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Relocation of the Atmosphere-Space Interactions Monitor (ASIM) on the International Space Station

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Abstract

The Atmosphere-Space Interactions Monitor (ASIM) is a 314-kilogram external payload attached to the Columbus module of the International Space Station (ISS). It was developed by the European Space Agency (ESA) and the main objective of ASIM is the study of the upper layers of the atmosphere and in particular, phenomena known as Transient Luminous Events and Terrestrial Gamma-ray Flashes.
On board since April 2018, ASIM has produced outstanding science.
ASIM mission was supposed to end in December 2021 when another payload was programmed to use its location. With its excellent health and science output, the idea was put forward to relocate ASIM somewhere else on the station instead of simply removing and trashing it.
With very little lead time, the ground teams managed to overcome all the hurdles to make this relocation possible. From a nadir viewing payload, designed to monitor the top of thunderstorms, ASIM has become a limb viewing one since January 2022. Remarkably, a limb viewing instrument was in the original plans for ASIM, but was descoped for financial reasons. The science produced at this new location is therefore quite complementary to the original location.

Keywords: ISS, environmental science, radiation physics

Acronyms/Abbreviations

ASIM Science Data Centre (ASDC)
Atmosphere-Space Interactions Monitor (ASIM)
Belgian User Support and Operations Centre (B.USOC)
Columbus External Payload Adapter (CEPA)
Columbus External Payload Facility (CEPF).
Data Handling and Power Unit (DHPU)
Emission of Light and Very low frequency perturbations from Electromagnetic pulse Sources (ELVES)
European Space Agency (ESA)
International Space Station (ISS)
Modular Multi-spectral Imaging Area (MMIA)
Modular X and Gamma ray Sensor (MXGS)
Space Test Program – Houston 7 (STP-H7)
Starboard Deck Nadir (SDN)
Starboard Deck X-direction (SDX)
Terrestrial Gamma-ray Flashes (TGF)
Transient Luminous Events (TLE)

1. Introduction

With its optical sensors and X- and gamma-ray detectors pointing towards the Earth, the Atmosphere-Space Interactions Monitor (ASIM) is an instrument suite designed to monitor the upper atmosphere to study Transient Luminous Events (TLE) such as sprites, jets and ELVES (Emission of Light and Very low frequency perturbations from Electromagnetic pulse sources) and Terrestrial Gamma-ray Flashes (TGF).

ASIM was mounted on the Columbus External Payload Facility in April 2018. It weighs 314 kg and has a size of about one cubic meter.

ASIM is operated by the Belgian User Support and Operations Centre (B.USOC), located in Brussels. B.USOC takes care of the general coordination for ASIM in the ISS ecosystem and carries out the requests from the science team. Terma, a Danish company, developed the ASIM payload for ESA and provides the engineering support. B.USOC collects all the data coming from the payload and transfers them to the ASIM Science Data Centre (ASDC) in Denmark. Post-processing and data dissemination is done by the ASDC. The core science teams are the Technical University of Denmark, the University of Bergen in Norway and the University of Valencia in Spain.

The payload is constantly active to monitor the skies, in search of TLEs, TGFs, interesting lightning events and auroras.

Since the beginning of the mission led by the European Space Agency (ESA), outstanding science has been produced. In total, more than 30 articles in high-impact peer-reviewed journals were published, two of which made the front page of the prestigious Science and Nature journals.

With such a science output and an excellent health, it was only natural to think about further extending to current 3-year mission plan. However it was already agreed that STP-H7 (Space Test Program – Houston 7), a NASA payload, would replace ASIM at its location at the end of 2021. Early in 2021, the idea was put forward to relocate ASIM to another part of the ISS instead of simply letting it burn in the atmosphere. After making the necessary adjustments both on ground and on board, ASIM was relocated to another location on the Columbus External Payload Facility in January 2022. Instead of being a nadir viewing payload looking directly towards Earth, ASIM is now a limb viewing payload.

In the first section of this paper, a brief overview of ASIM and highlights of four years of mission is presented.

The second part shows the challenges and coordination required for the relocation to occur from a programmatic, technical, and scientific perspective.

Finally, the change in science output and operational concept is explained. The robust design of the payload and the highly controllable settings for the instruments allow for a continued qualitative data collection within the new field of view.

