PLEOCHROISM PROPERTIES OF THE COMETARY MINERALS

I. A. Simonia [*]

School of Natural Sciences and Medicine, Ilia State University, Cholokashvili str., 3/5, Tbilisi 0162,Georgia

The present article deals with the phenomenon of luminescence of the mineral halos of the comets. It is shown that luminescence will be provided as a precondition for a stable and long-term coloration of mineral halos of the comets. It is proposed also that the pleochroism of the biaxial minerals of cometary halo will provide rapid changes or alternations of the colors of this halo. A mechanism of a rapid coloration of the cometary halo is proposed. Possible minerals responsible for such a rapid coloration are considered. Numerical conditions of occurrence of such the phenomenon are provided.

Keywords:comets—dust-–mineral-–pleochroism–luminescence

1. INTRODUCTION

Comets, as the small bodies of the Solar System, consisting of the icy, dust and gaseous components of matter, exhibit unique physical properties when moving on orbits during the evolutionary periods, and interact with external factors and forces. The icy nucleus of the comets surrounded by the gas, dust shells, is characterized by corresponding spectral and photometric features. Namely, the optical spectra of comet consist of the emissive and reflective components. The gas molecules of the cometary comas fluoresce resonantly. The dust and icy halos of comets, representing the clouds and shells of variously dispersed dust and ice grains, scatter the solar continuum [1]. Today, a number of daughter molecules and ions of cometary comas formed as a result of photo dissociation and photo ionization processes, are known and include $C_2, C_3, CN, CH, CO_2, OH, CO, NH, NH_2, CH_{II}, CO_{II}$ etc. [2]. There are known also the parent molecules – sources of the daughter ones. They include:

[*] E-mail: irakli_simonia@iliauni.edu.ge

$H_2O, HCN, C_2H_2, CH_3OH, C_2H_6, H_2CO$ [3].These lists are incomplete and permanently expanding.

The following minerals and their classes detected in comets: glassy silicate minerals, organic refractory material, iron sulfide [4]; crystalline iron silicates, magnesium and mixed iron-magnesium silicates [5,6]; osbornite, gelenite, spinele, diopside [7]; Pyrrhotite, pentlandite [8,9]; forsterite, fayalite, orthoenstatite, magnesite [10, 11]; crystalline Mg-rich silicates, Fe sulfides, glassy phases including GEMS [12]. These authors noted that "the Deep Impact mission excavated material from the surface of comet 9P/Tempel1. The mid-infrared spectra of the dust ejected by the impact into the coma were interpreted as resulting from a mix of grains with compositions of amorphous carbon, amorphous pyroxene, amorphous olivine, crystalline Mg-rich olivine and crystalline pyroxenes. "The mineralogy of CP-IDPs mostly consists of anhydrous crystalline phases such as Mg-rich olivines and pyroxenes, low-Ni Fe sulfides and sub-micrometer glassy phases called GEMS. "In the comets Halley, Hale-Bopp, Hyakutake, and C/2001Q4 (NEAT) were found crystalline olivine, orthopyroxene, various silicates and other minerals [13]. Mentioned authors had noted: "even though the proportion of GEMS grains that are presolar is not well established, it is clear that cometary dust is a mixture of grains with very divers origins."

According to the theory proposed [14–17] the frozen hydrocarbon particles of the icy halo of comets luminesce under the influence of solar electromagnetic and corpuscular radiations, while this, in its turn, is manifested in the presence of narrow emission lines in the optical spectra of comets. As proposed in [14,17] not only the icy particles of the cometary halo luminesce but the mineral dust of the cometary halo, as well. Thus, when approaching to the Sun, a comet (nucleus and a gas-dust shell), resonantly fluoresces(gases), photo-luminesces (ice, mineral dust) and scatters (dust, ice, and nucleus) the solar radiation which stimulate the complex of the relict cometary matter to release and, evaporate. The released pristine matter of the comets is being photo-transformed rapidly, with losing its primary properties. In addition, regarding to relatively long and consistent processes, the fast-flowing and repetitive phenomena occur in the comets, namely, a quick color change of the cometary atmospheres. Let us consider a possible nature of this phenomenon.

2. PLEOCHROISM OF THE COMETARY MINERALS

The solar electromagnetic radiation (X-ray, UV) excites the photoluminescence of the icy and dust shells of the comets, while the fluxes of energetic electrons and protons of the solar wind excite the cathodolminescence of these shells [14]. These processes are becoming strengthened with reducing the heliocentric

distances of the comets, moreover, for the case of photoluminescence of halo the process is stationary, while for the case of cathodoluminescence of the cometary dust -of an episodic, and is characterized by flaring nature. Each of these processes will have their own features: positions and profiles of luminescence emissions, the quantum yield of the luminescence, after glow periods, and luminescence quenching curves.
Luminescence of the cometary ice and dust stimulated by the solar radiation may be responsible for changing the color index of the cometary halo. However, this is appropriate for the long time intervals (weeks, months).There can also be rapid changes in the color index of the cometary halos (a period of several tens of hours). For this phenomenon another mechanism of "coloration" of the comet shells may be responsible.

