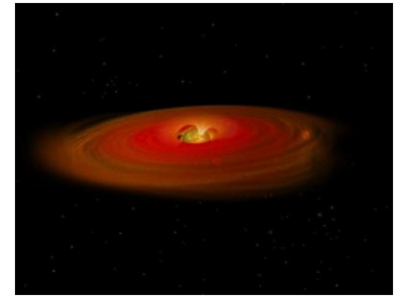
Chemical evolution from cores to disks



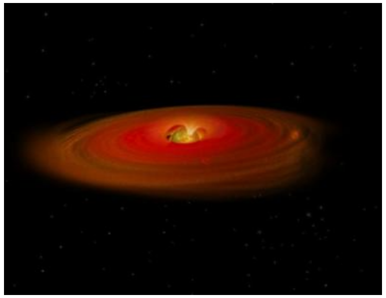
Ruud Visser
Leiden Observatory

February 1, 2010
NASA Goddard

NWO

Sterrewacht Leiden

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.

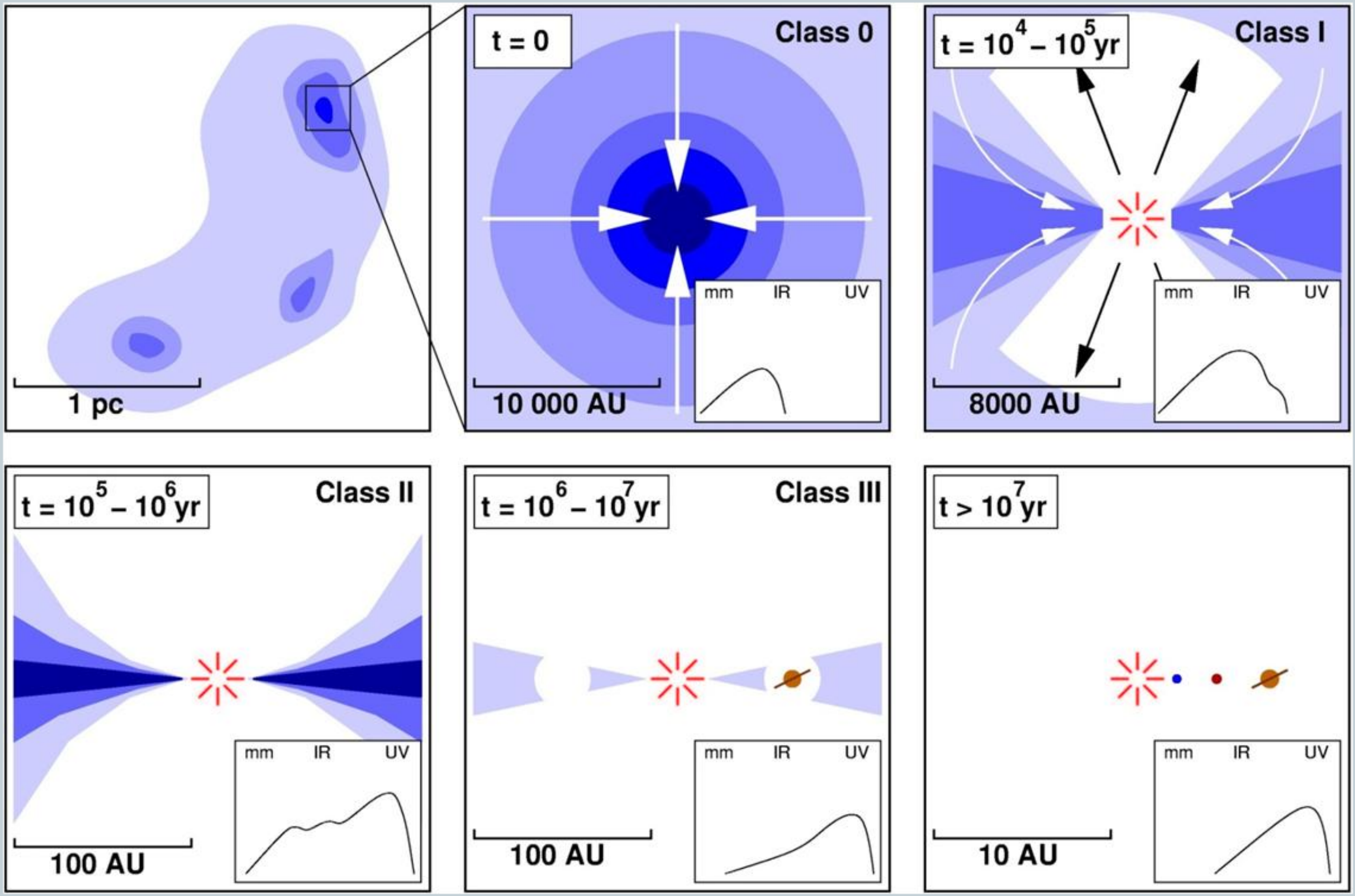
Outline

- 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

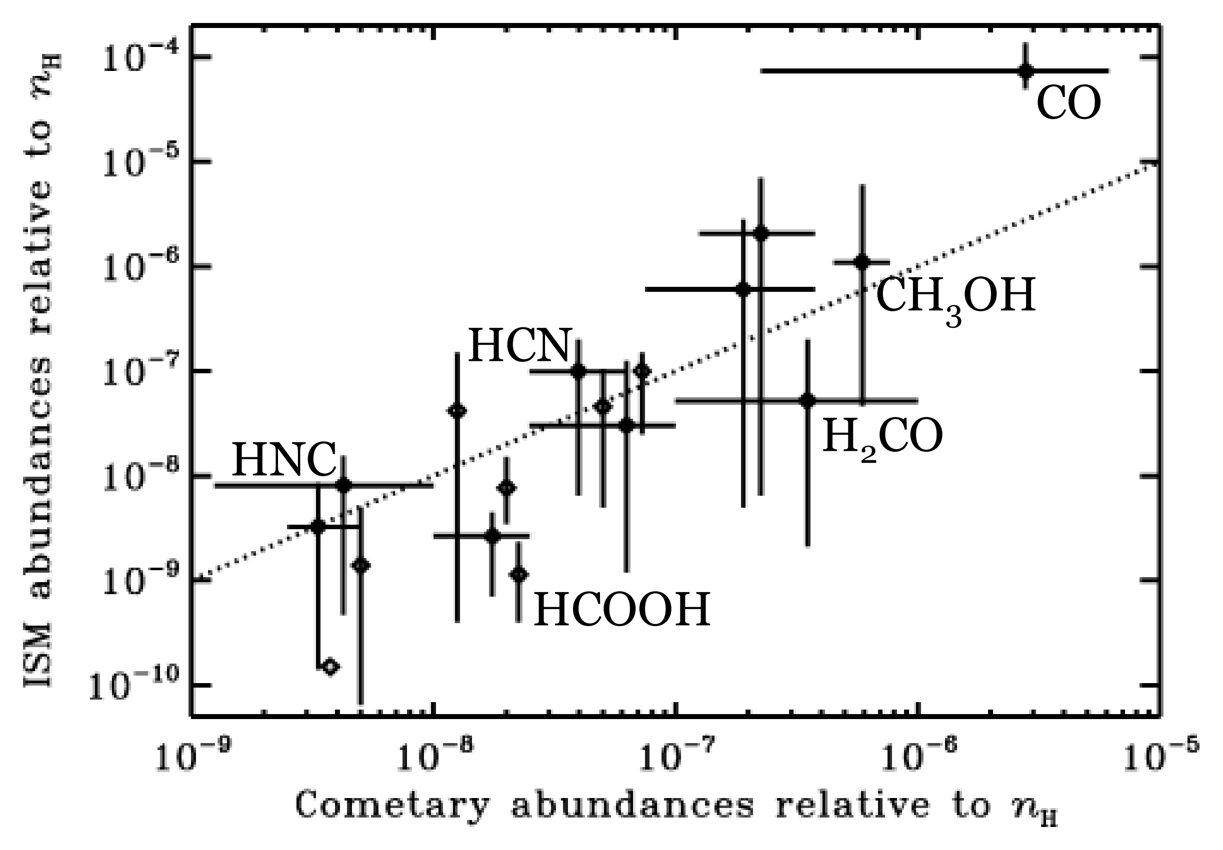


Jonkheid et al. (2006)

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?

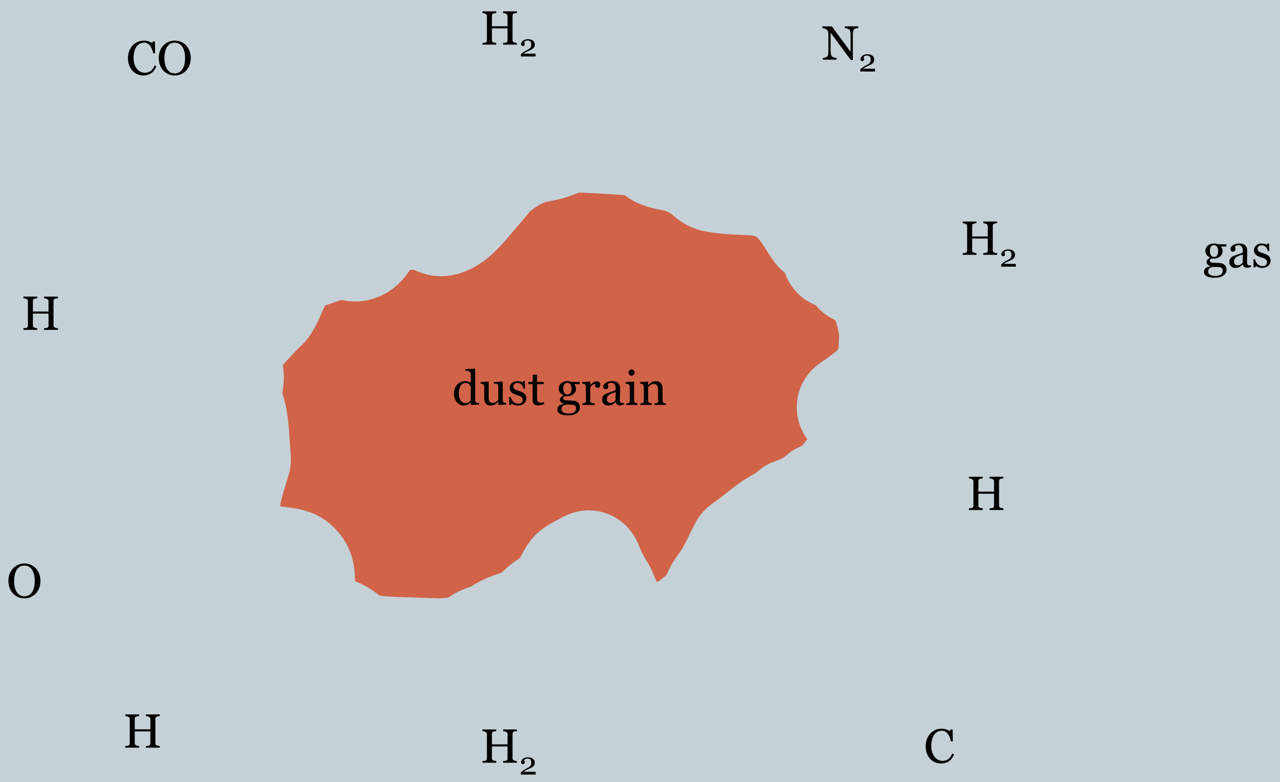
Comets: a view of the past?



