SPECTROPHOTOMETRIC STUDY OF PERIODIC COMET HALLEY (1982i)

P. S. GORAYA
Department of Astronomy and Space Sciences, Punjabi University, Patiala, India

and

B. S. RAUTELA, B. B. SANWAL, S. K. GUPTA
Uttar Pradesh State Observatory, Manora Peak, Nainital, India

and

H. K. DUGGAL and J. S. MALHI
Department of Astronomy and Space Sciences, Punjabi University, Patiala, India

(Received 7 February, 1989)

Abstract. Spectral scans of the head of periodic Comet Halley (1982i) have been presented and analysed in detail in the optical region ($\lambda\lambda$3200–7000 Å); for ten nights during pre-perihelion period. Emission features due to NH, CN, CH, C_3, and C_2 molecules have been identified. The behaviour of the variation of different emission lines strength as a function of heliocentric distance has been investigated. It is found that the comet exhibits night-to-night variation of brightness. The abundances and production rates of CN and C_2 species have also been derived.

1. Introduction

Comet P/Halley has drawn the attention of a large number of astronomers during its recent return in 1986. It is the most famous of its type and has become the most interesting object even for the general public. Thousands of astronomers have participated in the largest international observing programme (IHW) for Halley using the ground-based telescopes as well as space vehicles. We hope that Comet P/Halley will provide an excellent and unusual opportunity to investigate different cometary features.

Comet P/Halley was recovered on 16 October, 1982 ($r_H = 11.04$ AU; $V = 24.2$) by Jewitt and Danielson (1982); more than three years earlier to its perihelion passage. This is the earliest recovery ever made before for a periodic comet. Since its recovery, large number of professional and amateur astronomers have been engaged to observe this most fascinating object with a variety of sophisticated instruments. Because of all the favourable conditions this comet was observed from a large number of places and has resulted in many new discoveries.

Keeping in mind the scientific importance of Comet P/Halley we also joined the international observing programme and undertook the spectrophotometric part of observations. In the present investigation we report the first detailed spectrophotometric observations of Comet P/Halley during ten nights. The

Earth, Moon, and Planets **45**: 17–27, 1989.

TABLE I
Basic data of comet P/Halley (1982i)

Date (UT) 1985	Geocentric distance (Δ) AU	Heliocentric distance (Y) AU	Predicted m_1
Nov. 22.72	0.64	1.62	6.8
23.63	0.63	1.60	6.8
26.61	0.62	1.56	6.6
27.61	0.62	1.54	6.5
29.62	0.62	1.51	6.4
30.62	0.63	1.50	6.4
Dec. 5.57	0.67	1.42	6.3
18.57	0.88	1.22	6.2
27.52	1.06	1.08	6.0
28.54	1.08	1.07	6.0

geocentric distance (Δ), the heliocentric distance (r) and the predicted total magnitude ($m_{\perp}$) of the comet on different nights are summarized in Table I.

2. Observations

We observed Comet P/Halley on ten nights during the months of November and December, 1985 at the Cassegrain focus ($f/13$) of the 104-cm reflector of Uttar Pradesh State Observatory. The instrumentation is same as described earlier (Goraya *et al.*, 1982, 1984). The Hilger and Watts spectrum scanner giving a dispersion of 70 Å mm^{-1} in the first order was used. A circular diaphragm of 3 mm corresponding to 45 arc sec as projected on the head of the comet was adopted for obtaining the spectral scans of the comet. An exit slit of 0.7 mm corresponding to 50 Å band pass was used for admitting the spectrum to fall on the photomultiplier tube. A cooled (−20 °C) EMI 9658 B photomultipler tube and standard d.c. techniques were employed for detecting and recording the signal. The observational procedures are the same as described earlier (Goraya *et al.*, 1982, 1984). Three spectral scans of the comet were obtained every night and were reduced to instrumental magnitudes individually at a step of 25 Å. Finally, the mean instrumental magnitudes of the scans were adopted. Scans of the neighbouring sky were also taken before and after each comet scan to eliminate the contribution of the background sky.

