Open access • Book Chapter • DOI:10.1007/978-94-017-2071-7_32

Mid-Infrared Spectroscopy of Persistent Leonid Trains — Source link

Ray W. Russell, George S. Rossano, Mark A. Chatelain, David K. Lynch ...+4 more authors

Institutions: The Aerospace Corporation, Search for extraterrestrial intelligence

Published on: 01 Jan 2000 - Earth Moon and Planets (Springer Netherlands)

Topics: Meteoroid

MID-INFRARED SPECTROSCOPY OF PERSISTENT LEONID TRAINS

RAY W. RUSSELL, GEORGE S. ROSSANO, MARK A. CHATELAIN, DAVID K. LYNCH, TED K. TESSENSOHN, ERIC ABENDROTH, AND DARYL KIM
Space Science Applications Laboratory,
The Aerospace Corporation, M2-266, P.O. Box 92957, Los Angeles, CA 90009-2957
E-mail: Ray.W.Russell@aero.org

and

PETER JENNISKENS
SETI Institute, NASA ARC, Mail Stop 239-4, Moffett Field, CA 94035

(Received 16 August 2000; Accepted 1 September 2000)

Abstract. The first infrared spectroscopy in the 3–13 micron region has been obtained of several persistent Leonid meteor trains with two different instrument types, one at a desert ground-based site and the other on-board a high-flying aircraft. The spectra exhibit common structures assigned to enhanced emissions of warm CH_4, CO_2, CO and H_2O, which may originate from heated trace air compounds or materials created in the wake of the meteor. This is the first time that any of these molecules has been observed in the spectra of persistent trains. Hence, the mid-IR observations offer a new perspective on the physical processes that occur in the path of the meteor at some time after the meteor itself has passed by. Continuum emission is observed also, but its origin has not yet been established. No 10 micron dust emission feature has been observed.

Keywords: Meteors, meteoroids, mid-IR spectroscopy, persistent trains

1. Introduction

Spectroscopy of meteors and persistent trains in the infrared (IR) part of the spectrum from about 3 to 13 microns has long been expected to be a useful tool in our efforts at understanding the composition of meteoroids

This paper reports the first mid-IR spectra of Leonid persistent trains obtained with an imaging spectrograph, taking full spectra with each scan, situated onboard the 1999 Leonid Multi-instrument Airborne Campaign on a mission to the Mediterranean, and with a wavelength-scanning spectrometer on the ground at the Starfire Optical Range at Kirtland AFB in New Mexico.

2. The Observations

The data were acquired with the Aerospace Mid-wave InfraRed Imaging Spectrograph (MIRIS) and the Circular Variable Filter wheel spectrometer (CVF). The MIRIS uses a liquid nitrogen-cooled 2D 256 x 256 InSb array and a grism (combination grating and prism, Rossano *et al.* 2000) to obtain long-slit spectra and zeroth order broadband images in the 3-5.5 micron spectral region (ibid). The slit was constructed to permit slitless spectroscopy and imaging of meteors in the center 128 rows of the array, and also to permit narrow slit (5 pixels wide in the dispersion direction) spectroscopy of meteor persistent trains in the 64 rows near the top of the array and the 64 rows near the bottom of the array. MIRIS was deployed aboard the USAF Flying Infrared Signature Technology Aircraft (FISTA) as part of the 1999 Leonid MAC effort (Jenniskens *et al.*, 2000). The spectral resolving power is about 50 (due to the extended nature of the source and the slit width), and spatial pixel size was about 0.8 mrad (0.046 °). The sensor viewed the sky through a ZnSe window while the FISTA was flying at about 10–12 km, where the sensor was above the majority of the Earth's atmosphere, and more than 99% of the water vapor. Complete spectra were obtained at 24 frames per second with an observing efficiency of about 40%, generating gigabytes of data during the MAC.

The CVF uses three multi-layer interference wedges and an Si:As back-illuminated blocked impurity band (BIBIB) detector element cooled to liquid helium temperatures to obtain spectroscopy from 2.5 to 14.5 microns with a spectral resolving power of about 60, with an off-axis parabola as the collecting optic in a custom setup created for this event. It was mounted on a steerable alt-azimuth telescope mount at the Starfire Optical Range (SOR), Kirtland AFB (New Mexico), and the field of view was approximately 0.25 degree. Data were obtained in a step-and-integrate mode as DC voltages with the sensor viewing the sky or sky plus meteoroid train. Each spectrum required about 5–10 minutes a command to turn the plane to a proper heading, and then the eyeball mount was steered by hand while monitoring the CCD image to position the slit of the IR sensor on the train.

