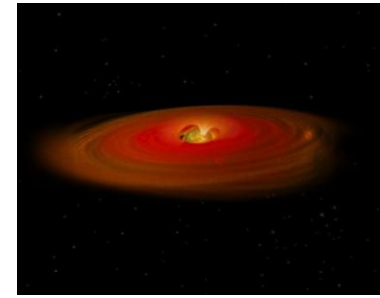
Chemical evolution from cores to disks

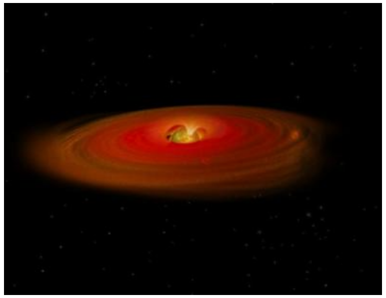


Ruud Visser
Leiden Observatory

January 26, 2010
California Intitute of Technology

Sterrewacht Leiden

Chemical evolution from cores to disks



<u>Take-home message</u>

Chemical models ranging from molecular cloud cores to circumstellar disks are required to understand chemical composition of the solar system

Outline

- Introduction and motivation
- Model description
- Results
  - Freeze-out and evaporation
  - Full chemistry
  - Silicate dust: amorphous vs. crystalline
- Conclusions and outlook

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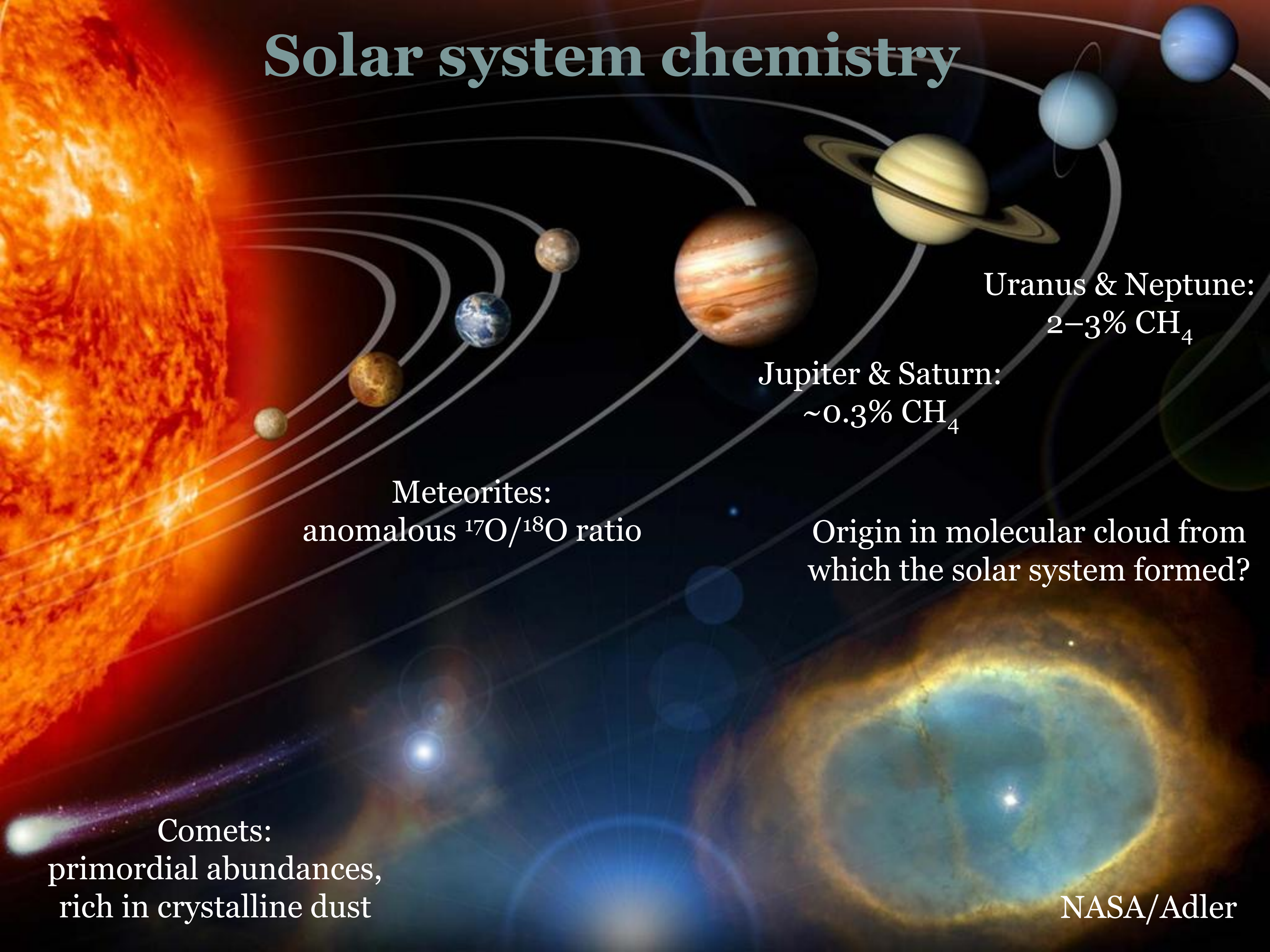
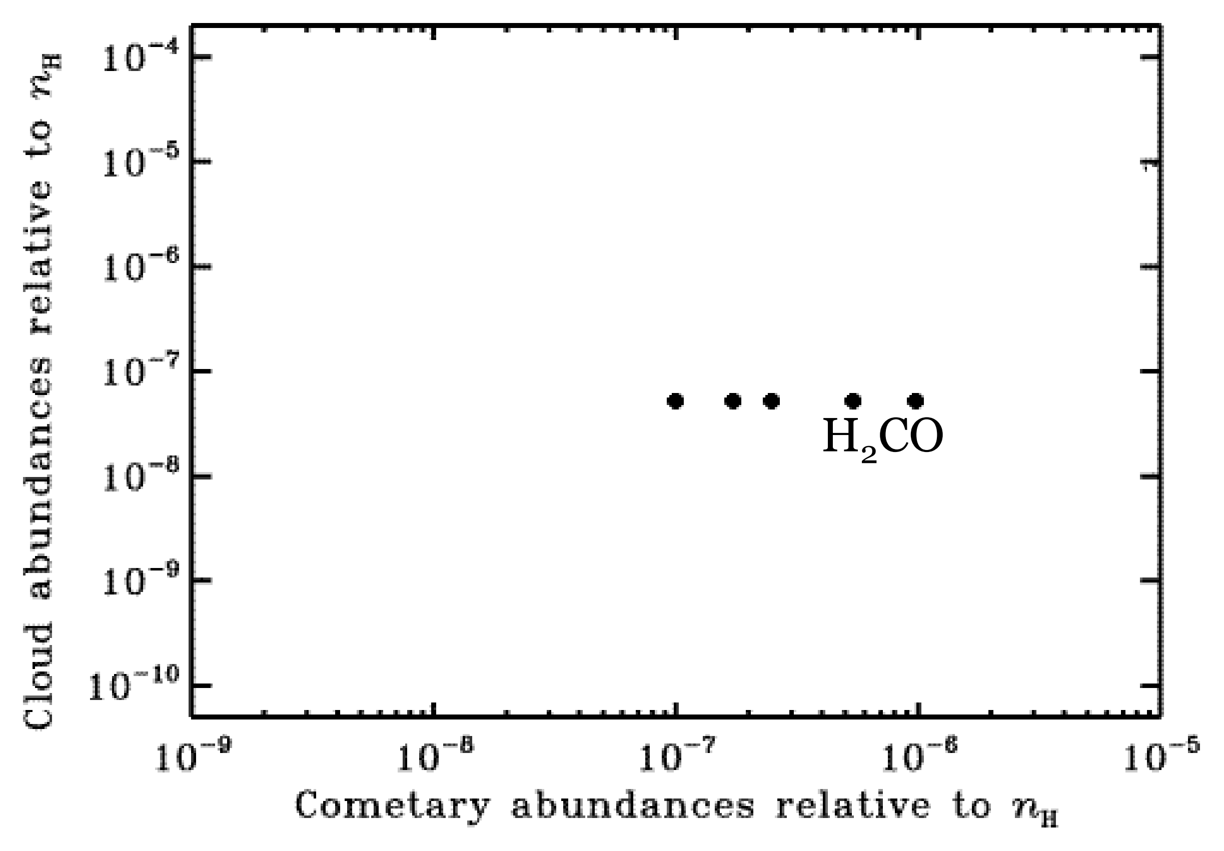
Solar system chemistry



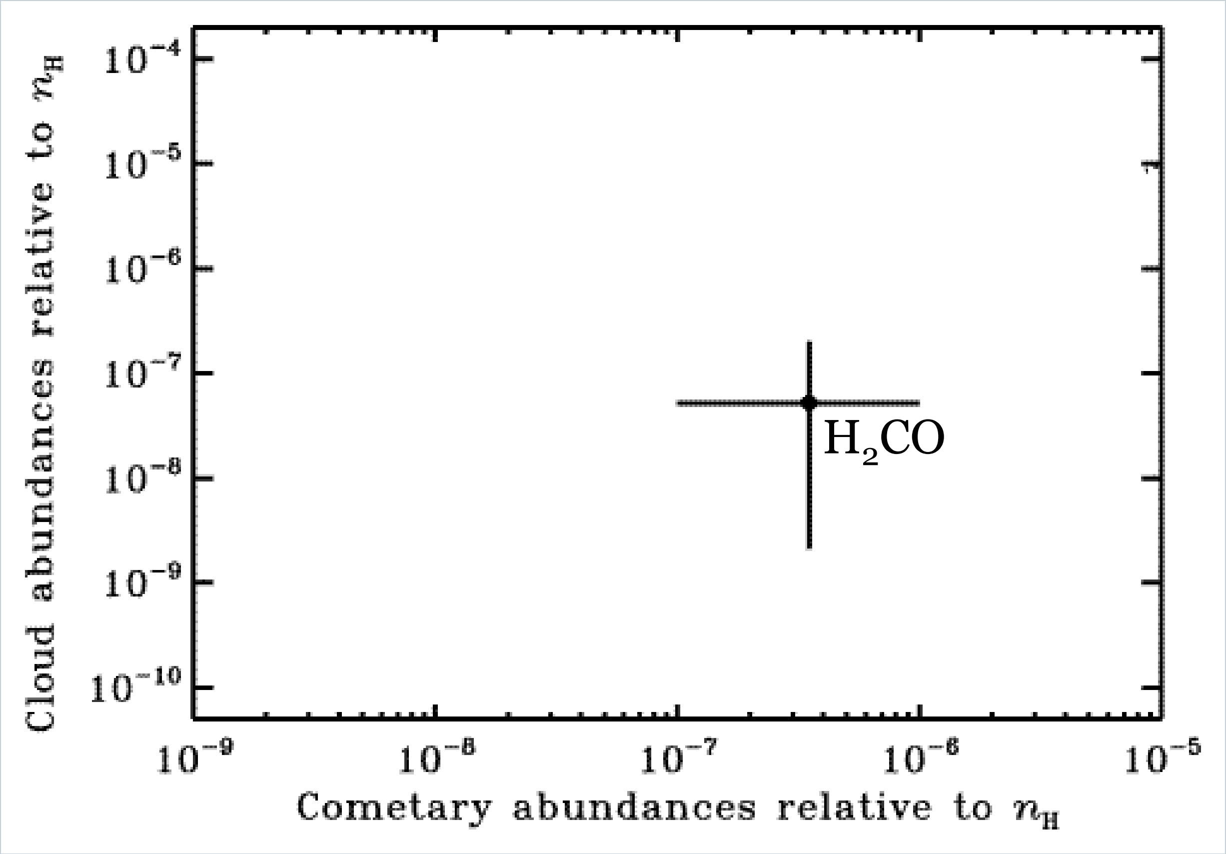
Comets: a view of the past?



