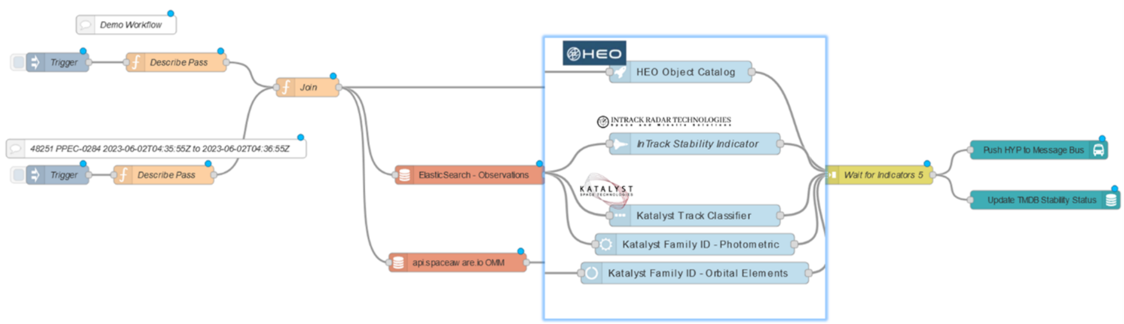


Fig. 8: The class violator Node RED flow for Object D 48251. This flow incorporates models from Katalyst, IRT and HEO to provide multiple indications of Object D being a payload. This object is unknown in the catalog.

This workflow automatically ingest recent Unified Data Library (UDL) data (shown in red) using the secure messaging API for the most up to date EOObservations and Elsets. The data is streamed into Katalyst's statistical and machine learning models (shown in blue) to output in-family scores and object type probabilities. These models include the ML Track Classifier, Photometric Family ID, and Orbital Elements Family ID. The ML Track Classifier uses classical and deep learning methods to ingests observation metadata over the track length (mag, phase angle, ra, dec etc.) to output probabilities of active payload, inactive payload, rocket body or debris classes. In addition to machine learning methods, we developed simple statistical models that build distributions of object types and output an in family score, from 0-1 of how similar an object is to the object type distribution. These models help contextualize what patterns more advanced machine learning models are recognizing by visually displaying where the elsets or magnitudes falls within the distributions (shown in Figure 9). In combination, these models provide multiple independent indications of predicted object type based on the input data to determine with higher confidence if an object is out of family with its catalog type.

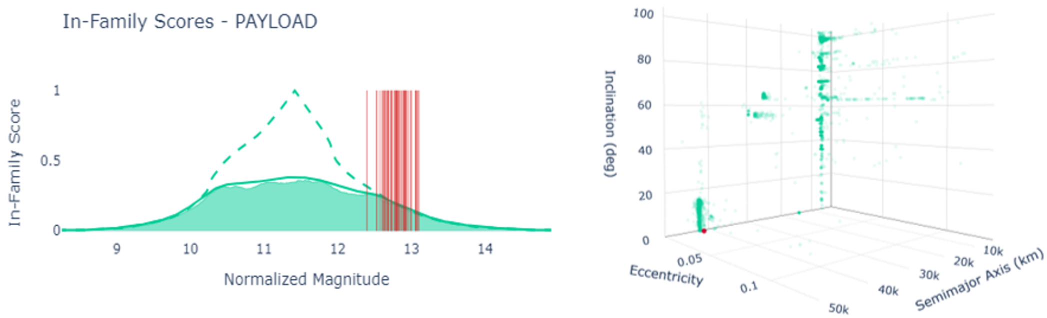


Fig. 9: The photometric family ID model for payload objects is shown on the left. The red lines show the tested magnitudes of a rocket body object from the catalog. The orbital elements family ID distribution for payloads is on the right with the tested elsets in red.

Katalyst's models were containerized and have REST APIs to enable quick integration with other cohort members. IRT's stability assessment app was incorporated in the workflow to provide further classification between stable and unstable objects. Additionally, HEO's Object Catalog imagery was incorporated in the flow to provide in-space observations of the unknown payload by providing the satellite number of the object. All of these applications were combined to output a nomination message to Digital Arsenal's SpaceAware.io visualization globe to display the true and false indications of an active payload that was previously cataloged as unknown object (shown in Figure 10). Integration of applications into the SDA TAP Lab mission system is discussed more in Section 5.

