The delivery of organic material to the early solar system

Ruud Visser
Ewine F. van Dishoeck, Steven D. Doty,
Cornelis P. Dullemond and Edwin A. Bergin

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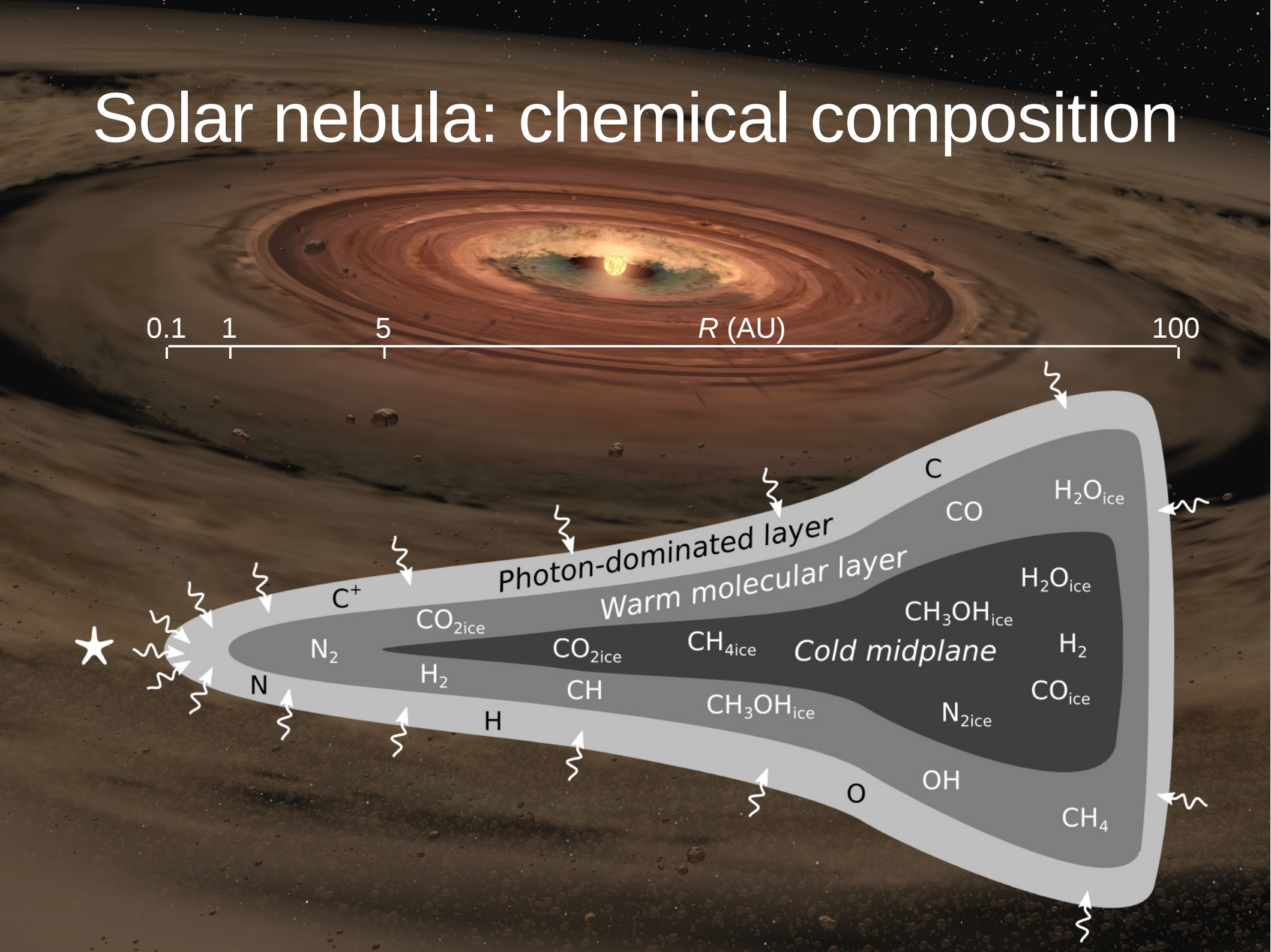
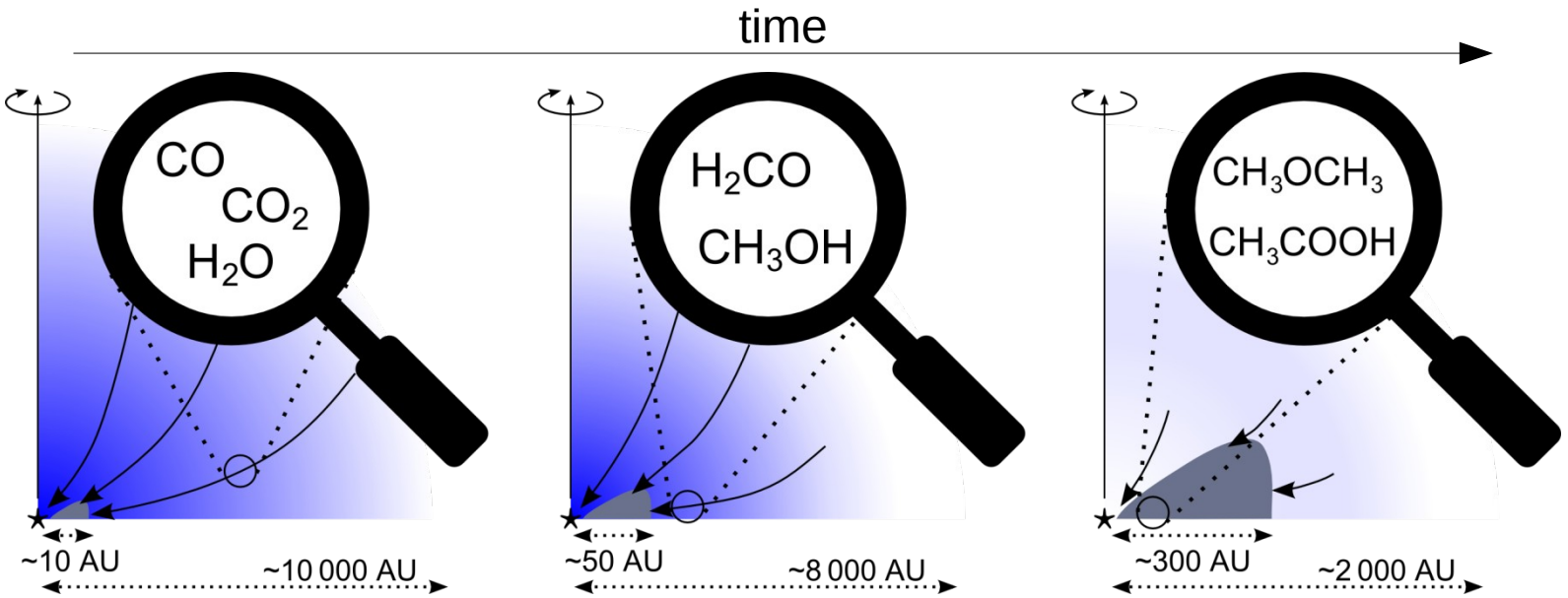
Solar nebula: chemical composition



