How small molecules betray dust evolution in planet forming disks

Hogerheijde, M.R.

How small molecules betray dust evolution in planet forming disks

Michiel Hogerheijde
Leiden University & University of Amsterdam

Eva Bøgelund, Vachail Salinas, Mason Carney, Leon Trapman, Jeroen Terwisscha van Scheltinga
Ilse Cleeves, Stephano Facchini, Davide Fedele, Ryan Loomis, Karin Öberg, Charlie Qi, Ewine van Dishoeck Catherine Walsh, Jonathan Williams, David Wilner, and many more

Universiteit Leiden
University of Amsterdam
NWO

How small molecules betray dust evolution in planet forming disks





Eva Bøgelund, Vachail Salinas, Mason Carney, Leon Trapman, Jeroen Terwisscha van Scheltinga
Ilse Cleeves, Stephano Facchini, Davide Fedele, Ryan Loomis, Karin Öberg, Charlie Qi, Ewine van Dishoeck Catherine Walsh, Jonathan Williams, David Wilner, and many more

Universiteit Leiden
University of Amsterdam
NWO

How small molecules betray dust evolution in planet forming disks





Eva Bøgelund, Vachail Salinas, Mason Carney, Leon Trapman, Jeroen Terwisscha van Scheltinga
Ilse Cleeves, Stephano Facchini, Davide Fedele, Ryan Loomis, Karin Öberg, Charlie Qi, Ewine van Dishoeck Catherine Walsh, Jonathan Williams, David Wilner, and many more

Universiteit Leiden
University of Amsterdam
NWO

How small molecules betray dust evolution in planet forming disks





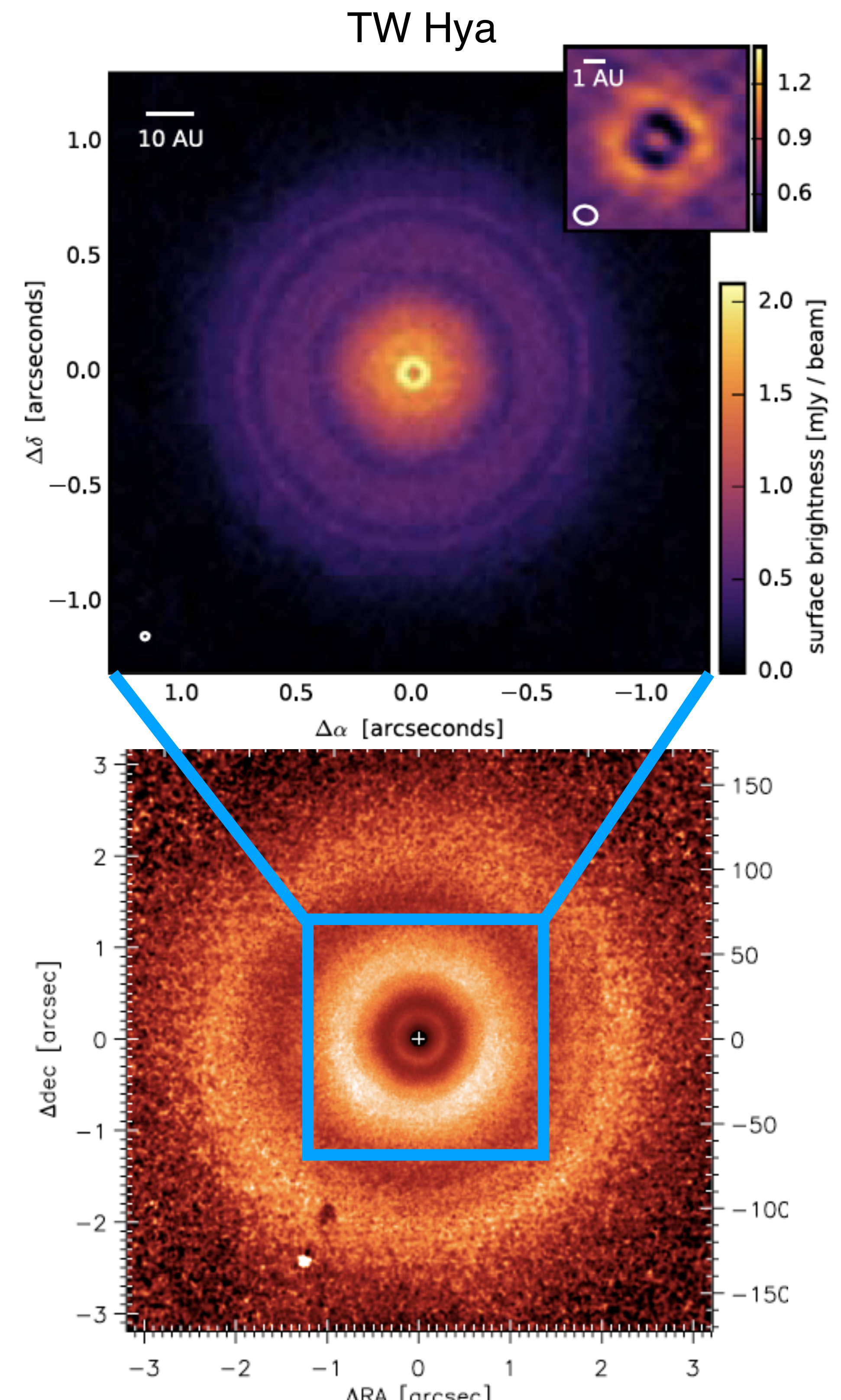
Eva Bøgelund, Vachail Salinas, Mason Carney, Leon Trapman, Jeroen Terwisscha van Scheltinga
Ilse Cleeves, Stephano Facchini, Davide Fedele, Ryan Loomis, Karin Öberg, Charlie Qi, Ewine van Dishoeck Catherine Walsh, Jonathan Williams, David Wilner, and many more

Universiteit Leiden
University of Amsterdam
NWO

Introduction

- Disks form planets efficiently
  - Exoplanets are ubiquitous
  - Time scale of formation <few Myr
- Dust grows: sub-μm → mm → cm → m → km → planetesimals → planetary cores
- ALMA has shown significant evolution of mm-sized grains
- Scattered light (e.g,, SPHERE; GPI) shows rich structures in <μm-sized particles

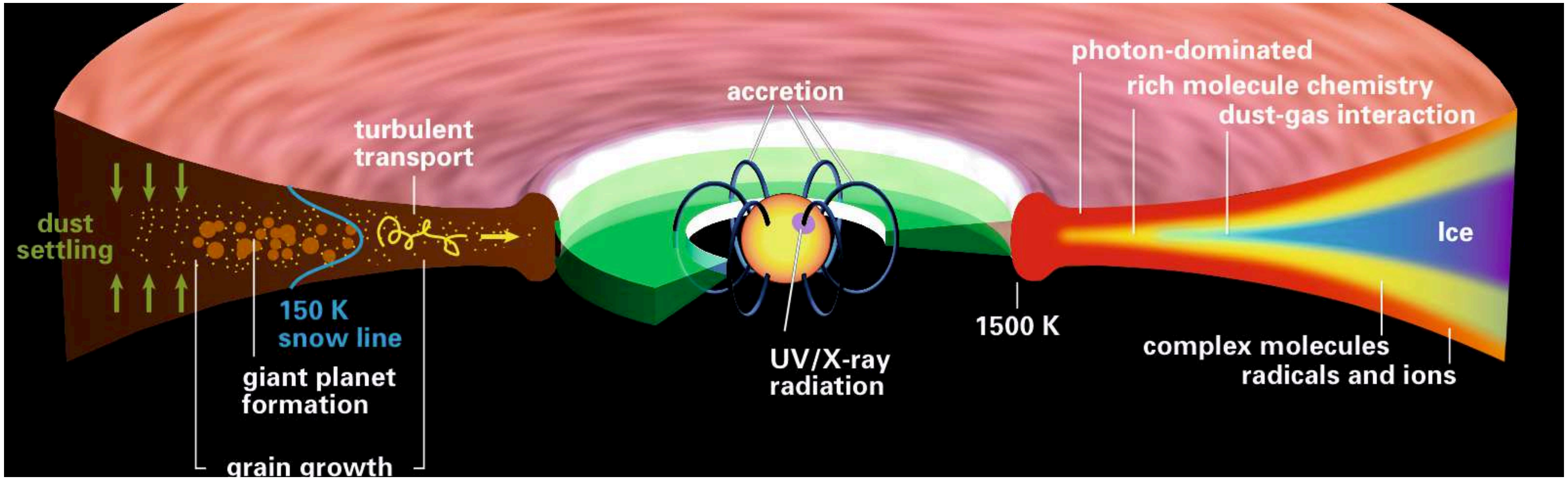
- **This talk: *chemistry* can add information about the *evolving dust***



Andrews+16; van Boekel+16

Chemical processes

- Small dust grains are
  - main source of optical/infrared opacity → temperature
  - important source of ultraviolet extinction → penetration of the UV field

