About the use of a modified brightness parameter for photometric observations of comets

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Abstract. The aim of this paper is to study the mathematical features of a cometary photometric parameter, which is called by us a "modified intensity". It is defined as $\epsilon(l) = E(l)l$, where $E(l)$ is the intensity of a separated gas emission on a projective (pericentral) distance l to the cometary nucleus. The Haser's model of the parent and daughter gas molecules distribution is used. It is pointed out that the parameter profile ϵ could be used directly for a prompt analysis both of the main generation mechanism of the observed emission s, as well as of a rough parent molecules scale length estimation in the range of 50% precision.
Key words: comets, cometary photometry, parent molecules

Върху използването на модифициран яркостен параметър за фотометрични наблюдения на комети

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Целта на тази статия е да се изследват математическите свойства на кометен фотометричен параметър, който беше наречен от нас "модифицирана яркост". Той е дефиниран като $\epsilon(l) = E(l)l$, където $E(l)$ е интензимността на отделна газова емисия на проективно ("перицентрално") разстояние l от кометното ядро. Иползва се моделът на Хазер за разпределението на родителските и дъщерните молекули. Показано е, че видът на профила на ϵ директно може да да бъде използван за експресен анализ както на основния генерационен механизъм за наблюдаваната емисия s, така също и за груба оценка на параметъра на протяжност на комата на родителските молекули в рамките на 50% точност.

1 Introduction

It is well known that for monochromatic photometric observations of comets the intensity E is a basic parameter in the analysis of the cometary processes. It is connected with the substance distribution in the cometary atmosphere projection. In accordance with Haser (1957), E is defined as:

(1) $E(l) = kf(l)/l$

where k is a constant, connected with some initial characteristics of the cometary substance and the excitation mechanism of the corresponding emission; $f(l)$ represents the cometary gas substance distribution along the line of sight at a distance l from the cometary center.

The changes of $f(l)$ are limited in such a way that its dividing a decreasing function. For this reason, $E(l)$ is sometimes unsuitable for theoretical analysis. This inconvenience can be removed by the modification (1):

(2) $\epsilon(l) = E(l)l = kf(l)$

$\epsilon(l)$ will be called 'modified intensity'. Its changes will be determined according to the change of $f(l)$.

The modified intensity has been previously used by Larson and Secanina (1984) for the interpretation of the photometric profiles of Halley's comet, obtained by photographic observations in 1910 at the Mount Wilson Observatory. Later $\epsilon(l)$ was used by Komitov et. al. (1988) and Ivanova et al. (1990) for the interpretation of observations of the comets Halley (1986) and Bradfield (1988 XII) at the Rozhen National Observatory.

2 The modified intensity and the basic excitation mechanism of cometary emissions

It is known that in the larger part of the cometary atmospheres the motion of the gas particles can be regarded as non-collisional. The main sources of production and destruction of atoms and molecules of the various chemical components are the photo-processes. In this case, the spatial distribution of the gas particles is well described by Haser's model (1957).

The analysis of $\epsilon(l)$ in terms of this model shows that the variations of the modified intensity can be reduced to the following three main cases:

1. Absence of gas emission. The observed radiation is only a result of the solar radiation, reflected by the cometary dust. The modified intensity profile is constant in all coma, except the most outer regions, where the light pressure acceleration effect should be taken into account.

2. The basic sources of the gas emissions excitation are the fluorescent excitation of parent molecules and the photo-dissociative excitation of daughter molecules at the moment of their generation. In this case, $\epsilon(l) = const$ in the inner and middle regions of the coma. In the outer regions, however, it is a decreasing function as a result of gas depletion by photo-processes. Therefore, there is no extremum of $\epsilon(l)$ in this case.

3. A basic source of the observed radiation is the fluorescent excitation of daughter molecules. In this case, the analysis of f(l) shows that $\epsilon(l)$ contains an extremum point - maximum.

These peculiarities of $\epsilon(l)$ are very useful in studying the nature of the cometary emissions.

3 The modified intensity maximum location

According to Haser's model for the distribution of the daughter molecules, the following formula will be valid for parameter k at fluorescent excitation;

(3) $k{=}2N(R_n)R_n^2\beta_p/(\beta_d - \beta_p)v_p/v_d g$

and for $f(l)$:

(4) $f(l) = B_d(l) - B_p(l)$

respectively, where

(5.1) $B_d(l) = [\pi/2 - \int_0^{x_d=\beta_d l} K_0(x_d)dx_d]exp(\beta_d Rn)$

and

(5.2) $B_p(l) = [\pi/2 - \int_0^{x_p=\beta_p l} K_0(x_p)dx_p]exp(\beta_p Rn)$

In (3),(4),(5.1) and (5.2), the following labels are used:

R_n - the nuclear radius, $N_p(R_n)$ - the parent molecules density on the nuclear surface, g - radiation factor (it is constant for each separate emission), $\beta_p= 1/(v_p\tau_p)$, $\beta_d = 1/(v_d\tau_d)$, where v_p and v_d are the average radial velocities of the parent and daughter molecules, respectively and, τ_p and τ_d - their lifetimes. K_0 is the modified Bessel's function of the second kind, zero order; $1/\beta_p$ and $1/\beta_d$ are labeled as 'scale lengths' and they characterize the extension of the parent and daughter molecules coma, respectively. The condition for extremum in this case will be:

(6) $d[B_d(l) - B_p(l)]/dl{=}0$

and

(7) $d[\int_0^{x_d} K_0(x_d)dx_d - \int_0^{x_p} K_0(x_p)dx_p]/dl{=}\ 0$

respectively and it is supposed that:

$\exp \beta_p R_n \approx \exp \beta_d R_n = 1$

Since, however,

$d[\int_0^{x_d} K_0(x_d)dx_]/dl = \beta_d$

(8.1) $d[\int_0^{x_d} K_0(x_d)dx_d]/dx_d = \beta_d K_0(x_d)$

and

$d[\int_0^{x_p} K_0(x_p)dx_p]/dl = \beta_p$

(8.2) $d[\int_0^{x_p} K_0(x_p)dx_p]/dx_p = \beta_p K_0(x_p)$

it follows that

(9) $\kappa K_0(\kappa x_p) - K_0(x_p) = 0$

and hence

$\kappa = \beta_p/\beta_d < 0$

In order to obtain the second derivative of $\epsilon(l)$ we use the properties of the relation between the modified Bessel's function $K_0(x)$ and $K1(x)$ and the circumstance that in (3) $\kappa < 0$. We, therefore, obtain:

(10) $\kappa[\kappa K_1(\kappa x_p) - K_1(x_p)] < 0$

where K_1 is a modified Bessel's function of the second kind, first order. Condition (10) shows that a maximum of $\epsilon(l)$ is possible. If we take for a unit of distance in the coma the parameter $1/\beta_p$, the solution of equation (9) towards x_p for different values of κ will give the pericentral distance l_{max} of the $\epsilon(l)$ function maximum in units of $1/\beta_p$.

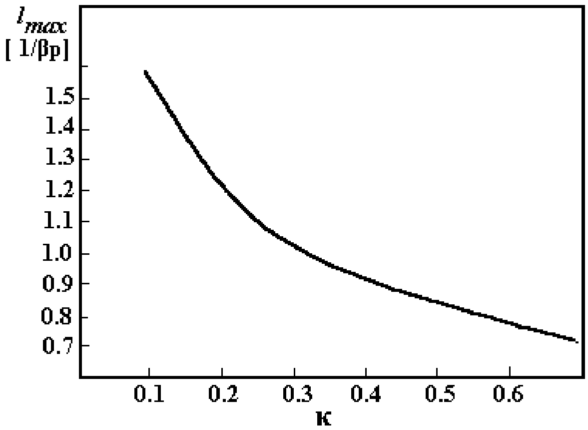

Fig. 1. The "$\kappa - \epsilon(l)$" dependence

The results of a similar numerical solution are presented in Fig.1. It shows that for a real interval of κ changes from 0.1 to 0.7, the values of l_{max} change only twice and the mean value is approximately 1. In other words, the position of the $\epsilon(l)$ maximum point corresponds to the scale length of the parent molecules coma with a precision of about 50%.

The curve in Fig.1 might be used for quantitative interpretation of the observed data. Parameter $1/\beta_p$ of the CN parent molecules in the comet Halley was determined to be 90000 km on May 8th, 1986 by photographic narrow-band filter observations (Komitov et al., 1988) and the lower limit of $1/\beta_p = 170000$ km was estimated. The maximum of $\epsilon(l)$ is at 80000 km, i.e. 0.9/ β_p. As Fig.1 shows, it corresponds to $\kappa = 0.4$ and hence $1/\beta_d =$ 360000 km. Since the lifetime of the CN molecules at heliocentric distance of 1.75 a.u. is approximately 830 000 km, then their radial velocity is about 0.4 km/s. This value is in a good agreement with the Bobrovnikov's formula for the mean neutral coma gas expanding radial velocity for the corresponding heliocentric distance (Bobrovnikov,1954).

4 Conclusion

The studied in this paper features of the modified intensity $\epsilon(l)$ function shown that they could be successfully used for a prompt analysis of the cometary narrow-band photometry observations in two aspects: 1. For an identification of the dominant type of emission - dust light scattering by neutral parent or daughter gas molecules emission; 2. For a rough estimation of the parent molecules scale length on the base of modified intensity parameter maximum if the main gas emission process is connected to a fluorescent excitation of daughter molecules.

It should also be noted briefly that the ϵ-parameter could be very effectively used for analysis of the gas chemistry and dynamics in the inner coma gas-dust structures such as jets (Komitov et al., 2000) as well as for detecting of ice particles halo near to the cometary nuclei.

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