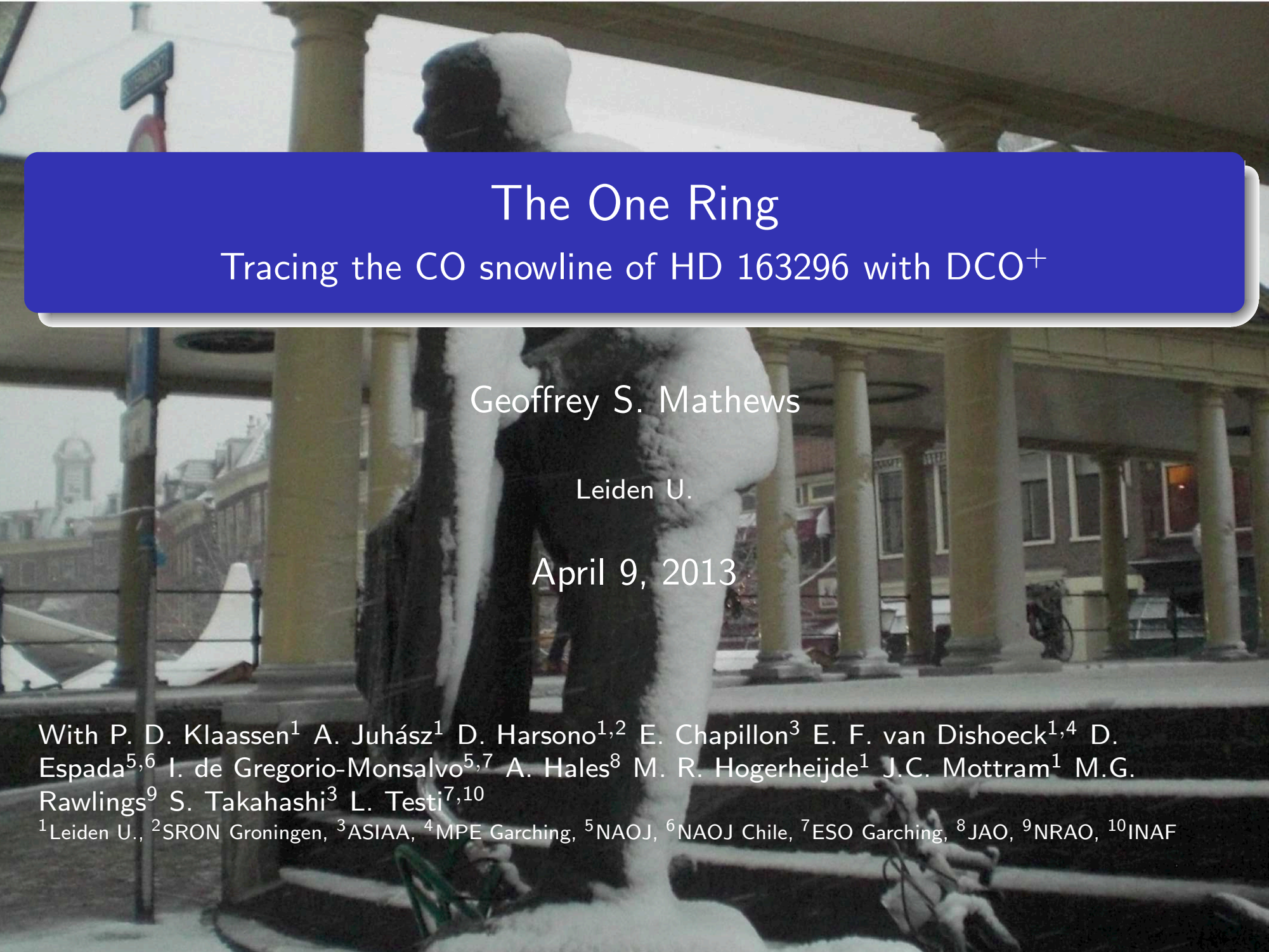


The One Ring

Tracing the CO snowline of HD 163296 with DCO^+

Geoffrey S. Mathews

Leiden U.

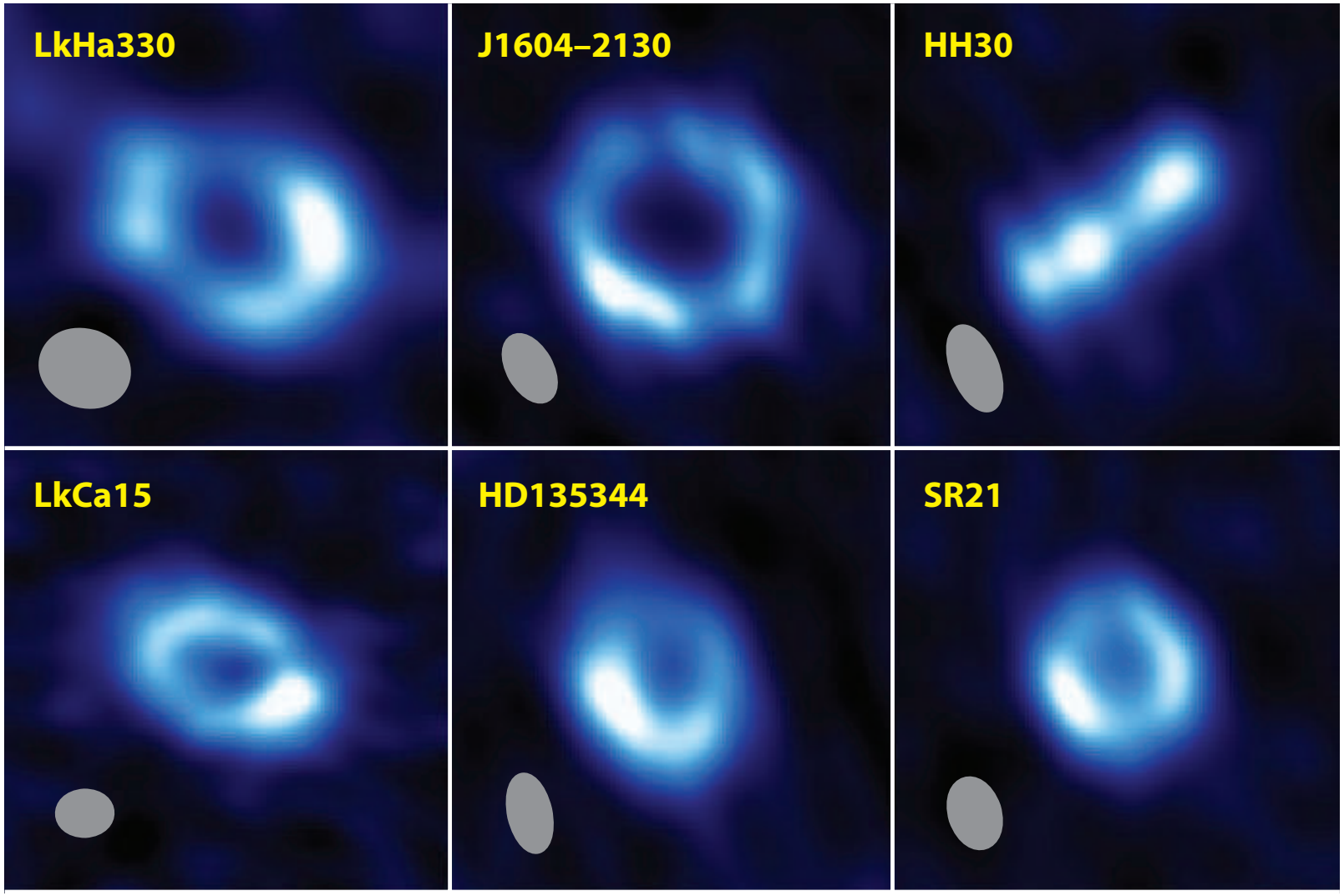
April 9, 2013

With P. D. Klaassen[1] A. Juhász[1] D. Harsono[1,2] E. Chapillon[3] E. F. van Dishoeck[1,4] D. Espada[5,6] I. de Gregorio-Monsalvo[5,7] A. Hales[8] M. R. Hogerheijde[1] J.C. Mottram[1] M.G. Rawlings[9] S. Takahashi[3] L. Testi[7,10]

