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Radio-optical observations of meteors by BLM radar: preliminary results

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Abstract. We present preliminary results of a joint radio-optical test carried out by the BLM bistatic radar system and a LLTV camera located approximately below the radar hot-spot. The observations were performed during the peak of the Perseids activity in 2004. Tens of coincidences have been detected during the shower display. Some advantages of simultaneous radar-optical observations are discussed here.

Key words. Meteors – Meteoroids – Radar – Interplanetary dust

1. Introduction

Every day Earth encounters a huge amount of interplanetary dust grains and meteoroids, having velocities ranging from 11.2 km/s up to 72.8 km/s. During the interaction with atmosphere, meteoroids are enable to create both light and ionization. Since meteors are usually visible for only a fraction of second and it is impossible to predict when and in which part of the sky they will appear, the observations of these phenomena are very difficult to be performed. In spite of this forthcoming, different techniques have been developed for the meteor investigation (e.g. video and optical systems, radars, acoustic and seismic detectors, VLF-ELF receivers). Among them, radars are able to detect the smallest particles whereas optical measurements, even if less sensitive, are complementary to these techniques, providing useful information on some prominent meteor processes (e.g. ablation, fragmentation , etc.). Therefore the combination of these two different experimental approaches can be extremely useful for drawing a more complete description of the meteor phenomenon into the atmosphere. First attempts of radio-optical coincidence were made in 1946. In 1985 Znoljil et al. investigated the association between optical and radio meteors by visual telescopic observations and radar echoes recorded in 1972-73 at the Ondrejov radar operating at 37.5 MHz (Znojil et al. 1985). The search of correlated events based on agreement of time and range pointed out that radar echoes followed by a fraction of a second the optical detection. By analyzing visual observations and radar returns from the Springfield radar, Jones and Webster found that more than half of the bright meteors produced head echoes. They accepted optical-radar associations only within ±1 s time in-

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terval, with the position of the radar echo coinciding approximately with the visual sighting of the optical meteor (Jones & Webster 1991). More recently, joint optical-radar observations of meteors collected near the peak of the Leonid activity in 2002, showed that radar echoes were detected below the determination of the optical meteor (Brosch et al. 2004).

2. Equipment

The radar observations were carried out by the BLM (Bologna-Lecce-Modra) radar, a VHF meteor forward-scatter facility operating at a frequency of 42.770 MHz and equipped with two receiving stations. It consists of a transmitter located at Budrio near Bologna (44.6°N; 11.5°E, Italy) and the receivers are at Lecce (40.3°N; 18.2°E, Italy) and Modra (48.4°N; 17.3°E, Slovakia). The system was built up in 1996 for a systematic monitoring of meteor activity in order to study meteor flux from different baselines directions and consequently to study the structure and potential sources of the population in a close surroundings of the Earth's orbit. Detailed description of the radar and its operation can be found elsewhere (Cevolani et al. 1995). In 2004 we have installed an optical station at Campomarino (41.9°N; 15.0°E, Italy), nearly below the radar hot-spot (the zone in which the main receiver lobe intersects the transmitter one) of the baseline Bologna-Lecce. This zone is the most suitable for the optical system location because the maximum concentration of detected radio events is found within the hot-spot. The map of the set-up is shown in Fig. 1.

Optical observations were collected with a LLTV (Low-level Light TV) camera MINTRON model MTV-12V1C-EX, similar to that tested for optical meteor detection by ESA/SSD (see: http://www.rssd.esa.int/meteors/index.html). The camera is equipped with a CCD Sony ICX249AL having 795x596 pixels of 8.6 x 8.3 microns in size. The optics chosen for the experiment is an aspherical high-speed lens with 8 mm of focal length and F0.8 of relative aperture. The resulting optical set-up covers a field of view of 44.9°x34.0° with a scale of about 3.4 arcmin per pixel. In order to center the field of view to the hot-spot, the camera was oriented toward azimuth 346.2° and elevation of 59.8° above the local horizon. The output of the LLTV is a PAL-standard (50 odd-even interlaced frames per second), so the videos were recorded on VHS tapes and subsequently they were digitized for the elaboration and meteor identification. The LLTV has the capability to integrate up to 128 frames, corresponding to an integration time of 2.56 seconds. Anyway, since meteors appear as fast moving sources in the field, the integration time has been set to a value of 0.04 seconds.

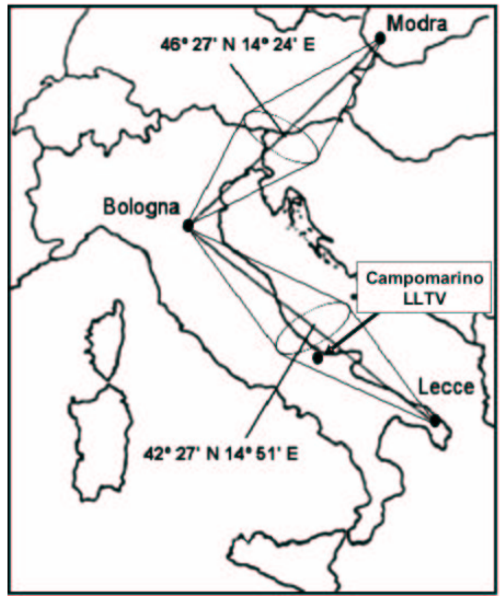

Fig. 1. Geography of the BLM Forward-Scatter meteor radar and the Campomarino LLTV Station. The ovals represent the 'hot-spots' (maximum concentration zones) of meteor trails detected by the radar.

3. Observations and results

For the joint optical-radar observations the Perseid 2004 meteor shower was selected especially for its high activity, rich of bright meteors, and for the favorable moonlight conditions near the peak of the stream (August 12-13).

