OH AND O_2 AIRGLOW EMISSIONS DURING THE 1998 LEONID OUTBURST AND THE 2002 LEONID STORM

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Abstract. In order to enhance our understanding of the possible influence of meteor ablation on the enrichment in OH and O_2 of the lower thermosphere we studied intense Leonid meteor activity by using the SATI (Spectral Airglow Temperature Imager) interferometer of the *Instituto de Astrofísica de Andalucía*. We measured the emission rate and rotational temperature of OH and O_2 airglow emission layers during two observation periods of high meteoric activity: the 1998 Leonid outburst and the 2002 Leonid storm. The results show that there is not a clear relation of O_2 and OH airglow emission and rotational temperature with meteoric activity.

Keywords: airglow, Leonids 1998 and 2002, lower thermosphere, O_2, OH, meteor

1. Introduction

The study of meteor showers can provide us with detailed information about the deposition mechanism of cometary matter into the Earth's atmosphere. The systematic observation of meteors using all possible techniques, but especially meteor spectroscopy, provides information about the processes that occur in the lower thermosphere when meteor ablation introduces small dust particles and probably also organic compounds and volatiles included between the mineral grains. It is well known that cometary dust from 55P/Tempel-Tuttle comet reaches the terrestrial atmosphere at a mean velocity of 71 km/s. When the meteoroid enters the upper atmosphere, the collisions with atmospheric compounds cause the meteoroid ablation and the material is dispersed along the meteor column. The average atmospheric temperature in the atmospheric region where meteor ablation occurs is around 200 K (Salby, 1996). From meteor spectra we know that during the ablation process the meteor-column temperature rises to 4000–5000 K (Ceplecha, 1973), producing a plasma that is in quasi-local thermodynamic equilibrium and is called the main component (Borovicka, 1993; Jenniskens et al., 2002). The temperature of this component decreases very quickly, as deduced by

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Borovicka and Jenniskens (2000) who analyzed the temporal evolution of a Leonid persistent train at the time of the afterglow. According to these authors, the ablation temperature decreases following an almost exponential decay, and reaches the temperature of the thermosphere again in only a few seconds. Additionally, a hot temperature component ($T \approx 10{,}000$ K) has been detected in meteor spectra (Borovicka, 1993; Borovicka and Betlem, 1997; Borovicka et al., 1999; Borovicka and Jenniskens, 2000). The source of the emissions of this high-temperature component remains unknown although it has been postulated that it is the cloud of meteoric vapour surrounding the meteoroid (Borovicka, 1993; Jenniskens et al., 2000a, 2000b). The mass associated with this high-temperature component is usually less than that of the main component (Borovicka and Betlem, 1997; Trigo-Rodríguez, 2002; Trigo-Rodríguez et al., 2003). It is well known that the result of the ablation processes is the formation of metal layers in the upper atmosphere (Plane, 1991). The formation and fast dissipation of dust layers during high meteoric activity have recently been deduced (Mateshvili et al., 2000). However, the results are not always positive; because from Lidar observations Höffner et al. (2000) were unable to detect an enhancement of the upper atmosphere potassium layer in a short time scale, just two hours after the 1999 Leonid storm.

We used an interferometer to determine the variations on the O_2 airglow layer, with emission altitude peak situated at around 95 km (Witt et al., 1979, 1984; Harris, 1983; Greer et al., 1986; Ogawa et al., 1987; Murtagh et al., 1990; Siskind and Sharp, 1991; López-Moreno et al., 1995), and on the OH airglow layer, placed around 87 km (Baker and Stair, 1988). We attempted to assess their possible link to meteoric activity. The effect of the meteoric process on these layers, if it really exists and is detectable with the accuracy of our instrument, would be detectable by interferometric determination of the temperature and emission rate of the OH Meinel and O_2 atmospheric airglow emission layers during periods of high meteor activity.

2. Instrumentation, Data Reduction and Observation Site

To study the O_2 atmospheric (O-1) and the OH Meinel nightglow emission layers we used the Spectral Air glow Temperature Imager (SATI) interferometer. This instrument allows the dynamics and temperature in the mesopause region to be monitored by observing both emission layers. This instrument is usually employed for ground-based observations of these airglow emissions and to detect gravity waves within the requirements of the Planetary Scale Mesopause Observing System (PSMOS) program.