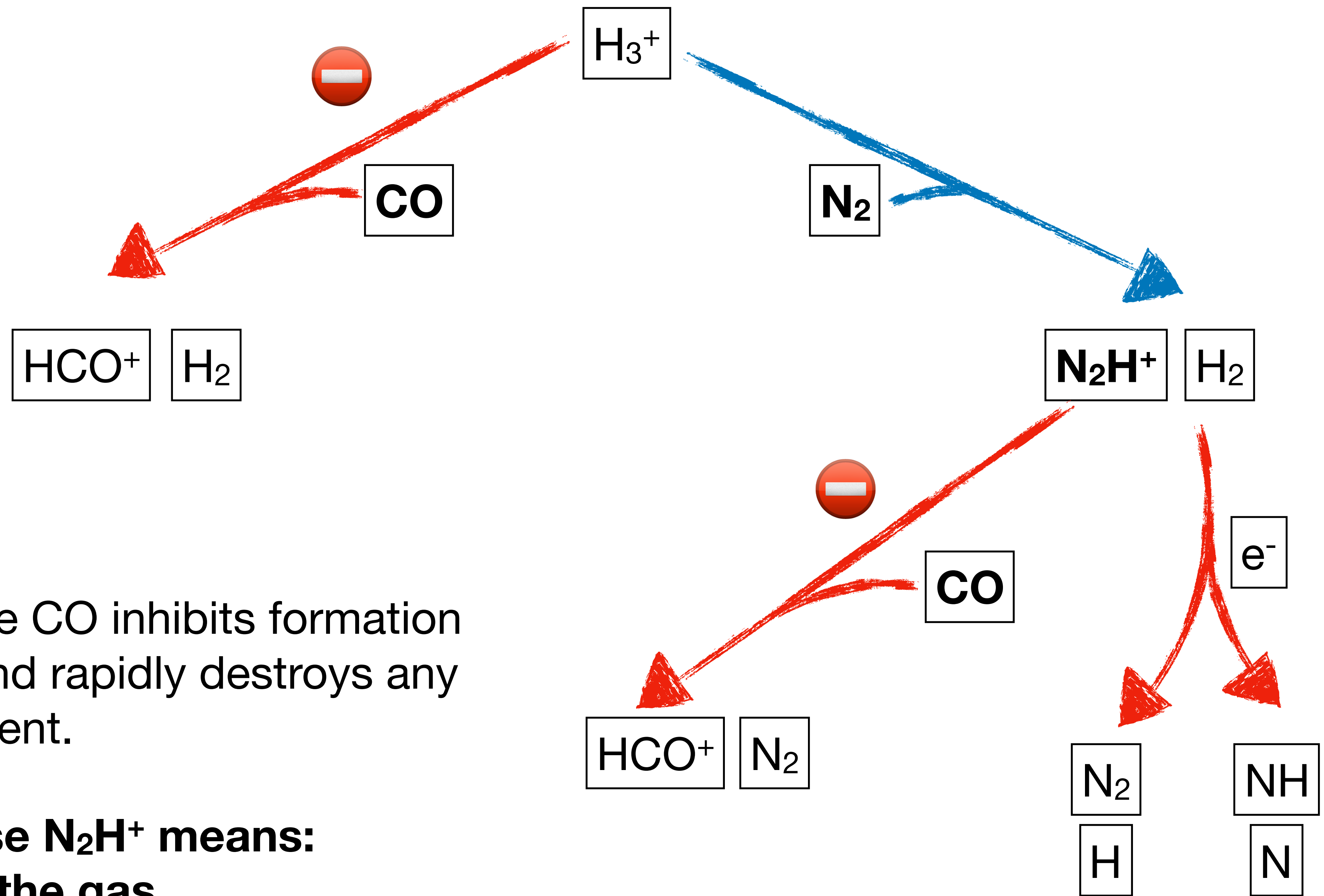


Henning+Semenov13

⇒ **dust steers chemistry**

- freeze out / sublimation of volatiles if *T* gets low enough: **snow lines**/surfaces
- **photodissociation** of molecules when UV-field gets strong enough
- **photo-desorption** of volatiles off ices when UV-field is strong enough

N_2H^+ and N_2D^+

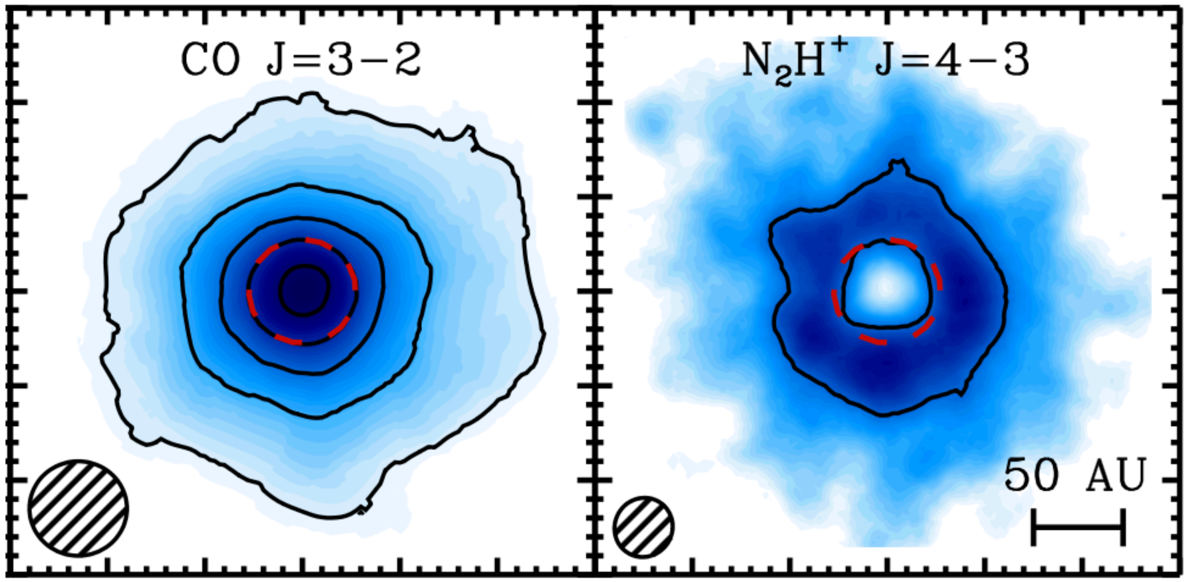


Gas-phase CO inhibits formation of N_2H^+ and rapidly destroys any N_2H^+ present.

Gas-phase N_2H^+ means: no CO in the gas.

