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On the Nature of Unidentified Cometary Emission Lines

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Abstract—The nature of unidentified cometary emission lines is discussed. A model of ice particles in cometary halos as a mixture of frozen polycyclic aromatic hydrocarbons (PAHs) and acyclic hydrocarbons is considered. The properties of frozen hydrocarbon particles are described and 5–7% of the unidentified cometary emission lines are considered as the photoluminescence of frozen hydrocarbons. The positions of unidentified emission lines in the spectrum of Comet 19P/Borrelly are compared with the positions of quasi-lines in the photoluminescence spectra of PAHs that were dissolved in acyclic hydrocarbons at a temperature of 77 K and that constitute a polycrystalline solution.

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INTRODUCTION

Let us consider the problem of unidentified cometary emission lines. Previously (Simonia, 2004), we interpreted some of the unidentified cometary emission lines as the photoluminescence of frozen hydrocarbon particles (FHPs). We suggested an FHP model and calculated the ratio of the photoluminescence flux to the scattered solar radiation flux, F_{lum}/F_{sc}. This ratio at high quantum yield of FHP photoluminescence (50% or more) and FHP albedos within the range 0.1–0.3 is large than unity. This ensures relatively easy detectability of the luminescence signal. In the above paper, we also compared the positions of unidentified cometary emission lines in the spectrum of Comet 122P/de Vico with the positions of fluorescence and phosphorescence emission lines of frozen polycrystalline solutions, i.e., polycyclic aromatic hydrocarbons (PAHs) and acyclic hydrocarbons (AHs) at T = 77 K (PAH + AH). Our comparative analysis showed that 28 aromatic molecules are contained in the FHPs of the ice halo of Comet 122P/de Vico. Thus, at least 7% of these emission lines were identifiable in terms of the photoluminescence mechanism. We suggest that the ice halos of comets contain variously sized FHPs luminescing in various ranges of the optical spectrum under solar ultraviolet radiation. To confirm our previous results, we compared the positions of unidentified emission lines in the spectrum of Comet 19P/Borrelly with the positions of fluorescence and phosphorescence emission lines in the quasi-line spectra of polycrystalline PAH + AH solutions (the temperature of the frozen solution is T = 77 K). The results of our comparative analysis are presented below.

THE PHOTOLUMINESCENCE OF FROZEN HYDROCARBON PARTICLES

Over a prolonged period, the resonance fluorescence of rarefied gases in cometary atmospheres was considered as the only cometary emission mechanism. At the same time, most of the comets also possess a developed halo, which is a cloud of dust or ice particles.

The question of whether a halo of ice particles is present in comets is still under discussion. We believe that the surface layers of the ices of cometary nuclei could be the suppliers of ice particles, including FHPs. The absorption of solar ultraviolet radiation by the ice particles of cometary halos followed by the reradiation of absorbed energy into optical emission (photoluminescence) has not been considered previously. At the same time, hundreds of unidentified cometary emission lines have remained the subject of only a passive study. We believe that the studies of the interaction between the solar electromagnetic radiation and the ice particles of cometary halos should be extended; particular attention should be paid to the photoluminescence of small particles.

Frozen hydrocarbon particles under solar ultraviolet radiation can luminesce in the form of narrow emission lines and their series in various ranges of the optical spectrum. The change in the FHP composition or in the concentration of the polycrystalline mixture components under external effects can lead to a broadening of the narrow lines to the point of appearance of broad structureless emission lines.

Broad structureless emission lines are observed in reflection nebulae and other Galactic objects (Witt and Vijh, 2004). These bands in the wavelength range 5400–9400 Å are called the extended red emission. Models of luminescing dust grains capable of being the sources of the extended red emission from reflection

Results of our comparative analysis

PAH name	Solvent	3	4
Diphenylene oxide $C_{12}H_8O$	n-heptane	4507	4507.03
Diphenylene sulfide $C_{12}H_8S$	n-heptane	4256	4256.01
Chrysen $C_{18}H_{12}$	n-hexane	4000	4000.28
1,2-Benzpyrene $C_{20}H_{12}$	n-hexane	5876	5876.98
Tetraphene $C_{18}H_{12}$	n-octane	3909	3909.41
	n-hexane	4085	4085.33
3,4-Benzpyrene $C_{20}H_{12}$	n-octane	4085	4085.33
	n-hexane	4507	4507.03
1,2-5,6-Dibenzanthracene $C_{22}H_{14}$	n-hexane	4140	4140.11
3,4-8,9-Dibenzpyrene $C_{24}H_{14}$	n-hexane	4483	4482.50

nebulae and other objects have been suggested in several papers. For example, Duley et al. (1997) considered the photoluminescence from hydrogenated amorphous carbon particles. Ledoux et al. (2001) and Witt and Vijh (2004) considered silicon nanoparticles as the main source of this extended red emission.

