Gas and ice during low-mass star formation

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NWO

Sterrewacht Leiden

Today's modeling question

- During star formation, material accretes from a molecular cloud onto a growing circumstellar disk. How do the abundances of the gaseous and solid forms of CO, H_2CO and H_2O change in this process?

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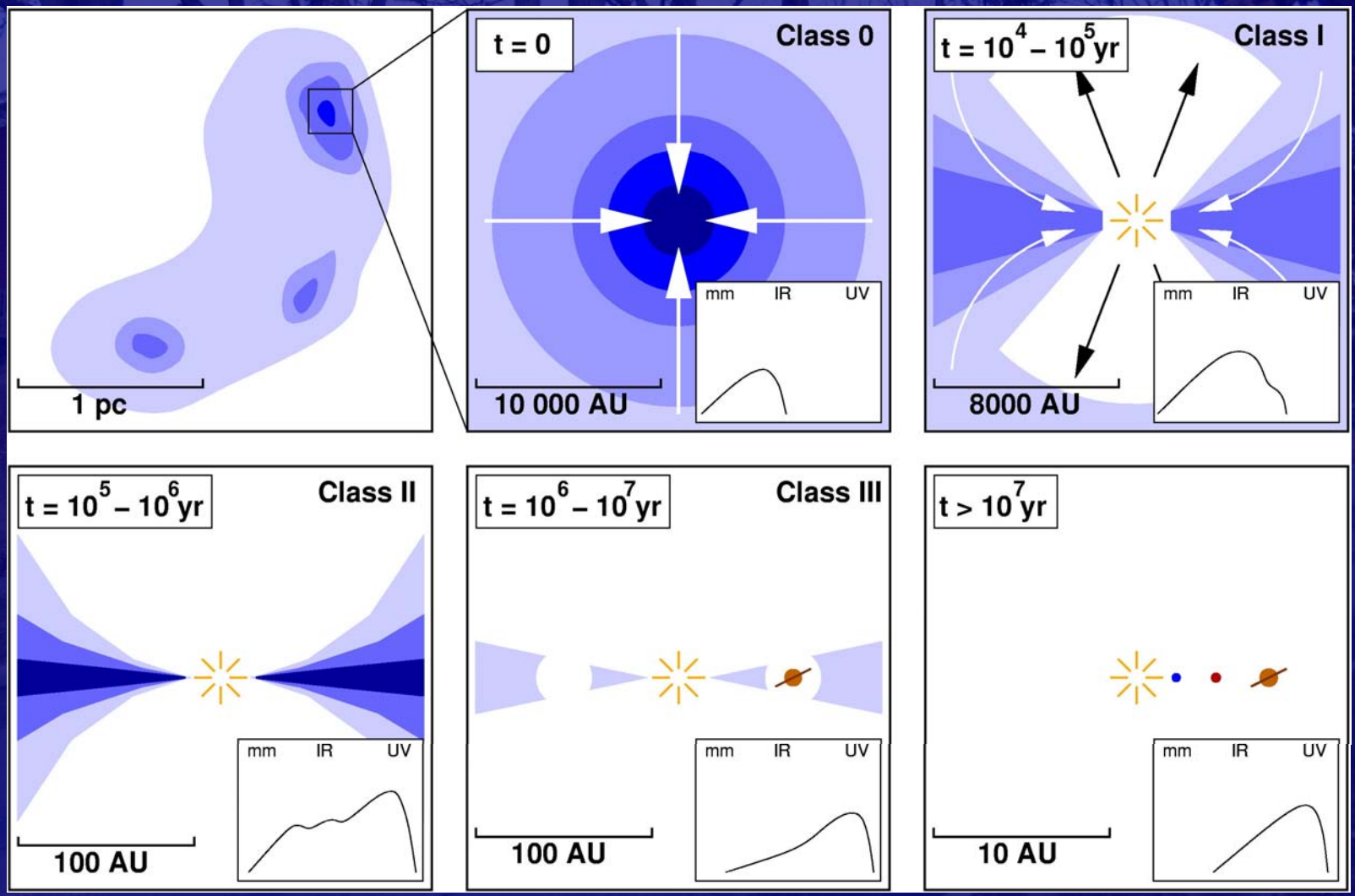
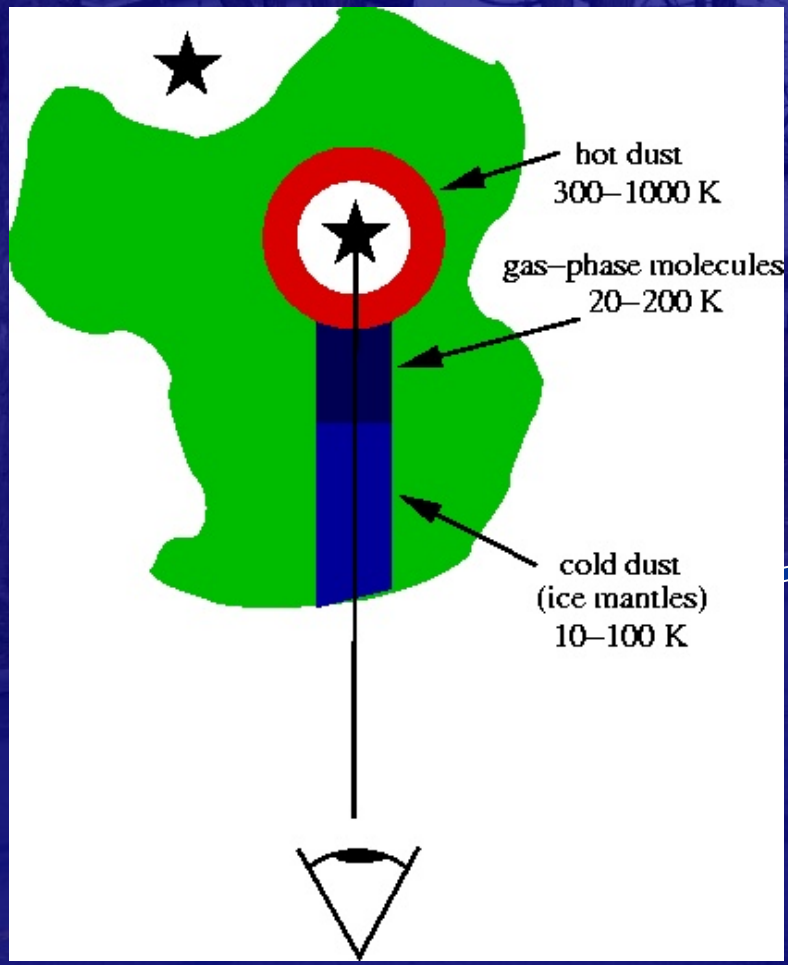
Star and planet formation

(low-mass stars)

