DE GRUYTER Open Astron. 2019; 28: 1–12

Research Article

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Photoluminescence and Cathodoluminescence of the Solid Cometary Substance

https://doi.org/10.1515/astro-2019-0003
Received Mar 05, 2018; accepted Jul 02, 2018

Abstract: We have proposed that solar ultraviolet and corpuscular radiations may excite photoluminescence and cathodoluminescence of the solid cometary substance including mineral halos of comets. Main characteristics of such possible luminescence and physical mechanisms of these phenomena have considered. Results of the tentative identification of previously unknown cometary emissions and data of laboratory research of meteorites are presented. We have shown as well that cometary solid substance may demonstrate red luminescence – similar of red luminescence by the circumstellar dust. Some other aspects of the problem have also been considered.

Keywords: asteroids, comets, mineralogy, solar wind, solar radiation

1 Introduction

The investigation of comets and asteroids is an important trend in the modern astrophysics (Le Roy *et al.* 2015; Quirico *et al.* 2016). The Solar System bodies are exposed to solar X-ray and ultraviolet radiations as well as to fluxes of charged particles of the solar wind. UV photons and charged particles can cause luminescence from the surfaces of atmosphereless bodies including comets, asteroids, and transneptunian objects. Solar UV photons and charged particles may cause also photo- and cathodoluminescence of the cometary mineral and icy halos. These luminescence phenomena were discussed for the first time by Simonia & Simonia (2004); Simonia (2007, 2011, 2016). Detection and identification of these phenomena from small bodies of the solar system can become a new efficient method for the study of their surface and dusty halo composition, particularly for the mineralogy and the possible presence of silicate and carbonaceous dust.

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2 Possible photoluminescence andcathodoluminescence of comets substance

The photoluminescence of comets can be of fluorescence or phosphorescence character depending on the chemical-mineralogical composition of its surface and halo material. Under low temperature conditions, complex organics such as PAHs can demonstrate a bright photoluminescence with a high quantum yield within 50-90% (D'Hendecourt *et al.* 1986; Gudipati *et al.* 2003). The photoluminescence may provide the information on the chemical and mineralogical composition, temperature, and some peculiarities of crystal lattice (point defects) of cometary materials including mineral substance. The photoluminescence spectra of cometary substance will vary in intensity, band positions and shapes depending on the characteristic properties of the specific materials of their surfaces and halo. The detection of photoluminescence from ground-based telescopes will depend (i) on the quantum yield of the photoluminescence of the material of the given comet and (ii) on the albedo of the cometary substance. The minimum, but sufficient condition for detection of the photoluminescence of the comets will depend on a combination between a high quantum yield of the photoluminescence (L) of the material and an as low as possible albedo (A) of the latter. Numerically this can be expressed as $L \geq 50\%$, $A \leq 0.2$. The temperature of the cometary substance will have a high importance, as under low temperature conditions the quantum yield of photoluminescence of many substances increases significantly (Gudipati *et al.* 2003). In contrast to the conditions of laboratory experiments, the natural cosmic material is subjected to the influence of the whole range of the solar shortwave electromagnetic radiation spectrum. This, in turn, can favor a high intensity of photoluminescence of cometary substance.In many cases, photoluminescence intensity may not be weaker than the scattered solar radiation, but can dominate over the latter Simonia (2007, 2011). Taking into account the definite similarity between meteorites and certain comets it seems reasonable to carry out a series of laboratory experiments for comprehensive research of photoluminescence of meteorites and, in particular, of carbonaceous chondrites in context of cometary substance luminescence problem. This will allow to create a database for comparative analysis (*e.g.*, micro-and nano-minerals from nature and experiment, Gucsik *et al.* 2012b).