In this interferometer a conical mirror provides an image from an annular field of view centered to 30° of the optical axis, with a semiamplitude 7.1°

wide. It collects light from an annular sky area with inner and outer radii of 47 and 64 km, respectively, at a reference altitude of 95 km, i.e., just inside the meteoric level. A Fresnel lens below of the conical mirror ensures that the entrance pupil is focused on the CCD to prevent spatial intensity non-uniformities from appearing as spectral non-uniformities. Two interference filters are interposed in front of the CCD camera to obtain the interferogram. This provides a circular image interferogram that possesses a spectral distribution in the radial direction and a spatial imaging property in the azimuth coordinates.

The SATI data reduction was performed using the operational and scientific software developed by Wiens et al. (1997). The method of reduction of the airglow images is described in López-González et al. (1999), whereas the method used to obtain simultaneously the temperature, emission rate and background continuum is explained in detail by López-González et al. (2004). Although the SATI instrument usually operates during nights without moonlight, we implemented observations reducing the integration time of the exposure during the 2002 Leonid storm.

In the reduction procedure we also take into account the continuum sky emission that still remains in the airglow spectrum after subtraction of the emission coming from the OH and O_2 emission that is named background. The origin of this background continuum has been interpreted as due to the radiative association of NO + O (see e.g., Wraight, 1977); weaker sources of continuum emission in a dark night are the zodiacal, galactic and extragalactic diffuse lights. We note that the background obtained for the 1998 nights with completely dark conditions and that obtained for not-so-dark nights of 2002 are quite different, even though the Moon was almost gone in the 2002 nights. In order to avoid the effect of the background in our measurements we followed a systematic reduction procedure. Once we obtain a airglow spectrum from one image $S(\lambda)$, the observed spectrum is the result of multiplying a normalized modelled spectrum $M = \mathrm{f}(\lambda)$ plus a constant background. It can be synthesized in the following linear equation:

$$S(\lambda) = A \times M(\lambda) + B \tag{1}$$

A library of normalized synthetic spectra for temperatures between 110 and 290 K is used in a least-squares fitting. The fitting was performed for each spectrum, and the one that yields the minimum fitting error gives the temperature T, the emission rate A, and the continuum background B, simultaneously (López-González et al., 2004). This procedure allows full automation of the observation process using hardware diagnostics. The derivation of the rotational temperature and emission rate from the interferogram is based on the comparison between several synthetic spectra and the image spectrum measured seeking the best fit. In this way we obtain the value for the observed magnitudes: emission rate and rotational temperature of the O_2 and OH layers besides the background continuum values (López-González et al., 2004).

The SATI interferometer that we used to deduce changes in the mesospheric regions during high meteor activity is in an excellent location belonging to the *Instituto de Astrofísica de Andalucía*: the Sierra Nevada Observatory (Granada, Spain), 3°23′05″W longitude, 37°03′51″ N latitude, and is placed at an altitude of 2896 m.

3. Observations

Taking into account the excellent opportunity to use the SATI interferometer to study the influence of meteors on the mesosphere during high meteoric activity, we decided to perform observations during the expected Leonid storms. In the following sections we will analyze the results obtained during these remarkable events.

3.1. THE 1998 LEONID OUTBURST

Today we know that the 1998 Leonid outburst was one of the most impressive Leonid displays. During 16–17 November a remarkable sample of extremely large Leonid meteoroids encountered our planet, producing an extraordinary show of bright meteors known as the ‘‘Fireball night’’. Asher et al. (1999) demonstrated that such a notable display was produced by a component rich in large meteoroids ejected from comet 55P/Tempel-Tuttle in 1333 and that moves around the Sun in a resonant orbit. The fireballs produced by these large particles were characterized by persistent trains that were visible for many minutes due to the presence of luminous mechanisms that are still poorly understood (Borovicka and Jenniskens, 2000). Such persistent trains are significant for us because they prove the interaction of meteoroids with the atmosphere; moreover, their persistent influence on the upper atmosphere could be especially important for direct detection using the SATI interferometer.

The SATI observations conducted under excellent night sky conditions during the 1998 Leonids period made it possible to obtain airglow images with a 2-min exposure time. In order to study the possible appearance of meteors in the field of view, in Figure 1 we present the rotational temperature, emission rate and background derived from SATI interferograms between the nights of 13–14 and 20–21 November 1998. Asterisks correspond to OH and black dots to O_2 measurements. The continuous line shows, for comparison, the derived meteor activity (Arlt, 1998).

