日本天文学会2020年春季年会
2020年3月19日

SPICAの水輝線観測が明らかにする原始惑星系円盤の熱・力学構造

SPICA observation of water line emission reveals thermal and dynamical structures of protoplanetary disks

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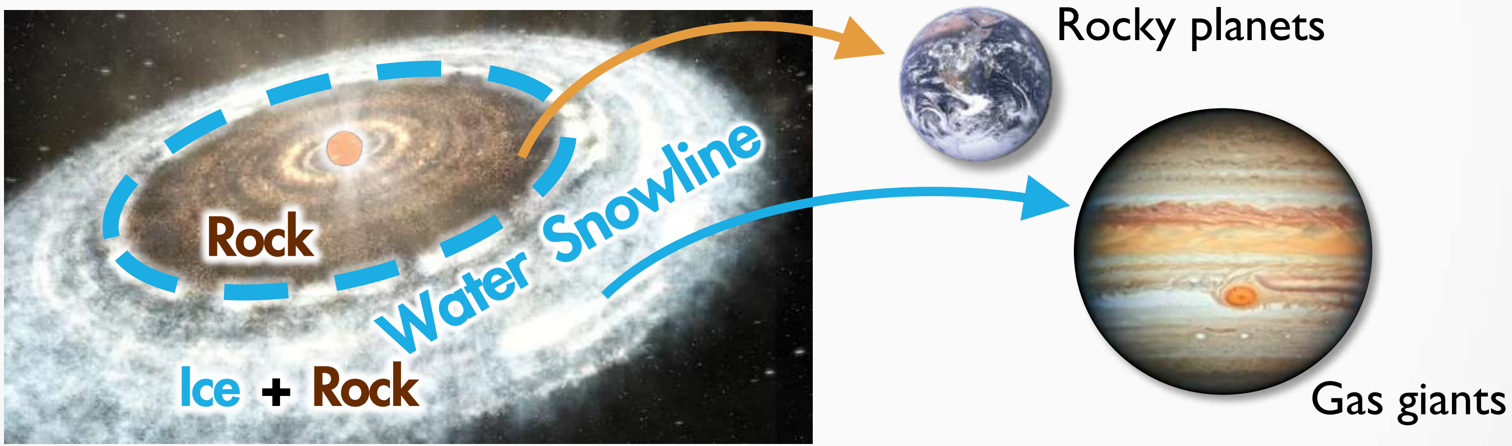
and SPICA planet formation WG

Water snowline in planet formation

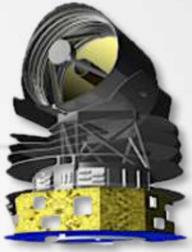
- Water snowline at "disk midplane" is a key factor to determine the basic architecture of planetary system (e.g., Hayashi1981)



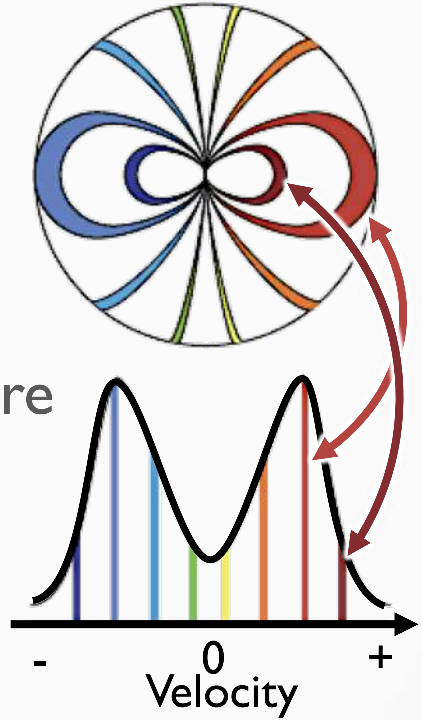
Protoplanetary Disk : Alexandra Angelich (NRAO/AUI/NSF)

