# METEOR OBSERVATIONS FROM SPACE WITH THE SMART PANORAMIC OPTICAL SENSOR HEAD (SPOSH)

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## ABSTRACT

We have developed the camera concept and breadboard SPOSH (Smart Panoramic Optical Sensor Head), designed for observations of transient phenomena on the night hemisphere of Earth (or other planets) from an orbiting spacecraft. The camera features a highly sensitive (1024 x 1024) CCD chip, a wide (>120°) field of view, is typically operated at a high rate (2 frames / sec), and has sophisticated built-in software for event detections and reporting. The event detection for the breadboard is currently optimized for the identification of atmospheric meteors. The instrument was successfully tested under real-sky conditions during prominent meteor showers of 2004.

## 1. INTRODUCTION

The Earth is constantly bombarded by extraterrestrial material. The arrival of these objects from space is typically associated with the celestial phenomenon of “shooting stars”, “fireballs”, or (technically speaking) “meteors”, well-known to observers of the night sky. Clear skies permitting, an observer on the ground can witness 1-10 meteors brighter than magnitude +6 ($10^{-1}$ to $10^{6}$ grams) during any typical night. During strong showers, this rate may increase by orders of magnitude. Observations of these meteors in the Earth’s atmosphere yield valuable data on the population of small objects in the near-Earth space, which otherwise would remain undetected. While meteor observations from the ground have a long tradition in the history of Solar System science, small satellites in Earth orbit equipped with appropriate imaging systems offer new perspectives to studies of the meteor complex from a highly elevated platform above the cloud deck.

Fig. 1: SPOSH breadboard at dusk, ready for meteor observations

Unfortunately, conventional CCD camera systems are not particularly suited for this type of observations: Most meteors are faint and move fast (max: 70 km/s). Also, a very large field of view must be covered over considerable time scales to obtain meaningful statistics on the meteor population. Hence, a camera system must expect a high data rate and large volume of images. In the past two years, we have developed a camera breadboard that is designed to handle these challenges of meteor observations from space.

## 2. SPOSH CAMERA

SPOSH (Smart Panoramic Optical Sensor Head) was designed and built under contract for ESA/ESTEC according to stringent specifications. SPOSH (Fig. 1) is equipped with a highly sensitive 1024 x 1024 E2V CCD 47-20 chip and has a custom-made optical system (Fig. 2) with a wide horizontal and vertical field of view of 120° (diagonal: 168°). The sensitivity of the system is sufficient to detect point objects having a magnitude of +6 with a SNR > 5, moving at a speed not faster than 5°/sec.

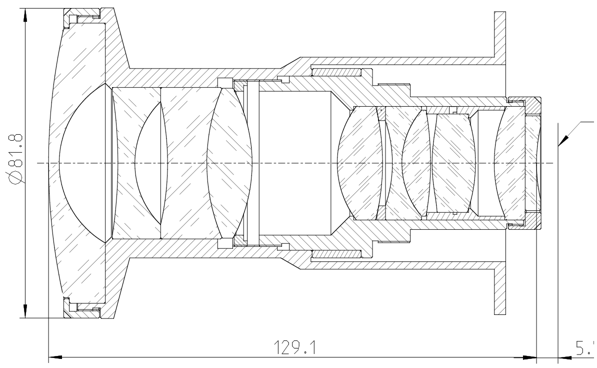



Fig. 2: The optical system of SPOSH consisting of a fish-eye lens (FishAenar II 1/7), with 9 single lenses arranged in 7 groups. To achieve a large aperture in combination with a small F#-Number, an aspheric surface is introduced. The front lens is made of fused silica. Entrance pupil diameter: 6.5 mm, effective focal length: 6.93 mm, total mass: 956 g.

The camera has a sophisticated processing unit prepared to interface with a spacecraft system. The 14-bit images can be analyzed on the fly within this unit at high rates up to 2 per sec. Custom-made software is used to identify transient phenomena in images; the breadbord is currently optimized for the detection of meteors. To reduce data rate, only those images (or windows of interest) are returned to the user that contain meteors. Should SPOSH be selected for a space mission, it is well conceivable that detection algorithms for other planetary nighttime phenomena, as aurorae, electric discharges, impact flashes, etc. can be implemented in the unit.