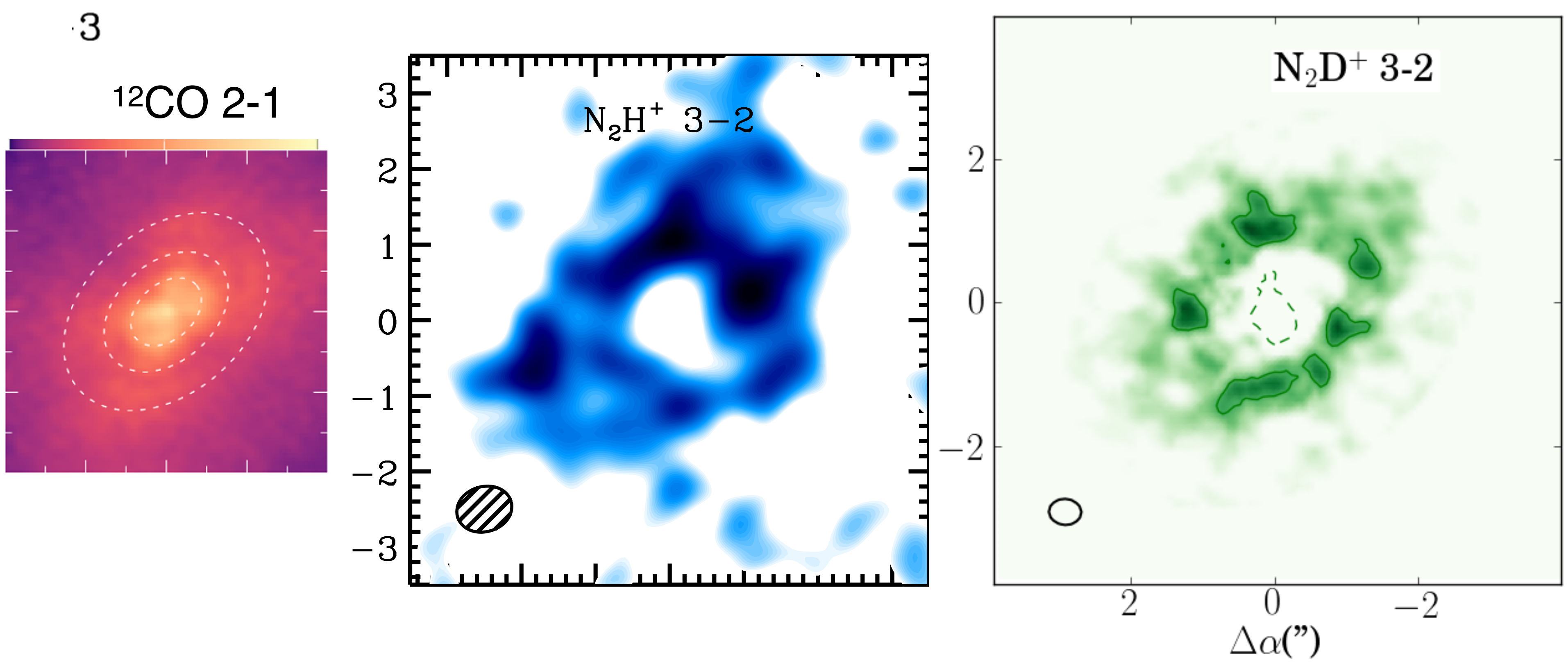
N_2H^+ and N_2D^+

- Rings of N_2H^+ outside the CO snow line / surface



TW Hya

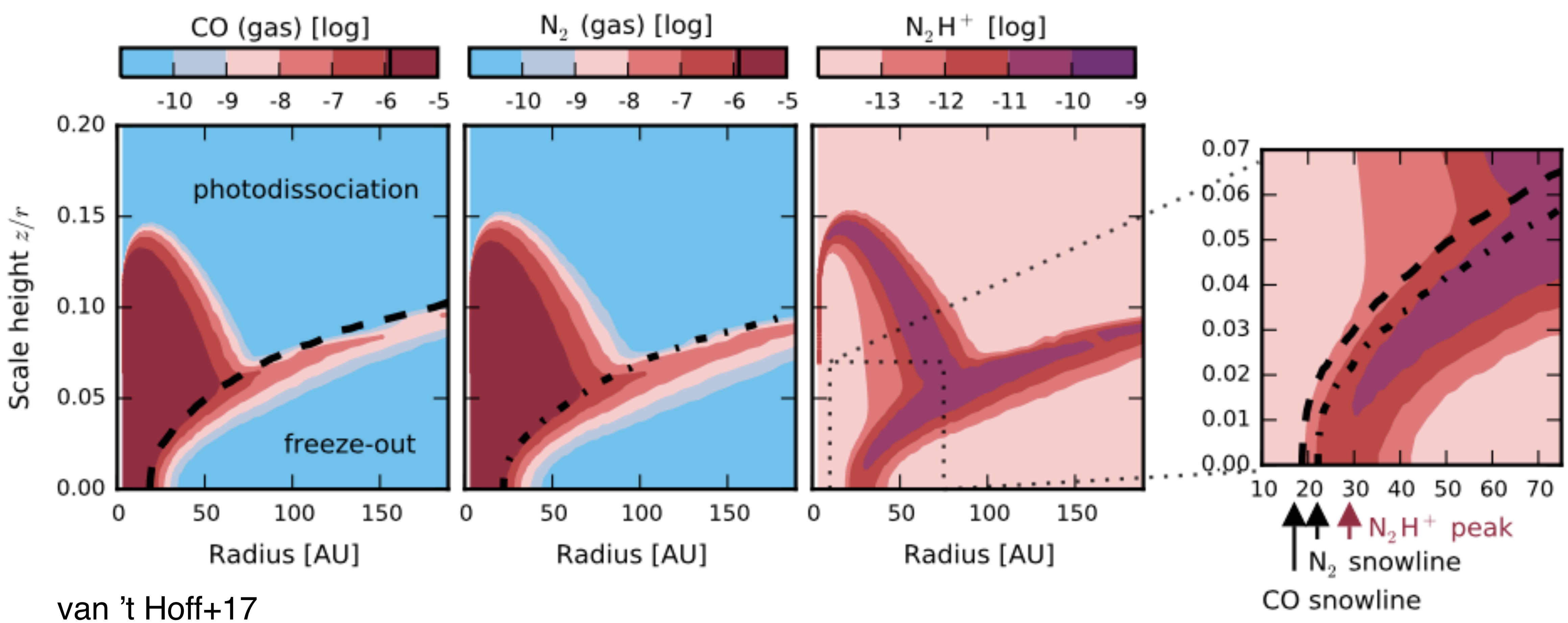
Qi+13, 15; Isella+16; Salinas+17



HD163296

N_2H^+: a caveat

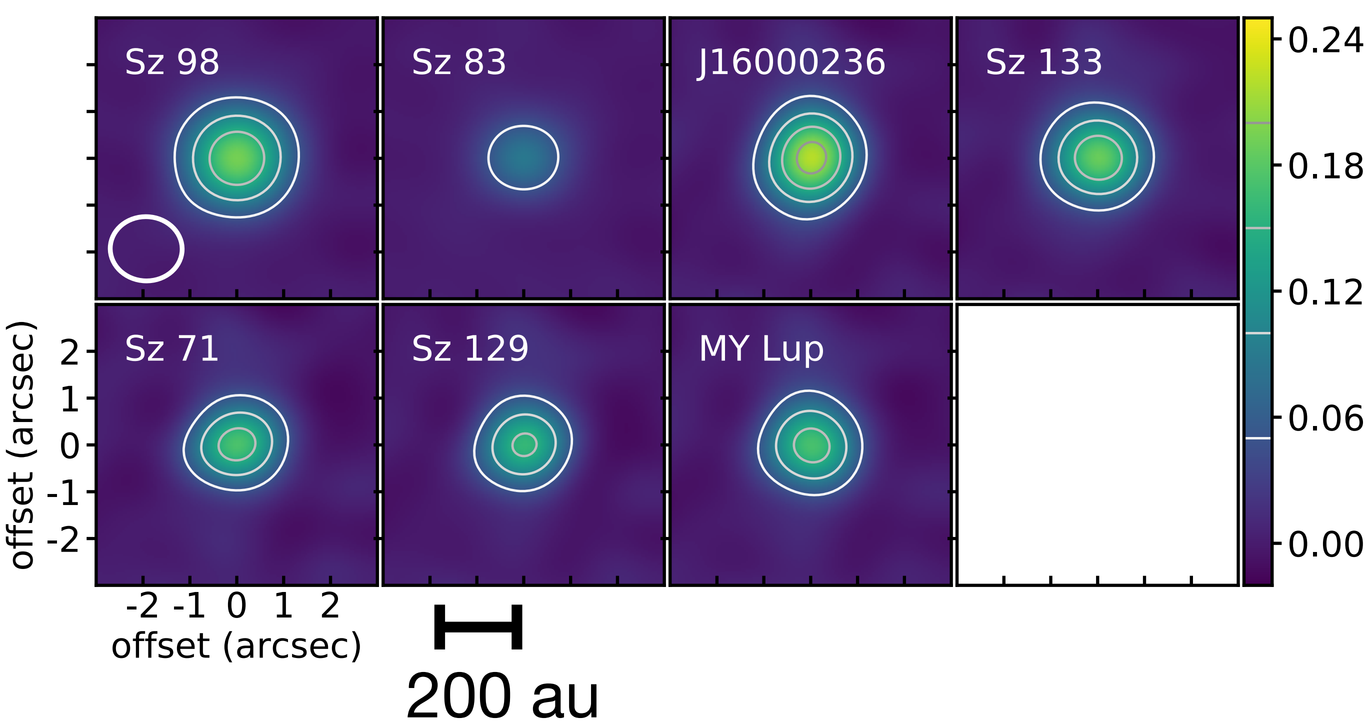
- Caveats (e.g., van 't Hoff+17):
  - 'Snow line' defined as 50%-CO freeze out, but N_2H^+ requires much larger CO depletion → ring moves outward
  - N_2H^+ also formed in upper layer where CO is already photodissociated but N_2 isn't yet.
  - Schwarz+19: excitation of N_2H^+ in TW Hya is high (~40 K)

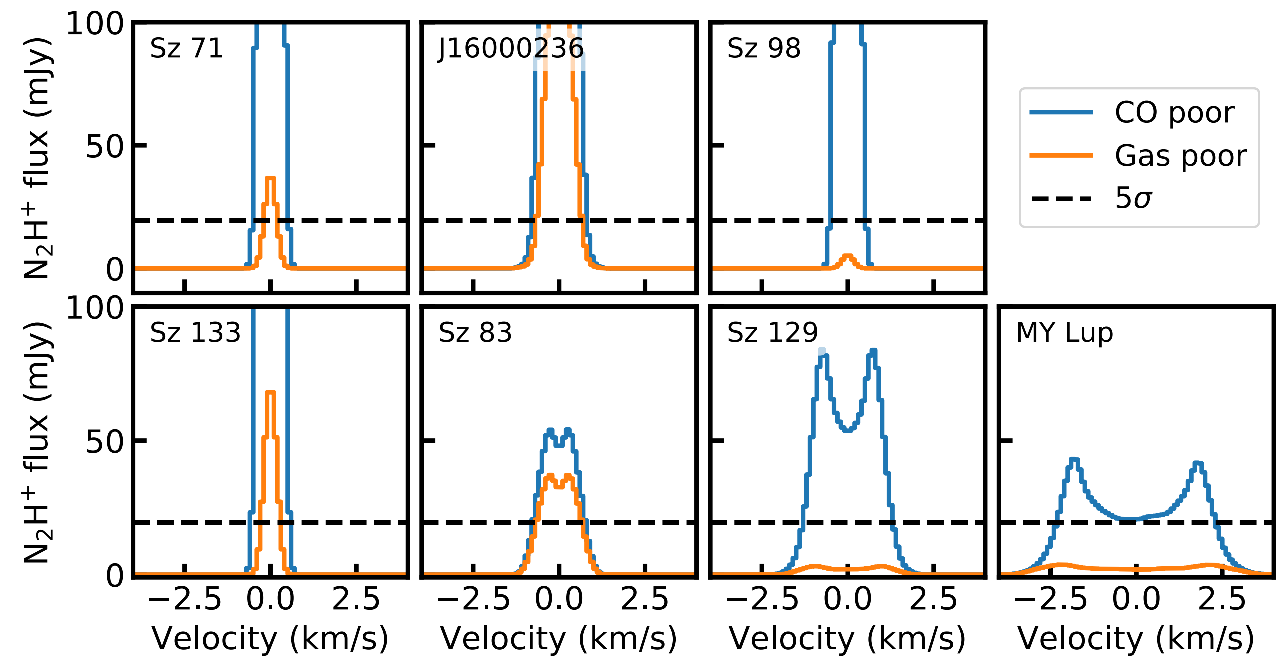


van 't Hoff+17

N_2H^+ and the 'missing CO' mass

- Corollary: N_2H^+ traces disk gas that is 'CO-dark' → solves 'missing mass' problem
- Ongoing work by Trapman et al.
  - Gas-poor vs gas-rich models predict very different N_2H^+ lines
  - Model predictions for several disks in Lupus:





- For recent observations of N_2H^+ as a gas tracer: see Anderson+19

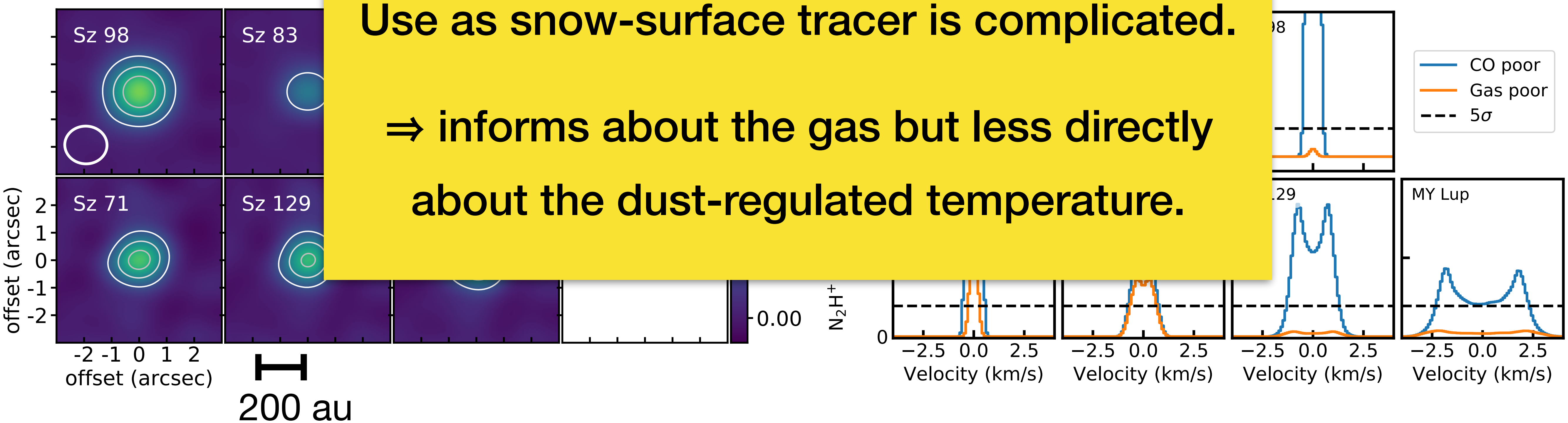
N_2H^+ and the 'missing CO' mass

- Corollary: N_2H^+ traces disk gas that is 'CO-dark' → solves 'missing mass' problem
- Ongoing work by Trapman et al.
  - Gas-p
  - Model

N_2H^+ is a good tracer of CO-dark gas.

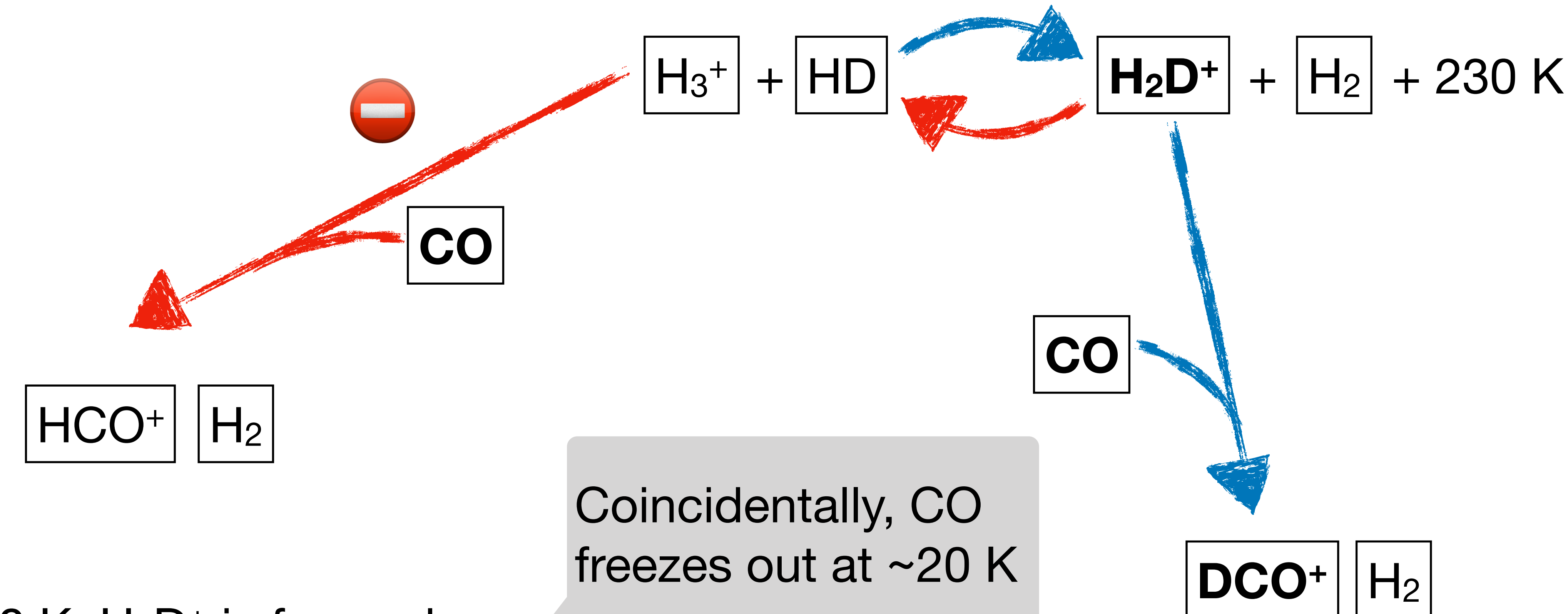
Use as snow-surface tracer is complicated.

⇒ informs about the gas but less directly about the dust-regulated temperature.



- For recent observations of N_2H^+ as a gas tracer: see Anderson+19

DCO^+



Below ~20 K, H_2D^+ is favored.

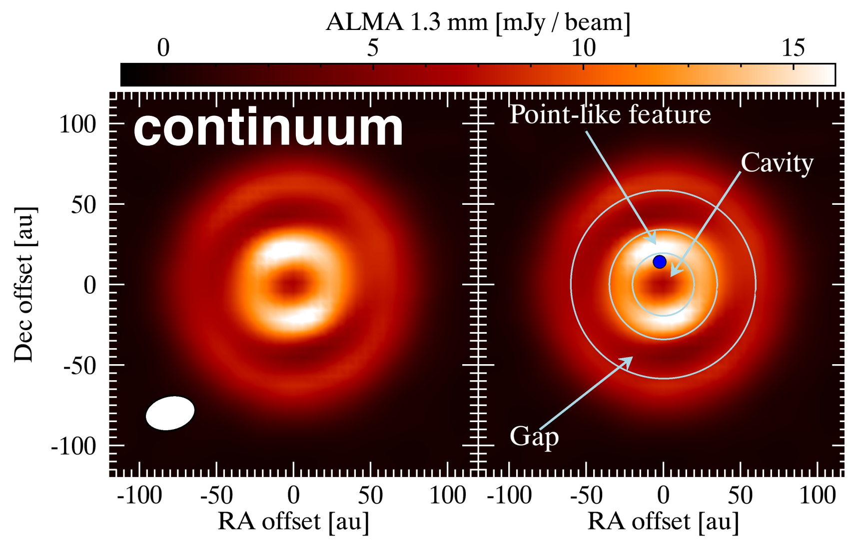
Gas-phase CO inhibits formation of H_2D^+.

