A Ground-based UV Light Source for the EUSO Mission

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Abstract

The Extreme Universe Space Observatory (EUSO) mission will measure the fluorescence signal produced by Extensive Air Showers (EAS). To determine the intrinsic shower luminance and hence the energy of the incident cosmic ray, a correction must be made for attenuation in the atmosphere. This correction will be determined on an event-by-event basis by atmospheric sounding with a LIDAR. We report here on a "ground truth" concept to verify EUSO's measurements of intrinsic shower luminance.

1. Ground-based Light Source (GLS) Concept

The Extreme Universe Space Observatory (EUSO), attached to the International Space Station (ISS) for a 3-year mission, will detect the fluorescence signals produced by Extensive Air Showers (EAS) in Earth's night-side atmosphere. Proper analysis of the fluorescence signal requires knowledge of the transmission properties of the intervening atmosphere. These parameters will be determined by atmospheric sounding techniques with a separate Lidar System (LS), co-located with EUSO, during the mission. The LS will profile the UV scattering and absorption as a function of depth in the atmosphere to determine the attenuation of the UV fluorescence signals reaching EUSO. To validate the LS results, a second, independent system consisting of a set of Ground-based Light Sources (GLS) is planned. The GLS will provide a direct test of the accuracy of the reconstructed luminosity of EAS under atmospheric conditions observed by EUSO.

Our GLS concept is based on xenon flash lamps with high-intensity output in short microsecond flashes. A total of 11 lamps, 10 ground-based units and 1 airborne unit, will be deployed to different geographical locations. On average, the ISS will fly over one of the GLS sites each night throughout the EUSO mission. As EUSO approaches one of these sites, the unit will be activated automatically. The GLS will remain within EUSO's FOV for 10-60 seconds. We estimate that >500 photoelectrons per flash will be generated in the focal plane detectors for the baseline EUSO design and an assumed 50% atmospheric transmission[1]. This signal is large enough to trigger EUSO and acquire an image of the flash. The LS will then automatically point in the direction of the GLS location and probe

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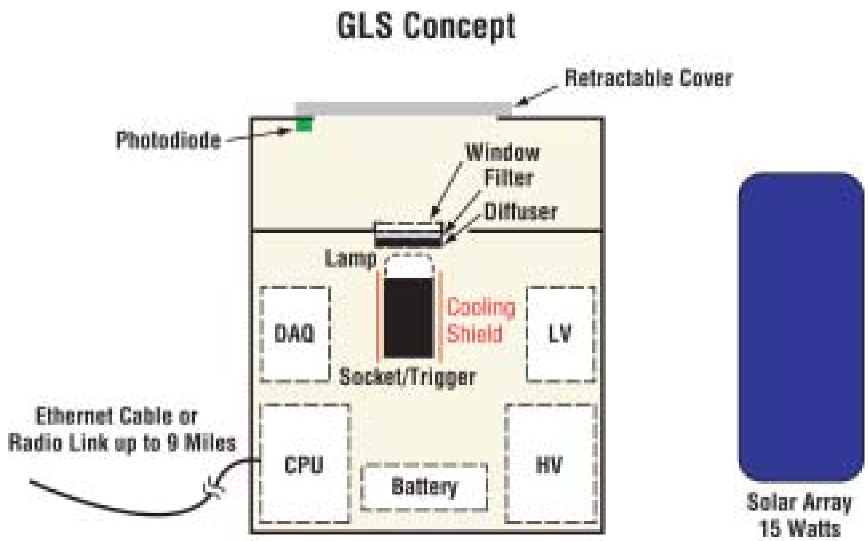

Fig. 1. Diagram of a single GLS unit showing the basic elements.

the current atmospheric conditions. The captured data will be recorded on the flight-data system and transmitted to the ground. The atmospheric attenuation will be determined from the recorded images of the GLS flashes and their known photon flux. This result will be compared to the parameter derived from the LS data.

2. GLS Design

The central element of each GLS unit is a xenon flash lamp with strong output in the UV region. Our present concept is based on the Hamamatsu flash lamp L6604[2] which has a flash-to-flash stability of 3%, spatial uniformity better than 95% over a 60° FOV and has a life cycle of $>10^7$ flashes. A thin diffuser will be used to ensure the spatial variation is below 1% over a 5° arc. Four flash lamps will be grouped together to form a single GLS unit and housed in a weatherized canister. Three lamps use narrow band-pass filters centered on the principal N_2 fluorescence lines at 337, 357, and 391 nm. The fourth lamp uses a wide band-pass filter (330-400 nm) like that proposed for the EUSO focal surface. The weatherized canister has an upward looking window made of UV transmitting glass that is covered by a remotely controlled mechanical shutter(Fig. 1).

