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Detection of transient events on planetary bodies

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Abstract. Transient phenomena on planetary bodies are defined as luminous events of different intensities, which occur in planetary atmospheres and surfaces, their duration spans from about 0.1 s to some hours. They consist of meteors, bolides, lightning, impact flashes on solid surfaces, auroras, etc. So far, the study of these phenomena has been very limited, due to the lack of an *ad hoc* instrumentation, and their detection has been performed mainly on a serendipitous basis.
Recently, ESA has issued an announcement of opportunity for the development of systems devoted to the detection of transient events in the Earth atmosphere and/or on the dark side of other planetary objects. One of such a detector as been designed and a prototype (*Smart Panoramic Optical Sensor Head*, SPOSH) has been constructed at Galileo Avionica S.p.A (Florence, Italy).
For sake of clarity, in what follows, we classify the transient phenomena in "Earth phenomena" and "Planetary phenomena", even though some of them originate in a similar physical context.

Key words. Meteor, lightning, impact flash, Smart Panoramic Optical Sensor Head

1. Earth phenomena

Transient luminous phenomena on Earth occur mainly in its atmosphere at different heights. Their origin is due essentially to the interaction of cosmic debris with the high layers of atmosphere and the electric activity that is present in it at different levels.

Interest for meteors is mainly due to the information they can provide about the history of the Solar System. Lightning is a phenomenon of high interest in different scientific fields, including studies of the water cycle.

1.1. Meteors

Asteroids and comets are the sources of small interplanetary bodies. The collisions between asteroids in the main belt, besides producing km-sized asteroids, generate huge numbers of fragments having sizes spanning from a hundredth of millimeter to some tens of meters, intermediate between classical asteroids and interplanetary dust. These bodies are called *meteoroids*. Whatever the origin of a meteoroid belonging to the Solar System is, its geocentric velocity spans from 11.2 km s^{-1} to 72.8 km s^{-1}.

During the atmospheric flight the atoms of the meteoroid disperse in the atmosphere forming a trail, the *meteor*, which looks like a

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Send offprint requests to: M. Di Martino long and narrow cylindrical column. The trail length can reach several kilometers. A typical value spans from 10 to 20 km, while the heights where the phenomenon begins are between about 120 and 75 km. Time duration of meteor phenomenon spans from 0.5 to 3 s.

1.2. Bolides and superbolides

Due to orbital perturbations with Jupiter, Saturn and Mars, and also under the influence of radiative mechanisms like the Yarkowsky effect, meteoroids originating in the asteroid main belt can be inserted into orbits crossing those of the terrestrial planets: Mercury, Venus, Earth and Mars. Therefore, there are a lot of small bodies, having dimensions of some meters, which can interact with our planet and generate bolides. Bodies having mass larger than 1,000 kg generate superbolides, of magnitudes –17 or lower. For meteoroids having diameter of some tens of meters the bolide can be brighter than the Sun (apparent magnitude –27). Superbolides are rare events, which would need a global observing network, in order to be studied in a systematic way (Ceplecha, 1999).

1.3. Meteor observations from space

Still to be explored is the systematic monitoring of meteors from satellites in orbit around Earth. If q is the height in km of the satellite from the Earth surface, and M the meteor absolute magnitude, the apparent magnitude of the meteor observed from orbit is given by:

$$m = M - 10 + 5\log(q - 100) \quad (1)$$

Considering the sensor limit magnitude on board the satellite +6.0 and the height 400 km, from equation (1) it follows that from orbit only meteors having absolute magnitude lower than M=+3.6 will be detectable.

1.4. Lightning

A typical lightning is composed by a series of electron discharges, in average four. The duration of each discharge is 35 ms, while the duration of the series spans from 0.1 to 0.25 s, but can reach 23 s. In the electric discharge the temperature of the atmospheric gas can reach 20,000 K, while the peak optical power is in the range $710^7 310^9$ W (Russel, 1993). From the Pogson relation between flux density and magnitude, and using the above-mentioned typical values, we can derive the magnitude difference between two bodies having different fluxes. Considering as reference flux the optical solar constant F_1 (1.83 10^2 W m^{-2}), the magnitude m_1 is the apparent Sun visual magnitude (-26.74). The apparent visual magnitude of a lightning, having an optical power of 310^9 W and observed from a height q (km) on the Earth's surface, is:

$$m_{lightning} = 5\log(q) - 27.0 \quad (2)$$

Assuming a 400 km height, the apparent peak magnitude of a lightning is –14, larger than the Moon apparent magnitude (-12.5). Then, a lightning can be revealed without difficulty through the clouds and on the background of anthropic lights.

2. Planetary phenomena

They essentially consist in the same events we can observe on Earth, except impact flashes on the surface of atmosphereless bodies.

2.1. Meteors on Mars

As we have seen, on Earth a meteor occurs when a meteoroid interacts with the atmosphere between 120 and 70 km. In spite of the difference in the chemical composition of the Earth and Mars atmospheres, at the same conditions (atmosphere density, meteoroid mass and velocity), the meteors show the same luminosity because less than 3% of the trail emitted radiation is produced by atmospheric atoms. Considering the same meteoroid mass and velocity, the meteors on Mars occur about 20 km lower (Adolfsson et al., 1996) and are very similar to the terrestrial ones.