2. ASIM mission and highlights

2.1 The payload

ASIM consists of three subsystems (see Fig. 1):
- Modular Multi-spectral Imaging Array (MMIA)
- Modular X and Gamma-ray Sensor (MXGS)
- Data Handling and Power Unit (DHPU)

These subsystems are mounted on a Columbus External Payload Adapter (CEPA) which itself attaches to the Columbus External Payload Facility (CEPF).

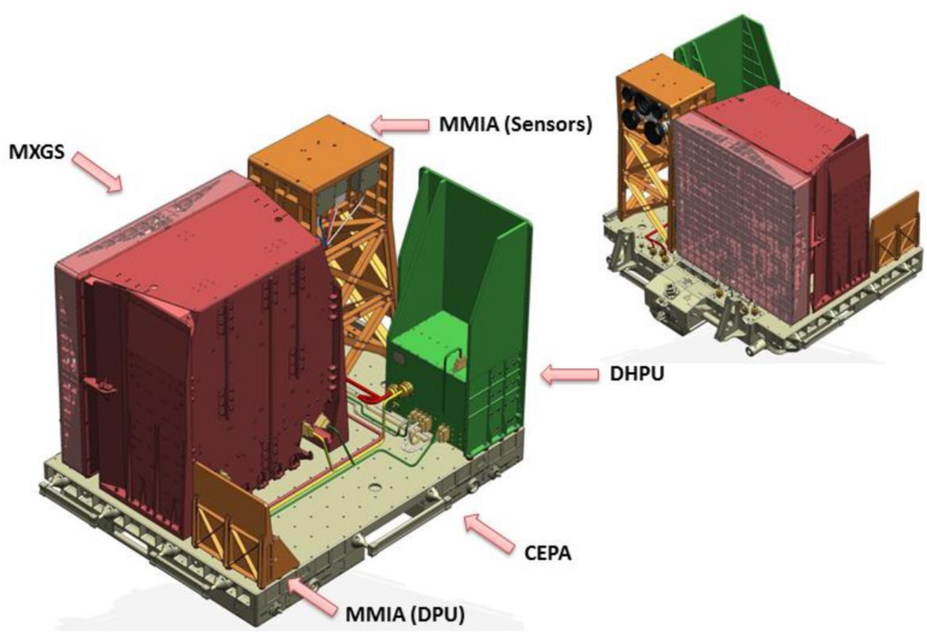

Fig. 1. ASIM payload with the three subsystems depicted: MMIA (sensors and Data Processing Unit or DPU), MXGS and DHPU. The subsystems are mount on a CEPA. Image credit: Terma.

DHPU is the payload computer and power distributor. It is the interface between Columbus (data management, power systems) and the payload. It also converts the power input from Columbus to adequate power for the various subsystems. It is used to monitor and control the facility.

The MMIA instrument contains the optical sensors of the payload: two cameras on two different bands provide the spatial resolution and three photometers in the ultraviolet band provide the temporal resolution.

The MXGS instrument consists of one low and one high energy detector layers. The low energy detector is made of Cadmium-Zinc-Telluride crystals. There is a coded mask at the aperture of the detector designed to determine the direction of arrival of the particles hitting it. The high energy detector is a layer of Bismuth Germanium Oxide scintillators coupled to photomultiplier tubes.

The payload was installed at the Starboard-Deck-X-direction (SDX) location on the CEPF. From there, both instruments point almost directly towards the nadir direction, studying the Earth atmosphere and thunderstorms from the top. The relocation put ASIM on the Starboard-Deck-Nadir direction (SDN) location of the CEPF. This new vantage point allows the instruments fields of view to focus towards Earth horizon and study the target atmospheric phenomena from the side.

2.2 The science objectives

The main objective of ASIM is to study Transient Luminous Events (TLEs) and Terrestrial Gamma-ray Flashes (TGFs) generated by the electrical activity of thunderstorms, as illustrated in Fig. 2. TGFs are flashes of gamma-rays from thunderstorms generated by energetic electrons. TLEs are electrical discharges that include blue glimpses at the top of thunderstorms, blue jets, gigantic jets, red sprites and ELVES.

