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Study of UV background by the ISUAL experiment

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Abstract. The UV background is an important noise for space borne air-fluorescent experiments such as OWL. However, very little is known about the UV background. One of its possible sources is lightning. Some upper atmosphere lightning could emit strong UV light and be misidentified as an up-going neutrino signal. The ISUAL (**I**mage of **S**prite: **U**pper **A**tmosphere **L**ightning) experiment on ROCSAT 2 will make global surveys of lightning induced luminous phenomena from orbit. This experiment employs a six-channel spectrophotometer with two channels targeting at 337.1nm and 391.4nm, which are the UV signals used by air-fluorescent experiments. The ISUAL will measure the global distribution of upper atmosphere lightning and airglow. Such information could help experiments such as OWL to reduce background noise due to lightning.

1 Introduction

Since the discovery of 3.2×10^{20}eV event by the Fly's Eye group (Bird et al., 1995), the search for cosmic rays with energy beyond the GZK cutoff is becoming more important and popular. Because of the extremely low flux, the detection of ultra high energy cosmic rays (UHECR) requires a very large collecting area. An alternative approach is moving the detector to space using the atmosphere as calorimeter. Employing techniques similar to those of the Fly's eye experiment, fluorescent light detectors such as Orbiting Wide angles Light collectors (OWL) and AirWatch flying at high altitude can cover more area than any ground based detector. The main channel of detection is the UV light from N_2^+, which is excited by charged particles in the air shower initiated by primary cosmic rays. However, little is known concerning the UV background of the atmosphere.

There are approximately 2000 thunderstorms and 100 lightning happening at any time on the Earth surface. Lightning produces bright light and which can blind the fluorescent light detector for a short period of time. Assuming that the OWL cover $10^5 km^2$ on ground, the expected number of thunderstorms in the field of view is

$$(2000 \times 10^5 \mathrm{km}^2)/(4\pi R_E^2) = 0.04$$

where $R_E = 6371.2$km is the mean Earth radius. Assuming that each lightning last for 300ms, then the dead time rate is approximately

$$\frac{100 \times 10^5 \mathrm{km}^2}{4\pi R_E^2} \times \frac{300\mathrm{ms}}{1\mathrm{s}} \simeq 0.06\%$$

The situation is worse when OWL fly over an active thunderstorm, there could be several flashes of lightning happening in the same period. The peak lightning rate and dead time rate should be much higher than the estimated values. From the operation experience of the Fly's Eye, the dead time could rise from less than 1% to several 10% when an thunderstorm and lightning happen. The thunderstorm could be a major source of noise for OWL.

The discovery of upper atmosphere lightning (UAL) by Franz et al. (1990), arouses much research interest in these energetic atmospheric electric activities. The ISUAL will make global surveys of lightning induced luminous phenomena from orbit. It is equipped with a six-filter photometer, which records the UAL in various wavelengths. Three filters target at the UV range which are used by the Fly's Eye type fluorescent detector. The ISUAL could provide the vital information about the UV background noise due to lightning and airglow for space-borne UHECR detector.

2 ISUAL project

2.1 ROCSAT-2

The ROCSAT-2, (**R**epublic **O**f **C**hina, Taiwan, **SAT**ellite No. **2**), is designed to perform near realtime remote sensing of

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the ocean and landmass in the vicinity of Taiwan. In addition to the remote sensing mission, the scientific mission, ISUAL, will investigate the UAL phenomena. To achieve these objectives, a small class (weights ∼700kg), low earth-orbit remote sensing satellite has been developed. The satellite will fly at a sun-synchronous orbit of altitude 891 km and inclination angle $98.99°$. The launch date of ROCSAT-2 is scheduled in mid 2003 and it will stay on orbit for five years.

The National Space Program Office is responsible for the system design, testing, and integration of ROCSAT-2. The ISUAL collaboration consists of the National Cheng Kung University and the National Central University from Taiwan, the University of California, Berkeley from USA, and the Tohoku University from Japan.

2.2 Scientific background

A lightning releases approximately 20 GW of power and some can cause huge transient electric fields (several to 10s KV/m) in the upper atmosphere (Uman, 1987). These fields can cause particle acceleration, heating, and energy dissipation. Such high potential could change the global electric circuit distribution (Hays and Roble, 1979) and even produce gamma rays (Fishman et al., 1994). Surprisingly, the effects created by these fields were not directly observed until quite recently.

To date, three types of UAL have been observed namely, sprite, blue jet and elves. Sprites are the most spectacular luminous phenomena, which occur above thunderstorms in the mesosphere (Sprite observations, 92-96). Other luminous phenomena include blue jets (Wescott et al., 1995), and elves (**E**missions of **L**ight and **V**LF perturbation due to **E**lectromagnetic pulse **S**ources) (elves observations, 92-97).