<u>Key question: Where is the water snowline in PPDs?</u>

Observations of line emission of water by SPICA



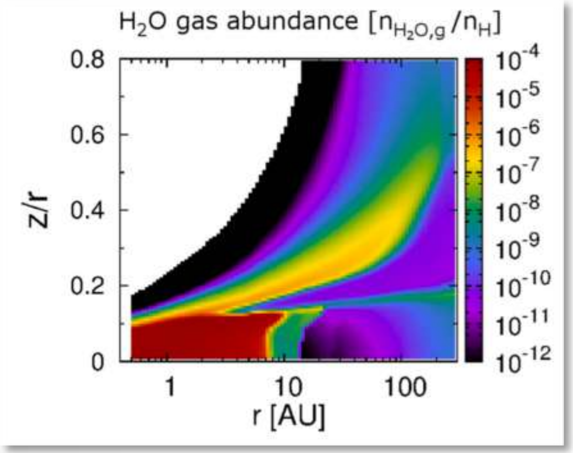
- Direct imaging is difficult
  - Snowline ~ a few au (T Tau.)
- Velocity profiles of line emission has information on spatial flux structure
  - PPDs ~ Kepler rotation
  - Intensity as a function of v → emitting region
  - Flux ~ B(T) (tau>>1) or $n_{up}(E_{up})$ (tau<<1)



from Dionatos 2015

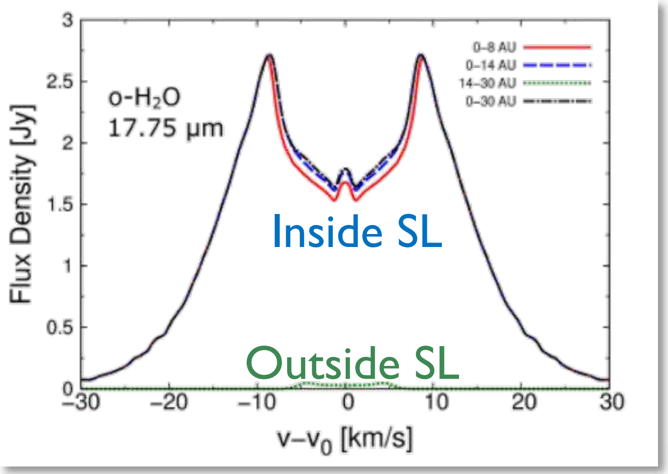
Locating snowline from water line profiles

Model: Herbig Ae
(Nomura+07; Notsu+17)



Synthetic observation

ortho-$H_2{}^{16}O$ 17.75μm
Small A_{ul} (3×10^{-3} s^{-1}) , Eup ~ 1000 K

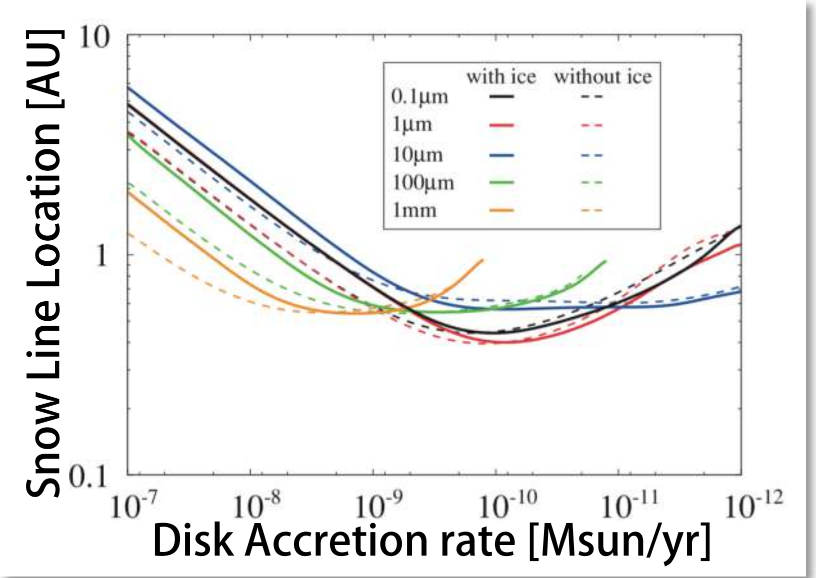


- The location of the snowline can be obtained from the line profiles with small A_{ul} (10^{-6}~10^{-3} s^{-1}) and large E_{up} (~1000K)
- Observations by SPICA plan to locate the snowline location for tens of PPDs

see **Z225b (poster by Notsu)**, **Z226b (poster by Nakagawa)**, Notsu+16, 17, 18