[1]Leiden U., [2]SRON Groningen, [3]ASIAA, [4]MPE Garching, [5]NAOJ, [6]NAOJ Chile, [7]ESO Garching, [8]JAO, [9]NRAO, [10]INAF

Overview

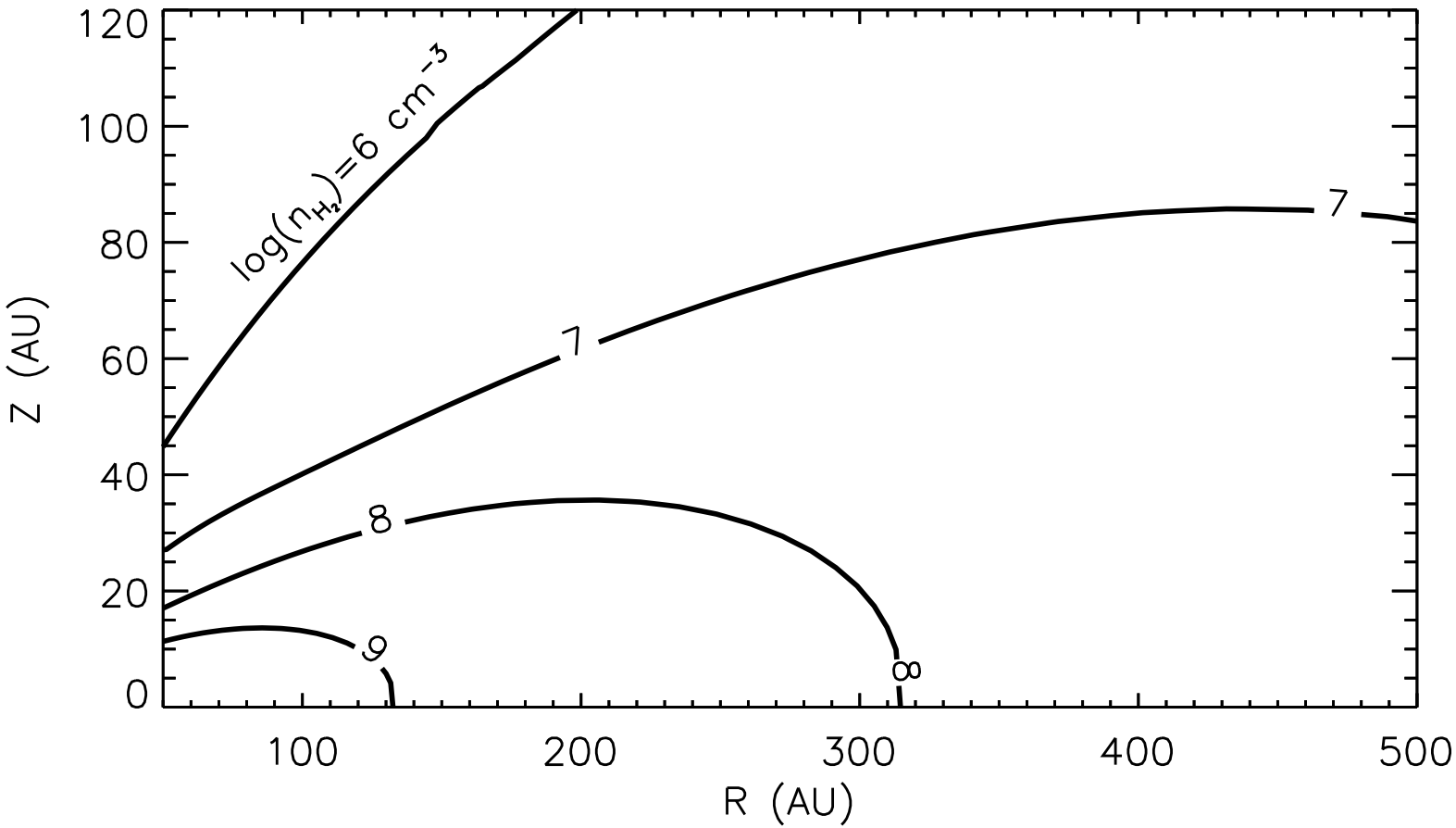
Progress in observing the midplane dust...