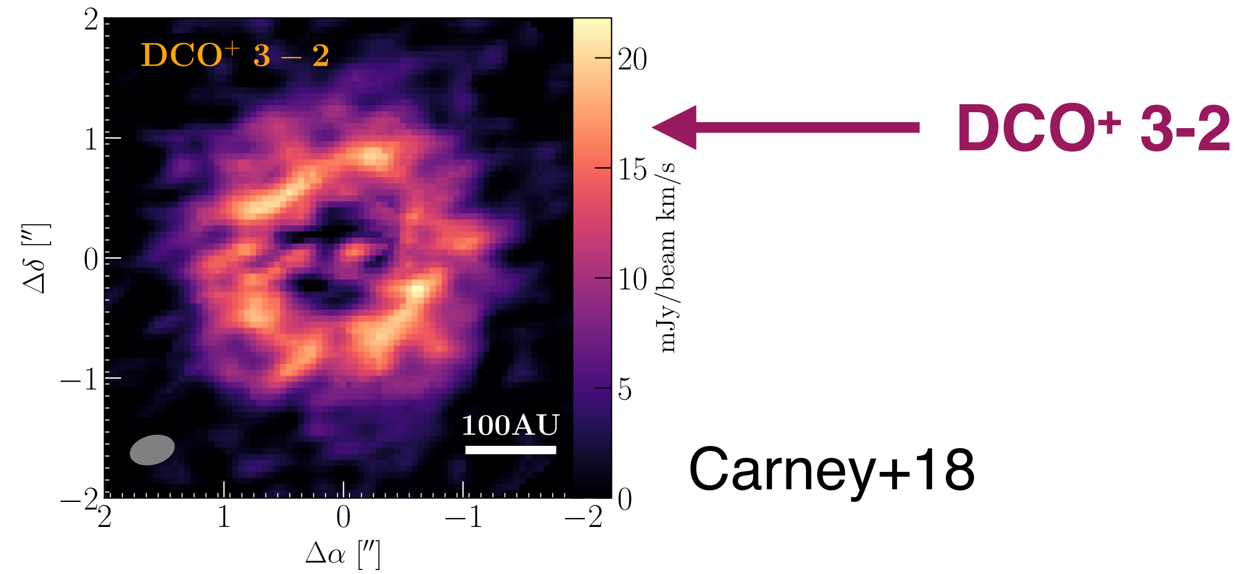
A small amount of CO is needed to convert H_2D^+ into DCO^+.

Gas-phase DCO^+ means:
CO is largely, but not completely, gone from the gas.

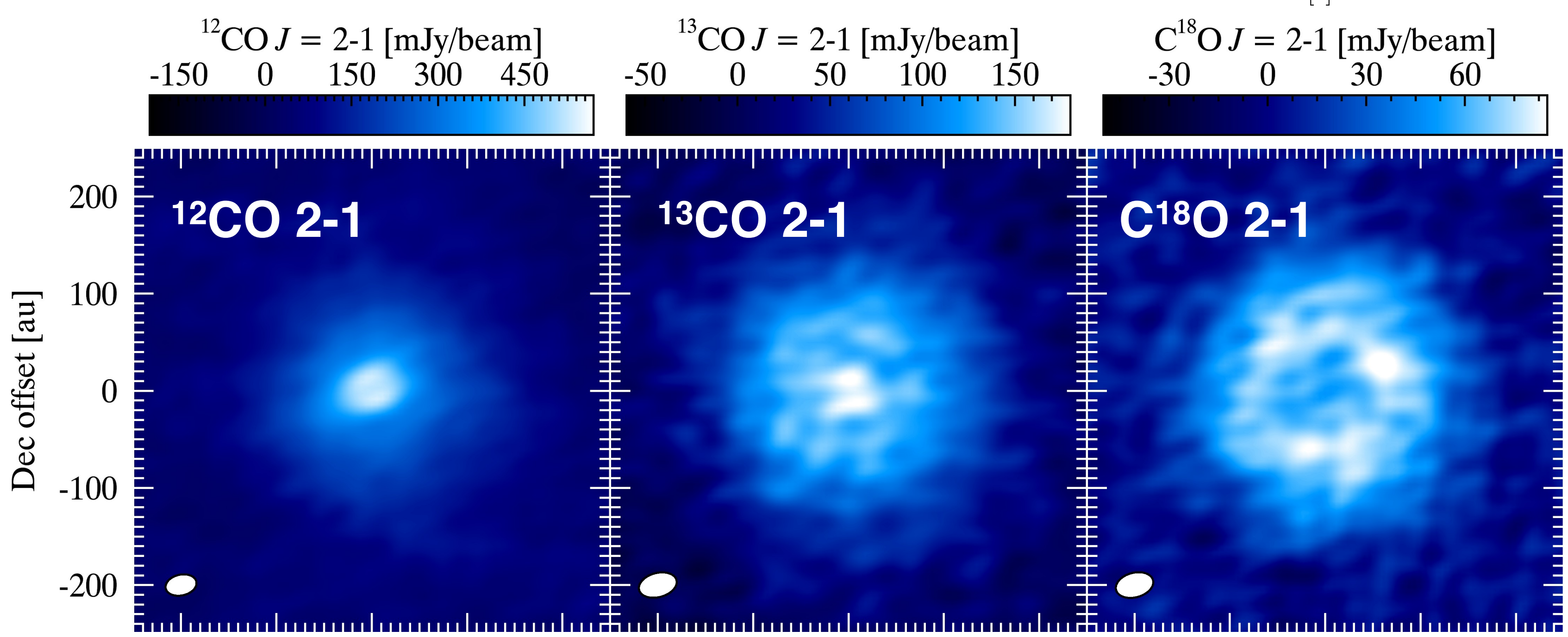
DCO+

- **HD169142:**
  - DCO+ traces cold region outside outer 'mm ring', not otherwise detectable





Carney+18

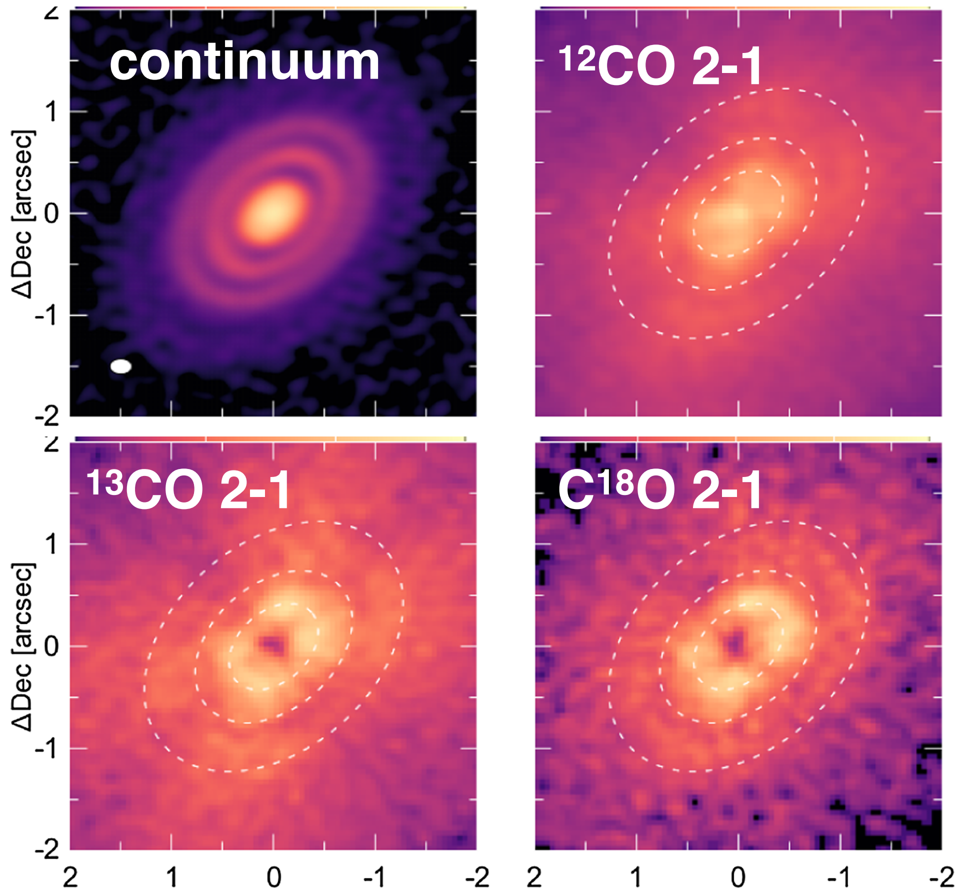


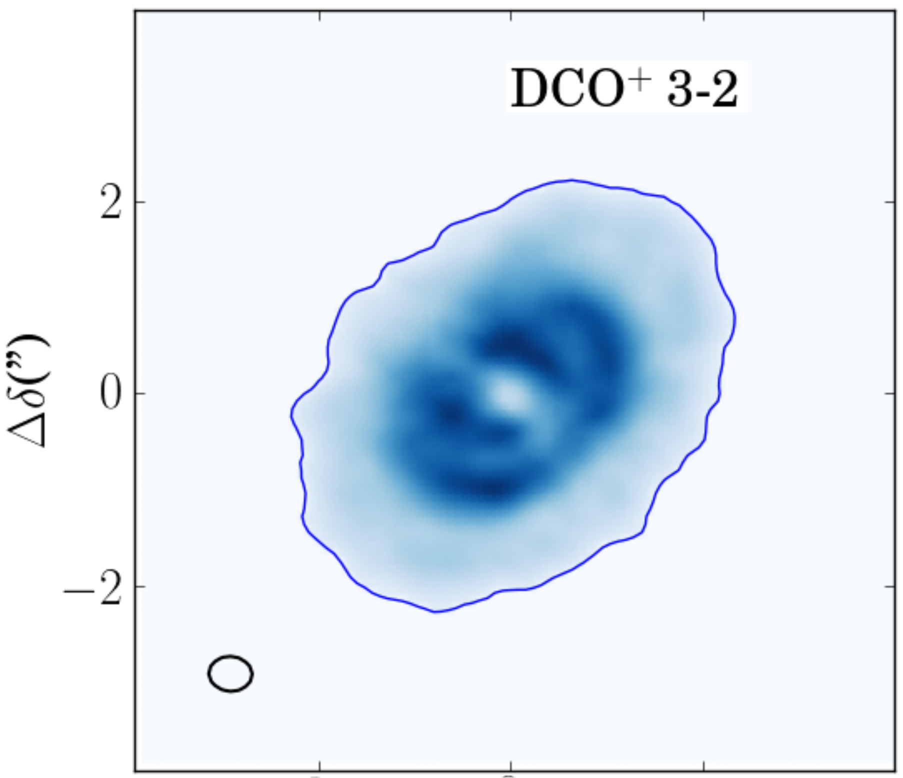
Even $C^{18}O$ is optically thick in midplane; cold region effectively hidden.