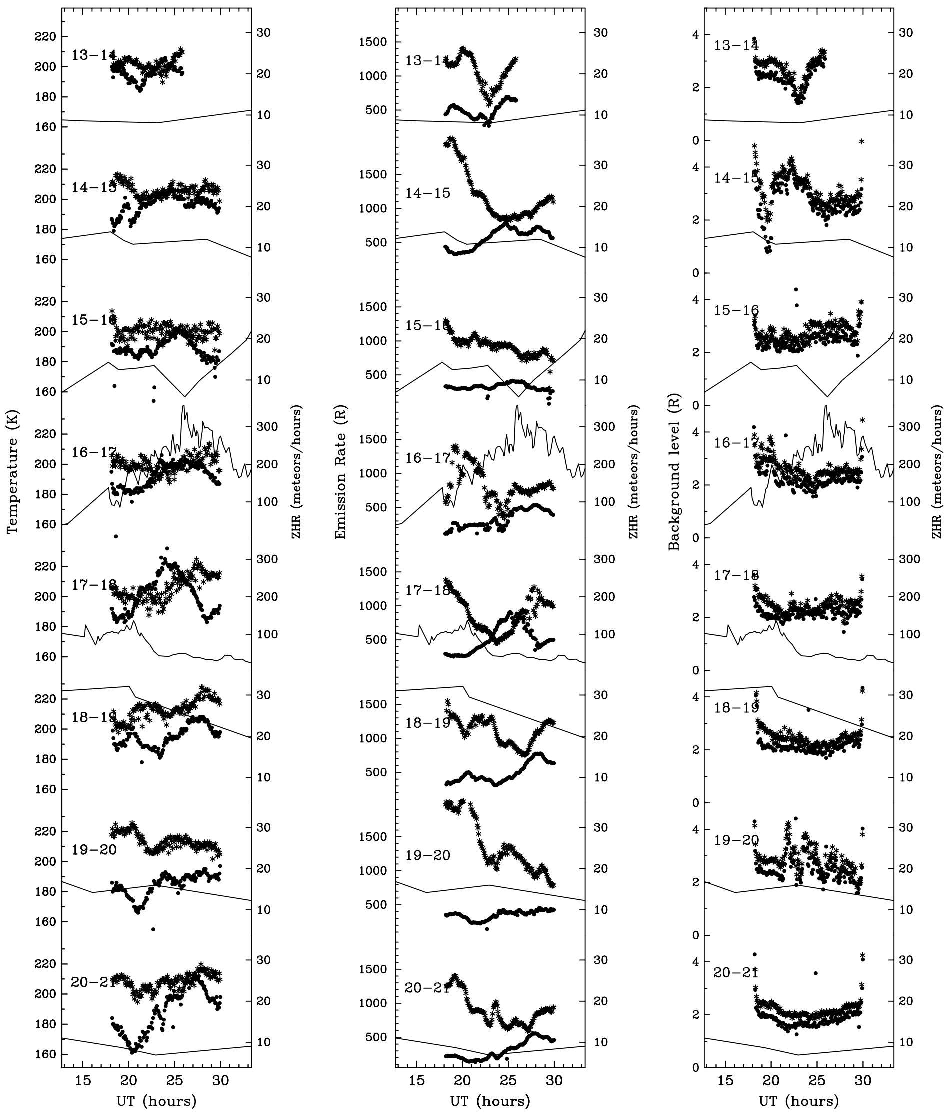

Figure 1. Rotational temperature, emission rate and background derived from SATI interferograms between the 13–14th and 20–21th November 1998 nights. Asterisks correspond to OH and black dots to O_2 measurements. The continuous line shows for comparison the derived meteor activity (Arlt, 1998).