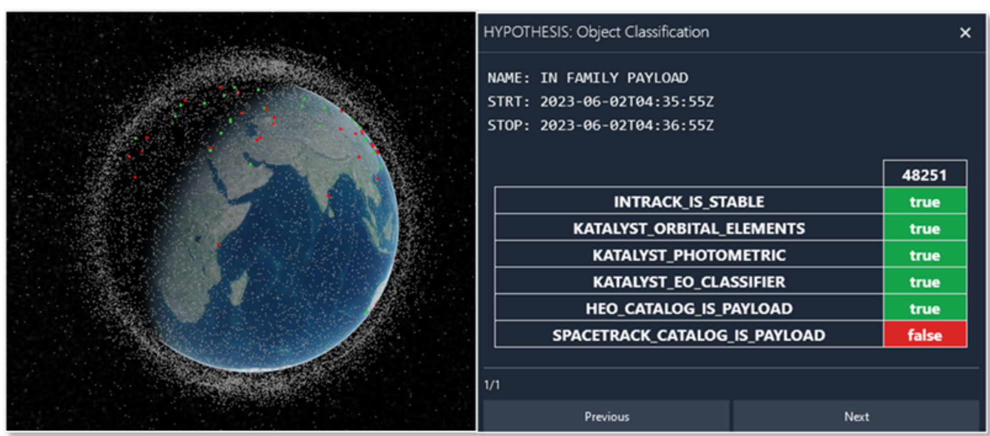


Fig. 10: The Hypothesis Object Classification message is shown with true/false indicators from each model in the Node RED flow.

This workflow demonstrated automated characterization and target interrogation capabilities that were combined in collaboration with other cohort members to nominate and prioritize potential threats in the catalog for further investigation. These nominations can help prioritize tasking and mitigate surprise from unknown threats.

5. APPLICATION INTEGRATION

The cohort explored and settled on the use of Node-RED[19] for integrating the SDA TAP Lab mission processing system due to a suggestion from Digital Arsenal. Node-RED is a browser-based process flow editing system that provides built-in functions for standard process, ways to build custom subflows, and edit the system collaboratively. The SDA TAP Lab kill-chains were decomposed into a process flow where each organization could integrate their capabilities, such as queries to external APIs. This allowed for routing of common SDA mission message payloads between capabilities. Thus processes could build and add further information ontop of each other regarding the object or event in the kill-chain. Once matured, the kill-chain applications described in Section 3 were integrated into a collaborative process with applications from many organizations. This microservice infrastructure inside Node-RED allowed for rapid integration of parallel processes which offers a democratized system over a stove-piped mission data processing chain. Node-RED also afforded the cohort rapid prototyping, live editing, and system integration from any contributor into the system. This system was built with a focus on automation where a process was automatically driven based on events, time, or evolution of indicators. The system could also be initiated with manual triggers with parameters set to rerun historical scenarios for testing and tuning applications.

The inaugural Project Apollo Tech Accelerator Cohort demo day demonstrated an integrated process flow with applications from Katalyst Space Technologies, InTrack Radar Technologies, and HEO in Figure 8. This process demonstrated parallel assessment on two resident space objects which where aggregated into a threat assessment on if the objects where displaying CCDM and indication of intent for operational surprise. The SDA mission processing chains continue to evolve in complexity and scale as illustrated by an example taken from Cohort 3 demonstration day in Figure 11.

