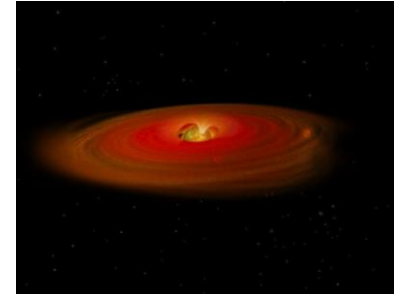




Chemical evolution from cores to disks



Ruud Visser
Leiden Observatory

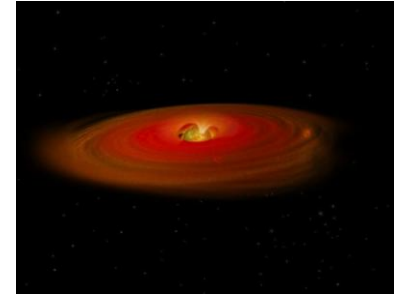


February 2, 2010
Carnegie Institution of Washington





Chemical evolution from cores to disks



Take-home message

Chemical evolution is an integral part of star formation and 2D chemical-dynamical models are essential for its understanding.

Outline



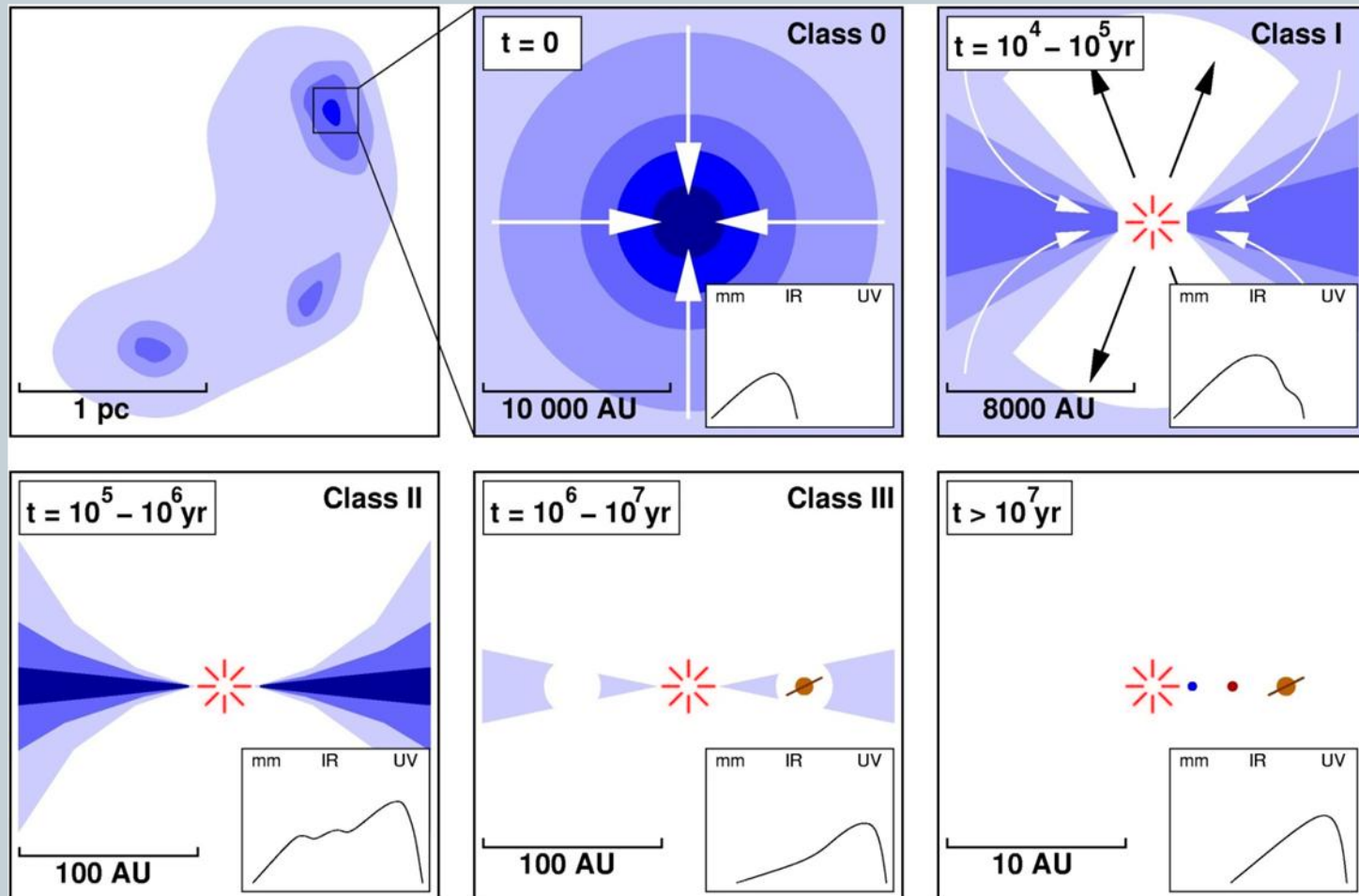
- Introduction and motivation
- Model description
- Results
 - Freeze-out and evaporation
 - Full chemistry
 - Silicate dust: amorphous vs. crystalline
- Herschel: WISH
- Conclusions and outlook

Outline



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

Low-mass star formation

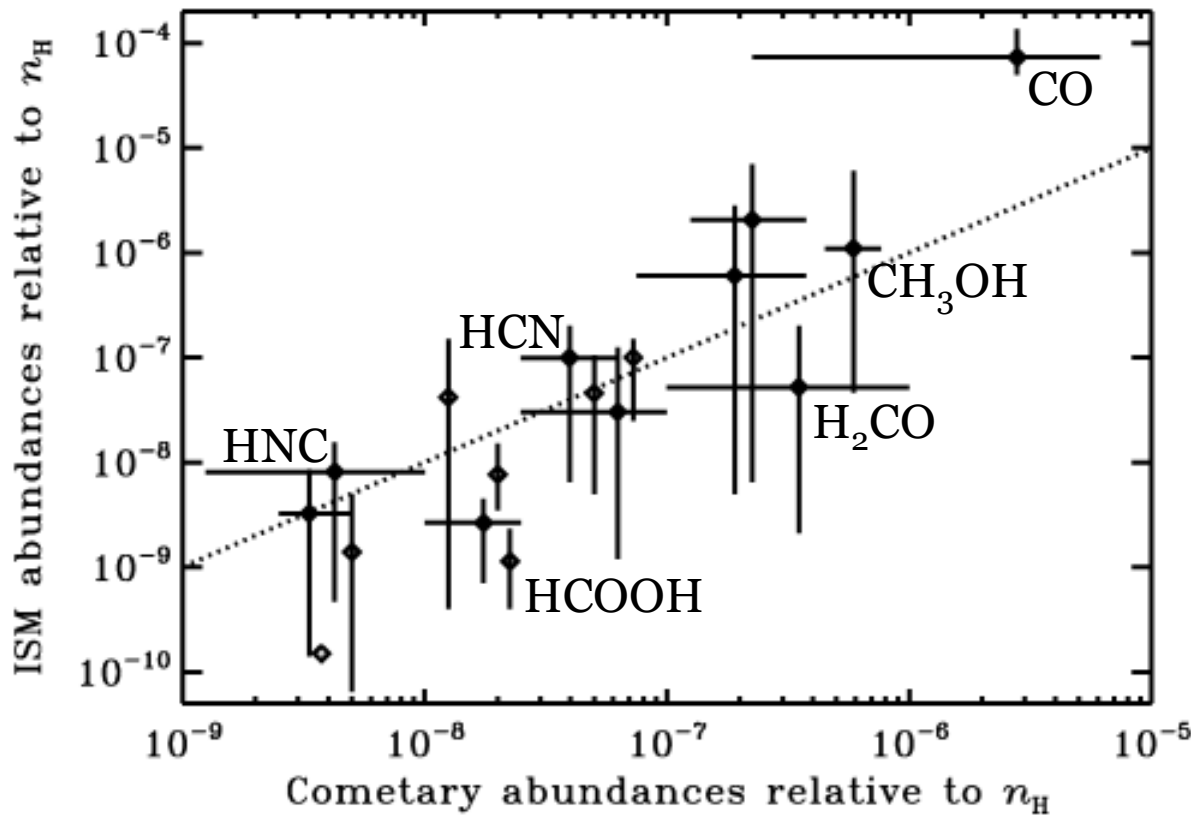


Open questions in star formation



- When is the disk first formed?
- How do its size and mass evolve?
- How does material flow onto it from the envelope?
- How do the early stages of star formation affect the outcome of planetary systems?
- Why are Uranus and Neptune rich in H_2O , NH_3 and CH_4 , while Jupiter and Saturn are not?
- What fraction of cometary ices is truly pristine?

Comets: a view of the past?



- Error bars indicate spread between sources
- Dotted line: hypothetical one-to-one relationship
- Comets in general similar to ISM, but individual differences exist

