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IDENTIFICATION AND CHARACTERISATION OF SPACE OBJECTS THROUGH NON-EARTH IMAGING

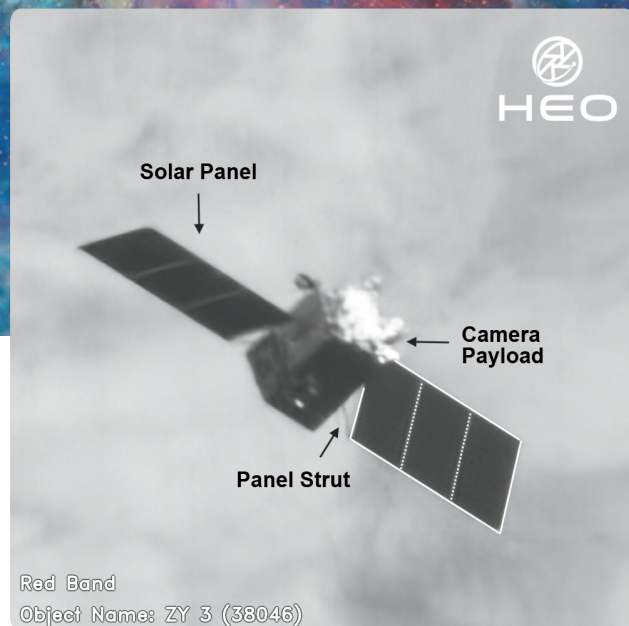


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Identification and Characterisation of Space Objects Through Non-Earth Imaging

How HEO's Non-Earth Imaging Technology rapidly identifies and characterises adversarial spacecraft



Non-Earth Imagery of ZY-3 by HEO

A New Era of In-Orbit Insights

Identifying and characterising Resident Space Objects (RSOs) is crucial for space operations, including attribution, accurate tracking, and assessing capabilities and threats to prevent operational surprises. Historically, satellite characterisation has relied on observations from ground-based sensors, including non-resolved optical and radar. However, these approaches only provide limited characterisation, often leading to large uncertainties and limited effectiveness in real-world applications.

Recent advancements in the use of space-based assets, specifically in flyby Non-Earth Imaging (NEI), are transforming how one approaches RSO characterization. Flyby NEI captures resolved imagery of RSOs, enabling the identification of specific components like solar panels, thrusters, antennas, and payloads. This approach quickly differentiates between active payloads, rocket bodies, and debris, as well as confirmation of satellite class based on comparison with known satellite types.

This paper outlines HEO's flyby NEI methodology, highlighting its use for rapid RSO identification and characterisation. We also examine real-world cases where HEO has successfully characterised RSOs, including a case study on the Cosmos 2558 satellite, demonstrating the application of NEI in threat assessment where timing is crucial.

The Commercial Opportunity

The rapid increase in objects in space, driven by national and commercial launch providers, poses a growing challenge for traditional technology. Over the last five years, more organisations have entered space for scientific, commercial, and military purposes, and this trend is expected to continue. Ride-share launches, such as SpaceX's Transporter-11 mission deploying 116 payloads into low Earth orbit, have accelerated satellite development and reduced costs. However, they've also complicated space domain awareness (SDA), as identifying and characterising newly launched spacecraft has become more difficult.

Traditionally, ground based observations, predominantly radar and non-resolved optical observations, have been relied upon to provide SDA information. While these methods are effective for tracking the position of RSOs and generating state information to predict the future position of RSOs, they have been less effective at providing identification and characterisation information. Prior to 2016, identification and characterisation of active RSOs was less critical as the average payload to launch ratio was approximately two, making it relatively simple to identify RSOs based on their orbital state data and activity status (i.e. manoeuvres). With the introduction of ride-share missions, the payload to launch ratio has increased to 12, making identification and characterisation of newly launched RSOs increasingly challenging.

