Studies of Gaseous Protoplanetary Disks using SPICA : Summary of Discussion

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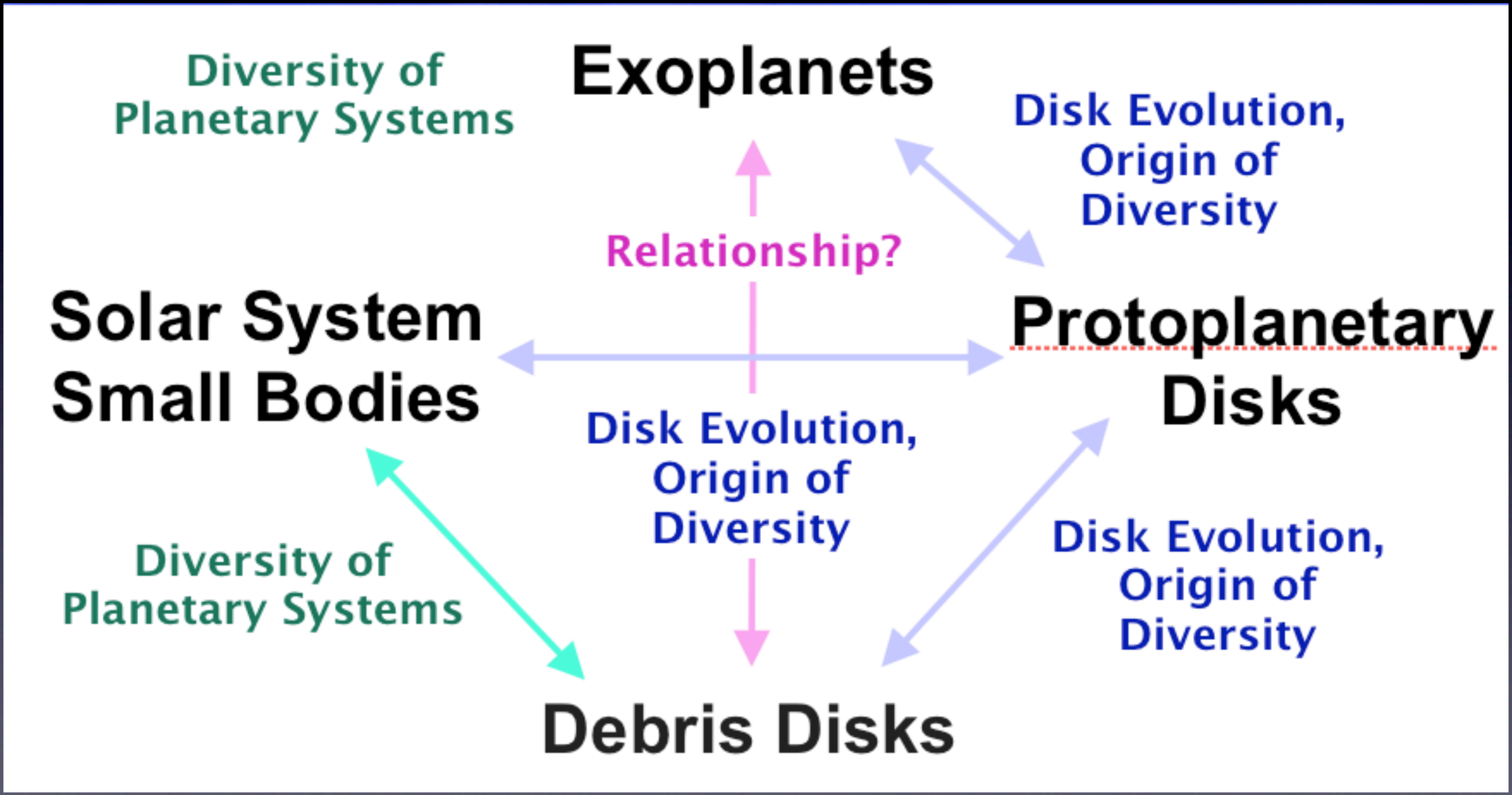
Sciene Working Group, Task Force etc.

Targets & Relationship to Study Exoplanets and Planet Formation



(From a slide in 2009)

Planetary Systems：Objective #2

- 科学目的 Objective
  - 惑星系形成領域のガスの散逸過程および構造の進化を観測し、木星型惑星の形成メカニズムや地球型惑星の生成条件を明らかにする。
    - We will reveal the formation mechanism of gas giant planets and initial condition of terrestrial planet formation, by observing the dissipation of gas and their structural evolution in planet-forming regions.
- 科学目標 Target
  - 若い星の周りの暖かいガス（100-1000 K）に伴う輝線を観測し、起源を確定する。原始惑星系円盤に付随する輝線を用いて残存ガスの量を求め、主星の質量や年齢との相関を解明する。
    - With unprecendented sensitivity at 20-40 um, we will survey for emission lines which could be (or are) associated with warm gas (100-1000 K) in protoplanetary disks. Using lines associated with disks, we will measure the amount of gas and how it varies with stellar mass and ages.
  - 高分散赤外線分光観測によりガスのさまざまな速度成分の輝線強度比を求め、円盤の空間構造、物理状態、化学組成の分布を明らかにする。
    - We will elucidate the geometric, physical and chemical structure of proto-planetary disks by measuring the motion of gas with high-dispersion infrared spectroscopy.

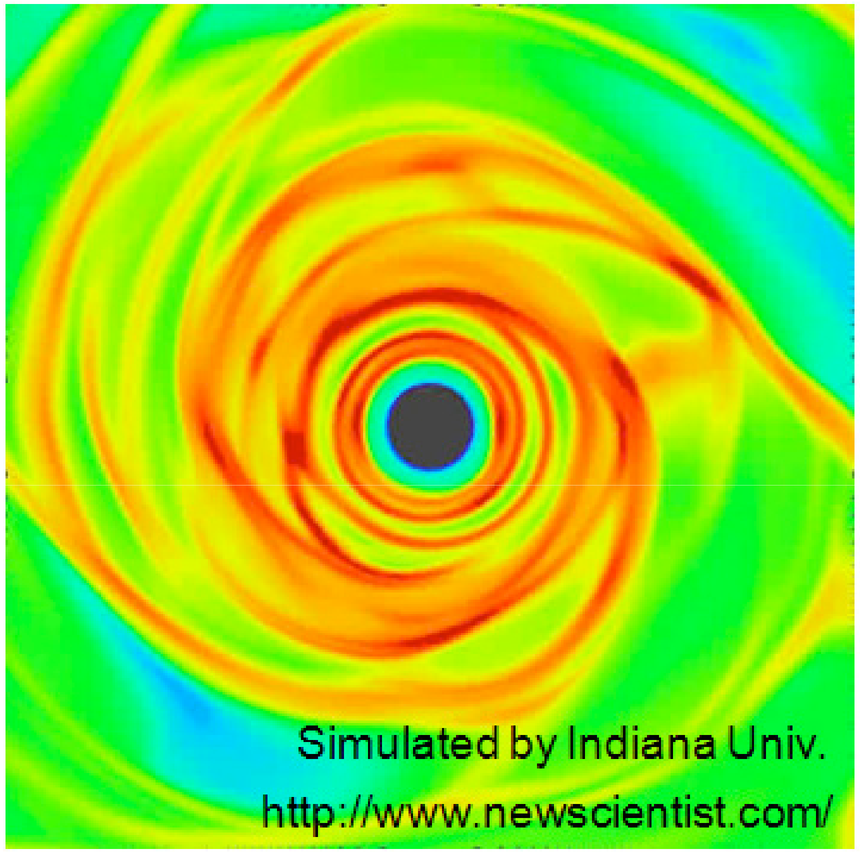
中間赤外線中分散分光装置　MIRMES

中間赤外線高分散分光装置　MIRHES

遠赤外線分光撮像装置　SAFARI

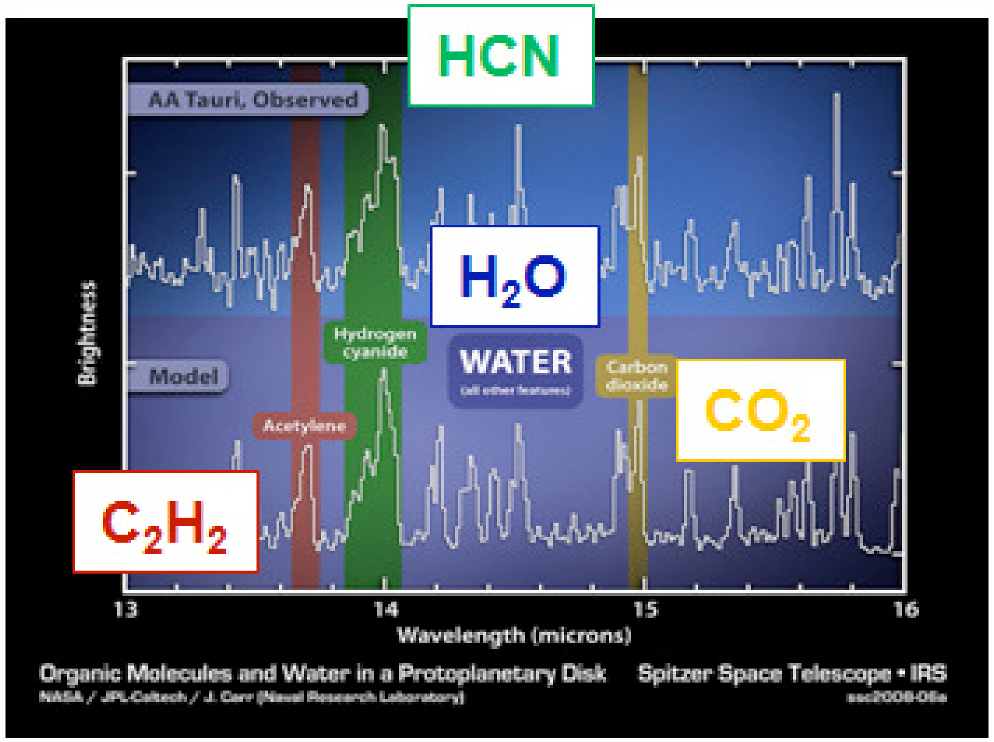
(From a slide for Mission Required Document)

Evolution of Gas Disks in Planet-Forming Regions



- Theories suggest important roles of gas for planet formation. These include (1) gravitational instability which could form planets without dust accumulation, and (2) gas drag on solid material, determining the population and orbits of terrestrial planets.

