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# METALLIC ATOMS AND IONS IN COMETS: COMET HALLEY 1986 III

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## Abstract

The origin of metallic atoms and ions in the cometary comae is investigated theoretically. Two effects are revealed in the comas of bright comets, namely Na anomalous type effect is possible within the gas-dust jets of comet P/Halley 1986 III due to cooling cometary dust by cryogenic gas flow from the nucleus, and the production of ions of refractory elements ($Fe^+$, $Si^+$, etc.) at large heliocentric distances is possible in the comas of the Halley type dusty comets due to high-velocity impacts between cometary and zodiacal dust particles. Spectral observations of comets with high sensitivity and spatial resolution are important for studying both comets and interplanetary dust.

## Introduction

The investigation of a metallic component in comets is important in different aspects. The emissions of the refractory metallic atoms (Fe, Ni, Si, etc.) have usually been detected in Sun-grazing comets at heliocentric distances $R \simeq 0.01$ AU (see, e.g., Preston, 1967; Oppenheimer, 1980, and references therein). Meanwhile, in situ measurements carried out within the coma of comet P/Halley 1986 III by VEGA and GIOTTO spacecraft near $R = 1$ AU led to the discovery of metal ions of the $Fe^+$ type (Gringauz et al., 1986; Krankowsky et al., 1986; Balsiger et al., 1986).

Anomalous distribution (i.e. intensity maximum displaced from the cometary nucleus towards the Sun) of the Na D-line emissions in the head of the bright comet Mrkos was detected by 200-inch Palomar telescope in 1957, the origin of which is the puzzle in the physics of comets (cf. Greenstein and Arpigny, 1962; Wurm, 1963; Dobrovolsky, 1966; Ibadov, 1985).

Metallic atoms have the low ionization potentials and in this connection the short photoionization time scale - of the order of $10^4$ sec at $R = 1$ AU (Shklovsky, 1960; Wurm, 1963), so that generation mechanisms of metal atoms may also be important in the problem of the ionization of the cometary matter, particularly, of the inner coma, giving the onset of the ray structure of the ion tails of comets (see Marochnik, 1964; Jackson and Donn, 1968; Wurm, 1968).

In the present report the problem of the origin of metal atoms and ions in cometary comae related to the data from VEGA and GIOTTO spacecraft is considered taking into account both modern view on the physical conditions in the near-nuclear region of bright comets and high-velocity interaction between cometary coma and Zodiacal dust cloud.

## Possible anomalous distribution of sodium atom emission in the coma of comet Halley

Sodium atom emissions are observed at heliocentric distances $R \lesssim 1$ AU not only in the cometary heads but also in the type II cometary tails (see Levin, 1964), i.e. at cometocentric distances which are essentially more than the photoionization scale length for sodium atoms. This indicates that the source of metallic atoms are dust particles emitted from the cometary nucleus and irradiated by solar radiation.

The rate of evaporation of dust particles depends on their temperature exponentially, so that for the appearance of the anomalous distribution of free sodium atoms in the cometary head it is essentially not only the character of a distribution of dust particles concentration (for example, the presence of a dust envelope) in the coma, but also of dust particles temperature $T = T(r)$. This question is actual and requires the special consideration in connection with the essential progress, achieved during the last years in the understanding of the physical conditions in the cometary comas.

The temperature of gas in the inner comae of both telescopic and bright comets is extremely low: $T_g \lesssim 200$ K at cometocentric distances $r \lesssim 10^3$ km (see, e.g., Shimizu, 1976; Bisikalo and Strelnitskij, 1985; Marov and Shematovich, 1987). Along with that the density of molecules near the nuclei of bright comets is sufficiently great ($n_g \gtrsim 10^{13}$ molecules/cm$^3$ see Dobrovolsky, 1966 p.204; Shulman, 1987 p.18), so that the application of a vacuum approximation to the thermal regime of dust particles of the cometary atmospheres become invalid: the depression of the temperature of cometary dust due to cooling by intense gaseous flow from the subsolar zone of a nucleus is possible (Ibadov, 1987a). The displacement of the zone of the onset of dust particles evaporation and, respectively, of the zone of maximal concentration (and emission) of sodium atoms towards the Sun is determined as

$$r_{max} = 2.5\,[\alpha\, V_g\, \dot{M}_g\, R^{3/2} / (\varepsilon^{1/4}\, \text{æ}^{3/4}\, \mu_g\, k_s)]^{1/2} = \left\{ \begin{array}{l} 7\times10^5 \;/k_s^{1/2}\,, \\ 2\times10^6 \;/k_s^{1/2}\,. \end{array} \right.$$

Here the numerical estimate is made for comet Halley 1986 III, when the formula parameters (in CGS) have the following values: accomodation coefficient of the gas molecules (of the $H_2O$ type) on the surface of dust grain $\alpha$ ($T_g \lesssim 200$ K) = 1; the local mean thermal velocity of molecules of gas $V_g$ ($T_g = 200$ K) = $5\times10^4$ cm/s; the gas production rate of the nucleus $\dot{M}_g$ ($R = 0.8$ AU) = $4\times10^7$ g/s, the molecular weight of sublimating molecules $\mu_g = 18$ (Gringauz et al., 1986); the integral coefficients of an absorption of the solar radiation and a heat emission from dust grain $\varepsilon = \text{æ} = 1$ for the upper line (corresponds to strongly absorbing particles with the albedo $A \simeq 0$) and $\varepsilon = \text{æ} = 0.1$ for the lower line (corresponds to metallic particles); $k_s = S_a / S_t$ is the anisotropy coefficient of matter ejection from the cometary nucleus, $S_a$ is the area of the effectively emitting subsolar zone (i.e. the area occupied by gas-dust jets) of the nucleus, $S_t$ is the total surface of the nucleus, so that at $k_s = 0.1$ (Keller et al., 1986) we have $r_{max} = 20$ km and 70 km for the two types of dust particles, correspondingly. During the periods of cometary brightness outbursts when $\dot{M}_g$ increases by several times $r_{max} \simeq 100$ km.