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

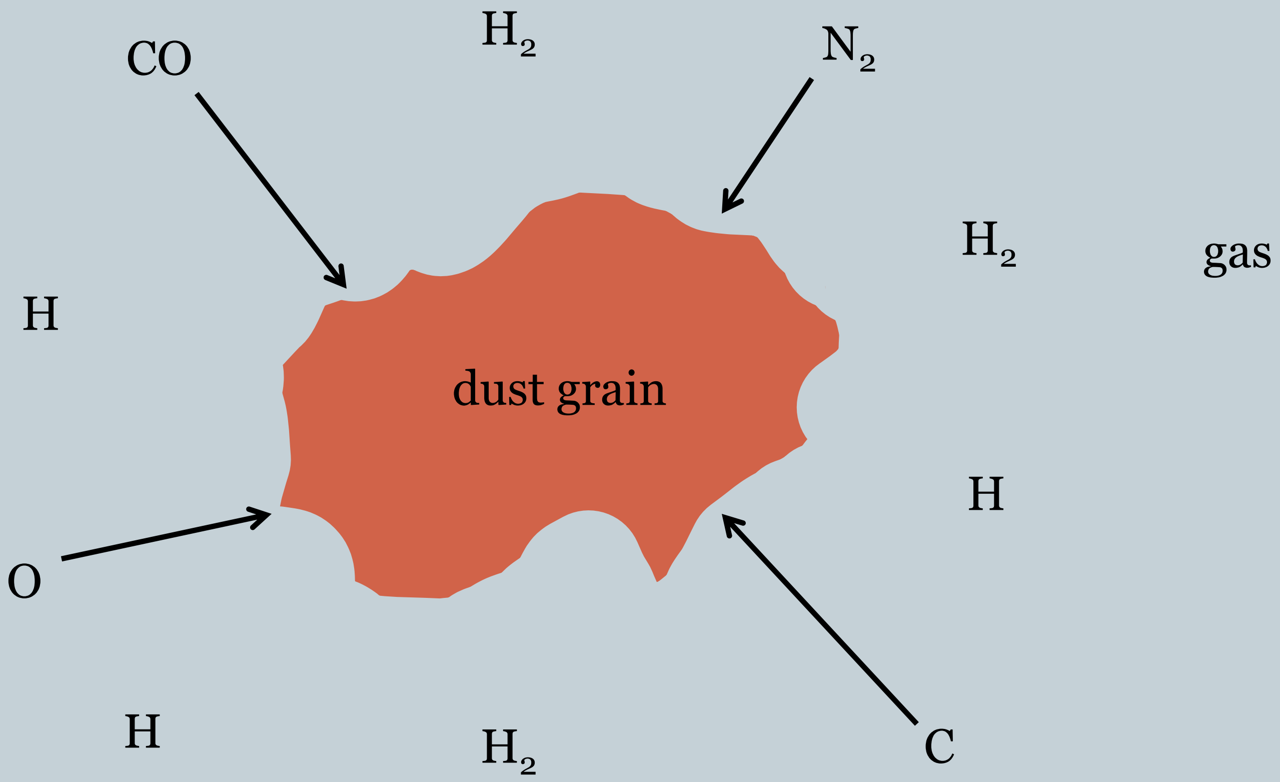
Bockelée-Morvan et al. (2000, 2004), Schöier et al. (2002)