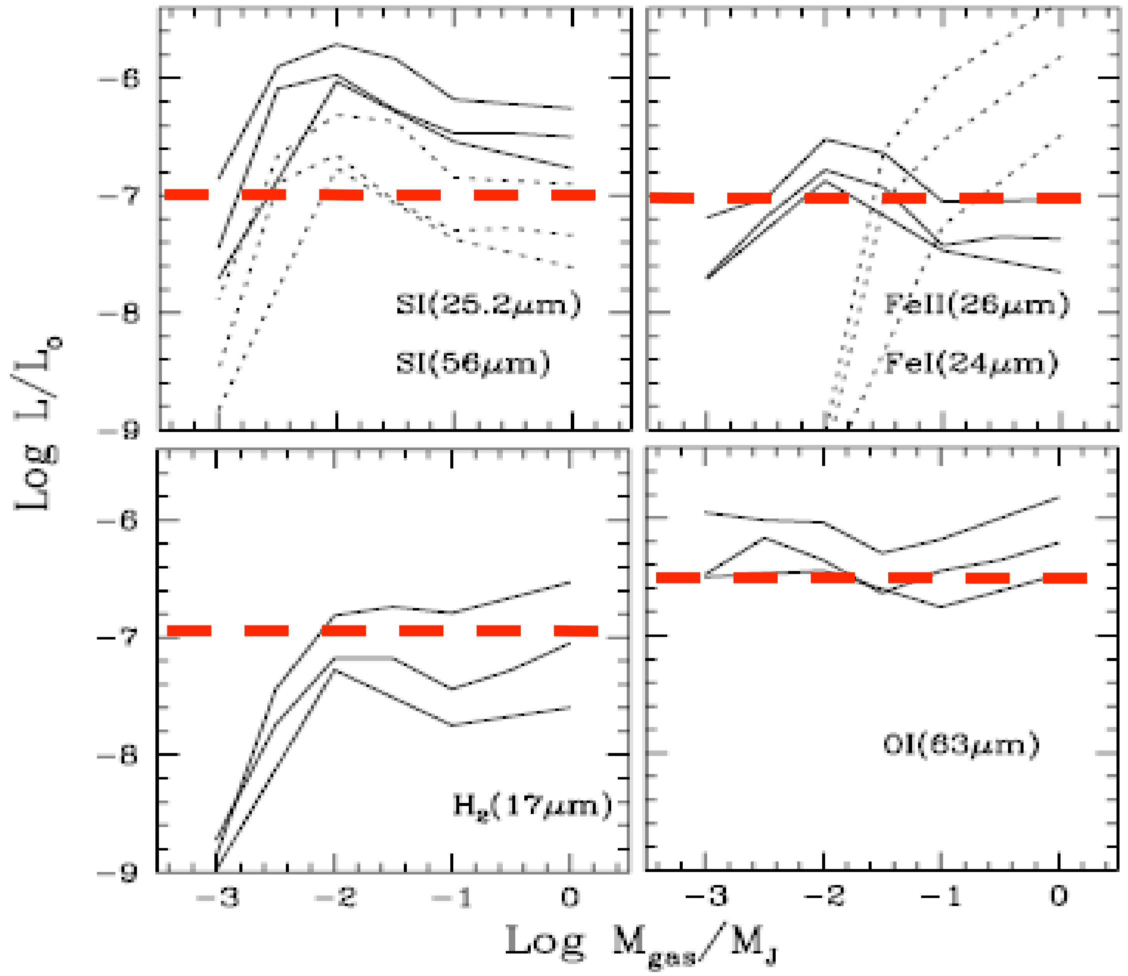
- IR Spectroscopy at 4-40 µm is a powerful tool for observing planet-forming regions
- Space telescopes allow such observations at any wavelength with high sensitivites.



Spectrum of a disk observed using Spitzer (upper) and a model (lower)
(Press Release in 2008)

(From a slide for Mission Required Document)

Evolution of Gas Disks in Planet-Forming Regions

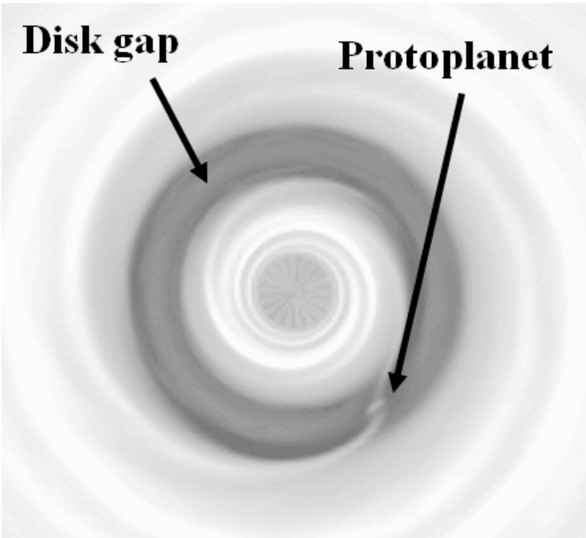


(Gorti & Hollenbach 2004, M~1 M_{solar}, t~10 Myr)

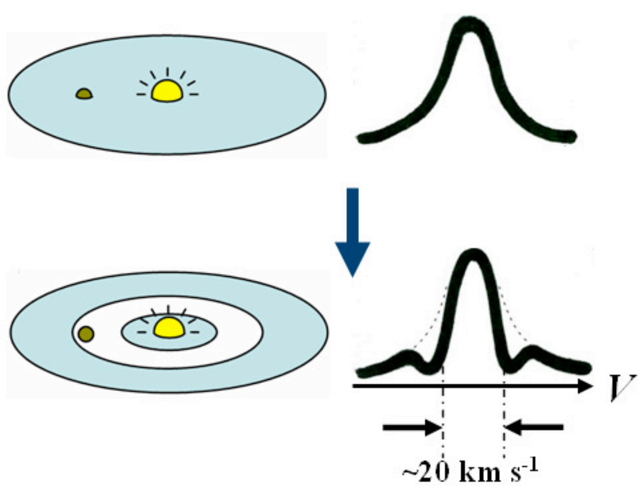
- Superb detection limits of SPICA spectrographs are sufficient for observing MIR-FIR lines predicted by disk models, even for those IR excess is diminishing.

Approximate detection limits of SPICA spectrographs, assuming the distance of the target of 140 pc

- High-res. spectroscopy would allow us to observe the evolution of disk structture due to planet formaion.



(Bryden et al. 1999)



(From a slide for Mission Required Document)

Target Lines & Research Goals

- **H_2 0-0 S(0) @28 μm, 0-0 S(1) @17 μm, etc.**
  - **Amount of warm gas, column density distribution**

    ⟶ Evolution of the disk structure

- **Atomic/Ionic Forbidden Lines**
  - **Dissipation Timescale of the gas disk**

    ⟶ Formation scenario of gas giants

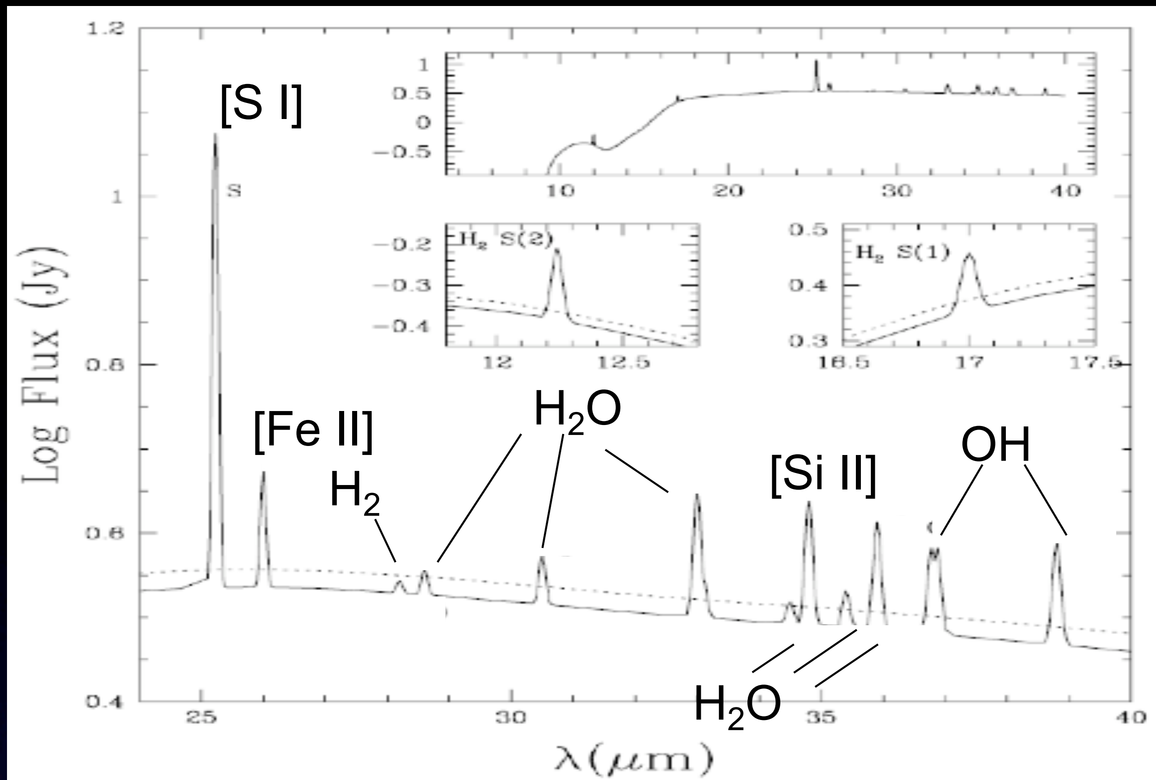
    Evolution of terrestrial planets

[Ne II] 12.8 μm
[Ne III] 15.5 μm
[Fe I] 24 μm
[S I] 25.2 μm
[Fe II] 26 μm
[Si II] 34.8 μm etc.