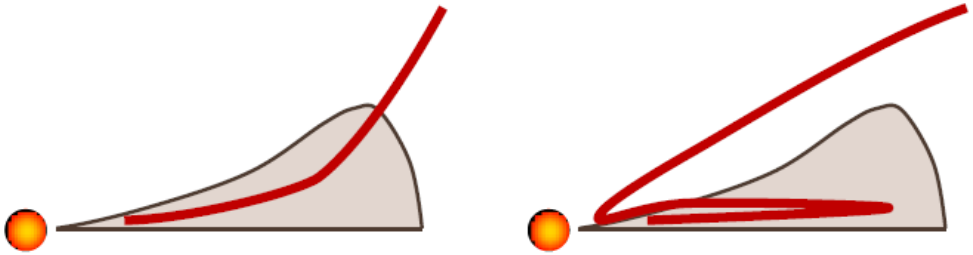
Chemical evolution model

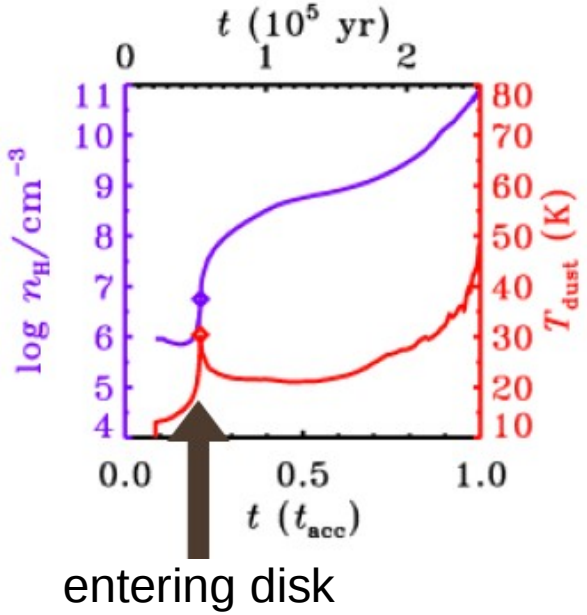


- From pre-stellar core to protoplanetary disk
- Two-dimensional, axisymmetric
- Full gas-phase chemical network
  - with photodissociation
  - with freeze-out and evaporation
  - without isotopes or grain-surface chemistry

Infall trajectories

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

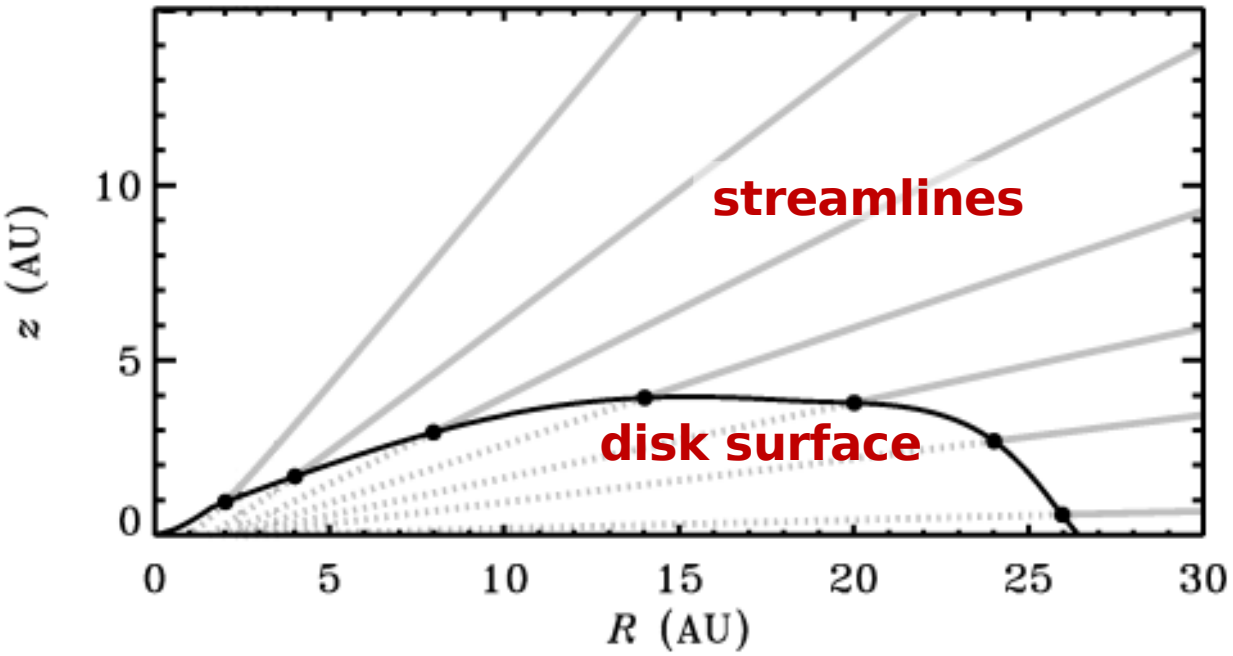




- Different trajectory shapes
- Jump in *n*, *T* upon entering disk

Visser et al. (2009, 2011)