Chemical processes



CO

H₂

N₂

H

H₂

gas

dust grain

H

O

H

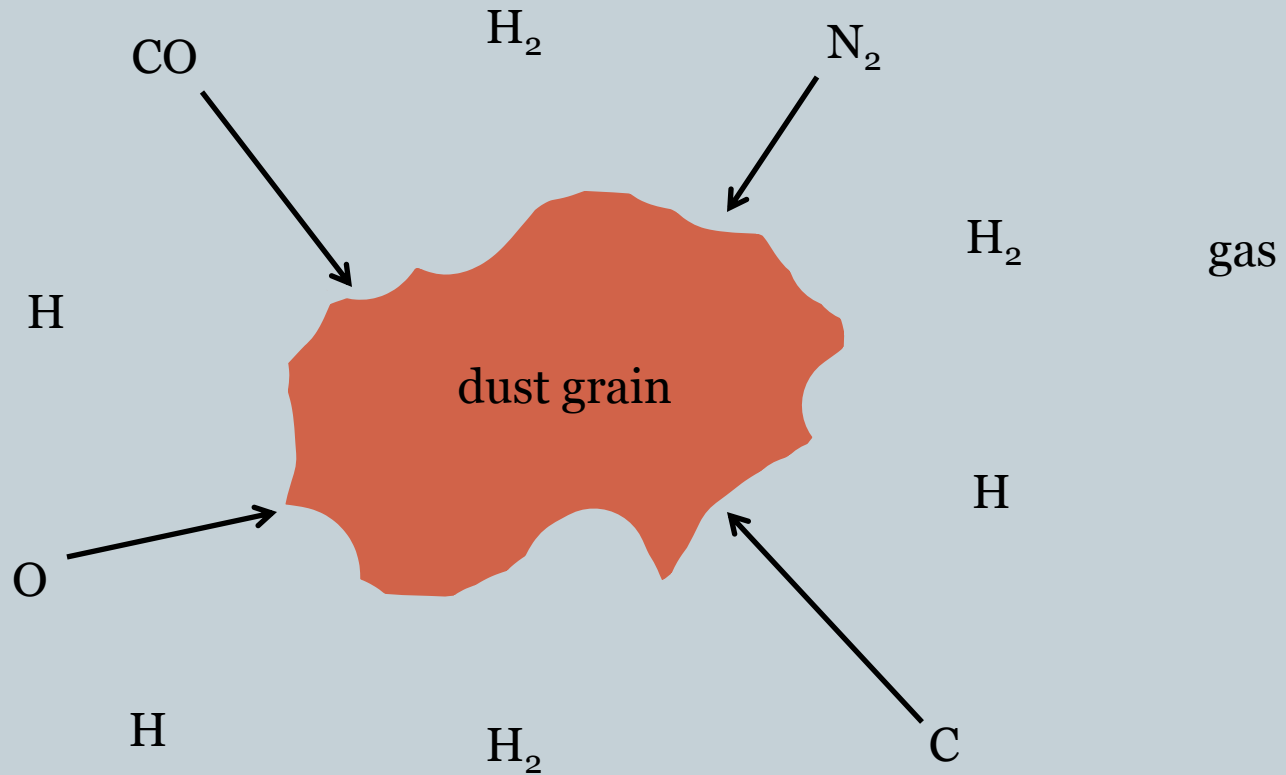
H₂

C

Chemical processes



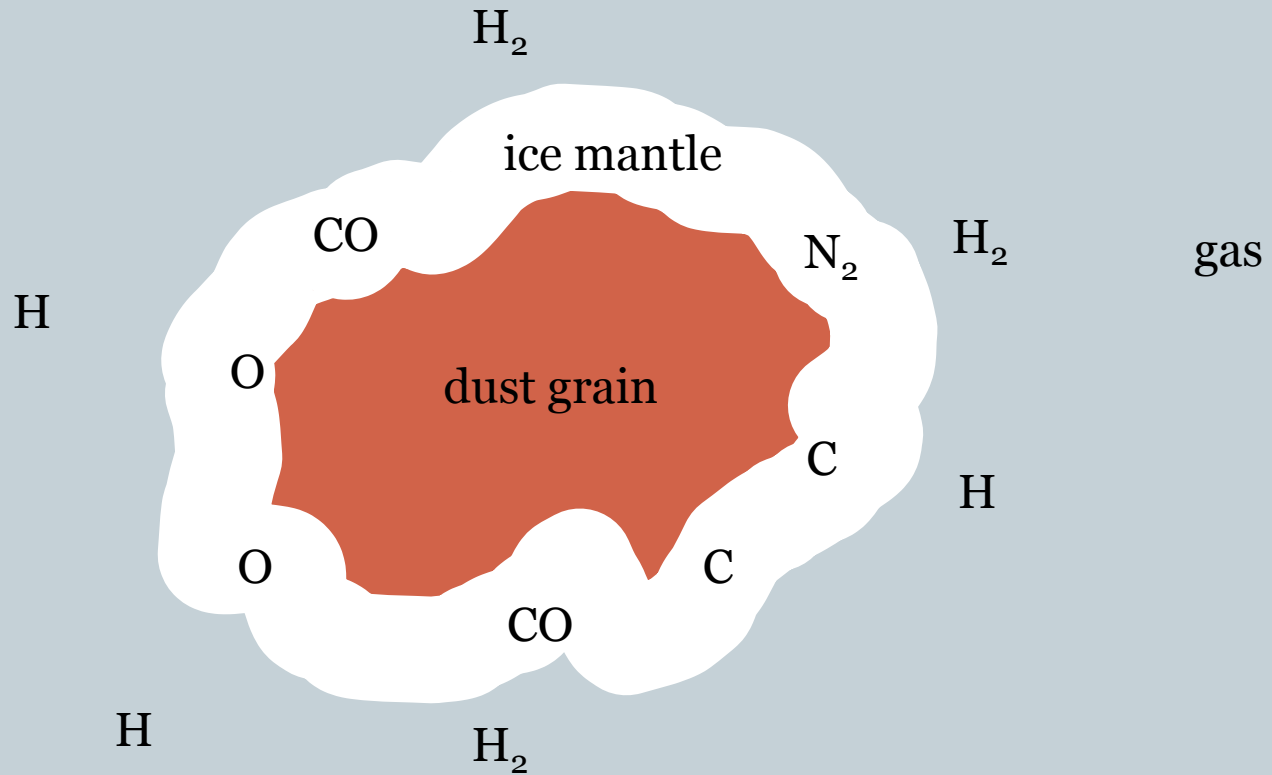
- Freeze-out



Chemical processes



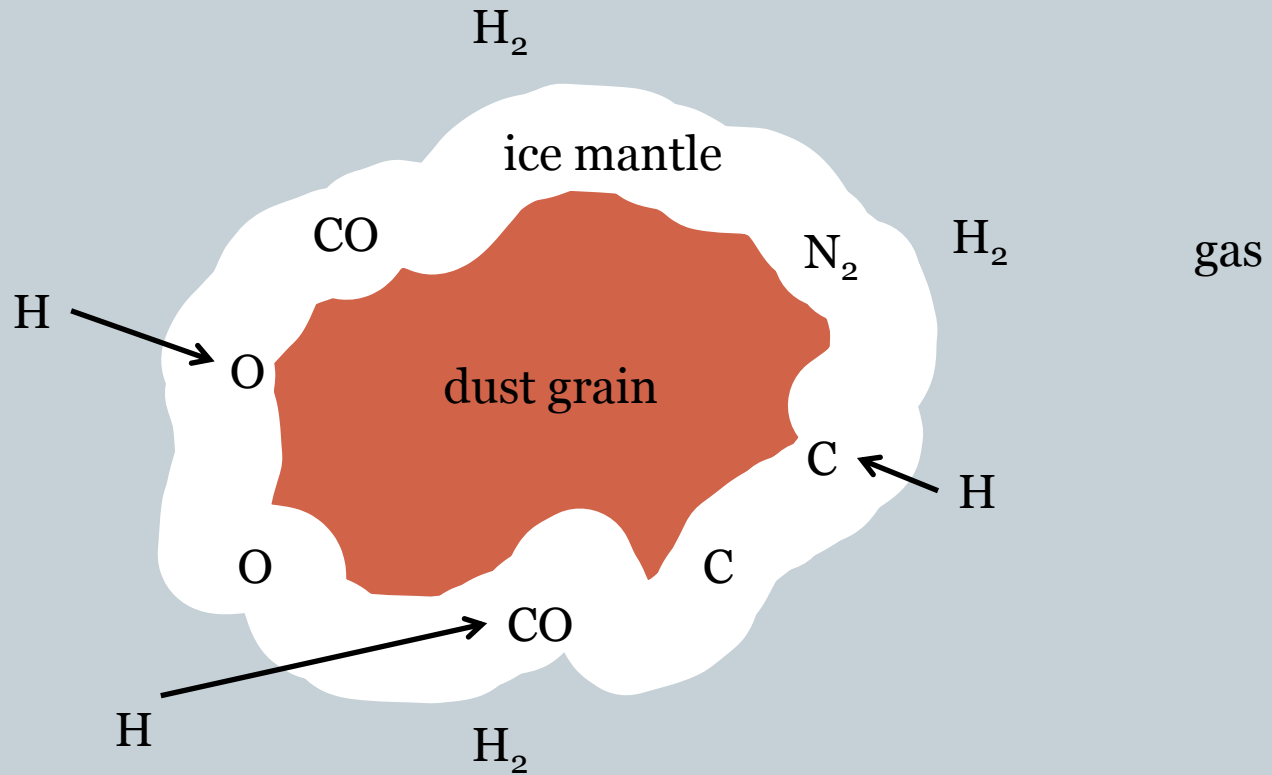
- Freeze-out



Chemical processes



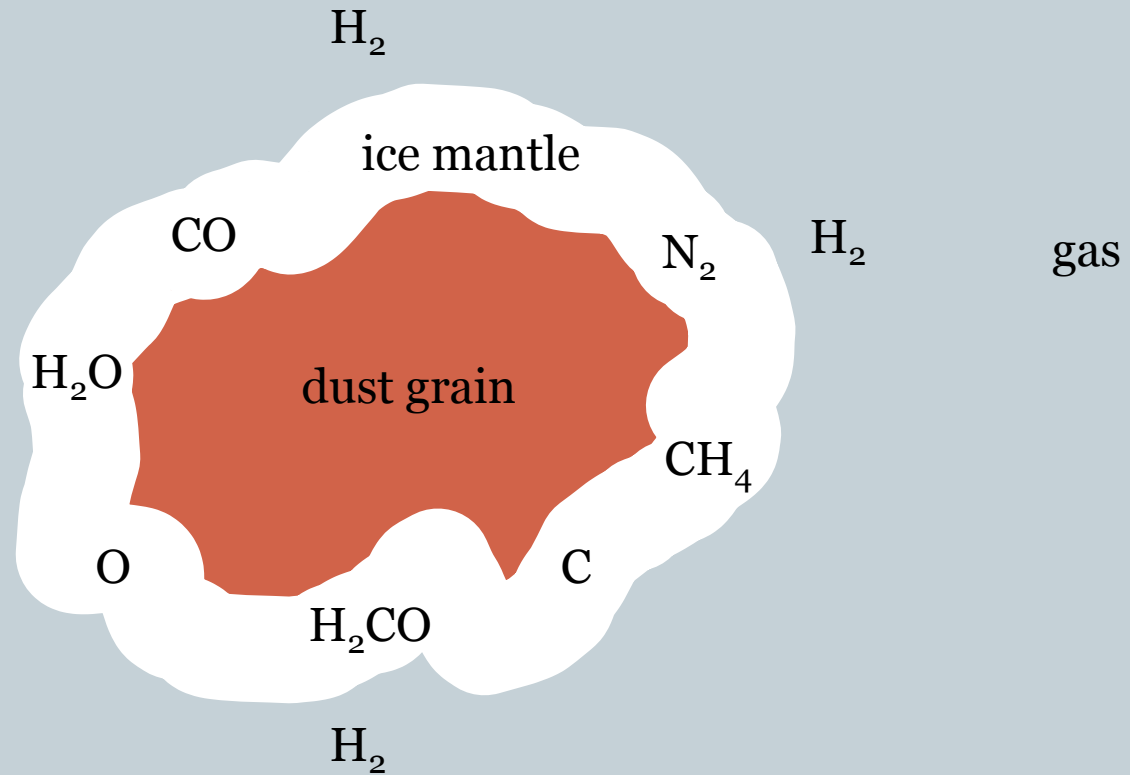
- Grain-surface hydrogenation



Chemical processes



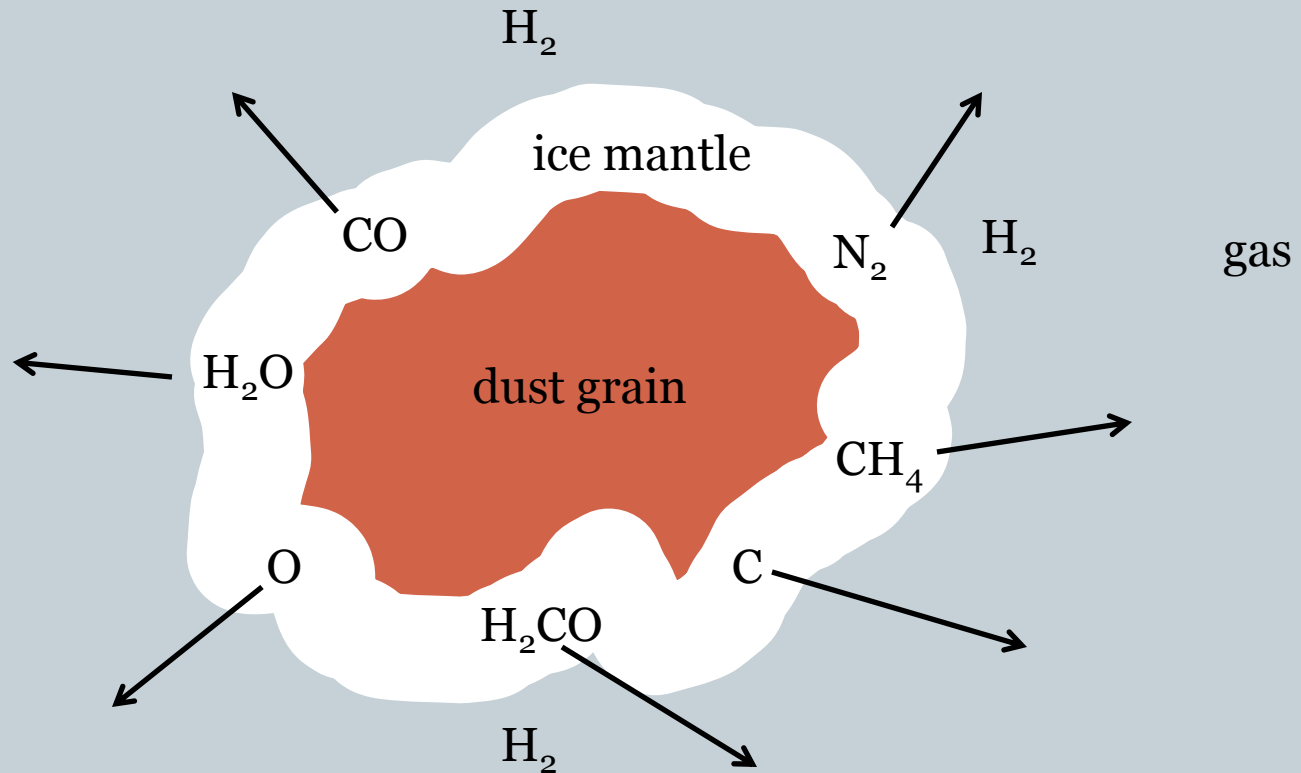
- Grain-surface hydrogenation



Chemical processes



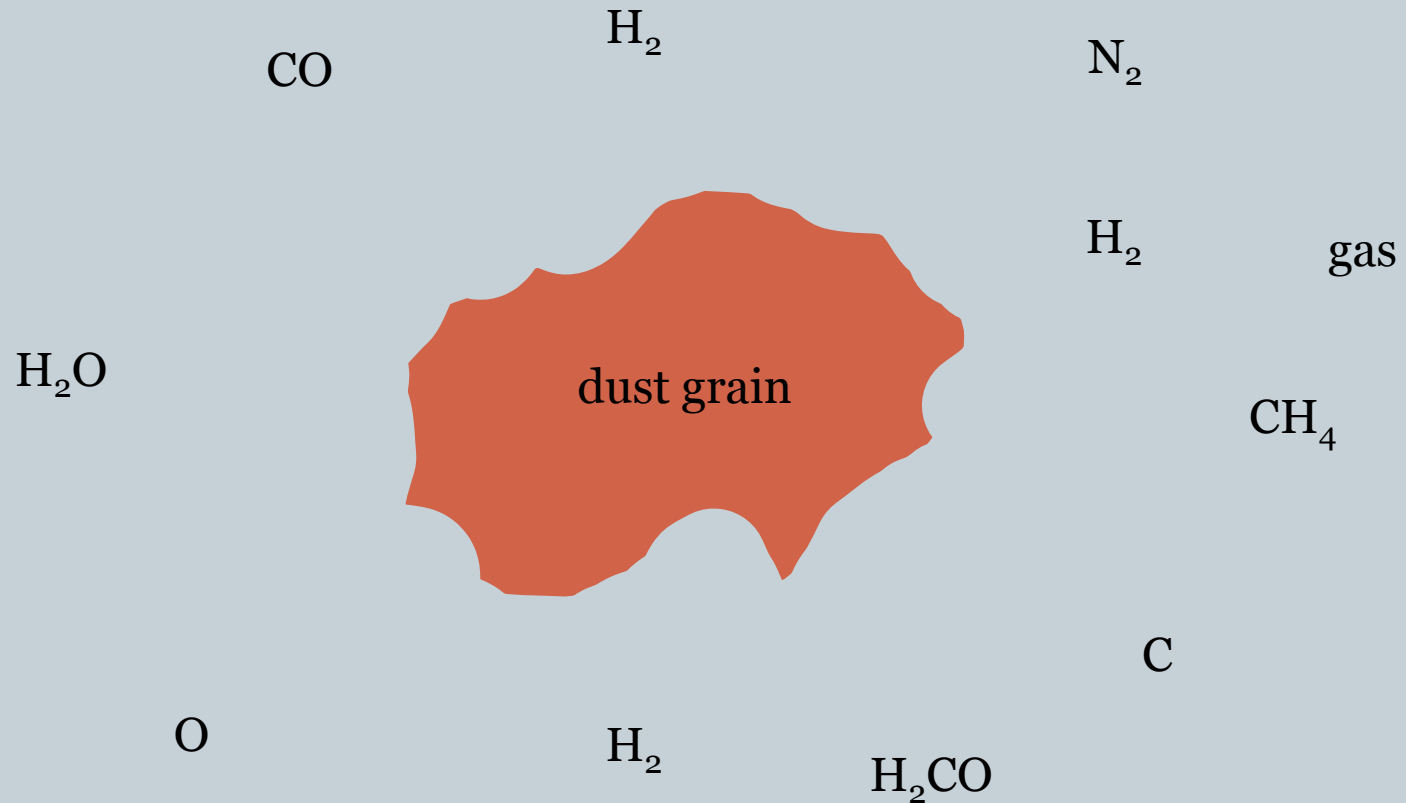
- Evaporation



Chemical processes



