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Intensity Distribution of Cyanogen and Carbon Bands in Comet Everhart (1964h)

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The intensity distributions of CN (0,0), C_3 and C_2 (4737) bands in the head of Comet Everhart 1964*h* are derived from two objective-prisma spectrograms. The maximum lifetimes of radicals are about 100 hours, and of parent molecules about 20 hours.

1. Introduction

The intensity distribution of the main emission bands in cometary heads has been intensively studied in past years. Very new aspects of this topic have recently been given, particularly by ARPIGNY (1965), DEWEY and MILLER (1966), HASER (1966), MALAISE (1966), MILLER (1965) and WURM and BALASZ (1963). The determination of lifetimes of parent molecules and radicals is one determination of lifetimes of parent molecules and radicals is one of extremely significant as well as difficult methodological problems.

The following study of the intensity distribution of the CN-, C_2-, and partly C_3^- emissions in the head of Comet Everhart 1964h is based on two objective-prisma spectrograms on which the monochromatic images of each band are distinctly separated. This method was used by VORONTSOV-VELYAMINOV (1960) in a study of density distribution in Comet 1943 I and seems to be very effective when the speed of the camera permits a short exposure and the focal length reasonable linear dimensions of the monochromatic image. For this purpose the Schmidt-telescope 120/80 cm, focal ratio 1:3, of the Hamburg Observatory, Hamburg-Bergedorf, is obviously very suitable. With this instrument, equipped with the 4° objective prisma, two spectrograms of Comet Everhart (1964h) were obtained during two successive nights on 3 and 4 September 1964.

2. Observation material and the reduction method

The dispersion is about 590 Å mm^{-1} at H_γ and 270 Å mm^{-1} at H_ε. The ratio of the scales at the centre of the focal plane is 1 mm = 83″. Angular dimensions of the focal image of a point source of the C_2- or CN-band emissions are 15″ to 20″, which represents a prolongation or deformation of the monochromatic coma along the spectrum. The broadening of the spectrum (nearly in the proper motion of Comet) perpendicularly to the dispersion is only 5″ which guarantees a reasonable width and density of the stellar spectra and causes only a small deformation in the size of the monochromatic coma in the same direction. The exposure was 8 minutes on 3 September and 10 minutes on 4 September.

Table 1. Slit dimensions of the microphotometer

Plate No.		Date (UT)	Linear dimensions in mm	Enlargement	Equivalent in seconds of arc
1	GS 3249	3.89 Sept. 1964	1.5×4	1 : 20	$6.3'' \times 16.8''$
2	GS 3257	4.89 Sept. 1964	1.0×4	1 : 20	$4.2'' \times 16.8''$

The linear size of the comet's spectrum on both plates is approximately 4.0×5.5 mm, i.e. $336'' \times 462''$. On the boundaries of the "elliptical" coma limited by these values the density of the coma image equals the mean level of the background density. Three main emission bands in the spectral range of 3600 to 4800 Å, i.e. CN (0,0), C_3 and C_2 (0,1) can easily be identified by direct examination. On Plate GS 3249 of 3 September, which is of higher quality, some other emissions are detectable on the spectrum axis. However, the blending of the monochromatic images of the coma in C_3 by CN only is significant, while the overlapping of CN by C_3 is negligible.

The presence of CO^+ emissions is not confirmed with sufficient certainty although the sunward eccentric position of the photometric nucleus may be accepted as an indication of the existence of the tail.

The calibration curve was constructed from photoelectric data in the UBV system for 17 field stars in the range of 3.85^m to 10.79^m in V and 4.31^m to 13.05^m in U-colour. The measurement was carried out especially for calibration purposes by A. Mrkos at Mt Kleť Observatory. The magnitude and the colour of γ Serpentis determines the zero point of the photometric scale. The effective wavelength of the U-filter coincides quite well for the CN-band and can be accepted for the C_3 band, too. However, the C_2 4700 band was calibrated from combined values for the B- and V-colours with regard to the $B-V$ colours of the comparison stars. The calibration curve was constructed separately for each spectral range. The slope od the calibration curve expressed in γ is presented in Table 2.