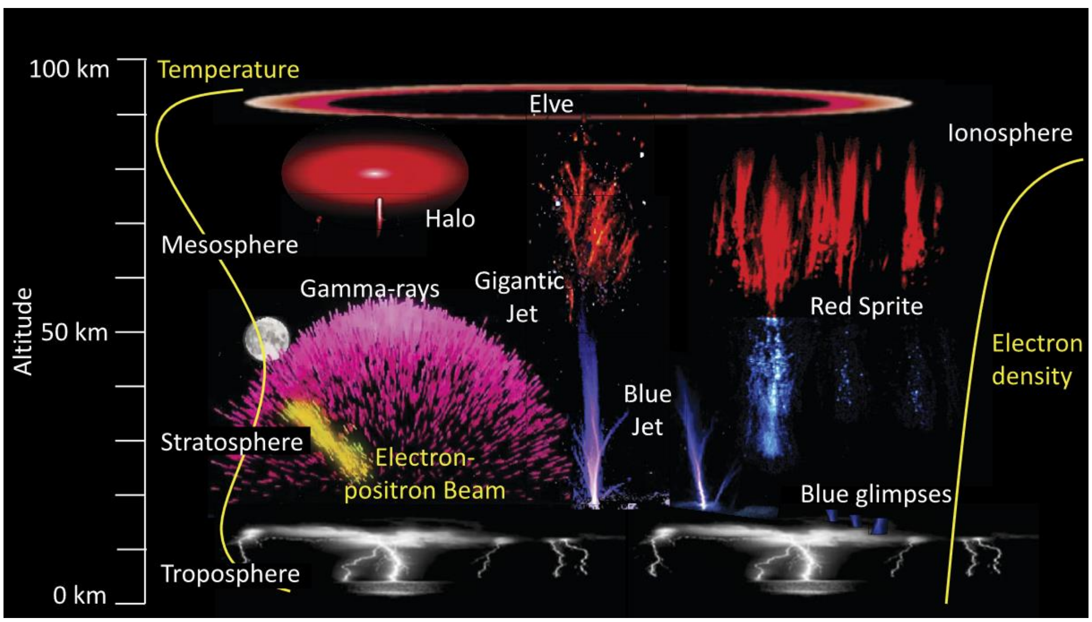

Fig. 2. The collection of upper atmospheric phenomena powered by thunderstorms. Credit: Technical University of Denmark and NASA.

The core objectives are [1]:
– To conduct a comprehensive global survey of TLEs and TGFs covering all local night times and seasons
– To secure data for understanding the fundamental kinetic processes of TLEs and TGFs
– To understand the relationship of TLEs and TGFs to lightning activity

The instruments were designed to fulfil these objectives and in particular, to understand the dynamics of these phenomena at a very fine spatial and temporal resolution. The complete list of objectives can be found in the ASIM experiment science requirements document [1].

2.3 History of the 4-year mission

ASIM was launched on 3 April 2018 and installed on the Columbus external payload facility on 13 April with the Space Station Remote Manipulator System. Power was provided and the commissioning started as soon as ASIM came alive on the station.

Within a couple of days, the first surprise arose: the low energy detectors of the MXGS instrument turned out to be sensitive to the light reflected by the Earth. This high sensitivity caused MXGS to go into a reduced science collection mode, which meant a significant loss of science. Practically this implied that the collection data from these detectors had to be stopped whenever the Earth below was sunlit, about one third of the time.

It was decided to deal with this in an operational manner. Instead of updating the flight software, the operators would prepare and uplink accurate command schedules daily, which would configure the instrument for day passes.

In collaboration with the science team, the 3-month commissioning went on and resulted in an excellent health check of the payload and the tuning of many science parameters. To improve the science return in actual ISS conditions, the need for instruments software update was also identified and would be implemented on-board in March 2019 and tested through a delta-commissioning.

At the end of 2018, the ISS survey imaging analysis team noticed that ASIM might have been hit by a meteoroid or orbital debris. The multilayer insulation of the MXGS instrument was indeed peeled in a corner. A robotic arm survey was requested and put in place to analyse further the issue. The close-up survey indicated no sign of any hit on ASIM.

The most serious anomaly for ASIM came in 2019 when the operations team realized that the mass memory unit of ASIM was corrupted, preventing any science collection. The recovery procedure, troubleshooting and ground tests lasted for about two weeks before ASIM was successfully recovered after reinitializing the disk on board.

In January 2020 the first major paper was published and hit the front page of Science [4]. This paper described the first observation of a gamma-ray flash in association with ELVES. It confirmed the theory that gamma-ray flashes occur at the onset of a lightning pulse, which generates ELVES in the early stage of a lightning flash.

A first extension to the original 2-year mission was secured and it was agreed that ASIM could continue monitoring the skies until the end of 2022.