Chemical processes



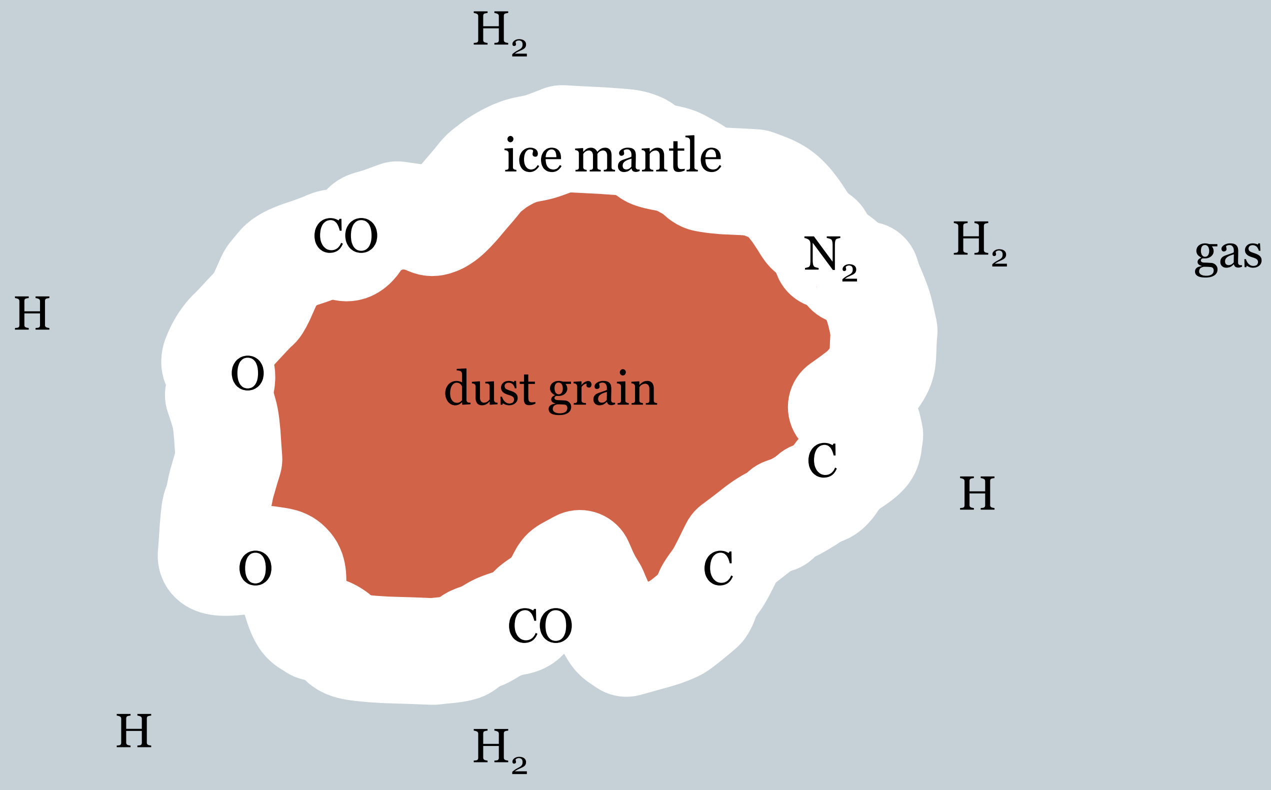
Chemical processes

- Freeze-out



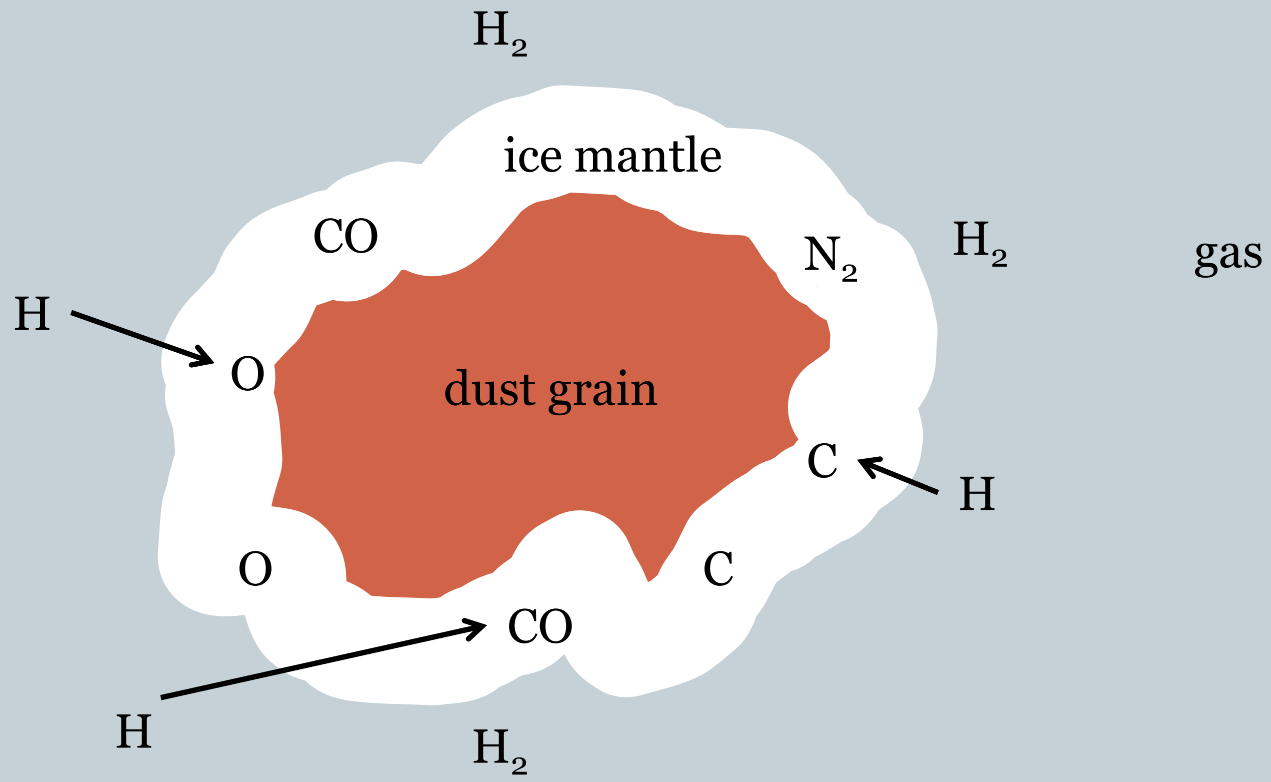
Chemical processes

- Freeze-out



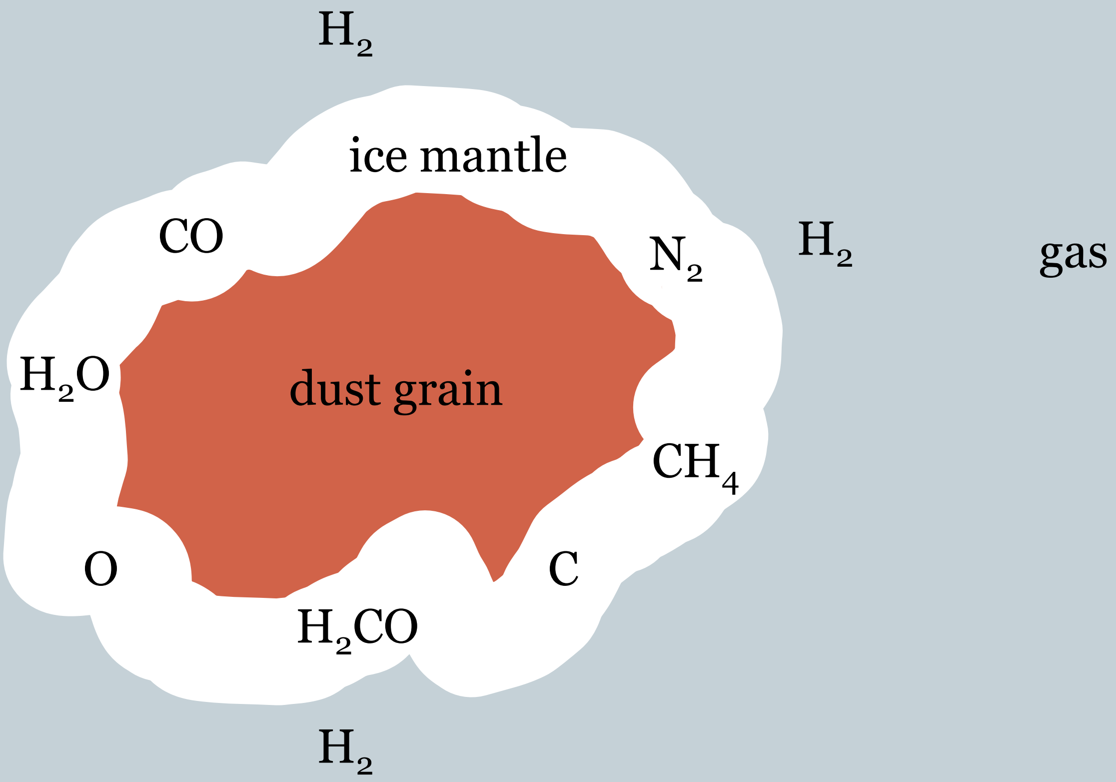
Chemical processes

- Grain-surface hydrogenation



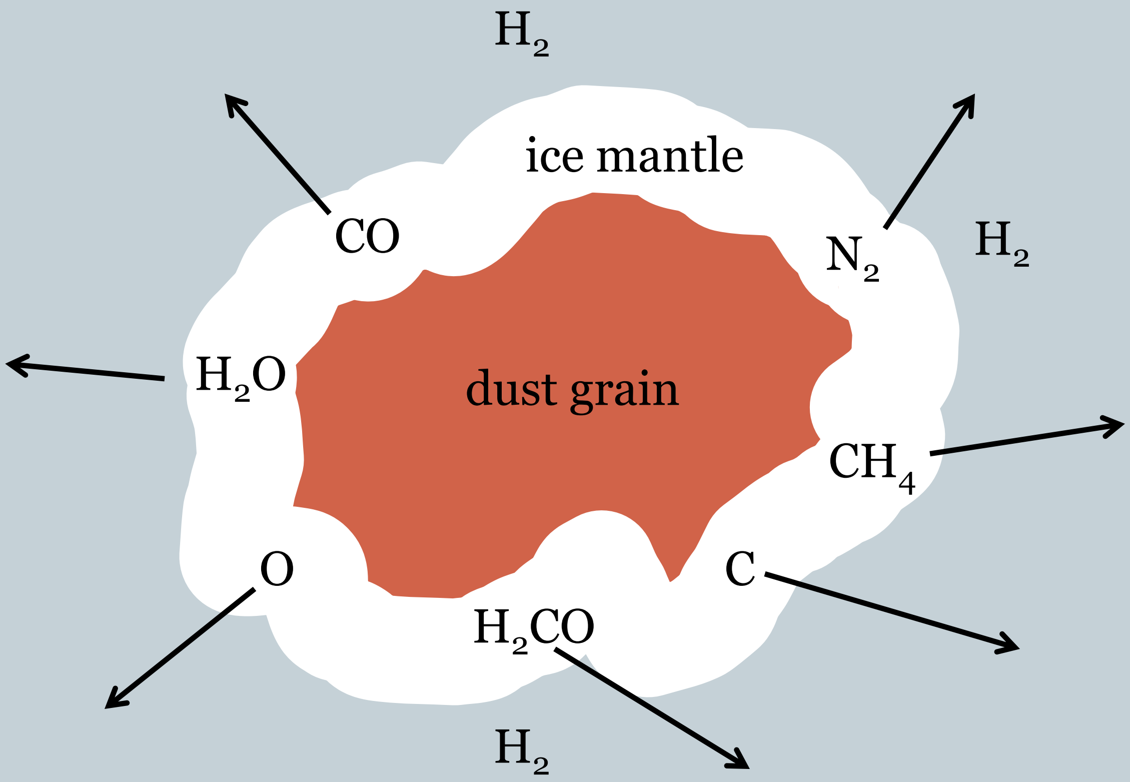
Chemical processes

- Grain-surface hydrogenation



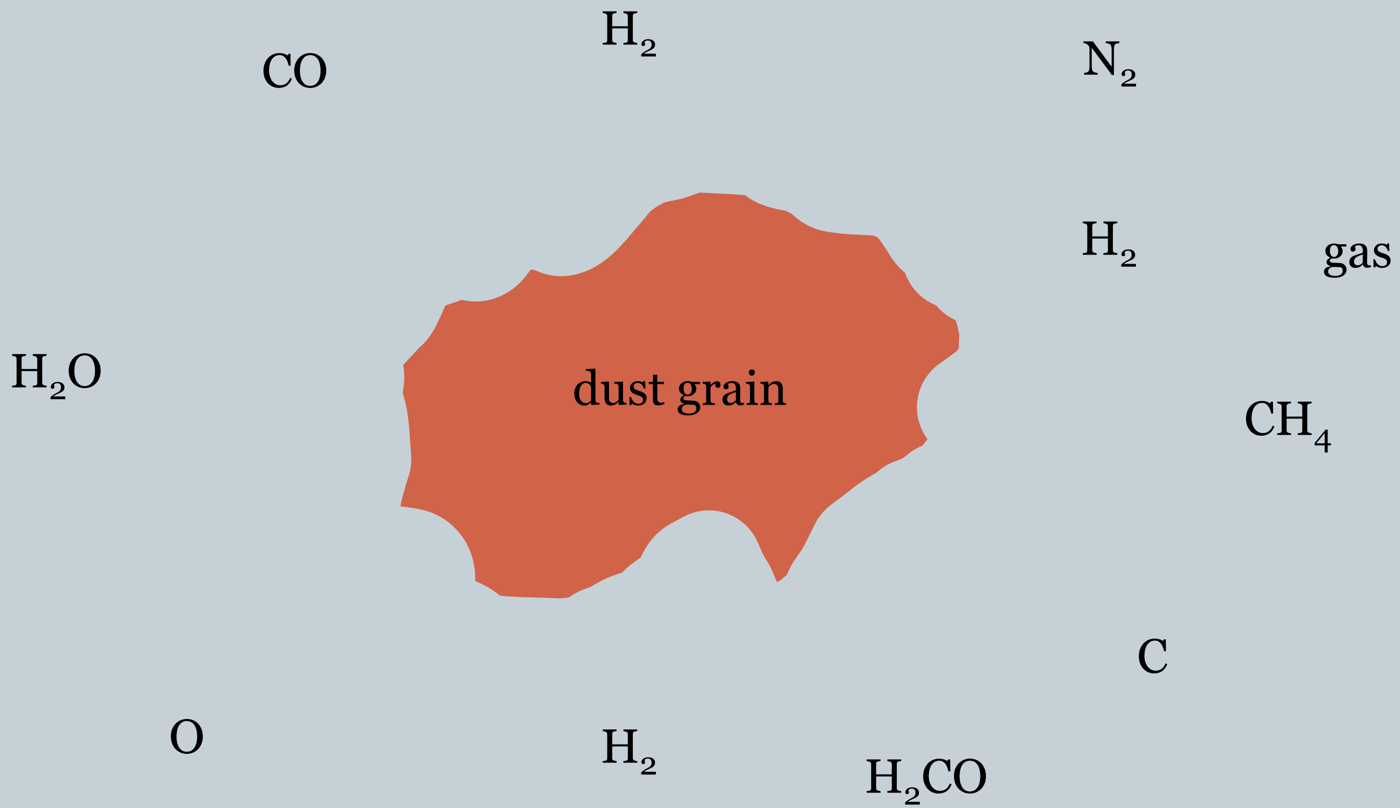
Chemical processes

- Evaporation



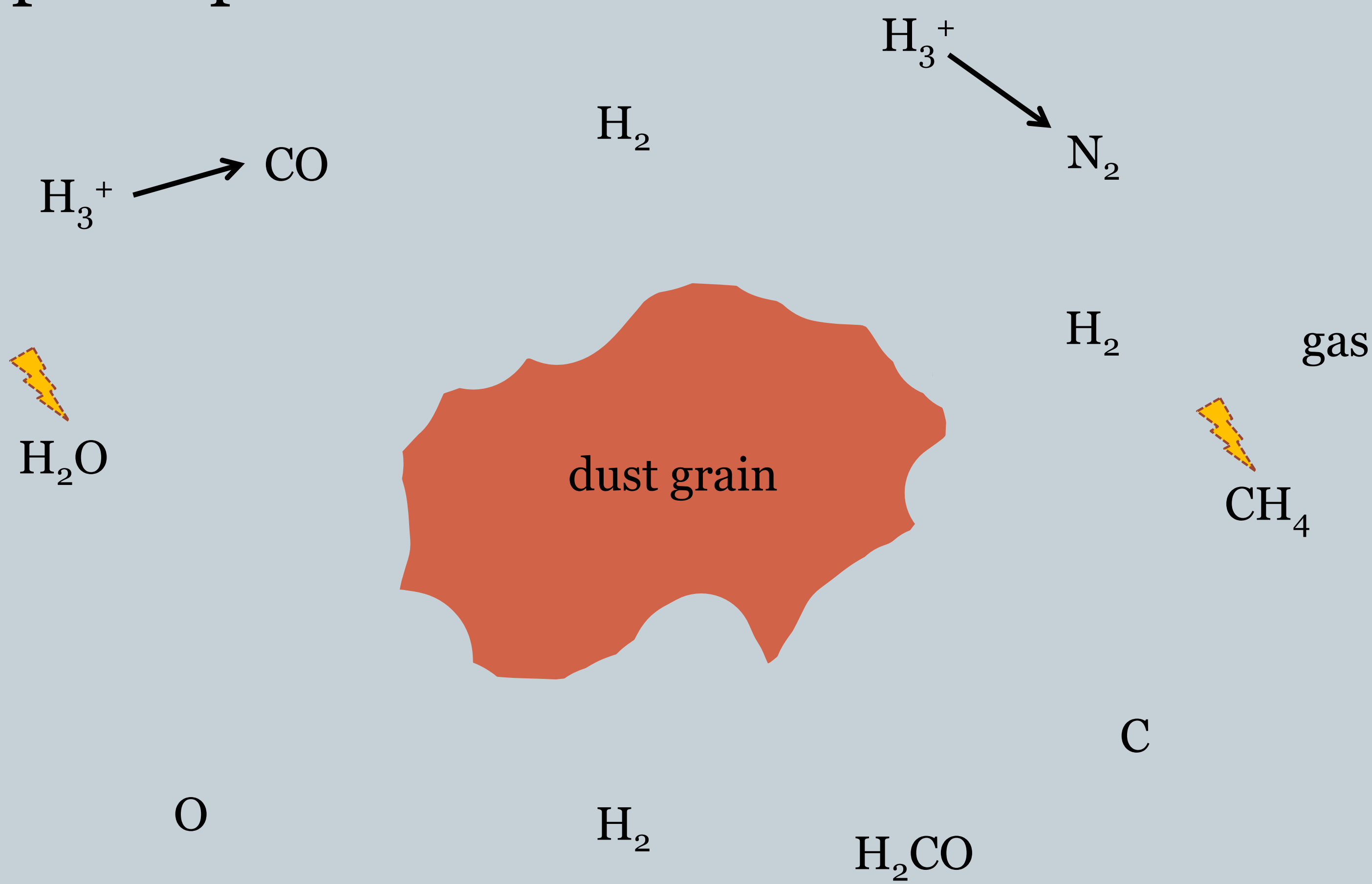
Chemical processes

- Evaporation



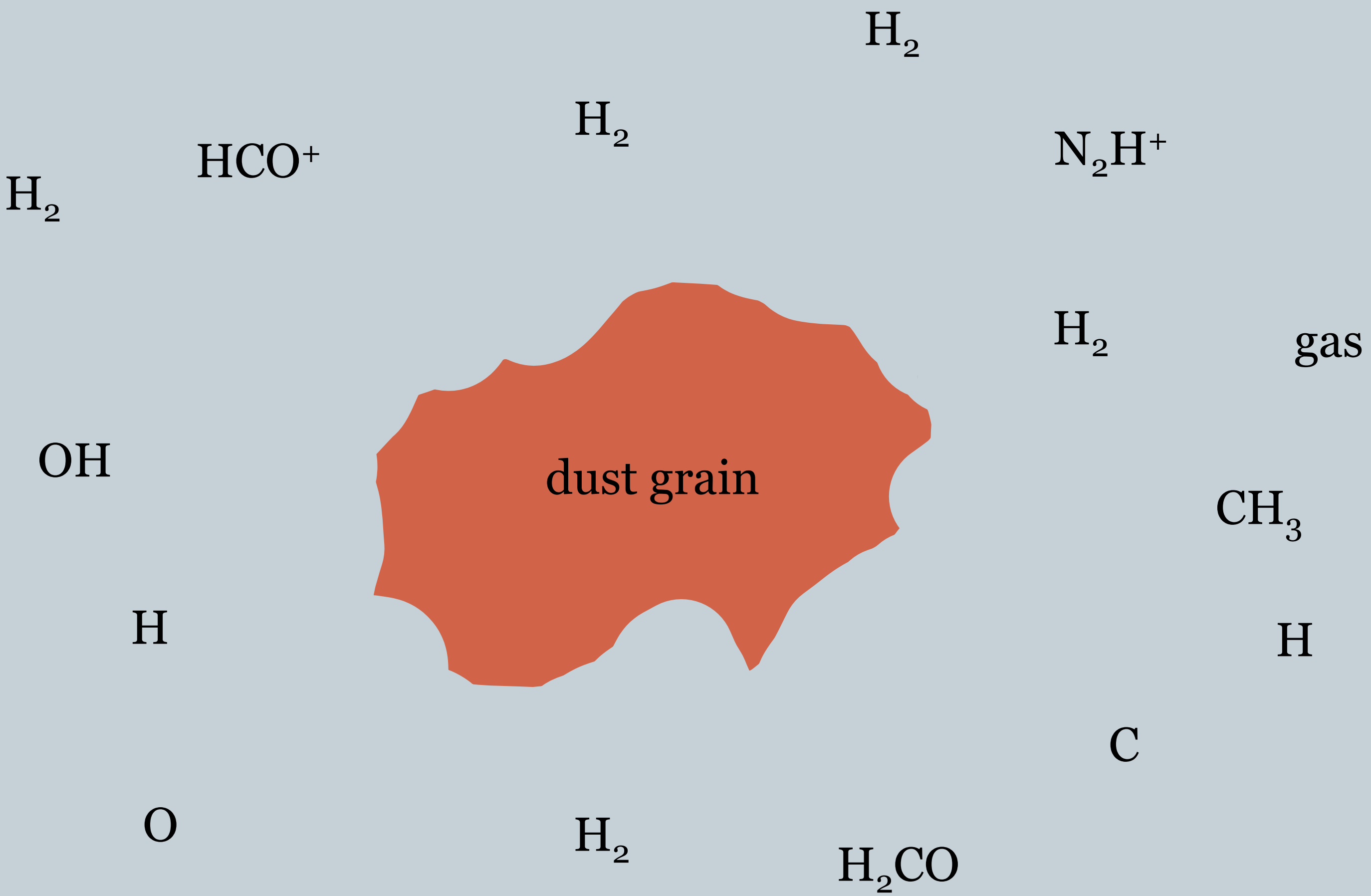
Chemical processes

- Gas-phase processes



