1. INTRODUCTION

It has been clear for more than a decade that the absorbing surfaces or photospheres of T Tauri disks had to be "flared," i.e., curved upward away from the disk midplane, to explain the typical observed spectral energy distribution at infrared wavelengths (Kenyon & Hartmann 1987). Because of flaring, the irradiation of the disk by the central star tends to dominate the disk heating at large radii (Calvet et al. 1991, 1992). Since the amount of flaring depends upon the temperature structure, which in turn depends upon the flaring-dependent irradiation, the self-consistent structure in general must be solved iteratively (Kenyon & Hartmann 1987; D'Alessio 1996; D'Alessio et al. 1998, hereafter Paper I; D'Alessio et al. 1999a). The dust grains control the absorption and emission of radiation and therefore the knowledge of their properties help determine the disk structure.

In a previous paper (D'Alessio et al. 1999b, hereafter Paper II), we constructed models for T Tauri disks in which the vertical disk structure was self-consistently solved assuming well-mixed dust with properties characteristic of interstellar grains. We found that the resulting models were too geometrically thick, which is also the case of the two-layer flared disk models of Chiang & Goldreich (1997, 1999). Our models also exhibited too little millimeter and submillimeter (sub-mm) wavelength emission, in comparison with observations. These deficiencies can in principle be relieved or eliminated by models including grain growth and settling to the disk midplane, processes which are thought to be essential precursors to planet formation (e.g., Beckwith, Henning, & Nakagawa 2000). Even without settling, grain growth alone can help improve the comparison with observations, since for a given dust mass growth can increase the long-wavelength opacity at the same time it decreases the optical and near-infrared opacity; the latter effect reduces the apparent disk thickness at short wavelengths, and can even reduce the true disk vertical scale height by reducing irradiation heating.

It is generally thought that some grain growth must have occurred in T Tauri disks to explain the spectral indices of the long-wavelength disk emission in some systems (Beckwith & Sargent 1991, hereafter BS91; Mannings & Emerson 1994; Pollack et al. 1994, hereafter P94). Unfortunately, the details of this process are poorly understood. We are therefore motivated to adopt a parameterized approach with few parameters to make an initial exploration of the effects of dust growth on T Tauri disk structure.

In this paper we present sequences of detailed, physically self-consistent disk models with power-law size distributions. The models assume complete mixing between dust and gas and solve for the vertical disk structure self-consistently including the heating effects of stellar irradiation as well as local viscous heating. For a given total dust mass, grain growth is found to decrease the vertical height of the surface where the optical depth to the stellar radiation becomes unity and thus the local irradiation heating, while increasing the disk emission at mm and submillimeter wavelengths. The resulting disk models are less geometrically thick than our previous models assuming interstellar medium dust, and agree better with observed spectral energy distributions and images of edge-on disks, like HK Tau/c and HH 30. The implications of models with grain growth for determining disk masses from long-wavelength emission are considered.

Subject headings: accretion, accretion disks — circumstellar matter — stars: formation — stars: pre–main-sequence

ABSTRACT

We present detailed models of irradiated T Tauri disks including dust grain growth with power-law size distributions. The models assume complete mixing between dust and gas and solve for the vertical disk structure self-consistently including the heating effects of stellar irradiation as well as local viscous heating. For a given total dust mass, grain growth is found to decrease the vertical height of the surface where the optical depth to the stellar radiation becomes unity and thus the local irradiation heating, while increasing the disk emission at mm and submillimeter wavelengths. The resulting disk models are less geometrically thick than our previous models assuming interstellar medium dust, and agree better with observed spectral energy distributions and images of edge-on disks, like HK Tau/c and HH 30. The implications of models with grain growth for determining disk masses from long-wavelength emission are considered.

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