In January 2021 the front page of Nature relayed a second major ASIM paper [5]. This marked the first time that ESA ISS experiment findings were featured in a Nature front-page article. It describes the observation of a blue jet, a lightning-like, atmospheric electric discharge that fan into cones as it propagates from the top of thunderclouds into the stratosphere. Fine characterization of five intense short blue flashes, accompanied by ELVES were observed and studied in this paper.

To optimize further the science return, an illumination test using the NASA robotic arm was executed in August 2021. The most critical operational constraint for ASIM is that the photometers of the MMIA instrument must be powered off prior to any significant light entering their field of view. While ASIM software manages the ISS day-night transitions automatically, if other lights (such as the robotic arm ones) are planned to enter MMIA field of view, this must be dealt with through coordination and manual actions. The test carried out allowed to derive an improved boundary zone for robotic activities.

December 2021 saw the publication of the third major ASIM paper in Nature [6]. While not in the original science objectives, ASIM detected a giant flare of a magnetar (a strongly magnetized neutron star). The full energy range of the main burst phase of such a flare was recorded without suffering from saturation effects, which allowed for a fine characterization and resolution of this phenomenon.

The end of ASIM seemed final with the arrival on the station of the STP-H7 payload, designed for the SDX location that was occupied by ASIM. However, to continue its fruitful mission, the idea was put forward to relocate ASIM to a secondary science location for the duration of the STP-H7 mission. With a lot of effort and preparation, ASIM was moved to the SDN location in January 2022 and is currently continuing its complementary science collection.

A graphical view of ASIM history and major events is provided in Fig. 3.

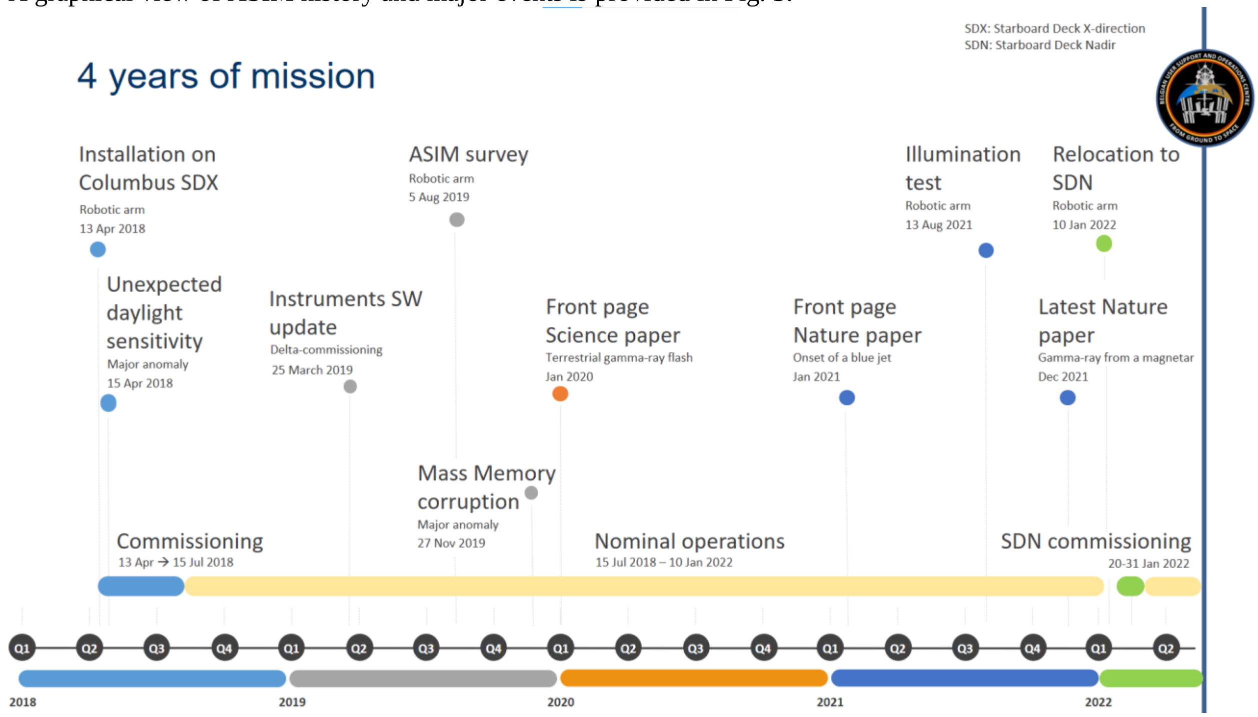

Fig. 3. Graphical view of ASIM history. The colours of the circles correspond to the year depicted in the bottom.

