How small molecules betray dust evolution in planet forming disks

Michiel Hogerheijde
Leiden University & University of Amsterdam

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Ilse Cleeves, Stephano Facchini, Davide Fedele, Ryan Loomis, Karin Öberg, Charlie Qi, Ewine van Dishoeck Catherine Walsh, Jonathan Williams, David Wilner, and many more

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   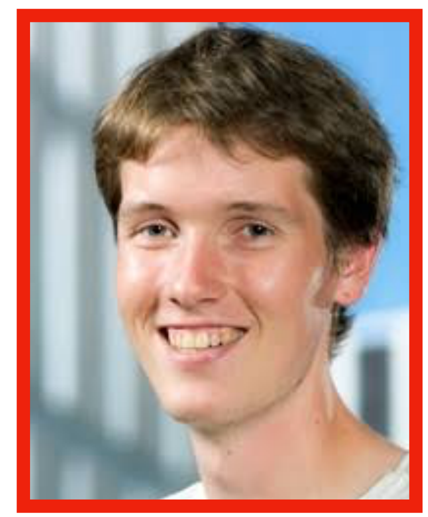 

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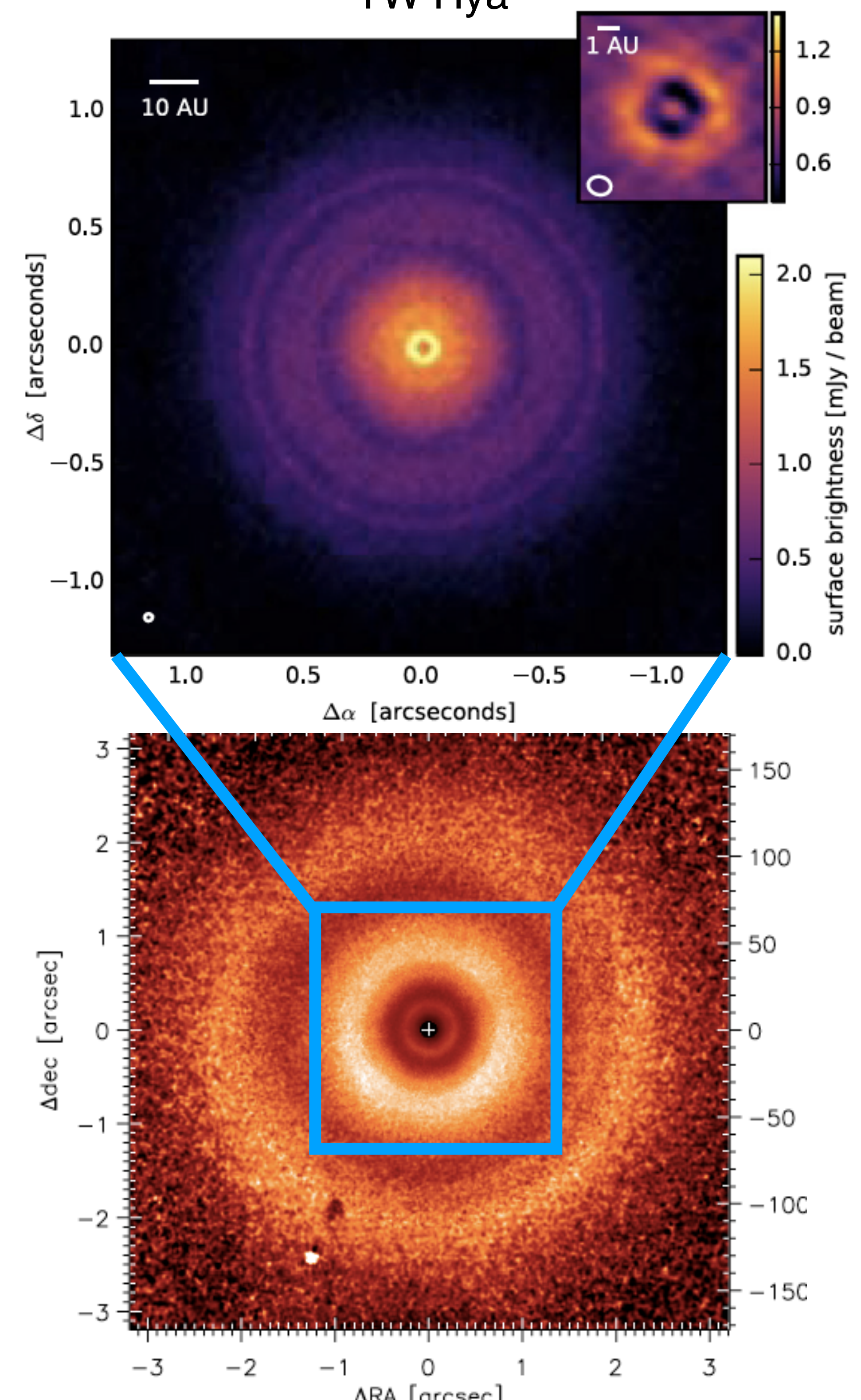
Introduction

