SPICA Science Workshop 2009

Mid-Infrared Molecular Hydrogen Emission from Protoplanetary Disks

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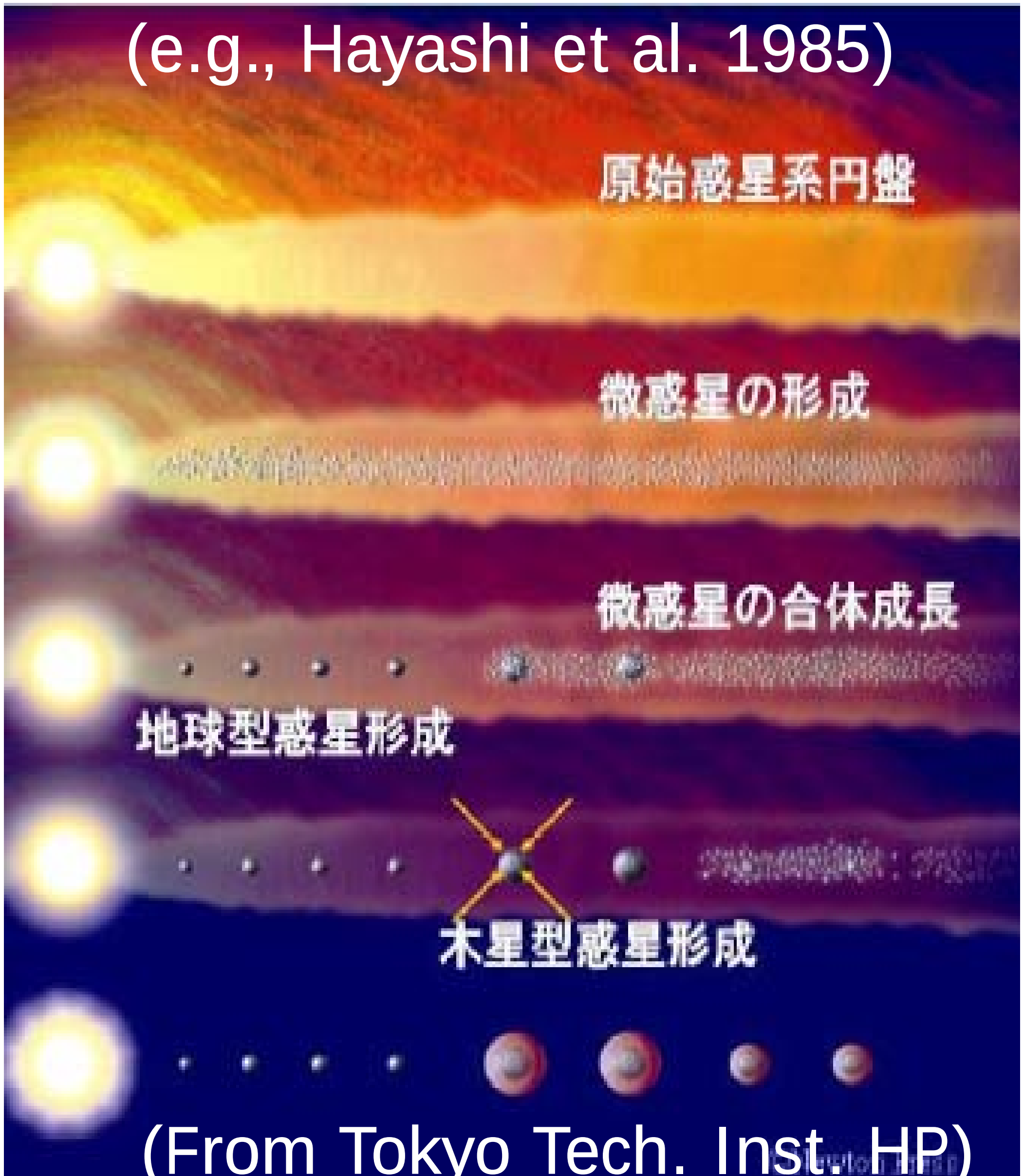
§ 1 Introduction

From protoplanetary disk to planets

(e.g., Hayashi et al. 1985)



(From Tokyo Tech. Inst. HP)