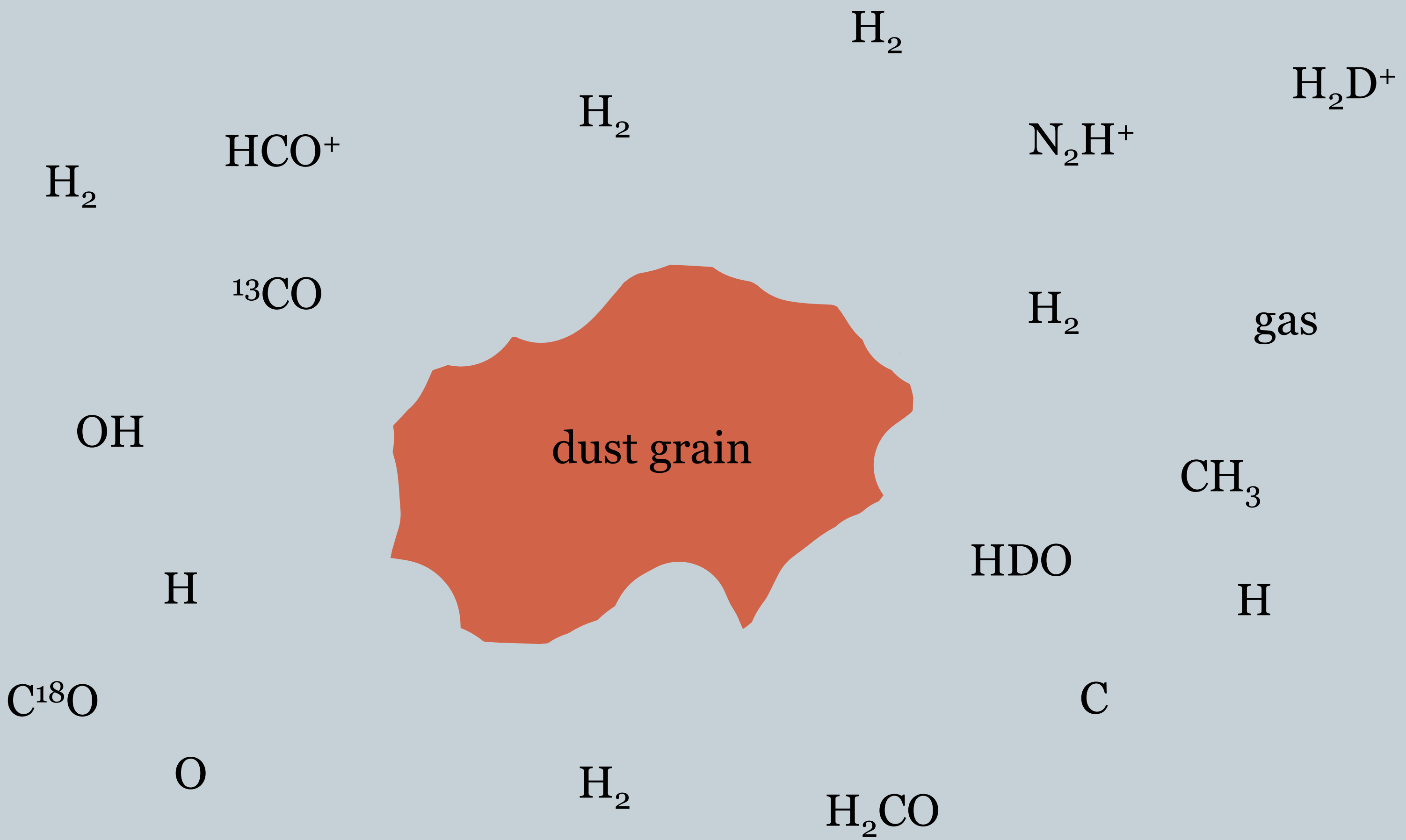
Chemical processes

- Gas-phase processes



Chemical processes

- Isotopes



Outline

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

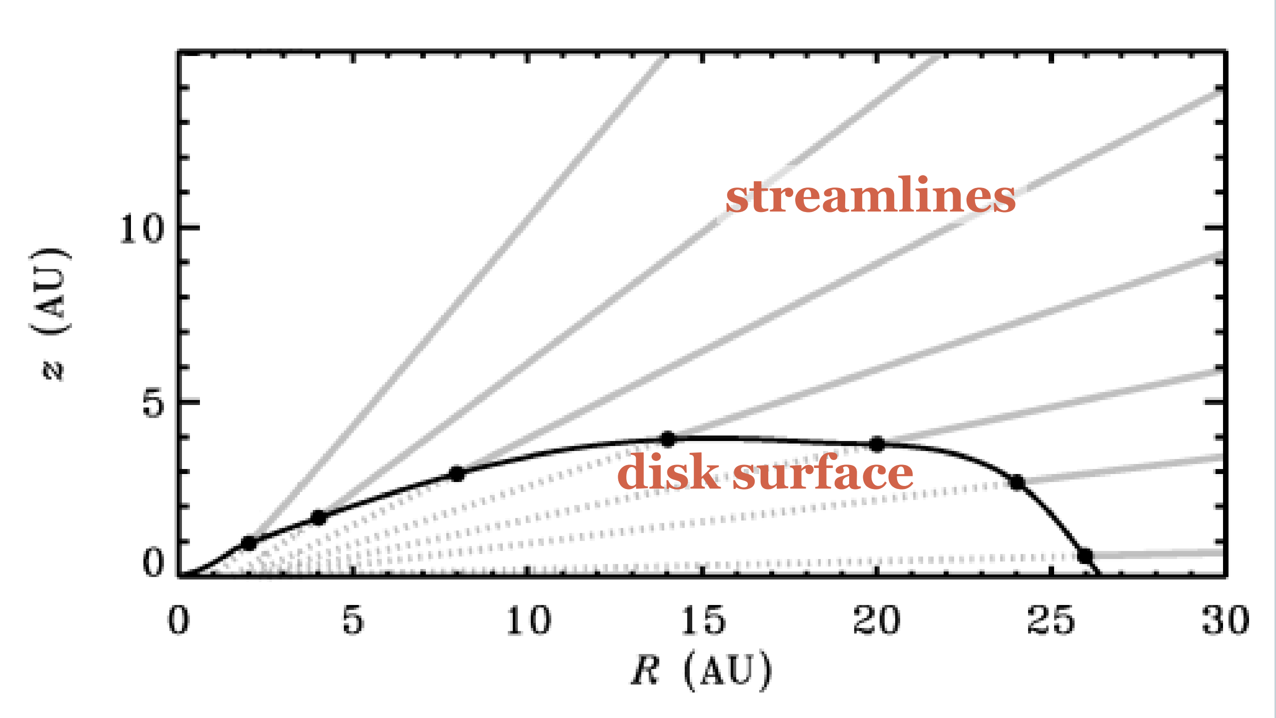
Analytical star formation model in 2D

- Fast to run, high resolution,
  easy to change initial conditions
  Cloud mass (M_0), rotation rate (Ω_0), sound speed (c_s), ...
- Density & velocity: inside-out collapse
- Viscously evolving disk (α=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)

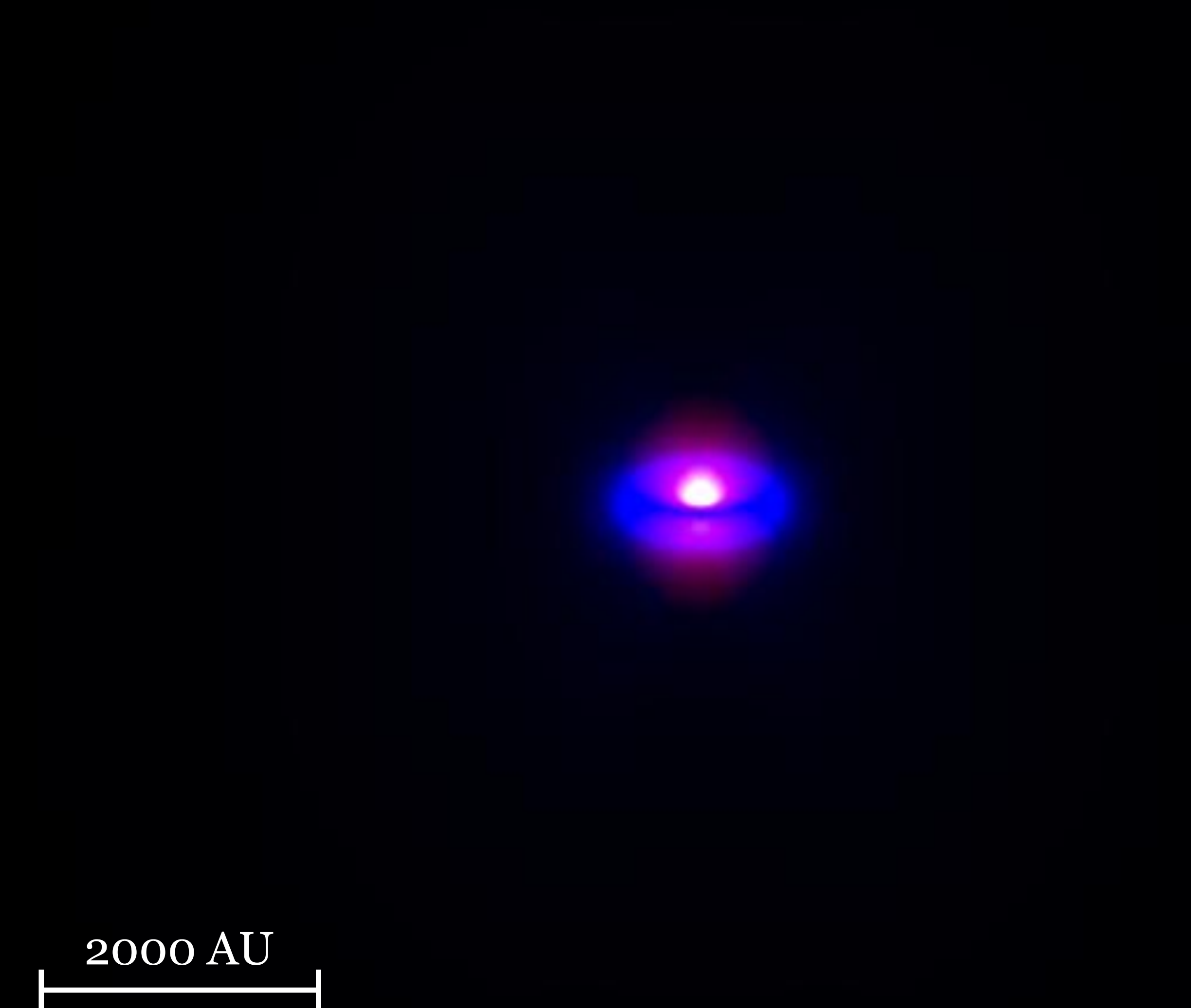
Visser et al. (2009)