- 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***

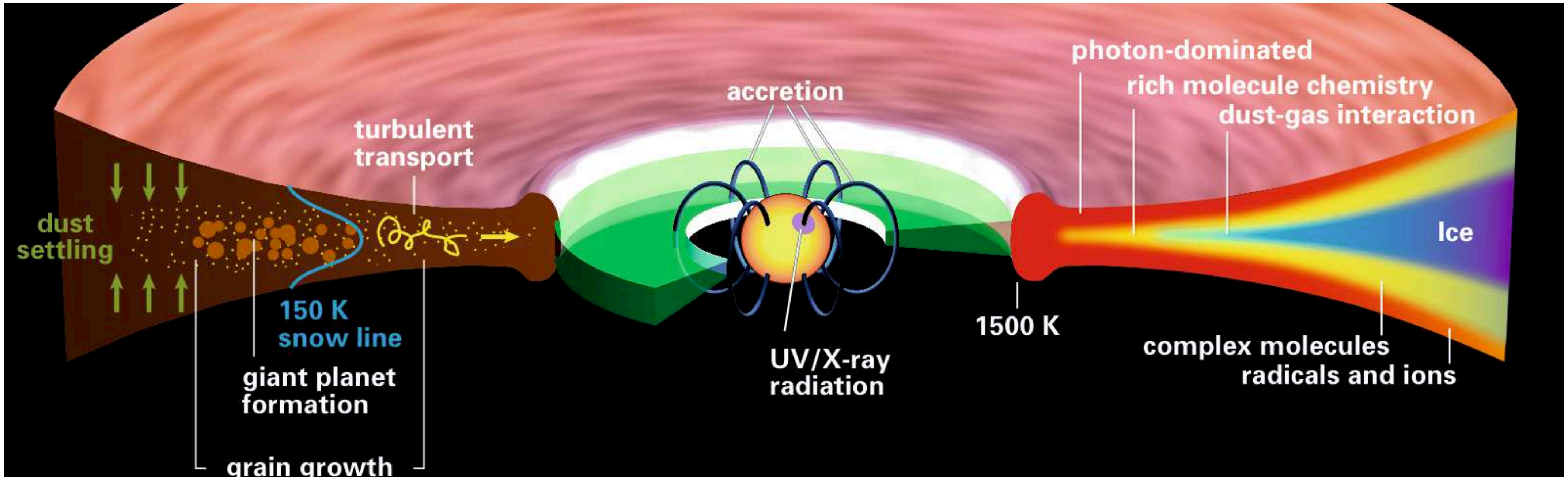
TW Hya



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

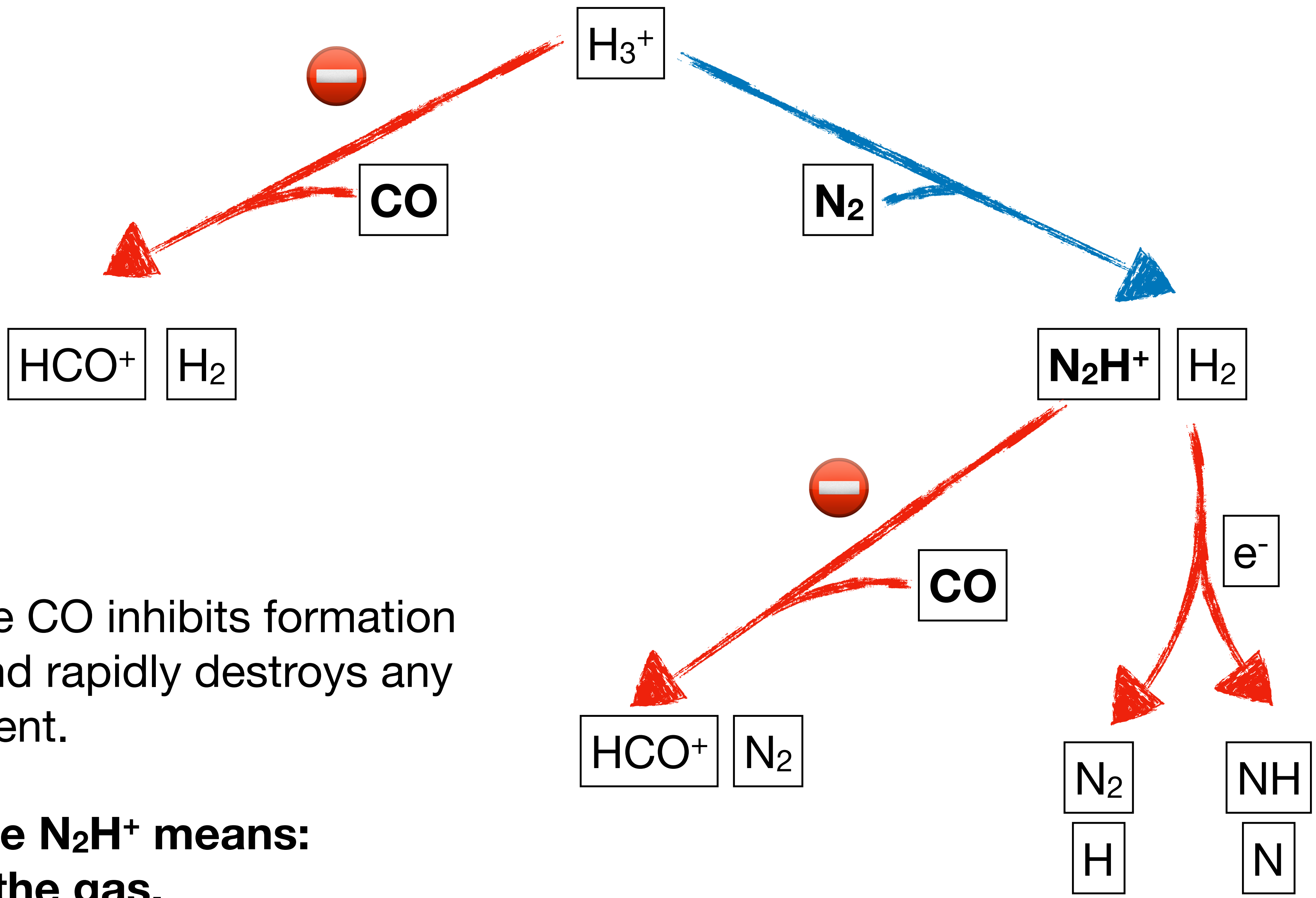


Henning+Semenov13

⇒ **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^+

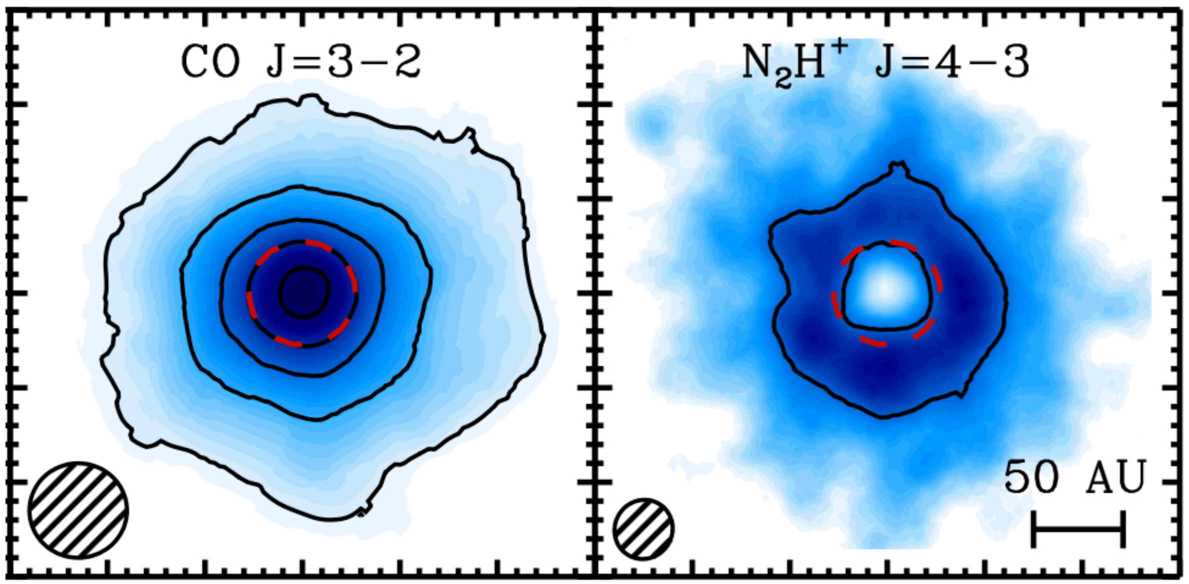


Gas-phase CO inhibits formation of N_2H^+ and rapidly destroys any N_2H^+ present.

