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# PHOTOMETRIC PARAMETERS OF COMET KOHOUTEK 1973 XII

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*An analysis of the 2796 visual observations as well as of 282 V, B or U photoelectric observations was carried out using a two-parametric model for the light curve of the comet. After having applied an aperture correction to the visual observations, the following photometric parameters were derived: before perihelion $n = 2.5$, after perihelion $n = 3.6$ and a drop of $m_O$ by 1.5 - 1.9 after the perihelion passage. From the UBV photoelectric data the coma was found to be more gaseous before the perihelion passage.*

## VISUAL OBSERVATIONS

Altogether 2796 visual observations of Comet 1973 XII in the period from September 22 to December 23, 1973 and from December 31, 1973 to March 22, 1974 have been used in order to analyze the light curve of the comet before and after perihelion. Most of these observations came from Japan, USA and Germany.

The observing conditions of Comet 1973 XII were approximately the same before and after perihelion. The large atmospheric extinction diminished the accuracy of visual estimates of the cometary brightness in both periods; the mean error of one estimate was about ±0.6 mag. We have taken into account the aperture correction (AC) as the only systematic effect depending on time, and therefore on the distance of the comet from the sun. Our results (Table I) are based on a new method which will be described elsewhere (Kleine, Kohoutek, in preparation). They differ slightly from each other in the periods before and after perihelion passage.

TABLE I

APERTURE CORRECTION:

$$m_{1,cor} = m_1 - a\ (D - D_o)$$

| Author | Material | $D_o$ [cm] | a [mag. $cm^{-1}$] refractors | N | reflectors | N |
|---|---|---|---|---|---|---|
| Bobrovnikoff (1941a,b) | 45 comets | 6.78 | 0.067 | 1804 | ---- | ---- |
| Morris (1973) | 22 comets | 6.78 | 0.055 | 480 | 0.019 | 227 |
| This paper | Comet 1973 XII | 6.78 | 0.026 | 1921 | 0.014 | 875 |
| | | 0 | 0.037 | | 0.021 | |



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Our method implies a dependence of AC on the zero point, *i.e.*, on the reference aperture $D_o$. We use $D_o = 0$ as well as $D_o = 6.78$ cm in order to compare our correction with the results of Bobrovnikoff (1941 a,b) and Morris (1973).

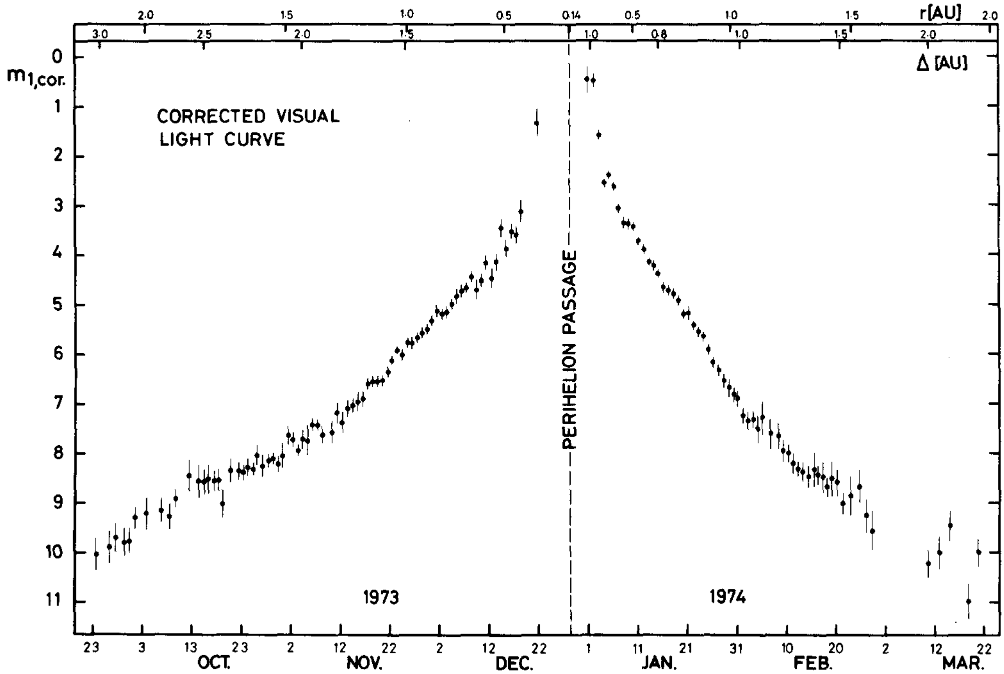


*Figure 1. Corrected visual light curve based on 2796 visual observations: Angione* et al. *1975; Bennett 1973, 1974, 1975; Ceplecha 1975; de la Cotardiere 1974; Goto 1974; Kiev Comet Circulars 1973, 1974; Milon 1974; German Observer's Network.*

