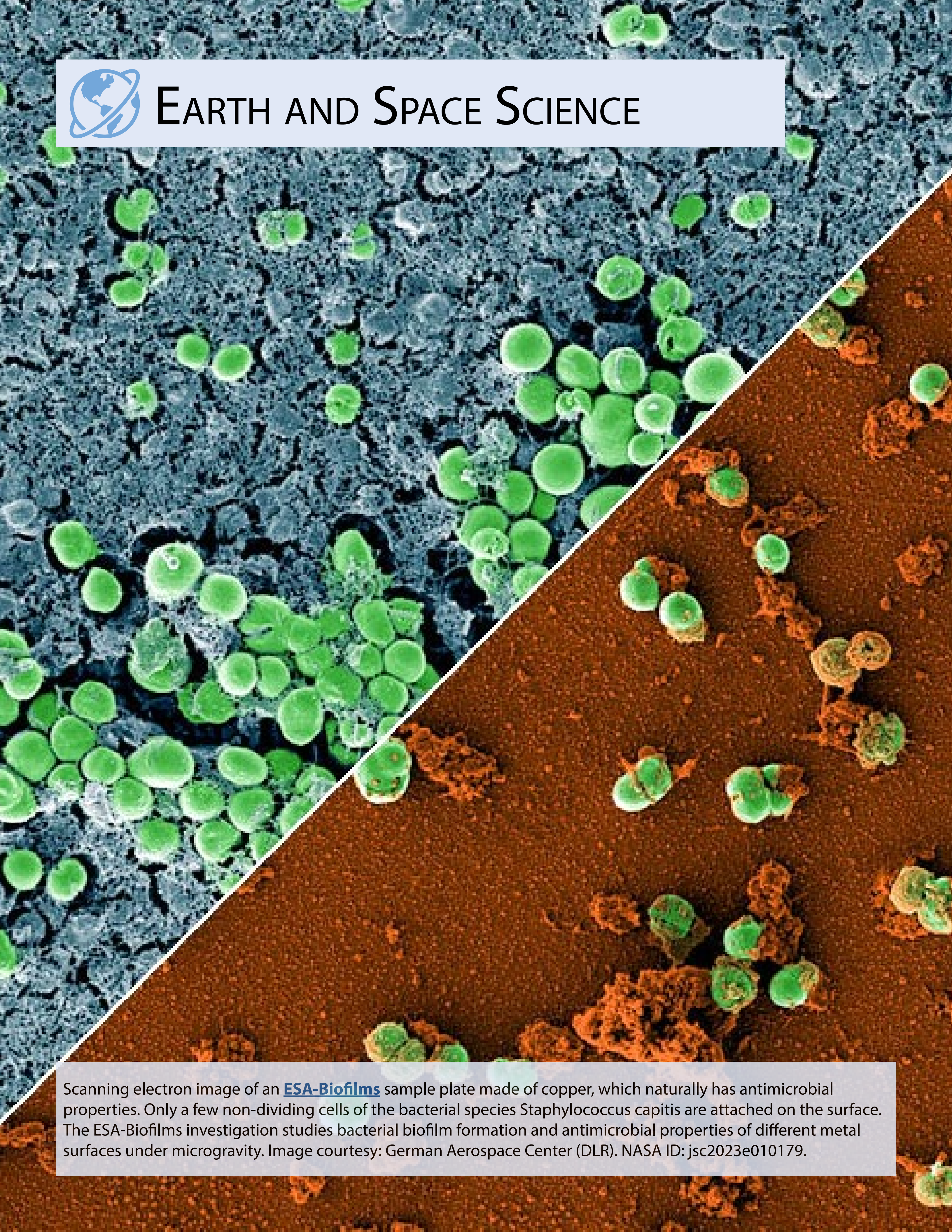
Earth and Space Science



Scanning electron image of an **ESA-Biofilms** sample plate made of copper, which naturally has antimicrobial properties. Only a few non-dividing cells of the bacterial species Staphylococcus capitis are attached on the surface. The ESA-Biofilms investigation studies bacterial biofilm formation and antimicrobial properties of different metal surfaces under microgravity. Image courtesy: German Aerospace Center (DLR). NASA ID: jsc2023e010179.

Highlights in Earth and Space Science

The position of the space station in low Earth orbit provides a unique vantage point for collecting Earth and space science data. From an average altitude of about 400 kilometers, details in such features as glaciers, agricultural fields, cities, and coral reefs in images taken from the space station can be combined with data from orbiting satellites and other sources to compile the most comprehensive information available. Even with the many satellites now orbiting in space, the space station continues to provide unique views of our planet and the Universe.

