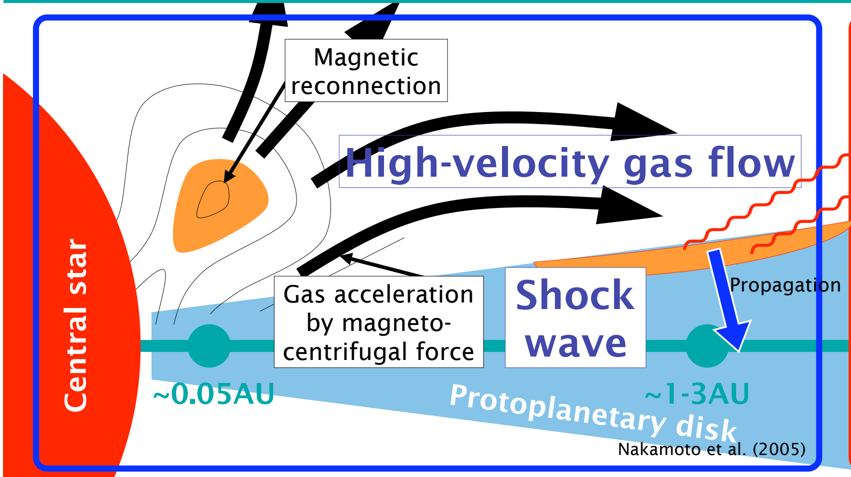
Atomic Line Emission from Shock Waves generated in Protoplanetary Disk

Hitoshi Miura[1,2], Taishi Nakamoto[3]
[1]Univ. of Tsukuba
[2]Research Fellow of the Japan Society for the Promotion of Science
[3]Center for Computational Physics
miurah@ccs.tsukuba.ac.jp



Atomic Line Emission

Can we see?

High-velocity gas wind can produce shock waves at upper region of protoplanetary disks (Nakamoto et al. 2005). The shock waves would dissociate disk gas molecules (e.g., H2, Co, H2O). Dissociated atoms (e.g., C, O, S, N) emit line photons. If the atomic line emission is strong enough, we could observe these lines and investigate the dynamics of the protoplanetary disk. Moreover, it is known that the shock waves induce the thermal processing of dust particles (e.g., Iida et al. 2001), it would be the direct evidence of the thermal evolution of dust particles in the protoplanetary disk.

1. Model & Basic Equations

Hydrodynamics

Shock propagation

$$\frac{\partial V}{\partial m} - \frac{\partial u}{\partial m} = 0$$

$$\frac{\partial u}{\partial m} + \frac{\partial p}{\partial m} = F$$

$$\frac{\partial E}{\partial m} + \frac{\partial up}{\partial m} = uF + G$$

Godunov Method (van Leer 1979)

Non-equilibrium chemical reaction

Dissociation & Ionization of Gas

e, H+, H, H2, H2O, O, O+, CO, C, C+, CH, OH, S, S+, N, N+

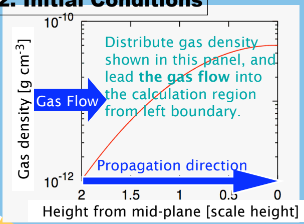
Only Gas-phase reaction

Hollenbach & McKee (1979, 1989)
Neufeld and Hollenbach (1994)

Geometrical Structure of the shock front is nearly the same as one-dimensional plane-parallel (**Nakamoto et al. 2005**). So, we consider one-dimensional propagation problem.

V: specific volume
u: velocity
p: pressure
E: energy
F: external force
G: energy source

2. Initial Conditions



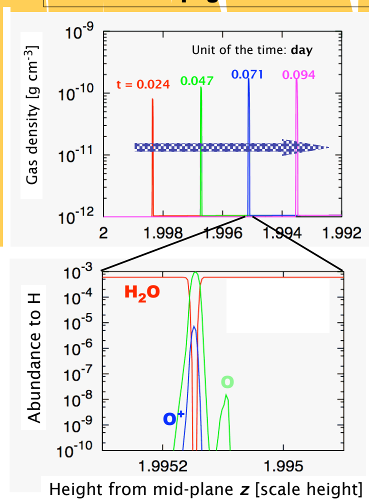
Disk (Minimum Mass Solar Nebula Model, Hayashi et al. 1985)
✓ density (see left panel)
✓ velocity = 0
✓ temperature = 200K (@ 2AU)

Gas Flow
density = ρ_w , velocity = v_w

Parameters adopted in this study

$\rho_w = 10^{-13}, 10^{-12}, 10^{-11}$ g cm^{-3}
$v_w = 70, 100$ km s^{-1}

3. Shock Propagation & Chemical Evolution



Shock waves generated at z = 2 **(disk surface)** propagates toward mid-plane by ram pressure of the gas flow. The propagation speed of the density peak is about **10 km s^{-1}**.