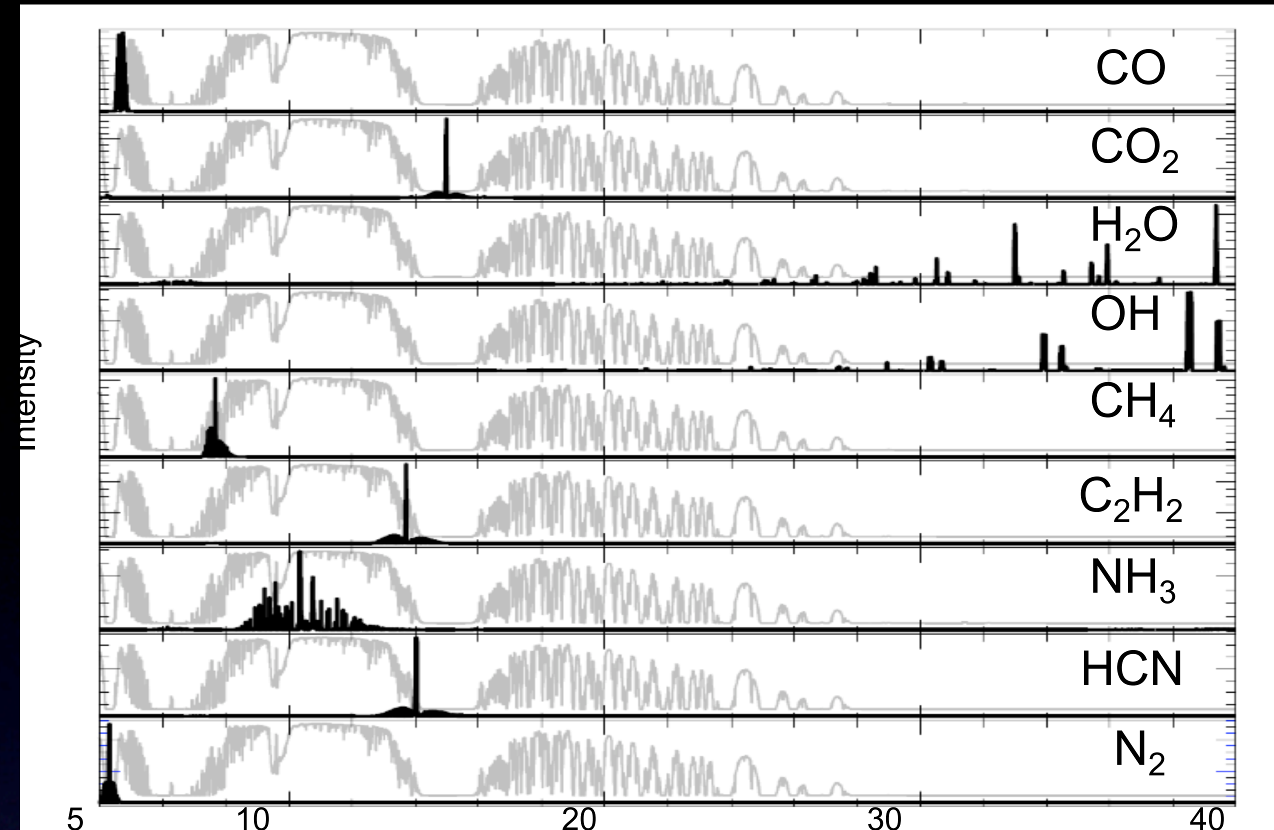
- **Other Molecular Lines**
  - **More details about physical/chemical conditions**

    ⟶ Conditions of ongoing planet formation

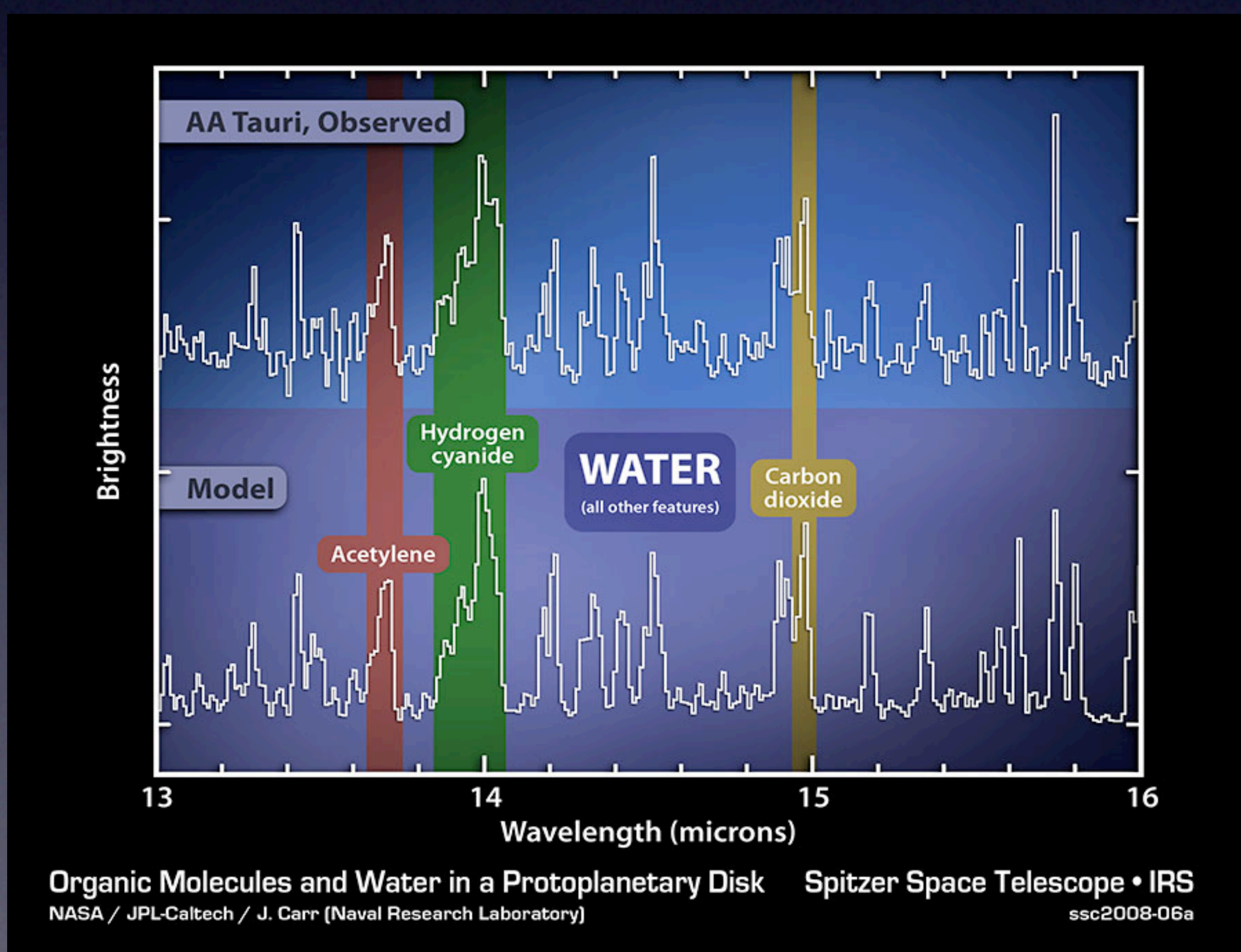
(From a slide for high-res. spectroscopy at TMT, Feb 2010)



