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Sodium resonance lidar observations during 2001 Leonid meteor shower over Wuhan

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Abstract **Here is the first report on the observation of meteor ablation trails with lidar in China. Four long-lived Na ablation trails were observed during the 18/19 Nov. 2001 Leonid meteor shower with a sodium resonance lidar over Wuhan. The mean altitude of the 4 trails is 97.95 km, consistent with Leonid high entry velocity (~72 km/s). The peak density averages about 3380±3633 cm^{-3}, and the abundance is (2.33±1.49)×10^{8} cm^{-2}, both of which are higher than those previously observed for sporadic meteor trails. The RMS width is 359 m and the meteor's age is 81 min, indicating that they are long duration meteor trails. These observation results are quite different from those of sporadic meteor trails, but comparable to the 1998 and 1999 Leonid report. Five night observations from 17 Nov. to 23 Nov. suggest that the 2001 Leonid meteor shower does not have a significant impact on the abundance of the background Na layer.**

Keywords: sodium resonance lidar, Leonid shower, Na/sodium layer.

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It has been recognized that the metal layers in the mesosphere and lower thermosphere result from the meteor ablation[1]. The characteristics of the Na density enhancement caused by the meteor ablation are significantly different from those of the sporadic Na layers. Therefore it is feasible to utilize the sodium resonance lidars to detect meteors. This 2001 Leonid meteor shower is one of the most splendid in the recent 30 years in China, providing a good opportunity to study the characteristics of meteor ablation trails and the impact of meteors' influx on the sodium layer. From 18:30LT on 18 Nov. to 06:00LT on 19 Nov., the lidar system of Wuhan University was operated to probe the Na layer over Wuhan (30.5°N, 114.4°E), and 4 Na ablation trails were observed.

1 Experimental configurations

The lidar system of Wuhan University (WU-Lidar) has been established to study the middle atmosphere by the Rayleigh and sodium resonance fluorescence technique and was put in operation since 8 Mar., 2001. It transmits laser beam produced by a tunable dye laser pumped by the second harmonic beam of a Na:YAG laser.

Table 1 Parameters of WU-LIDAR

Transmitter:		
	Nd:YAG laser	Dye laser
Wavelength	532 nm	589 nm
Line width		1.5 GHz (1.73 pm)
Pulse energy	350 mJ	60 mJ
Repetition rate	20 Hz	20 Hz
Pulse width	6 ns	6 ns
Beam divergence	0.5 mrad	0.5 mrad
Receiver :		
Telescope aperture	0.52 m	
Field of view	1.0 mrad	
Bandwidth	1.0 nm	
Range bin length	640 ns	

A Na vapor cell is used to monitor whether the dye laser is tuned to the D2 line of Na absolutely. The backscattered photon counts are stored in a PC via the receiving system that includes a telescope, a PMT and a multichannel scaler. In the case of normal nighttime observation, the range bin length of the lidar is 96 m and the time resolution is 4 min. Presented in Table 1 are the parameters of the lidar.

2 Observations and discussion

In Fig. 1, the nocturnal variation of the vertical distribution of the Na density is shown. As seen, the density of the sodium layer before midnight was lower, and the layer was confined in an altitude range between 82 and 100 km. It tended to increase after 02:00LT and the upper boundary of the layer expanded upward, reaching 105 km at 04:00LT. However, the lower boundary showed little variation. At 04:00LT, a strong downward sporadic sodium layer occurred at the altitude of about 90 km. It lasted up to 06:00LT, when our observation terminated.

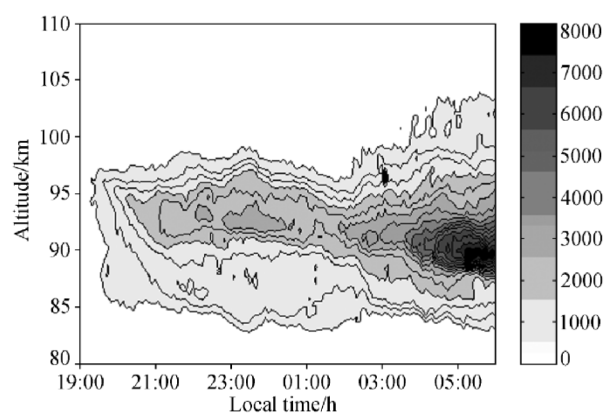

Fig. 1. Nocturnal variation of Na density on 18, 19 Nov., 2001.