Dust size growth & settling

↓

Planetesimal formation

↓

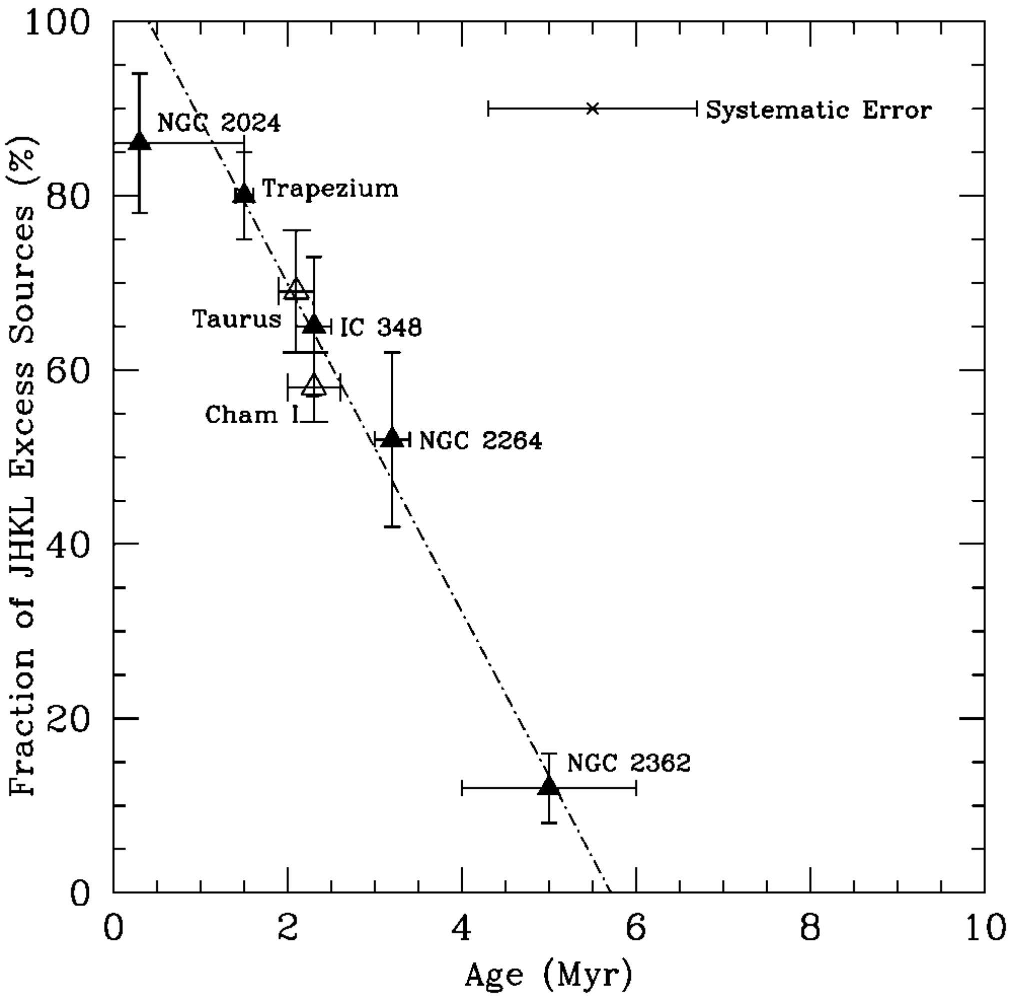
Collisional growth, Planet formation

↓

Gas dispersal

→ Planetary system formation

Dispersal of Dust Grains in PPDs



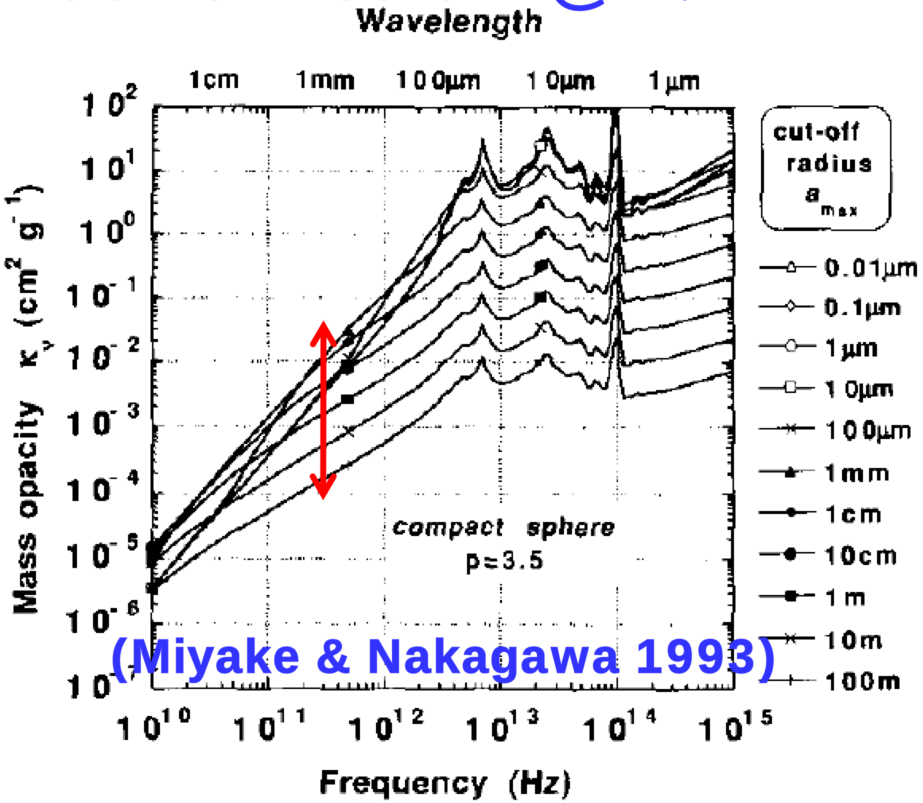
(Haisch et al. 2001)

Obs. of NIR dust cont. emission : Dispersal time of dust near the central star ~10^6yr

How about timescale of gas dispersal ?

Observation of Gas Mass in PPDs

Dust emission @ λ~mm

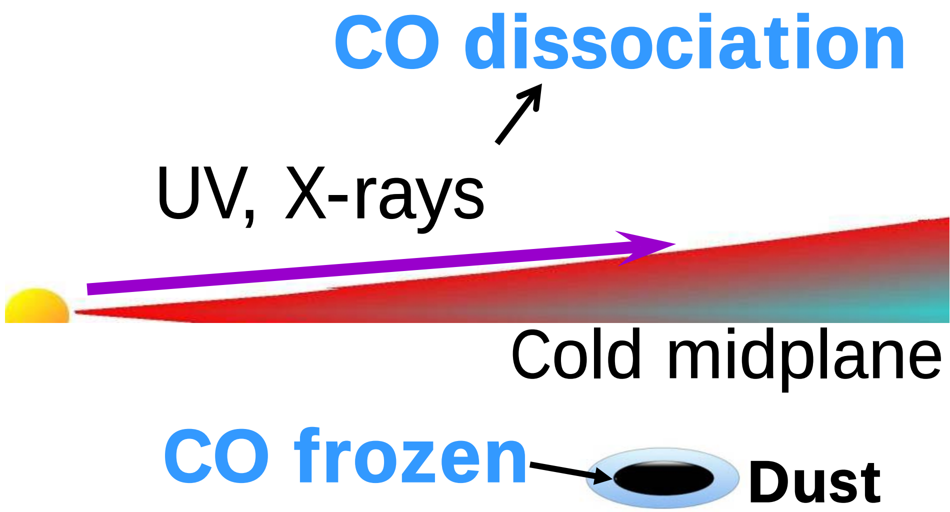


(Miyake & Nakagawa 1993)