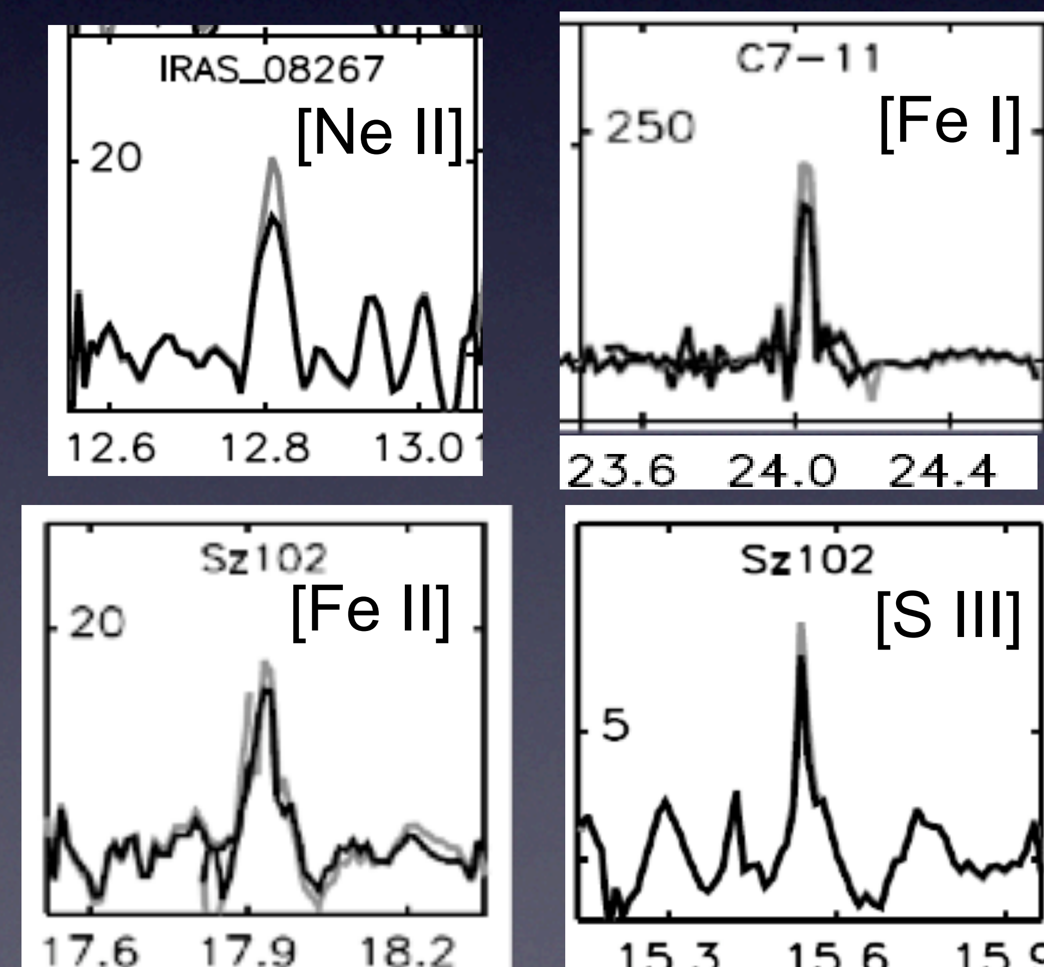
(Gorti & Hollenbach 2004)



(Optically Thin, 1000 K)



(Spitzer Press Release in 2008)

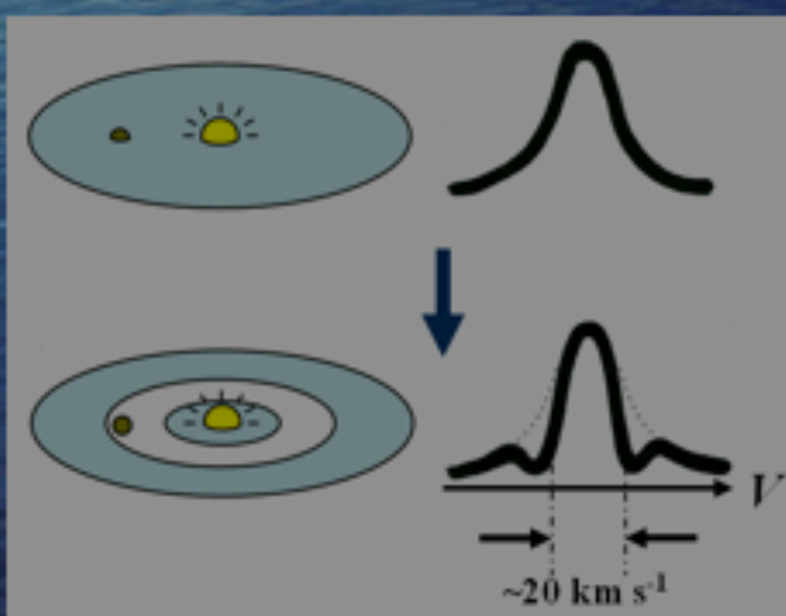


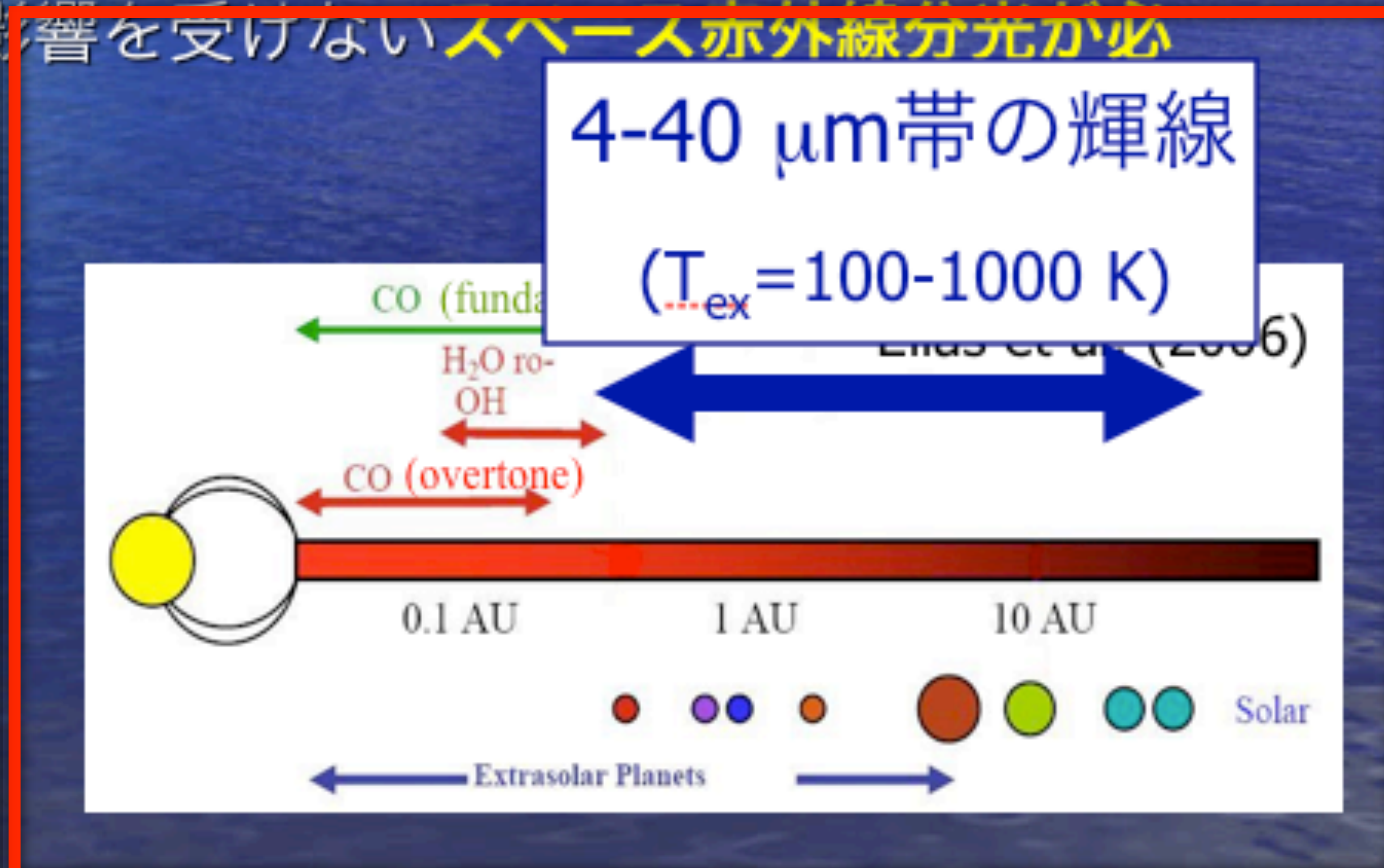
(Lahuis et al. 2007)

