Toward an Investigation of the Carbon Coma of Comet 1959 k

Astronomy

1966

SovietRxiv

Abstract

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UDC 523.66

Astronomy

D. O. Mokhnach

Toward an Investigation of the Carbon Coma of Comet 1959 k

(Presented by Academician B. P. Konstantinov, February 12, 1966)

To explain the law of the distribution of surface brightness found by F. Miller (^1) in comet 1959 k, a model (^2) was proposed which satisfied the observations in the direction perpendicular to the radius vector, for certain values of the physical parameters. Further development of the theory has led to a change in the values of some quantities and of the model itself.

1. On the value of the initial velocity of the C_2 molecules. If one of the parameters—the repulsive acceleration $g = 0.36$ cm/sec^2, which corresponds to $f = 0.02$, the residual intensity 0.80, the temperature of the Sun $T = 5750$°K, and $r = 1$ a.u.—may be considered trustworthy, this cannot be said of the value of the initial velocity $v_0 = 1.2 \cdot 10^5$ cm/sec adopted in the previous model. With such an initial velocity the carbon atmosphere can be observed out to a distance of 200,000 km from the photometric center. To check the previously adopted (Miller, Mokhnach) value of v_0, the apparent density was determined in the direction of the radius vector out to a distance of $\pm 14 \cdot 10^9$ cm from the photometric center. For $v_0 = 1.2 \cdot 10^5$ cm/sec we have

$$N(14,0) = 0.006; \qquad N(-14,0) = 0.020; \qquad N(10,0) = 0.025;$$
$$N(-10,0) = 0.034.$$

We see that for $v = 1.2 \cdot 10^5$ cm/sec the isophotes cannot be circular out to a distance of $15 \cdot 10^9$ cm, i.e., such a value of the initial velocity does not satisfy F. Miller' s observations. To obtain circular isophotes at this distance for $g = 0.36$ cm/sec^2, calculations show that the smallest value of v_0 must be $3 \cdot 10^5$ cm/sec. This is the value we adopted in constructing the new model. It does not contradict the assumption that the parent molecules decay under the influence of corpuscular radiation from the Sun. But an increase in v_0 leads to a decrease in the value of τ—the lifetime of the molecules under photodissociation.

2. Formula for calculating the apparent density with allowance for photodissociation of the emitting molecules. In constructing the model (^2) it was assumed that at a distance of 20,000 km from the center of emission it is possible to neglect the influence of dissociation. Such an assumption does not simplify the mathematical part of the problem and greatly complicates the physical interpretation. Therefore, in constructing the new model we assume that the dimensions of the cloud of parent molecules are small compared with the dimensions of the carbon coma. The heliocentric distance of the comet changed only insignificantly at the end of April 1959, which allows the acceleration to be considered constant in the first approximation. For calculating the apparent density we obtain the formula

$$N(x,y) = \frac{2n_0}{v_0} \int_{t_1}^{t_2} \frac{e^{-t/\tau}\, dt}{t\sqrt{-gt^4/4 + (v_0^2 - gx)t^2 - (x^2 + y^2)}}. \tag{1}$$

This integral cannot be expressed in finite form. For $x = 0$, by integration by parts we obtain

$$N(0,y) = \frac{2n_0}{v_0 y} \left[\frac{\pi}{2} e^{-t_2/\tau} + \frac{1}{\tau} \int_{t_1}^{t_2} e^{-t/\tau} \operatorname{arctg} \frac{t_2}{t_1} \sqrt{\frac{t^2 - t_1^2}{t_2^2 - t^2}}\, dt \right]. \tag{2}$$

Formula (2) gives the distribution of the visible density along the Oy axis and is convenient for any method of approximate calculation.

3. Determination of τ from observations. Using formula (2), values of the visible density were calculated for different τ, with 4 significant figures. The quantity J given in Table 1 must be multiplied by $2n_0/v_0$ in order to obtain $N(0,y)$.

Table 1

$10^{-9}y$, cm	$10^9 J_{0,2\cdot 10^5}$	$10^9 J_{0,25\cdot 10^5}$	$10^9 J_{0,3\cdot 10^5}$	$10^9 J_{3,0\cdot 10^5}$
0,3	4,549	4,657	4,733	4,994
0,6	2,047	2,132	2,193	2,467
1,2	0,8529	0,9148	0,9604	1,207
1,8	0,4826	0,5317	0,5687	0,7893
2,4	0,3105	0,3508	0,3818	0,5813
3,0	0,2145	0,2484	0,2749	0,4570
6,0	0,05471	0,07101	0,08497	0,2112
9,0	0,01958	0,02832	0,03648	0,1312
12,0	0,008990	0,01301	0,01800	0,09214
15,0	0,003625	0,006472	0,009 07	0,06924

The calculations were performed on an electronic computer. The error of the quantities given in Table 1 does not exceed one unit in the last digit.

From Table 1 it is seen that for $\tau = 2 \cdot 10^4$ sec, for y in the interval from 0.3 to $1.8 \cdot 10^9$ cm, the law $R^{-1.25}$ is satisfied with an error of less than 5%; for

$\tau = 2.5 \cdot 10^4$, the law is $R^{-1.21}$; for $\tau = 3 \cdot 10^4$ sec, the law is $R^{-1.18}$; and for $\tau = 3 \cdot 10^5$ sec, the deviations from the law R^{-1} are less than 3%.

In the interval from $y = 2.4 \cdot 10^9$ cm to $y = 15 \cdot 10^9$ cm, the values of J for $\tau = 3 \cdot 10^4$ sec differ least of all from the law R^{-2}. Deviations from this law for $\tau = 2 \cdot 10^4$ sec are very large ($J \sim R^{-2.7}$) and would be noticeable when measuring the plates. For $\tau = 3 \cdot 10^5$, we practically obtain the law R^{-1}.

