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New color images of transient luminous events from dedicated observations on the International Space Station

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ABSTRACT

During July–August 2011, Expedition 28/29 JAXA astronaut Satoshi Furukawa conducted TLE observations from the International Space Station in conjunction with the “Cosmic Shore” program produced by NHK. An EMCCD normal video-rate color TV camera was used to conduct directed observations from the Earth-pointing Cupola module. The target selection was based on the methodology developed for the MEIDEX sprite campaign on board the space shuttle Columbia in January 2003 (Ziv et al., 2004). The observation geometry was pre-determined and uploaded daily to the ISS with pointing options to limb, oblique or nadir, based on the predicted location of the storm with regards to the ISS. The pointing angle was rotated in real-time according to visual eyesight by the astronaut. We present results of 10 confirmed TLEs: 8 sprites, 1 sprite halo and 1 gigantic jet, out of <2 h of video. Sprites tend to appear in a single frame simultaneously with maximum lightning brightness. Unique images (a) from nadir of a sprite horizontally displaced form the lightning light and (b) from the oblique view of a sprite halo, enable the calculation of dimensions and volumes occupied by these TLEs. Since time stamping on the ISS images was accurate within 1 s, matching with ELF and WWLLN data for the parent lightning location is limited. Nevertheless, the results prove that the ISS is an ideal platform for lightning and TLE observations, and careful operational procedures greatly enhance the value of observation time.

1. Introduction

Space-based observations of Transient Luminous Events (TLEs) were conducted sporadically from the Space Shuttle (Boeck et al., 1994, 1998; Yair et al., 2004) and the International Space Station (Blanc et al., 2004; Jehl et al., in press), and are being carried out routinely by the ISUAL detector on-board the FORMOSAT-2 satellite (Chern et al., 2003). The advantage of the vantage point offered by orbiting platforms for TLE research is clear: a daily global coverage, large-scale storm areas monitored simultaneously, and a diminished atmospheric influence on the emitted radiation (Yair, 2006; Blanc, 2010). There is an obvious difference between the campaign-mode observations conducted thus far from the space shuttle or the ISS and a continued survey, the latter offering the possibility to generate a “climatic” picture of TLE occurrence on a global scale (Chen et al., 2008). Future payloads on-board the ISS intend to conduct long-term observations, with the advantage of the higher spatial resolution due to the lower ISS orbital altitude as compared to polar satellites. Such are the Japanese GLIMS experiment (Ushio et al., 2011) and the European ASIM payload (Neubert et al., 2008). Additionally, the upcoming Taranis satellite will perform observations of TLEs and TGFs (Terrestrial Gamma Flashes) from the orbit with additional capabilities in the X and gamma-ray parts of the spectrum (Blanc et al., 2007). Recently, Jehl et al. (2013) used non-dedicated observations of the nocturnal part of the ISS orbit, and found 15 sprites in full color, above thunderstorms observed from oblique and limb angles at ranges 400–2200 km. The video they analyzed was composed of still images, taken by the Nikon D3S camera with exposure times between 0.4–2 s. Jehl et al. (2013) were able to analyze the spectra of the sprites and confirm the main emissions in red are from molecular nitrogen N_2(1P) bands and the lower, blue parts of sprite tendrils are from the N_2^+(1N) band. By comparing the brightness of the observed sprites to that of stars and planets in the images, they were able to deduce the brightness of sprites.

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In the summer of 2011, Japan's NHK TV channel collaborated with JAXA astronaut Dr. Satoshi Furukawa, who was part of Expedition 28/29 to the ISS, in order to perform specially dedicated and directed space-based observations of TLEs as part of their “Cosmic Shore” documentary. This 1-month campaign was planned in a manner similar to the MEIDEX sprite campaign in 2003 (Yair et al., 2003), in which space shuttle's Columbia astronauts manually directed the camera toward pre-determined targets that were within the space shuttle cameras filed-of-view. The ISS orbits the Earth in a 57° inclination orbit, at altitudes between 370 and 400 km. It therefore covers any given region for just a few minutes, the coverage time of any given area being a function of the proximity to the ground track. Unlike the limited field-of-view and pointing capability offered by the cameras on-board the shuttle during the MEIDEX, the ISS has a unique observation dome with multiple windows, known as the Cupola, which enables un-paralleled 360° coverage of the earth from nadir to limb views. The aim of the NHK production team was to image sprites and other TLEs, as well as meteors, nuctilucent clouds, aurora and airglow, all occurring at mesospheric altitudes. The astronaut used the Cupola to hunt for these phenomena while manipulating the camera in the proper direction.

