REUSING EXISTING SPACE INFRASTRUCTURE TO IDENTIFY AND MONITOR RESIDENT SPACE OBJECTS

Gian Luigi Somma*, Portia Bowman, Marc Dayas, Simon Walker, Simon Reid, Chris Brunskill

D-Orbit UK Ltd, Regent House, 316 Beulah Hill, London, SE19 3HF, UK,
** Corresponding Author Email: gianluigi.somma@dorbit.space*

ABSTRACT

Residential Space Objects (RSOs) might be difficult to track from the ground depending on their orbital parameters and physical properties. Traditionally, ground facilities perform measurement campaign via optical and radar instruments. Such measurements might be strongly influenced by local weather conditions, light pollution, and degraded by hundreds or thousands of kilometres of atmosphere. On-orbit monitoring can provide a platform for closer proximity and broader coverage of the space environment.

An opportunity presented itself to explore the feasibility of repurposing D-'Orbit's ION-mk01 platform (launched in September 2020) to acquire SSA/SST data and convert them into standardised formats, such as TLE and TDM, to be used for derived SST services. Thanks to the UKSA SST Program, we identified market needs and SST data and services opportunities. We developed an SST Roadmap and identified the benefits of an SST orbital platform. The existing hardware in orbit and its mission architecture was reused and expanded to adapt the current and future ION platform for the generation of SST data and services.

Results from previous ground tests were reviewed to gain additional insights, and a newly build testbeds were also used. Pictures taken from both the ground and in-orbit were compared to night sky simulation and confirmed that the existing hardware could capture stars and deep-sky objects with a magnitude lower than 5.

The projects successfully achieved its objectives despite the platform, ground facilities and operations were not designed initially for those tasks. Future works include the evolution of the platform and mission architecture to improve SST capabilities further.

***Tags**: Space Debris, SSA, SST, in-orbit monitoring*

1 INTRODUCTION

This paper presents how at D-Orbit, we reused the existing space infostructure built for the first ION mission SCV-001 (Satellite Carrier Vessel 001) for generating new Space Situational Awareness (SSA) and Space Surveillance and Tracking (SST) data and services to identify and monitor residential space objects.

1.1 Paper structure

This paper is structured as follow:

- Section 2 provides a literature review with background information on the problem of identifying and monitoring space objects (§2.1) and of keeping catalogues updated (§2.2). Finally, §2.3 introduces on-orbit monitoring as a possible solution.
- Section 3.2 illustrates how D-Orbit wants to be a responsible user for a sustainable circular space economy by reusing the ION platform (presented in §3.1) for generating SST data and services (§3.3). Section 3.3 illustrates the process that led from the idea to the actual results; while §3.4 introduces the UKSA (United Kingdom Space Agency) SST Program that funded this programme.
- Section 4 highlights the results. It presents an SST Roadmap (§4.1) and explores the benefits of having an SST platform directly in orbit (§4.2). We conducted preliminary studies to explore the existing possibilities (§4.3) before planning and executing the changes needed to reuse the existing ION architecture and generate SST data and services (§4.4).Finally, §4.5 presents and analyses pictures of stars and deep-sky objects from ground and orbital tests.
- Section 5 reports future works and, finally,
- Section 6 summarises the findings and presents the conclusions.

2 LITERATURE REVIEW

Before diving into describing the changes applied to repurpose the architecture to support the ION spacecraft, we should understand why there is the need for SSA and SST in the first place, what are the current problems and needs and how those can be solved (Figure 1).

In recent years there is an increasing number of launches (Figure 2, Figure 3), and orbits are becoming more crowded [1], with increasing risks of collision with space debris that constitute the majority of the Resident Space Objects (RSOs).

2.1 Description of the RSOs identification and monitoring problem

Residential Space Objects might be difficult to track from the ground, depending on their orbital parameters (with altitude being the most important one), object size, material, and surface characteristics.

Traditionally, ground sites consist of optical and radar instruments located in permanent facilities (i.e., with a fixed location) and record measurements through hundreds or thousands of kilometres of atmosphere, which degrade the object measurement, e.g., to atmospheric scattering.

Existing ground-based facilities have limitations in the sizes and range of objects that they could detect. Indeed, despite having state-of-the-art instruments, they could miss out small but still dangerous objects (e.g., from 1 to 10 cm in size). For example, the Space Surveillance Network (SSN) has is threshold detection limited to 10 cm in the Low Earth Orbit (LEO) and 1m in the Geosynchronous Earth Orbit (GEO) [2], [3].

In addition, RSOs measurements might also be affected by additional (transient) phenomena such as light pollution, local weather conditions, electromagnetic interferences.

Public, private, or military organisations collect the data from those campaigns and integrate them with known data in database or archives. However, satellite owners and operators often do not publicly share data on their spacecraft, while objects information might be kept private or secret to the end-users even if present in the database due to commercial, strategic, or military reasons.

As result, the RSOs catalogues might be incomplete up to 40%, not only for the aforementioned reasons but also due to the lack of widespread orbital monitoring campaigns and the natural expiration of SST data.

2.2 The consequences of an incomplete RSOs database

The low quality or even lack of SST measurement can lead to a series of issues depending on the type of objects we refer to and our interests.

From the operational perspective, the exact spacecraft location is crucial in all mission phases, but especially in the Launch and Early Operations Phase (LEOP) to locate the spacecraft and commission it as soon as possible. Such knowledge is also crucial during all orbital manoeuvres, including collision avoidance, close proximity, rendezvous and docking operations.