A single-board computer (SBC) operates the GLS autonomously. Prior to an overflight, the flash lamps are activated for several minutes to stabilize the light output. The mechanical shutter is opened and the lamps are fired sequentially during the overflight. A photodiode monitors the output of the GLS unit during operation. The SBC collects the housekeeping data (pulse-height-spectrum, temperature, time stamp) and relays it to the facilities located nearby at the host site. The data can then be accessed through the world-wide web. We use a bi-directional communication link in order to receive data from the GLS unit and to update the orbital parameters of the ISS in the SBC memory. Power for the GLS unit will be derived from a solar panel with integrated battery. The ancillary components are all interfaced to the SBC. The shutter is the only moving part of the GLS unit and uses microswitches to monitor the shutter operations.

3. Laboratory Calibration

The usefulness of the GLS concept depends on knowing the output intensity accurately. The manufactures[1] data shows that this is readily achievable for our application. To verify the uniformity and repeatability of the flash tubes and to derive the absolute photon flux of the assembled units, we will construct a laboratory measurement station to make a precise map of the light intensity for each GLS unit. The intensity map will be measured over a wide FOV on a 5°x5° two-dimensional grid. A calibrated photomultiplier tube with a pinhole aperture will move across the FOV of the GLS on a curved track. The photomultiplier tube will stop at 5° intervals where the absolute photon flux per flash will be measured. The GLS unit is mounted on a stage that tilts the entire assembly in 5° intervals to generate the second dimension of the intensity map. The combination of a highly uniform and repeatable flash and measured intensity maps will ensure that the photon flux emitted by the lamps are known accurately.

4. Deployment

The deployment strategy for the GLS units will test several atmospheric conditions. The GLS consists of two variations of the basic unit described above: (1) An airborne version and (2) a stand-alone version. The airborne unit will be installed in an upward viewing portal of a P-3B research aircraft stationed at NASA's Wallops Flight Facility (WFF). A BK11 glass bubble to protect the GLS unit from the slipstream of the aircraft encloses the portal. Flight operations will be scheduled to coincide with ISS overflights and will take place approximately monthly. These flights will be performed over land and over the open ocean with average flight times lasting 1 and 2 hours respectively. The additional flight time for ocean flights ensures the city lights on the U.S. eastern seaboard are outside the EUSO FOV. Each underflight by the P-3B will target a specific pass of the ISS and an altitude between 2 and 6 km.

The 10 stand-alone units will be deployed to strategic ground locations at the start of the EUSO mission. We consider scientific facilities, such as mountaintop cosmic-ray neutron monitoring stations, as possible host stations to locate the GLS units because they can provide access to the Internet and some minimal support by the local staff. Of special interest are island locations, such as Hawaii, that will provide atmospheric conditions representative of the open ocean. Also, locations with high geographical latitude are particularly useful because they provide a high occurrence of nighttime overflights, especially during local winter. The final site selection will also consider the accessibility and availability of communications. Ten spare GLS ground units will be deployed as needed, later in the mission.

5. Operations and Data Analysis

Operations for the airborne unit includes transporting the GLS to WFF and installing it in the aircraft. Flight plans will be developed that consider the weather, targeted ISS overflight opportunity, and desired altitude. Prior to a rendezvous with the ISS ground track, the aircraft anti-collision lights will be turned off to prevent unwanted background at the aircraft location or from reflections off nearby clouds. The GLS will be activated once the aircraft is within EUSO's FOV. During the exposure the housekeeping data for the GLS will be monitored.

The operations for stand-alone units will include updating ISS orbit parameters and retrieving the housekeeping data from each GLS unit. A file containing a table of ISS overflight times for each specific GLS location will be uploaded into the SBC memory and updated as needed. The housekeeping data will be analyzed to determine the functional status of each unit. Arrangements will be made with the local sponsors at the site to provide some basic maintenance for the GLS units that will otherwise run autonomously.

The GLS data analysis will be performed in parallel with the main EUSO data analysis activity. Calibrated EUSO data will be retrieved from the EUSO Science Data Center in Lisbon, Portugal and searched for time periods containing overflights of a GLS site. This data will contain all relevant information concerning each overflight, such as the measured luminosity of the GLS and the LS data. A comparison of the GLS measured attenuation and the values derived from the LS analysis will be made.

6. References

1. Andrew Allen, Hamamatsu Corporation, Personnel Communication (2002).
2. Xenon Flash Lamps, Hamamatsu Photonicsi K.K, http://www.hamamatsu.com.