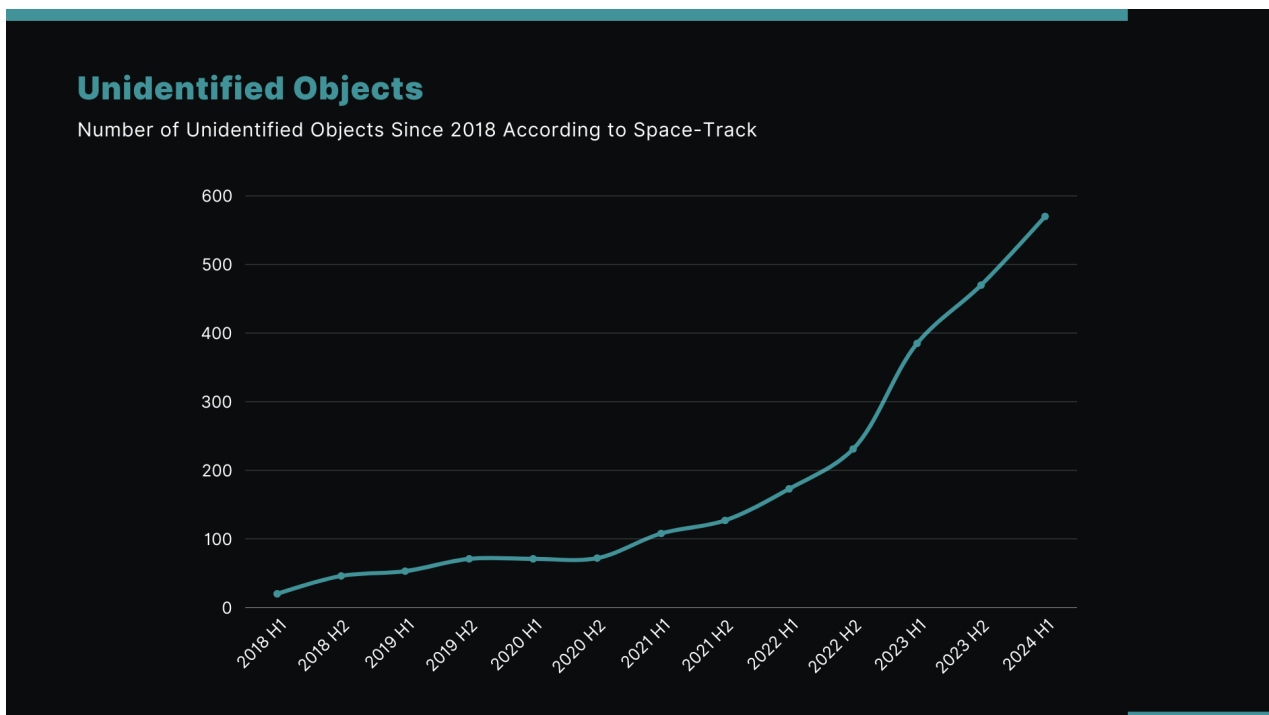


Figure 1: Number of unknown objects since 2018 according to Space-Track

As of August 2024, there are more than 700 unidentified RSOs in the Space-Track catalogue maintained by the 18th Space Defense Squadron, a large proportion of which have come from foreign launches. It is expected that this number will continue to increase without a pronounced improvement in identification and characterisation capabilities as international launch providers increase the cadence of ride-share missions.

Flyby NEI provides significantly more information than traditional characterisation techniques and presents a potential solution to both reduce the number of unidentified RSOs currently on orbit as well as to rapidly identify and characterise newly launched RSOs in the future.

HEO's Non Invasive Approach to NEI

HEO engages in flyby NEI. NEI is the use of space-based telescopes and sensors to collect resolved imagery of other objects in space. The term flyby refers to instances where space

objects naturally orbit past the imaging satellite. Taking advantage of naturally occurring flybys allows HEO to collect data in a non-invasive manner, without the need to actively adjust orbit to rendezvous with different objects, an activity both resource and time intensive.