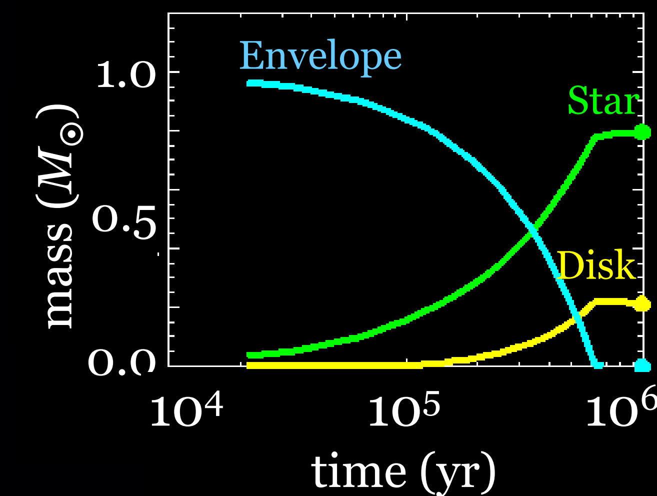
From one to two dimensions



- 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

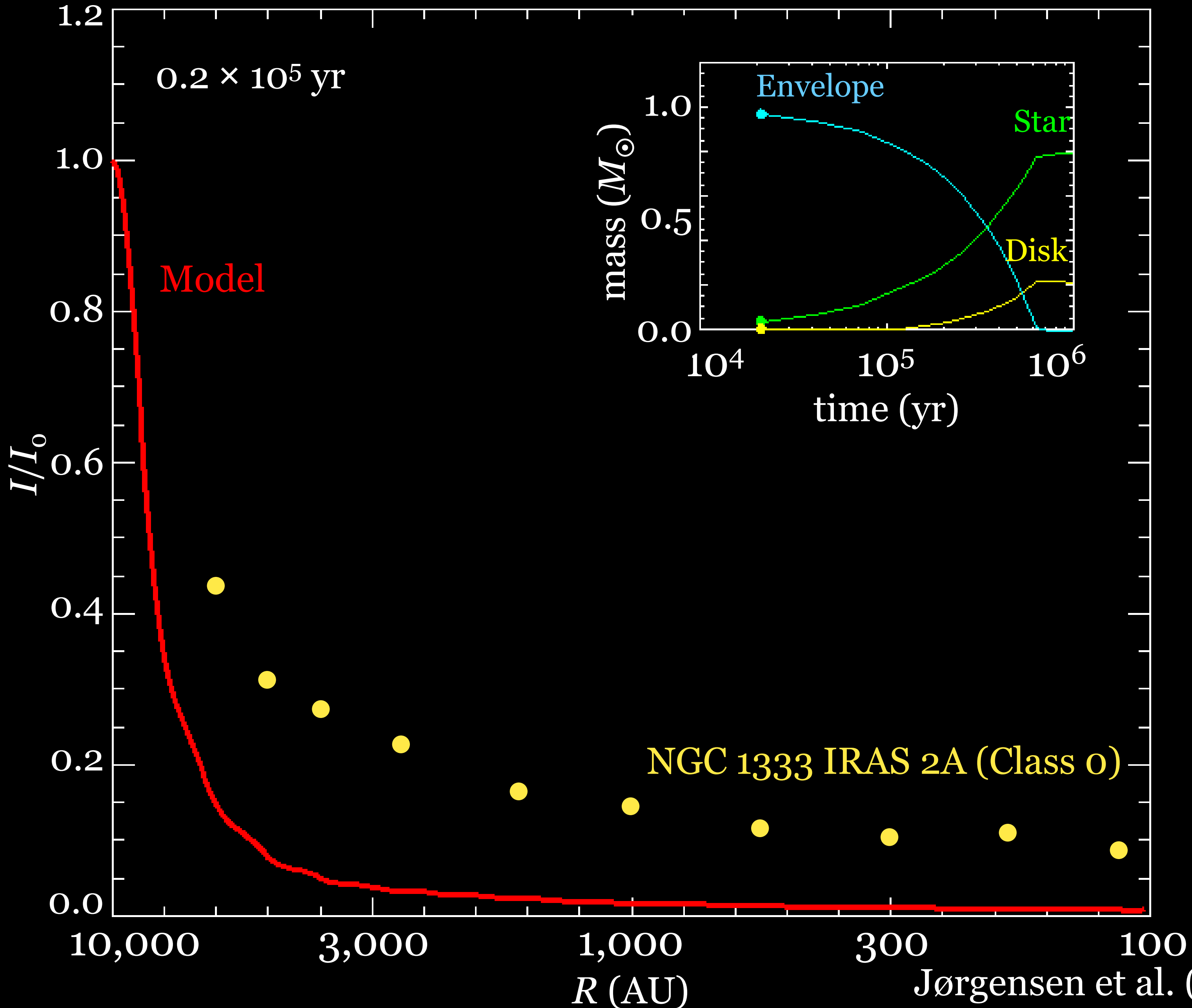




850 µm, 24 µm, 8.0 µm

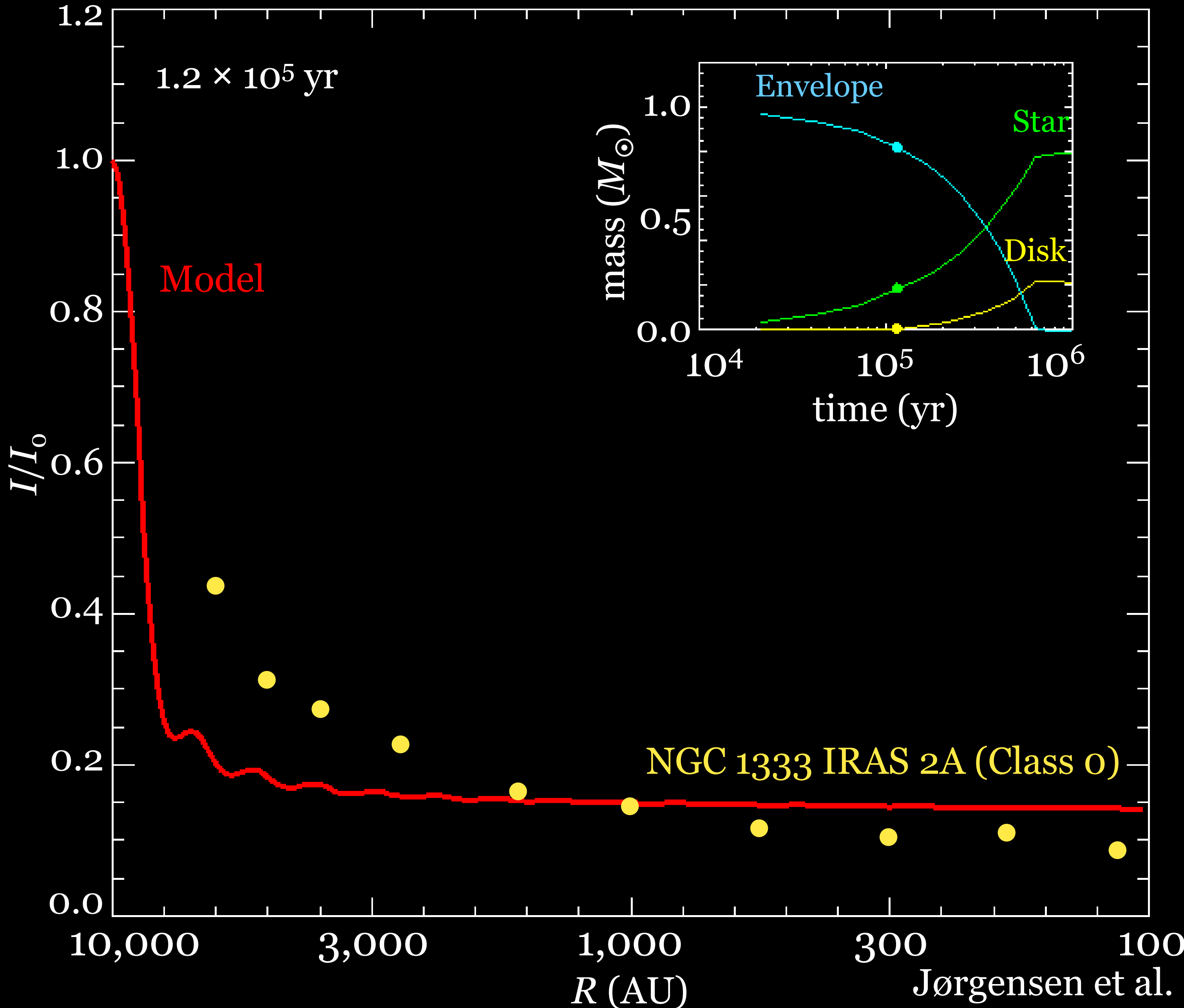
Jørgensen et al. (2009) based on Visser et al. (2009)

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



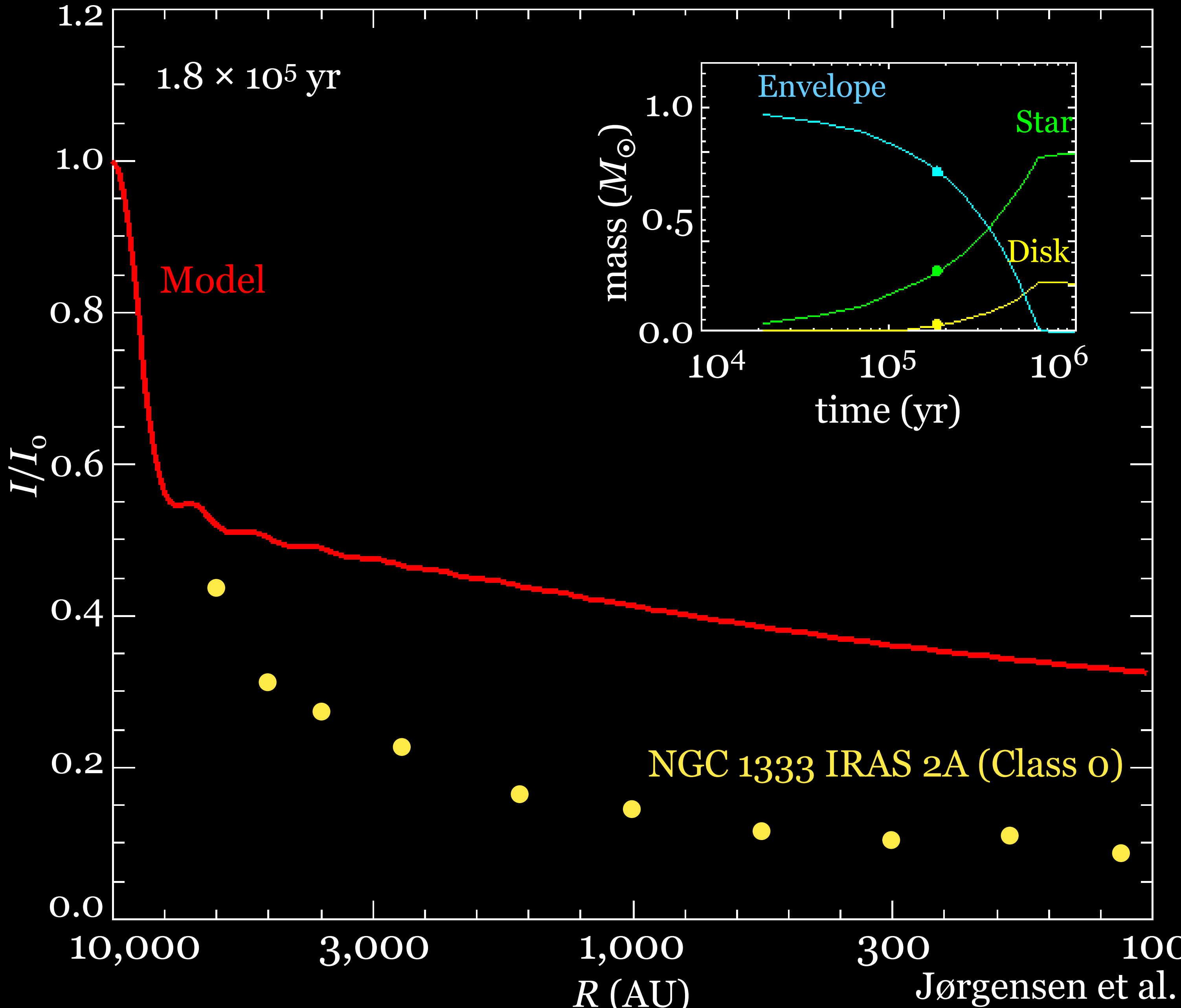
Jørgensen et al. (2009)

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



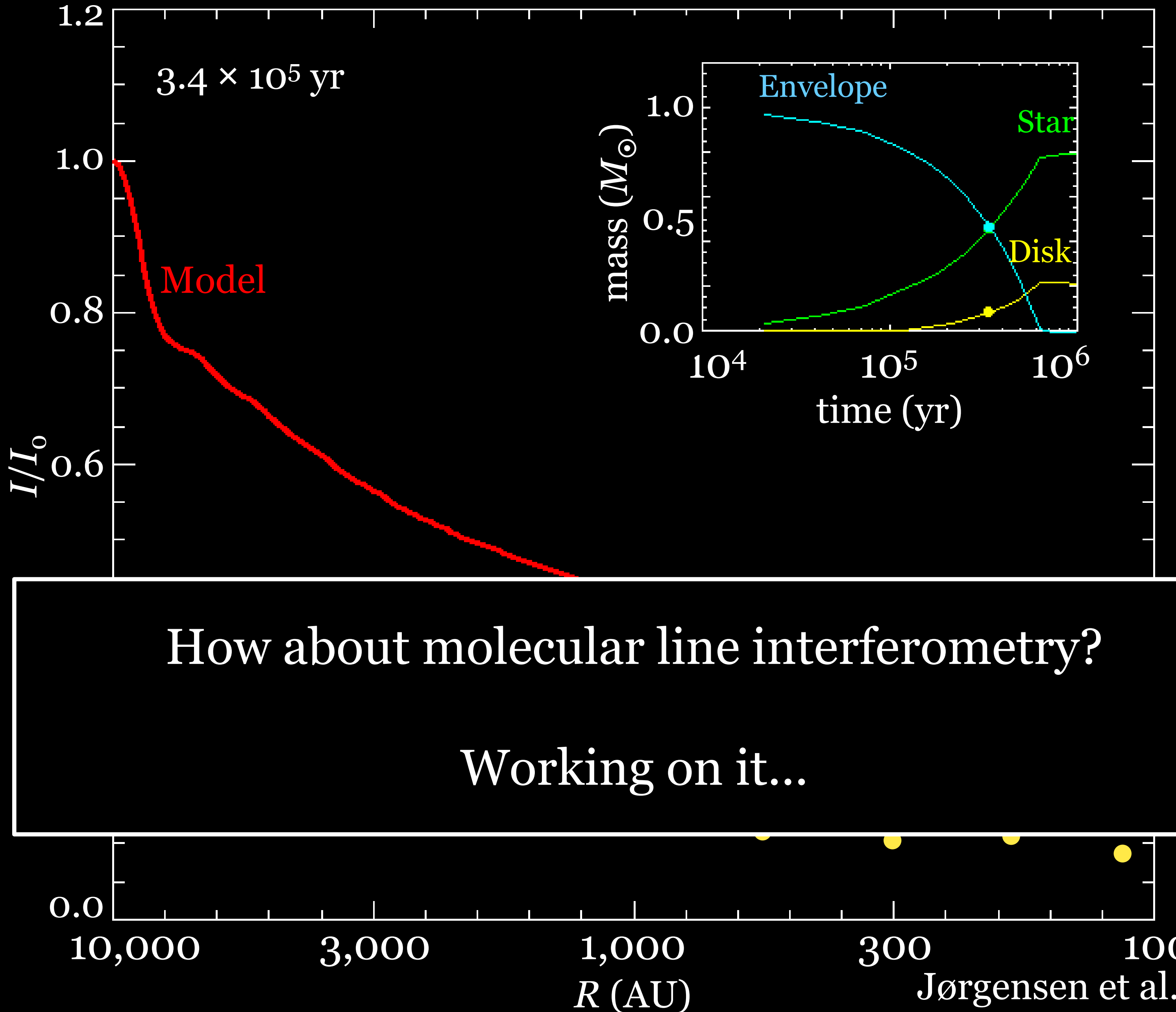
Jørgensen et al. (2009)

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



Jørgensen et al. (2009)

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



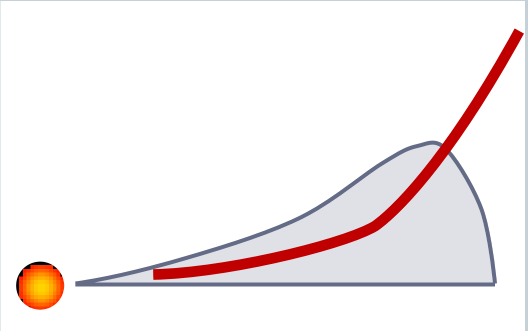
How about molecular line interferometry?

