PF-02-0027

Effects of magnetically driven disk winds on the gas surface density evolution and dust growth in protoplanetary disks

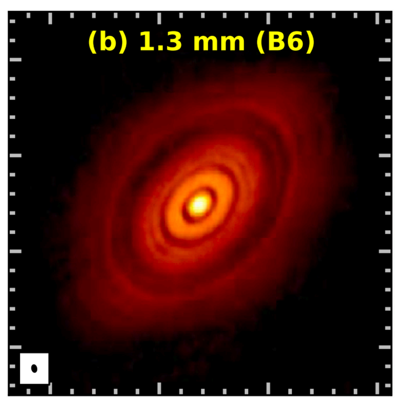
Tetsuo Taki,[1] Hiroshi Kobayashi,[2] Eiichiro Kokubo,[1,3] Takeru K Suzuki[1]

1: The University of Tokyo, 2: Nagoya University
3: National Astronomical Observatory of Japan

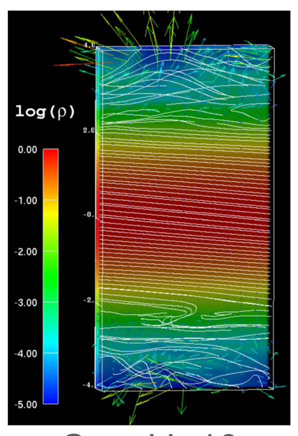
Introduction

Why the Magnetically-driven disk winds (MDWs) ?

- The main driver of the protoplanetary disk evolution?



ALMA partnership+15

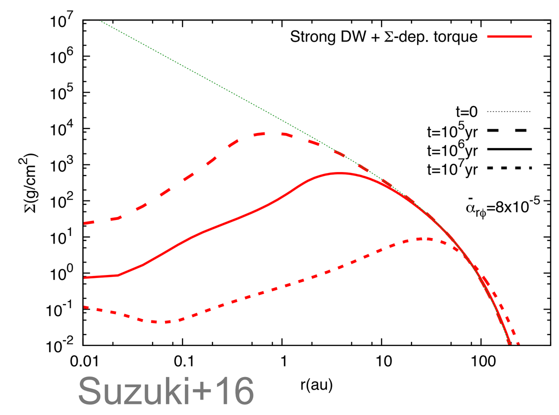


Suzuki+10

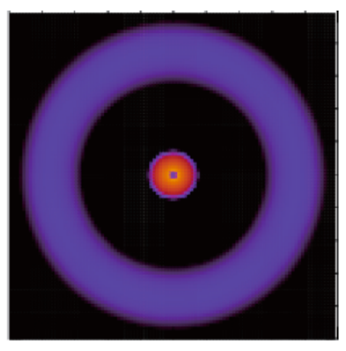
Both **observations** and **MHD simulations** indicate that **the turbulence doesn't work well**, at least near the midplane.

Another driver of disk evolution is needed. **The MDWs are prime candidates** for it.

- Impacts on the dust distribution in disks?