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

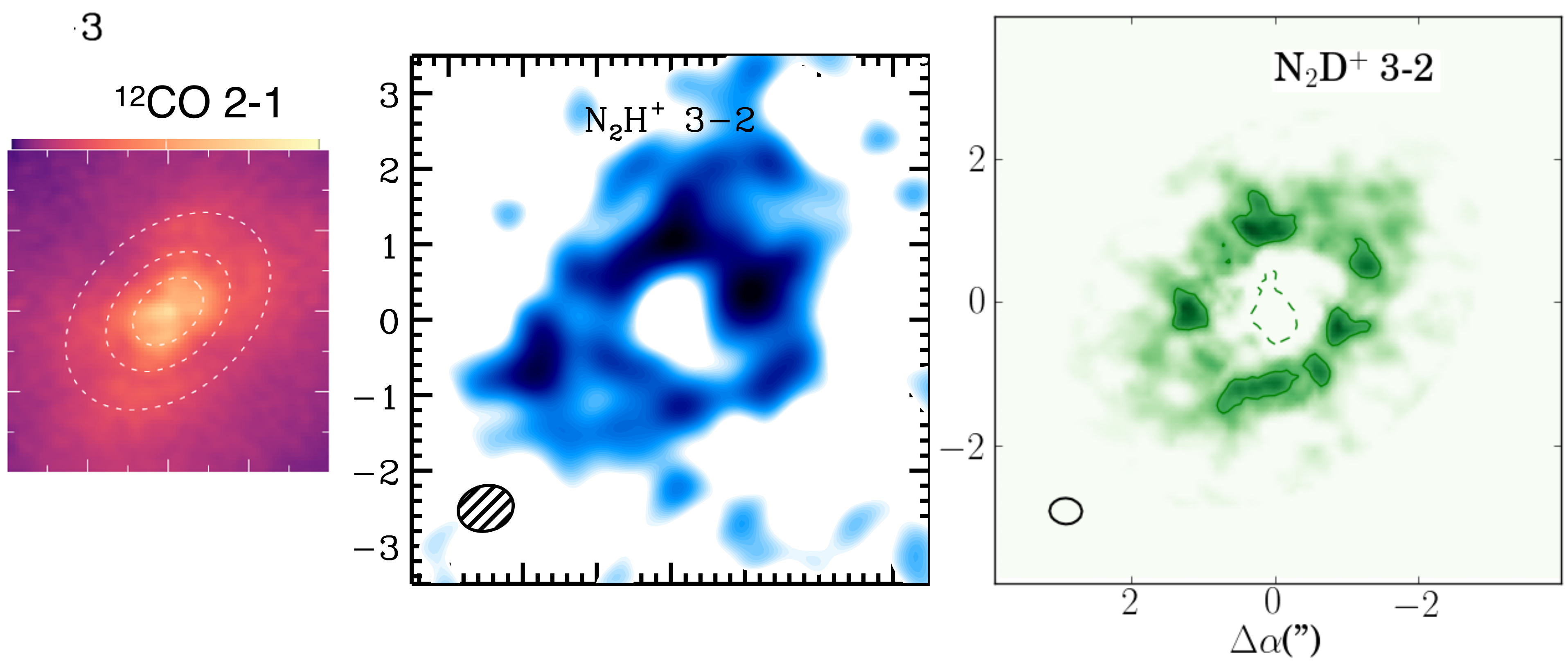
N_2H^+ and N_2D^+

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



TW Hya

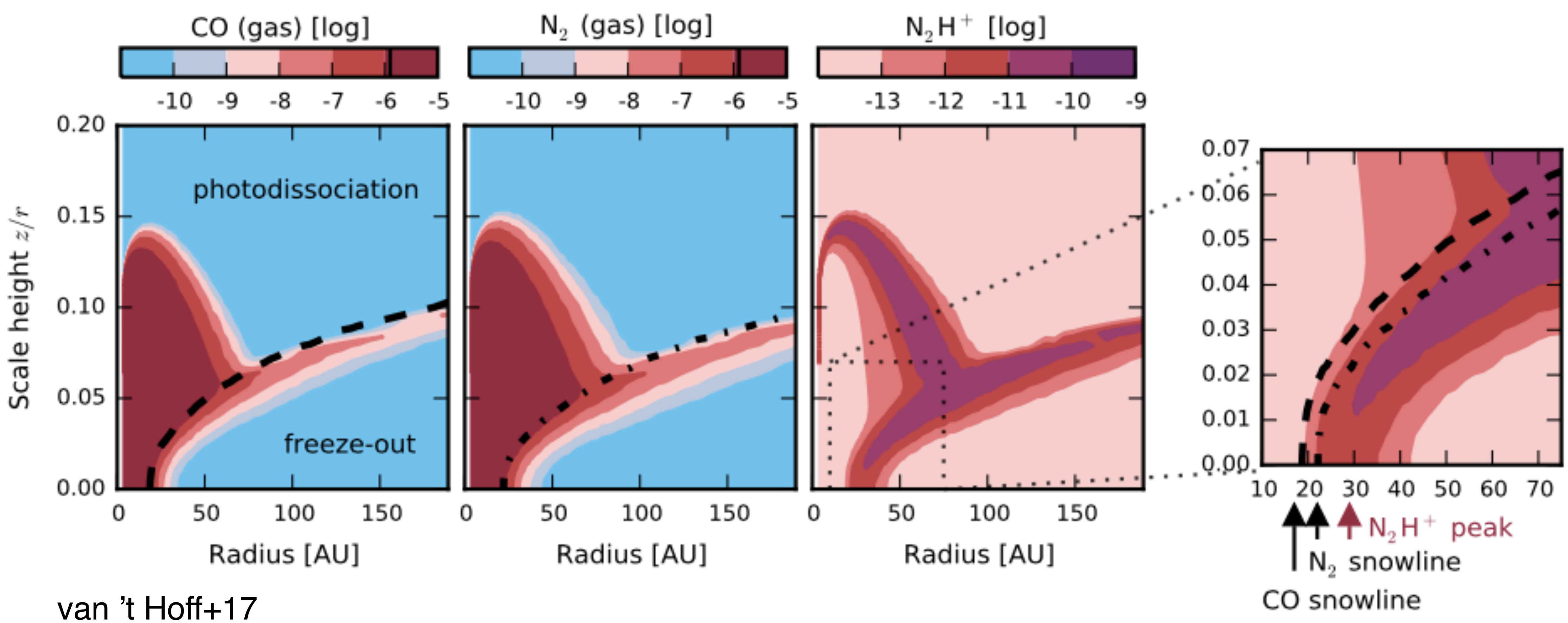
Qi+13, 15; Isella+16; Salinas+17



HD163296

N_2H^+: a caveat

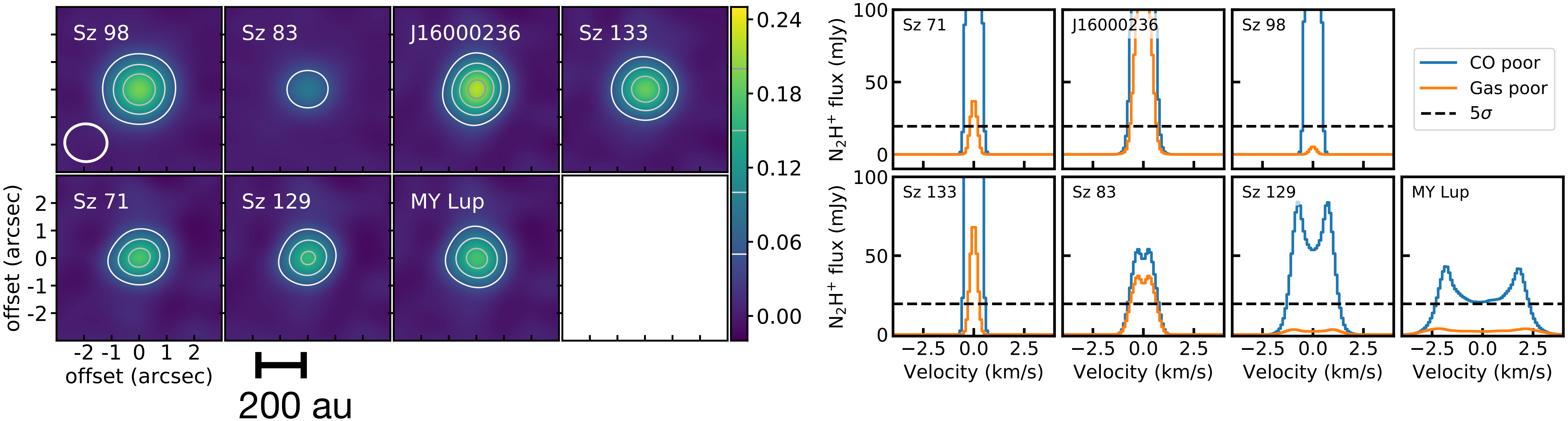
- Caveats (e.g., van 't Hoff+17):
  - 'Snow line' defined as 50%-CO freeze out, but N_2H^+ requires much larger CO depletion → ring moves outward
  - N_2H^+ also formed in upper layer where CO is already photodissociated but N_2 isn't yet.
  - Schwarz+19: excitation of N_2H^+ in TW Hya is high (~40 K)