The light curve (Fig. 1) was constructed using 136 daily means which were corrected to the reference aperture $D_o = 0$. At the beginnings or ends of the observing periods the time interval of a daily mean was increased in order to contain at least three observations. The curve before and after perihelion covering the range of about 9 magnitudes appears smooth without flares.

The two-parametric model for the light curve was applied in the well-known form:

$$m = m_o + 2.5\ n \log r; \tag{1}$$

here the corrected magnitudes $m_{1,cor.}$ were reduced to a unit of geocentric distance assuming the $\Delta^2$-law. At first the absolute magnitudes $m_o$ and photometric exponents n were computed using all visual observations before (A all) and after (B all) perihelion passage (Table II). If we omitted the last observations before perihelion (A) as well as the first observations after perihelion and the observations in March 1974 (B), we received nearly the same values $m_o$, n but somewhat smaller $\sigma_m$ (standard deviation in magnitudes of the daily means).

TABLE II

PHOTOMETRIC PARAMETERS

$m_o$, n (Visual Observations)

| Period | Int. | Date (1973 - 1974) | r [AU] | N | without AC $m_o$ | without AC n | without AC $\sigma_m$ | with AC $D_o = 6.78$ $m_o$ | with AC $D_o = 0$ $m_1$ | with AC n | with AC $\sigma_m$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre- | A all | Sep. 22-Dec. 23 | 2.2-0.3 | 1148 | 5.42 | 2.68 | 0.20 | 5.37 | 5.11 | 2.55 | 0.18 |
| perihelion | A | Sep. 22-Dec. 19 | 2.2-0.4 | 1144 | 5.42 | 2.66 | 0.19 | 5.37 | 5.12 | 2.53 | 0.17 |
| Post- | B all | Dec. 31-Mar. 22 | 0.2-2.0 | 1648 | 6.85 | 3.64 | 0.20 | 6.84 | 6.63 | 3.57 | 0.20 |
| perihelion | B | Jan. 3-Feb. 27 | 0.3-1.6 | 1597 | 6.87 | 3.63 | 0.16 | 6.86 | 6.65 | 3.57 | 0.15 |

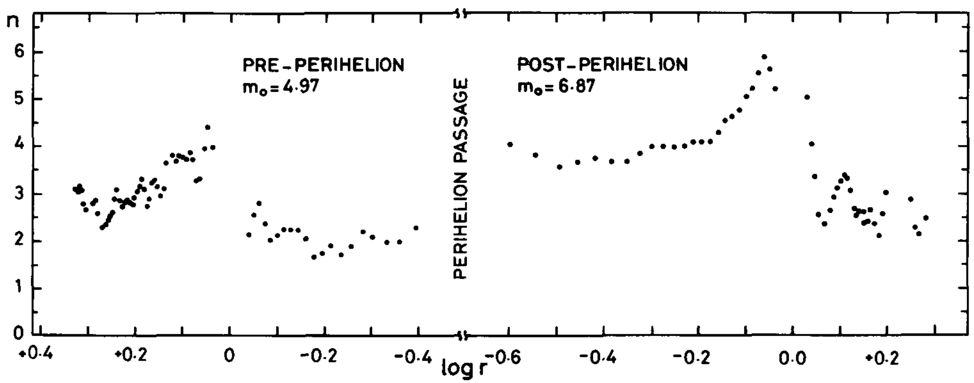


*Figure 2. Time variation of the photometric exponent n.*



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The photometric parameters calculated either without or with aperture correction differ somewhat from each other, but the following conclusions can be stated: (1) The absolute brightness of the coma after the perihelion passage was about 1.5 mag. lower than before; (2) The mean photometric exponent of the coma increased clearly after the perihelion passage.