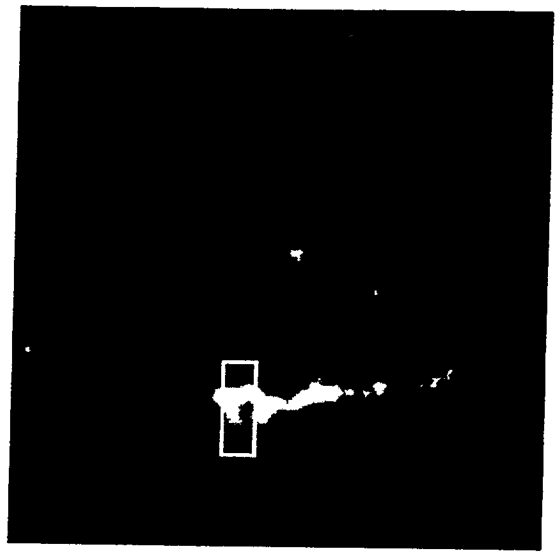

Figure 1. Approximate position of the MIRIS slit on the "Y2K" persistent train at 04:02:19 UT on Nov. 18, 1999. The white box indicates the location of the MIRIS slit and the dark marker in the top center of the image was used for positioning the camcorder relative to the image intensifier.

3. Results

3.1. MIRIS RESULTS

The airborne MIRIS data were obtained the night of the storm, 18 Nov. 1999 UT, with the best spectrum recorded being that of the so-called "Y2K" train (Figure 1), caused by a -13 magnitude Leonid fireball at 04:00:29 UT (Jenniskens and Rairden, 2000). The train was observed from about 04:02 to 04:09 UT. During our observations, the train was at an altitude of 83.2 ± 1.0 km, which corresponds to positions 14–18 in Jenniskens and Rairden (2000), at a distance of 205 km from the FISTA aircraft and 19° above the eastern horizon at the airplane's altitude.

The train was observed by MIRIS in both zeroth and first orders. It was first observed as a zero order image in the slitless region of the

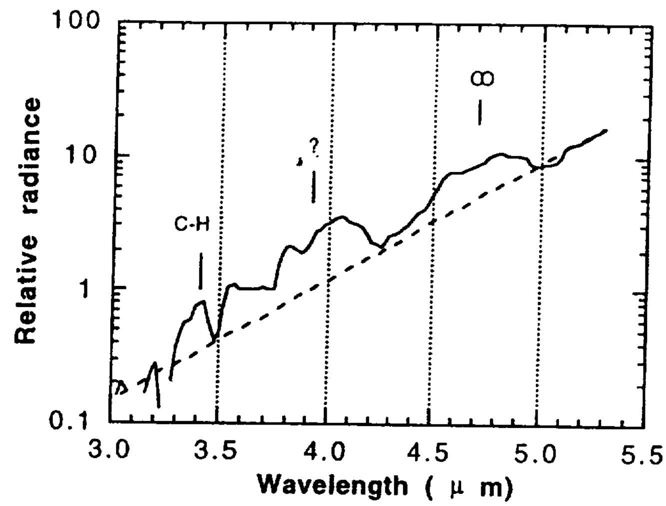

Figure 2b. Semi-log plot of the intensity from the "Y2K" train at 04:02:19 UT reported by MIRIS.

The same data are shown in a semi-log plot to bring out the molecular bands superposed on a continuum rising towards five microns (Figure 2b). Note that the alternative placement of the continuum, with a CO_2 band in absorption, is a less likely choice because it would imply a very high abundance of absorbing molecules and / or solid materials in atmospheric windows from 3.4–4 μm and around 5 μm, for example.

The nature of this continuum is not understood at this time. We are trying to assess the relative likelihood of thermal emission by small solid particles versus a molecular origin such as blended water vapor lines typically found in this part of the spectrum. No optically thick (blackbody) or thin (graybody) thermal emission at $T > 1000$ K, such as would be seen from hot dust grains, has been detected at this time after the passage of the meteor. Such a hot thermal emission would have resulted in a continuum rising towards shorter wavelength in this regime.