Fig. 2 presents the example of the meteor ablation trail observed at 03:05LT on 19 Nov. It has a peak density of 7200 cm^{-3} at 96.5 km, which is much larger than that of the background Na layer. We define the distance between the two altitudes whose density is $e^{-1/2}$ of the peak density as the RMS width. Then the RMS width of the trail is around 270 m, apparently narrower than that of the sporadic Na layer, which is about 2 km[2]. Since the density profile was attained by accumulating 4800 shots, the duration time of the meteor ablation trail should be less than 4 min.

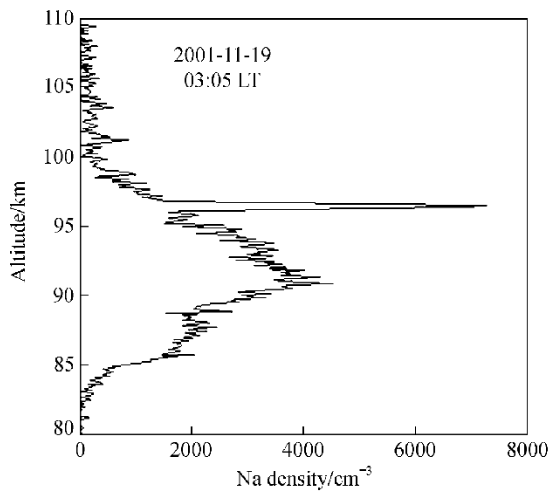

Fig. 2. Na density profile measured at 03：05LT on 19 Nov., 2001. The dense narrow layer at 96.5 km is a meteor ablation trail.

As Asher predicted, the first enhancement of the meteoritic input for the meteor shower would occur at 18:01LT on 18 Nov. and have an influx rate of 2500 meteors per hour[3]. The second one with an influx rate of 9000 meteors per hour would reach at 01:31LT on 19 Nov. The strongest burst would arise at 02:19LT on 19 Nov. and hold an influx rate of 15000 meteors per hour. It has been verified by the International Meteor Organization (IMO) report that the prediction is quite closer to the actual observation.

High temperature induced by the frictional heating can vaporize meteors and even make meteor material ionized as they enter the atmosphere. Neutralization occurs in no more than 1 s because of high electron densities in the trails. Initially the extent of the neutral Na atoms deposited in a meteor trail is only a few meters in diameter[4]. Molecular diffusion then causes the trail to broaden both vertically and horizontally. We assume that the Na concentration holds a Gaussian distribution with a mean square radius ($e^{-1/2}$ radius) that increases linearly with time. According to Grime et al.[5], the corresponding mean square radius can be expressed as

$$\sigma^2 = 2Dt + \sigma_0{}^2, \tag{1}$$

where D is the molecular diffusivity, t is the elapsed time since ablation, and σ_0 is the initial ablation trail radius. The age of a meteor is defined as the elapsed time between the ablation and the lidar observation. Molecular diffusivity can be calculated with a high accuracy as it is determined primarily by atmospheric density and temperature. Thus the age of a meteor trail can be estimated with the value of its RMS width and molecular diffusivity, assuming that the initial radius is negligible. In Table 2, we list the characteristics of the 4 meteor trails observed during 2001 Leonid meteor shower.

The 4 meteor trails are characterized by their long durations with ages longer than 50 min, while a typical sporadic meteor only lasts no more than 10 min because of the molecular diffusion and eddy diffusion[6]. The average peak Na density of the meteor ablation trails is 3380 ±3633 cm^{-3}. In 1988 and 1989, Gardner observed 5 long-lived meteor trails and reported an average peak density of 2400±500 cm^{-3}. The accumulating time is 60 s[6]; Chu et al.[4] observed 7 meteor trails during the Leonid meteor shower in Nov. 1998 and found the average peak density to be $(198\pm144)\times10^3$ cm^{-3}. The accumulating time is 10 s for Chu et al.'s observation. Compared with the observation reported by Chu et al., the Na density we report here is much lower. As our Na lidar's accumulating time was set to be 240 s, while a meteor's age (t) is usually not longer than 240 s, the Na peak density appears to be lower, about t/240. Moreover, the visual scope of Na lidar is confined to a radius of 100 m at the altitude of 100 km, and wind field also played a role. The meteor trail might be partly in the visual scope of the lidar and the wind might cause the meteor trail to drift out of the visual scope of the lidar. All these factors result in the lower peak density.

