

# On the possible luminescence nature of unidentified cometary emissions

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**Abstract** New investigations of the photoluminescence of frozen hydrocarbon particles of icy cometary halo have been made. The process of photoluminescence of icy particles in the ultraviolet solar radiation field is considered. The comparative analysis of laboratory and observed data leads to the preliminary identification of some sixty eight photoluminescent emission features in the spectra of 109P/Swift–Tuttle and 23P/Borisen–Metcalf comets. Formulae are given for the calculation of the efficiency of the photoluminescence of icy organic particles in the cometary halo.

**Keywords** Astrochemistry · Radiation mechanisms: non-thermal · Comets: general

## 1 Introduction

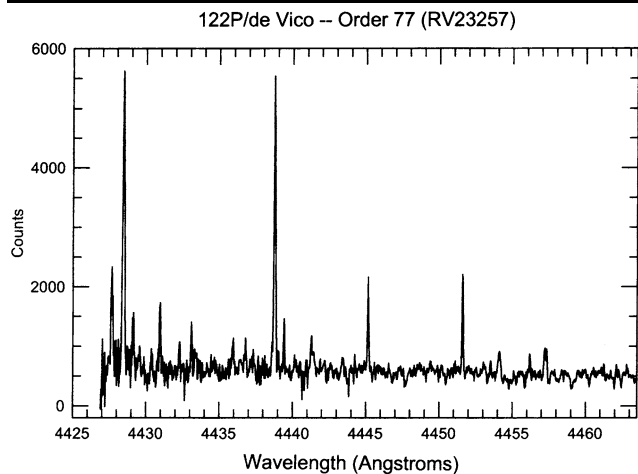
Comet spectra are rich in numerous emission lines and bands in the visible region. Emissions of corresponding molecules including the emissions of C<sub>2</sub>, CH, CN, CO<sub>2</sub>, NH, NH<sub>2</sub>, OH, S<sub>2</sub>, etc., are detected in the spectra of comets at different heliocentric distances. Due to wide differences in age and dust content, the comets display a variety of daughter molecules their haloes. The molecules of cold and rarefied comet atmospheres absorb the solar electromagnetic radiation and reemit it at the same wavelengths. This phenomenon is known as the resonance fluorescence of comet

gases. It is natural that, the dust of comets in the form of silicate and carbon grains, as well as the fine-grained icy particles that make the icy cometary halo, cause the appearance of weak continuous spectrum of comets. Thus, the spectra of comets include both the molecular emission of fluorescent nature and the solar continuum scattered by dust. The comet spectra are rich in numerous unidentified emissions. These narrow lines are found mainly in the visible region, and they are seen in the spectra of nearly every comet. Frequently, these unresolved lines cannot be identified by standard methods, including the methods of comparison with laboratory sources of radiation (Brown et al. 1996; Cochran and Cochran 2002). However, in some cases, it became possible to establish the fact that such unidentified emissions belong to the radiation of comet ions. This is evidenced by the profiles of unidentified emissions obtained by several authors, including (Arpigny 1995; Wyckoff et al. 1999). At the same time, until recently, a great number of unidentified emissions has been considered as the radiation from unknown sources. But the situation was slightly changed after the publication of the works by Simonia (2004, 2005). In these works the author explained the nature of unidentified cometary emissions, in particular, he showed that unidentified emissions of comet spectra are possible photoluminescence of frozen hydrocarbon particles being the part of icy cometary halo. The model of such particles, i.e. of photoluminescence sources was proposed.