Much is still unknown in the research of UAL. The current understanding is summarized briefly as follows. When a positive charged cloud releases charge by lightning to ground (parent lightning), there will often be an upward going lightning to upper atmosphere. The red sprite occurs in 40-100km altitudes, spreads out approximately 1000 km^2, and lasts for about 3-10ms. The red color on the top of sprite comes mainly from the first positive bands of neutral nitrogen (N_2 1PG). The colors at the bottom of sprite, which are called *tendrils*, include blue, purple, and red. The blue jet shoots out from the cloud top to altitude 40-50 km, lasts approximately for 200-300 ms, and has a funnel shape. The blue color is not well understood and could be a mixture of N_2 2PG and N_2^+ 1NG. The elves occurs on cloud top, at altitude approximately 75-105km, spreads out approximately 100-300km, and lasts for only 0.1-1ms. The elves could come from the interaction of ionosphere and electromagnetic pulse, which heats the electron then releases the visible lights in the N_2 1PG band.

2.3 Mission Objectives

Major science objectives of the ISUAL instrument are as follows.

- Determine the location and timing of luminous phenomena above thunder clouds and investigate their spatial, temporal and spectral properties.
- Obtain a global survey of upper atmospheric optical flash transients (sprites, elves, blue jets).
- Investigate the global distribution of the auora and airglow intensity as a function of altitude.

To study the temporal properties requires a burst mode that can analyze the time response of these fast discharge events and a continuous mode that has continuous coverage. The sprite mode must be able to take extremely fast snap shots after the onset of lightning. In the airglow mode, it is necessary to operate the CCD at fast framing rate (180 frames per second).

To study the spatial properties, it is necessary to direct the field of view toward the limb of the Earth. Assuming that a satellite is at altitude of 891 km and the instruments take a dip angle of $-27.68°$, the limb is approximately 3373 km from the satellite. In the vertical dimension the field of view is relatively small ($3.15°$) covering an altitude range on the limb of approximately 185.5 km.

To separate the parent lightning from the subsequent UAL, three techniques are used: the spatial separation from limb viewing camera, the selection from multiple spectral filters, and triggering the camera only after detection of lightning.

2.4 ISUAL Instruments

To satisfy the above requirements, the ISUAL consists of a limb viewing imager, a set of six boresighted filtered spectrophotometers, and an array photometer. These three sensor packages are controlled by an associated electronics package (AEP).

Table 1. ISUAL system specifications

	Imager	Spectro-P.	Array-P.	AEP
Weight (kg)	6.6	5.4	11	5.1
Power (Watt)	14.0	6.8	16.4	19.4
Length (mm)	362	237	410	228.6
Width (mm)	240	141	244	177.8
Height (mm)	240	231	290	98
Acceptance (sr cm^2)	0.2262	0.0868		
Common features				
Field of View	$20\times 3.15°$			
Operating temperature	$-20°$ C to $+30°$ C			
Survival temperature	$-55°$ C to $+55°$ C			

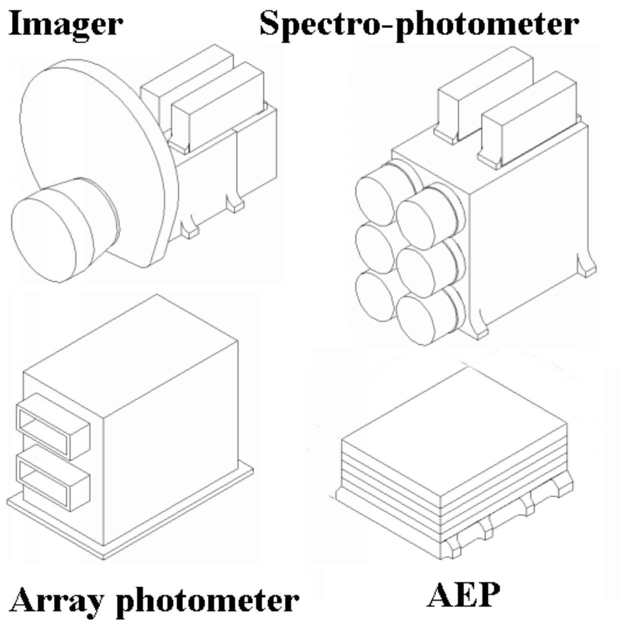

Fig. 1. ISUAL instruments.

(1) The ISUAL Imager

The imager is a 512 x 512 pixels CCD designed to capture five images in quick sequence. The imager operates continuously and five data frames are captured when the photometer signals the presence of a flash event in the field of view. This method of operation obtains high temporal resolution framing of the image. The images are digitized by an A/D converter in the imager package, the digital data are sent to the AEP when the trigger conditions are satisfied.

Table 2. ISUAL Imager Parameters

Aperture Area	12.6 cm^2
Number of Pixels	512 x 80
Focal length of Optics	62.5 mm
Field of View per pixel	$0.039°$
Wavelength pass band	420 - 800
Filter 1	658 - 740 (1PN_2 without H_a)
Filter 2	762
Filter 3	427.8
Filter 4	630
Filter 5	557.7
Filter 6	732
Exposure duration	1-30 ms, programmable
Repetition Rate	180 frames/sec

The ISUAL imager is a versatile instrument capable of multiple functions. It is a survey instrument for determining the statistical properties of sprites and other high altitude flashes, such as latitude, longitude and local distributions, and their altitude distributions. It is an instrument which enables the study of individual flashes, their altitude/time development, and spectral spatial properties. With the inclusion of a filter wheel, ISUAL can select specific airglow wavelengths (channels 2, 3, 4, and 5), for studying the altitude distributions of the airglow luminosity.