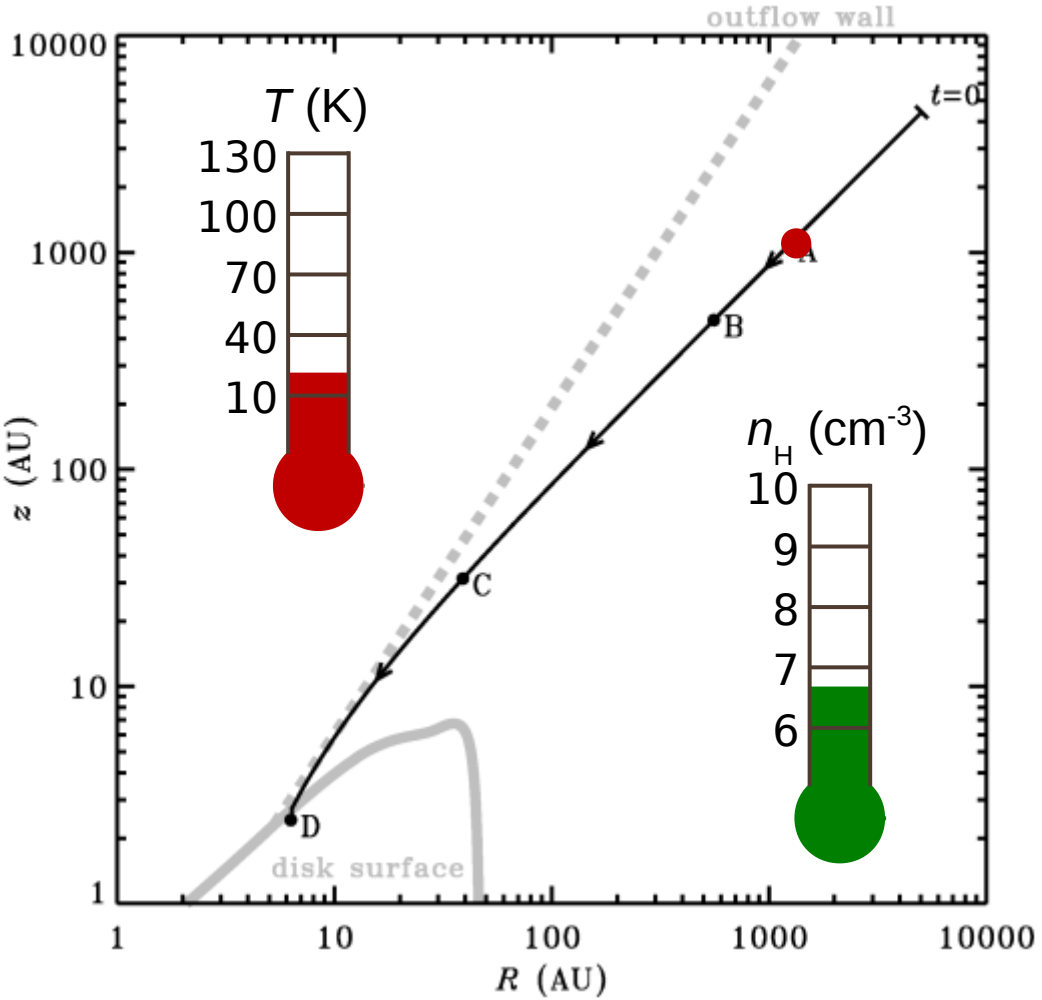
From one to two dimensions



- Previous collapse models treated disk as completely flat
- Include vertical structure:
  - accretion occurs further out
  - accretion shock becomes weaker