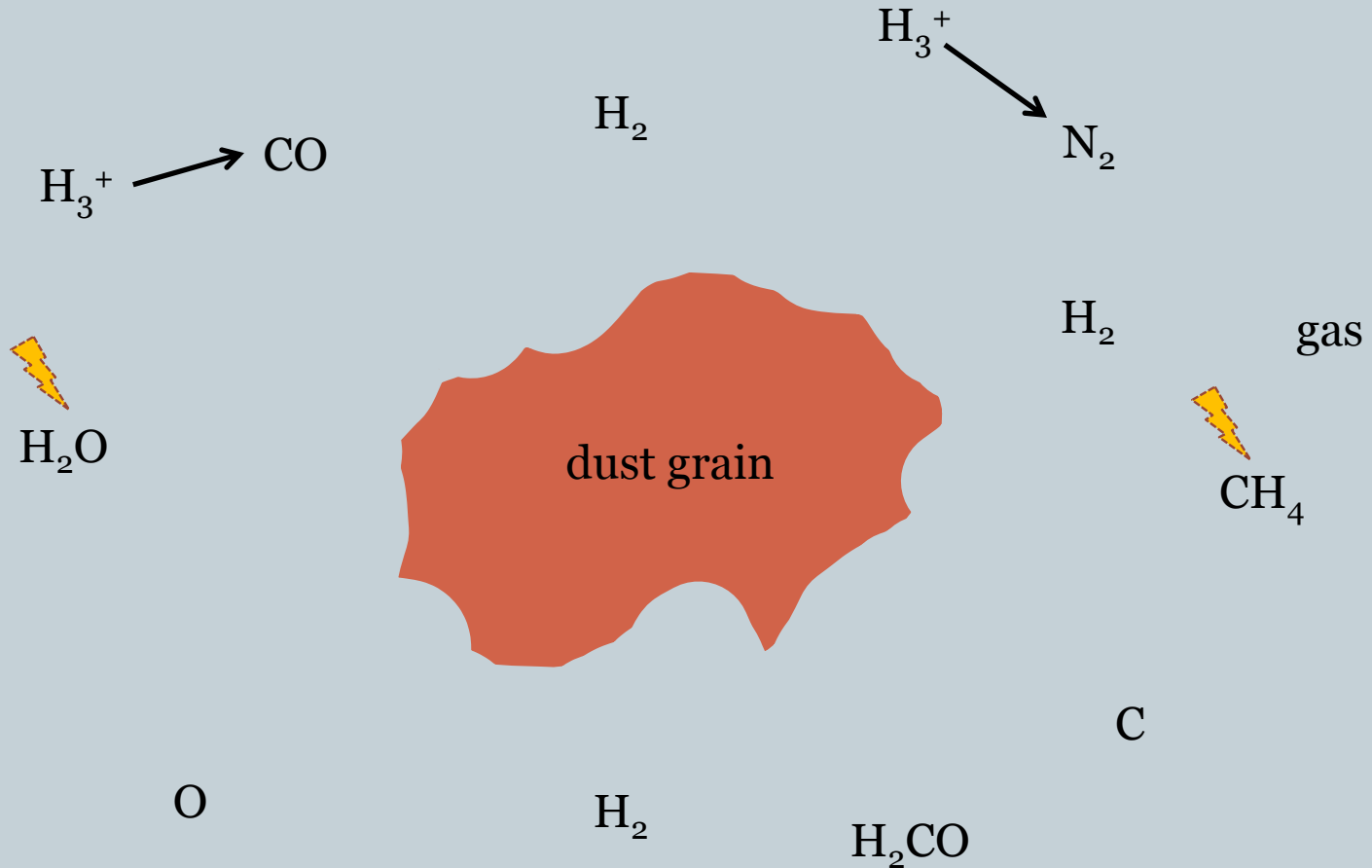
- Evaporation



Chemical processes



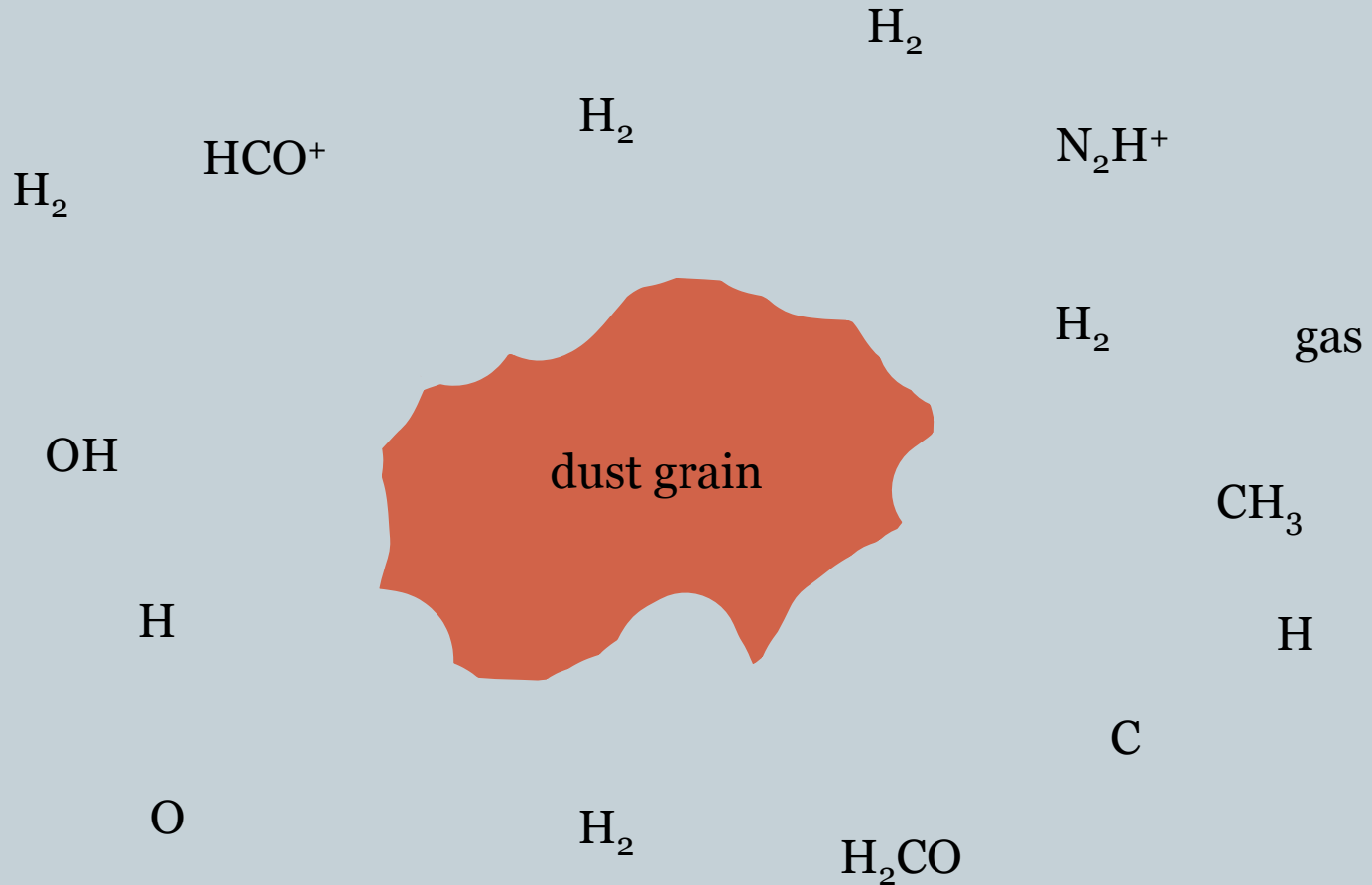
- Gas-phase processes



Chemical processes



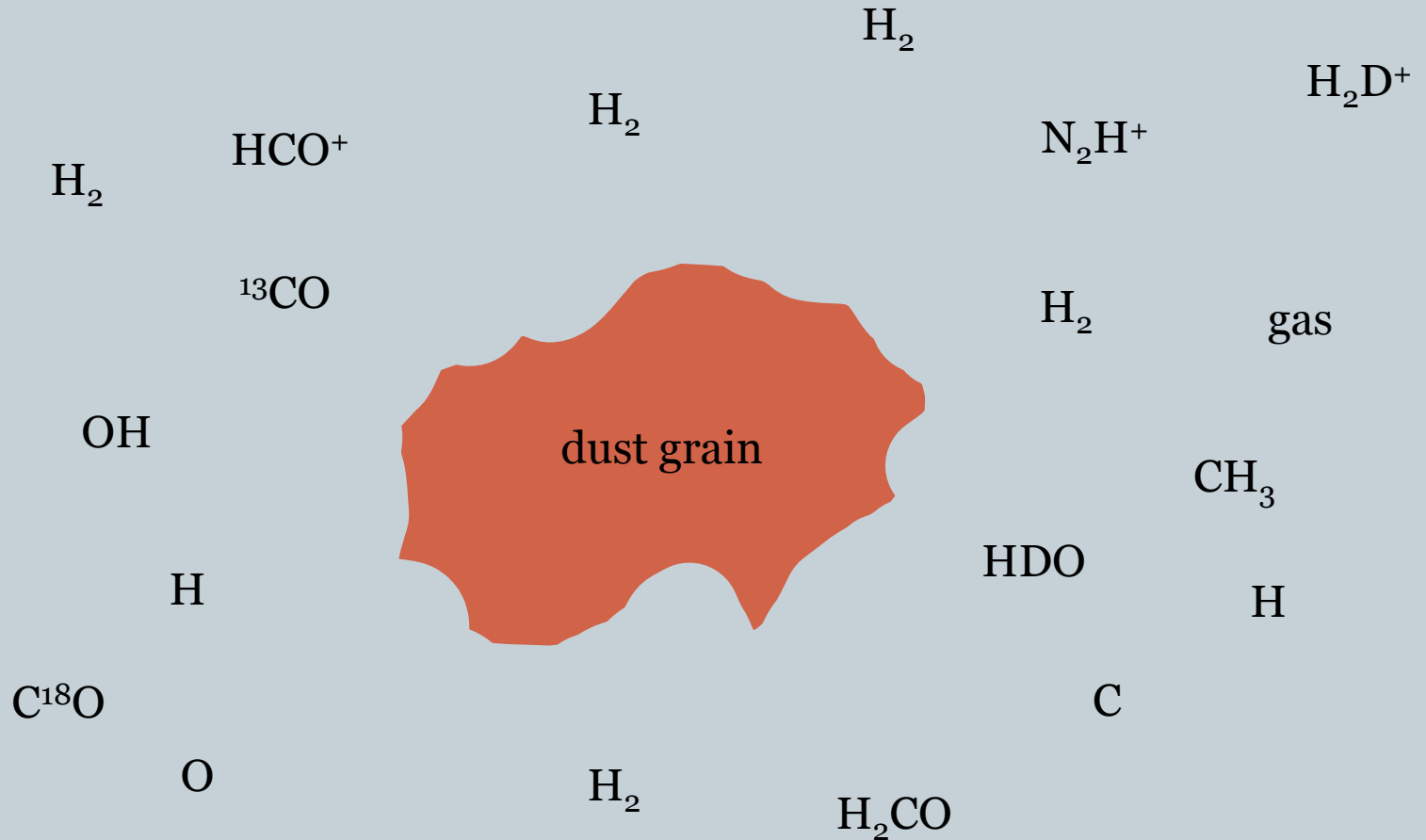
- Gas-phase processes



Chemical processes



- Isotopes



Outline



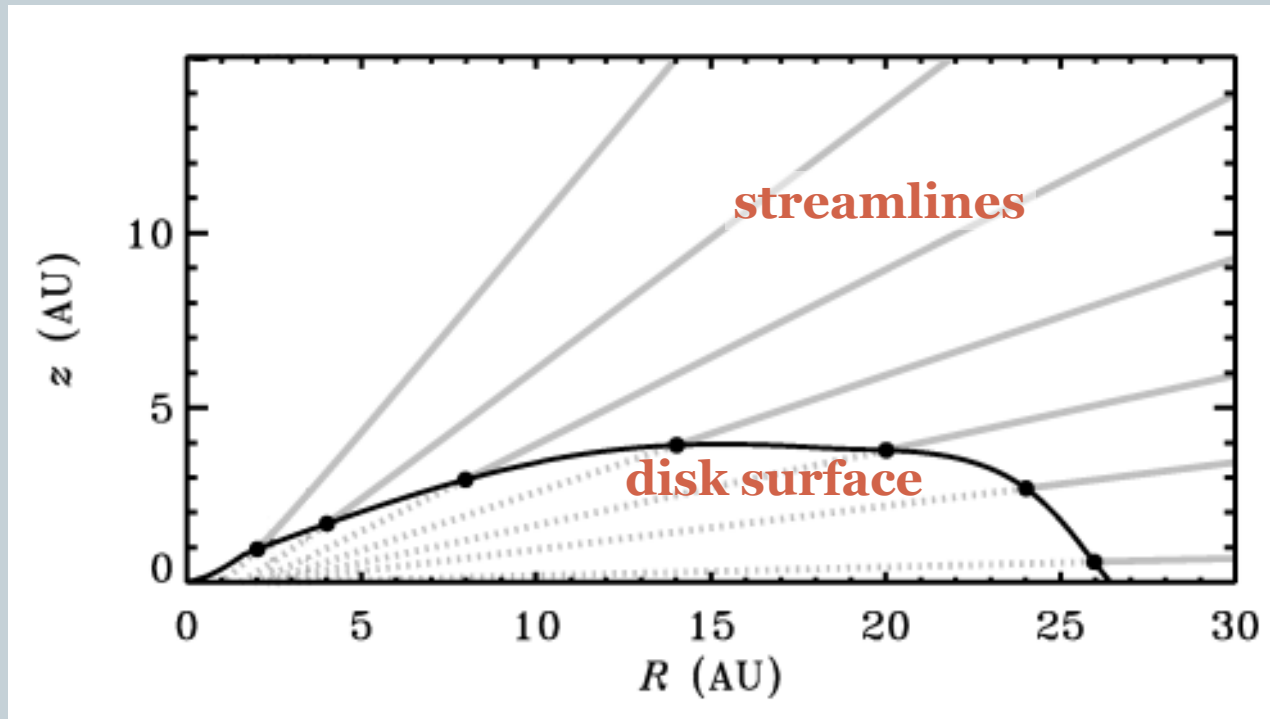
- Introduction and motivation
- **Model description**
- Results
 - Freeze-out and evaporation
 - Full chemistry
 - Silicate dust: amorphous vs. crystalline
- Herschel: WISH
- Conclusions and outlook

Analytical star formation model in 2D



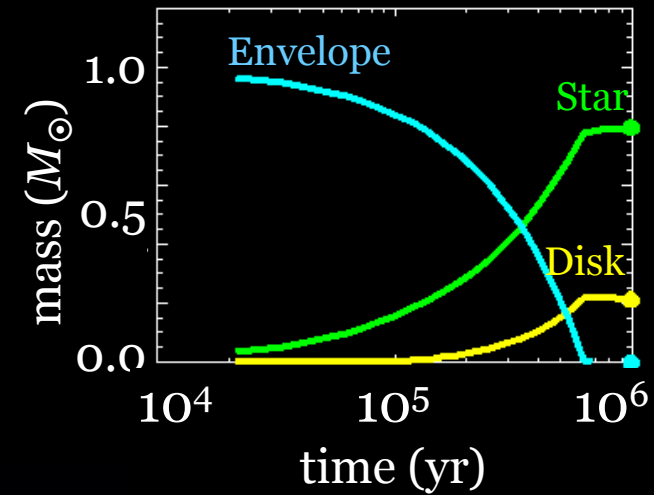
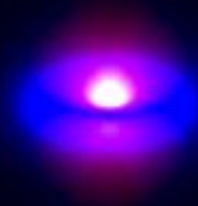
- Fast to run, high resolution, easy to change initial conditions
Cloud mass (M_o), rotation rate (Ω_o), sound speed (c_s), ...
- Density & velocity: inside-out collapse
- Viscously evolving disk ($\alpha=0.01$)
- Dust temperature (important!) from full radiative transfer
- Physics compare well with hydrodynamical models
- Density profiles compare well with observations
- Refs.: Shu (1977), Cassen & Moosman (1981), Yorke & Bodenheimer (1999), Dullemond & Dominik (2004), Brinch et al. (2008a,b), Jørgensen et al. (2009)