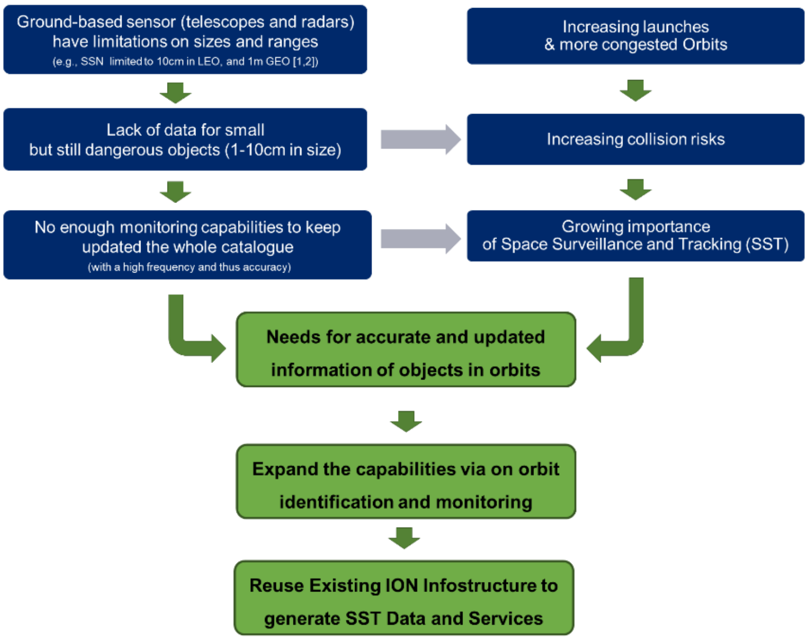

Figure 1. Diagram on how increasing launches and collision risks drive the needs to expand space object identification and monitoring capabilities.

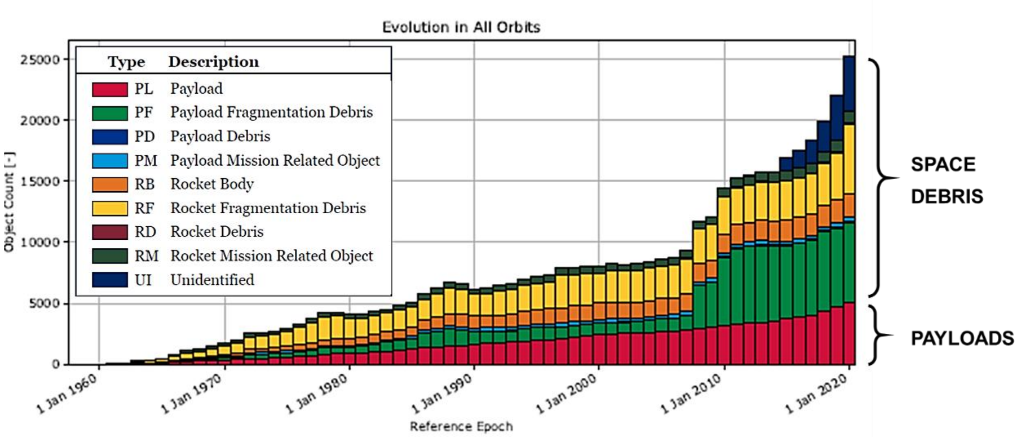

Figure 2. Evolution of the number of objects in all Earth orbits [1].

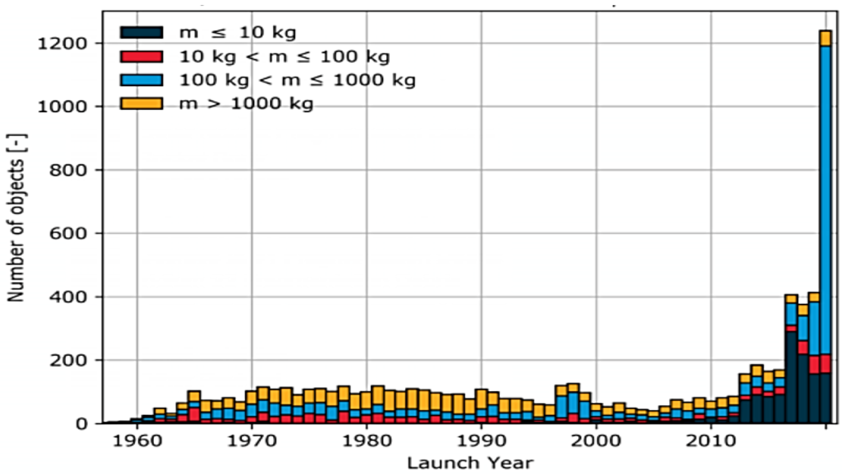

Figure 3. Payload Launch Traffic with the perigee height between 200 and 1750 km [1].

The identification, tracking and monitoring of inactive objects are also important to:

- Estimate the flux of debris in which a spacecraft could intercept during its operations. Indeed, even small debris could lead to anomalies, failures, or performance degradation.
- Evaluate eventual protective shielding, avoidance manoeuvres or operations that might need to take place, such as the "shelter in place" performed by astronauts onboard the International Space Station (ISS), and their frequency (e.g., to estimate the propellant consumption during the spacecraft operational lifetime).
- Improve the orbit selection during the mission design phase to lower collision risks.
- Model the environment, characterise the objects and make long-term predictions to reduce risks and find a solution to mitigate and remediate the space debris problem.

In addition, information on objects position needs to be frequently updated via monitoring campaigns. Indeed, the errors in the forecasted object's position grow at the point of making a measure unusable in a matter of days. This behaviour is caused by the propagation of error and uncertainties in propagators and models (e.g., long-term and lower-order orbital perturbations). Moreover, some physical phenomena are stochastic by nature and cannot be accurately predicted (such as the solar cycle and atmospheric drag at low altitudes).