Williams & Cieza 2011

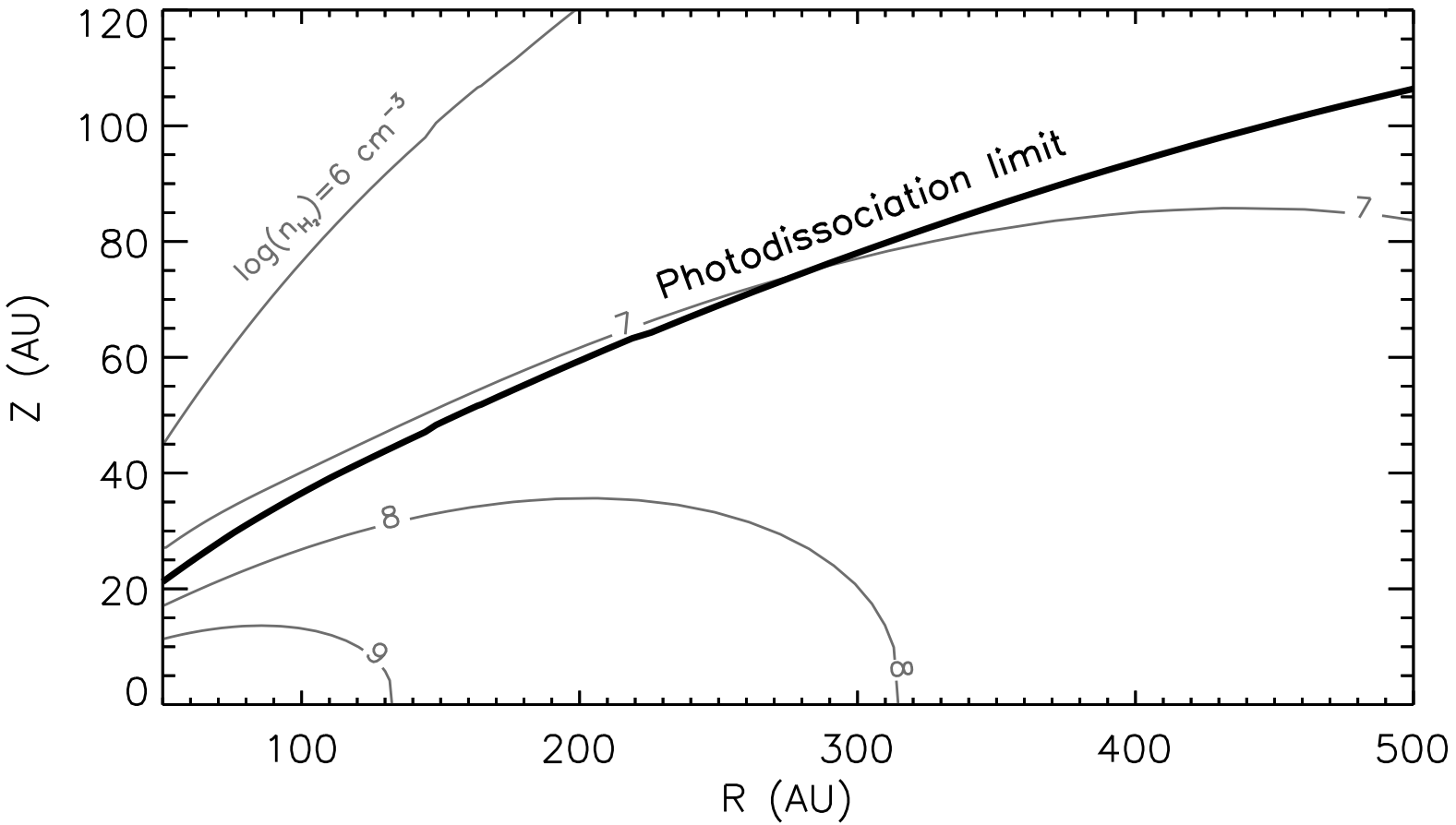
... but the gas can be more difficult

H_2 dominates the mass but is largely unobservable



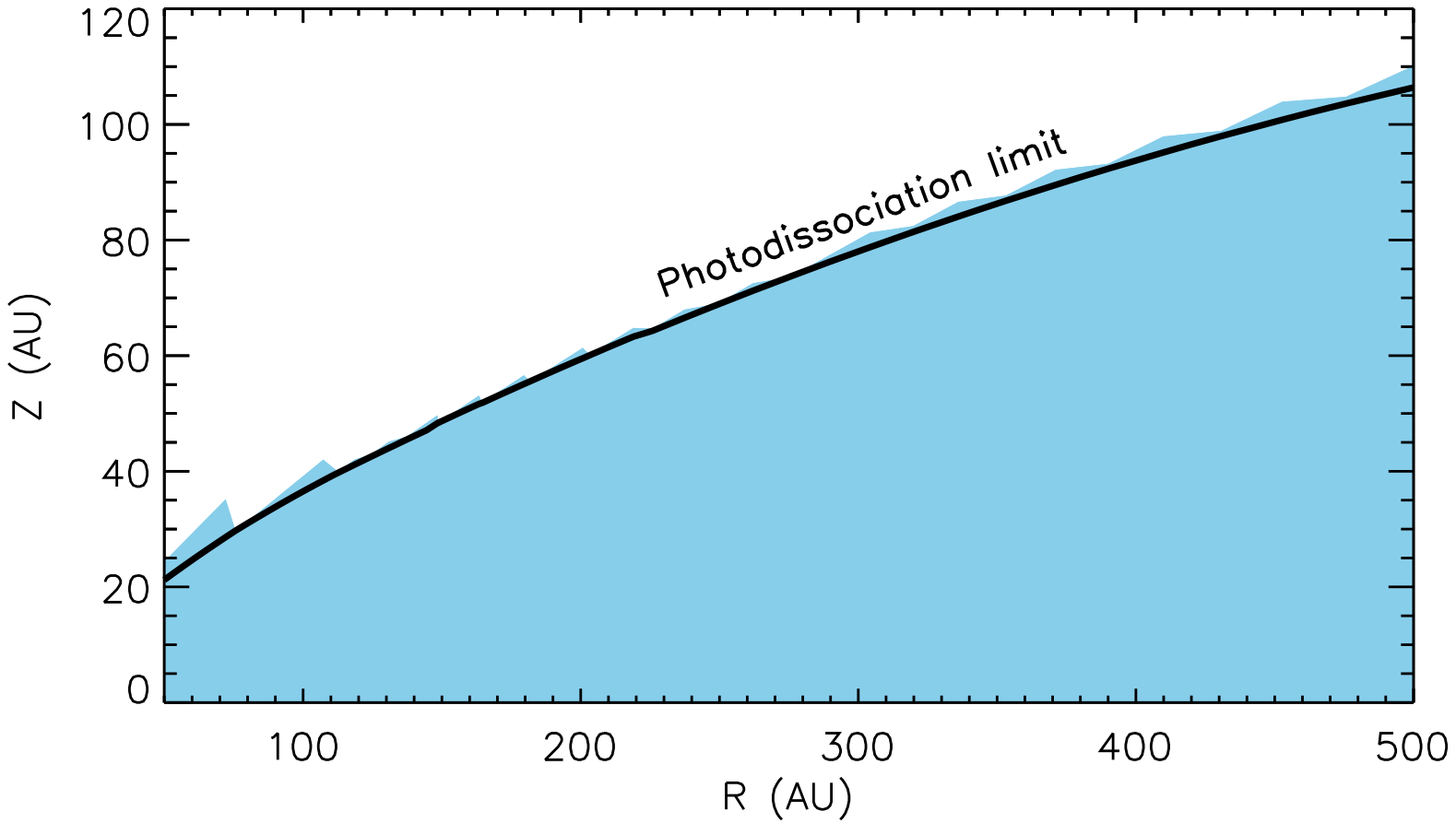
... but the gas can be more difficult

At sufficient column depth, photodissociation becomes negligible



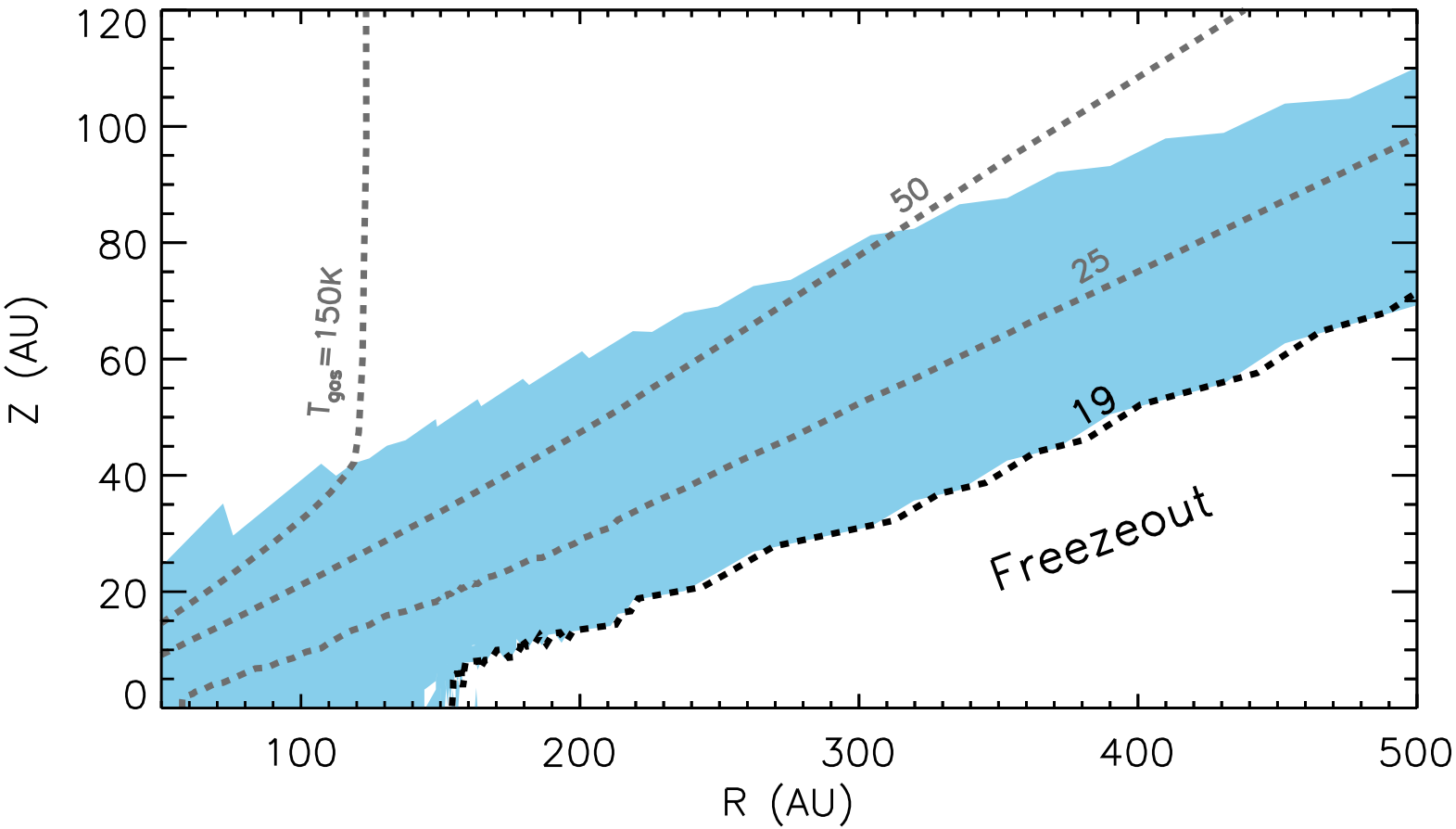
... but the gas can be more difficult

Molecules such as CO can survive...



