Exposing the Long Lives of Satellite Forming Disks

Yuri I. Fujii[1], Satoshi Okuzumi[2], Takayuki Tanigawa[3], Shu-ichiro Inutsuka[1]

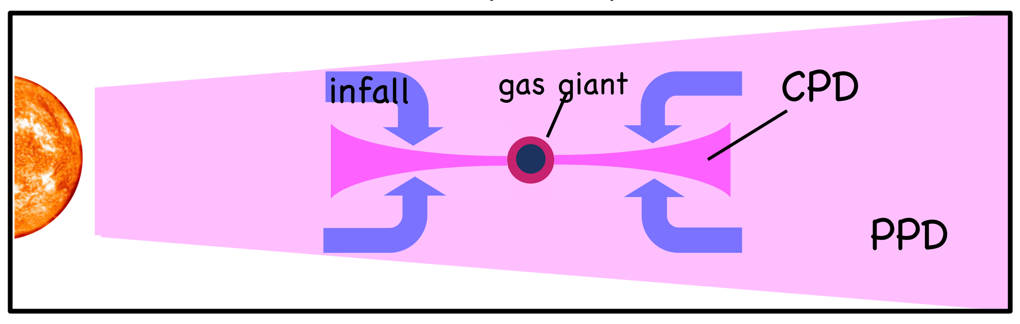
1 Nagoya University, 2 Tokyo Institute of Technology, 3 Hokkaido University

1. Background

Circumplanetary disks : Gaseous disks which appear during gas giant formation

➡ Sites of satellite formation

①Gas infall from a protoplanetary disk



Not many studies start from the formation

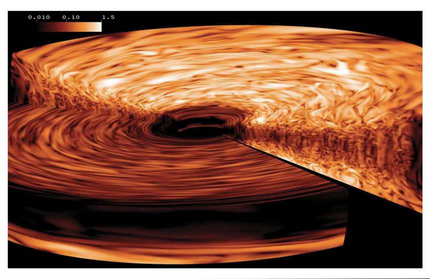
②Viscous evolution of disks

⇒ Uncertain

What is the accretion mechanism？

Most promising:

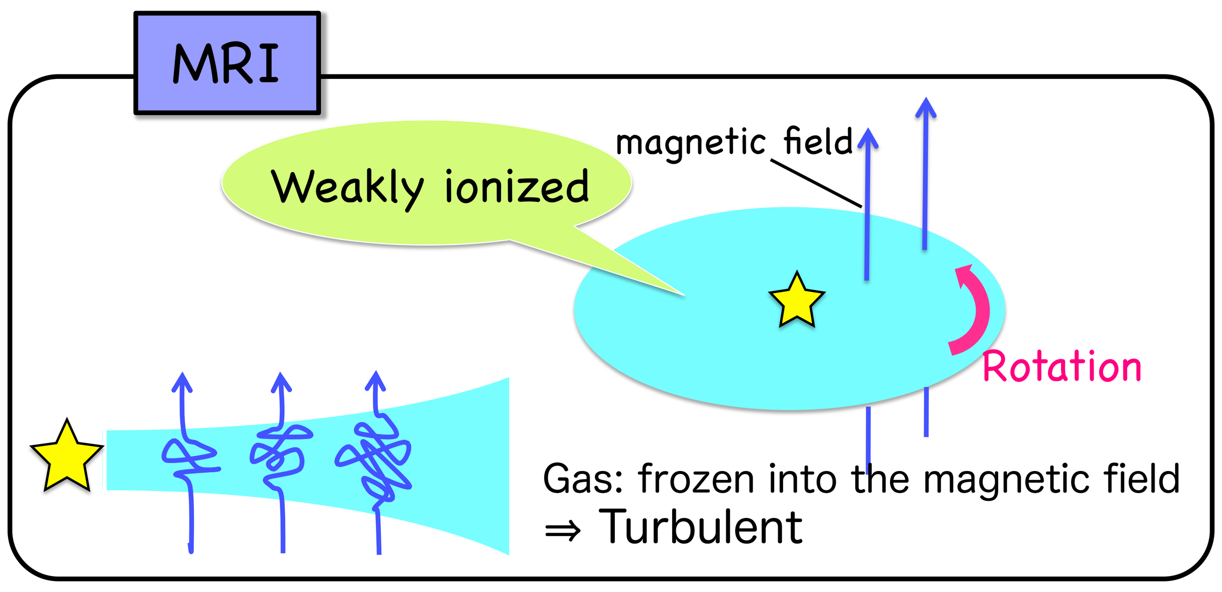
Magnetorotational instability (MRI)



