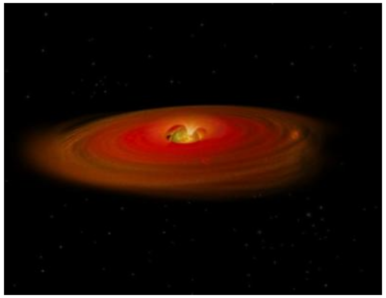
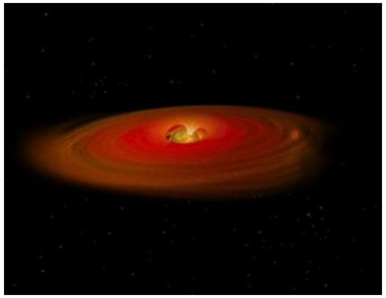
Chemical evolution from cores to disks



Ruud Visser
Leiden Observatory

January 20, 2010
University of Texas at Austin

Chemical evolution from cores to disks



Take-home message

My 2D model is a great new tool to study the chemical evolution during low-mass star formation

Outline

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

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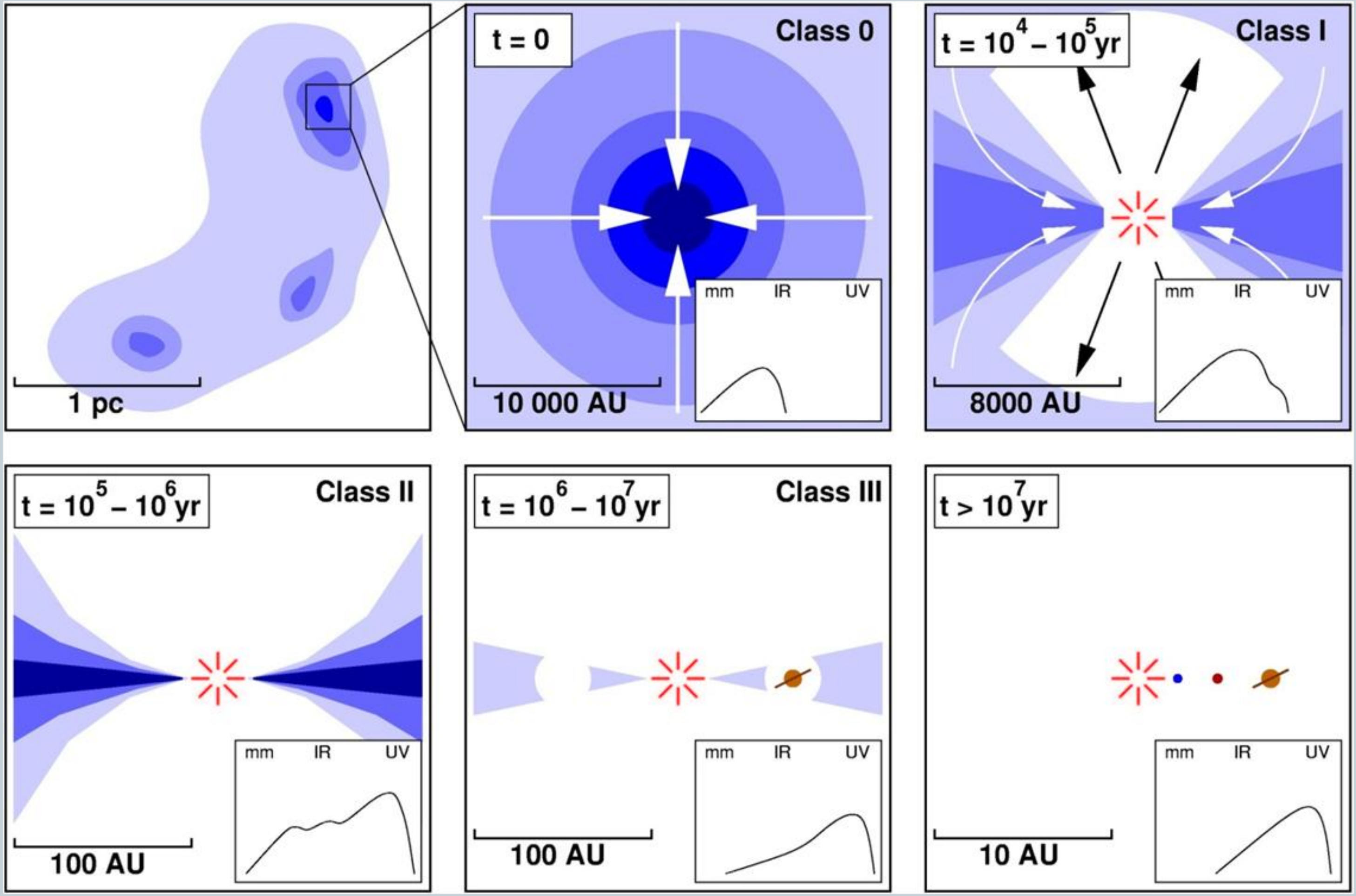
Low-mass star formation

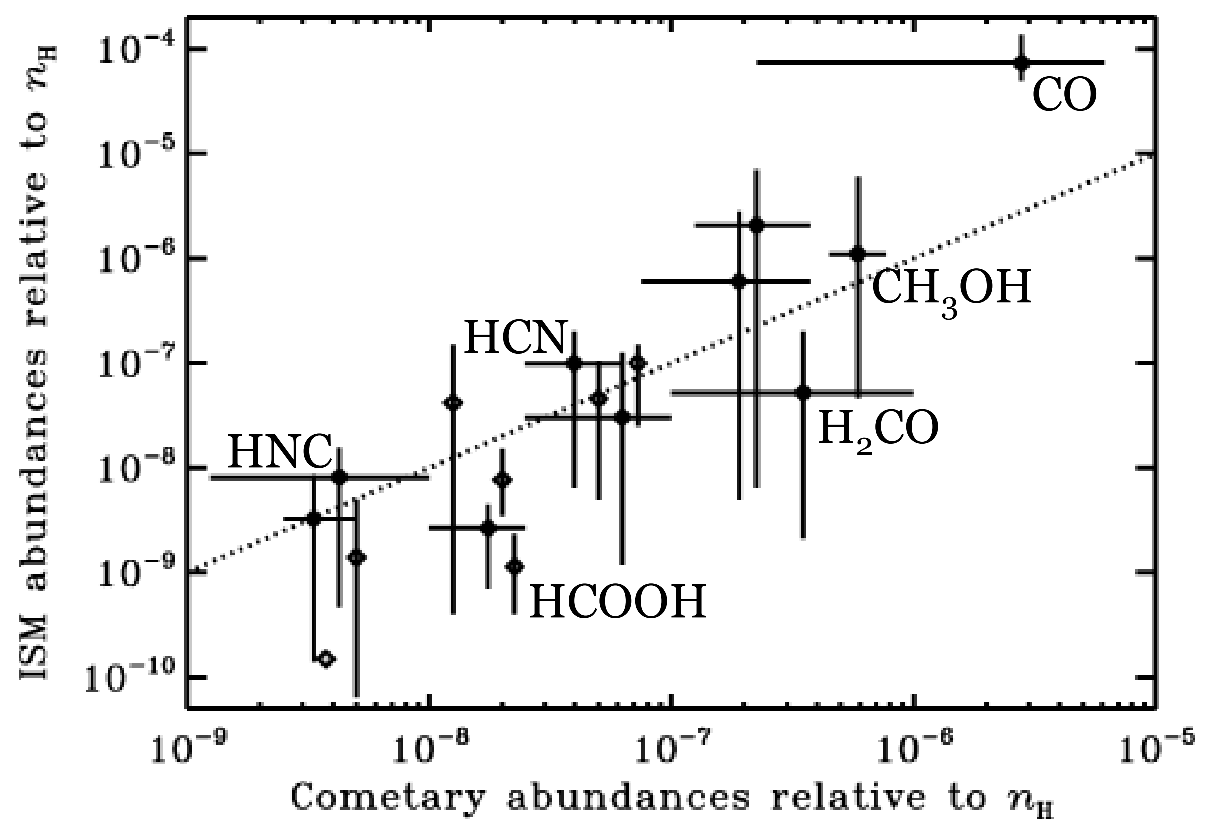


Jonkheid et al. (2006)

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?

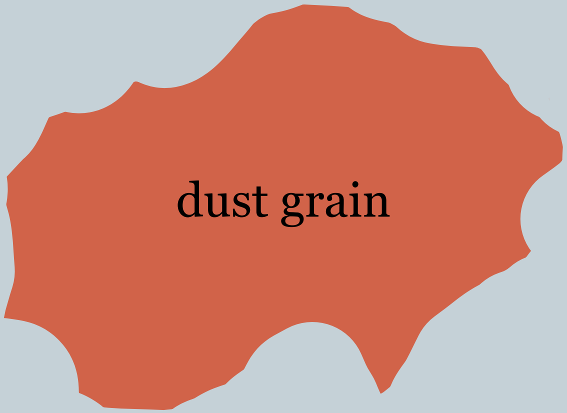


- Error bars indicate spread between sources
- Dotted line: hypothetical one-to-one relationship