2. Observation methodology

The camera used for the space-based observations for the Cosmic Shore campaign was a unique Ultra High Sensitive TV color camera by FLOVEL (http://www.flovel.co.jp/english/index.html). The camera has a single 2/3 in. EM-CCD (Electron Multiplication CCD) with 1288(H) × 724 (V) pixels and 700 TV lines. The camera's sensitivity is 0.02 lx in color and 0.001 lx in black-and-white. It is slightly inferior to that of the Watec-902H, a video camera often used in ground-based sprite observations (Yair et al., 2009a, 2009b), which has a stated minimum illumination detection of 0.0003 lx at f1.4. With a frame-rate of 30 frames per second the temporal resolution is low compared to the present-day capabilities of high frame-rate cameras (Cummer et al., 2006; Marshall and Inan, 2005). The camera had a C-mount for 4 different lenses that were used and rotated according to the daily target list (Table 1). There were 3 modes of observations based on an a filter mounted on the lens: (a) without any filter (b) with an IR-cut filter that blocks all wavelengths above 680 nm and (c) with a filter centered at 766.5 nm with FWHM of 14.03 nm (peak transmission 78.87%). A filter with similar properties was used by Blanc et al. (2004) for nadir observations of sprites, with the aim of effectively blocking lightning light and allowing only the 762 nm line from sprites to be detected. In practice, after evaluating the camera performance in the first few observations, most TLE observations were conducted without any filter.

The pointing of the camera from within the Cupola dome toward the target was performed manually by the astronaut, and no accurate record of the pointing azimuth was kept. This was different from the MEIDEX sprite campaign where the camera was mounted on computer-controlled gimbal with a 0.5° pointing accuracy (Yair et al., 2004). In addition, the time stamp on the video image was inserted through a keypad and not through the ISS GPS clock, with an accuracy of 1 s. Such a poor time stamping precludes efforts to detect the parent flash for the observed TLE in lightning data from global networks such as WWLLN (World-Wide Lightning Location Network) or ELF data from specific stations. Nevertheless, using weather satellite images and stars that appeared in some of the images, and noting the aspect ratio of the lightning illuminated cloud-tops (explained in Appendix A) we were able to reconstruct the pointing azimuth within a reasonable accuracy. Clearly, future instruments on-board the ISS should require that pointing and time-stamping will be automatically recorded on the image.

The meteorological conditions for sprite-producing storms are well-known and have been reviewed by Williams and Yair (2006) and Pasko et al. (2011). The maps for TLE occurrence published by Chen et al. (2008) show that sprites occur mostly over land, and Elves and halos are found particularly above the oceans. In order to maximize the potential for successful observations in the limited time-frame allocated to filming the documentary, we had to carefully select targets with high probability of lightning activity and TLE production. The selected targets were determined based on the potential for severe thunderstorms, deduced from the daily aviation forecast maps (Ziv et al., 2004) relative to the position of the ISS. We used the Aviation Weather Center (http://aviationweather.gov) daily significant weather forecast maps (SIGWX) to select regions with high probability for convective activity and thunderstorm such that they were within the camera field-of-view, as deduced from the ISS trajectory and the distance to the limb (2240 km). For increasing the chance for success, only storms with predicted “Frequent Cb” (Cumulonimbus) and cloud tops above 45 Kft (~14 km) were selected. Additionally, we targeted tropical storms and hurricanes over the Indian, Atlantic and Pacific oceans. We should point out that the AWC forecast maps only give18–24 h forecasts in a 12 h update cycle. We therefore relied on the fact that in summer the ITCZ shows daily persistence and convective centers embedded within it move rather slowly. For tropical disturbances and typhoons (hurricanes) we used two-day trajectory prediction supplied by the National Hurricane Center (http://nhc.noaa.gov). The recommended time-windows for the observations were plotted using the STK software and arranged according to consecutive ISS orbits along with a priority list and technical information, and uploaded to the crew via a daily JEDI-message 36 h in advance (“Joint Execute package Development and Integration”). As the results show, such a procedure was remarkably successful and in 14 relatively short observations windows, 10 confirmed TLEs were recorded. The geometry of the observation and the derivation of TLE dimensions are described in Appendix A.

Table 1
List of lenses and respective fields-of-view in degrees.

	Focal length (mm)	F number	diagonal	horizontal	vertical
Schneider/Cinegon	4.8	f1.8	112.3	101.5	60.4
Fujinon/Zoom lens	8 × 7.6		70.5	62.9	37.0
Schneider/Xenon	17	f0.95	36.6	32.1	18.0
Schneider/Xenon	25	f0.95	24.5	21.3	12.0

3. Results and discussion

In total, during this short dedicated campaign, 10 separate TLEs were detected and imaged above thunderstorms in different parts of the world, in proximity to the ISS ground trajectory (Table 2). This section will only describe unique and outstanding observations, as “common” sprites in color are now being routinely observed in the CEO (Crew Earth Observations) program, as reported by Jehl et al. (in press), and can be seen in short ISS video excerpts posted on NASA's Youtube channel (see for example: http://www.youtube.com/watch?v=FnN1gjJ_Sc4).

One common feature to all sprites in the ISS video we analyzed is the fact that they seem to appear in the frame when the brightness of the parent lightning reaches the maximum intensity. Within the resolution of regular-rate video imaging, this fact indicates that sprites are generated when, or immediately after,