Proliferation of sensors in different orbits is key to conducting NEI at scale. HEO achieves this by leveraging existing Earth Observation (EO) cameras, supplemented by HEO's purpose built NEI cameras in regions with low coverage, to perform high-cadence, resolved images of RSOs in space. These cameras, operated to engage in NEI through HEO's software, set the foundation for space object identification and capability efforts.

HEO's Sensor Coverage

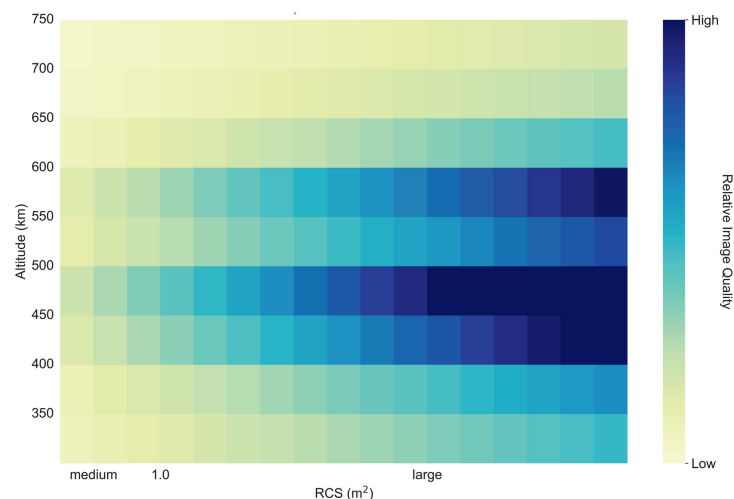


Figure 2: HEO's current sensor coverage (November 1, 2024). NEI collected in dark blue bands yields better imagery

As of August 2024, HEO has access to a network of 46 space-based sensors which are utilised to capture NEI. This sensor network includes a range of EO sensors (both panchromatic and multi-spectral), as well as HEO's own purpose built NEI cameras. Through distribution of these sensors over different altitude bands and inclinations, HEO is able to provide high cadence flyby NEI of a large portion of the LEO regime up to an altitude of approximately 750 km. Figure 2, depicts HEO's current sensor coverage, in terms of expected image quality as a function of altitude and target RSO size. Areas in the figure that are more blue indicate good coverage enabling more reliable characterisation, while white/yellow indicates altitude and object sizes where characterisation is challenging due to lack of suitable sensors. HEO plans to further increase coverage to both the high LEO and geostationary orbital regimes as well as increase capability within the LEO regime to improve image quality and reduce image delivery time.

HEO's Approach to Space Object Characterisation

Once resolved imagery is collected through NEI, HEO's space mission analysts go through a step-by-step approach to identify and characterise the object being imaged. The space mission analysts are supported by a suite of in-house automated and semi-automated analysis tools.

Below, figure 3 demonstrates the process HEO's space mission analysts follow to identify and characterise an object through NEI.