- Comets in general similar to ISM, but individual differences exist

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

Chemical processes



CO

H_2

N_2

H_2

gas

H

dust grain

H

O

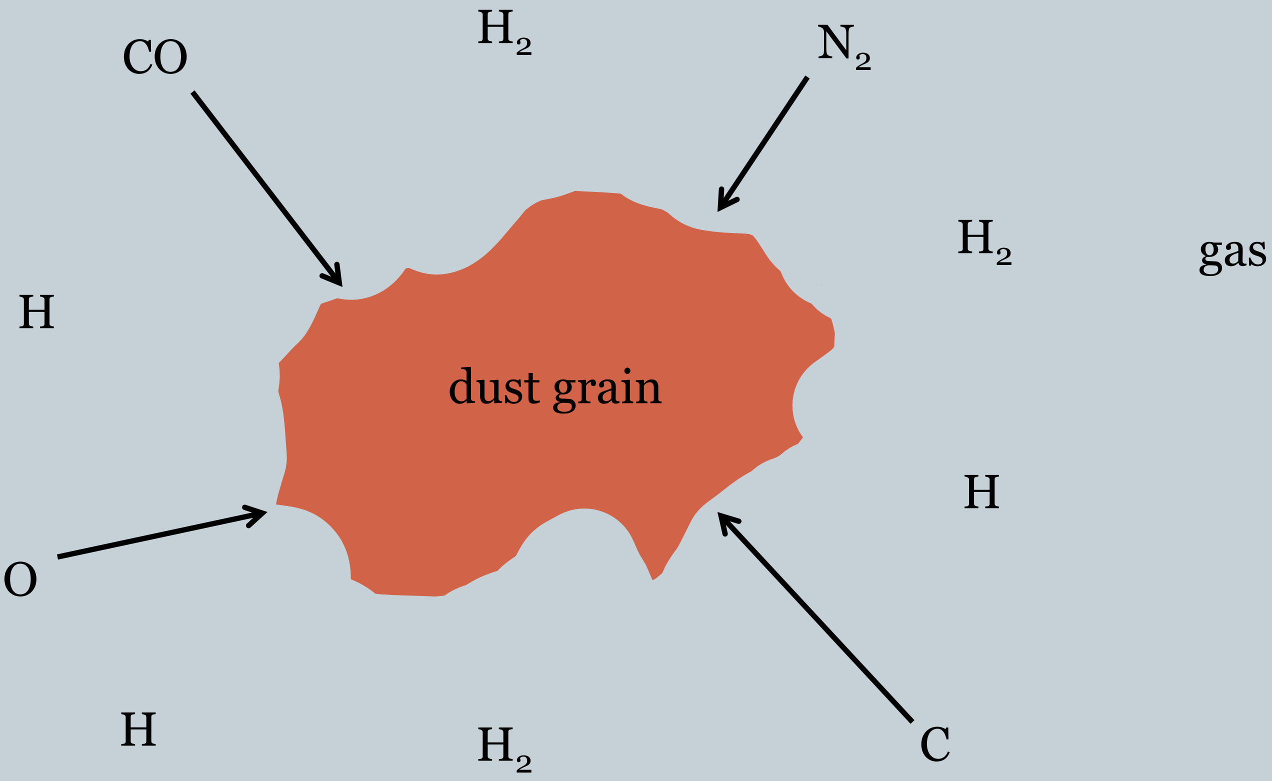
H

H_2

C

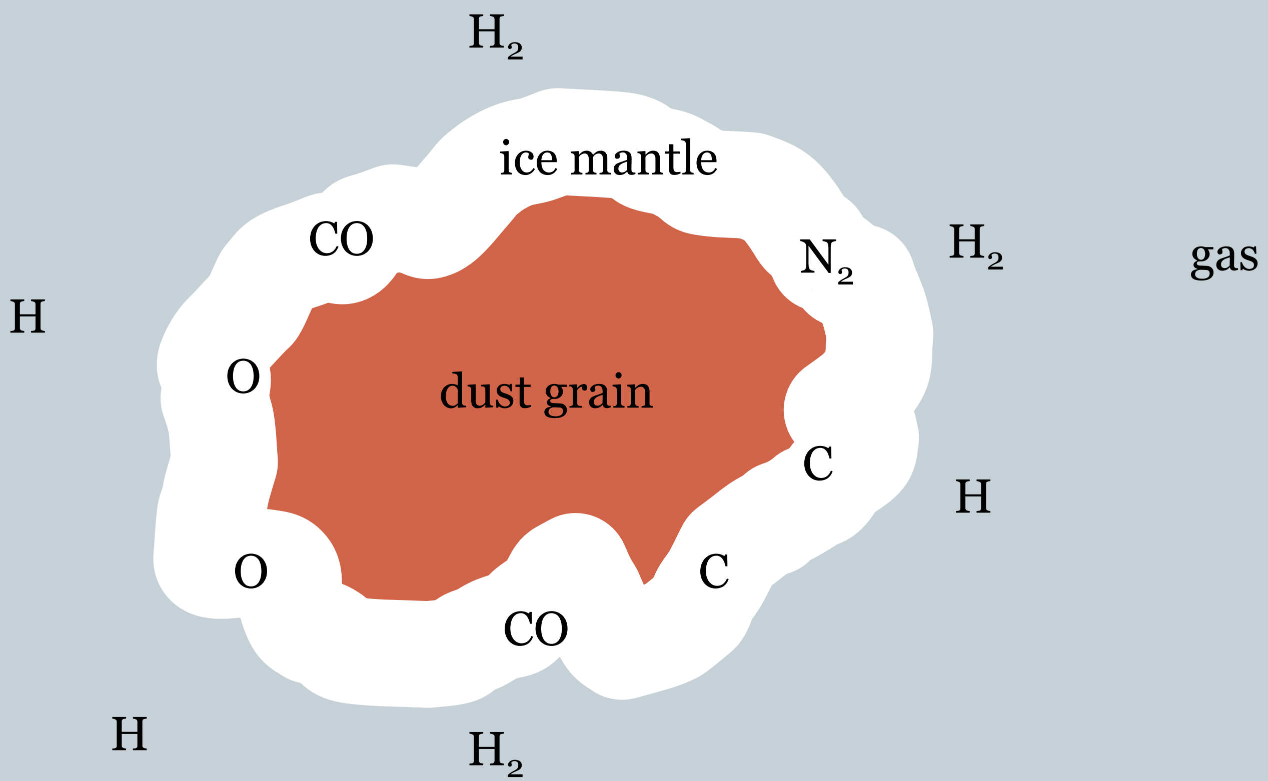
Chemical processes

- Freeze-out



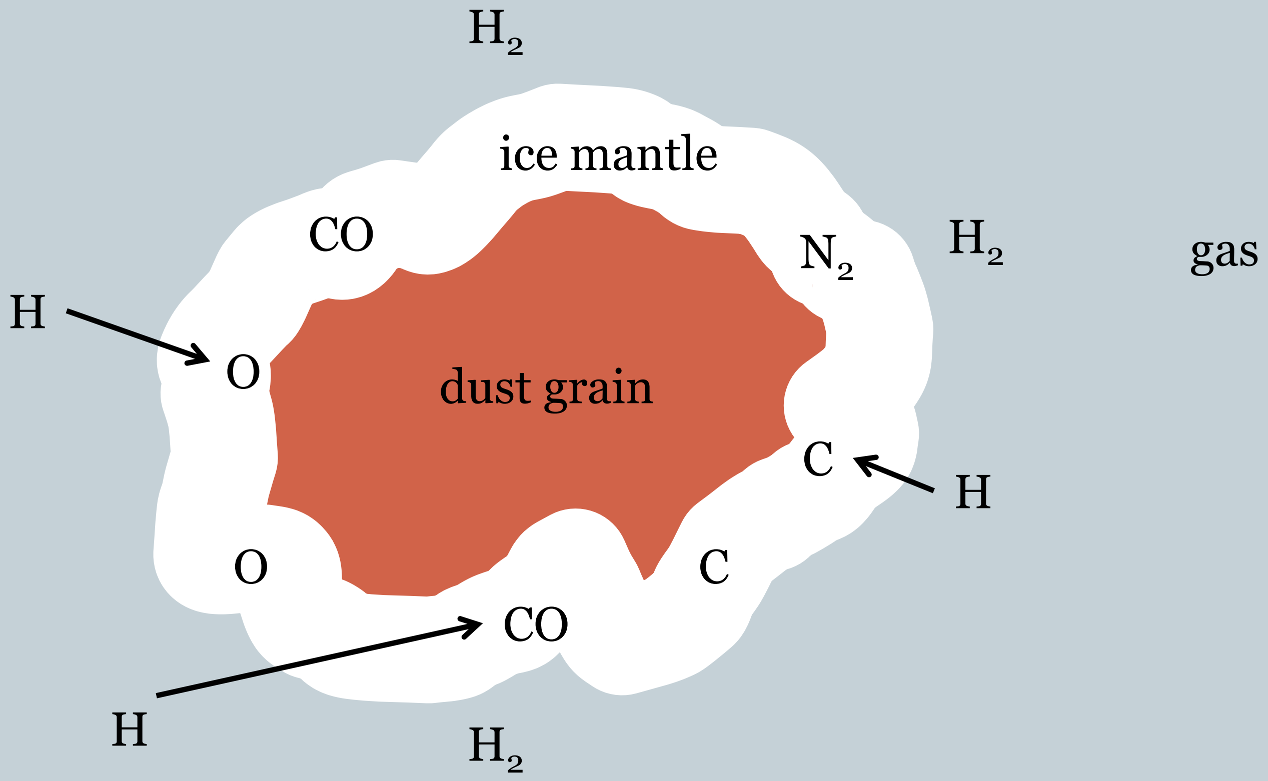
Chemical processes

- Freeze-out



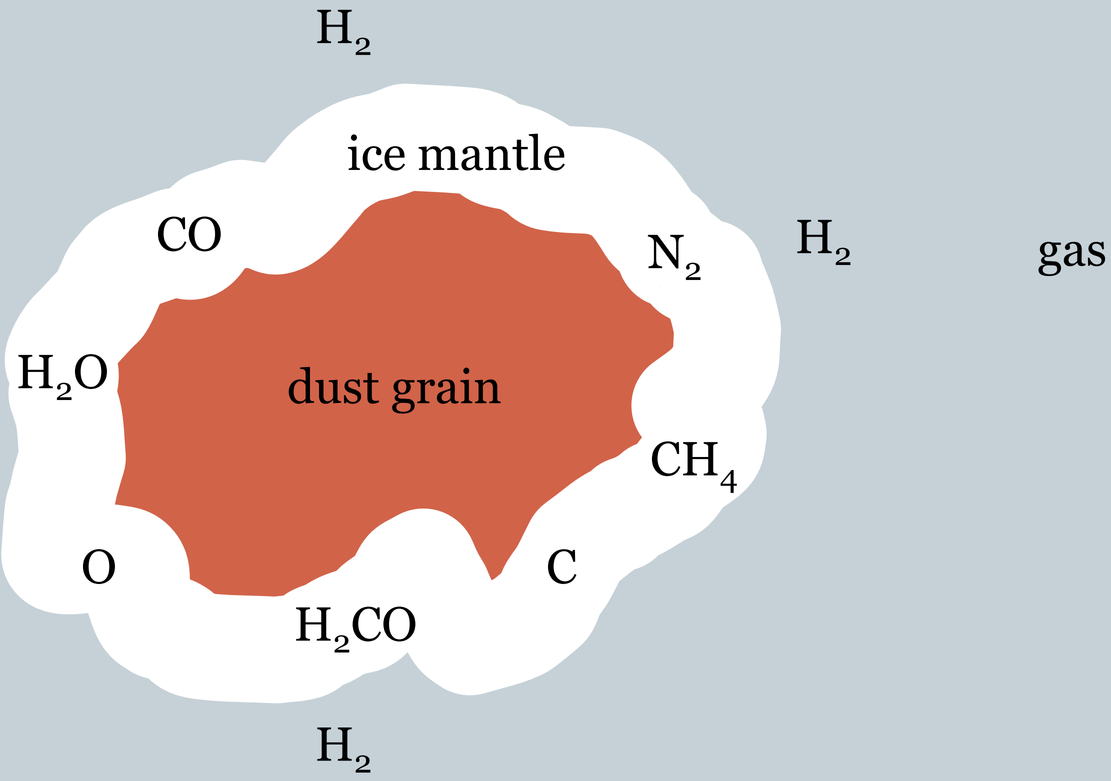
Chemical processes

- Grain-surface hydrogenation



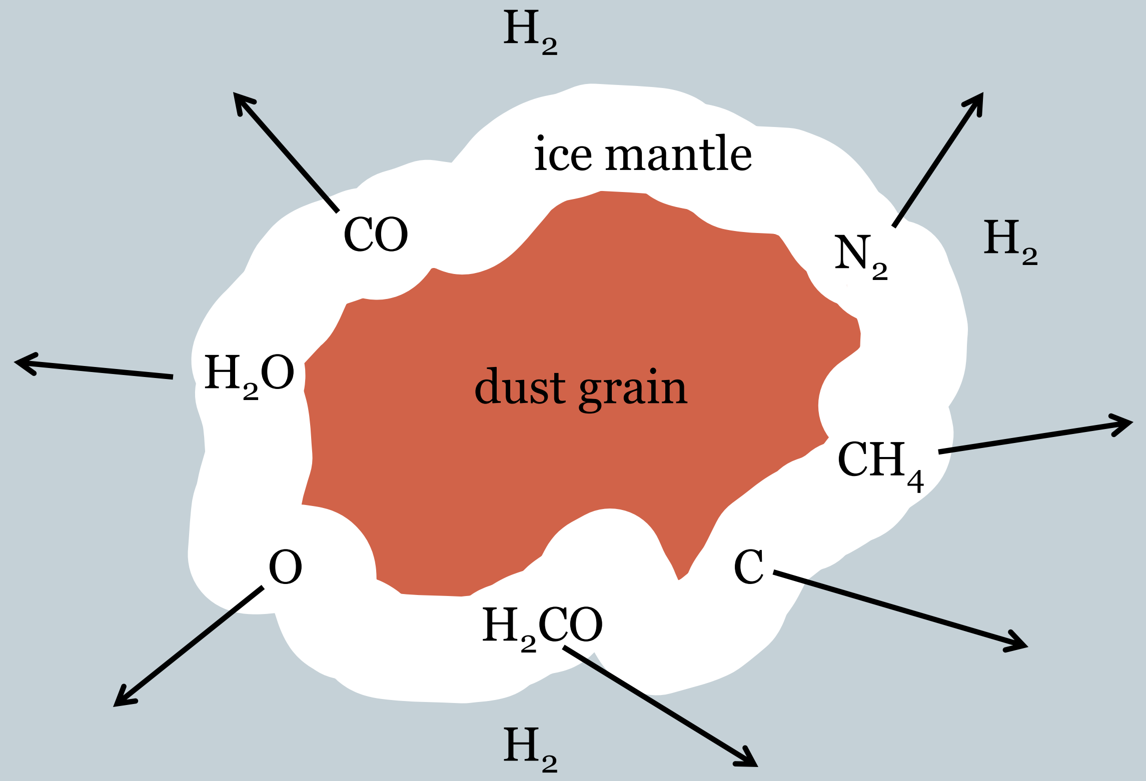
Chemical processes

- Grain-surface hydrogenation