Moreover, on August 11 of the same year an enhanced activity of Perseids was predicted by numerical models (Lyytinen & van Flandern 2004). The search for optical counterparts of radar echoes was conducted using the temporal coincidence of the optical and radar detections. This method is not probably the most reliable, but it is the only available in case of lacking information on the direction and range of radio-echo.

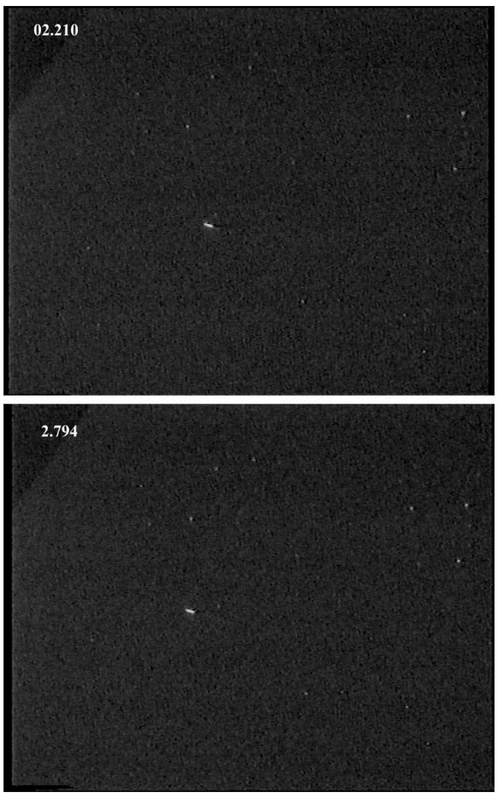

Fig. 2. Two frames of optical meteor detected on 11 August at 23h 31m 47s UT associated to the radio echo n.42926.

Optical observations were carried out in three consecutive nights starting from 20.30 UT on 11 August and lasted 8 hours for each night. At present only the optical data recorded on 11 August have been analyzed and we found about twenty common radar-optical events. Fig. 2 shows two frames of the meteor recorded by LLTV on 11 August at 23h 31m 47s UT, optical counterpart of the long duration radio echo n. 42926 which initial part is plotted in Fig. 3.

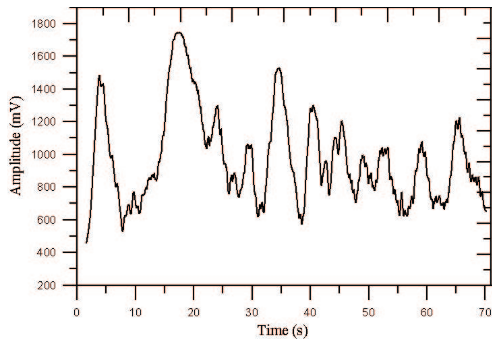

Fig. 3. Smoothed profile of the first part (71s) of the echo n. 42926, detected by BLM radar.

The duration of the optical meteor was found to be 1.9 s, whereas the corresponding echo was lasting 154.3 s, about 80 times greater. This discrepancy, with the optical event shorter than the radar one, was found to be common to all radio-optical meteors that we analyzed so far. The great difference between radar and optical durations cannot be explained taking into account only the lower sensitivity of LLTV camera that is able to detect only the brightest part of the meteor trail.

A possible solution is that the high-density ionized trail producing radio-echo dissipates in a time longer than the light emission phenomenon. Anyway, this behaviour is also in agreement with the hypothesis of the charge clouds (meteoric ions or dust) formed below the trail and this would explain why 'plasma' could produce radar echoes even though the meteor itself is no longer visible (Brosch et al. 2004).

Our observations show that the number of radio-echoes is much higher than optical events and, in the case of coincidence, the visual meteor was associated to a long duration echo (overdense echo). This result was expected since radars are more sensitive than any optical device in detecting small particles. Nevertheless, the LLTV camera observed a few optical meteors without the radio counterpart. The missing radio counterparts could be due to the unfavorable orientations of the trails. The radar cross section of an meteor trail for a forward-scatter radar strongly depends on the bistatic angle (i.e. half of the angle between the transmitter and the receiver at the reflection point) and in addition, on the angle between the meteor path and the propagation plane (i.e. the plane defined by transmitter, receiver and reflection point) (McKinley 1961). Therefore it is quite difficult to find some correlations between important parameters derived from photometric measurements (e.g. the mass of meteoroid) and the features of the echo profiles, if the geometry of the meteor trail is not well known. Anyway, interferometric radar measurements could provide the lacking information and be of great support in more detailed studies.

4. Conclusions

The low-cost proposed experiment outlines that these preliminary results are encouraging in the search of radar-optical coincidences, even if further improvements in the observational apparatus are requested.

At first, the number of radio-optical coincidences could be increased by improvement of the optical system in terms of sensitivity and by adding a proper software able to identify meteors in real-time during the video capture. The SPOSH (Small Optical Sensor Head) camera is an optical device that provides such requirements, being designed for observations of transient phenomena on the night hemisphere of Earth or other planets from an orbiting spacecraft. A prototype SPOSH was developed by Galileo Avionica in collaboration with Osservatorio Astronomico di Torino and it is able to detect and identify automatically meteors of +6.5 magnitude moving at 5^{o}/s (Koschny et al. 1991).

Furthermore, the parameters necessary to correlate photometric curves and echo profiles can be obtained in the near future by the new radar facility MIRA (Meteor Interferometer Radar Array) - which will improve the present BLM radar after installing an interferometric-range finding system.

We are confident that such measurements will be very useful to investigate the structure of meteoroids, to deepen the knowledge of the physical processes involved during their interaction with atmosphere, and finally, to identify particles distribution within the meteor streams.

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