11. SOME UNUSUAL SPECTRA OF METEORS FROM THE PALOMAR 18-INCH SCHMIDT FILE

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ABSTRACT

Five meteoric spectra have been studied that were obtained during the period mid-June to mid-December, 1966. They include spectra of a Perseid, a Geminid, and three sporadic meteors. Four were photographed on Royal Pan emulsion without a filter; the Geminid on Tri X Aerecon with a GG11 filter.

Lines in the spectrum of one of the sporadic meteors indicate that two meteoroidal fragments were involved which diverged with increasing atmospheric penetration and which flared at different altitudes, indicating that the flares were not the result of atmospheric stratification.

The second sporadic and the Perseid were photographed about 2½ hours apart. The sodium D line is strong in the Perseid but does not appear in the sporadic spectrum. If present, it is blended with the diagonal sequence $\Delta v = +4$ of the first positive group of the neutral nitrogen molecule, which appears in both spectra. A line questionably identified as the forbidden line of oxygen at 5577 Å appears faintly in the sporadic. The strength of the N_2 sequence in these two spectra, and the absence of the D line in the sporadic, are very unusual. The proximity in time of appearance of these two spectra, and the absence of the N_2 bands from the other two sporadic spectra, suggest that a temporary atmospheric condition may be responsible for the strength of the nitrogen radiation.

The Geminid has as its principal feature the $\Delta v = +3$ sequence of the first positive group of N_2. We have not previously observed this band in meteors as low in velocity as the Geminids.

The five meteoric spectra discussed in this paper were photographed by Barbon with the 18-inch Schmidt of the Palomar Observatory. They appeared on objective prism spectrograms as an unexpected by-product of a search of the galactic caps for bright, compact galaxies and quasi-stellar objects. It is interesting to note that between 1940 and 1957 only four spectra of meteors were obtained with this instrument. Two of them were studied by Russell (1957), but the other two were too faint to justify reduction. Data concerning the 1966 spectra are listed in Table 1.

The four spectra photographed on the same emulsion contained 16 lines in common and five additional lines measured in three of the spectra. The wavelengths and identifications of these lines are contained in Table 2. All are low-excitation lines of Fe, Ca, Mg, and Na, and all but Fe 24 are listed by Millman (1963) as multiplets that are particularly strong in the spectra of meteors. The multiplet numbers are taken

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Table 1

No.	Date (1966)	Film h	Film m	Center °	Center ′	PST h	PST m	Exposure m	Emulsion	Filter	Shower
1	June 15	13	04	+22	46	8	28	30	Royal Pan	None	None
2	Aug. 17	23	18	+ 6	30	11	29	35	Royal Pan	None	None
3	Aug. 18	00	07	+ 0	45	2	08	35	Royal Pan	None	Perseid
4	Nov. 14	02	06	− 5	17	10	14	35	Royal Pan	None	None
5	Dec. 10	10	23	+35	27	2	24	30	Tri X Aerecon	GG11	Geminid

Table 2

Wavelength Observed	Wavelength Laboratory	Multiplet	Wavelength Observed	Wavelength Laboratory	Multiplet
3570·3	3570·1	Fe 24	4042·5	4045·8	Fe 43
3581·2	3581·2	Fe 23	4064·8	4063·6	
3648·9[a]	3647·8		4224·5[a]	4226·7	Ca 2
3719·7	3719·9	Fe 5	4265·3	4271·8	Fe 42
3733·5	3736·0	Fe 21	4301·7[a]	4307·9	
3745·8	3747·6		4378·0	4379·7	Fe 41 Fe 2
3833·1	3832·1	Fe 20 Mg 3	4425·8	4427·3	
3857·0	3859·9	Fe 4	4461·4	4461·7	
3880·4	3878·6		5180·3	5179·2	Mg 2
3897·7[a]	3897·7		5893·0[a]	5893·0	Na 1
3924·4	3925·3				

[a] Line observed in three out of the four spectra.

from Moore's (1945) Multiplet Table of Astrophysical Interest. The five spectra are shown in part in Figure 1.

