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Opacities for protoplanetary disks

D. Semenov

Astrophysical Institute and University Observatory, Schillergäßchen 2-3, 07745 Jena, Germany

Th. Henning

Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany

M. Ilgner

Astrophysical Institute and University Observatory, Schillergäßchen 2-3, 07745 Jena, Germany

Ch. Helling and E. Sedlmayr

Center for Astronomy and Astrophysics, TU Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Abstract. A new opacity model relevant to the conditions of protoplanetary disks is developed. As primary absorbers, dust grains of different compositions, sizes, and shapes and various atoms, ions, and molecules are considered. The Rosseland and Planck mean opacities are computed and compared to recently compiled opacity tables. The influence of different Rosseland mean values on the thermal structure of an accretion disk is studied.

1. Introduction

Recently, a few comprehensive dust models relevant to the physical conditions of protostellar cores or protoplanetary disks were proposed by Henning & Stognienko (1996) and Pollack et al. (1994). The latter authors considered the composition and abundances of solid and gaseous species in molecular cloud cores and protoplanetary disks in detail. Henning & Stognienko investigated the influence of grain aggregation in the early phases of protoplanetary disks and effects of various types of silicates and the role of iron for the dust opacities.

A number of papers deal with the calculation of Rosseland or/and Planck mean opacities of the stellar winds or atmospheres of cool stars, for instance, Alexander & Ferguson (1994) and Helling, Winters, & Sedlmayr (2000). Helling et al. calculated these quantities for wide ranges of density, temperature, and composition and showed the importance of molecular opacities for the dynamics of the winds of AGB stars. Alexander & Ferguson computed a set of opacity tables for various elemental abundances by accounting for absorption and scattering due to both gas and dust species.

However, there is a lack of papers which focus on the calculations of the dust and gas opacities for the conditions of protoplanetary disks based on the best estimates of the dust composition and recent improvements in molecular and atomic line lists. We introduce such a new dust-gas opacity model that works for gas densities between 10^{-18} g cm^{-3} and 10^{-7} g cm^{-3} and temperatures between 5 K and 10 000 K. The opacity tables are available via the Internet: *http://www.astro.uni-jena.de/Users/henning/Opacities/opacities.html.*

2. Dust Opacities

In order to calculate dust-dominated opacities, we apply the scheme proposed in Semenov et al. 2002:

- Pollack compositional model is used (Pollack et al. 1994);
- the evaporation temperatures of the dust materials are taken to be dependent on gas density;
- the grains are considered as either chemically homogeneous spherical or aggregate particles or inhomogeneous (composite) aggregates;
- the aggregates are supposed to consist of small (0.01μm) spherical subgrains;
- for the size distribution a modified MRN function is applied, where the modification consists of an inclusion of large (up to 5μm) dust particles;
- the spectral representation of inhomogeneous media is employed for the aggregate grains in order to model the influence of their fractal structure on the optical behaviour (Henning & Stognienko 1996);

3. Gas Opacities

As gas-dominated opacities we use the opacity tables calculated by a new model of Helling (2001). The calculations have been performed using the opacity sampling data of several million spectral lines of CO, TiO, SiO, H_2O, CH, CN, C_2, C_3, HCN, C_2H_2, CO_2, O_2, N_2O, CH_4, O_3, NO, SO_2, NO_2, NH_3, HNO_3, OH, H_2CO, N_2, H_2S, HO_2, beside continuum absorption from H^+, H^-, H+H, H_2^-, H_2^+, He, He^-, C, Mg, Al, Si as well as Thomson scattering on free electrons and Rayleigh scattering for H and He. The Rosseland and Planck mean gas opacities were computed for the solar abundances taken from Anders & Grevesse (1989).

4. Relation between the Dust and Gas Opacities

As has been discussed by many authors, whenever dust is present it completely dominates the opacity and one can neglect the gas species in this case. Following this approach, we use either dust opacities for temperatures below $\sim 1\,700$ K (depending on the density) or gas opacities for higher temperatures.