Suzuki+16



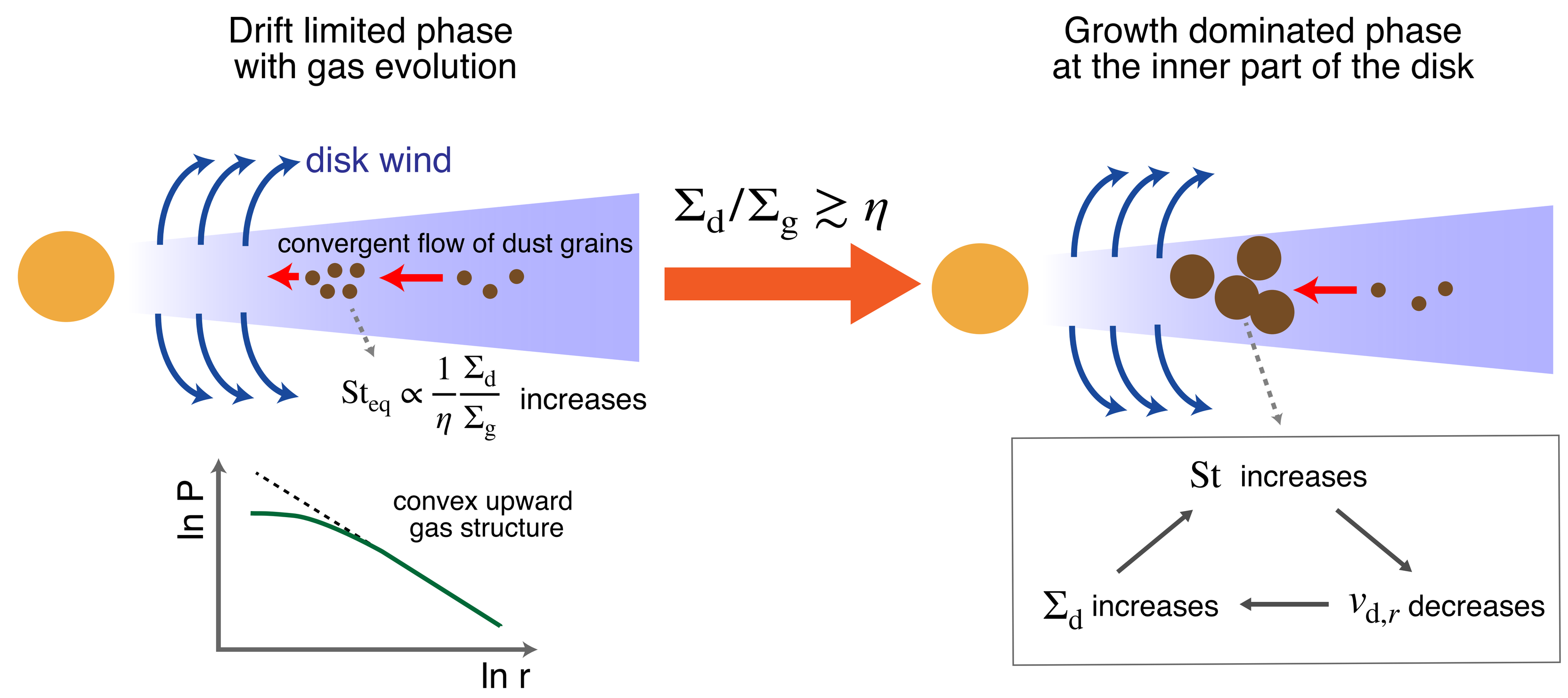
Takahashi+Muto 18

Disk structure could be modified from the viscous accretion disks.

Dust distribution is also modified.

Summary

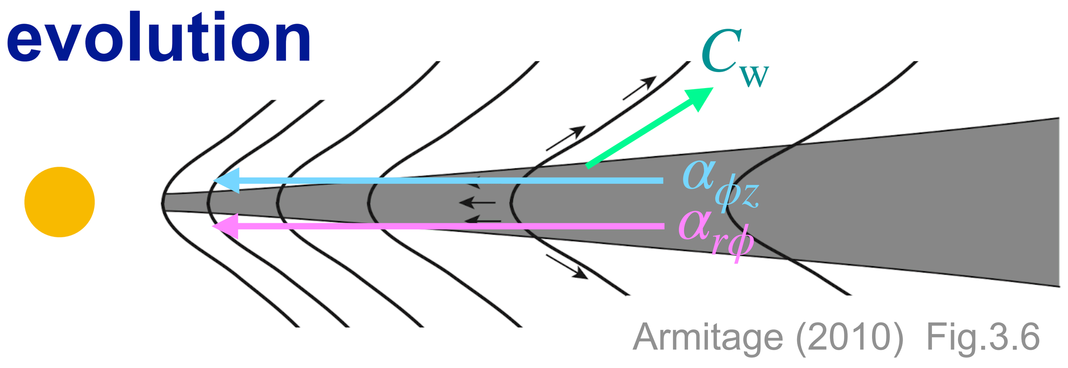
We found the conditions for **a disk structure** in which **rapid dust growth occurs** (Taki+2021).



