Infrared Emission From Gas in Optically Thick Disks

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ABSTRACT

We present preliminary models of the infrared emission from gas in young disks with optically thick dust. We focus on the separate calculation of the gas and dust temperatures near the disk surface, where gas and dust decouple and their temperatures differ. We use a modified Chiang and Goldreich (1997) dust disk model to numerically determine the dust temperature. The gas temperature near the surface is determined by a thermal balance calculation, which includes a self-consistent computation of the chemistry and disk vertical structure. The disk spectrum is then computed, including the dust continuum and gas emission lines. Our preliminary disk model is for a passive disk, with no heating due to viscous accretion, orbiting a 1 Myr old solar-type star. We present the thermal structure, chemistry, main heating and cooling processes in the disk, resulting emission lines and mass loss rate by photoevaporation caused by the stellar radiation field.

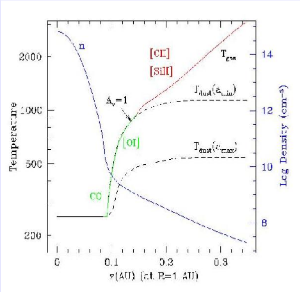
MODEL DESCRIPTION

- "Two-layer" modified Chiang & Goldreich (1997) dust disk model
- Stellar radiation field with excess UV and X-rays typical of young stars
- Vertical density structure and chemistry calculated self-consistently by imposing thermal balance, ***steady-state*** chemistry and pressure equilibrium.
- Models assume ***passive*** disks, no accretion or viscous heating
- Dust and gas are assumed well-mixed, i.e., there is no dust settling.
- Heating due to X-rays, stellar and interstellar UV field, exothermic chemical reactions and other mechanisms. Cooling due to atoms and molecules, collisions with dust (see Gorti & Hollenbach 2004)
- Gas temperature equal to dust in midplane, differs near the surface.
- Line intensities of various ionic, atomic and molecular species calculated.
- Photoevaporation from disk surface as determined by gas density and temperature from disk model and analysis following Adams et al. (2004).

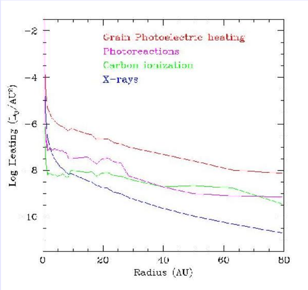
MODEL PARAMETERS

- $M_* = 1\ M_o$; $R_* = 2\ R_o$; $T_* = 6000$ K
- Stellar Radiation: Kurucz model
  UV for a 1 Myr star; $L_{UV}/L_{bol} = 0.1$
  Xrays from 0.5-10 keV; $L_X/L_{bol} = 10^{-3}$
- Disk size: 0.35 AU < r < 80 AU
- Surface density distribution: $\Sigma(r) \sim r^{-1}$
- Disk mass: $M_{gas} = 0.05\ M_o$; $M_{dust} = 0.01\ M_{gas}$
- Dust grain size: 50 Å < a < 20 μm
  $dn/da \sim a^{-3.5}$
- Dust composition: Astronomical Silicate
- 73 species of H, C, O, S, Fe, Mg, Si and 540 reactions

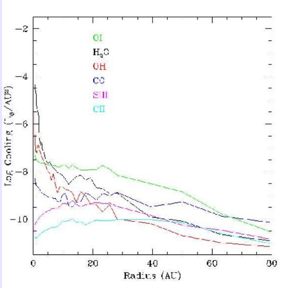
OPTICALLY THICK DISK MODEL: RESULTS



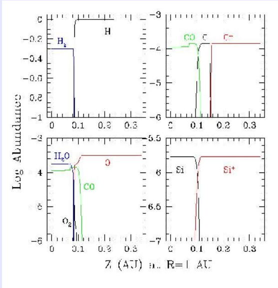
Gas and Dust temperature as a function of height at 1AU. The colored lines mark the regions where the line emission from the indicated species originate.



The dominant heating mechanisms in the disk surface as a function of disk radius, integrated vertically through the disk from above the optically thick midplane.



The main coolants in the disk. The cooling is integrated vertically through the entire disk and is shown as a function of radius.



The transitions of some important chemical species at R=1AU.

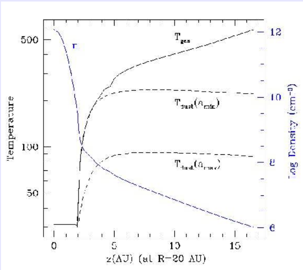
Gas Emission Lines

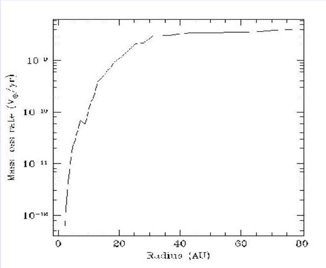
Line	*Wavelength*	*Line luminosity*	*R=600 (Spitzer)*		*R=3x10⁴ (SOFIA, Herschel)*	
			Line/cont. Ratio	*Flux at 100pc*	*Line/cont. Ratio*	*Flux at 100pc*
[SiII]	34.8μm	$3.9 \times 10^{-6}\ L_o$	1.2%	0.1 Jy	60%	4.8 Jy
[OI]	63μm	$2.1 \times 10^{-5}\ L_o$	---	0.9 Jy	210%	46.8 Jy
[CII]	158μm	$9.0 \times 10^{-7}\ L_o$	---	0.1 Jy	43%	5.0 Jy
CO 15-14	174μm	$3.0 \times 10^{-7}\ L_o$	---	0.03 Jy	14%	1.5 Jy

Summary

- Main heating mechanisms are Grain Photoelectric heating, X-rays and photoionization and photodissociation reactions.
- Gas emission arises from the "superheated" surface layer where gas is typically hotter than the dust.
- Emission from [OI]63μm, [SiII]34.8μm, [CII]158μm and CO dominate. H_2 and [SI]25.2μm emission is weak.
- Though line luminosities are above Spitzer's sensitivity, strong continuum emission makes lines difficult to detect.
- Herschel and SOFIA may be able to detect emission from young disks and can spectrally resolve the lines.

PHOTOEVAPORATION





Results

- Photoevaporation of disk due to the radiation field of the central star can be significant.
- Gas at the base of the flow has densities ~ 10^6 cm^{-3}, and temperature 500-1000 K.
- Mass loss rate increases with radius and the disk photoevaporates from the outside.
- Disk beyond 20 AU with mass 0.01 M_o is photoevaporated on timescales ~ 10 Myr.

References

Adams, F.C., Hollenbach, D., Laughlin, G., Gorti, U. 2004, ApJ, 611, 360
Chiang, E., Goldreich, P. 1997, ApJ, 490, 368
Gorti, U., Hollenbach, D. 2004, ApJ, 613, 424