PHOTOELECTRIC PHOTOMETRY OF COMET KOHOUTEK (1973f)

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1. Introduction

Comet Kohoutek (1973f) has been observed with the 50 cm (f/15) reflecting telescope of the European Southern Observatory, La Silla, Chile, on fourteen nights between January 16 and 30, when the heliocentric and geocentric distances of the comet were r=0.66 - 1.00 A.U. and Δ = 0.81 - 0.96 A.U., respectively. The 40" and 80" diaphragms were used for the photometry of the cometary head (EMI 6256 A photomultiplier) in the UBV system and with six inter-ference filters: CN 3884 $\overset{\circ}{A}$, CO^+ 4267 $\overset{\circ}{A}$, C_2 4737 $\overset{\circ}{A}$, C_2 5172 $\overset{\circ}{A}$, cont. 5300 $\overset{\circ}{A}$ and Na 5893 $\overset{\circ}{A}$.

The atmospheric conditions were good but the accuracy of our observations was lower than usual due to large extinction (air mass 2.5 to 4.3) and twilight. The mean error of one measurement of log F in all but Na 5893 $\overset{\circ}{A}$ filters can be estimated at +0.02, whereas the accuracy through the Na filter was substantially lower.

2. UBV Observations

Observations in UBV system are given in Table 1 (N - number of measurements in the respective night). They are also presented in Fig.1, but reduced to the distance of Δ = 1 A.U. and corrected to standard circular area of D(40") = 2.90 x 10^4 km and D(80") = 5.80 x 10^4 km in diameter, respectively, centered on the cometary nucleus. The above areas correspond to those seen in the diaphragms of 40" and 80" and from the distance 1 A.U. For that correction the mean intensity gradients in the coma were applied as deduced from the measurements in both diaphragms.
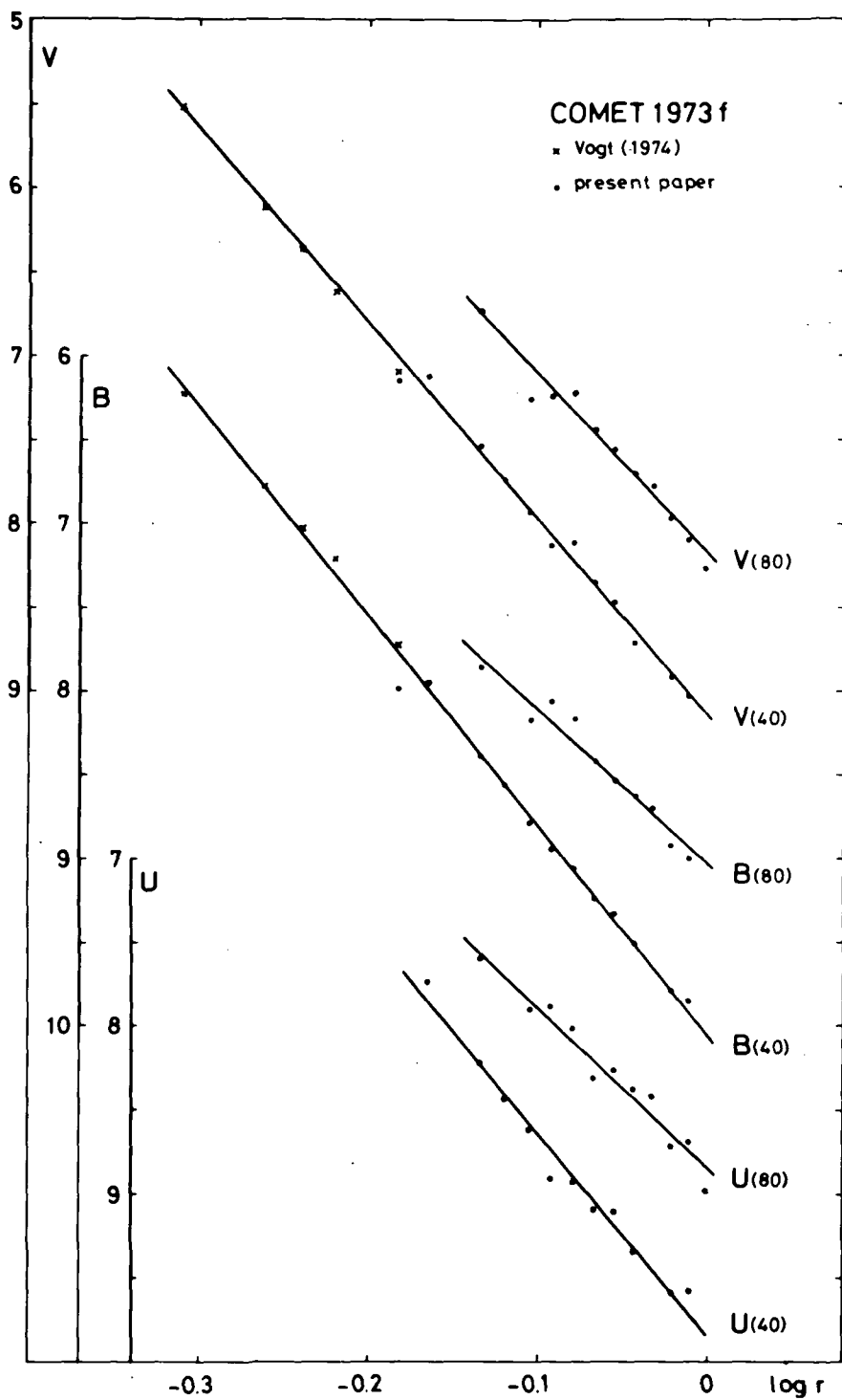
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Fig. 1   The reduced brightness of Comet 1973f in UBV system