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

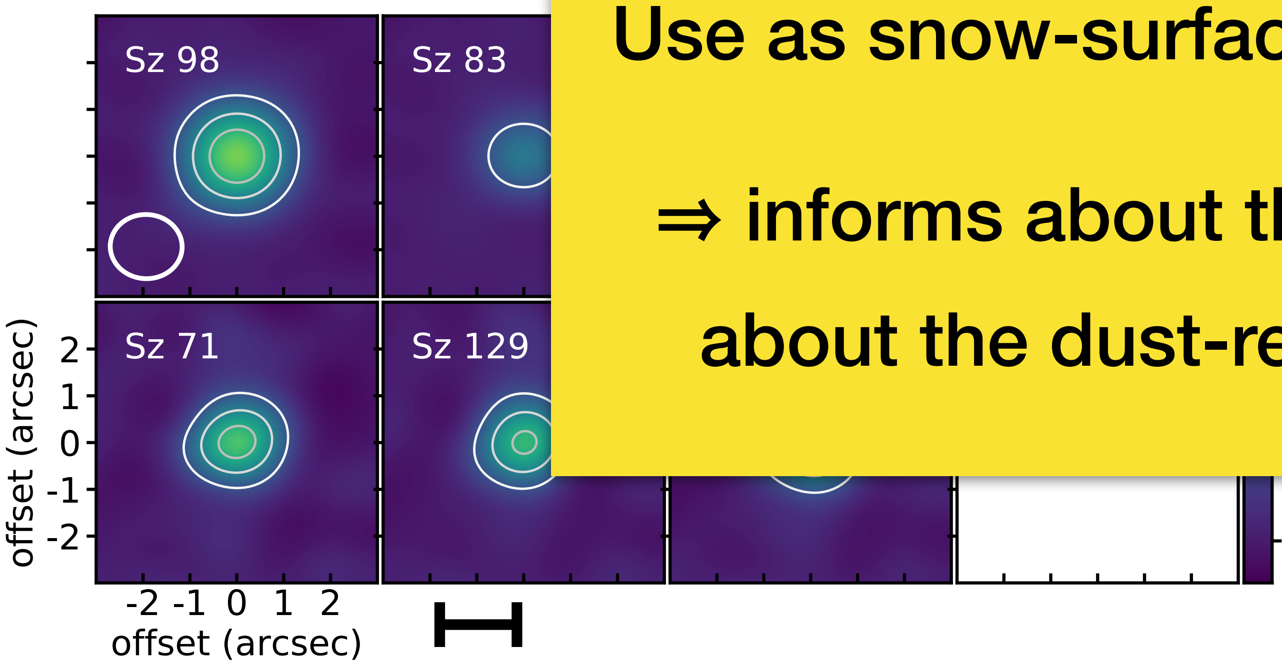
N_2H^+ and the 'missing CO' mass

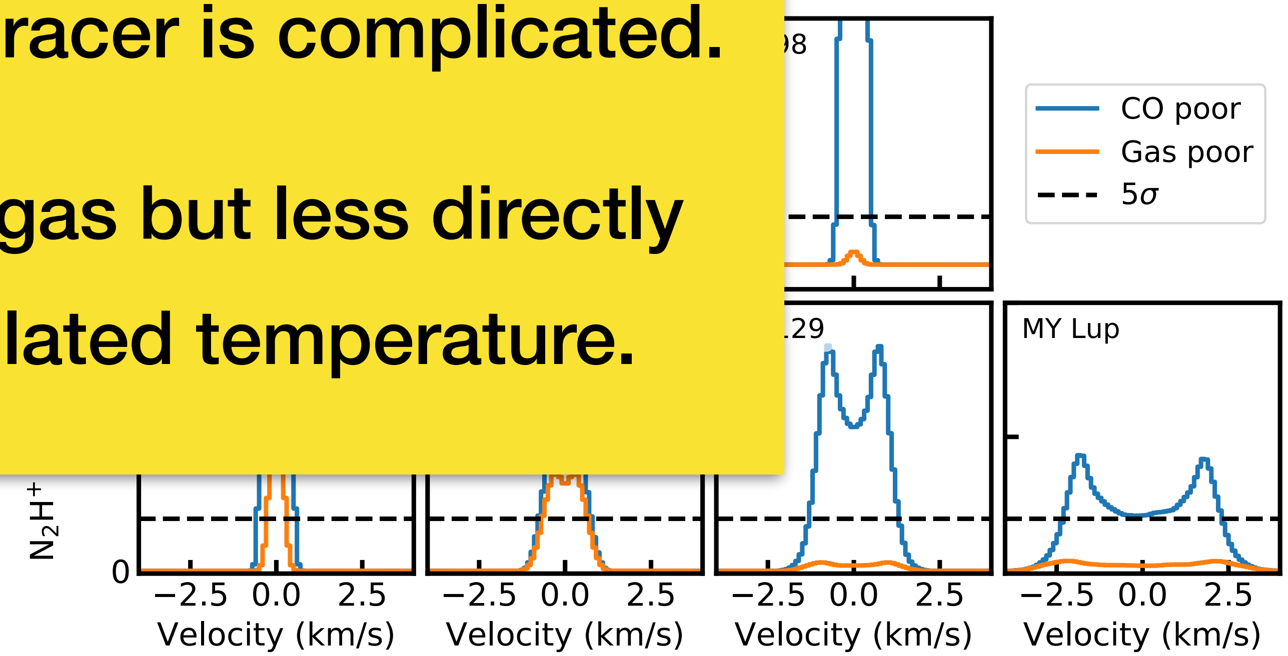
- Corollary: N_2H^+ traces disk gas that is 'CO-dark' → solves 'missing mass' problem
- Ongoing work by Trapman et al.
  - Gas-p
  - Model

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.





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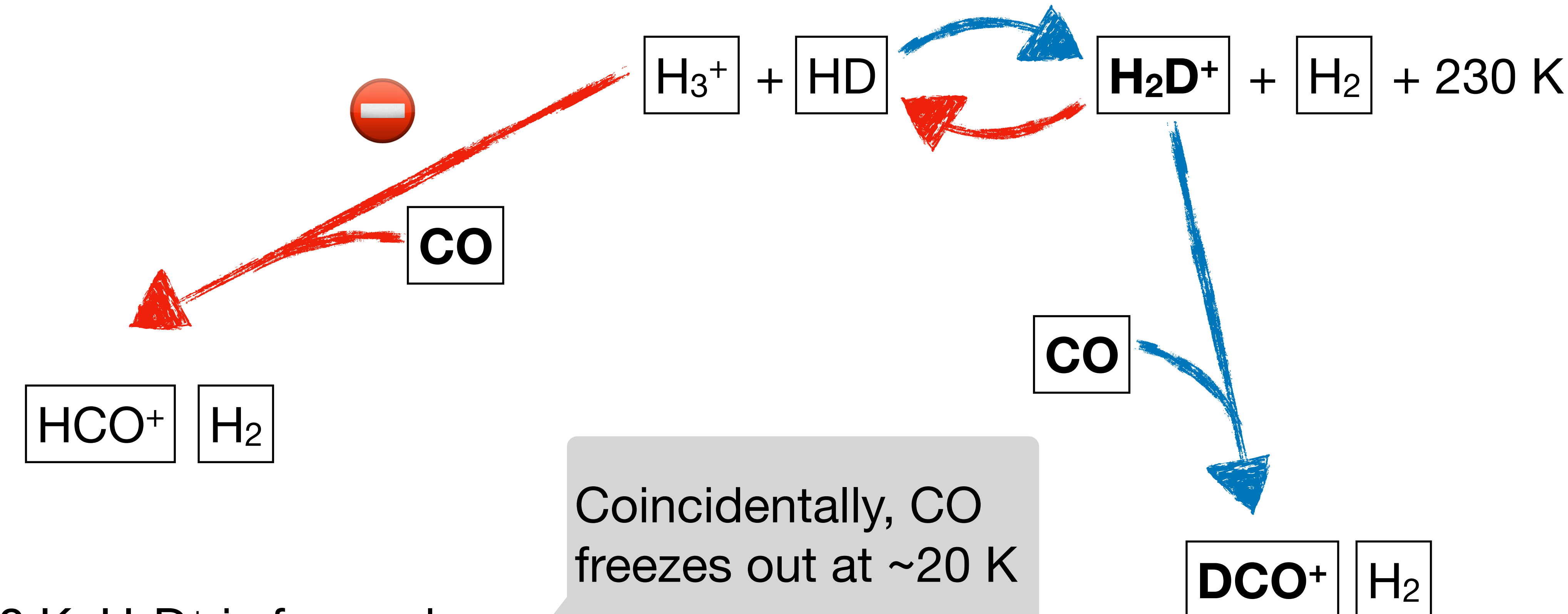
DCO^+



Below ~20 K, H_2D^+ is favored.

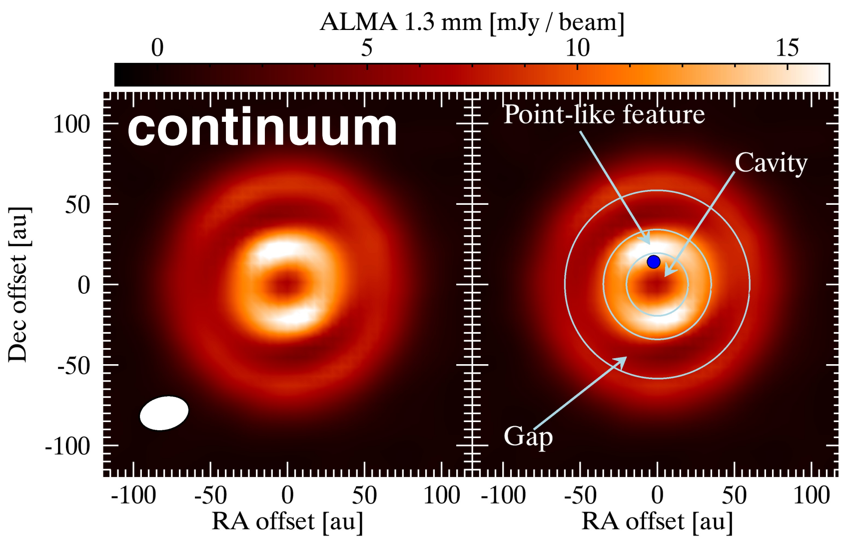
Gas-phase CO inhibits formation of H_2D^+.

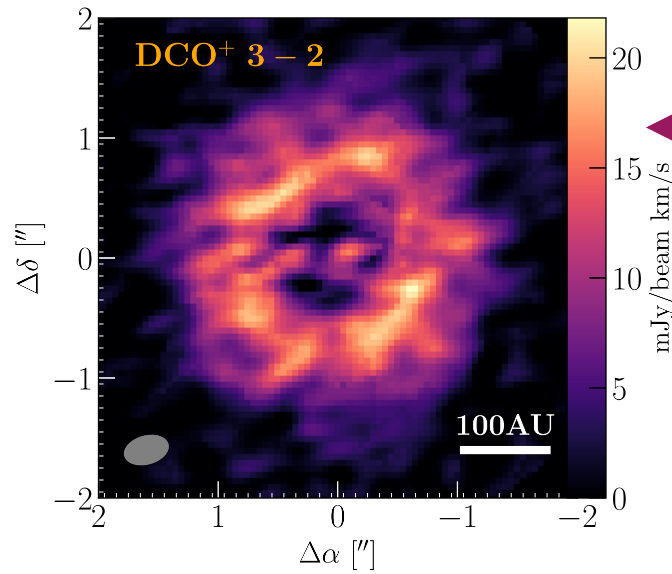
A small amount of CO is needed to convert H_2D^+ into DCO^+.