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3. Relocation and challenges

The idea of a relocation was first brought up in early 2021. Because of the STP-H7 payload scheduled for the SDX location on Columbus by the end of 2021, ASIM was to move in order to make room for the NASA payload.

To make this relocation a reality, many things had to happen in less than one year: study the technical feasibility, secure another ASIM extension, arrange for the robotic relocation (performed by the NASA ROBO team), work the required Columbus software patch, prepare the operations and write updates of the interface documents.

After a somewhat slow start, different items were worked in parallel at the beginning of April 2021 to ensure that this endeavour would be feasible on time. While the science and operations teams were working on securing the extension funding at their respective institutions, the technical feasibility was being analysed by the payload developer and Columbus engineers.

The new location selected would be SDN. The mechanical interfaces would be the same and luckily, no hardware modification would be necessary. Fig. 4 shows the original and new locations on Columbus.

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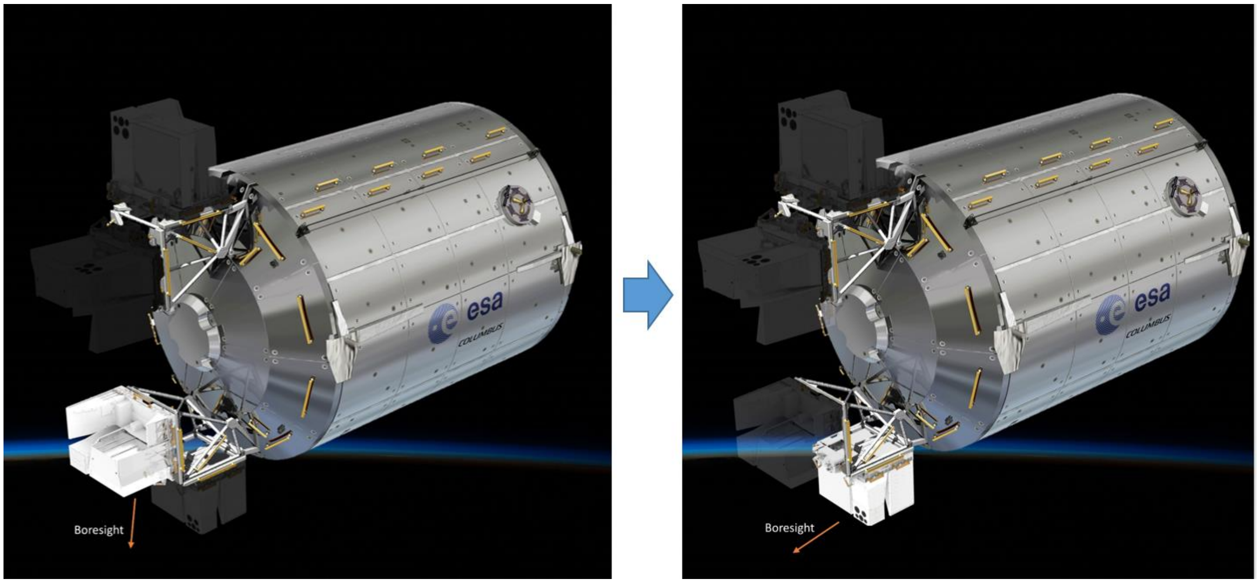

Fig. 4. Original ASIM location on SDX (left) versus new location on SDN (right) on Columbus. Credit: Terma.

On the technical side, the largest effort was put on the data management issues. For ASIM to be able to communicate perfectly with Columbus, updates would be required on the mission database and on the Columbus low rate data management, using Mil Bus 1553 communications. Both ground and flight systems would be updated. A test simulating part of this new setup was successfully performed with the ground model at B.USOC in September 2021.

On the operations side, products updates were required: flight rules, payload regulations, ground procedures and interface documents. An “SDN” commissioning was also prepared to validate the functional and science output at the new location.

Thanks to excellent coordination and collaboration, in about 9 months, many different parties ranging from operations to engineering to science were able to work together to accomplish a feat that had most likely never been done: an external payload relocation.