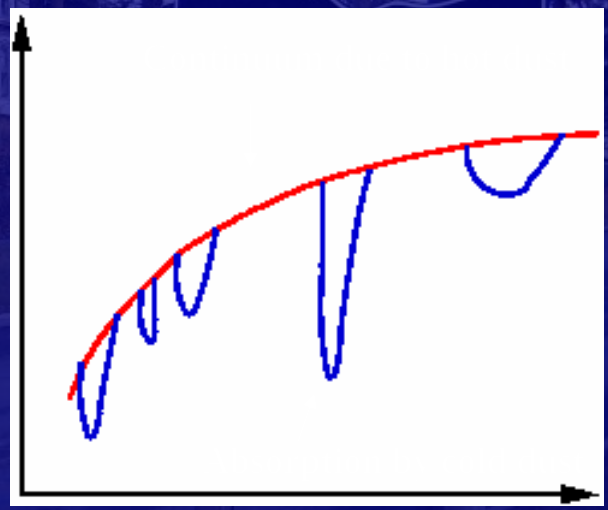


Jonkheid et al. 2006

Infrared observations



Flux

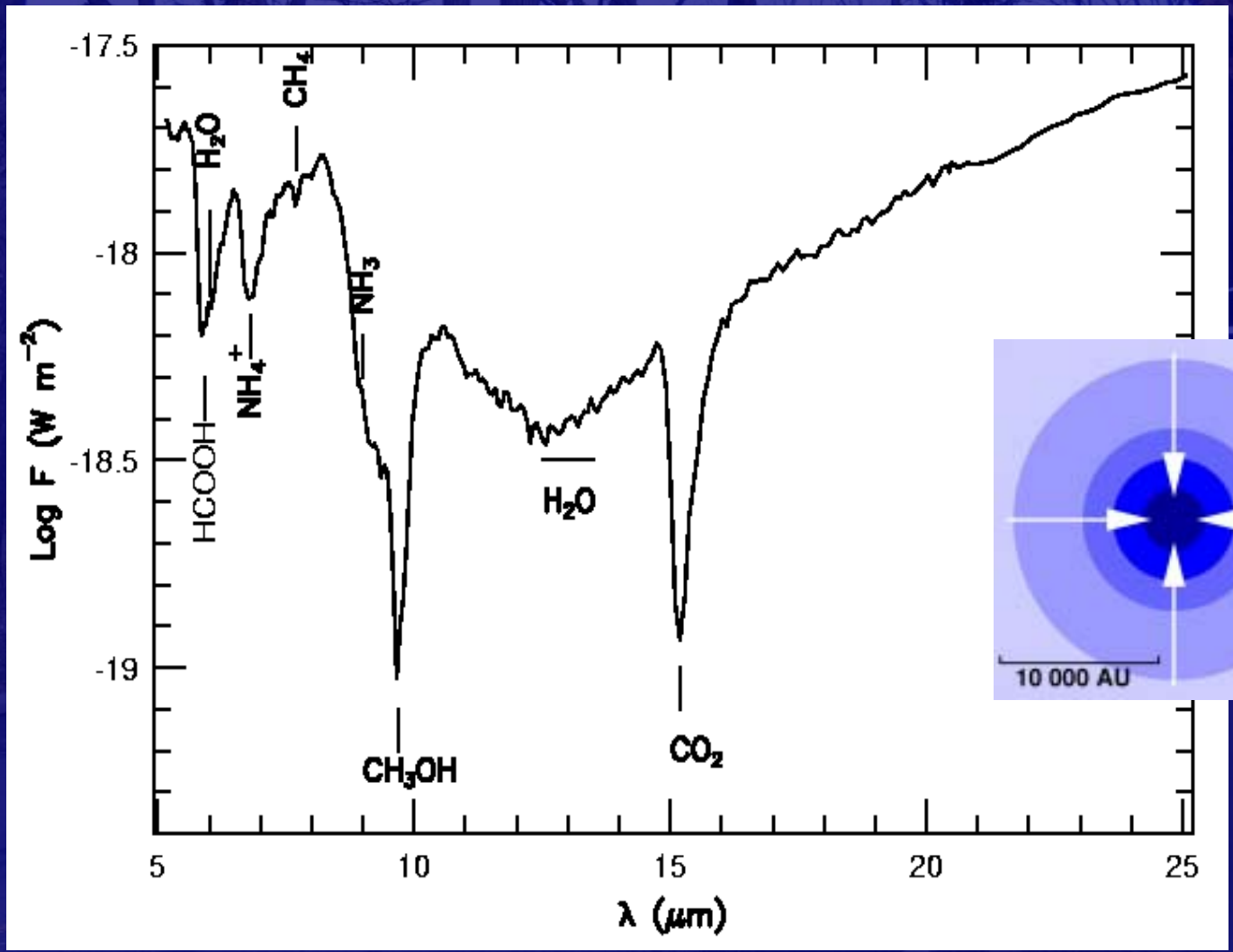


Wavelength

Vibrational transitions of various molecules

Ices: observational evidence

(embedded source)



Boogert et al. 2008

Chemistry: gas and ice

- Chemical composition of space: gas & silicate/carbonaceous dust
- Gases may freeze onto dust (adsorption), or evaporate once frozen (desorption)
- No liquids in space
- Gas/ice ratio depends on T, n, but note: kinetic process

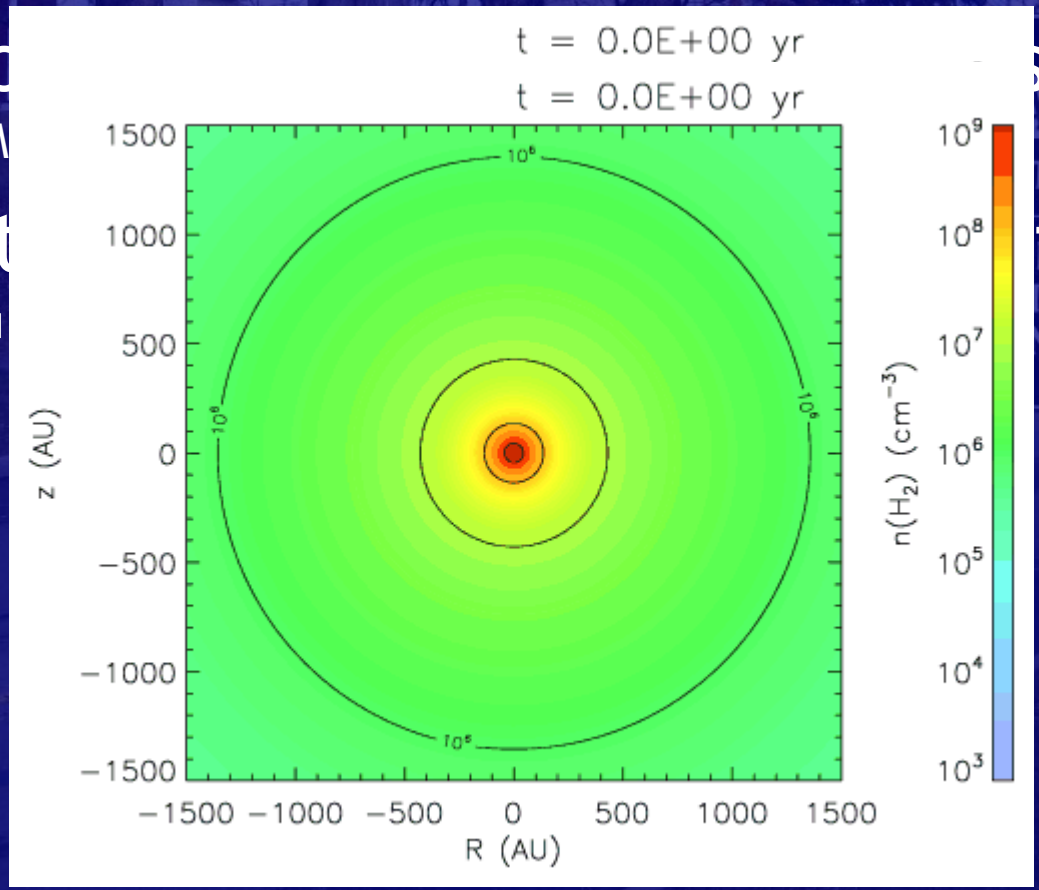
$$k_{ads} \propto n\, T^{0.5}\, m^{-0.5}$$