3.2. CVF RESULTS

Ground-based CVF data were obtained on five trains that occurred during the nights of Nov. 17 and 19, 1999 UT. Due to cloud cover on the night of the peak of the shower (Nov. 17/18), no spectra were collected that night. The IR signatures were observed to last at least as long as the visible signatures, in some cases more than 20 minutes. On

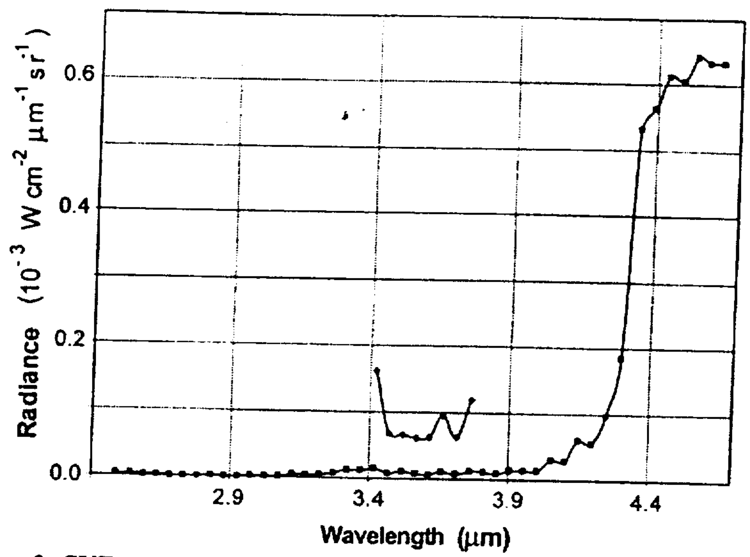

Figure 3. CVF spectra of the train of the meteor that occurred shortly before 10:06 UT, Nov. 19, 1999. The measurements were started at 10:06 UT (short spectrum) and at 10:11 UT (full scan). The effect of the decreasing train intensity between the acquisition of the narrow spectral piece and the full coverage can be seen.

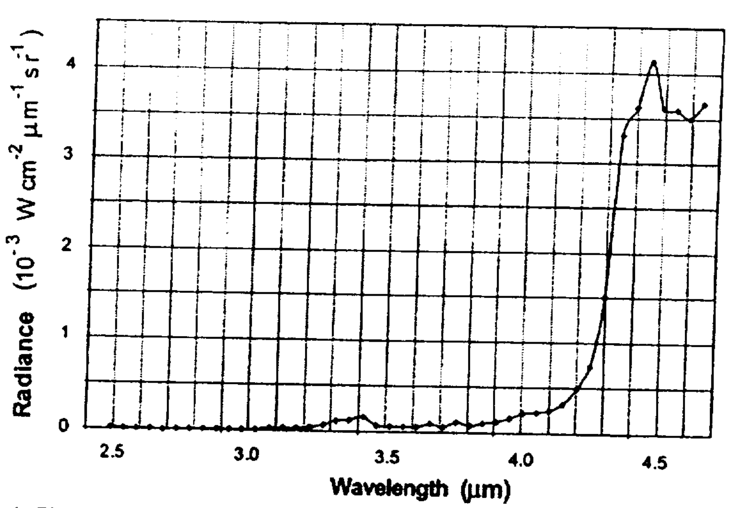

Figure 4. Short wavelength wedge CVF scan of the train of a second meteor at 12:26 UT. These data were taken from 12:27 to 12:32 UT Nov. 19, 1999. Compare to Figure 3.

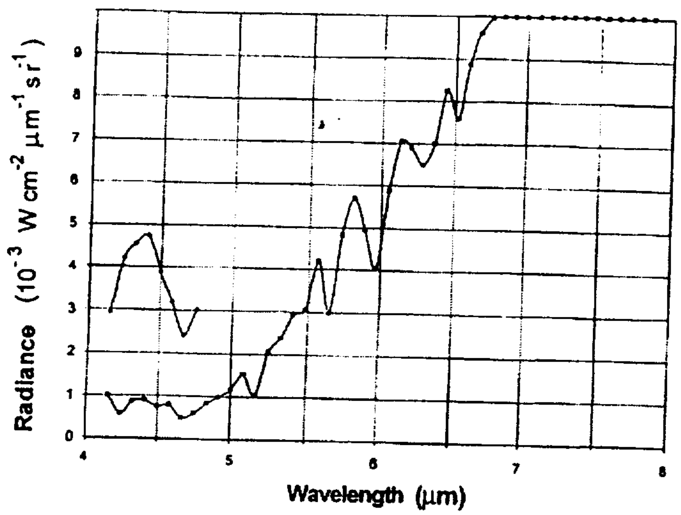

Figure 5. CVF spectrum of the train of meteor 10:05 UT Nov. 19, 1999, taken at 10:16 UT, with a strong H_2O emission peak. Inset shows the earlier narrow scan at time 10:07 UT, with strong CO_2 emission at 4.3 microns (same units as Figure 4).