- Plot abundances from several comets
- Plot abundances from several molecular clouds

Bockelée-Morvan et al. (2000, 2004), Schöier et al. (2002)

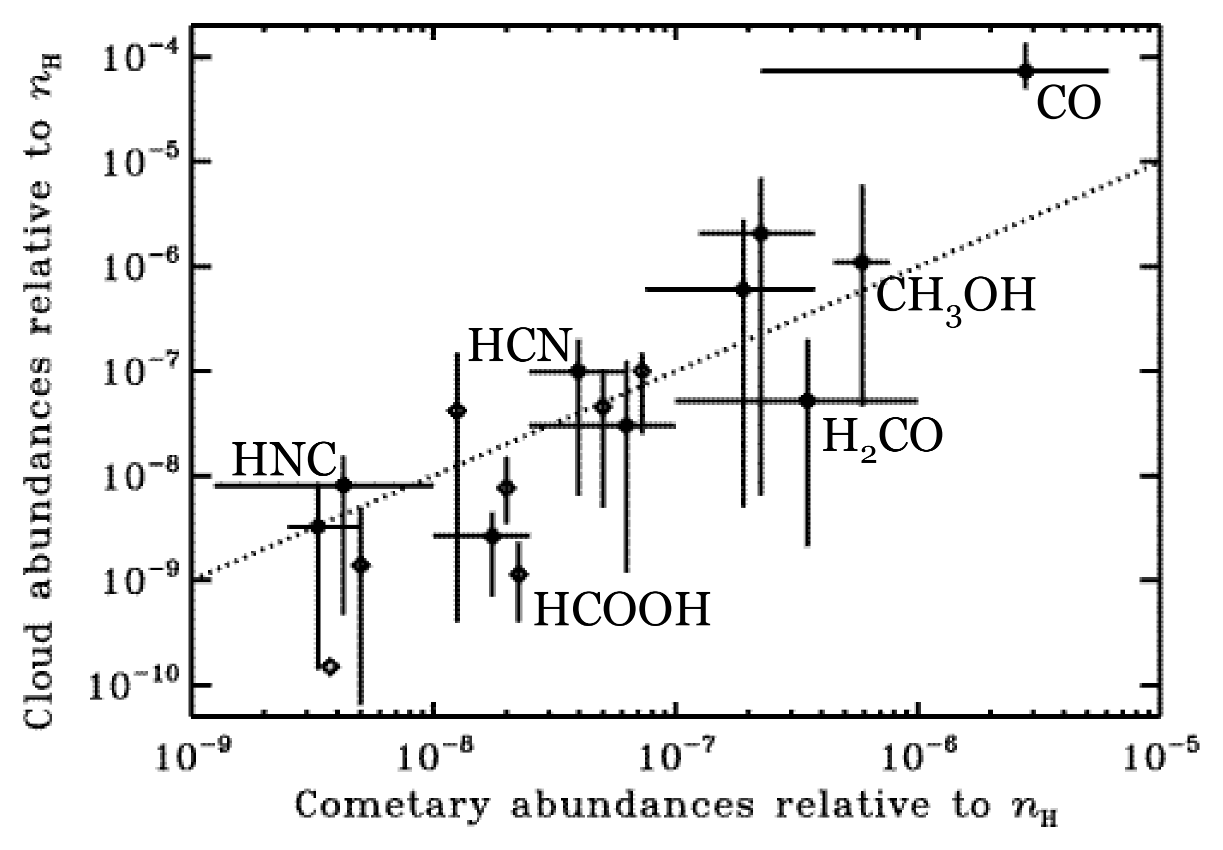
Comets: a view of the past?



- Plot abundances from several comets
- Plot abundances from several molecular clouds
- Plot as average with spread

Bockelée-Morvan et al. (2000, 2004), Schöier et al. (2002)

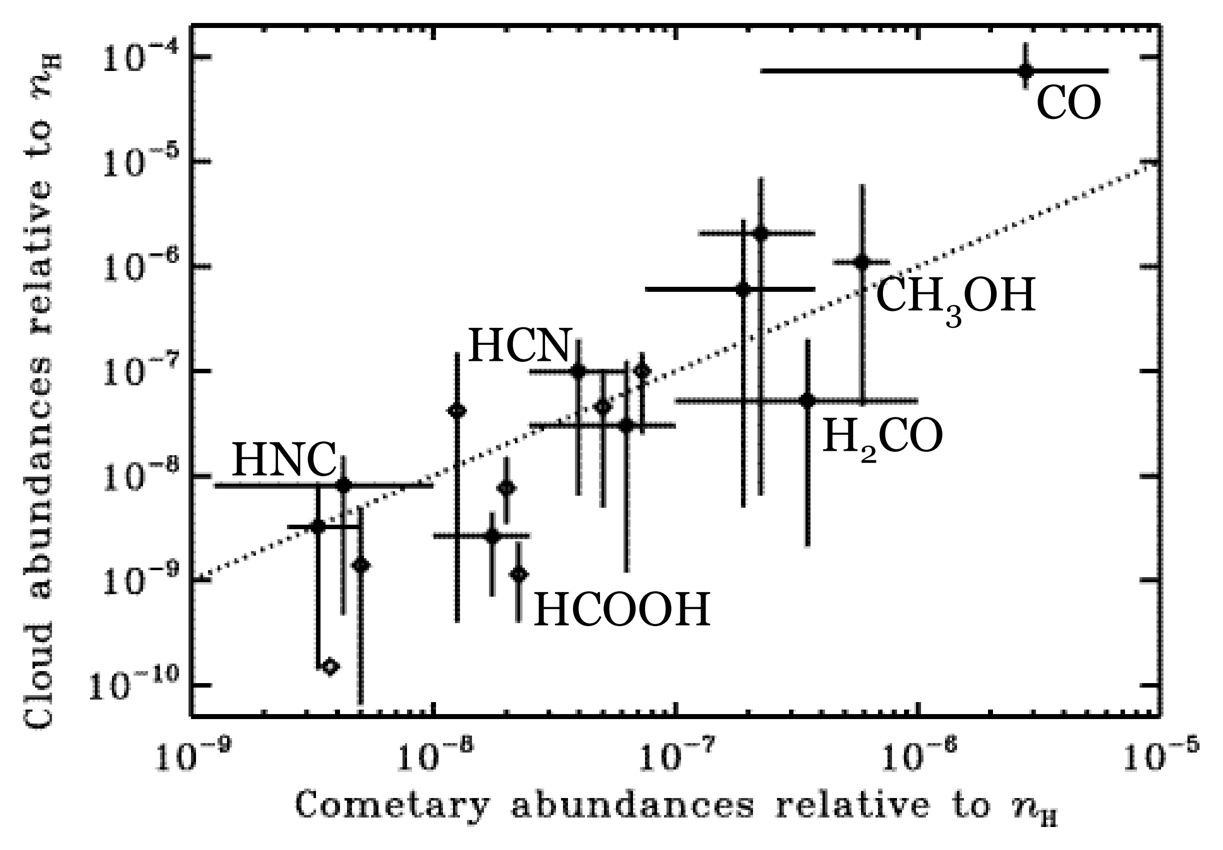
Comets: a view of the past?



- Plot abundances from several comets
- Plot abundances from several molecular clouds
- Plot as average with spread
- Do for sample of species

Bockelée-Morvan et al. (2000, 2004), Schöier et al. (2002)

Comets: a view of the past?



- Dotted line: hypothetical one-to-one relationship
- Comets in general similar to ISM, but individual differences exist

Bockelée-Morvan et al. (2000, 2004), Schöier et al. (2002)

My approach

- Hypothesis: current chemical composition of the solar system is due to processes during its formation
- Generalize the problem: also look at other solar systems that are currently forming
- Simulate star formation, solve chemical evolution within that framework
- Initial focus on a few key molecules (e.g. CO, H_2O)