Tentative identification of the remaining lines in spectrum No. 1 was readily accomplished except in the case of two unquestionably visible lines: one at 5232 Å and one at 5981 Å, for which no reasonable identification could be found in Moore's (1945) Finding List. Upon further examination of the whole spectrum, three additional factors were noted. First, these two lines were to the red of the magnesium triplet at 5180 Å and the D line of sodium by similar linear amounts. Second, bursts were observed on the line at 5893 Å for which there were no counterparts on the line at 5981 Å, and vice versa. Finally, measures of the separation of 5893 and 5981 at 3-mm intervals revealed a progressive increase in separation, as indicated in Figure 2. The separation of the D line and the magnesium line does not show such an increase, indicating that the effect is not the result of a change in plate scale. The data strongly suggest that the spectra of two discrete meteoroidal fragments are nearly superimposed on this film.

Millman and Cook (1959) obtained a spectrum in which splitting was observed during the last half of the recorded portion of the trail. The definition was described as "not very good because of both lens aberrations and the blurring that results from

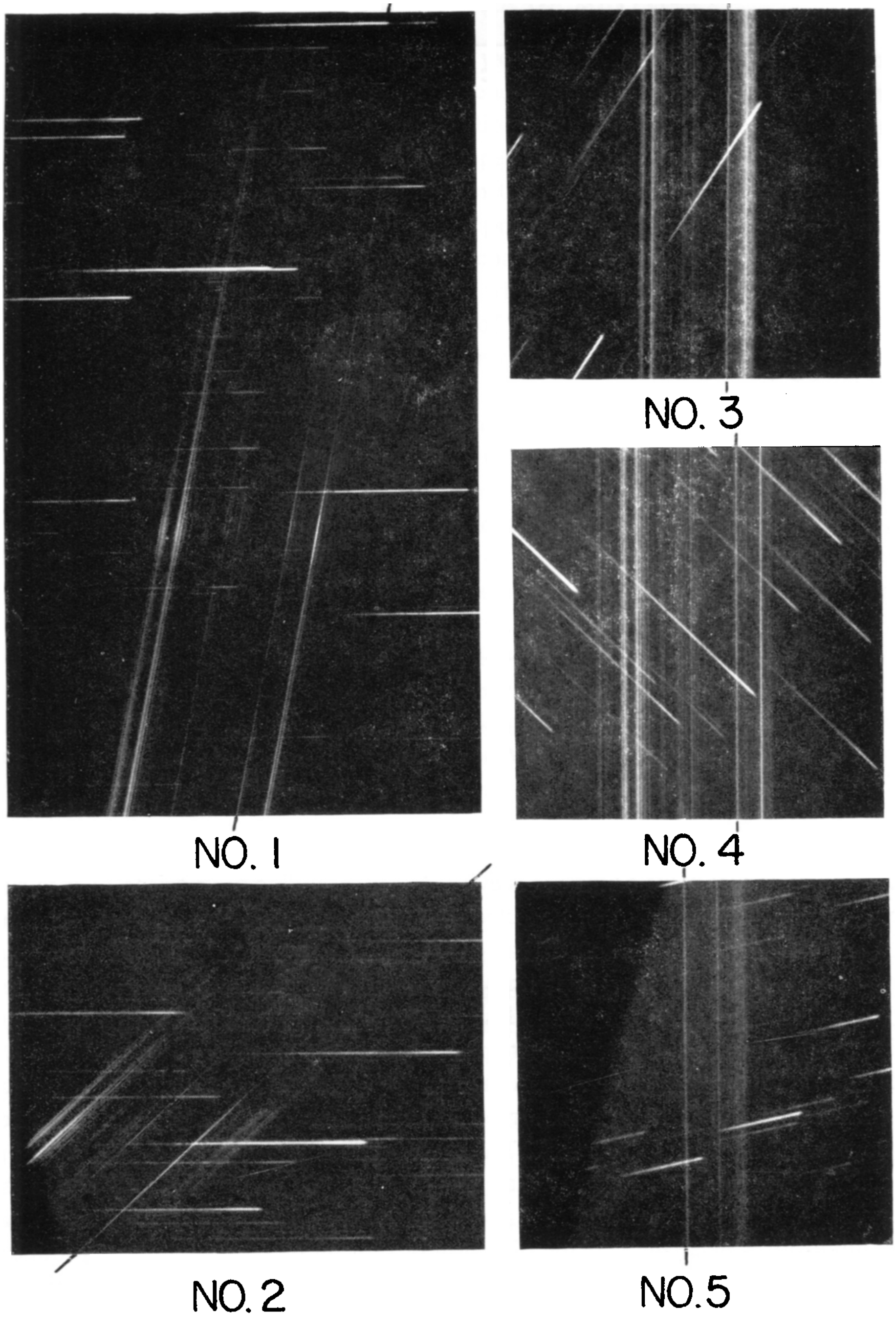

FIG. 1. *Five meteoric spectra from the Palomar 18-inch Schmidt file. The spectra are numbered as in Table 1. Wavelength increases to the right in all cases. The marked line is the magnesium triplet at 5180 Å, the only line common to the five spectra.*

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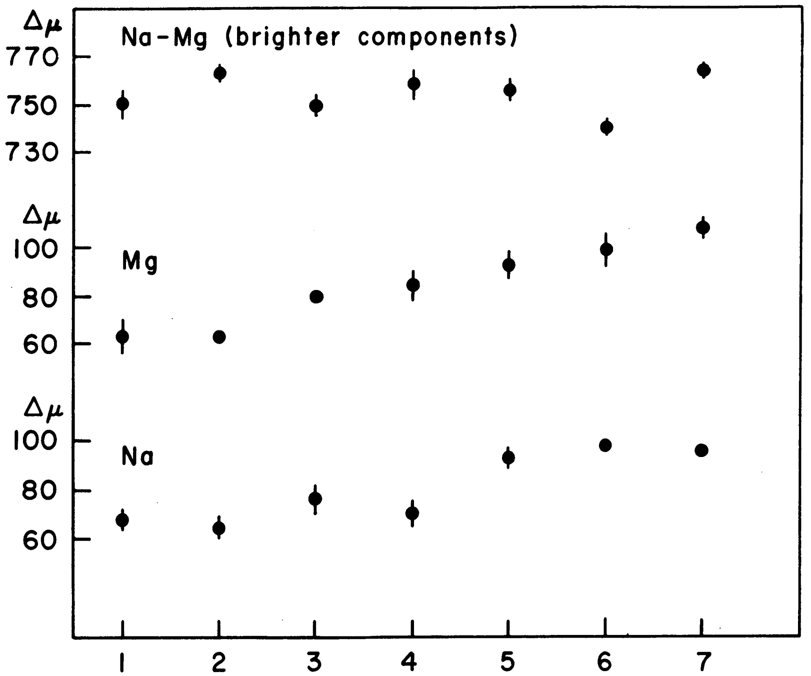

FIG. 2. *The upper row shows the separation of the brighter magnesium line and D line at seven 3-mm intervals. The lower rows show separations of the two magnesium lines and the two D lines at the same intervals.*

splitting of the meteor image". If splitting is responsible for the double lines in this spectrum, remarkably little blurring is evident. A line-by-line comparison of spectrum No. 4, in which no splitting is suspected, with spectrum No. 1 reveals only one line in No. 1 to the violet of 5180 Å that does not appear also in No. 4. It is a faint component of Fe 43, the brighter lines of which are present in both spectra. Most of the lines in the spectrum of the less luminous component are so faint or have fallen so close to lines in the brighter spectrum that no confusion appears.