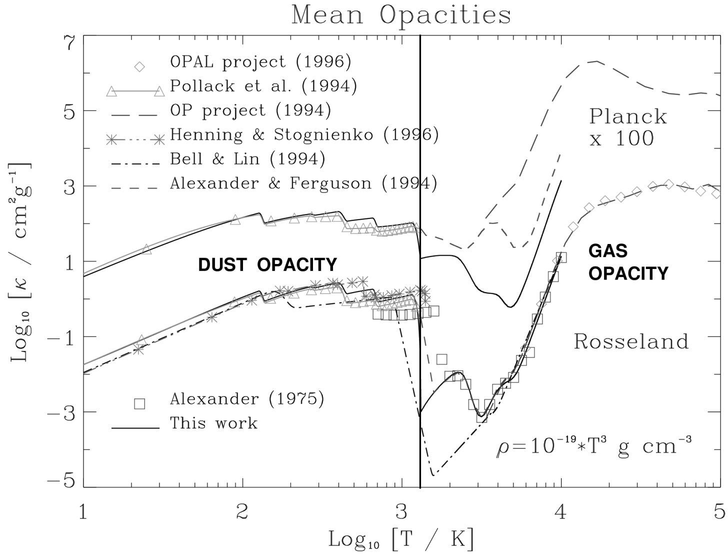

Figure 1. The Rosseland and Planck mean opacities calculated by recent opacity models.

5. Results

We compare the Rosseland and Planck mean opacities calculated by recent opacity models in Fig. 1. As can be clearly seen, the main advantage of our model is that it works well for a wide range of the gas temperatures and densities, where diversity of the relevant physical processes causes the many recent models to fail. Interestingly, there is no large difference between the dust-dominated opacities ($T \lesssim 1\,500$ K). The reason is that corresponding dust models use rather similar assumptions about grain sizes and composition, resulting similar values for the monochromatic opacities and, consequently, the Rosseland and Planck means.

On the contrary, for gas-dominated opacities ($T \gtrsim 1\,500$ K) the difference between the various models may reach about three orders of magnitude for the Rosseland mean or even more for the Planck mean opacities. The behaviour can be explained by the fact that we take into account the formation of many complex molecules under low temperatures ($T \lesssim 3\,000$ K) and use up-to-date atomic and molecular line lists in order to calculate the frequency-dependent opacities.

In addition, we study how different Rosseland mean values may affect the thermal structure of accretion disks. We use a full 2D hydrodynamical code designed to simulate the interaction of the protoplanetary disk matter with a protoplanet and apply three different opacity tables to compute the disk midplane temperature (courtesy to G. D'Angelo). The result is shown in Fig. 2, where the corresponding disk model parameters are indicated. One may immediately figure out that the temperature values can differ by up to 50%. The reason is that the Bell & Lin (1994) model incorporates only homogeneous spherical dust grains made of silicate and water ice as the source of the opacity, whereas we use a more advanced compositional model and treat the grains to be aggregates by their structure. This leads to the higher values of the monochromatic opacities

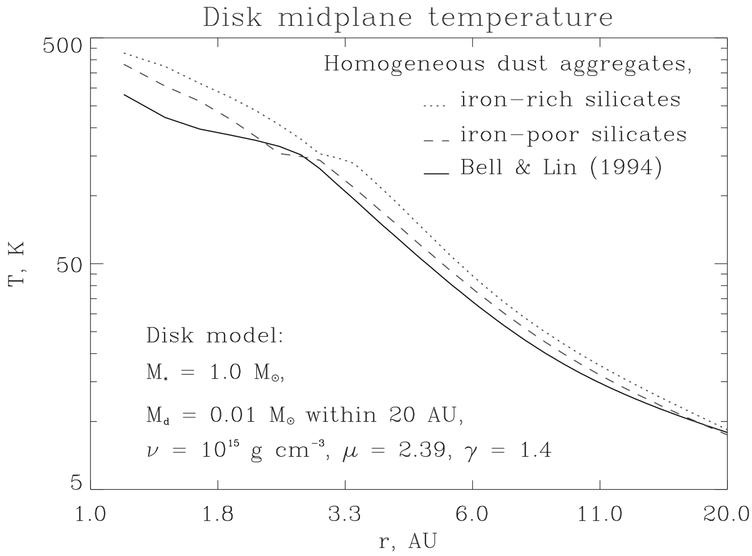

Figure 2. The disk midplane temperature obtained with three different opacity tables.

and, consequently, to the higher values of the Rosseland mean opacities for our model compared to the model of Bell & Lin. In turn, it causes the disk midplane temperature to be higher for the former opacity table.

It shows that one shall be careful in applying any particular opacity model in modern hydrodynamical simulations.

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