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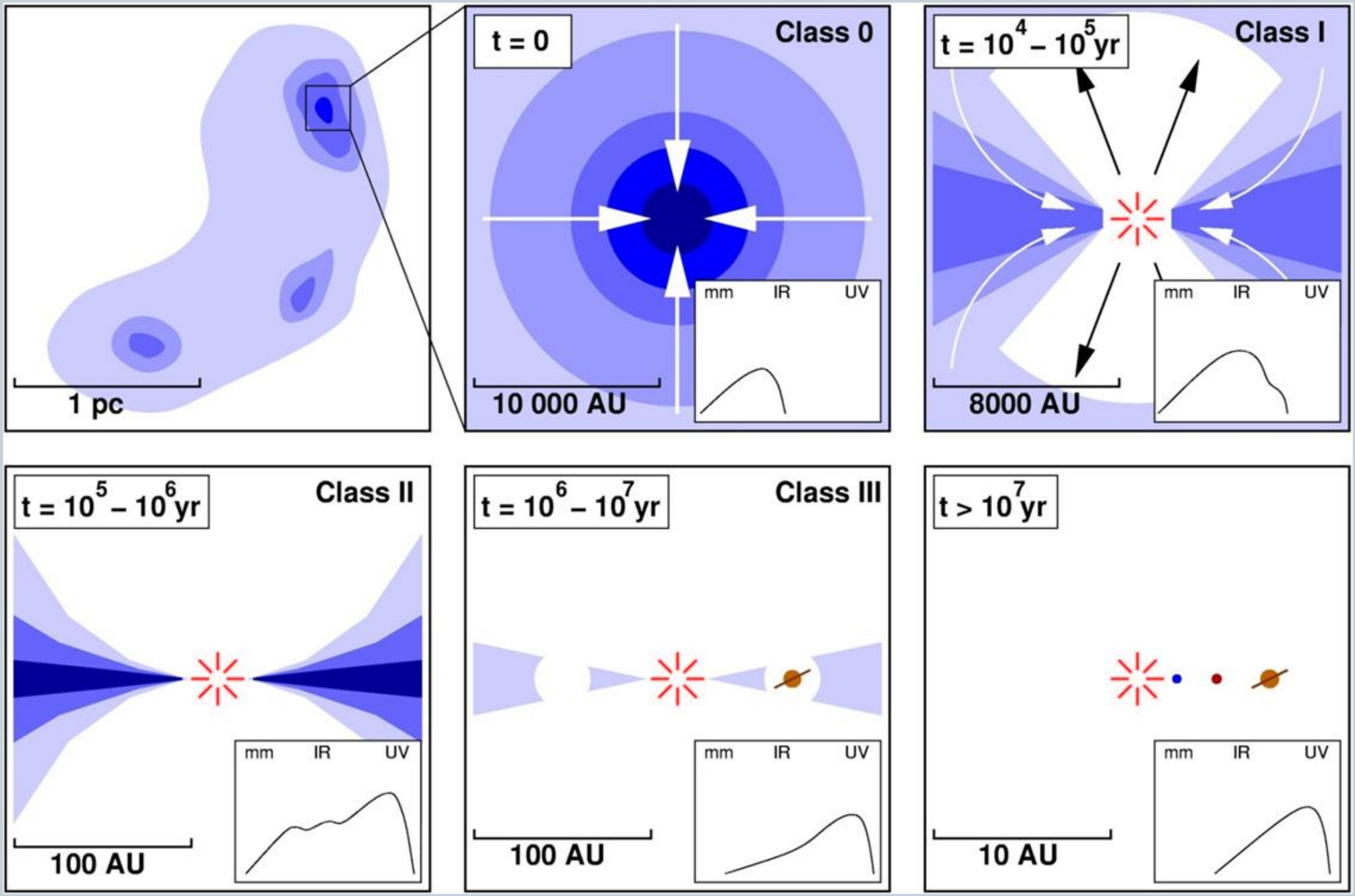
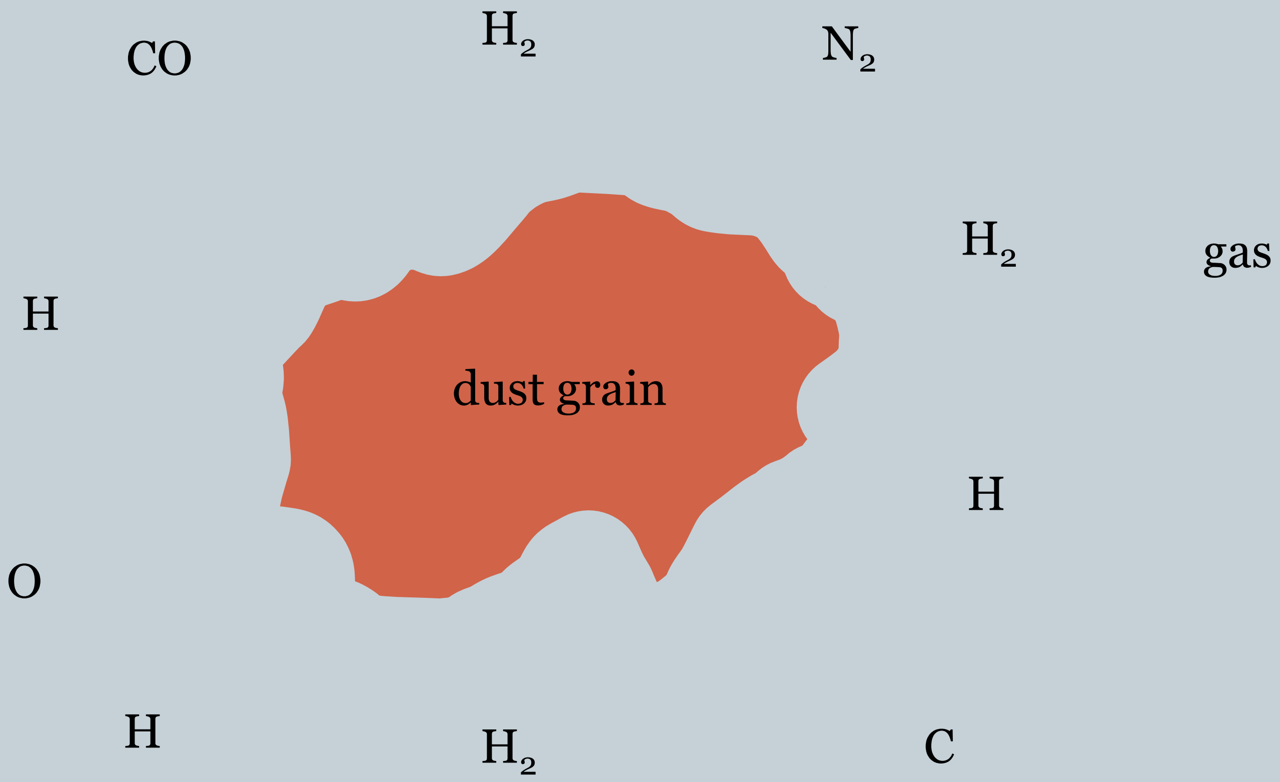
Low-mass star formation



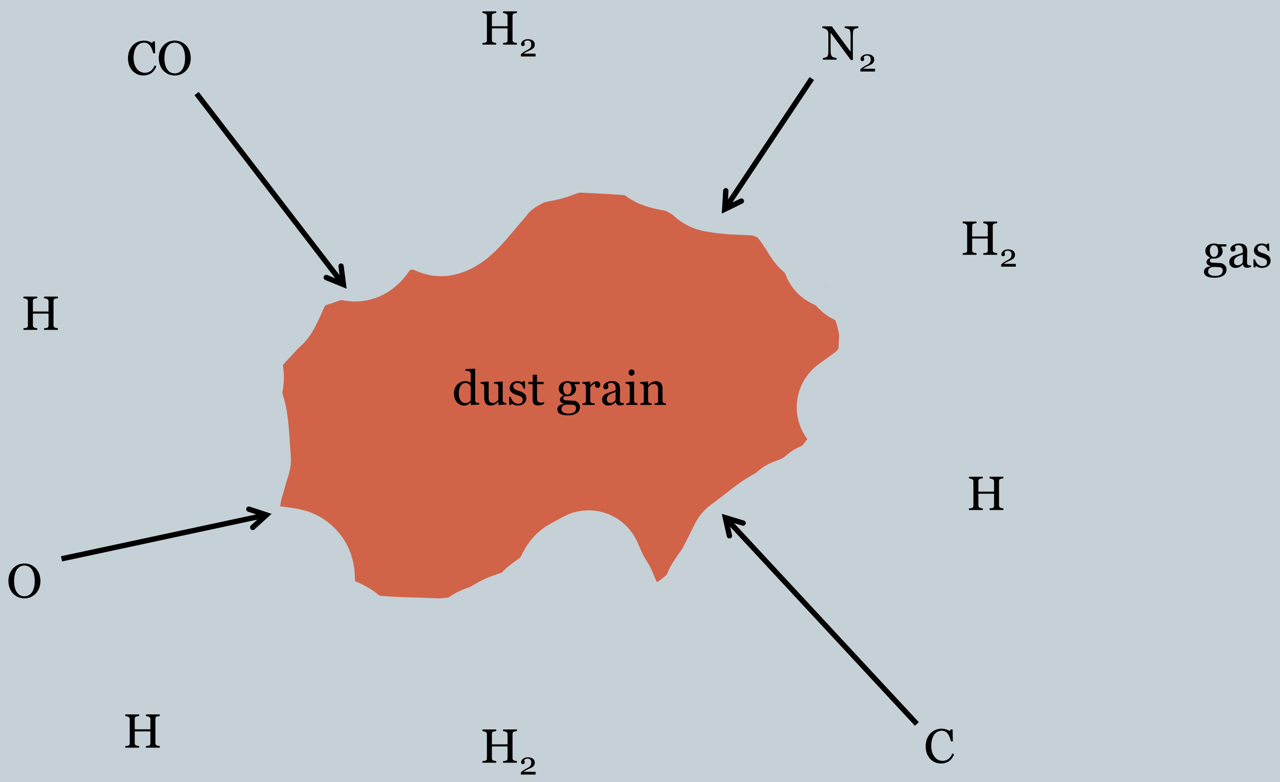
Jonkheid et al. (2006)