2.3 On-orbit monitoring as solution

The value of monitoring from orbit is to complement the existing data catalogue and fill in the gaps for specific regions or targets of interest. For example, detailed target characterisation (shape, size, tumbling state, identification) is difficult to do with the existing ground-based sensors which are primarilyfocused on tracking all possible objects. Additionally, the uncertainty on the position of the objects measured from ground can be up to a kilometre, which makes planning efficient collision avoidance manoeuvres difficult. A space-based sensor, located in an orbit similar to the target objects, could reduce the position uncertainty and track the object throughout its orbit, rather than when just in view of the ground.

However, it could take many years to plan, design, assembly, test, validate and verify and finally launch n a new mission dedicated exclusively to SST. In this regard, D-Orbit’s key advantage is that the platform already exists (with two spacecrafts in orbit and other currently being assembled) and its nominal orbits - due to its primary rideshare mission objectives. - are among the most densely populated LEO regions both in terms of space debris to observe and of valuable active satellites that could benefit from additional SST data.

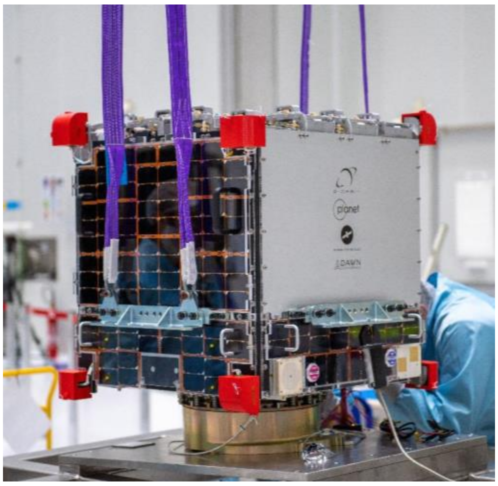

Figure 4. The ION-mk01 platform used in the SCV-001 mission fully loaded with 12 satellites and two other customers'” payloads while being integrated on the launcher in September 2020.

Figure 5. The ION-mk02 platform used in the SCV-002 mission launched in January 2021.

3 METHOD

3.1 The InOrbit NOW service

D-Orbits provides InOrbit NOW, an innovative launch service designed to host customers payloads and spacecraft and release them into precise, independent orbital slots, enabling them to start their space mission quickly and in optimal operational conditions. The platform also guarantees the customers'” spacecraft deployment thanks to the high-quality standards, fault-tolerant mechanism and redundant systems installed onboard. The InOrbit NOW service covers from the payload integration from multiple operators up to its deployment in orbit a few weeks after the launch.

D-Orbit is flying an extensive and long-term series of Satellite Carrier Vessel missions based on the ION platform, a low-cost, responsive, modular, and redundant small satellite platform.

The first iteration of the ION platform, called ION-mk01, was launched in September 2020 with the SCV-001 mission (Figure 4). The platform successfully transported and precisely delivered CubeSats from different customers (the maximum platform capacity was 48U in volume). After successfully completing its primary deployment mission, it continues to operate in an extended-operation mode.

ION-mk02 is the second iteration of the SCV platform, and it was launched just four months after the SCV-001 mission, i.e., in January 2021 (Figure 5). This newer version was heavily upgraded in components and performances. It can transport and carry a volume up to 64U or a combination of small spacecraft up to 160 kg.

The ION platform is also equipped with various onboard equipment that can be repurposed as sensors for RSO monitoring, including star cameras (Figure 6), antennas, and signal processing hardware. Integrating the monitoring of RSOs into the nominal mission architecture and operations opens new opportunities to monitor the LEO environment and supply SSA/SST data source for use by other stakeholders.

Moreover, thanks to the frequent launches, D-Orbit also offers rideshares opportunities both for spacecraft and payloads (i.e., sub-system or instruments) for in-orbit Demonstrators and Validators (IOD, IOV). For example, remaining in the space debris field, payloads could be IOD and IOV missions to prepare for the future Active Debris Removal (ADR) and In-Orbit Servicing (IOS), key milestones to achieve a sustainable use of space and support a circular space economy.

Concerning this project, D-Orbit is interested in partnering with manufactures of on orbit SST hardware (or low size, weight, and power terrestrial sensors that can easily be adapted) to provide flight opportunities on the regularly launched platform.

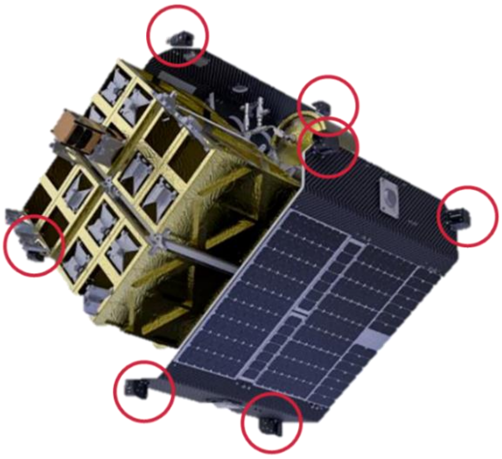

Figure 6. Location of the ION-mk02 star tracker cameras.

3.2 Responsible space users for a sustainable circular space economy

D-Orbit's business approach goes beyond its economic benefit: all the performed activities aim at producing a wider benefit for humanity and deliver a positive impact on society. D-Orbit places equal emphasis on three pillars: profit, benefit, and global impact. We design products and services to solve global challenges with a high social impact. Our internal organisation leverages the value of people and positive relationships with all our stakeholders.

For those reasons, D-Orbit was one of the first European companies to be registered as a Benefit Corporation (B-Corp) and the first certified space industry B-Corp worldwide [1].

As IOS and Space Logistics providers, we need accurate and timely information of objects in the orbits we operate to perform informed collision risk assessments and accurately deploy our customers with minimal risks. This need is aligned with D-Orbit's will to be a responsible space actor and contribute to a future Space Traffic Management (STM) Network.