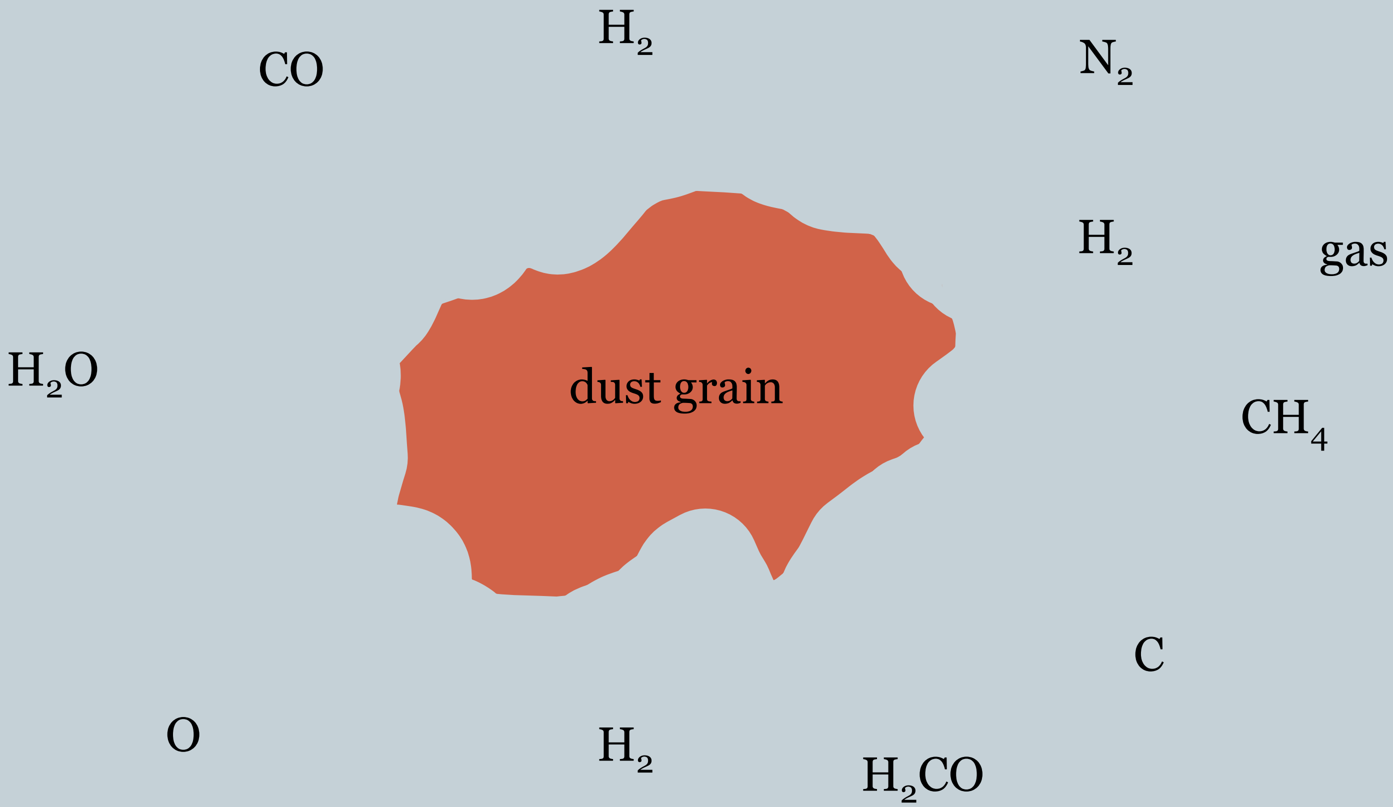
Chemical processes

- Evaporation



Chemical processes

- Evaporation



H_2

CO

N_2

H_2

gas

H_2O

dust grain

CH_4

C

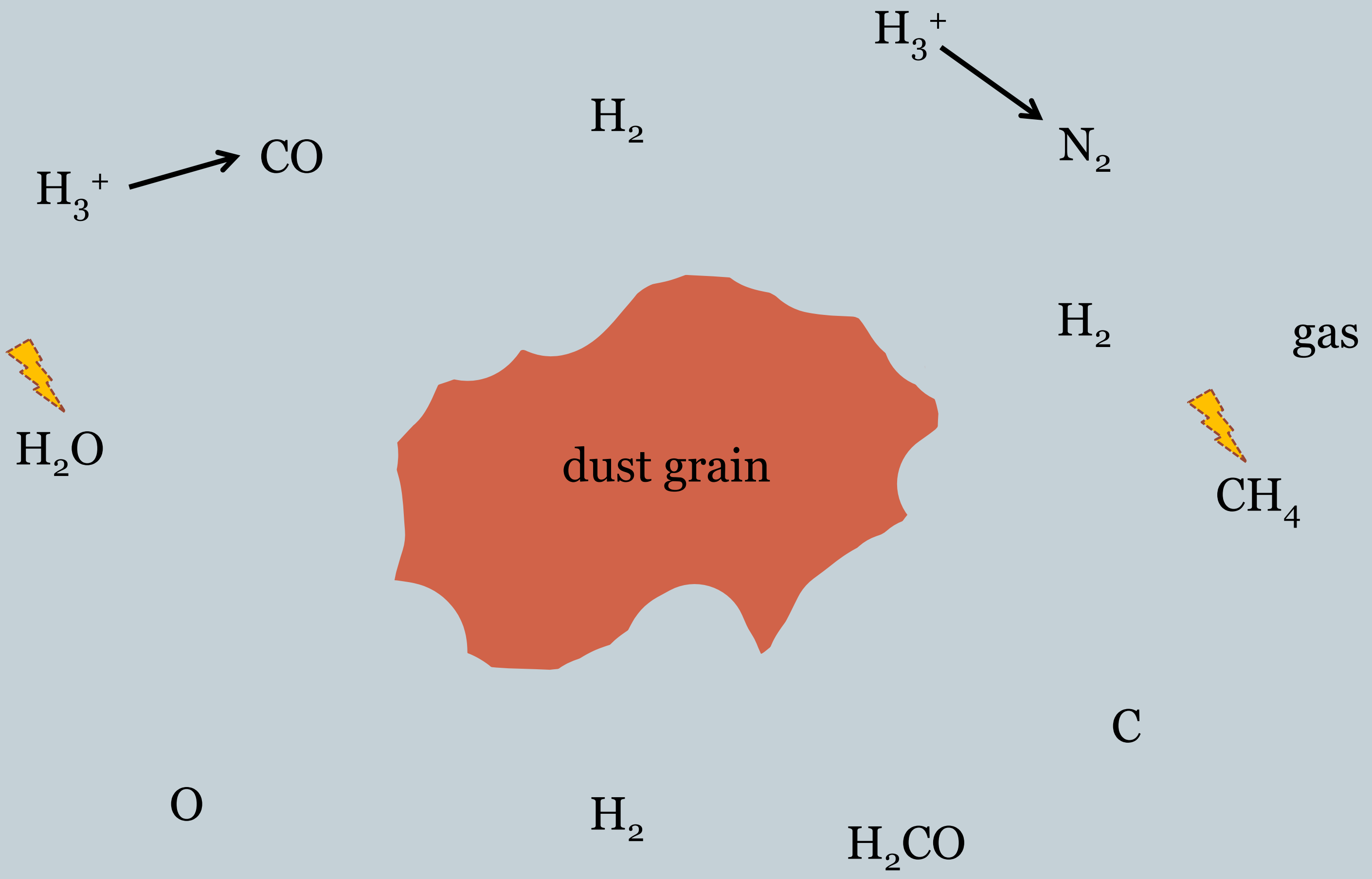
O

H_2

H_2CO

Chemical processes

- Gas-phase processes



H_3^+ → N_2

H_2

H_3^+ → CO

H_2

gas

H_2O

dust grain

CH_4

C

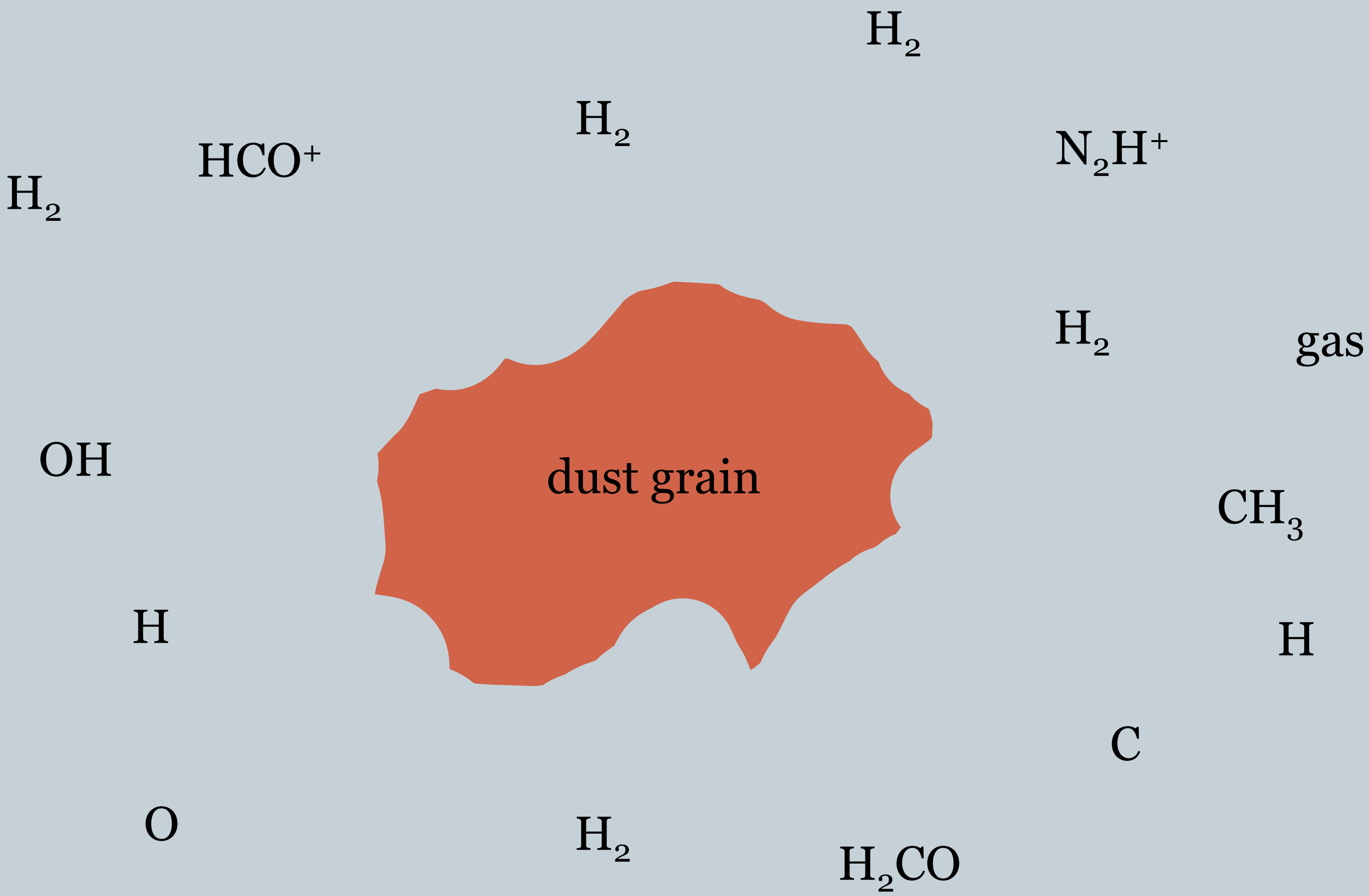
O

H_2

H_2CO

Chemical processes

- Gas-phase processes



H_2

H_2

N_2H^+

HCO^+

H_2

H_2

gas

dust grain

OH

CH_3

H

H

C

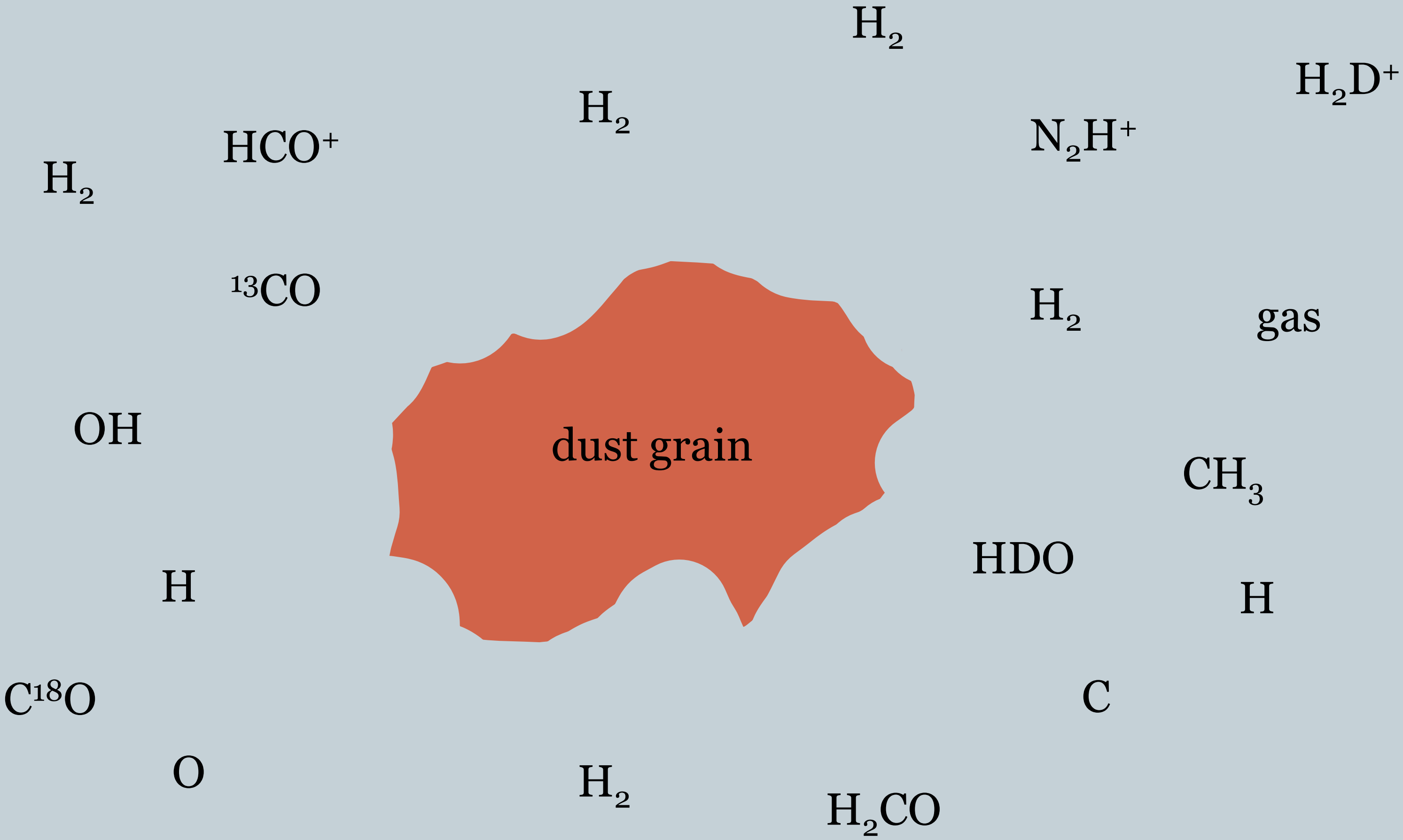
O

H_2

