Mem. S.A.It. Suppl. Vol. 6, 146

Memorie della
Supplementi

The Leonid storms: an astrobiology target

G. Pupillo[1,2] G. Cevolani[1] G. Bortolotti[1] C. Franceschi[1] G. Grassi[1] A. Hajduk[3] V. Porubčan[3] and G. Trivellone[1]

[1] CNR - ISAC, Via Gobetti 101, I-40129 Bologna, Italy
[2] DET, Universitá di Firenze, I-50139 Firenze - Osservatorio di Campi Salentina, 73012 Campi Salentina (Lecce), Italy
[3] Astronomical Institute of the Slovak Academy of Sciences, 845 04 Bratislava, Slovakia
e-mail g.pupillo@isac.cnr.it

Abstract. High meteor rates and exceptional activity of Leonids in the 1998-2002 years offered an unique opportunity to study interaction processes of extremely fast particles with the atmosphere and the role of meteoric chemistry in supplying organic matter to the early Earth at the time of the origin of life. Recent airborne missions supported by concerted ground-based campaigns worldwide, provided a huge amount of new data on the composition and morphology of meteoroids, the physical conditions in meteors, and their influence on the Earth's atmosphere. Atmospheric chemistry is essential in creating useful prebiotic compounds. Leonid MAC (Multi-Instrument Aircraft Campaign) provided the first evidence that organic molecules may survive the meteor phase (Jenniskens et al. 2000) with the discovery that most light emission occurs in a comparatively mild temperature (about 4300 K) air plasma in almost local thermodynamic equilibrium just behind the meteoroid (Boyd 2000).

Key words. Leonids, meteors, astrobiology

1. Introduction

All potential exogenous pre-biotic matter arrived to Earth by ways of our atmosphere, where much material was ablated in rarefied flows of high (up to 270) Mach number. Airborne missions performed in connection with ground-based campaigns were able for the first time to monitor the recent (1998-2003 years) Leonid showers offering a glimpse into the physical conditions of the ablation process and atmospheric chemistry associated with high-speed meteors. Modern instruments were deployed for meteor observations, which included optical video imagers and slitless spectrographs, mid-infrared sensors, submillimeter spectrometers and LIDAR (Light Detection an Ranging).

Refractory organic carbon in extraterrestrial materials is a likely source of prebiotic compounds. Organic carbon is abundant in the cometary grains probed by the GIOTTO and VEGA spacecraft, making up some 23% by weight of the comet mass fraction and some 66% by weight of dust grains once the volatile compounds have evaporated (Jenniskens et al. 2000). Organic matter carried to Earth via meteors is not necessarily broken down into atoms or diatomic

Send offprint requests to: G. Pupillo

molecules and may survive in the form of larger molecules (Jenniskens et al. 2004). The survivability of extraterrestrial organic matter at relatively high temperatures was proposed by many investigators (Brownlee et al. 2002).

2. Meteor Spectroscopy

The radiation emitted during the flight of a meteoroid through the atmosphere is an important factor in the body's interaction with the atmosphere. Chemical composition, structure, shape and even bulk density for most of meteoroids entering the Earth's atmosphere are poorly known. Information about the chemical composition of a meteoroid may be derived from the observational data, especially from spectra. Bright, fast meteors belonging to main meteoroids streams (especially, Perseids in August, Orionids in October and Leonids in November) exhibit one or more flares late in the trajectory. Spectral lines of meteoroids were studied in a wide spectral range including near-UV, visible and near-IR bands. The present knowledge on chemical composition of meteoroids shows that: (i) more than 90% of meteoroids near the Earth have chondritic (the most common meteorite type) chemical composition; (ii) few percent of meteoroids have composition of other types of meteorites (iron and achondrites); (iii) some meteoroids contain large amount of light organic material (i.e. the CN molecule).