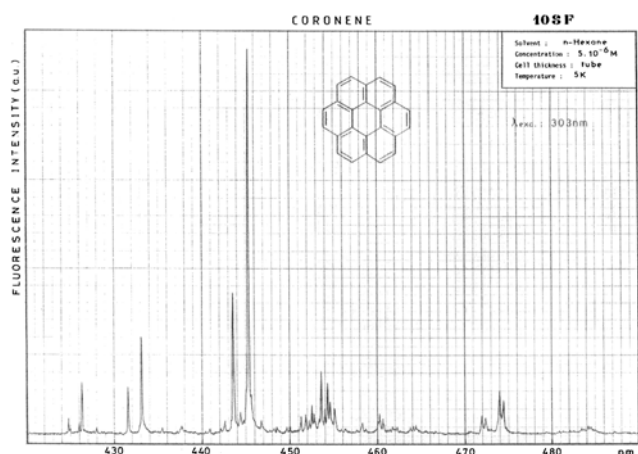
Figure 1 is part of the 122P/de Vico comet spectrum. The following lines are unidentified: 4433.11 Å and 4451.59 Å. (Reproduction from Cochran and Cochran 2002.) Figure 2 is fluorescence spectrum of frozen mixture of hydrocarbons (Coronene C<sub>24</sub>H<sub>12</sub> + *n*-hexane). (Reproduction from Nakhimovsky et al. 1989.) The following distinct lines are in this fluorescence spectrum: 4434 Å and 4451 Å. On the bases of comparative analysis (within ±1 Å) lines 4433.11 Å;

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**Fig. 1** Part of 122P/de Vico comet spectrum



**Fig. 2** Fluorescence spectrum of frozen mixture (Coronene  $C_{24}H_{12}$  + *n*-hexane)

4451.59 Å (122P/de Vico comet) were identified as fluorescence of FHP (Coronene  $C_{24}H_{12}$  + *n*-hexane 4433 Å; 4451 Å) (Simonia 2005).

The present work is the continuation of early suggested concepts, and the results of new investigations are described.

## 2 Frozen hydrocarbon particles of cometary halo—the process of photoluminescence

It is known that polycyclic aromatic hydrocarbons are included in comet substance (Ehrenfreund and Charnley 2003). Frozen mixtures of polycyclic aromatic hydrocarbons and acyclic hydrocarbons are very likely a constituent of icy comet nuclei (Simonia 2004). As the comet approaches the Sun, with the intensification of sublimation processes of ices and mechanical destruction of icy surfaces of nuclei, the ejection of fine-grained icy particles of different shape is started into near-nucleus space. This process

causes the formation of icy cometary halo of characteristic size and shape. Such halo can contain fine-grained icy particles consisting of frozen mixture of polycyclic aromatic hydrocarbons and acyclic hydrocarbons. The frozen hydrocarbon particles (FHP) can contain the additional impurities as a part of solid solution or as a mechanical inclusions (e.g. carbonaceous inclusions in the form of particles of sub-micron dimensions). Both the chemical structure and the dimensions of FHPs can be different depending on a number of factors, including the temperature of the surface layer of nuclei matter, the velocity of formation of icy particles, the density of frozen mixture, etc. The particles of icy cometary halo, like other solid components of comet atmosphere (silicate dust), after absorbing the solar short-wave radiation (UV and X-ray) will reradiate it as lines and bands in the visible region of the spectrum.

This process is the photoluminescence of solid cosmic matter, i.e., of icy particles and silicate dust. In fact, Stocks luminescence of solid comet substance takes place when the condition  $E_{\text{absorb}} > E_{\text{rad}}$  is satisfied. The process of photoluminescence of the icy particles and silicate dust of comets will be characterized by the properties caused by external factors: the heliocentric distance of the comet, the temperature and specific chemical composition of solid matter, the phase of solar activity, the age of comet, etc. Taking into account the last laboratory results (Gudipati et al. 2003), proving the high quantum yield of the photoluminescence of frozen organic, below will consider the case of photoluminescence of frozen hydrocarbon particles of icy cometary halo. The average intensity of the photoluminescence of cometary halo component consisting of FHP, can be expressed as:

$$I_{\text{comp}} = N \int_{z_1}^{z_2} w dw, \quad (1)$$

where  $N$  is the number of FHP in halo participating in the process of photoluminescence, and  $w$  is the energy of luminescence radiation (of the corresponding wavelengths), which can be changed within  $z_2 > w > z_1$ . The average intensity of  $I$  can experience the changes with the change of heliocentric distance. At definite heliocentric distances (most probably up to perihelion)  $I$  will reach its maximum value. Here, it should be noted that the passing of comet perihelion accompanied with the intensive heating of solid comet matter, can lead to the characteristic quenching of luminescence with subsequent irreversible losses of luminescence properties in solid matter.

