Gerrit van der Plas, 21/03/2013

Disk Observations II: Gas

What I want you to know/have in 45 minutes:

Examen!

1: What is the role of gas in disk/planet formation/evolution?
Cual es el papel del gas en la formacion/evolucion del disco protoplanetario/planeta?

2: A feeling for the possibilities that gas offers as a disk tracer
Una idea de las posibilidades que ofrecef el gas como medidor del disco protoplanetario

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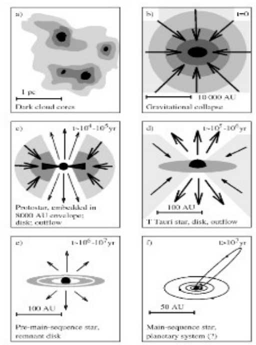
Disk Observations II: Gas

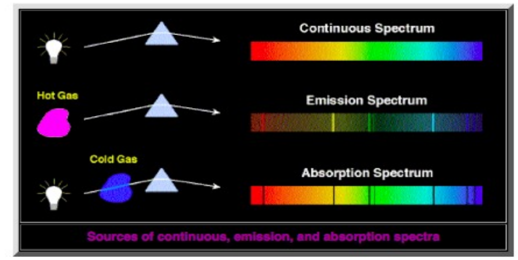
1 *Disk formation + dispersal*

- Formation
- Dissipation timescale
- Dissipation processes
- Gas giant planet formation timescales:
  - Gravitational fragmentation (<< 10^6 years, Boss et al. 2006).
  - Core accretion 1-10 x10^6 yrs (Pollack et al. 1996; Lissauer et al. 2006).



Hogerheijde (1998)

2 *Gas emission*



Continuous and discrete spectra

3 *Gas Diagnostics*

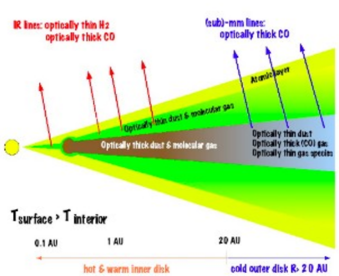
Where is the observed emission produced?

→ Important concepts:

1: Inner / outer disk

2: Interior / surface layer

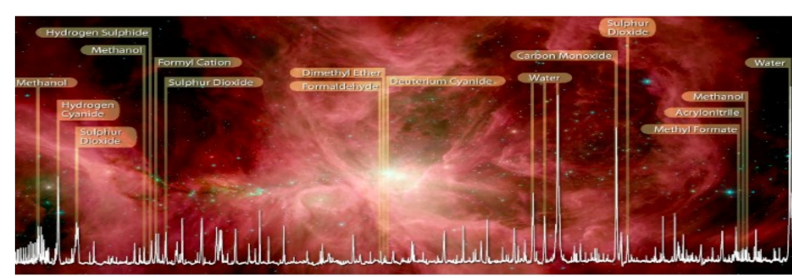
3: Optical depth medium



Carmona 2010

4 *Toolbox: Spectroscopy*

- 3 examples: line profiles, rotational diagram, disk (chemical, structural) modeling



Role of Gas in Planet formation

- Gas rotates (slightly) sub-Keplerian → head-wind for the dust particles (Wyatt, 100 yr for 1 m rocks..)
- Gas giant formation (Wyatt), Gravitational Instabilities (Wyatt), planetary atmospheres, ...
- Planet migration (Wyatt)
- Remnants in our solar system

Disk evolution

- Formation (this slide)
- Dissipation timescale, processes
- Gas giant planet formation timescales:
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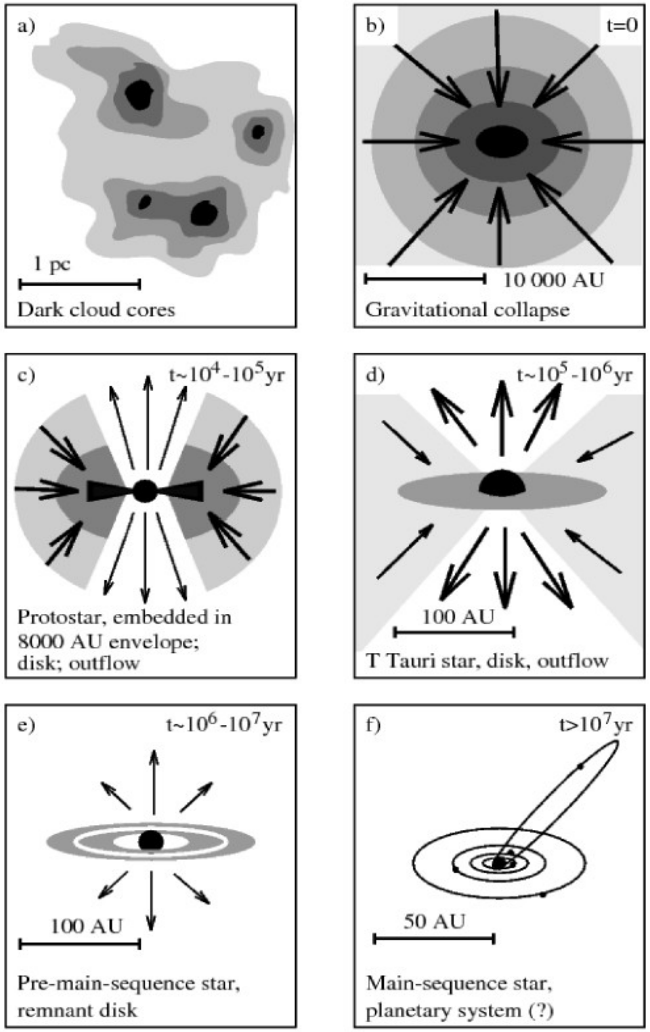
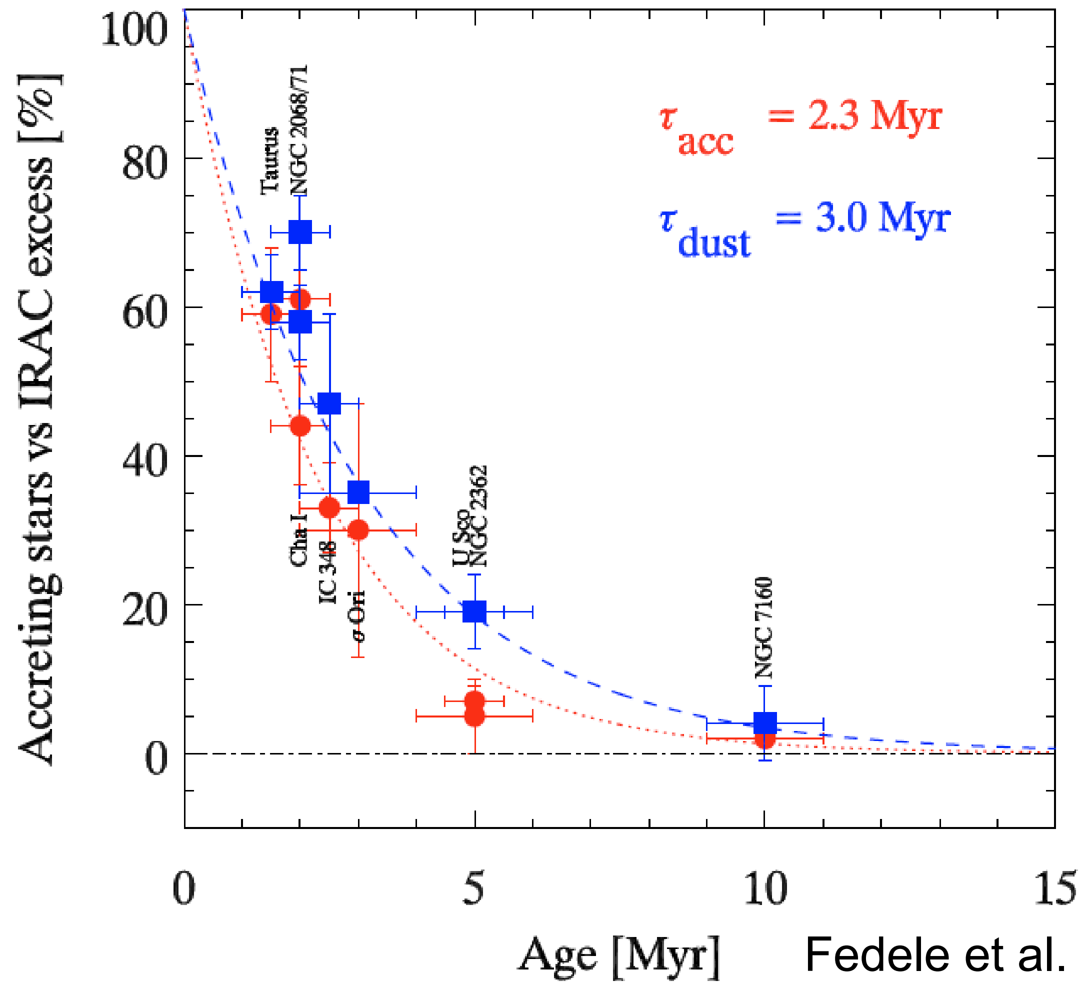