## 3. BREADBOARD TESTS

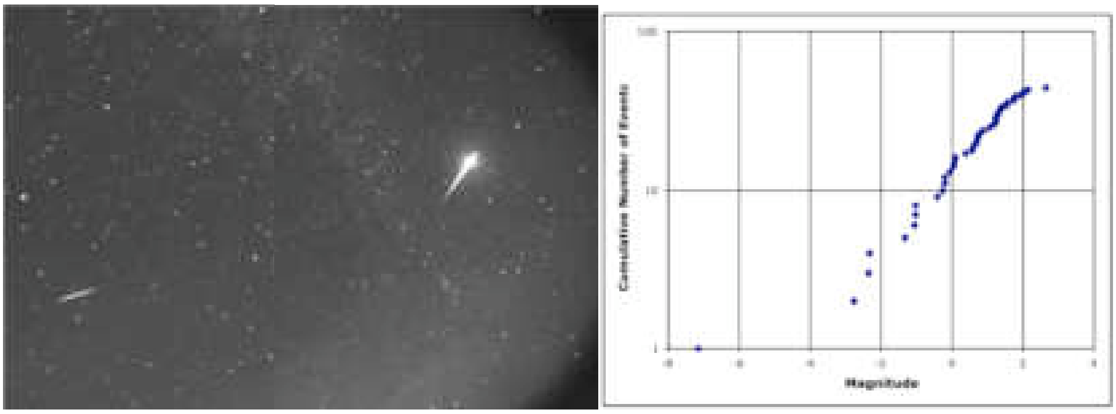
In conclusion of our breadboard development, we have carried out tests under laboratory and real-sky conditions during major meteor showers of 2004.

### 3.1 Laboratory Tests

The camera was first examined in the laboratory, to verify that the required camera performance parameters, e.g. field of view, spatial resolution, sensitivity, and SNR, were met. Further tests were carried out at the Planetarium Jena to verify the performance of the event detection software.  A Xenon lamp projector was used to mimic meteor events travelling in the artificial planetarium sky at different speeds, durations, and brightness, according to a defined event sequences.  Essentially, all of the events were detected, and no false detections occurred under these nearly perfect laboratory conditions.

## 3.2 Perseid Campaign

The first real-sky campaign was carried out on 10-13 August, 2004 at the Thüringer Landessternwarte, Tautenburg Observatorium.  Excellent viewing was available and approx. 45 meteors were recorded in the night from August 11 alone.  During this early test, images were obtained using a commercial CCD system while the analysis was done offline in the lab using a prototype version of the SPOSH camera software.  The detected meteors were calibrated for magnitudes.  Magnitude/frequency relationships (Fig. 3) and meteor lightcurves were studied (Fig. 4)



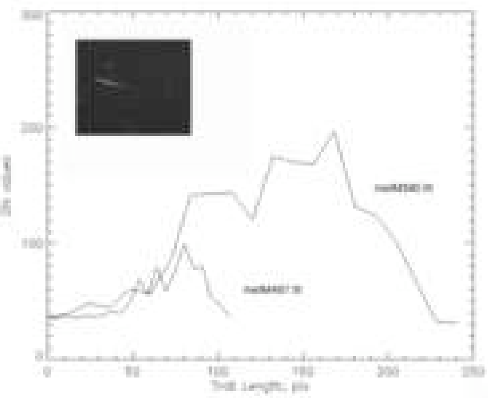



Fig. 3: Two examples of faint and bright Perseid meteors (estimated magnitudes: +2 and -6), as well as cumulative number of detected events vs. event magnitude (top)

Fig. 4:  Typical maximum-type lightcurves of meteors (left)

## 3.3 Leonid Campaign

This second campaign was carried out from 17 – 20 November, 2004 from the Kanzelhöhe Solar Observatory (located in Austria, at the southern flanks of the Alps) and Lake Sobot in close proximity.  The fully functional camera breadboard, including the wide-field optical system and a built-in version of the detection software were tested for the first time. More than 30 meteors were automatically detected by the software. In addition, valuable images of star fields in the clear sky were obtained which will later be used to verify camera optical parameters.

### 3.4 Geminid Campaign

This so far most involving campaign, was carried out from 10 - 15 December 2004 from various observing stations on Tenerife Island, Spain. The camera was equipped with an updated version of the detection software including a new window-based user interface. A second camera model was used to discriminate meteor detections from suspected cosmic ray hits, but also to obtain images with different viewing perspectives for geometric analyses of the meteor trajectories. Unfortunately, seeing was not optimum, and only few (but nonetheless spectacular, Fig. 5) meteors were detected.