Chemical processes



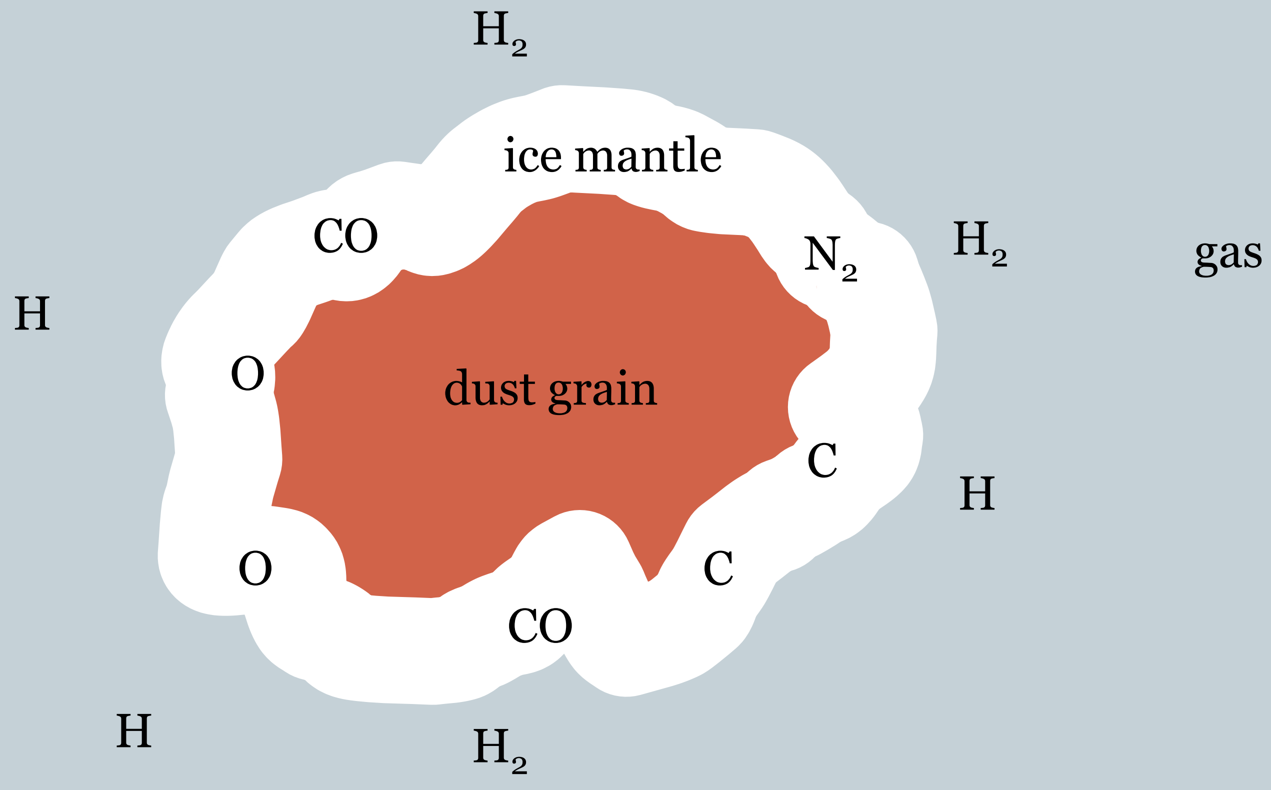
Chemical processes

- Freeze-out



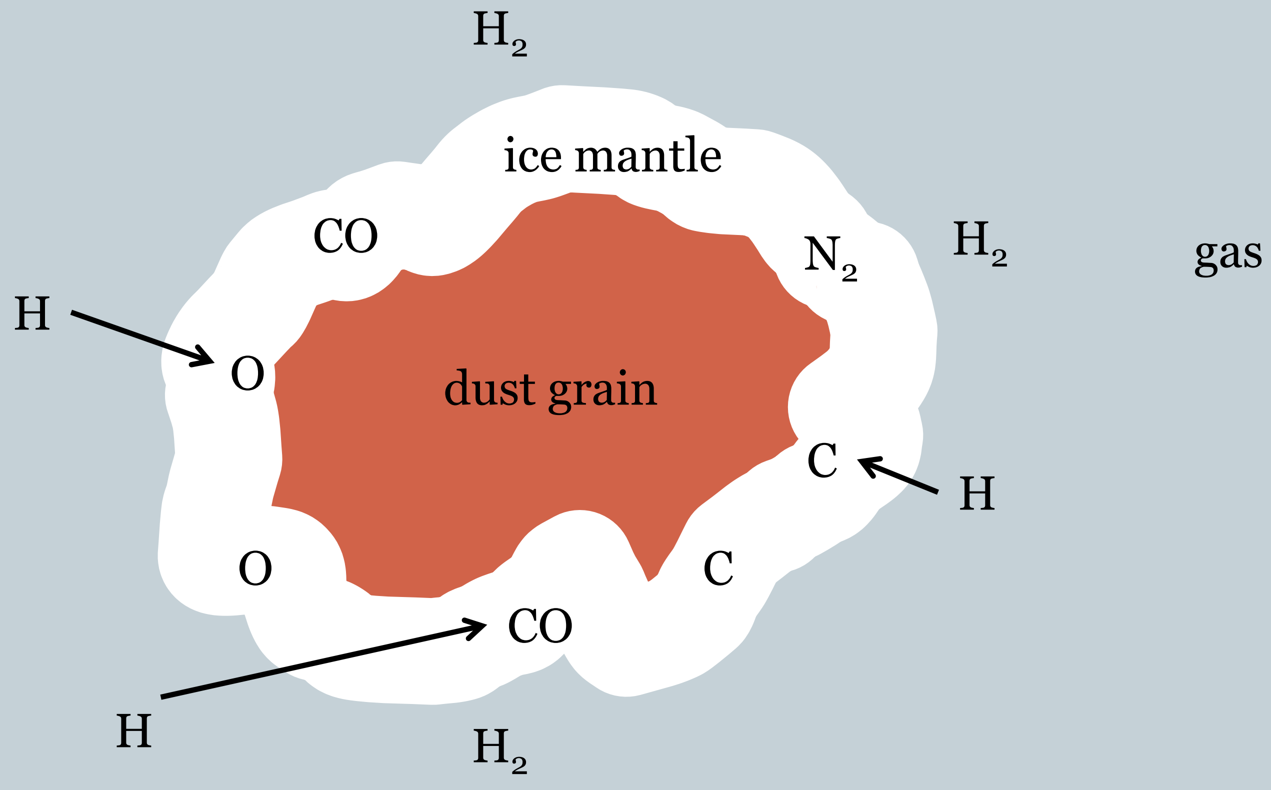
Chemical processes

- Freeze-out



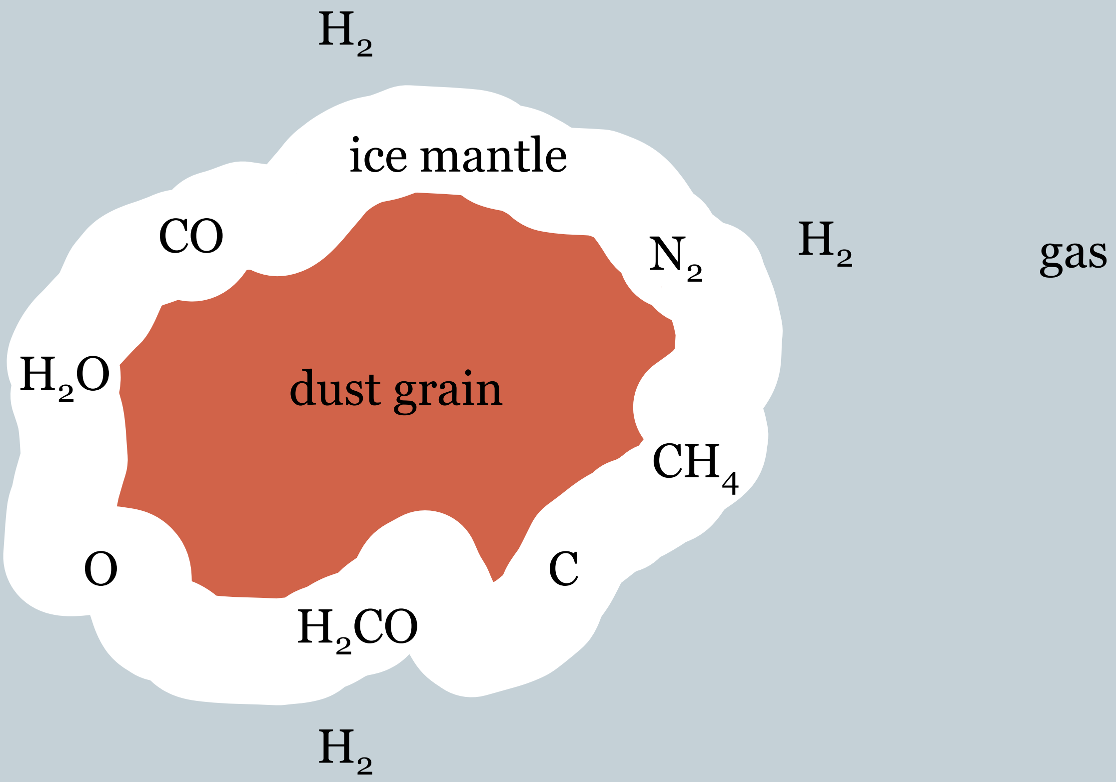
Chemical processes

- Grain-surface hydrogenation



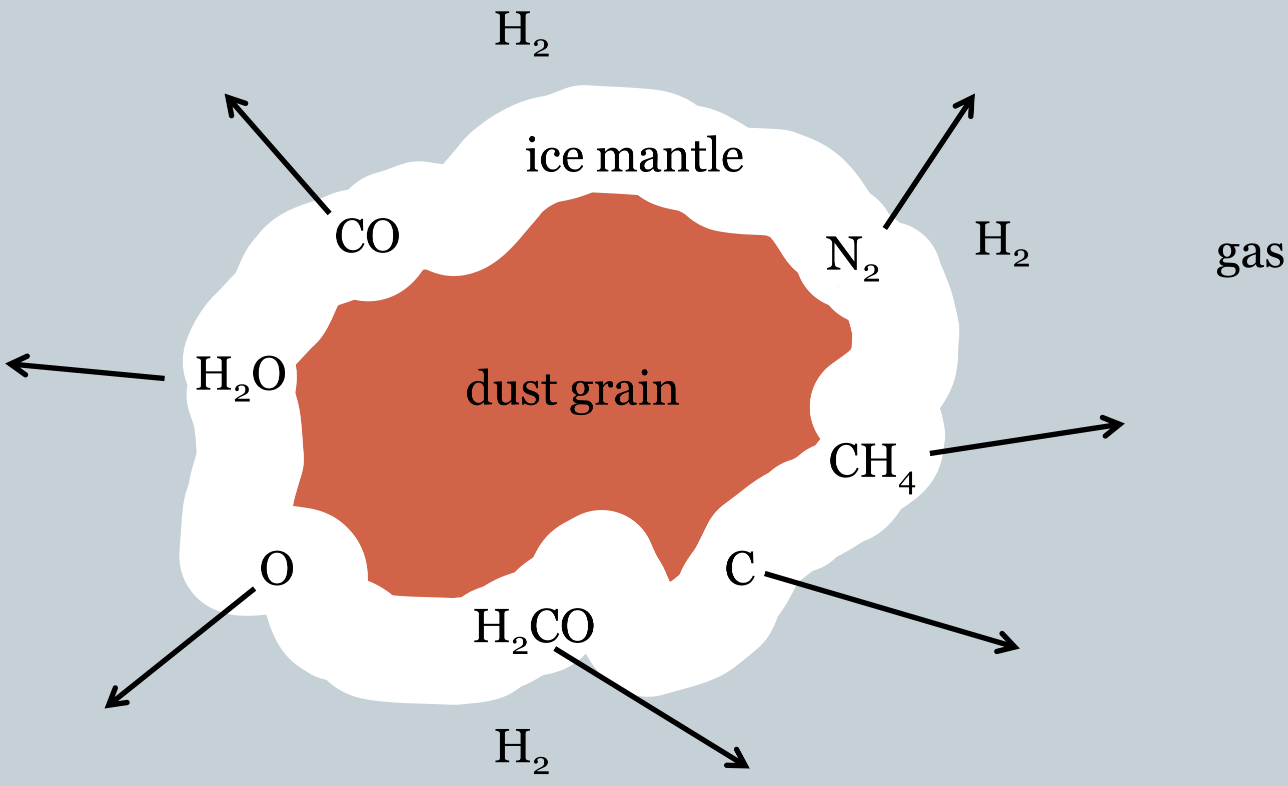
Chemical processes

- Grain-surface hydrogenation



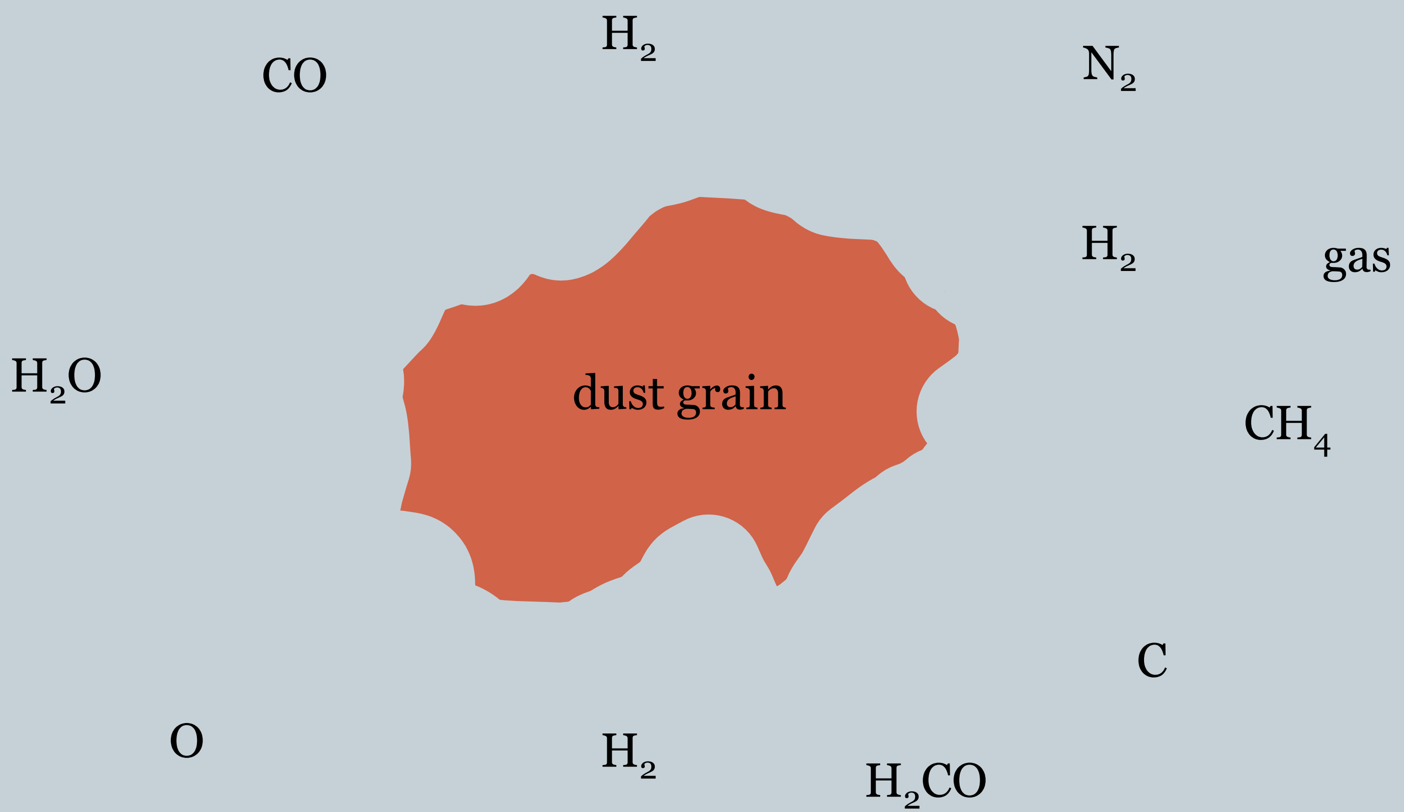
Chemical processes

- Evaporation



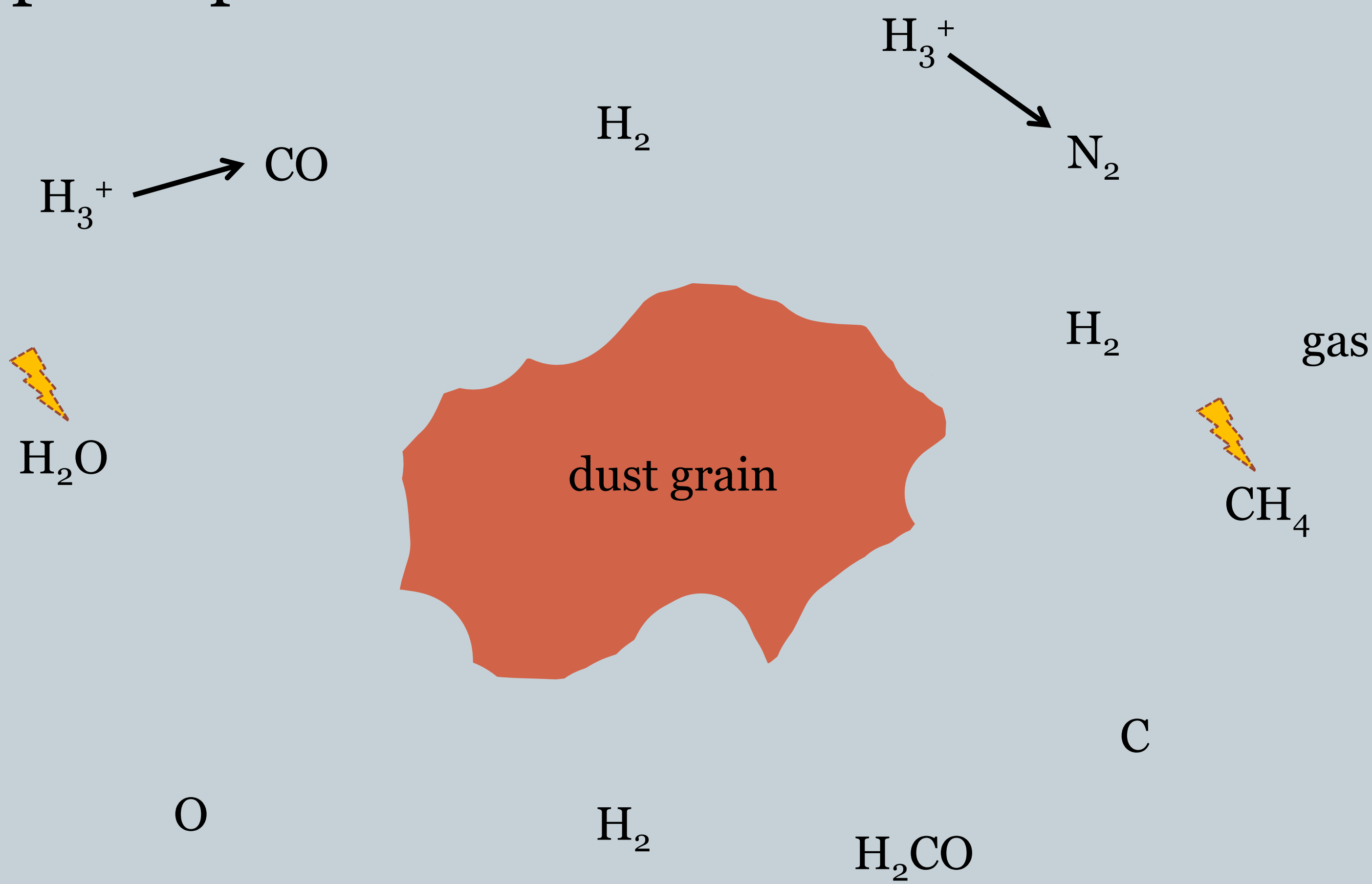
Chemical processes