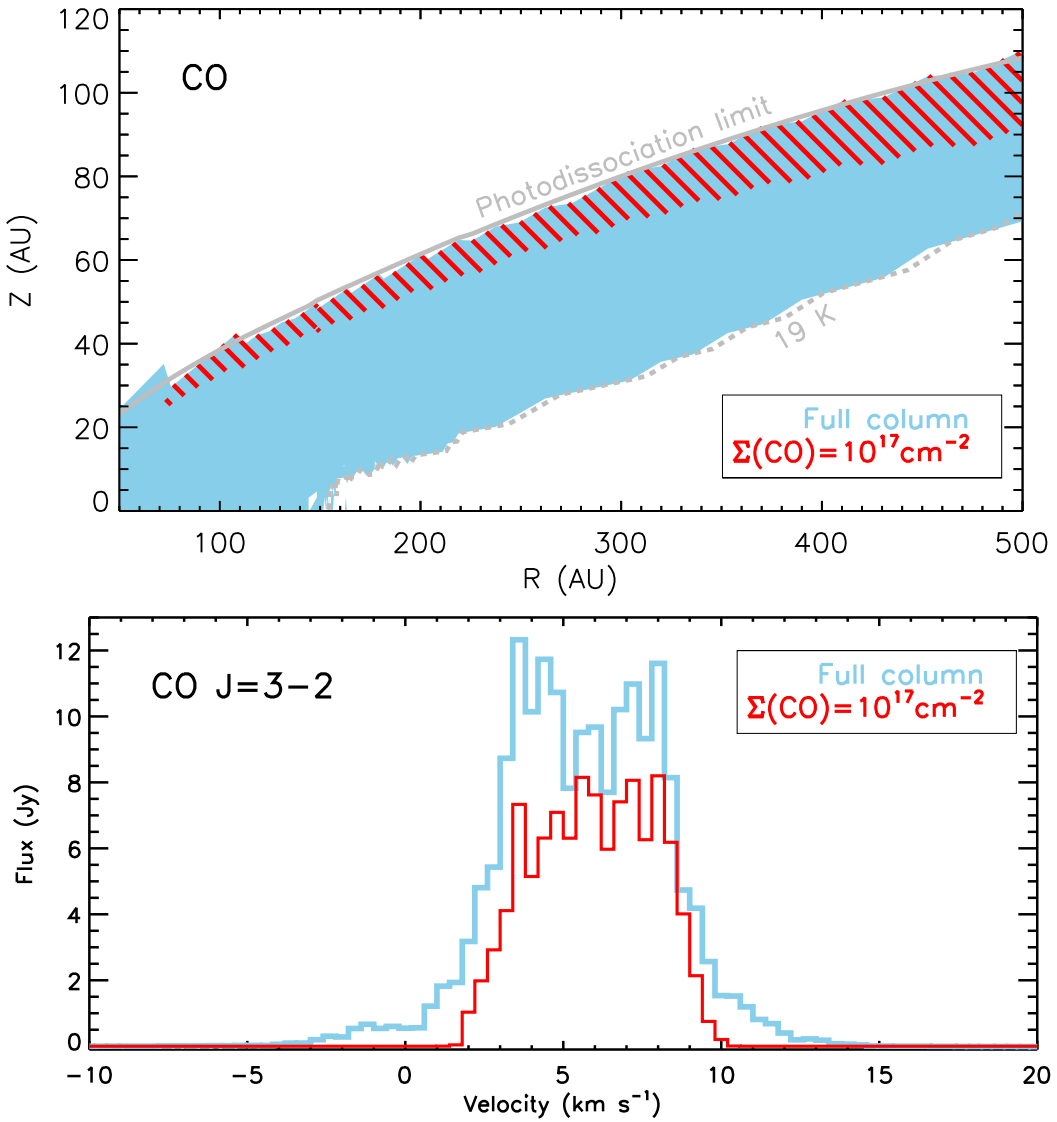
... but the gas can be more difficult

... but will freeze out at low temperatures



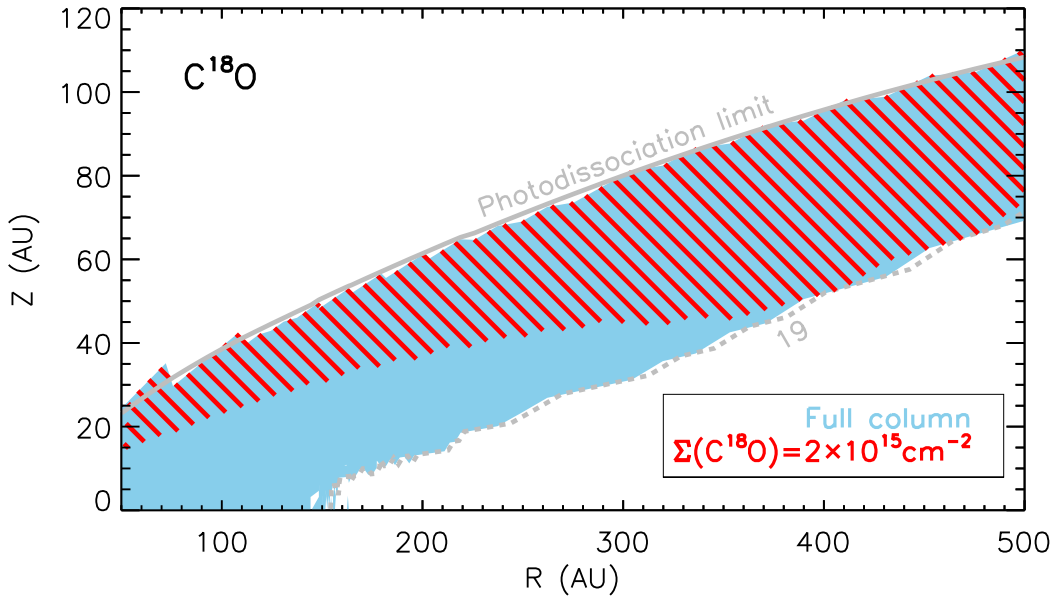
... but the gas can be more difficult

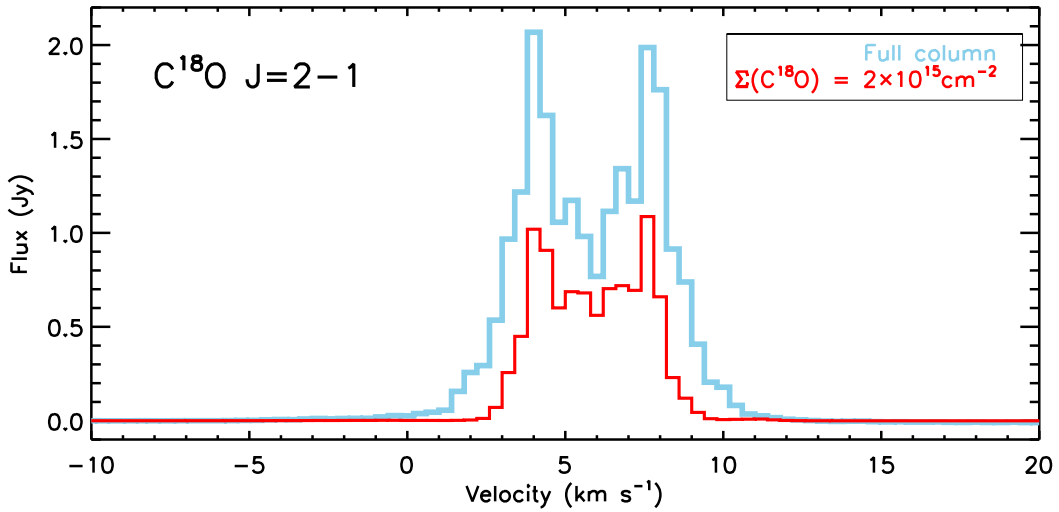
Optically thick CO traces the disk surface



