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LUMINESCENCE OF COSMIC DUST-- A RESULT OF THE INTERACTION OF RADIATION WITH SOLID MATTER

I. A. Simonia

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1. Introduction

More than 20 years have passed since observations of the photoluminescence of dust in reflecting and other nebulae began [1]. The basic physical features of the dust photoluminescence process for these objects have been described elsewhere [2]. The observational data include data on the extended red emission of the reflecting and other nebulae [3]. Discussions continue on the physical and chemical properties of the dust responsible for the extended red emission. The luminescence of cosmic dust is a ordinary result of the interaction of the interaction of radiation with solid matter. The accompanying luminescence processes may be extraordinary. These possible processes require experimental confirmation. The luminescence of cosmic dust must be regarded as one of the manifestations of the interaction of radiation with solid matter. The main mechanism of this interaction is the absorption of optical radiation from stars by the dust, leading mainly to heating of the dust. The characteristic emissions (absorption in some cases) are observed in the IR spectra of stars with dust disks for shells [4]. The radiation also interacts with the gaseous component of circumstellar gas-dust matter. However, the IR emission of the gas has several other, different spectral characteristics.

2. Possible forms of cosmic dust luminescence

The dust in nebulae is constantly subjected to irradiation by short wavelength electromagnetic radiation and charged particle fluxes. Cosmic dust particles of micron and nanometer sizes continuously absorb and reprocess the IR

E. K. Kharadze Abastumani National Astrophysical Observatory, Georgia; e-mail: iraklisimonia@yahoo.com

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radiation, as well as x-ray and gamma photons with various energies. Dust particles with different mineral compositions, shapes, and sizes are also subjected to constant bombardment by fluxes of fast electrons and protons. As a result of these interactions, the physical and chemical properties of the dust particles evolve and one type of radiation is converted to another. Energy is constantly reworked with the participation of a solid substance-- the cosmic dust. One indicator of these processes is the luminosity, as a form of nonthermal radiation resulting from the interaction of radiation with the matter. The different kinds of radiation will excite luminescence in dust particles of various chemical and mineralogical compositions with characteristic spectra, ways the absorbed energy is transported in the body of a dust particle, afterglow periods, and quenching kinetics. The major forms of luminescence in cosmic dust particles include: (1) photoluminescence of the particles excited by the UV radiation from stars, and (2) cathodoluminescence of cosmic dust excited by fast electron and proton fluxes that form part of a stellar wind. Other possible processes should not be excluded, in particular, thermoluminescence [5] and ion-luminescence of cosmic dust. UV photons (from the illuminating star) excite photoluminescence in circumstellar dust with variable dispersion. Here the atoms in the dust material go from the ground state to an excited state on absorbing the energy of incident photons and then return to the ground state while emitting optical photons of lower energies. The absorbed energy can reach the luminescence centers in the body of a dust particle in various ways, depending on the state of the particle (crystalline or amorphous). Each dust particle in a nebula will luminesce in a characteristic band that depends on a number of factors, including its chemical and mineralogical composition. If we assume a high level of chemical and mineralogical variety in the dust in a given nebula, then we may expect superposition of the individual spectral components leading to the appearance of broad bands in the spectrum of the nebula. Here the picture might be thus: each reflecting or other nebula would have broad emission in different spectral bands that is characteristic of only of that nebula. Nevertheless, current observational data indicate otherwise. The spectra of reflecting nebulae are found to consist either of extended red emission or of isolated, fairly narrow emissions of luminescence origin. It is necessary to determine numerically the basic photoluminescence properties of nebular dust, including: (a) the average photoluminescence intensity I_{avg} of the dust of a given nebula, and (b) the duration T of the photoluminescence from this nebula. *I* propose writing the average intensity I_{avg} of the dust photoluminescence of nebulae in the form