$$k_{des} \propto \exp(-E_b/kT)$$

Ice	E_b/k (K)
CO	960
H_2CO	1760
H_2O	4820

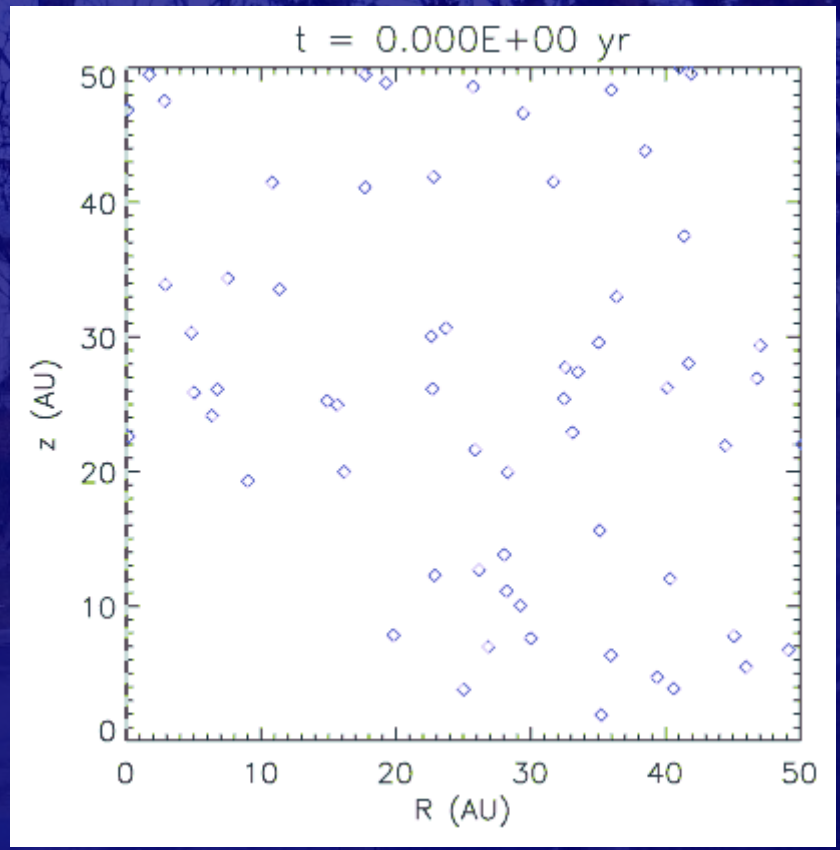
Star formation details

- Spherical inside-out collapse starting from *singular isothermal sphere*
  (Shu 1977; see also Larson 1969, Penston 1969)
- Rotatic sk
  (Cassen & M
- Magnet ing
  (Galli & Shu



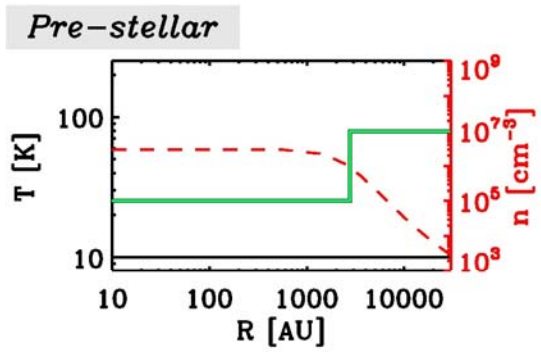
Disk formation details

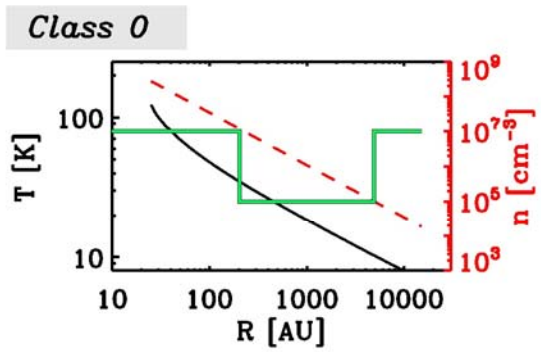
- Material accretes inside centrifugal radius:
  $R_{cen} \propto c_s\, t^3\, \Omega^2$
- Conservation of angular momentum pushes some material beyond R_{cen}

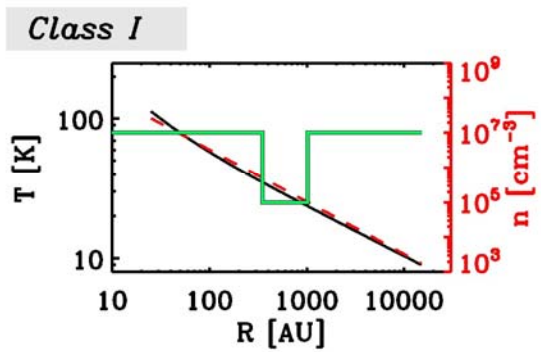


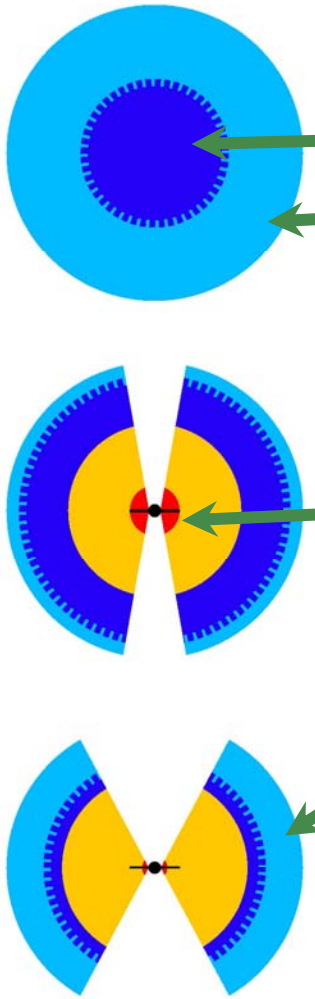
Missing link: transition from cloud to disk