Systematic deviations were found between the observed and theoretical light curve which could be explained as a variation of the photometric exponent with time. We derived the following "local" values of $m_0$ at a distance r = 1 AU: $m_0$ (A) = 4.97, $m_0$(B) = 6.87 (AC for $D_0$ = 0); $m_0$(A) = 5.22, $m_0$(B) = 7.08 (AC for $D_0$ = 6.78). The time dependence of n could then be constructed as shown in Fig. 2.

## UBV PHOTOELECTRIC OBSERVATIONS

We have compared the visual observations with the wide-band photoelectric V (n = 136), B (97) and U (49) measurements from the same period: our own observations (Kohoutek 1974) were completed by data given in the literature.

The photoelectric UBV magnitudes of the coma correspond to different diaphragms. Free of any correction are the colours B-V, U-B: we have received the following mean values:

| | $\overline{\text{B-V}}$ | $\overline{\text{U-B}}$ |
|---|---|---|
| pre-perihelion | +0.74 | -0.24 |
| | ± .01 | ± .04 |
| post-perihelion | +0.84 | -0.21 |
| | ± .02 | ± .02 |

The plot B-V vers. ρ (projected radius of the diaphragm in km) shows B-V nearly constant within the whole interval of ρ (7000-120,000 km), whereas U-B decreases with increasing ρ (Fig. 3): from $-0^m.08$ at $\rho = 10^4$ km to $-0^m.44$ at $\rho = 10^5$ km.

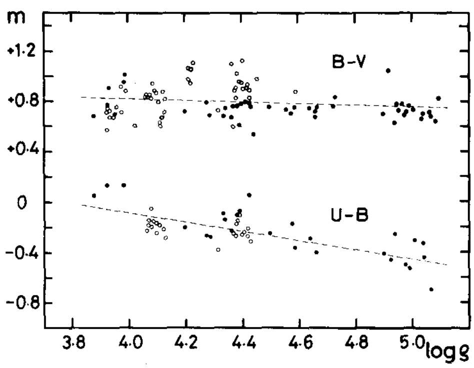


*Figure 3. Photoelectric B-V and U-B colors of the coma as a function of the projected radius of the diaphragm ρ [km]. Full circles - pre-perihelion, open circles - post perihelion. The following observations were used: Angione,* et al. *1975; Davis 1974; Kiselev, Chernova, 1974; Kohoutek 1974; Maran 1974; Ney, E. P., Ney, W. F. 1974; Ney, E. P.,* et al. *1974; Rieke, Lee 1974; Scaltriti,* et al. *1974; Seeds, Michael 1974; Shipman 1974; Svoreň, Tremko 1975; Vogt 1974.*

This can be explained due to the difference in the scale lengths for destruction of CN (in U system) and $C_2$ (in B and V system) molecules. In order to transform UBV magnitudes of the coma to a unique area the following distribution of molecules, D(R), within the head was assumed (Haser 1957):

$$D(R) = \frac{\text{const.}}{R^2} \cdot (e^{-\beta_o R} - e^{-\beta_1 R}), \tag{2}$$

R - radial distance from the nucleus, $\beta_o$, $\beta_1$ - reciprocal scale lengths for destruction of the observed species and for the decomposition of parent molecules into the observed species, respectively. After integration of Eq. (2) along a line of sight through the comet, luminosity $L_g$ of the gas coma could be expressed as a function of projected radius $\rho$ of the diaphragm

$$L_g(\rho, r = 1) = \text{const}_1 \cdot \rho \cdot F(\beta_o, \beta_1, \rho); \tag{3}$$

for the function $F(\beta_o, \beta_1, \rho)$ see for example A'Hearn, Cowan (1975).

As to the dust coma, the simplest distribution of dust particles D(R) = const./$R^2$ would lead to the luminosity

$$L_d(\rho, r = 1) = \text{const}_2 \cdot \rho \tag{4}$$

The UBV light curves were constructed for two standard radii $\rho_o = 2.5 \times 10^4$ km and $5 \times 10^4$ km lying approximately in the middle of the interval of $\rho$. Although the real cometary coma is a mixture of gas and dust, we calculated $m_o$, n (i) for a pure gas coma assuming $\beta_o$ (V) $\equiv$ $\beta_o$ (B) $\equiv$ $\beta_o$ ($C_2$-molecules) = $1.5 \times 10^5 \cdot r^{-2}$, and $\beta_o$ (U) $\equiv$ $\beta_o$ (CN-molecules) = $6.8 \times 10^{-6} \cdot r^{-2}$ (Delsemme, see A'Hearn, Cowan 1975); the ratio $\mu = \beta_1 / \beta_o$ = 5, 10 and 20 was adopted; (ii) for a pure dust coma (Table III).