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

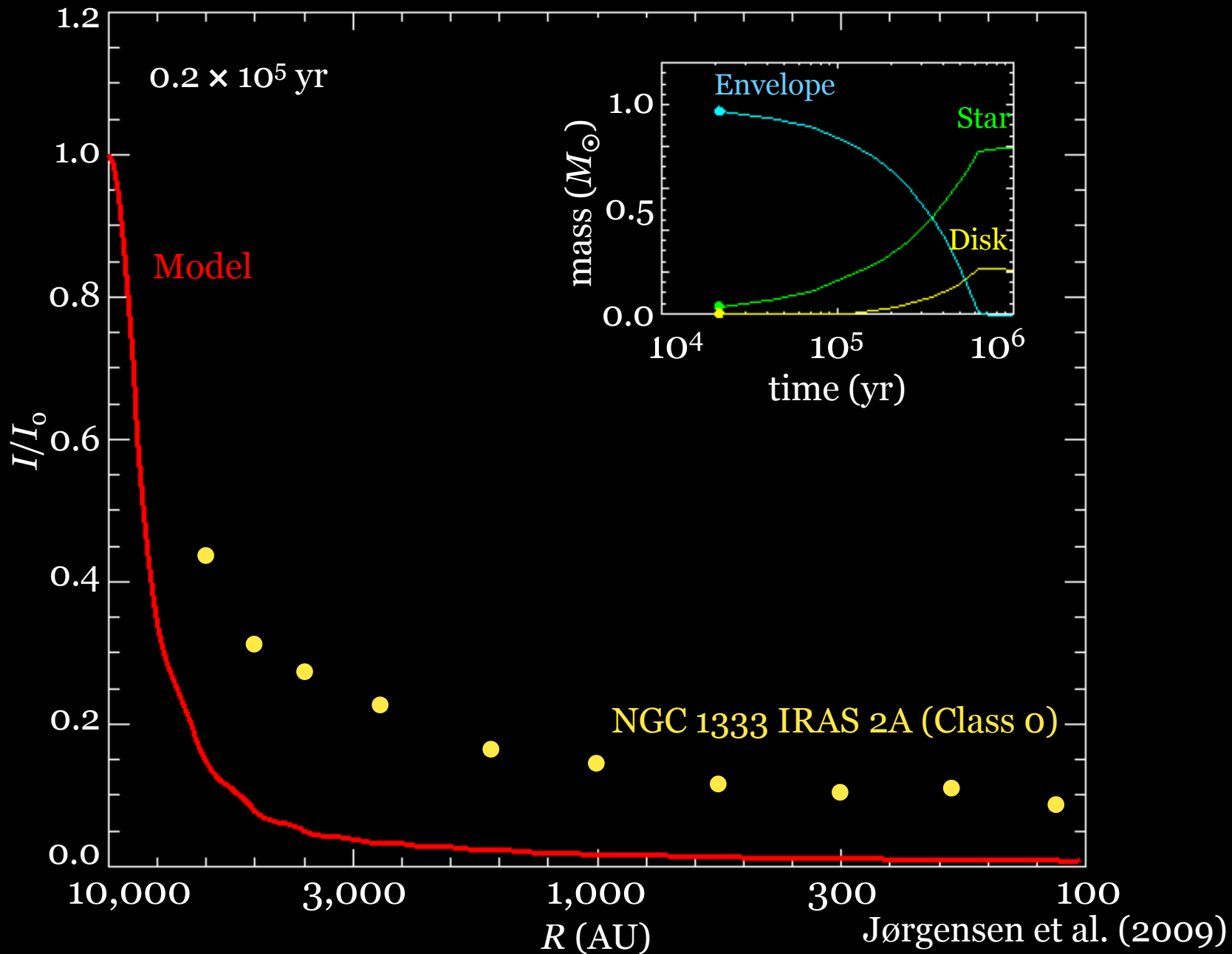
Infrared/submm image of collapsing core



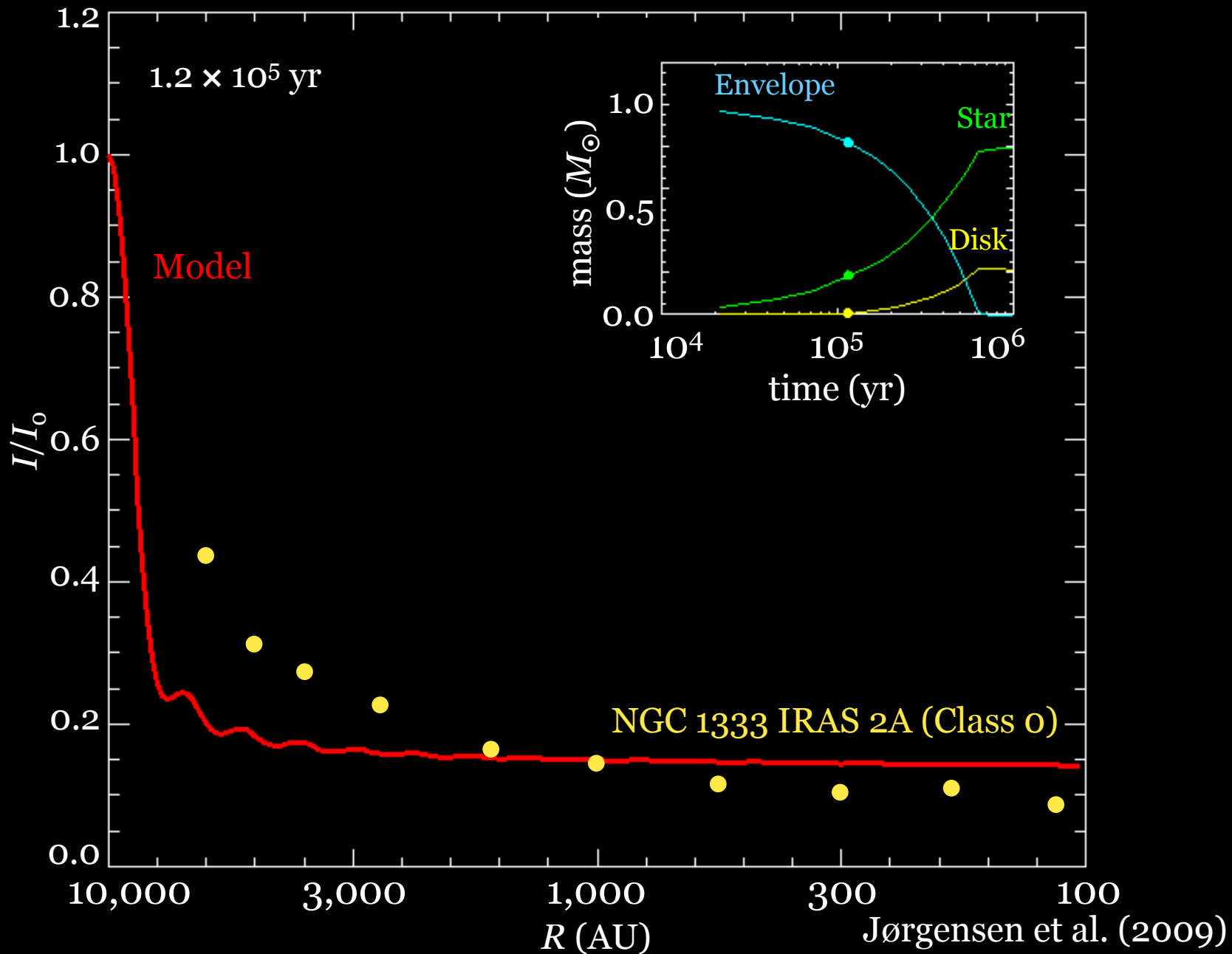
2000 AU

850 μm , 24 μm , 8.0 μm

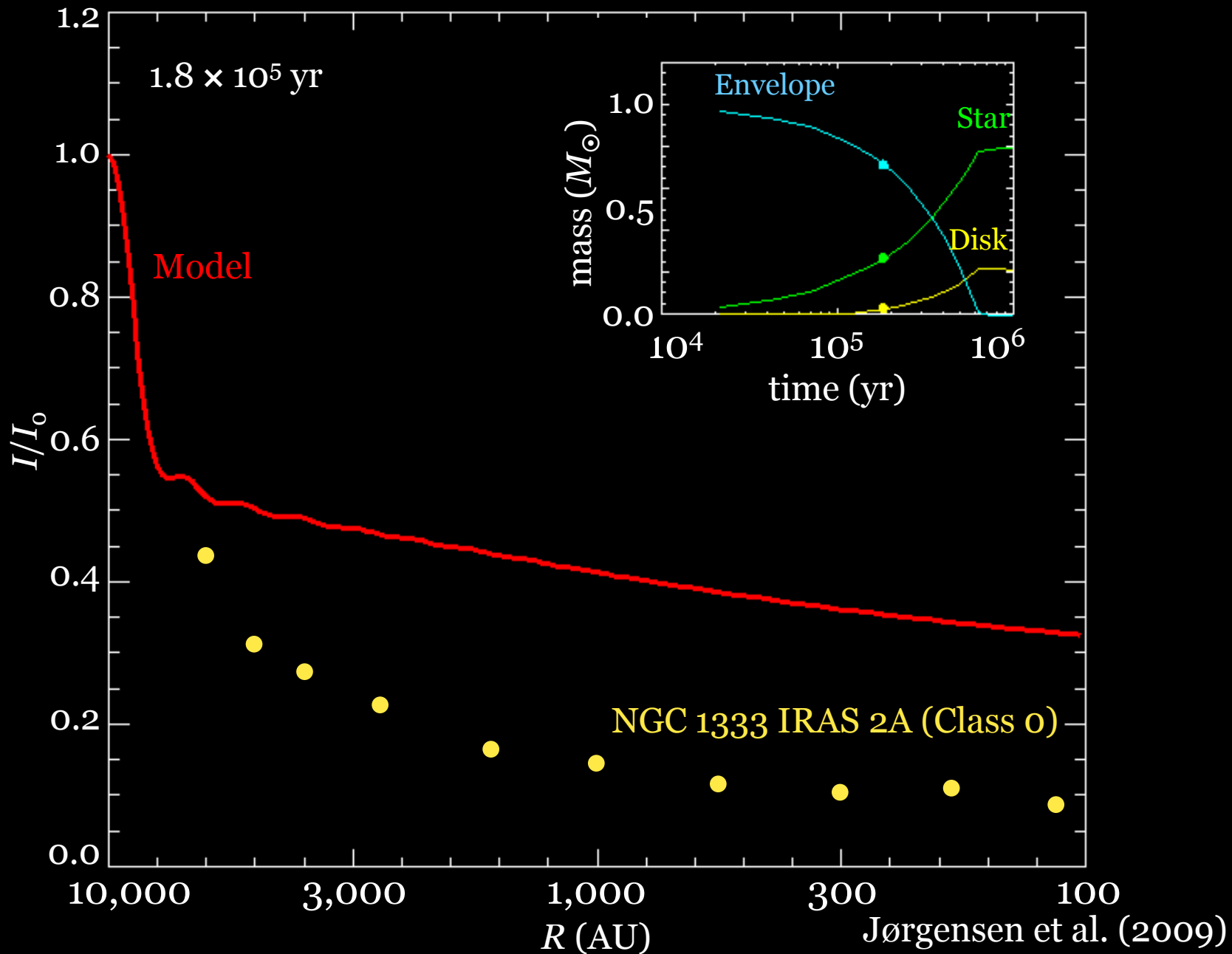
Sub-mm model visibilities (350 GHz/850 μm)



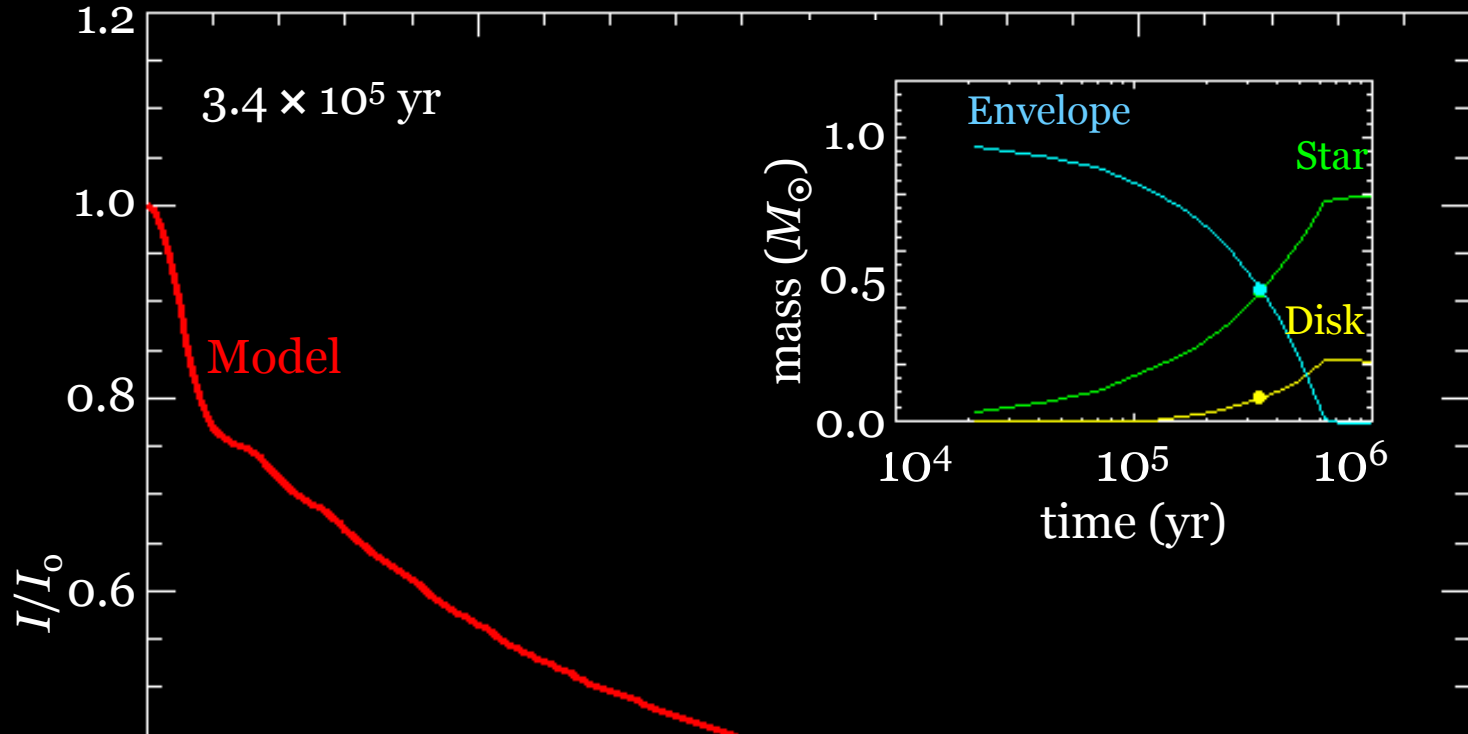
Sub-mm model visibilities (350 GHz/850 μm)



Sub-mm model visibilities (350 GHz/850 μm)



Sub-mm model visibilities (350 GHz/850 μm)



How about molecular line interferometry?

