Scanning electron image of monospecies biofilm isolated from the space station. The image was colored to visualize the bacterial cells (orange) embedded in the biofilm matrix (blue). The ESA-Biofilms investigation studies **bacterial biofilm** formation and antimicrobial properties of different metal surfaces under microgravity. NASA ID: jsc2023e010175

Publication Highlights

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. From the beginning of station to date, more than 900 articles have been published in the area of Earth and Space Science.

The Roscomos-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 raining down on Earth. Its optical system of 36 multianode photomultiplier tubes capable of detecting single photons allow exceptional imaging during day/night and night/day transitions (Figure 10). Mini-EUSO is the first mission of a larger program (JEM-EUSO) with about 300 scientists from 16 countries.

In FY-23, five publications described the advanced technology of the telescope. In one of the publications, released in the *Journal of Physics: Conference Series*, researchers demonstrated the proper functionality of Mini-EUSO, with regular collection of ultraviolet emissions data since 2019.

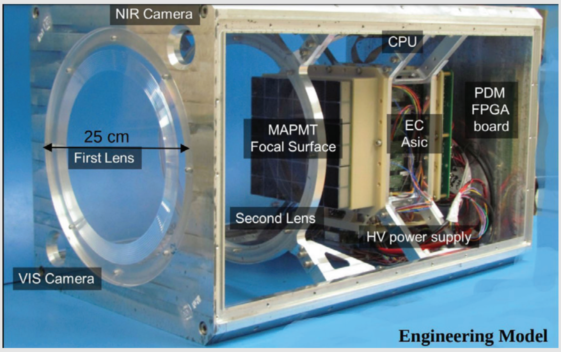

Figure 10. Mini-EUSO mock-up displaying three main compartments (optics, focal surface, and data acquisition). *Image adopted from Marcelli, Journal of Physics: Conference Series.*

Air showers, a cascade of ionized particles and electromagnetic radiation that produce a streak of fluorescent light when ultrahigh-energy cosmic rays enter the Earth's atmosphere, have been studied by ground telescopes located in the Northern and Southern hemispheres. Observing the fluorescent light from space with a telescope such as Mini-EUSO allows researchers to determine the energy of the cosmic rays, the arrival direction, and the position of the shower.

The high spatial and temporal resolution of Mini-EUSO provides the capability to study Transient Luminous Events (TLEs), Emission of Light and Very Low Frequency perturbations due to Electromagnetic Pulse Sources (ELVES), meteors, strange quark matter, space debris, marine phytoplankton bioluminescence, marine pollution, geomagnetic disturbances, ultra-high energy cosmic rays, and climate effects.

The ESA investigation **Atmosphere-Space Interactions Monitor (ASIM)**, which has been installed externally on the station's Columbus module since early 2018, monitors thunderstorm activity and its impact on the Earth's atmosphere and climate. From the top of station without cloud obstacles, ASIM can better detect different types of transient luminous events such as blue jets, red sprites, green ghosts, halos, and ELVES to provide in-depth data of these high energy emissions.

Marcelli L, Battisti M, Belov A, Bertaina M, Cambiè G, et al. The Mini-EUSO telescope on board the ISS: in-flight operations and performances. Journal of Physics: Conference Series. 2022 November; 2374 (1): 012048. DOI: *10.1088/1742-6596/2374/1/012048*

Publication Highlights

Earth and Space Science

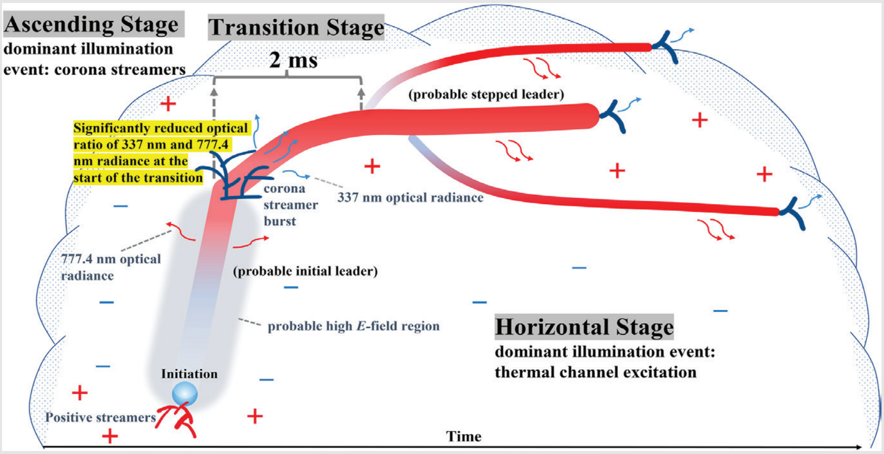

Figure 11. Diagram showing the stages of in-cloud lightening development. *Image adopted from Huang Geophysical Research Letters.*