Among the cometary minerals revealed by [18], there is the ones with well-expressed properties of pleochroism - enstatite. We listed below some of minerals with pleochroism properties. Thus, to the composition of the icy, mineral halo of comets, these transparent or translucent minerals with the properties of pleochroism can belong in the form of biaxial crystals of different shapes and masses. All listed minerals has belong to mineral classes (types) which were discovered in comets (see references in section 1). We have derived data of mineral pleochroism from: webmineral.com; mindat.org; mineralcatalog.com.ua; gemdat.org; [19]. Minerals with pleochroism properties are diopside $CaMgSi_2O_6$(clinopyroxene,transparent/translucent,color of pleochroism: yellow, green, blue); enstatite $Mg_2Si_2O_6$ (orthopyroxene, translucent, color of pleochroism: red, yellow, green); bronzite $(Mg, Fe^{2+})_2[SiO_3]_2$(orthopyroxene, transparent, color of pleochroism: yellow, green); fayalite $Fe_2^{2+}SiO_4$ (olivine, transparent/translucent, color of pleochroism: red, yellow).

Listed minerals has clear color of pleochroism or some color tints. A comet approaching to the Sun, surrounded by the mineral halo consisting of a complex of the biaxial (or uniaxial) micro-crystals, will be exposed to integral solar light - the radiation of the optical range 4000 − 8000 Å. When the integral solar light passes through these biaxial multi-dispersed micro-minerals, they will become to color in one of the possible colors e.g. red, yellow green, or blue. For the terrestrial observer in case of the phase angle of a comet ($\alpha = 90°$) and the perpendicular location of the optical axis of the micro-mineral grain to the line of sight, this will be expressed in a particular color index ($m_B < m_R$). Over time, a spatial orientation of the extended dust micro-particles of the halo will be changed due to the axial rotation (or turn) of the cometary nucleus.

Consequently, the angle between the direction of the solar light passing and the optical axis of the corresponding micro-crystal will also be changed. In this case, the optical axis of the crystal (a micro-mineral grain) will already be positioned along the line of sight. This, in turn, willed to replacement of the color with the opposing one – red, as expressed in the condition $m_B > m_R$. In other words, an terrestrial observer, in the first case will fix the color index of the halo at the moment of pass of the solar light along the optical axis of the crystals, while in the second case the observer will fix another color index when the sunlight passes perpendicularly to the optical axis of the micro-crystals, comprising the mineral halos of the comets. The axial rotation of the comet nucleus and correspondingly, turning of the comet shells in a form of the heavy dust clouds, will mostly predetermine a spatial orientation of the asymmetric micro-mineral dust particles, with alternating positions of their optical axes in longitudinally and perpendicularly the line of sight of the terrestrial observer. In other words, for terrestrial observer the comet appears to be something more relatively blue or something more relatively red. Such alternation will occur quickly over several ten hours. Biaxial micro-crystal (mineral dust particle of halo) may also rotate around its optical axis. It will provide appearance of additional color or tint – yellow or green, and etc. Let us list here the necessary minimum of the conditions for observing this kind of phenomenon: $\alpha \leq 90°$ and $\Delta T \approx 1/4P$, where α is the phase angle of the comet, ΔT is the period of change of the color index, and P – is the period of the axial rotation of comet nucleus. These conditions are obvious for both the cases of the phase angle and the orientation of the conditional subsolar point of the cometary halo, that suffered a change by 90° during 1/4 part of the period of axial rotation of the comet nucleus. Pleochroism, of cometary halo micro-minerals, may occur with a rapid alternation of the color index of the cometary halo. We suggest naming such a phenomenon as a rapid coloration of the cometary halo.

Observation, fixing of this kind of phenomenon will make it possible to determine:

1) an approximate period of axial rotation of the comet nucleus; and

2) chemical- mineralogical composition of the mineral component of the cometary halo.

Peculiarities of such a phenomenon or difficulties of its detection may be associated with inclination of the cometary orbit to the ecliptic plane or inclination of the axis of rotation of the comet nucleus to the plane of its orbit and the specific content of minerals (biaxial micro-crystals, characterized by pleochroism) in the gas-dust shells of the comets.

