Cosmic very small dust grains as a natural laboratory of mesoscopic physics

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In this presentation, we present a model of interstellar dust emission that incorporates mesoscopic-scale physics.

The number of atoms contained in cosmic very small dust grains (VSGs) ranges from 100 to 10,000 atoms. Therefore, the VSGs belong to the mesoscopic scale --- an intermediate scale between microscopic and macroscopic. At the mesoscopic scale, the finiteness of the grain size brings non-negligible effects on their physical properties. In particular, the models describing properties of bulk materials cannot be applied mainly for the following reasons. 1. The longest wavelength of lattice vibration modes is limited by the grain size. The number of thermal excitation modes becomes a few, making it difficult for VSGs to hold thermal energy by vibration modes, especially at low temperatures [1]. 2. Since VSGs are expected to have irregular shapes, the degeneracy of the energy levels is broken. Furthermore, the VSGs exhibit various shapes, leading to a diverse distribution of energy levels among them.

We have constructed a model describing the thermal and optical properties of graphite VSG [2], which have free electrons, with the above mesoscopic properties taken into account. A method of energy level statistics, devised by Kubo (1962) [3], was applied for the first time to model the thermal properties of the free electrons in cosmic graphite VSGs. It is impossible to ascertain the energy level distribution of individual grains, but since what we observe is emission and absorption by an ensemble of grains in interstellar space, considering their statistical features is sufficient. Furthermore, because VSG's shape distribution is anticipated to take various forms, the energy levels of free electrons around the Fermi level are considered randomly distributed. This allows the graphite VSGs to effectively have a large number of thermal excitation modes even in a cold VSG.

The SED of thermal emission from graphite VSGs calculated using these models predicts that the graphite VSGs not only produce the mid-infrared excess emission but also emit a significant amount of energy in the millimeter and submillimeter wavelengths.

In this presentation, we further apply this model to polycyclic aromatic hydrocarbons (PAHs) and demonstrate their thermal emission SED. Although their absorption cross-section is different from graphite, essentially the same model can be applied since the molecular structure of PAHs is similar to graphite, and possesses free electrons. We will then provide the total SED of thermal emission from carbonaceous grains and silicate by superposing their thermal emission with a size distribution [4], assuming that large carbonaceous grains are graphite and small carbonaceous grains are PAHs. Comparisons between the model prediction and the observed SED of the interstellar dust grains are shown.

References

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