This advanced technology provides weather information to alert communities, martime vessels, and aircraft in the path of dangerous storms. A NASA ScienceCast video further demonstrated all the benefits of this investigation.

In a new study published in the journal of *Geophysical Research Letters*, researchers combined radio signals and optical imaging to study the transition of 30 in-cloud flashes in detail. Researchers identified lightning changes that transitioned from upward leaders (i.e., positively charged "cold" lightning initiated and rising from a tall building, tower, or wind turbine) to scattered horizontal emissions across the clouds (Figure11). From space, this phenomenon was observed as blue radiance that rapidly dissipated at the onset of the transition compared to red radiance that remained virtually unchanged. An observation of reduced blue/red optical ratio coinciding with *initial breakdown pulses* (i.e., early electromagnetic field pulses emitted by lightning), led researchers to suggest that changes in the electromagnetic field form large currents of leader channels. Therefore, lightning transitions may begin when the electric charge in the main leader channel has reached its maximum.

Additional cloud-to-ground measurements reported similar transitions from upward and stepped leaders (i.e., lightning that develops downward in quick steps), suggesting a connection. Researchers hypothesize that upward and stepped leaders have different physical properties.

The **NASA investigation Neutron star Interior Composition Explorer (NICER)** analyzes neutron stars, bright star residues that remain after the explosion of massive stars, providing new insights into their nature and behavior. NICER also includes the Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) to demonstrate a GPS-like capability by detecting bright millisecond pulses in the cosmos (i.e., pulsars) to enable autonomous navigation throughout the solar system and beyond.

In a new study published in *The Astrophysical Journal*, researchers updated mathematical models of timing accuracy to investigate the rotational period of six pulsars. This study was a significant undertaking from an international collaboration of six countries (Chile, the Netherlands, France, Germany, Poland, Japan, and the US). The accurate measurement of

Huang A, Cummer S, Pu Y, Chanrion O, Neubert T, et al. Transition in optical and radio features during the early development of negative intracloud leader. Geophysical Research Letters. 2022 November 28; 49(22): e2022GL100594. DOI: 10.1029/2022GL100594.

pulsars' rotational period allows researchers to infer their properties and prompt their classification. Additionally, precise timing calculations allow researchers to examine the potential effects of pulsar rotation on gravitational waves.

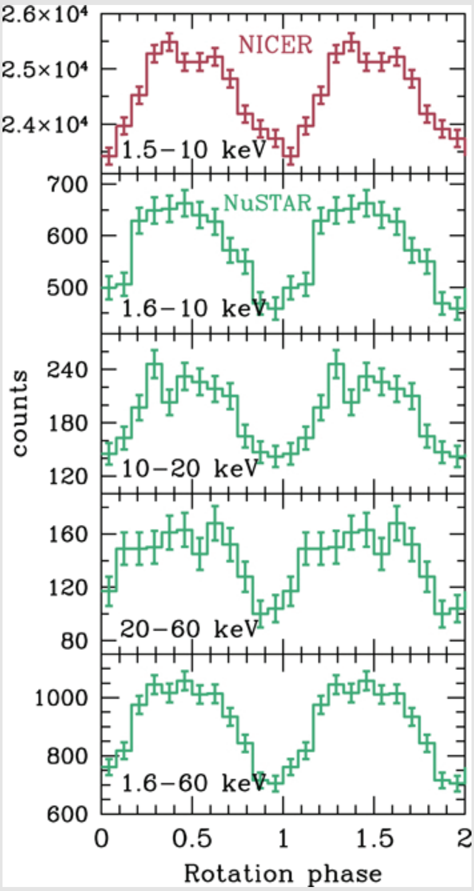

Figure 12. Two rotation cycles for one of the five pulsars examined by NICER and NuSTAR. Data from multiple space instruments allowed researchers to adjust previous calculations to better understand the spinning of neutron starts. *Image adopted from Ho, The Astrophysical Journal.*

Through calculations of multiple data obtained from NICER, Chandra, and NuSTAR, researchers reported new, corrected rotation numbers for two pulsars by considering when the actual pulse occurred and the time of arrival of the pulse to Earth (Figure 12). Additionally, the timing baselines of three pulsars were extended three to four times over previous calculations. For a young energetic pulsar, researchers detected 15 glitches over 4.5 years of data collection. These glitches in pulsar monitoring denote timing irregularities that may result from detached superfluid vortices.