Hogerheijde (1998)

Gas dispersal timescales

Infrared excess / ongoing accretion



Fedele et al. (2011)

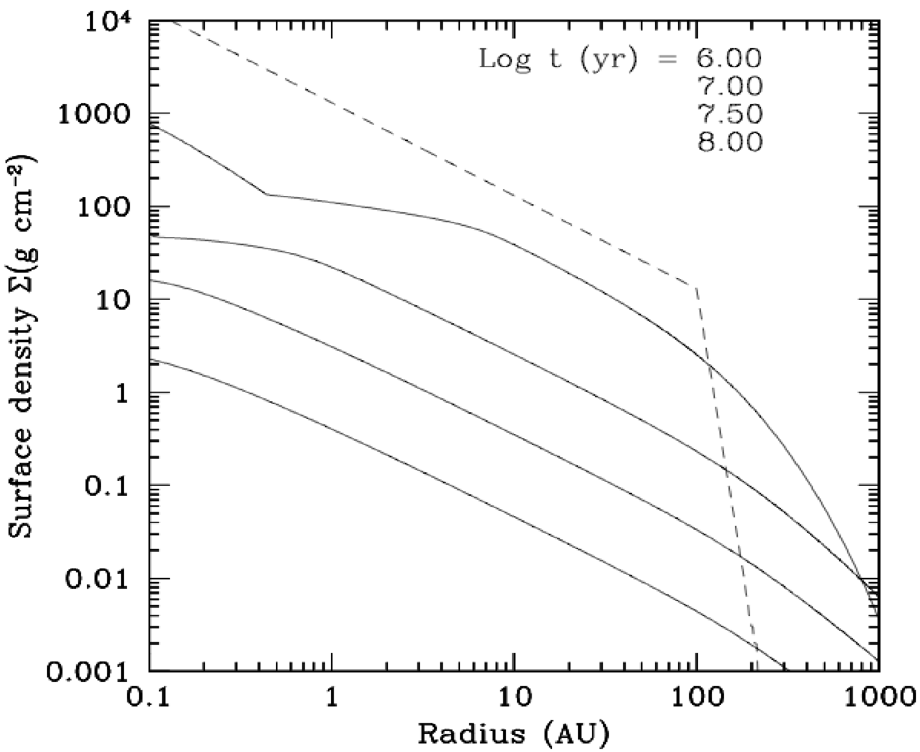
Gas dispersal mechanisms

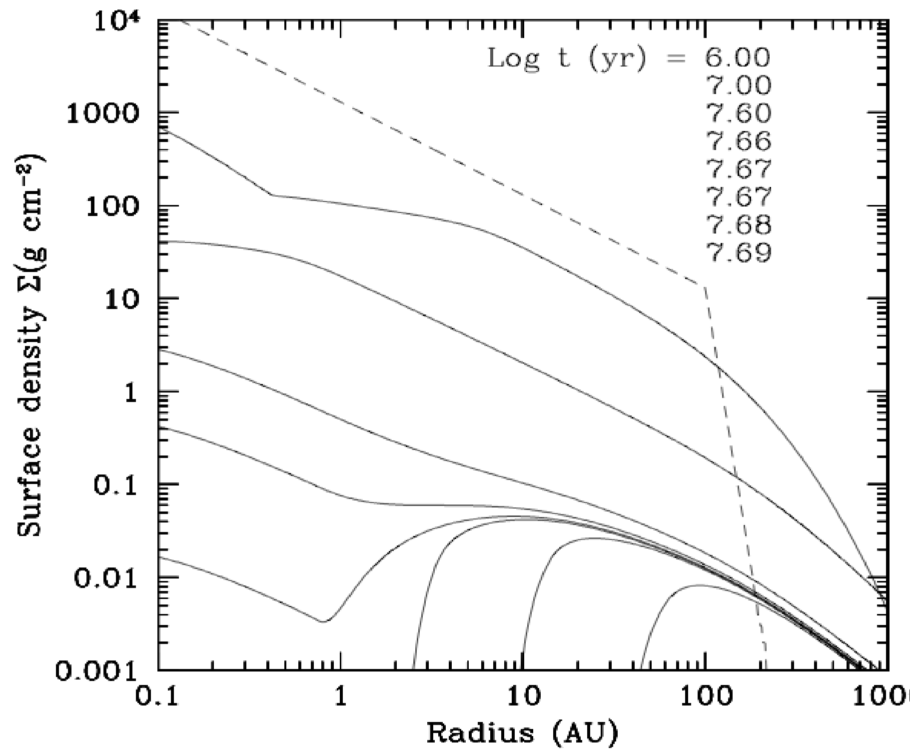
- Viscous evolution: re-distribution of angular momentum (yes, but...)
- Photoevaporation: “burning of” the disk atmosphere at larger radii
- Clearing by planets?
- A reminder: gas giant planet formation timescales are
  - Gravitational fragmentation (<< 10^6 years, Boss et al. 2006).
  - Core accretion 1-10 x10^6 yrs (Pollack et al. 1996; Lissauer et al. 2006).