Simple ice model: step abundance









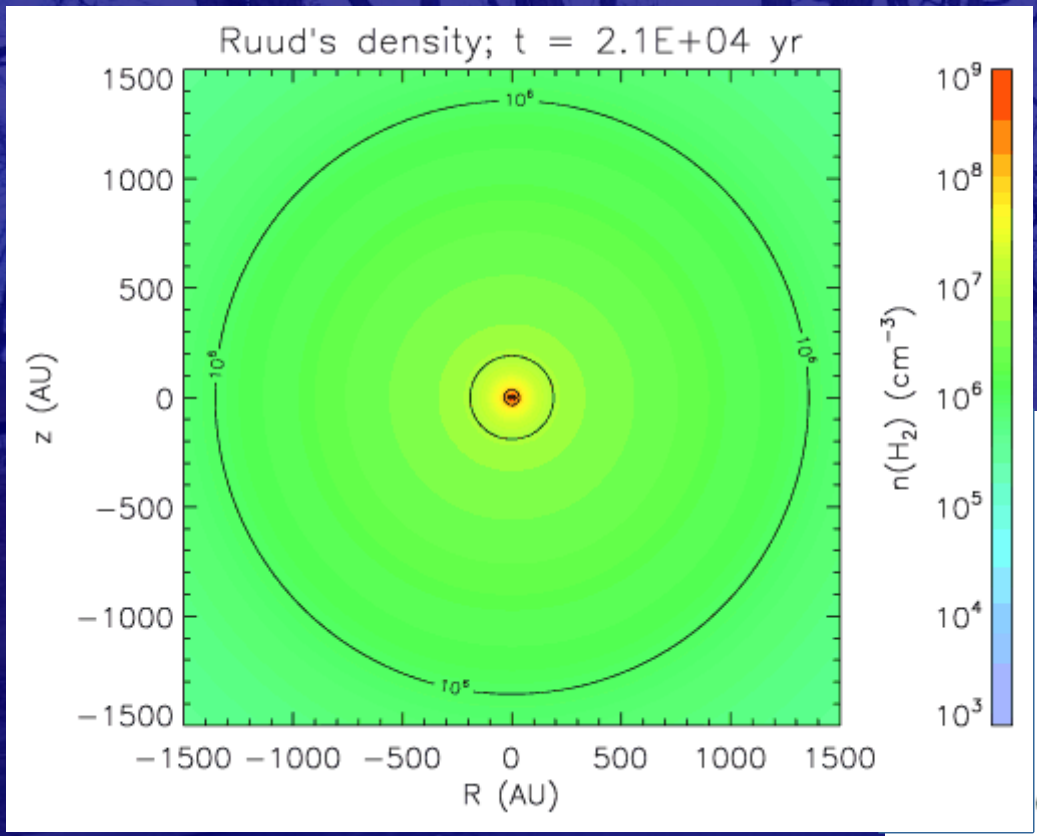
- Pre-stellar core
  - Low temperature
  - Ices in center
  - Gas at edge
- Protostellar core
  - Temp. gradient
  - Evaporation in center
  - Further out like pre-stellar stages
- Freeze-out zone smaller for class I than class 0

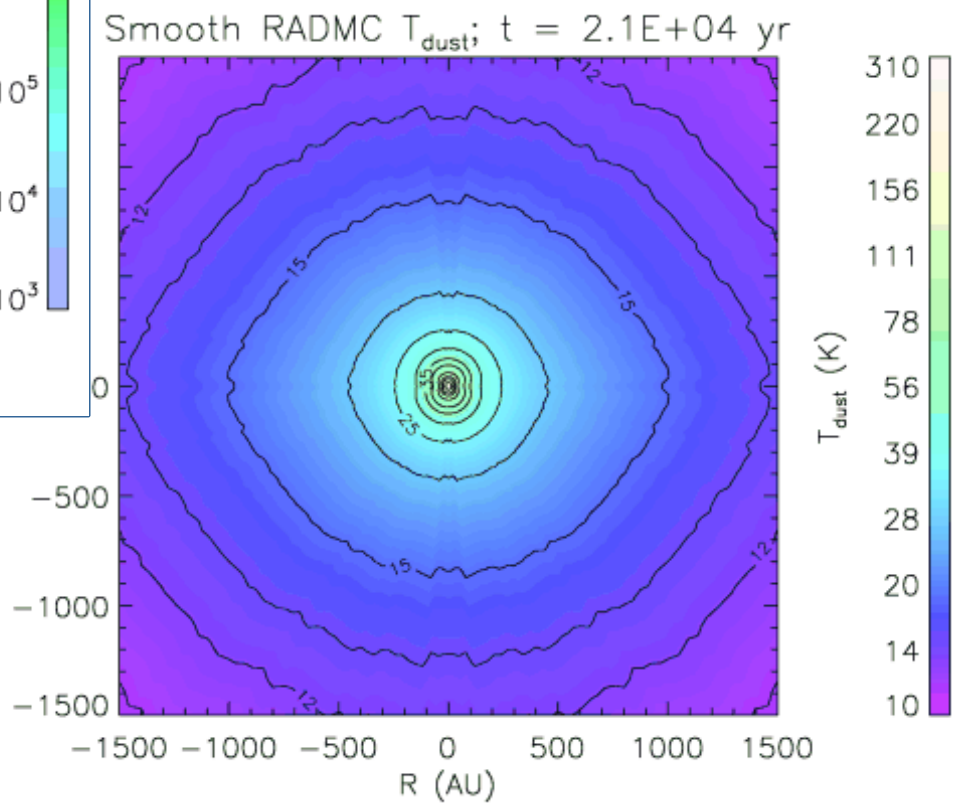
Jørgensen et al. 2005

Our model

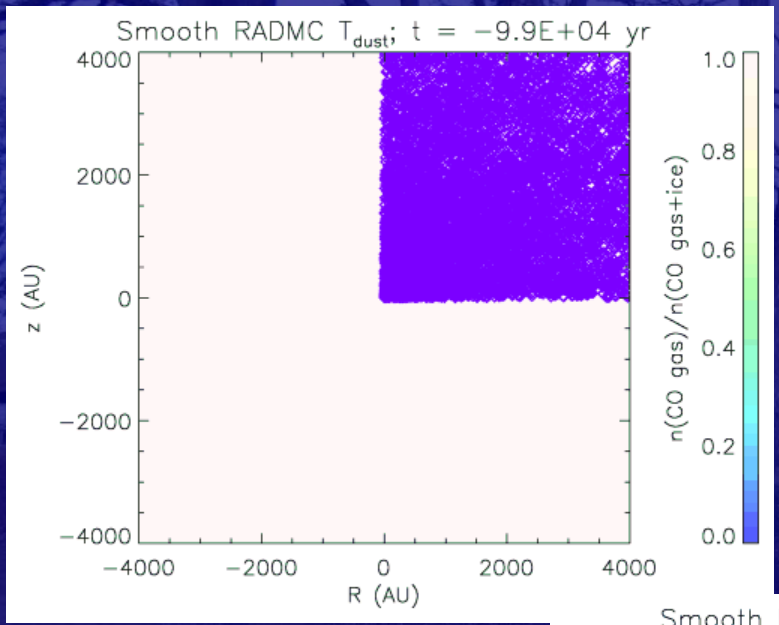
- Solve gas/ice in Lagrangian frame:
  - n, v from TSC84 and α disk model
  - T_{dust} from radiative transfer and set $T_{gas} = T_{dust}$
  - Infall trajectories from v → x, z, n and T as function of t
  - Add static pre-collapse phase