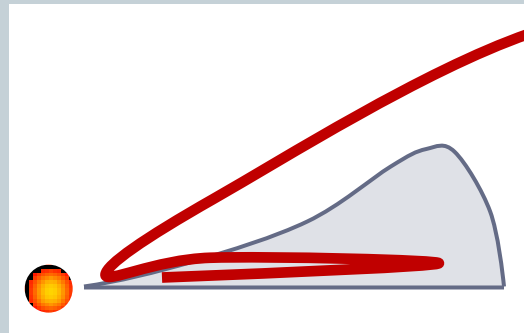
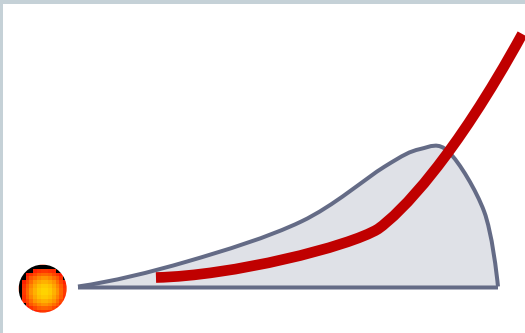
Working on it...



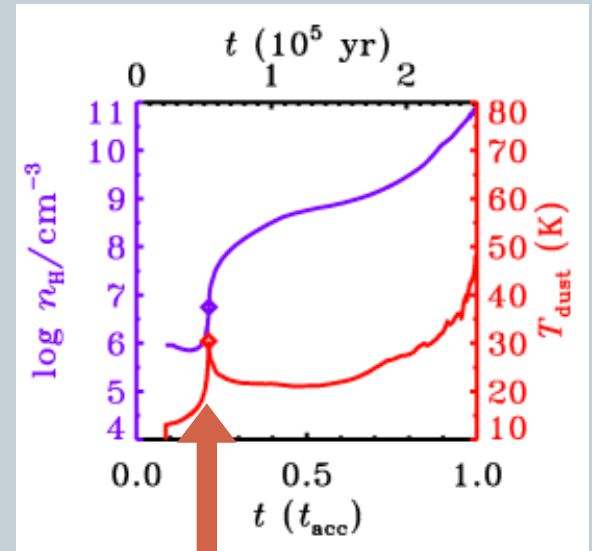
Infall trajectories



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



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

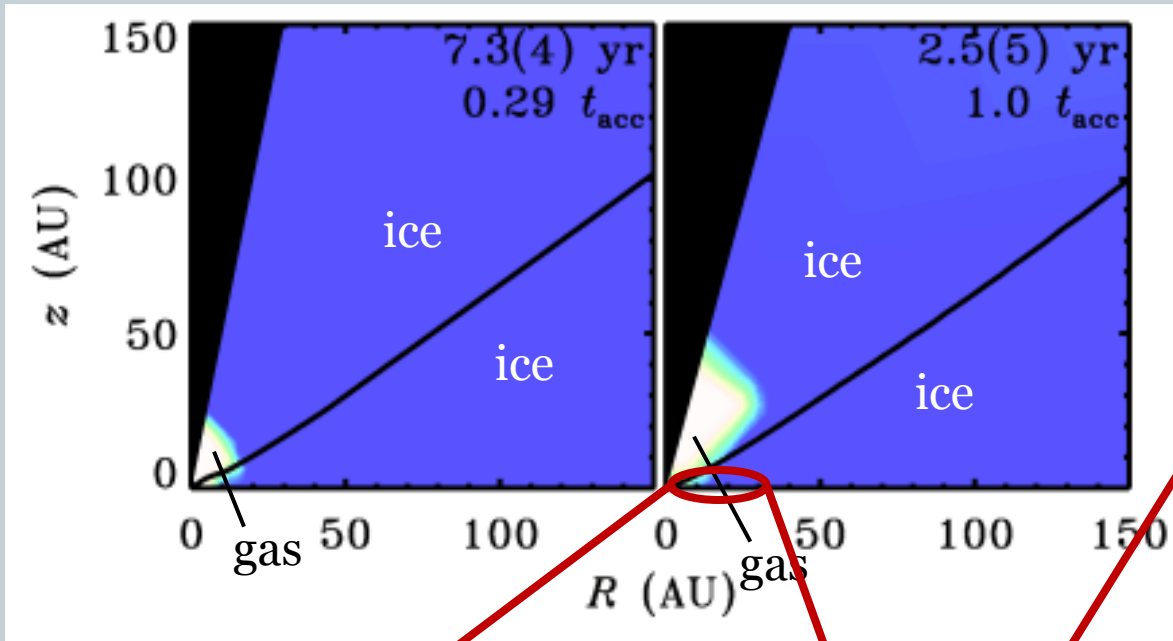


Outline



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

Gas and ice: H₂O

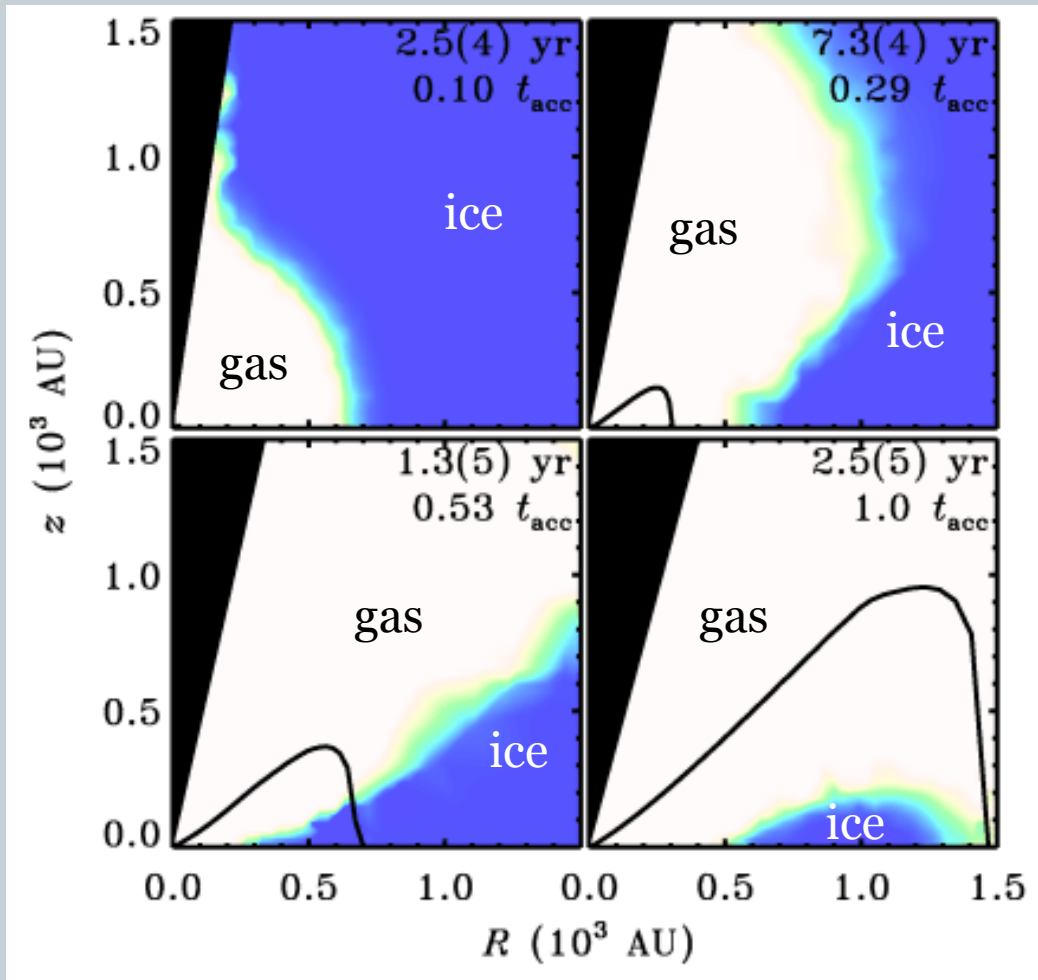


blue: all ice
 white: all gas
 black: outflow
 black curve: disk surface

$M_o = 1.0 M_{\text{sun}}$
 $\Omega_o = 10^{-13} \text{ s}^{-1}$
 $c_s = 0.26 \text{ km s}^{-1}$

- H₂O remains solid except inner ~5 AU
- H₂O in comet-forming zone, depending on parameters:
 - either unprocessed (always frozen)
 - or processed (evaporated and re-frozen)

Gas and ice: CO



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

$$M_o = 1.0 M_{\text{sun}}$$
$$\Omega_o = 10^{-13} \text{ s}^{-1}$$
$$c_s = 0.26 \text{ km s}^{-1}$$

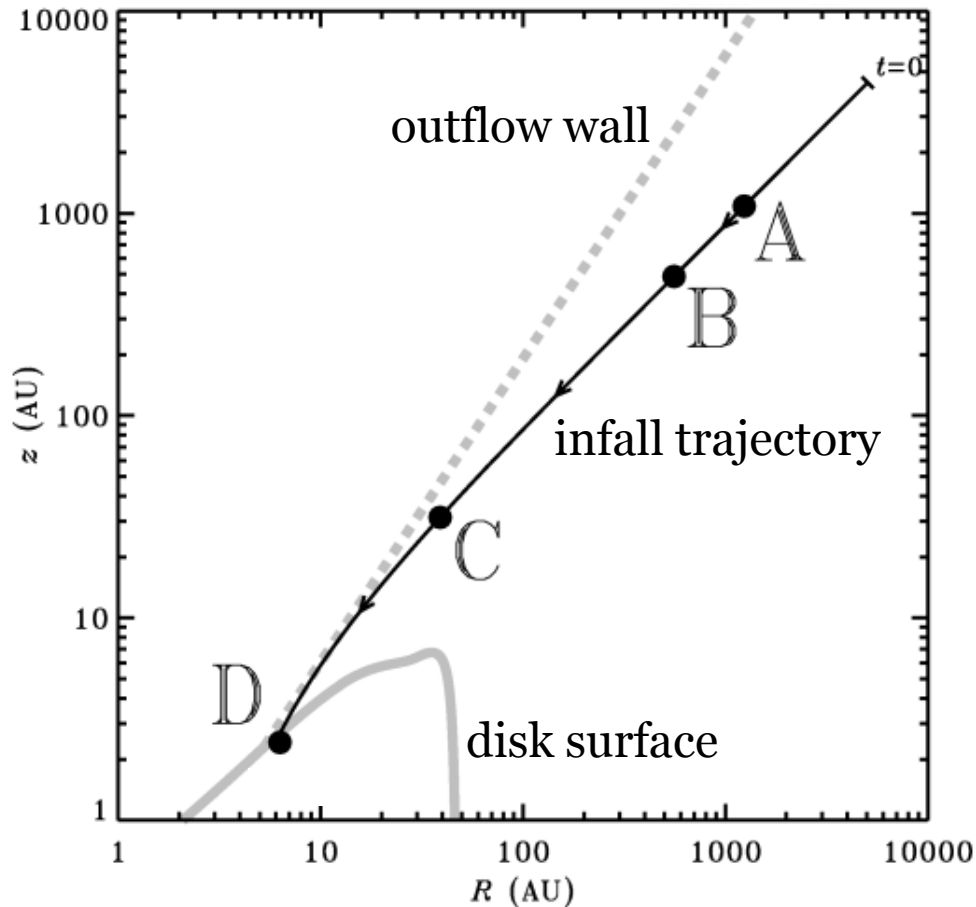
CO desorbs during infall, re-adsorbs in disk below 18 K