Gas dispersal mechanisms

Viscous evolution of disk

(+ photo evaporation)





Gorti et al. (2009)

MAD

Gerrit van der Plas, 21/03/2013

1

MAD

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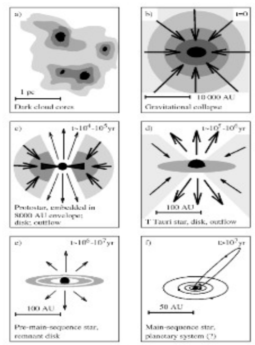
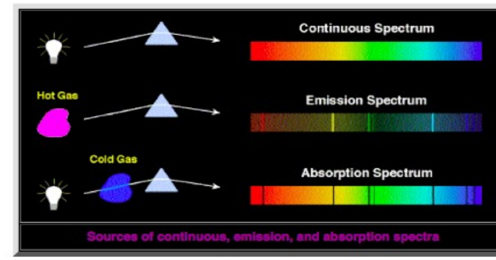


Hogerheijde (1998)

2

MAD

Gas emission



Continuous and discrete spectra

3

MAD

Gas Diagnostics

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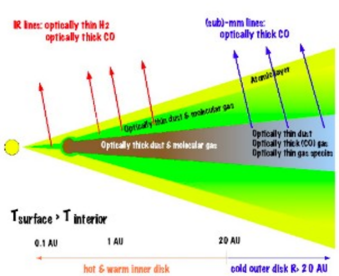

Carmona 2010

4

MAD

Toolbox: Spectroscopy

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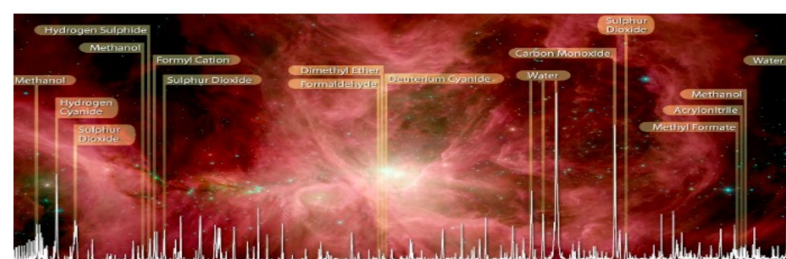
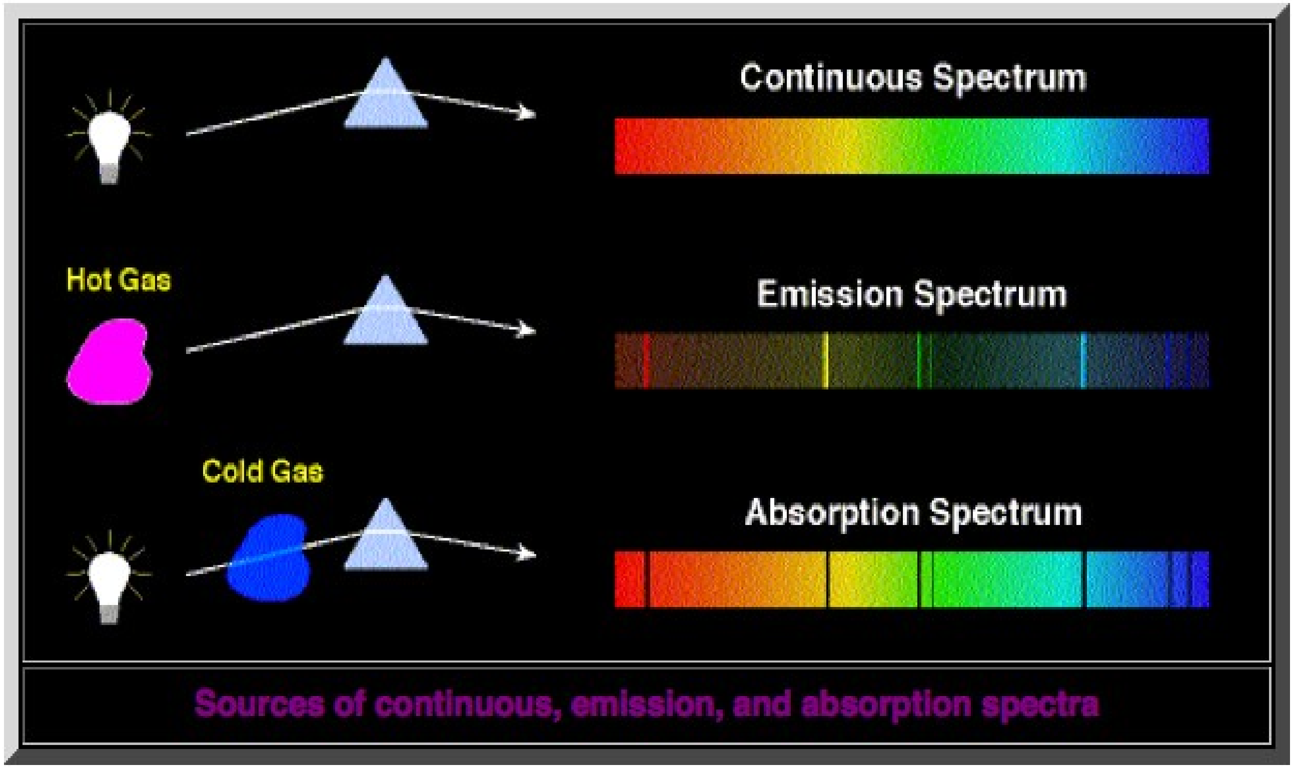


