# SEARCH FOR ORGANIC MATTER IN LEONID METEOROIDS

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**Abstract.** Near-ultraviolet 300–410 nm spectra of Leonid meteors were obtained in an effort to measure the strong B $\rightarrow$ X emission band of the radical CN in Leonid meteor spectra at 387 nm. CN is an expected product of ablation of nitrogen containing organic carbon in the meteoroids as well as a possible product of the aerothermochemistry induced by the kinetic energy of the meteor. A slit-less spectrograph with objective grating was deployed on FISTA during the 1999 Leonid Multi-Instrument Aircraft Campaign. Fifteen first-order UV spectra were captured near the 02:00 UT meteor storm peak on November 18. It is found that neutral iron lines dominate the spectrum, with no clear sign of the CN band. The meteor plasma contains less than one CN molecule per 3 Fe atoms at the observed altitude of about 100 km.

**Key Words:** Astrobiology, CN, exobiology, Leonids 1999, meteors, meteoroids, origin of life, spectroscopy, ultraviolet

## 1. Introduction

Refractory organic carbon is thought to be an abundant compound of cometary meteoroids, making up some 23 % of the comet mass fraction and some 66% of meteoroid mass once the volatile compounds have evaporated (Greenberg, 2000). This organic carbon has its origins in ring structures, and some graphitization by stacking of those rings (e.g. Koidl *et al.*, 1990). Ultimately, temperature increase leads to decomposition by loss of $H_2$, CN, CH, $C_2$, and $C_2H$. Hydrocarbon radicals higher than $C_2$ are so excited by their formation that they rapidly fission into lower products, leaving only the thermally stable single and double carbon radicals, unless prevented by rapid radiative cooling. Carbon atoms are present too, but at lower abundance because of thermodynamic considerations.

Of these, the CN radical is the most easily detected because of a strong $B \rightarrow X$ transition of low energy potential. This electronic transition has a band head at 388.3 nm in the near ultraviolet. Figure 1 shows simulated emissions for a typical meteor wake temperature of 4,300 K (Jenniskens *et al.*, 2000a). The use of two instrumental resolutions in Figure 1 shows how the shape of the band is affected by a lower spectral resolution.

The CN radical is also a product of aerothermochemistry in an $N_2$/ $CO_2$ atmosphere, so CN may also be formed from the deposition of kinetic energy of the meteor in the air at altitude.

Unfortunately, the CN band is found in a part of the meteor spectrum that is rich in atomic iron lines from ablated meteoric metals. This demands high-resolution spectroscopy in order to differentiate between iron lines and the CN band. Here, we report on one experiment to study the possible presence of CN in the spectra of Leonid meteors. These results were obtained during the 1999 Leonid meteor storm, from the perspective of FISTA during the Leonid Multi-Instrument Aircraft Campaign (Jenniskens *et al.*, 2000b).

## 2. Method

The camera consisted of the following parts: An ATE Noctron Image Intensifier with a UV-Nikkor 105 mm f/4.5 objective lens, a 600 lines/mm diffraction grating mounted in front of the objective, and a Nikon 230–410 nm passband filter mounted in front of the grating. The intensifier was optically coupled to a Cidtek CID video camera model 3710-D, and data were stored on Hi-8 video tape cassettes. The camera had a field of view of 8 x 11 degrees and gave a better than 2 nm resolution in first order over the wavelength range of 290 to 410 nm. The objective bandpass filter prevented visible wavelengths from overlapping higher order UV spectra.

The wavelength scale was calibrated in the laboratory. A plot of the relative spectral sensitivity is shown in Figure 2. Sensitivity at the short

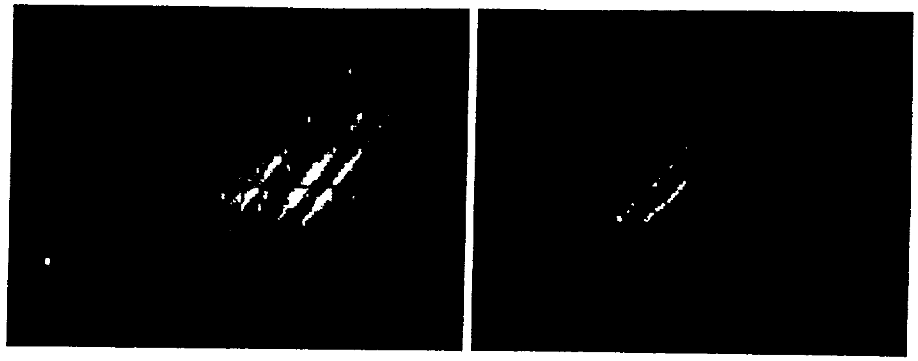

*Figure 3.* Cropped composite of four video fields for the 02:36:40 UT (left) and the complete 02:09:30 UT (right) meteors. The bright star is beta Cephei. Meteors entered the frame from the upper right. Spectral dispersion is horizontal, with shorter wavelengths toward the left.

TABLE I

| Time (UT) | Mv* | Remarks | Time (UT) | Mv | Remarks |
|---|---|---|---|---|---|
| 01:49:29 | 0 | high altitude only | 02:09:26 | – 2 | first order |
| 01:51:57 | +1 | first order | 02:21:13 | +1 | first order |
| 01:54:24 | – 1 | zero +part first | 02:28:04 | +1 | first, faint |
| 01:55:51 | 0 | part first, long λ | 02:34:12 | -.- | 2nd order, faint |
| 01:57:33 | – 1 | 2nd order, faint | 02:36:40 | – 2 | first order |
| 02:00:24 | 0 | first order | 02:47:57 | – 1 | high altitude only |
| 02:00:35 | 0 | part first, long λ | 03:09:58 | 0 | part first, long λ |
| 02:08:28 | 0 | first order | | | |

* Assumed meteor height = 100 km for normalized distance = 100 km (magn.).