The disk structure is determined by **the balance between** $\alpha_{r\phi}$, $\alpha_{\phi z}$ **and** C_w (Taki+ in prep.).

Method & Simulation Settings

1-D gas+dust disk evolution with the MDWs + grain growth



Armitage (2010) Fig.3.6

gas surface density

$$\frac{\partial \Sigma_g}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\Sigma_g v_{g,r}\right) + C_w\left(\rho_g c_s\right)_{mid} = 0$$

$$v_{g,r} = -\frac{2}{r^2\Omega_K\Sigma_g}\left[\frac{\partial}{\partial r}\left(r^2\Sigma_g\overline{\alpha_{r\phi}}c_s^2\right) + r^2\overline{\alpha_{\phi z}}(\rho_g c_s^2)_{mid}\right]$$

wind mass loss (green), wind torque (blue), turbulent viscosity (red)

dust surface density

$$\frac{\partial \Sigma_d}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(r\Sigma_d v_{d,r}) + (\rho_d v_{d,z})_{mid}\max\left(-1.8St + C_w, 0\right) = 0$$

Fitting formula from the result of Miyake+(2016)

$$v_{d,r} = \frac{v_{g,r} - 2St\eta v_K}{1 + St^2}$$

: Takeuchi+Lin (2002)

grain growth

$$\frac{\partial m_p}{\partial t} + v_{d,r}\frac{\partial m_p}{\partial r} = \frac{2\sqrt{\pi}a^2\Delta v_{pp}}{h_d}\Sigma_d$$

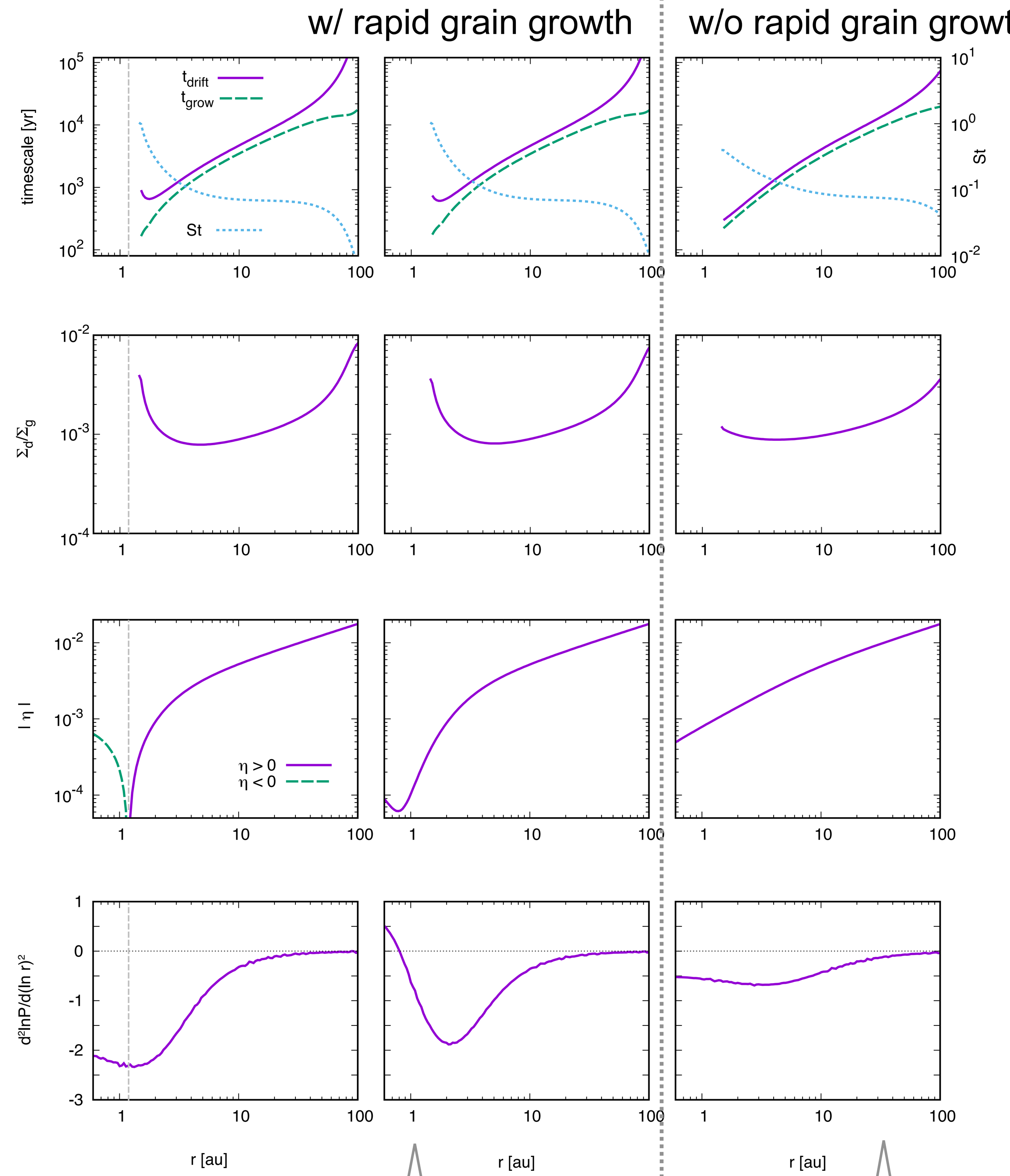
: single size approximation (Sato+2016)