Meteor spectroscopy is a traditional but still perspective method of studying the chemical composition and other properties of meteoroids and their parent bodies. More theoretical and observational work is needed to take full advantage of this method. UV meteor spectroscopy from space could lead to new progress, by detecting new elements not discovered so far in visible light and by providing more data on the hot meteor plasma (Borovicka 1999).

Previous observations have shown that meteors radiate strongly even in the UV band. The Perseid and Alpha Capricornid meteors are able to produce a peak irradiance at a distance of 100 km in the OH emission at 3085 Å and 3100 Å, respectively. This may be indicative of significant amounts of H_2O in these meteors (Harvey 1977).

UV observations from space of meteor streams particularly rich of bright meteors (Quadrantids, Lyrids, Perseids, Orionids, Leonids) allow us to detect spectral lines of new elements and compounds which are known to radiate also in other spectral bands (Fig. 1). Another important aspect is to study meteors as a vector for the delivery of organic matter keeping benefit from UV images of meteors streams (especially, the fastest Leonids at geocentric velocities of 70 km/s). UV spectra of Leonid meteors and afterglow were obtained during the Leonid MAC 1999 campaign with an objective grating (slit-less) spectrograph aboard the FISTA aircraft (Jenniskens et al. 2000). Several first-order UV spectra were obtained near the storm peak in the morning of November 18, 1999 (Rairden et al. 2000).

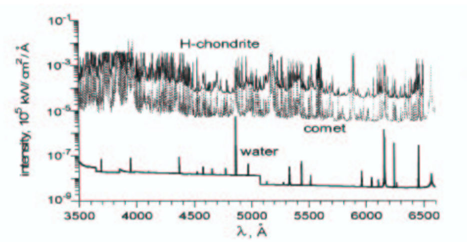

Fig. 1. The spectrum of radiation emitted from the vapor at the head of a bolide in the passband of groundbased observations. Similar lines are present both in the H-chondrite and comet spectra due to the high contents of dust and metallic atoms in meteorites and comet substance. The emitted air radiation mainly belongs to the UV spectral range (Popova et al. 1999)

Leonid meteors yield rich astrobiology research results. A great deal of organic matter is thought to survive the rapid heating of Earth' atmosphere (Jenniskens et al. 2004). The fingerprint of complex organic matter, identical to space-borne cometary dust, was discovered in the path of a bright Leonid fireball by the spectroscopy of the formed vapor cloud just behind the meteor head. Further investigation mainly in the UV is requested to ensure that traceair compounds are not contributing to the detection. A confirmation could have important implications for the existence and survival of life's precursors in comet materials that reach Earth.

The interaction of meteoroids with the atmosphere generates molecules that may have played a role in the origin of life on Earth. After the Leonid MAC NASA's first Astrobiology mission in 1999, it appears very interesting the hypothesis that extraterrestrial materials may have been brought to Earth at the time of the origin of life.
The study of fast shower meteors can help to clarify a role of meteors in creating prebiotic conditions on Earth. This is because the wake temperatures of all meteors are in the same narrow range of 3900 ± 900K, as derived from the meteoric metal atom emission lines (Borovicka & Betlem 1997). Relevant atmospheric chemistry can occur in two regimes: (1) the extended wake of the meteors at temperatures of about 4300 K and (2) at the interface layer between impinging air and ablation products at temperatures of about 10000 K. Right at about 4200 K is where the production of linear carbon chains such as C_2 and C_3 peaks (Jenniskens et al. 2000). Under these conditions small amount of aromatic hydrocarbons are expected to be formed upon cooling, as well as compounds rich in $C = O$ and $C - N$ groups. Assuming organic compounds are common to Leonid meteoroids, the lack of observed C, C_2 and CN emission from the combustion of organic matter in the ablating meteoroids implies that organic compounds survive as large molecular fragments. To test this hypothesis, CN emission in meteor spectra has been searched in an airborne experiment during the 2001 Leonid meteor storm (Jenniskens et al. 2004). The meteor's light-emitting air plasma, which included products of meteor ablation, contained less than 1 CN molecule for every 30 meteoric iron atoms. It appears that very little of that organic nitrogen decomposes into CN molecules during meteor ablation in the rarified flow conditions that characterize the atmospheric entry of meteoroid 50 micron - 10 cm in size. The authors conclude that the most likely explanation for the lack of CN molecules in the meteor plasma is that meteoric organic matter is lost in the form of a large range of relatively complex molecules or perhaps as an amorphous carbon solid with embedded metal (Brownlee et al. 2002). If the organic matter survives as large molecules, this implies that bonds are prevented from breaking by rapid radiative cooling