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

DCO+

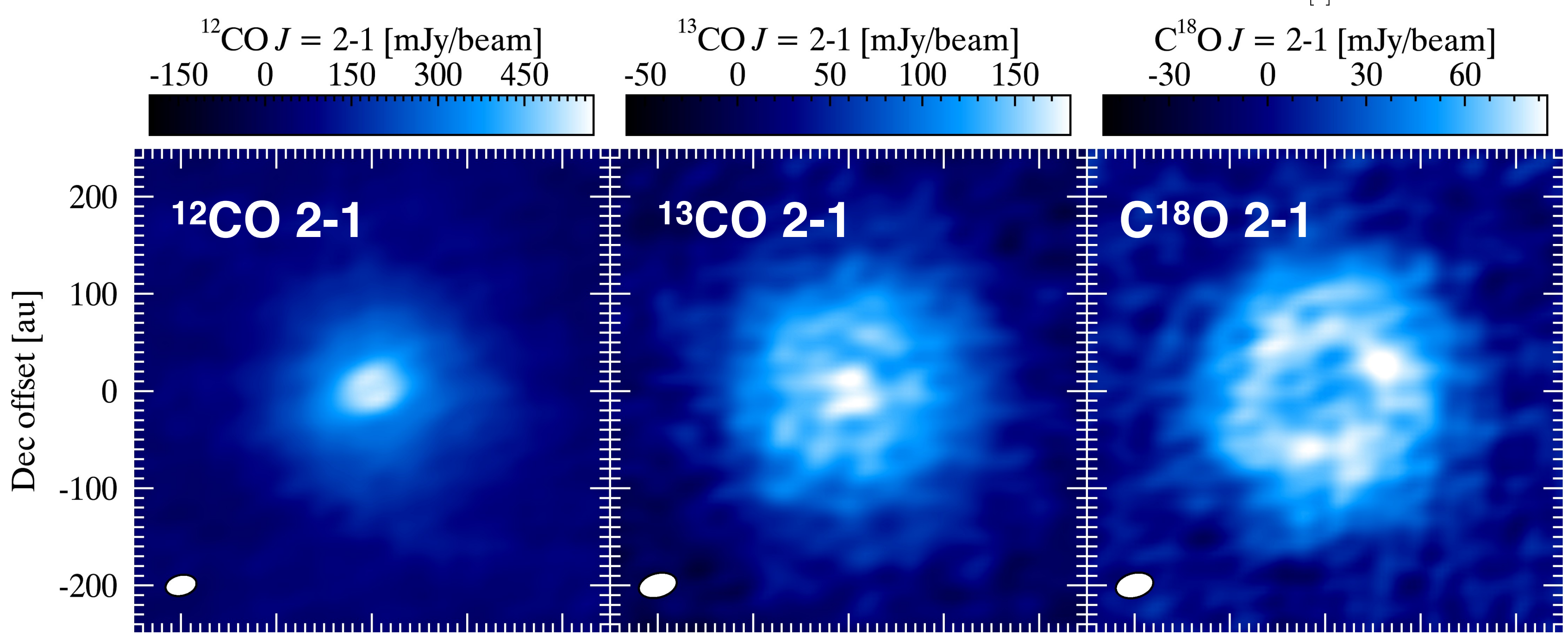
- **HD169142:**
  - DCO^+ traces cold region outside outer ‘mm ring’, not otherwise detectable





DCO+ 3-2

Carney+18

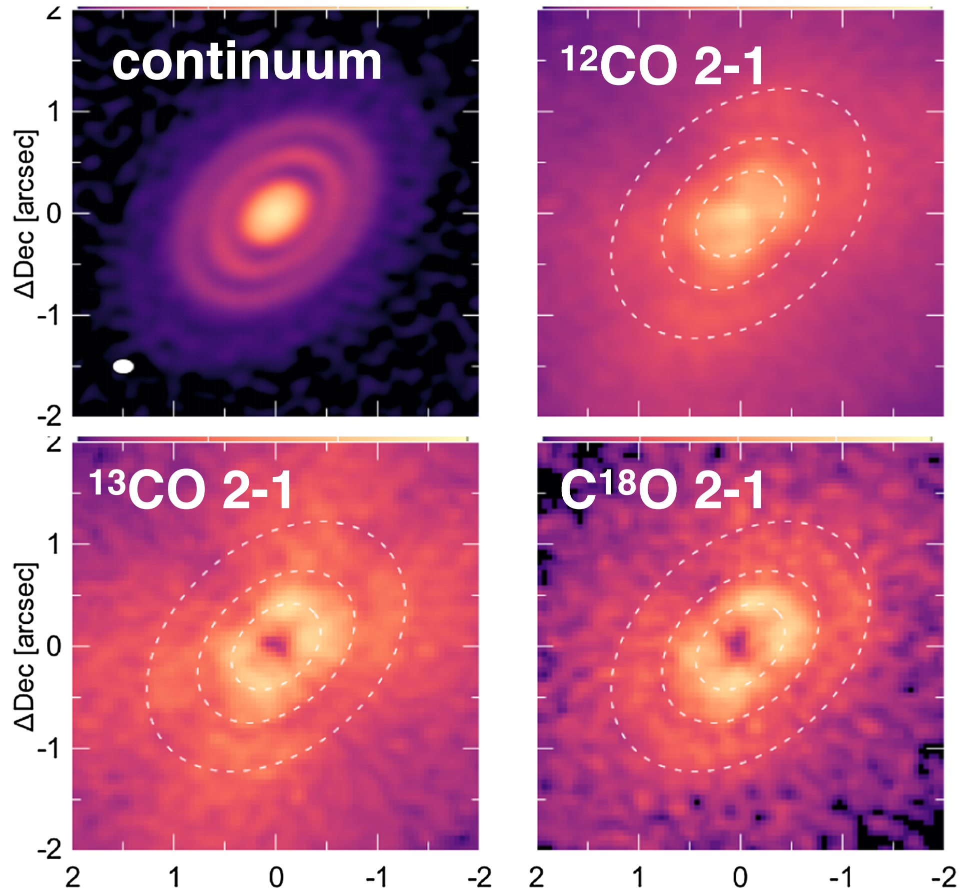


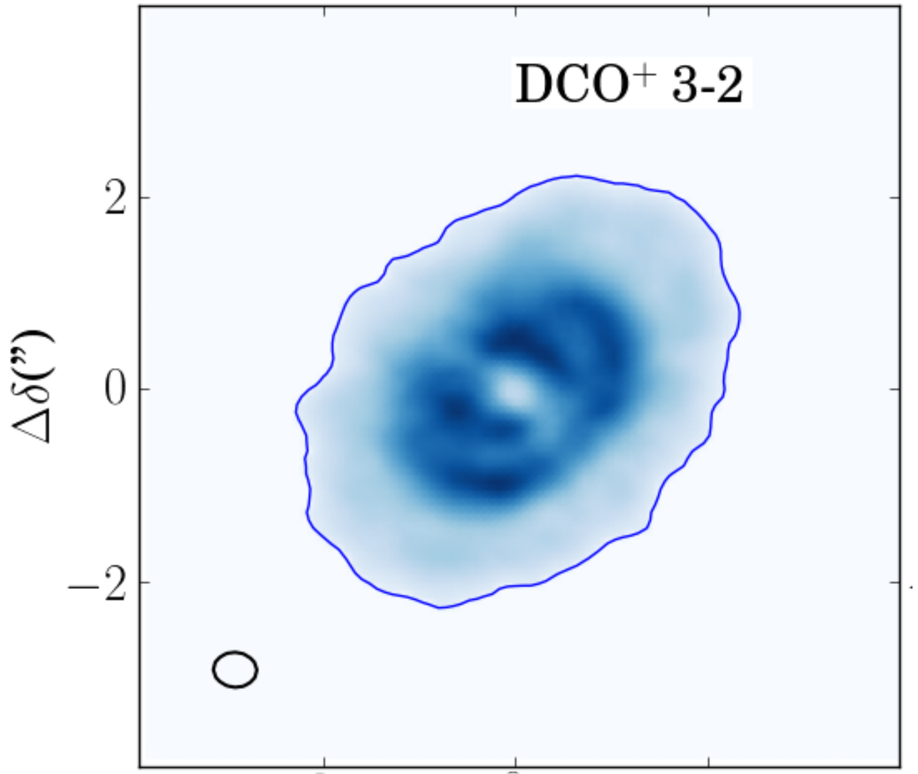
Even $C^{18}O$ is optically thick in midplane; cold region effectively hidden.