Table 2. Coefficients of calibration curve

Plate No.		Date (UT)	$\gamma_1(u)$	$\gamma_2(u)$	$\gamma_1(b)$	$\gamma_2(b)$
1	GS 3249	3.89 Sept. 1964	1.6	2.3	1.2	2.0
2	GS 3257	4.89 Sept. 1964	1.2	2.1	0.9	2.1

Note: In column $\gamma_1(u)$ are values for underexposed range in U-colour area, $\gamma_2(u)$ the same for linear part of calibration curve. The two following columns contain values for B-colours.

The photometric tracing was carried out:

1. in the direction of dispersion, i.e. along the „axis" of spectrum;
2. perpendicularly to the „axis" of the spectrum. The maximum density in the monochromatic image was at the zero point of tracing where the sunward direction has a negative sign.

Every emission band was traced in 0.02mm of 0.05mm steps up to $\pm$ $\pm$ 10mm. The slit dimensions (see Table 1) were chosen with regard to the actual spectrum width of the comparison stars and the density range on the plate.

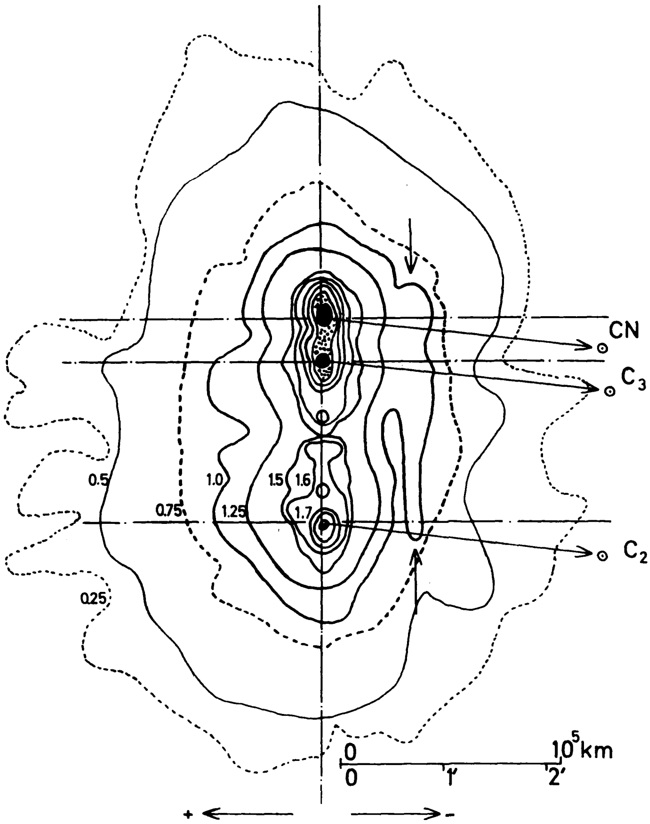

Fig. 1. *The isophote map of the objective spectrograms of Comet Everhart 1964*h. *Plate GC 3249, 3 September, 1964. The isophotes correspond to log I = 1.85; 1.80; 1.75; 1.70; 1.60; 1.50; 1.25; 1.00; 0.75; 0.50; 0.5; 0.25. The arrows point to the secondary maximum which was supposed to be a gaseous condensation moving away from the nucleus. The projected radius vector Comet--Sun is marked by symbols ⊙ separately for each band.*

3. Integrated flux of emission bands

This measurement permits the construction of isophotes and the determination of the „integrated" monochromatic magnitudes of CN-, C_3-, and C_2-bands.

The integrated brightness of the monochromatic image was determined as follows:

If the dimensions of the microphotometer slit is $da'' \times \Delta b''$ and the measured image has an elliptical shape, then for the total illumination it holds that

$$E = \frac{\pi b''}{2\Delta b''} \int_{-a''}^{+a''} s(a'')\, \mathrm{d}\, a'' \qquad (1)$$

where a'' and b'' are the semiaxes of the elliptical image and $s(a'')$ is the illumination at a'', da''.