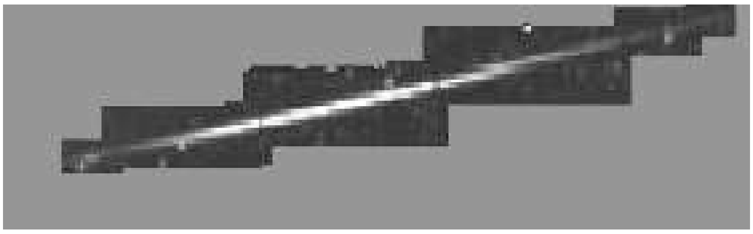


Fig. 5: Slow-moving (approx. 33 km/s) Geminid detected on 8 consecutive images, extending over more than 50 pixels. The camera operated at a frame rate of 2 frames per second. The Figure shows the windows of interest returned by the camera processor

## 4. OBSERVATIONS FROM ORBIT AND FLIGHT MODEL DESIGN

Cosmonauts and astronauts have frequently reported seeing meteors on the night hemisphere of Earth. However, these events have never been observed by dedicated instrumental means.

We wish to make a prediction on the number of meteor detections by a camera like SPOSH from space. Using a nominal mission scenario in circular Earth orbit, 400 km above the ground, the camera will cover an area of approx. 2 Mio $km^2$ (neglecting planet curvature), an area approx. twice the European Fireball network (Oberst et al., 1997; 2004). A meteor traveling at a maximum speed of 70 km/s will spend approx. 0.04 seconds time in each pixel on the focal plane along the meteor's apparent trajectory ("dwell time"). Consider that the EN, working at an efficiency of 3 hours per day, captures approx. 50 meteors per year having magnitudes brighter than -6 (Oberst et al., 1997), the camera will detect one of these bright events every 24 hours of operation over the night hemisphere. However, the camera is sufficiently sensitive to capture meteors as faint as m=+4. Assuming a power-law magnitude/frequency distribution of the meteors with a constant slope (see Fig. 3), and taking into account the larger distance in space, we estimate that the number of detected meteors will increase five hundred fold. Hence, a flight model version of SPOSH on an orbiting satellite would enjoy a large number of event detections.

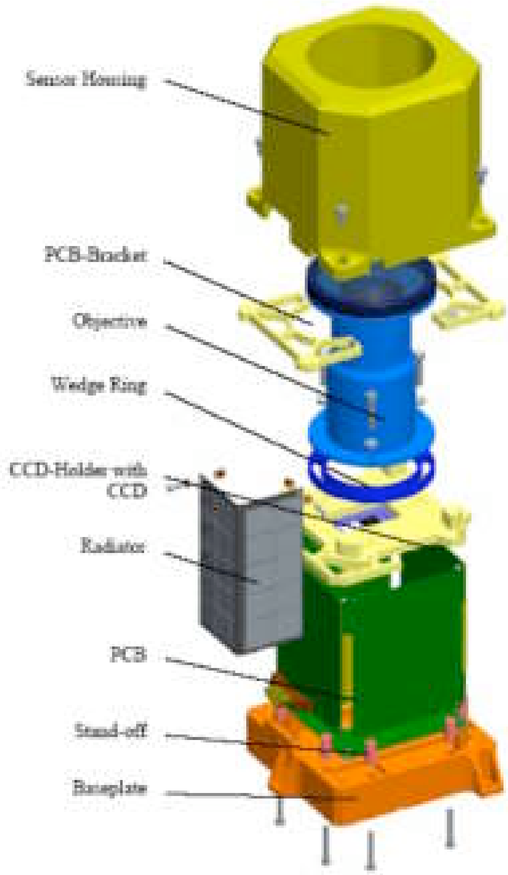



Fig. 6: SPOSH flight model (top) with envelope dimensions 142 mm x 130 mm x 162 mm, and exploded view (left)

The flight model was designed to minimize size, mass, and power consumption over what we now have in the breadboard. In addition, we included appropriate shielding against radiation and thermal elements, e.g., a dedicated radiator (Fig. 6). With a nominal shielding of 3 mm walls against radiation (30 krad requirement), we obtain a total instrument mass of 2.33 kg (approx. 1.1 kg for the shielding alone). However, for a one-year mission in low Earth orbit, e.g. on board the SSI, a shielding of <1 mm would be fully acceptable. We also anticipate that the optics can be manufactured with low-mass components. Hence, we estimate that a flight model can be developed with a total mass of < 1.5 kg. The total power consumption for both, Camera Head and Digital Processing Unit is estimated to be less than 4.5 Watts.

## 5. CONCLUSIONS

The monitoring of nighttime planetary hemispheres for transient events is a scientifically rewarding undertaking, and new instruments are available to carry out this challenging task. The tests altogether demonstrated that SPOSH has excellent low light level performance, as well as excellent geometric characteristics over the large field of view. The built-in software reliably detects even faint m=+4 real-sky meteors, which are then available for full radiometric and geometric analysis. On the basis of the available breadboard, a flight model can be developed at moderate mass and power requirements.

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