At any heliocentric distance (except for near perihelion region), the duration of photoluminescence of any selected FHP will be equal to:

$$T = t + \tau, \quad (2)$$

where  $t$  is the time of the action of exciting shortwave radiation, and  $\tau$  is the period of afterglow of FHP. For  $\tau = 0$  and  $\tau > 0$  cases, the fluorescence and phosphorescence of FHP will take place, respectively. The real time of FHP photoluminescence will depend also on specific chemical composition of the frozen mixture, the temperature of FHP matter, the phase of solar activity, the flux of galactic cosmic rays, etc.

The frozen mixtures of PAH + AH, being the part of the ices found in cometary nuclei, can be regarded as the solid mixture of solvent and solvate. The PAH act as the solvate, and the acyclic hydrocarbons as the solvent. The PAHs dissolved in acyclic hydrocarbons form a unified solid solution. The optical properties of the solution are determined by the properties of solvent, by the conditions of crystallization of solution, by the existence of luminescent component, by the character of interaction between the solution components and by the content of additional impurities in the solution. The presence of polycrystalline solutions in comet ices is rather probable. The frozen (PAH + AH) mixtures being the part of comet nuclei and having a high degree of chemical diversity (as is evident by the multiplicity of aromatic hydrocarbons) are the reservoirs—the sources of luminescent FHPs. Obviously, the individual FHP may vary from micron to submillimeter dimensions. FHP will have the characteristic color inherent in frozen mixture of PAH and acyclic hydrocarbons. In case of low concentrations of additional impurities, FHP is gray icy particles. Just the particles of such kind are the part of icy cometary halo.

Under the action of solar shortwave radiation and of fluxes of electrons with different energies, FHPs will intensively luminesce in the range of 3000–7500 Å (it is necessary to note that the processes of photo- and cathodoluminescence differ, mainly, in the characteristic properties of delivering the exciting energy). The other components of halo (e.g. silicate dust) will also luminesce, but with less quantum yield. The luminescence spectrum of specific FHP will be determined by: (a) chemical composition of mixture; (b) PAH concentration in polycrystalline solution; (c) existence of impurities; (d) temperature of mixture; (e) phase of solar activity. For FHPs of different chemical compositions and of different temperatures, the solar UV radiation will cause the luminescence of different spectral compositions. The laboratory results showed that at liquid oxygen temperature 54.3 K, the diffused bands of luminescence spectra of many crystalline organic compounds break down into a series of narrow band or lines (Pringsheim 1949). In the case of comet FHPs, these icy particles in the halo can potentially display two types of luminescence spectra:

- (1) Spectra consisting of wide diffuse bands, or
- (2) Spectra in the form of a series of narrow bands or lines

The width of the corresponding photoluminescence emissions will depend on the temperature of the particle material.

However, to establish the exact character of this dependence, it is necessary to carry out the laboratory experiments with FHP analogs under the conditions similar to those found in comets. The width of the luminescence emission can serve as an indicator of the temperature range, in which a given FHP exists. Laboratory experiments show that at polycyclic aromatic hydrocarbons dissolved in acyclic hydrocarbons (e.g. in *n*-pentane) and held frozen at a temperature of 77 K or lower, give a luminescence spectrum in the form of a series of numerous, very narrow lines (Shpolski 1959). In photochemistry, such spectra are called quasi-linear luminescence spectra. The position, interposition and relative intensities of these lines on the wavelength scale are characteristic and unique to each molecular structure and are an indicator of the normal electronic-vibration state of the corresponding molecular structure. It is likely, therefore that in the comet FHP, the frozen mixtures of PAH + AH also give rise to quasi-linear narrow line luminescence spectra when excited by solar UV radiation.