(Balbus & Hawley 1991)

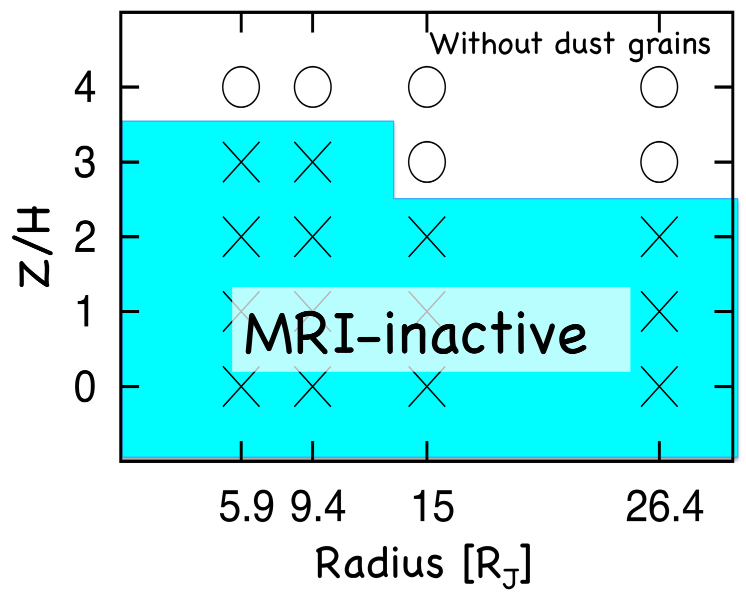
Important in PPDs

(Flock et al. 2011)



☆Previous work☆

We estimated the MRI activity in CPDs using a model of Canup & Ward (2002)



Mostly MRI-inactive

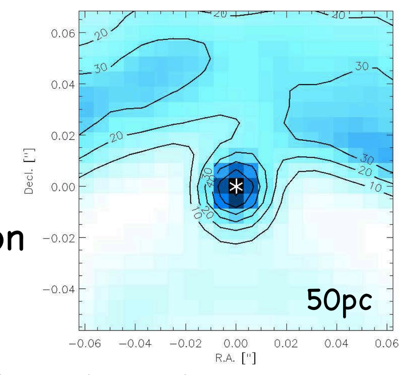
Fujii, Okuzumi & Inutsuka (2011)

2. Aim & Motivation

Understand the structure and evolution of CPDs

Possibly observable in the near future

⇒ Confirm the theories



Simulation of ALMA observation (Wolf & D'Angelo 2005)

Begin with the surface density structure

Infall rate on to a CPD Accretion stress in CPD	⇒Surface density ※See Section 3

Mass infall rate

⇒ Tanigawa, Ohtsuki & Machida (2012)

Detailed analysis of 3D simulation

⇒ Viscous parameter α will provide a realistic surface density profile of a CPD

Use formulae of Okuzumi & Hirose (2011) to determine the viscous parameter α

Investigate the MRI activity in realistic disks

3. Surface density

Diffusion equation of a disk

$$\frac{\partial \Sigma}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(3r^{\frac{1}{2}}\frac{\partial}{\partial r}\left(r^{\frac{1}{2}}\nu\Sigma\right)\right) + f$$

r : radius of CPD , Σ: surface density, $\nu = \alpha c_s H$: dynamical viscous parameter

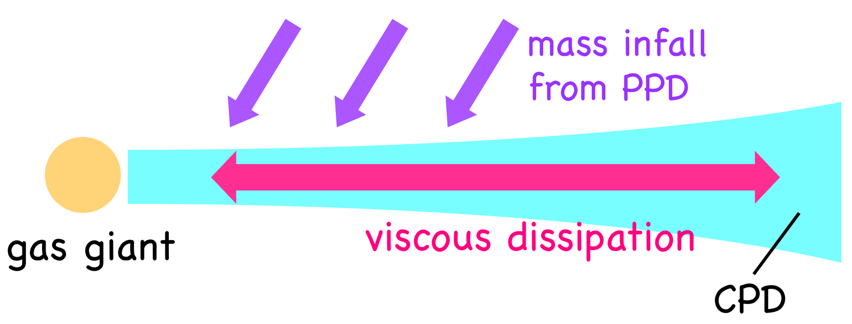
Give f only for r < 0.01AU (=20R$_J$)