Results

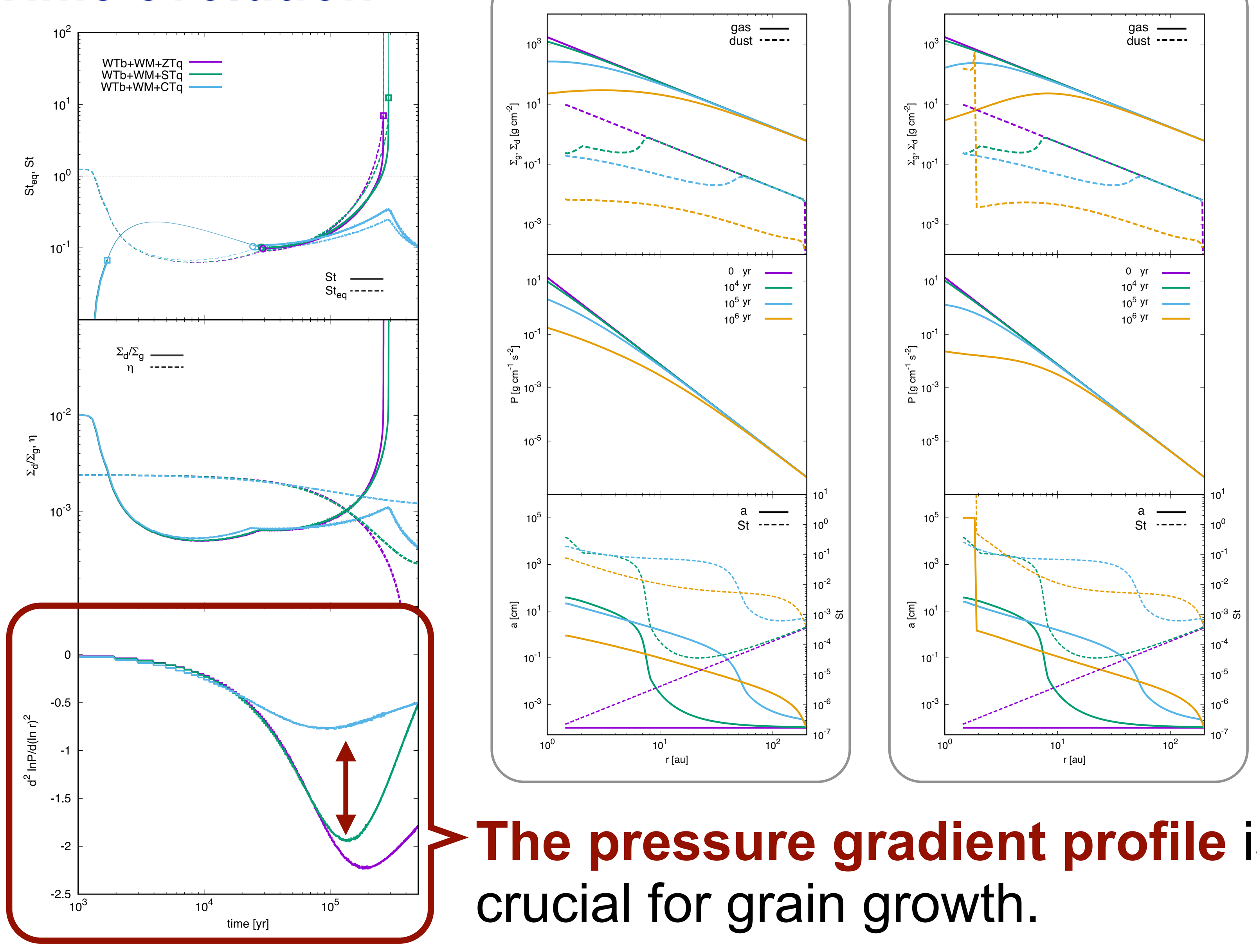
We test **three cases** of the wind-torque model.

