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## A STUDY OF ULTRAVIOLET METEOR SPECTRA

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# A Study of Ultraviolet Meteor Spectra

IAN HALLIDAY

ABSTRACT—The spectra of one Lyrid and one Perseid meteor are used as the basis for a list of spectral line identifications in the ultraviolet range from 3100 to 4000 A. Lines from six neutral atoms and five ions are listed, including the first identifications of Ti II and Cr II in meteor spectra. No lines are attributed to Si I or Co I. An enduring line at 3836.5 A was observed between heights of 87 and 75 km in the Lyrid spectrum. No satisfactory identification for this line was found since its association with lines of Fe I or Mg I is considered doubtful.

RÉSUMÉ—Le spectre d'un météor des Perséides et d'un autre des Lyrides constituent une base fondamentale permettant de dresser une liste afin d'établir l'identité de raies spectrales dans le champ d'activité 3100 à 4000 Å de l'ultraviolet. Les raies de six atomes neutres et de cinq ions comprenant les premières identifications de Ti II et de Cr II dans un spectre météorique y sont données. Aucune raie n'est décelée de Si I ou de Co I. On constate une raie persistante à 3836.5 Å entre les hauteurs de 87 et 75 km dans le spectre des Lyrides. Cette raie étant tellement rapprochée de Fe I ou Mg I, il semble fort douteux qu'il soit possible de l'identifier de façon satisfaisante.

## Introduction

A meteor spectrograph designed for photography of the ultraviolet spectra of meteors began operation at the Meanook Meteor Observatory, Alberta, in 1957. The camera employs quartz optics and a 300-line-per-mm transmission diffraction grating mounted on a quartz blank. The instrument was included in a description of the spectrographic equipment at the Meanook and Newbrook Observatories (Halliday, 1958).

Most detailed lists of spectral line identifications in meteor spectra are limited at the short-wavelength end, near 3650 A, by the transmission of the optics (Millman, 1956; Halliday 1961, 1963; Ceplecha and Rajchl, 1963; Ceplecha, 1966). Two prismatic meteor spectra photographed with the 18-inch Schmidt telescope on Mount Palomar were described by Russell (1957). They recorded lines down to about 3400 A with modest dispersion but the meteors were not particularly bright.

## Observational Material

This paper presents a list of line identifications in the ultraviolet region between 3100 and 4000 A. The identifications are based on the spectra of two bright meteors supported by other, somewhat less detailed spectra. The two meteors are a Perseid and a Lyrid and both were recorded by several cameras. The basic observational data are summarized below.

### *Perseid*

A brilliant Perseid was photographed at Meanook and Newbrook at $8^h\ 15^m\ 30^s$ U.T., August 12, 1963. Two spectrograms of this meteor were reproduced recently in a paper dealing with meteor-wake radiation (Halliday, 1968). Exposure U2388 showed extremely good definition in the second- and third-order spectra of the $\lambda3700 - 4000$ region; hence it is used as the primary reference in this spectral region. The camera focal length was 203 mm, with a 400-line-per-mm grating yielding second- and third-order dispersions of 60 and 40 A/mm, respectively, on Kodak Tri-X Aerecon film. Portions of these orders are reproduced in Figure 1.

### *Lyrid*

The most detailed spectrogram secured with the ultraviolet quartz spectrograph was produced by a Lyrid meteor at $6^h\ 57^m\ 38^s$ U.T., April 22, 1966. Six spectrographs recorded this bright meteor. The ultraviolet spectrum was on exposure V1990 and is reproduced in Figure 2 with an en-

