Planetary and Space Science 59 (2011) 1–9

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

The Smart Panoramic Optical Sensor Head (SPOSH)—A camera for observations of transient luminous events on planetary night sides

J. Oberst [a,b,*], J. Flohrer [a], S. Elgner [a], T. Maue [c], A. Margonis [a,b], R. Schrödter [a], W. Tost [a], M. Buhl [d], J. Ehrich [e], A. Christou [f], D. Koschny [g]

[a] German Aerospace Center, Institute of Planetary Research, Rutherfordstr. 2, 12489 Berlin, Germany
[b] Technical University Berlin, Institute for Geodesy and Geoinformation Sciences, Germany
[c] Max-Planck Institut for Solar System Research, Germany
[d] Technical University Berlin, Institute for Air- and Space Technology, Germany
[e] Jena-Optronik GmbH, Germany
[f] Armagh Observatory, United Kingdom
[g] ESA/ESTEC, Netherlands

ARTICLE INFO

Article history:
Received 26 March 2010
Received in revised form
14 September 2010
Accepted 15 September 2010
Available online 29 September 2010

Keywords:
SPOSH
Lightning
Aurorae
Impact flashes
Meteors

ABSTRACT

We have developed a camera dedicated to imaging faint transient noctilucent phenomena, such as aurorae, electric discharges, meteors or impact flashes, on dark planetary hemispheres. The Smart Panoramic Optical Sensor Head (SPOSH) is equipped with a back-illuminated 1024×1024 CCD chip E2V 47–20 with up to 90% quantum efficiency and has a custom-made optical system of high light-gathering power with a wide field of view of $120^{\circ} \times 120^{\circ}$. Images can be obtained over extended periods at high rate to make monitoring for transient events possible. To reduce the data transmission rate, only those images (or relevant portions thereof) that contain events are returned to the user. The camera has a sophisticated processing unit prepared to interface with a spacecraft system, for image processing and event detection at rates of up to 3 images per second at full resolution. While software optimized for detection of any noctilucent phenomenon can be implemented, the software is currently optimized for the detection of meteors. Over the past years, we have routinely carried out outdoor tests with 4 camera breadboard units that demonstrate that the camera has excellent radiometric performance and geometric resolution at low light levels over its large field of view. The camera has been demonstrated to capture meteors of magnitudes as faint as $+6^{m}$ moving at angular speeds of 5°/s. The camera opens up new science opportunities for planetary missions.

1. Introduction

While cameras on planetary missions of the past decade have demonstrated ever increasing performance and spectacular science accomplishments, practically all imaging experiments have been limited to the systematic mapping of the illuminated parts of planetary surfaces or the targeted observations of known surface features. However, there is now an increasing interest in the imaging of the dark hemispheres to search for, identify, and explore luminous phenomena, such as noctilucent clouds and aurorae, or to continuously monitor the dark hemisphere for transient events such as electrical discharges (lightning), and meteoroids entering planetary atmospheres or impacting the surface.

The phenomena or events are typically very faint, short-lived, or both, and therefore require a camera with high sensitivity and fast imaging rate. For the detection and reporting of meteors, impacts, or lightning within long observing hours, a high imaging rate, large data throughputs, and a sophisticated real-time image processing and detection scheme is required. Also, in order to monitor a large area, the camera must have a wide field of view. In 2003/2004 a camera system was designed and developed to meet these requirements in a joint effort by DLR (German Aerospace Center) and Jena-Optronik under a contract by ESA (Fig. 1). The paper discusses the design philosophy of this camera, the technical realization of a camera breadboard, and the results from various tests that have been carried out. Finally, the prospects for space deployment of the camera are discussed.

2. Science rationale

Here, we briefly summarize the properties of nocturnal phenomena that are to be observed.

* Corresponding author at: German Aerospace Center, Institute of Planetary Research, Rutherfordstr. 2, 12489 Berlin, Germany. Tel.: +49 30 67055 336; fax: +49 30 67055 402.
E-mail address: Juergen.Oberst@dlr.de (J. Oberst).

0032-0633/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pss.2010.09.016

Fig. 1. SPOSH breadboard camera head (left). SPOSH camera mounted on a tripod at dusk, equipped with a rotating shutter (right).