Visser & Dullemond (2010)

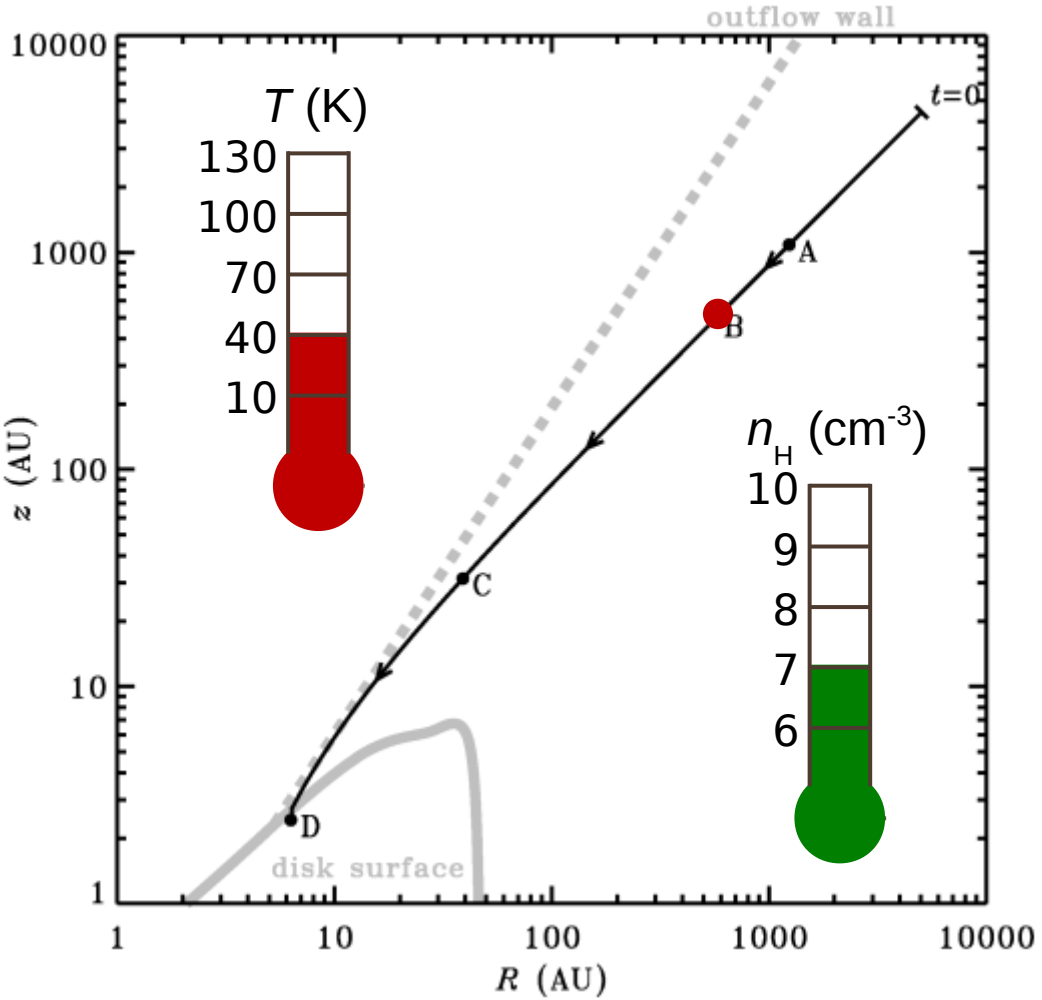
Chemistry along one trajectory



- Point A:
  - CO, N_2, O_2 evaporate
  - HCO^+, N_2H^+ formed
  - H_2O, CH_4, NH_3, NO remain frozen

Visser et al. (2011)