Also the UBV photoelectric observations show a decrease of the absolute brightness and an increase of n after perihelion. As expected the differences of $m_o$ and n among the three gas models ($\mu$ = 5, 10, 20) are small and the $m_o$, n values depend on the reference radius of the coma. From the standard deviations we see that the gas model describes the UBV light curves before perihelion better than the dust one, whereas both models are comparable in the post-perihelion period.

Another possibility has been tried in order to check the gas- and dust-model of the coma. We referred the photoelectric V-magnitudes to the mean visual light curve and found the relation $\Delta V = V - m_{vis}$ vers. log $\rho$ to be nearly linear. This relation would reflect a brightness distribution within the coma, if the possible changes in this distribution during the whole period were neglected. We applied both the gas model (Eq. 3; $\beta_o = 1.5 \times 10^{-5}$, $\mu = 6.6$) and the dust model (Eq. 4) and received the following standard deviations (in magnitudes)

| | $\sigma_{gas}$ | $\sigma_{dust}$ |
|---|---|---|
| pre-perihelion | 0.30 | 0.40 |
| post-perihelion | 0.30 | 0.29 |

As in the previous test we found the contribution of dust in the visual to be greater after perihelion than before.

## CONCLUSIONS

Since September 1973 the brightness of the cometary coma was increasing with the mean photometric exponent of about n = 2.5 and reached the value $m_o$ =



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TABLE III

PHOTOMETRIC PARAMETERS

$m_o$, n (UBV Photoelectric Observations)

| Period | Coma Model | V $\rho_o = 2.5 \times 10^4$ $m_o$ | V $\rho_o = 2.5 \times 10^4$ n | V $\rho_o = 5 \times 10^4$ $m_o$ | V $\rho_o = 5 \times 10^4$ n | B $\rho_o = 2.5 \times 10^4$ $m_o$ | B $\rho_o = 2.5 \times 10^4$ n | B $\rho_o = 5 \times 10^4$ $m_o$ | B $\rho_o = 5 \times 10^4$ n | U $\rho_o = 2.5 \times 10^4$ $m_o$ | U $\rho_o = 2.5 \times 10^4$ n | U $\rho_o = 5 \times 10^4$ $m_o$ | U $\rho_o = 5 \times 10^4$ n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pre- | gas | | | | | | | | | | | | |
| perihelion | $\mu$ = 5 | 7.73 | 3.70 | 7.02 | 3.14 | 8.45 | 3.73 | 7.73 | 3.19 | 8.27 | 3.98 | 7.31 | 3.61 |
| | $\mu$ = 10 | 7.66 | 3.66 | 7.07 | 3.12 | 8.41 | 3.63 | 7.81 | 3.10 | 8.19 | 4.00 | 7.36 | 3.56 |
| | $\mu$ = 20 | 7.63 | 3.58 | 7.10 | 3.14 | 8.41 | 3.50 | 7.88 | 3.06 | 8.14 | 3.97 | 7.42 | 3.53 |
| | dust | 7.93 | 3.13 | 7.18 | 3.13 | 8.65 | 3.22 | 7.89 | 3.22 | 8.22 | 3.80 | 7.47 | 3.80 |
| post- | gas | | | | | | | | | | | | |
| perihelion | $\mu$ = 5 | 8.42 | 3.91 | 7.72 | 3.24 | 9.23 | 3.95 | 8.54 | 3.29 | 9.04 | 4.60 | 8.08 | 4.02 |
| | $\mu$ = 10 | 8.46 | 3.83 | 7.87 | 3.28 | 9.27 | 3.87 | 8.69 | 3.32 | 9.06 | 4.42 | 8.23 | 3.87 |
| | $\mu$ = 20 | 8.50 | 3.82 | 7.97 | 3.34 | 9.30 | 3.84 | 8.77 | 3.36 | 9.09 | 4.29 | 8.37 | 3.86 |
| | dust | 8.53 | 4.39 | 7.78 | 4.39 | 9.31 | 4.41 | 8.56 | 4.41 | 9.14 | 4.44 | 8.39 | 4.44 |