Along with Comet P/Halley, the standard stars α Leonis and α Lyrae were observed for evaluating atmospheric extinction correction and to convert instrumental magnitudes of Comet P/Halley into standard magnitudes. The instrumental magnitudes of the comet were converted to absolute values with the help of standard stars. The absolute values of magnitudes thus obtained correspond to the recent calibration of standard stars given by Taylor (1984). The standard monochromatic magnitudes (m_λ) were converted to fluxes (F_ν) by using the relation

$$\log F_\nu = -19.447 - 0.4 m_\lambda. \tag{1}$$

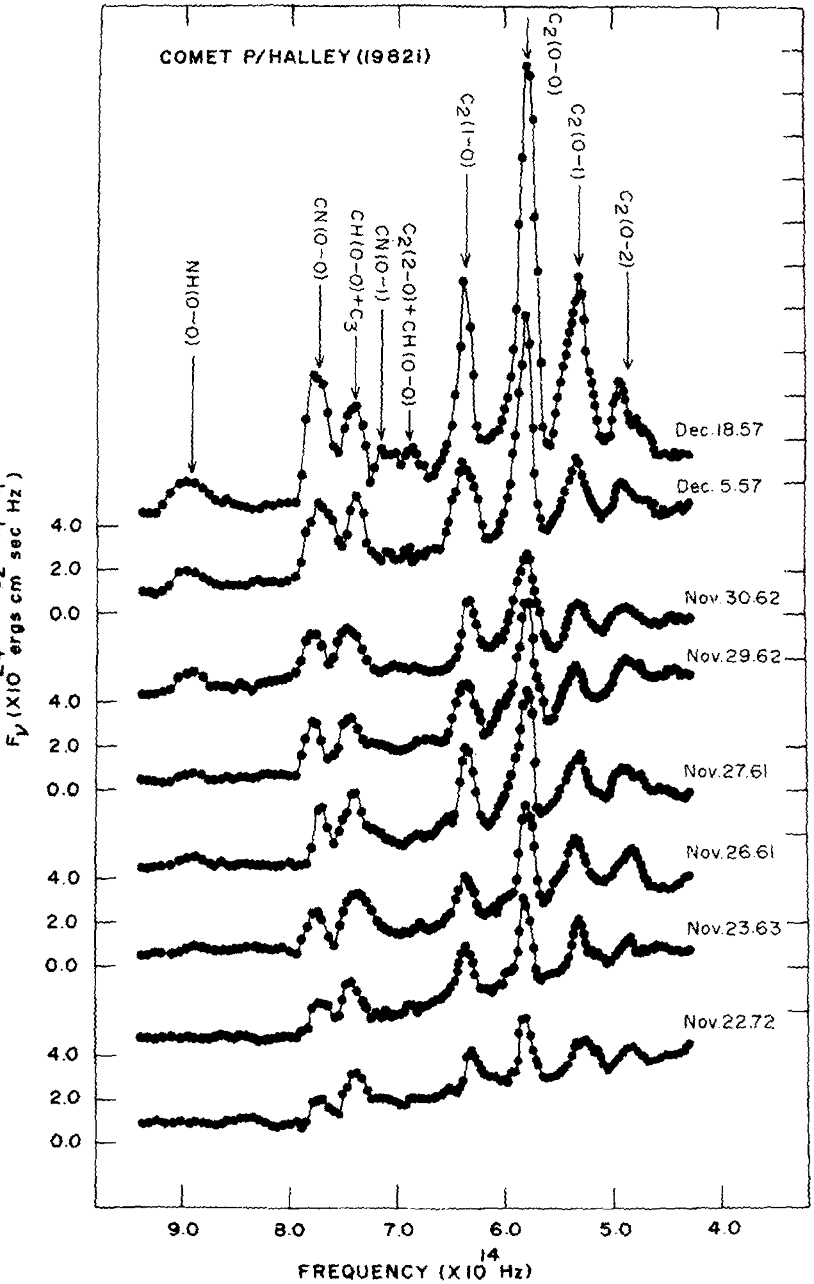
3. Strength of Different Emission Features