Figure 2 shows the results obtained for the night of 16–17 and 17–18 November, together with the rate of meteor activity during those nights. In this figure on the night of 16–17 November the background level seems to keep a similar level as meteor activity grows. There is no clear correlation between background, emission rates, rotational temperatures and 1998

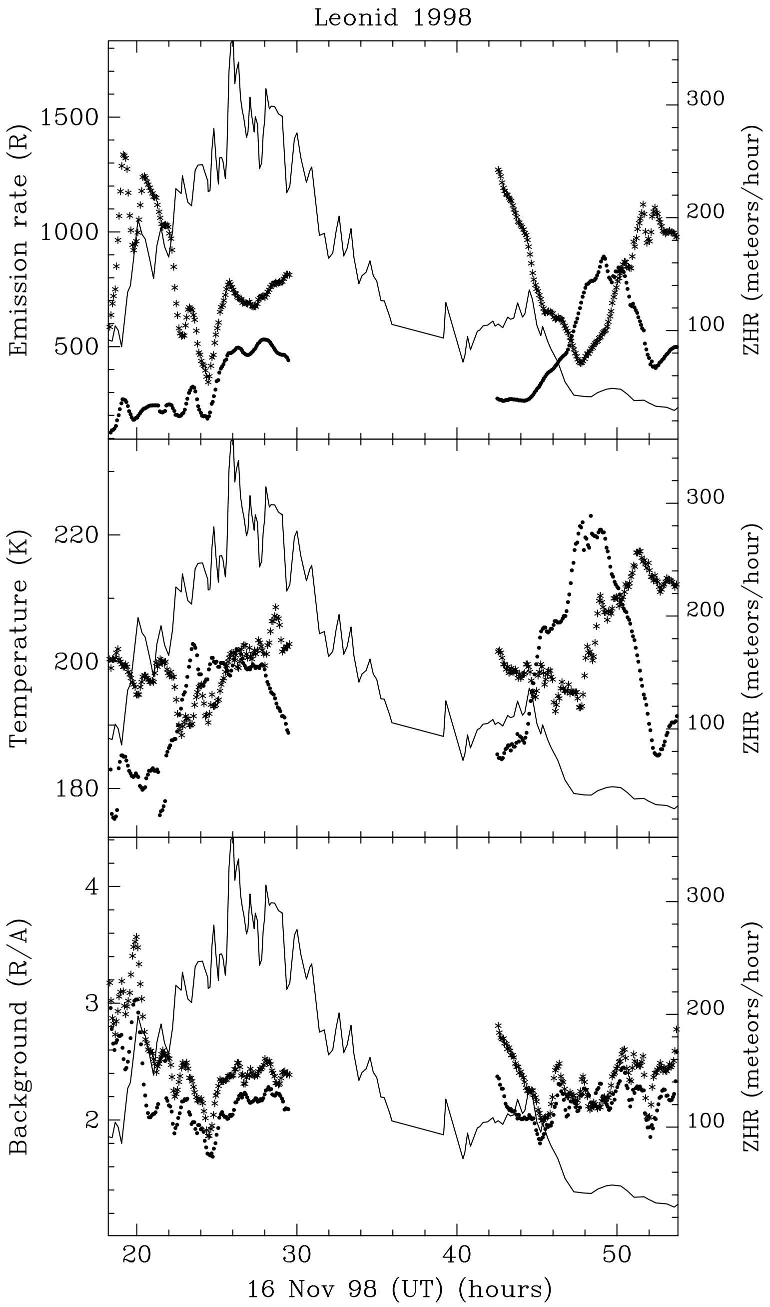

Figure 2. Emission rate, rotational temperature and background derived from SATI interferograms for 16–17th and 17–18th November 1998 nights. Asterisks correspond to OH and black dots to O_2 measurements. The continuous line show for comparison the derived meteor activity (Arlt, 1998).

meteor activity. In fact, by looking at the emission rates, rotational temperatures and background levels obtained on the night prior to, and following, the maximum meteor activity it is not easy to deduce a correlation between airglow activity and meteor activity.

3.2. THE 2002 LEONID STORM

The 2002 storm was observed from several stations of the Spanish Photographic Meteor Network (SPMN) in Andalucia (Spain) but some of them under changing weather conditions and with a full moon (see, e.g. Trigo-Rodriguez et al. 2004). In order to study the possibility of SATI detecting the appearance of meteors in their interferograms, our first step was to analyze the background, emission rates and rotational temperature deduced from them. In order to separate the possible appearance of meteors in the different sectors of the sky, an analysis of the image in different sectors was performed but no significant differences were found.

