FeO "ORANGE ARC" EMISSION DETECTED IN OPTICAL SPECTRUM OF LEONID PERSISTENT TRAIN

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Abstract. We report the detection of a broad continuum emission dominating the visual spectrum of a Leonid persistent train. A comparison with laboratory spectra of FeO "orange arc" emission at 1 mbar shows a general agreement of the band position and shape. The detection of FeO confirms the classical mechanism of metal atom catalyzed recombination of ozone and oxygen atoms as the driving force behind optical emission from persistent trains. Sodium and iron atoms are now confirmed catalysts.

1. Introduction

Bright fireballs of fast meteors leave persistent trains that are visible for many minutes because of a luminous mechanism that is poorly understood. The persistent trains are significant, because they display the wind direction and velocity at altitude and probe the interaction of meteoroids with the atmosphere. A better understanding of the luminous mechanism is needed to make full use of the unique opportunity of probing the physical conditions in the meteor's path many minutes after the meteor (Jenniskens *et al.*, 2000). The first optical spectra of long lasting persistent trains were obtained by eye and with slit-less spectrographs and, consequently, were of low resolution. Visual

during the airborne Leonid MAC campaign. We report here the first slit-spectra of a persistent train. All spectra were taken minutes after the meteor appeared and should characterize the mechanism of the persistent glow.

2. Instrumental techniques

The airborne instrument consisted of a compact mount of two optical telescopes: a Celestron Firstscope f5.0/400 mm for low 2.1 nm resolution at 200 - 850 nm wavelengths (Figure 1- "a") and an OptoSigma UV achromat lens 47.0 mm, f = 149.4 mm ("b") for high 0.3 nm resolution at 300-440 nm wavelengths. The telescopes are connected with a 2-meter 600-micron fused-silica patch fiber with SMA905 connectors and 74-UV collimating lenses ("c") to a dual channel Ocean Optics miniature fiber optics spectrograph SD2000 ("d"). The near-UV telescope is connected to a 2400 l/mm holographic grating with UV Detector Upgrade and detector collection lens and a fixed 25-micron slit installed (master). The VIS-NIR telescope was connected to a 600 l/mm blazed grating (400 nm) with a fixed 50 micron slit (slave). The whole assembly can be rotated and pointed to a persistent train. A co-aligned f2.8/100mm Mullard XX1332 intensified camera (Figure 1e) is used for training the telescopes at the persistent train. Its field of view is about 19 x 15 degrees and star limiting magnitude about +8.2. The camera is connected to a video headset display (I-goggles) that is worn by the operator, who also handles the data storage on a Sony Notebook laptop computer and carries an external trigger to start the exposure. Several persistent trains were observed with this instrument at its lowest resolution.

3. Results

The train left by the 3:30:33 UT meteor on November 18, 1999 (Figure 2), provided both successful pointing and data gathering in a timely manner. We obtained six 30s exposures for the train starting at 4m59s, 6m00s, 6m52s, 13m29s, 14m8s, and 15m03s after the first appearance of this meteor. The train was observed low in a southern direction towards the coast of Tunisia. Individual spectra are too noisy for analysis. The combined spectrum is reproduced in Figure 3, yet without correction for spectral response of the instrument. The spectra show the forbidden green line at 557.7 nm of OI, Na emission at 589.5 nm, and a broad

Figure 4 shows the result after subtraction of the airglow spectrum and correction for the wavelength dependent sensitivity of the system. Note that the sensitivity of the visible channel falls off gradually below 450 and above 700 nm. After background subtraction, a residual 557.7-nm OI emission feature remains plus residual sodium and the broad continuum emission. OH Meinel bands may be present at 610-640 nm (6,1) and 680-700 nm (7,2).
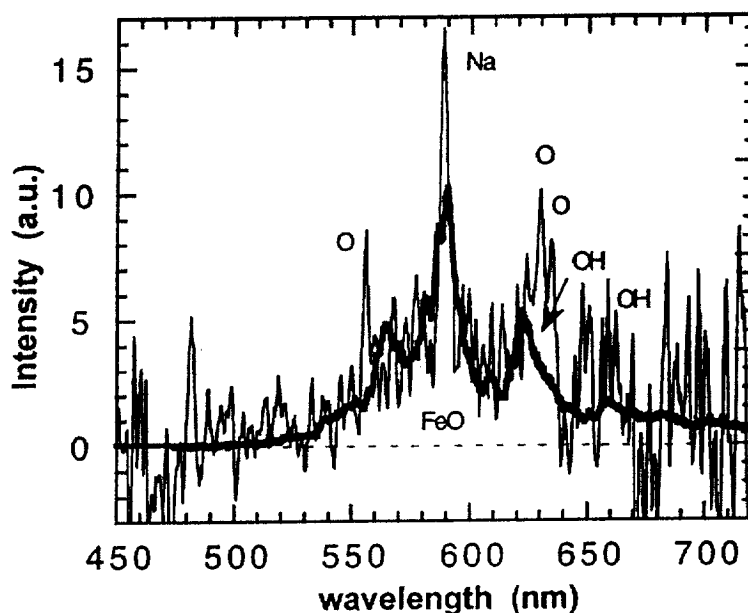

Figure 4. Persistent train spectrum of the 3:30:33 UT meteor after subtraction of airglow background and normalization for the instrument's spectral response. Also shown is an overlay of a laboratory spectrum of the FeO "orange arc" emission bands (thick line).