Density and temperature

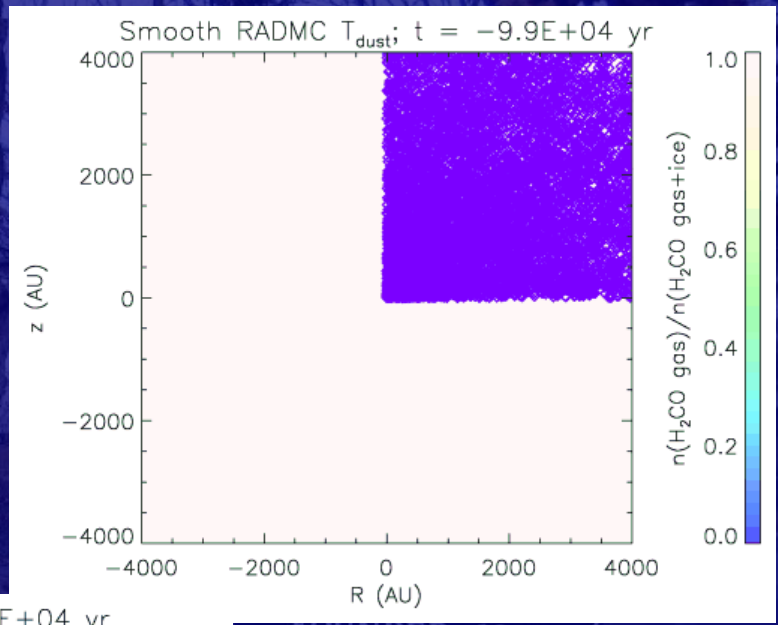




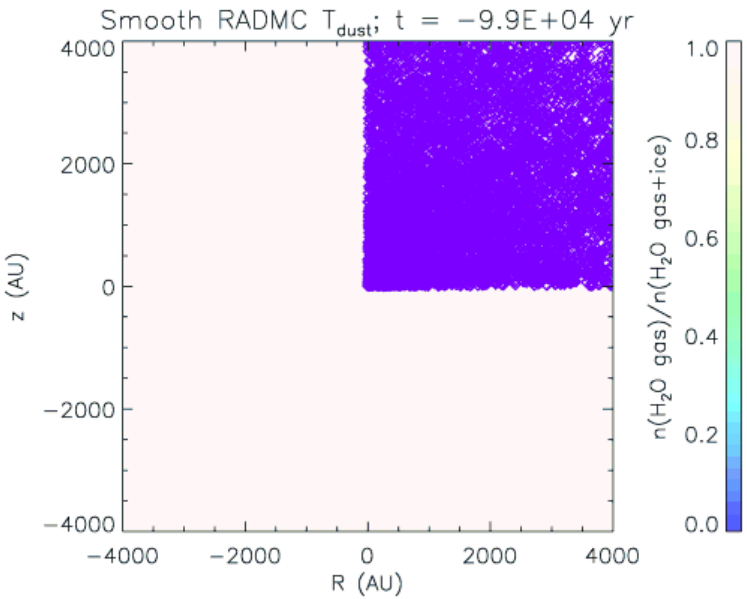
CO, H_2CO, H_2O



CO



H_2CO



H_2O

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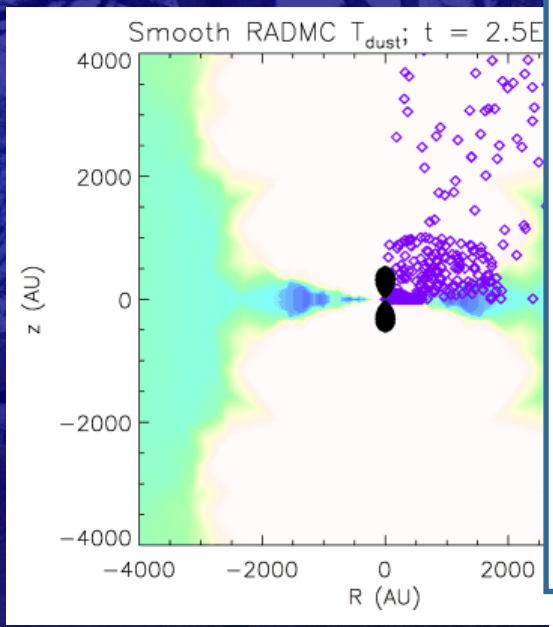
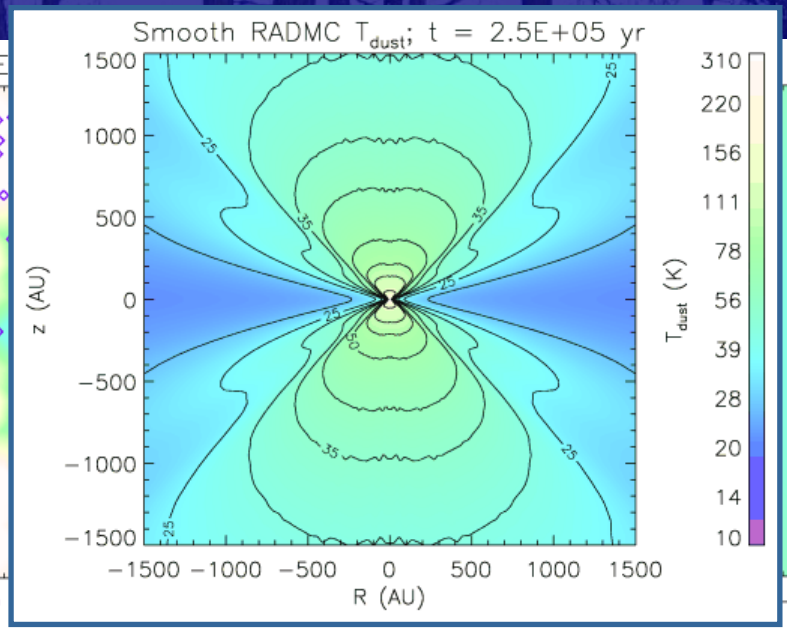
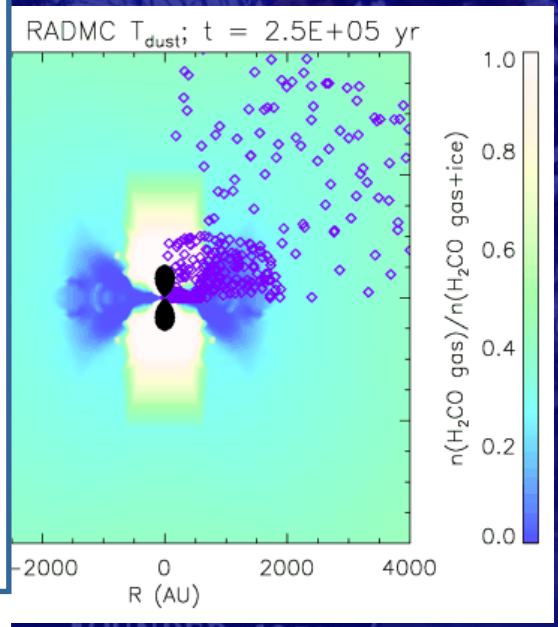
CO, H_2CO, H_2O