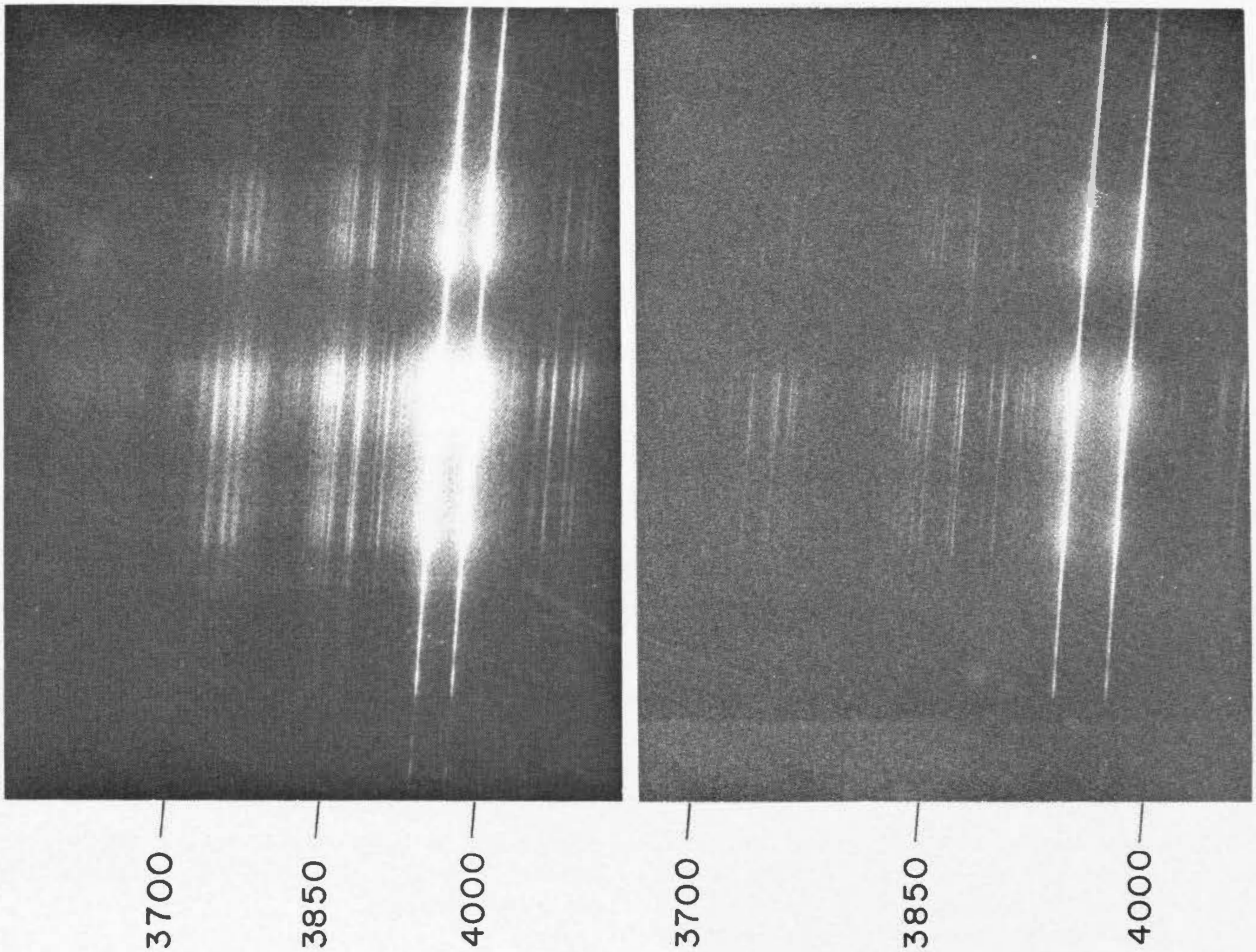

Figure 1. Exposure U2388, August 12, 1963. Portions of the second- and third-order spectra. Meteor motion from top to bottom.

larged portion in Figure 3. A rotating shutter with a closed-to-open ratio of 2:1 occulted this spectrogram 11.2 times per second and the most detailed portion of the meteor spectrum was produced by a short flare very near the bottom end of the next-to-last segment. The spectrum was recorded on Kodak spectroscopic 103-O emulsion on a glass plate with a dispersion of 159 A/mm.

## Line Identifications

The wavelength measurements were performed as in an earlier study of Perseid meteors (Halliday, 1961) and the identifications, listed in Table 1, also follow the same pattern. Successive columns list the measured wavelength, the identification of the atom or ion with the multiplet number from Moore's (1945) tables, and the laboratory wavelengths of those lines which are considered to be significant contributors to the feature. From 3118 to 3665 A the measures are based on plate V1990; from 3679 to 4001 A exposure U2388 was used. Most of these measures are from the third-order spectrum but some twelve features were detected only in the stronger second order and these are indicated by a II in the final column.

## Discussion of Identifications

Table 1 lists 82 separate features and the identifications involve 50 multiplets of 11 different atoms or ions. These multiplets are listed in Table 2. As in previous cases some of these multiplets are involved only in blended features and Table 3 lists 17 multiplets for which the identification is considered doubtful. None of the eleven atoms or ions in Table 2 would be removed from the list if all the doubtful multiplets were discarded.

Brief comments follow on each atom or ion involved in the identifications.

*Mg I.* Multiplet 3 is prominent and well resolved.