Nevertheless, we suppose that in most cases of the orbital configuration of the comet, content of corresponding minerals of the cometary halo, would be satisfactory for the ground-based detection and investigation of this phenomena. Regarding observability and detectability of a rapid coloration of the cometary halo, it seems to be necessary to envisage the following circumstances:

1) possible spatial heterogeneity and irregularity of the mineral halos of the comets;
2) possible different spatial orientation of individual micro-grains - comprising components of the halo;
3) transparency (or Translucence) of each individual mineral micro-grain in general.

These circumstances are essential for the observability aspect of the research. However, if taking into consideration a higher probability of the chemical and mineralogical homogeneity of the mineral halo of the comets and the fact that the dust micro-minerals are transparent in most cases, as well as the factor of the light pressure (the solar light), we may conclude that a phenomenon of a rapid coloration of the cometary halo will be observable and detectable by the ground-based optical instruments and receivers. Recently, it was shown in the works [20–22] that for the comets C/2013 UQ4 (Catalina), 41P/Tuttle-Giacobini-Kresak in case of the phase angle $\alpha = 48°$ a rapid change of the B-R color index of the cometary halo is observed, that takes place during $2 - 3$ days. In our opinion, this indicates a rapid coloration of these mineral halo of the comets, while the periods of alternation of "color" (2- 3 days) can be 1/4 period of the axial rotation of their nucleuses. We do not exclude that for deeper understanding of the process of a rapid coloration of the cometary halo, the orbital instruments may become necessary. In fact rapid color variation of the cometary coma may be indirect sign of silicates, GEMS and oxide micro-minerals presence.

3. DISCUSSION

As the comets approach to the sun, the gas-dust shells of their nucleuses begin to form. The evaporating (released) matter of the comet nucleuses forms the gas comas and the icy and mineral dust halos. Under the impact of a hard solar electromagnetic radiation and the fluxes of the energetic charged particles of a solar wind, the parent molecules – the relict substances of the comet nucleuses are disintegrated into the daughter fragments, various derivatives, with losing primary properties of pristine matter. The spectral and photometric investigations of cometary atmospheres are in fact an analysis of the secondary properties of the cometary matter acquired with the constant interaction of cometary gas and dust with external factors and forces - solar radiation and gravity. For detection and further research the cometary relict matter, some different methods and approaches are required. As we have already indicated above, time and color of the cometary halo, in other words, a rapid variation of color, are the key factors in this issue. The icy and mineral halo of the comet nucleuses can luminesce intensely under the influence of the solar short-wavelength electromagnetic radiation and the fluxes of fast electrons and protons of the solar wind. Periodic rapid alternation of the color of comet halos may indicate chemical and mineralogical features of the minerals comprising these halos. Namely, spectra of the cathodoluminescence of a number of minerals may be characterized by two excesses (peaks) in the blue and red regions. We have proposed also that here it may be another explanation too - a different mechanism, that predetermines a rapid variation of color of the cometary halos. An integral solar light passing alongside the optical axis of the biaxial micro-crystals will get a certain color. The same light passing through the same micro-crystals (mineral halos of comets) but in this case perpendicularly to their optical axes will colorize these micro-crystals in another color (or tint). Taking into account the axial rotation of the comet nucleus when turning the sub-solar point of the halo by 90°, for the ground-based observer in the system the Sun - Comet - the Earth, a color of the cometary halo will be alternate and becoming first bluish and after a few tens of hours yellowish or reddish, and etc. The solar light pressure or electric, magnetic properties of micro-minerals of cometary dust halo may provide the same spatial orientation of all micro-minerals of the halo for the short time. This phenomenon, that we have named as a rapid coloration of the cometary halo conditioned by pleochroism of minerals, may become an effective channel of information about the physical and chemical properties of cometary minerals. It should be noted that an investigation of alternation of color of the cometary halo, regardless of its predetermining mechanisms - luminescence, pleochroism (immediately after the cometary bursts, flares), provides the possibilities for detection of the relict matter of the comets.

The phenomenon of a rapid coloration may have an unstable, episodic nature that will be conditioned by heterogeneity of cometary halo; the differences in the chemical-mineralogical composition and orientation of halo's micro-mineral dust particles. We do not exclude the cometary mineral halos may contain another classes or sub-classes of pleochroic minerals.

4. CONCLUSION

A color alternation of the comet halos is optical phenomenon. We have proposed mechanisms explaining such alternations through discussing the actual question - is it the luminescence of comet halo minerals or the pleochroism of the same minerals? Observation and a correct interpretation of this phenomenon open up a new opportunity in understanding the nature and features of the solid cometary matter.

Special international observational program for the study of these phenomena as well as the analysis of archival data allow us to make a critical breakthrough in understanding the nature of icy and mineral comet halos, with confirming, rejecting, or modernizing and deepening our proposed explanations of these physical phenomena.

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