The Solar System small bodies are also influenced by the fluxes of solar corpuscular radiation, solar wind and plasma clouds. Solar flares have an important role in the processes of interaction of radiation with the surfaces of atmosphereless bodies. Solar corpuscular radiation can interact also with mineral halos of comets. At the distance of 1 AU from the Sun, the proton fluxes of the solar wind can vary within 10^8-10^{10} $cm^{-2}s^{-1}$ (Noyes 1983). Relativistic particles require not less than 8 minutes for propagation at the distance of 1AU, the electrons of 50 KeV or ions of 100 MeV amu^{-1} require 18 minutes and for ions 1 MeV amu^{-1} – 2.9 hours. For large and small solar flares the characteristic values of released energies can be expressed as follows: (3-5) $\cdot 10^{31}$ erg for electrons (of 20 KeV and higher) and (1-3) $\bullet 10^{31}$ erg. – for protons (of 20MeV and higher) (Noyes 1983). The release of a significant amount of energy during the solar flares takes place for a short period of time, in average, for tens of minutes. The fluxes of solar electrons and protons colliding with comets and other small bodies, in the absence of permanent magnetic fields, will cause an intensive cathodoluminescence of the solid materials of the mentioned bodies. The intensity of cathodoluminescence of the cometary substance can be especially high after solar proton flares. Cathodoluminescence of different materials is studied experimentally in the laboratory. Upon the bombardment of any matter with electrons, a great part of the kinetic energy of electrons penetrating into the matter is spent on heating and a smaller part of the energy – on excitation of cathodoluminescence and secondary electron emission. The particles of different energies can penetrate into the material containing luminophors at different depths (Leverenz 1950). For example 10 KeV electrons penetrate to average depth of a few microns. During the cathodoluminescence the energy is absorbed by all sites of crystal lattice and then is passed to the luminescence centers. Götze (2000) showed for the general case that, cathodoluminescence intensity is proportional to the acceleration voltage and the current density, but the power level used is limited by destruction of the specimen under electron bombardment. The basic process of cathodoluminescence involves the excitation of an electron to a state of higher energy followed by the emission of a photon in UV, visible or IR ranges, when the electron returns to the state of lower energy. The color and intensity of cathodoluminescence are conditioned by the real structure of the crystal lattice (exsolved phases, defects, impurities), which can be related to the conditions existing during crystallization. When the cometary substance is bombarded by electrons or protons, its surface or halo grains can start luminescing. The duration of cathodoluminescence of a small body will vary from some minutes to several hours. Too long exposure of cosmic luminophors to high-energy electrons (protons) can cause the luminophor destruction resulting in a full or partial loss of their luminescence properties. The practical detection of cathodoluminescence of small bodies will depend on: 1) quantum yield of cathodoluminescence of the substance of the given small body; 2) albedo of the given small body. Numerically, for the case of cathodoluminescence $L \geq 30\%$, and $A \leq 0.1$ will be favorable for detection from ground-based telescopes. Note that photoluminescence of comets and other small bodies is a long-term and stationary phenomenon, while the cathodoluminescence of small bodies is of short-term and flare character, although part of the latter, arising only from solar wind particles will also be a long-term phenomena varying only with the activity of the solar cycle.

Laboratory investigations shown that the spectral response of cathodoluminescence of one and the same meteoritic minerals is modified with the presence of different impurities and activators. The color of cathodoluminescence of meteoritic minerals depends also on the peculiarities of crystal lattice and different defects of specific minerals (Götze 2000). The cathodoluminescence spectra of meteorites are variable and show several separate narrow or wide emission bands. Cathodoluminescence spectra of minerals are frequently characterized by the presence of several pronounced peaks at a time, generally, two or more peaks in blue and red regions. For example, the spectrum of cathodoluminescence of diamond is characterized by two peaks near 435 nm and 615 nm. Taking into possible account the similarity of meteorites and mineral grains of cometary halos, one can expect that the spectra of cathodoluminescence of cometary halos will be similar to the spectra of their meteoritic analogs. The peculiarities of the cathodoluminescence of meteorites will be characteristic of the corresponding cometary halos as well and this fact will help the detection and characterization of cathodoluminescence of the latter. However, the use of laboratory analogs may not always be appropriate as it is necessary to consider the difference between laboratory and cosmic conditions. In the laboratory, the cathodoluminescence of cosmic analogs (mixture of minerals,) is excited by fluxes of low-energy charged particles, while the substance of cometary grains is bombarded with the fluxes of high-energy particles under low temperatures. At the same time, the quantum yield of the cathodoluminescence of cometary solids can be rather high and the spectral composition slightly different from that of meteorites. Diamond, quartz, forsterite and some other minerals are luminescing in red and other spectral regions under the action of the fluxes of electrons, X-ray and UV-photons. The spectra of luminescence of these minerals are often characterized by wide structureless bands in the red region with a peak near 6000 Å. The red luminescence of the dust in reflection, planetary and protoplanetary nebulae, the so-called extended red emission - ERE is well known (Furton & Witt 1992; Duley *et al.* 1997; Witt & Vijh 2004). The luminescence of the dust of nebulae appears as wide featureless bands in the range of 5400-9400 Å, peaking near 6100 Å (Ehrenfreund & Charnley 2000). If substance of cometary halos has red or reddish color and these halos consist of the above-mentioned mineral grains, we assume that comets can be also the sources of some kind of luminescence emission analogous to the interstellar ERE. However, such red luminescence emission can slightly differ from the usual ERE both in profile and in peak position. The results of laboratory investigation on revealing the fluorescence of IDPs and carbonaceous chondrites can serve as a justification of our hypothesis (Quirico *et al.* 2005). Interesting are also the results of Dartois *et al.* (2005); Chang *et al.* (2006); Keller *et al.* (2006). In the first case, luminescence is attributed to amorphous carbon, while in the second case, it is attributed to the presence of diamonds with specific impurities (nitrogen atoms) in the lattice. Both explanations are based on careful laboratory experiments. The presence of amorphous carbon in ISM dust is a well-recognized fact while the presence of nanodiamonds has been established in a few sources. Finally in the third case, Stardust samples do reveal the presence of a carbon phase analogous to the one detected in IDPs and previously studied by Quirico *et al.* (2005) who recorded their fluorescence spectra during Raman studies.

The fluxes of solar electrons and protons, X-rays and UV photons can excite the luminescence (with different intensities, spectral composition and duration) of the substance of comets and other small bodies. Detection of the luminescence of comets will depend on: the geocentric distance of comets, the quantum yield of the luminescence from their materials, the phase of solar activity, the temperature of the surface of the body, the energy of exciting radiation. The spectral composition of the luminescence of a specific cometary halo will depend on the chemical-mineralogical composition of the halo substance, on the energy of exciting radiation, the specific state of minerals, including the presence of various specific defects in the crystal lattice.