M_p=0.4M_J, a_p=5.2AU, T=123K

(planet mass) (orbital radius)

Ionization source:

cosmic rays, X-rays, radionuclides



$$f = 1.3\times10^{-3}\left(\frac{\Sigma_p}{143\ \mathrm{g\ cm^{-2}}}\right)\left(\frac{R_J}{r}\right)\ \mathrm{g\ cm^{-2}\ s^{-1}}$$

(Tanigawa, Ohtsuki & Machida, 2012)

Σ_p: surface density of PPD、 R_J: Jovian radius

4. MRI growth condition

Magnetic Reynolds number $Re_m > 1$

$$Re_m = \frac{v_{Az}^2}{\eta\Omega} \sim \frac{2c_s^2}{\eta\beta\Omega}$$

v_{Az}: Alfvén velo. (z component)
η: magnetic diffusivity
Ω: Keplerian frequency
C_s: sound speed
T : temperature

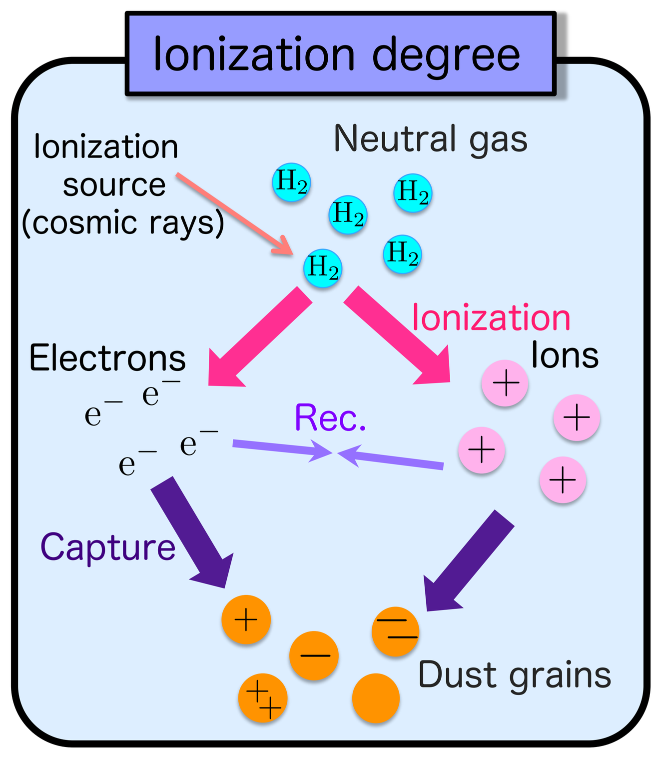
$$\eta = 234\left(\frac{T}{1\ \mathrm{K}}\right)^{1/2} x_e^{-1}\ \mathrm{cm^2\ s^{-1}}$$

Ionization degree

$$\beta = \frac{P_{gas}}{P_{mag}}$$

(gas pressure/magnetic pressure)

Fujii et al. (2011)



※$2\pi v_{Az}/\Omega$ < H also required

(wavelength of most unstable mode λ_{max} < H)

sizes of MRI-active region ⇒α (Okuzumi & Hirose 2011)

5. Results

Fujii, Okuzumi, Tanigawa & Inutsuka (in prep)

Surface density is needed to investigate MRI activity

α is unknown → begin with α=0.05

Estimate MRI-active region → update α

Re_m> 1 & H > λ_{max} ⇒ MRI-active region

Estimate surface density again with updated α

However no MRI-active region at r<20R$_J$!