- Evaporation



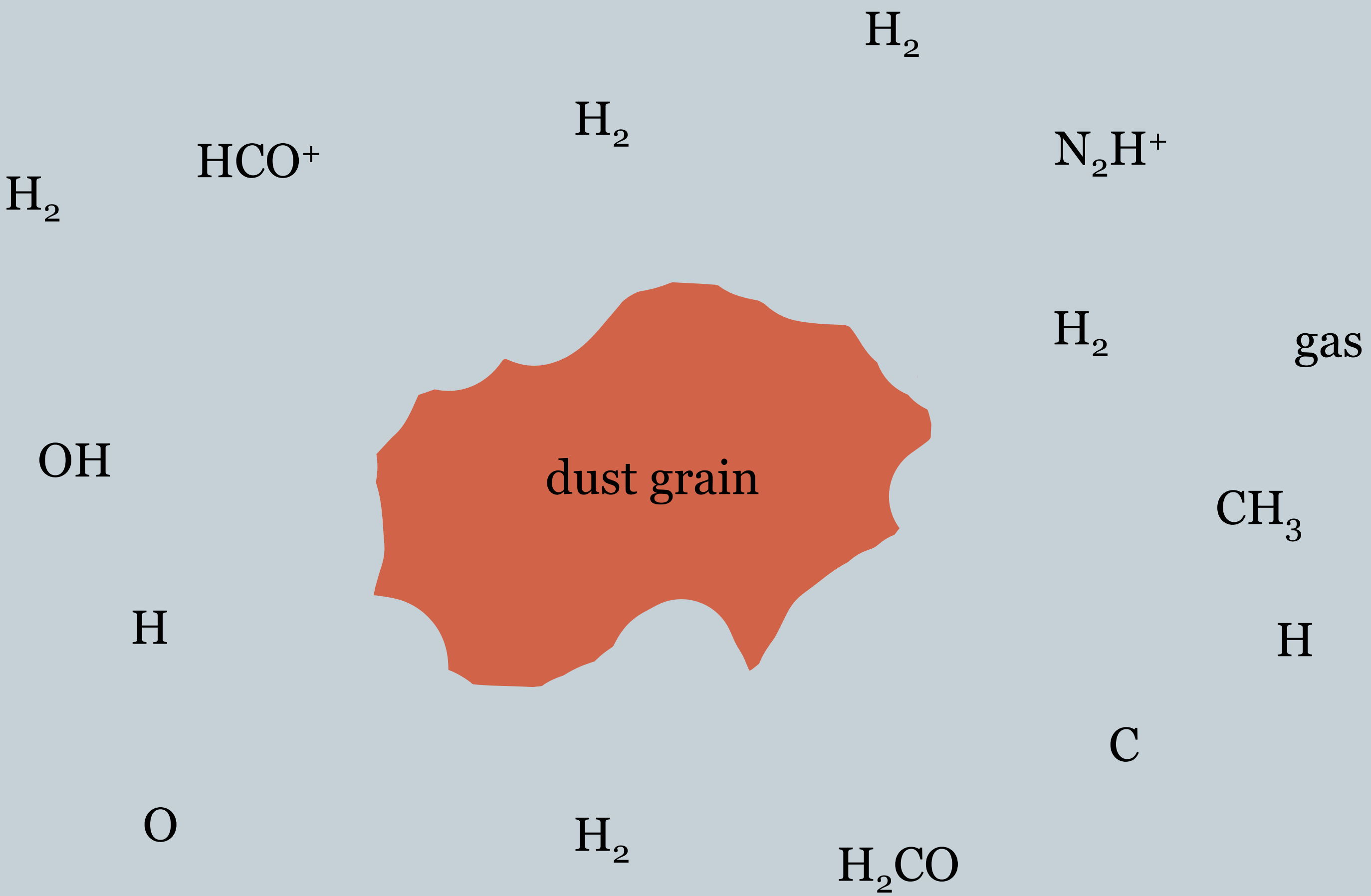
Chemical processes

- Gas-phase processes



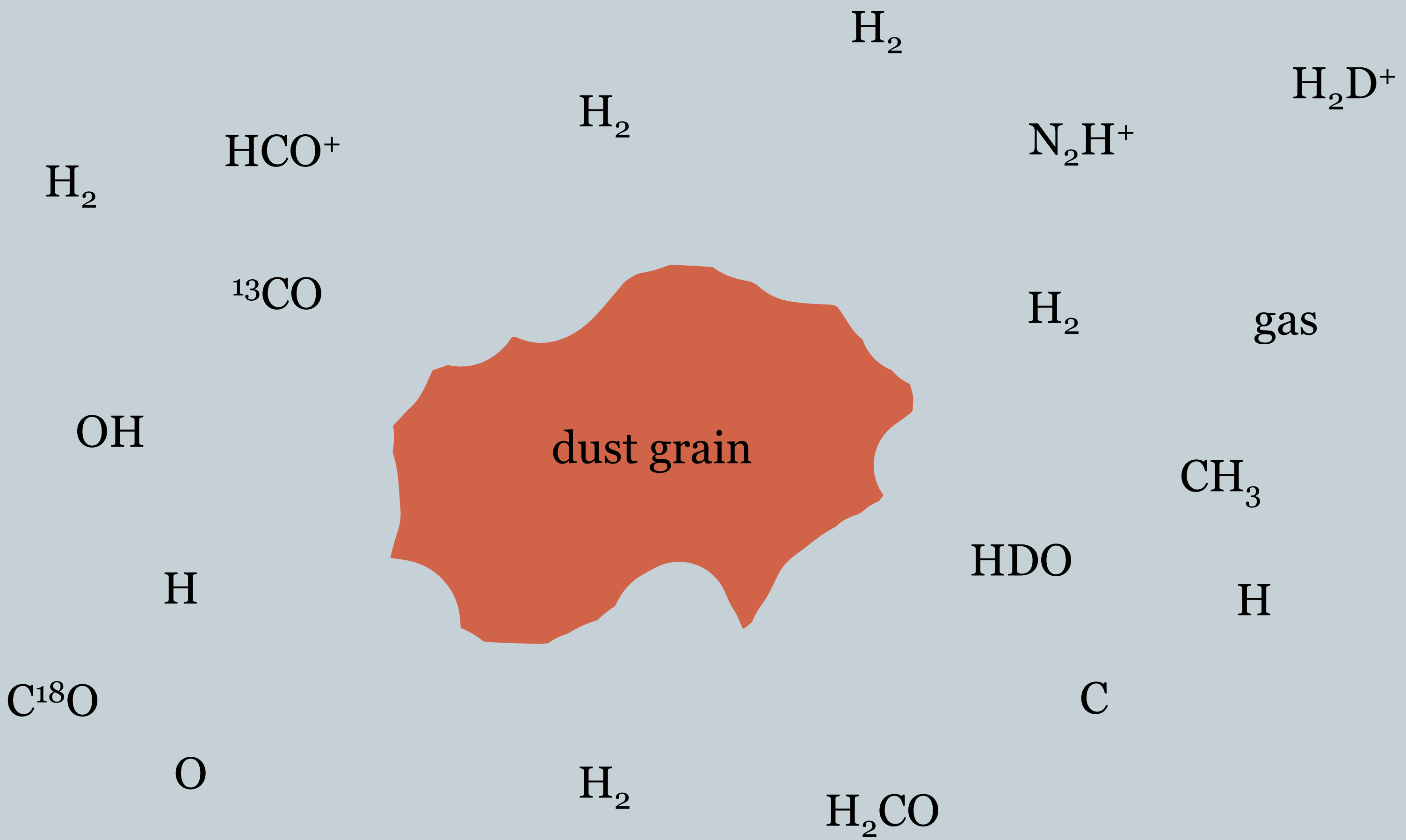
Chemical processes

- Gas-phase processes

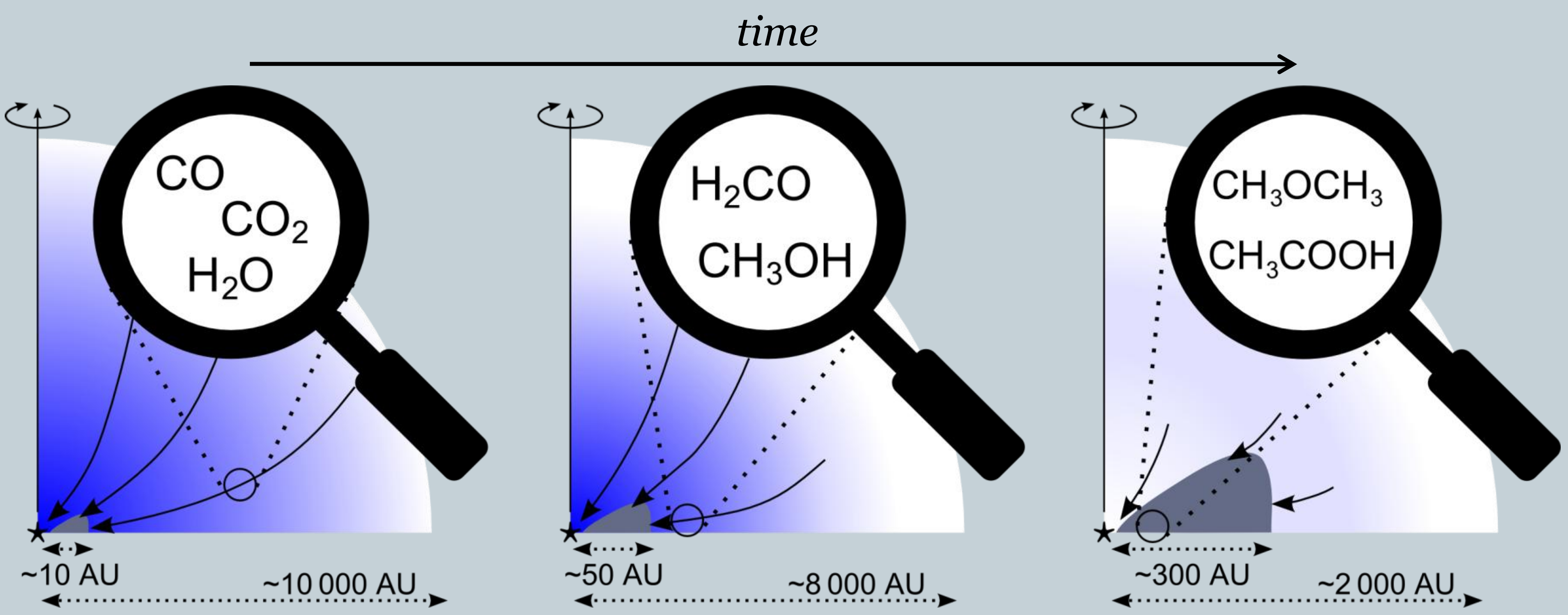


Chemical processes

- Isotopes

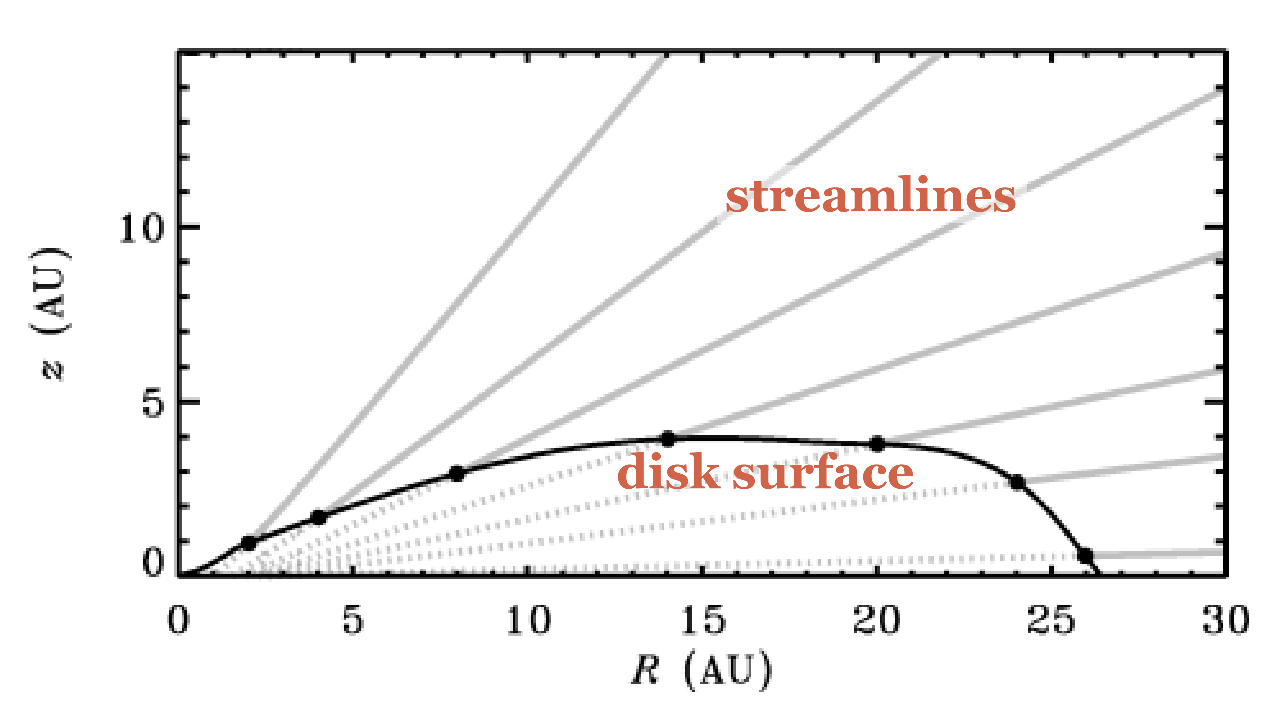


Chemistry during star formation



How do abundances change during star formation?
What does this tell us about the physics?

From one to two dimensions

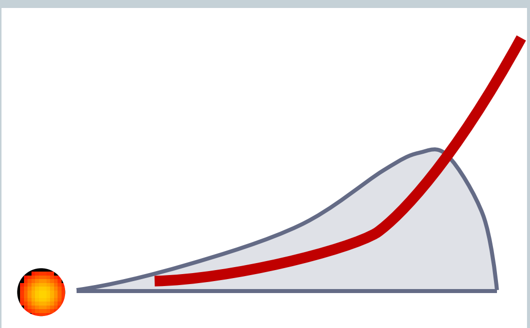