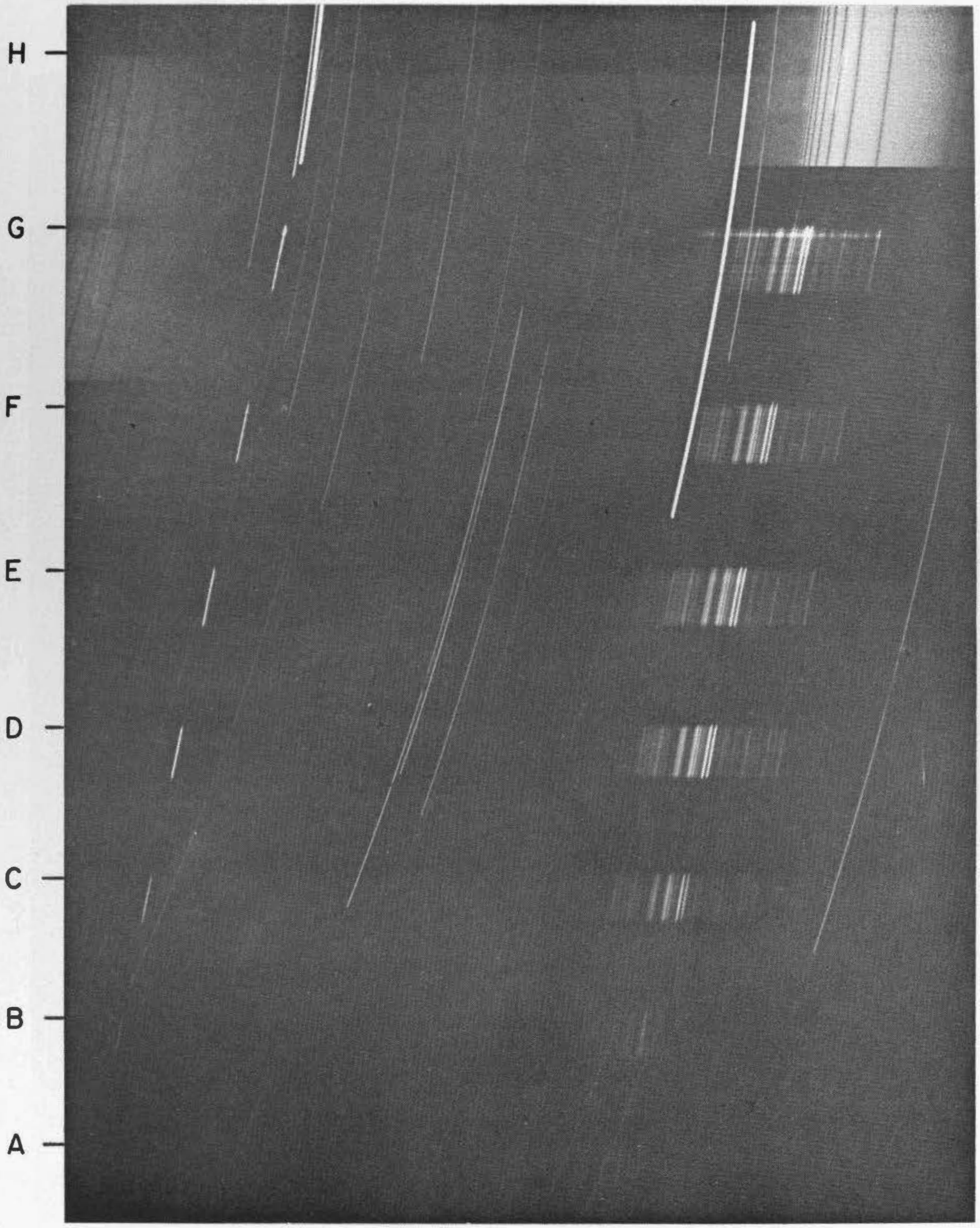

Figure 2. Exposure V1990, April 22, 1966. Letters indicate lower ends of meteor segments. Meteor motion from bottom to top.