The important source of observational data for investigation of luminescence of the solid cometary substance might be the high-resolution spectra of various comets. Cometary atlases and other spectral data sets were published in last decades, for example, spectral atlas of 122P/deVico comet (Cochran & Cochran 2002) (Figure 1). In conjunction with lab-data for minerals luminescence it might be unique platform for the comparative analysis and description of physics and chemistry of the cometary solids.

Cochran & Cochran (2002) obtained optical spectrum of 122P/deVico comet by means of 2.7 m Harlan Smith telescope of McDonald Observatory and Coudé echelle spectrograph. The spectral resolving power was 60, 000 and signal/noise ratio extremely high. They noted that, for deVico comet gas/dust ratio was one of the highest known for a comet. They revealed bright unidentified emissions and weak features in the spectrum of this comet.

In our opinion optical spectrum of this bright comet will be suitable observational dataset for the comparative analysis in investigation of cometary dust properties.

3 Cathodoluminescence-based Laboratory Astromineralogy of the refractory minerals from Kaba meteorite – main methodology

Cathodoluminescence-based laboratory astromineralogy utilizes minerals (in meteorites) from nature and experiment (experimentally grown samples) to get more insights about the planetary bodies as well as stellar objects and their formation processes. This method may be used also for investigations of cometary solids (the comparative analysis). It is a powerful technique that has been applied to the astrophysics providing useful information about the forsterite (Gucsik *et al.* 2012a, 2013, 2016; Nishido *et al.* 2013) crystallization processes in the young Solar Sys-

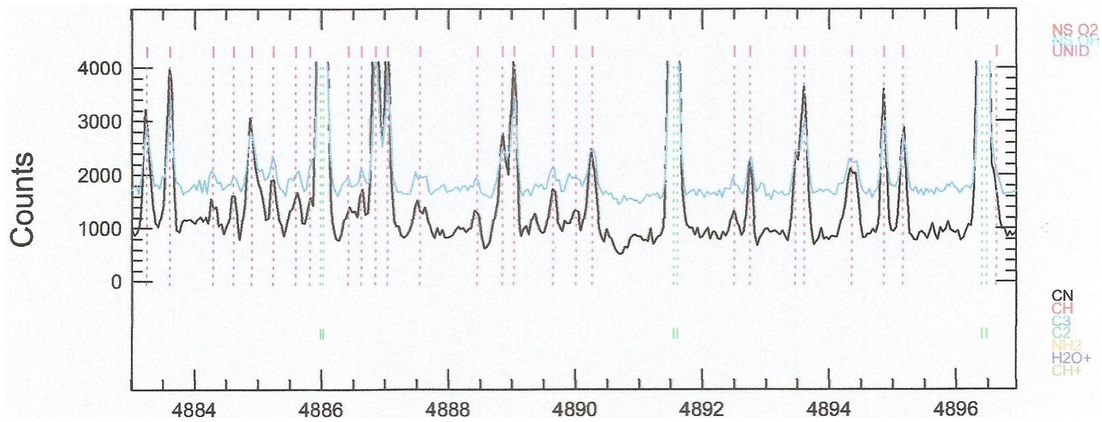

Figure 1. The Fragment of optical spectrum of 122P/deVico comet (Cochran & Cochran 2002). In the x axis – wavelengthes in angstroms. Black spectrum from 4 October 1995. Blue spectrum from 3 October 1995. Emission line lists and plots of 122P/de Vico comet spectra are available in digital format from the Planetary Data Systems Small Bodies Node.

tem, the spectral properties of the phyllosilicates on Mars (*i.e.* Gavin *et al.* 2013), as well as space weathering process (especially shock metamorphism) in the planetary bodies such as Mars (*e.g.* Kayama *et al.* 2012) and asteroid Itokawa (Gucsik *et al.* 2017). Gucsik *et al.* (2012b) performed a systematic cathodoluminescence study of the micro-and nanodiamond samples, which were studied at room and liquid nitrogen temperature in order to understand more about the temperature-dependence of the spectral properties of diamond in the planetary nebulae. According to their results, it was found that a well-pronounced peak centered at around 730 nm in the electromagnetic spectrum of the HPHT (high-pressure high-temperature) diamond may be assigned to the defect-related recombination center indicating a possible source for the Extended Red Emission.