[Δ = 1 A.U.; standard circular area of 2.90 x 10^4 km (40)

and 5.80 x 10^4 km (80) in diameter] as a function of log r.

Table 1

UBV Observations

Date (U.T.) 1974	Δ [A.U.]	r [A.U.]	Diaphragm 40"				Diaphragm 80"			
			V_{obs}	B_{obs}	U_{obs}	N	V_{obs}	B_{obs}	U_{obs}	N
Jan.16.032	0.807	0.657	6.98:	7.83:	-	1	-	-	-	
17.027	.808	.684	6.96	7.80	7.58	2	-	-	-	
19.029	.817	.735	7.38	8.24	8.06	1	6.56	7.66	7.41	2
20.023	.824	.760	7.58	8.42	8.28	1	-	-	-	
21.030	.832	.786	7.79	8.65	8.46	2	7.10	7.99	7.73	2
22.031	.842	.810	7.99	8.82	8.77	2	6.99	7.90	7.73	2
23.031	.853	.835	7.99	8.94	8.79	1	6.99	8.01	7.86	1
24.033	.865	.859	8.25	9.14	8.98	2	7.32	8.28	8.18	2
25.035	.878	.883	8.37	9.24	9.00	2	7.45	8.40	8.14	3
26.031	.893	.906	8.62	9.42	9.24	1	7.61	8.51	8.27	1
27.027	.909	.930	-	-	-		7.69	8.60	8.33	1
28.034	.926	.953	8.85	9.73	9.52	1	7.90	8.84	8.63	1
29.033	.943	.976	8.98	9.80	9.52	1	8.05	8.94	8.63	1
Jan.30.032	0.961	0.998	-	-	-		8.23	-	8.94	1

In order to increase the time interval of observation we used the photoelectric measurements which were made by Vogt (1974) at La Silla under similar conditions. The B and V magnitudes in the diaphragms of 29" and 45", respectively, were also corrected to standard circular area of 40" (Δ = 1 A. U.).

The absolute magnitudes, m_o, and the photometric exponents, n, derived from the well-known formula

$$m = m_o + 2.5 \, n \log r \qquad (1)$$

are given in Table 2 together with the respective interval of log r. The absolute colour indices in the 40" and 80" diaphragms differ from each other only slightly and within the observing errors: $(B-V)_{o, (40")}$ = 0.90, $(U-B)_{o, (40")}$ = -0.20; $(B-V)_{o, (80")}$ = 0.86, $(U-B)_{o, (80")}$ = -0.19.

The comet's brightness has been diminishing rather quickly after the perihelion passage, in fact more rapidly in the inner part of the head (n between 4.6 and 5.0) than in the outer part (n between 3.6 and 4.2). When extrapolating the best determined straight lines of V(40") and B(40") back to the perihelion, $V_{max}(40") \sim$ -0.7 and $B_{max}(40")$ $\sim$ -0.5 can be obtained.

Assuming a density law $d(\rho) \sim \rho^{-2}$ (ρ is the distance from the nucleus) for the emitting molecules and dust particles in the spherically symmetrical head, an intensity law $I(\rho) \sim \rho^{-1}$ can be derived, which leads to the magnitude difference $\Delta m = m(40") - m(80") = 0.75$ for the diaphragms used. Our observations show $\Delta m > 0.75$ and continuously growing with time. The mean values are: $\Delta m_V = 0.904$, $\Delta m_B = 0.817$, $\Delta m_U = 0.853$. The difference between the observed and theoretical Δm-values reflects the deviation from the ρ^{-1} law and can be expressed by $\rho^{-\mathcal{H}}$; obviously