Halliday (1963) studied a spectrum in which split lines, converging in the direction of motion of the meteor, were observed in the wake photographed in the occulted sections of the main meteoric trail. There was also a tendency for one component to show slightly more irregularity than the other. Halliday explained this phenomenon as "a time exposure of the expanding column of meteoric gas, taken while the luminosity is decaying". If the direction of motion of the meteor that produced spectrum No. 1 had been observed visually and found the same as the direction of increased line separation of the spectral images, the dual particle explanation of the unidentified lines would be on firmer ground. Even without this evidence, the splitting in spectrum No. 1 is apparently quite a different phenomenon from that observed by Halliday. If we assume that two particles were involved in spectrum No. 1, that the plane through their trajectories was perpendicular to the line of sight, and that the terminal height was 65 km, the separation of the two fragments when first observed was about 5 m, increasing at disappearance to about $8\frac{1}{2}$ m. By contrast, Halliday's spectrogram indicated a separation of 40–80 m, attained in $0\overset{s}{.}02$ or less. If the meteoroids in spectrum No. 1 were approaching, a fraction of the apparent increase in their separation is caused by the change in their distance from the telescope. Unless their trajectory makes an angle with the line of sight of less than 20°, however, the physical increase in separation of the meteoroids in flight is an order of magnitude more important than their decrease in distance from the observer in producing the apparent increase in separation.

Strong additional evidence that two meteoroids produced spectrum No. 1 is provided by the irregular pattern of flares on two of the lines. There is a pronounced flare at the end of the 5981 Å line for which no counterpart exists at 5893 Å. Previously, however, the 5893 Å line increased noticeably in brightness five times, whereas 5981 Å exhibited nothing more than a gradual decrease in brightness. Millman (1935) describes a meteor trail photographed at Harvard in 1910, "which divides successively into four parts. There are many small bursts along the divided portion of the path and in many cases, though not all, two parallel trails brighten in exactly the same way at the same point, indicating that some bursts are caused by a variation in the atmospheric conditions at different levels". Rinehart (1951) photographed a Perseid which appears double along the latter portion of its trail and in which the components vary in brightness in essentially perfect unison. The bursts in spectrum No. 1 are clearly not to be attributed to encounters of the meteoroids with atmospheric layers.

Figure 3 shows densitometer tracings of this spectrum at three points along the path of the meteoroid. The blend at 3833 Å is seen to grow fainter more rapidly than the neighboring iron lines because of decreased radiation from the magnesium triplet. The rapid fading of the ultimate line of neutral calcium at 4227 Å between the first and second tracing is still more pronounced. In none of the other four spectra did this line attain comparable strength. Spectrum No. 1 is also the only one of the five to show the lines of aluminum at 3945 Å and 3961 Å. Even in this spectrum they are very faint.

The meteoroid that produced spectrum No. 2 was traveling approximately at right angles to the direction of the Perseid radiant. The most interesting and elusive portions of this spectrum are the features to the red of the magnesium line at 5180 Å. Identification of these features is hampered by a low dispersion, averaging 940 Å/mm between the Mg line and the D line. The 'band' at the long wavelength extremity of the spectrum is attributed to a blend in which the Fe 62 multiplet is probably a primary contributor. A cursory comparison with the other spectra of Figure 1 shows No. 2 to be lacking a D line. The strengths of the multiplets of Mg at 5180 Å and of Fe at 3735 Å and 3835 Å indicate spectrum No. 2 to be of Millman's (1963) type bX.