Dust evolution in disks

→ Large uncertainty in dust opacity

CO line emission



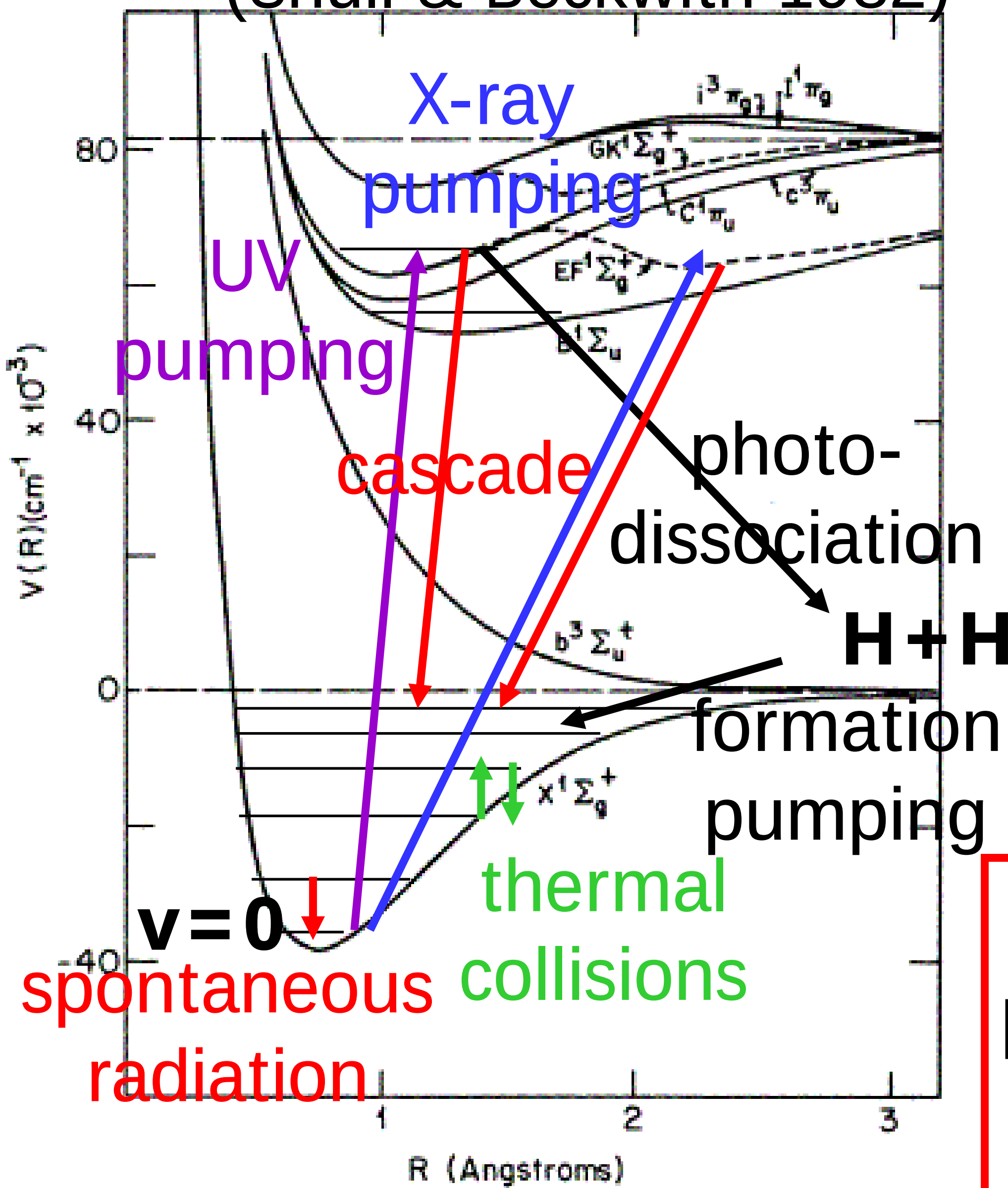
Photodissociation, Frozen-out

→ Large uncertainty in CO abundance

➡ Importance of H_2 line emission obs.

H_2 Excitation, H_2 Line Transition

(Shull & Beckwith 1982)



UV

Fluorescent lines from excited electronic states

Near-IR

Rovibrational lines (thermal / non-thermal)

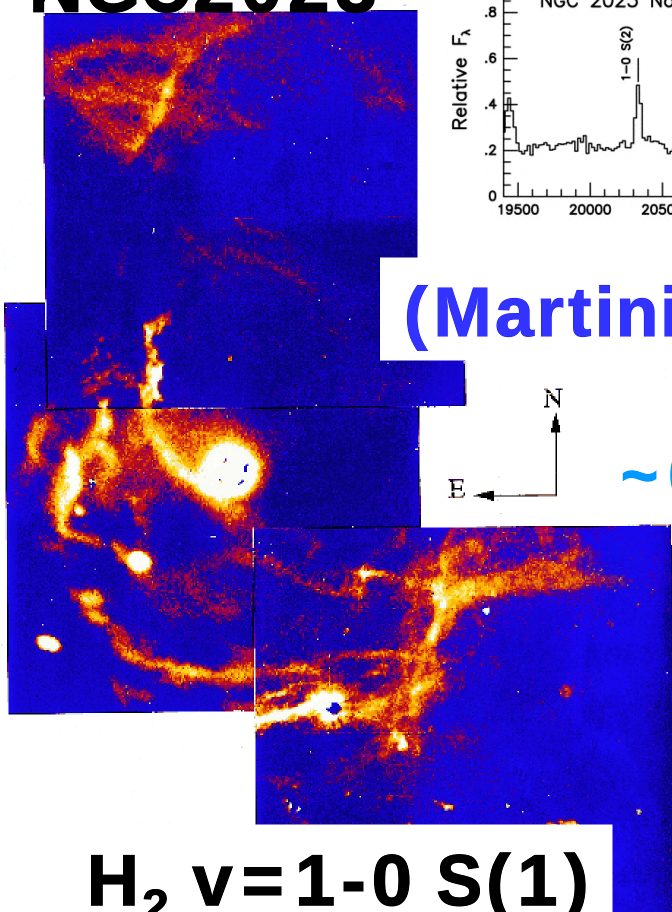
Mid-IR

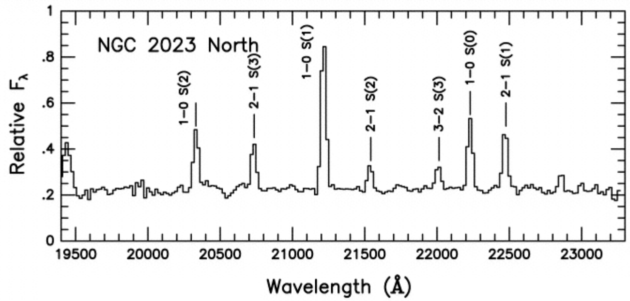
Pure rotational lines (thermal)

Obs. of H_2 Line Emission (NIR)

Reflection nebula

NGC2023





(Martini et al. 1999)

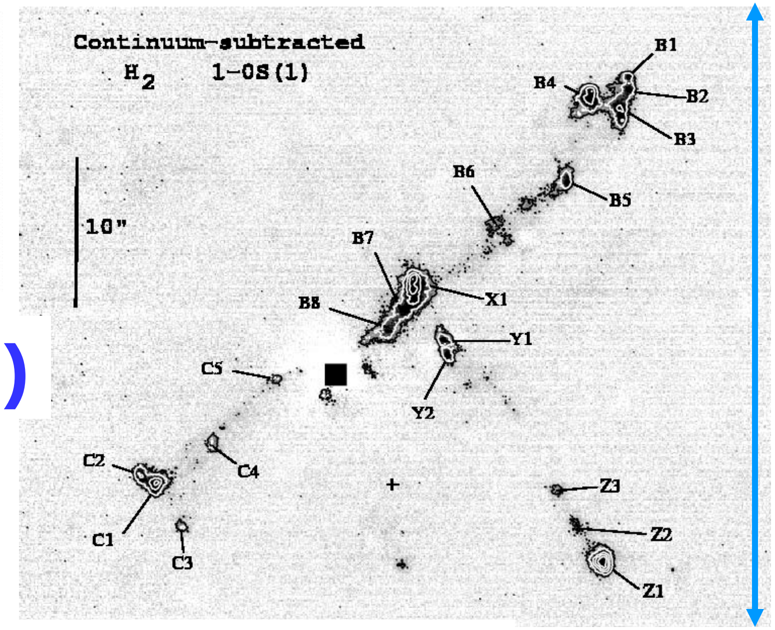
~0.3pc

H_2 v=1-0 S(1)

