# Effects of Accretion Flow on Chemical Structure and Dust Distribution in Protoplanetary Disks

H. Nomura[1], Y. Aikawa[2], Y. Nakagawa[2], and T.J. Millar[3]

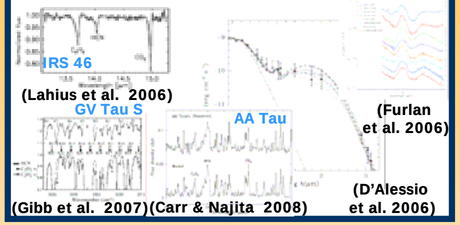
1. Kyoto Univ. Japan, 2. Kobe Univ. Japan, 3. Queen's Univ. Belfast, UK

## ABSTRACT

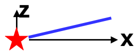
We have studied the effects of the gas accretion flow on the distribution of molecules in hot inner regions as well as on the spatial and size distribution of dust particles in protoplanetary disks. Our results have shown that the high $C_2H_2$ abundance observed toward young disks may suggest relatively high accretion velocity (>50cm/s) in the disks. Also, the observed infrared excess radiation of dust continuum can be reproduced when the density of the surrounding cloud is high (>$10^4$cm$^{-3}$) or the viscous parameter is high enough ($\alpha$>0.001). In addition, we propose observational diagnostics of the gas accretion flow and the dust evolution in the disks using ALMA.

## INTRODUCTION

Molecular lines, Si feature, SED in inner disks




## DISK MODEL




gas density : vertical hydrostatic equilibrium
surface density : steady accretion model

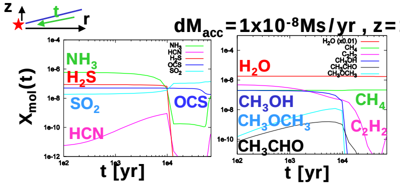
dust temperature : local radiative equilibrium
- stellar irradiation
- viscous heating

gas temperature : local thermal equilibrium
$(\Gamma_X + \Gamma_{pe} + L_{gr} - \Lambda_{line} = 0)$
$\Gamma_X$ : X-ray heating
$\Gamma_{pe}$ : FUV heating
$\Lambda_{line}$ : radiative cooling
$L_{gr}$ : gas-grain collisions

(Nomura & Millar 2005, Nomura et al. 2007)

## Evolution of molecular abundances

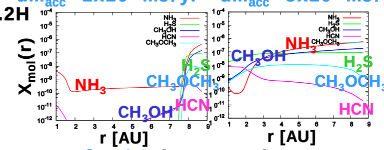
dM$_{acc}$=1x10$^{-8}$Ms/yr , z=1.2H




Parent species($CH_3OH$, $H_2S$)
→ Daughter species ($CH_3OCH_3$, $SO_2$ etc.)
timescale : t~$10^{4\text{-}5}$yr

## Spatial distribution of molecules

dM$_{acc}$=1x10$^{-8}$Ms/yr  dM$_{acc}$=5x10$^{-8}$Ms/yr
z=1.2H



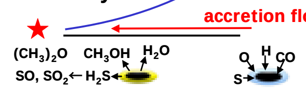

dM$_{acc}$=1x10$^{-8}$Ms/yr ($\tau_{acc} > \tau_{react}$)
: high abundances only near the evaporation radius

dM$_{acc}$=5x10$^{-8}$Ms/yr ($\tau_{acc} < \tau_{react}$)
: parents: uniform, daughters: high at the inner disk

## Effect of Accretion Flow on Chemical Structure

Disk Accretion:
gas disk dispersal
gaseous planet formation,
migration of (proto)planets

↔ Theory: MRI? Observation?




Icy mantle evaporation⟶
observational diagnosis of disk accretion?

### Chemical kinetic models

$$\frac{d(n_\alpha v_\alpha)}{ds} = \sum A_{\alpha\beta} n_\beta + \sum_{\beta,\gamma} B_{\alpha\beta\gamma} n_\beta n_\gamma$$

Chemical reaction network :
209 species, 2203 gas-phase reactions
Initial condition: ice evaporation

$CH_4$, $C_2H_2$, $C_2H_4$, $C_2H_6$, CO, $CO_2$, $O_2$, $H_2O$, $H_2CO$, $CH_3OH$, $C_2H_5OH$, $N_2$, $NH_3$, $H_2S$, OCS

(Nomura & Millar 2004)

## Comparison with warm infrared lines

**Model**

$H_2O$ : $H_2O$/CO ~ 2
$CH_4$ : $CH_4$/CO ~ 0.0015
: spatially uniform
$C_2H_2$ : $C_2H_2$/CO ~0.4
: partly destroyed?
↔ accretion flow?
$CO_2$ : $CO_2$/CO~0.02
: easily destroyed
HCN : lower than obs.
initial condition?