3. Radar measurements

In recent years radar measurements have brought new light in different research fields by a multidisciplinary approach involving planetology, Earth's upper atmosphere, satellite safety and astrobiology. Innovative observing techniques are able to study the physical properties of meteors as they interact with the atmosphere, since each wavelength regime from sub-millimeter radio to the visible-ultraviolet wavelengths gives a different type of information. Systematic radio observations of meteoroid streams carried out in the past decade by radar techniques, such as the BLM (Bologna-Lecce-Modra) forward-scatter radar facility, and further joint campaigns between ground-based radars and space sensors, must be considered a powerful tool to investigate: (i)the mass distribution of particles within a meteoroid stream (Cevolani & Pupillo 1999); (ii) the structural/dynamical aspects of those main meteor streams particularly rich of very bright meteors (fireballs and bolides) that are expected to an enhanced (outburst or storm) activity (Cevolani et al. 2000); (iii) the interaction processes (ablation, catastrophic fragmentation, explosive episodes with final flares mainly emitting in the UV band) of the interplanetary bodies with the atmosphere (Cevolani et al. 1998).; (iv) the radiation-idrodynamical simulations of the plasma formation, heating (at different temperatures) and motion under the shock compressed air radiation in front of the body.

The forward scatter (FS) BLM meteor radar system constructed by the "METEORS" group of the ISAC-CNR performed in the last decade systematic observations of meteoroid streams, including the Leonid stream, particularly active in the 1998-2002 yearly period (Fig. 2-3). In 1998-2002, the large number of long duration echoes corresponding to more massive particles (fireballs and bolides) observed near the time of the peak of the shower, makes these years particularly interesting for studies in astrobiology, in order to know:

– fate of organic matter during ablation;
– differential ablation of inorganic and organic matter;
– conditions in meteor wake plasma;
– atmospheric chemistry;
– formation of solid debris containing organic matter;
– aerothermochemistry (synthesis of molecules)

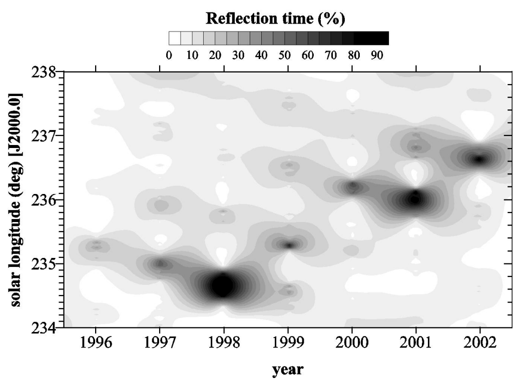

Fig. 2. Activity of 1996-2002 Leonids vs. the solar longitude, as deduced in terms of reflection time by the BLM radar facility.