3.3 The idea of reusing a space architecture for SST

D-Orbit is a space logistics company. It has already launched several spacecraft and plans to launch several additional ones in the near future.

We have a unique opportunity to reuse the existing infrastructure and spacecraft after their primary mission (i.e., deploying or operating the customers' payloads) and further iterate to improve SST capabilities.

D-Orbit cares for the "health" of the space environment, as demonstrated by receiving the B-Corp certification (§3.2), and repurposing the ION infostructure for SST is a crucial step to make a positive impact on the space environment and a significant contribution to solving the global challenges constituted by space debris and STM, generating thus a high impact for all the actors and users of the space environment.

3.4 UKSA SST program

While we were preparing the ION platform for its inaugural flight with SCV-001, the UKSA was investing in an SST Programme and provided over £1m to seven firms to help advance novel sensor technologies and the smart algorithms needed to interpret the generated SST data.

This programme's ultimate goal is to lay the foundations of a future automated space traffic management systems that will keep functioning satellites safe from other spacecraft and space debris.

4 RESULTS

4.1 SST roadmap

As a contribution to the UKSA SST Programme (§3.4), D-Orbit established a consortium with Strathclyde University and NORSS

- to repurpose ION's onboard Star Trackers for SST data collection and generation of SST services; and
- to explore the use of passive bistatic radar technique for detection and identification or orbital objects [4].

We also planned (and are following) a three-phase SST Roadmap to repurpose rather than build from scratch an SST capable spacecraft.

The first phase, completed successfully, consisted of exploring how the current technology, hardware and infostructure could be exploited for SST purposes and included preliminary tests in orbit with the ION-mk01 platform.

The next step is the experimentation phase, which started with the iterations of the hardware and technologies to be tested on the ION-mk02 platform in the SCV-002

[1] A Benefit Corporation is a model of private enterprise that commits to producing public benefit to all the stakeholders: customers, society, workers, suppliers, the community, and the environment while pursuing profitable goals. The B-Corp certification is a third-party validation of the company's positive impact on the stated goals.

mission and looks beyond to improve further the ION platform for SST purposes with dedicated hardware or payloads. The third phase is commercialisation, looking to future market demands for on-orbit sensing, adding values to our existing operations, and complementing our future ambitions as commercial space transportation logistics providers.

4.2 The benefits from having an available platform on orbit

Results from the scoping activity highlighted that the ION platform could be extremely valuable for collecting SST data, being co-resident with potential target objects. It is expected that this data can be used with a variety of different applications, depending on the customer.

Both SCV missions (i.e., 001 and 002) were launched in a Sun-Synchronous Orbit (SSO), which is among the most densely populated LEO regions. Future ION missions might be launched to other LEO orbits; however, this does not exclude that the spacecraft could potentially reside or be manoeuvred in orbits more valuable for SST purposes.

Having a spacecraft already operating in space and adapting its instruments and existing architecture offers many challenges, several benefits, and some drawbacks.

Indeed, reusing the existing ION infrastructure and platform allows to achieve results in a shorter amount of time compared to design, build, test, validation and launch of a dedicated SST mission from scratch. However, the existing hardware might not reach the same level of performances simply because it was not explicitly designed for SST purpose. Nevertheless, several benefits exist from having an available platform in orbit.

A market analysis identified multiple users. i.e., commercial enterprises, institutional organisation, and educational institutions could benefit from a wide range of in-orbit SST services.

The SST data can be generated in orbit by (re)using optical sensors (e.g. the star trackers), or with passive radar sensing [4], or via future (internal or 3rd-party) dedicated SST Payloads hosted on the ION platform (including IOD/IOV). Moreover, the data collection could be performed in multiple modalities, such as dedicated SST campaigns, but also via an opportunistic SST data collection that leverage the existing (and future) presence of ION spacecraft without the need for additional manoeuvres.

The data generated from optical and radar sensors can then be processed on the ground or directly on board. It can even be elaborated further, including multiple sensors data to improve the orbit determination's accuracy or better characterise the targets (e.g., provide a better estimate of the ballistic coefficient).

Both raw and elaborated data can be provided as services directly as raw SST Data, Two-Line Elements (TLE) or Tracking Data Message (TDM), and then can be combined with third party data into a collision avoidance (CA) service.

Moreover, it is possible to complement ground-based SST measurements with orbital sensors to

- Expand SSA/SST catalogues (e.g., detecting small-size objects or surveying orbits where there is a lack of data);
- Provide coverage in orbital regions out of range of ground facilities.
- Accurately measure and monitor the debris environment near high-priority targets or highly valuable targets (such as constellations, ISS, or other orbits with future crewed missions).
- Provide onboard real-time SST data processing, e.g., for in-orbit collision avoidance.

Further Research and Development (R&D) activities could be performed, such as:

- use the ION platform to calibrate ground SSA/SST sensor.
- provide a platform as a quick first-response to perform on-orbit follow-up, e.g., after an orbital collision.
- perform targeted space debris campaign, e.g., to characterise specific regions in a particular size and range (e.g. the sub-millimetre size in GEO) or to perform a pre-launch environment assessment (e.g. for large constellations).

Lastly, the platform could also be exploited for other activities not strictly related to SST. For example, remaining in the space debris field, an additional instrument could be designed and launched in one of the many future ION launches to investigate and better characterise the radiation environment of low-surveyed orbital regions. This example mission could benefit both researchers in enhancing existing models of the radiation environment and space manufacturers to improve the radiation hardening of space components and ultimately reduce the failure of components (or whole spacecraft) in orbit.

4.3 Exploring possibilities with preliminary studies

Backed by funding from the UK Space Agency and taking advantage of the launch of ION-mk01, an opportunity presented itself to explore the feasibility of the use of the ION platform, its sensors, and its operational modes to acquire SSA/SST data and evaluate its use for generating SST data and converting it into standardised formats, such as TLE and TDM.