Snap shots

Zero | **Σ-dependent** w/ rapid grain growth | **constant** w/o rapid grain growth



Time evolution



The pressure gradient profile is crucial for grain growth.

Discussion

What does determine **the pressure gradient profile**?

→ **The local balance between** $\alpha_{r,\phi}$, $\alpha_{\phi,z}$ **and** C_w.

$$\cancel{\frac{\partial\Sigma}{\partial t}} - \frac{1}{r}\frac{\partial}{\partial r}\left\{\frac{2}{r\Omega}\left[\frac{\partial}{\partial r}\left(r^2\Sigma\alpha_{r\phi}c_s^2\right) + r^2\alpha_{\phi z}\rho c_s^2\right]\right\} + C_w\rho c_s = 0.$$

Assumptions:

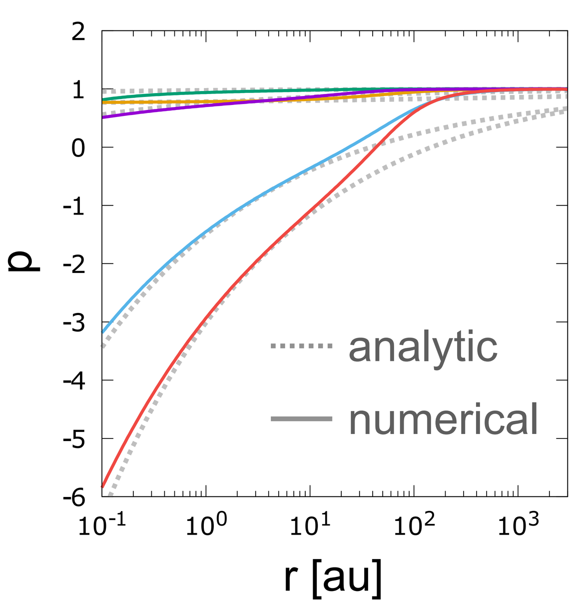
$\Sigma \propto r^{-p}$, $c_s \propto r^{-q}$

$\alpha_{\phi z} \propto \Sigma^{-l}$, $\alpha_{r\phi} \propto r^0$, $C_w \propto r^0$

isothermal

$$p = -\frac{\partial \ln\Sigma}{\partial \ln r} = f\left(\frac{\alpha_{\phi z}}{\alpha_{r\phi}}, \frac{C_w}{\alpha_{r\phi}}\right)$$

← Analytically solvable under the above assumptions



This estimate **almost reproduce radial gas profiles**.