The monochromatic illumination by stars E_s is approximated by a strip in the spectrum $\Delta b'' \times A''$; for the illumination of the monochromatic image of coma E_c it holds that

$$E_c = \frac{\pi b''}{2(\Delta b'')^2} \cdot A''^{-1} \int_{-a''}^{+a''} s(a'') \, \mathrm{d}\, a'' = E_s \, 2.512^{-(m_s - m_c)} \tag{2}$$

where m_s is the magnitude of comparison star and m_c the magnitude of the measured areas of the cometary image in the mean wavelength.

For practical purposes the following approximation will be accepted

$$\int_{-a''}^{+a''} s(a'') \, \mathrm{d}\, a'' \approx s(a_{k=0}) + 2 \sum_{k=1}^{n} s(a_k) \tag{3}$$

where a_{k+1}, a_k are points on the axis a, hence $a_{k+1} - a_k = \mathrm{d}\, a$, and $s(a_k)$ is the illumination in d a.

Table 3 gives the average integrated magnitudes of the CN-, C_3-, and C_2-bands. Because no distinct differences between the two plates were found, only average values are presented for the magnitudes as well as for the fluxes in Table 4. These values are referred to the area of $80'' \times 84''$. The total estimated magnitudes of the CN-band agree within the limits of probable error with the interpolated magnitudes obtained in *Pg* colour by Vsekhsvyatsky (see KONOPLEVA and GORAZDO-LESNYKH (1966)). However, BEYER's (1966) visual magnitudes are about 2 magnitudes brighter than the value for the C_2-band in this paper. Similar differences can be found between Beyer's visual estimations and the photoelectric measurements in 1.5′ diaphragm by BOUŠKA and MAYER (1966). Recently, MRKOS (1967) reported that visually obtained brightnesses of faint comets are systematically overestimated in comparison with photoelectrically determined magnitudes in a relatively large diaphragms. The average differences are about one or one and a half of magnitude, and they are larger than can be explained by the use of relatively small areas in the photoelectric procedure. Such a systematic overestimation of the brightness of a faint comet by the visual method cannot reasonably be explained. But the differences found in this paper are due to ratio $C_2(\Delta v = +1)/C_2(\Delta v = 0)$.

Table 3. Average integrated stellar magnitudes for cyanogen and carbon bands

	m
CN (3883 Å)	9.1
C_3 (4050 Å)	[10.5]
C_2 (4737 Å)	10.2

Table 4. Average flux and luminosity of Comet Everhart 1964*h*

Molecular band	L_c(erg/sec)	F_c(erg/cm²sec)
CN(0,0) 3883	2.46×10^{18}	0.92×10^{-9}
C_2 (1,0) 4737	0.83×10^{18}	2.6×10^{-10}