... but the gas can be more difficult

Isotopologues (e.g. $C^{18}O$) probe the midplane, but also the bulk gas



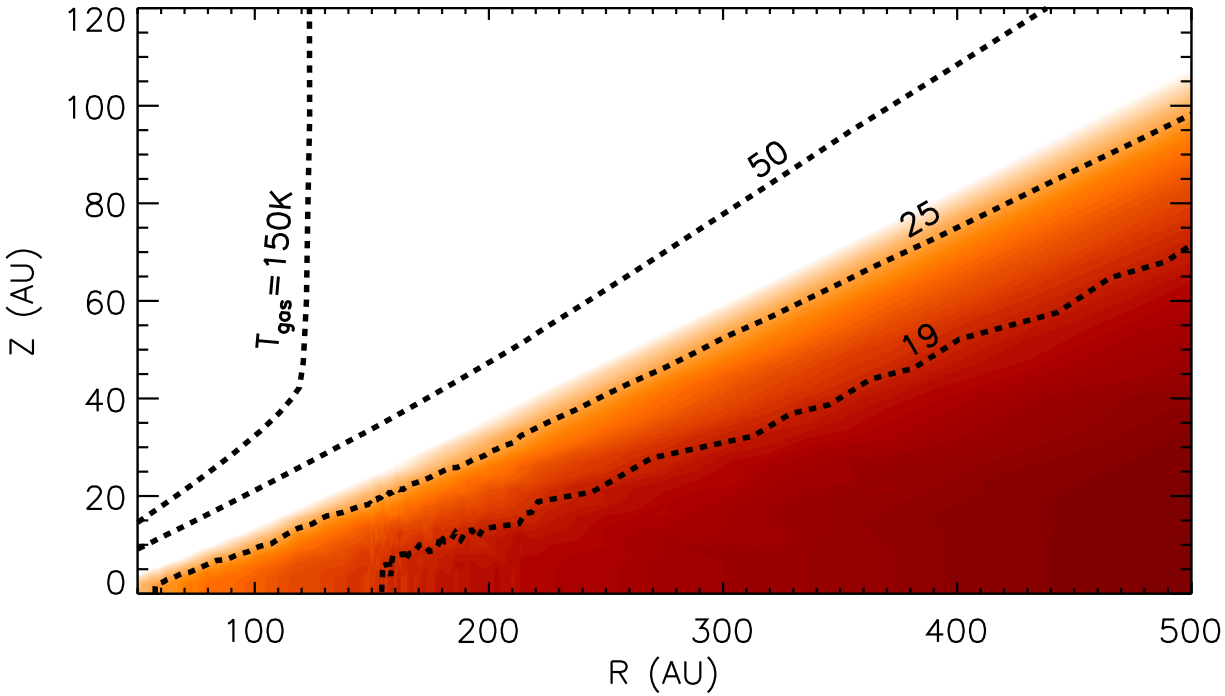


Overview

Formation of progenitor molecules makes DCO$^+$ abundance rise at low temperatures...

$H_3^+ + HD \Leftrightarrow \mathbf{H_2D^+} + H_2 + 220$ K (exothermic forward reaction)

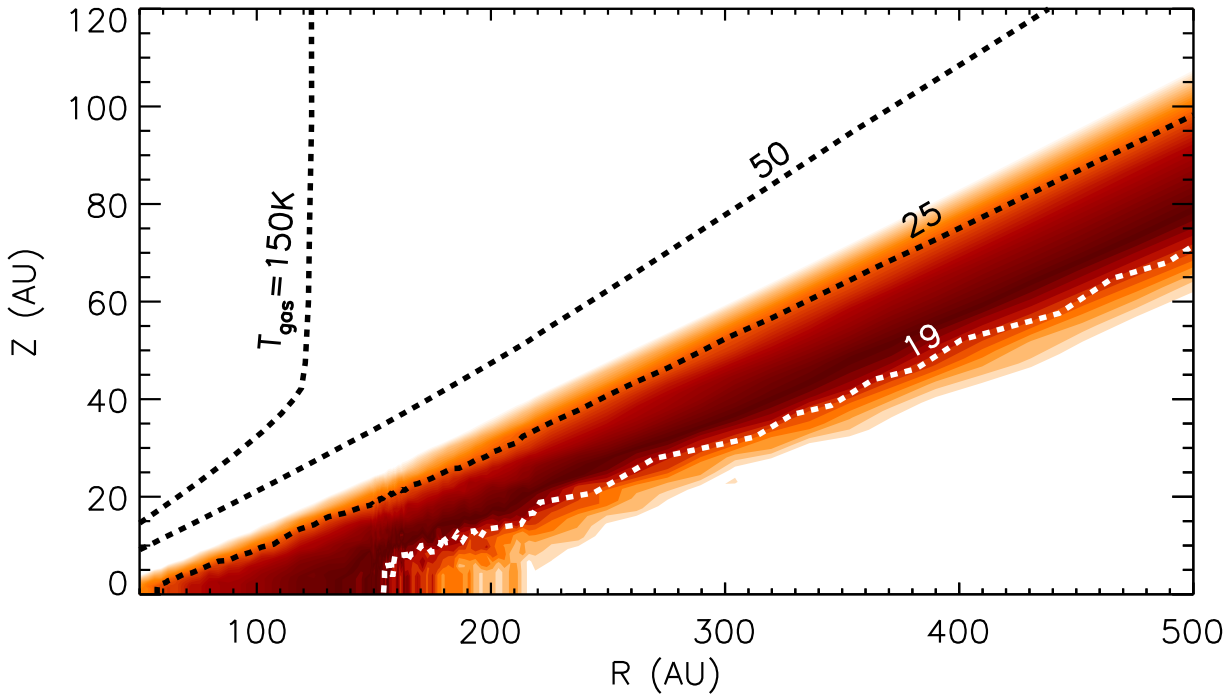
$\mathbf{H_3^+} + CO \Leftrightarrow H_2 + HCO^+$ (CO freezeout inhibits H_3^+ destruction)



e.g. Wootten 1987, Roberts & Millar 2000, Pagani et al. 2009, Jorgensen et al. 2004, Aikawa et al. 2002

