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EMISSION BAND PHOTOMETRY OF COMET IKEYA-SEKI (1965f)

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Summary

Photoelectric measures of emission band intensities of C_2 (1, 0) and CN (0, 0) of the coma of Comet Ikeya-Seki (1965f) are reported. The measured fluxes are utilized to determine the number of molecules of C_2 and CN that contribute to the observed emission.

1. *Introduction.* Narrow band photometric studies of comets in recent years have attempted to derive molecular abundances as well as the total number of molecules of a particular species within the cometary head. Spectrum scans and the use of interference filters isolating the emission bands are the two procedures that enable an evaluation to be made with good accuracy, when carried out photoelectrically. We report here on the results of measurements of Comet Ikeya-Seki (1965f) made at Kodaikanal on November 17.984, when the heliocentric and geocentric distances of the comet were 1·013 a.u. and 1·05 a.u. respectively.

2. *Observations.* The head of the comet was isolated in the focal plane of the telescope by a circular aperture of 2·5 mm diameter corresponding to a projection of 155″ on the sky. Hence, our estimate of the total number of molecules refers to those contained in a cylinder of diameter 121 300 km centred on the cometary nucleus. Five interference filters, having the characteristics described in Table I, isolated the emission bands as well as selected regions of the continuum. Two of these, measured the radiation in the CN (0, 0) and C_2 (1, 0) bands. The continua measured at 4310 Å, 4860 Å and 5890 Å respectively were utilized to determine the contribution of the continua through the filters used for measuring the emission intensities. Our prismatic spectra (**1**) of November 3 and 4 show the absence of Na-emission at $r = 0{\cdot}6$. Hence we may infer that the radiation transmitted by the 5890 Å filter at $r = 1{\cdot}013$ a.u., originated entirely from the cometary continuum

Table I

Interference filter characteristics

Type of filter	Schott & Genossen	Baird atomic	Baird atomic	Baird atomic	Baird atomic
Intended for	CN (0, 0) at 3888 Å	Continuum at 4300 Å	C_2 (1, 0) at 4737 Å	Continuum at 4860 Å	Continuum at 5875 Å
Peak transmission wavelength	3859 Å	4310 Å	4720 Å	4860 Å	5875 Å
Peak transmission to	33·5%	65%	63%	46%	52%
Full width at $T = 0{\cdot}8$ to	42 Å	57 Å	27 Å	13 Å	39 Å
Full width at $T = 0{\cdot}5$ to	94 Å	75 Å	46 Å	31 Å	66 Å
Full width at $T = 0{\cdot}3$ to	132 Å	88 Å	62 Å	50 Å	84 Å
Full width at $T = 0{\cdot}2$ to	163 Å	97 Å	71 Å	65 Å	97 Å
Full width at $T = 0{\cdot}02$ to	273 Å	133 Å	124 Å	132 Å	163 Å

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* Received in original form 1967 February 22.

and was free of any interference from Na-emission. In the case of radiation isolated by the 4310 Å filter there is the possibility of weak contamination by the CH band at 4300 Å. Our slit spectrum of October 30 shows up the presence of the (0, 0) band of the $A^2\Delta$–$x^2\pi$ system. A study of the intensity tracing of this plate indicates that if our flux measurements through the 4310 Å filter were carried out on October 30, for a cometary heliocentric distance of $r=0{\cdot}46$, the contribution of the CH emission would not have exceeded 10 per cent. In the absence of spectral information around $r=1{\cdot}01$ a.u. we have assumed that the CH contribution to our measured flux at 4310 Å is negligibly small and hence can be ignored.

The comparison star used for determining the energy values was θ Crt for which Oke (2) has measured the energy distribution. The measured magnitude differences between the comet and θ Crt, after correction for extinction, enable us to calculate the flux values at the five chosen wavelength locations. This is possible by using Oke's energy distribution of θ Crt and the V magnitudes of θ Crt (4·9, Johnson & Morgan (3)) and of the Sun (−26·78, Allen (4)). We assumed, following Code (5), that the value of the monochromatic flux from a star of visual magnitude V = 0·00, and B–V = 0·00 is $3{\cdot}8\times10^{-9}$ erg cm^{-2} s^{-1} Å^{-1} at 5560 Å.

3. *Results.* The fluxes measured at 3888 Å and 4737 Å have a contribution from the background continuum which needs to be eliminated before we proceed to the computation of the molecular densities. These are easily done directly, using the technique of photoelectric spectrum scans. When interference filters are used, the continuum contribution can be evaluated only indirectly.