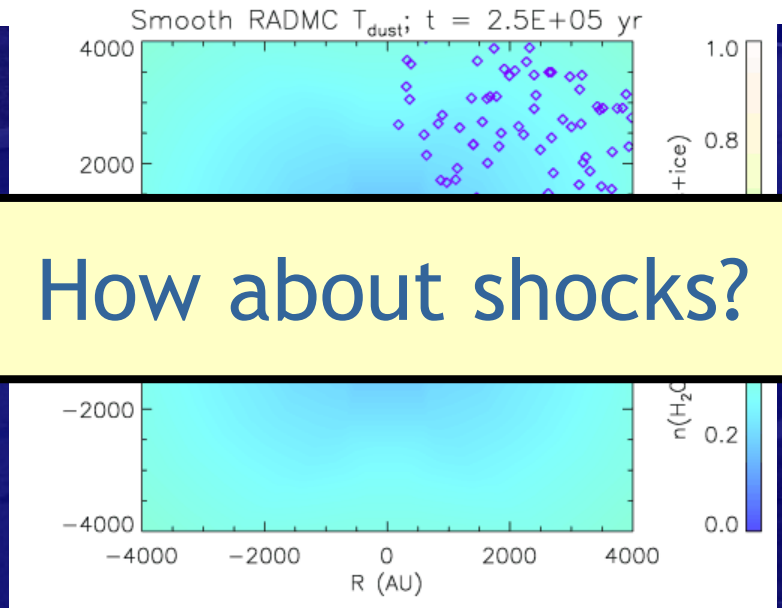


CO





H_2CO

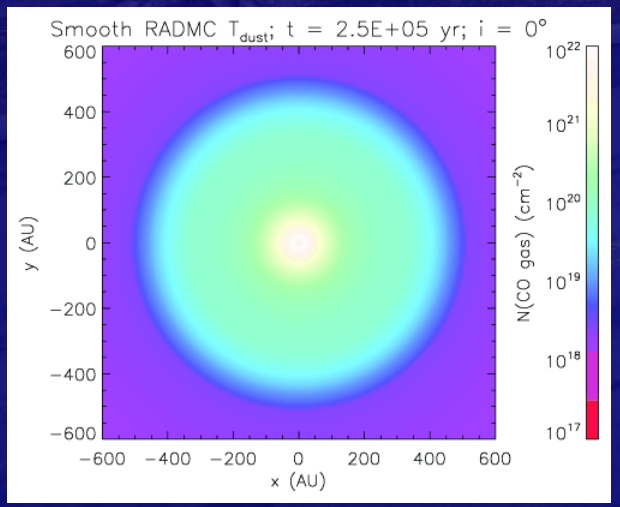


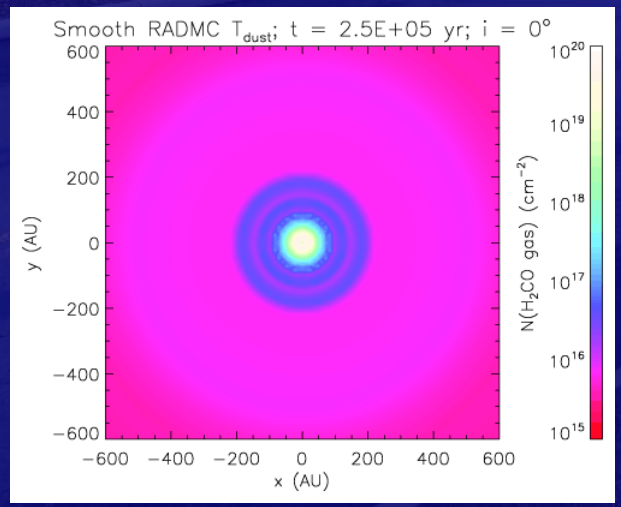
How about shocks?

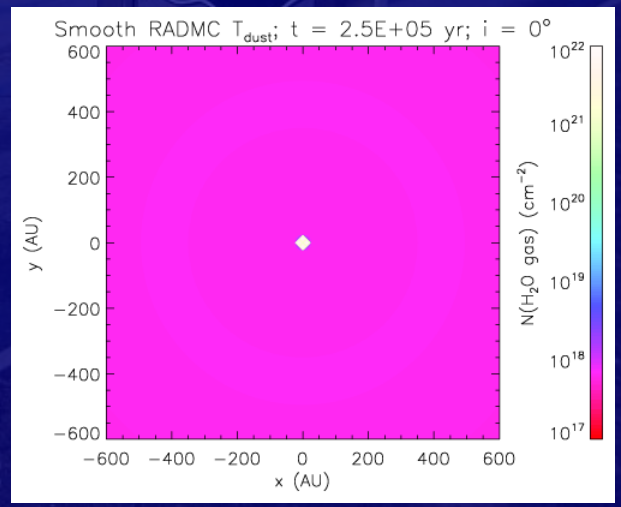
Models vs. obervations

- Observers see column densities, not volume densities
- Observations have finite resolution
  - JCMT: ~1000 AU @ 150 pc
  - ALMA: few AU @ 150 pc