UBV Photoelectric Observations

| Period | r [AU] | $\rho$ [km] | coma model | V N | V $\sigma$ | B N | B $\sigma$ | U N | U $\sigma$ |
|---|---|---|---|---|---|---|---|---|---|
| pre perihelion | 1.9 - 0.8 | 8000 - 125,000 | gas | 59 | 0.24 | 46 | 0.28 | 26 | 0.27 |
| | | | dust | | 0.35 | | 0.42 | | 0.59 |
| post-perihelion | 0.3 - 1.3 | 6000 - 65,000 | gas | 77 | 0.24 | 51 | 0.17 | 23 | 0.13 |
| | | | dust | | 0.23 | | 0.18 | | 0.15 |



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5.1 (5.4) for AC $D_0 = 0$ ($D_0 = 6.78$) at the distance 1 AU. After the perihelion passage the decrease of brightness passed according to n = 3.6 and the absolute magnitude dropped by 1.5 mag. for the two-parametric model, and even by 1.9 mag. when we compared the "local" values of $m_0$. The contribution of dust and gas to the visual brightness of the coma was estimated from the UBV data using two different methods. In both approaches the coma was found to be more gaseous before perihelion than afterwards. The observed changes in the coma luninosity and composition could be ascribed to the respective decrease of both the molecular production rates as well as the production rates of dust.

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## *DISCUSSION*

*DELSEMME: Kleine and Kohoutek's photometric work is relevant to our target here, because, in principle, it can be connected to the vaporization properties of the cometary nucleus and therefore, to its chemical nature and its origin.*

*Before going further, I want however to mention a few words of caution: Visual and U,B,V, magnitudes are not an acceptable substitute for monochromatic brightnesses in the lights of the different radicals and of the continuum. It is too bad that not enough observers use the proper filters to separate the lights from dust and from different radicals like $C_2$, $C_3$, CN, or ions like $H_2O^+$ and $CO^+$, whereas too many still use the U, B , V system which has been developed for stars and is totally inappropriate for comets.*

*The situation being what it is, Kleine and Kohoutek must be commended for their careful handling of a large amount of heterogeneous data, but their results must still be looked at with some caution. This being understood, variations* *with distance of the exponent n of the brightness law (Fig. 2) clearly shows two different features: Before perihelion, n goes down from 3 to 2 and remains near 2 for all distances shorter than 1 A.U., clearly showing that the vaporization steady-state prevails, whereas a radiative term is no more negligible for distances 1.5 to 2.5 AU. Combined with the magnitudes at discovery (near log r = 0.6) these photometric curves can be used to show that the temperature of the nucleus has constantly been in the general range of 110 to 120° K during comet Kohoutek's approach (Delsemme p. 199, in "Comet Kohoutek," NASA-SP 355, 1975). It is significant to note that, at steady state, water ice would vaporize at 195° K whereas carbon dioxide would at 107° K (rotating nucleus near 1 AU). Since this temperature does not change much during the vaporization steady state, there are good reasons to believe that* $CO_2$ *controlled the vaporizations during comet Kohoutek's approach before perihelion. (If water had controlled vaporization , with the same magnitude at discovery, comet Kohoutek would have been some seven magnitudes brighter at perihelion!) After perihelion, n was suddenly much larger than 2, indicating that* $CO_2$ *was no more available to vaporize freely. The transition to a new steady state took obviously a long time, the unsteady conditions showing some oscillations; since a new steady state was clearly not reached before r = 2 AU, nothing can be said about the stuff controlling the vaporizations then; a reasonable guess would suggest water.*

*GEHRELS: In past years we made many observations of the wavelength dependence of polarization, with selected filters to isolate the continuum, but they remain unpublished because we cannot fit the Mie theory. It may be possible to fit to the photometry alone or to the polarimetry alone, but not the two together, even when avoiding the fitting to phase variations (because these probably contain variation in solar distance and particle size). Possibly the particles are of irregular shape and fairly large size. The problem is further discussed in "Planets, Stars and Nebulae, studied with Photopolarimetry" (T. Gehrels, ed.), Univ. Ariz. Press, Tucson, Arizona, 1974.*



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