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COMETS AS OBJECTS FOR MODELLING PHENOMENA IN STELLAR SYSTEMS

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The idea of the production of metal atoms, metal ions and X-ray radiation due to the generation of a high-temperature explosive phase in cool regions of space from high-velocity collisions of dust particles is developed. Modern data on the ion and dust comae of comets along with data on the Zodiacal dust cloud, on the one hand, and atom/ion composition of cool stellar envelopes along with cosmic X-ray radiation, on the other hand, indicate the essential role of dust–dust collision processes in both comets and star dust envelopes in stellar systems.

KEY WORDS Comets, star dust envelopes, stellar systems, modelling, high-temperature phase, metal atoms/ions, X-ray radiation

1 INTRODUCTION

New methods of investigation, especially extra-atmospheric observations at different ranges of the electromagnetic radiation of the Universe and *in situ* measurements during missions to Solar System objects have led to essential expansion of the data base on space systems of different scales.

The discovery of the extrasolar cosmic X-ray radiation (1962, Sco X-1) was complemented by detection of an intense diffuse component. The distribution of the intensity of this background component in the soft X-ray range (0.1–2 keV) has a quasi-isotropic nature including the direction of the galactic plane where an extragalactic component below 2 keV is absorbed strongly. It indicates the presence of physical processes resulting the generation of a high-temperature ($T = 3 \times 10^5$–10^7 K) phase in the interstellar medium within 100–200 pc of the Solar System (Longeir and Sunyaev, 1971; Tanaka and Bleeker, 1977; Apparao *et al.*, 1979).

Physical processes giving rise to extended soft X-ray emission from planetary nebulae have also to be established (Apparao and Tarafdar, 1989; Kreysing *et al.*, 1992). Besides, observations of dusty discs of young stars led to the detection of the β Pictoris phenomenon including the appearance of Fe II, Mg II and Na I lines (Lagrange *et al.*, 1987; Grinin *et al.*, 1994, 1995).

The discovery of ions of refractory metals of the type Fe II in the coma of comet Halley 1986 III at large heliocentric distances ($R = 0.8$–0.9 AU) by the *VEGA* and *GIOTTO* missions posed the problem of searching for new mechanisms of ionization of the comae of comets and so establishing the origin and diagnostic potential of metal ions like Fe II (Balsiger *et al.*, 1986; Gringauz *et al.*, 1986; Krankowsky *et al.*, 1986). At the same time the modern state of spectral observations of comets is such that the cleaning possibility of studying comets in the X-ray range is important (Ibadov, 1985, 1987, 1996a).

In such a situation an interdisciplinary problem arises, namely, the joint analysis of the corresponding data on different objects considered for revealing phenomena and mechanisms which are common for these objects.

2 THE SIMILARITY OF COMETS AND STELLAR OBJECTS

According to results of ground-based and extra-atmospheric observations of comets and *in situ* measurements during the *VEGA* and *GIOTTO* missions to comet Halley nuclei of comets are intense sources of gaseous-dusty matter. The rate of loss of matter by nuclei of bright comets like Mrkos 1957 V and Halley 1986 III is $\dot{M}_c = 10^7$–$10^9/R_c^2$ g s^{-1}, so that the density of the flow of matter ejected from an active zone of the nucleus is

$$J_{0c} = \frac{\dot{M}_c}{4\pi r_{oc}^2 k_a R_c^2} = 10^{-5}/R_c^2 \text{ g cm}^{-2}\, s^{-1}. \tag{1}$$

Here $r_{oc} = 1$–10 km is the radii of cometary nuclei, $k_a = 0.1$ is the fraction of an area of the actively sublimating surface of the nucleus with respect to its total area, R_c is the heliocentric distance of a comet in AU.

The density of matter near the surface of a cometary nucleus is equal to

$$\rho_{oc} = \frac{J_{oc}}{V_{mc}} = 10^{-10}/R_c^2 \text{ g cm}^{-3}, \tag{2}$$

where V_{mc} is the velocity of a radial expansion of the cometary coma.

The orbital velocity of motion of the cometary gaseous-dusty cloud near the perihelion is determined as the parabolic velocity of the comet

$$V_c = \left(\frac{2GM_\odot}{r_c}\right)^{1/2} = \frac{40}{R_c^{1/2}} \text{ km s}^{-1}, \tag{3}$$

where G is the gravitational constant, $M_\odot$ is the mass of the Sun, $r_c = 215 r_\odot R_c$ is the heliocentric distance of the comet, $r_\odot$ is the solar radius.

The passage of bright comets through the interplanetary medium is accompanied by a complex of physical processes. The interaction of the gaseous-dusty comae of where $M_s = 10M_\odot$ is the mass of the star, R_s is the distance of dust particles from the centre of the star in AU.