Figure 3 shows the emission rates, rotational temperatures and background derived from SATI interferograms during the 2002 Leonid storm together with the rate of meteor activity throughout the observation interval. The background level obtained from the airglow images is also shown. This level is high because there is some background light coming from the full moon during that night. Nevertheless, almost the same level is maintained over the whole time of observation. There are interesting features in the background level that almost coincide with the level of meteor activity. However, looking at the rotational temperatures and the emission rates, no clear relation with the 2002 Leonid meteor storm seems to exist. The O_2 rotational temperature seems to increase during the maximum meteor activity, but this rise is not observed in the OH rotational temperature. On the other hand, OH emission rates seem to increase during the interval of the meteor storm, while O_2 emission rates do not show any correlation with the storm. Kristl et al. (2000) found that OH emission rates follow a correlation with the 1999 Leonid storm but the O_2 emission rates do not. In any case, the presence of the full moon together with not very good meteorological conditions do not allow us to draw firmer conclusions about the relation between these airglow features and the 2002 Leonid meteor storm.

4. Discussion

One of the more important points of discussion is the possibility of separating the meteoric effect from other induced atmospheric changes, such as the presence of gravity waves, on the interferogram. This turns out to be

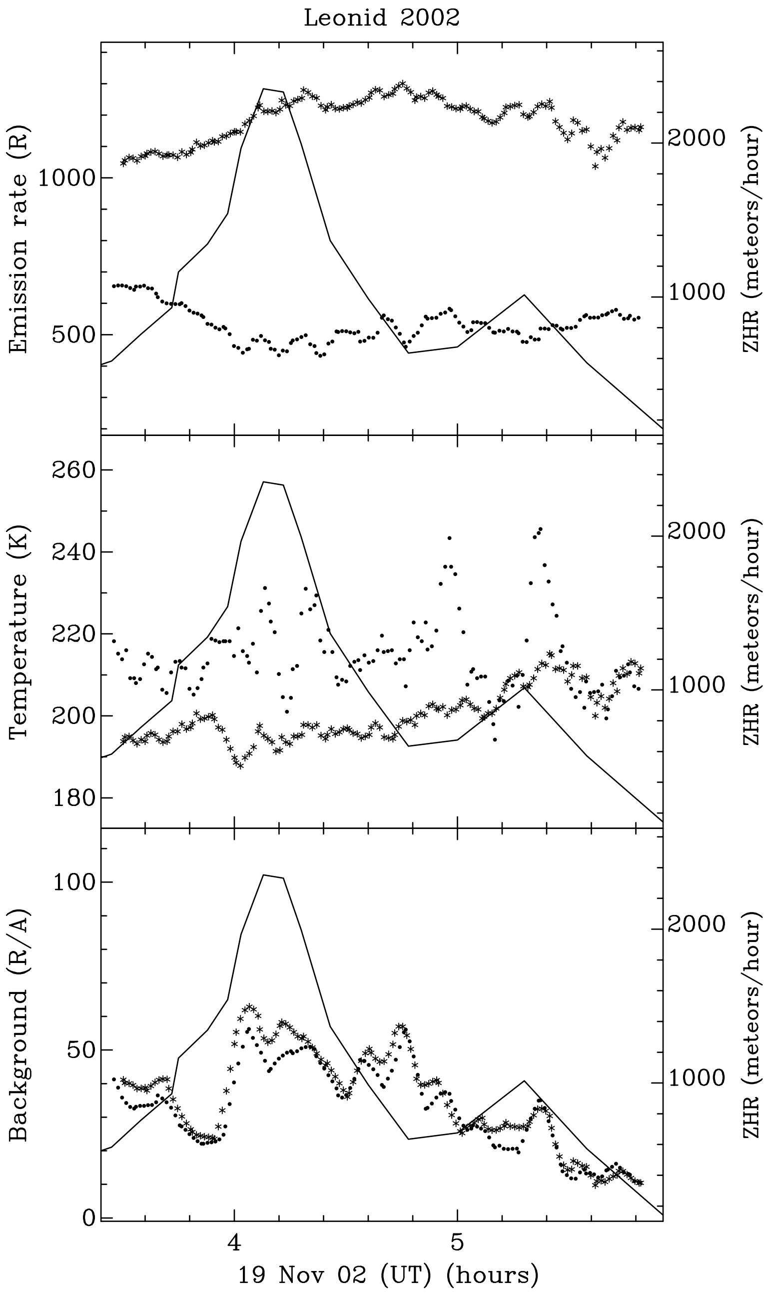

Figure 3. Emission rate, rotational temperature and background derived from SATI interferograms during the 2002 Leonid storm. Asterisks belong to OH and black dots to O_2 measurements. The continuous line show for comparison the derived meteor activity (Jenniskens, 2002; Arlt et al., 2002).

