Photometric studies of comets at the Kleť Observatory

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Received: August 18, 1999

Abstract. The preliminary results of the comet surface photometry performed in the framework of the small bodies programme of the Kleť Observatory are discussed. The integrated brightness of the tail of comet 122P/de Vico has been used for the determination of the dust flow characteristics in the tail. It is shown, that in the dusty tail near coma, where the contribution of small "fluffy" and unstable dust particles to the surface brightness of the tail is substantial, the decrease of integrated brightness with distance indicates effects of some kind of disintegration mechanism. The apparent lifetime of grains inferred from the tail photometry is less than one day at the heliocentric distance 1 AU. This effect might be caused either by sublimation or by electrostatic charge disruption of grains, and even the albedo change should be considered.

Since the narrow streams are presented on the tail images of 122P/de Vico obtained with a R filter, a substantial contribution of the ionized molecular species must be considered as another alternative. Among the most abundant ions of the plasma tail are CO^+ and H_2O^+. The contribution of each of these species to the ion tail brightness in the red region must be considered. Nevertheless, the discussed method for the determination of the dissipation coefficient may also be applied here for the ion tail. In such a case the effective lifetime of these species at heliocentric distance 1 AU, is significantly shorter that 10^5s. Preliminary analysis of the brightness distribution in the coma of 19P/Borrelly indicates that a population of larger dust grains for which $\mu \lesssim 1$ dominates there.

Key words: comets – 19P/Borrelly – 122P/de Vico – cometary dust

1. Introduction

It is well known that the shape of the coma and comet tail predominantly depends on the ejection velocity, acceleration and lifetime of the molecules and dust particles. Although direct measurements of the expansion velocity can be provided by several methods, the quantities mentioned above can be determined by indirect methods. Since the new CCD surface imagining process allows high quality surface photometry of extended objects like comets, we examine some CCD images of comets 19P/Borrelly and 122P/de Vico, recently obtained at the Kleť Observatory in attempt to prove the efficiency of an applicability classical photometric method for the determination of the dust coma characteristics.

The observations of the comet were performed under photometric conditions at the 0.57-m f/5.2 telescope equipped with a CCD camera SBIG ST-6. The spectral sensitivity of the CCD camera is cut down at $\lambda = 570$ nm toward shorter wavelengths and it is limited in pass-band up to $\lambda \lesssim 900$ nm. In combination with the red filter R the maximum sensitivity is at about 670 nm with FWHM $\simeq 90$ nm. On the CCD images the molecular emissions are suppressed, but not completely. Thus the images represent the shape and intensity distribution of the dusty coma and tail. However, some emission features of gaseous components as CO^+ $A^2\Pi_i$–$X^2\Sigma^+$ at $\lambda \simeq 630$ nm, O $[^1D]$ lines at $\lambda = 630$ and 636 nm, NH_2 at 690 nm and H_2O^+ at 570–757 nm are still present, namely ionized compounds in the plasma tail.

Although the results described in this paper are aimed at the assessment of comet activity in regard to the dust, the contribution of the neutral gaseous and plasma component must be considered as additional factors. Tab. 1 and 2 provide an overview of the observational data. The data reduction comprises of bias level subtraction.

Table 1. Observational circumstances of comet 19P/Borrelly. Observers: C = Z.Moravec, M = M. Tichý, Q = J. Tichá, V = V. Vanýsek

Design.	Observ.time 1994 mm dd.ddd	Exp. [sec.]	β [°]	Δ [AU]	r [AU]	10^3 km per pixel [N-S]	10^3 km per pixel [E-W]	Observer(s)
941013	10 14.152	120	45.8	0.852	1.382	1.16	0.99	C,M,Q,V
941014	10 15.119	30	45.9	0.844	1.380	1.15	0.98	M,Q
941015	10 16.039	30	45.9	0.836	1.378	1.14	0.99	M,Q
941101	11 02.180	30	44.7	0.721	1.365	0.98	0.83	C,M
941122	11 23.164	20	39.6	0.632	1.426	0.84	0.72	C,M
941206	12 07.189	30	35.0	0.618	1.467	0.87	0.74	C