DISCOVERY

ESA's **Atmosphere-Space Interactions Monitor (ASIM)** was launched to station in early April 2018 and installed on the Columbus external payload facility a few weeks later (Figure 11). Since that time, ASIM has been continuously monitoring the Earth's upper atmosphere with a mission to study sprites, jets, Emission of Light and Very Low Frequency perturbations due to Electromagnetic Pulse Sources (ELVES), and Terrestrial Gamma-ray Flashes (TGFs) occurring during thunderstorm activity.

TGFs are phenomena related to thunderstorms and lightning but occurring above them or from within a storm cloud and directed upward. The ASIM Modular X- and Gamma-ray Sensor's high energy detector is used to detect TGFs while its low energy detector is used to image TGFs once identified. Notably, ASIM was the first space-based instrument with TGF imaging capability.

Figure 11. View of ASIM installed on the Columbus External Payload Facility. NASA ID: iss057e055411.

In a study published in *Scientific Reports,* investigators used ASIM data to identify and discuss three bright TGF events with similar durations and observation distances.[10] The investigators correlated data from ASIM with data from several other lightning detection systems, both on the ground and in space, to obtain details on the three TGFs' lightning parent events.

In all three TGF events, the parent convective cell developed 15 to 45 minutes before the TGF event. One of the three TGF events occurred close to the southwest coast of Mexico, an area with much better lightning flash detection capability than the other two events. In this case, investigators noted that: a) the TGF occurred when lightning rates dropped (from 3.7/minute to 1.1/minute in the area of study) and b) negative lightning flash rates went almost silent for five minutes and then sharply increased in the minute just before the TGF occurred. It's believed this trend may be evidence of a strong buildup of negative potential in the cloud, which may be a requirement for the TGF to occur.

Research such as this allows investigators to better understand TGF phenomena and increases our limited understanding of the thunderstorm conditions that contribute to TGF formation.

EXPLORATION

An international team of researchers used the **[CALorimetric Electron Telescope (CALET)]** attached to station externally to study the relationship between ElectroMagnetic Ion Cyclotron (EMIC) waves and electron precipitation from the Earth's radiation belts to the upper atmosphere. JAXA's investigation CALET answers questions regarding high energy astrophysics, including the origin of cosmic rays, discovering evidence of nearby cosmic ray sources, and the existence of dark matter (Figure 12).

In a new study, however, the instrument sensitivity to million electron volts (MeV) enabled it to be used to study radiation belt electron precipitation[11]. Data from the Van Allen probes was combined with data from CALET, where the Van Allen probes provided the EMIC wave data and CALET was used to characterize the MeV electron precipitation events from its low Earth orbit perspective.

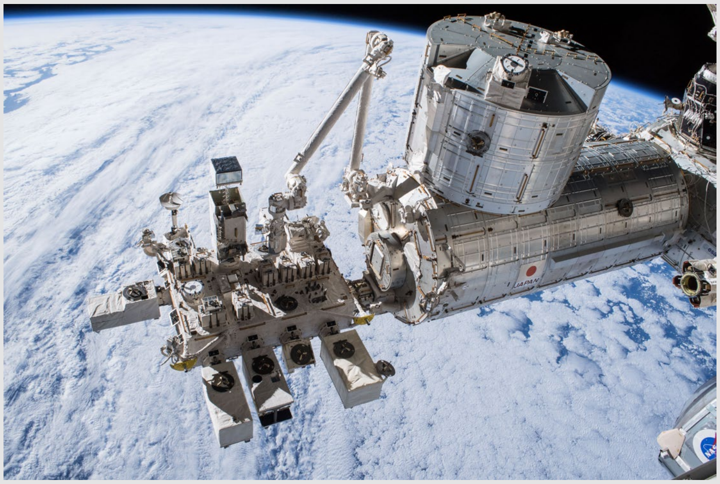


Figure 12. View of the Kibo laboratory module from the Japan Aerospace Exploration Agency. It includes CALET and other payloads. NASA ID: iss055e006395.

EMIC waves are a form of plasma wave in the Earth's magnetosphere and can drive electron precipitation events lasting several hours. Electrons in the radiation belts can cause hazards to both humans and electronics, while electrons precipitated into the upper atmosphere can result in changes to the atmospheric chemistry and subsequent ozone depletion.

With this research published in *Geophysical Research Letters*, researchers used CALET to confirm that long duration EMIC waves can drive electron precipitation into the Earth's atmosphere lasting multiple hours. The magnitude of the electron precipitation can vary significantly over time, depending on several factors (wave properties, resonance, and population of the trapped electrons).

Studies such as this help scientists better understand and characterize the hazards associated with this area around our planet.