2.2. Meteors on Venus

Meteors on Venus could be observable from orbit and, due to the higher density of the Venusian atmosphere, the interval 120-70 km for the meteors on Earth corresponds to 300-200 km on Venus. This means that the apparent brightness from orbit will be higher with respect to a similar event on Earth. Moreover, the height where the meteor phenomenon occurs on Venus is larger than the haze and cloud upper limit (80 km), allowing the observation from space. Assuming a height of 600 km and a distance of 250 km from the Venusian meteor, we estimate that on Venus meteors are apparently 0.2 magnitudes brighter than on Earth.

2.3. Meteors on Giant Planets

Considering the same conditions (mass and velocity of the meteoroids and atmospheric density), even on giant planets (Jupiter, Saturn, Uranus, and Neptune) meteors have to be as luminous as on the other planets.

In the case of Jupiter, by using the law of the atmospheres, we obtain that the interval 120-70 km for the meteors on Earth corresponds to the interval 290-115 km on the giant of the Solar System. These values have been computed considering as level zero the atmospheric layer at the pressure of 100 mbar. A meteor trail in the Jupiter atmosphere has been observed during the Voyager 1 fly-by (Cook and Duxbury, 1981).

3. Impact flashes

The Moon, as all the Solar System bodies, has undergone a continuous bombardment by asteroids, comets and meteoroids since its formation. Meteoroid impacts on the Moon have been detected in the past visually and by the Apollo Lunar Seismic Network. Several observers have claimed to have detected optical flashes on the Moon, but any of such events has never been confirmed in an independent way, until the impacts on 18 and 19 November 1999 due to Leonid shower.

The detection of impact flashes by using a camera on board a lunar satellite should be much more efficient, if compared with the ground-based observations. In fact, being the distance much lower, even the impact of meteoroid having small mass should be detectable. Considering q_L the spacecraft height (in km) from the Moon surface, the impact flash magnitude is given by:

$$m = m_T + 5\log(q_L) - 27.9 \quad (3)$$

where m_T is the event magnitude as seen from the Earth. Assuming that the limiting magnitude of the sensor is +6, from low orbits (within 5,000 km from the lunar surface), flashes that from the Earth should appear as magnitude +15 could be visible. This fact should allow to study very low mass meteoroids and to take spectra of the impact phenomenon, at present completely unknown. The same considerations are valid for Mercury and the galilean moon.

4. Electric discharges

Lightning have been detected on every planet with an atmosphere, except Mars. On Saturn, Uranus and Neptune, atmospheric electric activity has been recorded in the radio VLF band (Russell, 1993). Due to the high opacity of the Venus, Saturn, Uranus and Neptune atmospheres, candidate planets to image atmospheric electrical discharges are Mars and Jupiter.

4.1. Observation of Mars lightning

Due to the prevalence of Martian dust devils and dust storms, an understanding of the underlying physics of electrical discharges in Martian dust clouds is critical for future Mars exploratory missions. Mars low atmospheric pressure and arid, windy environment suggest that the dust near the surface of Mars is even more susceptible to triboelectric charging than terrestrial dust. Electrical discharges on Mars should occur more frequently but at lower intensities than those seen on Earth.

4.2. Observation of Jupiter lightning

The Voyager 1 and 2 spacecrafts performed the first observations of lightning on Jupiter in 1979. Later, even the Galileo spacecraft has monitored the electric activity in the Jupiter atmosphere. A typical Jovian storm is about 1,500 km in diameter and produces about 20 flashes per minute. The heights of the flashes are between 2 and 5 bar atmospheric pressure layer, in the region where the H_2O clouds are located. This suggests that the lightning generation mechanism is analogous to the terrestrial one (convective electrification of the clouds). In the visible band, the flash intensity ranges from $4.3 10^8$ J (for those having mean energy) to $6.6 10^9$ J for the more energetic ones (Russel, 1993). The total power is larger with respect to the optical one for a factor between 10^2 e 10^3 (Borucki and McKay, 1987). Assuming a typical duration of 35 ms, as for the terrestrial lightning (Zarka, 1985), the optical power span from $1.2 10^{10}$ W to $2 10^{11}$ W 10^5 km, and, if observed from orbit, the corresponding apparent magnitudes are negative till a distance of 10^5 km from the top of the Jupiter clouds.

5. Conclusions

So far, the study of luminous transient phenomena on planetary bodies has been very limited, due to the lack of an *ad hoc* instrumentation, and their detection has been performed mainly on a serendipitous basis. In practical terms, recently, ESA issued an announcement of opportunity for the development of systems devoted to the detection of transient events in the Earth atmosphere and on the dark side of other planetary objects. One of such a detector as been designed and a prototype has been constructed at *Galileo Avionica S.p.A.* (Florence, Italy). Its characteristics are the following:

Field of view: 120;
Limit magnitude: +6 m_V
Size: 10 x 10 x 10 cm;
Mass: 1,560 g
Power consumption: 4.9 W

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