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)





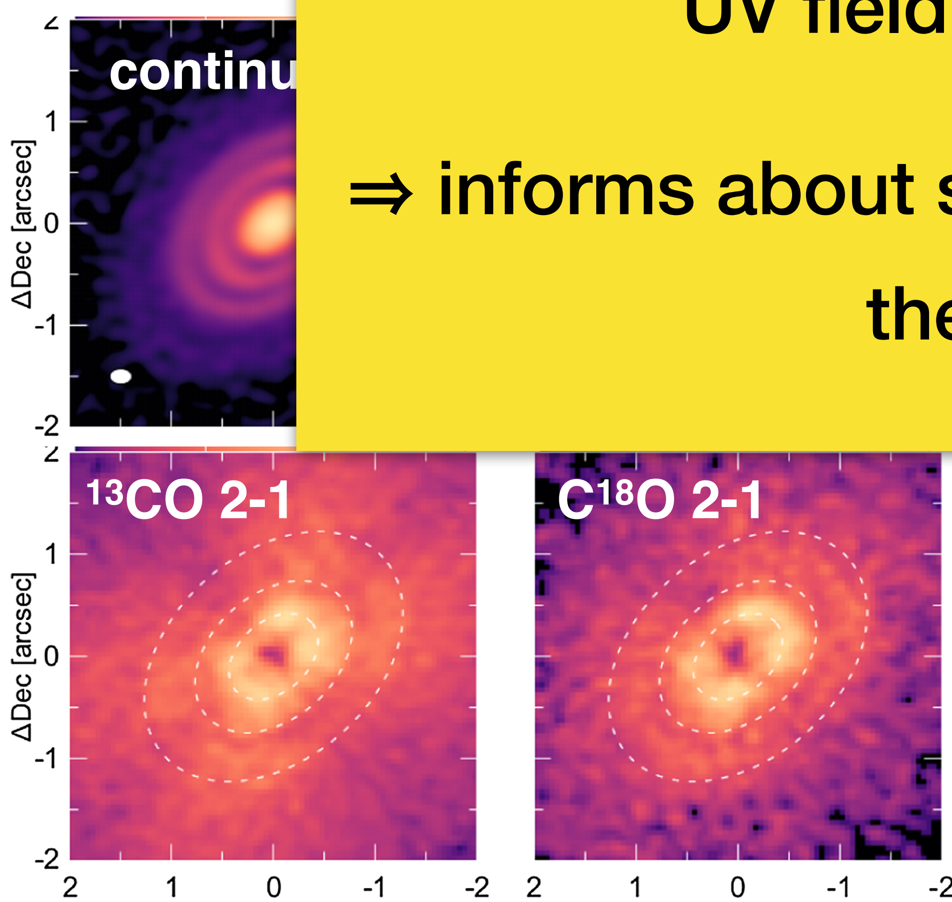
Salinas+17,18

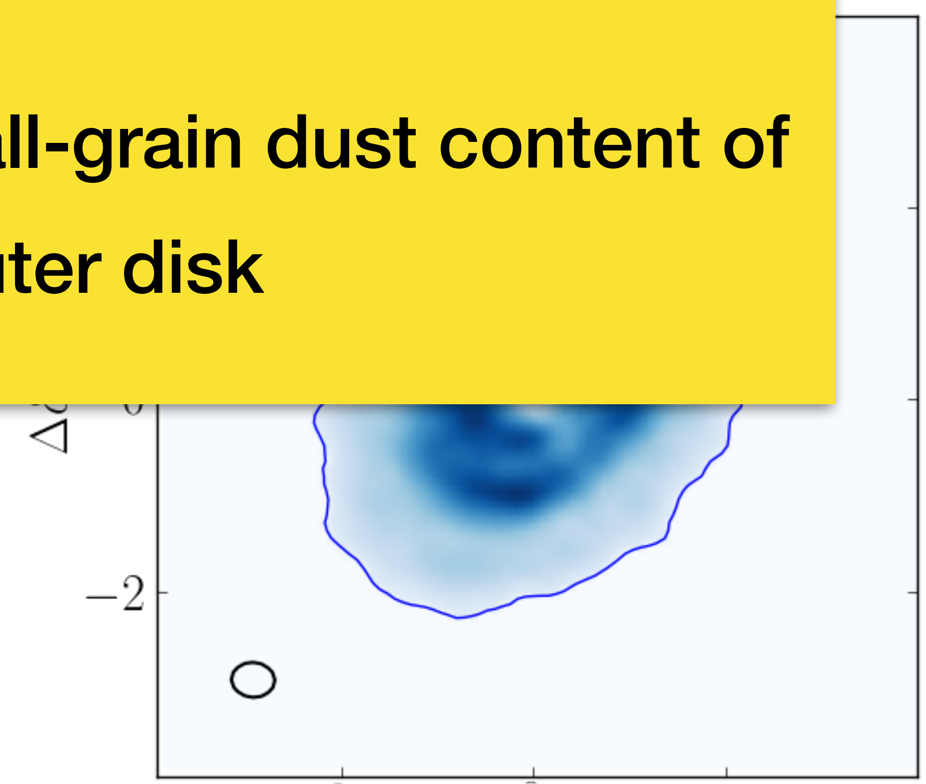
DCO$^+$

- **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

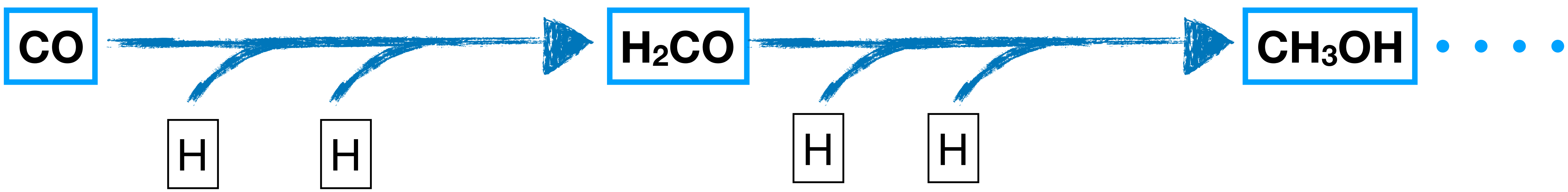