4. New science geometry

The first design of ASIM mission in the early 2000s contained two complementary optical instruments: a nadir viewing one and a limb viewing one [2]. Due to costs reasons, the limb viewing instrument was cancelled and ASIM ended up with this optical bench with two cameras and three photometers looking in the nadir direction, directly towards the ground.

About two decades after the first ASIM designs, the original wish, in a way, would come true: ASIM would observe the Earth atmosphere phenomena from the side as well.

The field of view of the MMIA optical instrument is a 61.4 degree. At the SDX location, looking at the thunderstorms from the top, this yields a footprint of about 400 km with a pixel resolution of 400m.

The field of view of MMIA at SDN would not produce an enclosed area as depicted in Fig. 5. Instead, it would cover a half-open area larger than the area covered at SDX, but with a poorer spatial resolution.

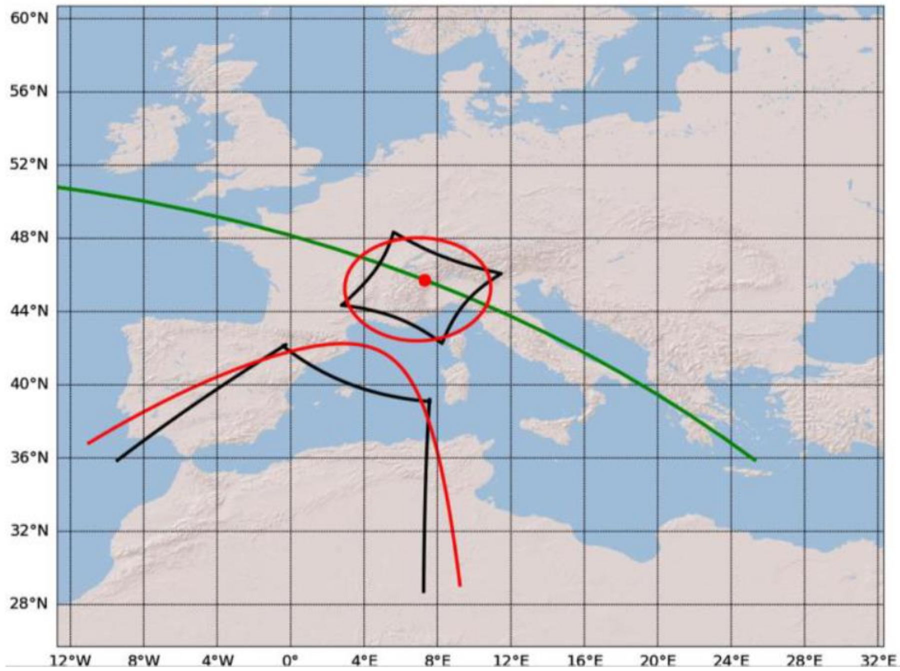

Fig. 5. Comparisons of ground projections of MMIA instruments field of views. The black lines are for the cameras, the red lines are for the photometers. The green line is the ISS trajectory and the red dot is the ISS location.

The round and square field of view are the projections at the original SDX locations while the ones resembling parabolas (bottom) are from the new SDN location. Credit: Technical University of Denmark.

The main science advantages for the new configuration are [3]:

- The field of view covers a far larger area of the Earth, and volume of the atmosphere
- Simultaneous events at different altitudes are seen separately in a column
- Altitude determination is easier
- Weaker TLEs without the lightning background from below are more visible
- ELVES, a type of TLE, will be visible with the optical cameras and the UV photometer
- Improved aurora detection

These advantages come at the cost of the following drawbacks [3]:

- Events that produce UV, X-rays and gamma-rays attenuated by atmospheric absorption
- A large part of the field of view above the Earth's atmosphere
- A large part of the field of view above the horizon obstructed by elements of the ISS
- Geolocation determination more difficult, especially for events that originate above Earth locations that are beyond the horizon

ASIM was relocated on 10 January 2022 and switched on again 11 days later, after the required Columbus software patch was implemented on board.

The SDN commissioning started immediately and all system checks were positive. Over the next two weeks, the operations team worked in close collaboration with the science team to recalibrate the instruments and optimise the science return at the new location. In particular, the cameras optical settings and MXGS high energy detector power thresholds had to be updated.

The flexibility of the instruments software (several thousands of ground-modifiable parameters) allowed for an easy optimisation of the science output.

There was concern that the Moon would somehow alter the science collection, now that part of the field of view of the instruments was facing space. An image collection of the Moon was carefully planned and executed (see Fig. 6) and it was concluded that the Moon poses no threat to the MMIA science collection.