The spectral scans of Comet P/Halley reduced to absolute fluxes are shown in Figure 1. The different emission features are indicated by vertical arrows pointing downwards. This figure obviously shows the emission due to NH(0–0) λ3360 Å, CN(0–0) λ3880 Å, CH(0–0) + C_3 λ4050 Å, CN(0–1) λ4200 Å, CH(0–0) λ4350 Å and Swan Band Sequence C_2(2–0) λ4350, C_2(1–0) λ4700 Å, C_2(0–0) λ5160 Å. C_2(0–1) λ5640 Å and C_2(0–2) λ6190 Å species. A visual inspection of these spectra shows that there are large variations in the strength of different emission bands. The continuum level has also been changed noticeably during the observing period. The interesting feature to be noted is that as the comet approaches the Sun, there is continuous growth in the strength of all emission bands accompanied by the weakening of the continuum level. Another feature of remarkable interest is the intensity reversal of CN(0–0) and CH(0–0) + C_3 emission bands. During early days of observations the CN(0–0) band was weaker than CH(0–0) + C_3 band (i.e., on 22, 23, 26, and 27 November 1985) during the following days both bands become comparable in strength (i.e., on 29 and 30 November 1985); then the CN(0–0) band become stronger than that of CH(0–0) + C_3 band during next observations (i.e., on 5, 18, 27 and 28 December 1986). The NH(0–0) emission was absent on 22 and 23 November, 1985 but was found present on 26 November, 1986 and onwards.

For deriving the emission strength of different species we measured the total area under different emission bands relative to the continuum. The continuum in the spectrum was drawn by selecting wavelength regions free of emission lines. The area of different emission bands was converted into flux. The total apparent fluxes in different emission bands relative to C_2(0–0) band flux are listed in Table II. These relative fluxes displayed in Figure 2 show that Comet P/Halley exhibits night-to-night variation in the strength of different emission bands in addition to the continuous increase of emission strength as it approaches the Sun. This implies that the gradual increase in the overall brightness of the comet is also accompanied by night-to-night fluctuations as its heliocentric distance decreases.

4. Number of CN and C_2 Molecules

The total number of molecules (N) of CN and C_2 contained in a cylinder of diameter 45 arc sec in the line of sight and extending through the head of the comet can be derived from the total energy emitted in the CN and C_2 emission bands. A gross estimate of the total number of molecules of different species is made by using the well known relation (cf. O'Dell and Osterbrock, 1962)


COMET P/HALLEY (1982i)
NH(0-0)
CN(0-0)
CH(0-0)+C3
CN(0-1)
C2(2-0)+CH(0-0)
C2(1-0)
C2(0-0)
C2(0-1)
C2(0-2)
Dec.18.57
Dec. 5.57
Nov.30.62
Nov.29.62
Nov.27.61
Nov.26.61
Nov.23.63
Nov.22.72
Fν (X10^-24 ergs cm^-2 sec^-1 Hz^-1)
FREQUENCY (X10^14 Hz)
9.0
8.0
7.0
6.0
5.0
4.0
22.0
18.0
14.0
10.0
6.0
2.0
4.0
0.0