Calculation for location of snowline

- Snowline location is determined by disk temperature structure
  - calculated by considering stellar irradiation & accretion heating
- But, there are uncertainties in disk parameters (e.g. Oka+2011)
  - accretion rate, opacities, turbulent strength



Oka et al. (2011)

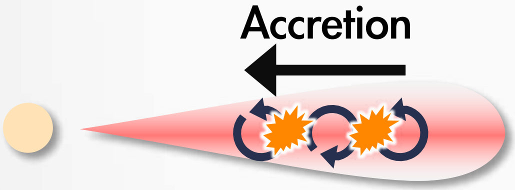
Uncertainty of accretion mechanism

Classical turbulent disk (Shakura&Sunyaev73)

- Turbulence drives disk accretion
- Uniform turbulence releases heat into optically thick region
- Efficient accretion heating

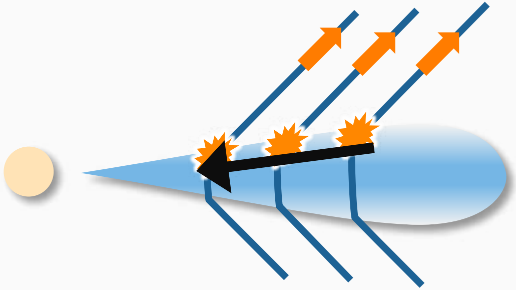
Laminar disk (Bai&Stone13; Gressel15)

- MRI (classical turbulent source) is suppressed by magnetic diffusion
- Magnetic disk wind drives disk accretion



Turbulence-driven accretion

→ Hot



MHD-driven accretion

How different is the temperature structure of the laminar disk??

Temperature profile of MHD-controlled accretion disk

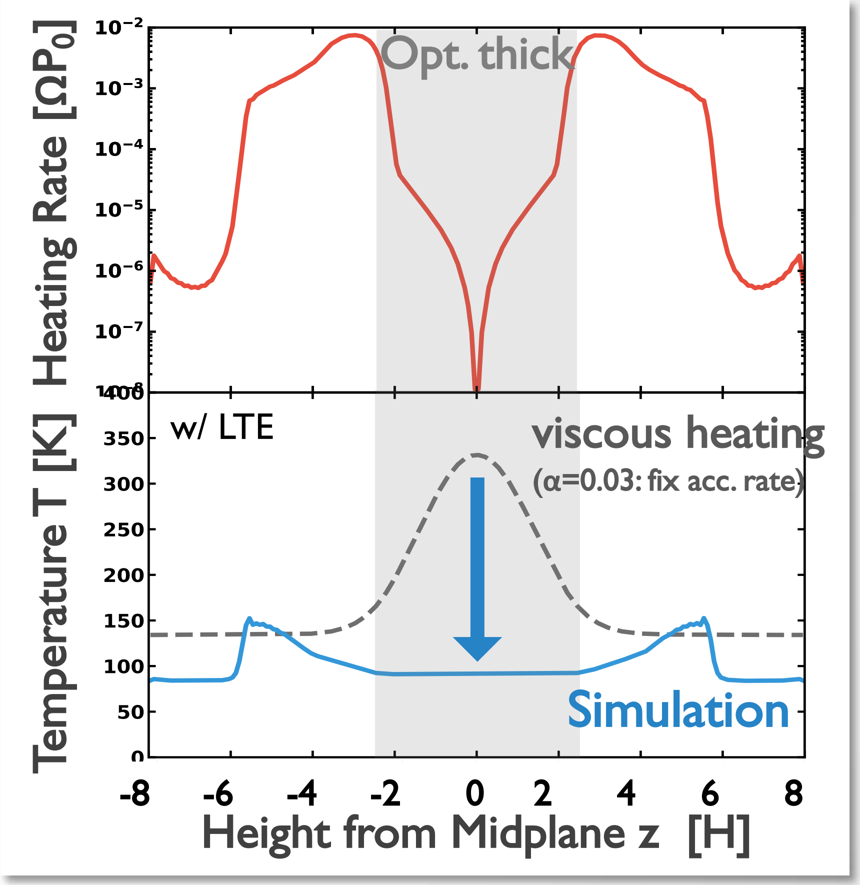
Non-ideal MHD simulations with stratified shearing box

