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Chemistry and thermal balance in a transitional disk: the gas around HD141569A

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Abstract. The disk around HD141569A is one of the few examples of a disk in the transitional stage between gas-rich HAeBe disks and dusty Vega-like debris disks. The disk is optically thin in the continuum, but there is still gas present as shown by observations of CO rotational lines by Zuckerman et al. (1995) and Dent et al. (2005), and of CO rovibrational lines by Brittain et al. (2003). A model was made to calculate the gas temperature and chemistry of the disk. The model uses a 1-dimensional code for photon dominated regions to calculate the chemistry in the radial direction; this was repeated at different angles with respect to the midplane to get a full coverage of the (R, z) plane. Since the disk is optically thin to continuum radiation and the stellar radiation is much more intense than the interstellar radiation field a 2-dimensional radiative transfer is not needed here. Line radiation responsible for the dissociation of H_2 and CO has to be treated separately, since these molecules can become self-shielding. An additional contribution to the photodissociation rate for these molecules by the interstellar radiation field is added to the chemical network. This rate has a value of 50% of the unshielded interstellar photodissociation rate at the disk's surface; for deeper layers this rate is scaled by shielding functions for the column densities of H_2 and CO between the present position and the surface.

The HD141569A disk has a peculiar dust distribution: there is a large inner hole (out to $R = 150$ AU) and two ringlike structures at 185 and 325 AU, the latter of which is likely caused by two M-dwarf companions HD141569B and C (Augereau & Papaloizou 2004). From SED fitting of the disk by Li & Lunine (2003) it was found that the dust grains are large ($1\,\mu\text{m} < a < 1\,\text{cm}$) and porous ($P = 0.73$). PAHs are present in the disk (Li & Lunine 2003, Weinberger et al. 2004); in this model it is assumed that the PAH abundance with respect to hydrogen is constant throughout the disk with a total PAH mass of $7.1 \times 10^{-6} M_\oplus$, corresponding to an abundance of $\sim 10^{-9}$ H atom^{-1}.

The resulting chemistry and temperature structures resemble those found by Kamp & Bertoldi (2000) and Kamp & van Zadelhoff (2001) for Vega-like debris disks and by Jonkheid et al. (2004) and Kamp & Dullemond (2004) for T-Tauri disks: the upper layers have high temperatures and mostly atomic and ionized species, while the lower layers are cooler and molecular (see Figure 1). The gas temperatures are significantly higher than the dust temperature in the optically thin part of the disk. The most important differences with these models are due to the peculiar dust distribution: it causes relatively low molecular abundances in the inner hole as H_2 formation is suppressed there, and also low temperatures due to the lack of heating of the gas by photoelectric heating of the large grains. It can be seen from Figure 1 that the mass of the disk has a significant effect on the resulting gas temperature and chemistry: in low-mass disks the relative importance of photoelectric heating is higher, since the mass in grains and PAHs is kept constant in all models, while cooling is less efficient due to the lower densities. It can also be seen that the abundances of H_2 and CO are strongly affected by the gas mass due to the stronger effects of shielding at higher column densities.

From the computed chemistry and gas temperatures the shape and intensity of molecular emission lines were determined using the 2-D accelerated Monte Carlo radiative transfer code by Hogerheijde & van der Tak (2000). By comparing the predicted emission lines with the observed spectra the gas mass of the disk was constrained. It is found that a $\sim 5\,M_\oplus$ disk fits

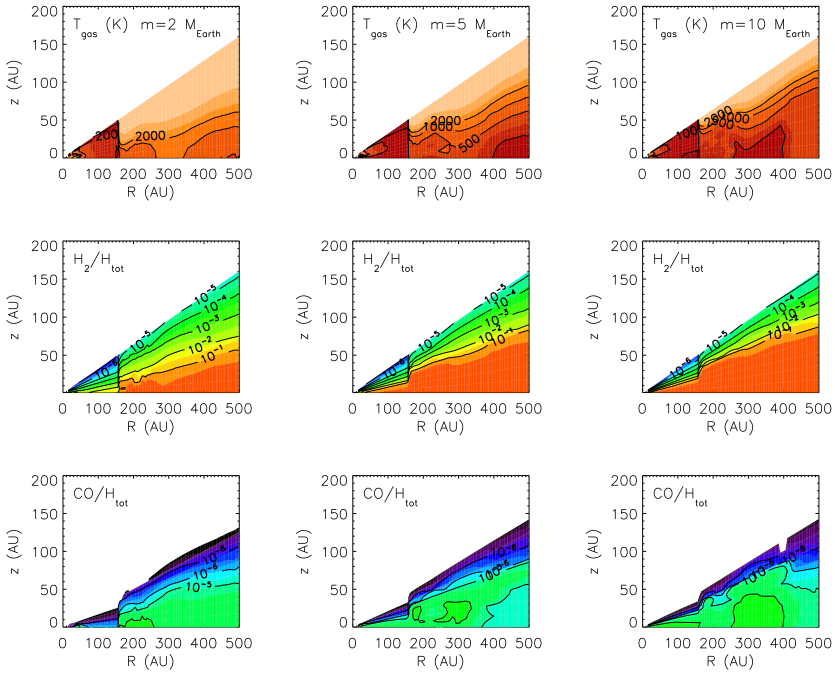

Figure 1. Temperature and chemical structure for models with $m_{\rm gas} = 2\,M_\oplus$ (left column), $m_{\rm gas} = 5\,M_\oplus$ (middle column) and $m_{\rm gas} = 10\,M_\oplus$ (right column). In all models the dust mass was kept constant at $22\,M_\oplus$

the observations quite well. The total mass of dust in the disk is $\sim 22\,M_\oplus$, giving a gas/dust ratio of less than unity.

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