Thus, the passage of cold cometary-like objects (dust clouds) through circumstellar dust envelopes (stellar zodiacal dust cloud) is accompanied by high-velocity ($>$ 10–100 km s^{-1}) impacts of dust particles. This process results in the production of metal atoms, metal ions, including multicharged ions, and X-ray radiation. Analogical processes occur in quickly moving envelopes of eruptive stars and, also, in high-velocity (100–300 km s^{-1}) clouds falling onto the disc of the Galaxy and colliding with dust clouds of the interstellar medium. Such collision processes occur intensively also during the passage of spacecraft through the atmospheres of comets.

3 CONCLUSIONS

Comets and certain types of stellar system objects such as eruptive stars, planetary nebulae, young stars with dust envelopes and comet-like dust clouds, WR-type stars, and high-latitude clouds falling onto the disc of the Galaxy are characterized by a process which is common to all these objects. It is the impact of dust particles with high ($>$ 10–100 km s^{-1}) relative velocities.

Collisional processes with the participation of dust particles of such objects result in the production of hot plasma on heavy elements (Fe, Si, O, etc.) in cool regions of space. Correspondingly, metal atoms, metal ions, including multicharged ones, and X-ray radiation are generated in such regions.

Bright comets may be considered in a broad sense, including in programmes of future missions, as objects for modelling physical processes in the envelopes of intensively evolving stellar objects. Further joint investigations of comets and stellar systems, in both theoretical and observational aspects, are an actual problem.

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comets with the Zodiacal dust cloud results in the development of meteor-like and explosion-type processes.

The rate of influx of interplanetary dust into the cometary coma is

$$J_{mz} = \rho_z V_{cz} = 10^{-15}/R_c^2 \text{ g cm}^{-2} \text{ s}^{-1}, \tag{4}$$

where ρ_z is the density of the Zodiacal dust cloud, and V_{cz} is the relative velocity of cometary and interplanetary dust.

Calculations show that the origin of ions like Fe II in the coma of comet Halley 1986 III is mainly connected not with the sputtering of cometary dust by the solar wind protons, but with the production of hot expanding plasma blobs from the impacts of zodiacal dust particles with the dust coma of the comet (Ibadov, 1996b). Moreover, generation of a high-temperature ($T = 3 \times 10^5$–10^7 K) phase in the comae of comets in the inner heliosphere ($R = 0.01$–1 AU) from collisions of dust particles indicates that certain comets are active emitters of X-ray radiation ($h\nu = 0.1$–5 keV) and, hence, they are potential objects of high-energy astrophysics. Thus, comets and zodiacal dust cloud in the inner heliosphere may be studied by methods of X-ray astronomy along with these of radio, infrared, optical and ultraviolet astronomy (Ibadov 1985, 1996a).

The nearest objects to comets in respect of the properties under consideration are eruptive stars, stars with extended atmospheres and dust envelopes. Indeed, the rate of loss of matter by Wolf–Rayet (WR) stars is $\dot{M}_s = 10^{-5} M_\odot \text{ yr}^{-1}$. Hence, the density of the flow of ejected matter near the surface of the star is equal to

$$J_{ms} = \frac{\dot{M}_s}{4\pi r_s^2} = 10^{-4} \text{ g cm}^{-2} \text{ s}^{-1}, \tag{5}$$

and the corresponding density of the matter is

$$\rho_{os} = \frac{J_{ms}}{V_{ms}} = 10^{-12} \text{ g cm}^{-3}. \tag{6}$$

Here $r_s = 10 r_\odot$ is the distance from the center of the star, $V_{ms} = 1000$ km s^{-1} is the velocity of radial expansion of the star's atmosphere.

The distribution of the electron temperature in the extended stellar atmospheres of WR type stars, $T_e(r_s > 5r_\odot) < 5 \times 10^4$ K, corresponds not to a chromospheric-coronal model, but to a nebular model of the atmosphere (Cherepashchuk, 1981; Khaliullin and Cherepashchuk, 1982). Cooling of the expanding stellar atmosphere, similar to expanding (> 10–100 km s^{-1}) envelopes of eruptive stars, is accompanied by the production of dust particles directly in the atmosphere due to condensation of atoms of refractory elements like C, Fe, Si. A corresponding strong excess of infrared radiation from such objects has been discovered (Arkhipova, 1981; Kostyakova, 1982; Bochkarev, 1992).

The orbital velocity of motion of particles of the circumstellar dust envelope equals

$$V_{cs} = \left(\frac{GM_s}{r_s}\right)^{1/2} = \frac{100}{R_s^{1/2}} \text{ km s}^{-1}, \tag{7}$$

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