Unfortunately, we did not have at our disposal numbers determining the change of the visible density along the radius vector and in the perpendicular direction; therefore, relying on F. Miller' s qualitative conclusions about the circular form of the isophotes and on a law close to R^{-2} in the interval from $R = 20\,000$ km to $R = 150\,000$ km, we may regard the value $\tau = 3 \cdot 10^4$ sec as quite probable.

4. On the possibility of photodissociation of C_2 by the far-ultraviolet radiation of the Sun. F. Miller (^{1}) notes that comets 1959 k, 1955 e, and 1955 g had practically identical brightness distributions, despite the fact that the comets of 1955 were observed at a smaller heliocentric distance than comet 1959 k. The lifetime of molecules under photodissociation is inversely proportional to the quantity $W = \frac{1}{4}(r_\odot/r)^2$, where $r_\odot$ is the radius of the Sun and r is the heliocentric distance of the comet. When r decreases, the lifetime τ correspondingly decreases. If the initial velocities v_0 are assumed to be approximately the same for all three comets, then we should expect, in the comets of 1955, a more rapid fall of surface brightness than in comet 1959 k (see Table 1). Since this was not noted in the observations, one must suppose that the energy flux causing dissociation in 1955 was smaller than in 1959.

As rocket investigations show (^{4,5}), the flux of solar radiation in the region $\lambda < 1100$ Å is determined by 52 lines, which in years of high-

activity give, at a distance of 1 AU, 6 erg/cm$^2 \cdot$sec, and in years of minimum 2 –3 erg/cm$^2 \cdot$sec. If it is assumed that the probability of dissociation with subsequent excitation for C$_2$ is large compared with dissociation without excitation, then dissociation of C$_2$ requires the absorption of quanta with energy greater than 10.6 eV, i.e. $\lambda < 1170$ Å.

Taking the mean wavelength of the short-wave radiation causing dissociation to be 800 Å, we obtain, at a distance of 1 AU, $2.4 \cdot 10^{11}$ photons/cm$^2 \cdot$sec. In order to obtain a lifetime $\tau = 3 \cdot 10^4$ sec, the effective dissociation cross section σ_d must be $1.4 \cdot 10^{-16}$, which is quite probable.

We see that, by explaining the observed law of the distribution of surface brightness in the carbon coma by photodissociation of C$_2$ molecules by the extreme ultraviolet radiation of the Sun, we obtain plausible numerical values, which, of course, require refinement.

6. **Estimate of the emission coefficient.** The principal emissions of C$_2$ in the head of the comet have wavelengths λ4380, 4700, 5164, 5334, 6186 Å, with the most intense being λ4700 Å. According to O' Dell' s observations (^{3}), the flux in λ4700 Å is $3 \cdot 10^{18}$ erg/sec at $R = 1.2 \cdot 10^{10}$ cm. In the

absence of dissociation $(^2)$, the flux would be twice as large. Then, for an isotropic emission constant, the law R^{-1} would be obeyed, and the number of molecules in a circle of radius R could be calculated from the formula

$$\iint_{(L)} N\,dx\,dy = \frac{2\pi^2 R n_0}{v_0},$$

where (L) is a circle of radius R.

At a distance of 1 AU, the energy of solar radiation in the vicinity of $\lambda 4700$ Å is equal to 215 erg/cm$^2\cdot$sec per 1 Å, or $5.4\cdot 10^{13}$ photons/cm$^2\cdot$sec. Calculating the absorption coefficient for resonance radiation from the formula

$$\sigma = \pi e^2\lambda^2 f/mc^2\Delta\lambda,$$

we obtain $\sigma = 4\cdot 10^{-15}$.

Therefore we assume that at $\lambda 4700$ Å one act of absorption and emission occurs in 5 sec at a heliocentric distance of 1 AU. Consequently,

$$\frac{2\pi^2 R n_0}{v_0}\,\frac{nv}{5} = 6\cdot 10^{18}, \quad n_0 \sim 10^{25}.$$

If radiation at other frequencies is taken into account, then the value may quite plausibly be taken as

$$n_0 = 10^{26}.$$

The residence time of C_2 molecules in the comet' s head, for $v_0 = 3\cdot 10^5$ cm/sec and $g = 0.36$ cm/sec^2, is $1.5\cdot 10^6$ sec. Therefore the total number of C_2 molecules (and decay products) may be taken as equal to $1.5\cdot 10^{32}$. We have obtained a value close to $10^{32.8}$, which is given by Wurm $(^6)$. V. A. Ambartsumian $(^7)$ obtained $N(C_2) = 4\cdot 10^{32}$ molecules for a comet of brightness $0^m.0$, located at 1 AU from the Sun, for $f = 1$ and allowing for molecules with radiation $\lambda 5500$ Å.

Leningrad Agricultural
Institute

Received
17 I 1966

REFERENCES

[1] F. Miller, Ap. J., **134**, 1007 (1961).
[2] D. O. Mokhnach, DAN, **157**, No. 2 (1964).
[3] O' Dell, Publ. Astr. Soc. Pacific, **73**, No. 430, 41 (1961).
[4] G. M. Nikolsky, *Geomagnetism and Aeronomy*, **3**, No. 5 (1963).
[5] H. E. Hinteregger, Preliminary results of observations of the far ultraviolet spectrum of the Sun in the upper atmosphere, *Ultraviolet Radiation of the Sun and the Interplanetary Medium*, IL, 1962.
[6] B. M. Middlehurst, G. P. Kuiper, *The Solar System*, **4**, 1963, p. 589.
[7] V. Ambartsumian, *Theoretical Astrophysics*, 1939, p. 217.

Note: Figure translations are in progress. See original paper for figures.