The mean occurrence altitude of the 4 meteor trails is 97.95 km, and the RMS width of the occurring altitudes is 1.22 km. Kane and Gardner catched 101 meteor trails from 1977 to 1989 with Na lidar and Fe lidar, reporting a

Table 2 Characteristics of the 2001 Leonid Na meteor trails

No.	Time (LT)	Altitude/km	Abundance of background layer/cm^{-2}	Abundance of meteor trail/cm^{-2}	Peak density/cm^{-3}	RMS width/m	Age/s
1	02:55	98.12	3.05×10^9	1.84×10^8	2070	280	2860
2	03:00	97.73	3.14×10^9	1.18×10^8	1600	450	8370
3	03:05	96.49	3.14×10^9	4.52×10^8	7290	270	3130
4	05:35	99.46	5.47×10^9	1.79×10^8	2560	430	5130
Mean		97.95	3.70×10^9	2.33×10^8	3380	360	4870
Std.		1.22	1.18×10^9	1.49×10^8	2630	20	2540

mean altitude of 89.0 km, and a RMS width of 3.3 km. Hoffner et al.[7] employed Fe lidar to observe 3 Leonid meteor trails in 1998 and the calculated mean altitude was 99.7 km. Chu et al.[8] observed 7 long duration meteor trails during 1998 Leonid shower at Starfire Optical Range. The mean altitude reported is 94 km. Chu et al.[4] also observed 18 meteor trails in Okinawa with Fe lidar. The mean altitude was 95.67 km, and the RMS width was 3.93 km. The distinction in the mean altitudes for various observations may be attributed to the difference in the meteor entry speeds. According to the astronomical observations the entry speeds of the Leonid meteors (72 km/s) are two times larger than those of the sporadic meteors (~30 km/s). As Chu et al.[4] pointed out, if one assumes that a meteoroid begins to ablate when the atmosphere drag reaches a critical threshold, the altitude difference for ablation can be computed approximately by the following formula:

$$\Delta z \approx H \ln(v_1/v_2), \qquad (2)$$

where H is the atmospheric scale height, v_1 and v_2 are respectively Leonid meteors entry speed and sporadic meteors entry speed. If we choose $H \approx 6.25$ km to the mesopause altitudes, the formula yields an altitude difference of 5.5 km, which approaches our observations result (8.59 km).

The Na abundance in the meteor trails averages about $(2.33 \pm 1.49) \times 10^8$ cm^{-2}, which is 6.3% of the background Na abundance. From the report of Kane et al.[1], the Na abundance in trails is 2.8×10^7 cm^{-2}. That is 0.5% of the 5.4×10^9 cm^{-2} background Na layer. Chu et al.[8] reported a meteor abundance of $(4.80 \pm 3.87) \times 10^9$ cm^{-2} and the background abundance of $(9.15 \pm 1.17) \times 10^9$ cm^{-2}. The proportion is 5.2%. In another experiment, Chu et al.[4] found the Fe abundance in meteor trails to be 1.06×10^9 cm^{-2}. According to the assumption that Fe substance is 17 times of Na in meteoroid[6], the corresponding Na abundance was estimated to be 6.2×10^7 cm^{-2}. This value is also much less than that in our observation, even our accumulating time is much longer and this will cause a lower result. It may be caused by our lidar sets of time and altitude resolution which are only sensitive to those meteor trails with high density and/or long duration time[9]. Compared with the observations by lidars with the similar sets to ours, it shows that Na abundance in meteor trails varies significantly with time and location. In general, the Na abundance for the Leonid meteor shower is higher than those yielded by sporadic meteors.

The abundance of background Na layer measured during the Leonid meteor shower on and off the peak night is plotted versus time in Fig. 3. They were computed between 01:00LT and 03:30LT to minimize biases associated with tides and other diurnal variation. As shown in Fig. 3, the Na abundances increase gradually in 4 nights during the 5 night observations, which is probably associated with temperature variation[10], and as shown in the right bottom of Fig. 3, the background sodium abundance exhibited little variation when the meteor influx was at its