Fedele, Carney+17

DCO$^+$

- **HD163296:**
  - DCO$^+$ traces cold outer region
    - extent limited by return of photodesorbed CO / radial temperature inversion
  - DCO$^+$ inside 100 AU formed through a warmer deuteration channel (involves CH_2D^+, C_2HD^+, etc)

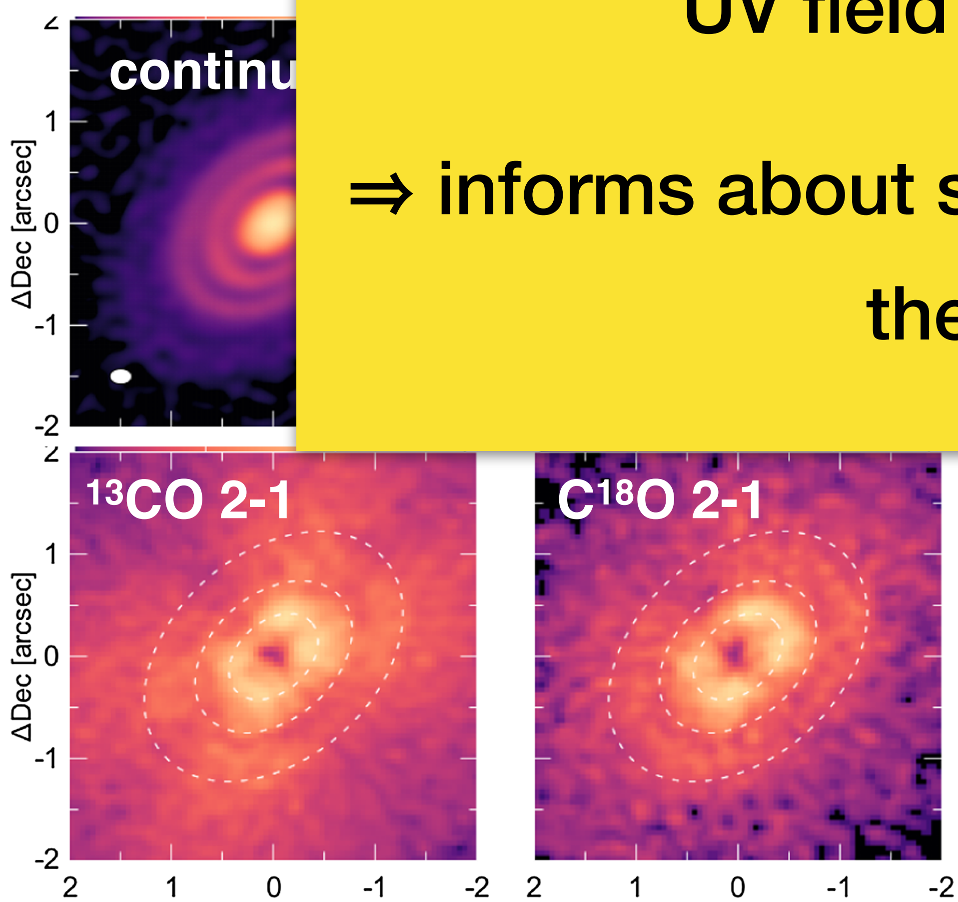


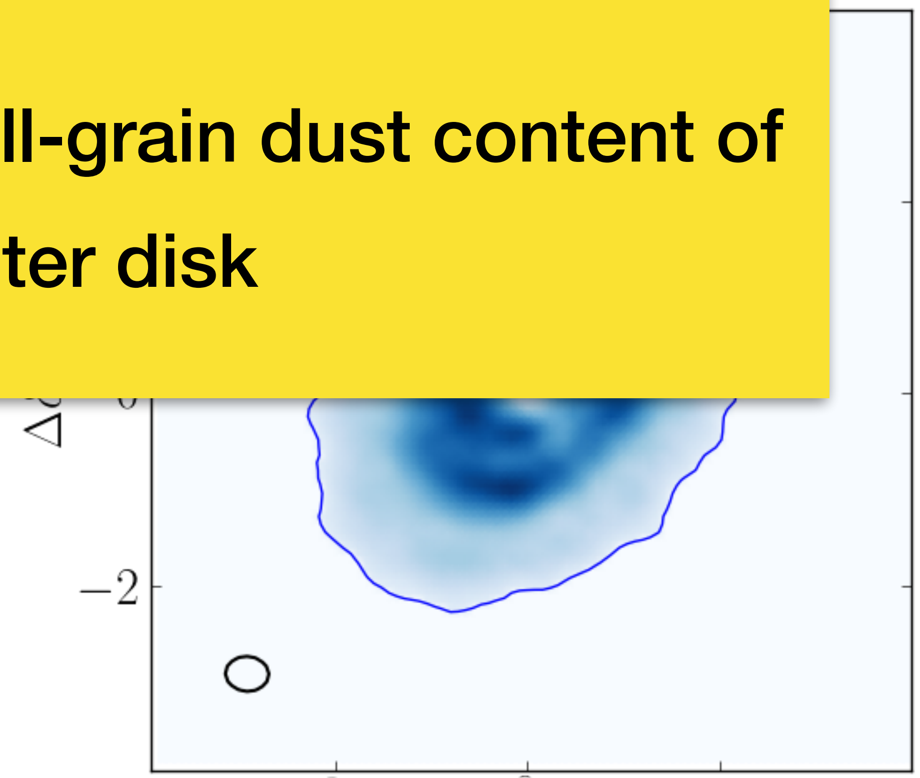


Salinas+17,18

DCO$^+$

- **HD163296:**
  - DCO$^+$ traces cold outer region
    - extent limited by return of photodesorbed CO / radial temperature
  - DCO$^+$ … nnel
    (involv…





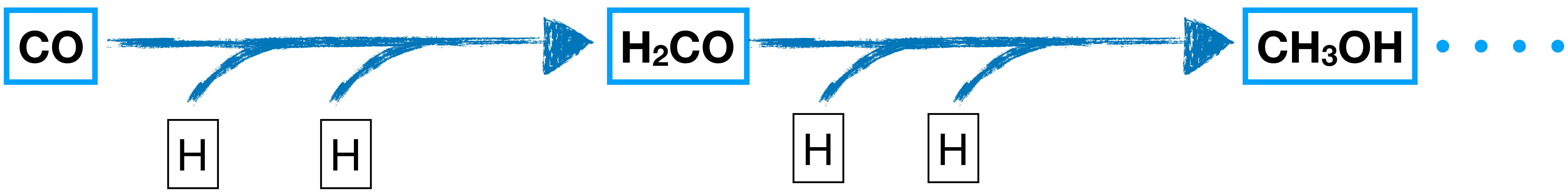
Presence and extent of DCO$^+$ place strong constraints on the temperature structure and UV field in the outer disk