- Energy dissipation
  by magnetic diffusion at 3H
  - Strong B-diffusion at z < 2H
- Removal of accretion energy

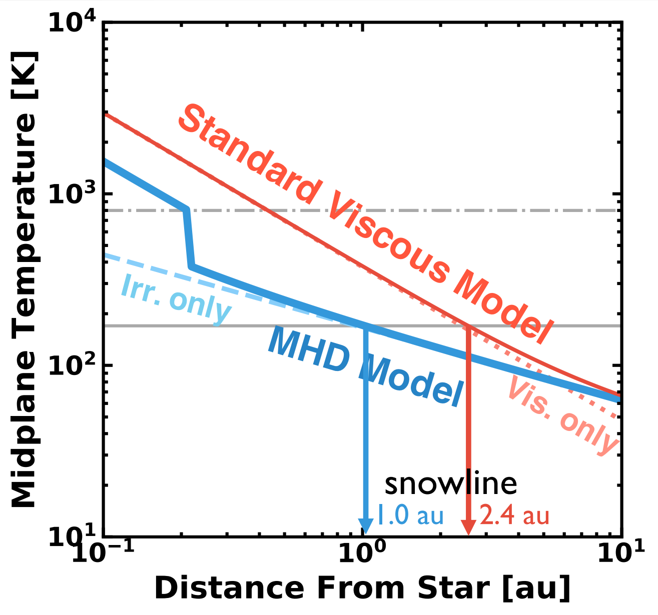
↓

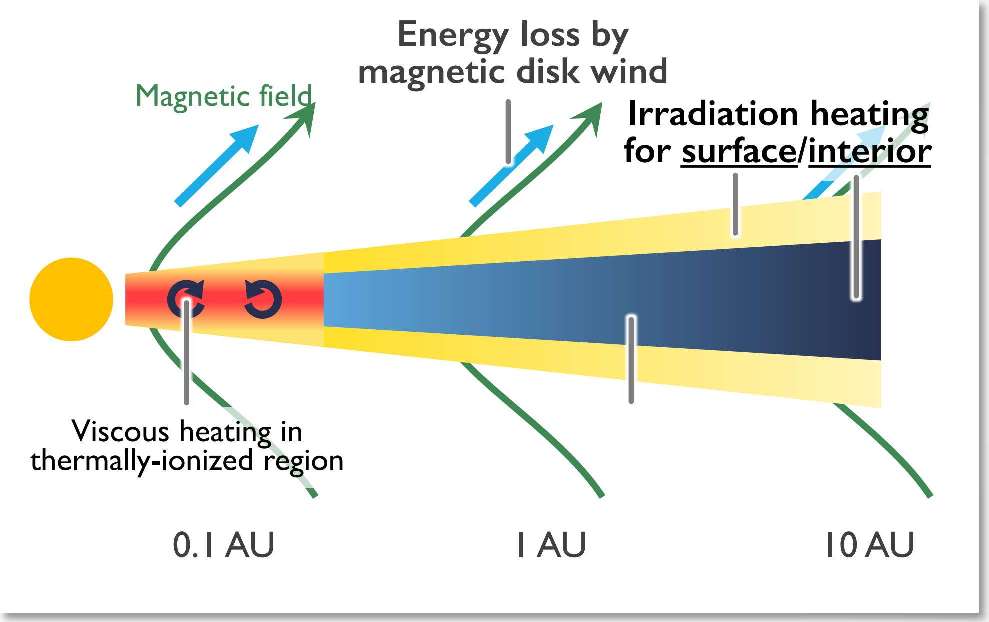
- **Inefficient accretion heating**
- Disk temperature is significantly reduced from classical model

