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INTERSTELLAR EXTINCTION AND POLARIZATION WITH HOMOGENEOUS AND COMPOSITE GRAINS

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(Invited paper)

ABSTRACT. We discuss possible ways to solve problems arising due to non-unique interpretation of interstellar extinction and linear polarization.

1. Introduction

The interpretation of the observations of interstellar (IS) extinction and IS linear polarization serves for estimates of the dust grains properties like size, chemical composition, shape, and structure. However, these properties are not uniquely determined. This ambiguity arises because the particles with different properties produce the similar extinction and polarization that manifests the Stokes principle of optical equivalence [1]. Below we briefly analyze the problems appearing due to non-unique interpretation and possible ways of solving them. More discussion of the solid particles properties in the different objects and various aspects of dust modelling can be found in [2, 3, 4, 5, 6].

2. Extinction

The average IS extinction curve in the visible-near UV can be approximated by the power law $A(\lambda) \propto \lambda^{-1.3}$ [7]. Such wavelength dependence can be produced by submicron-sized particles with typical radii $\langle r \rangle \approx 0.05 - 0.1\,\mu$m. In this case, we need to choose smaller particles for more absorbing materials like amorphous carbon or iron and larger particles for less absorbing materials like silicate or ice. This illustrates that *from the wavelength dependence of extinction one can determine only the product of the typical particle size on refractive index but not the size or chemical composition of dust grains separately*. In order to solve this problem, it needs to take into account the dust-phase abundances and reproduce the absolute extinction. Unfortunately, abundances are known for a restricted number of diffuse and translucent clouds only [8].

The far-UV extinction varies strongly in different directions and can be explained using tiny particles with typical radii $\langle r \rangle \approx 0.01 - 0.03\,\mu$m. The most promising extinction feature is the UV bump near λ=2175 Å. *A problem is to identify this feature*. As carrier candidates, there have been considered various materials with isotropic and anisotropic properties as well as organic molecules (see discussion in [2, 3]). However, carbonaceous

species and especially graphite are the favorite material. The bump can be also reproduced with polycyclic aromatic hydrocarbons (PAH molecules) [9, 10]. But the attempts to support such an identification using UV bands of PAHs are failed up to now [11, 12].

The *interpretation* of the IS extinction has been performed many times using *homogeneous spherical particles* with various size distributions: from very simple like exponential [13] or power-law [14] to rather complicated containing up to 11 parameters [9].

More complicated *silicate core-ice mantle cylinders* have been used for simultaneous interpretation of IS extinction and polarization [15, 16]. However, it was found that the extinction only slightly depends on the particle shape and orientation [3, 17].

The decrease of estimates of metal abundances in the solar atmosphere called for new dust models able to produce the same extinction with a smaller amount of solid material. A solution to the problem was found in the admixture of vacuum — material available in any amounts. By these means *dust models with fluffy, porous and aggregate particles* have been developed. Multi-component dust mixtures can be introduced as "composite" particles obtained after the mixing of optical constants of several materials using one of the effective medium theory (EMT) rules [18, 19] or inhomogeneous (composite) particles with layers or inclusions from different materials whose optical properties are calculated using rather advanced light scattering theory. Unfortunately, exact calculations are possible for complex aggregates of rather small sizes only [20, 21, 22], therefore, very complicated particles are replaced by more simple "optically equivalent" ones. The EMT-Mie approach can be used if the very porous particles have small (in comparison with the wavelength of incident radiation) "Rayleigh" inclusions. At the same time, the optical properties of heterogeneous spherical particles having inclusions of various sizes (Rayleigh and non-Rayleigh) and very large porosity were found to closely resemble those of spheres with a large number ($\geq 15 - 20$) of different layers [23]. *Multi-layered porous grains* allow one to reproduce the extinction curves using current solar abundances [24, 25, 26, 27].

3. Polarization

IS linear polarization usually has a maximum in visible and declines in the IR and UV. It is caused by the linear dichroism of the interstellar medium due to the presence of non-spherical oriented grains. Non-spherical particles produce different extinction of light depending on the orientation of the electric vector of incident radiation relative to the particle axis. *The interpretation of polarimetric observations is a complicated task.* It includes computations of the polarization cross-sections $C_{\rm pol} = 1/2(C_{\rm ext}^{\rm TM} - C_{\rm ext}^{\rm TE})$ and averaging of them for given particles size and orientation distributions. In order to alleviate the calculations, particles of simple shapes (usually infinite cylinders or homogeneous spheroids) are considered and particles are assumed to be perfectly aligned. Besides this, the modelling is often performed for only one angle between the direction of alignment and the line of sight $\Omega = 90^\circ$ [28, 29, 30]. *All together leads to improper inferences about the efficiency of grain alignment and properties of aligned grains.*

Modelling of the IS polarization usually accompanies modelling of the IS extinction. Early models dealt with *homogeneous cylindrical grains* having the picket fence or perfect rotational (2D) orientation [13].

Later, a more advanced model with *partly aligned silicate core-ice mantle cylindrical particles* was developed [15, 16, 31]. This model includes the alignment mechanism of paramagnetic relaxation (Davis-Greenstein type orientation) [32]. The Davis-Greenstein mechanism seems to be ineffective in dense clouds that gave rise to the development of the grain alignment mechanism in anisotropic radiation field due to radiation torques [33]. However, recent findings have cast some doubt on the efficiency of radiation torques [34].

Homogeneous spheroids of different sizes with perfect orientation have been used for calculations of the polarizing efficiency, visual and UV polarization [29, 35, 36]. A more complicated model including a mixture of carbonaceous and silicate spheroidal grains with imperfect alignment was developed in [17, 37]. This model was applied to the interpretation of IS extinction and polarization observations of seven stars.

Note that the considerations of more complex non-spherical particles (coated spheroids, ellipsoidal particles, composite spheroids) are restricted by the simplest cases of grain alignment [38, 39, 40].

In conclusion, we can emphasize that the determination of dust properties from IS extinction and polarization is not an intractable problem. But it requires rather delicate approaches which must include accurate treatment of light scattering by inhomogeneous non-spherical particles with imperfect alignment.

Acknowledgments

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