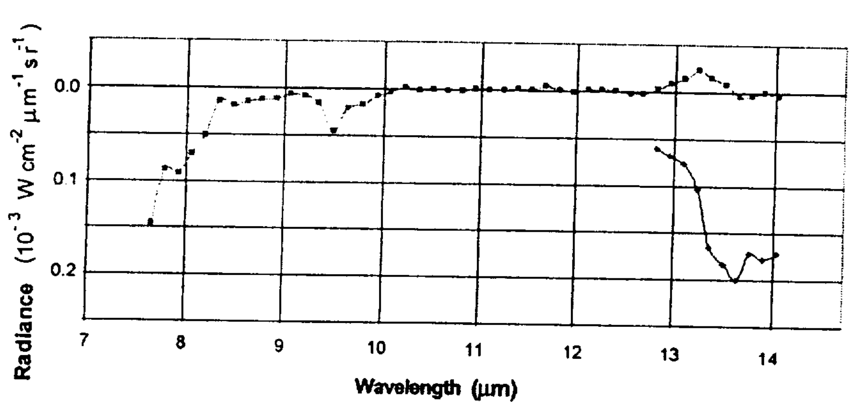

Figure 6. CVF spectrum from 7.5 to 14.5 microns of the same train observed to obtain the data shown in Figures 3 and 5. The data acquisition consisted of taking the short pieces in all three figures first, followed by the acquisition of the entire 2.5 to 14 micron spectrum. The strong absorption seen near 13 – 14.5 microns is unexplained, as is the dip from 7.7 to 8.3 microns (same units as Figures 4 and 5).

materials created in the wake of the meteor. None of the molecules detected here has been observed in the visible range. As such, the mid-IR observations offer a whole new perspective on the physical properties of meteor trains.

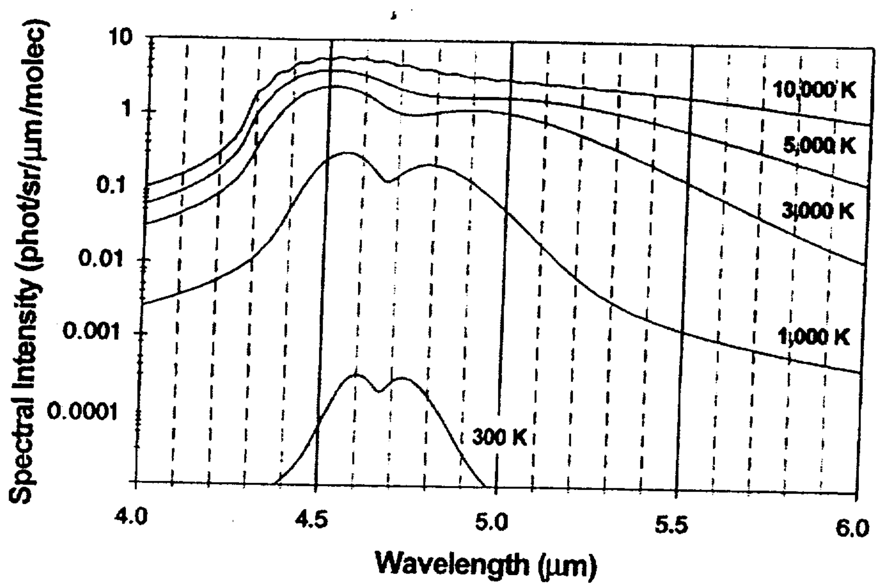

Figure 7. Model calculations for hot, optically-thin CO molecules. These spectra go from cool on the bottom to hot on the top. They have been smoothed to a resolving power of 100 to better compare the shapes with the train data.