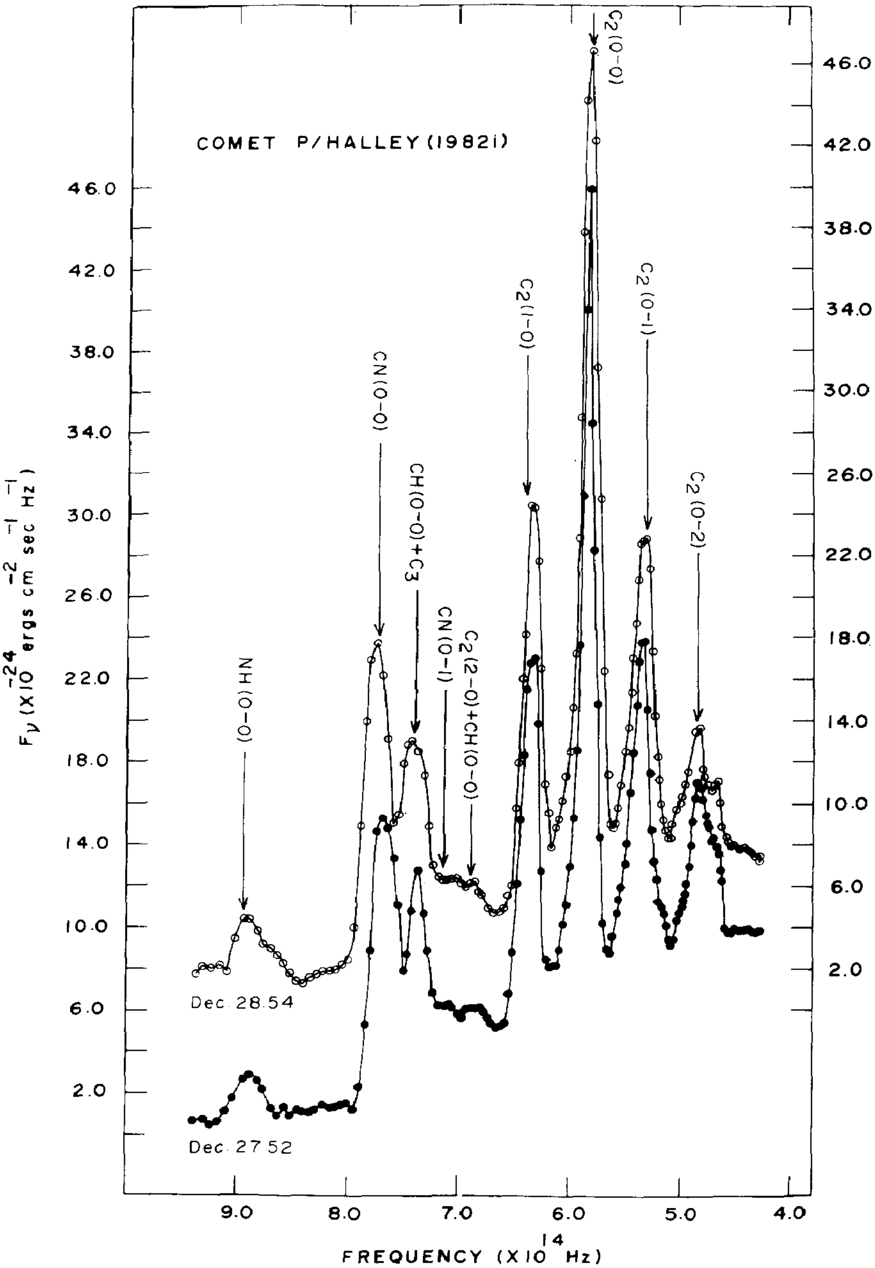


Fig. 1(a, b). Flux distribution in Comet P/Halley.

TABLE II
Observed fluxes of emission bands relative to C_2(0–0)