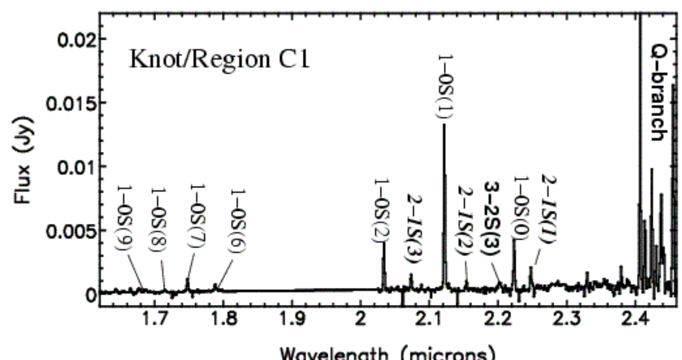
(Field et al. 1998)

Strong UV irradiation

Jet IRAS 18151



~0.01pc



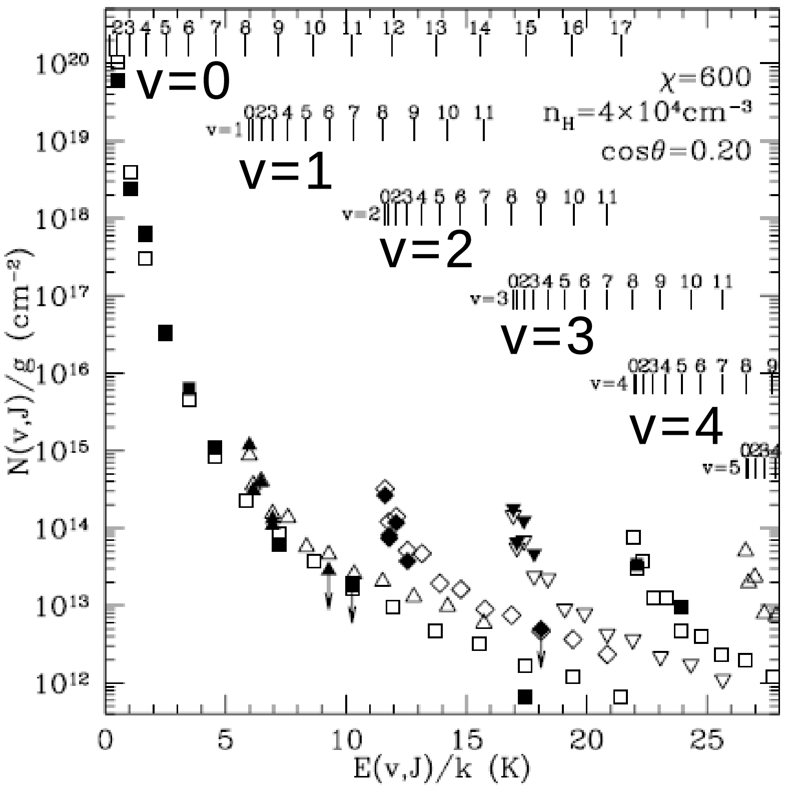
(Davis et al. 2004)

High Temperature

Obs. of H_2 Line Emission (M&NIR)

Reflection nebula S140

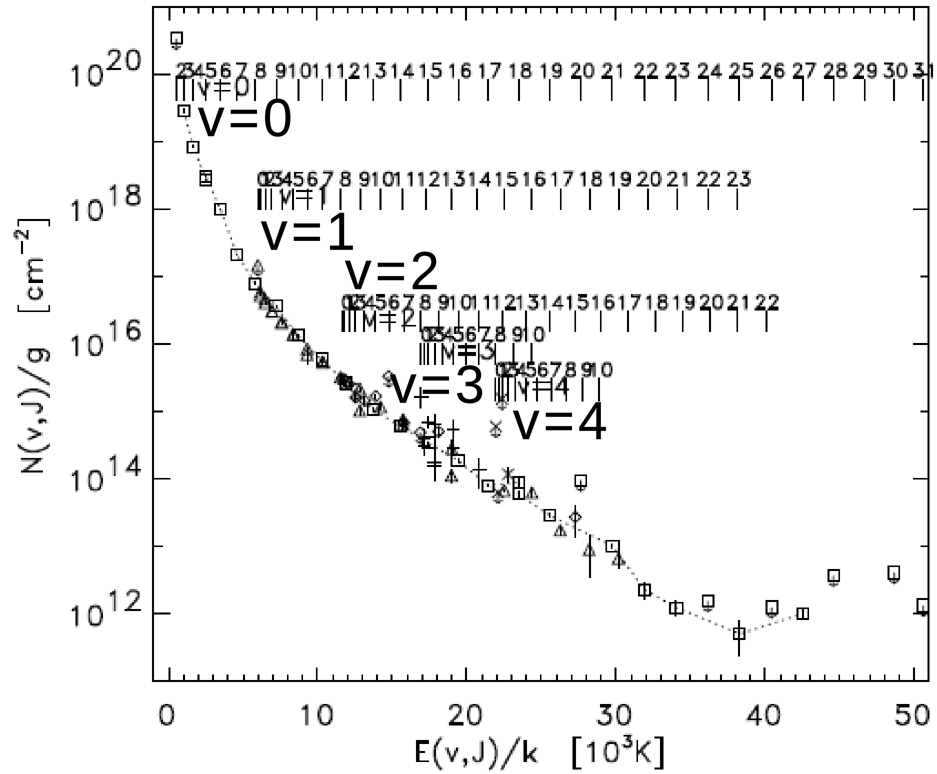
MIR (LTE) NIR (NLTE)



Strong UV irradiation

Jet Orion Peak1

MIR (LTE) NIR (LTE)



High Temperature

MIR line obs. : ISO

(Bertoldi et al. 1999)