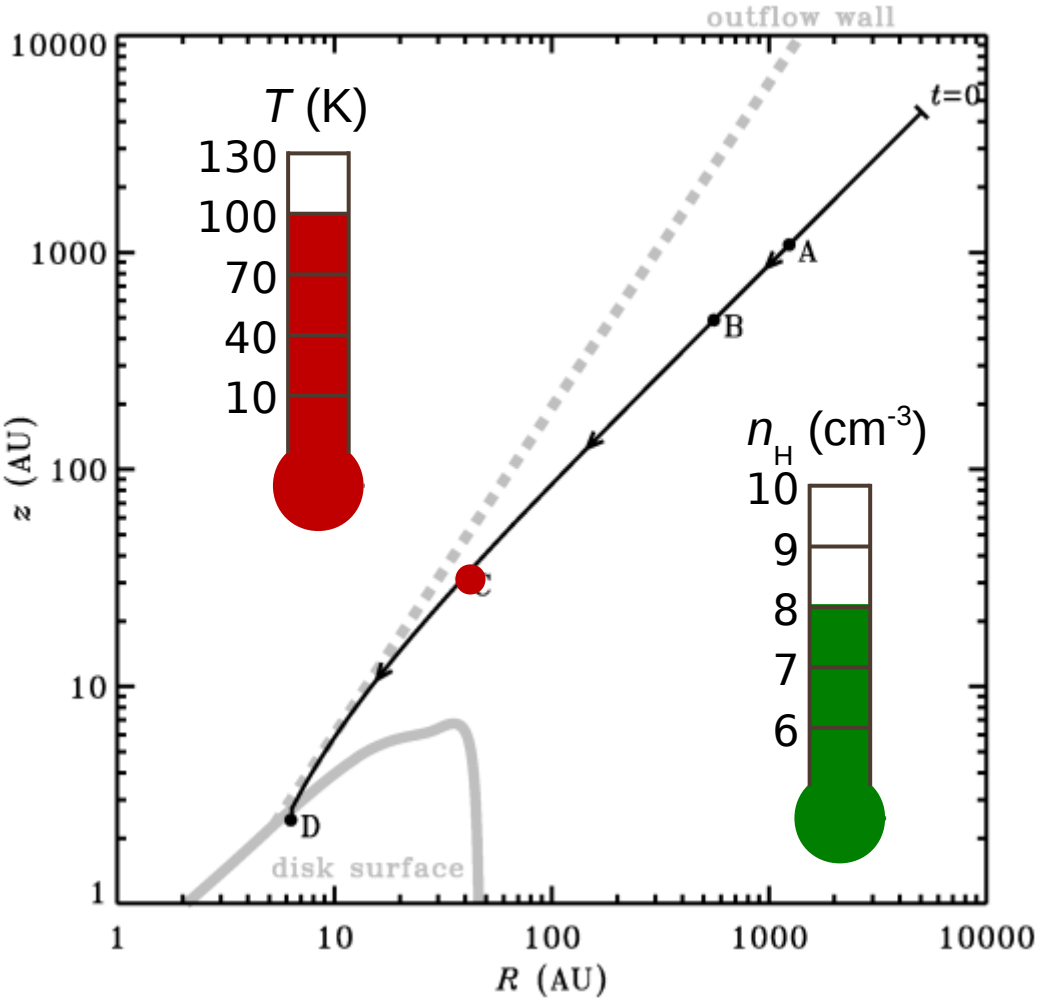
Chemistry along one trajectory



- Point B:
  - CH_4, NO evaporate
  - CO, N_2, O_2 remain in gas
  - H_2O, NH_3 remain frozen

Visser et al. (2011)