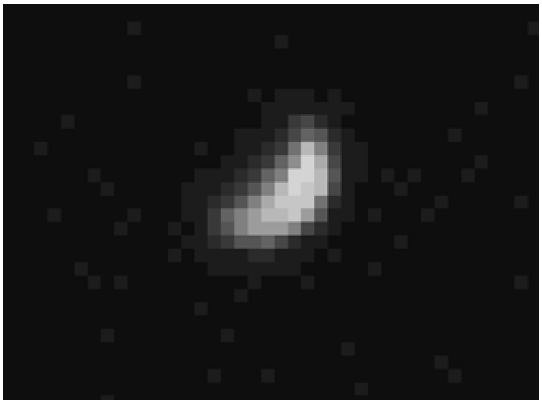

Fig. 6. Moon image from MMIA camera during SDN commissioning. Credit : Technical University of Denmark

An ELVES was imaged for the first time in the mission thanks to this new geometry (see Fig. 3). Due to the relatively faint nature of the ELVES, it was impossible to discern them from thunderstorms at the previous location from a top down configuration. The ELVES in Fig. 7 is located 85 km over the Pacific Ocean.

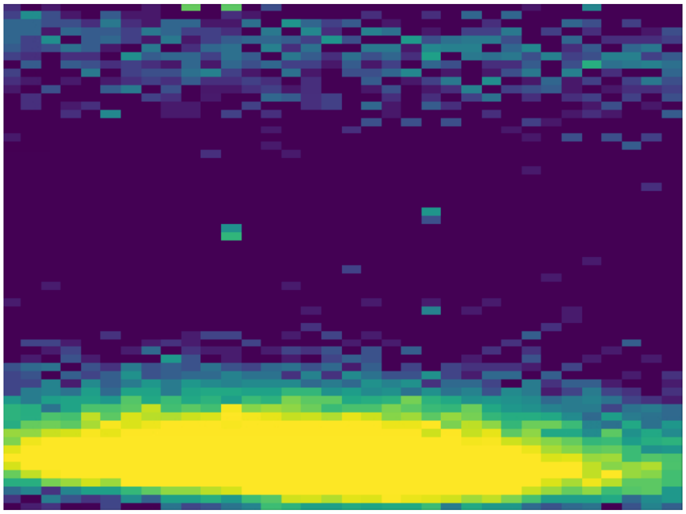

Fig. 7. First ELVES imaged by MMIA. The ELVES is seen on the top area and the much more intense lightning flash is at the bottom. Credit: Technical University of Denmark

Another change of this relocation is the impact of the beta angle on the thermal behavior and science.

The beta angle is the angle between the ISS orbital plane and the Sun-Earth direction. At the highest beta angles (twice a year around the winter and summer solstice), the orbit of the ISS is completely lit – for a few days, the ISS does not fly behind the Earth.

At high negative beta angles, before the ISS nights disappear entirely, there is a large halo on the Earth horizon which disturbs MMIA data collection. To keep recording meaningful science data, this issue is being dealt with operationally. Depending on the current beta angle, operators modify MMIA science parameters to ensure that false event triggers are not recorded, preventing further science collection.

The thermal behavior has also changed. At this new location, ASIM is not shadowed as much by Columbus and MMIA radiator faces the Earth instead of space. As a result, ASIM is generally hotter. On a few occasions, the MMIA instrument switched off automatically because a temperature limit was reached and had to remain off until the conditions were more favorable. This behavior was never experienced at the SDX location.

While the ASIM science community is very happy that the mission can continue on SDN, the scientists hope that ASIM can be relocated back to SDX to resume the more interesting nadir-viewing observations [3]. The ground teams are currently working towards this goal for early 2024.

5. Conclusions

Since 2018 ASIM has been a very successful mission with excellent science output and health. With much more to discover in the field of Transient Luminous Events and Terrestrial Gamma-ray Flashes, it was only natural to be bold and search for ways to extend the mission.

For the first time on Columbus, an external payload was relocated. This endeavour took great will, coordination and a lot of effort from all parties involved and was accomplished in only about a year.

Although the geometry of the observations has changed, the science at the new location is quite complementary to the original science and first results indicate that the output is still excellent.

In early 2024 ASIM is scheduled to return to its original location after the STP-H7 payload has vacated the spot. It will remain there for the rest of its 7-year safe operational life.

Acknowledgements

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