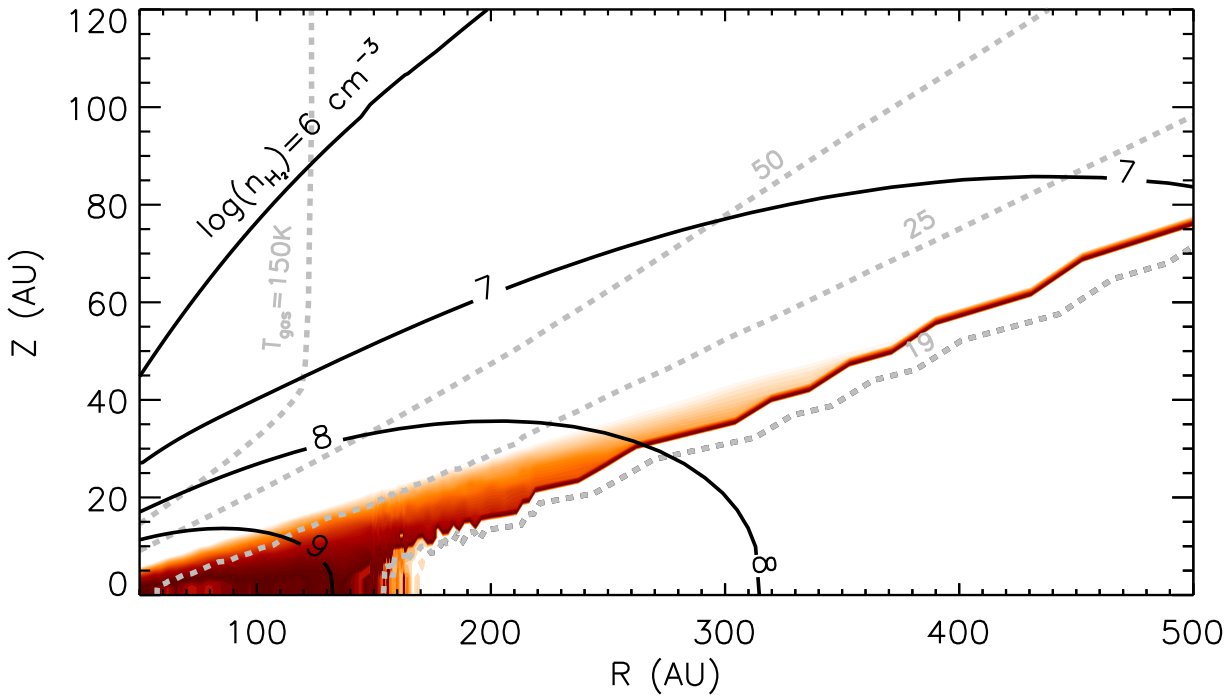
... but CO freezeout will make DCO$^+$ abundance fall at the CO snowline

$$H_2D^+ + \mathbf{CO} \rightarrow H_2 + DCO^+$$



e.g. Wootten 1987, Roberts & Millar 2000, Pagani et al. 2009, Jorgensen et al. 2004, Aikawa et al. 2002

Brightest DCO$^+$ emission is likely from the midplane near the CO-snowline

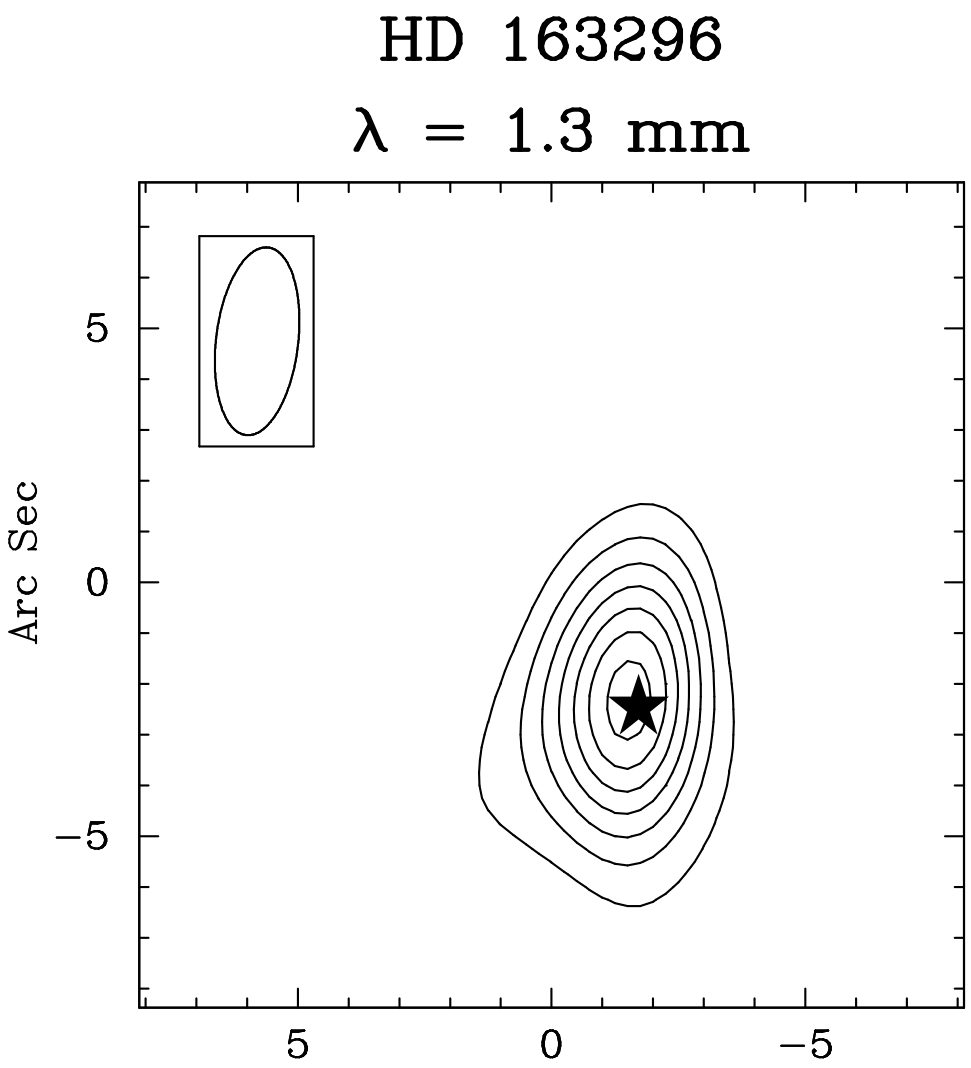


e.g. Wootten 1987, Roberts & Millar 2000, Pagani et al. 2009, Jorgensen et al. 2004, Aikawa et al. 2002

Overview

HD 163296 - a frequent prototype

- Spectral type A1
- Distance 122 pc
- Age 4 Myr
- large, massive disk
- molecule rich