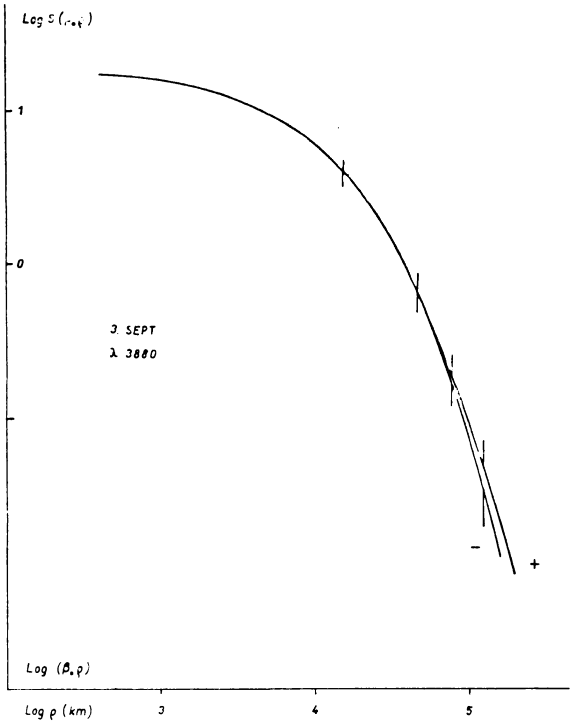

Fig. 2. *The intensity distribution of CN on Plate GS 3249.*

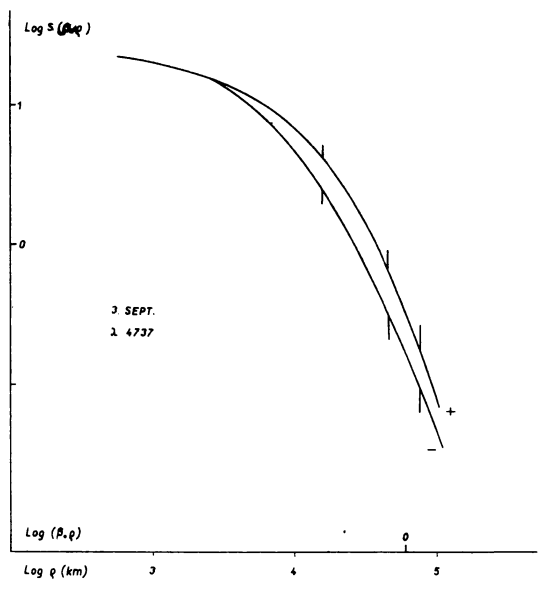

Fig. 3. *The intensity distribution of C_2 on Plate GS 3249.*

4. The lifetime of molecules

The results of the photometric tracing in each monochromatic image are shown in Figs. 2, 3, 4, 5, 6, and 7 where the dependence of the logarithm of the surface bright-