§ 2
H_2 Line Emission from Protoplanetary Disks
- Observations -

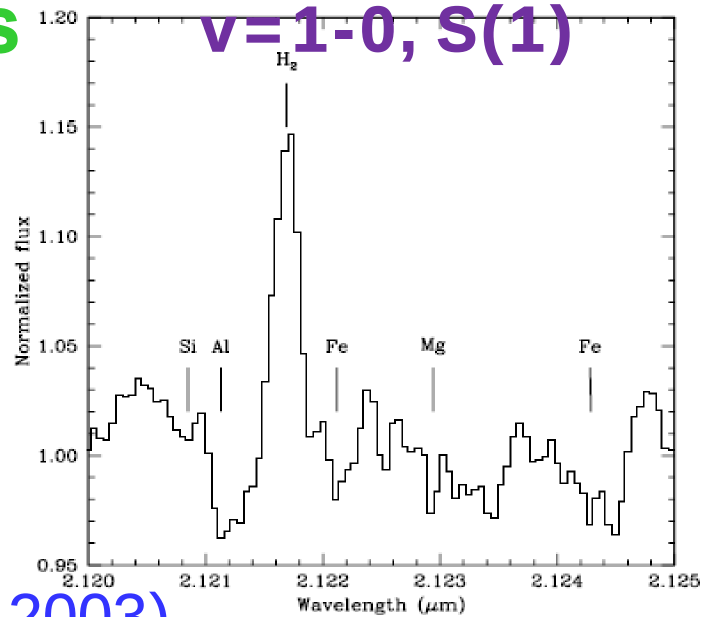
H_2 Line Obs. towards TTSs (NIR)

Detection of `Quiescent' lines

F~10^{-15}erg/s/cm^2, Δv~10-30km/s

→ **H_2 lines originating from disks**

(cf. UV lines : Herczeg et al. 2002)



GG Tau, TW Hya, LkCa 15, DoAr 21

IRTF/CSHELL (R=21,500)

NOAO/Phoenix (R~60,000)

(Weintraub et al. 2000, Bary et al. 2002, 2003)

LkHa 264

Subaru/IRCS (R=20,900) (Itoh et al. 2003)

VLT/CRIRES (R=45,000) (Carmona et al. 2007)

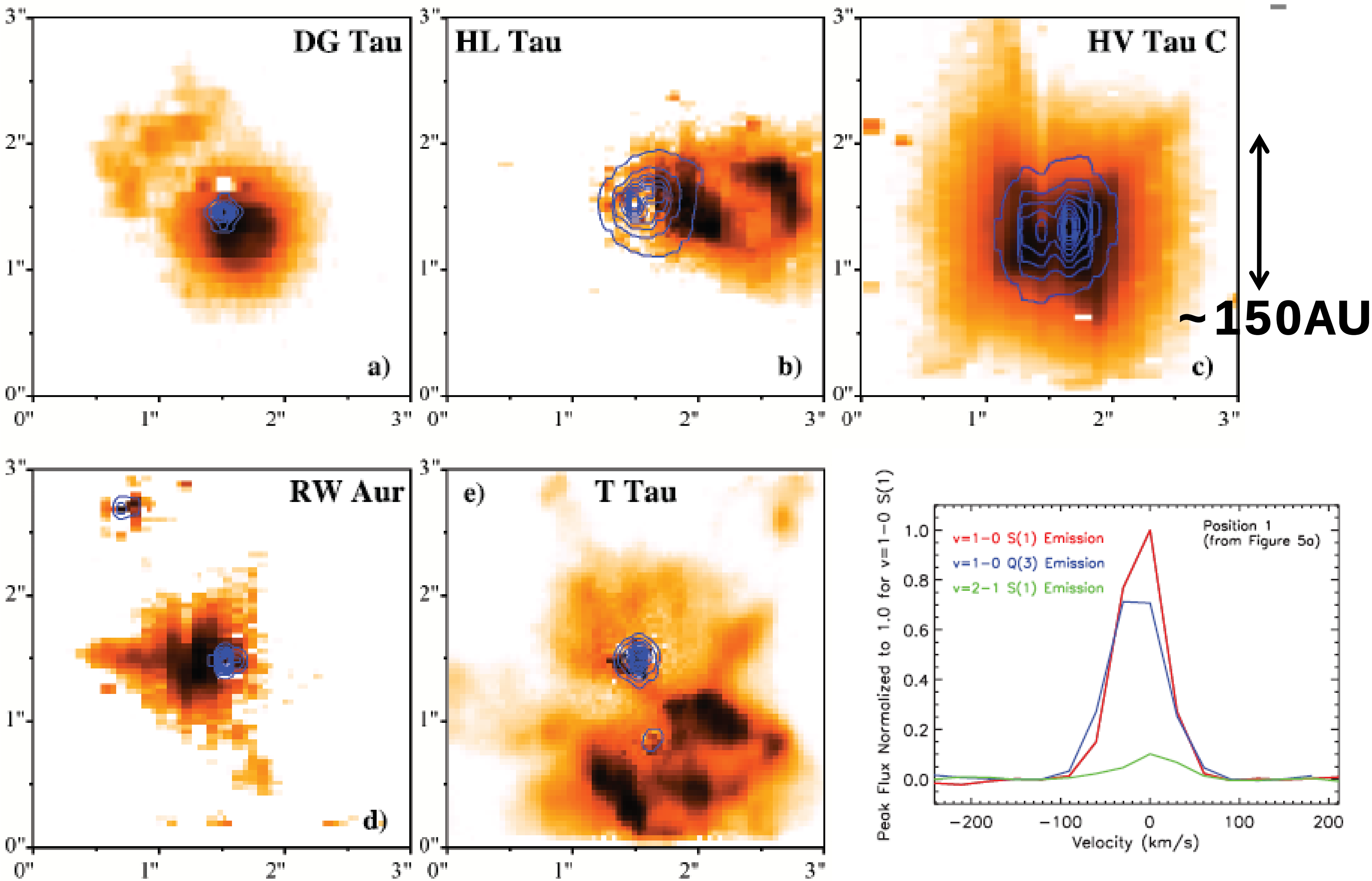
ECHA J0843

Gemini/Phoenix (R=62,400) (Ramsay Howat & Greaves 2007)

5 T Tauri stars & HD97048 in Cha I

Gemini/Phoenix (R~60,000) (Bary et al. 2008)

H_2 Line Obs. towards TTSs (NIR)



1-0 S(1)@2.12μm Gemini/NIFS (R~5300) (Beck et al. 2008)

H_2 Line Obs. towards TTSs (MIR)

ISO observations

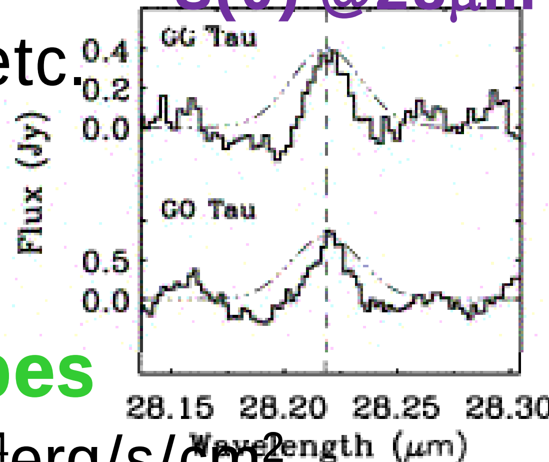
GG Tau, GO Tau, LkCa 15, etc.