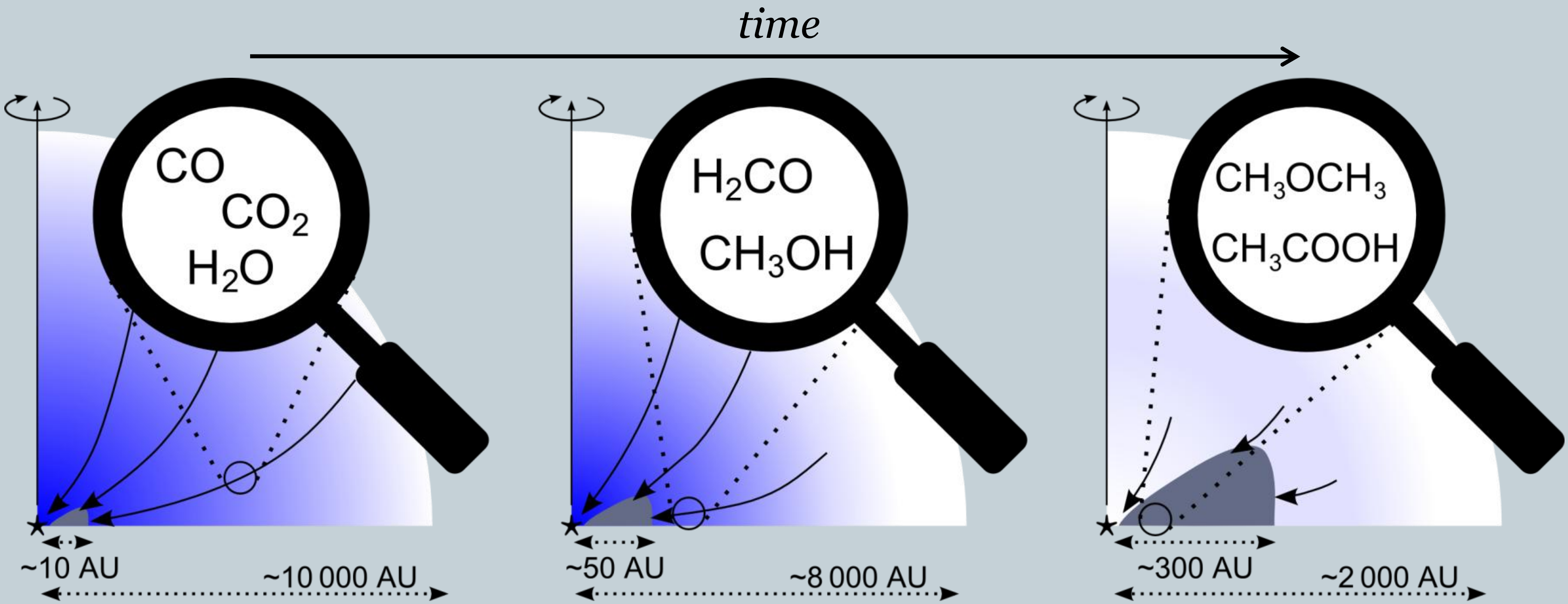
H_2CO

Chemical processes

- Isotopes



Chemistry during star formation



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

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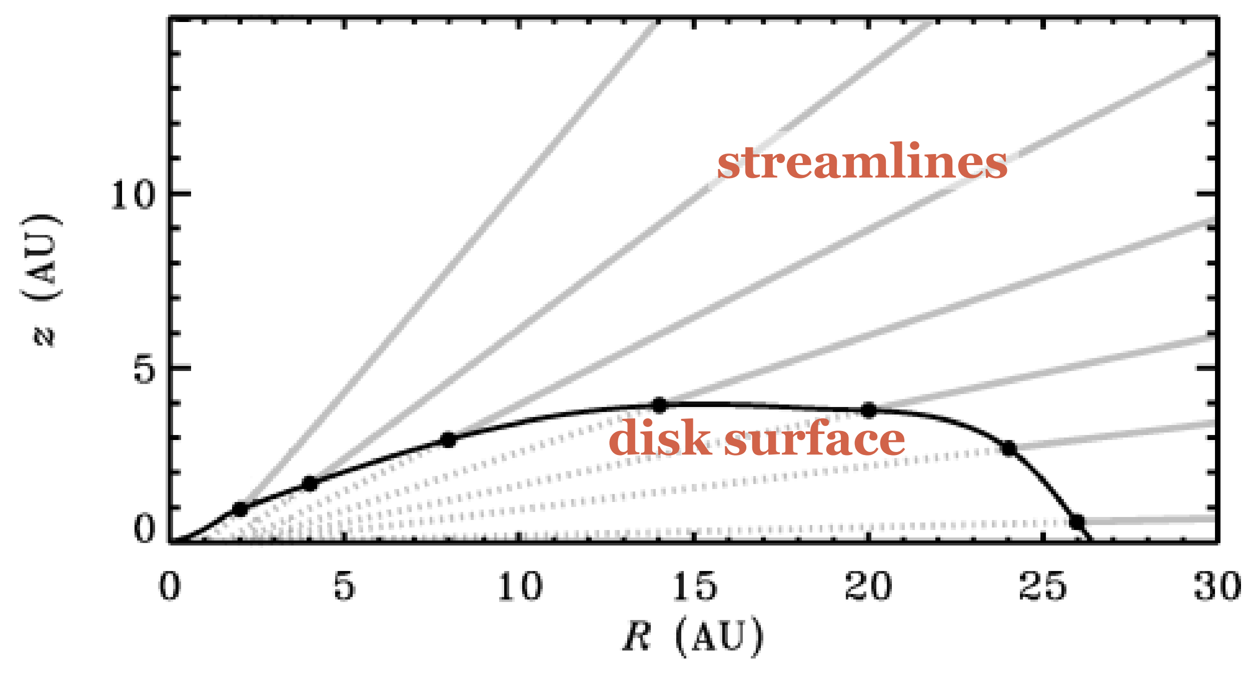
Analytical star formation model in 2D

- 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 (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)

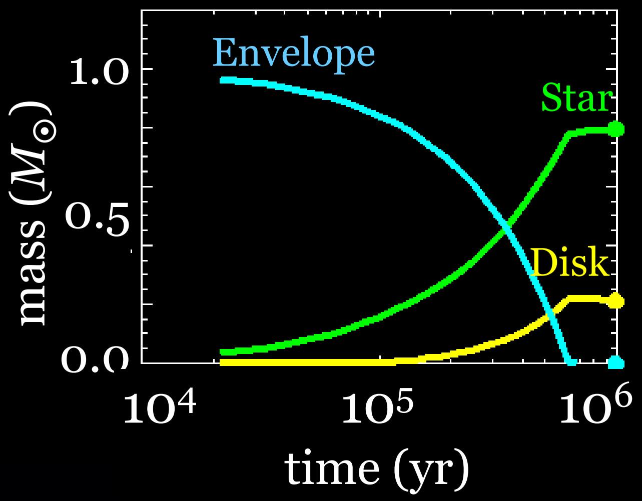
From one to two dimensions



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

Visser & Dullemond (subm.)

