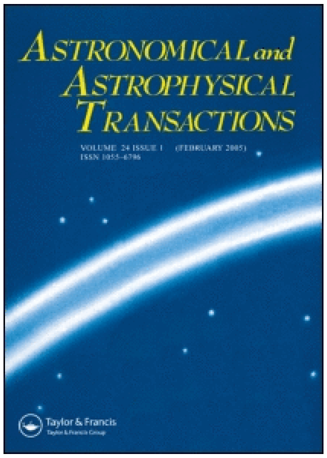

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MODELING OF INTERSTELLAR EXTINCTION WITH COMPOSITE DUST GRAINS

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A model of interstellar dust must satisfy two conditions: dust grains have to be of the reasonable structure and chemical composition and explain basic observations. The latter are the interstellar extinction law and the depletion of interstellar elements. In this work, a new model of composite dust grains is considered. To calculate cross-sections of such particles the exact theory of light scattering by multi-layered grains is used. The results of modeling are compared with observations of the interstellar extinction toward the stars ζ Oph and θ^1 C Ori.

Keywords: Interstellar extinction; Dust models

1 INTRODUCTION

The first requirement to any model of interstellar dust is the explanation of the observed extinction law taking into account dust-phase element abundances in the interstellar medium (ISM). The standard approach of getting the amount of heavy elements locked in the interstellar grains is the subtraction of observed gas-phase abundances from the cosmic ones. However, the cosmic abundances of elements are not yet conclusively established. During many years the solar abundances were used as the reference ones. But photospheres of the early-type stars are not so rich in heavy elements as the Sun is (see Fig. 1). Such a revision of the reference abundances posses a problem of "carbon crisis": abundances of the most important dust forming elements (C, O, Mg, Si, Fe) requiring by any dust model turn out to be greater than the dust-phase abundances available in the ISM.

It seems that the most probable structure of dust grains is the composite one (*e.g.*, in the form of aggregates including small particles of different materials and voids (Mathis and Whiffen, 1989)). Perhaps, such grains can provide more extinction per unit volume than compact homogeneous particles.

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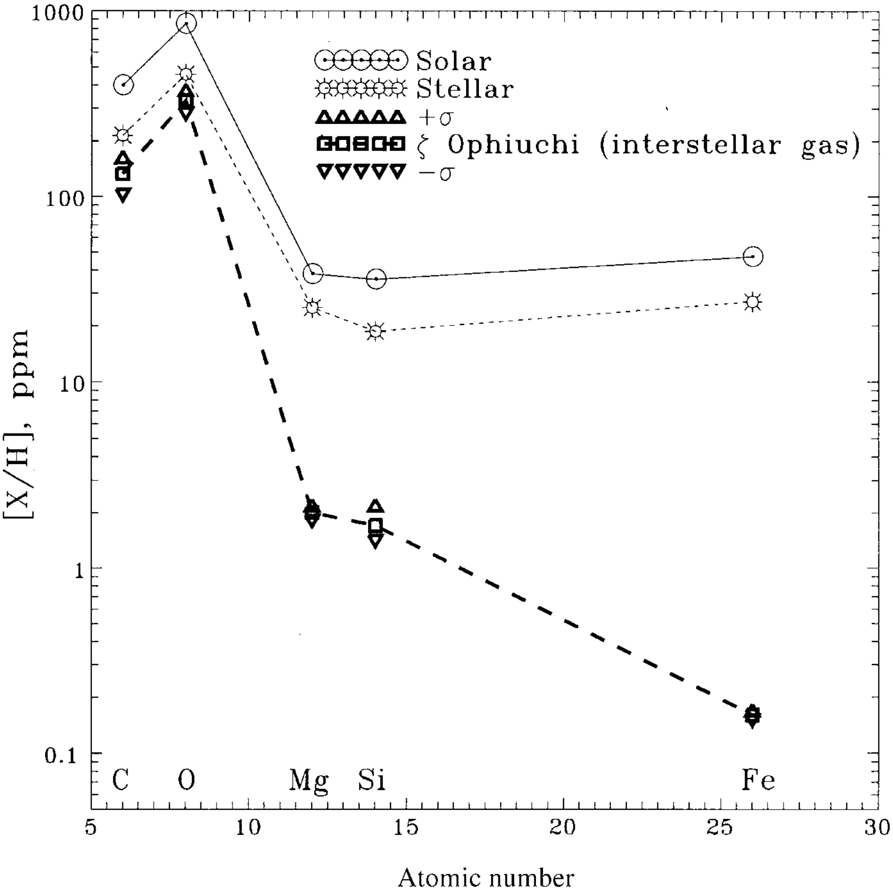

FIGURE 1 Old (solar) and modern (stellar) reference abundances of dust-forming elements (Snow and Witt, 1996; Sofia and Meyer, 2001) supplemented with observed gas-phase abundances in the ISM toward ζ Oph (Cardelli *et al.*, 1993; Cardelli *et al.*, 1994; Savage *et al.*, 1992). The dust-phase abundances are obtained as the difference between the reference abundances (circles and stars) and the gas-phase ones.