The bright features are at 357, 373 and 382 nm and no single emission line is responsible for the features. Indeed, they are broader than the instrumental resolution. There are small changes in the profile of the spectra at different positions along the trajectories that help discriminate between the various contributions in the spectrum. Figure 4 shows two traces of the 02:36:40 meteor. The main features remain at about constant relative intensity. However, features near 345 and 355 nm are relatively stronger in the latter spectrum, while features at 332, and possible the Ca II doublet at 392 and 395 nm are weaker.

The expected Leonid spectrum over the range 350–410 nm was calculated by Jiri Borovicka and is given in Jenniskens *et al.* (1998).

The strong features are readily identified as due to clusters of numerous Fe emission lines. There are some disparities. The 382 nm cluster is stronger in the observations than the 373 cluster. Also, there is strong diffuse emission observed between 330 and 370 nm that is not matched by the synthetic spectrum. Figure 6 shows the difference between synthetic and a mean of all observed meteor spectra. The meteor head plasma Ca II lines in the +0 magn. spectrum published in Jenniskens *et al.* (1998) are too strong in comparison to the observations, suggesting that there is less contribution from the meteor head than expected.

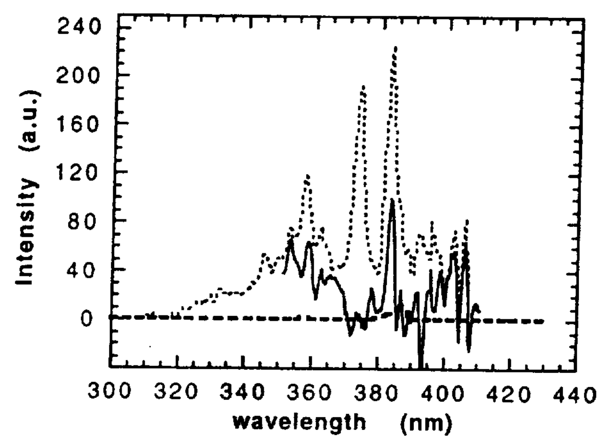


*Figure 6.* Difference between synthetic and observed spectrum. The dotted line is observed spectrum, while the solid line is observed minus synthetic. The dark dashed line shows the highest possible CN contribution.

The broad emission at short wavelength is the most prominent feature. It may have a band reversion at about 370 nm and stretches to 320 nm. The origin of this emission remains unknown. Excess emission at 382 nm is also clearly present, overlapping one of the Fe bands, the source of which is unknown also. The 382 nm excess is not caused by CN emission. Figure 1 shows that the expected CN emission band at our instrumental resolution should peak at about 389 nm.

## 4. Discussion

### 4.1. ABUNDANCE OF CN IN THE METEORIC PLASMA

Fortunately, the CN band head coincides with a minimum of Fe line density (Figure 5). The CN emission would have been detected if the expect that all of the nitrogen is released as CN. In that case, our upper limit is strong enough to say something significant about the organic matter in meteoroids.

This is with the caveat that some of the Fe may not be released as atomic iron atoms, but stay in a solid form in the form of meteoric debris. That would imply even lower CN abundances. Less likely is that some organic carbon may have been lost at high altitudes, where the excitation temperatures are low enough to cause relatively faint luminosity. Possibly, a fraction of nitrogen is also released as NH and $N_2$. Clearly, other techniques at detecting organic matter in general, or nitrogen in particular, have to be explored to address this possibility.

### 4.3. EXPECTED ABUNDANCE FROM LTE AEROTHERMOCHEMISTRY

The –2 magnitude Leonid meteors studied here have a mass of about 0.44 gram, of which 0.033 gram is iron (Delsemme, 1991). That iron is ablated and distributed over a path length of about 17 km (Betlem *et al.*, 2000), in a cylindrical al volume of at least 2 meter radius (Jenniskens *et al.*, 2000a). That gives a mean density of [Fe] = $2 \times 10^9$ atoms / $cm^3$. The calculated CN abundance for a 4,300 K air plasma in LTE at 95 km altitude for a total concentration of CN equals $1.0 \times 10^5$ molecules of CN per cubic centimeter. Hence, the expected [CN]/[Fe] is about $5 \times 10^{-5}$.

At first sight, this implies that our observations do not put a strong upper limit on the efficiency of aerothermochemistry in the meteor plasma. However, the effective volume of air that may be processed directly or indirectly by the kinetic energy of the meteor may well be much larger than suggested above. In fact, Jenniskens *et al.* (2000a) found an effective volume $10^6$ times larger from the intensity of OI line emission. This would increase the [CN]/[Fe] to 50 atoms / $cm^3$, significantly above our detection limit. It is crucial, therefore, to measure the effective volume of air processed by the meteors in a direct manner in order to measure the efficiency of the aerothermochemistry process.

## 5. Conclusions

CN atoms are detected at less than 1 per 3 Fe atoms in the plasma of 1899 ejecta Leonid meteors at altitudes of about 100 km. This implies that either the Leonid meteoroids contain less than half the organic carbon that is present in comet Halley's dust, or a significant fraction of the nitrogen is not released in the form of CN radicals.