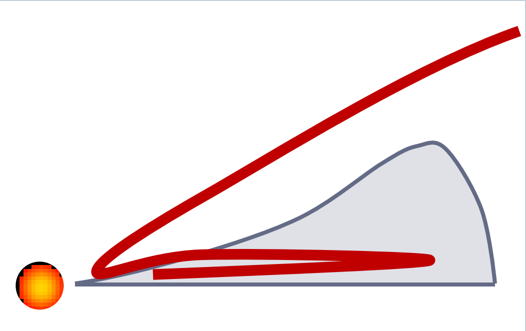
Working on it...

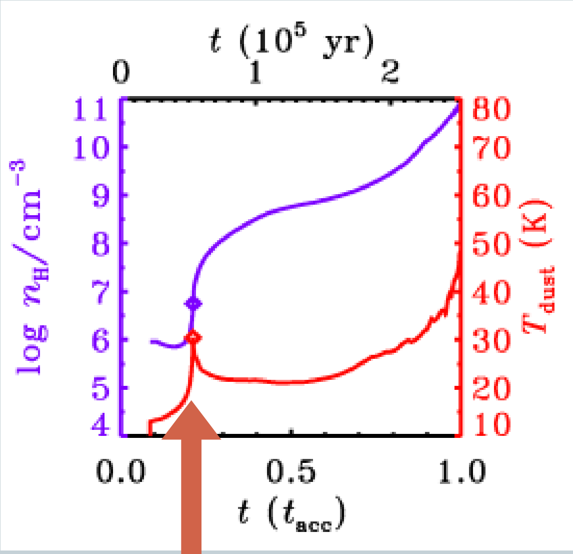
Jørgensen et al. (2009)

Infall trajectories

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







entering disk

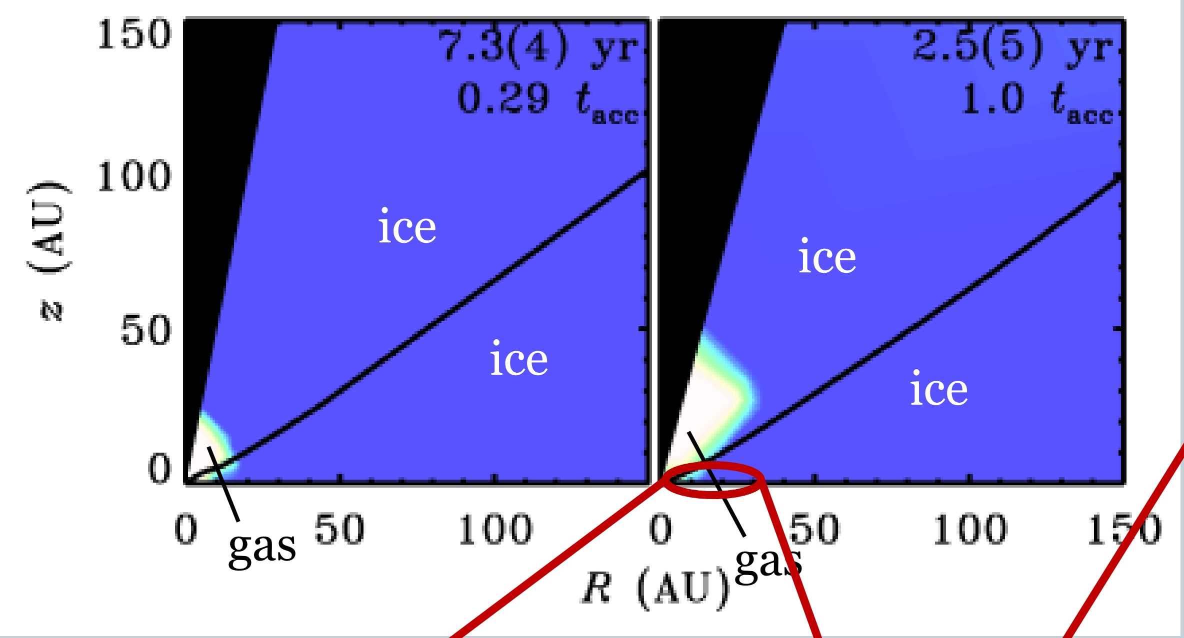
- Different trajectory shapes
- Jump in n, T upon entering disk

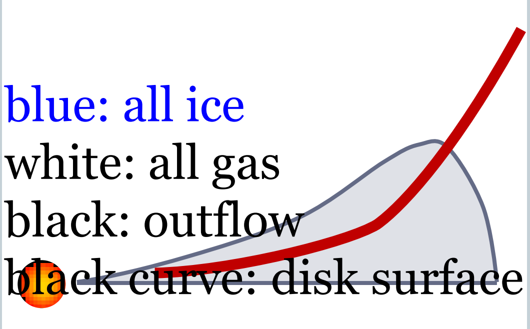
Visser et al. (2009) , Visser et al. (in prep.)

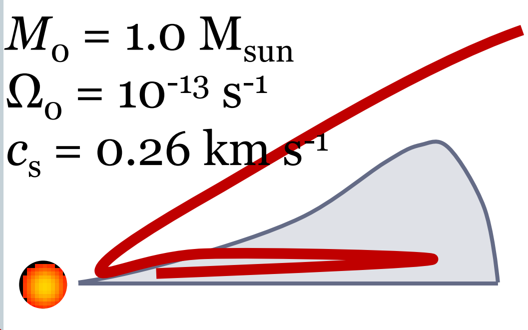
Outline

- 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: H_2O



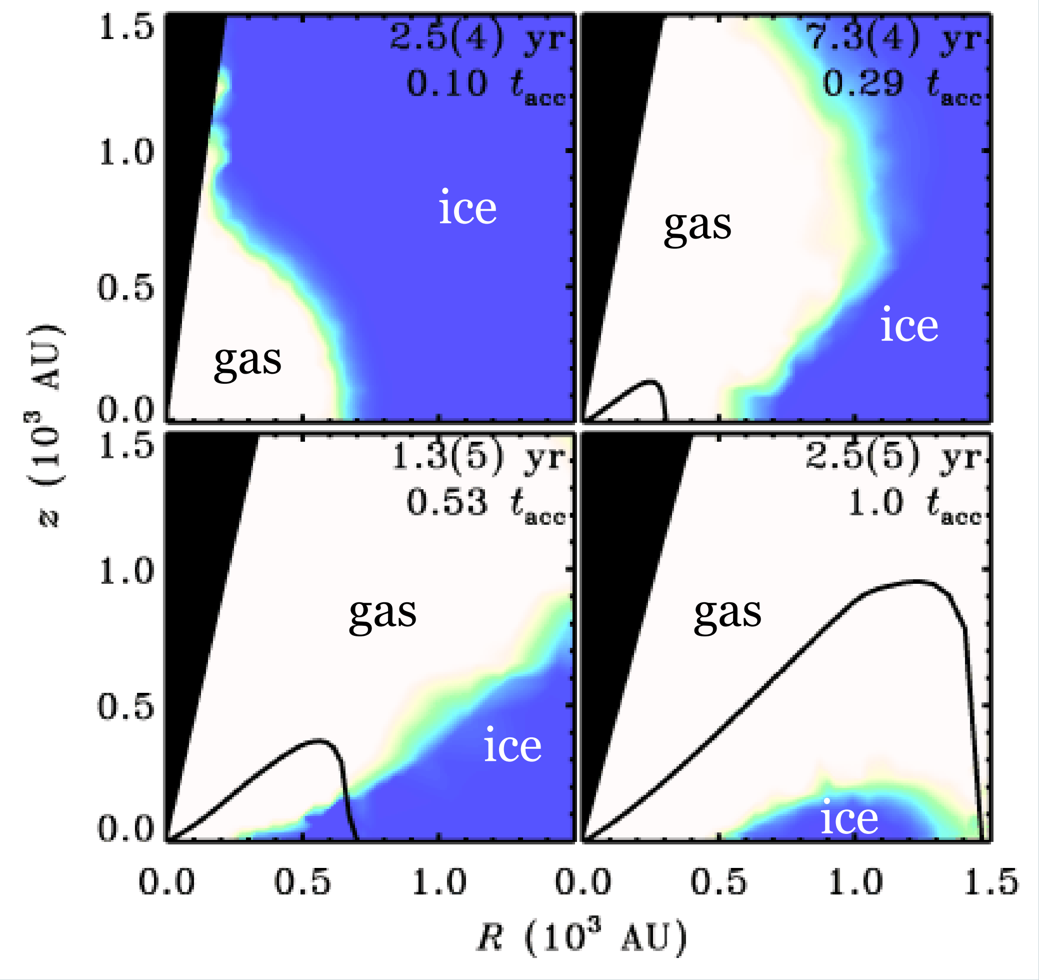




- H_2O remains solid except inner ~5 AU
- H_2O in comet-forming zone, depending on parameters:
  - *either* unprocessed (always frozen)
  - *or* processed (evaporated and re-frozen)

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}

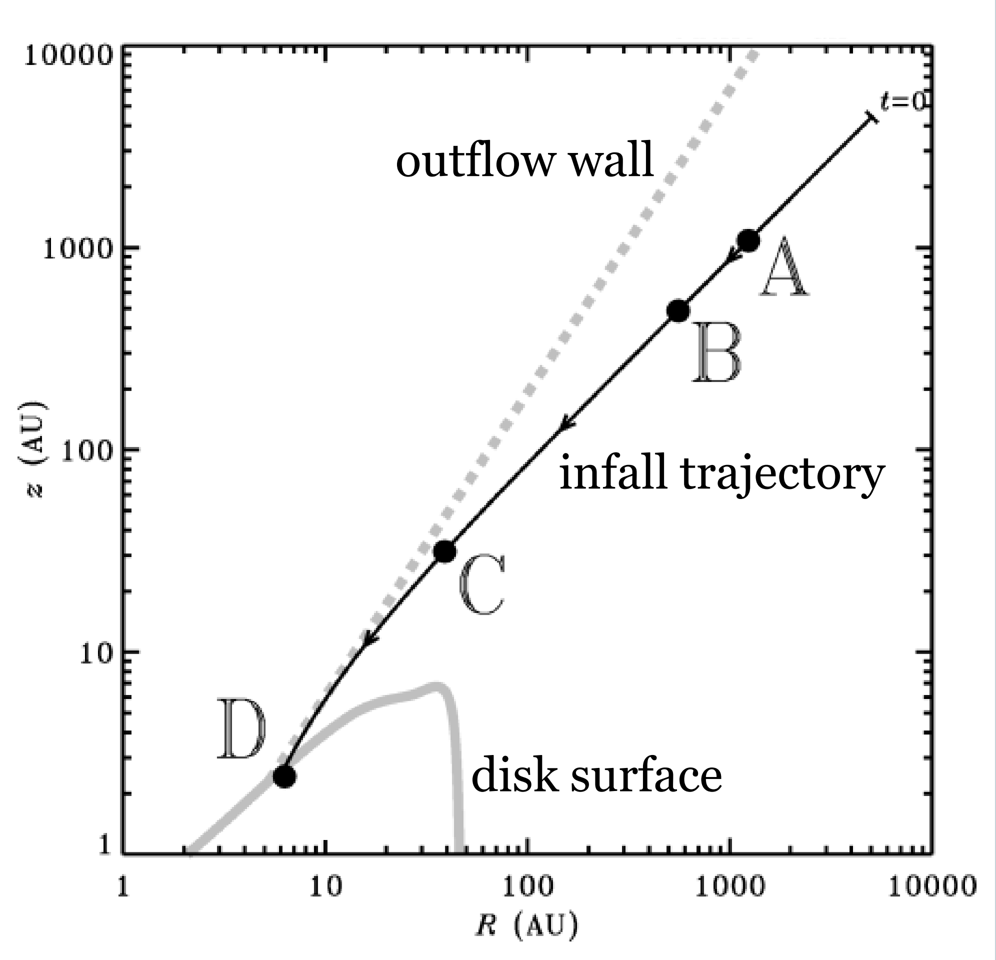
CO desorbs during infall, re-adsorbs in disk below 18 K

Visser et al. (2009)

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, N_2)