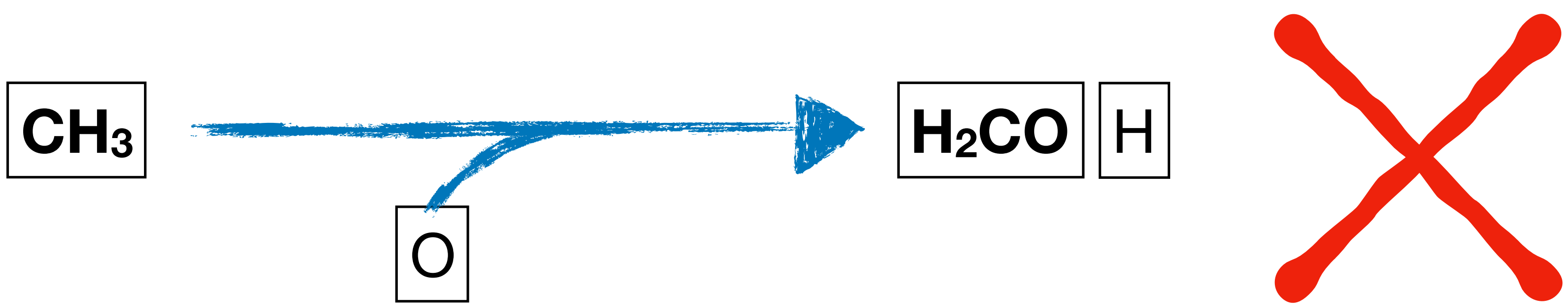
Salinas+17,18

H_2CO and CH_3OH

- Grain surface (ice) formation route

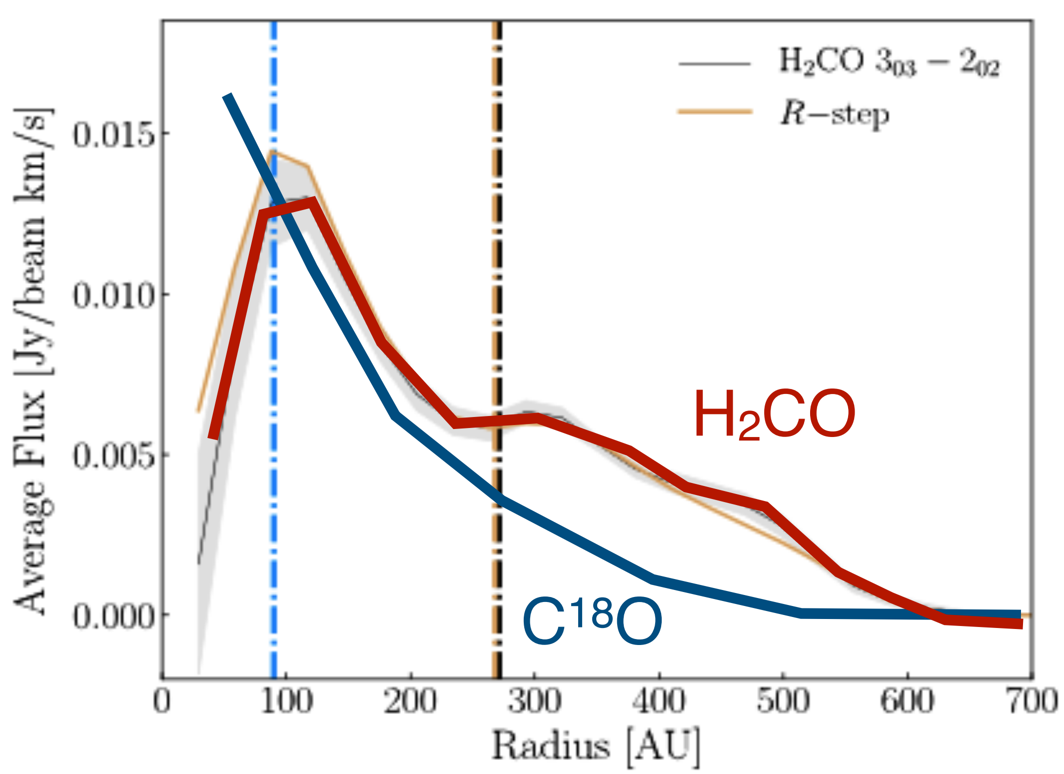


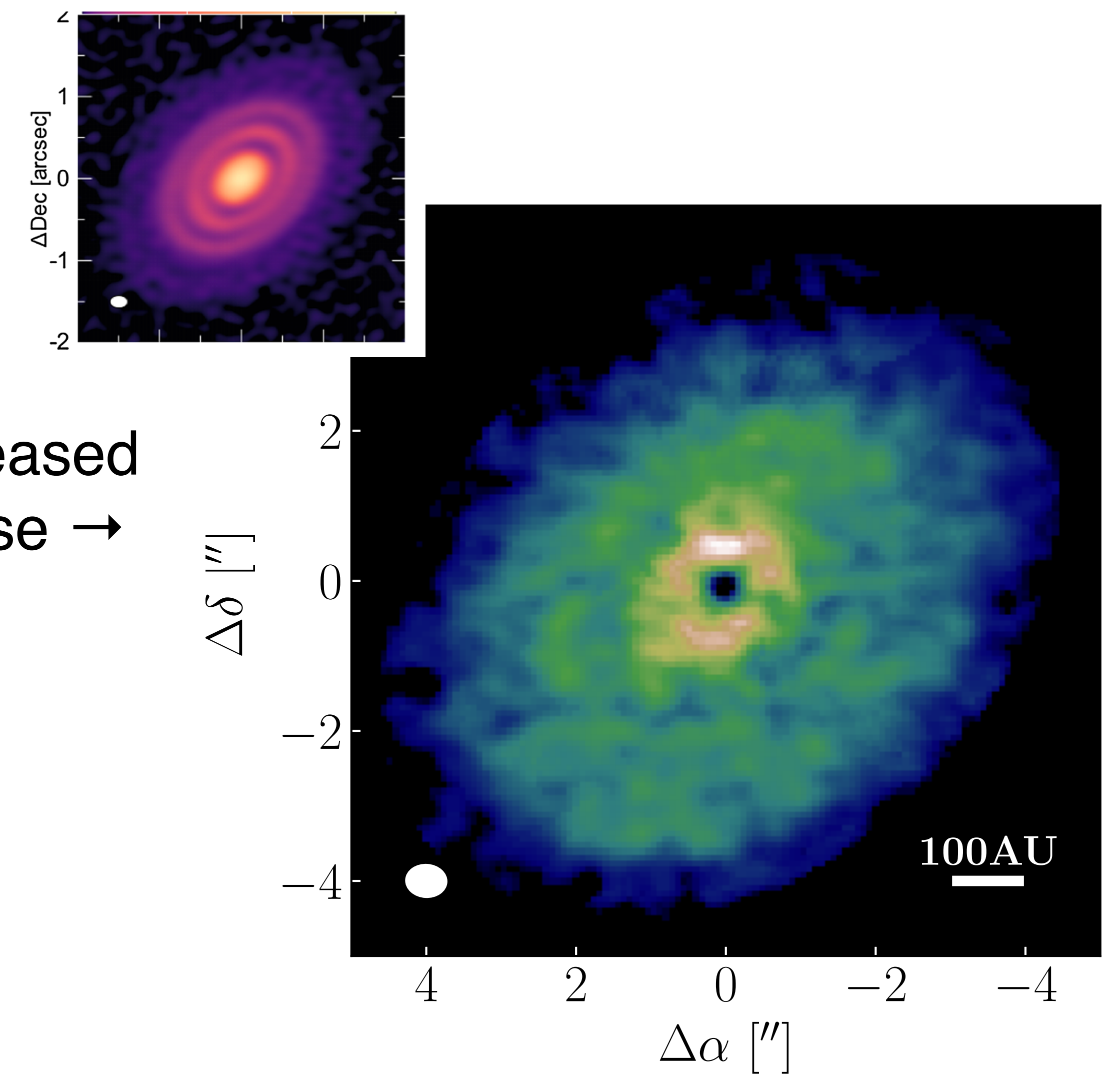
- Gas-phase formation route



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 ?