If you are interested in learning more about Earth observations from station, including past, present, and future remote sensing investigations, as well as funding opportunities to develop new investigations, read our **Researcher's Guide to: Earth Observations.**

EXPLORATION

JAXA's external **Monitor of All-sky X-ray Image (MAXI)** experiment was launched on STS-127 in July 2009 and was the first experiment platform to be installed on the Japanese Experiment Module (JEM) Exposed Facility. MAXI is a survey instrument with the primary goals of conducting early detection of X-ray transient events and providing long-term monitoring of X-ray fluctuation of known sources. It can scan the sky for both hard and soft X-rays, defined as 6-20 keV and 2-6 keV X-rays, respectively. Similarly, intensity is categorized as high (> 0.6 photons s–1 cm–2) or low (< 0.6 photons s–1 cm–2), resulting in classifications of Low-Hard (LH) and High-Soft (HS) states.

In a paper published in *Monthly Notices of the Royal Astronomical Society*, researchers combined MAXI X-ray data with optical data sets from the Zwicky Transient Facility (ZTF) and the Las Cumbres Observatory Global Telescope (LCOGT) network to study five Aquila X-1 (Aql X-1) outbursts in a ~3.6 year period starting in 2016.[12] The purpose of the study was to develop a greater understanding of the mechanisms behind X-ray and optical wavelength outbursts from Aql X-1, a low-mass X-ray binary system located in the Aquila constellation (Figure 13).

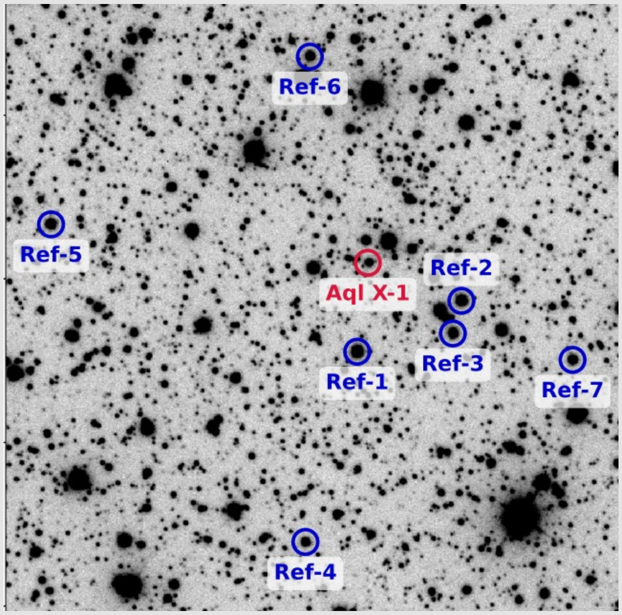


Figure 13. Sky chart with seven reference stars to identify Aql X-1. *Image adopted from Niwano, Monthly Notices of the Royal Astronomical Society*.

Three of the five outbursts transitioned from an LH to an HS state, while the other two were present only as LH events. The researchers showed that although the HS optical spectral energy distribution outbursts could theoretically originate from either the accretion disc (irradiated disc model) or as synchrotron radiation from the jet, the data fits a simplified irradiated disc model. Optical color correlation in the HS state was also supported by the simplified irradiated disc model.

Survey instruments such as MAXI are invaluable in tracking targets of interest, identifying changes such as the outbursts described in this paper, and promoting collaboration with other research platforms such as the ZTF, LCOGT, and Neutron star Interior Composition Explorer (NICER).

BENEFITS FOR HUMANITY

NASA's external [Earth Surface Mineral Dust Source Investigation (EMIT)] was developed by the Jet Propulsion Laboratory, launched to the space station on July 14, 2022, and installed robotically. Its primary goal is to assess the mineral composition of dust in the Earth's dust source regions and generate maps of these regions, but EMIT researchers have shown it can also be used to locate and quantify methane and carbon dioxide point sources effectively.

To perform its mission, EMIT uses an imaging spectrometer to analyze reflected solar radiation spanning the visible-to-shortwave infrared wavelengths (381 to 2493 nm). It collects data in 80 km wide paths, covering 1,360,000 km^2 per day, with a resolution of ~60m per pixel as the station orbits the Earth. The 381 to 2493 nm wavelengths used for dust analysis are also well suited to allow identification and quantification of methane and carbon dioxide sources, the two main human generated greenhouse agents.