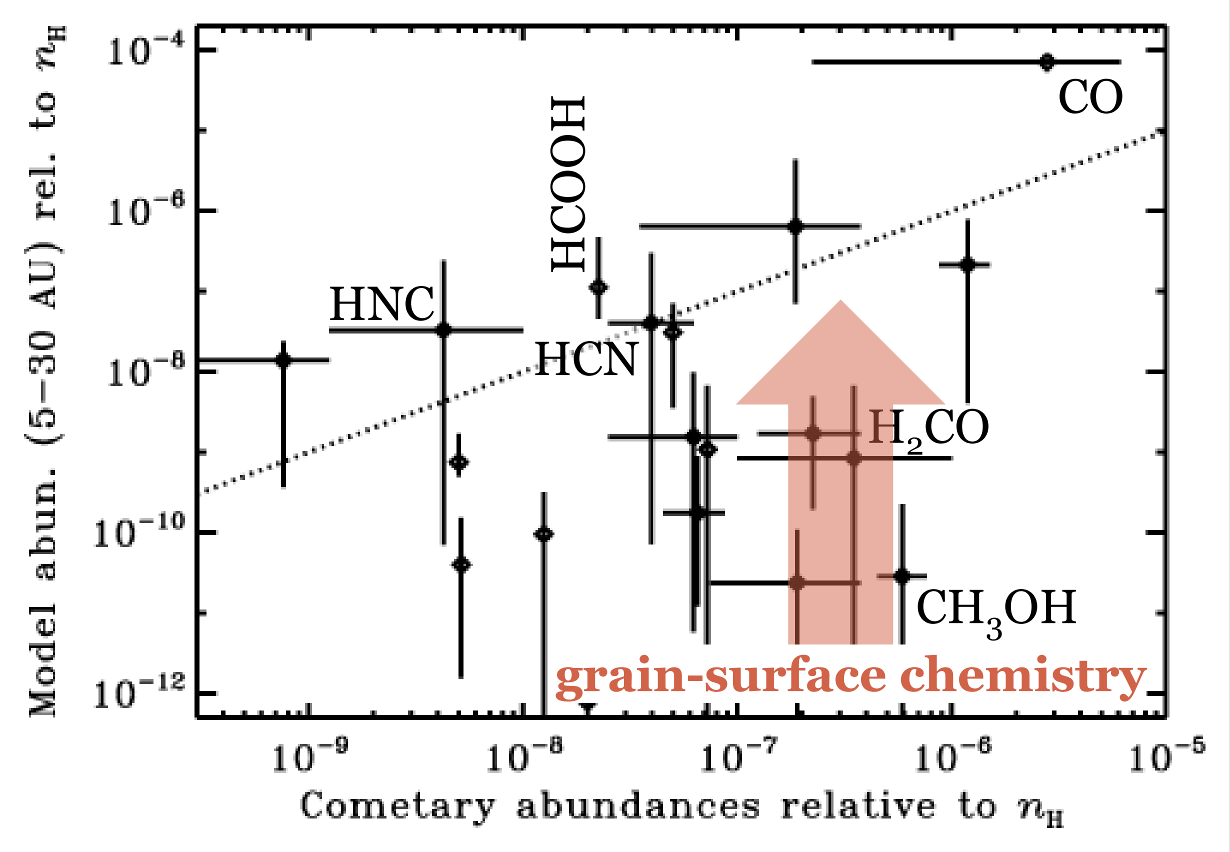
B: intermediates evaporate (e.g. CH_4, NO)

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



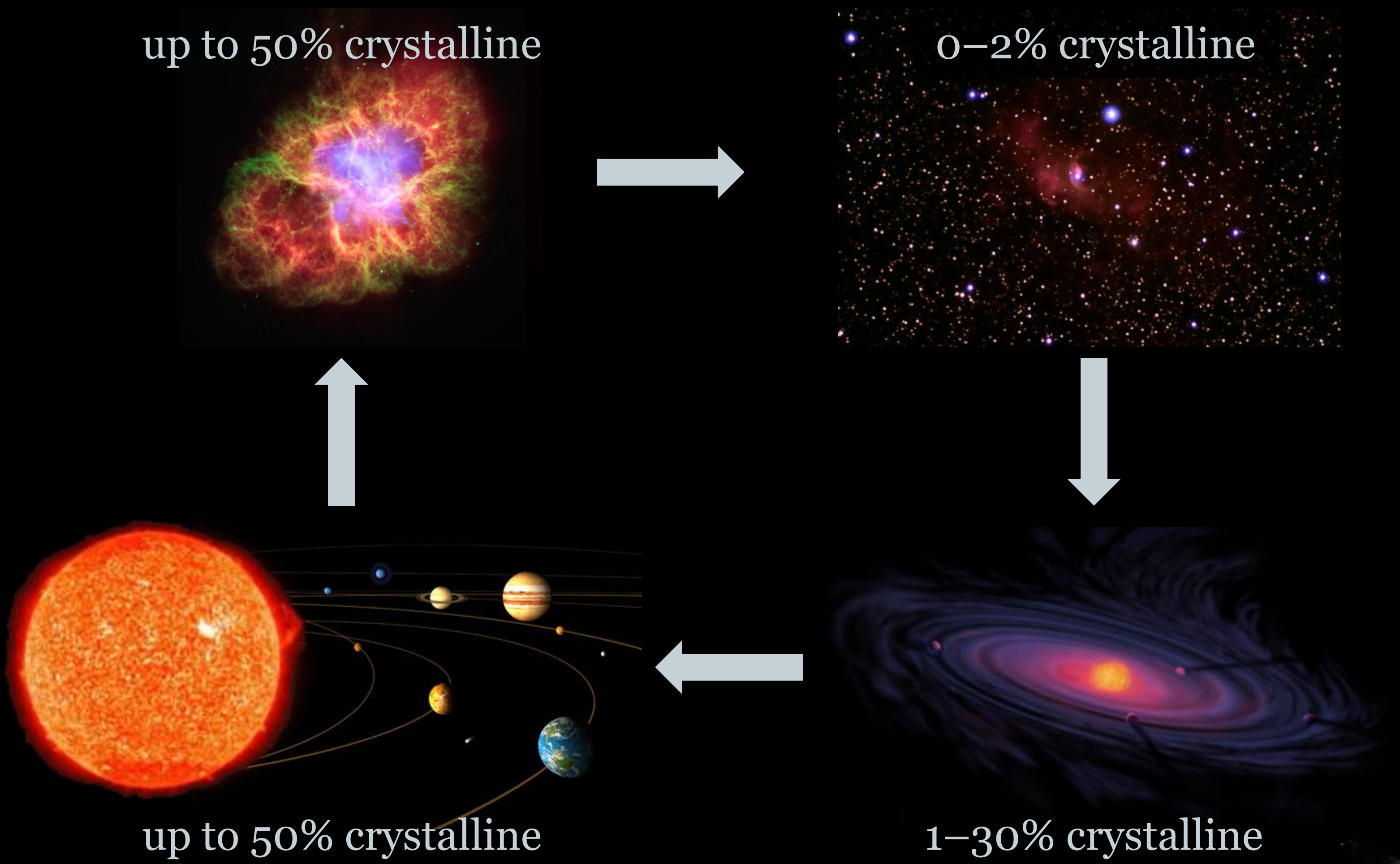
- Dotted line: hypothetical 1-to-1 relationship
- Many model abundances differ from cometary abundances
- Grain chemistry? Initial conditions? Mixing? Episodic accretion?

Visser et al. (in prep.)

Outline

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

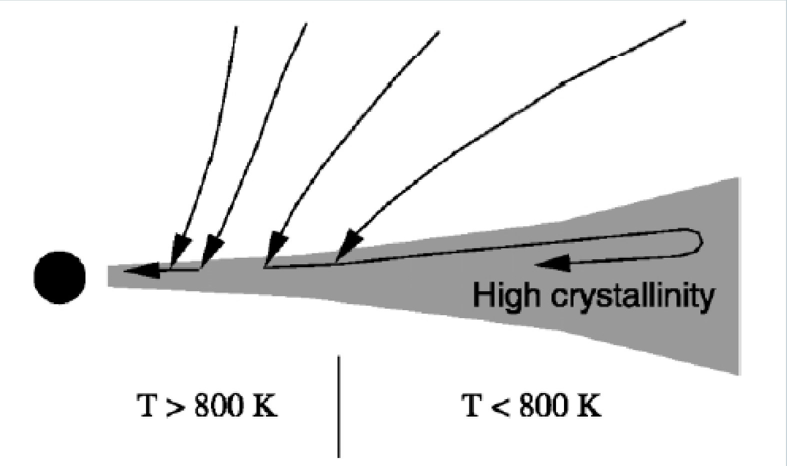
From crystalline to amorphous and back



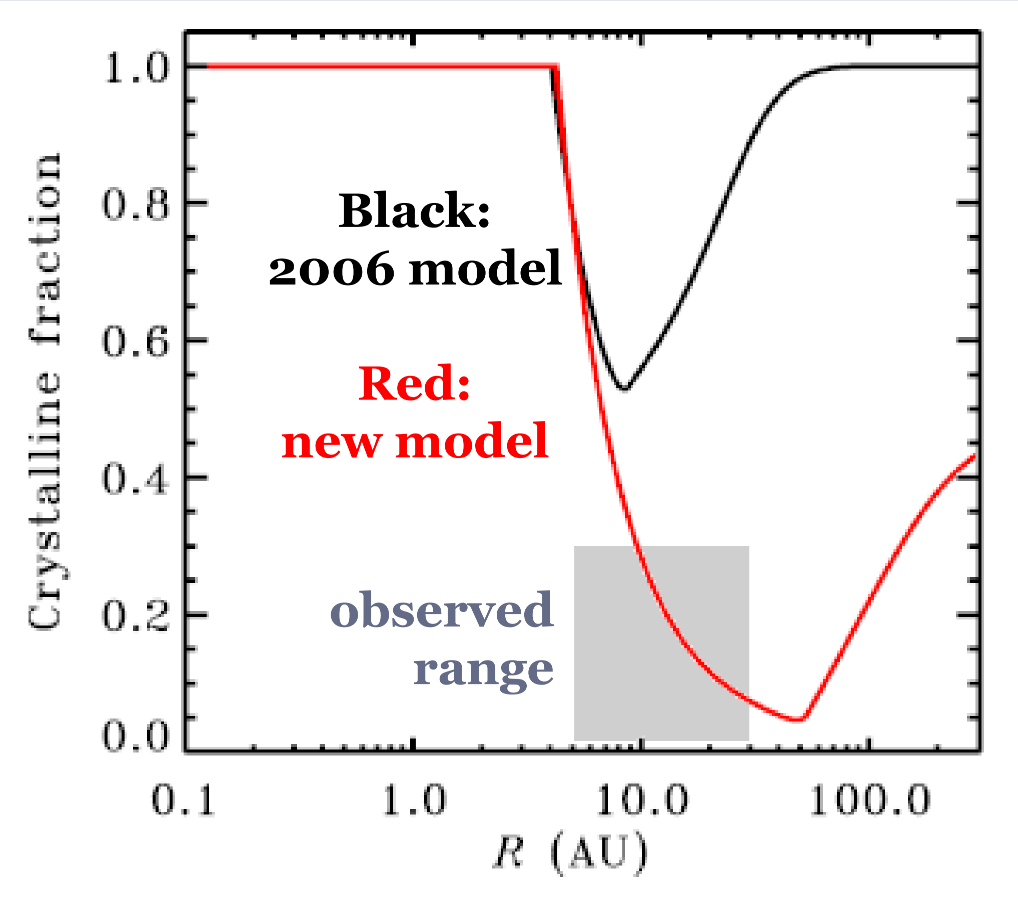
Origin of crystalline silicates in disks

- 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.)