The work was divided into three principal areas. In each area, the technical feasibility was analysed and complemented by a commercial analysis to establish sustainable service models to support these methods' continuous development [5].

The first one consisted of reusing the ION-mk01 platform while on-orbit after its primary space transportation mission was completed. In collaboration with SST Specialists NORSS, this work package focused on identifying the available hardware and mission architecture and compared with those needs to capture and process non-stellar objects passing in the ION cameras' field of view. A data acquisition plan was then defined to capture images of stars, deep-sky objects, and RSOs and perform tests on the achievable quality and validation of the data transmission and processing chain. The work included exploring data provision models to establish how these data can be disseminated to organisations responsible for providing conjunction alerts and other space environment services and subsequently validated and characterised.

The second area consisted of analysing the future roadmap of ION launches over the next two years. The aim was to identify and study SSA/SST mission concepts that utilised the infrastructure and the satellites being launched for the commercial space transportation system. This analysis included consideration of novel sensor concepts, in particular bistatic, passive SAR techniques (developed by Strathclyde University, [4]), and hosted payloads provided by third parties. The aim was to set a baseline of what could be achieved without fundamental modification of the primary mission concepts.

The final area performed a first-order exploration of the roadmap for future ION bus technologies based on existing ones developed for the space transportation services. The aim was to identify and specify mission concepts of dedicating an ION-derived platform for RSO monitoring and acquisition of SSA/SST data, for example, via collaboration with external parties and hosting SST-dedicates customers payloads.

4.4 Reusing the existing architecture

The original architecture for the SCV-001 mission consisted of the ION-mk01 spacecraft, a Ground Station Network (GSN) and the Mission Control Centre (MCC), as depicted in Figure 7.

We decided to reuse the existing architecture for SST purpose by including SSA Organisations and an SST Data Processing centre with a direct interface with the final users (Figure 8).

However, as we described earlier, during the UKSA funded programme, we were already building and launching the next version of ION, i.e. the mk02. Therefore, we planned to adapt and include this additional mission in the architecture (Figure 9) that was successfully launched toward the end of the UKSA-funded SST Programme (January 2021).

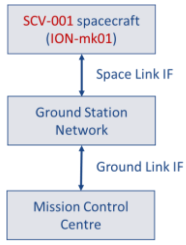

Figure 7. A schematic of the original architecture for the ION-mk01 SCV-001 mission.

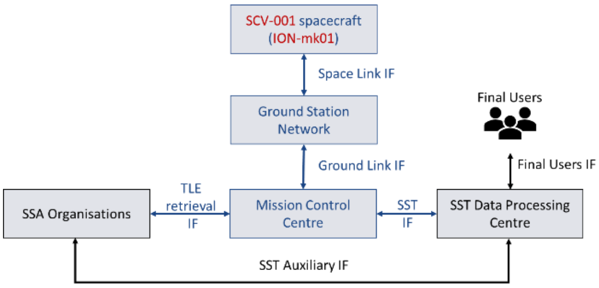

Figure 8. Reusing the architecture for the ION-mk01 SCV-001 mission.

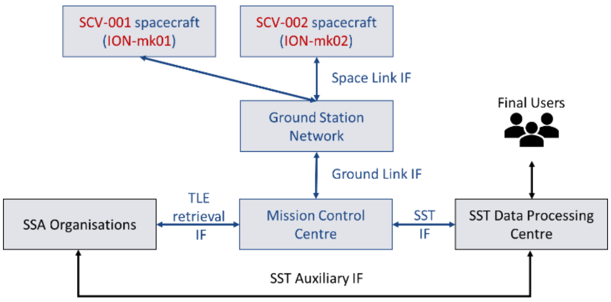

Figure 9. Adapting the existing architecture for SCV-002 and ION-mk02.

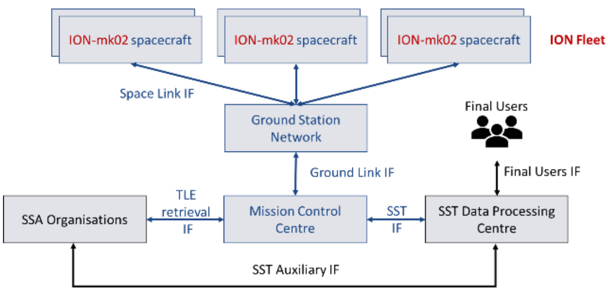

Figure 10. Evolving the architecture for the ION Fleet.

Looking forward and planning ahead, we also decided to design an evolved architecture that could include and support the future ION Fleet (Figure 10) that could significantly increase the amount of in-orbit generated SST data.

In addition to the mission architecture changes, there was also the need for additional operations. Indeed, additional windows to capture SST data were planned, scheduled, and operated; new procedures were developed and put in place; while additional passes were booked or reserved to download the newly generated data.

4.5 Reusing the existing hardware

The performed changes were not limited to a redefinition of the mission architecture or the planning and execution of additional operations. Indeed, the existing hardware needed to be tuned for executing operations for which it was not originally designed. For this reason, tests were performed on the ground with existing or newly built testbeds to validate both software and hardware.

Ground tests have already been performed during the star trackers' iterative design to validate that the instrument could effectively record lights from the stars.

Those tests were successful but were not designed to record and evaluate the instrument capability to detect non-stellar objects. As results, the existing data was reviewed to extract additional useful information, while a new testbed was built in the UK, where the team and the consortium partners are located. This review also benefited the design and test of the camera configuration and data chain specific for SST purposes.