quite complicated and will be discussed separately for both periods of observation. During the 1998 Leonid outburst, important atmospheric activity before, during and following the nights of maximum meteor activity is clearly visible. On comparing the level of background on the night of maximum meteor activity with the previous and next days, no clear feature is found indicating more activity on that day than on the others. There seem to be clear tendencies in the patterns of variation of O_2 and OH emission rates during these days, and a correlation in the patterns of variation of O_2 and OH rotational temperatures. The O_2 variation always are above that of OH and could be interpreted as a propagating wave. Other observations at mid-latitude places during autumn or early winter (Takahashi et al., 1986; Scheer and Reisin, 1990; Taylor et al., 2001) have shown the presence of long periodic and almost sinusoidal variations with a 6–10 h period which have been interpreted as a propagating wave perturbation, although its nature as a tidal-type perturbation or gravity-wave is not yet clear (Taylor et al., 2001).

Figure 3 shows that during the 2002 Leonid storm no important variations in the O_2 and OH airglow emissions were derived. The rotational temperature of both layers also seems to be independent of storm activity. Finally, the background derived from the images appears not to be correlated clearly with meteoric activity. The absence of additional observations on other days due to bad weather and full moon makes it difficult to reach more detailed conclusions.

5. Conclusions

We have obtained no clear evidence that the 1998 Leonid outburst led to an outstanding enhancement of the O_2 and OH rotational temperature in the upper atmosphere. Results from the 2002 Leonid storm are more difficult to obtain due to moonlight and bad weather conditions. In any case, we believe that a clear correlation between the 1998 and 2002 Leonid storms and airglow activity cannot be deduced from the data. If an airglow influence existed, the shape of the behavior of background, emission rates and rotational temperatures in both high meteoric activity periods would be correlated although it was out of phase. In any case we think that more data are needed, including that obtained during the maximum activity of different meteor showers, in order for us to determine which of these features are coming from the atmospheric activity itself and which would be related to meteor activity. In order to clarify this point, future observations overlaying the interferometer field with video imaging are in progress. They would be useful in identifying fast meteor sources moving in correlated exposures. Covering the same field of view using different techniques would allow us to determine if some observed patterns are associated to meteoric activity.

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References

Arlt, R.: 1998, *WGN* **26**(6), 239–248.

Arlt, R., Krumov, V., Buchmann, A., Kac J., and Verbet, J.: 2002, *WGN* **30**(6), 205–212.

Asher, D. J., Bailey, M. E., and Emel'yanenko, V. V.: 1999, *Irish Astron. J.* **26**, 91–93.

Baker, D. J. and Stair Jr., A. T.: 1988, *Phys. Scripta* **37**, 611–622.

Borovicka, J.: 1993, *A&A* **279**, 627–645.

Borovicka, J. and Betlem, H.: 1997, *Planet. Space Sci.* **45**, 563–575.

Borovicka, J., Stork, R., and Bocek, J.: 1999, *Meteorit. Planet. Sci.* **34**, 987–994.

Borovicka, J. and Jenniskens, P.: 2000, *Earth Moon and Planets* **82–83**, 399–428.

Ceplecha, Z.: 1973, *Bull. Astron. Inst. Cz.* **24**, 232–242.

Greer, R. G. H., Murtagh, D. P., McDade, I. C., Dickinson, P. H. G., Thomas, L., Jenkins, D. B., Stegman, J., Llewellyn, E. J., Witt, G., Mackinnon, D. J., and Williams, E. R.: 1986, *Planet. Space Sci.* **34**, 771–788.

Harris, F. R.: 1983, *EOS. Trans. AGU* **64**, 779.

Höffner, J., Fricke-Begemann, C., and von Zahn, U.: 2000, *Earth Moon and Planets* **82–83**, 555–564.