CO H_2CO H_2O

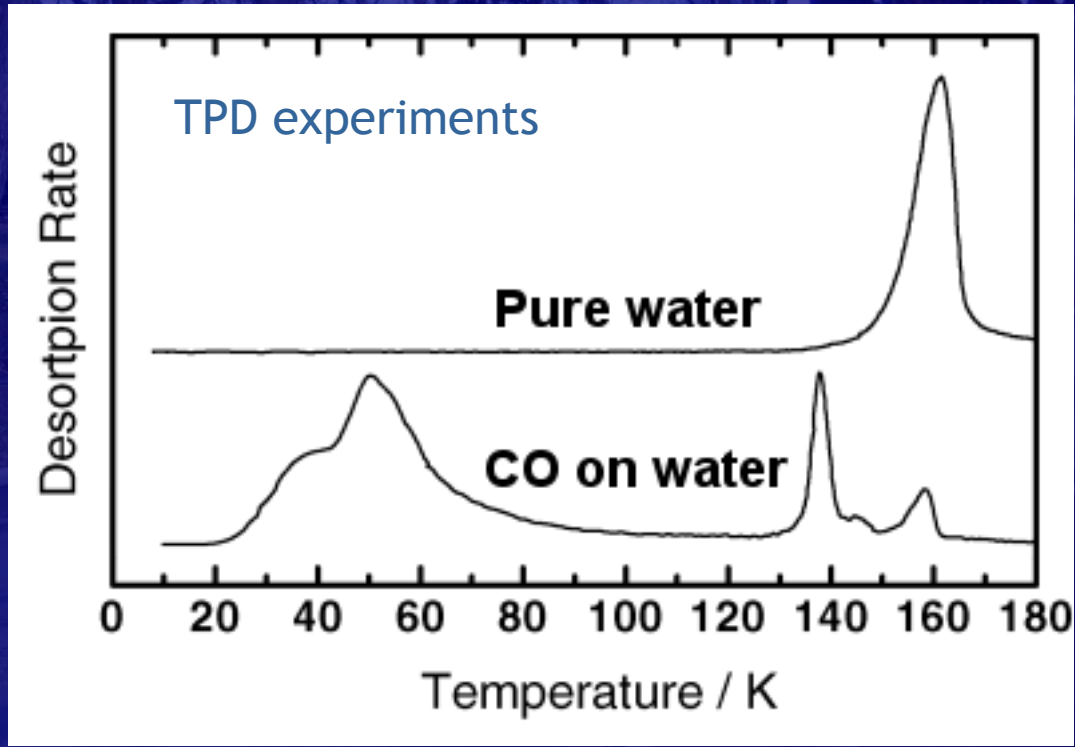






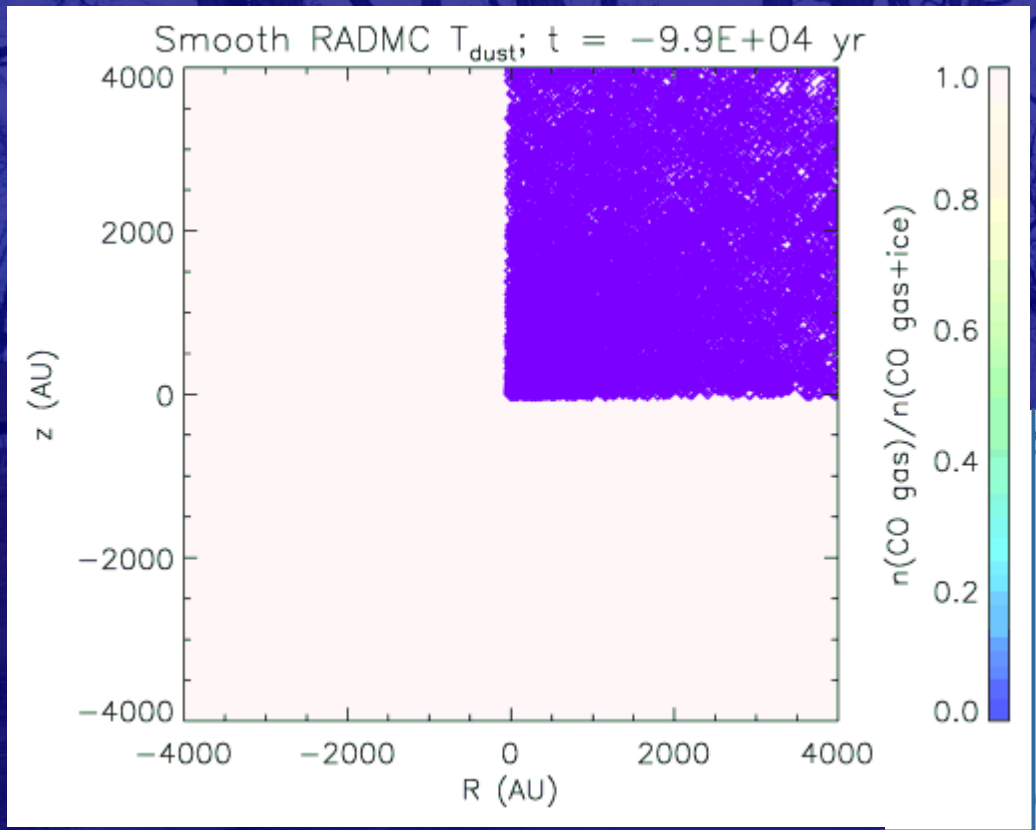
Ice mixtures

- H_2O most abundant ice → desorption of other ices depends on H_2O
- CO mixed with H_2O desorps in four steps
  - multilayer
  - monolayer
  - volcano
  - co-desorption
- Model with four flavours of CO ice