⇒ informs about small-grain dust content of the outer disk

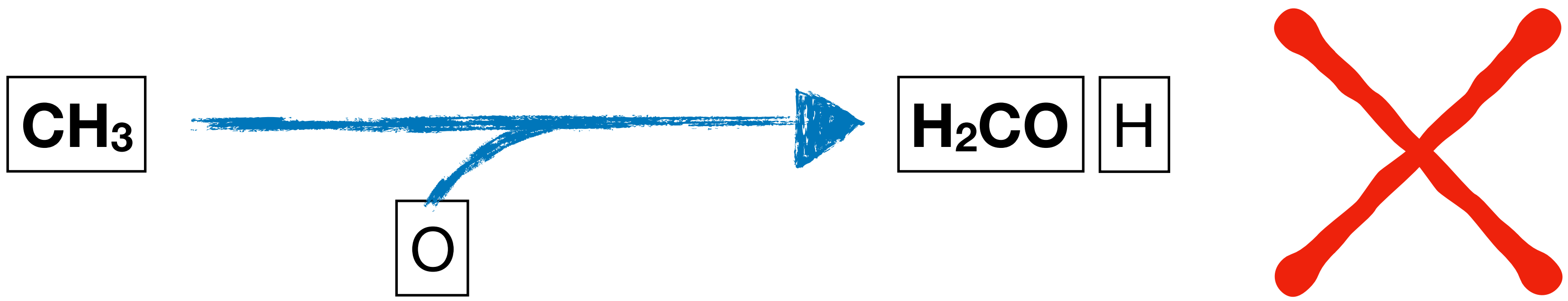
Salinas+17,18

H_2CO and CH_3OH

- Grain surface (ice) formation route

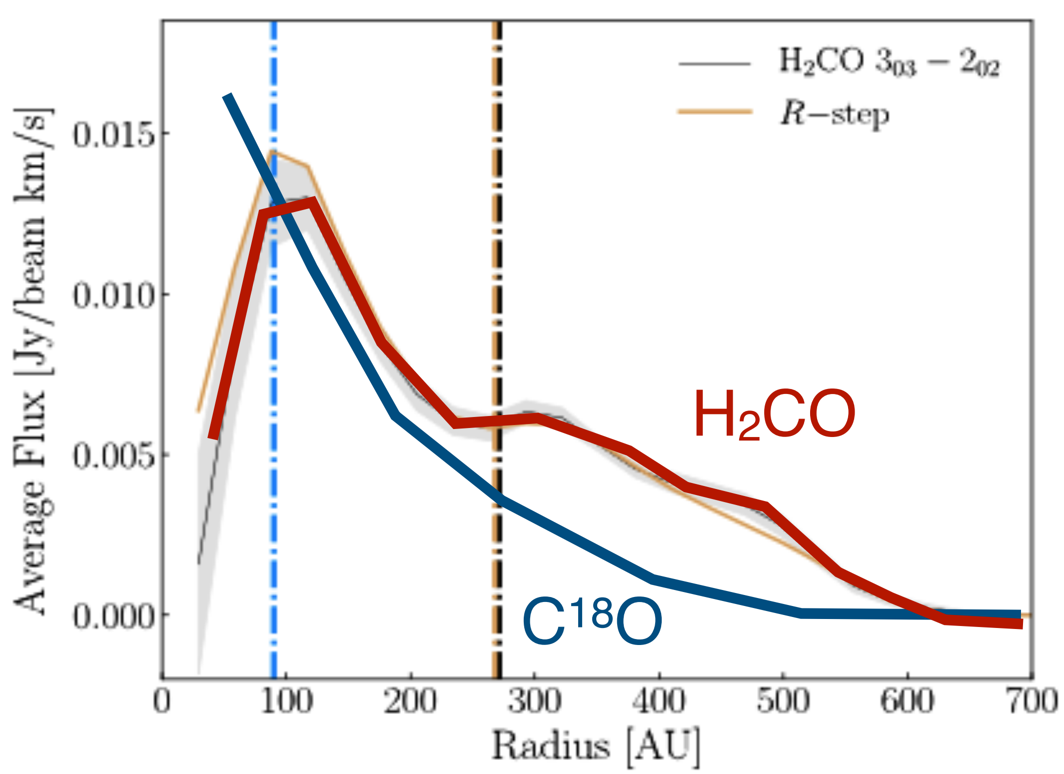


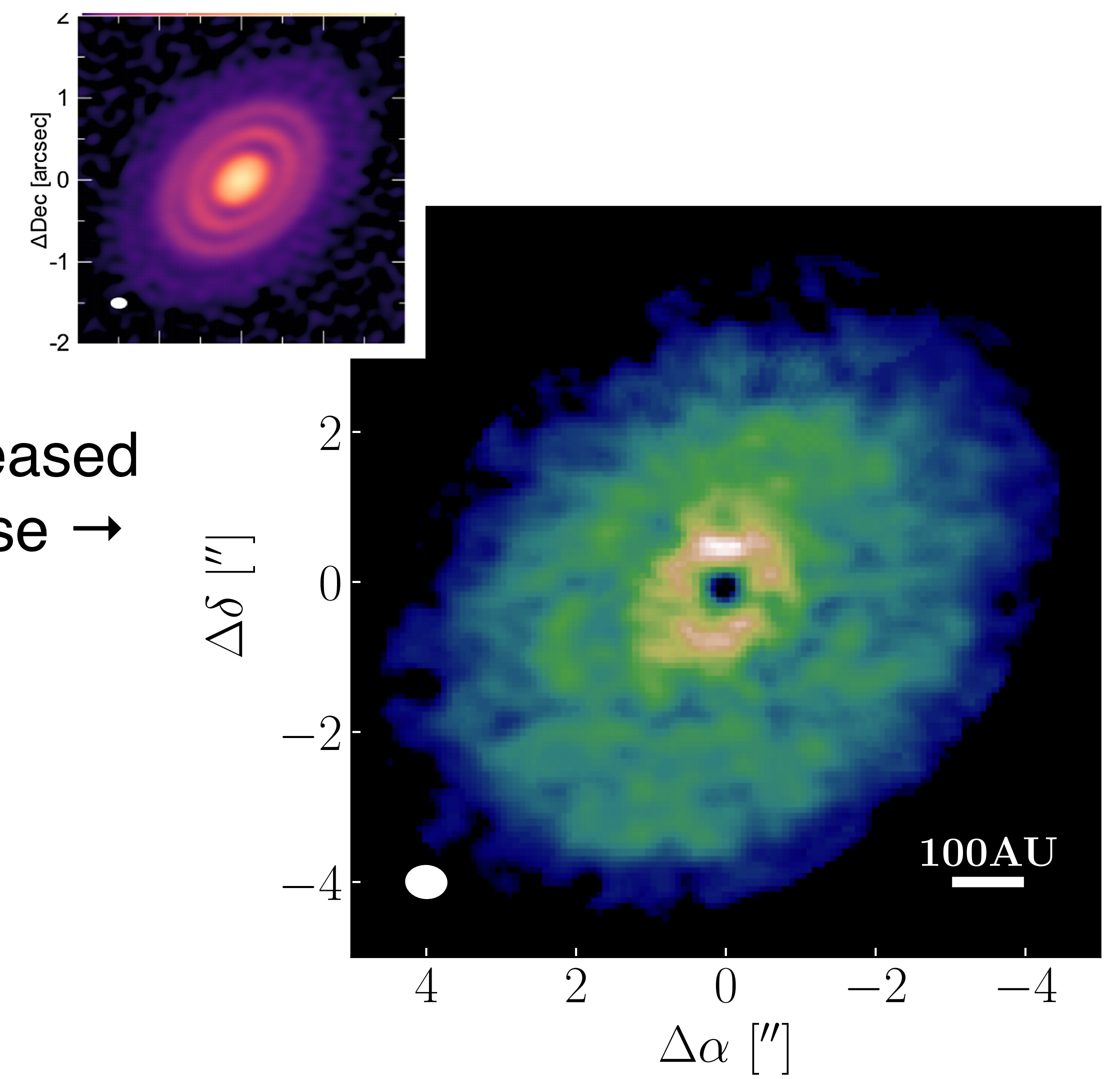
- Gas-phase formation route



H_2CO

- H_2CO in disks formed by both paths (gas-phase and grain-surface
  - e.g., Öberg+17; Loomis+15
- HD163296 (Carney+16):
  - H_2CO also reveals both paths
  - Increase of H_2CO outside 'mm-ring': increased UV penetration → CO returns to gas phase → increased H_2CO production ?

