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

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Observation of molecular hydrogen line emission from protplanetary disks is important because it directly traces gaseous masses of the disks, which have great influences on planetary system formation. Thanks to recent high spectral resolution and high sensitivity observations, it has become possible to detect molecular hydrogen line emission from the disks in the near-infrared (NIR), mid-infrared (MIR), and ultraviolet (UV) wavelength bands. Meanwhile, the dust particles in the disks are believed to increase in size and settle towards the disk midplane, which leads to planet formation. These processes are expected to affect molecular hydrogen emission from the disks through changes in dust opacity and photoelectric heating rate on dust grains.

In order to investigate the effects of dust size growth and settling, we have modeled disk structure, level populations of molecular hydrogen and the line emission from the disks, using dust size distribution model first, and then calculating the size distribution practically by solving coagulation equation for dust particles. As the dust size distribution model, we assume that the distribution is proportional to the dust size to the power of -3.5, and change the maximum dust size as 10 micron, 1mm, and 10 cm.

First we have modeled self-consistently the density and temperature profiles of gas and dust in the disk on the assumptions of vertical hydrostatic equilibrium and local thermal balance between heating and cooling. We adopt the stellar UV radiation model which reproduces observations towards a T Tauri star, TW Hya. As a result, the gas temperature at the surface layer of the disk drops as the dust particles grow because the rate of photoelectric heating on dust grains decreases due to the reduction of the number of dust particles.

Next, making use of the physical structure, we have calculated level populations of molecular hydrogen in the disk on the assumptions of statistical equilibrium among the levels. In consequence, the level populations change from local thermodynamic equilibrium (LTE) into non-LTE distributions as the dust particle growth. It is because the gas temperature drops and the collisional excitation becomes less effective, while the dust opacity reduces and the UV pumping process becomes dominant in controlling the level populations.

Then, we have computed the line emission from the disks, using the above physical and chemical profiles, and found the following changes appear as the dust particles grow; in the NIR wavelength bands, where ro-vibrational transition lines appear, the lines with the upper levels of high vibrational energies have relatively stronger intensity, because the level populations become in non-LTE. Meanwhile, in the MIR wavelength bands, where pure rotational transition lines appear, the lines with the upper levels of low rotational energies have relatively stronger intensity, because the level populations are in LTE and the gas temperature drops. Finally, in the UV avelength bands, where transition lines from the excited electronic states appear, many lines have relatively similar strength because the level populations in the ground electronic states become in non-LTE.

In addition, we have solved coagulation equation for dust particle growth, taking into account the settling towards the disk midplane. And then we have modeled disk structure, level populations of molecular hydrogen and the line emission from the disk, using the resulting dust size distributions. As a result, the line emitting regions move towards midplane as the dust particles settle. The line intensities and the intensity ratios become similar to the results obtained using the above-mentioned dust size distribution model with the maximum dust size of 100 micron.