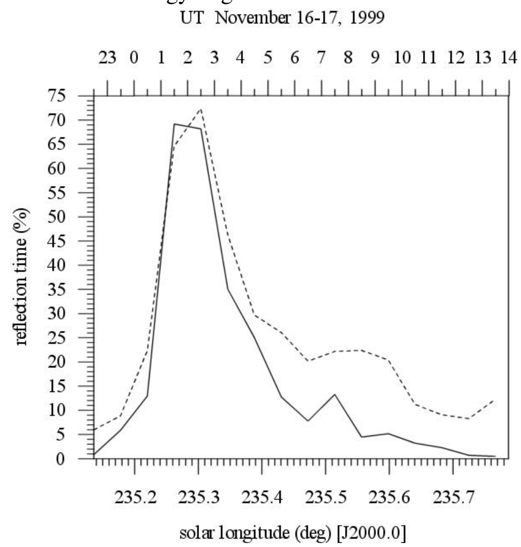

Fig. 3. Reflection time of radioechoes (*in percentage*) vs. the solar longitude, recorded at the stations of Lecce (*continuous line*) and Modra (*dashed line*) during the maximum of the Leonids 1999

4. Conclusions

Leonid outbursts and storms in the 1998-2002 period gave an opportunity to deepen our knowledge on the influence of meteoric matter falling into Earth's atmosphere and the delivery of organic matter through meteors. Half of the mass influx of meteoroids is carbon-rich (25-50%) cometary matter (Delsemme 1991). Hence, meteors contributed at least 1×10^9ton/yr of organic carbon to the early Earth if all organic carbon survived the ablation processes. Complex organic matter in meteoroids does not fully decompose into diatomic constituents or atoms during the most intense phase of meteor ablation, and that meteoric organics are most likely lost in the form of large molecular fragments cooled by radiative cooling and the loss of hot molecular fragments. This makes the product of meteor ablation and subsequent chemistry potentially the dominant source of complex organic molecules on the early Earth at the time of the origin of life. Of particular interest for astrobiology is the possible detection of organic carbon in meteor ablation by its 3.4 micron feature corresponding to the CN band emission, as molecules in stratospheric aerosols, or indirectly from its interaction with the airglow chemistry. CN is a product of reactions involving nitrogen embedded in the complex organic matter or interactions between the meteoric carbon atoms and atmospheric N_2 (Jenniskens et al. 2004). Furthermore, hydrogen emission in the spectra of bright meteors must be deeply investigated as a potential marker for the exogenous delivery of organics and water (Jenniskens & Mandell 2004).

References

Borovicka, J. 1999, in Meteoroids 1998, eds. Baggaley and Porubčan, Published by: Astronomical Institute, Slovak Academy of Sciences, Bratislava, 355

Borovicka, J., & Betlem, H. 1997, Planet.Space.Sci., 45, 563

Boyd, I. D. 2000, Earth, Moon and Planets, 82-83, 93

Brownlee, D. E., Oswiak, D. J., Kress, M. E., Taylor, S., & Bradley, J. 2002, Lunar and Planetary Conference, LPI contribution No.1109

Cevolani, G., Gabucci, M. F., Grassi, G., & Trivellone, G. 1998, Planet.Space.Sci., 46, 869

Cevolani, G., Pupillo, G. 1999, Il Nuovo Cimento C, 22, 747

Cevolani, G., Pupillo, G., Hajduk, A., & Porubčan, V. 2000, Earth, Moon and Planets, 82-83, 265

Delsemme, A. H. 1991, in Comets in the post-Halley era, vol.1, Kluwer, Dordrecht, 377

Harvey, G. A., 1977, ApJ, 217, 688

Jenniskens, P., et al. 2000, Earth, Moon and Planets, 82-83, 57

Jenniskens, P., et al. 2004, Astrobiology, 4, 67

Jenniskens, P., & Mandell, A. M. 2004, Astrobiology, 4, 123

Popova, O. P., Nemtchinov, I. V., & Kosarev, I. B. 1999, in Meteoroids 1998, eds. Baggaley and Porubčan, Published by: Astronomical Institute, Slovak Academy of Sciences, Bratislava, 367

Pupillo, G., Cevolani, G., & Trivellone, G. 2001, in Proc. of 3rd European Conference on Space Debris, ESOC, SP-473, vol.1, 231

Rairden, R. L., Jenniskens, P., & Laux, C. O. 2000, Earth, Moon and Planets, 82-83, 71