Gas emission



Continuous and discrete emission

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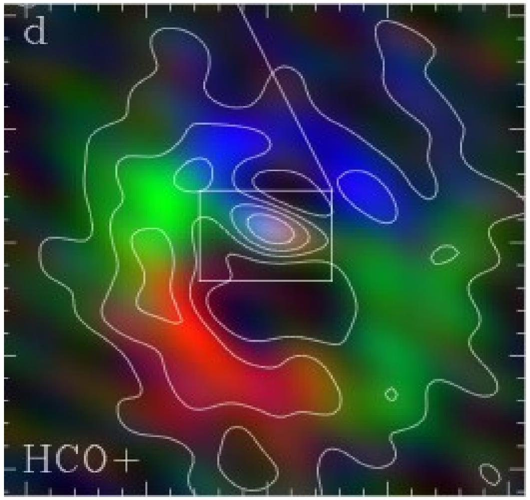
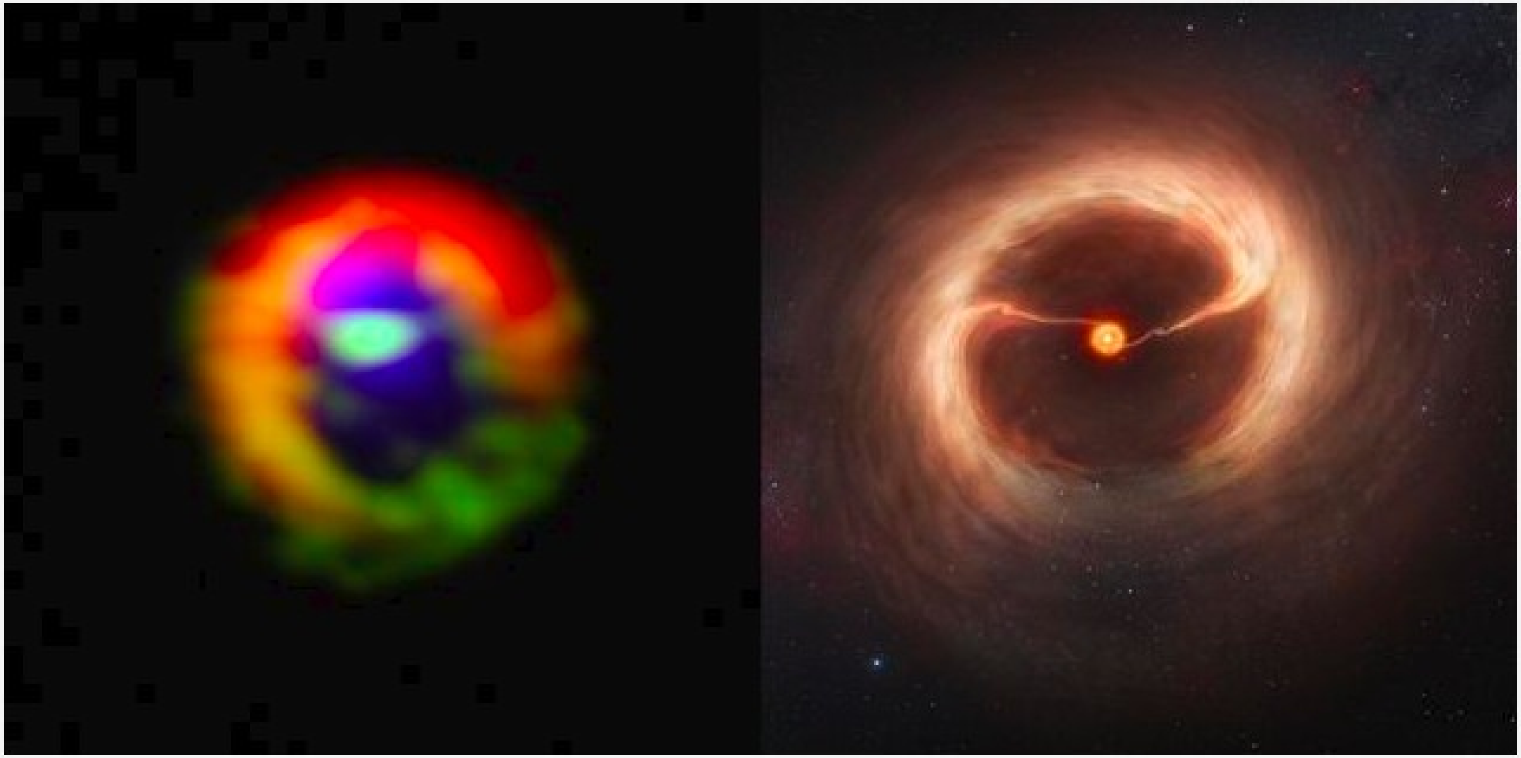
Bonus: HD 142527



Observations of gas flows inside a protoplanetary gap. HCO+ emission line



Casassus et al. (2013)

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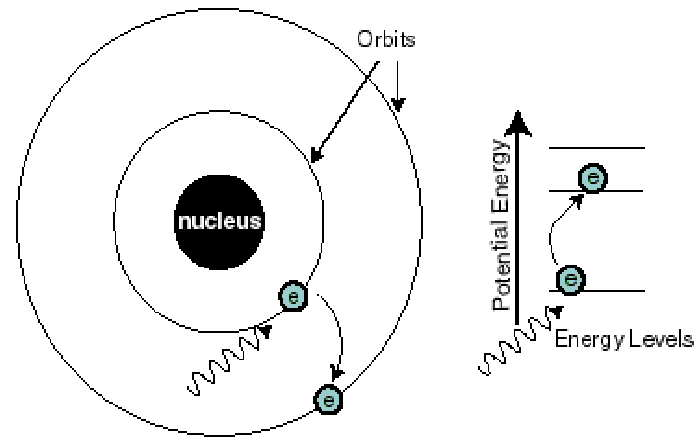
Gas emission

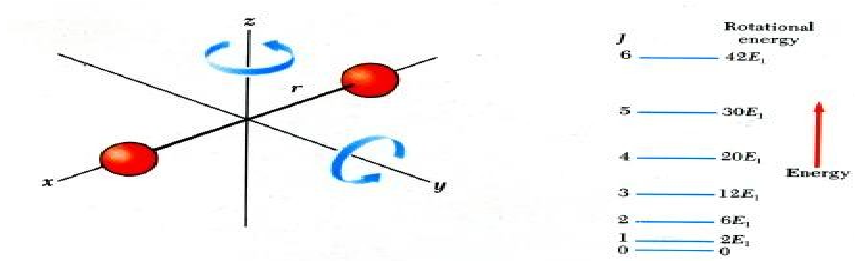
Atoms:

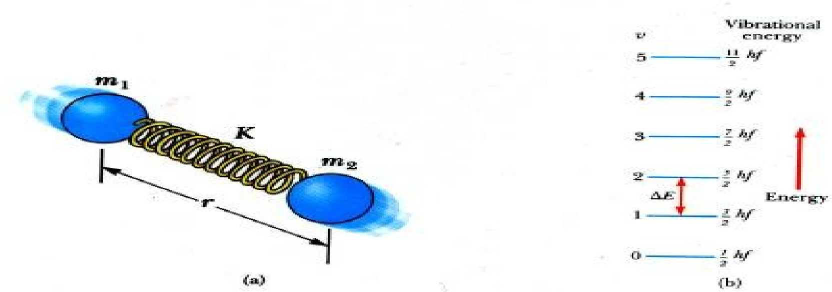
- Discrete energy states
- Distribution energy states = f(T)



Molecules:

- Discrete energy states
- Distribution energy states = f(T)
- **Rotation**, **vibration**, electronic state and electron spin state





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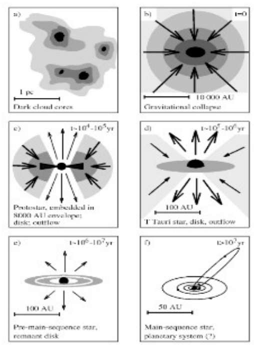
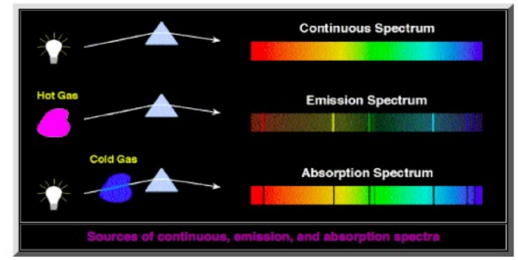


Hogerheijde (1998)

2

Gas emission



Continuous and discrete spectra

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3

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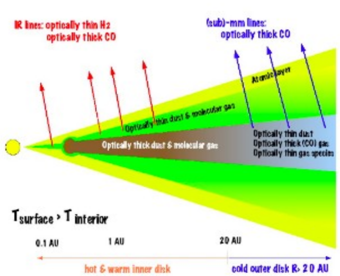