The magnitude differences between θ Crt and the comet at 4290 Å, 4861 Å and 5890 Å provide us with the means of studying the energy distribution in the cometary continuum. These are plotted in Fig. 1, together with the energy distribution curves of θ Crt, HD 27836 and HD 28291, all referred to the value of 4300 Å. The latter two stars are members of the Hyades cluster, having spectral types G1 V and G8 V respectively, for which Oke & Conti (6) have determined the energy distribution in their spectra. The cometary magnitude differences (4300–4861 Å) and (4300–5890 Å) simulate the energy differences seen in a typical G8 V star. Hence we may assume that the cometary continuum has an energy distribution similar to that of a G8 V star.

We have measured the transmitted radiation of α Hya (K4 III; B–V = 1·41) by the five filters. When we use the comet continuum measures at 4300 Å and 5890 Å and transform the magnitude difference between them to a B–V colour, we get a value of +0·76, or a colour excess of +0·14, caused by the scattering in the cometary halo. The B–V colour thus derived is in accord with the value measured for a G8 V star.

We next evaluate the percentage contribution of emission and continuum to radiation transmitted by the filters that isolate the emission bands. We do this by using the magnitude differences between θ Crt and the comet, the energy distribution of θ Crt and van Bueren No. 69 in the Hyades and the B, V magnitudes of these two stars, together with the combined response curves of the filter–1P21 combination. We utilize in this evaluation the fact that the cometary continuum has an energy distribution similar to that of a G8 V star. We thus find that 81 per cent of the radiation transmitted by the 4737 Å filter is the emission contribution, with 19 per cent due to the continuum. In the case of the 3883 Å filter, 95 per cent is the emission contribution.

We now need to know the fraction of the total radiation of the emission band that is detected by the filter–photomultiplier combination. We used for this purpose a slit spectrum of the comet obtained at Kodaikanal on October 30 . 986 (1) and assumed that the emission profile of the Swan $\Delta v = +1$ sequence is independent of r, as shown by McKellar & Climenhaga (7). From the intensity contour of the $\Delta v = 1$ sequence and the response curve of the filter–detector combination, we evaluate the fraction of the C_2 emission in the $\Delta v = 1$ sequence measured on November 17 . 984. We find that the 4737 Å filter transmitted 22 per cent of the C_2 (1, 0) band and the 3888 filter transmitted 35 per cent of the CN (0, 0) band. Hence, the flux values at 3888 Å and 4737 Å are readily determined. The corresponding luminosities are calculated by multiplying the flux values by $4\pi\Delta^2$ (Δ here is the comet–Earth distance). These yield the total radiant energy originating in a cylinder extending through the comet in the line of sight and of diameter 121 300 km. We give in Table II the flux values and luminosities thus obtained.