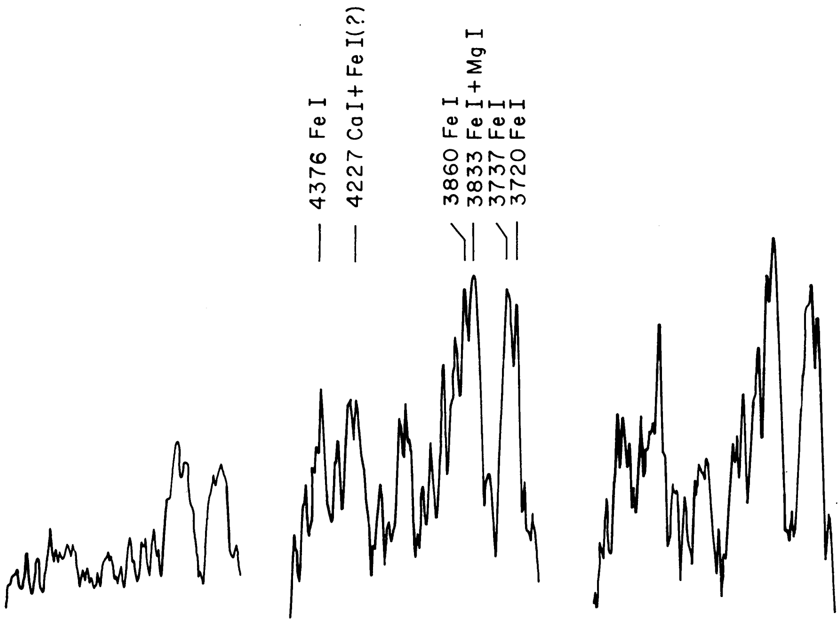

FIG. 3. *Densitometer tracings of spectrum No. 1 at three points along the trail. Note progressive decrease in density of 3833 relative to 3860 and the sharp decrease in 4227 between the first two tracings, reading from right to left.*

Millman (1963) published a spectrum in which the D line is displaced slightly toward the radiant relative to the other lines, but the line is strong and clearly present. We are unaware of any examples of this type of spectrum, taken on panchromatic emulsion, from which the D line is completely absent. In place of the missing D line is a broad band extending from about 5735 Å to 6000 Å. Possible explanations for this peculiar feature include the following:

(1) It may be an out-of-focus image of the D line. This explanation is untenable because star trails crossing the band are sharp; so is the line at 5180 Å.

(2) It may be a column of radiating sodium vapor, expanding radially from the path of the meteoroid. This explanation suffers from the difficulty in conceiving how an initial bright image of the D line could fail to appear, especially since it is known to be strong in spectra of this type (Russell, 1964).

(3) It may be the $\Delta v = +4$ diagonal sequence of the first positive group of the neutral nitrogen molecule. Millman and Cook (1955) attributed one of two large rises in the continuum of a carefully analyzed Perseid spectrum to the $\Delta v = +3$ and $+4$ diagonal sequences of the first positive group. Sequences with Δv greater than $+4$ were absent from their spectrum. The absence of the $\Delta v = +3$ sequence from spectrum No. 2 can probably be attributed to the limited sensitivity range of the emulsion. This spectrum does show, as the first feature to the red of the Mg line at 5180 Å,

a broad line at 5406 Å, a wavelength straddled by the $\Delta v = +5$ sequence. It seems more likely that this feature is a blend of lines rather than the $\Delta v = +5$ band. In the first place, spectrum No. 4 contains a partially resolved feature in the same wavelength range, but shows no evidence of the stronger N_2 sequences. Secondly, a spectrum obtained by Russell (1960) with the same instrument shows an indistinct feature in this position, a strong $\Delta v = +3$ sequence, but no $\Delta v = +4$ sequence. In both of these cases it is difficult to account for the absence of the $\Delta v = +4$ sequence if the feature at 5406 Å is the $\Delta v = +5$ band.

The fourth and faintest line to the red of 5180 Å in spectrum No. 2 falls practically at the wavelength of the forbidden O I line at 5577 Å. Although there is marginal evidence that higher on the recorded path the line is relatively stronger, its persistence with decreasing altitude casts doubt on this identification.

Spectrum No. 3 is remarkably similar to spectrum No. 2 in all but one important respect: No. 3 has a strong D line superimposed on the $\Delta v = +4$ sequence of N_2. This eliminates the possibility of relating the absence of the D line from No. 2 to the strong N_2 radiation at that wavelength.

Spectra Nos. 2 and 3 are the only ones in this series, or in any other to our knowledge, in which this N_2 radiation is so prominent. Hence it is worth noting that the mid-exposure times of these spectrograms differ by only 2^h39^m. This suggests the possibility of a local atmospheric condition as a contributing cause of the N_2 bands. A check of the A.A.V.S.O. *Solar Bulletin* for August, 1966, indicates sunspot activity during August to have been on about the same level that existed the previous June, the month in which spectrum No. 1 was recorded. Solar activity was reported as high at the end of the month, a class-3 flare occurring on August 28 as a large sunspot group crossed the meridian, but this event was 10 days later than the appearance of the two meteors under consideration.