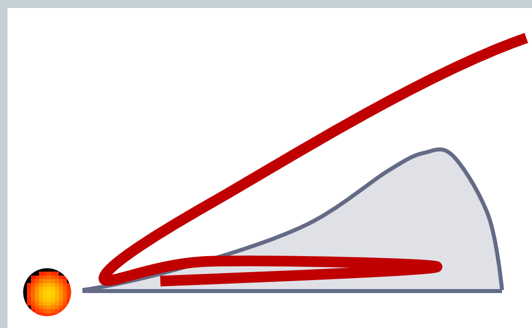
- Previous collapse models treated disk as completely flat
- Include vertical structure: accretion occurs further out
- Accretion shock is weak, except in very inner part

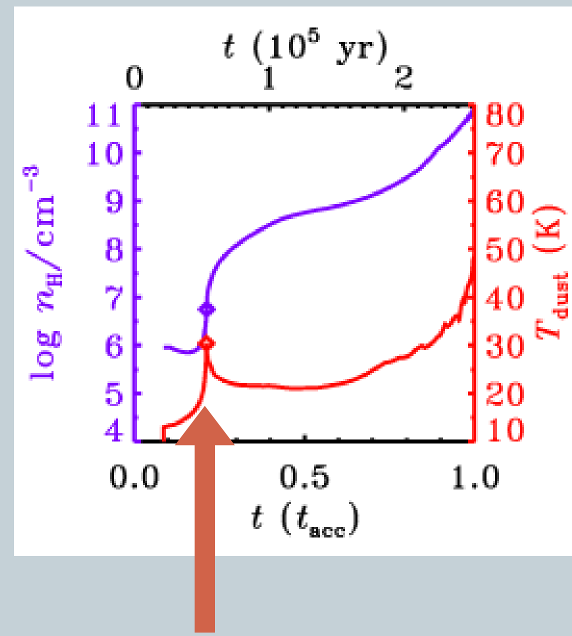
Visser & Dullemond (subm.)

Infall trajectories

- Need to solve chemistry dynamically: compute n, T along many trajectories







- Different trajectory shapes
- Jump in n, T upon entering disk

entering disk

Visser et al. (2009) , Visser et al. (in prep.)