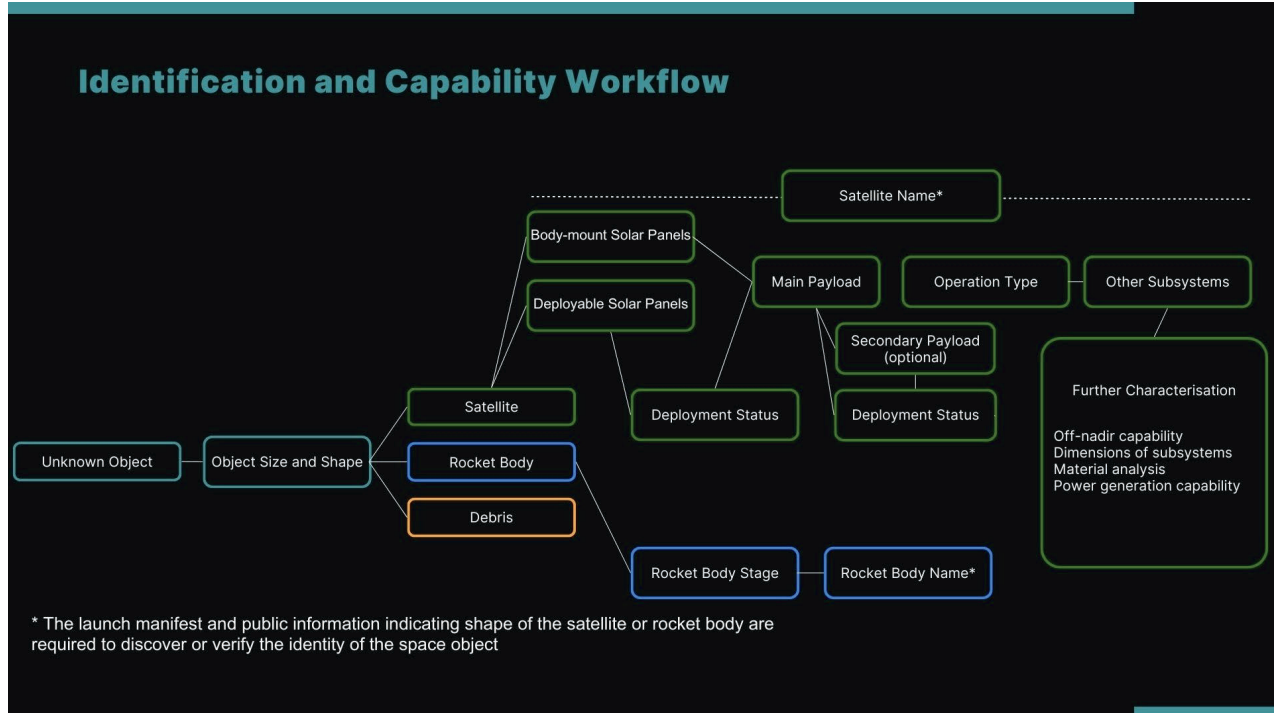


Figure 3: HEO's identification and capability workflow

To date, HEO has identified and characterised over 80 objects before any public catalog, 66 of which are still listed as unknown.

The following sections present several examples where HEO successfully applied its technologies to identify and characterise unknown and adversarial objects.

Leveraging in-orbit insights

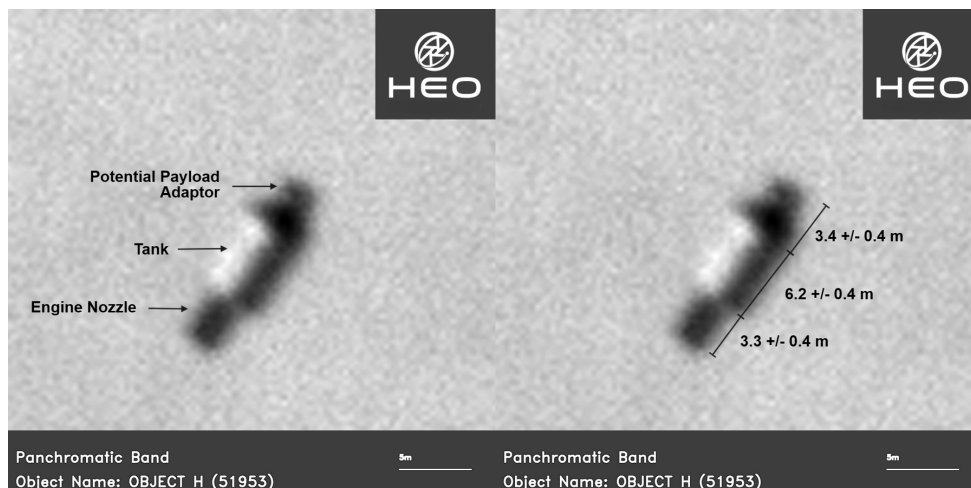


Figure 4: Identification and characterisation of unknown Object H (51953): Identified by HEO as Long-March 2C.
(left) Object H (51953): Component Labels (right) Object H (51953): Measurements