Table 2

UBV Photometric Parameters

System	V(40")	V(80")	B(40")	B(80")	U(40")	U(80")
n	4.64 ±.08	4.22 .41	4.99 .07	3.64 .40	4.82 .32	3.79 ±.34
m_o	9.14 ±.03	8.16 .07	10.04 .03	9.02 .08	9.84 .08	8.83 ±.06
$\Delta \log r$	-0.31 to 0.0	-0.13 to 0.0	-0.31 to 0.0	-0.13 to 0.0	-0.16 to 0.0	-013 to 0.0

Table 3

Parameters of Interference Filters

Filter	CN(0-0) 3884 Å (1)	C_2(1-0) 4737 Å (1)	CO^+(2-0) 4267 Å (2)	C_2(0-0) 5172 Å (1)	Continuum 5300 Å (1)	Na 5893 Å (1)
Peak transm. wavelength [Å]	3892	4747	4265	5180	5306	5917
Peak transm. [%]	42	58	67	78	73	65
Full width at half maximum [Å]	74	52	23	54	56	59

(1) Thinfilm Products, Inc.   (2) Spectrum Systems, Inc.

$$\mathcal{H} = 2 - \frac{2 \, \Delta m}{5 \log(D_2/D_1)} \quad , \tag{2}$$

where D_2, D_1 are the respective diameters of the diaphragms. Physically it reflects (a) the production of visible radicals from parent molecules in this part of the inner coma, (b) the deviation from the regular ejection of particles from the nucleus and/or (c) the dissociation of the molecules by sunlight. This last effect can probably be neglected due to the large trajectory of molecules before dissociation compared with the size of the diaphragms used. According to (2) we have: $\mathcal{H}_V = 0.80$, $\mathcal{H}_B = 0.91$, $\mathcal{H}_U = 0.87$.

3. Observations through Interference Filters

The luminosities of the cometary head in the 40" and 80" diaphragms and through the interference filters (see Table 3) were measured using the comparison star η Hya, for which Hayes (1970) has published the energy distribution. We adopted the V magnitude of η Hya to be 4.289 (Blanco et al., 1968 - mean value), the V magnitude of the Sun -26.74 (Allen, 1973), and the flux from a star of zero visual magnitude outside the atmosphere to be 3.73×10^{-6} erg. cm^{-2} . s^{-1} in the V region (Allen, 1973). The observed fluxes, F_{obs}, are given in Table 4 for CN 3884 Å, C_2 4737 Å and 5172 Å, and continuum at 5300 Å.

Analogically to UBV data, the differences $\Delta m = m(40") - m(80")$ for molecules CN, C_2 as well as for dust in the continuum were found to be larger than expected according to the simple intensity law, and increasing with time. We found the following mean values: $\mathcal{H}_{CN} = 0.75$, $\mathcal{H}_{C_2} = 0.77$, and $\mathcal{H}_{5300} = 0.90$. The $\mathcal{H}_{5300} < 1$ can be explained by the diminishing ejection of dust particles from the nucleus. Probably both effects (a) and (b) are responsible for $\mathcal{H}_{CN, C_2} > 1$.

Table 4
Observed Fluxes of Emission Bands and Continuum
$[\text{erg.cm}^2 \cdot \text{s}^{-1}]$

Filter	$\log F_{obs}$							
	CN 3884 Å		C_2 4737 Å		C_2 5172 Å		Cont. 5300 Å	
Diaphragm	40"	80"	40"	80"	40"	80"	40"	80"
Jan.16.032	-9.234		-9.802		-9.290		-10.002	
17.027	-9.209 -9.154 -9.199		-9.792 -9.668		-9.305 -9.211 -9.250		-9.967 -9.913	
19.029	-9.413	-9.048 -9.067	-9.901	-9.554 -9.600	-9.444	-9.096 -9.122	-10.115	-9.822 -9.846
21.030	-9.521 -9.519	-9.233 -9.144	-10.054 -10.042	-9.814 -9.691	-9.615 -9.602	-9.337 -9.324	-10.287 -10.277	-10.030 -9.922
22.031	-9.592 -9.613	-9.208 -9.230	-10.159 -10.135	-9.779 -9.801	-9.679 -9.696	-9.305 -9.289	-10.350 -10.357	-10.034 -9.997
23.031	-9.600	-9.190	-10.095	-9.732	-9.691	-9.307	-10.350	-10.012
24.033	-9.685 -9.705	-9.313 -9.319	-10.247 -10.243	-9.873 -9.877	-9.788 -9.802	-9.431 -9.424	-10.478 -10.421	-10.106 -10.141
25.035	-9.721 -9.732	-9.331 -9.347 -9.358	-10.298 -10.290	-9.910 -9.929 -9.929	-9.850 -9.841	-9.465 -9.479 -9.460	-10.498 -10.493	-10.134 -10.167 -10.162
26.031		-9.414		-9.994		-9.543		
27.027		-9.457		-10.006		-9.575		-10.231
28.034	-9.941	-9.532	-10.499	-10.122	-10.047	-9.668	-10.686	-10.318
29.033	-9.982	-9.585	-10.553	-10.183	-10.115	-9.727	-10.749	-10.380
Jan.30.032		-9.667		-10.264		-9.815		-10.434
F_{obs} / F_{cont}	14.8	16.4	2.33	2.44	4.45	4.67	1	1
Δm	0.944		0.927		0.925		0.822	