The gas flow interacts with the density peak at its left side and produces shock front. The relative velocity between the gas flow and the density peak is **80-90 km s^{-1}**. Molecules in the gas flow are dissociated to be atomic forms. Small amount of the atoms is ionized.
The right side of the density peak is also a shock front, which is produced by the collision with rested disk gas. It is found that very small amount of the disk gas is dissociated.

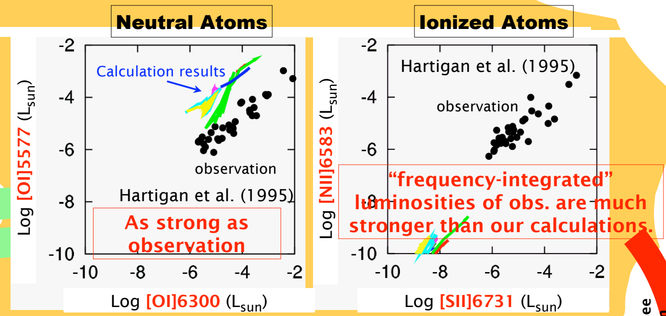
Here, we calculate the gas density, temperature , chemical composition, and of course the line emissivities as a function of the height from the mid-plane. We can obtain **the line luminosity** by integrating the emissivity whole disk.

In order to integrate, we have to know the total area in which the gas emits atomic line emissions. In this study, we estimate the area **10 (AU)^2**.

References: [1] Nakamoto et al. 2005. Lunar and Planetary Science Conference, abstract#1256. [2] Iida et al. 2001. Icarus 153, 430-450. [3] van Leer 1979. J. Comp. Phys. 32, 101-136. [4] Hollenbach and McKee 1979. ApJ. Suppl. 41, 555-592. [5] Hollenbach and McKee 1989. ApJ. 342, 306-336. [6] Neufeld and Hollenbach 1994. ApJ. 428, 170-185. [7] Hayashi et al. 1985. In Protostar and Planets II (Univ. of Arizona Press, Tucson), pp.1100-1153. [8] Hartigan et al. 1995. ApJ. 452, 736-768.

Protostars and Planets V, the Big Island of Hawaii, Oct. 24-28, 2005.

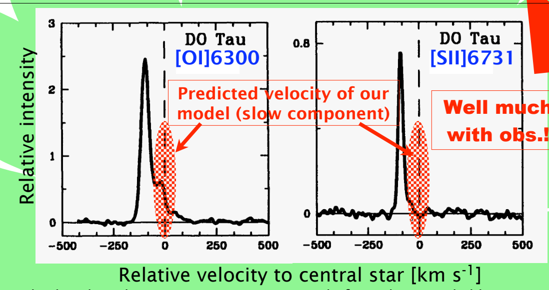
4. Comparison with Observations



For **neutral atom ([OI] lines)** , it is expected that our model produces strong line emission enough to explain observations. On the contrary, for **ionized atoms ([SII] and [NII] lines)**, the expected line luminosities are much smaller than observations. The reason is thought to be rapid gas cooling due to Lyman a emission. Lyman a emission cools the gas down to about 104 K, and ionized atoms would rapidly recombine with electron.

However, if we see the line spectrum...

5. Velocity structure of emitting region (Doppler shift)



It is thought that these line spectrums are composed of two distinguishable components; high-velocity component (~ -100 km s^{-1}) and low-velocity component (~ 0 km s^{-1}). Our model is predicting the low-velocity component. Obs. of DO Tau shows the low-velocity component of **[OI] line spectrum**, but not of **[SII] line spectrum**.

6. Identification of the shock

1. **Relative velocity to the central star ~ a few tens km s^{-1}**
   high-velocity comp. (~ a few 100 km s^{-1}) might be from other mechanism.
2. **[OI] lines are strong, but ionized lines are faint**
   line ratio at low-velocity component is important
3. **Relation with X-ray Flare**
   delay about 10 days

SUMMARY

- **Emitting region has small relative velocity (~10 km s^{-1}) to the central star (low-velocity component)**
- **[OI] lines are strong enough as expected from obs., however, ionized lines are very faint.**
- **There are the same feature in some observations of T Tauri type stars**
- **Positive corelation with X-ray Flare**