In November 2023, HEO imaged Object B (NORAD: 51947) and Object H (NORAD: 51953), two tracked but unidentified objects launched by China in March 2022. The launch resulted in 8 tracked objects published to SpaceTrack (7 listed as large RCS objects and 1 medium RCS object). As of August 2024 all 8 of the objects from this launch remain unidentified on SpaceTrack, listed as Objects A – > H. As can be seen in Figure 4, a key advantage of resolved NEI compared to non-resolved observations from ground based optical or radar is that key characteristic features are directly observable in the processed imagery, enabling rapid assessment and identification of the object. The tank, engine nozzle and payload adapter are clearly visible in the imagery allowing the object to be easily identified as a rocket body. Even this level of characterisation is important for effective utilisation of resources, as the classification of the object as a rocket body as opposed to an active object, significantly reduces the potential threat level of the object.

HEO then conducted measurement analysis on each of the identified individual components with the data depicted in Figure 4b. HEO positively identified Object H as a Long-March 2C rocket body by cross-referencing these measurements with known data on Chinese launch vehicles, along with publicly available information and tracking data from the launch.

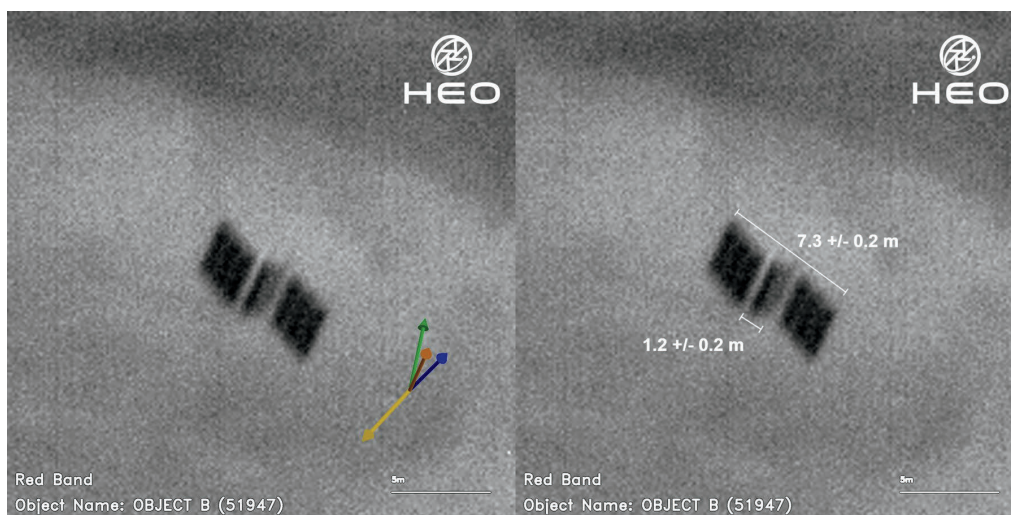


Figure 5: Identification and characterisation of Object B (51947) : Identified by HEO as Yinhe-2. (left) Object B (51947) : Image vectors (right) Object B (51947) : Measurements

Figure 5 presents the NEI of Object B (NORAD: 51947), originating from the same launch as Object H. Unlike Object H, Object B was clearly identified as a satellite, featuring two deployed solar arrays and a central bus. Measurements derived from Figure 5b estimate the hard body radius, including solar panels, at approximately 7.3 metres, with the satellite bus measuring about 1.2 metres in width. Vectors in Figure 5a provide insights into the object's orientation without requiring a full attitude analysis: the yellow vector points to the Sun, the green vector indicates nadir, the blue vector shows the target's velocity, and the orange vector highlights relative velocity in the image, revealing motion blur direction.