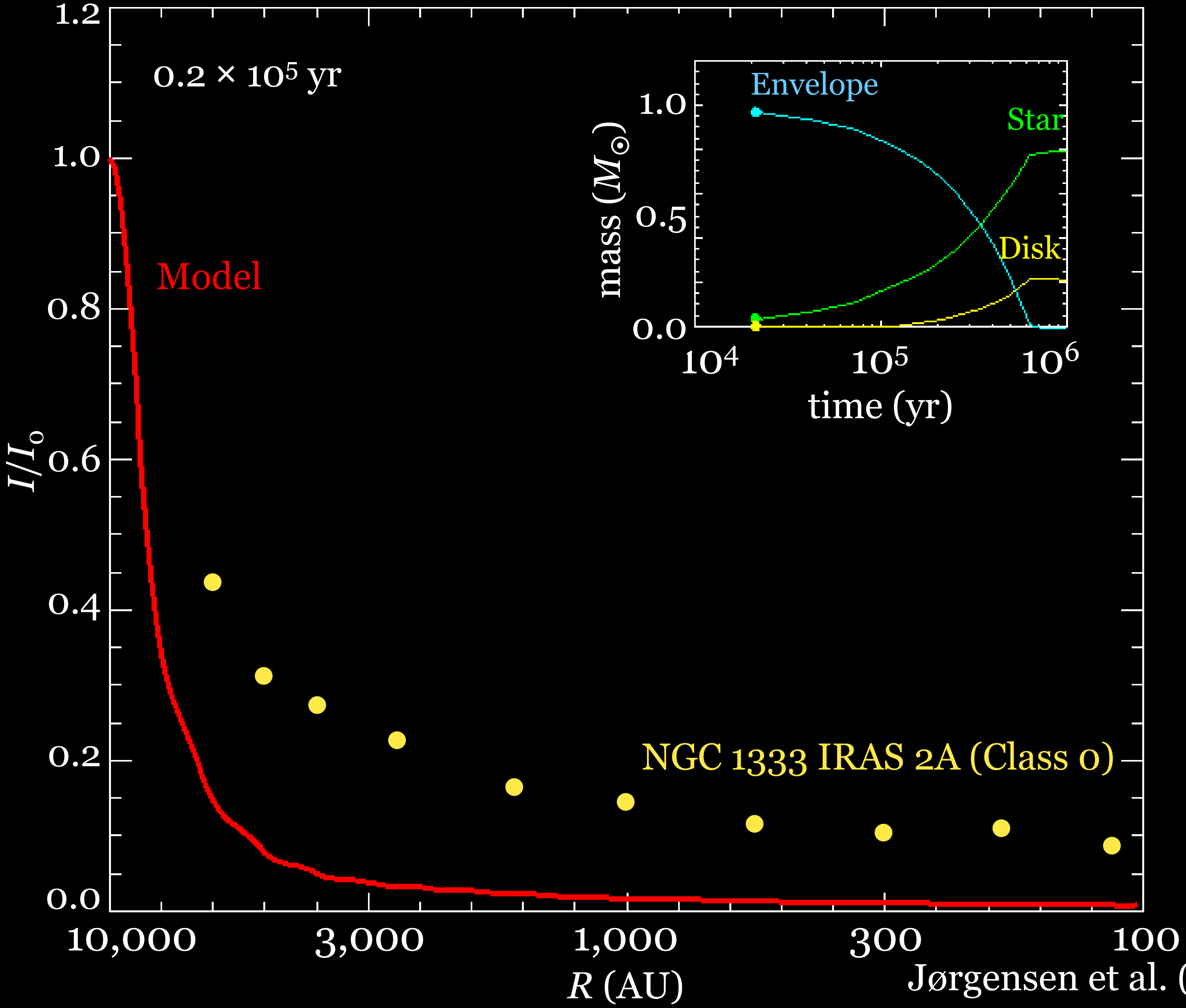
Infrared/submm image of collapsing core



850 μm, 24 μm, 8.0 μm

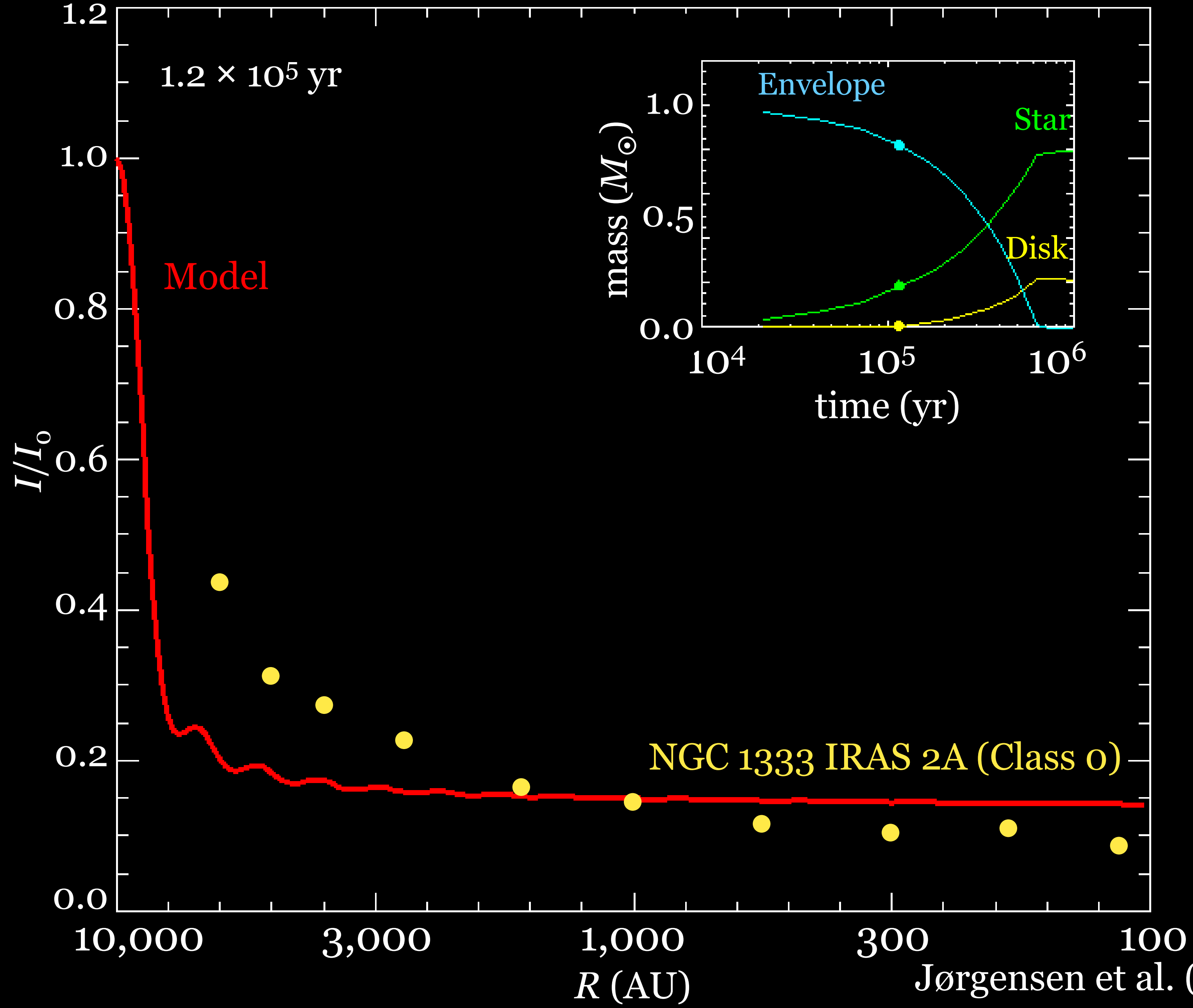
Jørgensen et al. (2009) based on Visser et al. (2009)

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



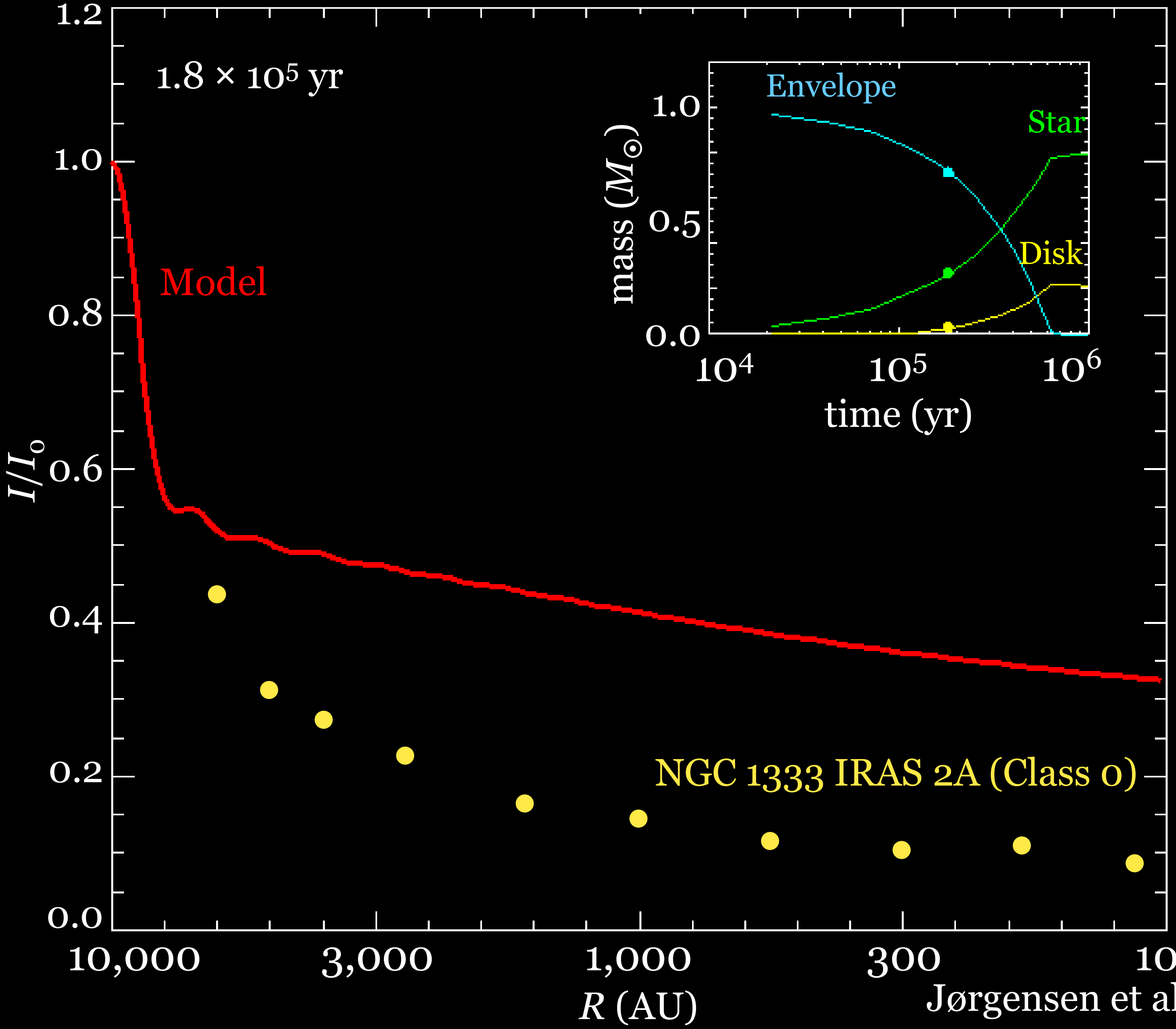
Jørgensen et al. (2009)

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



Jørgensen et al. (2009)

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



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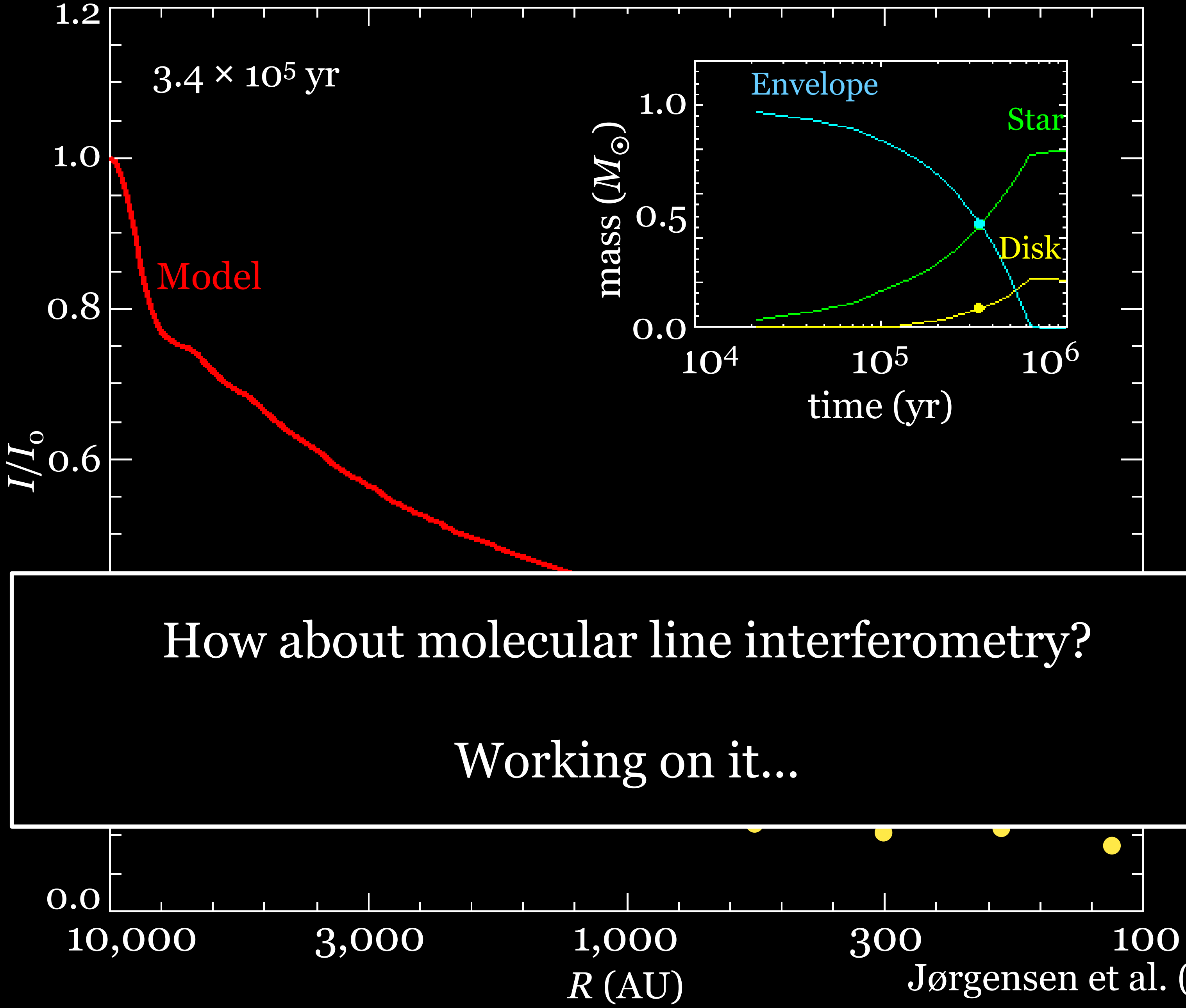
Sub-mm model visibilities (350 GHz/850 μm)



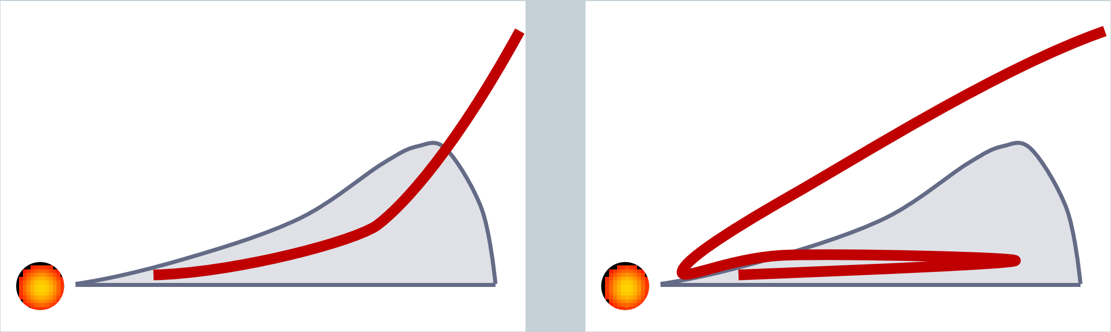
How about molecular line interferometry?