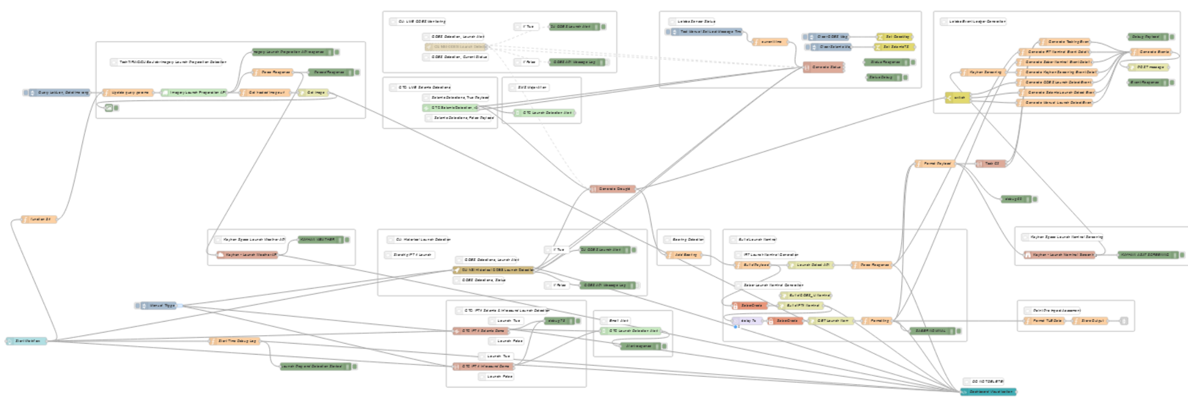


Fig. 11: Zoomed out illustration of the complex integrated system for launch preparation, detection, and re-acquisition from many organizations in for the Cohort 3 Project Apollo cohort demonstration day. There are many different processes connected to one another in this system. Image is quality is low to respect work of cohort members not apart of this paper.

6. COHORT BENEFITS AND SUCCESS

Participation in the cohort was unfunded for participants, however participation has provided many other direct benefits besides funding. Many cohort members, such as the organizations represented in this paper continue to participate and receive other soft benefits. Given the collaborative nature between organizations from the United States Government, FFRDCs, small and big companies, and academic institutions, the SDA TAP Lab continues to build momentum from cohort to cohort. The SDA TAP Lab has received visitations from many distinguished guests, such General Guetlein (Figure 12), Vice Chief of Space Operations (VSCO), General Garrant, Commander of the USSF Space Systems Command (SSC), and Congressmen from the House Armed Services Committee (HASC). From these visits, cohort members had an opportunity to brief their capabilities to these guest and reach a wider audience outside the lab.

Fig. 12: SDA TAP Lab visit from General Guetlein (Center). Cohort 2 members were given an opportunity to brief on their capabilities and contributions to the kill-chain. Image Credit: Major Allen, SDA TAP Lab Chief.

Since the SDA TAP Lab participation is voluntary, the intellectual property developed to address the kill-chains remains in the possession of those that develop it. This provides an environment for organizations to expose their applications behind protections such as API endpoints without the requirement to expose backends. If a organization successfully demonstrates a matured capability that is integrated and tested in the SDA TAP Lab mission system, organizations may be directed towards a sponsor or customer. This allows organizations to license these products in the future since they developed the capability on internal funding. This is one of the the routes to funding through the SDA TAP Lab.

Another route to funding at the end of the cohort sprints is through the demonstration day where each organization presents the capabilities they integrated. Those that demonstrate matured and tested capabilities may also find a performance work statement listed on the Global Data Marketplace where the demonstrated capabilities fulfil the bid requirements. A successful selection and negotiation on these bids leads to a performer receiving funding for a year long license with the SDA TAP lab as a cohort 'Winner'. Cohort 'Winners' have been:

- Katalyst Space
- Digital Arsenal
- Kayhan Space
- Intrack Radar Technologies
- Cloudstone Innovation
- Turion Space
- University of Colorado Boulder

The most important results from the cohort is the enhancements to the mission system. These partnerships created a system where the whole is greater than the sum of parts. This system will enable further deterrence and defeat of hostile threats to peace in space.

7. CONCLUSION

The SDA TAP Lab has provided a unique environment for a diverse representation from industry, FFRDCs, academia, and government organizations to collaborate on SDA problems and decompose kill-chains into surmountable problems. The cohort provided solutions that worked collaboratively in parallel and in serial to add the resiliency and redundancy needed for the mission. The cohort designed applications based on building an autonomous system that could pass information in the form of standard messages along the processing chain. The organizations of Katalyst Space, InTrack Radar Technologies, True Anomaly, HEO, and faculty from the University of Colorado Boulder were among the inaugural cohort and demonstrated key capabilities to the mission. These capabilities focused on defeating operational surprise in the form of CCDM through direct ascent and co-orbital threats to USSF assets on orbit. These organizations developed and integrated capabilities for automated analysis on prelaunch indicators, launch detection, re-acquisition, non-earth imaging, and hostility assessment. Alone, these are exquisite and novel contributions, but together as a system, these capabilities provide a greater corporate solution to enhance the SDA mission.

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