Outline



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

Full chemistry along one trajectory



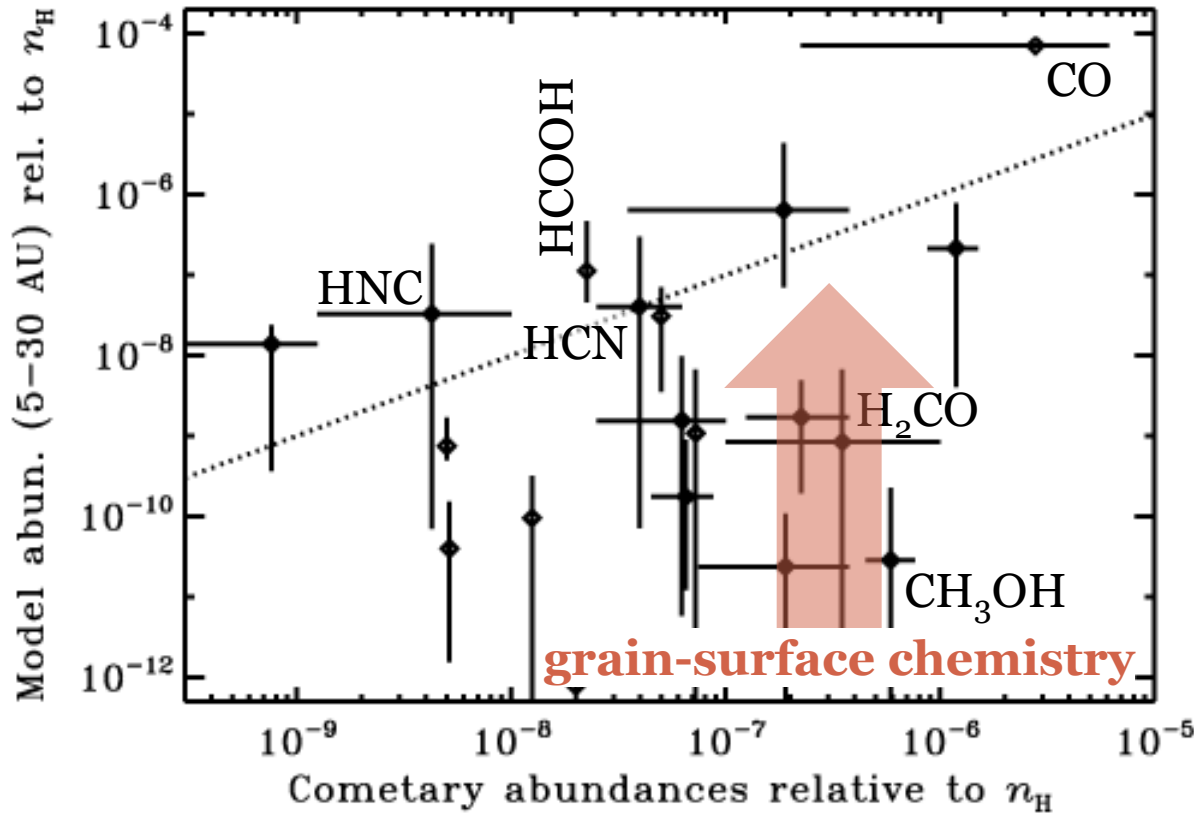
A: volatiles evaporate
(e.g. CO, N₂)

B: intermediates evaporate
(e.g. CH₄, NO)

C: strongly bound ices
evaporate (e.g. H₂O,
NH₃, CH₃OH)
photodissociation of
many species

D: some species reformed

Implications for comets



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

Outline



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

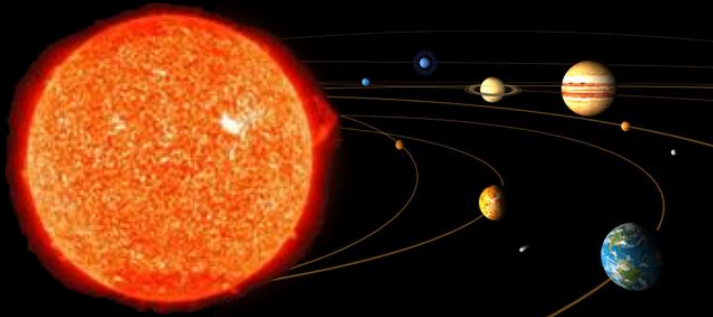
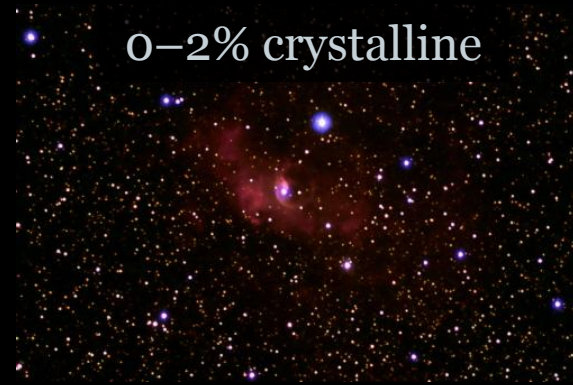
From crystalline to amorphous and back



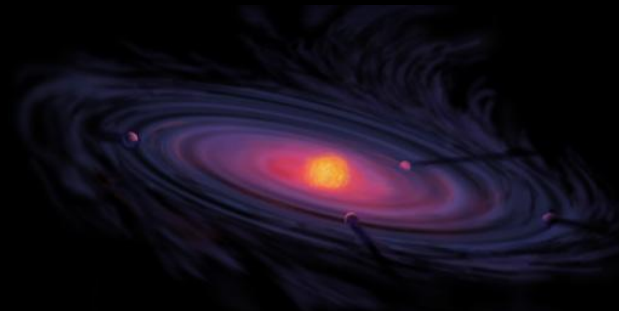
up to 50% crystalline



0-2% crystalline



up to 50% crystalline

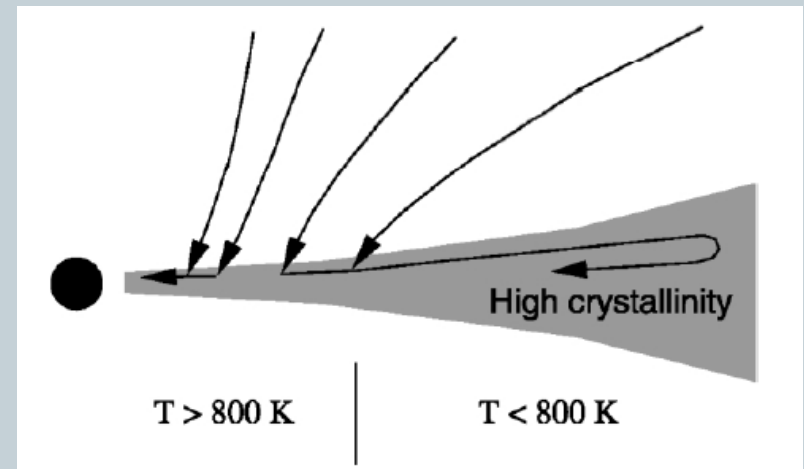


1-30% crystalline

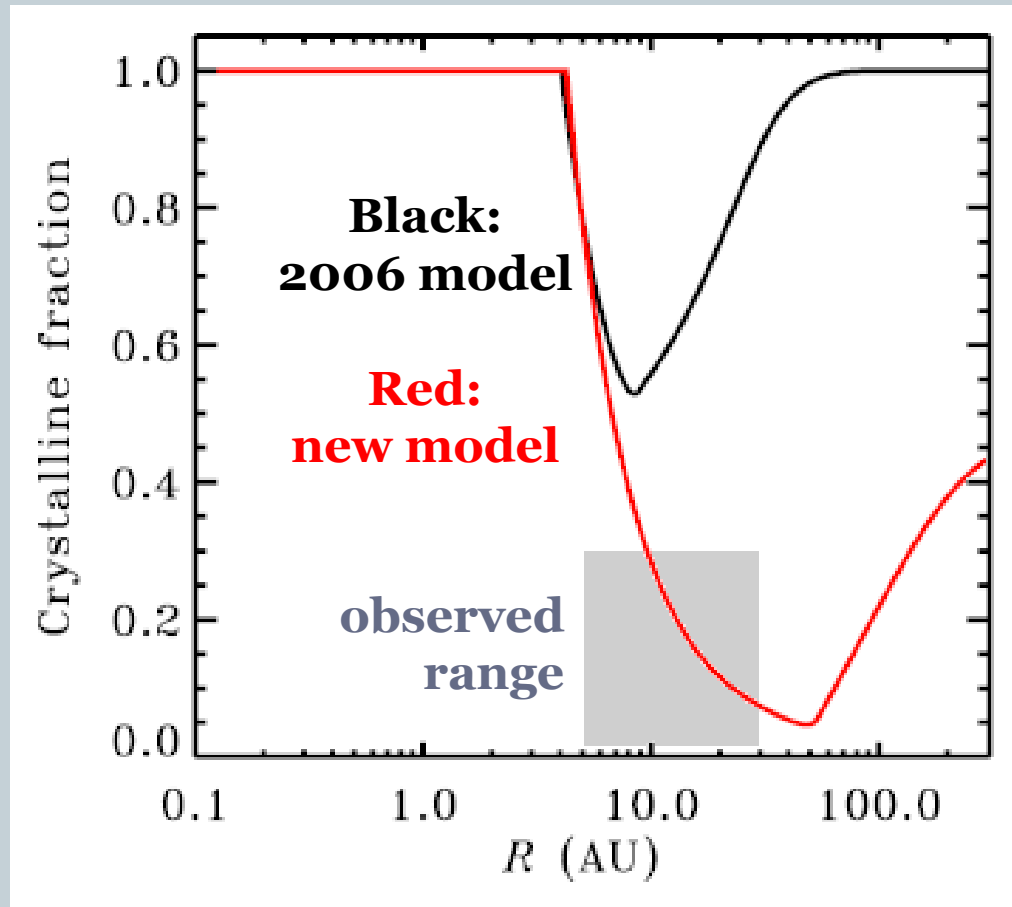
Origin of crystalline silicates in disks



- 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!

Outline



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

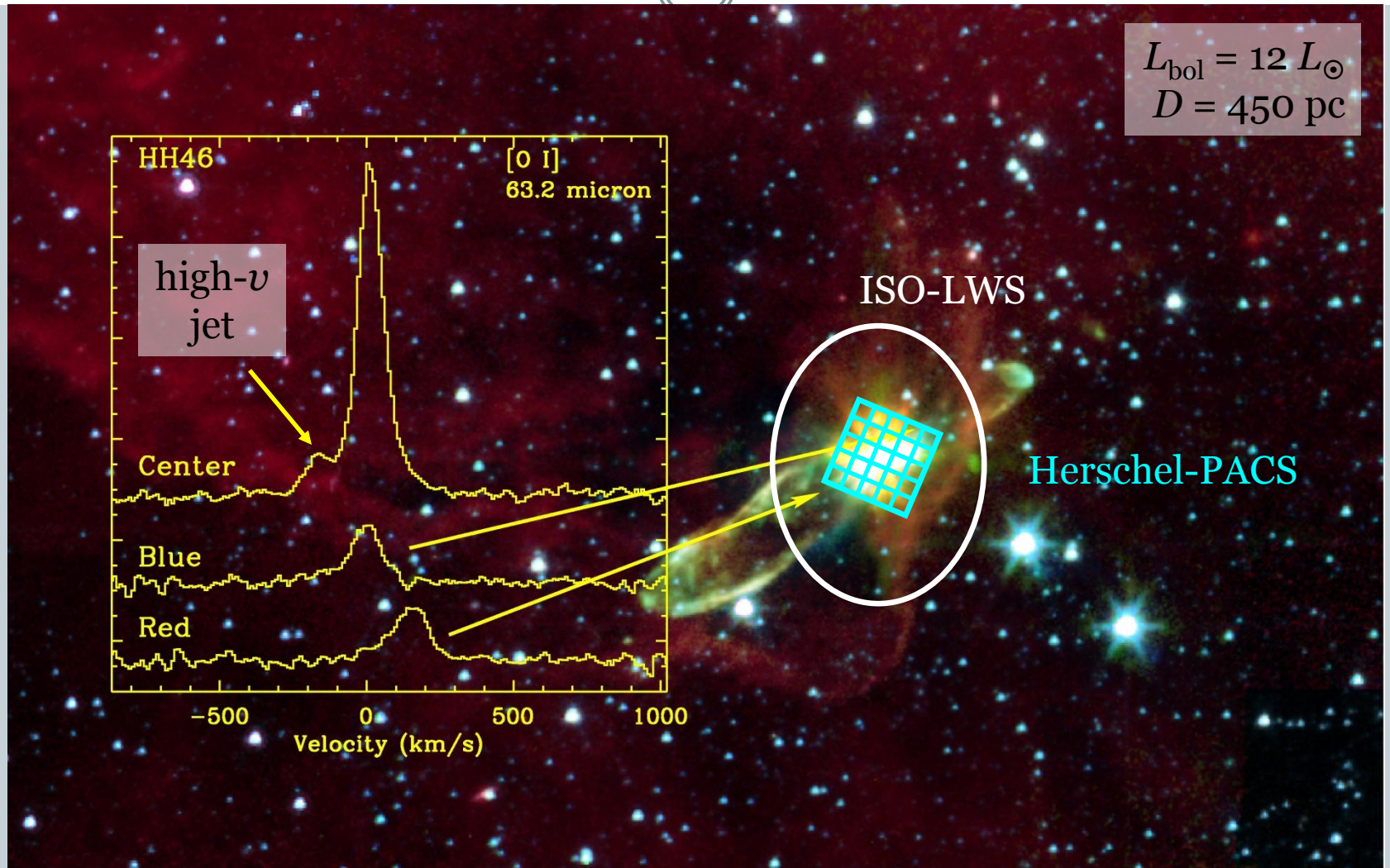
Water and CO with Herschel



- WISH: Water In Star-forming regions with Herschel
- PI: Ewine van Dishoeck
- 429-hr GT key program, focus on water
- ~90 sources from pre-stellar cores to disks
- Science demonstration phase:
 - L 1157: low-mass Class 0
 - HH 46: low-mass Class I
 - NGC 7129: intermediate-mass Class 0