Carmona 2010

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4

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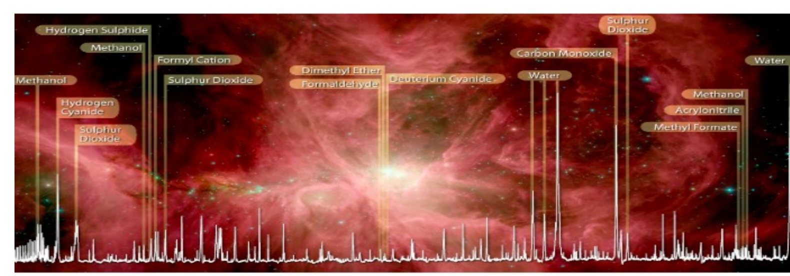

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Gas Diagnostics

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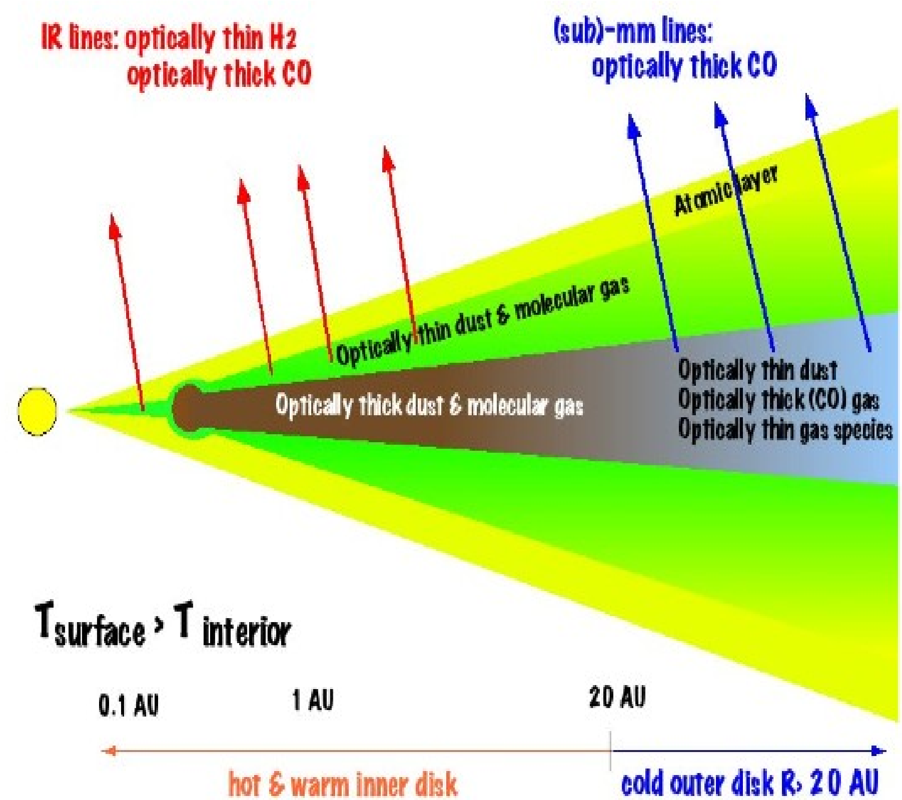
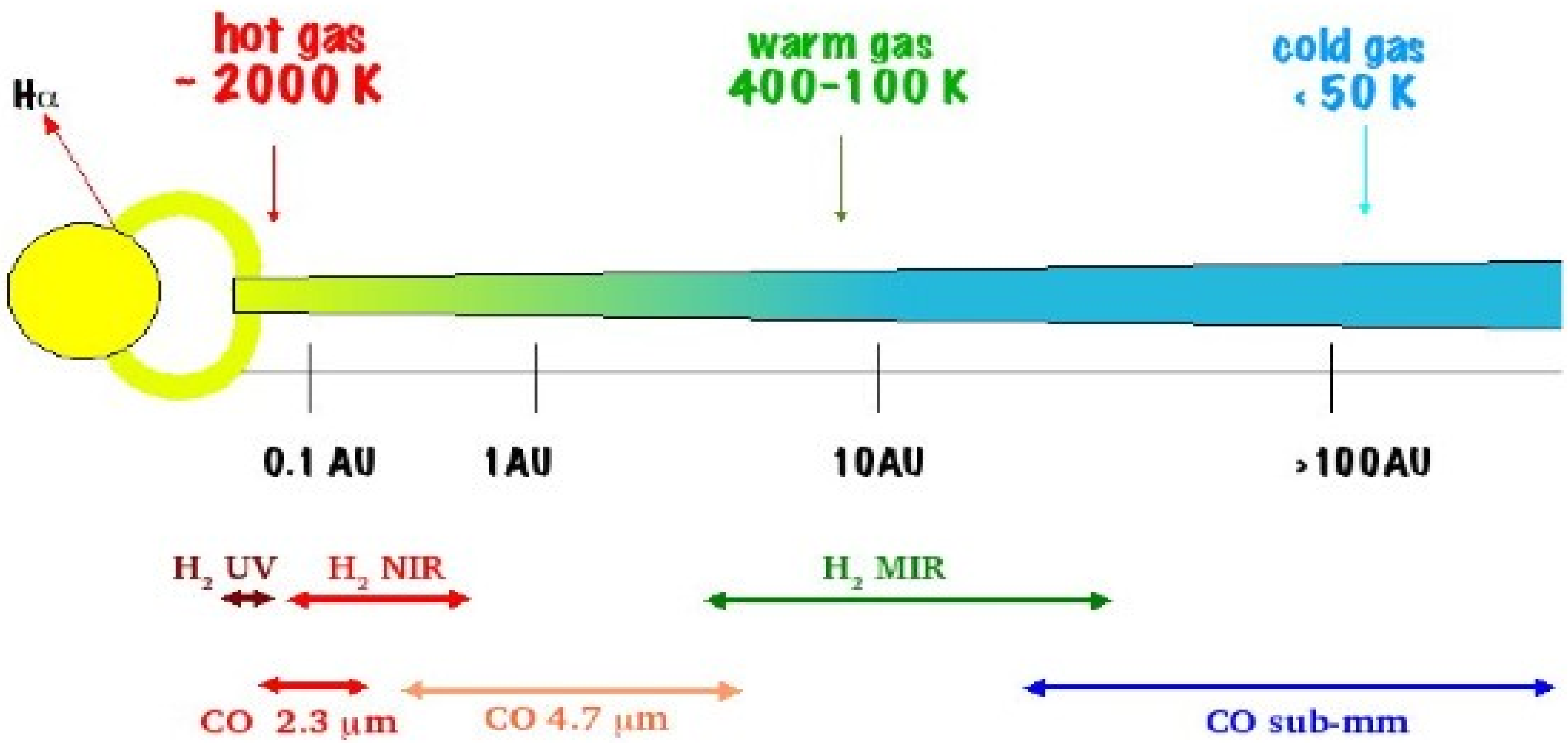
(= measure of transparency)



Carmona 2010

Gas Diagnostics



Carmona 2010

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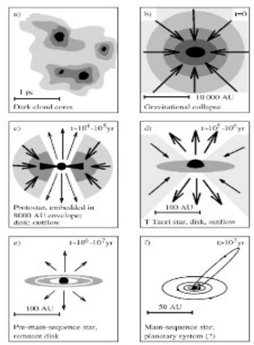

Hogerheijde (1998)