At small heliocentric distances, the luminescent emission lines of cometary FHPs can broaden appreciably with rising FHP temperature. It may well be that the luminescent FHP emission lines could become a continuum at certain temperatures. If the nucleus of Comet 19P/Borrelly is assumed to have been surrounded by a cloud of ice particles some of which were FHPs, then the FHPs in the halo of this comet must have luminesced in the optical spectral range. We compared the positions of unidentified emission lines in the spectrum of Comet 19P/Borrelly with the positions of fluorescence and phosphorescence lines of polycrystalline PAH + AH solutions at temperature $T = 77$ K. We used data on unidentified emission lines in the spectrum of Comet 19P/Borrelly from Churyumov et al. (2002) and a database of quasi-line luminescence spectra for aromatic molecules (Teplitskaya et al., 1978). It should be emphasized that the polycrystalline PAH + AH solutions investigated by Teplitskaya et al. (1978) are a chemical analogue of the FHP material. Our comparative analysis was performed with an accuracy of ±1 Å. The results are presented in the table. Column 1 gives the PAH names and formulas; column 2 gives the solvent names; column 3 lists the wavelengths of the luminescent emission lines of the corresponding polycrystalline solutions; and column 4 lists the wavelengths of the emission lines in the spectrum of Comet 19P/Borrelly with the status of unidentified emission lines in Churyumov et al. (2002).

Churyumov et al. (2002) tabulated 122 unidentified emission lines in the spectrum of Comet 19P/Borrelly. As we see, at least 6.5% of the previously unidentified emission lines in the spectrum of this comet represent the FHP photoluminescence. Our comparative analysis shows that at least 8 different PAH molecules may be contained in the FHPs of the ice halo of Comet 19P/Borrelly.

DISCUSSION

The FHPs of cometary ice halos luminesce under solar ultraviolet radiation. This radiation, which is absorbed by an FHP material in the form of a frozen PAH + AH mixture, transforms into optical emission (photoluminescence). The FHP luminescence spectrum is a series of narrow emission lines mostly in the wavelength range 3900–6500 Å. As has been noted above, a rise in FHP temperature will cause a broadening of the luminescent emission lines. Weak lines that have not been identified previously are detected in most comets (Wychoff et al., 1994; Cochran and Cochran, 2002; Brown et al., 1996; Churyumov et al., 2002). It now becomes clear that 5–7% of the unidentified emission lines in cometary spectra represent the FHP photoluminescence. At the same time, it should be noted that the dust halos of comets may contain a significant number of fine carbon particles and inorganic grains, including silicate particles of millimeter or submillimeter sizes. If we would be able to establish that these minerals can have a high quantum yield of photoluminescence at low temperatures, then the above averaged emission interval 5–7% could be extended considerably. This assumption is natural, because the dust halos of comets may be rich in various mineral particles undergoing temperature variations over an appreciably range with heliocentric distances of the comets. At the same time, it is clear that the sources of most of the unidentified cometary emission lines are the corresponding molecules—the fragments of more complex parent molecules.

The FHPs of cometary ice halos will interact with both the neutral and ionized components of the cometary atmospheres. The adsorption of cometary gases by the FHP surface layer will be the main manifestation of this interaction. This, in turn, will lead to enrichment of the FHP material with new chemical components. In several cases, adsorption will result in a change of the luminescent FHP spectrum, including the change of the intensity distribution in the series of corresponding emission lines. Most of the selected PAHs constituting polycrystalline solutions with AHs at $T = 77$ K in laboratory conditions demonstrated photoluminescence in the form of fluorescence, while a small fraction of the polycrystalline PAH + AH solutions demonstrated photoluminescence in the form of phosphorescence. This implies that certain FHPs, moving in the cometary atmosphere and escaping from the field of the direct action of ultraviolet radiation in the antisolar direction, will cease to luminesce, while other FHPs, being in the antisolar direction and no longer undergoing UV radiation, will continue to luminesce over a certain period. The latter case is FHP phosphorescence with a possible afterglow period from several seconds to tens of hours. In other words, FHPs of a certain chemical composition will luminesce only during the direct action of solar ultraviolet radiation, while FHPs of a different chemical composition will also luminesce after the termination of the action of ultraviolet radiation. The examples are: Chrysen + n-hexane—fluorescence; Diphenylene oxide + n-heptane—phosphorescence.

This is indicative of a complex, variable pattern of luminescence of cometary ice halos.

CONCLUSIONS

In this paper, we continued our description of the luminescence properties of frozen hydrocarbon particles in cometary ice halos. Our comparative analysis showed that at least 6.5% of the unidentified emission lines in the spectrum of Comet 19P/Borrelly represent the FHP photoluminescence. Eight aromatic molecules may be the main component of the FHP material. Other aspects of this problem were also discussed. Clearly, the studies in this direction must be continued.

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