Outline

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

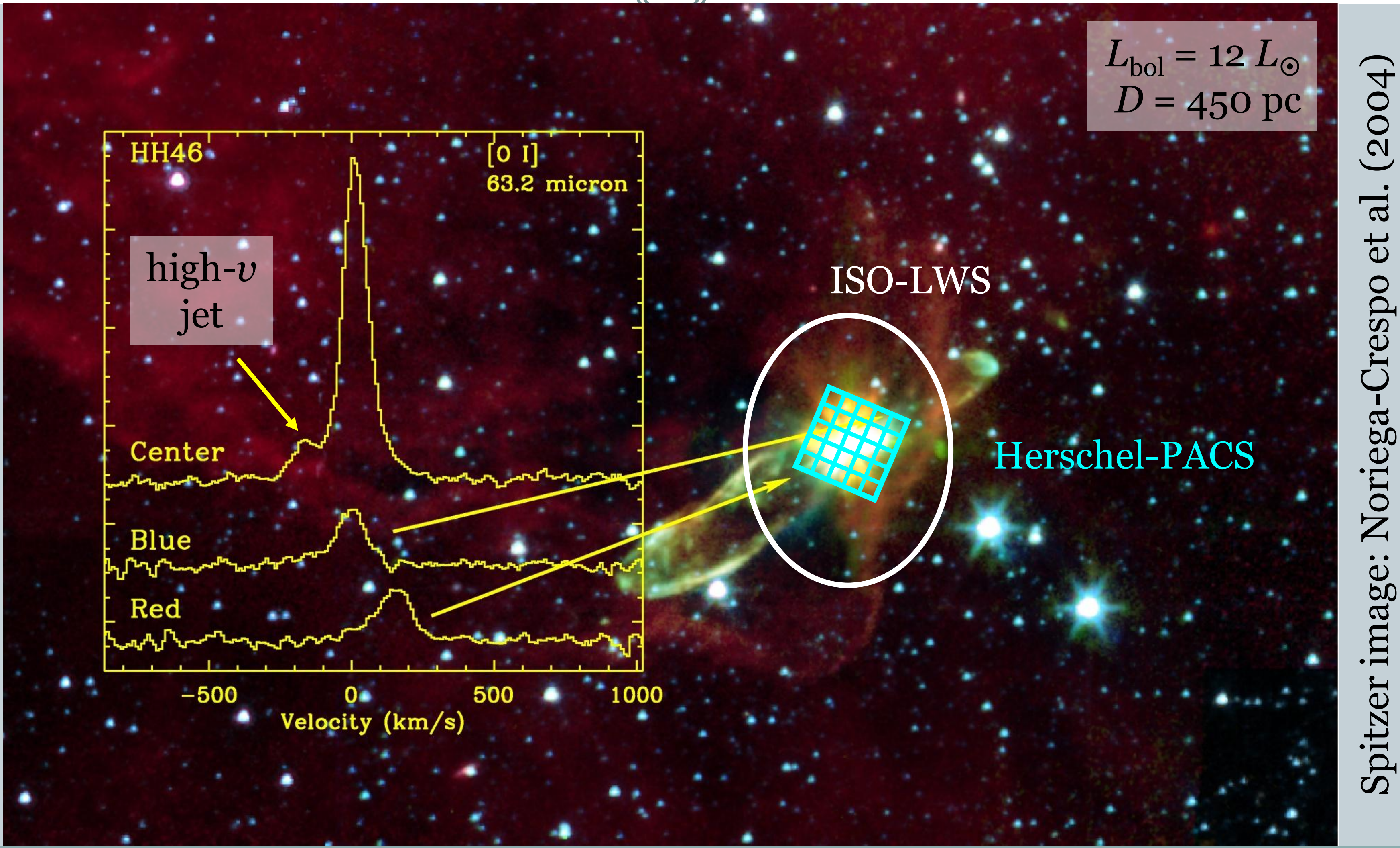
Water and CO with Herschel

- 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

WISH

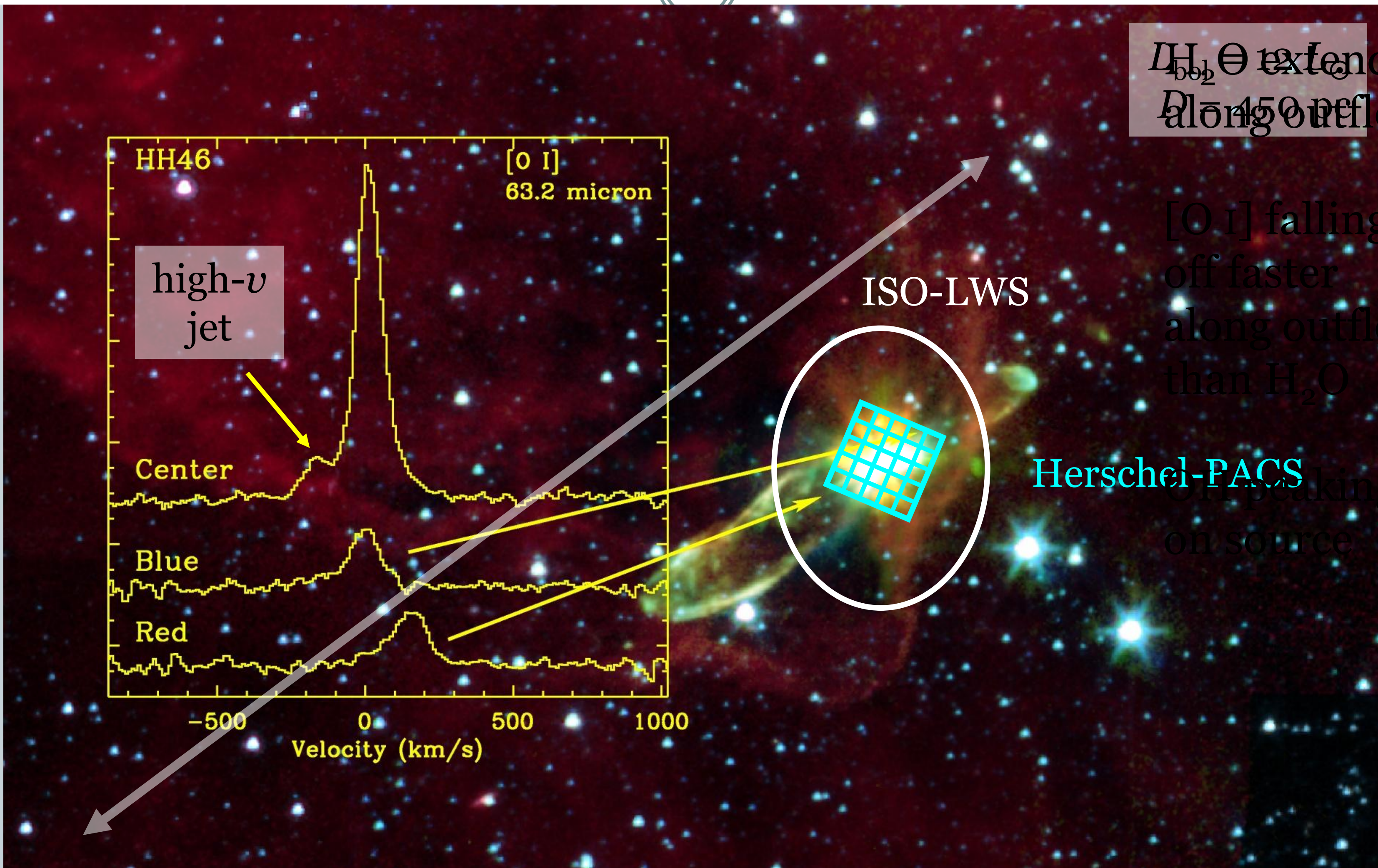
http://www.strw.leidenuniv.nl/WISH

[O I] in low-mass YSO HH46



van Kempen et al. (in prep.)

[O I] Spatial distributions YSO HH46

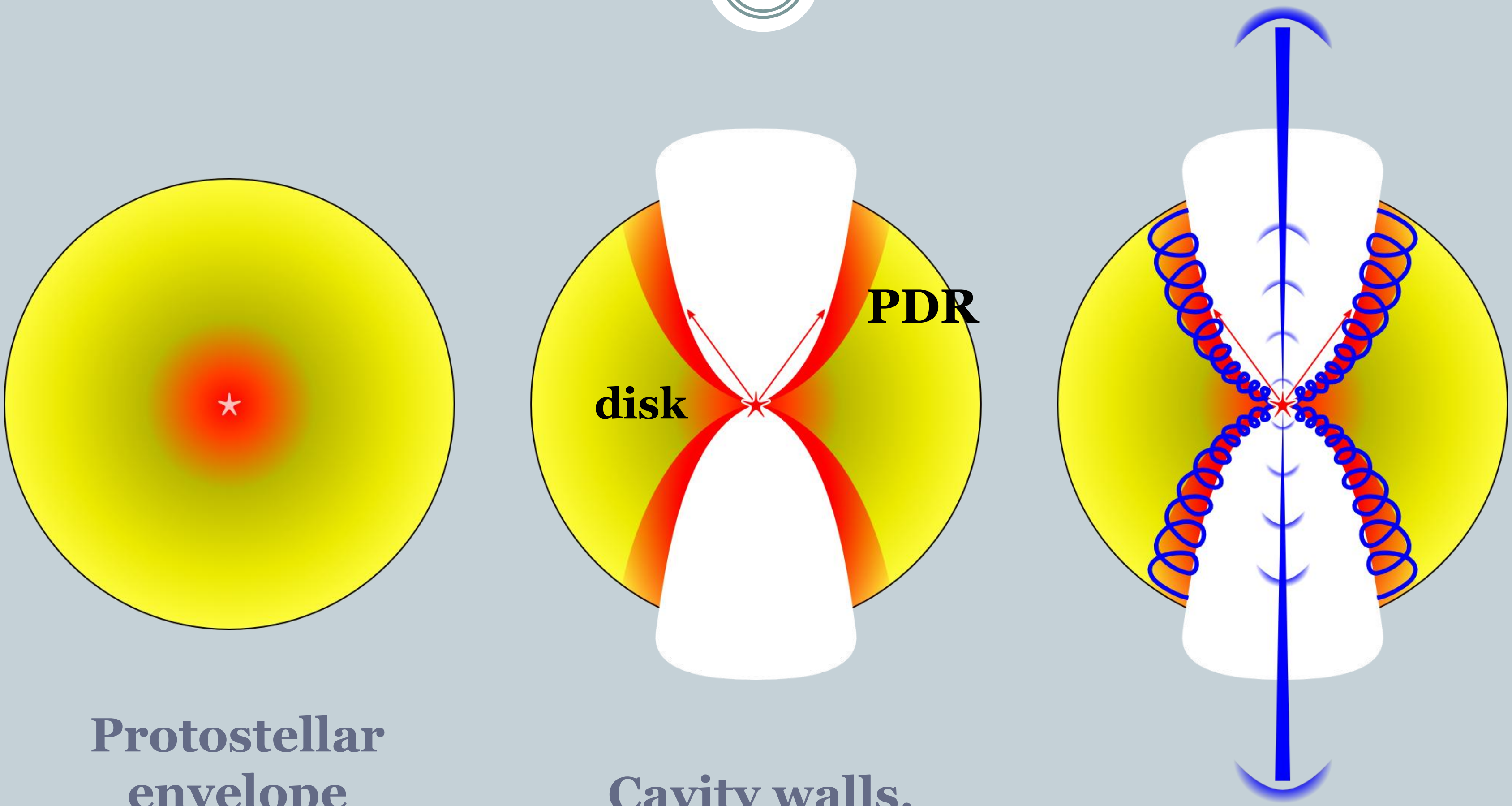


Spitzer image: Noriega-Crespo et al. (2004)

van Kempen et al. (in prep.)

Herczeg et al. (in prep.)

Dominant physical components?

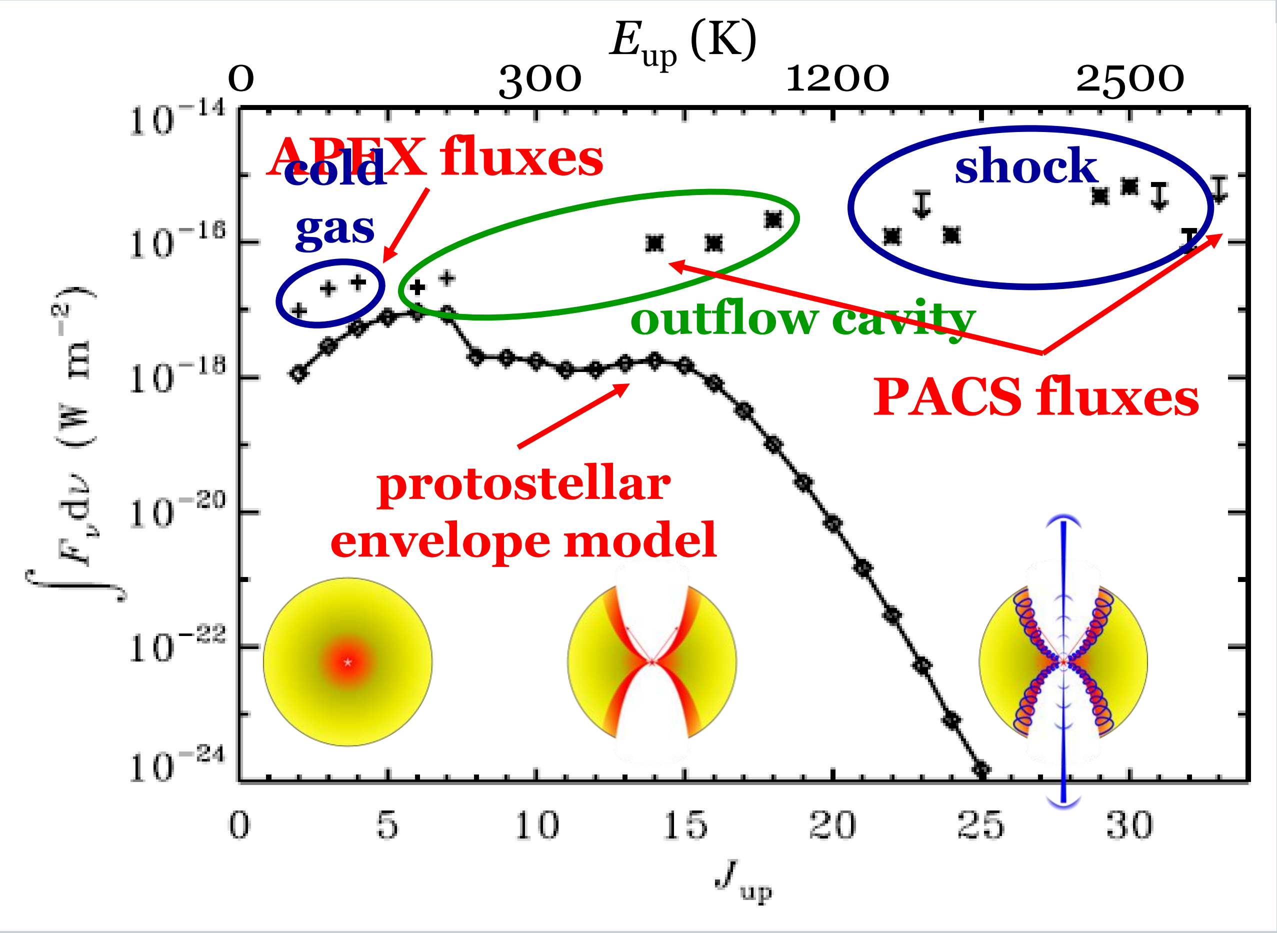


Protostellar envelope with hot core

Cavity walls, disk surface

Outflow shocks

Origin of hot CO?



Visser et al. (in prep.)

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