F~(2-7)x10^{-14}erg/s/cm^2

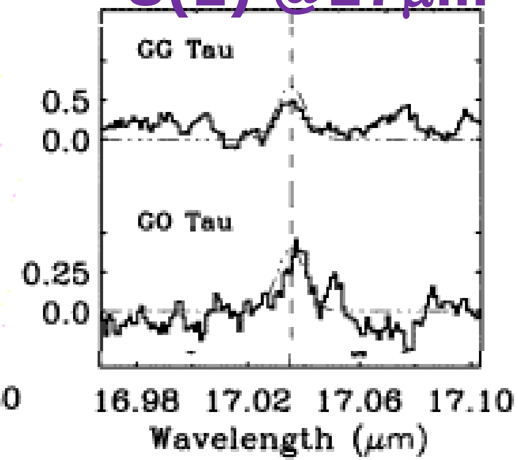
ISO/SWS (R~2,000-2,400)

(Thi et al. 1999,2001)

S(0) @28μm



S(1) @17μm



Ground-based telescopes

Only upper limits: F < ~10^{-14}erg/s/cm^2

GG Tau, DG Tau, etc., **S(1)@17μm, S(2)@12μm**

IRTF/TEXES (R~40,000-83,000) (Richter et al. 2002)

LkCa 15, etc., **S(1)@17μm**

Subaru/COMICS (R~5,000) (Sako et al. 2005), etc.

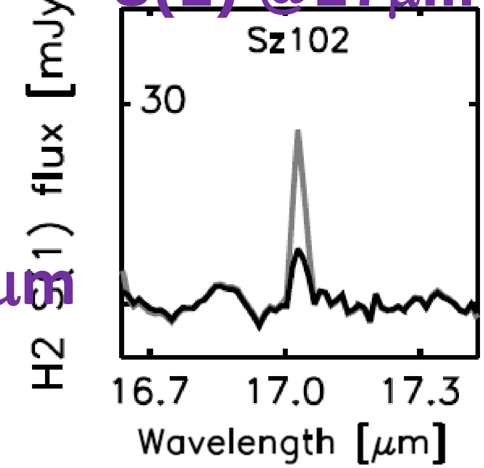
Spitzer observations 6 YSOs

S(0)@28μm, S(1)@17μm, S(2)@12μm, S(3)@9.7μm

Spitzer/IRS (R=600) F~(0.3-7)x10^{-14}erg/s/cm^2

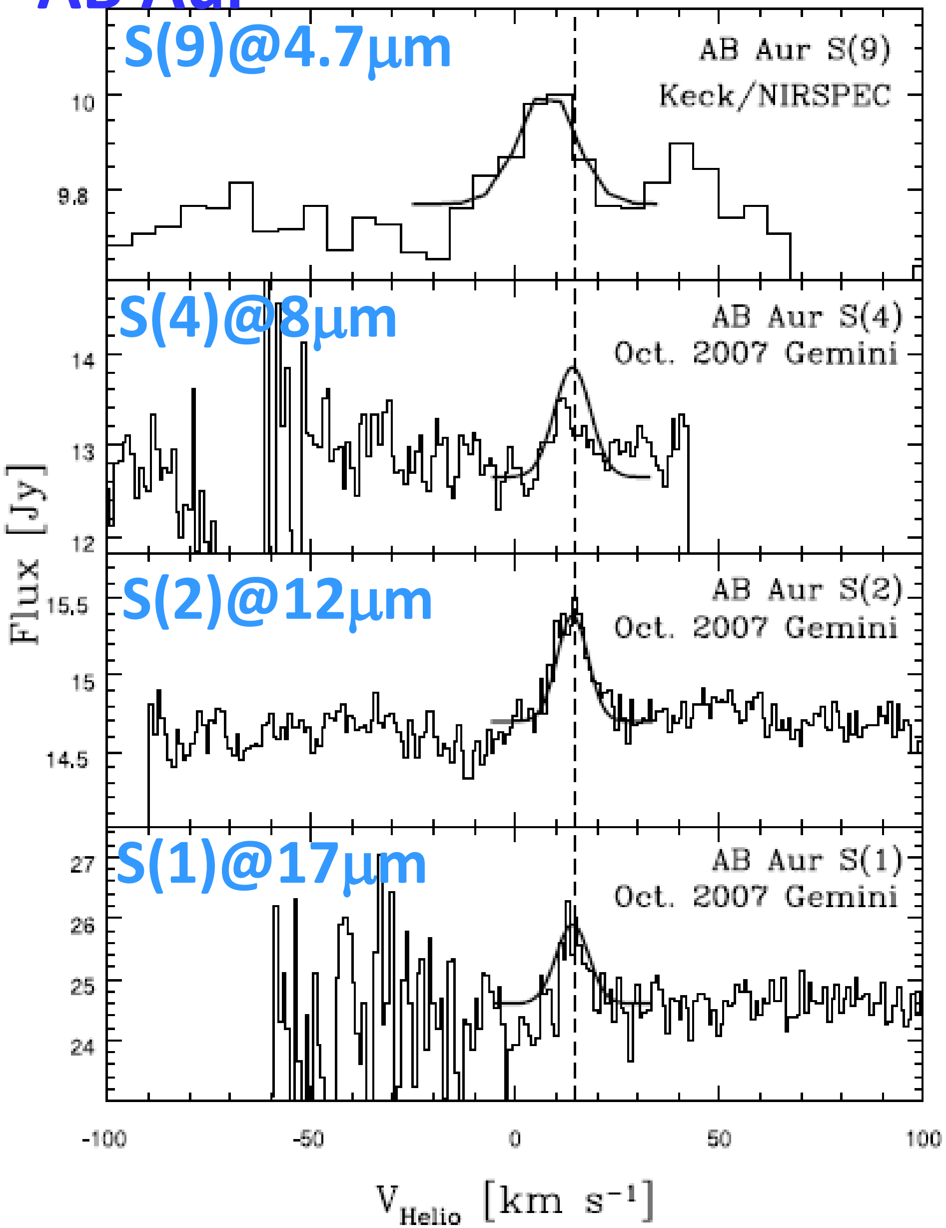
(Lahuis et al. 2007)