4.1. CO

The shape of thermal emission bands can be used to determine the excitation temperature of the responsible molecules. Figure 7 shows calculations for the CO molecule that is believed to be responsible for the band between 4.4 and 5.0 microns. The shape is significantly broader at the high temperatures of T ~ 5,000 K and T ~10,000 K that are reported for the hot and warm visible emissions from meteors. The train emission is more typical for a gas at T ~ 300 K, which is consistent with the observation by Borovicka and Jenniskens (2000) that the Y2K train temperature decreased from ~4,500 K to ~1,200 K in a mere two seconds. It is also consistent with the results from Chu *et al.* (2000), which determined the temperature of sodium emission from persistent trains using LIDAR measurements of the Doppler broadening of the

It is not certain that the rise itself must be due to warm water vapor band emission centered at 6.24 microns, or whether there may be thermal dust continuum emission analogous to that seen in cometary spectra. However, the absence of strong continuum dust emission in the 8–13 micron region (wedge 3, Figure 6) argues against a broad thermal dust continuum with or without silicate emission, and is consistent with the rapid decline expected in warm water vapor emission beyond 7 microns.

One difficulty with the warm water vapor interpretation is that the warm gas must have a temperature above 200–300 K relatively long after the meteor, to avoid being completely absorbed by warm lower atmospheric water vapor between the ground-based observation station and the meteor train.

4.5. OTHER FEATURES

Given the detection of CO_2 band emission at 4.2 microns (Figure 5, narrow scan), it was expected that strong CO_2 band emission would arise above 13 microns in the first narrow scan of Figure 6. However, It is unknown how a lack of emission in the long wavelength 16 micron CO_2 band can be explained in relation to the distant train. The constancy of the atmospheric emission at these wavelengths over the course of the night implies much less variation over the relatively short time between the observations of the train and of the sky (at the same elevation angle, but slightly different azimuth, a few minutes later) than the difference between the train and the sky. As long as the atmospheric emission is constant, this strongly suggests that the observed dip is a real phenomenon, and not an artifact of the sky subtraction process. The fact that the dip was seen in all the train spectra at these wavelengths (at least 3) is viewed as evidence for some real effect other than inaccurate sky subtraction. As we expected most of the observed CO_2 emission to originate close to the sensor along the line of sight from the ground to the train, and not to originate in the train itself, additional modeling of the amount of emission and absorption as a function of position along the line of sight will be undertaken in an effort to understand the data.

4.5. SYNTHESIS

Given our understanding of meteor grains based on spectroscopy of parent cometary dust, it is unlikely that the molecules that we believe are responsible for the emission reported here existed in molecular form in commonality of the spectra obtained from two platforms, one on the ground and one airborne, and with two dramatically different sensors, lends strong credence to the validity of the spectral structure seen emanating from these long-lived trains. Not all features have been identified with certainty. Obvious candidates are CH_4, CO, CO_2, and H_2O. No optically thick or thin thermal emission at > 1000 K has been seen to date, but continuum emission from cold ~ 300 K sources may be present. However, we have seen no evidence for expected emission in the wavelength region of the Si-O stretch vibration at 10 micron. The exact emission/excitation mechanisms for the long-lived (in some cases more than 20 minutes) IR signatures are still not understood. Future work will include modeling of the passage of the meteor through the atmosphere to investigate the heating and cooling of meteoric and atmospheric materials, and to model the molecular emissions at the various wavelengths to discriminate between atmospheric and meteoroid sources for the atoms.

Acknowledgments

We are grateful to the staff and crew of the FISTA and SOR, without whose strong support this work could not have been accomplished. This research is supported at The Aerospace Corporation by the Internal Research and Development program. The Leonid MAC was supported by NASA's Exobiology, Planetary Astronomy and Suborbital MITM programs, as well as by NASA's Advanced Missions and Technologies program for Astrobiology and NASA Ames Research Center. We thank Joe Kristl and his group at Space Dynamics Laboratory, Utah State University, for their assistance in the FISTA installation and operation, and for the loan of an eyeball mount and ZnSe window for use with MIRIS. Paul Zittel, The Aerospace Corporation, is acknowledged for providing the molecular emission spectra of CO. We thank referee Diane Wooden, whoes comments helped improve the paper. *Editorial handling*: Frans Rietmeijer.

References

Borovicka, J. and Jenniskens, P.: 2000, *Earth Moon and Planets* **82–83**, 399–428.
Boyd, I.D.: 2000, *Earth Moon and Planets* **82–83**, 93–108.