原始惑星系円盤の観測

ガス円盤の赤外輝線分光

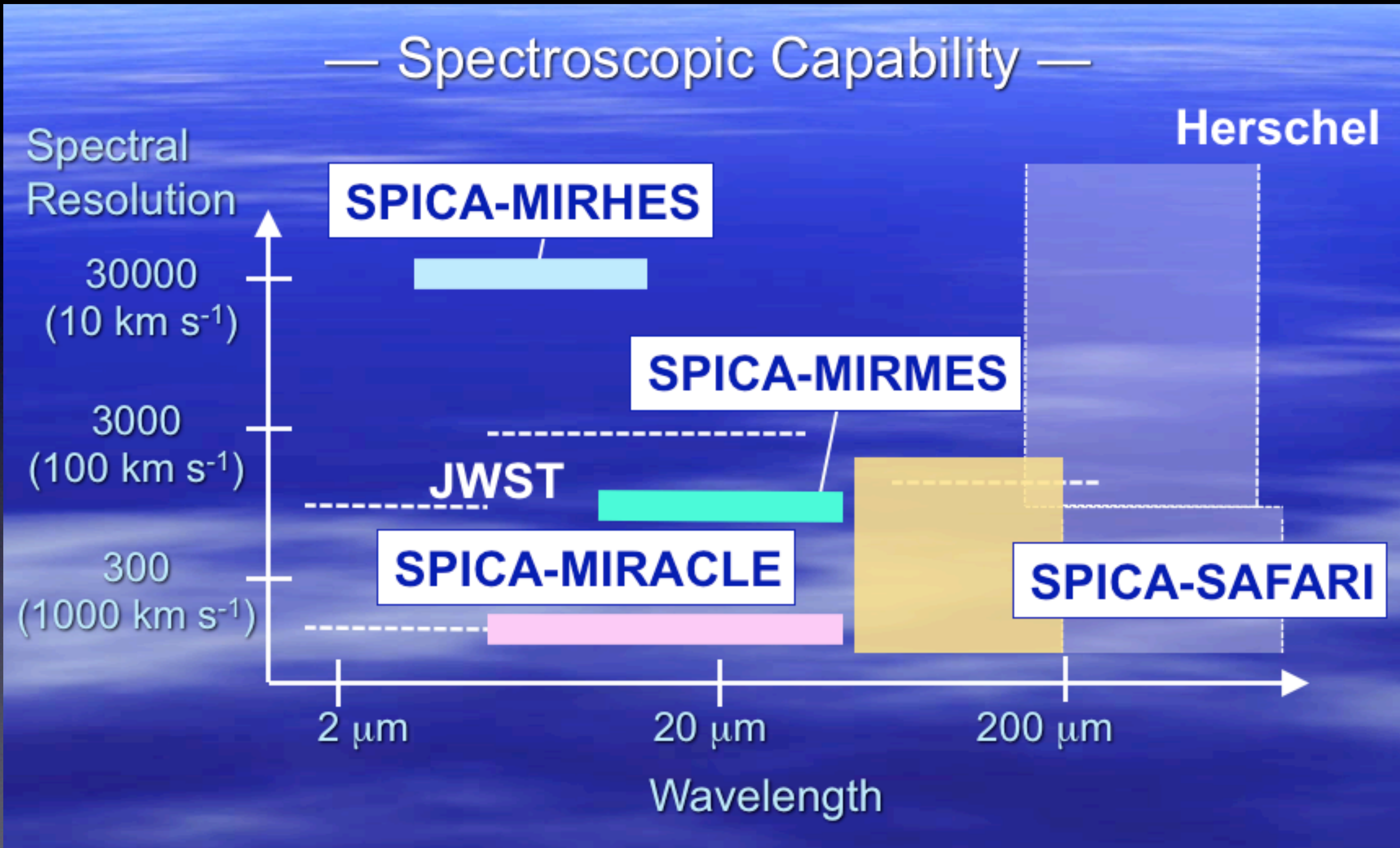
- 輝線プロファイルの観測により、直接空間分解できない領域 (R«30 AU @140 pc) の幾何構造や、各半径の物理・化学状態を観測可能
- れの太陽系と同様の空間スケールの領域を観測するには、大気の吸収の影響を受けないスペース赤外線分光が必須！





(From a slide in 2007)

Comparisons with Other Missions



(From a slide in 2009)

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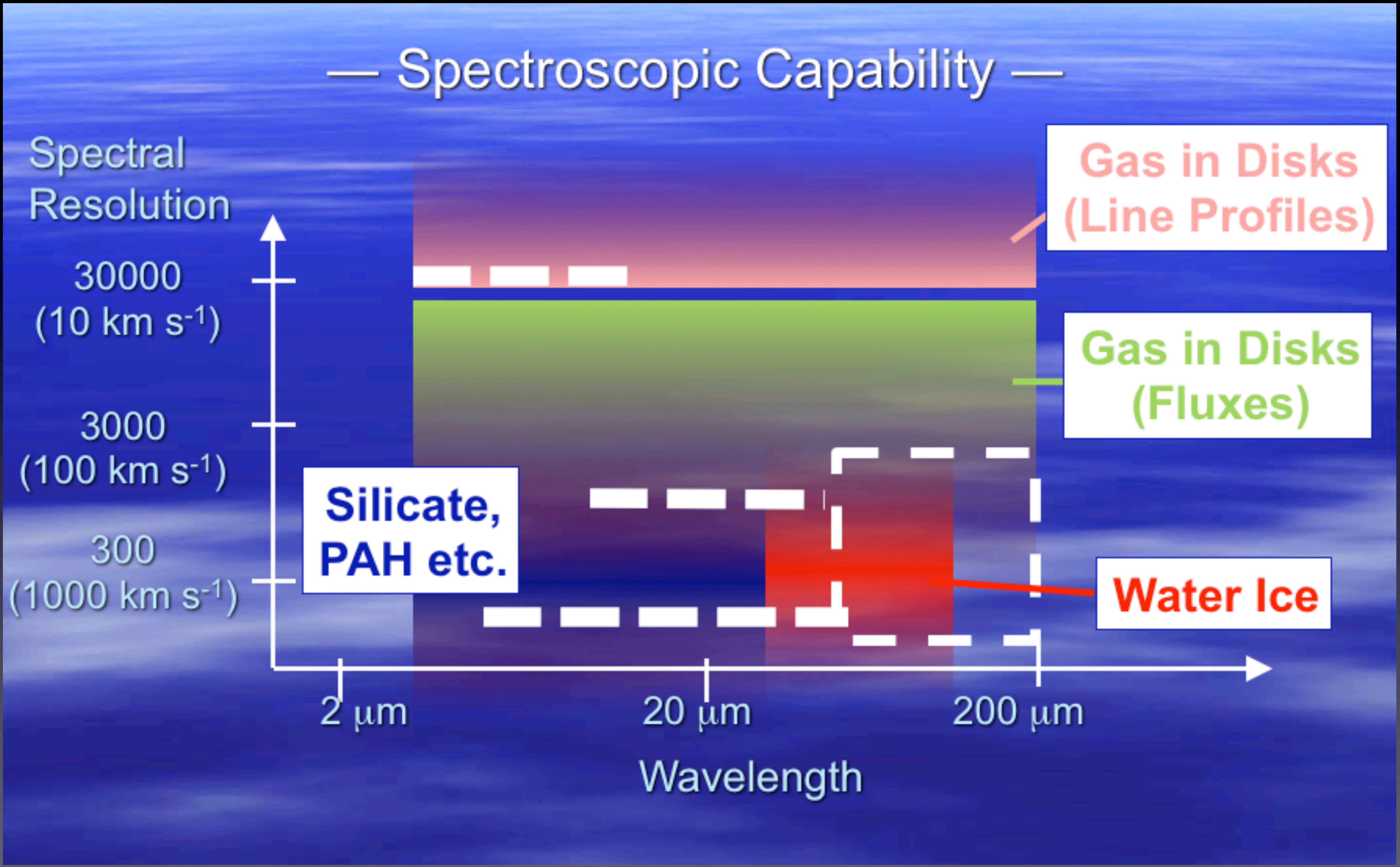

(From a slide in 2009)