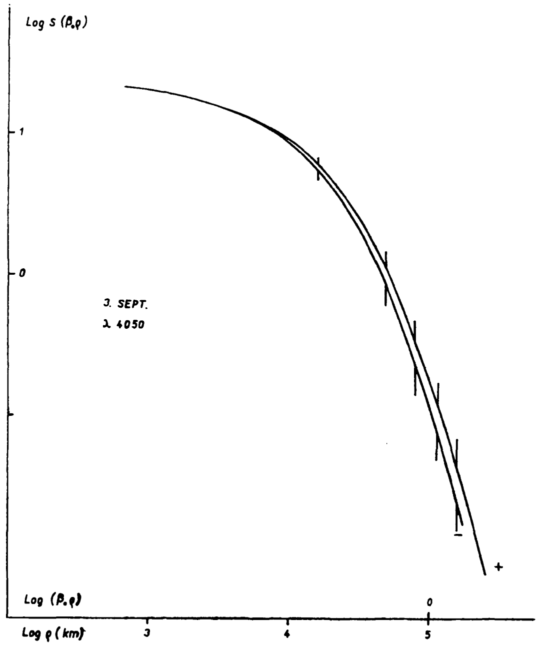

Fig. 4. *The intensity distribution of* C_3 *on Plate GS 3249.*

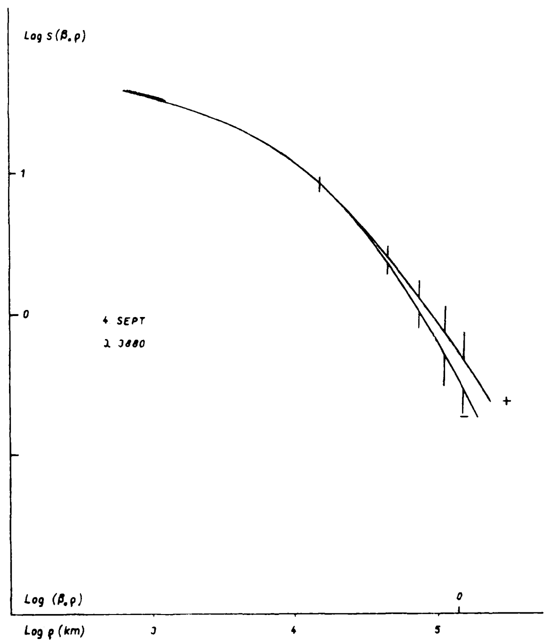

Fig. 5. *The intensity distribution of CN on Plate GS 3257.*

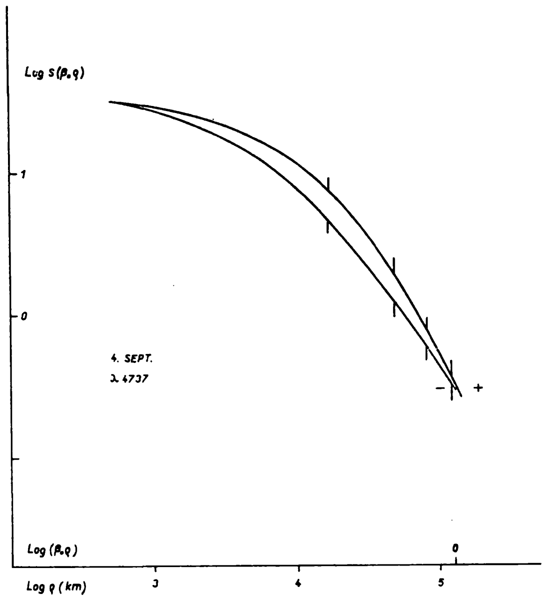

Fig. 6. *The intensity distribution of* C_2 *on Plate GS 3257.*

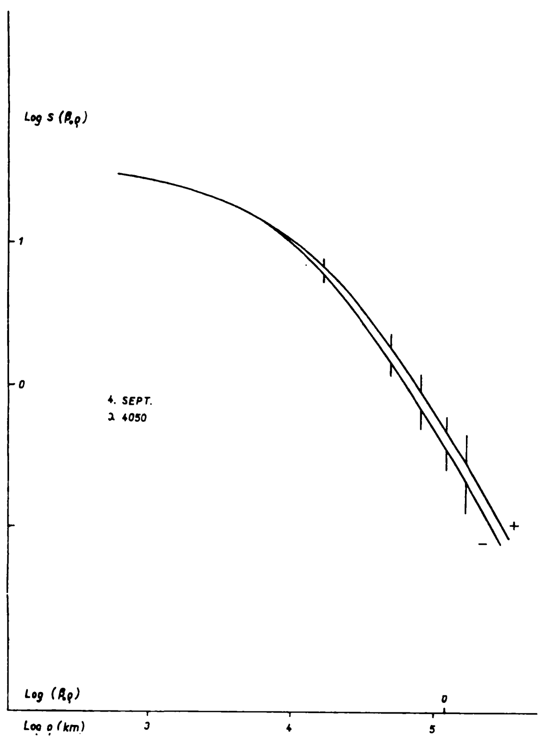

Fig. 7. *The intensity distribution of* C_3 *on Plate GS 3257.*

ness on the logarithm of distance is illustrated. The mean errors are marked by vertical lines on every curve. The minus sign indicates the decrease of surface brightness approximately in the sunward direction bearing from the nucleus, the plus sign holds for the opposite direction.

The projected radius vector Sun-Comet deviated from the direction of the microphotometer tracing by an angle of 6°. The intensity gradients in the sunward direction are systematically larger for the C_2 (4737 Å) as well as for the CN-band. The lifetime parameters were determined by fitting the observed course of log S with log ϱ on the theoretical curves, or log $S = - \varkappa \log \varrho$.

The method "cut and fit" was in this case applied on the theoretical curves or values of $\varkappa$ in the same manner as in previous papers by VANYSEK and TREMKO (1964) and VANYSEK (1965). The surface brightness for a simplified coma model (HASER [1957], [1966], O'DELL and OSTERBROCK [1962]) can be described by the relation

$$S_{(\beta_0 \varrho)} = \frac{1}{\beta_0 \varrho} [B(\beta_0 \varrho) - B(\beta_1 \varrho)] \tag{4}$$

where B is the modified Bessel function of second order. The mean lifetime τ_0 of dissociated and τ_1 of parent molecules and their velocities v_0, v_1, respectively, define β_0 and β_1

$$\beta_i = \frac{1}{v_i \tau_i}$$

The function $S_{(\beta_0 \varrho)}$ depending on the relation β_0/β_1 was tabulated in the above cited papers by Vanýsek and Tremko and by Vanýsek.