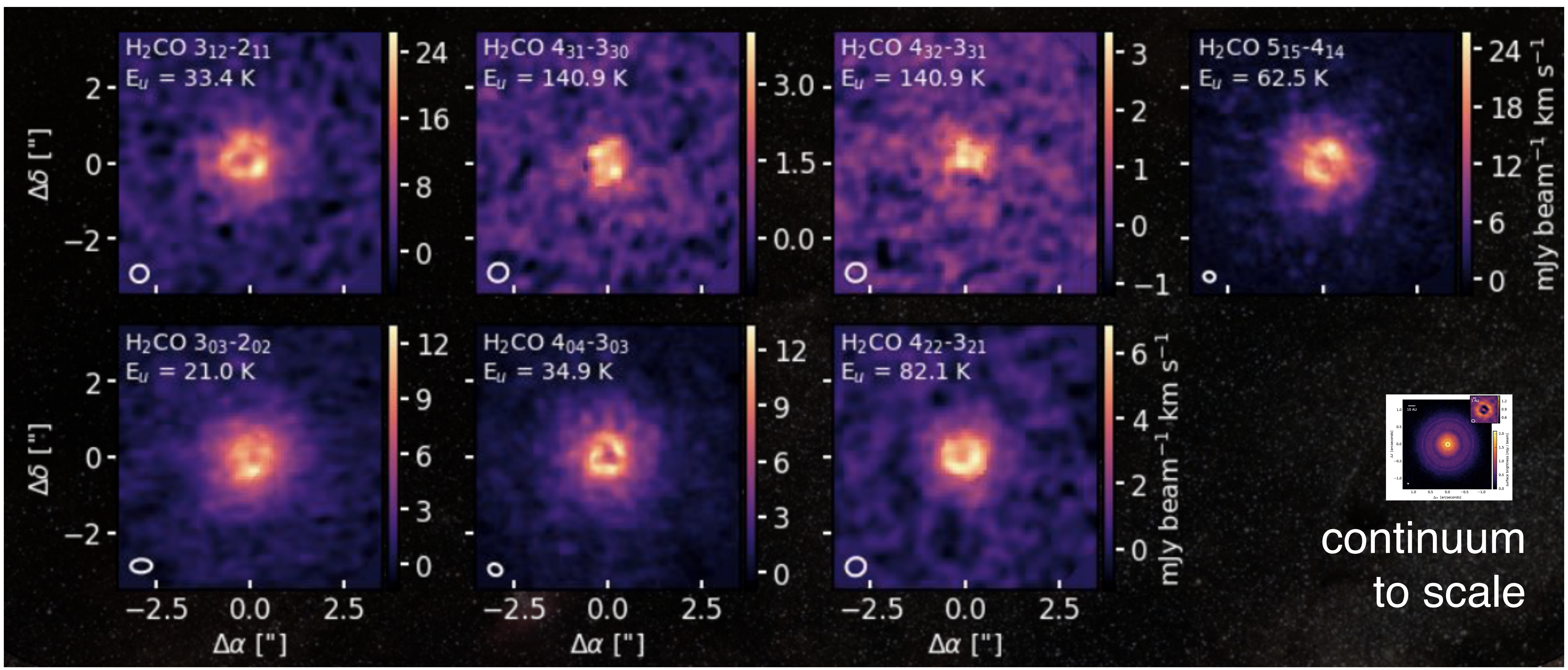




Carney+16

H_2CO

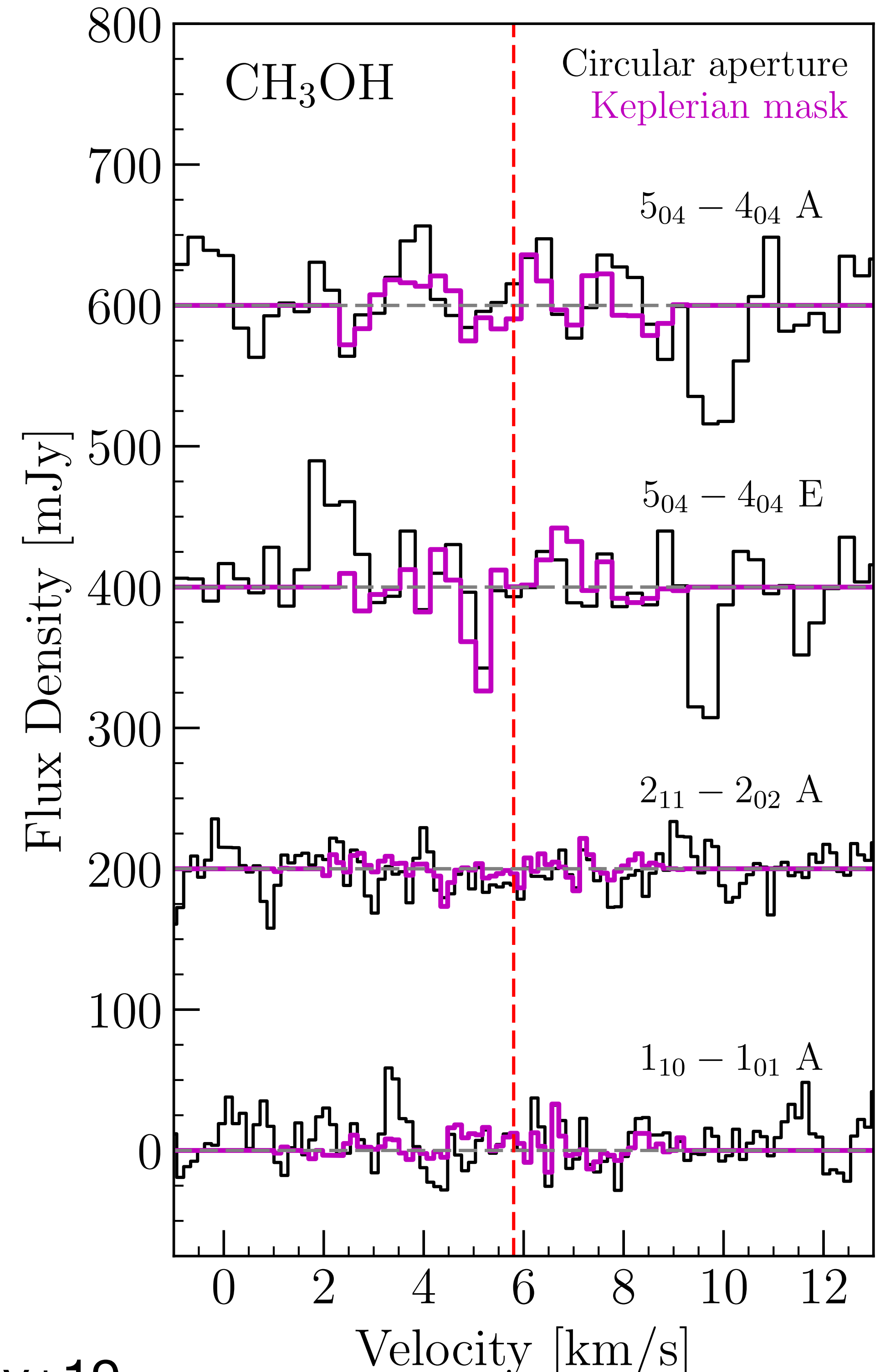
- TW Hya also has H_2CO emission extending across the disk
  - Recent observations by Cleeves et al. team
- See poster Jeroen Terwisscha van Scheltinga



H_2CO and CH_3OH

- CH_3OH detected in TW Hya (Walsh+16)
- Carney+19: HD163296
  - Strict <u>upper</u> limit of $CH_3OH/H_2CO<0.24$
  - cf. TW Hya: $CH_3OH/H_2CO\sim1.27$

- Harsher UV radiation from Herbig star destroys CH_3OH upon photodesorption?
- Recent thermal evaporation event in TW Hya?



Carney+19

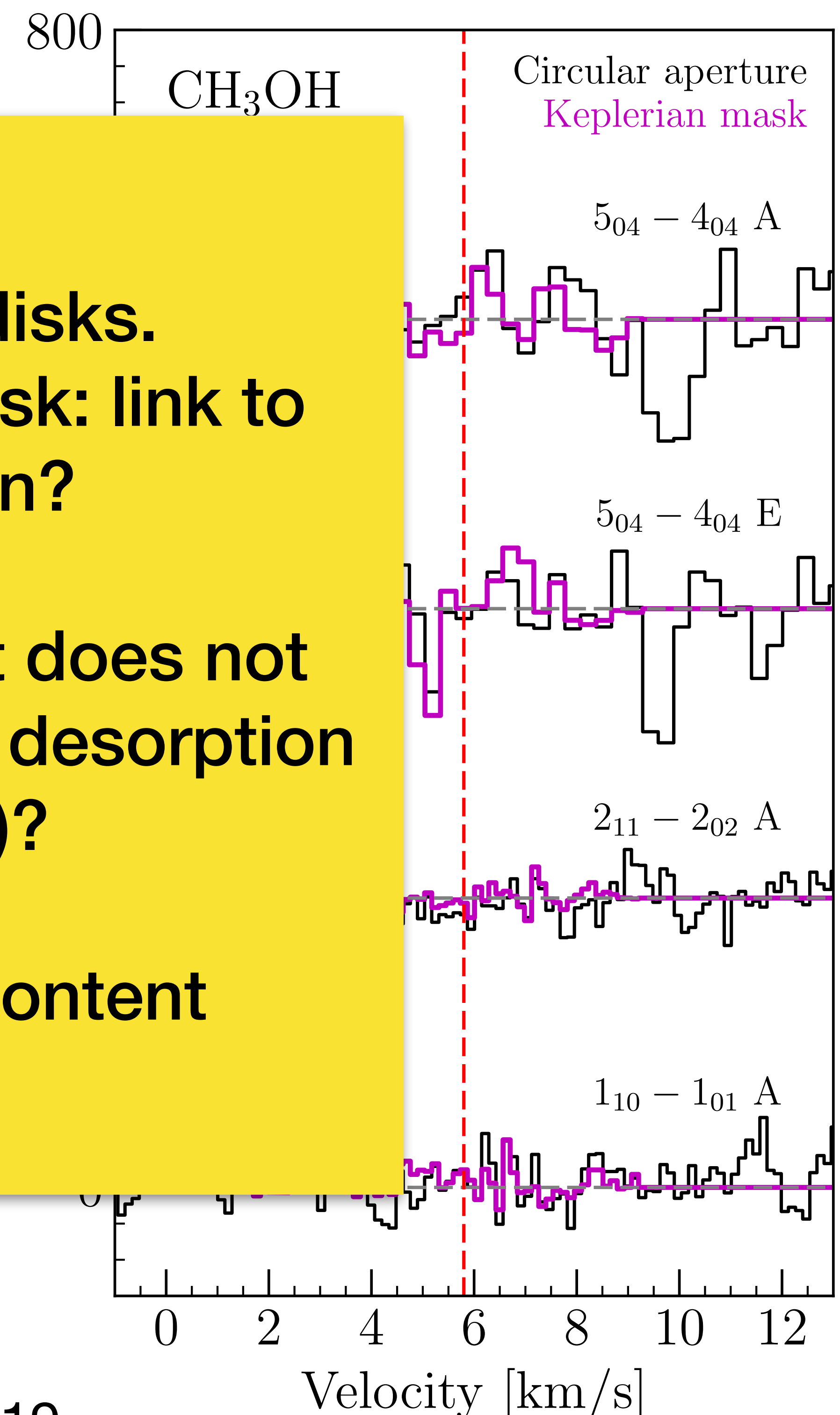
H_2CO and CH_3OH

- CH_3OH detected in TW Hya (Walsh+16)
- Carney+1
  - Strict
  - cf. TW
- Harsher U
  destroys
- Recent th

H_2CO extends across the disks. Increased H_2CO beyond mm-disk: link to increased UV penetration?

CH_3OH should be common, but does not appear to be so: dependency on desorption process (UV vs thermal)?

⇒ inform about small dust content



Carney+19

Conclusions

- Several simple molecules are readily detected and show clear radial structure
  - N_2H^+, DCO^+, H_2CO
- Radial distribution can be linked to the role of dust in the disk
  - by regulating the temperature structure
  - by regulating the UV penetration
- **⇒ Chemistry of these simple molecules provides independent and much needed constraints on the distribution of large and small dust particles**