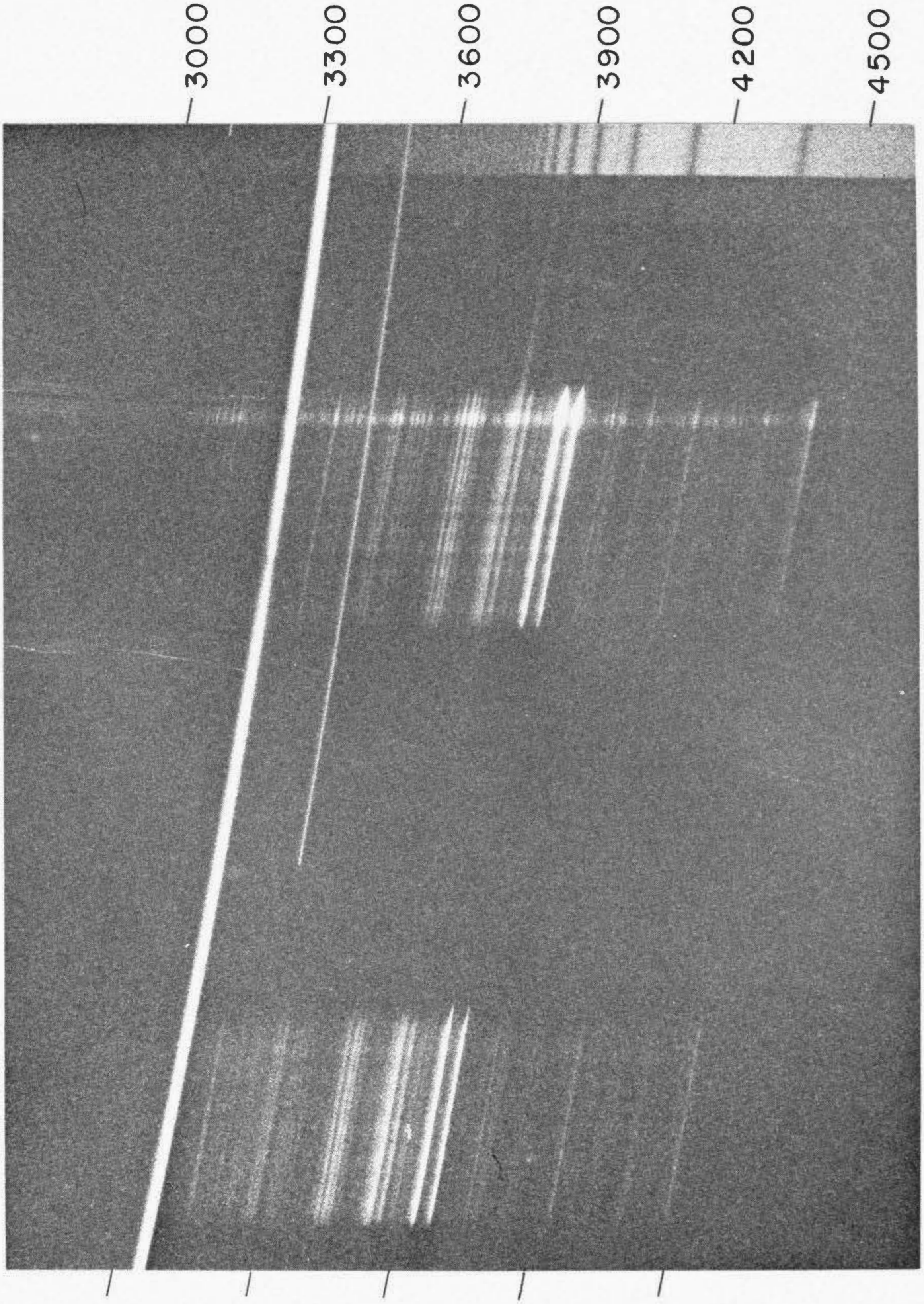

Figure 3. Enlarged portion of Figure 2 showing detail in ultraviolet meteor spectrum.