2.1. Meteors

Meteoroids and their parent bodies represent the building blocks of the planets that have survived to the present day and are consequently of great interest to planetary scientists. Meteoroids colliding with the Earth's atmosphere produce a streak of light (meteors), typically lasting 0.5–2 s. Meteors can range in brightness from events at the limit of visual detection ($V=+6.5$) to fireballs brighter than the Moon ($V=-14.8$) (see e.g. Table 4 in Oberst et al., 1998 for examples). Meteoroid physical properties range from fluffy objects (typically assigned to "meteor category" type IIIa and IIIb) to high-density meteoritic types (type I) (Ceplecha et al., 1998). While the higher-density objects are believed to originate from the asteroid belt or Near-Earth Objects (NEOs), the type III meteors probably originate from comets. In their cometary-type orbits they have relative speeds up to a maximum of $\sim$71 km/s at the top of Earth's atmosphere. There is considerable temporal variation of the meteor rate. Visual observers may typically see 5–10 sporadic meteors during a clear, moonless night away from city lights. If the Earth encounters meteoroids traveling in swarms and streams, meteor rates may increase to >100 per hour. For known meteor streams, e.g., the Perseids, Leonids, Geminids, times of increased meteor numbers can be predicted. From studies of the behavior of the meteor light curve the physical properties (e.g., strength, density) of the particle may be constrained. While most of our knowledge on the meteoroid environment is based on the observations of the terrestrial meteors, there is considerable interest in the meteoroid population in other parts of the Solar System. Meteors are believed to occur as well in other planets' atmospheres, such as Venus and Mars.

2.2. Meteoroid impact flashes

The Moon is an efficient meteoroid detector, as is attested by the large inventory of craters on its surface and by the substantial number of impacts recorded by the Apollo seismic station network (Dorman et al., 1978; Oberst and Nakamura, 1991). There have been previous efforts to observe lunar meteoroid impacts with optical techniques. Substantial numbers of historic sightings of Lunar Transient Phenomena (LTPs) are documented in the NASA Technical Report R-227 "Catalog of Reported Lunar Events", some of which may well represent meteoroid impacts (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19680018720_1968018720.pdf). However, it was not until 1999 that optical recordings of impacts on the Moon could be independently confirmed. During the peak of the Leonid meteor shower, at least 6 impact flashes estimated to have a duration of ca. 10–100 ms were recorded at estimated magnitudes between +3 and +7 (visual wavelengths) on a single night (Dunham et al., 2000). Monitoring of the dark hemisphere for impact flashes may shed light on the relationships between Lunar crater statistics, seismic detections of impacts, and terrestrial meteor rates. As in the case of the Moon, we should expect to see impacts on other airless bodies, such as Mercury, large asteroids, or Mars to some extent.

2.3. Atmospheric lightning

Lightning on Earth occurs as a result of natural charging phenomena and is observed to develop during rain or dust storms, but may also be associated with volcanic eruptions. For studies of Earth lightning more than a dozen Earth-orbiting spacecraft have flown dedicated lightning sensors (e.g., the TRMM, Tropical Rainfall Measuring Mission) to acquire and investigate the distribution and variability of total lightning over the Earth and to increase the understanding of underlying and interrelated processes in the Earth/atmosphere system (Christian, 1999; Christian et al., 1999). Radio frequency and optical measurements have detected electrical discharges on Jupiter, Saturn, Uranus, and Neptune. Hence, the phenomenon appears to be common in the Solar System (Rinnert, 1985; see also Leblanc et al., 2008 for a recent review). While there has been a long-lasting dispute on the existence of Venus lightning, recent data by the Venus Express Fluxgate magnetometer provide so far the strongest evidence for frequent occurrence of lightning discharges (Russell et al., 2010). A dedicated lightning detector (Takahashi et al., 2008) has been launched on board of Planet-C. On the other hand, there is a good possibility of lightning on Mars, as a result of the dynamics of wind and dust (Farrell and Desch, 2001). Its visual appearance is difficult to predict and may include filamentary discharges or small arcs, diffuse glows or diffuse flashes, similar to summer heat lightning on Earth. There is a possibility of emissions like "sprites" above the dust cloud tops. Studies of planetary lightning may provide insights into the composition, structure, and dynamics of the atmospheres and in particular into processes related to charging of dust particles or aerosols.

2.4. Noctilucent clouds and aurorae

Terrestrial noctilucent clouds occur at heights above 80 km, far above the troposphere. They may extend over large areas at high northern and southern latitudes and are typically observed around sunrise/sunset, when they reflect light from the sun below the horizon. They are believed to consist of ice-covered particles of interplanetary origin, while details of their formation and dynamics remain largely unknown.