Date (UT) 1985	Apparent flux (F) in C_2(0–0) band (ergs^2 cm^{-2} sec^{-1}) $\times 10^{-11}$	$F/F[C_2(0\text{–}0)]$									Luminosity (L) in the C_2(0–0) band (ergs sec^{-1}) $\times 10^{16}$
		NH(0–0)	CN(0–0)	CH(0–0) + C_3	CN(0–1)	C_2(2–0) + CH(0–0)	C_2(1–0)	C_2(0–0)	C_2(0–1)	C_2(0–2)	
Nov. 22.72	3.78	–	0.381	0.899	–	–	0.788	1.000	0.899	0.381	4.354
23.63	5.08	–	0.508	0.728	–	–	0.709	1.000	0.661	0.165	5.670
26.61	7.18	0.072	0.429	0.891	–	–	0.490	1.000	0.713	0.479	7.762
27.61	10.80	0.096	0.326	0.680	–	–	0.593	1.000	0.437	0.296	11.676
29.62	11.30	0.065	0.342	0.471	–	–	0.414	1.000	0.288	0.227	12.216
30.62	10.76	0.191	0.234	0.487	–	–	0.398	1.000	0.288	0.230	12.011
Dec. 5.57	14.98	0.175	0.606	0.379	0.019	0.017	0.555	1.000	0.370	0.166	18.912
18.57	33.84	0.139	0.404	0.233	0.089	0.051	0.390	1.000	0.501	0.152	73.700
27.52	53.60	0.108	0.651	0.392	0.075	0.056	0.601	1.000	0.565	0.338	169.376
28.54	69.20	0.142	0.581	0.370	0.062	0.035	0.500	1.000	0.445	0.211	226.976

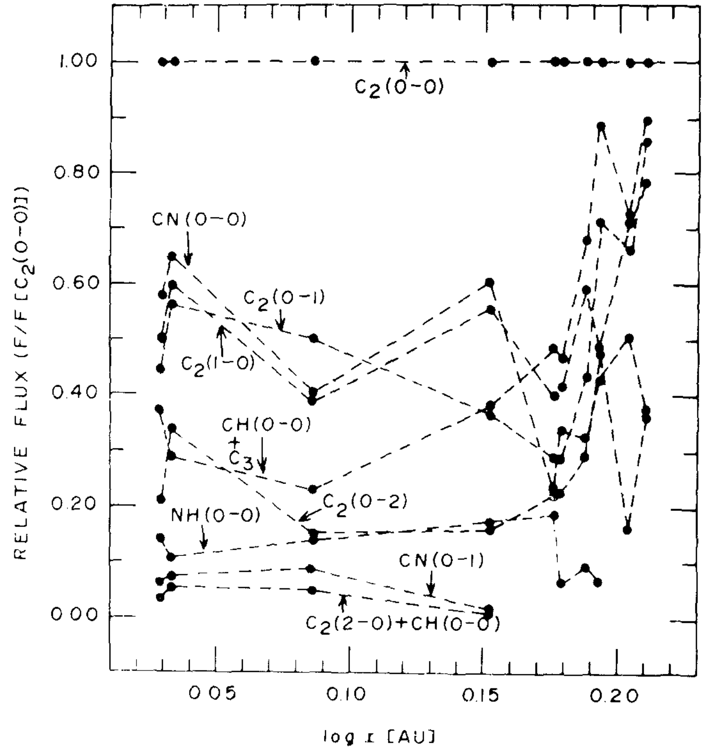


Fig. 2. Variation of the relative flux of emission bands as a function of heliocentric distance.

recently used by many authors (Sivaraman *et al.*, 1979; Goraya *et al.*, 1982, 1984, 1986):

$$N = \frac{Lm_e}{\pi e^2 f\, p\, \rho(\nu, r)}, \tag{2}$$

where

L = luminosity of the respective band;
m_e = mass of an electron;
e = charge of an electron;
p = the vibrational transition probability;
f = the oscillator strength; and
$\rho(\nu, r)$ = the solar radiation density at frequency ν at a heliocentric distance r.

The values of f, p and $\rho(\nu, r)$ used in our calculations are adopted from Lambert (1978) and Goraya *et al.* (1986) and are listed in Table III, along with the total number of molecules estimated by us.