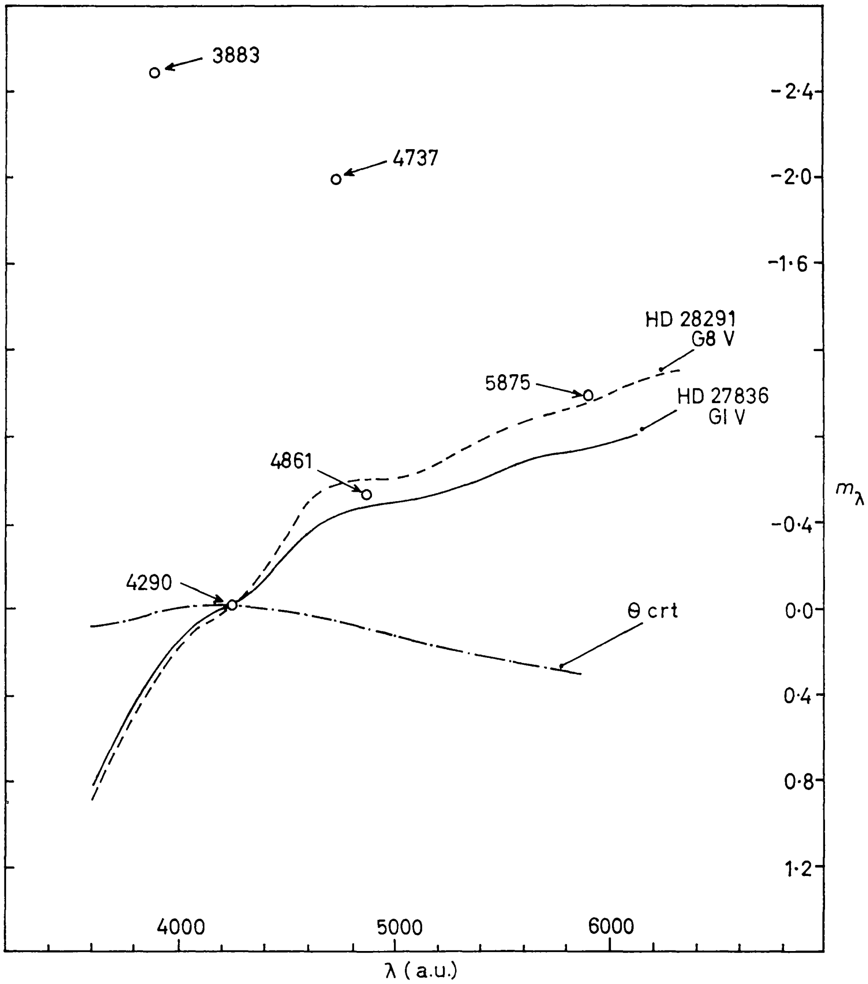

FIG. 1. *Energy distribution of comet Ikeya-Seki* (1965*f*). *The open circles represent the cometary magnitudes through the different interference filters. The energy distribution curves of HD* 28291, *HD* 27836 *and θ Crt are also shown. The energy units are monochromatic magnitudes relative to* 4300 Å.

The computation of the number of molecules in such a cylinder, through the comet, follows the procedure outlined by Wurm (**8**). Since resonance fluorescence is the origin of the cometary radiation, we have,

$$\frac{j}{h\nu}=\frac{\pi e^2 f}{h\nu m_e}\,P\rho(\nu')D(\mathrm{C}_2)$$

where j is the emission coefficient for the C_2 (1, 0) or CN (0, 0) band and $D(C_2)$, the density of the molecules per unit volume, $\rho(\nu')$ is the solar radiation density at the particular frequency and P is the vibrational transition probability. We use the molecular constants given in Table III for the emission bands: $\rho(\nu')=5{\cdot}265 \times 10^{-20}\,r^{-2}$ erg s cm^{-3} for the C_2 (1, 0) band and $1{\cdot}746\times 10^{-20}\,r^{-2}$ erg s cm^{-3} for the CN (0, 0) band, where r is the heliocentric distance. By integrating the relation given above over the entire line of sight, we obtain the number of molecules $N(X)$ contributing to the emission band. These are listed in Table II.

TABLE II

Fluxes, luminosities and number of molecules for comet Ikeya-Seki

λ	F_λ (erg cm^2 s^{-1})	L_λ (erg s^{-1})	$N(X)$
3888	$16{\cdot}445\times10^{-12}$	$51{\cdot}026\times10^{15}$	$1{\cdot}554\times10^{29}$
4737	$17{\cdot}47\times10^{-12}$	$54{\cdot}188\times10^{15}$	$1{\cdot}840\times10^{30}$

TABLE III

Molecular constants for emission bands in comet Ikeya-Seki

λ	Electronic transition	(ν', ν'')	f	P
3888 CN	$B^2\Sigma^+$–$X^2\Sigma^+$	(0, 0)	$2{\cdot}6\times10^{-2}$	0·92
4737 C_2	$A^3\Pi g$–$X^3\Pi u$	(1, 0)	$3{\cdot}0\times10^{-3}$	0·24

Arpigny (**9**) has shown that Wurm's approximate method of abundance determination is valid for CN but is less satisfactory in the case of the C_2 Swan system. The theoretical treatment of fluorescence of C_2 is complicated because of the large number of transitions and levels that needs to be considered. The various vibrational transitions leading up to the same upper level v' call for a knowledge of the relative populations of the lower levels. Lack of information on several aspects of the theoretical formulation make the evaluation of C_2 fluorescence subject to errors comparable to those that would be present in the case of the direct evaluation by Wurm's procedure. We feel that until this problem can be satisfactorily solved it would be more proper to utilize the intensities of the $\Delta v=0$ sequence for C_2 abundance determinations than the $\Delta v=+1$ sequence utilized by us.

The ratio $N(C_2)/N(CN)$ is 11·84. Kovar & Kovar (**10**) obtain a value of 9·0 for Comet Ikeya (1964f). The observational uncertainties would account for a difference of a smaller magnitude. The theoretical uncertainties are, however, of a larger magnitude. Until such ratios are available for several 'old' and 'new' comets, one can hardly speculate on the causes of the differences. These differences would occur mostly by virtue of the conditions about the comet for the dissociation of the parent molecules from which CN and C_2 originate. A wide variety of physical conditions could control the release of CN and C_2 without accounting for dissociation effects on CN and C_2 themselves. Conditions in the interplanetary medium, in particular the form of corpuscular radiation and associated magnetic fields, may be expected to be strong external agencies that can control the release of CN and C_2. Does the abundance ' ratio ' show a significant change with heliocentric distance? These and related questions await an answer that will be forthcoming only after extended, systematic and accurate observations become available for interpretation by a theoretical formulation that takes rigorously into account all the details of the physics of the emission process.

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