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Molecular hydrogen emission from protoplanetary disks : Effects of dust size growth and settling

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Abstract. We have modeled self-consistently the density and temperature profiles of gas and dust in protoplanetary disks, taking into account irradiation from a central star, as well as dust size growth and settling towards the disk midplane. Making use of this physical structure, we have calculated the level populations of molecular hydrogen and the line emission from the disk. As a result, the dust evolution changes the physical properties of the disk, and thus the line ratios of the molecular hydrogen emission.

Keywords. line: formation, molecular processes, radiative transfer, planetary systems: protoplanetary disks

1. Introduction

Thanks to recent high spectral resolution and high sensitivity observations, it has become possible to detect molecular hydrogen line emission from protoplanetary disks in the near- and mid-infrared, and ultraviolet wavelength bands. Historically, molecular hydrogen emission has been observed towards various kinds of astronomical objects, such as shock surfaces associated with star forming regions, reflection nebulae illuminated by nearby massive stars, planetary nebulae, etc., and the line ratios have been used as an indicator of some physical properties of the objects.

In protoplanetary disks dust particles are believed to stick each other and grow in size, as well as settle towards the disk midplane. As these processes are thought to be the first step of planet formation, it is of great interest to find observational evidence of this growth and settling. In this work we examine the effects of the dust growth and settling on molecular hydrogen emission from protoplanetary disks as an indicator of the pre-planet-formation processes.

2. Physical disk model and molecular hydrogen emission

· **Dust model** : Two kinds of model are used in this work: (A) dust grains whose spatial distribution is uniform and size distribution is proportional to $a^{-3.5}$ (a : dust radius) with maximum dust radii of 10 μm, 1mm, and 10 cm, and (B) dust grains whose spatial and size distributions are obtained by solving coagulation equations with an advection (settling) term for various sizes of dust particles.
· **Physical disk model** : We model self-consistently the density and temperature profiles of gas and dust in the disk by assuming vertical hydrostatic equilibrium, local thermal

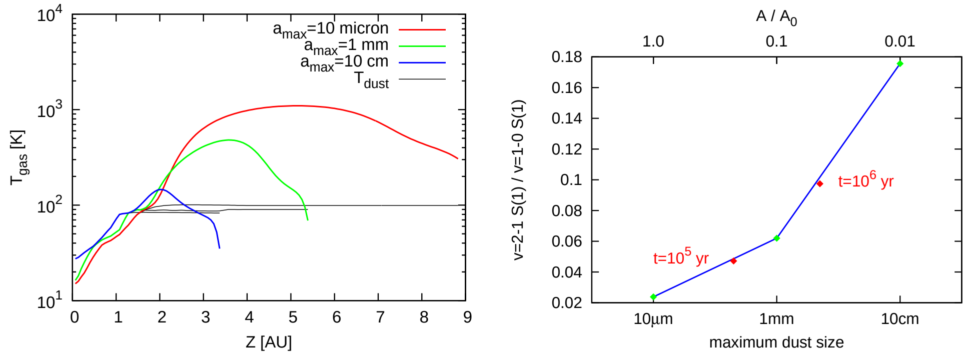

Figure 1. Left: The vertical gas temperature profiles at the disk radius of 10AU for the dust models (A) with the maximum dust sizes of $a_{\rm max} = 10\mu$m (red), 1mm (green), and 10cm (blue). Right: The line ratio of $v = 2-1\ S(1)/v = 1-0\ S(1)$ as a function of $a_{\rm max}$, on which we also plot the ratio obtained using dust model (B) at $t = 10^5$yr and 10^6yr after the dust grains start to evolve. A/A_0 on the top of the figure shows the total surface area of dust particles normalized by that for the model (A) with $a_{\rm max} = 10\mu$m.

balance between heating and cooling for gas temperature, and local radiative equilibrium for dust temperature. As stellar UV radiation we adopt the model which reproduces observations towards a classical T Tauri star, TW Hya.

· **Molecular hydrogen emission** : Making use of the physical structure, we calculate level populations of molecular hydrogen in the disk by assuming statistical equilibrium among energy levels. Then the line emission from the disk is computed by solving radiative transfer equation in near- and mid-infrared, and ultraviolet wavelength bands (see Nomura & Millar 2005 for details of the model).

3. Results

As a result of our calculation, the effects of the dust particle growth and settling appear in physical properties of the disk: (1) the gas temperature in the surface layer decreases (Fig.1, left) and (2) the ultraviolet radiation fields increases. Both of these result from the decrease of the total surface area of dust grains per unit gas mass, which leads to less efficient photoelectric heating of gas and less effective dust extinction of UV radiation.

In consequence of these changes in physical disk structure, the level populations of molecular hydrogen are in a highly non-LTE distribution because the UV pumping process becomes much more efficient than collisional excitation. This is reflected in the emission lines from the disk:- for example, the line ratio of $v = 2-1\ S(1)/v = 1-0\ S(1)$ increases with the dust evolution (Fig.1, right). More detailed results in other wavelength bands will be presented in the poster.

References

Nomura, H. & Millar, T.J. 2005, *A&A*, in press (astro-ph/0505126)