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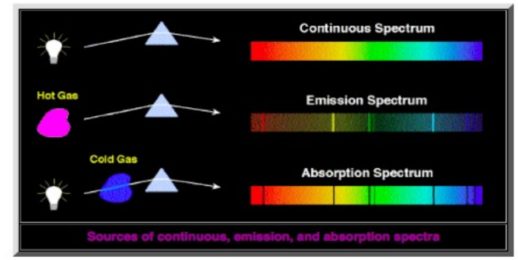
2

Gas emission



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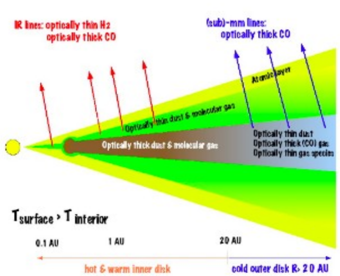

Carmona 2010

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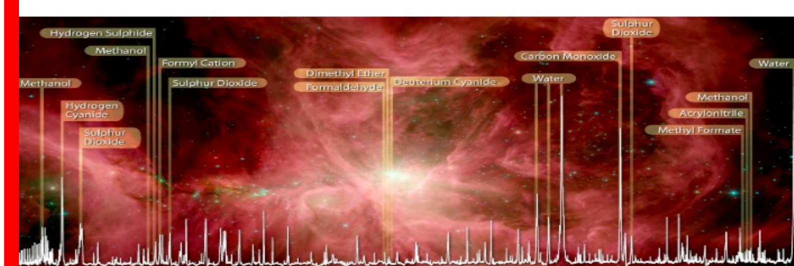

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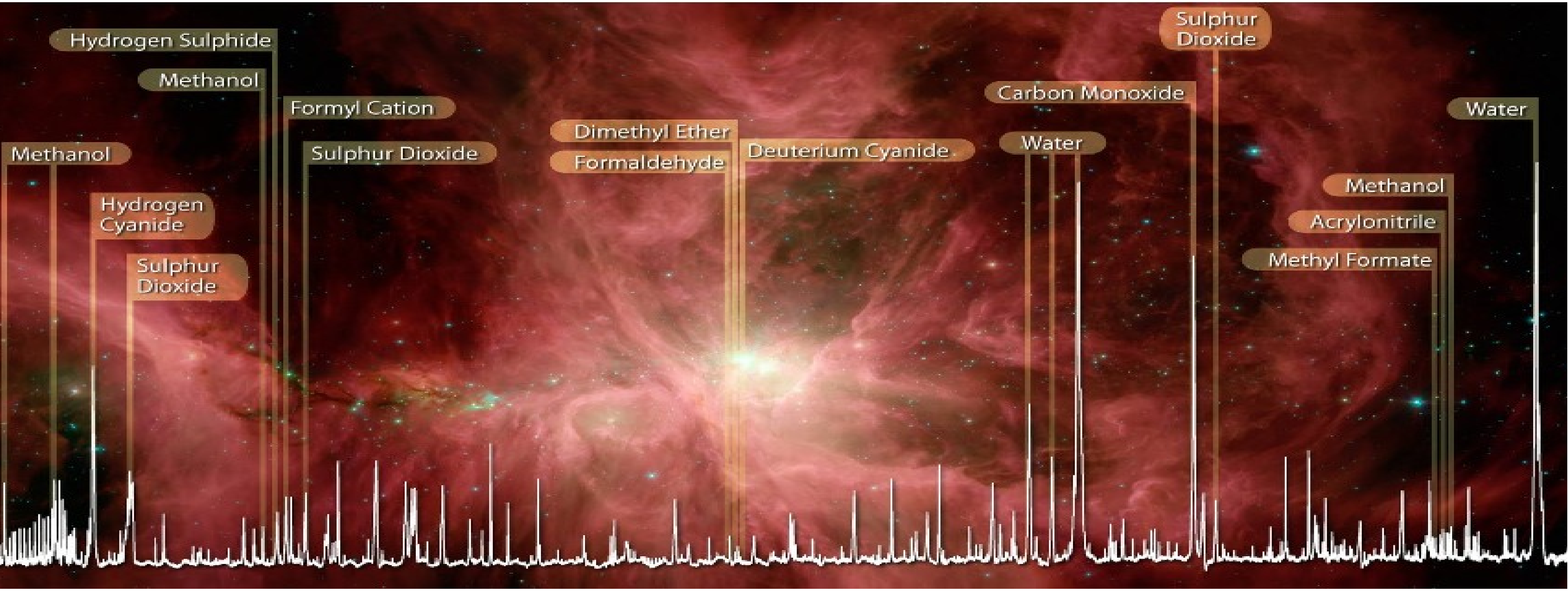


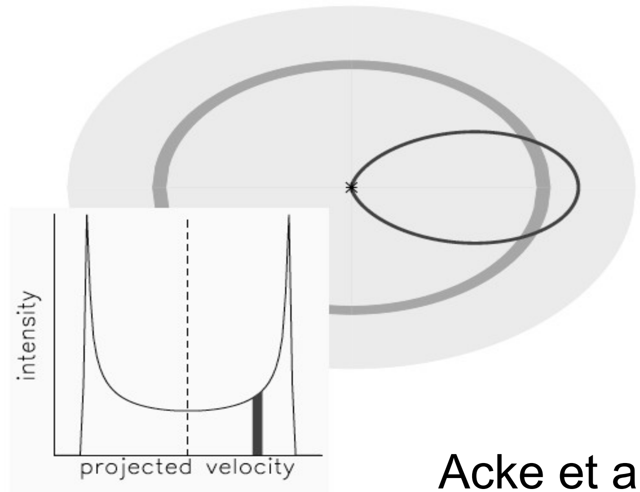
Line profiles

- Keplerian motion (3d law, circular orbits)