Jenniskens, P., Lacey, M., Allan, B. J., Self, D. E., and Plane, J. M. C.: 2000a, *Earth Moon and Planets* **82–83**, 429–438.

Jenniskens, P., Nugent, D., and Plane, J. M. C.: 2000b, *Earth Moon and Planets* **82–83**, 471–488.

Jenniskens, P.: 2002, *WGN* **30**(6), 218–224.

Jenniskens, P., Tedesco, E., Murthy, J., Laux, C. O., and Price, S.: 2002, *Meteorit. Planet Sci.* **37**, 1071–1078.

Kristl, J., Esplin, M., Hudson, T., Taylor, M., and Siefring, C.L.: 2000, *Earth Moon and Planets* **82–83**, 525–534.

López-González, M. J., Rodríguez, E., López-Moreno, J. J., Rodrigo, R., Wiens, R. H., Brown, S., Peterson, R. N., Sargoytchev, S., and Shepherd, G. G.: 1999, in López-González et al.(eds.), *Proc. XXV Annual European meeting on Atmospheric Studies by Optical Methods* pp. 136–139.

López-González, M. J., Rodríguez, E., Wiens, R. H., Shepherd, G. G., Sargoytchev, S., Brown, S., Shepherd, M. G., Aushev, V. M., López-Moreno, J. J., Rodrigo, R., and Cho, Y. -M.: 2004, *Annales Geophysicae*, in press.

López-Moreno, J. J., López-González, M. J., Rodrigo, R., Vidal, S., Jerónimo, J. M., Brown, V., and Greer, R. G. H.:1995, *ESA SP* **370**, 119–124.

Mateshvili, N., Mateshvili, I., Mateshvili, G., Gheondjian, L., and Kapanadze, Z.: 2000, *Earth Moon and Planets* **82–83**, 489–504.
Murtagh, D. P., Witt, G., Stegman, J., McDade, I. C., Llewellyn, E. J., Harris, F., and Greer, R. G. H.: 1990, *Planet. Space Sci.* **38**, 43–53.
Ogawa, T., Iwagami, N., Nakamura, M., Takano, M., Tanabe, H., Takechi, A., Miyashita, A., and Suzuki, K.: 1987, *J. Geomagn. Geoelectr.* **39**, 211–228.
Plane, J. M. C.: 1991, *Int. Rev. Phys.Chem* **10**, 55–106.
Salby, M. L.: 1996, *in Fundamentals of Atmospheric Physics*, Elsevier, London.
Scheer, J. and Reisin, E. R. 1990, *J. Atmos. Terr. Phys.* **52**, 47–57.
Siskind, D. E. and Sharp W. E. 1991, *Planet. Space Sci.* **39**, 627–639.
Takahashi, H., Sahai, Y., and Batista, P. P.: 1986, *Planet. Space Sci.* **34**, 301–306.
Taylor, M. J., Gardner, L. C., and Pendlenton Jr., W. R.: 2001, *Adv. Space Res.* **27**, 1171–1179.
Trigo-Rodríguez, J. M.: 2002, Spectroscopic analysis of cometary and asteroidal fragments during their entry into the terrestrial atmosphere, Ph.D. thesis (in Spanish), Publication of the University of Valencia.
Trigo-Rodríguez, J. M., Llorca, J., Borovicka J., and Fabregat, J.: 2003, *Meteorit. Planet Sci.* **38**, 1283–1294.
Trigo-Rodriguez, J. M., Llorca, J., Lyytinen, E., Ortiz, J. L., Sanchez-Caso, A., Pineda, C. and Torrell, A.: 2004, Icarus, in press.
Wiens, R. H., Moise, A., Brown, S., Sargoytchev, S., Peterson, R. N., Shepherd, G. G., López-González, M. J., López-Moreno, J. J., and Rodrigo, R.: 1997, *Adv. Space Res.* **19**, 677–680.
Witt, G., Stegman, J., Solheim, G. H., and Llewellyn, E. J.: 1979, *Planet. Space Sci.* **27**, 341–350.
Witt, G., Stegman, J., Murtagh, D. P., McDade, I. C., Greer, R. G. H., Dickinson, P. H. G., and Jenkins, D. B.: 1984, *J. Photochem.* **25**, 365–378.
Wraight, P. C.: 1977, *Planet. Space Sci.* **25**, 787–794.