**Observations**

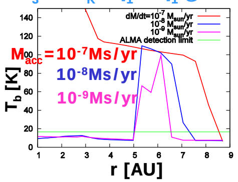
Relative abundances to CO

| Species | IRS 46 | GV Tau S | AA Tau |
|---|---|---|---|
| $H_2O$ | – | – | 1.3 |
| OH | – | – | 0.18 |
| HCN | 0.025 | 0.0031 | 0.13 |
| $C_2H_2$ | 0.015 | 0.0062 | 0.016 |
| $CO_2$ | 0.05 | – | 0.004 – 0.26 |
| $CH_4$ | – | < 0.0019 | – |

IRS 46: Lahius et al. 2006
GV Tau S: Gibb et al. 2007 (2008)
AA Tau: Carr & Najita 2008

## Prediction to ALMA observations

$CH_3OH$: $J_K$=$7_{-1}$→$6_{-1}$ @338GHz




$$F_{ul,\nu} = \int_{-z_\infty}^{z_\infty} n_u A_{ul} \frac{h\nu_{ul}}{4\pi} \exp(-\tau_{ul}) dz$$

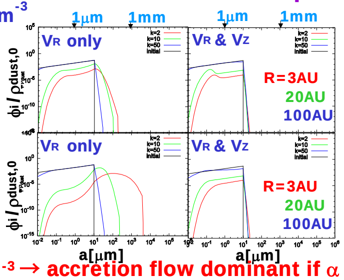
$n_u$: LTE distribution
(Hogerheijde & van der Tak 2000, Schoier et al. 2005)

ALMA 5σ detection limit
50 antennas, 1km/s, 0".1, 600s

Dependence of line emission on accretion flow
→ Observable by ALMA

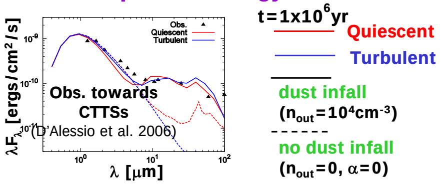
## Effect on size distribution of dust particles

n$_{out}$=10$^4$cm$^{-3}$
t=10$^6$yr
z=H




n$_{out}$=10$^4$cm$^{-3}$ → accretion flow dominant if $\alpha$ >10$^{-2\sim-3}$

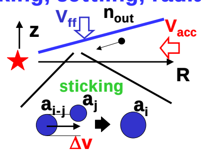
## Effect on spectral energy distribution




n$_{out}$>10$^4$cm$^{-3}$ or $\alpha$ >10$^{-2\sim-3}$
→ consistent with observations

## Effect of Accretion Flow on Dust Distribution

### Sticking, settling, radial motion of dust particles



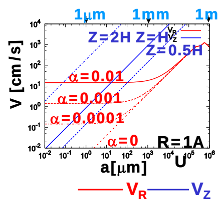

Δv: velocity differences
- Brownian motion
- settling & radial velocity differences
- turbulent induced velocity differences

$$\frac{\partial \varphi_i}{\partial t} + \frac{1}{R}\frac{\partial (R\varphi_i v_R)}{\partial R} + \frac{\partial(\varphi_i v_z)}{\partial z} = \frac{1}{2} m_i \sum_{j=1}^{i-1} \beta_{i-j,j}\varphi_{i-j}\varphi_j - m_i\varphi_i \sum_{j=1} \beta_{i,j}\varphi_j$$

$\beta_{i-j,j}=\pi(a_{i-j}+a_j)^2\Delta v\ p_s/m_{i-j}m_j$

turbulent mixing $V_z\varphi_i = -(\Omega_z^2/D_g)\varphi_i - D_0(\partial\varphi_i/\partial z)$

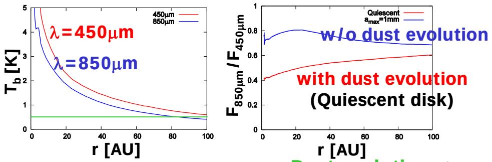
### Vertical and Radial Motion




Vertical ⇔ n$_{out}$
- gravitational force
- dust-gas friction

Radial ⇔ $\alpha$
- gas accretion flow
- dust-gas friction via sub-Keplerian rotation of the gas

## Prediction to ALMA observations




ALMA 5σ detection limit
50 antennas, 0".1, 600s

Dust evolution →
F$_{850\mu m}$/F$_{450\mu m}$↘@ inner disk

Dependence of spatial distribution of dust flux ratio on accretion flow
→ Observable by ALMA

## Summary

Distribution of hot molecules in inner disks
timescale of chemical reactions (~$10^{4\text{-}5}$yr) ≳ accretion time (~r/v$_r$)
→ high/low abundances of some species

Spatial and size distribution of dust particles
: controlled by infall from a surrounding cloud (vertical) or gas accretion flow (radial)
infrared excess ⇔ n$_{out}$>10$^4$cm$^{-3}$ or $\alpha$ >10$^{-2\sim-3}$

Observational diagnostics by ALMA