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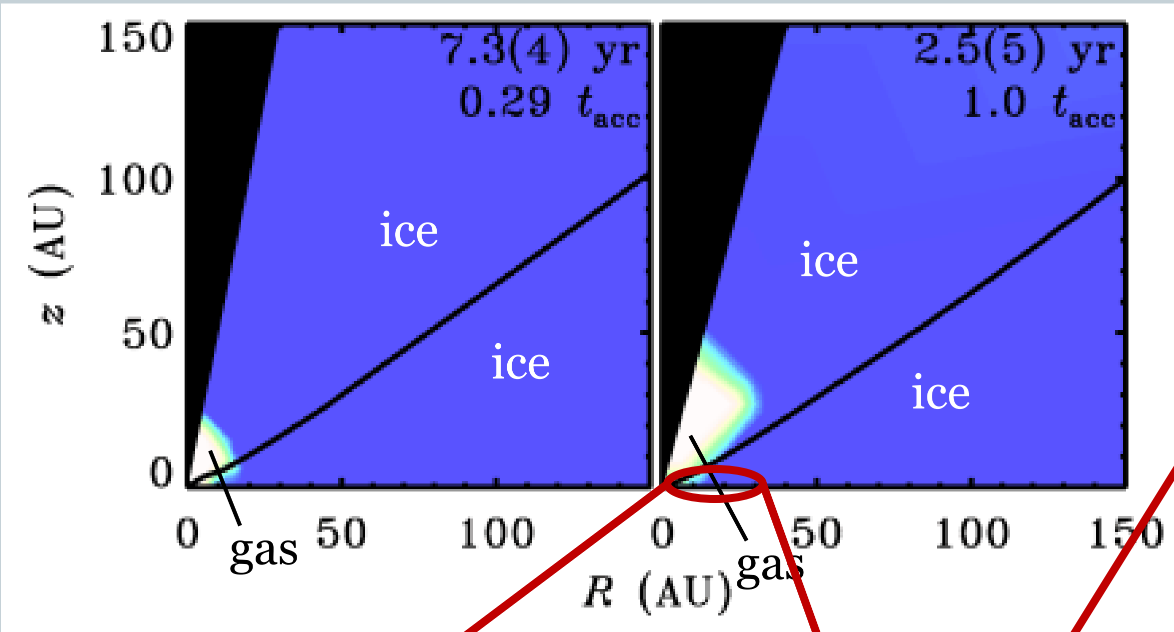
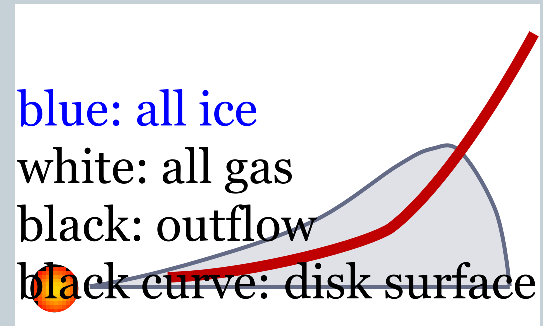
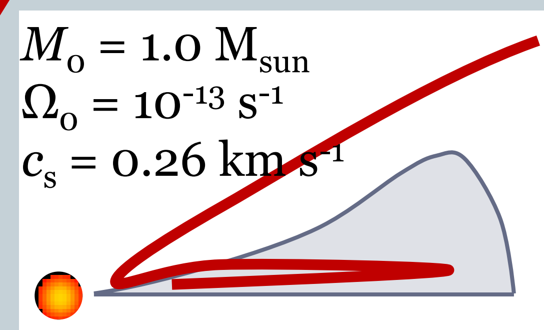
Gas and ice: H_2O



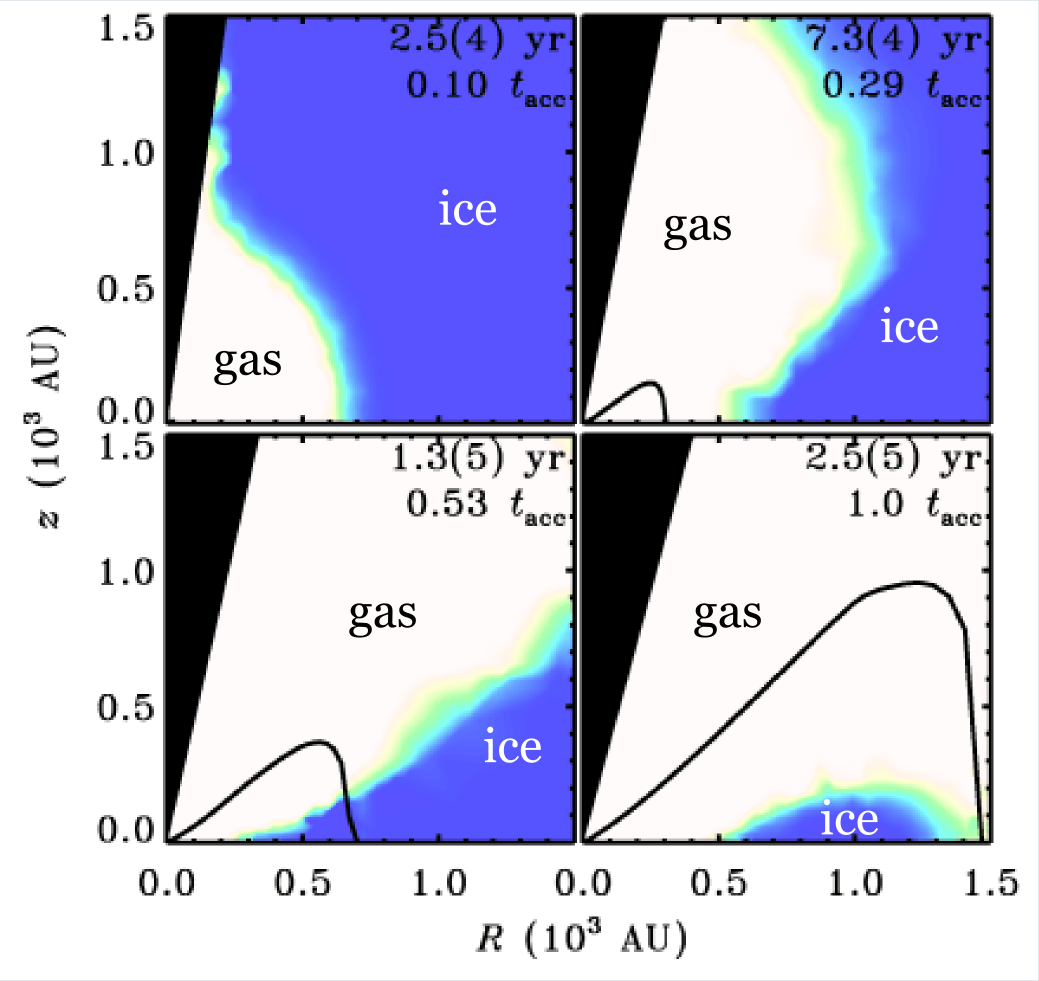




- H_2O remains solid except inner ~5 AU
- H_2O in comet-forming zone, depending on parameters:
  - *either* unprocessed (always frozen)
  - *or* processed (evaporated and re-frozen)

Visser et al. (2009)

Gas and ice: CO



blue: all ice
white: all gas
black: outflow
black curve: disk surface

$M_0 = 1.0\ M_{sun}$
$\Omega_0 = 10^{-13}\ s^{-1}$
$c_s = 0.26\ km\ s^{-1}$

CO desorbs during infall, re-adsorbs in disk below 18 K

Visser et al. (2009)

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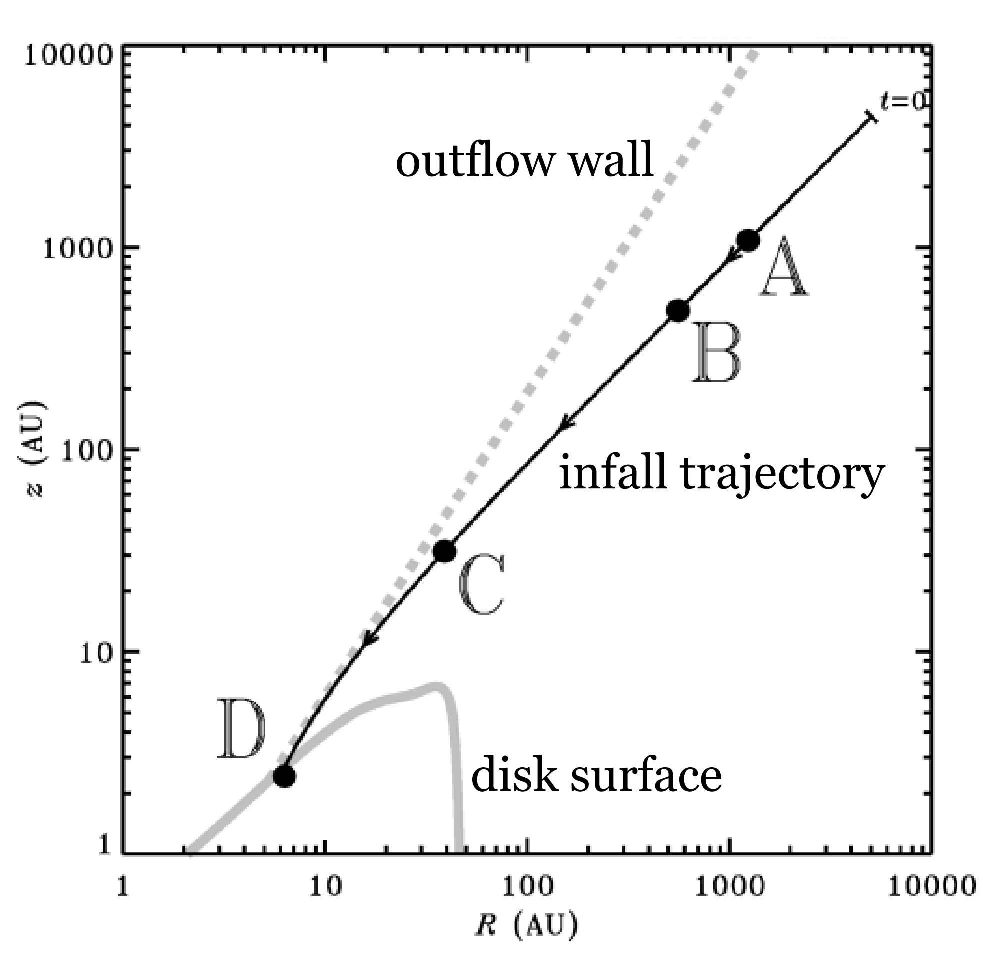
Full chemistry along one trajectory



A: volatiles evaporate (e.g. CO, N_2)