These advances in precise measurement enhances the understanding of pulsar properties and their effects on our solar system and planet.

The JAXA investigation **CALorimetric Electron Telescope (CALET)** is a high-resolution particle detector able to distinguish different types of particles from cosmic rays and dark matter. It includes an imaging and a total absorption calorimeter to measure energy loss and to observe the paths of high-energy cosmic ray nuclei. The hardware was launched to station in 2015 and installed on the Japanese Experiment Module Exposure Facility. Analysis of CALET data provides new insight into the source of cosmic rays, the nature of energy particle acceleration mechanisms, and the characteristics of interstellar space in our galaxy.

In a new study published in *Physical Review Letters*, through an extensive collaboration between Japan, Italy, and the United States, researchers examined helium particles from a large energy interval (~40 Giga-electron-volts to ~250 Tera-electron-volts) collected from 2015 to 2022. CALET measurements demonstrated that the helium spectrum fluctuates from lower to higher energy, and its

Ho WC, Kuiper LM, Espinoza CM, Guillot S, Ray PS, et al. Timing six energetic rotation-powered X-ray pulsars, including the fast-spinning young PSR J0058-7218 and Big Glitcher PSR J0537-6910. The Astrophysical Journal. 2022 November 1; 939(1): 7pp. DOI: 10.3847/1538-4357/ac8743.

most significant deviation shows energy increases (Figure 13). These measurements agree with other space instruments such as PAMELA, AMS-02, DAMPE, and CREAM.

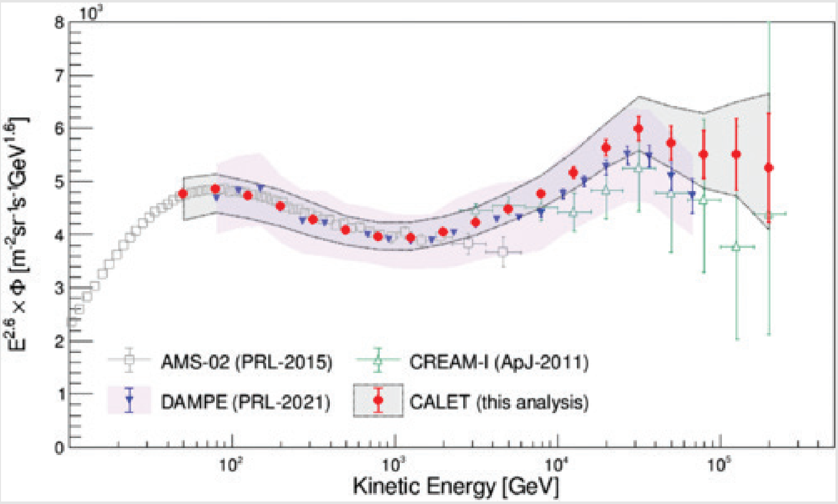

Figure 13. Cosmic ray helium spectrum as measured by multiple space instruments. *Image adopted from Adriani, Physical Review Letters.*

Unexpectedly, researchers found that at lower energies (slow-moving particles), there was a “hardening” of the spectrum – more helium nuclei than expected were found, whereas at higher energies (fast-moving particles), less helium was found. The presence of these “features” (increase and decrease of the particle flux depending on the energy) allowed researchers to assess which statistical model best explained these trends.

This study allows researchers to understand how cosmic rays travel and propagate through the galaxy, providing additional discrimination between the theoretical models proposed to explain their behavior and improve our understanding of cosmic ray origins.

Adriani O, Akaike Y, Asano K, Asaoka Y, Berti E, et al. Direct measurement of the cosmic-ray helium spectrum from 40 GeV to 250 TeV with the Calorimetric Electron Telescope on the International Space Station. Physical Review Letters. 2023 April 27; 130(17): 171002. DOI: 10.1103/PhysRevLett.130.171002.