The Calcium-Aluminum-rich Inclusions (CAIs) as refractory minerals are the first condensed from the cooling protoplanetary disk at early stages of Solar System formation. The Kaba meteorite is a well-known and less-metamorphosed CV3 carbonaceous chondritic meteorite, which fell in Hungary in 1857 (Weisberg *et al.* 1997; Krot *et al.* 1998). Thus, this meteorite provides us better understanding of the evolution of organic matter in solar system, too. Kaba contains a relatively high content of the carbonaceous matrix, chondrules, Calcium-Aluminium-rich Inclusions (CAIs), Amoeboid Olivine Aggregates (AOA), Isolated Olivine Grains and feldspars. According to Gucsik *et al.* (2013, and references therein) CAI has a complex texture, and consists of spinel, anorthite and augite (fassaite), where spinel grains (up to 10 μm in size) are surrounded by anorthite and augite grains. The composition of anorthite is $An_{95.6}Ab_{4.4}$. Augite shows $En_{45.5-55.1}Wo_{44.0-53.9}Fs_{0.6-0.9}$. CAIs in Kaba meteorite appear mostly composed by diopside, spinel, and anorthite (table 1) (Gucsik *et al.* 2013). The CAI's appear as an intermediate between fluffy (Allende-type) and fine-grained CAI's. An optical microscope-CL image shows a homogeneous distribution of CL red (anorthite) and blue (diopside) color arranged in a zoning pattern (Figure 2-3). Cathodoluminescence spectral properties of anorthite are related to the Mn^{2+} activators in Ca^{2+} positions, which are centered at 441, 583, 680, 695, and 705 nm (Figure 4). Laboratory data listed above might be useful for investigations of cometary solids, particularly in comparative analysis.

Table 1. Chemical composition of anorthite (An), spinel (sp) and diopside (Di) in Kaba meteorite (Gucsik *et al.* 2013).

	An4-1	Sp4-2	Di4-3	Di4-4
SiO_2	42.97	0.48	54.62	51.04
TiO_2				0.62
Al_2O_3	36.34	69.75	3.55	7.21
FeO			0.56	0.36
Cr_2O_3		0.39		
MnO				
MgO		27.78	18.91	14.97
CaO	19.83	0.18	20.98	24.69
Na_2O	0.5	0.55	0.71	0.38
Total	99.64	99.13	99.33	99.27
Fs			0.9	0.6
En			55.1	45.5
Wo			44	53.9
Or	0			
Ab	44			
An	95.6			

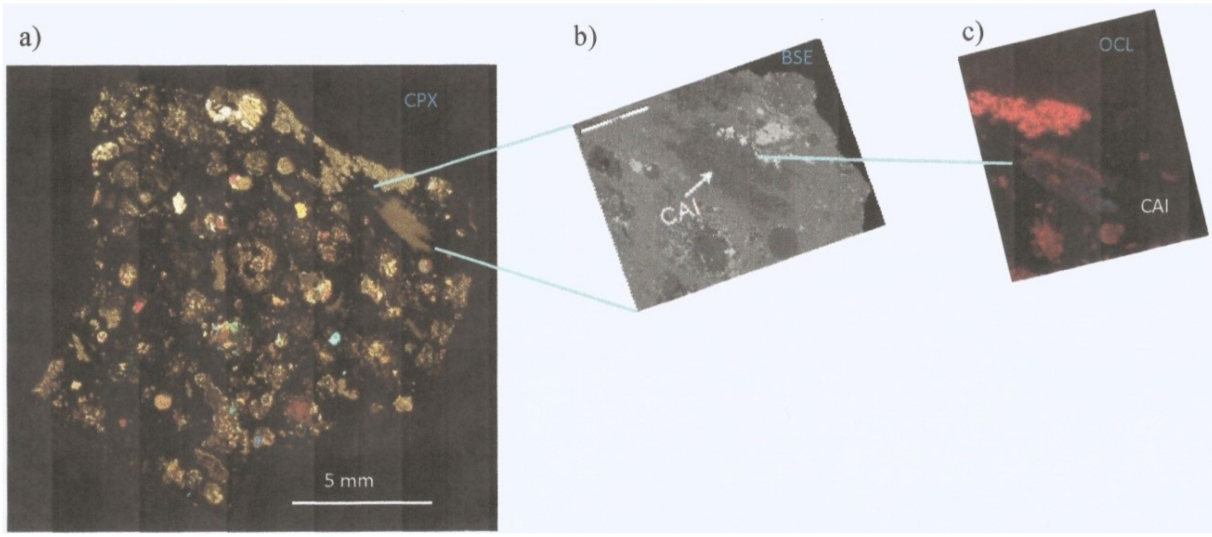

Figure 2. Optical (a), backscattered-electron (b) and optical microsocope-cathodoluminescence (c) show a Calcium-Aluminium inclusion in Kaba meteorite. An optical microscope-cathodoluminescence image shows a homogeneous distribution of cathodoluminescence red and blue color arranged in a zoning pattern.