(2) The Spectrophotometer

The six channel photometers use high time resolution burst mode data recording. The wavelength band selection is tabulated below.

Table 3. Spectrophotometer filter

Channel Number	Wavelength	Remark
1	120-170 nm	LBH N_2
2	200-400 nm	Broad band UV
3	337 nm	2P N_2
4	427.8 nm	1PG N_2
5	660-700 nm†	1P N_2
6	777.4 nm	lightning

Channel 1 may give a clear UV signature for triggering of sprite/elves and may not be blinded by the parent lightning. If this can be confirmed this channel might be used as a trigger. Channels 2, 3 and 4 would bring information about the electron energy distribution in the discharge events because they are excited by different electron energy thresholds. Channel 5 is a primary trigger looking at the well established 1P N_2 transition. Channel 6 is a lightning monitor for triggering.

A multiplexer is used to select one of the photometer channels for triggering. This selection is programmed via ground command. A fast analog comparator is connected to the multiplexer output and performs the triggering function. The comparison voltage is programmable by command through the Digital Processor Unit (DPU).

(3) The Array photometer

The array photometer optic consists of a set of cylindrical imaging lenses to accommodate the wide field of view required by the other boresighted optical observing systems. The array photometer has two distinct wavelength channels with different filters in each of the optical trains. Channels 1 and 2 use band pass filter of 350-450 nm and 550-850 nm respectively. The detector is a multi-anode photo multiplier resulting in 16 horizontal resolution stripes for each wavelength channel.

(4) Associated Electronic Package (AEP)

This unit contains large memory (128MB) arrays, the fast hardware data processing electronics, and the DPU. Most of the data are handled in the hardware by programmable logic arrays because of the requirement for high speed. The DPU is relatively simple. It is used mainly for handling the interface with the spacecraft, steering the data out of the large memories to the spacecraft for transmission and handling all the commands required to operate the instrument. The main electronic package contains the power converters which change the 28-volt raw spacecraft power into the various voltages required by the instrument.

A wide field of view sun sensor reduces the output of the high voltage supply so that the imager is protected even when looking directly into the sun. The nominal high voltage value is sent up by ground command and only by personnel using a special password. Thus, the DPU on its own does not have the key in its software code and therefore it cannot change the maximum permissible high voltage even in the event of a software crash or complete loss of control. An override feature allows the system to take data even if the sun sensor fails under the ON condition.

2.5 Operation of ISUAL

Science data are collected on the night side of orbit. Data are stored and compressed in on-board memory and transferred to the system control (S/C) memory at the end of each orbit. After 14 orbits, approximately one day, the data are telemetered from the S/C memory to the ground.

The ISUAL can be operated in three modes, sprite continous mode, sprite burst mode, and aurora/airglow mode.

In the sprite continuous mode, the imager is continuously taking images at a 180 frame/sec rate. The array photometer(Spectrophotometer) is continuously sampled at a 100(10) kHz rate. All data are written into a series of circular memory buffers. When trigger criteria are satisified, the logic array reads only a 50 x 50 data segment centered on the active pixels. These data are saved in mass memory for compression and transferred to telemetry memory. The trigger conditions can be selected from the channel, level, rise time, and pretrigger block size and post-trigger block size. The sprite burst mode, employs similar procedures as the continous mode but sample at 1000 kHz for a limited period.

In the aurora/airglow mode entire frames of Imager are stored. All instruments operate at a constant rate of 1 Hz. All data are saved, compressed, and transferred to S/C for downlink.

3 Discussion

3.1 Influence of upper atmosphere lightning to fluorescent light detector

The sprite and blue jet emit strong UV light and have higher chance to trigger the fluorescent light detector. The UHECR air showers are mostly detected in the near horizontal direction, while the UALs are mostly in the vertical direction. However, the shape of blue jet and the bottom tendrils of sprite resemble an upward going air shower initiated by neutrino (Cline and Stecker, 1999). The chance of mis-identification can be reduced by requiring the traveling speed to be compatible with speed of light c. The speed of particles in sprite and blue jet are less than $0.5c$, therefore, if sprite and blue jet trigger the OWL, it will not be recorded as a single air shower but a few consecutive showers. These signals could be easily removed by the software.

3.2 Dual capabilities of ISUAL and OWL

In the current plan of ISUAL operation, the system is triggered when channel 6 (777.4 nm) of the photo-spectrometer is triggered by the parent lightning. Under this condition, it is unlikely that ISUAL could detect air shower. If the trigger condition is changed to channel 1 (120-170nm), it is still very difficult to detect air shower due to the small FOV and light collecting area. The major contribution of ISUAL to OWL is the global survey of UV signals from lightning and the airglow.

If UAL can be a noise for OWL, it could also be a different kind of signal. The multiple upward going events can be used to reconstruct the UAL. With the advantage of large FOV, OWL could be a powerful detector of UAL after modifications of the trigger conditions and two operation modes, air shower mode and UAL mode.

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