The method applied here is based on the determination of the surface brightness profile. In the case of 122P/de Vico the radiation pressure acceleration and estimation of possible dissipative process in the dust tail were based on the decrease of the integrated brightness of cross-section profiles measured at various distances from the nucleus perpendicular to the tail axis. This method had been applied by Schwarzschild and Kron (1911) in a study of comet 1P/Halley, and by Vanýsek *et al.* (1959) on data concerning the comet C/1956 R1 (Arend-Roland). However, these studies were based on the photographic photometry. Similarly, the available data concerning the photometric profiles of inner coma of

Table 2. Observational circumstances of comet 122P/de Vico. †$\alpha = 90° - \beta$. Observers: C = Z. Moravec, M = M. Tichý, Q = J. Tichá, V = V. Vanýsek

Design.	Observ.time 1995 mm dd.ddd	Exp. [sec.]	β [°]	Δ [AU]	r [AU]	10^3 km per pixel	10^3 km per pixel $1/\cos\alpha$†	Observer(s)
951003	10 04.159	60	71.3	0.992	0.660	1.25	1.32	C,M
951004	10 05.160	60	71.9	0.985	0.659	1.24	1.30	C
951008	10 09.135	40	73.0	0.966	0.662	1.22	1.28	M,Q
951009	10 10.112	40	73.1	0.963	0.664	1.22	1.27	M

bright comets has been obtained mostly from photographic material only. Since the linearity of the CCD is guaranteed over many orders of the flux, it may be expected to provide more realistic data concerning the surface photometry of extended sources. The properties of the dust in the cometary tail, namely the size distribution, can be derived from the observed brightness distribution of the cometary dust tail by the application of the Finson-Probstein dynamical model (Finson and Probstein, 1968a, 1968b; Sekanina and Miller, 1973). However this model has some limitations and it is strongly dependent on the virtually unknown distribution of radiation pressure efficiency factor of the dust particle cross-section. Although the method in this paper is applied under simplifying assumption, the results indicate that at least the dissipation process in the tail can be regarded as one of most significant dust grain characteristics.

2. Determination of dissipation coefficient

The brightness B_s of integrated along the cross-section line l oriented perpendicular to the tail axis at the distance s from the nucleus is given by the relation

$$B_s = \int_0^\infty B_{s,l}\mathrm{d}l = \sum_{l=1}^{n} B_{s,l} \qquad (1)$$

where $B_{s,l}$ is the brightness measured in the pixel at point $[s, l]$.

The integrated brightness contains two components: the continuum of the scattered radiation on the dust grains and some molecular emission. Since from the observational data it is very difficult to discriminate the dusty component from the gaseous one, we have accepted two alternative assumptions: a) the scattering of the solar light on the small dust particles is dominant, and molecular radiation can be neglected, b) strong molecular emission of the plasma tail radiate on the continuum background.

2.1. The continuum radiation represents B_s

The following method of the estimation of the acceleration in the dust component of the cometary tail is based on the assumption that the surface brightness B_s of the tail at the distance s from the nucleus and heliocentric distance r is determined by the equation of continuity in the dust flow and the dimensionless life-time parameter $\tau_r = (t_s - t_0)k_r$ of the small particles defined by the dissipation coefficient k_r. Assuming that in a sufficient time interval $\Delta t \geq t_s - t_0$ the dust production rate is constant, then

$$B_s = B_{s_0} \left[\frac{s_x}{s_0}\right]^{\frac{1}{2}} e^{-\tau_r} \tag{2}$$

where $\tau_r = tk_r$. The time $t = t_s - t_0$ elapsed from the time of the passage of particles through the cross-section at s_0 is

$$t = \sqrt{\frac{2}{\mu g_r}} \left(s_x^{\frac{1}{2}} - s_0^{\frac{1}{2}}\right) \tag{3}$$