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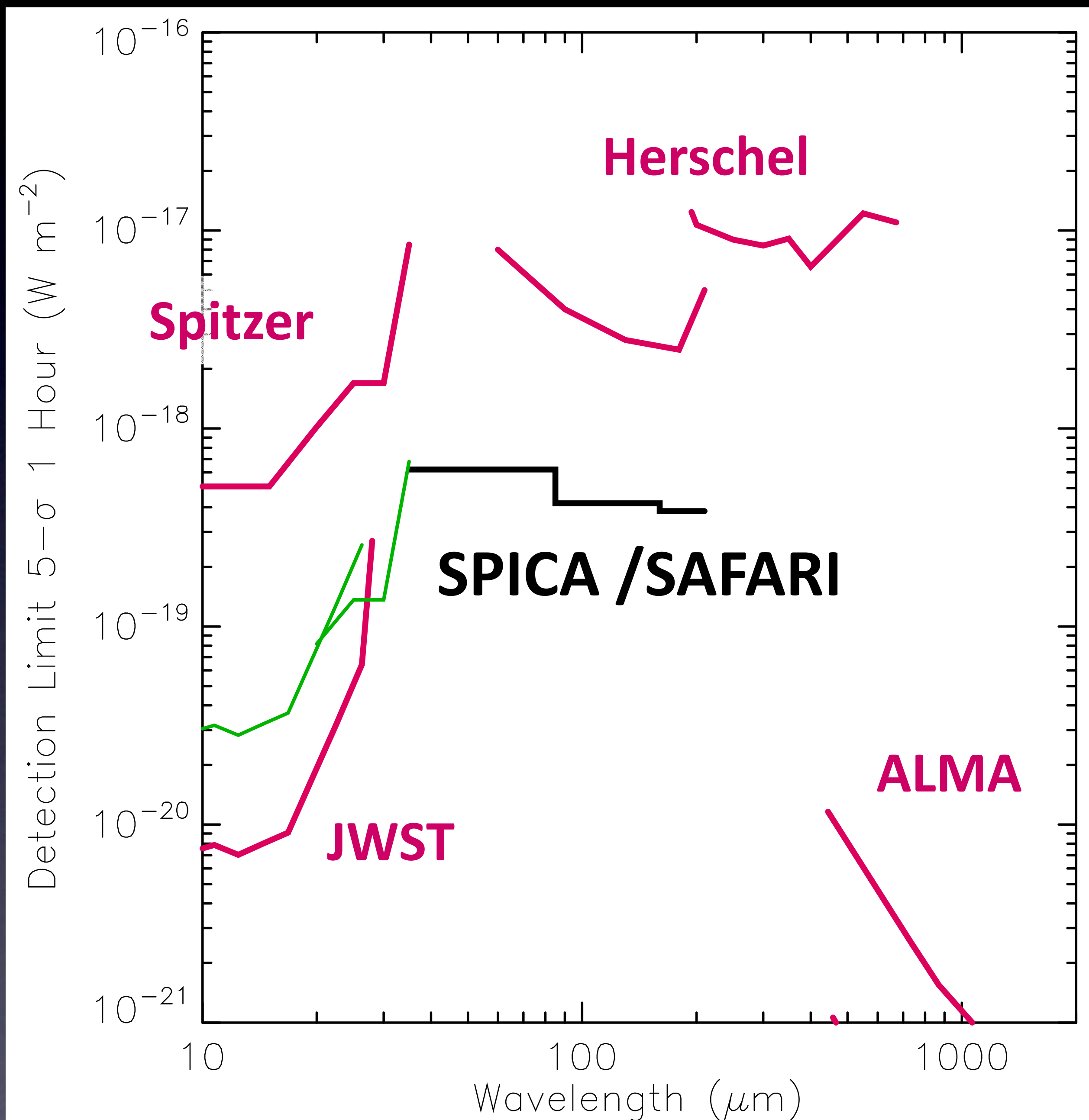
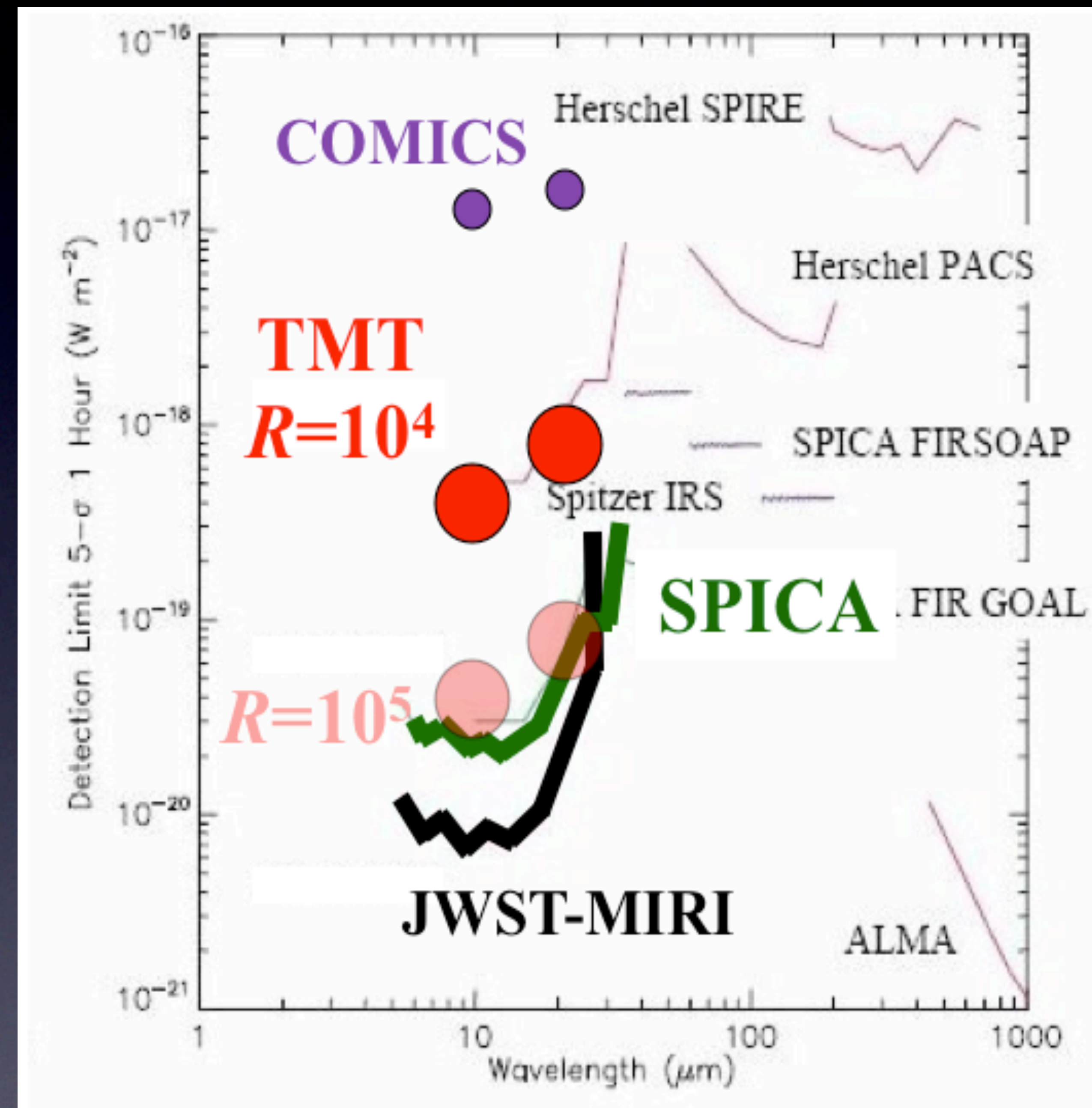


(Swinyard, private communication)



(older plot + Subaru & TMT, from a slide for high-res. spectroscopy at TMT)

Comparisons with Other Missions

Table 8: Improved Sensitivity Comapred with Spitzer-IRS

Instrument	R	Factor of Improvement continuum	unresolved lines	
JWST	3000	$\sim$12	$\sim$60	(F_{cont} < 10 mJy)
			$\sim$20	(F_{cont} > 100–350 mJy)
SPICA	1000	$\sim$7	$\sim$10	(F_{cont} < 10 mJy)
			$\sim$5	(F_{cont} > 100–350 mJy)
	30000	$\sim$1/4	$\sim$10	(F_{cont} < 100–350 mJy)
			$\sim$25	(F_{cont} > 400–1400 mJy)

Table 9: Improved Sensitivity Comapred with JWST-MIRI

Instrument	R	Factor of Improvement continuum	unresolved lines	
SPICA	1000	$\sim$1/2	$\sim$1/5	(F_{cont} < 10 mJy)
			$\sim$1/4	(F_{cont} > 10 mJy)
	30000	$\sim$1/50	$\sim$1/5	(F_{cont} < 10 mJy)
			$\sim$1.5	(F_{cont} > 400–1400 mJy)

Applied to the most of the samples of a large survey with Spitzer-IRS (Pontoppidan et al. 2010)

(From my report for sensitivity)

Priorities of modes in MCS

- **HRS-L: High**
  - Would offer a combination of a high sensivitiy and spectral resolutions at 12-18 μm
- **MRS-L: High**
  - Would offer an unprecedentedly high sensivity at 20-40 μm
- **HRS-S: Medium**
  - Detailed studies with CO with a superb sensitivity would be exciting, but we would also see some progress with TMT.
- **MRS-S: Medium**
  - Cannot beat JWST. Useful only for overcoming the time-variability problem of the targets, but may not be mandatory.

Roles of SPICA, TMT & JWST

-We want all of them!-

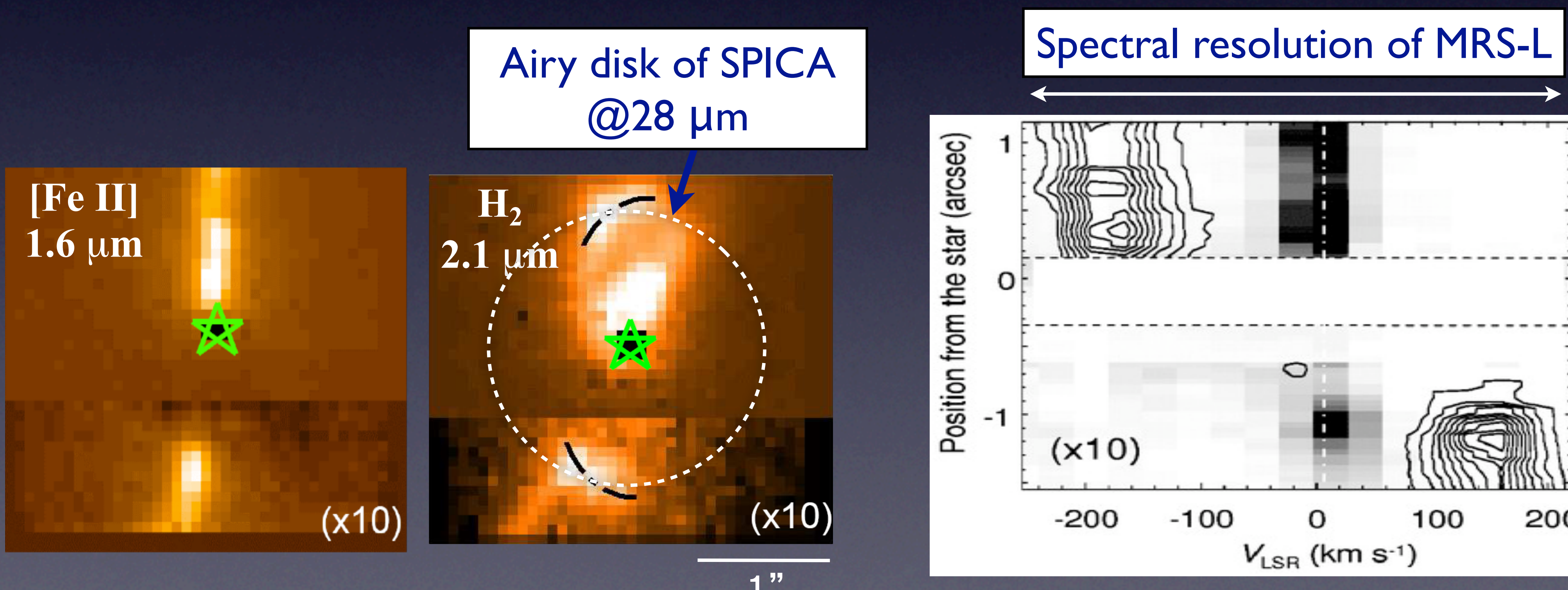
- **SPICA→High Spectral Resolution & Sensitivity**
  - Kinematics (thereby structures) in dozens of planet-forming regions
  - Physical/chemical conditions as a function or radius
  - Timescale for dissipation of gas disks @ T=100-1000 K
- **TMT→High Spectral & Angular Resolutions**
  - Kinematics & structures in bright planet-forming regions (minimizing emission contaminated from diffuse gas)
  - Effects of binary companions
- **JWST→Superb sensitivity (< 20 μm)**
  - Timescale for dissipation of *inner* gas disks
  - Detailed physical/chemical conditions integrated over the entire region

(Adapted from a slide for high-res. spectroscopy at TMT, Feb 2010)