TABLE III
Number of CN and C_2 molecules

Band	f	p	$\rho(\nu, r)$ erg cm^{-3}	log N									
				Nov. 22.72	Nov. 23.63	Nov. 26.61	Nov. 27.61	Nov. 29.62	Nov. 30.62	Dec. 5.57	Dec. 18.57	Dec. 27.52	Dec. 28.54
CN(0–0)	0.0342[a]	0.9200[b]	$4.214 \times 10^{-20} r^{-2}$ [b]	28.615	28.344	28.885	28.932	28.955	28.778	29.341	29.624	30.086	30.156
CN(0–1)	0.0024[a]	0.8108[b]	$6.910 \times 10^{-20} r^{-2}$ [b]	–	–	–	–	–	–	28.824	29.959	30.139	30.187
C_2(1–0)	0.0089[b]	0.2409[b]	$7.140 \times 10^{-20} r^{-2}$ [b]	29.869	29.927	29.881	30.129	29.976	29.946	30.240	30.546	30.989	31.028
C_2(0–0)	0.0239[a]	0.7335[b]	$6.445 \times 10^{-20} r^{-2}$ [b]	29.104	29.208	29.322	29.489	29.491	29.478	29.628	30.086	30.342	30.461
C_2(0–1)	0.0071[b]	0.2142[b]	$8.390 \times 10^{-20} r^{-2}$ [b]	30.005	29.976	30.123	30.076	29.898	29.885	30.150	30.733	31.041	31.057

[a] Lambert (1978).
[b] Goraya *et al.* (1986).

5. Production Rates of CN, C_3, and C_2 Molecules

Production rates can be derived from the total luminosity of the emission band. For making an estimate of the production rates of different molecules we assume that the excitation processes responsible in the coma of the comet are induced by solar radiation. Collisions within the coma and excitation by solar wind particles are neglected. For resonance scattering and fluorescence, the luminosity, L, is related to the total number of atoms or molecules, N, and to the emission rate factor, g, by the relation (Barth, 1969):

$$L = gN. \tag{3}$$

In terms of life time, τ, one have

$$Q = \frac{N}{\tau} = \frac{4\pi\Delta^2 F}{g\tau} = \frac{L}{g\tau}, \tag{4}$$

where

Δ = the comet–Earth distance;
F = the observed flux from the comet;
τ = the life-time of the scattering species; and
g = the probability that a solar photon will be resonantly scattered or produced by resonance fluorescence.

The values of g and τ used in our calculations are given in Table IV along with their sources. The production rates of CN, C_2 and C_3 molecules are listed in Table V. Actually, the lifetimes are never observed directly. They are derived by dividing the observed scale length, s, by the assumed mean expansion velocity of the molecules. The life-time, τ, is principally determined by photodestruction process. The product $g\tau$ is independent of heliocentric distance, r (Feldman *et al.*, 1974) and can be conveniently evaluated at IAU. The g-factors and life-times may be uncertain by as much as ±50% producing the same order of uncertainty in the production rates.

A plot of the variation of production rates of different species with heliocentric distance is shown in Figure 3. The production rates display night-to-night

TABLE IV
Life times and emission rate factors of CN, C_2, and C_3 species.

Species	Emission rate factor[a] (g) photon/sec/mol	Life time[b] (τ) sec	Product ($g\tau$)
CN	7.42×10^{-2}	14.8×10^{4}	1.098×10^{4}
C_2	4.38×10^{-2}	6.6×10^{4}	2.891×10^{3}
C_3	4.40×10^{-1}	4.0×10^{4}	1.760×10^{4}

[a]Newborn *et al.* (1978).
[b]A'Hearn and Cowan (1975).

TABLE V
Production rates of CN, C_2 and C_3 molecules

Date (UT) 1985	log r (AU)	log Q CN(0–0)	log Q CN(0–1)	log Q C_3	log Q				
					C_2(2–0)	C_2(1–0)	C_2(0–0)	C_2(0–1)	C_2(0–2)
Nov. 22.72	0.210	23.482	–	23.651	–	24.378	24.481	24.435	24.062
23.63	0.204	23.722	–	23.674	–	24.446	24.596	24.416	23.814
26.61	0.193	23.785	–	23.898	–	24.423	24.732	24.585	24.413
27.61	0.188	23.843	–	23.957	–	24.682	24.909	24.550	24.381
29.62	0.179	23.883	–	23.817	–	24.546	24.929	24.389	24.283
30.62	0.176	23.712	–	23.825	–	24.521	24.922	24.381	24.284
Dec. 5.57	0.152	24.322	22.811	23.913	23.359	24.864	25.119	24.695	24.338
18.57	0.086	24.737	24.078	24.292	24.820	25.301	25.710	25.409	24.891
27.52	0.033	25.305	24.364	24.880	24.819	25.850	26.071	25.823	25.599
28.54	0.029	25.386	24.412	24.982	24.738	25.897	26.198	25.848	25.522