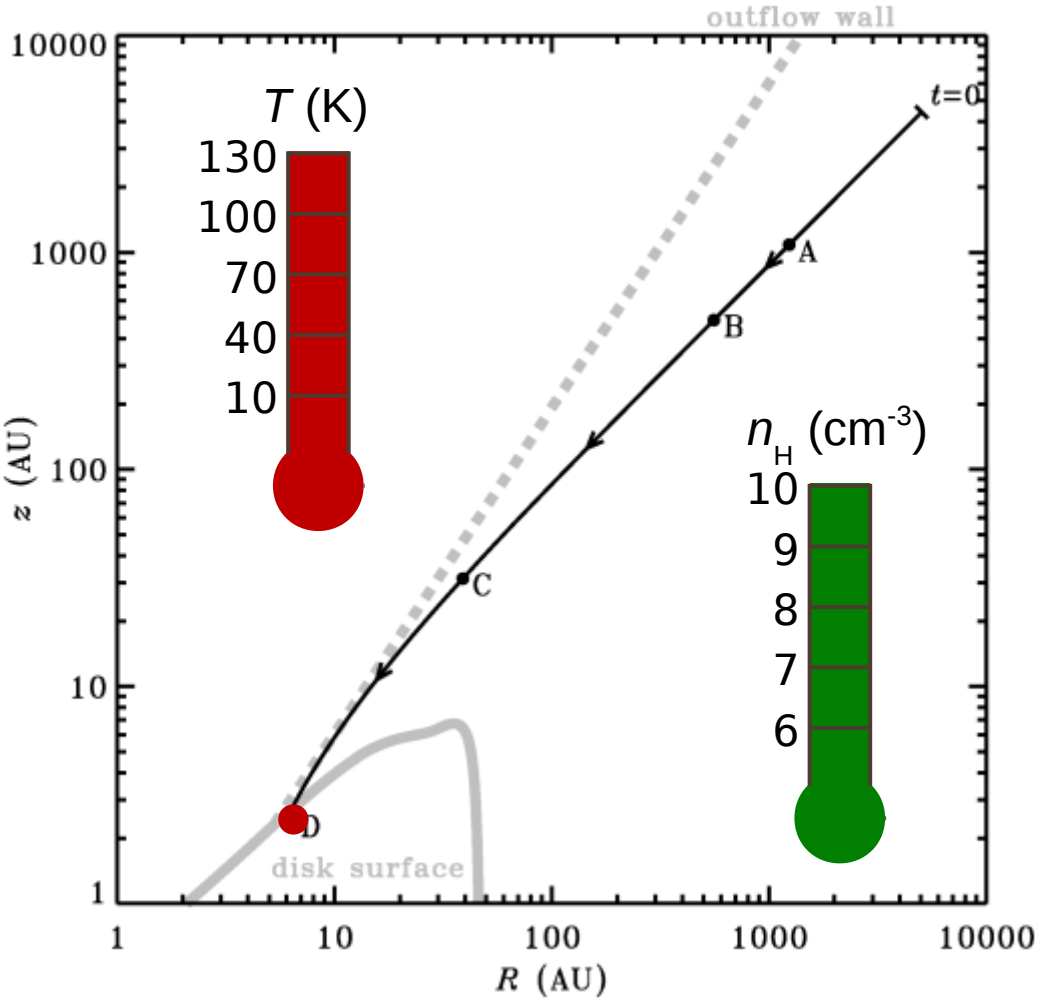
Chemistry along one trajectory



- Point C:
  - NH_3, H_2O evaporate
  - NH_3, H_2O, O_2, CH_4 photodissociated
  - CO, N_2 may survive

Visser et al. (2011)