TABLE 1. MEASURED WAVELENGTHS AND IDENTIFICATIONS

| $\lambda_{\text{meas}}$ | Atom or Ion | Mult. | $\lambda_{\text{lab}}$ | Order |
|---|---|---|---|---|
| 3118–3137 | Cr II | 5 | 3118.7 | |
| | | | 3120.4 | |
| | | | 3125.0 | |
| | | | 3128.7 | |
| | | | 3132.1 | |
| | | | 3136.7 | |
| 3157.8 | Ca II | 4 | 3158.9 | |
| 3170.0 | Fe II | 6 | 3170.3 | |
| 3180.0 | Ca II | 4 | 3179.3 | |
| | | | 3181.3 | |
| | Fe I | 155 | 3180.2 | |
| 3195.4 *b* | Fe I | 7 | 3193.2 | |
| | Fe I | 155 | 3196.9 | |
| | Fe II | 6 | 3192.9 | |
| | | | 3193.8 | |
| | Fe II | 7 | 3196.1 | |
| 3213.6 | Fe I | 7 | 3214.4 | |
| | Fe I | 158 | 3212.0 | |
| | Fe II | 6 | 3213.3 | |
| 3228.3 | Fe II | 6 | 3227.7 | |
| 3236.4 | Ti II | 2 | 3234.5 | |
| | | | 3236.6 | |
| | | | 3239.0 | |
| | Fe I | 7 | 3236.2 | |
| 3258.0 | Fe II | 1 | 3255.9 | |
| | Fe II | 81 | 3258.8 | |
| | | | 3259.0 | |
| 3276.1 | Fe II | 1 | 3277.3 | |
| 3362.8 | Ca I | 11 | 3361.9 | |
| | | | 3362.1 | |
| | Ti II | 1 | 3361.2 | |
| | Cr II | 21 | 3360.3 | |
| 3370.7 *b* | Ni I | 6 | 3369.6 | |
| | Ti II | 1 | 3372.8 | |
| | Cr II | 4 | 3368.1 | |
| 3385.1 *b* | Ti II | 1 | 3383.8 | |
| | | | 3387.8 | |
| | Cr II | 3 | 3382.7 | |
| 3410.3 *b* | Fe I | 83 | 3407.5 | |
| | Fe I | 85 | 3413.1 | |
| | Ni I | 19 | 3414.8 | |
| | Cr II | 3 | 3408.8 | |
| 3424.2 | Cr II | 3 | 3421.2 | |
| | | | 3422.7 | |
| 3440.8 | Fe I | 6 | 3440.6 | |
| | | | 3441.0 | |
| | | | 3443.9 | |
| 3462.6 | Fe I | 6 | 3465.9 | |
| | Ni I | 17 | 3461.7 | |
| 3475.2 | Fe I | 6 | 3475.4 | |
| | | | 3476.7 | |
| 3491.7 | Fe I | 6 | 3490.6 | |
| | Ni I | 18 | 3493.0 | |
| 3523.4 | Fe I | 6 | 3526.0 | |
| | Fe I | 24 | 3521.3 | |
| | Ni I | 18 | 3524.5 | |
| 3541.4 | Fe I | 326 | 3541.1 | |
| | | | 3542.1 | |
| 3568.6 | Fe I | 24 | 3565.4 | |
| | | | 3570.1 | |
| | Ni I | 36 | 3566.4 | |
| 3582.4 | Fe I | 23 | 3581.2 | |
| 3593.6 | Cr I | 4 | 3593.5 | |

| $\lambda_{\text{meas}}$ | Atom or Ion | Mult. | $\lambda_{\text{lab}}$ | Order |
|---|---|---|---|---|
| 3607.2 | Fe I | 23 | 3608.9 | |
| | Cr I | 4 | 3605.3 | |
| 3619.0 | Fe I | 23 | 3618.8 | |
| | Ni I | 35 | 3619.4 | |
| 3631.8 | Fe I | 23 | 3631.5 | |
| | Ca I | 9 | 3630.7 | |
| 3646.1 *b* | Fe I | 23 | 3647.8 | |
| | Ca I | 9 | 3644.4 | |
| 3665.6 | Ni I | 4 | 3664.1 | |
| | | | 3670.4 | |
| 3679.9 | Fe I | 5 | 3679.9 | II |
| 3686.7 | Fe I | 21 | 3687.5 | II |
| | Fe I | 385 | 3686.0 | |
| 3695.5 | Fe I | 394 | 3694.0 | II |
| 3705.7 | Fe I | 5 | 3705.6 | |
| | Ca II | 3 | 3706.0 | |
| 3709.1 | Fe I | 21 | 3709.3 | II |
| 3714.5 | Cr II | 20 | 3715.2 | II |
| 3719.8 | Fe I | 5 | 3719.9 | |
| 3727.7 | Fe I | 21 | 3727.6 | II |
| 3734.8 | Fe I | 21 | 3734.9 | |
| 3737.1 | Fe I | 5 | 3737.1 | |
| | Ca II | 3 | 3736.9 | |
| 3745.6 | Fe I | 5 | 3745.6 | |
| | | | 3745.9 | |
| 3748.6 | Fe I | 5 | 3748.3 | |
| | Fe I | 21 | 3749.5 | |
| 3753.7 | Fe I | 73 | 3753.6 | II |
| | Cr II | 20 | 3754.6 | |
| 3758.9 | Fe I | 21 | 3758.2 | |
| 3763.2 | Fe I | 21 | 3763.8 | |
| 3766.9 | Fe I | 21 | 3767.2 | II |
| 3787.4 | Fe I | 21 | 3787.9 | II |
| 3795.0 | Fe I | 21 | 3795.0 | |
| 3798.9 | Fe I | 21 | 3798.5 | |
| | | | 3799.5 | |
| 3806.0 | Fe I | 607 | 3806.7 | II |
| | Fe I | 608 | 3805.3 | |
| 3815.9 | Fe I | 45 | 3815.8 | |
| 3820.3 | Fe I | 20 | 3820.4 | |
| 3824.3 | Fe I | 4 | 3824.4 | |
| 3825.6 | Fe I | 20 | 3825.9 | |
| 3827.9 | Fe I | 45 | 3827.8 | |
| 3829.2 | Mg I | 3 | 3829.4 | |
| 3832.5 | Mg I | 3 | 3832.3 | |
| 3834.2 | Fe I | 20 | 3834.2 | |
| 3838.4 | Mg I | 3 | 3838.3 | |
| 3840.8 | Fe I | 20 | 3840.4 | |
| | Fe I | 45 | 3841.1 | |
| 3846.0 | Fe I | 124 | 3845.2 | II |
| | Fe I | 664 | 3846.8 | |
| 3849.9 | Fe I | 20 | 3850.0 | |
| 3856.3 | Fe I | 4 | 3856.4 | |
| | Si II | 1 | 3856.0 | |
| 3859.8 | Fe I | 4 | 3859.9 | |
| 3862.7 | Si II | 1 | 3862.6 | |
| 3865.2 | Fe I | 20 | 3865.5 | |
| 3872.5 | Fe I | 20 | 3872.5 | |
| 3878.5 | Fe I | 4 | 3878.6 | |
| | Fe I | 20 | 3878.0 | |
| 3886.5 | Fe I | 4 | 3886.3 | |
| 3888.6 | Fe I | 45 | 3888.5 | |
| 3895.8 | Fe I | 4 | 3895.7 | |
| 3899.8 | Fe I | 4 | 3899.7 | |
| 3903.2 | Fe I | 45 | 3902.9 | |
| 3906.3 | Fe I | 4 | 3906.5 | |
| 3920.5 | Fe I | 4 | 3920.3 | |
| 3923.3 | Fe I | 4 | 3922.9 | |
| 3933.7 | Ca II | 1 | 3933.7 | |
| 3944.8 | Al I | 1 | 3944.0 | |
| 3956.5 | Fe I | 278 | 3956.7 | |
| 3961.8 | Al I | 1 | 3961.5 | |
| 3968.6 | Ca II | 1 | 3968.5 | |
| | Fe I | 43 | 3969.3 | |
| 3996.9 | Fe I | 278 | 3997.4 | |
| 4001.7 | Fe I | 72 | 4001.7 | |