2 MODEL AND COMPUTATIONS

There are different approaches to calculate the optical properties of inhomogeneous grains.

The most popular one is based on the Effective Medium Theory (EMT) where the average optical constants are calculated to represent the mixture of materials. This method has a weak point because of its limited area of applicability: the EMT rules give the reliable results if the volume fraction of inclusions is less than 10% (Kolokolova and Gustafson, 2001).

Another approach is the use of the Discrete Dipole Approximation (DDA) where grains are represented as arrays of dipoles and each of them interacts with the external electromagnetic field and the fields produced by other dipoles. This way allows one to calculate the optical properties of grains with rather complicated internal structure. But DDA requires very large computational resources and does not provide the satisfactory accuracy in some cases.

In this paper the third approach for modeling is used. It is based on the exact theory of light scattering by multi-layered particles (Voshchinnikov and Mathis, 1999). The composite structure of dust grains is approximated by a set of very thin homogeneous layers while the porosity is taken into account by the addition of the layers of vacuum.

3 RESULTS

The model of composite spherical particles was used for fitting the extinction curves using the dust-phase abundances for stars ζ Oph (see Fig. 2) and θ^1 C Ori. The model consists of four grain populations:

I. Composite (multi-layered) particles of amorphous carbon and pyroxene with high degree of porosity (90%).
II. Compact graphite grains.
III. Composite magnetite grains with large amount of vacuum (98%).
IV. Compact grains of forsterite.

Used size distributions were power-law with exponential cut-off. Their parameters varied for different populations; graphite particles had a very narrow size distribution.

This model requires more carbon and other heavy elements in solid state than is available in the ISM if the stellar abundances are assumed as the reference ones. To fit the extinction toward ζ Oph ($E(\mathrm{B-V}) = 0.32\,\mathrm{m}$, $A(\mathrm{V}) = 0.94\,\mathrm{m}$, $N(\mathrm{H}) = 10^{21.13}\,\mathrm{cm}^{-2}$) one needs to use about 190–195 ppm* of carbon but the dust-phase abundance of carbon is about 80 ppm only (see Fig. 1). The similar problem occurs for the line of sight toward θ^1 C Ori ($E(\mathrm{B-V}) = 0.34\,\mathrm{m}$, $A(\mathrm{V}) = 1.87\,\mathrm{m}$, $N(\mathrm{H}) = 10^{21.6}\,\mathrm{cm}^{-2}$; Shuping and Snow, 1997).

But the necessary amount of elements is comparable or less than that in other models (*e.g.*, Mathis, 1996; Li and Greenberg, 1997).

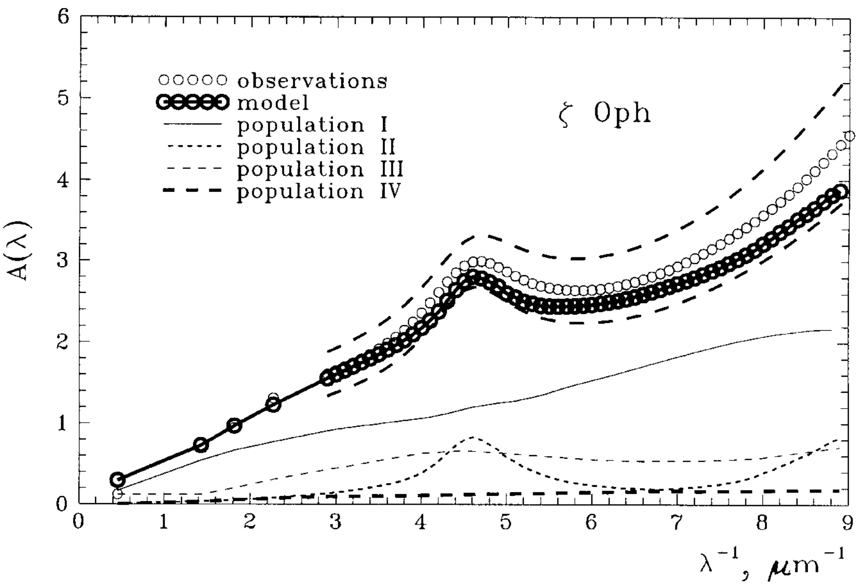

FIGURE 2 The wavelength dependence of extinction toward the star ζ Oph: observations (supplemented with errors of the parameterization given by Fitzpatrick and Massa, 1990; dashed lines) and theoretical results. The contribution of each population to the total extinction is shown.

* particles per million hydrogen atoms.

4 CONCLUSIONS

This is still an open question how to explain the observed value of extinction with reduced amount of heavy elements (*i.e.*, to increase the extinction to volume ratio). It seems that some enhancement of this ratio is expected if we take into account a possible grain non-sphericity. It is also improbable that larger extinction can be provided by an unknown material. The possible way to resolve the problem of "carbon crisis" is the re-examination of the reference cosmic abundances and the investigation of their regional dependence.

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