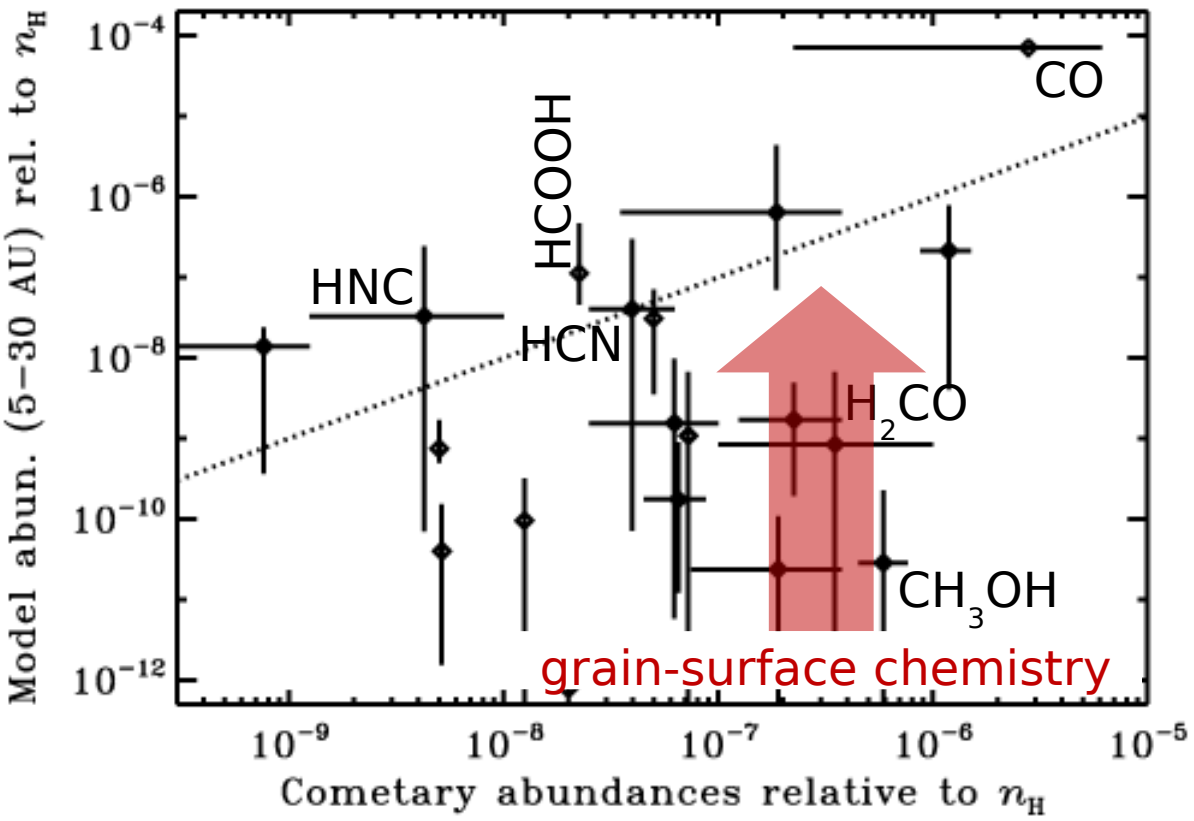
Chemistry along one trajectory



- Point D:
  - Some NH_3, H_2O, CH_4 reformed
  - CO, N_2 most abundant

Visser et al. (2011)

Implications for comets

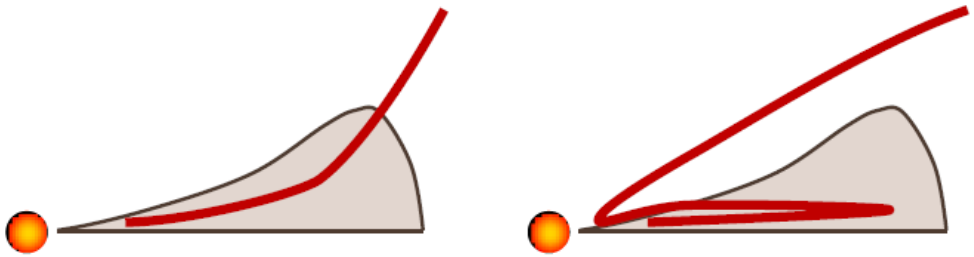


- Many model abundances differ from cometary abundances
- Suggestive of mixing or grain-surface chemistry?

Visser et al. (2011)

Implications for comets

- Model vs. observations:
  - Poor match with comet-forming zone
  - Good match with outer disk
- Points to mixed origin of cometary material
- More evidence:
  - Crystalline silicates in comets
  - H_2O o/p ratio in TW Hya disk lower than in comets



Visser et al. (2011)

Conclusions

- First 2D model to follow chemistry in detail
- Accretion shock very weak
- Temperature: key parameter in chemical processing

- Future work
  - Grain-surface chemistry
  - Isotopes
  - Mixing