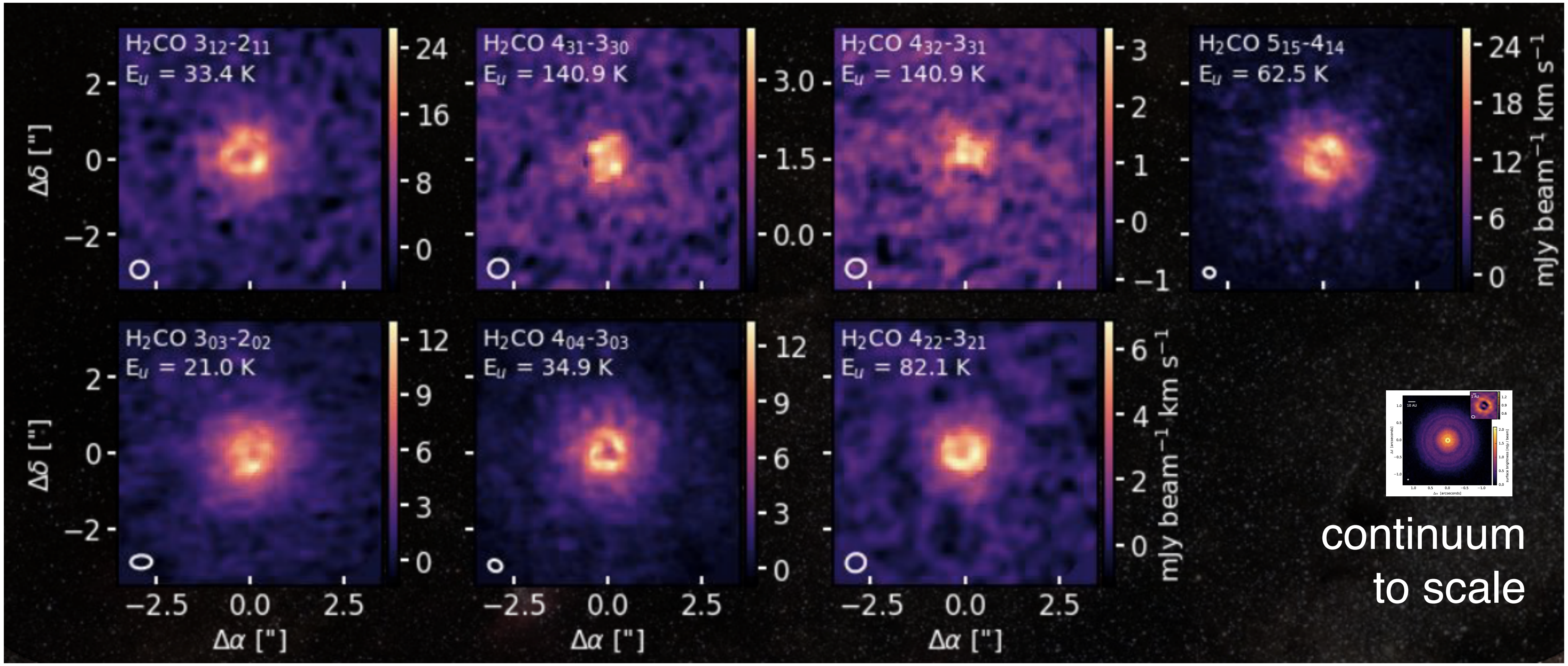




Carney+16

H_2CO

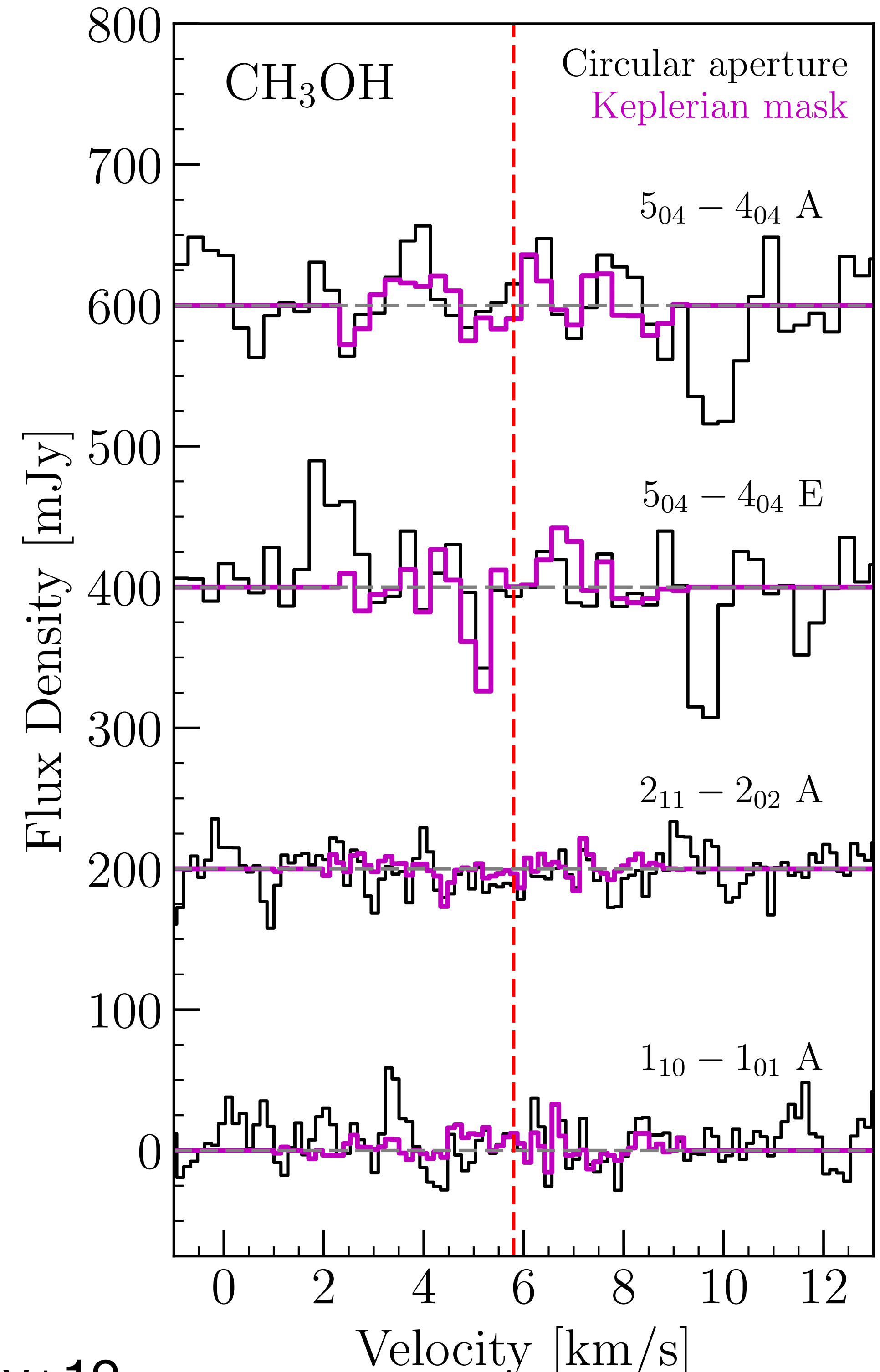
- TW Hya also has H_2CO emission extending across the disk
  - Recent observations by Cleeves et al. team
- See poster Jeroen Terwisscha van Scheltinga



H_2CO and CH_3OH

- CH_3OH detected in TW Hya (Walsh+16)
- Carney+19: HD163296
  - Strict upper 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

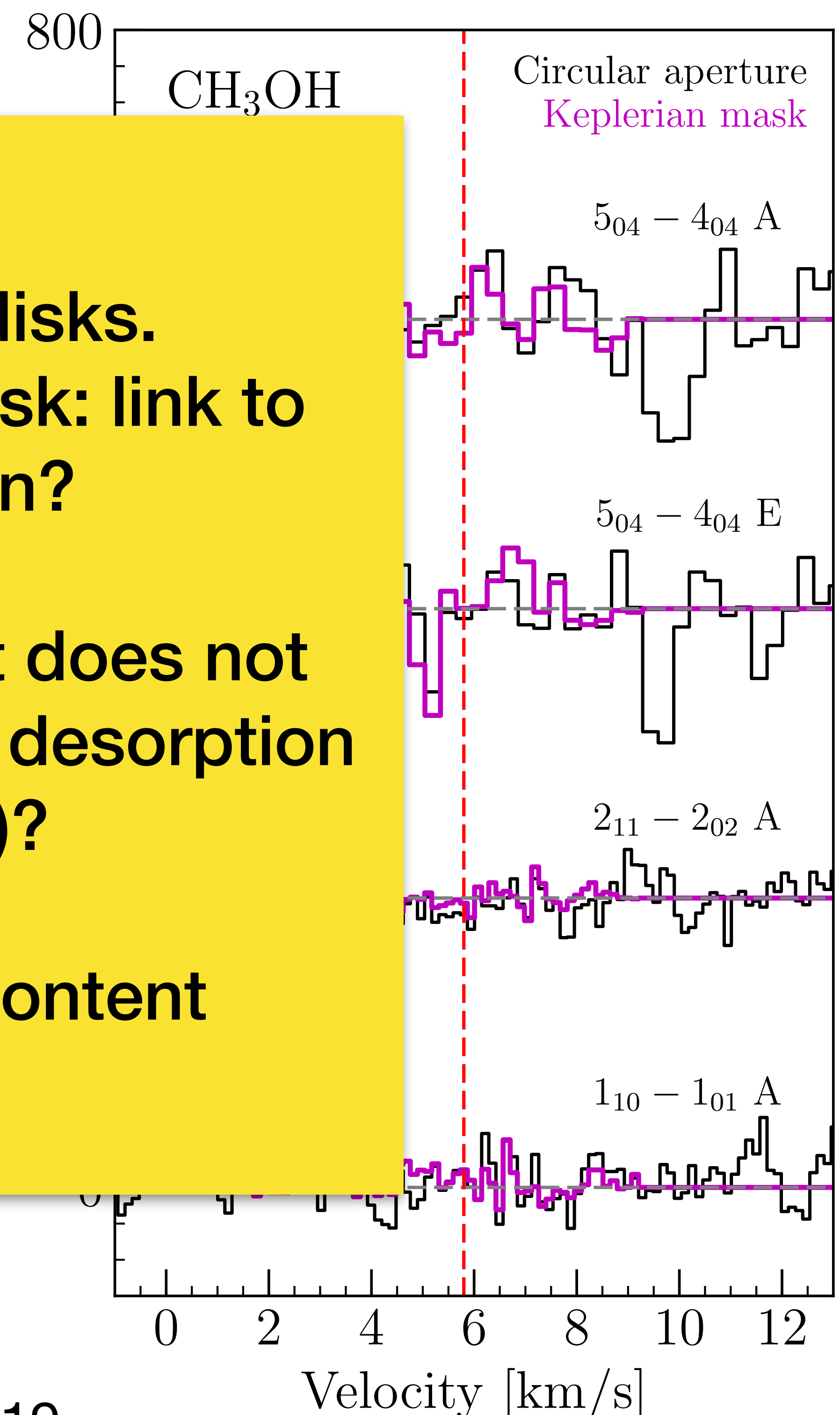
H_2CO and CH_3OH

- 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**