$$I_{cp} = S \int_{e_1}^{e_2} w dw , \tag{1}$$

where S is the surface area of the nebula whose dust returns the absorbed radiation in the form of photoluminescence photons and w is the photoluminescence energy of a given dust particle at the appropriate wavelengths such that $e_2 > w > e_1$. Not all the dust particles irradiated by the star of a nebula will luminesce; radiationless transitions of atoms in the dust material are possible. The proposed Eq. (1) does not describe a quantity observed from the earth, but a physical parameter of the star-dust system. It is also proposed that the duration T of the photoluminescence of the dust in a nebula be written in the form

$$T = t + T , \tag{2}$$

where t is the time that the short wavelength exciting radiation acts on a dust particle and T is the afterglow (fluorescence, phosphorescence) period of the dust particle. On the whole, Eq. (2) describes the photoluminescence time of the nebular dust. Cathodoluminescence of dust particles with different mineral compositions, shapes, and sizes acted on by fluxes of electrons and protons of appropriate energies is another possible form of luminescence. The mechanisms for photoluminescence driven by hard UV radiation and for cathodoluminescence excited by fluxes of fast electrons and protons differ only in the way the exciting radiation is delivered to the object. Fluxes of fast electrons and protons from stars can excite cathodoluminescence in circumstellar and interstellar dust. The characteristic spectrum of dust cathodoluminescence will be determined by (1) the chemical and mineralogical composition of the dust particles, (2) the state of the dust particles (crystalline, amorphous), and (3) the temperature of the dust. The dust in reflecting and other nebula may luminesce in corresponding spectral bands under the action of fluxes of electrons and protons with different energies. I conjecture that, if micron dust particles, such as Al_2O_3, SiO_2, C, TiC, etc., are being formed in the atmospheres of stars (for example, cold stars), they can fluoresce in the IR in the upper atmospheres of the stars and luminesce in the optical range on leaving the upper atmospheres. It will be possible to observe transitional fluorescence of this kind if the spectrum of the corresponding object is simultaneously characterized by the three following features: (1) the star's spectrum has a distinct excess at long wavelengths, (2) the radiation is not polarized in the region of the excess, and (3) the distribution of the radiation in the star's continuum spectrum differs form a Planck distribution (in terms of the profile and the position of the maximum). An analysis of the long wavelength regions of the spectra of N-type stars might turn out to be extremely interesting. We may also presume that the transformation in the luminescence spectral characteristics of a given cosmic dust particle with a specified chemical and mineralogical composition would reflect the evolution of its physical and chemical properties over the time it has moved in the star-dust cloud system. A micron dust particle of SiO_2 in different stages of evolution will be a source of luminescence emissions with different spectral compositions. The stages of evolution might include (1) pure (without a mantle) SiO_2 in the star's upper atmosphere, (2) a kernel of SiO_2 covered with an ice mantle at a substantial distance from the star, and (3) pure SiO_2 subjected to radiation processing for a certain time. Detecting changes in the spectral properties of the luminescence from circumstellar dust should make it possible to establish indirectly a number of physical and chemical characteristics of the dust and of the star-dust cloud system as a whole, including: (a) the chemical and mineralogical composition of the dust particles, (b) the temperature of the dusty matter, (c) the power of the exciting radiation, and (d) the stage of evolution of the dusty masses. These hypotheses each require experimental verification.

3. Conclusion

The luminescence of cosmic dust has been discussed. The various types of dust luminescence, including cathodoluminescence, were examined. Formulas were proposed for calculating the average intensity and duration of the photoluminescence from nebular dust. Some new hypotheses have been proposed.

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REFERENCES

1. A. Witt and R. Schild, *Astrophys. J.* **294**, 225 (1985).

2. W. W. Duley, S. Seahra, and D. A. Williams, *Astrophys. J.* **482**, 866 (1997).
3. A. Witt and U. Vijh, in: Astrophysics of Dust, A. Witt, G. Clayton, and B. Draine, eds., *Astron. Soc. Pac. Conf. Ser.* **309**, 125 (2004).
4. A. Li, in: Penetrating Bars Through Masks of Cosmic Dust, D. L. Block and K. Freeman, eds., *Springer*, (2005), p. 535.
5. K. Koike, M. Nakagawa, C. Koike et al., *PSS* **54**, 325 (2006).