S(1) @17μm

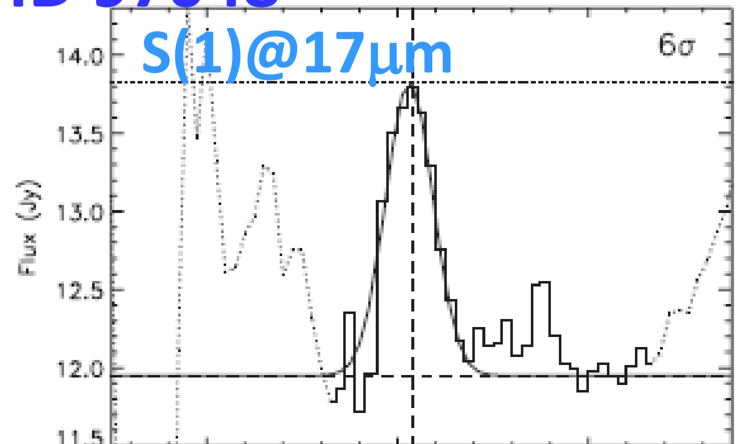


H_2 Line Obs. towards HAe (MIR)

AB Aur



HD 97048



Detection by ground-based telescopes

F~10^{-14}erg/s/cm^2, Δv~10-20km/s

AB Aur

Gemini/TEXES (R>80,000), (Keck/NIRSPEC (R=25,000))

(Bitner et al. 2007, 2008)

HD 97048

VLT/VISIR (R~14,000)

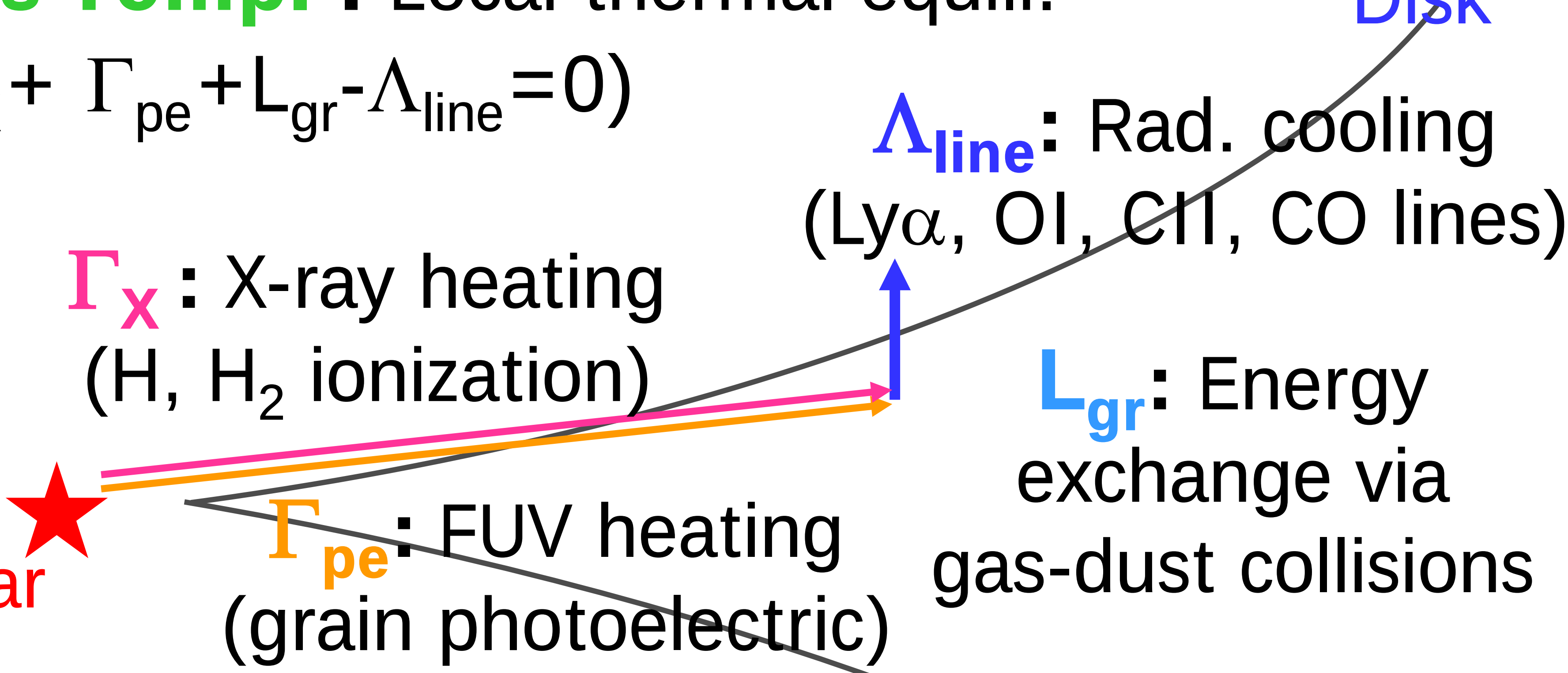
(Martin-Zaidi et al. 2007,2009)

§ 3
H_2 Line Emission from Protoplanetary Disks
- Modelling -

Thermal Processes in PPDs

Gas Temp. : Local thermal equili.