The energy distribution of the cometary continuum has been assumed to be of solar type. Then, the contribution of such a cometary continuum in the five interference filters could be calculated from the continuum measured in 5300 Å. The ratio of the observed total flux and the calculated continuum flux in the respective filter combination is also given in Table 4. We find that about 95 per cent of the radiation transmitted by the CN 3884 Å filter is the emission contribution and that the fraction of emissions by the C_2 4737 Å and 5172 Å filters are 58 and 78 per cent, respectively. On the other hand, the observed total flux in the CO^+ 4267 Å filter is only about 4 per cent larger than that of the continuum. Our slit spectra of January 6 to 14 show either a missing or only very faint CO^+ emission, so that the radiation transmitted by this filter should originate entirely from the cometary continuum. This fact supports strongly our assumption about the energy distribution of the cometary continuum.

Our measurements in the Na 5893 Å filter require special care. The sodium doublet was very strong on the slit spectra between January 5 and 8 (r = 0.33 to o.42 A.U.) and its brightness has diminished till January 12 (r = 0.54 A.U.) (Kohoutek, Rahe, 1974). The emission contribution in this filter was still about 75 per cent of the total observed flux on January 16 (r = 0.66 A. U.), but only about 18 per cent on January 17 (r = o.68 A.U.). After January 19 the emissions contributed only with 14 per cent assuming that the cometary continuum was of the solar type. If the natrium doublet was totally absent in $r \lesssim$ o.7 A.U., the measurements in the Na 5893 Å filter would represent a colour excess of $+0.^{m}16$ in the continuum, possibly caused by the scattering in the cometary head. Unfortunately, due to the very low quantum efficiency of the photomultiplier in that wavelength, the measuring errors were large

and the above result seems to be very uncertain. For that reason our assumption that the cometary continuum is of the pure reflection type has not been changed.

The observations through the interference filters were treated in the same way as in case of UBV data. The observed fluxes were reduced to Δ = 1 A.U. and corrected to standard linear area in the cometary head, D(40") and D(80"). First of all, the important ratio of the absolute brightness of the dust and of the gas coma, k = $F_{o,d} / F_{o,g}$, could be estimated. Assuming, that the effective band width in the U, B, V is 680 $\overset{o}{A}$, 980 $\overset{o}{A}$ and 890 $\overset{o}{A}$, respectively (Allen, 1973), we calculated the contribution of the cometary continuum to the total brightness in the respective colours. Putting $F_{o,cont} = F_{o,d}$ and $F_o(i) = F_{o,g} + F_{o,d}$, where $F_o(i)$ is the corrected flux energy in the i = V, B, U colour transformed from the absolute magnitude (see Table 2), we received the following results:

$$k_V(40") = 0.69 \qquad k_V(80") = 0.66$$

$$k_B(40") = 1.06 \qquad k_B(80") = 0.84$$

$$k_U(40") = 0.61 \qquad k_U(80") = 0.56 \ .$$

The dust coma is more concentrated toward the nucleus than the cometary gas. Besides, the increase of k with time in the interval between r 0.6 and 1.0 A.U. was found in all colours.

In order to know the fluxes of the emission bands, the fraction of their total radiation, that was passing through the respective filter, has to be determined. Besides, the contribution of other emissions in the filter was estimated, giving 7.3 per cent in the CN 3884 $\overset{o}{A}$

filter, 26 per cent in the C_2 4737 Å filter and 11 per cent in the C_2 5172 Å filter from the total emission flux. The corrected fluxes of the emission bands CN(0-0) $\Delta v = 0$, C_2(1-0) $\Delta v = +1$, and C_2(0-0) $\Delta v = 0$, respectively, are plotted versus $\log r$ on Figs. 2, 3 and 4 and compared with the total flux measured in the continuum 5300 Å (Fig. 5). The equivalent width of the 5300 Å filter was 46 Å .

In the first approximation there is a linear dependence of $\log F$ on $\log r$ in both 40'' and 80'' circular areas for the emission bands as well as for the continuum. The slopes, n, and the absolute brightnesses ($\Delta = r = 1$ A.U.), $\log F_o$, in the relation

$$\log F = \log F_o - n \log r \qquad (1a)$$

are given in Table 5. The interval of $\log r$ was -0.18 to -0.01 in the 40'' area and -0.13 to 0.0 in the 80'' area.