*b*—Feature noticeably broad.

TABLE 2. MULTIPLETS IDENTIFIED IN TABLE 1

| | | | |
|---|---|---|---|
| Mg I | 3 | Cr I | 4 |
| Al I | 1 | Cr II | 3, 4, 5, 20, 21 |
| Si II | 1 | Fe I | 4, 5, 6, 7, 20, 21, 23, 24, 45, 72, 73, 83, 85, 124, 155, 158, 278, 326, 385, 394, 607, 608, 664 |
| Ca I | 9, 11 | Fe II | 1, 6, 7, 81 |
| Ca II | 1, 3, 4 | Ni I | 4, 6, 17, 18, 19, 35, 36 |
| Ti II | 1, 2 | | |

TABLE 3. DOUBTFUL MULTIPLET IDENTIFICATIONS

| | |
|---|---|
| Cr II | 4, 20, 21 |
| Fe I | 7, 72, 73, 83, 85, 124, 158, 326, 385, 607, 608 |
| Ni I | 6, 35, 36 |

*Al I.* Multiplet 1 is present in the Perseid spectrum. It has been observed previously but may often be obscured by the effects of overexposure of the H and K lines of Ca II.

*Si II.* Multiplet 1 is a rather weak contributor in the Perseid spectrum.

*Ca I.* Two multiplets appear to be present and both would be expected on the basis of a comparison with other multiplets of Ca I normally observed in the visual region.

*Ca II.* Multiplet 4 is a definite contributor at λλ3158 and 3180. Multiplet 3 is blended with lines of Fe I while multiplet 1 (the H and K lines) is the strongest multiplet in the spectrum.

*Ti II.* This appears to be the first identification of titanium in meteor spectra. Two multiplets of Ti II contribute to four features although the strongest line of Ti II, at 3349 A, is unfortunately obscured by the zero-order image of *η Ursae Majoris.*

*Cr I.* Multiplet 4 is present although its strongest member is too close to an ultimate line of Fe I to be observed directly.

*Cr II.* Several multiplets of Cr II are definite or probable contributors. The shortest wavelength observed is a broad feature from approximately 3118 to 3137 A, attributed to multiplet 5 of Cr II.

*Fe I.* Many multiplets of Fe I are observed although they are not prominent in the 3100 to 3400 A region. Numerous weak multiplets of Fe I are included in the list of doubtful identifications.

*Fe II.* A few multiplets of Fe II are the major contributors to several features near the short-wavelength end of the list.

*Ni I.* The identification of Ni I is difficult with the dispersion of these spectrograms since it has no outstanding lines and is frequently involved in blends with lines of Fe I. However, several multiplets of Ni I appear to be required to explain the intensities of some of these blends.