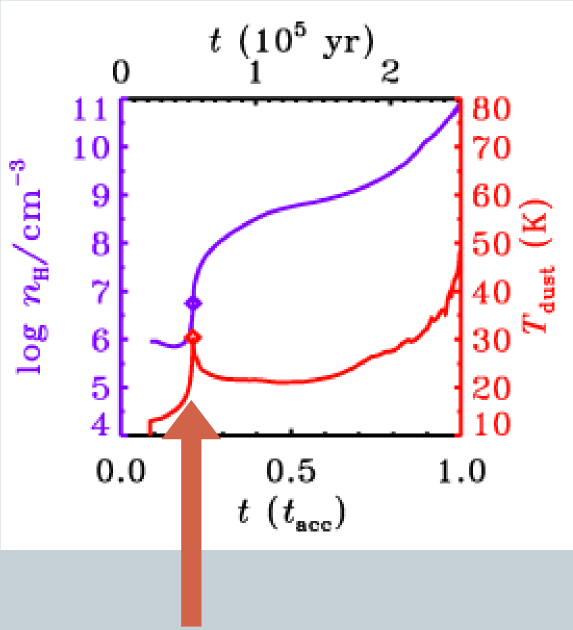
Working on it...

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.)

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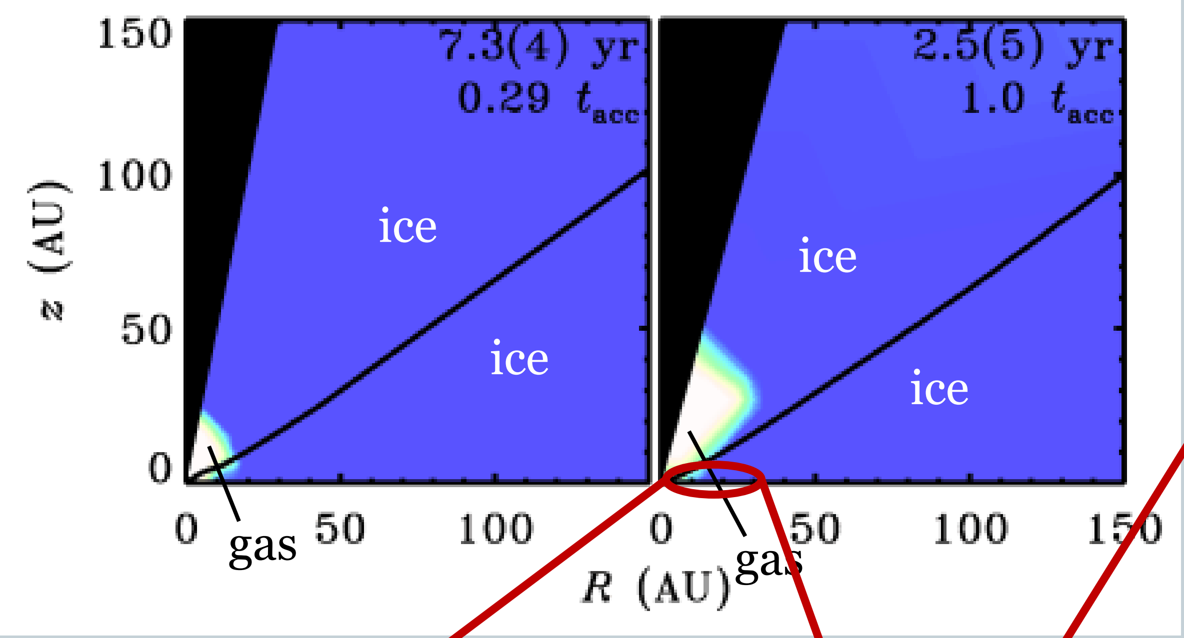
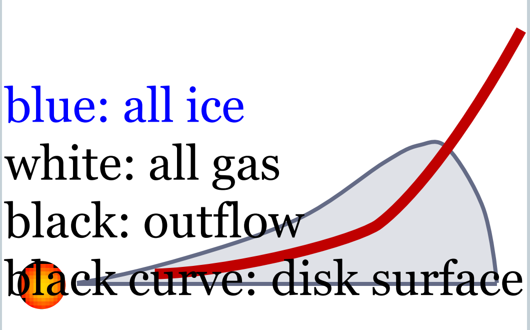
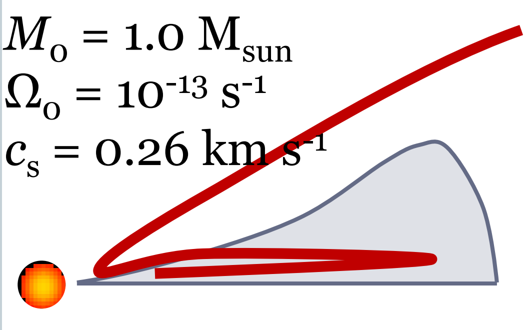
Gas and ice: H_2O





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

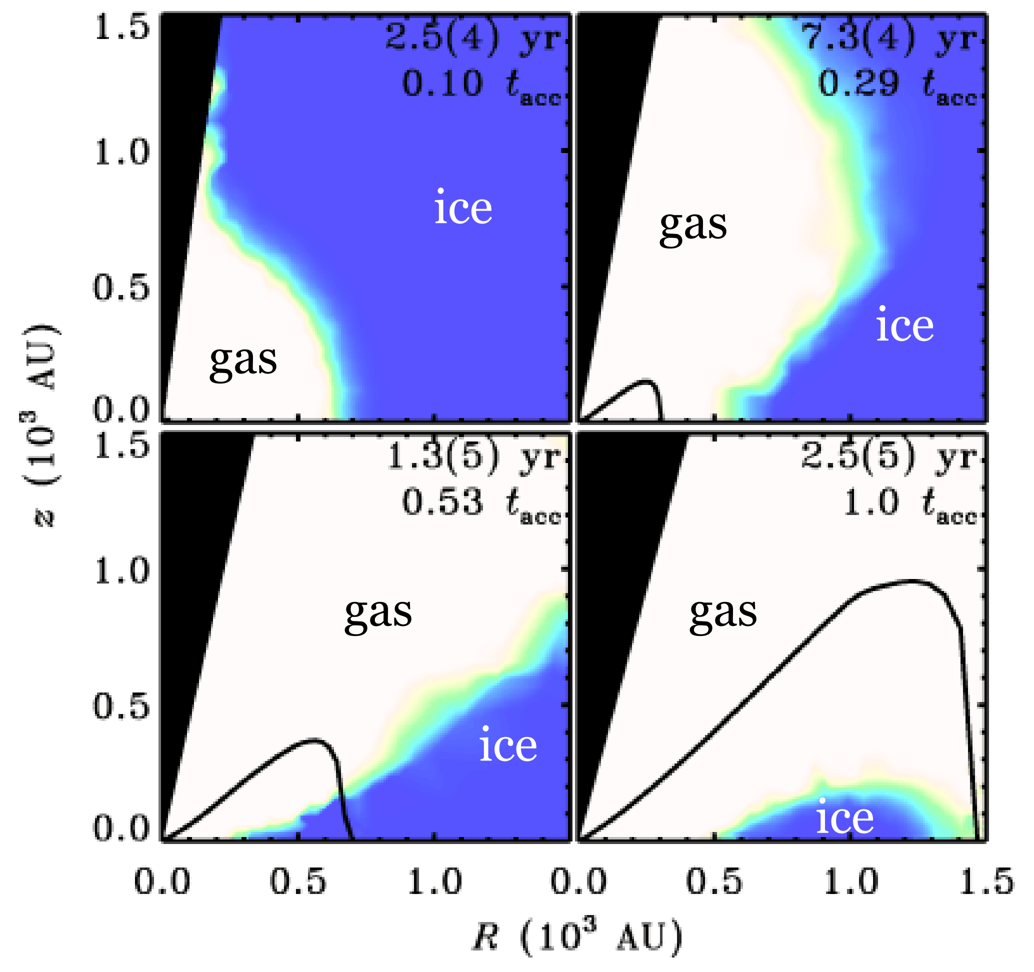


$M_0 = 1.0\ M_{sun}$
$\Omega_0 = 10^{-13}\ s^{-1}$
$c_s = 0.26\ km\ s^{-1}$

- 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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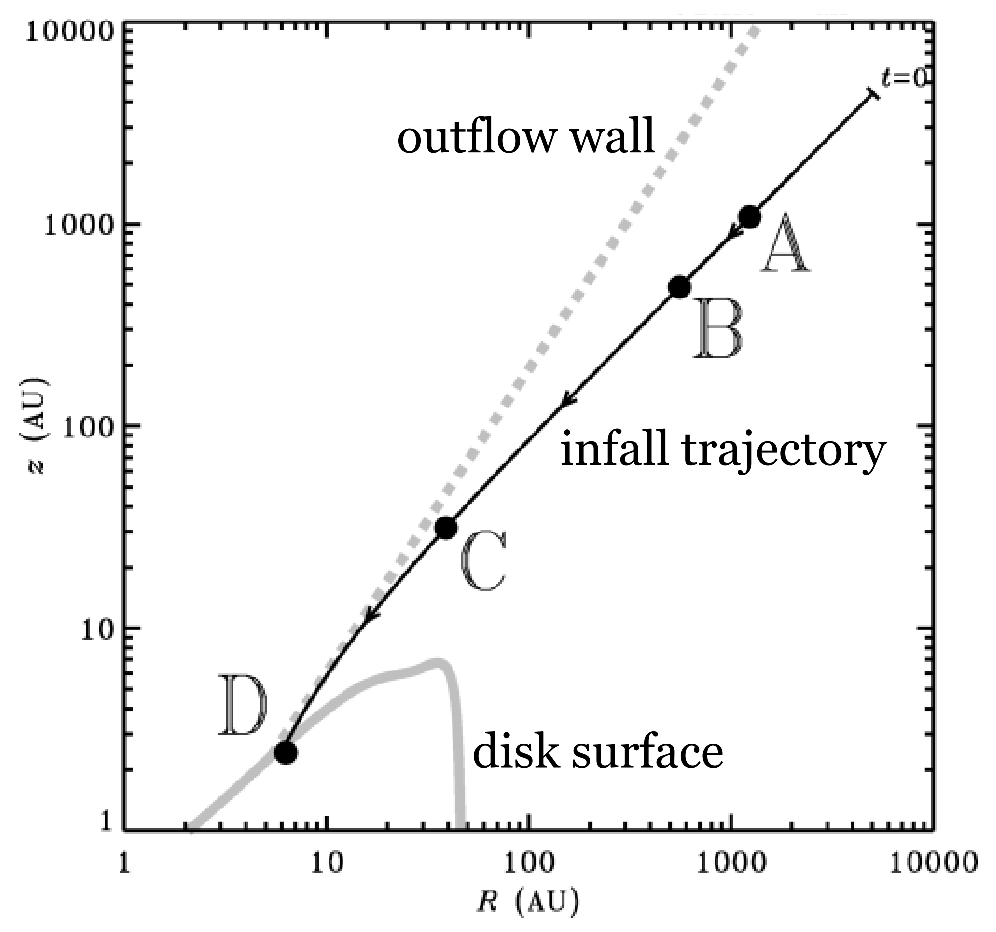
Full chemistry along one trajectory



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

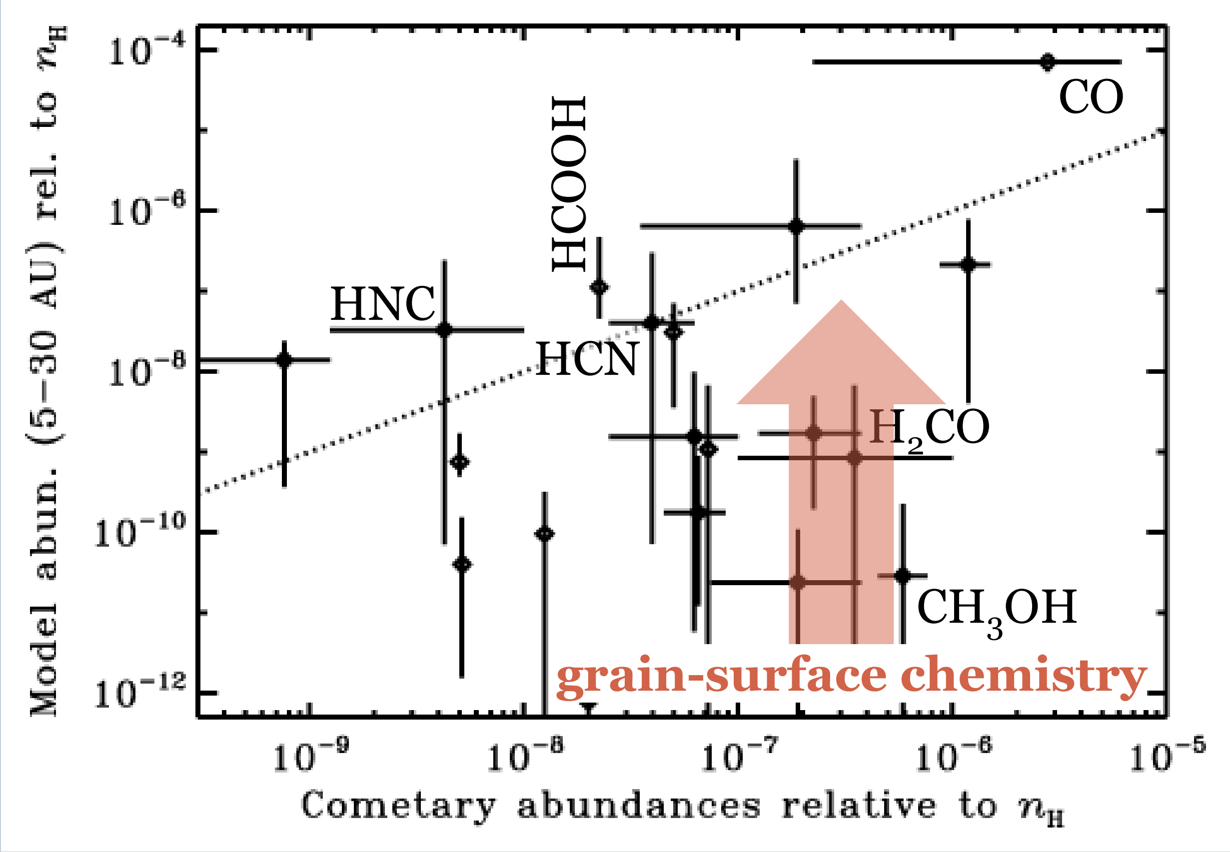
B: intermediates evaporate (e.g. CH_4, NO)

C: strongly bound ices evaporate (e.g. H_2O, NH_3, CH_3OH) photodissociation of many species (not CO!)