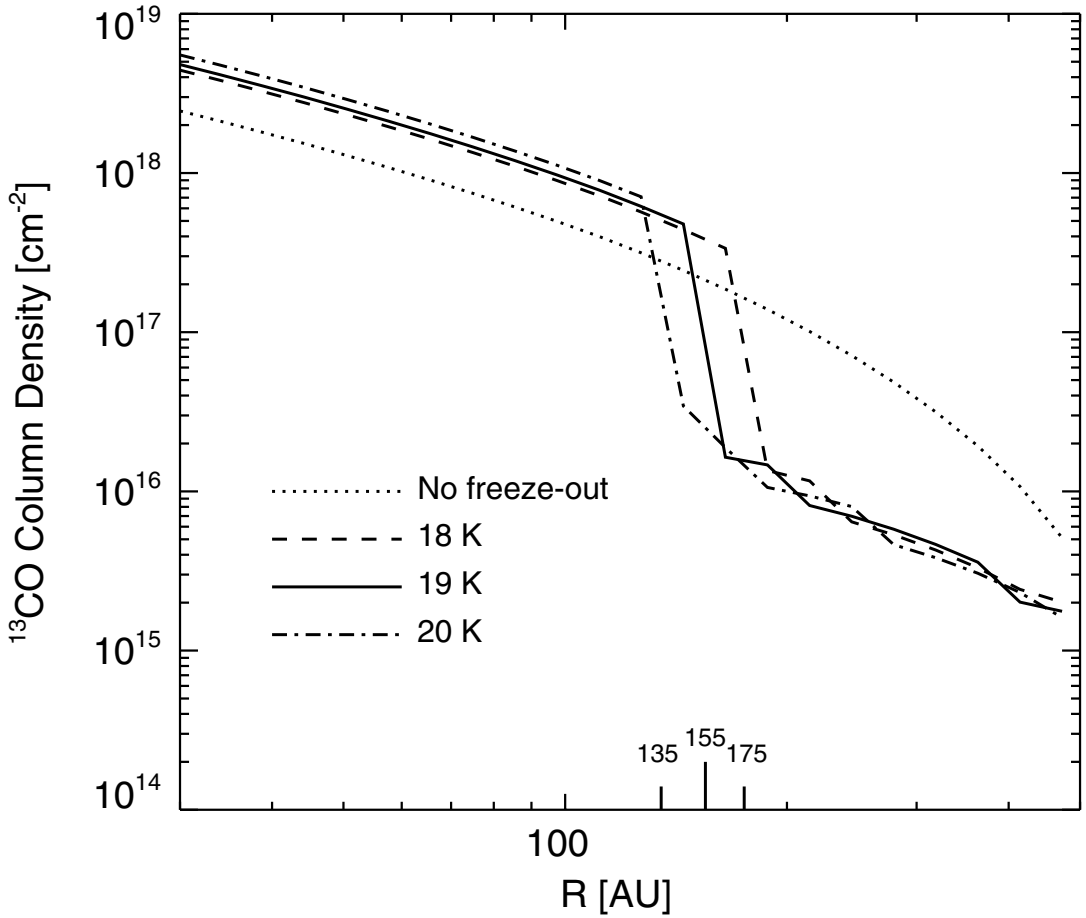


OVRO observations, Mannings & Sargent, 1997

HD 163296 - a frequent prototype

- Spectral type A1
- Distance 122 pc
- Age 4 Myr
- large, massive disk
- molecule rich

CO-snowline hinted at by fits to SMA ^{13}CO



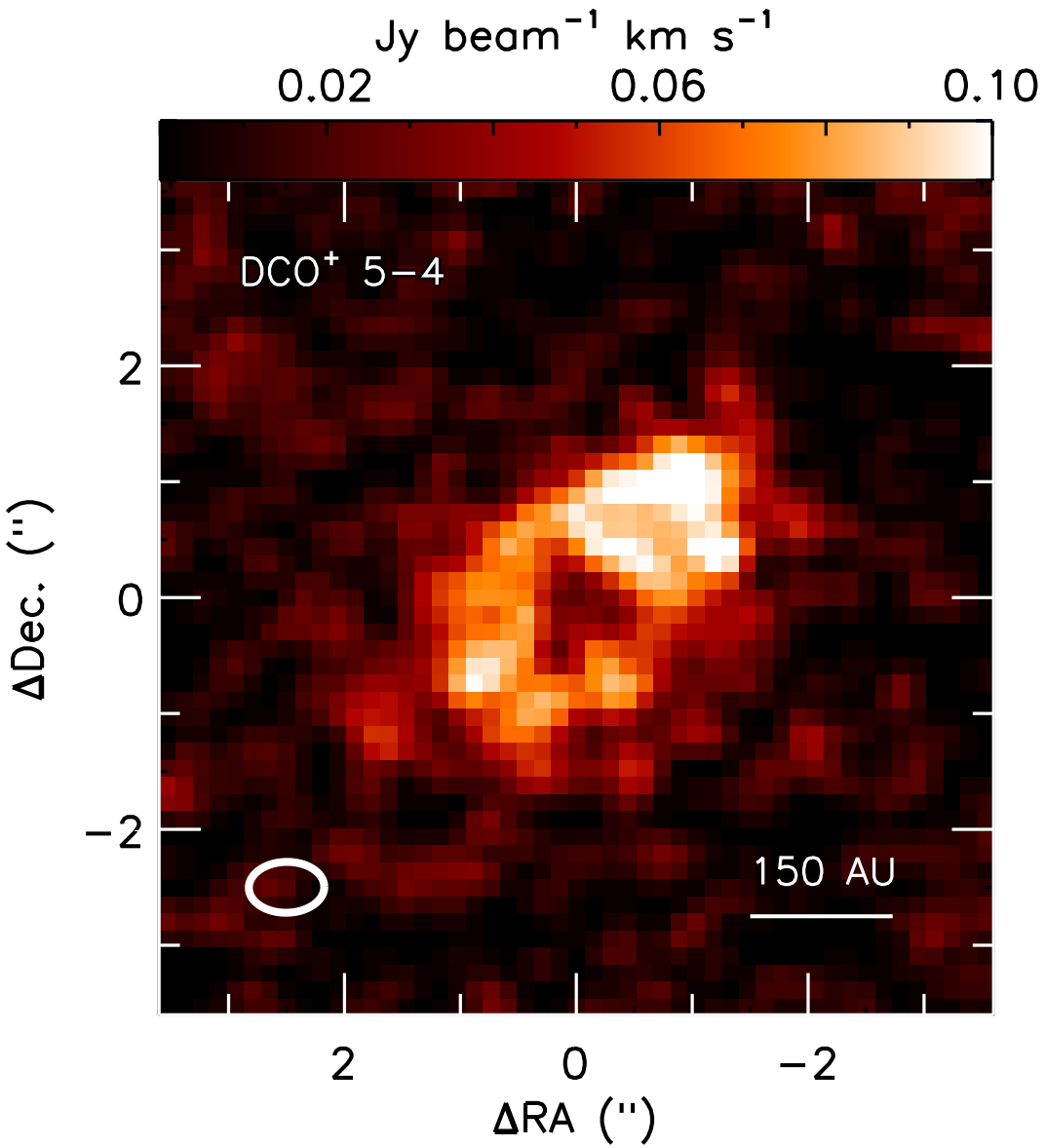
Qi et al. 2011

Science verification observations of HD 163296

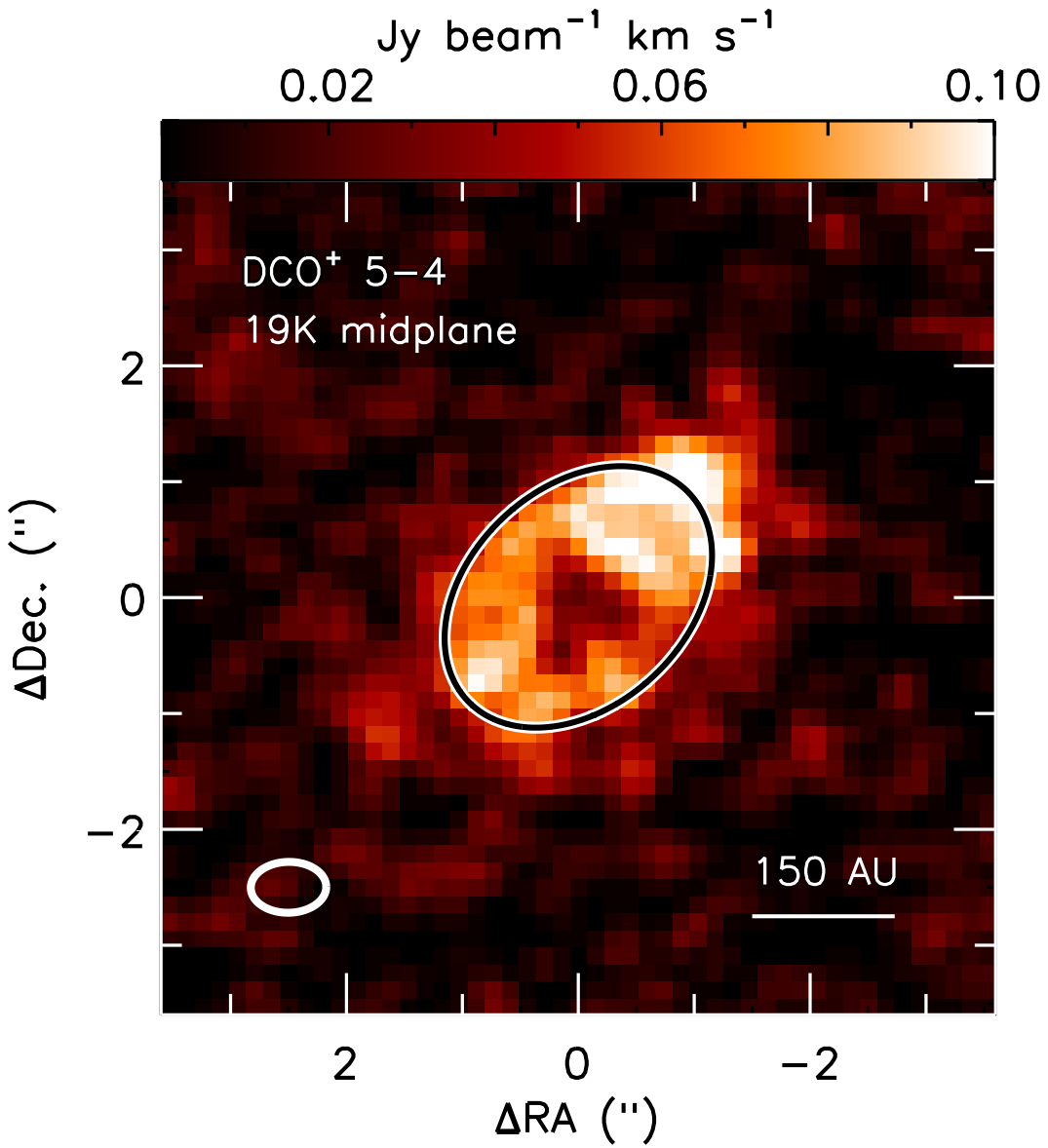
- 5 SB in June and July 2012
- Band 7
  - CO J=3-2 (345.796 GHz)
  - HCO^+ J=4-3 (356.734 GHz)
  - $H^{13}CO^+$ J=4-3 (346.998 GHz)
  - DCO^+ J=5-4 (360.170 GHz)
- $0\farcs45 \times 0\farcs65$ beam
- 1 hour total time on-source