For continuum at 5300 Å the following parameters were found: n(40'') = 4.51, $\log F_o$(40'') = -10.806; n(80'') = 3.81, $\log F_o$(80'') = -10.424.

The photometric exponents, n , lie for the emission bands as well as for the continuum in the same range as in case of the UBV data (see Table 2). Also n(40'') > n(80'') can be stated with the exception of the C_2(1-0) band probably because of larger observing errors.

4. Desorption Heats and Number of CN and C_2 Molecules

Using Levin's theory (1943) we may express the logarithm intensity of the gas constituent of the coma by
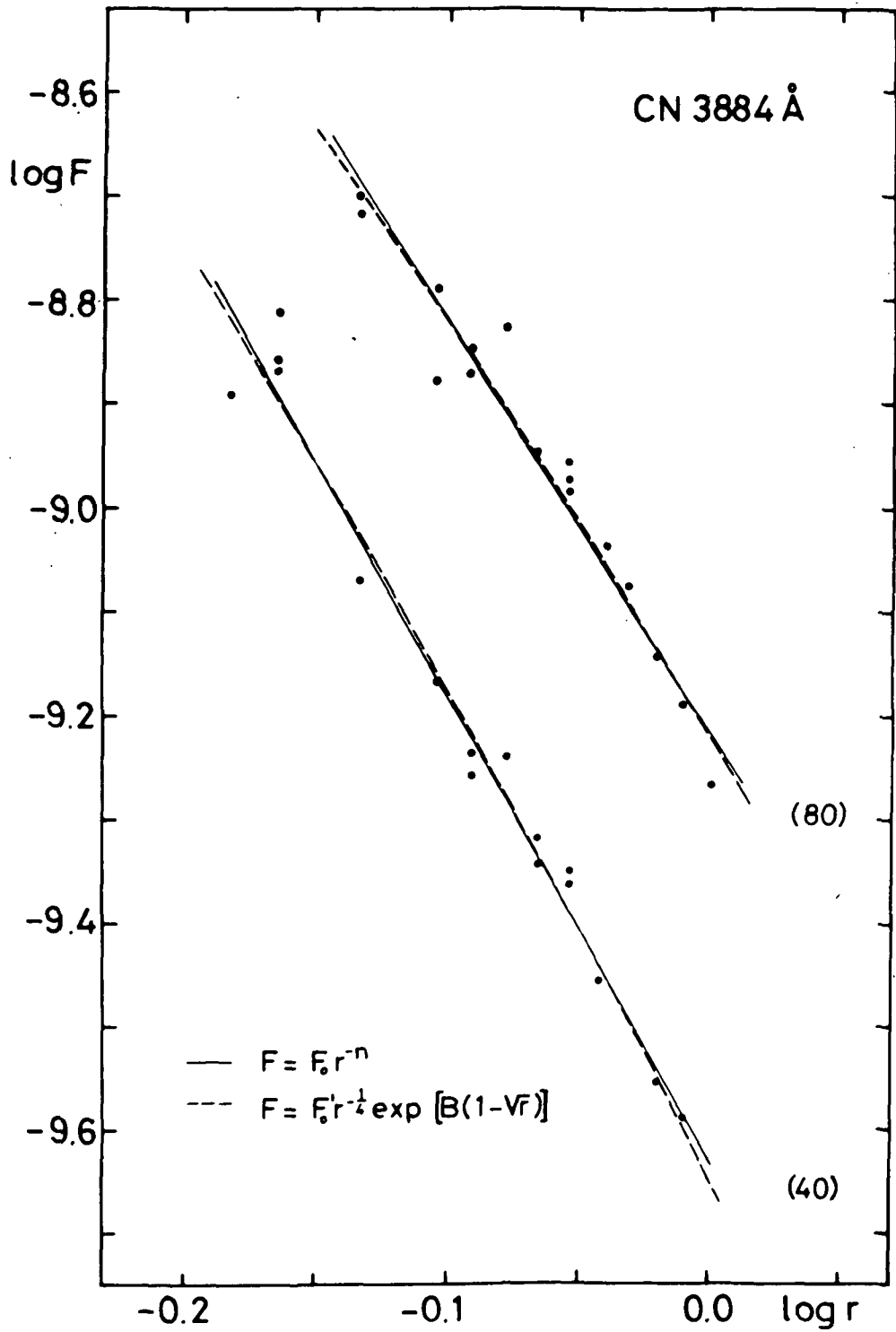
Fig. 2   The reduced flux of the CN(0-0) 3884 Å emission band as a
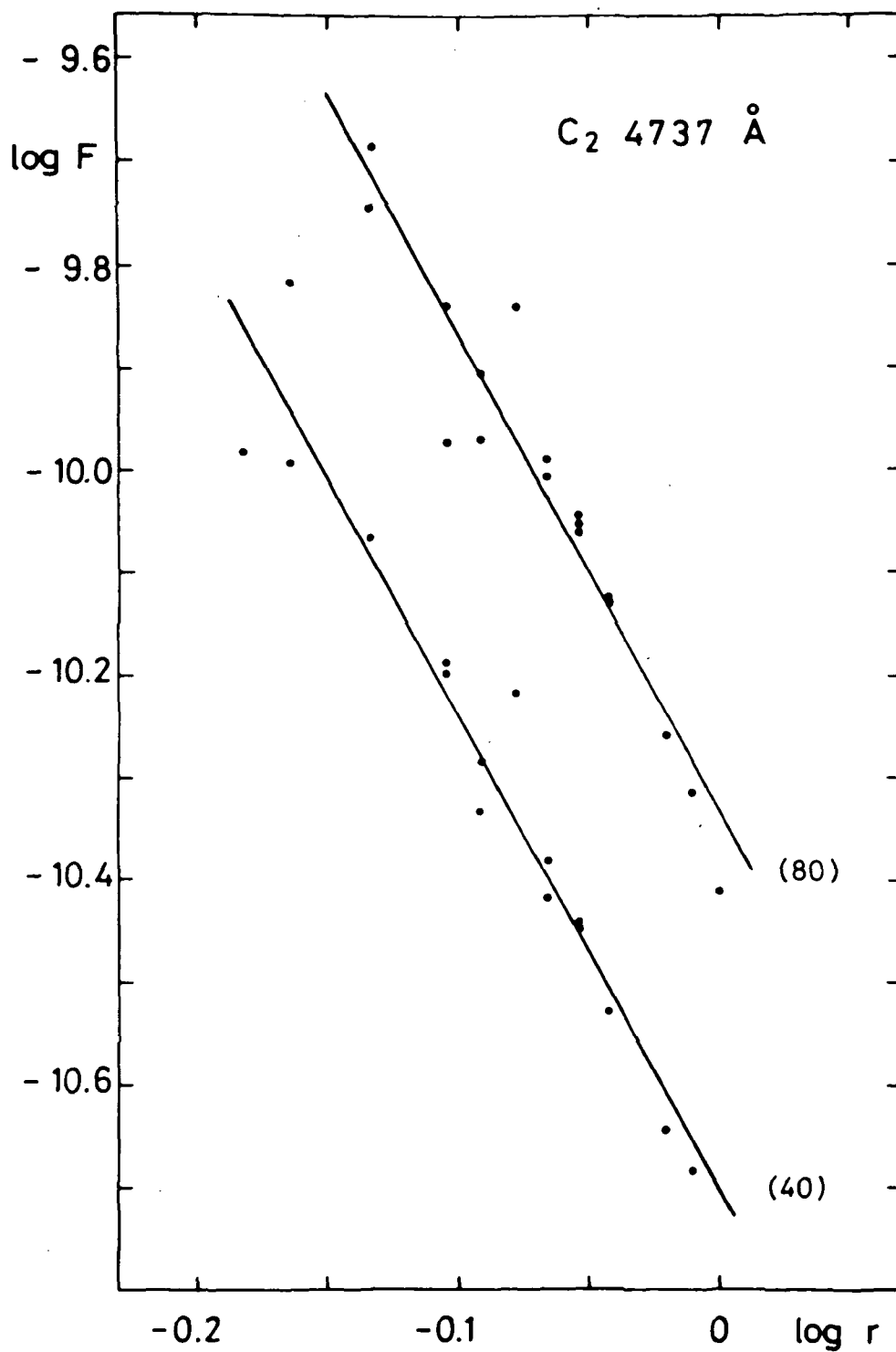function of heliocentric distance. See the text.