Spectrum No. 4 was photographed the night before the phenomenal 1966 Leonid shower. Unfortunately, the skies were cloudy over Palomar the night of the maximum. The tentative classification of this object as a Leonid was abandoned when calculation showed the Leonid radiant to be several degrees below the horizon at the time of the meteor's appearance. This is the best-exposed of the five spectra, and it has provided a valuable control, as already noted in the discussion of spectra Nos. 1 and 2. In Figure 4, spectrum No. 4 is used again in this capacity to provide a tracing of the D line without N_2 background for comparison with tracings of the same region of spectrum No. 3 (D line with N_2 background) and spectrum No. 2 (N_2 background without the D line). The tracings emphasize the differences that exist in each case.

Spectrum No. 5 is the only one of the group on a film sensitive enough in the red to show the $\Delta v = +3$ sequence of N_2. Note that despite the strength of $\Delta v = +3$, the $\Delta v = +4$ band is not evident. It should be mentioned also that this meteor, being a Geminid, had a geocentric velocity of 34 km/sec compared to a velocity of 60 km/sec

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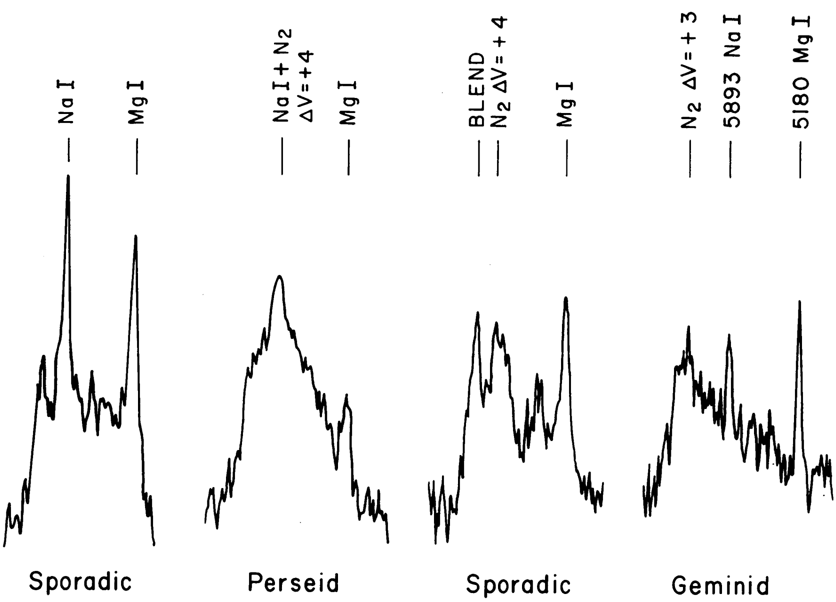

FIG. 4. *Densitometer tracings in the region of the D-line and Mg triplet: From left to right: sporadic spectrum No. 4, no N_2 band; Perseid, D line plus $\Delta v = +4$ band of N_2; sporadic spectrum No. 2, $\Delta v = +4$ band of N_2 but no D line; Geminid, D line plus $\Delta v = +3$ band of N_2.*

for a Perseid. The occurrence of the N_2 bands is thus less velocity dependent than Halliday (1960) reports to be true for the O I line at 5577 Å.

Summary

(1) The flares appearing on the D-line images of the double meteor occur independently at different heights and indicate no triggering of the flares by encounters with atmospheric strata with different physical properties.

(2) The unusual strength of the $\Delta v = +4$ diagonal sequence of N_2 in the spectra of two meteors photographed 2^h39^m apart may indicate an abnormal atmospheric condition at the time.

(3) The absence of the D line from one of the two spectra mentioned in item 2 above constitutes an unusual chemical vagary.

(4) A strong N_2 band is present in the Geminid spectrum, indicating that this feature has a low velocity dependence.

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DISCUSSION

Whipple: Dr. Russell, of course, has observed a split meteor, not two meteors. On longer focus telescope photographs I have seen a number that split before they showed photographically, one into four components.

Russell: I believe that I have referred to that meteor in the manuscript. Time prevented my mentioning it this afternoon.

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