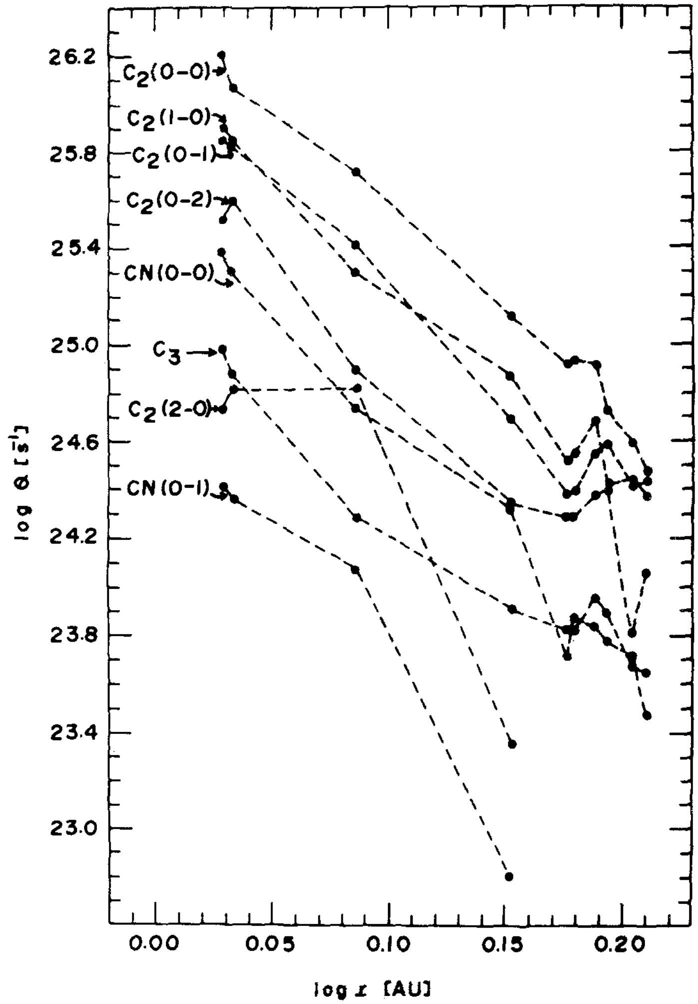


Fig. 3. Variation of production rates of emission bands as a function of heliocentric distance.

fluctuations but the general tendency is the increase in production rates with decreasing heliocentric distance.

References

Barth, C. A.: 1969, *Appl. Opt.* **8**, 1295.

Goraya, P. S., Singh, B. K., Chaubey, U. S., and Sanwal, B. B.: 1982, *The Moon and the Planets* **26**, 3.

Goraya, P. S., Rautela, B. S., and Sanwal, B. B.: 1984, *Earth, Moon and Planets* **30**, 63.

Goraya, P. S., Rautela, B. S., and Sanwal, B. B.: 1986, *Earth, Moon and Planets* **34**, 77.

Jewitt, D. C. and Danielson, G. E.: 1982, *IHW Newsletter* No. 2, p. 2.

Lambert, D.: 1978, *Mon. Not. R. Astr. Soc.* **182**, 249.

O'Dell, C. R. and Osterbrock, D. E.: 1962, *Astrophys. J.*, **136**, 559.

Sivaraman, K. R., Babu, G. S. D., Bappu, M. K. V., and Parthasarathy, M.: 1979, *Mon. Not. R. Astr. Soc.* **189**, 897.

Taylor, B. J.: 1984, *Astrophys. J. Suppl.* **54**, 259.