Please go back to a slide and take questions

Appendix I

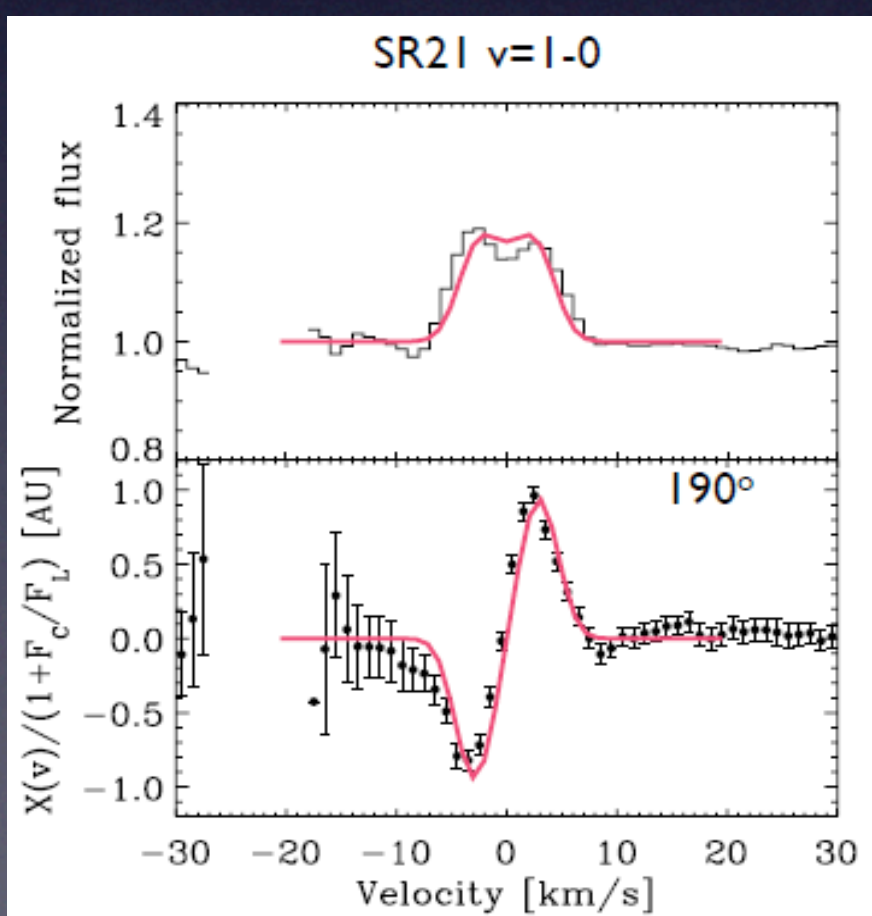
- **Contaminating emission from jets & winds**
  - < 100 km s^{-1}, thus H_2 and atomic/ionic forbidden lines in MRS can be contaminated.
  - could be discriminated using spectro-astrometry (see Appendix II) and/or models of line flux ratios

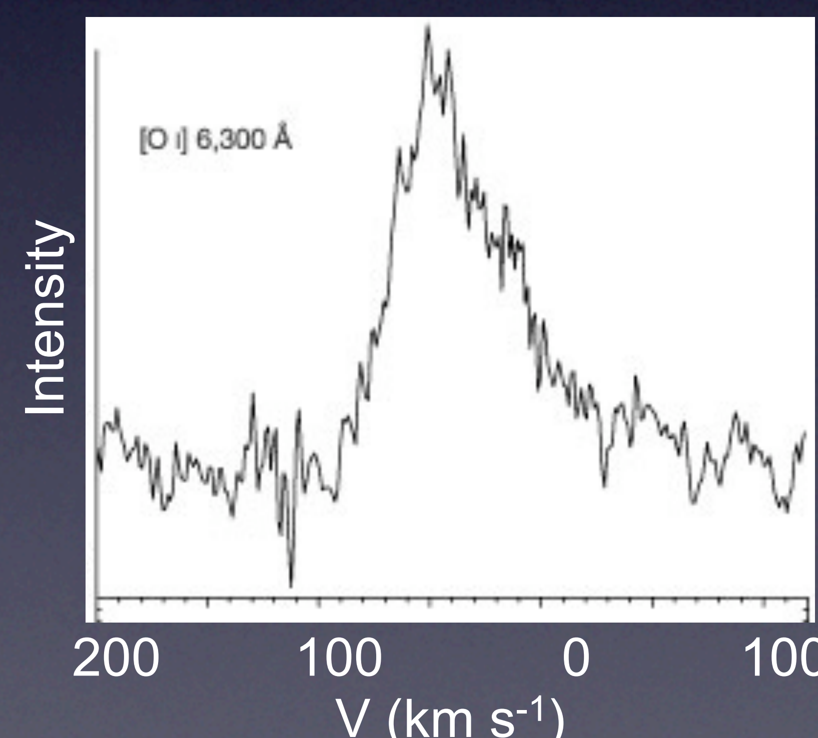


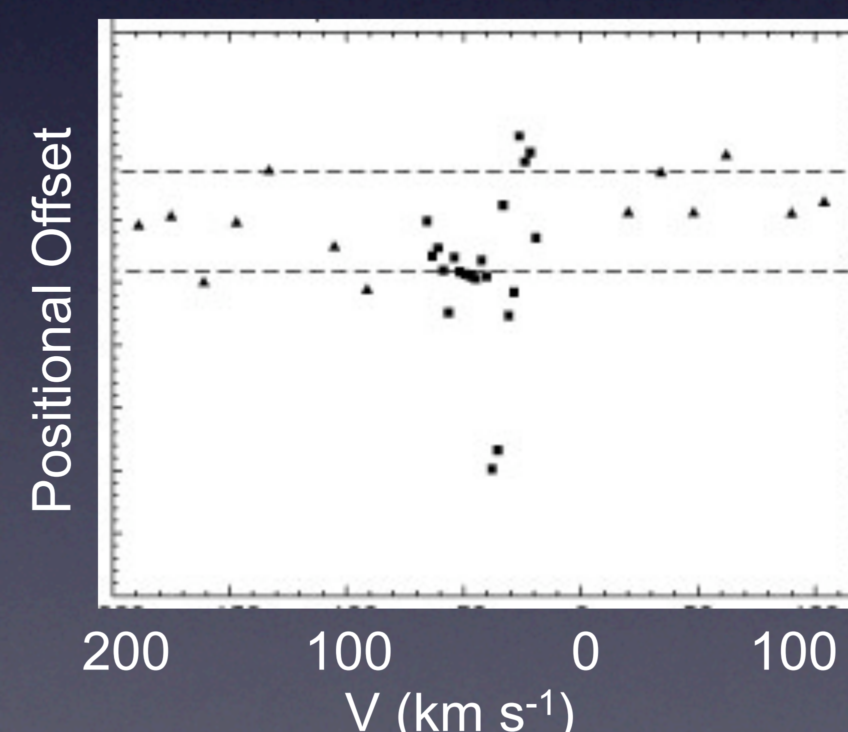
HL Tau (Takami et al. 2007)

Appendix II

- **Spectro-astrometry**
  - requires good pixel sampling of PSF (FWHM> 3 pix.)
  - probably ok with MRS-L (FWHM=4.3 pix. @ 28 μm) for discriminating emission between disks and jets/winds
  - not with HRS-L (FWHM=2.3 pix. @ 15 μm), but I personally agree with the present design priotizing the sensitivity & coverage