The radiation pressure acceleration in the anti-solar direction is

$$\mu g_r = \mu G M_\odot r^{-2} \tag{4}$$

where $GM_\odot = 1.3344 \times 10^{20}$ m^{3}s^{-2} is the solar-centric gravitation constant (by definition positive) and $\mu = \beta - 1$. The ratio $\beta = F_{rad}/F_\odot$ of the light-pressure F_{rad} to the solar-centric gravitation force $F_\odot$ is defined as

$$\beta = \Gamma \frac{\eta_p}{\rho_d a} \tag{5}$$

where $\Gamma = 5.78 \times 10^{-4}$ kg m^{-2}, η_p is the radiation pressure efficiency and ρ_d is the density of dust particles of radius a. In a straight and narrow dust stream, the value of radiation pressure acceleration must be significantly large and $\mu \geq 1$, thus the limit of mean radius and the dust grains density is constrained by the condition that $\rho_d a \ll \eta_p \Gamma$. For absorbing submicron particles $\eta_p \simeq 2$, and if $\mu \simeq 5$, then $\rho_d a \leq \Gamma/3 = 2 \times 10^{-4}$ kg m^{-2}. Therefore for particles of radii between 0.5 to 1 μm the densities should be in the range from 200 to 400 kg m^{-3} as can be expected for "fluffy" grains. It should be noted that in such case the ejection velocity v_e of the dust grains from the nucleus (for which an upper limit is about 1 km s^{-1}) can be neglected, because at the cometo-centric distance $s_0 = 5 \times 10^4$ km the cometo-centric velocity $v_s = \sqrt{v_e^2 + 2\mu g s} \gg v_e$. The sunward apex distance of the parabolic envelope formed by the dust coma $D = v_e^2/2\mu g_r$ will be about 7×10^3 km.

If the dust particles have the properties of "fluffy" and CHON grains some kind of disintegration mechanisms could be expected in the dust tail for instance sublimation by heating, disruption of grains by electrostatic charge or even change of the albedo. The dissipation coefficient represents a parameter indicating whether or not the lifetime of dust particles is substantially longer than their appearance in the tail structure, or if their optical efficiency remains unchanged. Therefore κ_r as well as μ are significant, but unfortunately not unbiased, parameters of the dust grains properties. Therefore the dissipation parameter can be expressed as

$$\kappa_r = \left(\frac{k_r^2}{\mu}\right)^{\frac{1}{2}} \tag{6}$$

or reduced at heliocentric distance $r = 1$ (in AU) $\kappa_1 = \kappa_r r^n$ where $n = 2$ is assumed. In this definition the dissipation coefficient is derived from observational data under the assumption of a nominal value of $\beta = 2$. The values of κ_r as well as of κ_1 obtained for comet P122/de Vico are summarized in Table 3.

Table 3. Comet 122P/de Vico. r = heliocentric distance, κ_r = dissipation coefficient at r, κ_1 = dissipation coefficient reduced at $r = 1$ AU, s_0 and s_n are distance limits used for k_r evaluation

Date	r [AU]	κ_r [s^{-1}]	κ_1 [s^{-1}]	s_0 10^3 km	s_n 10^3 km
1995 10 04	0.660	1.84 $\times 10^{-5}$	0.82 $\times 10^{-5}$	52.3	287
1995 10 05	0.659	1.83 $\times 10^{-5}$	0.82 $\times 10^{-5}$	52.3	235
1995 10 09	0.662	2.33 $\times 10^{-5}$	1.04 $\times 10^{-5}$	52.3	222
1995 10 10	0.664	2.40 $\times 10^{-5}$	1.05 $\times 10^{-5}$	52.3	327

2.2. Molecular features of the tail plasma dominate in B_s

It is evident that even the upper limit of the lifetime of the dust particles inferred from κ_r is only 14 hours. This finding contradicts the plausible assumption that the lifetime of the dust grains should be almost infinitely long. It must be noted, however, that the measurements were performed only up to the cometo-centric distance 3×10^5 km from the innermost coma. In this region the contribution of small "fluffy" and unstable dust particles to the optical efficiency of the dust tail may be still substantial and it may gradually decreases with the distance from the nucleus owing to grain disintegration into smaller submicron particles with different optical parameters.

On the other hand, since the narrow streams are present on the tail images of 122P/de Vico obtained with a R filter, a substantial contribution of the ionized molecular species must be considered as another alternative. Among the most abundant ions of the plasma tail are CO^+ and H_2O^+. The Baldet-Johnson and tail systems of CO^+ have numerous bands in near-UV and optical ranges up to 620 nm. Faint bands of ionized CO probably account for some ionic features in the tail, even in the red spectral region. H_2O^+ have strongest red lines at

615.8 nm. Therefore both ions may be responsible for ion tail structures on the red images. Since the ratio $N\,[H_2O^+]/N[CO^+]$ is highly variable from one comet to another and variable with time, the contribution of each of these species to the ion tail brightness in the red region is uncertain. Nevertheless, the method discussed above for the determination of the dissipation coefficient may also be applied for the ion tail. The value of β in this case is virtually unknown, but $\mu \gg 1$ is a realistic assumption. Thus, one can conclude that the effective lifetime of these ions at the heliocentric distance 1 AU is significantly shorter than 10^5s.