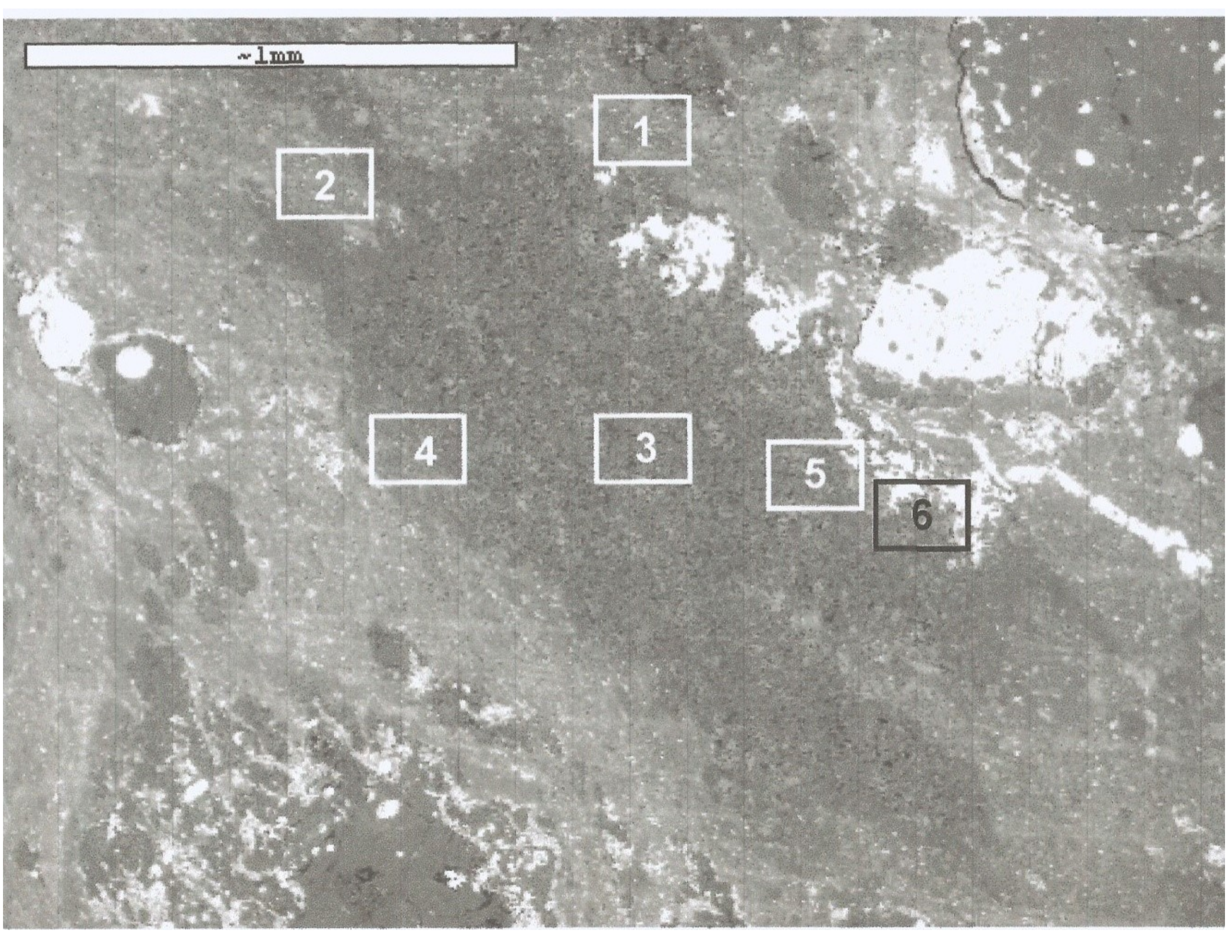

Figure 3. Backscattered Electron Imaging of a selected area of aCalcium-Aluminium inclusion from the Kaba meteorite showing the analyzing points for the cathodoluminescence spectral investigation.

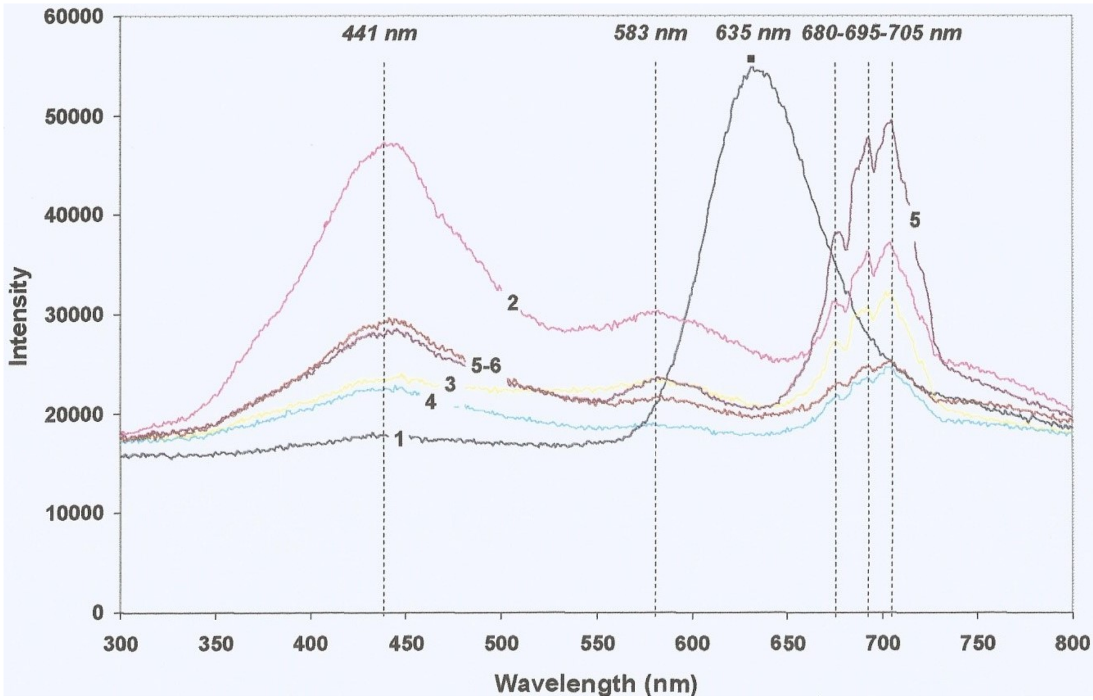

Figure 4. Cathodoluminescence spectral properties of diopside (red region only: 1) and anorthite (blue and red regions: 2-6) from the selected area of a Calcium-Aluminium inclusion in Kaba meteorite.