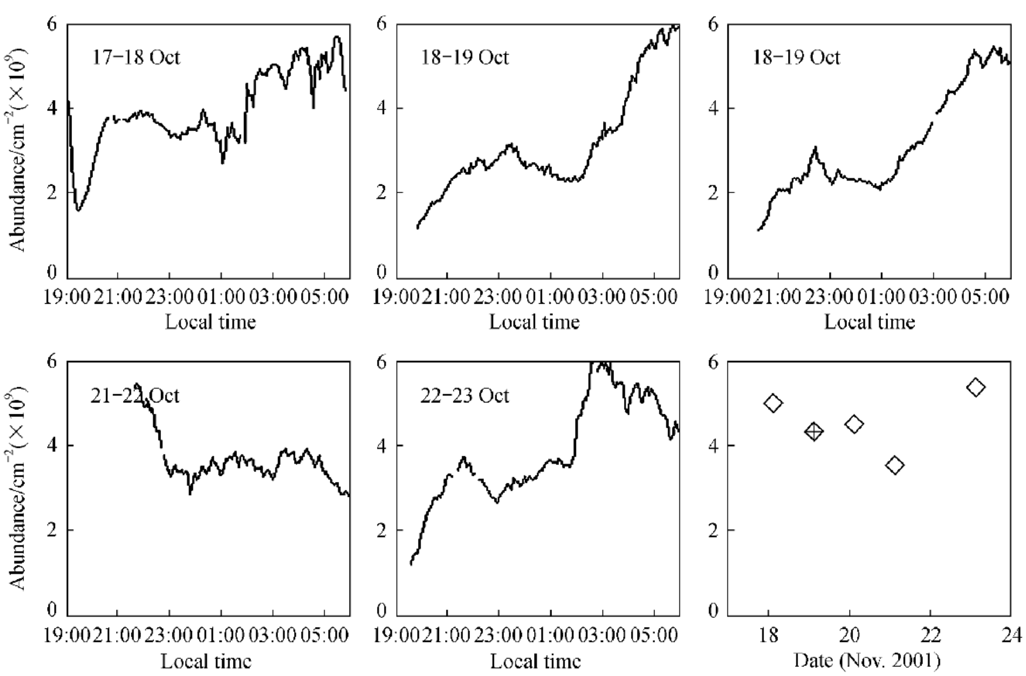

Fig. 3. Abundance variation of the Na layer during 2001 Leonid on and off the peak night. The diamond symbolized with "+"in the last one is of the peak night.

maximum and vanished. This suggests that the Leonid meteor shower does not have a significant effect on the background Na layer.

3 Summary

The 4 Na meteor ablation trails observed during the 2001 Leonid meteor shower provide a reasonable description of the meteoroid characteristics. The Na abundance, occurrence altitude, peak density, RMS width, and the meteor's age derived from this observation are apparently different from the results for sporadic meteors, but comparable to the previously observed for 1998 and 1999 Leonid showers. The average altitude from the high velocity Leonid meteors, 97.95 km, is higher than the slower sporadic meteors, which is only 89 km. The average peak density and the abundance are higher than those of sporadic meteors, too. Their magnitudes are 3380 ± 3633 cm^{-3} and $(2.33 \pm 1.49) \times 10^8$ cm^{-2} respectively. The RMS width is 359 m and the meteor's age is 4875 s (81 min). This indicates that the meteor shower events observed during the 2001 Leonid belong to long duration meteor trails. In this Leonid experiment, we did not detect any apparent change in the background Na layer caused by the meteor influx.

References

1. Clemesha, B. R., Sporadic neutral metal layers in the mesosphere and lower thermosphere, Journal of Atmospheric and Terrestrial Physics, 1995, 57(7): 725—736.
2. Yi, F., Zhang, S. D., Zeng, H. J. et al., Lidar observation of sporadic Na layers over Wuhan (30.5°N, 114.4°E), Geophysical Research Letters, 2002, 29(9): 59-1—59-4.
3. Asher, D. J., Leonid dust trail theories, Proc. International Meteor Conference, Frasso Sabino, 1999 (ed. Arlt, R.), International Meteor Organization, 2000, 5—21.
4. Chu, X., Pan, W., Papen, G. et al., Characteristics of Fe ablation trails observed during the 1998 leonid meteor shower, Geophysical Research Letters, 2000, 27(13): 1807—1810.
5. Grime, B. W., Kane, T. J., Collins, S. C. et al., Meteor trail advection and dispersion: Preliminary lidar observations, Geophysical Research Letters, 1999, 26: 675—678.
6. Kane, T. J., Gardner, C. S., Lidar observation of the meteoric deposition of mesospheric metals, Science, 1993, 259: 1297—1300.
7. Hoffner, J. U., von Zahn, U., McNeil, W. J. et al., The 1996 Leonid shower as studied with a potassium lidar: Observations and inferred meteoroid sizes, Journal of Geophysics Research, 1999, 104: 2633—2643.
8. Chu, X., Kelley, M., Durmmond, J. et al., Lidar observations of elevated temperatures in bright chemiluminescent meteor trails during the 1998, Geophysical Research Letters, 2000, 27(13): 1815—1818.
9. Grime, B. W., Liu, A. Z., Drummond, J. et al., Meteor trail advection observed during the 1998 Leonid shower, Geophysical Research Letters, 2000, 27(13): 1819—1822.
10. Helmer, M. J., Plane, M. C., Qian, J. et al., A model of meteoric iron in the upper atmosphere, Journal of Geophysics Research, 1998, 103: 10913—10926.

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