Fig. 3   The reduced flux of the $C_2(1-0)$ 4737 Å emission band as a function of heliocentric distance. See the text.
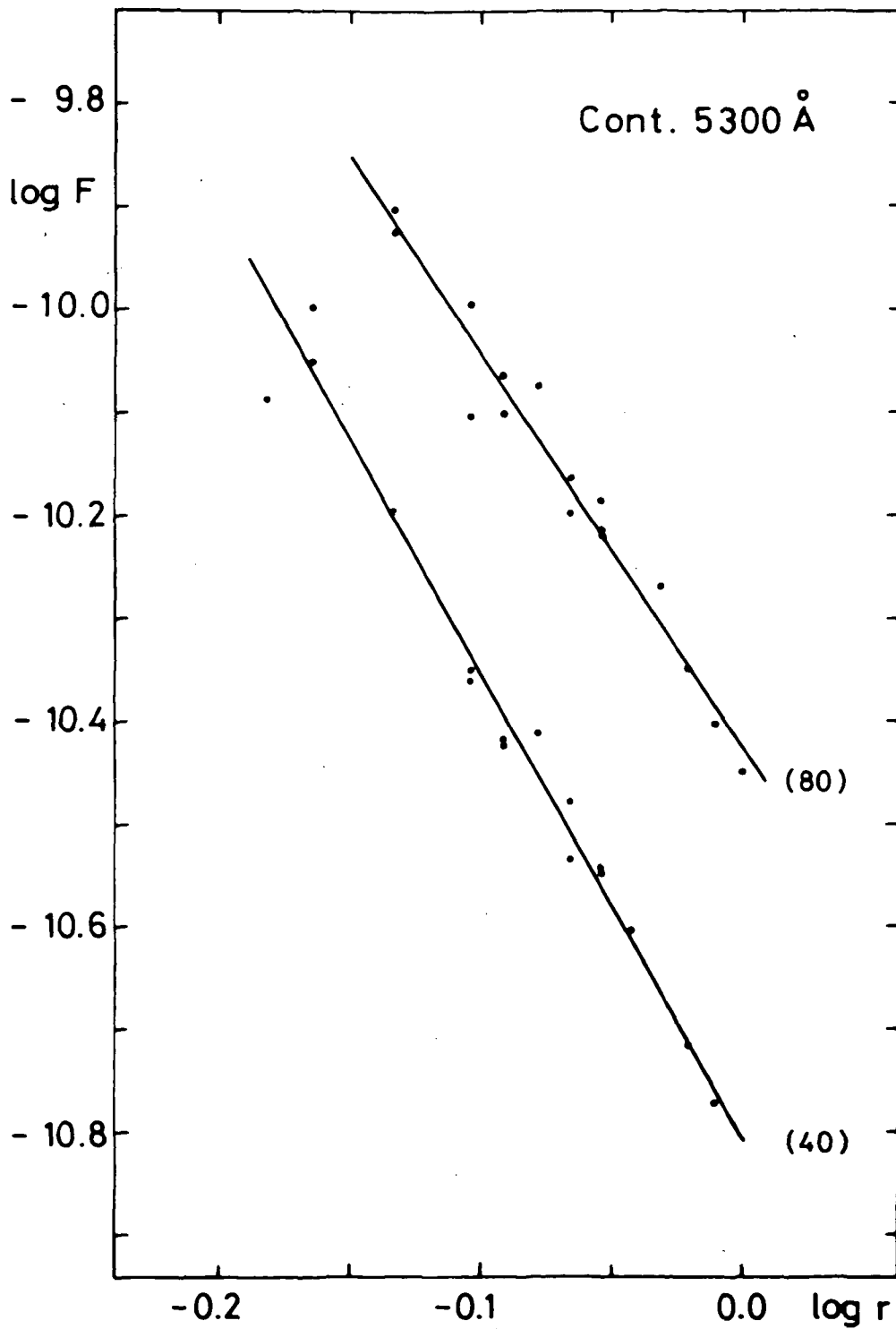
Fig. 4   The reduced flux of the $C_2(0-0)$ 5172 Å emission band as a function of heliocentric distance. See the text.