$(\Gamma_X + \Gamma_{pe} + L_{gr} - \Lambda_{line} = 0)$

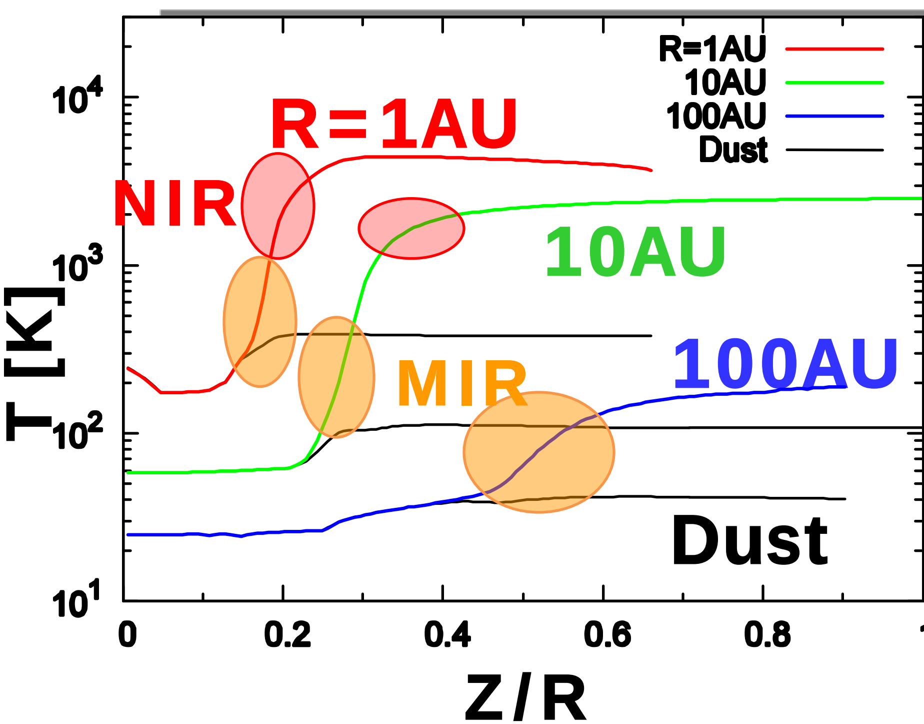


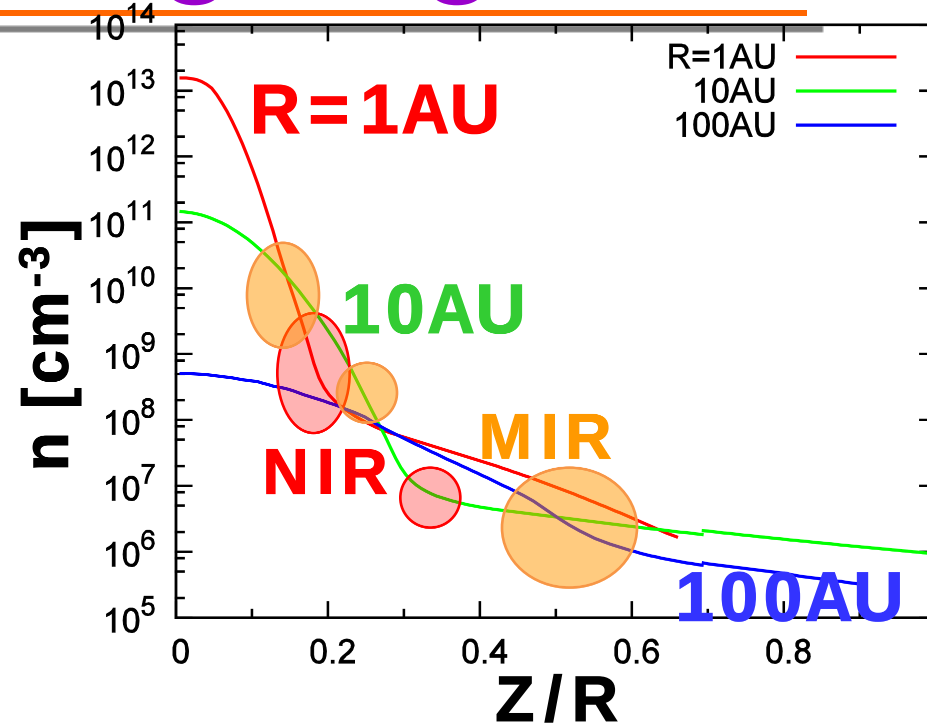
Dust Temp. : Local radiative equili.

Heating: Irradiation from central star

Cooling: Dust thermal radiation

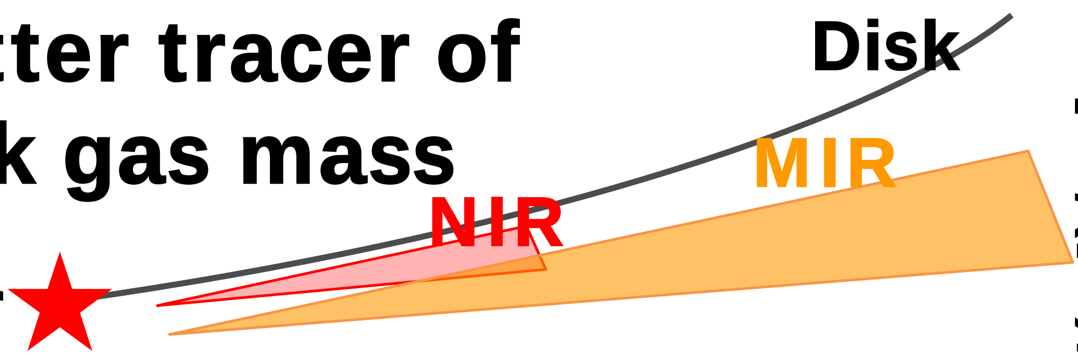
H_2 Line Emitting Regions



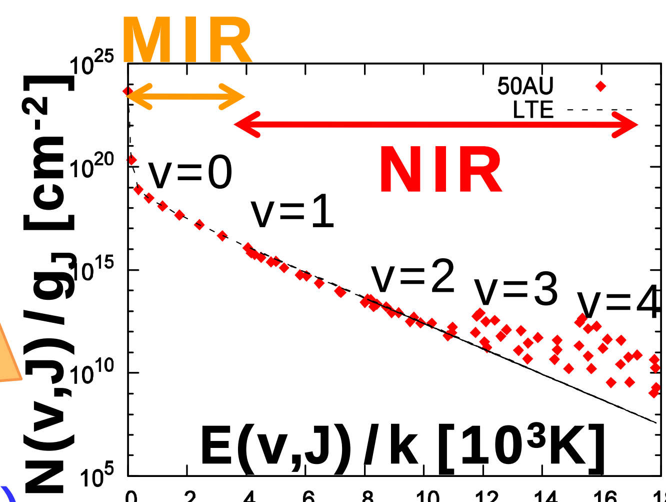


MIR emission lines :

Better tracer of disk gas mass



Star



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

H_2 Lines from HAe & T Tauri Disks

(Obs.: Bitner et al. 2008, Model: Nomura et al. 2007)

S(0)@28μm, S(1)@17μm, S(2)@12μm, S(4)@8μm

	Obs. (AB Aur)	HAe disk	T Tauri disk
S(0)		0.3×10^{-15}	0.01×10^{-15}
S(1)	$(6 – 11) \times 10^{-15}$	7×10^{-15}	0.2×10^{-15}
S(2)	$(5 – 9) \times 10^{-15}$	8×10^{-15}	0.1×10^{-15}
S(4)	15×10^{-15}	13×10^{-15}	0.3×10^{-15}

↓ [erg/s/cm^2]

SPICA→ Survey of H_2 lines from T Tauri disks

→ Understand gas dispersal time of PPDs

S(0)@28μm (vs. S(1)@17μm, S(2)@12μm) ?

Best gas mass tracer

⬌ small line flux (∵small Einstein coefficient)

§ 4 Summary

Mid-IR H_2 lines from protoplanetary disks

- **Good tracer of gas mass in disks**
- **High $\Delta\lambda/\lambda$ obs.** by Gemini/TEXES, VLT/VISIR
  Detection of quiescent lines of mid-IR H_2 emission from H Ae disks
- **SPICA + High Dispersion Spectrograph**
  → H_2 line detection from T Tauri disks
  → Understand gas dispersal time of protoplanetary disks

*** Obs. of line emission of molecules originating from grain surface reactions**