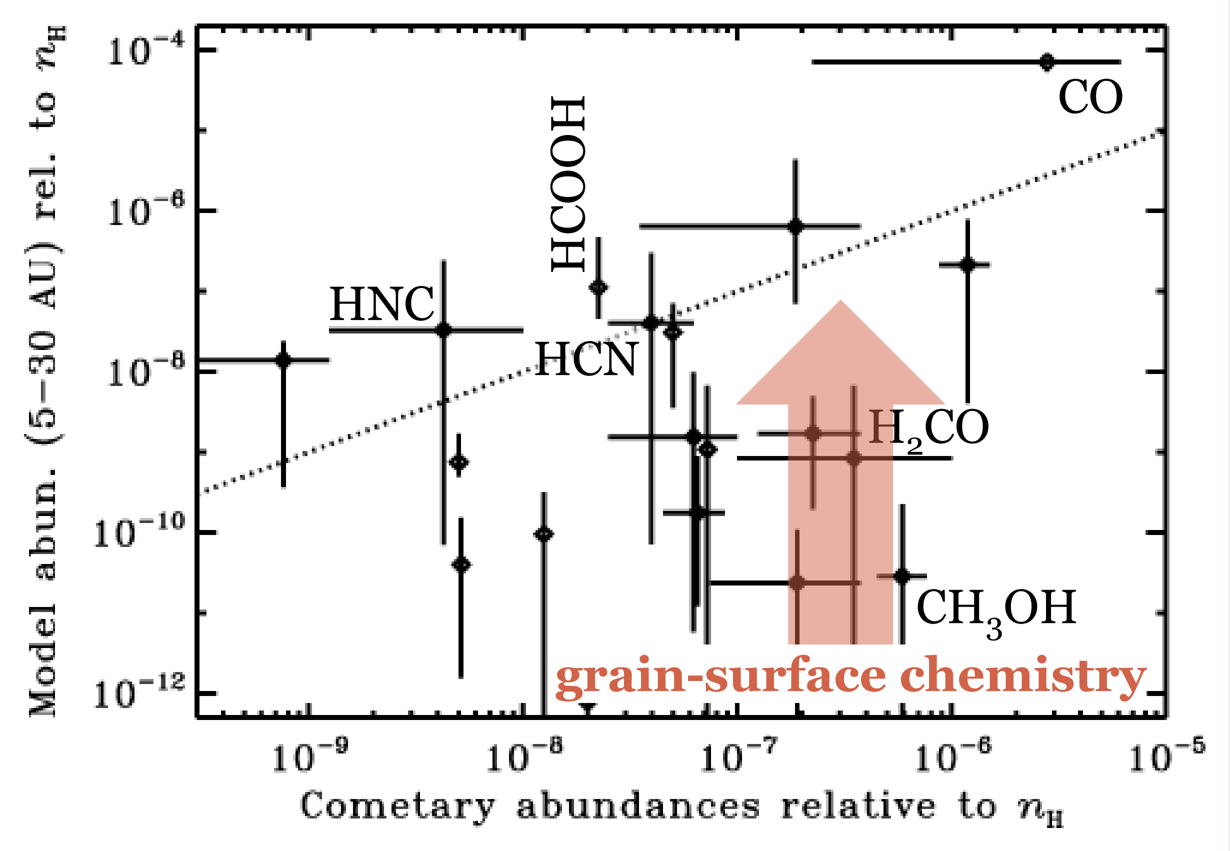
B: intermediates evaporate (e.g. CH_4, NO)

C: strongly bound ices evaporate (e.g. H_2O, NH_3, CH_3OH) photodissociation of many species

D: some species reformed

Visser et al. (in prep.)

Implications for comets



- Dotted line: hypothetical 1-to-1 relationship
- Many model abundances differ from cometary abundances
- Grain chemistry? Initial conditions? Mixing? Episodic accretion?

Visser et al. (in prep.)

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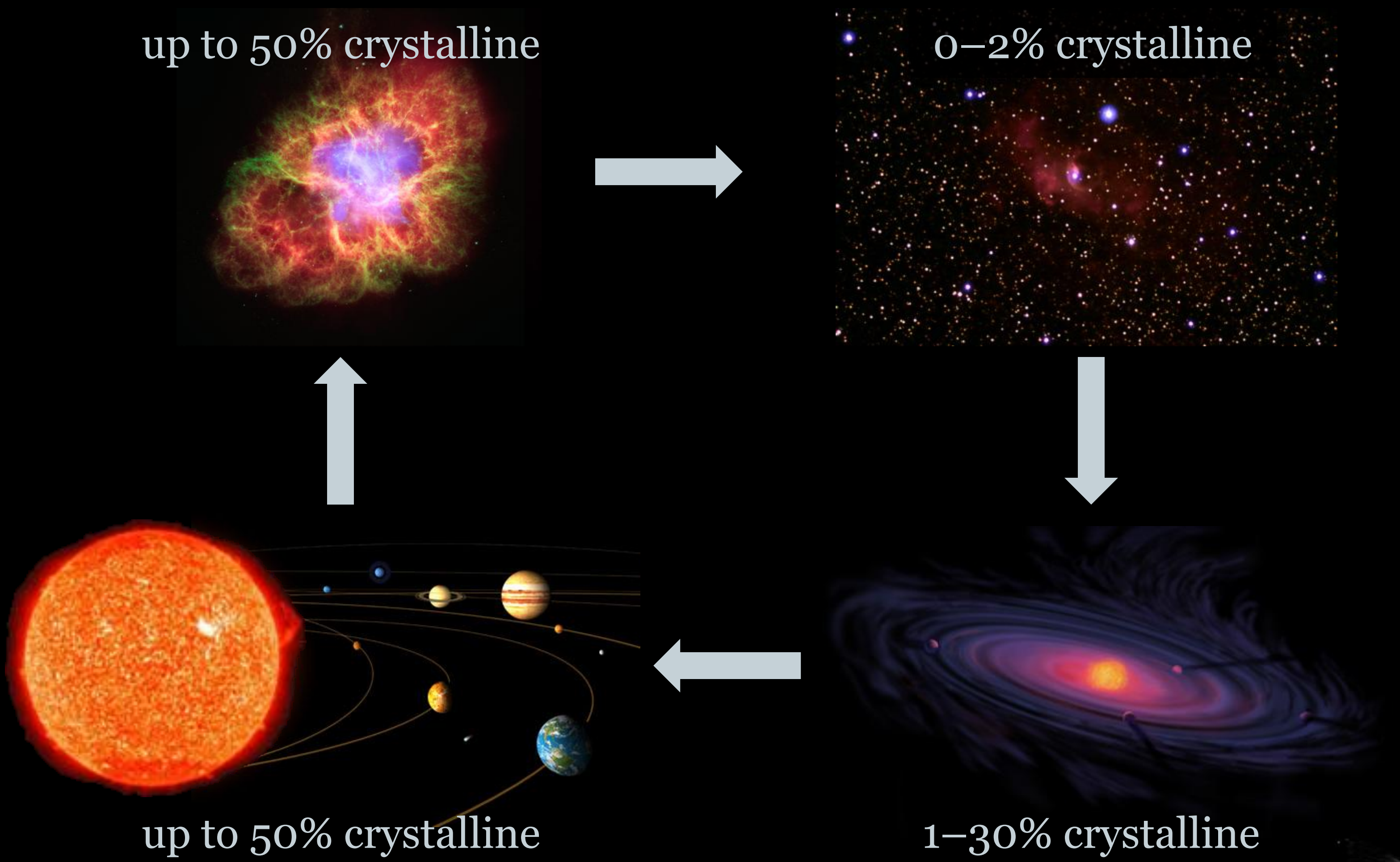
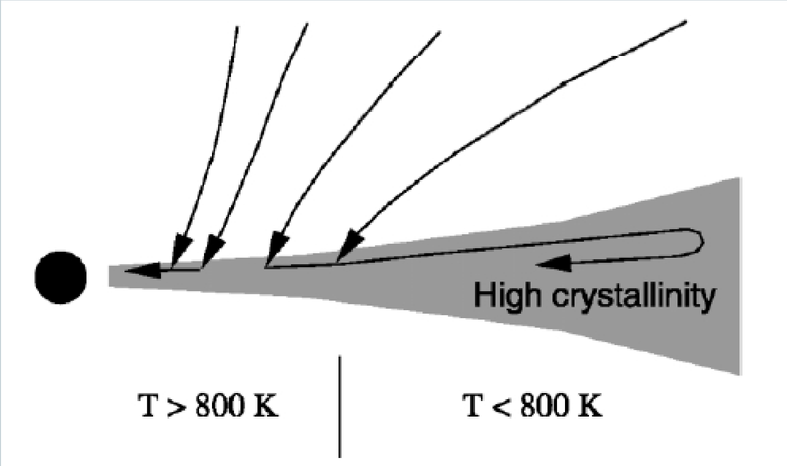
From crystalline to amorphous and back



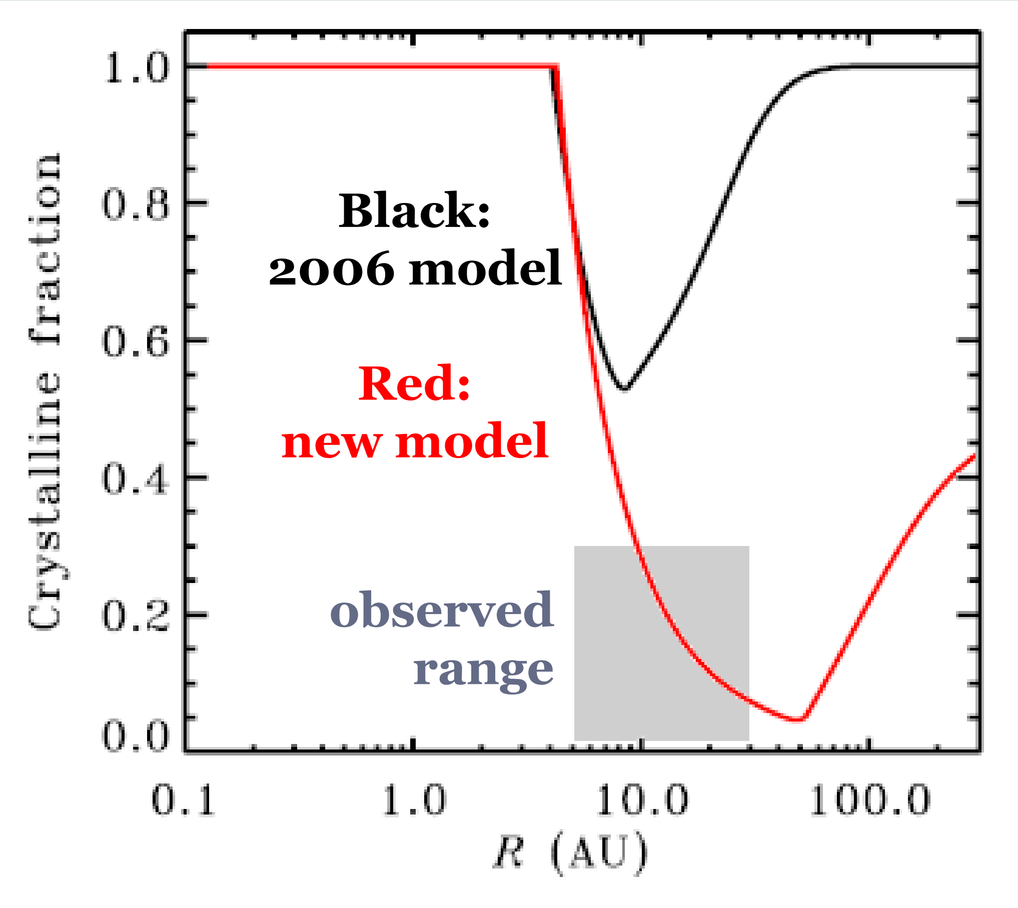
Origin of crystalline silicates in disks

- Crystallization by thermal annealing requires 800 K
- Crystalline silicates observed down to 150 K

- Dust accreting in hot inner region is crystallized
- Disk spreads out to conserve angular momentum
- Crystalline material transported to colder areas



Crystalline fractions



New model results in good agreement with observed range!

Visser & Dullemond (subm.)

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Conclusions

- First model to follow chemistry from molecular clouds to circumstellar disks in 2D
- Great tool for chemical evolution, but many challenges remain
- Beginning to understand how chemistry during early stages of star formation is linked to chemical composition of mature solar systems

Future work

- When and where are the complex organics formed?
- New challenges, new possibilities: isotopes
- Still an open question: why are Uranus and Neptune so chemically different from Jupiter and Saturn?
- How does episodic accretion affect all this?

Acknowledgments

- Thesis advisor
  - Ewine van Dishoeck
- Star-formation model
  - Steve Doty
  - Kees Dullemond
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  - Christian Brinch
  - Michiel Hogerheijde
- CO photodissociation
  - John Black