4 Luminescence of the cometary solids – results of comparative analysis

The dusty and the icy halo of comets are shells of micro and nanograins responsible for the scattering of the solar electromagnetic radiation. The cometary spectra are rich with the series of narrow emissions of unknown nature. These unidentified emissions were registered in the spectra of comets (Brown *et al.* 1996; Cochran & Cochran 2002; Cremonese *et al.* 2007; Kobayashi & Kawakita 2009; Dello Russo *et al.* 2013; A'Hearn *et al.* 2014). These emissions were assigned to multiple ionized molecules (Wyckoff *et al.* 1999; Cochran & Cochran 2002; Kawakita & Watanabe 2002). New theory suggests luminescence nature of unidentified emissions in the form of photoluminescence by frozen hydrocarbon particles (FHPs) of cometary halo (Simonia & Simonia 2004; Simonia 2007, 2011, 2013).

Silicate and carbonaceous dust (in form of micrograins and nanoparticles) of the cometary halo may luminesce also in the field of the solar electromagnetic and corpuscular radiations.

Silicate and carbonaceous cometary halo may luminescence under excitation by the solar electromagnetic and corpuscular radiation. Micro grains and nanoparticles of such a halo may luminesce as the series of narrow emission lines.We performed investigation of unidentified cometary emissions (narrow lines) for confirmation of proposed hypothesis of photoluminescence and cathodoluminescence nature of such emissions. For the specific case we selected the periodic comet 122P/de Vico. This comet has the following orbital characteristics: Q- 34.70 AU; q – 0.659 AU; e- 0.962; i- 85.3828°; P- 74.35yr. We performed a comparison of the spectral positions of unidentified cometary emissions (de Vico comet spectrum) with the spectral position of photo-luminescence and cathodoluminescence emissions of various minerals and substances (published lab data). We used also CL spectra of various minerals obtained by us (Gucsik *et al.* 2013). Accuracy of comparative analysis was ± 0.3 A. We used several published sources (Gorobetz & Rogozhin 2001; Gaft *et al.* 2005; McRae & Wilson 2008) as the laboratory dataset and a high-resolution Atlas of Comet 122P/de Vico (Cochran & Cochran 2002) as the observation data. Obtained results are given in the table 2. In the first column of the table are wavelength of unidentified emissions in the spectrum of the comet 122P/de Vico; second column – wavelength of luminescence emissions of lab minerals and materials; third column – the titles/formula of minerals; fourth column – methods of excitation; fifth column – temperature of the substance;

Table 2. Tentative identification of previously unknown emissions in 122P/de Vico comet spectrum.

comet unid	Mineral lum.	Mineral/Formula	Method of excitation	Temperature
6730.10	6730	Alumina, Al_2O_3	unknown	unknown
6760.08	6760		unknown	unknown
5829.98	5830	Anorthite, $CaAl_2Si_2O_8$	CL	77K
7000.06	7000		unknown	Room
4320.02	4320	Apatite, $Ca_5(PO_4)_3$	SEM	Room
5829.98	5830		L	Room
5400.20	5400	Aragonite, $CaCO_3$	unknown	Room
3959.89	3960	Calcite, $CaCO_3$	LIBS	unknown
3960.05	3960		SEM	Room
4000.09	4000		SEM	Room
4500.16	4500		OM	Room
4520.10	4520		LIBS	unknown
4529.97	4530		LITRLS	unknown
4530.14	4530		LITRLS	unknown
4779.92	4780		LITRLS	unknown
4879.73	4880		LITRLS	unknown
4880.15	4880		LITRLS	unknown
5200.13	5200		OM	Room
5299.72	5300		SEM	Room
5450.07	5450		SEM	Room
5800.10	5800		SEM	Room
5879.77	5800		SEM	Room
6479.88	6480		SEM	Room
8170.03	8170		LITRLS	unknown
4500.16.	4500	Cristobalite, SiO_2	OM	Room
3960.05	3960	Corundum Al_2O_3	LIBS	unknown
6719.98	6720		FL	unknown
6720.14	6720		FL	unknown
6760.08	6760		FL	unknown
4520.10	4520	Diamond, C	L	Room
4890.01	4890		LISSLS	77K
4890.26	4890		LISSLS	77K
4966.92	4967		UV	77K
5118.91	5119		unknown	unknown
5159.79	5160		LISSLS	77K
5159.95	5160		LISSLS	77K
5200.13	5200		L	Room
5230.03	5230		LISSLS	77K
5269.87	5270		LISSLS	77K
5270.11	5270		LISSLS	77K
5359.15	5359		unknown	unknown
5459.97	5460		LISSLS	77K
5819.92	5820		LISSLS	77K
7000.06	7000		LISSLS	77K
6350.04	6350	Diopside $CaMgSi_2O_6$	CL	77K
3929.28	3930	Dolomite, $CaMg(CO_3)_2$	LIBS	unknown
3959.75	3960		LIBS	unknown