The apparent absence of certain lines from these spectra is worth noting. Exposure U2388 (the Perseid) shows no indication of the strong line of Si I at 3905.5 A. A weak feature at 3906.3 A is identified with a weak member of multiplet 4 of Fe I at 3906.5 A. The dispersion of the third-order spectrum makes this identification secure and there is thus some reason to doubt whether lines of Si I have previously been observed in other spectra of inferior dispersion.

No lines are attributed to cobalt in Table 1. Its ultimate line, at 3453 A, would not be confused by other lines on plate V1990, hence it must be an extremely weak contributor. Previous identifications of cobalt were by Russell (1957) who recorded a line at 3452 A in one of the two spectra to reach this wavelength and by Ceplecha and Rajchl (1963) and Ceplecha (1966), who measured a line at 3894 A which they identified with Co I, 34. They included a few other lines of Co I as possible contributors to some blends.

## Enduring Radiation in the Ultraviolet

In a recent paper (Halliday, 1968) many of the multiplets commonly observed in meteor spectra were divided into five classes on the basis of their duration at a given point on the meteor trail. Class I multiplets decay very quickly and are not observed in meteor wakes. At the other end of the scale, the forbidden line of O I at λ5577 was the only entry in class V while class IV contains seven intersystem multiplets of low excitation which are normally enhanced in the wake spectrum. It was stressed that the observed intensities of wake lines may be strongly affected by the phasing of a rotating shutter relative to a particular flare and also by the orientation of the trail. Wake lines are enhanced when observed near the radiant of the meteor trail because of the increased path length containing the excited atoms.

The meteor of Figure 1 is the same Perseid used as the basis for classifying multiplets into the five classes. Exposure U2388, which provided the superior definition in the 3700 – 4000 A region of Table 1, was taken with camera U which does not have a rotating shutter. It thus records the integrated intensity of all lines and does not discriminate against any of the duration classes. The intense flare of this meteor was more than 70° from the Perseid radiant at both observing stations so no enhancement is expected from the orientation of the trail. This flare occurred in the height range from 84 to 83 km above sea level.

The lines identified in the more distant ultraviolet, from the Lyrid spectrum, came from a short flare close to the bottom of a segment, at a height of 76 km. The camera was occulted only 4 milliseconds after the flare (position *G* in Figure 2) hence the intense spectrum is relatively pure meteor-head radiation. Any class IV multiplets would be virtually excluded from the spectrum by the rotating shutter. As seen from Meanook this flare was 48° from the Lyrid radiant so again little or no enhancement due to trail orientation is involved.

The table classifying the duration of multiplets includes four multiplets of Fe I and one of Ca II between $\lambda\lambda$3700 and 4000. The ultraviolet Lyrid spectrum produced only one addition to the table – a puzzling feature at 3836.5 A. Figures 2 and 3 show this feature most clearly just below the intense flare until it is obscured by the overlapping first-order spectra of the stars *Alcor* and *Mizar*. Careful measures at nine positions on the line in the occulted portion of the spectrum below the flare were made to establish this wavelength. Extrapolation of the wavelength positions below the flare was assisted by the presence of measurable H and K lines in a final segment at 73 km height (position *H* of Figure 2) superposed on the spectrum of *Mizar*. On original prints of the spectrogram the line can be traced completely through the occulted portions of the spectrum in the four breaks preceding the segment with the flare, up to an atmospheric height of 87 km (position *C* of Figure 2) and down to 75 km where the stellar spectra interfere.

This feature is difficult to identify. The meteor was also photographed with cameras 10 and 150, two of the jumping-film spectrographs (Halliday and Griffin, 1963). These cameras do not have rotating shutters and reveal that the flare recorded by camera V was followed almost immediately by a longer flare of similar intensity and then by a general decline in brightness during the remainder of the trail. The enduring line at $\lambda$3836 follows this intensity variation closely and is insensitive to the relatively long occulted period (59 milliseconds) just below the flare observed by camera V. In other words its behavior is similar to the forbidden oxygen line at $\lambda$5577 and belongs in class V as a long-enduring feature.

The straightforward identification of the feature is to attribute it to Mg I, 3, an unresolved multiplet on this dispersion, with three of its five components well resolved in the Perseid spectrum, as listed in Table 1. Millman (1950) observed a rather similar line in the first spectrogram to show an appreciable wake or train spectrum and listed both the magnesium and iron multiplets as the identification. There is now substantial evidence available on normal meteor wakes and it may be profitable to consider multiplets 1, 2 and 3 of Mg I. The peculiar line in the Lyrid spectrum is not due to Fe I since other, stronger lines would then be observed.