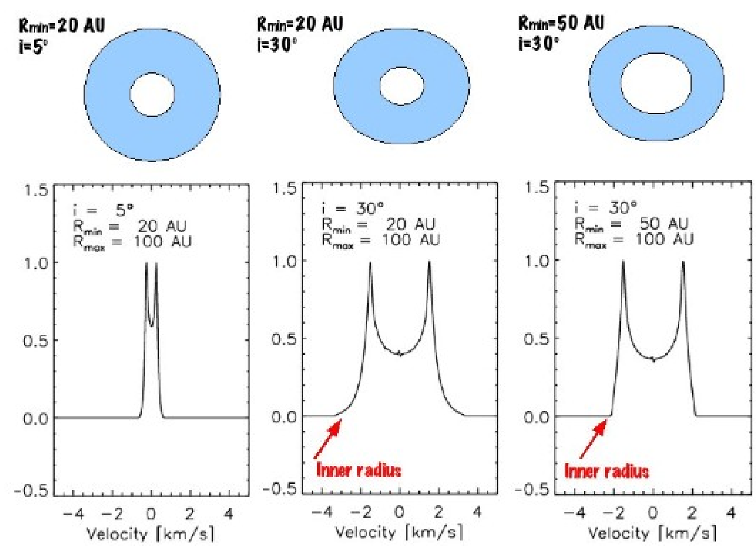
$$\frac{4\pi^2}{T^2} = \frac{GM}{R^3}$$

- Velocity function of distance from star and stellar mass

- Projected velocity (line-of-sight) → disk inclination



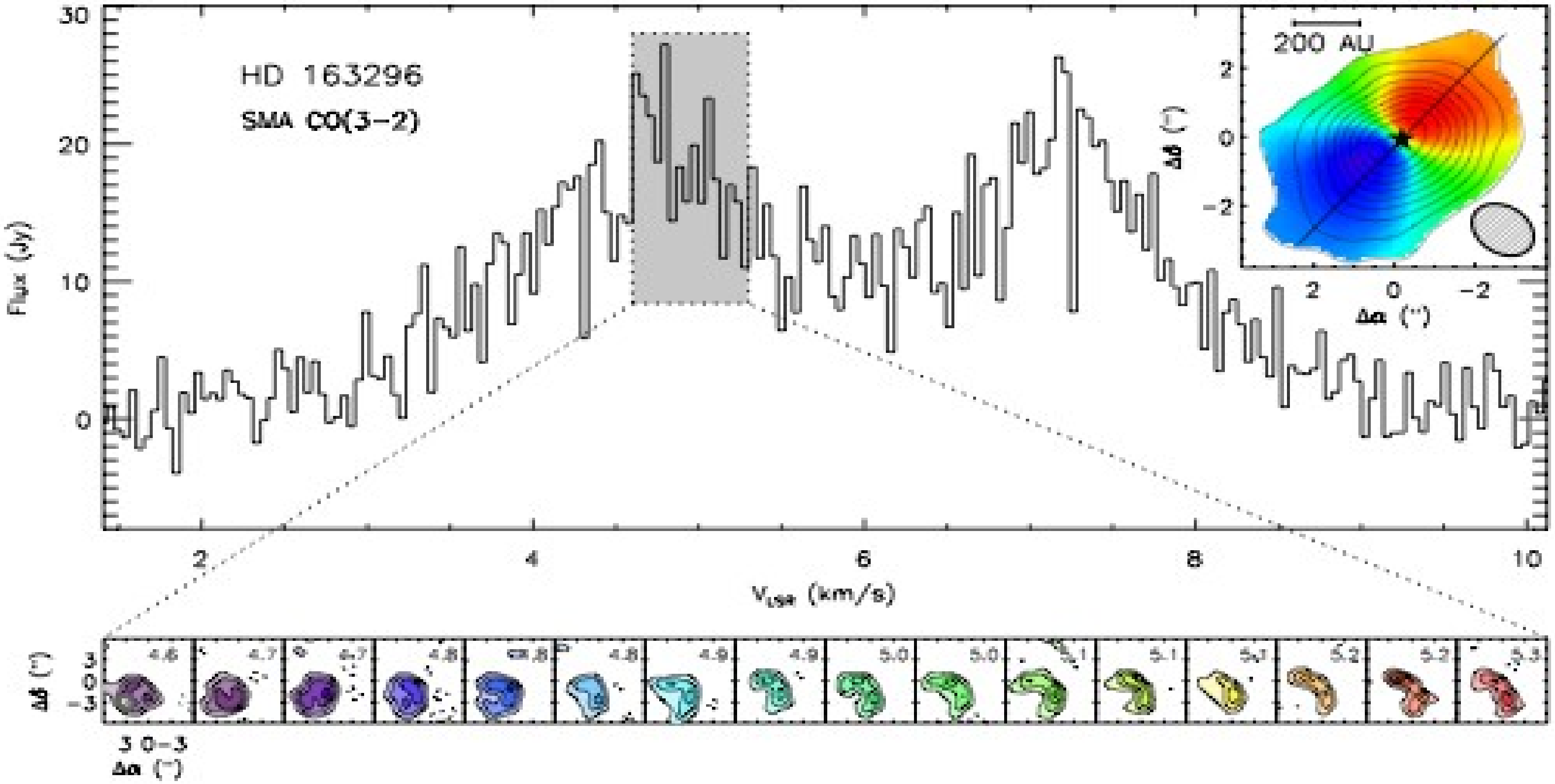
Acke et al. 2005



Carmona 2010

Line profile example

- HD 163296 CO J=3-2 with SMA: Characterizing Turbulence



Hughes et al. 2011

Rotational diagram

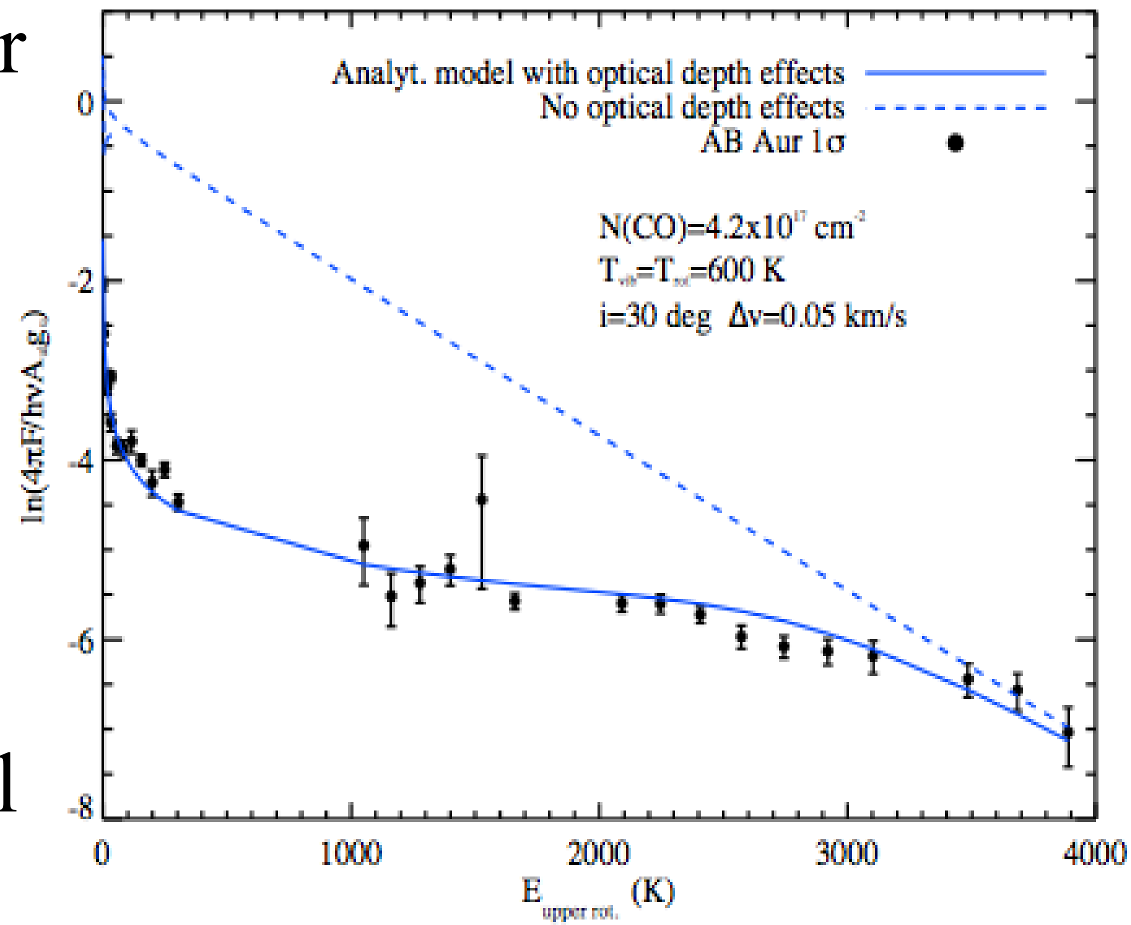
- The energy levels within an atom/molecule are populated according to the local excitation conditions (temperature, density, radiation field)
- Under certain assumptions (LTE, single temperature, optically thin), one can easily get local excitation conditions
- Keep in mind: where is emission coming from?