The satellite's distinct design, including three panels on each solar array, allowed us to generate a preliminary 3D model entirely from non-Earth imagery. To validate and enhance this model, we analysed publicly available data on the launch. Chinese media had reported on the satellites, which included six Yinhe-2 series satellites developed by Galaxy Aerospace for 5G broadband communications. Among these, five satellites featured two-panel solar arrays, while only one had three panels—a configuration matching our observations of Object B.

This level of subsystem characterisation, unattainable through ground-based data, was made possible with non-Earth imagery. By incorporating pre-launch imagery, we refined the model further, updating the satellite bus design from a rectangle to a trapezoidal cross-section. This highlights the critical role of NEI in delivering precise satellite identification and characterisation.

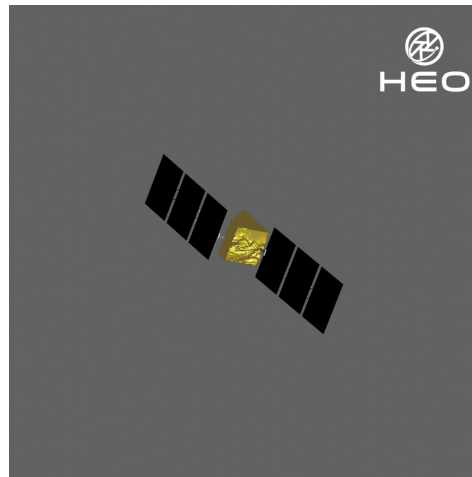


Fig. 6: Updated 3D model of Object B generated based on NEI

Case Study: Characterising and Monitoring an Inspector Satellite

Cosmos 2558 is a Russian military satellite with an unknown purpose. However, there is much public speculation that it is an 'inspector satellite', capable of manoeuvring close to other spacecraft. This speculation is due to the fact that Cosmos 2558 launched into the same orbit as USA 326, an American reconnaissance satellite. Soon after its launch, it appeared to be 'stalking' USA 326. Between its launch and March 2023, Cosmos 2558's orbital activity supported this theory.

HEO has characterised features of Cosmos 2558 through repeated observations. These include a typically light/reflective central body and 2 deployed solar panels. Due to its activity and suspected purpose, the central body most likely contains an optical telescope.

Figure 7 shows deblurred imagery that reveals the satellite's shape and overall design. From this imagery, dimensions, a 3d model and attitude can all be predicted.

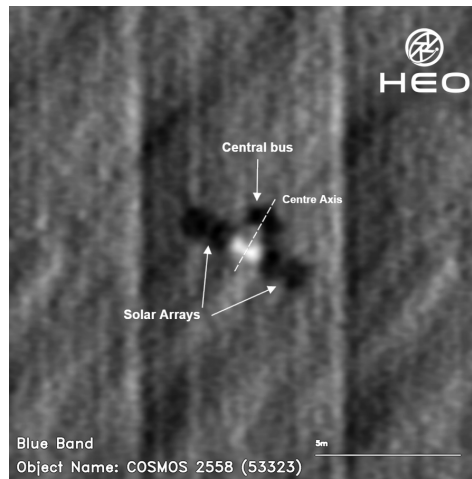


Figure 7: Resolved imagery of Cosmos 2558

The Time Is Now

As Earth's orbit grows increasingly crowded, the need for clear RSO identification becomes critical. The exponential growth in satellite numbers is on pace to overwhelm traditional tracking and identification methods.

Commercial NEI is emerging as a vital tool for making space activities more transparent. HEO's catalogue of over 2,500 non-Earth images, including those of 66 unknown objects, stands ready to assist organisations in identifying and characterising objects in space.

Reach out to our team at info@heospace.com for access to our catalogue or to request a custom NEI mission to identify an object that is not in our existing catalogue.