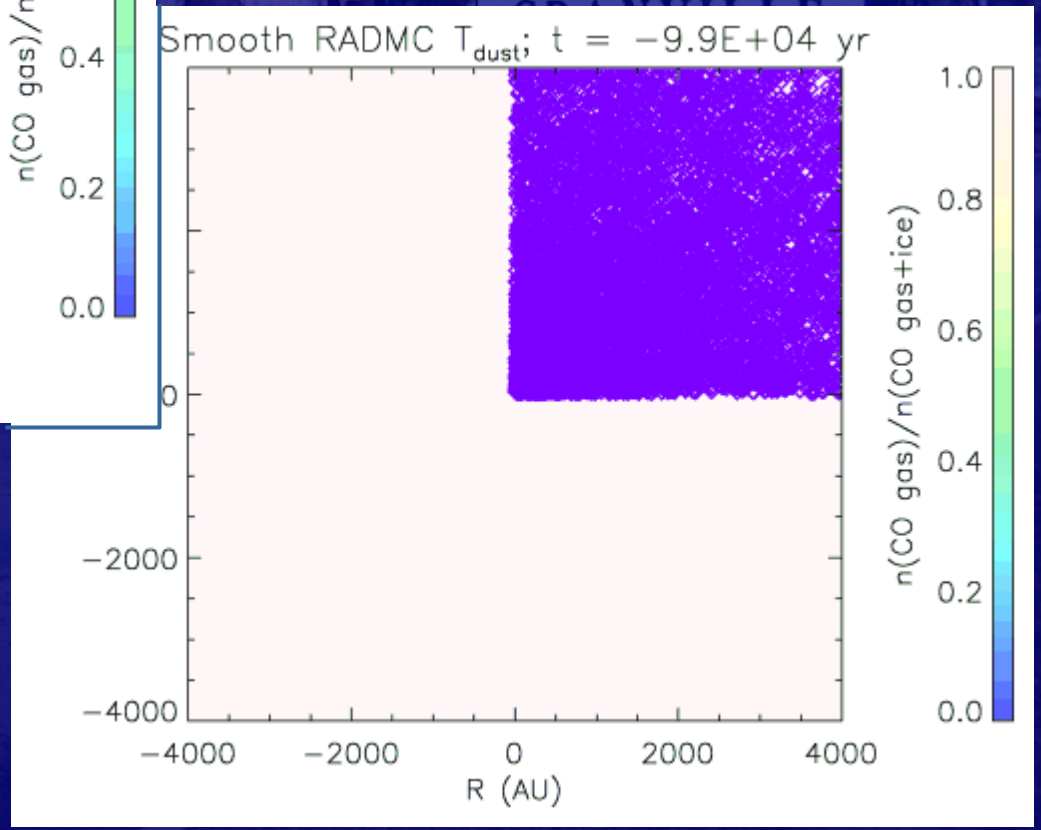
Collings et al. 2004, Viti et al. 2004

Density and temperature



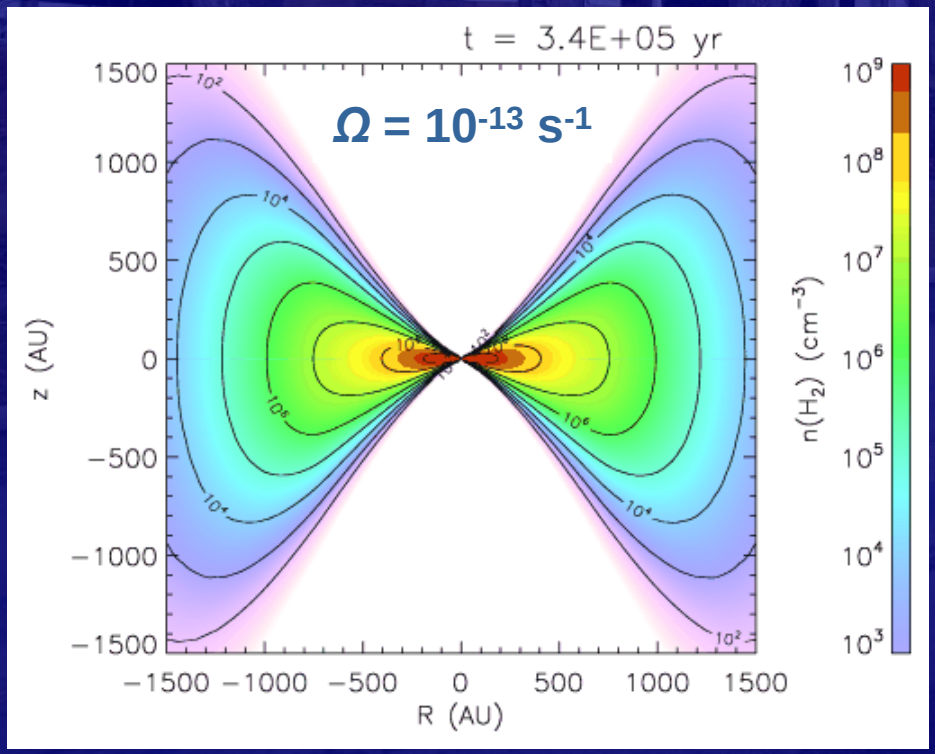
1 flavour of CO

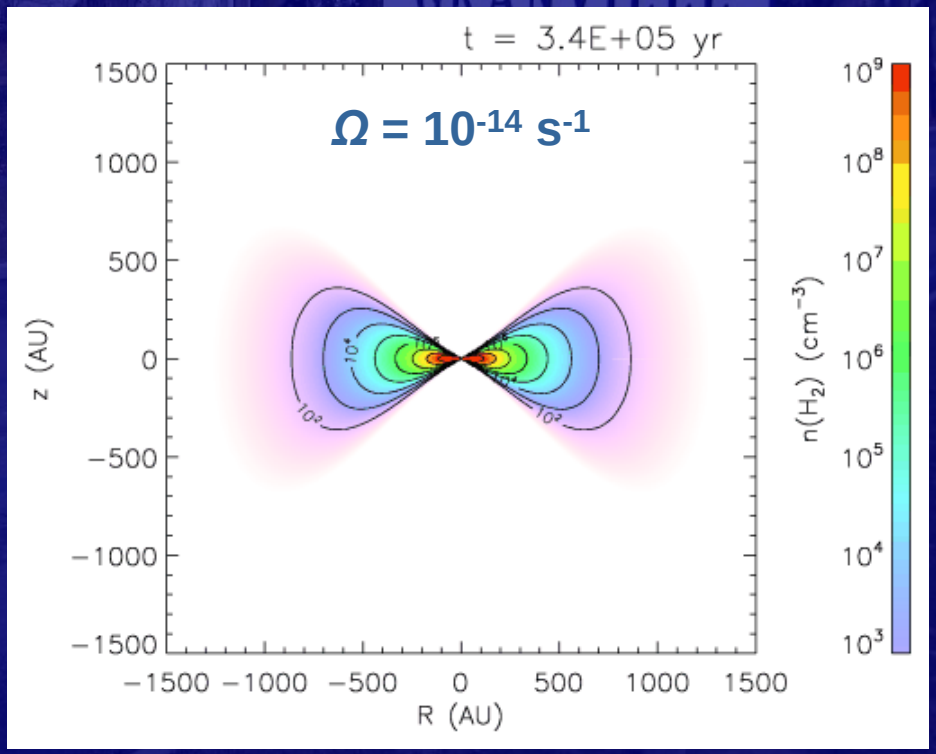
4 flavours of CO



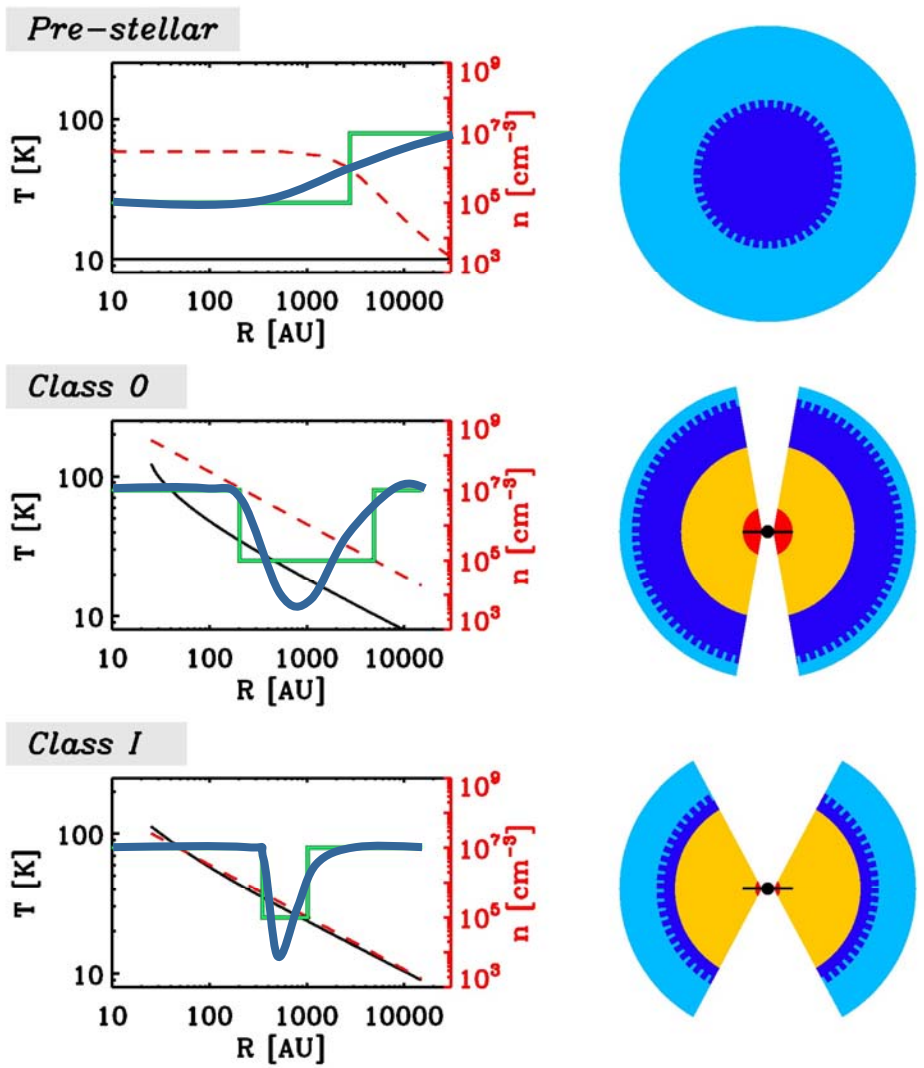
Future work: parameter space

- c_s: collapse timescale
- M_{env}: L_{star}, T_{dust}
- Ω: M_{star}/M_{disk}, R_{disk}





Step abundance?



- Abundance profiles are 2-dimensional
- Gas/ice transitions can occur over large radii
- Width and position of ice zone depends on E_b
- Nevertheless, step abundances are a valid zeroth-order approach

Conclusions

- Step abundances naturally explained
- Gas and ice abundances change as material accretes onto the disk:
  - CO ice evaporates during infall, re-freezes in disk
  - H_2O ice remains frozen
  - H_2CO ice partially evaporates, re-freezes
- Gas and ice zones change in time and depend on physical parameters
- Future work: expand chemical network, closer look at envelope/disk transition