The lifetime of dissociated or parent molecules depends proportionally on the adopted velocity v_0 or v_1. In Table 5 two values of β_0 and β_1 are given for $v_1 = v_0 = 1$ km sec^{-1} and $v_1 = v_0 = 0.36$ km sec^{-1}, respectively. The latter value of v_0 and v_1 is based on the observations of a small maximum in the density which was detected on

Table 5. Lifetime of C_2 and CN molecules

	β_1/β_2	v = 1 km/sec τ_0 sec	v = 0.36 km/sec τ_0 sec	v = 1 km/sec τ_1 sec	(v = 0.36 km/sec) τ_1 sec
			Plate GS 3249 (3.89 Sept. 1964)		
CN	5	6.4×10^4	1.74×10^5		
	10	1.0×10^5	2.75×10^5	1.0×10^4	(2.75×10^4)
C_3	5	6.4×10^4	1.74×10^5		
	10	1.0×10^5	2.75×10^5	1.0×10^4	(2.75×10^4)
C_2	10	6.4×10^4	1.74×10^5	6.4×10^3	(1.74×10^4)
			Plate GS 3257 (4.89 Sept. 1964)		
CN	5	1.0×10^5	2.75×10^5	2.0×10^4	(5.5×10^4)
	10	1.7×10^5	5.0×10^5	1.3×10^4	(3.3×10^4)
C_3	10	1.2×10^5	3.5×10^5	1.2×10^4	(3.5×10^4)
C_2	10	1.6×10^5	4.4×10^5	1.6×10^4	(4.4×10^4)

the isophote maps of Plate GS 3249. (In Fig. 1 this maximum is indicated by two arrows). The linear distance of this "cloud" on the first plate is about 3.9×10^4 km from the nucleus. On the second plate, which was taken approximately 24 hours later, a very fine increase in density of CN and C_2 is detectable at linear distances 7.2×10^4 km. If this phenomenon was virtually caused by any real motion of gaseous mass in the coma its average velocity was about 360 metres sec^{-1}.

Table 6. β_0 and β_1 for CN and C_2 molecules

	CN		C_2	
Date (1964)	β_0 (km^{-1})	β_1 (km^{-1})	β_0 (km^{-1})	β_1 km^{-1})
3 Sept.	10^{-5}	10^{-4}	1.5×10^{-5}	1.5×10^{-4}
4 Sept.	6×10^{-6}	6×10^{-5}	6.25×10^{-6}	6.25×10^{-5}

The best fit of the observed distribution of surface brightness to the theoretical one was for the cases when $\beta_0/\beta_1 = 10$. This holds for CN as well as for C_2. The values of the observed intensity distribution of C_3 are strongly deformed by the CN emission, and therefore this C_3-band was omitted from the following discussion of the density distribution.

5. Density distribution of molecules

The integrated brightness of coma was used for the determination of the density in the coma. For the flux $F_c(\Delta v)$ outside the atmosphere from the emission bands in the comet it holds that

$$F_c(\Delta v) = \frac{1}{4\pi \Delta^2} \sum L_{(v'v'')} Q_{(v'v'')} \tag{5}$$

where $\sum L_{(v'v'')}$ is the luminosity over all transitions which are taken into consideration and $Q_{(v'v'')}$ is a factor depending on the receptor parameters. If the flux in the spectral region of the band $L_{(v'v'')}$ is known with sufficient accuracy, then for the luminosity $L_c(\Delta v)$ of a particular band in the comet it holds that

$$L_c(\Delta v) = 4\pi\Delta^2 F_s(\Delta v)\ 2.512^{m_c - m_s} = 4\pi\Delta^2 F_c(\Delta v) \tag{6}$$

where $F_s(\Delta v)$ is the flux from the comparison star in the spectral range of the Δv sequence, m_c is the integrated magnitude of the comet and m_s is the star magnitude.