4.5.1 Ground tests

A simulation of the night sky and camera field of view for the ground test is shown in the top image of Figure 11. It represents the sky visible from the exact date, time, location, and altitude of the test equipment during the ground test. The bottom image in Figure 11 shows one of the pictures captured by the camera during the ground tests after post-processing. Note that an inverse filter was applied to ease the reader in identifying the details (however, not all details are visible compared to the raw data).

The simulated night sky and the actual image can be compared to identify stars and also deep-sky objects. Among them, *Orion*, and the *Great Orion Nebula* (*M42*) are visible on the top-left side of the image, while *Aldebaran* (*Alpha Tauri*) and the *Pleiades* (*M45*) are visible on the top right side, while the *Lepus*, *Eridanus* and *Cetus* are visible in the lower portion of the image.

Multiple objects with a magnitude lower than five were identified from the captured images. Those images were taken in a high-mountain location with low light pollution. However, images taken from space should be subject to no anthropic light pollution (when pointing away from Earth), and therefore it is expected that the camera could produce better results and capture objects with lower magnitudes.

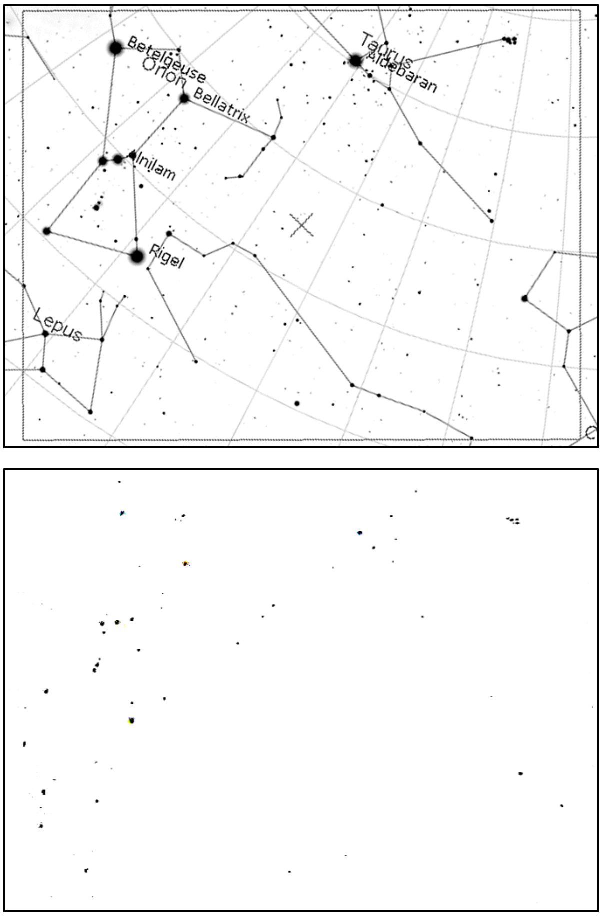

Figure 11. The simulated night sky and the camera field of view for the ground test (top) and one of the acquired images after post-processing.

Figure 12. The release of a Planet satellite captured by ION in September 2020.

4.5.2 SCV-001 and ION-mk01

Once all the payloads were successfully released in their planned orbital slots (Figure 12), the primary mission of the SCV-001 was successfully complete. The ION spacecraft entered then in its extended mission that, among the many objectives, included the capture of images for SST purposes.

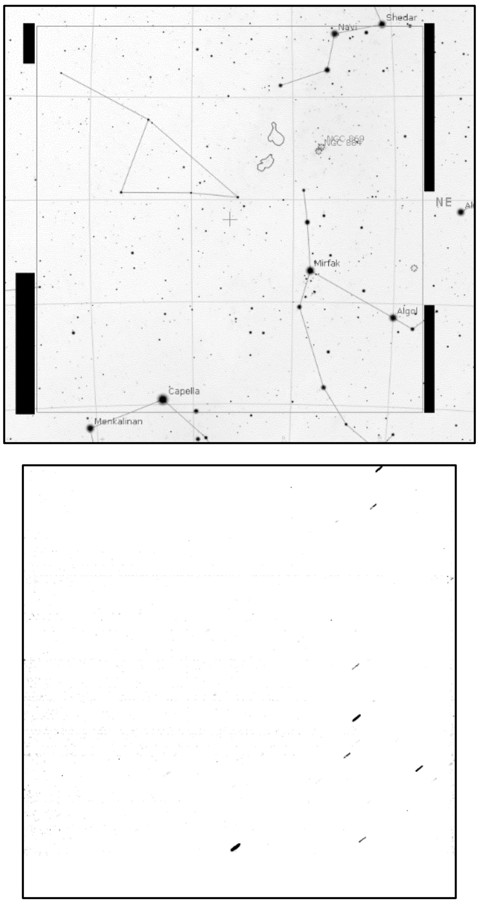

Figure 13. The simulated night sky and the camera field of view for an orbital test (top) and one of the acquired images after post-processing.

Similarly to Figure 11, Figure 13 reports two images, the simulated night sky and a picture taken during the SCV-001 extended mission.

Inside the simulated camera field of view (i.e., the top image of Figure 13), there are (from top to bottom) the constellations of *Cassiopeia*, *Camelopardalis* (i.e. the giraffe), *Perseus* and *Auriga*, with the bright *Capella* near the bottom border (*Alpha Aurigae*).

The bottom image of Figure 13 also presents some other features, not present in the ground pictures, such as the typical star trail due to the relative motion of the observer compared to the stars. This phenomenon is usually observed on the ground when taking pictures with (relative) long exposure without a camera or telescope mount that compensate for the Earth's rotation around its axis. Differently, in this case, the star trails were likely due to the residual relative movement of the spacecraft (while pointing) that was not initially designed for this type of pointing accuracy. This issue also resulted in less detailed images with fewer objects and higher magnitude (compared to ground tests).