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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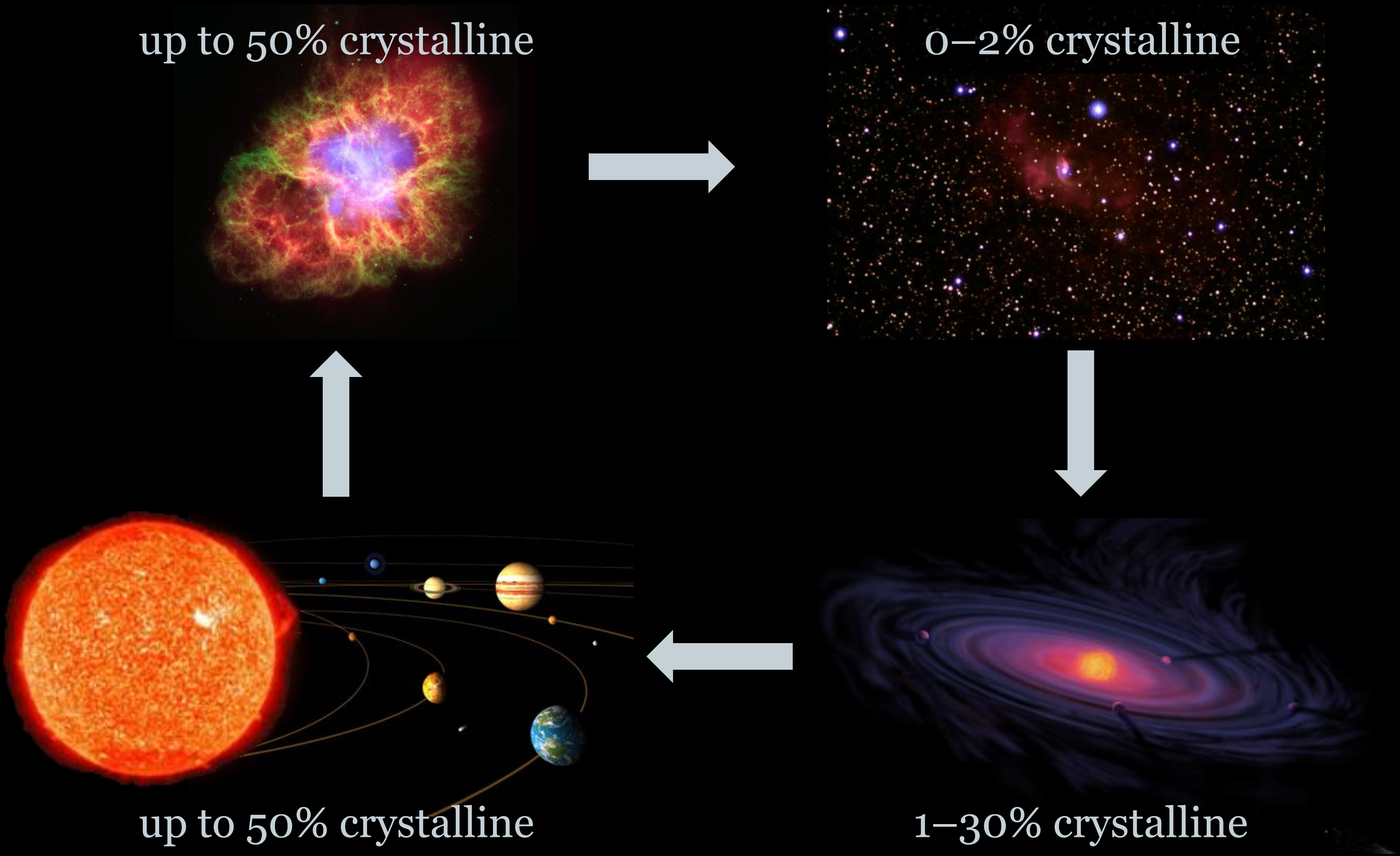
From crystalline to amorphous and back



up to 50% crystalline

0–2% crystalline

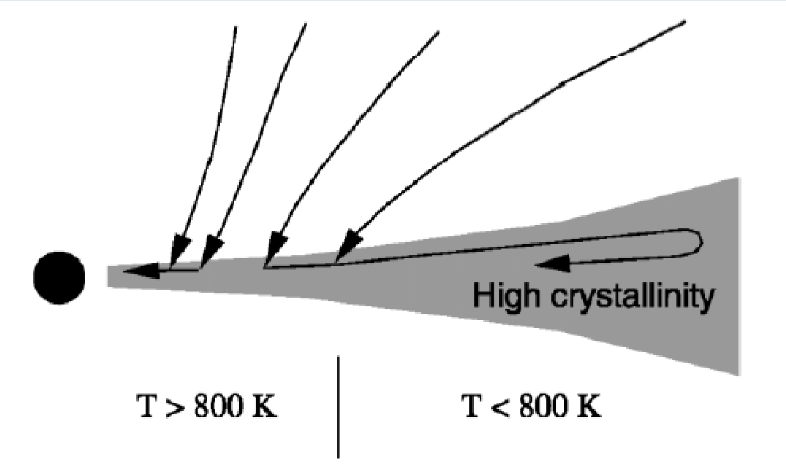
1–30% crystalline

up to 50% crystalline

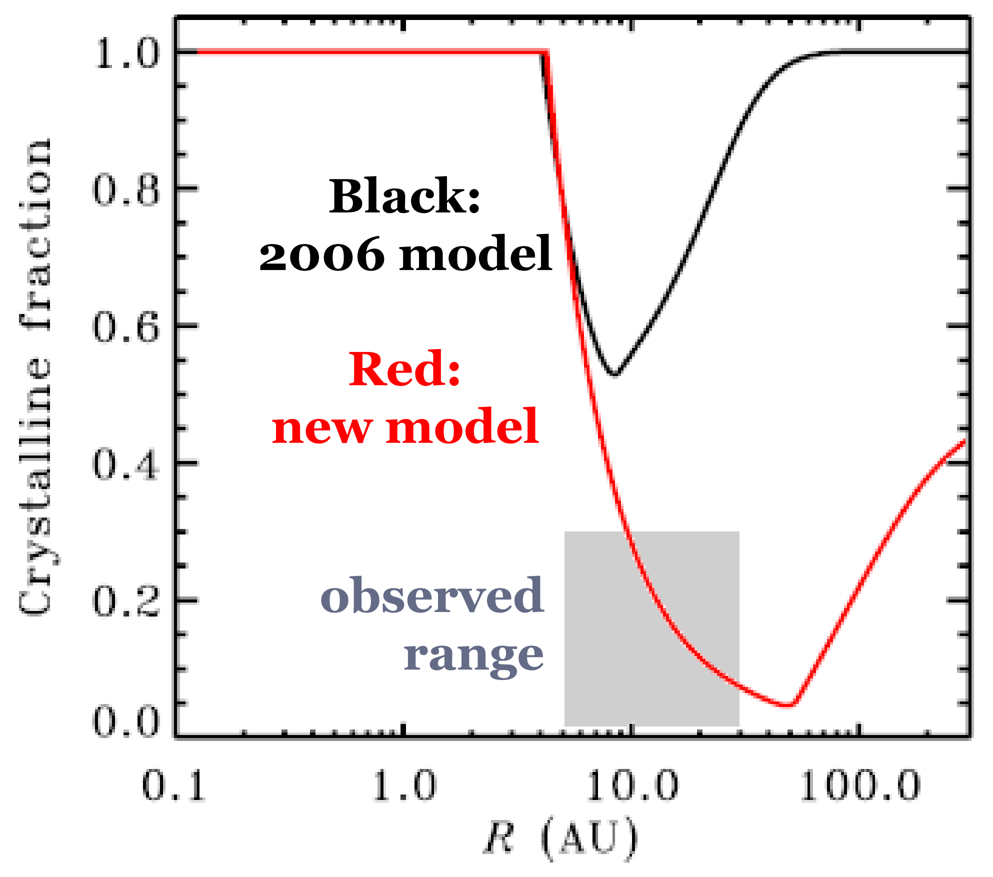
Origin of crystalline silicates in disks

- 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



Black: 2006 model

Red: new model

observed range

New model results in good agreement with observed range!

Visser & Dullemond (subm.)

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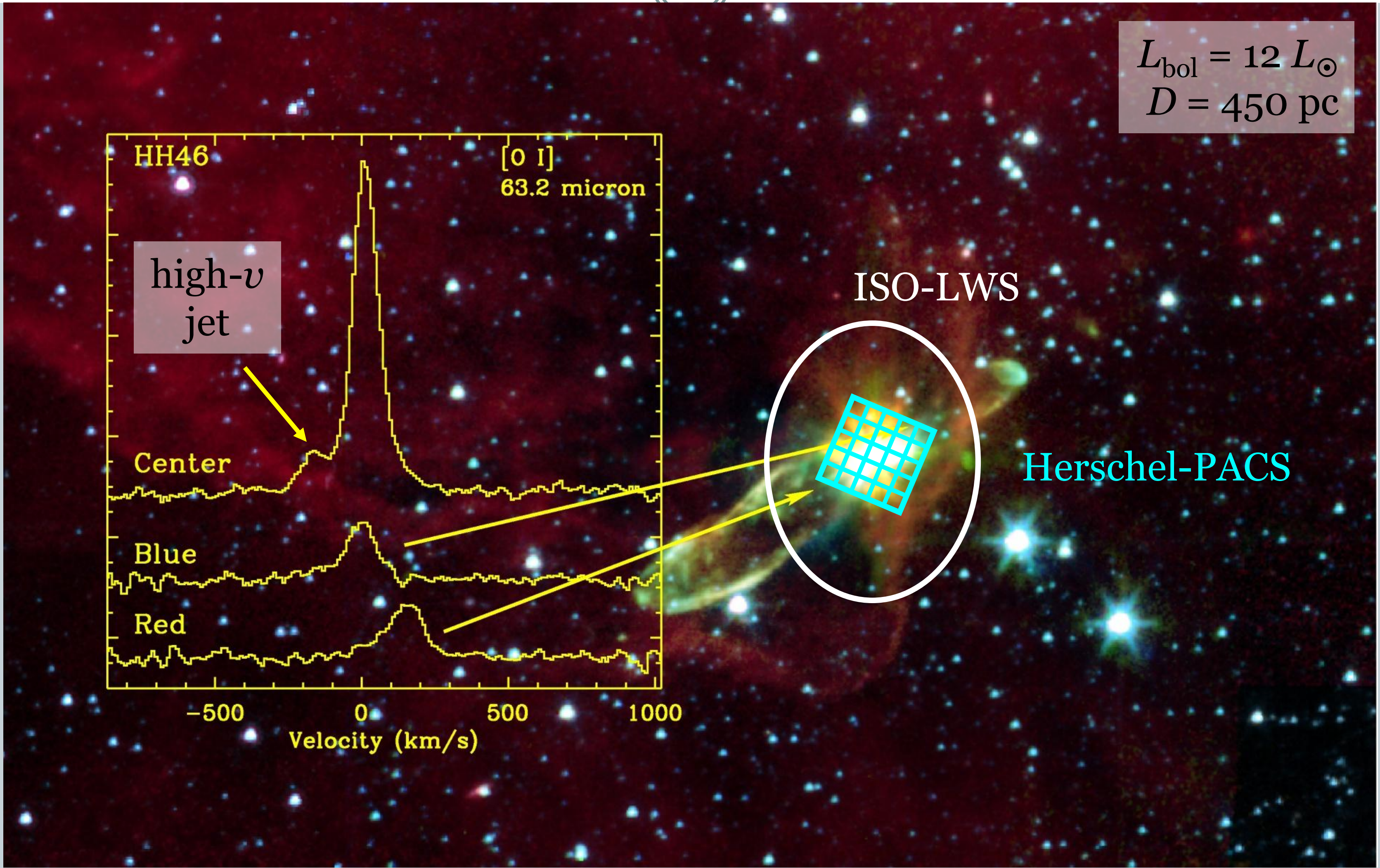
Water and CO with Herschel