Fig. 5   The reduced flux in the continuum at 5300 Å as a function of
heliocentric distance. The effective band width is 46 Å.

Table 5

Photometric Parameters of CN and C_2 Emission Bands

Band	CN(0-0), $\Delta v=0$		$C_2(1-0), \Delta v=+1$		$C_2(0-0), \Delta v=0$	
Diaphragm	40"	80"	40"	80"	40"	80"
n	4.50	3.98	4.62	4.64	5.01	4.55
$\log F_o$ [$erg.cm^{-2}.s^{-1}$]	-9.632	-9.219	-10.701	-10.330	-10.017	-9.614
B	9.51	7.88	9.79	9.53	10.67	9.33
$\log F'_o$ [$erg.cm^{-2}.s^{-1}$]	-9.650	-9.220	-10.721	-10.341	-10.037	-9.624
L [$cal.mol^{-1}$]	5670	4700	5830	5680	6360	5740
$\log L_o$ [$erg.s^{-1}$]	17.799	18.229	16.728	17.108	17.412	17.825

$$\log F = \log F'_0 - \frac{\alpha}{2} \log r + B(1 - r^\alpha) \log e \qquad (3)$$

where $B = L/RT_0$, L - desorption or evaporation heat, R - gas constant, T_0 - temperature of the nucleus at a distance of 1 A.U. The constant α in the relation $T = T_0 \cdot r^{-\alpha}$ corresponds to 0.5 if the nucleus is in a thermal equilibrium state. The constants B and $\log F'_0$ for the CN and C_2 emission bands are also given in Table 5 (for $\alpha = 0.5$). Both relations, (1a) and (3) differ only very slightly from each other as shown in the example of Fig. 2. The desorption heat L $[cal. mol^{-1}]$ was determined using $T_0 = 300^\circ K$. The mean parent molecule desorption heats of 5200 $cal. mol^{-1}$ and 5900 $cal. mol^{-1}$ for the predecessor of CN and C_2, respectively, differ from each other. They are larger than the value 4500 $cal. mol^{-1}$ which was found for CN and C_2 in Comet Rudnicki (1966e) (Mayer, O'Dell, 1968), or than the value 4800 $cal. mol^{-1}$ for C_2 in Comet Arend-Roland (1957 III) (Liller, 1965). If we use $\alpha < 0.5$ as recommended by some authors and still $T_0 = 300^\circ K$, we would receive B and L even larger: e.g. 6400 $cal. mol^{-1}$ (CN) and 7300 $cal. mol^{-1}$ (C_2) for $\alpha = 0.4$, or 8500 $cal. mol^{-1}$ (CN) and 9600 $cal. mol^{-1}$ (C_2) for $\alpha = 0.3$. For that reason it seems to be more justified to accept $\alpha = 0.5$ for Comet 1973f, assuming again T_0 as given above.

Following the method introduced by Wurm (1943) the number of molecules CN or C_2 in the cometary head can be calculated from the respective luminosities L:

$$N = L \frac{m_e}{\pi e^2 f p \rho(\nu, r)} \qquad (4)$$

where f is the oscillator strength, p is the vibrational transition probability and $\rho(\nu, r)$ is the solar radiation density at the given frequency and for the given heliocentric distance. We used the

molecular constants presented in Table 6 (for f see Wentink et al., 1964; for p see Fraser et al., 1954) and $\rho(\nu, r)$ resulting from the solar spectral irradiance data listed by Robinson (1966). The absolute luminosities appearing in Table 5 were calculated from the corresponding fluxes: $L_O = 4\pi\Delta^2 F'_O = 2.812 \times 10^{27} F'_O$. ($\Delta = 1$ A.U.). Then, the number of molecules CN and C_2 which radiated in the cylinders extending through the comet in the line of sight and of diameters D(40") and D(80") were determined (Table 6).

The ratio $N_O(C_2\ 5165)/N_O(CN) = 1.52$ or 1.46, and $N_O(C_2\ 4737)/N_O(CN) = 0.99$ or 0.88 for the 40" and 80" diaphragms is very low and comparable with the value 0.8 obtained for Comet Burnham (1960 II) by Arpigny (1965). Also Vanýsek (1969) found for Comet Ikeya-Seki (1968 I) a rather low value of $N(C_2)/N(CN) = 3.2$. It is interesting to notice that 1960 II as well as 1973f are very probably "new" comets and that the orbital eccentricity of 1968 I was also very high (0.99915).

There exists a discrepancy between $N(C_2)$ as derived from the $\lambda 4737$ and $\lambda 5165$ bands: $N_O(C_2\ 5165)/N_O(C_2\ 4737) \simeq 1.6$. An even larger difference in $N(C_2)$ was already found for Comet Ikeya (1964f) by Kovar and Kovar (1965).

5. Conclusions

Summarizing our results based on the photoelectric observations of Comet 1973f we may conclude:

After the perihelion passage the comet's luminosity was quickly diminishing partly due to declining ejection of both gas molecules and dust particles from the nucleus. The respective photometric parameters are given in Tables 2 and 5. Measurements in two

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Table 6

Number of CN and C_2 Molecules

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Band	f	D	$\rho(\nu,r)$	$N_o(40")$	$N_o(80")$
CN (0-0) 3884 Å	0.026	0.920	$1.90 \times 10^{-20} r^{-2}$	1.74×10^{30}	4.69×10^{30}
C_2 (1-0) 4737 Å	0.0030	0.237	$5.47 \times 10^{-20} r^{-2}$	1.73×10^{30}	4.14×10^{30}
C_2 (0-0) 5165 Å	0.0030	0.731	$5.58 \times 10^{-20} r^{-2}$	2.65×10^{30}	6.86×10^{30}

diaphragms, 40'' and 80'' in diameter, indicate the deviation from the intensity law ρ^{-1} for a spherically-symmetric coma and agree with the $\rho^{-\mathcal{K}}$-law; $\mathcal{K}$ decreases with increasing heliocentric distance, the mean $\mathcal{K}$ values lie between 0.75 and 0.91. The dust constituent of the coma was medium intense (k between 0.6 and 1.1), and the dust particles were probably of larger size because of the nearly pure reflecting cometary continuum. The desorption heats for CN and C_2 parent molecules were unequal (5200 and 5900 cal.mol^{-1}) and somewhat higher compared with former results. The ratio $N_o(C_2)/N_o(CN)$ was very low (0.9 to 1.5) and slightly depending on the choice of the C_2 emission band. Assuming $T_o = 300^o$ K, the constant $\alpha = 0.5$ has been accepted which corresponds to the equilibrium state of the nucleus.

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