This issue did not affect the accomplishments of the program objectives. Besides, this gave the option, as part of an agile process (Figure 14), to review and improve the software, operations, and mission architecture for the following mission, SCV-002, while hardware improvements are under study for future missions, where the hardware components were not yet procured or mounted on spacecraft in the Assembly Integration and Verification (AIV) facility.

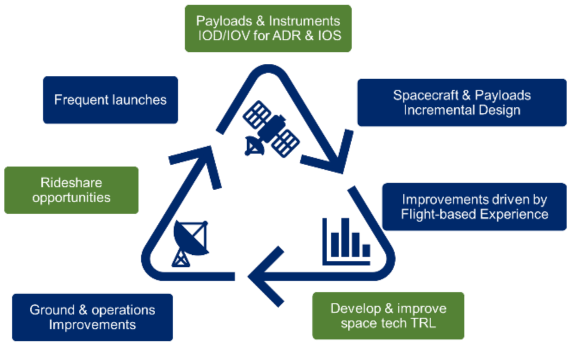

Figure 14. Opportunities derived from using the Agile Aerospace methodology.

4.5.3 ION-mk02 in SCV-002

Just four months after the start of the SCV-001, the SCV-002 mission successfully reached orbit and completed its primary mission of deploying the customers' spacecraft into their designated orbital slots.

Even if the camera was the same as the previous mission, SCV-002 used the newer and improved version of the platform (i.e., the ION-mk02). Besides, software and operations improvements took place, with additional opportunity and bandwidth to upload commands and download images with higher resolution (compared to those obtained with the ION-mk01 in SCV-001).

Indeed, Clear improvements in resolution and picture quality can be observed comparing Figure 15 and Figure 16 with Figure 12 and Figure 13, respectively.

Figure 15 depicts the first raw image of a star field received from SCV-002. Analysis is still ongoing, but a visual inspection shows promising results.

Figure 16 reports instead two of the recorded images with the camera pointed toward the ground, with the strait of Gibraltar, and Scotland with its islands covered in snow.

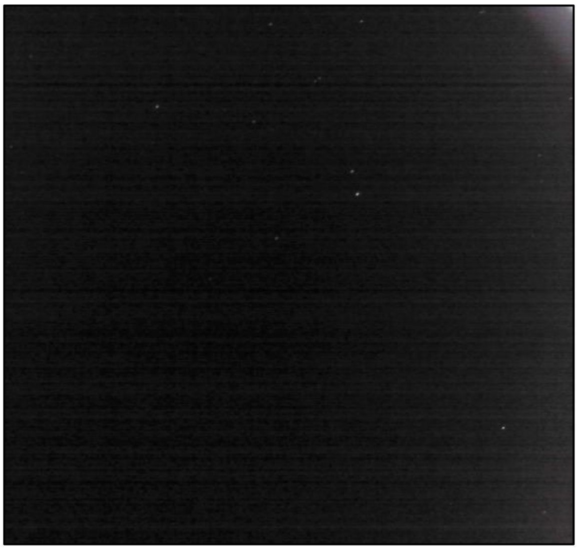

Figure 15. The first image of star field received from SCV-002.

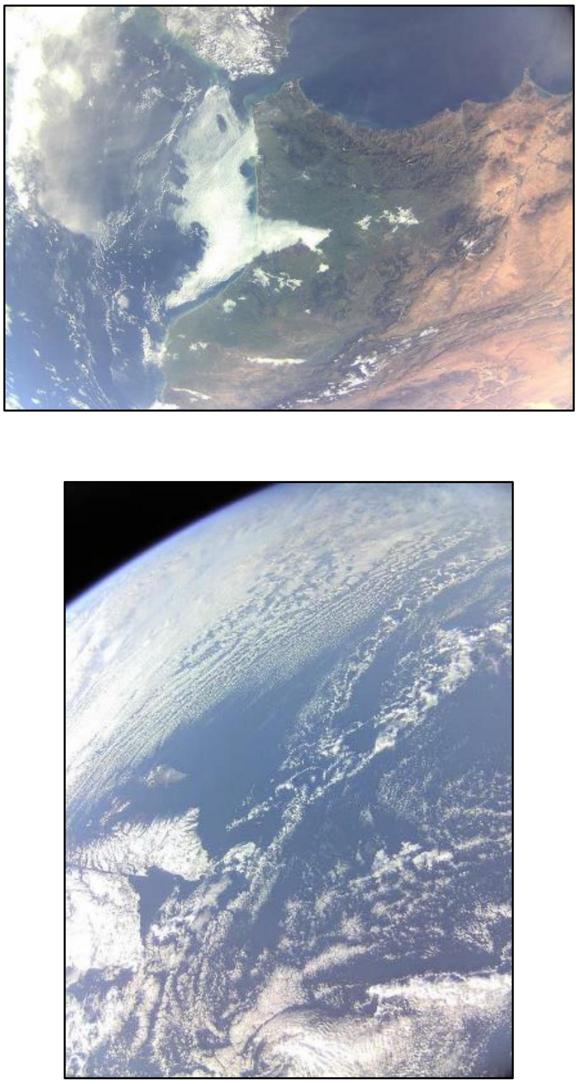

Figure 16. Earth images taken with the Star Tracker camera of SCV-002. The top image was captured over the Strait of Gibraltar, while in the bottom one is visible the North of Scotland (covered in snow), the Hebrides, the Orkney, and the Shetland Islands.

5 FUTURE WORKS

There is still future work to be performed due to the many possibilities that could be explored, such as

- Investigating a dedicated SST Mission that could exploit the full platform capability for SST purposes.
- Provide a "cloud in space" data processing service to deliver responsive and timely access to SST data and enable the automation of SST and STM services (e.g., via artificial intelligence and machine learning and currently being internally developed).
- Perform surveys (both general or tracking targets of interest in more detail) and collect SST data using the future ION fleet.
- Reuse the ION platform as an agile testbed available to customers and partners for R&D and IOD/IOV (Figure 14).
- Demonstrate complementary technologies from different actors (including IOS and ADR).