Formation timescale of satellites (Canup & Ward 2002)

$$\tau_A \approx 8\mathrm{yr}\left(\frac{R_s}{2500\ \mathrm{km}}\right)\left(\frac{3\times10^5\ \mathrm{g\ cm^{-2}}}{\Sigma}\right)\left(\frac{r}{15R_J}\right)^{3/2}$$

↑
10^7yr

To make Ganymede within a disk lifetime

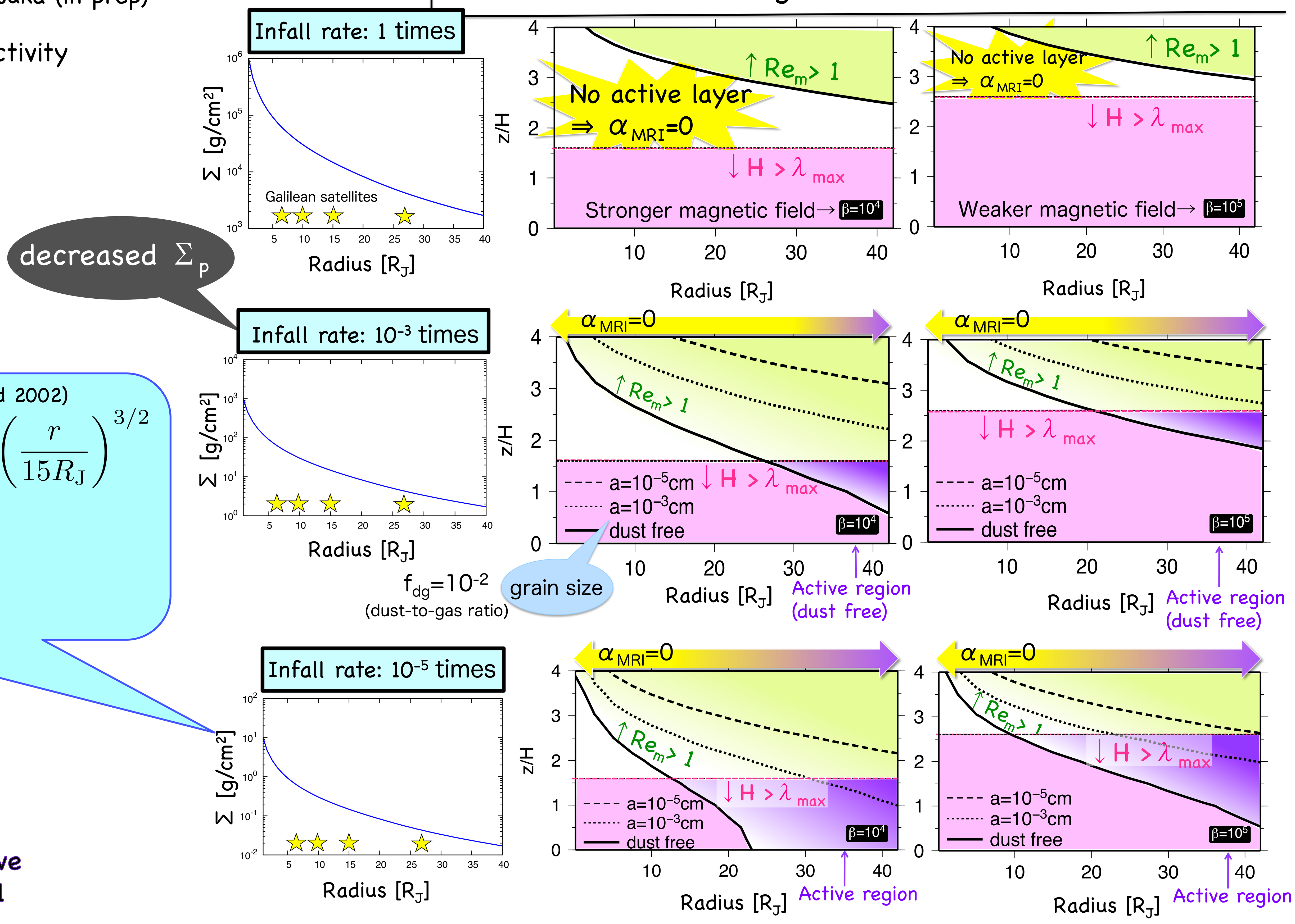
Σ > 10^{-1}g/cm^2 @15RJ

With dust grains:
difficult to be MRI-active

Similar results with other value of α

smaller: increase Σ→ difficult to be MRI-active

larger: difficult to be MRI-active even for α=1



6. Conclusion & Future work

Cannot get accretion stress, α, if we assume only MRI as an accretion mechanism.

- Do CPDs still survive after PPDs disappear?
- Are other mechanisms important?

We have to investigate other possible mechanisms such as gravitational instability and spiral density waves.