Taking into account the results of laboratory experiments, one can state that the lines of quasi-linear luminescence spectra of FHP can be extended at the material temperature  $T > 80$  K and at small PAH concentrations. The gradual extension of lines in the luminescence spectrum of icy particles can be observed with the decrease of heliocentric distance with the depletion of volatile FHP component. For example, if the material of specific FHP consists of PAH and *n*-hexane, the depletion process begins at the moment of heating the icy particle up to temperature  $T \sim 290$  K, at which the intensive evaporation of *n*-hexane is started. It is natural that, at the same time, the spectrum of luminescence of the corresponding FHP is changed. Thus, the degeneration of FHP can take place in the sources of short-term luminescence. The wide featureless short-lived luminescence emissions can arise at corresponding heliocentric distances. It is possible that, the emissions of such kinds may be similar in spectral position and in profile with extended red emission of dust of reflection, planetary and proto-planetary nebulae. It is known that in the spectra of many nebulae the wide featureless band are revealed in the range of 5400–9400 Å. These bands were called the extended red emission (ERE) and are interpreted as the photo-luminescence of nebulae dust (Duley 1992; Witt and Vijn 2004). In the spectra of comets and other small bodies of the solar system, the extended red emission of luminescence nature may also be observed under certain conditions. Among such conditions can be the corresponding heliocentric distance of the object, the chemical composition and the temperature of matter (icy particle, surface of the body), etc. The recent laboratory experiments (Quirico et al. 2005) showed that interplanetary dust particles and meteorite matter (carbonaceous chondrites) are also the sources of extended red emission of luminescence

nature. Of course, these suggestion requires observational verification, through the use of sensitive spectrographs and space-based or balloon-borne instrumentation.

Photo-chemical processing of the FHP by solar UV radiation will change its chemical composition and hence, its spectrum as a function of time and orbital position of the comet. The general character of photoluminescence of comet FHP is complex and changeable, requiring the separate consideration in each specific case. Besides, with due account of the assumption of similarity of chemical compositions of frozen organic mixtures in different comets, one can expect the appearance of identical luminescence emissions in spectra of different comets.

The important quantitative characteristic of photoluminescence is its, so-called, yield. The luminescence yield of two types is used: quantum and energy, simply—the luminescence yield. The quantum yield means the ratio of the number of emitted luminescence photons to the number of absorbed photons of exciting radiation  $q = N_{\text{lum}}/N_{\text{abs}}$ . The luminescence yield means the ratio of emitted energy of luminescence (at the corresponding wavelength) to the absorbed energy of exciting radiation  $\mu = E_{\text{lum}}/E_{\text{abs}}$ . Frequently, in scientific literature there is almost no difference between these mentioned characteristics. Some authors, using the term “quantum yield”, mean the energy ratio. It important to adhere to the corresponding differences, for the reason that, Galanin (1987) in his work noted that the quantum yield of luminescence of a number of compounds can be equal to unity or much higher than unity, and the luminescence yield (the ratio of energies for the same compounds) is not more than 20 per cent. In case of cosmic dust, in particular, dust and icy comet particles, the exact use of corresponding characteristic is especially important for instrumental tasks solving, particularly, the problem of registration of faint emissions. The dependence of luminescence yield  $\mu$  on quantum yield  $q$  is expressed by:

$$\mu = \frac{\lambda_{\text{abs}}}{\lambda_{\text{lum}}} q, \quad (3)$$

where  $\lambda_{\text{abs}}$  is the wavelength of absorbed exciting radiation and  $\lambda_{\text{lum}}$  is the wavelength of the maximum in luminescence spectrum. Generally speaking, in case of Stocks luminescence, the luminescence yield is always less than the quantum yield  $\mu < q$  (Pringsheim 1949). Simonia (2004) made the calculation of the ratio of photoluminescence flux to the flux of scattered solar radiation for corresponding wavelengths  $F_{\text{lum}}/F_{\text{scat}}$ . The calculation was carried out for the following conditions: FHP of millimeter dimensions, FHP photoluminescence yield  $\mu = 50$  per cent, albedo of FHP  $A = 0.1$ , etc. For different wavelengths it was established, that  $F_{\text{lum}}/F_{\text{scat}} > 1$ . This means that, the luminescence signal from FHP is above the scattered solar continuum. The result presented in the mentioned work is demonstrative and

can also extend to other cases. Following the similar conditions, including  $A = 0.1$ , and taking into account the obtained result  $F_{\text{lum}}/F_{\text{scat}} > 1$  and the character of the dependence  $\mu(q)$ , the author made the comparative analysis between the position of unidentified emissions of the spectra of comet from catalogue (Brown et al. 1996) and the position of photoluminescence emissions of chemical FHP analogs (Teplitskaia et al. 1978).