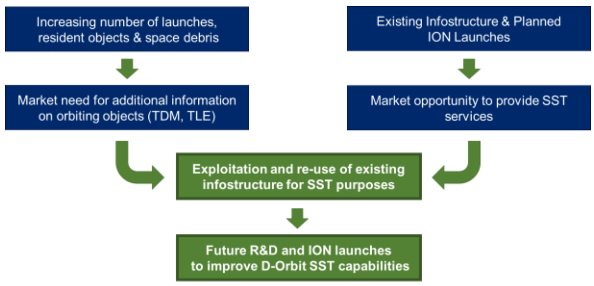

Figure 17. The market needs and opportunities that lead D-Orbit to exploit the reuse of existing ION spacecraft and infrastructure to generate SST data and services.

6 CONCLUSIONS

The number of objects orbiting around the Earth is constantly increasing, thanks also to the recent spike in the number of launches (§2.1), worsening the already alarming problems of space debris and in-orbit collision. Database of orbital objects are maintained by multiple organisations, but such database does not have yet a complete catalogue of all objects (e.g., from 1 to 10 cm in size) that could harm spacecraft (i.e., total, or partial loss of functionalities) (§2.2).

Moreover, there are not enough capabilities to monitor and update the information of all existing and newly identified objects. Indeed, due mainly to orbital perturbation, SSA/SST data (e.g., TLEs) gets obsolete in a matter of days. Therefore, Space Surveillance and

Tracking and Space Traffic Management are becoming increasingly important, and there is the need for more accurate and updated information of objects in space (Figure 17). Therefore, on-orbit monitoring and identification were proposed as a solution to this problem (§2.3).

D-Orbit provides space logistic services with the InOrbit NOW service. Among D-Orbit's products, the ION platform is a Satellite Carrier Vessel with the primary mission of quickly deploying customer's payloads into precise orbital slots, enabling them to start their space mission quickly and in optimal operational conditions (§3.1). We currently have an existing infrastructure to support the (current and future) ION platforms and a frequent launch programme in which we plan to develop space tech in new ways that we can offer to our rideshare customers as well.

D-Orbit strives for being a responsible space actor and, for this reason, became the first space industry to achieve the B-Corp certification worldwide (§3.2). Therefore, we decided to put our spacecraft and infrastructure to good use and exploit this unique opportunity to benefit the SSA field by reusing and the existing spacecraft and infrastructure to generate SST data and services (§3.3).

Thanks to the UKSA SST Program (§3.4), we identified a market need and an opportunity for SST services. Within this program, we developed an SST Roadmap (§4.1) and identified the benefits of having an available orbital platform for SST purpose (§4.2).

After conducting preliminary studies to explore the existing possibilities we planned and executed the changes needed to reuse the existing ION architecture for the generation of SST data and services (§4.3). The hardware already on orbit (or already manufactured and installed on the future ION) cannot be changed. However, operations, software and mission architecture could be adapted. The existing architecture was reused and expanded to adapt to the current and future ION programme (§4.4), and we plan to evolve this programme to improve SST capabilities further (§7).

Results from previous ground tests were reviewed to gain additional insights, and a newly build testbed was also used. Pictures taken from the ground were compared to simulations of the night sky and confirmed that the existing star tracker cameras (installed on the ION platforms) could capture stars and deep-sky objects with a magnitude lower than 5 (§4.5.1).

Those tests prepared us for the orbital tests performed during the extended mission of the ION-mk01 SCV-001 mission, during which images were successfully recorded and transmitted to the ground where they were post-processed (§4.5.2). Limitation in the platform hardware and existing architecture did not allow results as good as those achieved during the ground tests but did allow D-Orbit to identify the key bottlenecks and design changes needed to develop a fully functional commercial service. Neither the platform, the ground facilities or the operations were initially designed for those tasks; however, despite the experienced issue, the project achieved its objectives in demonstrating the ability to respond to innovative demands on orbit.

Just four months after the launch of SCV-001, a second mission, called SCV-002, delivered new customers' payloads into their desired orbits. Even though the same camera was installed, the improved version of the platform, i.e., ION-mk02, allowed to record and transmit higher quality pictures whose analysis is still ongoing but shows promising results (§4.5.3).

We still have further works to perform, and we plan to evolve the platform and architecture programme to improve SST capabilities further in the near future (§5), looking, as per our philosophy, to constant and continuous products and services improvements.

7 ACKNOWLEDGEMENTS

Part of this work was produced as an output of the UKSA-funded SST program.

We thank our consortium partners, the University of Strathclyde and NORSS, for their contributions to this project.

8 REFERENCES

[1] ESA, "ESA' s Annual Space Environment Report," 2020.

[2] NASA Orbital Debris Program Office, "Orbital Debris Quarterly News 2020 #2," *Orbital Debris, Q. News*, vol. 24, no. 2, pp. 1–13, 2020.

[3] H. Klinkrad, *Space Debris - Models and Risk Analysis*. 2006.

[4] I. Theodorou, C. Ilioudis, C. Clemente, M. Vasile, and J. Soraghan, "SISAR imaging for space debris based on nanosatellites," *IET Radar, Sonar Navig.*, vol. 14, no. 8, pp. 1192–1201, 2020, doi: 10.1049/iet-rsn.2019.0574.

[5] Planet, "What is Agile Aerospace? Learn Planet's Approach," Oct. 16, 2019. https://www.planet.com/pulse/what-is-agile-aerospace-learn-planets-approach/ (accessed Mar. 29, 2021).