Multiplet 1 of Mg I is a low-excitation, intersystem line at 4571 A, usually present in a strong meteor wake and it is one of the class IV multiplets. The upper level of multiplet 1 is also the lower level of multiplets 2 and 3. Multiplet 2 has an excitation of 5.09 ev for the upper state and its strongest line, at 5183 A, is often well resolved from other lines. The other two lines, near 5170 A, are usually blended with strong wake lines, of class IV, from Fe I, 1. Multiplet 3 of Mg I requires an excitation of 5.92 ev and, on low dispersion, is blended with multiplets 4 and 20 of Fe I. In the normal wake spectra of strong flares $\lambda$5183 of multiplet 2 is present but decays rapidly, typical of class II, which is in keeping with its high excitation energy for a wake line. Multiplet 3, with its higher excitation, would be expected to decay even more rapidly but might still be a class II multiplet. The presence of the lower-excitation lines from Fe I in the wake makes this difficult to check.

The spectrogram of the Lyrid meteor from camera 150 shows that the film jumped three times during the flight of the meteor and at these locations on the trail it is possible to search for wake radiation recorded as an apparent upward extension of a given line above the jump. One of the jumps was near a height of 87 km (the upper limit at which $\lambda$3836 was observed in the wake on camera V) and camera 150 shows no trace of wake radiation at this location, including Mg I, 2 at $\lambda$5176. The instrumental transmission of this camera at $\lambda$3836 is not great so the absence of this line as a wake feature on the spectrogram from camera 150 is understandable.

A search was made for molecular features which might explain the wake line observed by camera V. The Schumann-Runge band system of $O_2$ includes a band head at 3840.6 A but other members of the system should also be observed if this were the proper identification.

The measured wavelength of 3836.5 A for the enduring line should not be in error by much more than 1 A on this dispersion. The observed position is within the 9 A interval covered by the Mg I, 3 multiplet but from the intensity values given in different identification tables the expected position of the unresolved multiplet would be 3834.5 A. The discrepancy of 2.0 A is sufficient that the wavelength can not be interpreted as strong support for the identification with Mg I, 3.

In summary, then, an enduring feature observed at $\lambda$3836.5 between heights of 87 and 75 km in the wake spectrum of a Lyrid meteor can not be identified with confidence at present. Its behaviour suggests an origin associated with some atmospheric constituent, an association which is strengthened by the fact that most bright meteors do not show an enduring line at this wavelength.

An identification with Mg I, 3 remains a possibility but is not supported by the normal behaviour of various lines of Mg I.

### Future Observations

The spectral lines identified in this study can almost certainly be supplemented by other lines when brighter meteors are photographed with existing spectrographs. From the substantial number of blended features in Table 1 evidently higher dispersion would also improve the list of identifications, especially for lines from inconspicuous atoms such as Ni I or for determining the presence of atoms such as Co I.

Several of the multiplets already identified in these spectra should be contributors to normal wake spectra when an intense flare occurs just before the camera is uncovered, rather than just before it is occulted as in Figure 3. A careful search should be maintained for additional instances of the persistent feature at λ3836 and here again an improved dispersion could assist in the problem of its identification.

## Acknowledgments

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## References

Ceplecha, Z., 1966. Complete data on iron meteoroid (Meteor 36221): *Bull. Ast. Inst. Czechoslovakia*, v. 17, 195.

Ceplecha, Z., and J. Rajchl, 1963. The meteor spectrum with dispersion from 11 to 38 A/mm: *Bull. Ast. Inst. Czechoslovakia*, v. 14, 29.

Halliday, I 1958. Meteor spectroscopy with transmission diffraction gratings: *JRASC*, v. 52, 169.

———— 1961. A study of spectral line identifications in Perseid meteor spectra: *Publ. Dom. Obs. Ottawa*, v. 25, 1.

———— 1963. Diffusion effects observed in the wake spectrum of a Geminid meteor: *Publ. Dom. Obs. Ottawa*, v. 25, 45; *Smithsonian Contr. Ap.*, v. 7, 161.

———— 1968. The influence of exposure duration and trail orientation on photographic meteor spectra: *I.A.U. Symposium no. 33*, 91.

Halliday, I., and A. A. Griffin, 1963. A jumping-film camera for meteor photography: *J. Sci. Instr.*, v. 40, 187; *Publ. Dom. Obs. Ottawa*, v. 25, 39.

Millman, P. M., 1950. Spectrum of a meteor train: *Nature*, v. 165. 1013.

———— 1956. A complex Perseid meteor spectrum: *Sky and Telescope*, v. 15, 445.

Moore, C. E., 1945. A multiplet table of astrophysical interest: *Contr. Princeton Obs*. no. 20.

Russell, J. A., 1957. Spectra of two meteors from the file of the Palomar 18-inch Schmidt: *Pub. A.S.P.*, v. 69, 436.