Continued on next page

Table 2. ... continued

comet unid	Mineral lum.	Mineral/Formula	Method of excitation	Temperature
3960.05	3960		LIBS	unknown
4299.70	4300		LIBS	unknown
4590.13	4590		LIBS	unknown
4869.95	4870		LIBS	unknown
4879.73	4880		LIBS	unknown
4880.15	4880		LIBS	unknown
4880.30	4880		LIBS	unknown
5259.70	5260		unknown	unknown
5269.87	5270		LIBS	unknown
5270.11	5270		LIBS	unknown
6499.87	6500		SEM	Room
6610.09	6610		SEM	Room
4000.09	4000	Enstatite, $MgSiO_3$	IL	Room
6740.03	6740		unknown	Room
3929.28	3930	Fluorite, CaF_2	LITRLS	77K
3960.05	3960		LITRLS	77K
4069.97	4070		unknown	Room
4510.00	4510		LITRLS	unknown
4520.10	4520		LITRLS	unknown
4870.14	4870		LITRLS	unknown
4899.83	4900		LITRLS	unknown
5220.14	5220		unknown	Room
5400.20	5400		LITRLS	unknown
5680.23	5680		LITRLS	unknown
5879.77	5880		LITRLS	unknown
5950.72	5950		LITRLS	unknown
6159.73	6160		LITRLS	unknown
6219.91	6220		LITRLS	unknown
6509.91	6510		LITRLS	unknown
6510.21	6510		LITRLS	unknown
6570.15	6570		LITRLS	unknown
6730.10	6730		LITRLS	unknown
6779.82	6780		LITRLS	unknown
7000.06	7000		SEM	Room
8659.92	8660		LITRLS	unknown
8660.17	8660		LITRLS	unknown
4320.02	4320	Forsterite, Mg_2SiO_4	OM	Room
4520.10	4520		OM	Room
7149.85	7150		TEM	LN
3959.89	3960	Feldspar (K.Na)$AlSi_3O_8$	unknown	unknown
3960.05	3960		unknown	unknown
4120.09	4120		unknown	unknown
4299.70	4300		SEM	120K
4500.16	4500		unknown	Room
4869.95	4870		unknown	unknown
4870.14	4870		unknown	unknown
4890.01	4890		LITRLS	unknown

Continued on next page

Table 2. ... continued

comet unid	Mineral lum.	Mineral/Formula	Method of excitation	Temperature
4890.26	4890		LITRLS	unknown
5319.91	5320		LITRLS	unknown
5459.97	5460		LITRLS	unknown
6449.87	6450		LITRLS	unknown
7000.06	7000		SEM	Room
4560.14	4560	Gypsum $CaSO_4{\cdot}H_2O$	unknown	unknown
4560.25	4560		unknown	unknown
4669.82	4670		unknown	unknown
4929.94	4930		unknown	unknown
4930.20	4930		unknown	unknown
5269.87	5270		LIBS	unknown
5270.11	5270		LIBS	unknown
5210.23	5210	Habonite, $(Ca,Ce)(Al,Ti,Mg)_{12}O_{19}$	OM	Room
4000.09	4000	Jadeite $Na(Al,Fe)Si_2O_6$	unknown	Room
4000.09	4000	Kaolinite, $Al_2Si_2O_5(OH)_4$	SEM	Room
7500.05	7500	Kyanite, $Al_2O(SiO_4)$	L	Room
6499.87	6500	Magnesite, $MgCO_3$	OM	Room
5249.97	5250	Monticellite, $CaMgSiO_4$	unknown	Room
4500.16	4500	Oligoclase. $(Na,Ca)(Si,Al)_4O_8$	OM	Room
4899.83	4900		OM	Room
5210.23	5210		OM	Room
6570.15	6570		OM	Room
7000.06	7000		unknown	Room
5800.10	5800	Pectolite, $NaCa_2Si_3O_8(OH)$	L	Room
3900.28	3900	Periclase, MgO	SEM	Room
4500.16	4500		SEM	Room
5200.13	5200		SEM	Room
5259.70	5260		OM	Room
5800.10	5800		OM	Room
6849.75	6850		UV	Room
7039.92	7040		SEM	Room
7500.03	7500		OM/SEM	Room
4869.95	4870	Plagioclase, $(Na,Ca)AlSi_3O_8$	OM	Room
5800.10	5800		XL	Room
7000.06	7000		unknown	Room
6840.03	6840	Pyrope, $Mg_3Al_2(SiO_4)_3$	L	Room
6869.91	6870		L	Room
6990.08	6990		L	Room
4000.09	4000	Pyrophyllite, $Al_2Si_4O_{10}(OH)_2$	SEM	Room
3900.28	3900	Quartz SiO_2	LIBS	unknown
3910.24	3910		LIBS	unknown
4000.09	4000		UV	293 K
4120.09	4120		SEM	Room
4599.16	4500		unknown	unknown
4510.00	4510		OM	unknown
4560.14	4560		SEM	80 K