In a 30-day study published in *Science Advances*, emissions from sources such as power plants, cement plants, petroleum infrastructure, landfills, and coal mine vents were located and quantified (Figure 14). For example, the EMIT researchers showed the largest oil and gas methane emissions come from Turkmenistan (731 ± 148 tons/hour), Kazakhstan (207 ± 11 tons/hour), Iran (87 ± 48 tons/hour), and Uzbekistan (86 ± 22 tons/hour), findings that are consistent with previous studies.[13] Also, two large carbon dioxide plumes (~1571 and ~3511 tons/hour) were identified as belonging to two coal-fired power plants in the Xinjiang Uygur Autonomous region of China.

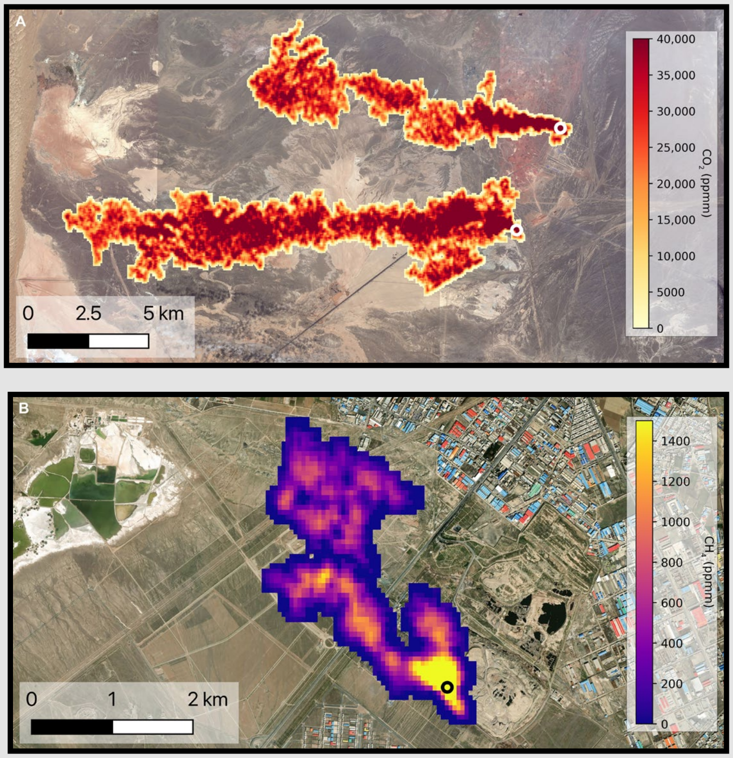


Figure 14. Carbon dioxide plumes from two power plants (top image) and methane plumes from a landfill. *Image adopted from Thorpe, Science Advances*.

Carbon dioxide and methane are primary anthropogenic agents (human-produced agents) driving environmental changes and need to be budgeted, categorized by source and sector, and quantified in order to better understand and address environmental concerns. Platforms such as EMIT give researchers the tools to accomplish this important task.

BENEFITS FOR HUMANITY

The Roscosmos-ASI-ESA investigation **Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory (Mini-EUSO)** is a state-of-the-art multipurpose telescope designed to examine terrestrial, atmospheric, and cosmic ultraviolet emissions entering Earth's atmosphere. Its optical system of 36 multianode photomultiplier tubes capable of detecting single photons allows exceptional imaging during day/night and night/day transitions (Figure 15). Mini-EUSO has been onboard station since August 2019 and is the first mission of a larger program (JEM-EUSO) that includes about 300 scientists from 16 countries.

Figure 15. Digitized image of space debris around Earth. *Image adopted from Mini-EUSO research team video.*

Data from Mini-EUSO has recently been used to test a new machine learning algorithm to detect space debris and meteors when space objects move across the field of view of the telescope. The study, published in the *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, reports that the highly sensitive algorithm, called **Refined Stacking Method and Convolutional Neural Network (R-Stack-CNN)**, is an improved version of a previous machine learning method expected to become more significant and useful as increasing traffic of satellites and spacecraft sharing the same orbits add to the risk of collisions.[14] Millions of unidentified pieces of space debris could be removed from their orbit once detected.

The R-Stack-CNN model showed precision of 88.2%, a 2% improvement over the standard method used before, and detected 63.4% more events. Researchers improved the detection of space debris and meteors by using many instances of simulated and real data, enabling offline detection, and including light curves that provide information about the rotation rates of the objects and their physical characteristics. These upgrades allowed researchers to reduce false positives and increase the reliability of the algorithm.

Despite the challenges of detecting opaque objects with a moving telescope, a changing background of clouds, light emissions from cities, Moon reflections, and the small fraction of optimal conditions during twilight, researchers employed an advanced neural network used in computer vision that allowed them to classify information more accurately.

The R-Stack-CNN algorithm could be implemented on ground-based telescopes or satellites to identify space debris, meteors, or asteroids and increase the safety of space activities.

References

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