- 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

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

[O I] in low-mass YSO HH46



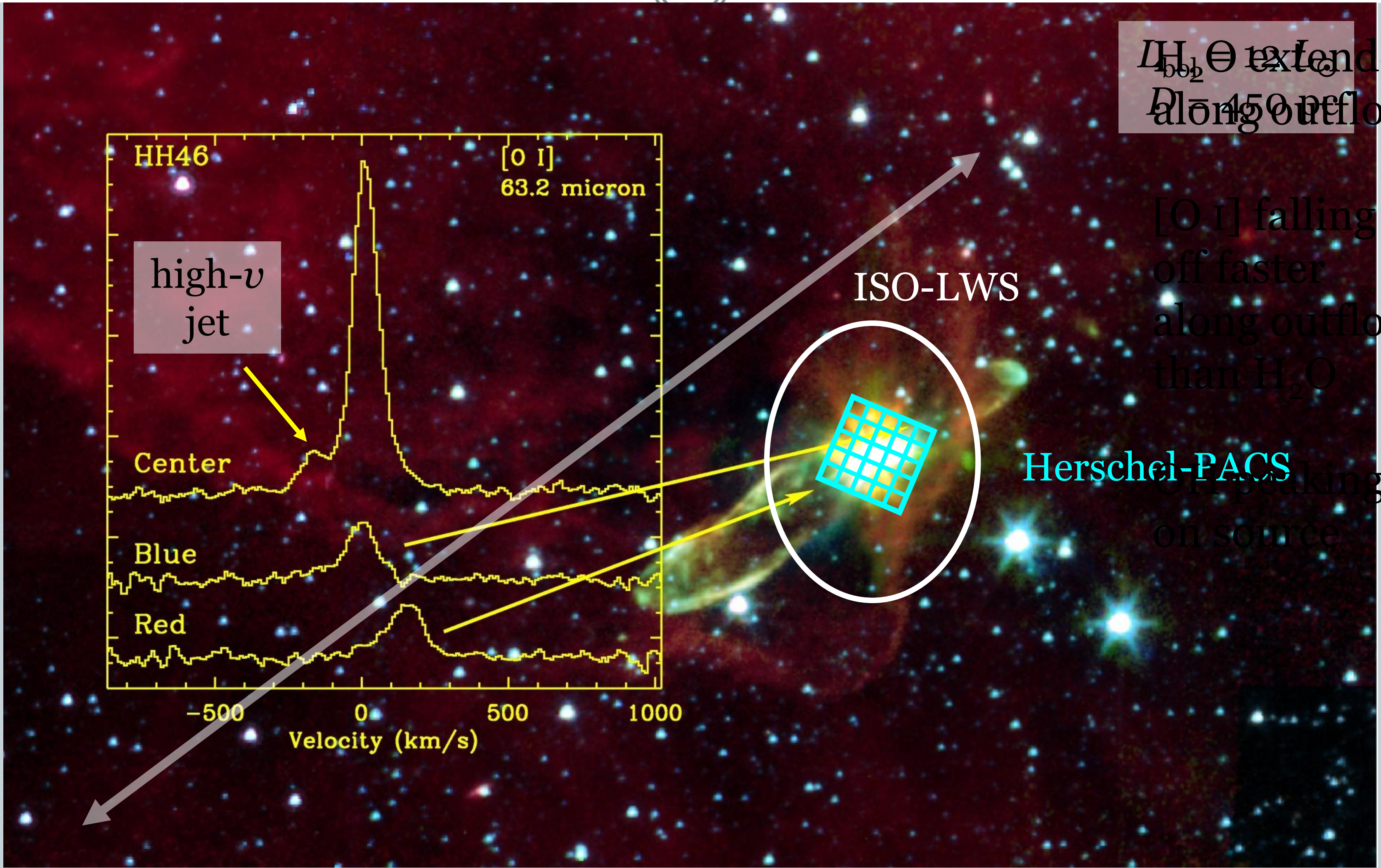
$L_{\mathrm{bol}} = 12\ L_{\odot}$
$D = 450$ pc

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

van Kempen et al. (in prep.)

[O I] YSOs: HH46

Spatial distribution



Herschel-PACS

high-υ jet

$L_{bol} = 12 L_\odot$
$D = 450$ pc

H_2O extended along outflow

[O I] falling off faster along outflow than H_2O

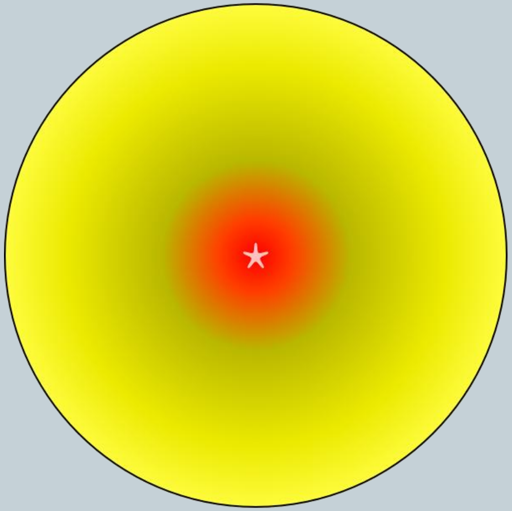
OH peaking on source

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

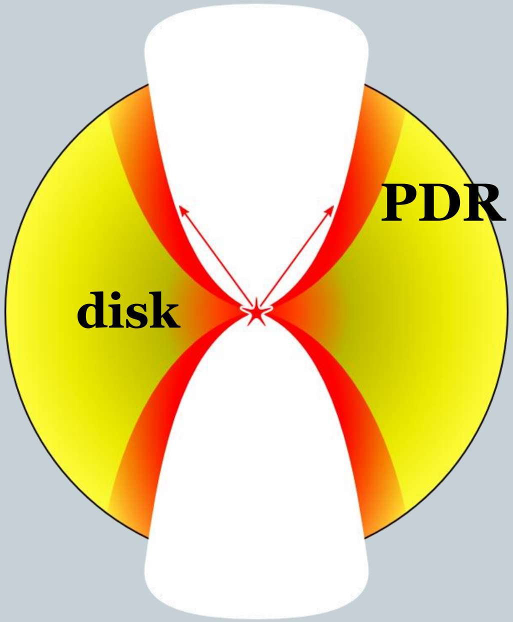
van Kempen et al. (in prep.)

Herczeg et al. (in prep.)

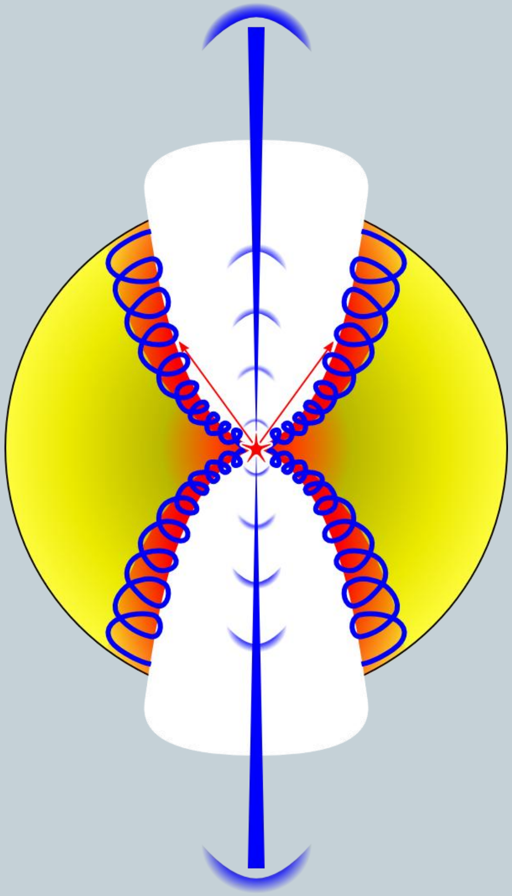
Dominant physical components?



Protostellar envelope with hot core

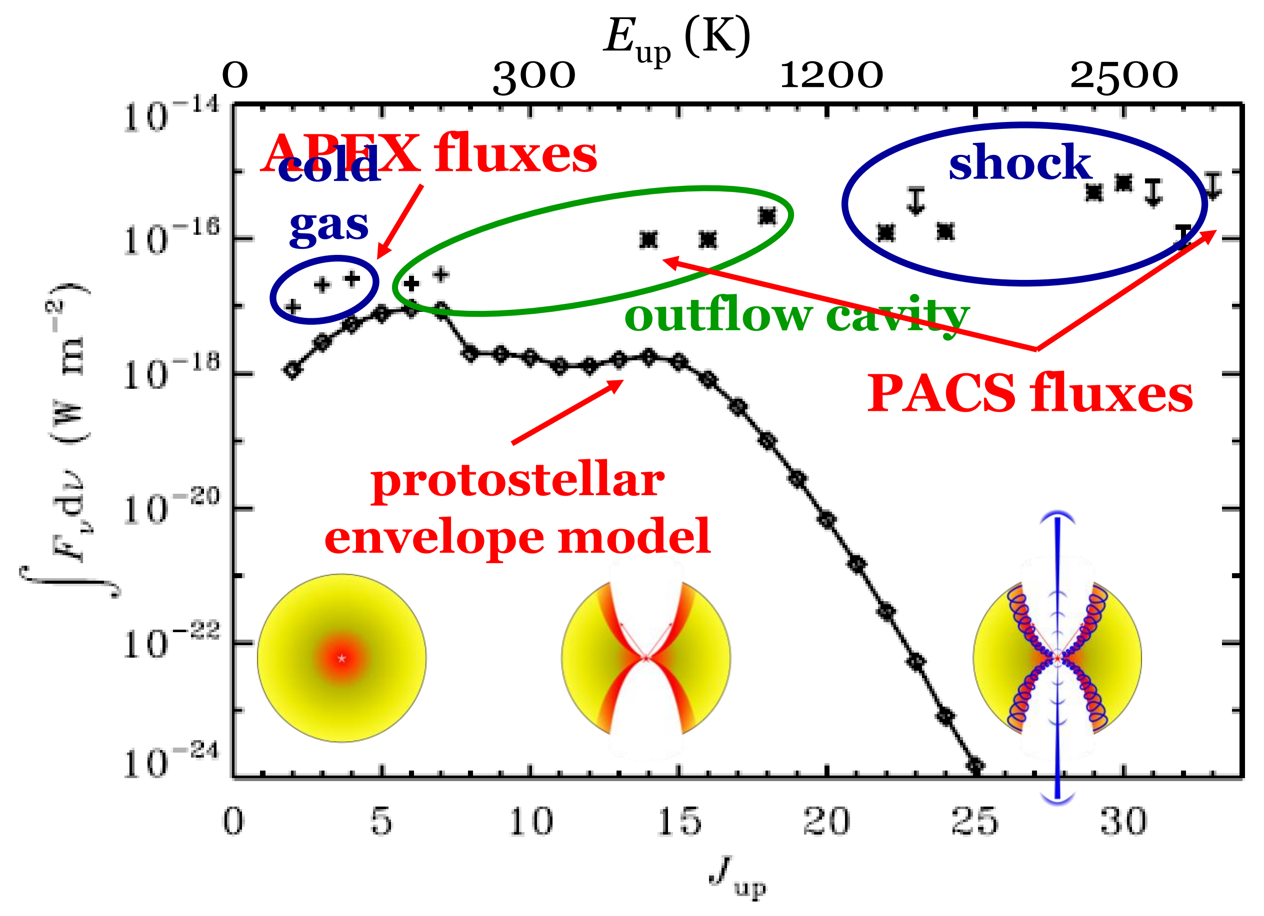


Cavity walls, disk surface



Outflow shocks

Origin of hot CO?



Visser et al. (in prep.)

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Conclusions

- First model to follow chemistry from pre-stellar cores to circumstellar disks in 2D
- Great tool for chemical evolution, but many challenges remain
- Thermal annealing followed by radial transport is responsible for at least part of observed silicates
- 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?
  - Formation of complex organics
- 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