The spectroscopic observations confirm that the most intense emission arises from the Na D-line, almost certainly through the Chapman airglow mechanism:

$$Na + O_3 \rightarrow NaO + O_2 \tag{1}$$

$$NaO + O \rightarrow Na(3^2P, 3^2S) + O_2 \tag{2}$$
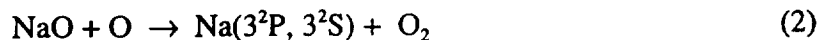
light from coastal villages of Tunisia? Such contamination was not present earlier in the night, when ARIA was farther to the East. Indeed, the difference-spectrum (Figure 4) is not unlike that of airglow emission spectra monitored at Kitt Peak and Mount Hopkins Observatories, for example, which also show a broad emission feature centered at 590 nm (e.g., Massey and Foltz, 2000). This broad emission feature was assigned to high-pressure sodium (HPS) lamps of nearby cities. Upon further inspection, we find that the feature does not increase in intensity with other artificial emissions. Also the shape of the airglow band is somewhat broader and slightly shifted from the HPS emission in the light polluted skies over Silicon Valley (Figure 5).
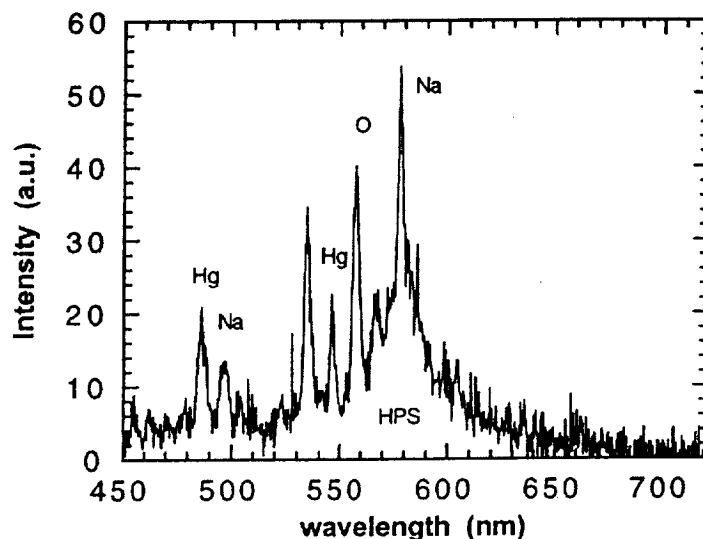

Figure 5. High-pressure sodium (HPS) and other artificial emissions measured with the same instrument in the light-polluted Silicon Valley, California.

Support for the assignment of the key chemical mechanisms of Equations 1-4 comes from the low-resolution slit less spectrum of a bright persistent train reported by Borovicka and Jenniskens (2000). The train itself is visible as excess emission in zero order, while the first order spectrum clearly identifies the train as the source of the spectral feature. This spectrum has a nearly identically shaped broad band as in Figure 4. The NaI emission associated with this train was not observed,

$$MgX^+ + e^- \rightarrow Mg^* + X \tag{8}$$

where MgX^+ represents the molecular ions formed in reactions 5–7 (Rowe *et al.*, 1981). Abe *et al.* reported MgI in the spectrum from a bright Leonid fireball at about 10 nm resolution (380–600 nm) wherein this assignment was confirmed by the presence of several other MgI lines at 457, 470, and 553 nm. However, they also identified atomic lines of CaI (443 nm) and FeI (418, 486 and 537 nm), although with less good agreement between theory and observation. Possibly, these emissions are of relatively short duration. The train spectra were obtained shortly after the meteor had extinguished, at a time when the train was still spatially confined on the sky and measured gas temperatures were relatively high. It is possible that the MgI emission is part of a phenomenon called the meteoric afterglow (Borovicka and Jenniskens, 2000), but less important when the train has had time to cool.

In summary, the optical spectrum discussed here confirms the classical mechanism for train luminosity. We find that FeO rather than FeI contributes to the train luminosity. Future work under better observing conditions and with improved instruments are expected to increase the number of metal atom catalysts beyond Na and Fe, and may reveal other chemical processes in the meteor path.

Acknowledgements

References

Abe, S., Ebizuka, N., Watanabe, J.-I., Murayama, H, and Ohtsuka, K.: 2000, *Meteoritics Planet. Sci.* 35, in press.