The comparative analysis was made within  $\pm 1 \text{ \AA}$  accuracy. The obtained results are presented in the Table 1.

It should be noted that, for each coincided emission the calculation of the value of luminescence yield  $\mu$  was derived from expression (3).  $\lambda_{\text{abs}}$  is the wavelength of exciting radiation (the region of absorption of corresponding mixture) and  $\lambda_{\text{lum}}$  is the wavelength of the chosen luminescence emission (of the same mixture). The value  $q = 90$  per cent was taken according to Gudipati et al. (2003). The table contained only the emissions, for which  $\mu \geq 50$  per cent. Such condition was satisfied for obtaining the additional numerical confirmation of the possibility of registration of faint photoluminescence emissions of corresponding comets. In the first column of the Table 1 the wavelengths of unidentified cometary emissions are given, according to Brown et al. (1996), in the second column—the wavelength of photoluminescence emissions of laboratory analogs of FHP; in the third one—the chemical formula and the name of corresponding polycyclic aromatic hydrocarbons and the name of solvents, and in the fourth column—the calculated yield of luminescence  $\mu$  in percents.

Within  $\pm 1 \text{ \AA}$  some 68 emissions from the total of 559 unidentified emissions given by Brown et al. (1996) may be provisionally identified as photoluminescence emissions of FHPs.

Based upon these identifications we may conclude that photoluminescence emissions of FHP account for at least 12.2 per cent of the total number of unidentified emissions in the spectra of these comets. It is likely that most of the remainder are ionic in nature.

In the process of comparative analysis was used the data on wavelengths of exciting UV radiation given in the work by Teplitskaia et al. (1978). The range of changes of wavelengths of exciting UV radiation was 2850–3660  $\text{\AA}$ . Taking into account the peculiarities of the process of comparative analysis, it should be noted that, in the case of coincidence of the wavelengths of unidentified emissions with the wavelengths of luminescence of several polycrystalline mixtures at a time (within  $\pm 1 \text{ \AA}$ ) the most closely located laboratory lines of corresponding molecules were chosen. Besides, the abundance of any molecules in cosmic medium as well as the yield of their luminescence was also taken into account. The cases of coincidence of the positions of separate unidentified emissions with the positions of luminescence emissions of several molecules at a time can be explained