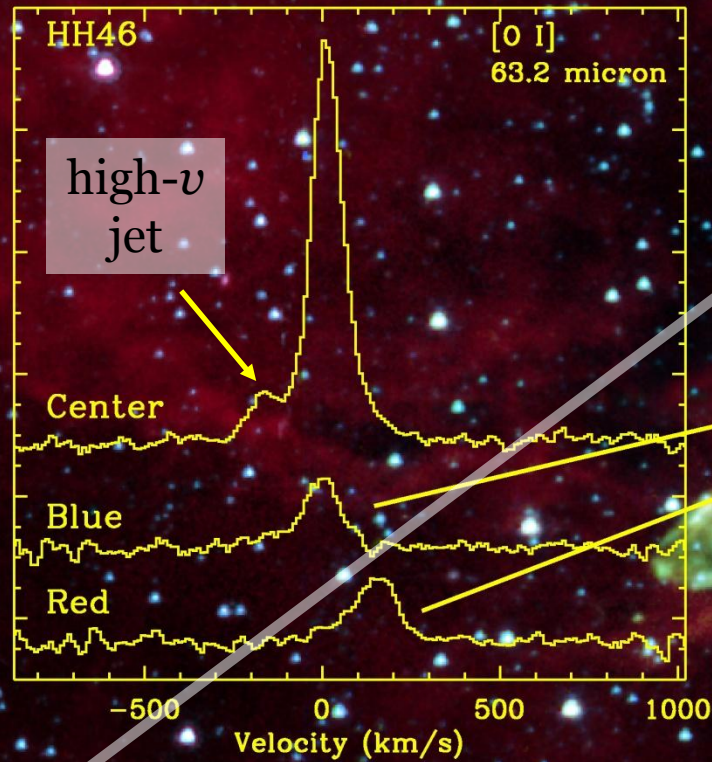


[O I] in low-mass YSO HH46

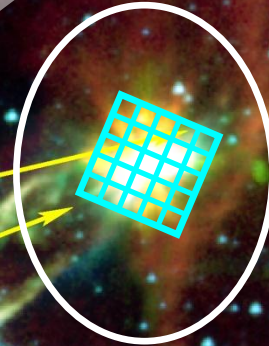


Spitzer image: Noriega-Crespo et al. (2004)

[O I] Spatial distribution in HH46



ISO-LWS



Herschel-PACS

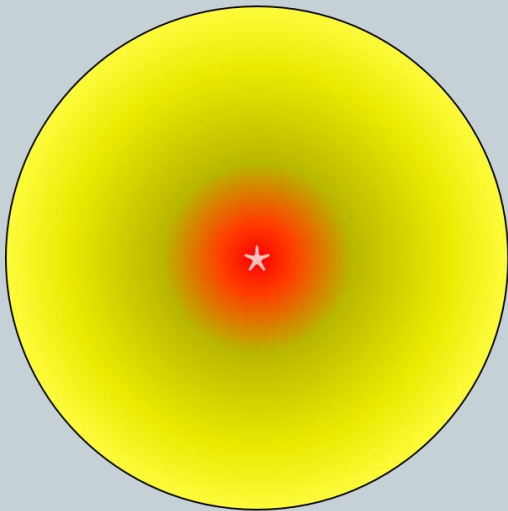
$\Delta \theta_{bb2}$ extended
along outflow

[O I] falling
off faster
along outflow
than H_2O

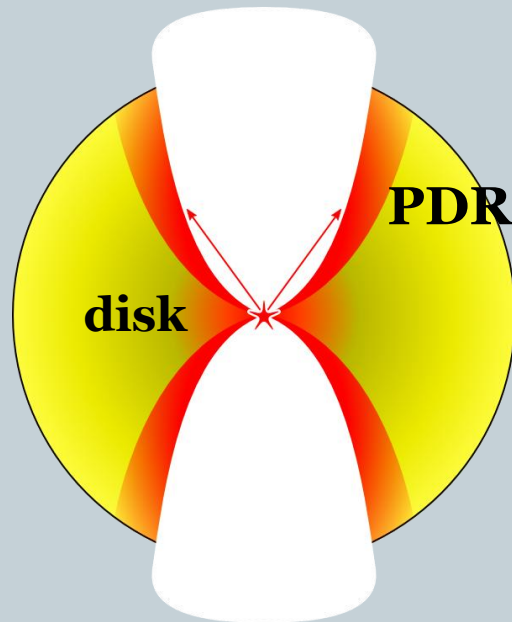
on source

Spitzer image: Noriega-Crespo et al. (2004)

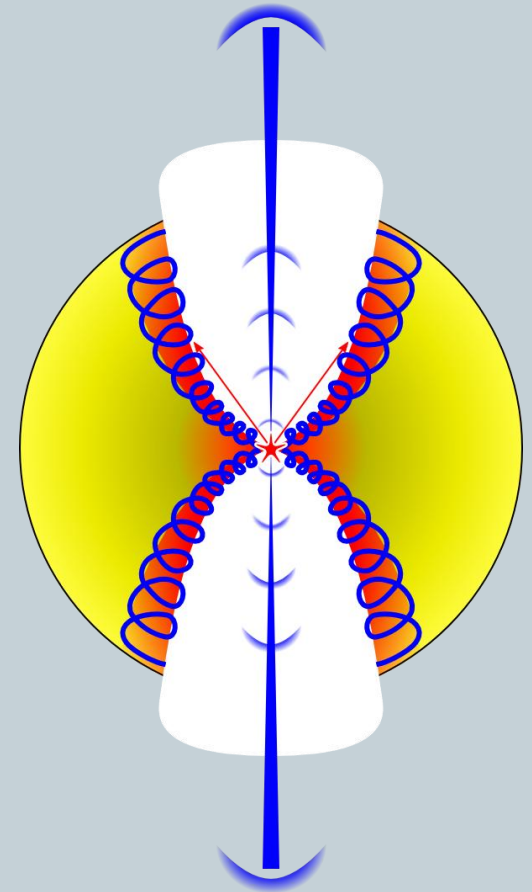
Dominant physical components?



Protostellar
envelope
with hot core

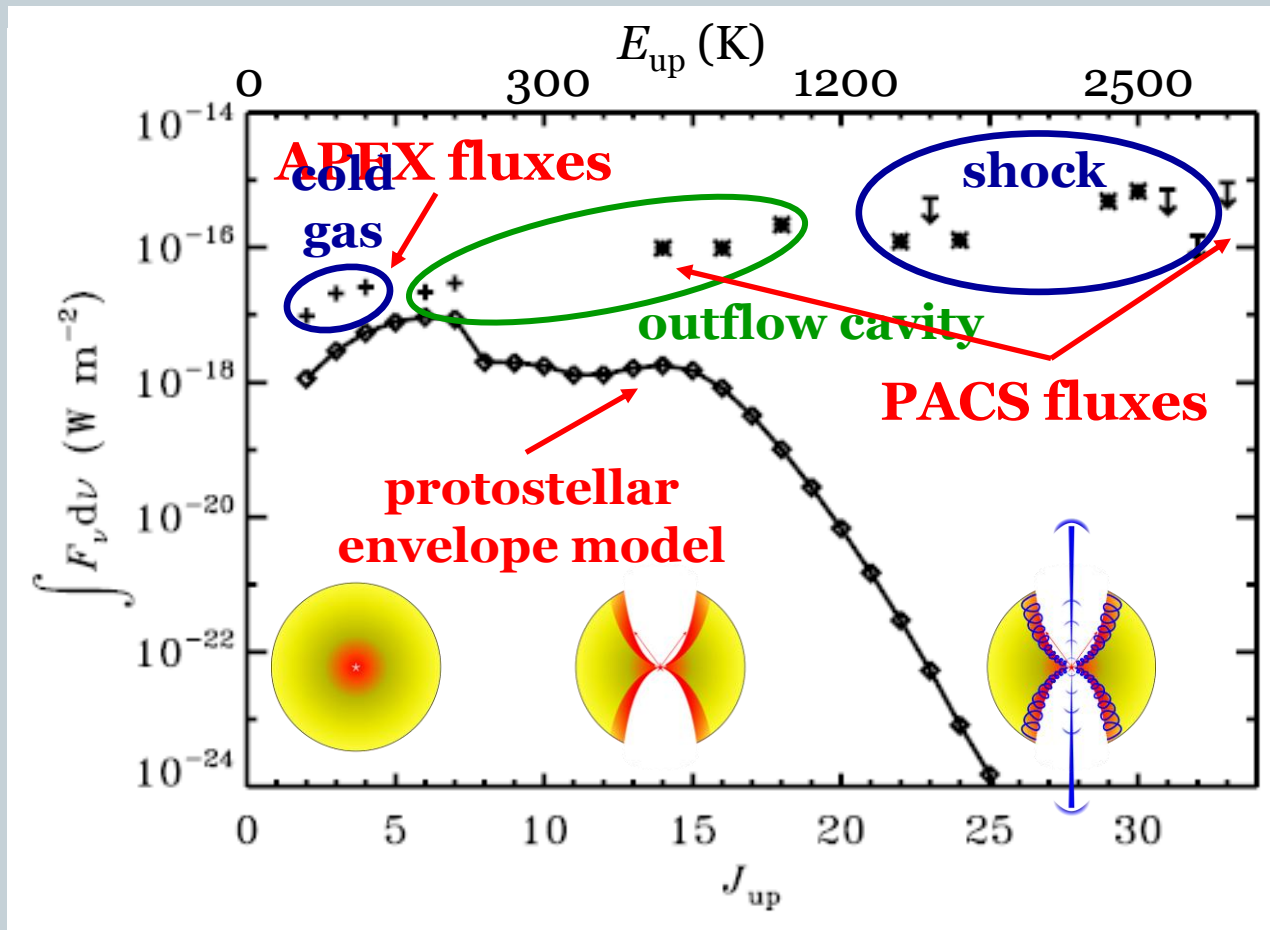


Cavity walls,
disk surface



Outflow shocks

Origin of hot CO?



Outline



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

Conclusions



- Chemical evolution is an integral part of star formation
- First model to follow chemistry from pre-stellar cores to circumstellar disks in 2D
- Results look promising, but many challenges remain
- First Herschel results (H_2O , CO, O I, OH) offer new insights into star formation

Future work



- How do line profiles change in time?
 - Compare with observations by SMA, JCMT, IRAM 30m, ...
 - Analyse WISH data from Herschel
 - Make predictions for ALMA
- When and where are the complex organics formed?
- New challenges, new possibilities: isotopes
- 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

- **Collapse model**

- Steve Doty

- Kees Dullemond

- Jes Jørgensen

- Christian Brinch

- Michiel Hogerheijde

- **CO photodissociation**

- John Black

- **WISH**

- EvD, SD, CB, MH

- Lars Kristensen

- Tim van Kempen

- Greg Herczeg

- Umut Yıldız

- Simon Bruderer

- Susanne Wampfler

- Arnold Benz

- Brunella Nisini

- ... many more