The mean density in the cometary head with diameter ϱ is

$$D(\varrho) = \frac{3a(\Delta v)}{4\pi\, \varrho^3 h\nu} L(\Delta v, \varrho) \tag{7}$$

where $a(\Delta v)$ depends on Einstein's coefficients and the relative population of the electronic levels.

For the estimation of the C_2 density the $A_{v'v''}$ coefficients for $v', v'' = 1.0; 2.1; 3.2; 4.3$ are used from STOCKHAUSEN and OSTERBROCK's paper (1963). The relative population data for the upper electronic term were corrected in regard to the differences in heliocentric distances.

The number of molecules of C_2 determined from the $\Delta v = 1$ band depends practically on $A_{v'v''}$ and the relative population for 1,0 and 2,1 transitions, since the accuracy of the luminosity value itself is not high. From Stockhausen and Osterbrock's values of $A_{v'v''}$ and $N(v')/N(v'')$ for C_2 $a(\Delta v) = 11.8$. The value of $a(\Delta v)$ for CN (0,0) is higher by the factor 3 (see WURM [1963]) and then $a(\Delta v) \doteq 30$ is probably a good approximation.

The density distribution follows from the relation (see O'DELL and OSTERBROCK [1962]):

$$D(\varrho) = D(\varrho_1) \left(\frac{\varrho_1}{\varrho}\right)^2 \frac{\beta_0}{\beta_0 - \beta_1} \left[\exp(-\beta_0\varrho + \beta_0\varrho_1) - \frac{\beta_0}{\beta_1} \exp(-\beta_1\varrho + \beta_1\varrho_1)\right] \quad (8)$$

where ϱ_1 is the distance at which the distribution function reaches its maximum

$$\varrho_1 = \frac{1}{\beta_0 - \beta_1} \ln \frac{\beta_0}{\beta_1} \quad (9)$$

The results for $D(\varrho_1)$ and $D(\varrho)$ are shown in Table 7.

Table 7. Mean density of CN and C_2

Date (1964)	ϱ_1 km	D(CN) N/cm^3	ϱ_1 km	$D(C_2)$ N/cm^3
3 Sept.	2.56×10^4	17.1	1.71×10^4	8.3
4 Sept.	4.26×10^4	3.8	4.0×10^4	0.6
	ϱ	D(CN) N/cm^3	ϱ	$D(C_2)$ N/cm^3
Average values	1×10^4	83	3.0×10^4	2.4
	2×10^4	27	6.0×10^4	0.4
	4×10^4	6.6	—	—
	6×10^4	2.4	—	—

6. Conclusion

The data following from the intensity distribution of molecular emission bands in Comet Everhart (1964*h*) confirmed several conclusions which followed from the discussions of observations concerning other comets:

The intensity distribution in the coma deviate from the ϱ^{-1} law and can be approximated by $\varrho^{-\varkappa}$ where the exponent $\varkappa = f(\varrho)$. The values of $\varkappa$ increase with distance and reach 1 about 5×10^4 km from the nucleus. In the case of Comet Everhart the course of $\varkappa$ was practically identical for C_2, C_3 as well as for CN band. At the distance $\varrho = 5 \times 10^3$ km $\varkappa = 0.3$ to 0.5 (see Table 8). Similar results were found by MALAISE (1966) for Comets Ikeya and Burnham.

The upper limit for the lifetime of both kinds of dissociated molecules (CN, C_2) is about 3×10^5 sec, i.e. 100 hours. When $v_0 \approx v_1 = 0.3$ km sec^{-1} and if $\beta_0/\beta_1 = 5$ is taken

Table 8. Mean values of $\varkappa$

Date (1964)	log ϱ (km)	2.6—3.0	3.5—4.0	4.0—5.0
3 Sept.	Plate GS 3249	0.3	0.8	1.5
4 Sept.	Plate GS 3257	0.5	0.8	1.0

into consideration the maximum lifetime of the parent molecules is 20 hours. The latter value depends strongly on the determination of the density distribution in inner parts of the coma. The results of the photoelectrical measurements of this comet obtained by Bouška and Mayer three weeks later indicated a relatively lower value of $\beta_0/\beta_1 = 5$, too.

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