Mori+2019



Snowline depends on disk dynamics

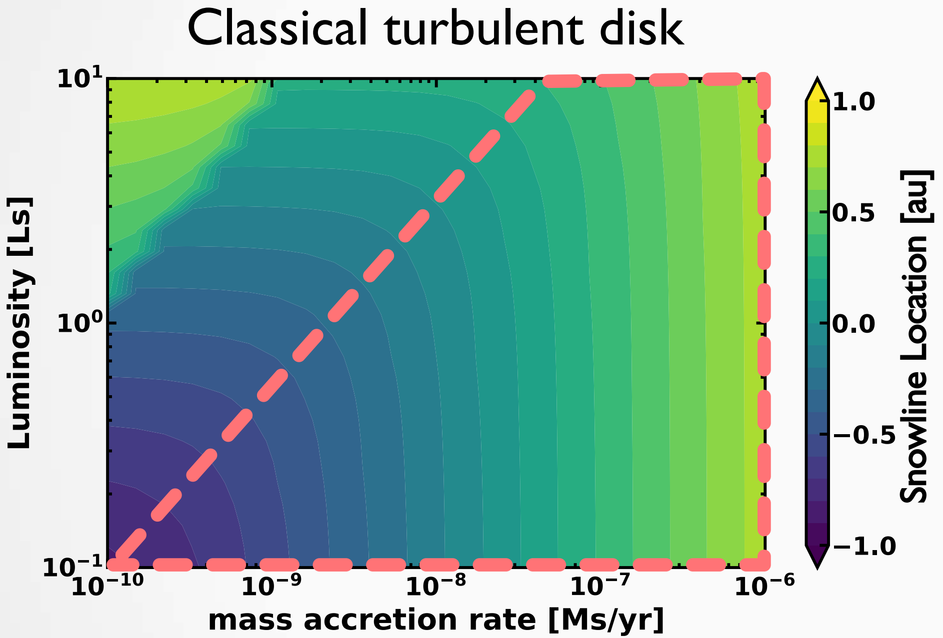


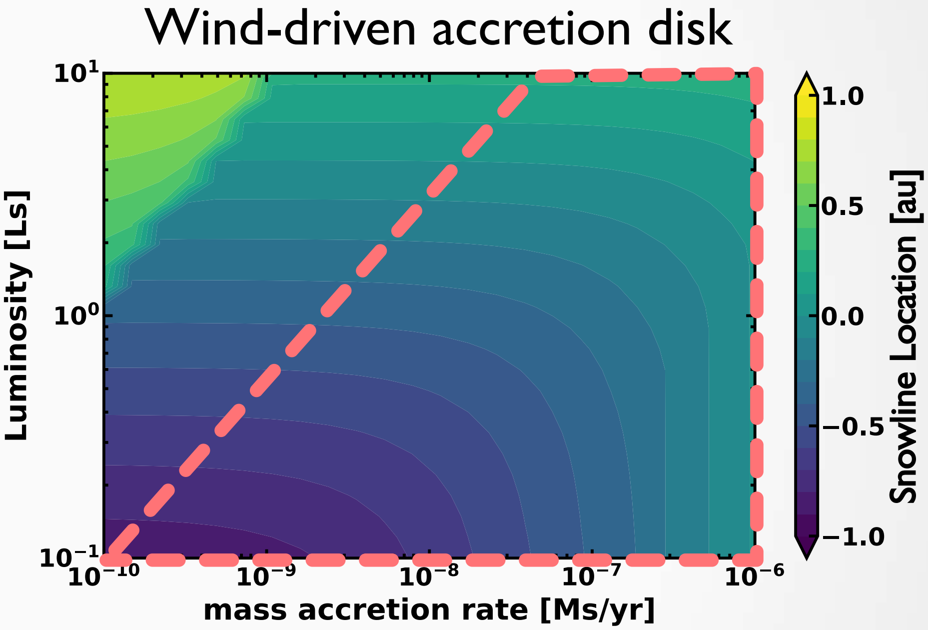


Mori+ in prep.

Theoretical prediction of snowline location is still uncertain

Location of water snowline with different disk models





Detrmining/constraining the snowline location tell us how efficiently PPDs are heated & what are plausible disk models

calculated by S. Mori

Summary

- SPICA plans to observe the emission line of water vapor to determine the location of the water snowline for tens of PPDs
- In theory of PPDs, the location of the snowline have many uncertainties
  - Disk dynamics (turbulence or not) affects temperature profile
- If we locate the snowline from the observation by SPICA,
  the location tells us the dynamics and accretion mechanisms of the inner region of PPDs, in addition to the thermal structure