**Table 1** The results of comparative analysis

Observed wavelength (Å)	Laboratory analogues wavelength (Å)	Formula and name of hydrocarbons	Luminescence yield (%)
4074.03	4074	1,2 benzpyrene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	75.1
4011.71	4011	Anthracene C <sub>14</sub> H <sub>10</sub> <i>n</i> -hexane	76.2
4001.78	4002	Anthracene C <sub>14</sub> H <sub>10</sub> <i>n</i> -heptane	76.4
4038.31	4038	Tetraphene C <sub>18</sub> H <sub>12</sub> <i>n</i> -octane	81.5
4045.38	4045	1,2-5,6 dibenzanthracene C <sub>22</sub> H <sub>14</sub> <i>n</i> -hexane	81.4
4014.56	4014	3,4 benzpyrene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	82
4358.41	4358	Diphenylene oxide C <sub>12</sub> H <sub>8</sub> O <i>n</i> -hexane	58.9
4452.20	4452	1,12 benzperylene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	74
4525.12	4525	Fluorene C <sub>13</sub> H <sub>10</sub> <i>n</i> -hexane	57.7
4551.61	4552	Fluorene C <sub>13</sub> H <sub>10</sub> <i>n</i> -hexane	57.3
4527.73	4528	Diphenylene oxide C <sub>12</sub> H <sub>8</sub> O <i>n</i> -heptane	56.6
4548.92	4549	Diphenylene sulphide C <sub>12</sub> H <sub>8</sub> S <i>n</i> -heptane	61.3
4522.13	4523	Triphenylene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	62.3
4516.87	4517	3,4 benzpyrene C <sub>20</sub> H <sub>12</sub> <i>n</i> -octane	72.9
4542.99	4543	Coronene C <sub>24</sub> H <sub>12</sub> <i>n</i> -hexane	72.5
4574.14	4574	3,4-9,10 dibenzpyrene <i>n</i> -hexane	72.0
4558.08	4558	Anthracene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	72.3
4561.89	4561	Anthracene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	72.2
4565.45	4566	Perylene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	72.1
4589.30	4589	3,4-8,9 dibenzperylene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	71.8
4530.17	4530	1,2 benzanthracene C <sub>22</sub> H <sub>14</sub> <i>n</i> -hexane	72.7
4648.00	4649	Diphenylene oxide C <sub>12</sub> H <sub>8</sub> O <i>n</i> -hexane	55.2
4617.46	4617	Triphenylene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	62.4
4615.76	4615	Triphenylene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	61
4646.56	4646	Triphenylene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	60.6
4631.67	4632	3,4-9,10 dibenzpyrene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	71.1
4620.45	4621	1,2-3,4 dibenzpyrene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	71.3
4656.86	4657	1,2-3,4 dibenzpyrene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	70.7
4650.85	4650	2,3 ortho-phenylene pyrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	70.8
4625.08	4625	2,3 ortho-phenylene pyrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -octane	71.2
4705.60	4706	Triphenylene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	59.9
4790.48	4791	Perylene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	68.8
4783.81	4784	3,4-8,9 dibenzpyrene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	68.9
4794.28	4794	Tetracene C <sub>18</sub> H <sub>12</sub> <i>n</i> -nonane	68.7
4883.24	4883	3,4-9,10 dibenzpyrene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	67.5
4897.37	4897	3,4-9,10 dibenzpyrene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	67.3
4808.14	4809	Perylene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	68.5
4827.26	4827	Perylene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	68.2
4874.54	4874	Perylene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	67.6
4830.89	4830	3,4-8,9 dibenzperylene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	68.2
4840.04	4840	3,4-8,9 dibenzperylene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	68
4821.62	4821	3,4-8,9 dibenzperylene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	68.3
4835.97	4835	3,4-8,9 dibenzperylene C <sub>24</sub> H <sub>14</sub> <i>n</i> -hexane	68.1
4834.88	4834	1,2 benzotetracene C <sub>22</sub> H <sub>14</sub> <i>n</i> -hexane	68.1
4869.42	4870	1,2 benzotetracene C <sub>22</sub> H <sub>14</sub> <i>n</i> -hexane	67.6
4800.98	4800	2,3 ortho-phenylene pyrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	68.6
4957.45	4957	Phenanthrene C <sub>14</sub> H <sub>10</sub> <i>n</i> -hexane	58.1