Continued on next page

Table 2. ... continued

comet unid	Mineral lum.	Mineral/Formula	Method of excitation	Temperature
4590.13	4590		SEM	290 K
4610.09	4610		SEM	80 K
4640.19	4640		SEM	unknown
4809.87	4810		unknown	unknown
5389.96	5390		unknown	Room
6219.91	6220		SEM	Room
6359.73	6360		SEM	Room
6489.78	6490		SEM	Room
6499.87	6500		SEM	unknown
6529.80	6530		unknown	unknown
6928.85	6929	Sapphire Al_2O_3	unknown	Room
7149.85	7150		SEM	Room
6329.74	6330	Sodalite $Na_8(Al_6Si_6O_{24})Cl_2$	L	Room
6779.82	6780		L	Room
5215.96	5216	Spinel $MgAl_2O_4$	OM	Room
5249.97	5250		OM	Room
6899.90	6900		OM	Room
3960.05	3960	Topaz $Al_2SiO_4F_2$	LIBS	unknown
4549.99	4550		L	Room
6840.03	6840		L	Room
6990.08	6990		LIBS	unknown
7000.06	7000	Wollastonite $CaSiO_3$	L	Room
8400.16	8400		L	Room

Concluded

The instrumental technique used to excite the luminescence is noted in the fourth column. For example, laser-induced breakdown spectroscopy (LIBS), laser-induced time-resolved luminescence spectroscopy (LITRLS), laser-induced steady state luminescence spectra (LISSLS), cathodoluminescence (CL) has been categorized into scanning electron microscopy (SEM); optical microscope (OM); transmission electron microscope (TEM), while photoluminescence has been divided to UV, laser induced (L), photoluminescence (PL). Other methods recorded are thermoluminescence (TL), proton or ion luminescence (IL), and X-ray excited luminescence (XL). Where emission is known to be cathodoluminescence in origin but unknown instrumentally, it has been listed as OM cathodoluminescence; similarly where the photoluminescence is unknown in detail, it is listed simply as photoluminescence.

On bases of comparative analysis we identified luminescence emissions of the following minerals and materials: alumina, anorthite, apatite, aragonite, calcite, corund, cristobalite, diamond, dolomite, enstatite, feldspar, fluorite, forsterite, gypsum, habonite, jadeit, kaolinite, kyanite, magnesite, monticellite, oligoclase, pectolite, periclase, plagioclase, pyrope, pyrophyllite, quartze, sapphire, sheelite, sodalite, spinel, topaz, wolastonite. Appearance of several minerals of the mentioned list causes some questions and uncertainties about their potential origin in the cosmic environment. Therefor obtained results has the tentative character.

At the same time we cannot exclude that mineral halo of de Vico comet may contain micrograins and nanodust particles of corundum, diamond, enstatite, fluorite, forsterite, magnesite, periclase, quartz, and some others. Mostly potential abundant substances in mineral component of de Vico comet halo are the following: quartz, calcite, and periclase. The individual dust grains and particles of the mentioned chemical and mineralogical composition may formed the spherical shell around de Vico comet nucleus. This dusty shell may luminesce in the field of the solar electromagnetic and corpuscular radiation. The spectral characteristics of luminescence of each class of dusty particles (positions, profiles, intensity, etc) might be different on the various heliocentric distances. Complicated character of de Vico comet spectrum might be partly conditioned by complexity of dusty shell of this comet.

We can assume, that quartz and calcite's substance might form main component of mineral substance of de Vico comet nucleus. At the same time, such mineral as diamond, forsterite and some others could concentrate in dusty reservoirs and patches of de Vico comet nucleus. At the small heliocentric distances such reservoirs could transformed to the active sub-surface sources of de Vico comet despite of its physical shape, sizes, and abundance are reflected the evolutionary way of this comet from the ancient Solar System to present one. The certain amount of the mineral substance of this comet may belong to relict matter.It is well-known that in sungraisers spectra are presented emissions of Fe, Ni, Na, Cr, Si, Mg, K, Mn, and Al (Andrienko & Vaschenko 1981). In majority cases mineral substance tentatively identified by us in de Vico comet halo contain these chemical elements. At the same time several minerals of the presented list belong to meteoritic substance.

5 Conclusion

We have proposed that the solid cometary substance including silicates, organics and substance of asteroids may luminesce in the field of the solar radiations. We have described mechanisms of photoluminescence and cathodoluminescence processes of the solid substance of the solar system small bodies. We have demonstrated that intensity of luminescence signal produced by cometary dust could be comparable with intensity of the scattered solar light in case of high quantum yield of luminescence and low albedo of the cometary dusty substance. We have presented here results of our laboratory investigations and the comparative analysis of lab data with observational data – cometary spectra. Proposed theory and hypothesis requires the laboratory confirmation on bases of investigations of the cosmic substance including meteorites and the lunar samples.

Acknowledgment: Authors are grateful to Mr. Mihály Nagy (Debrecen, Hungary) for providing a Kaba sample for this study and Professors Kiyotaka Ninagawa and Hirotsugu Nishido at Okayama University of Science (Okayama, Japan)providing SEM-CL data of CAIs of Kaba meteorite as well. AG was supported by the Fulbright Visiting Professorship at the University of Arizona (Tucson, Arizona, in 2016/17).

Authors express their gratitude to Dr. Louis d'Hendecourt and anonymous reviewers for the valuable discussion.

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