3. Inner coma of 19P/Borrelly

The preliminary analysis of the brightness distribution in the coma of the comet 19P/Borrelly indicates a population of larger dust grains for which $\mu \leq 1$ dominates there. In Tab. 4 values of exponent n are summarized in the relation for the coma brightness distribution

$$B_\rho = B_{\rho_0} \left(\frac{\rho}{\rho_0}\right)^n \tag{7}$$

These values are derived from photometric profiles measured in four direction relative to the central coma condensation. Table 4 summarizes values of exponent n in four directions relative to the central coma condensation (N = north, E = east, S = south and W = west). The distance limits ρ of the validity of the given value n are expressed in 10^3 km. It is evident that $n \simeq 1$ as could be expected from the standard models of the coma. Preliminary results have shown that the brightness distribution in the inner coma is controlled mainly by larger particles.

Table 4. Comet 19P/Borrelly, values of the exponent n (N = north, E = east, S = south and W = west of the central condensation). Distance limits ρ are expressed in 10^3 km

Date	N	ρ	S	ρ	E	ρ	W	ρ
1994 10 14	1.25	≤25	1.15	≤25	0.8	≤10	1.11	≤30
1994 10 14	-	-	-	-	1.5	≥15	-	-
1994 10 15	1.28	≤30	1.16	≤25	0.75	≤30	1.46	≤10
1994 10 15	-	-	-	-	≥1.5	≥10	1.1	≥15
1994 10 16	1.05	≤13	1.68	≤10	0.8	≤10	1.48	≤30
1994 10 16	≥1.5	≥15	1.25	≤25	1.27	≥15	-	-
1994 11 02	1.08	≤25	1.15	≤25	0.6	≤10	1.05	≤30
1994 11 02	-	-	-	-	1.4	≥15	-	-
1994 12 07	1.25	≤25	1.40	≤30	0.9	≤20	≃1.0	≤30
1994 12 18	1.25	≤25	1.15	≤25	≃1	≤20	≃1.0	≤30

4. Conclusions

Since the joint occurrence of light elements in CHON particles with silicates strongly points to the presence of an organic abundant component in cometary dust particles (Grün *et al.* 1990). It could be assumed that the dust grains are composed of a somewhat fluffy mineral core which is imbedded in an even more fluffy refractory organic mantle, where the binding material may be polymerized hydrocarbons (Boehnhardt *et al.* 1990), then the structure and composition of such particles might be unstable in the solar radiation field and in the solar wind. We have applied a simple method on the surface photometric data of 122P/de Vico comet to check the validity of this assumption. It is shown, that in the dusty tail near the coma, where the contribution of small "fluffy" and unstable dust particles to the surface brightness of the tail could be substantial, the decrease of integrated brightness with distance indicates the effects of some kind of disintegration mechanism. The apparent lifetime of grains inferred from the tail photometry is less than one day at the heliocentric distance 1 AU. It might be either sublimation by heating, disruptions of grains by electrostatic charge, or even the change of the albedo.

It is nonetheless very difficult to exclude another plausible possibility that the fast decrease in the integrated brightness B_s is either caused by the plasma tail ions emission in the red spectral range, or it is in fact an effect of dissipation of the molecular plasma species combined with the disintegration of the dust grains in the cometary tail. Unfortunately there is no available narrow band photometric or spectroscopic data from which one could distinguish the plasma from the dust tail structures in the spectral range 570 up to 800 nm.

The preliminary results of the brightness distribution in the coma of 19P/Borrelly have shown that $n \simeq 1$ as could be expected from the standard models of the coma. It indicates that population of larger dust grains for which $\mu \lesssim 1$ dominates there.

Acknowledgements. This study was supported by the Grant Agency of the Czech Republic, Reg. No. 205/96/0042 and Reg. No. 205/96/0213.

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