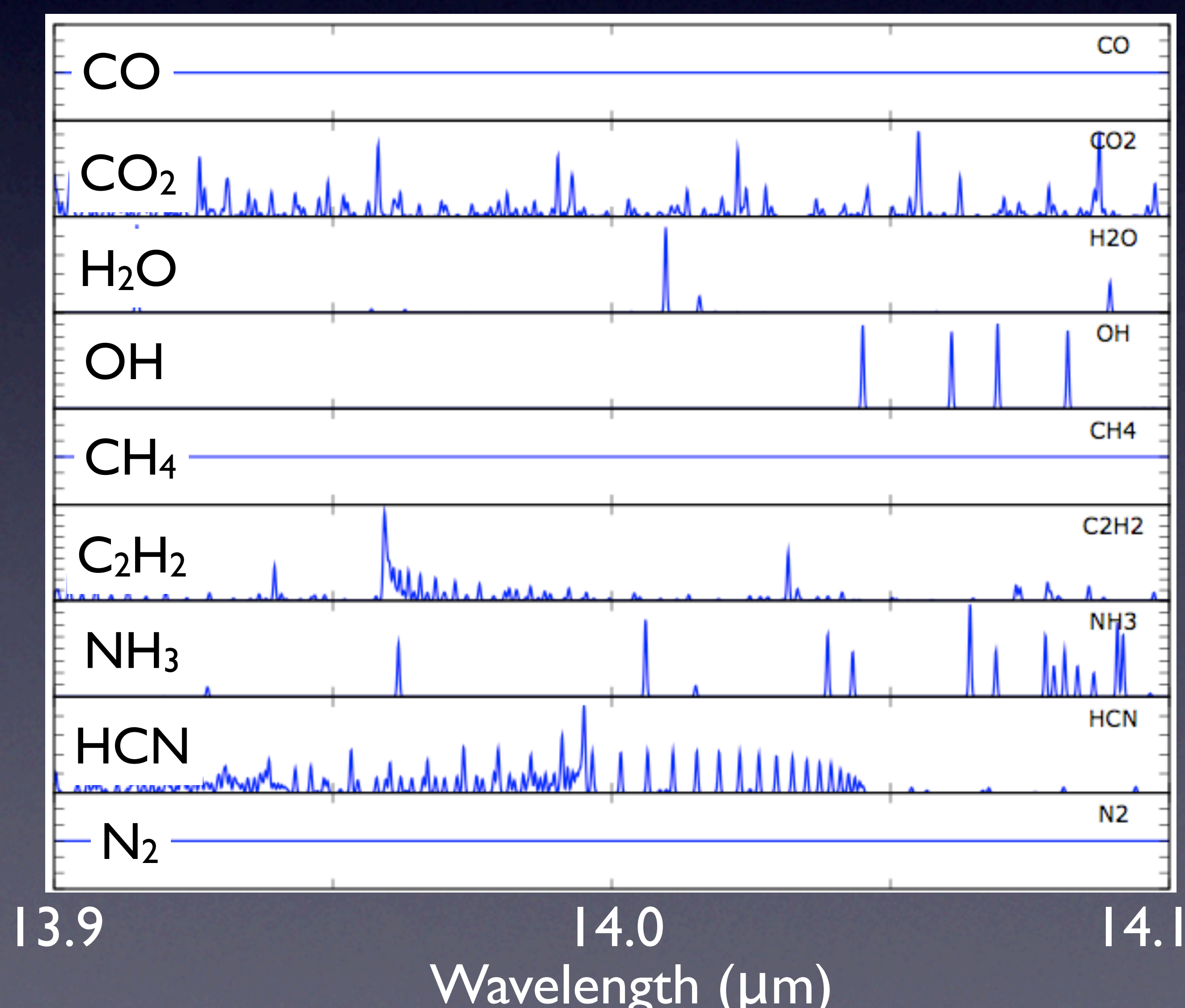


Spectro-astrometry of disk & jet emission
(Pontoppidan et al. 2008, Whelan et al. 2005)

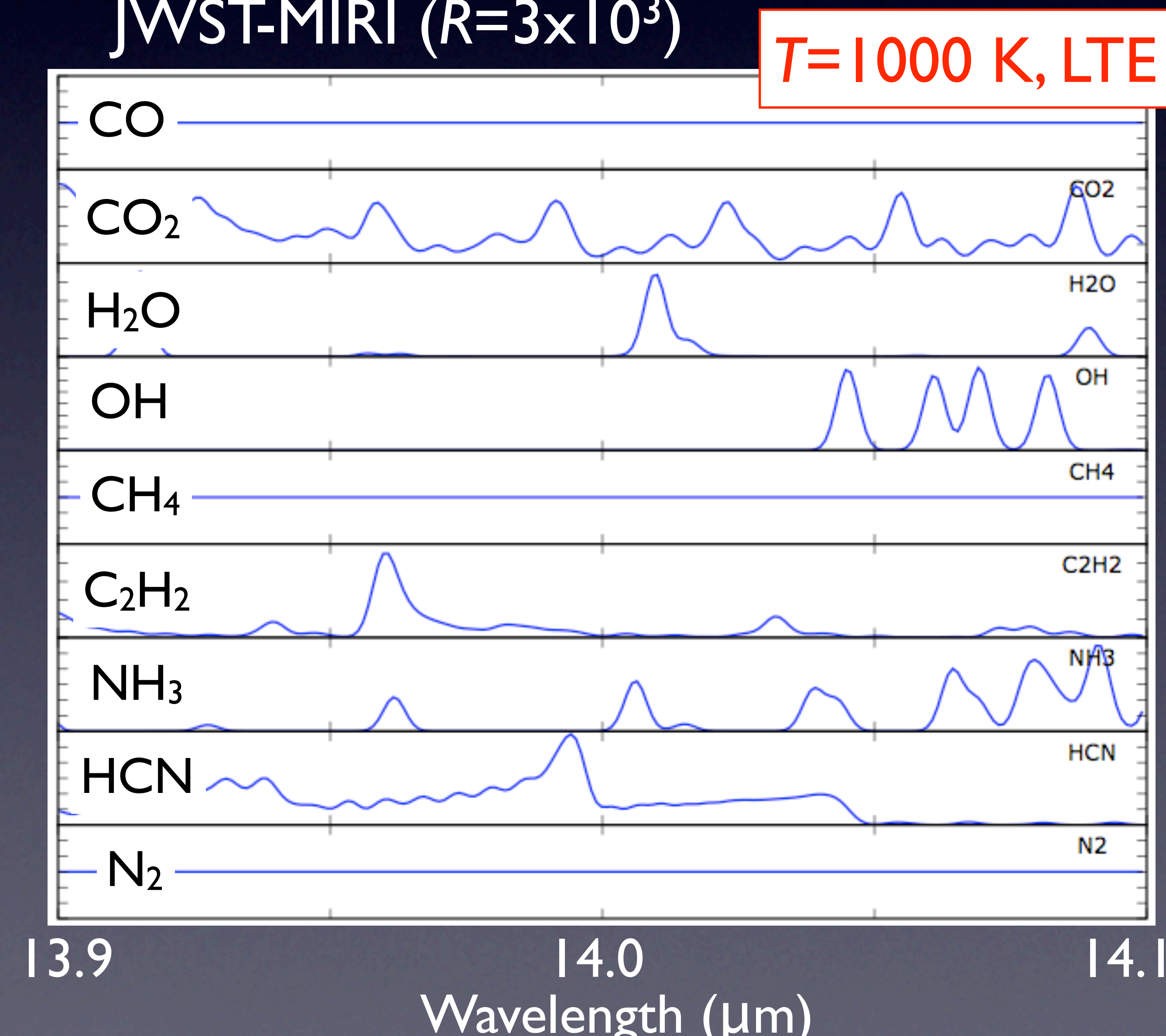
Appendix III

- **Deblending molecular bands**
  - works significantly better with MRCS-HRS than JWST-MIRI
  - highly depend on temperature and composition of gas

MRC-HRS (R=3x10^4)



JWST-MIRI (R=3x10^3)



Appendix III

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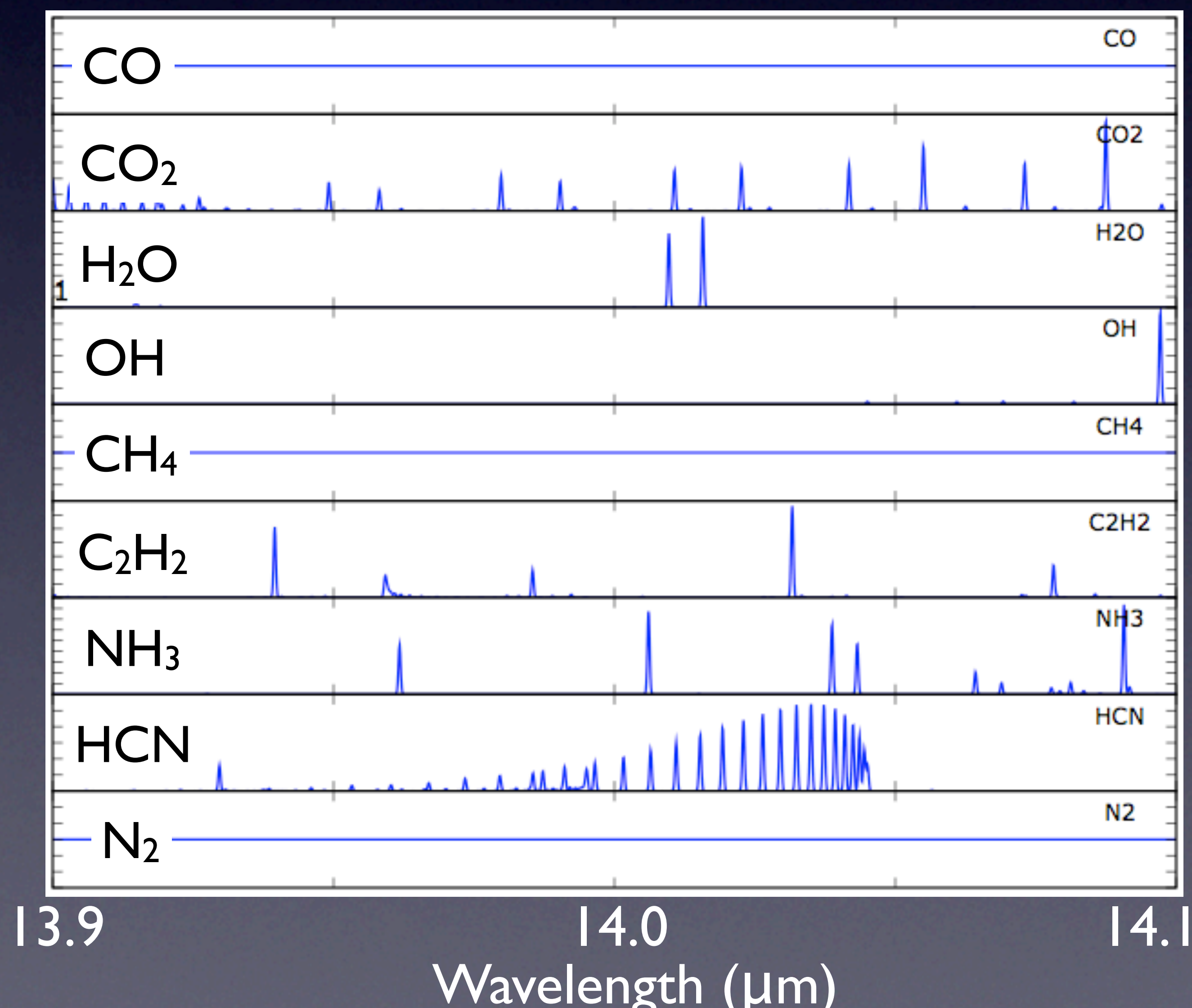
  - highly depend on temperature and composition of gas

MRC-HRS (R=3x10^4)



JWST-MIRI (R=3x10^3)