**Table 1** (Continued)

Observed wavelength (Å)	Laboratory analogues wavelength (Å)	Formula and name of hydrocarbons	Luminescence yield (%)
4910.49	4910	Anthanthrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	67.1
4921.49	4921	Triphenylene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	57.2
4914.51	4915	2,3 ortho-phenylene pyrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	67.0
5060.42	5060	Phenanthrene C <sub>14</sub> H <sub>10</sub> <i>n</i> -hexane	56.9
5025.35	5025	2,3 ortho-phenylene pyrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	65.6
5004.27	5005	2,3 ortho-phenylene pyrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -octane	65.8
5050.30	5051	2,3 ortho-phenylene pyrene C <sub>22</sub> H <sub>12</sub> <i>n</i> -octane	65.2
5158.86	5159	Coronene C <sub>24</sub> H <sub>12</sub> <i>n</i> -hexane	63.8
5175.54	5176	Tetracene C <sub>18</sub> H <sub>10</sub> <i>n</i> -nonane	63.6
5313.56	5313	Phenanthrene C <sub>14</sub> H <sub>10</sub> <i>n</i> -hexane	54.2
5318.15	5318	Chryzene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	50.8
5351.42	5352	Chryzene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	50.4
5366.47	5366	1,2 benzpyrene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	57.0
5475.09	5476	1,2 benzpyrene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	55.9
5479.22	5479	1,2 benzpyrene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	60.1
5884.00	5884	Pyrene C <sub>16</sub> H <sub>10</sub> <i>n</i> -hexane	52.0
5869.35	5870	1,2 benzpyrene C <sub>20</sub> H <sub>12</sub> <i>n</i> -hexane	56.1
5910.91	5910	Tetraphene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	55.7
5934.27	5935	Tetraphene C <sub>18</sub> H <sub>12</sub> <i>n</i> -hexane	55.5
6301.38	6301	1,2 benzperylene C <sub>22</sub> H <sub>12</sub> <i>n</i> -hexane	55.3
5952.99	5952	Fluoranthene C <sub>16</sub> H <sub>10</sub> <i>n</i> -hexane	55.3

by a high degree of abundance of aromatic compounds both in cosmic medium and on the earth.

Brown et al. (1996) obtained the spectra of corresponding comets by using Hamilton spectrograph of Lick Observatory. The spectral range was 3800–9900 Å with spectral resolution of  $\lambda/\Delta\lambda \sim 42000$ .

Two factors limit the number of possible identifications. First, Brown et al. (1996) noted that the unidentified emissions of corresponding comets were narrow, spectrographically unresolved lines. This limited the possibility to compare the profiles of corresponding emissions. This narrowness of both the unidentified lines and the quasi-linear luminescence spectra of polycrystalline mixtures is an important argument in favor of photoluminescence nature of a number of unidentified emissions. Second, the atlas of aromatic molecules (Teplitskaia et al. 1978) has a long-wave limit near 6700 Å. this, naturally, limited the total number of the emissions which could be identified.

### 3 Conclusion

It has been established that, FHPs of icy halo of corresponding comets contains 24 molecules, including anthracene, phenanthrene, chryzene, coronene, etc. In fact, the frozen

hydrocarbon particles of icy cometary halo are chemically rather different and make a large complex of aromatic compounds.

As a result of comparative analysis, it became possible:

- (1) To show that at least 12.2 per cent of unidentified emissions of the spectra of corresponding comets are possible photoluminescence of FHP and to confirm the results obtained by Simonia (2004, 2005).
- (2) To determine the chemical composition of the definite part of icy particles of the halo of corresponding comets.
- (3) To show the high degree of abundance of polycyclic aromatic hydrocarbons in comet matter.

The Stardust mission has confirmed presence of aliphatic and aromatic hydrocarbons in 81P/Wild 2 comet matter (Sandford et al. 2006; Keller et al. 2006).

In the present paper the main process of possible photoluminescence of frozen hydrocarbon particles of icy cometary halo was described. The expressions were proposed for calculation of the average intensity and the duration of photoluminescence of cometary FHP. The comparative analysis of spectral positions of unidentified emissions of cometary spectra, given in the catalogue (Brown et al. 1996) and of quasi-linear luminescence emissions, given in the atlas (Teplitskaia et al. 1978) was made. The comparative analysis

was carried out with  $\pm 1 \text{ \AA}$  accuracy, on the basis of which 68 emissions of comets 109P/Swift–Tuttle and 23P/Brorsen–Metcalf were identified as the FHP photoluminescence of their icy halo. 24 aromatic molecules were identified being the part of FHP of the mentioned comet. The importance of registration and study of the luminescence of the solid component of cometary matter and other small bodies of the solar system became clear. This new channel of information will allow to study more thoroughly the physical and chemical properties of cometary matter, its origin and evolution. The registration of the photoluminescence of solid cometary organic can become an important “instrument” for astrobiological investigations. This problem should be considered separately with the due account of all aspects of the origin and evolution of living matter.

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