$$\frac{N^{i+1}}{N^i} = \frac{Z^{i+1}}{Z^i} \frac{2}{n_e h^3} (2\pi m_e kT)^{3/2} e^{-\frac{\chi_i}{kT}}.$$

$$\frac{N_j}{N_i} = \frac{g_j}{g_i} \exp\left[-(E_j - E_i)/kT_{ex}\right]$$

Rotational diagram example

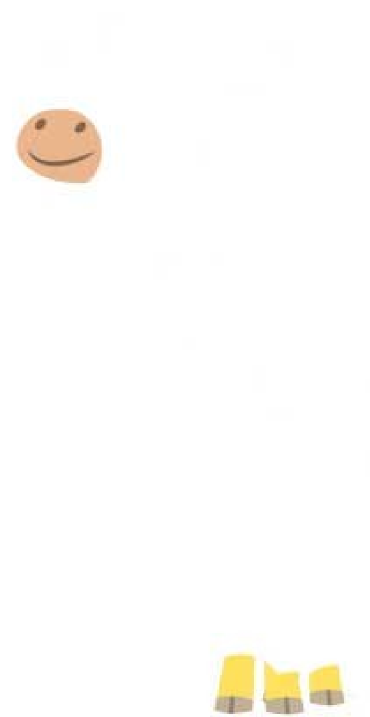
- CO lines from AB Aur (ro-vibrational)
- Assumptions: single temperature LTE, with/without optical depth
- Note deviation from straight line → optical depth effect



Thi et al. 2013

Quiz

Quiz



Quiz

Gerrit van der Plas, 21/03/2013

Quiz

Gerrit van der Plas, 21/03/2013

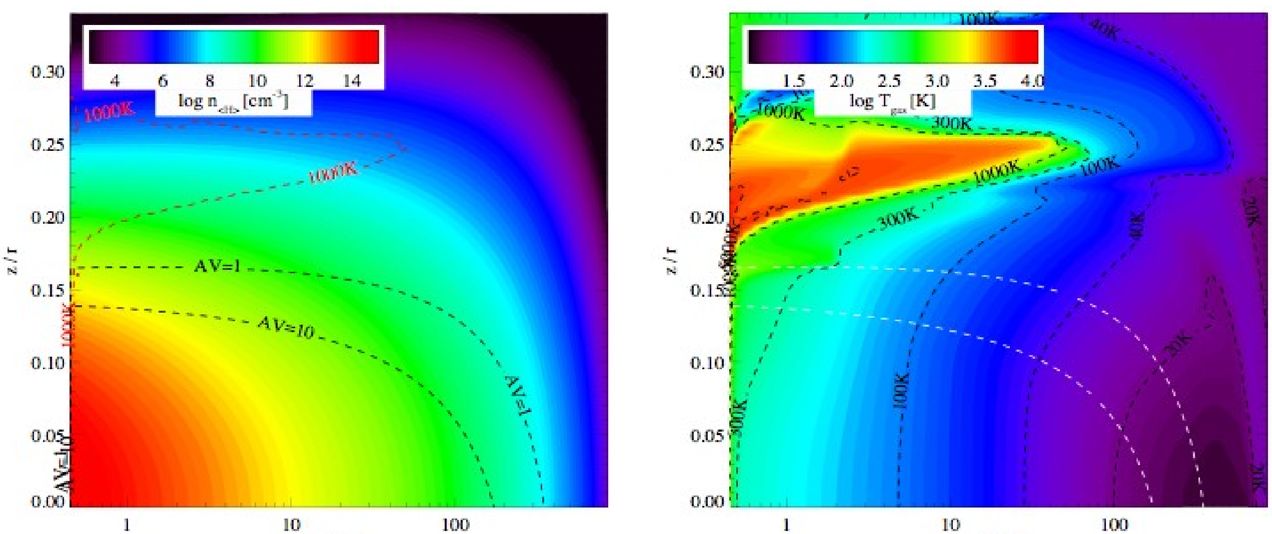
1 model to combine them all

1 model to combine them all

- Studying 1 tracer at a time introduces many degeneracies
- These can be lifted by using more constraints (observations)
- This is not easy (chemical network, dust+gas treatment, computational power, ….)
- State of the art (at the moment) is to smartly combine models for the disk dust and gas structure.

Example: HD 163296

Species	λ [μm]	ν [GHz]	"low UV" model	"high UV" model	Fully mixed model	Power-law	Observed Flux
OI	63.18	4745.05	200.6	222.0	191.4	170.3	193.1 (58.2)
OI	145.52	2060.15	6.29	7.33	5.39	4.59	< 8.5
CII	157.74	1900.55	8.32	8.40	11.2	9.98	–
p-H_2O $3_{22} \rightarrow 2_{11}$	89.99	3331.40	1.22	1.68	1.20	0.353	< 9.4
o-H_2O $2_{12} \rightarrow 1_{01}$	179.52	1669.97	4.40	4.19	2.43	3.94	< 14.5
o-H_2O $2_{21} \rightarrow 2_{12}$	180.49	1661.64	0.847	0.993	0.618	0.243	< 16.2
o-H_2O $4_{32} \rightarrow 3_{12}$	78.74	3810.01	2.33	2.94	2.20	0.840	< 15.0
o-H_2 S(1)	17.03	17603.78	1.15	1.59	1.15	0.572	< 28
OH	79.11	3792.19	4.59	6.31	5.40	2.71	< 17.0
OH	79.18	3788.84	4.78	6.54	5.59	2.82	< 17.0
CO J=36-35	72.85	4115.20	0.335	0.489	0.423	0.132	< 11.6
CO J=33-32	79.36	3777.63	0.497	0.704	0.578	0.197	< 22.8
CO J=29-28	90.16	3325.12	0.763	1.03	0.732	0.311	< 11.1
CO J=18-17	144.78	2070.68	1.91	2.31	1.49	0.851	< 13.1
CO J=3-2	866.96	345.80	1.26	1.27	1.22	1.49	1.65 (0.39)
CO J=2-1	1300.40	230.54	0.401	0.401	0.397	0.464	0.379 (0.118)
^{13}CO J=1-0	2720.41	110.20	0.0122	0.0115	0.0120	0.0127	0.0124 (0.007)



Tilling et al. 2012

HD 163296

HD 163296: 2 faces of the disk + model

Data

I. Gregorio, F. Menard, et al. in prep.

Model

What I want you to remember:

- Gas plays a large role in disk and planet formation + evolution
- (most) gas tracers do not trace the whole disk. Always ask yourself which physical conditions you are probing
- Gas observations + interpretation have a bright future with increasingly powerful telescopes and analysis methods