Thus, the displacement of the brightness maximum of the sodium D-lines (and emissions of other atoms and molecules ejected from grains) towards the Sun to the cometocentric distance $r_{max} = 20$–$70$ km is possible within gas-dust jets of comet Halley due to depression of dust temperature (and its evaporation rate) caused by expanding cryogenic relatively dense gas in the nearnuclear region. As shows above formula, the gas production rate of a comet may be determined, if the value of a displacement of emission maximum of the sodium type volatile metal atoms is determined from observations. So, it is important spectral observations of comets with high spatial resolution.

## Origin of refractory metal ions in the coma of comet Halley 1986 III

The presence of the $Fe^+$ type ions in the comet Halley's coma was discovered by the VEGA and GIOTTO in situ measurements on march 1986 (see Gringauz et al., 1987). At the same time calculations show that at heliocentric distances under consideration ($R \geq 0.8$ AU) the sublimation of refractory dust particles of the cometary coma in the field of electromagnetic and corpuscular radiations of the Sun is negligibly small for appearing the detectedions of the Fe type (Ibadov, 1980; Dobrovolsky and Ibadov, 1981; Ip and Axford, 1986; Geiss et al., 1986).

In the head of comet Halley the dust to gas production rate ratio $\mu \equiv \dot{M}_d / \dot{M}_g \geq 0.1$ (Sagdeev et al., 1986). The passage of such dusty comets through the Zodiacal dust cloud is accompanied, mainly, not by the meteor-like, but by the explosion-type process, namely by production of expanding plasma clots from high-velocity collisions of cometary and zodiacal dust particles (Ibadov, 1987b).

Using the continuity equation for the mass flow of the ionization products of colliding dust particles we can find the relation for the quasistationary concentration of metallic ions in the region of collision, $n_i (r_e , R)$; $r_e$ represents the action radius of the explosion-type mechanism, i.e. the cometocentric distance where the intense transformation of dust particles onto plasma clots takes place.

According to GIOTTO measurements the concentration of ions in the cometary coma varies as $1/r$ in the region of $r \lesssim 10^4$ km (Balsiger et al., 1986). Taking it into account, the radial distribution of the concentration of ions, produced from collision of cometary and interplanetary dust, may be presented in the form

$$n_i(r,R) = [(k_m A_i \rho_s V)/(m_i V_i)](r_e / r), \quad r_e = \dot{M}_d \sigma_{dd} / (4 m_d V_d k_s).$$

Here $k_m$ is the coefficient for producing plasma clots from cometary and interplanetary dust; $A_i$ is the mean abundance of the kind i element in the colliding dust grains (in stony meteoroids $A_i = 0.15$, $0.2$, $0.15$ for Fe, Si, Mg, respectively); $\rho_s \equiv \rho_s(R)$ is the spatial mass density of the Zodiacal dust cloud; $V \equiv V(R)$ is the relative velocity of the colliding dust particles; $m_i$ is the ion mass; $V_i$ is the expansion velocity of the coma ion component; $\sigma_{dd} = 2\pi a^2$ is the effective cross section for the collisions of cometary and zodiacal dust particles, $m_d$ is the probable mass of the coma dust particles, $V_d$ is the mean velocity of their outflowing from the nucleus.

Using the value of the concentration of $Fe^+$ ions measured by Vega-2 spacecraft $n_i$ ($r = 2 \times 10^9$ cm, $R = 0.8$ AU) $\simeq 1$ ion $cm^{-3}$ (Gringauz et al., 1987) and accepting $k_m = 2$, $A_i(Fe) = 0.2$, $V = 8 \times 10^6$ cm/s, $m_i = 10^{-22}$ g

$V_i = 10^5$ cm/s, $\dot{M}_d$ (R = 0.8 AU) = $10^7$ g/s, $\sigma_{dd} = 6\times10^{-8}$ cm$^2$ , $m_d$ = $10^{-12}$g, $V_d$ = $5\times10^4$ cm/s, $k_s$ = 0.3 (Sagdeev et al., 1986; Keller et al., 1986) we find by above formula $\rho_s$ (R = 0.8 AU) = $6\times10^{-22}$ g cm$^{-3}$. This value corresponds to the expected mean mass density of the interplanetary dust (see, e.g., Grun et al., 1985).

## Conclusion

Distribution of the emissions of atoms of volatile metals, such as Na, may serve as indicators of physical conditions in the inner coma of comets, particularly, in the gas-dust jets.

Ions of refractory elements, such as $Fe^+$ , detected in the coma of comet Halley 1986 III by VEGA and GIOTTO spacecraft, may be generated due to high-velocity impacts between cometary and zodiacal dust particles, and may serve as indicators of interplanetary dust clouds.

Spectral observations of comets with high sensitivity and spatial resolution are important for studying both comets and interplanetary dust.

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