ALMA Photo: Tim van Kempen

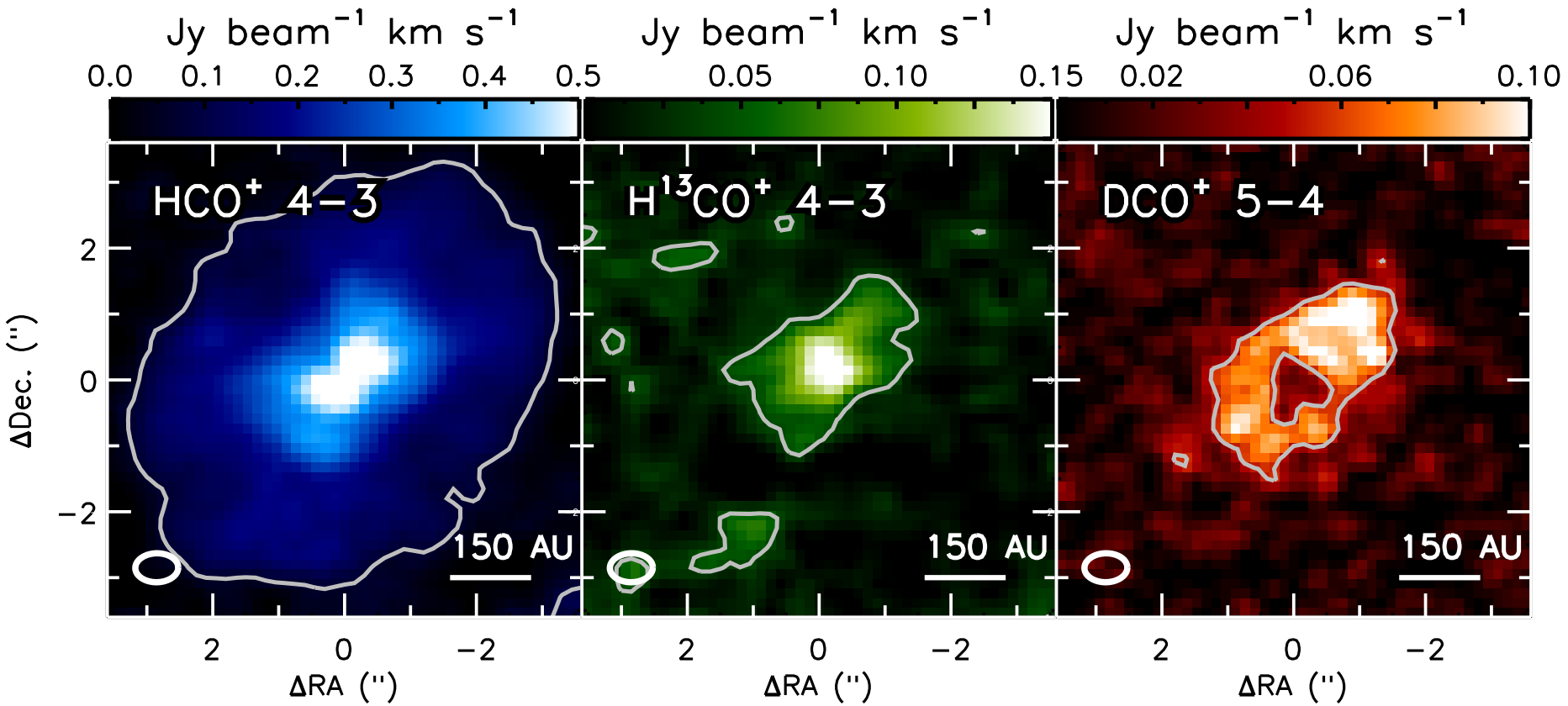
The One Ring: DCO^+ J=5-4 with ALMA



The One Ring: DCO^+ J=5-4 with ALMA

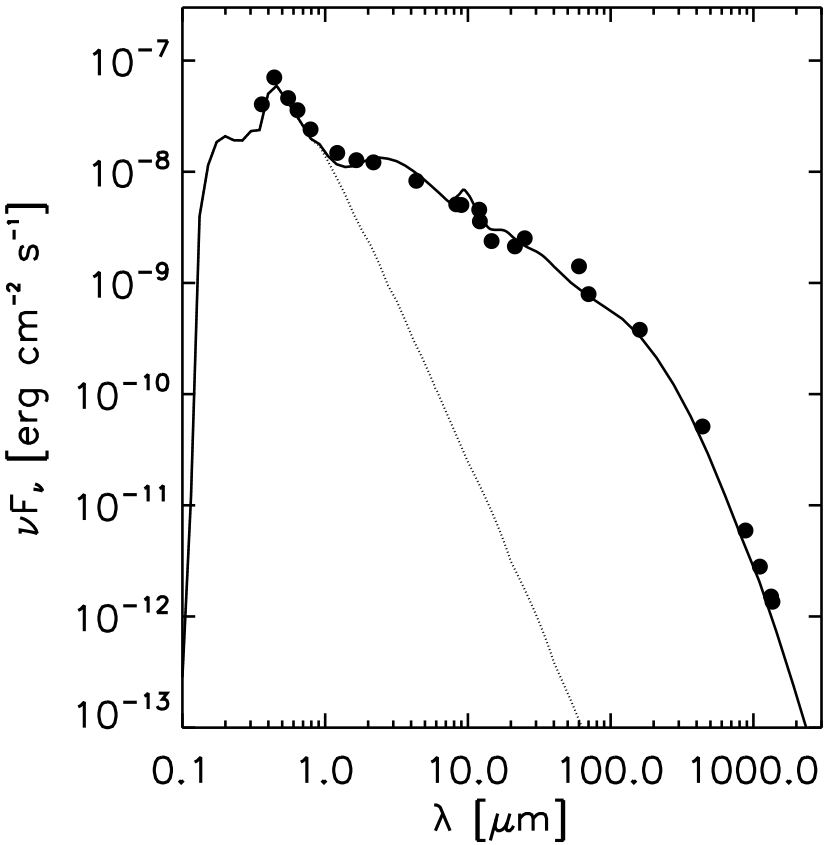


HCO^+ isotopologues for comparison



Overview

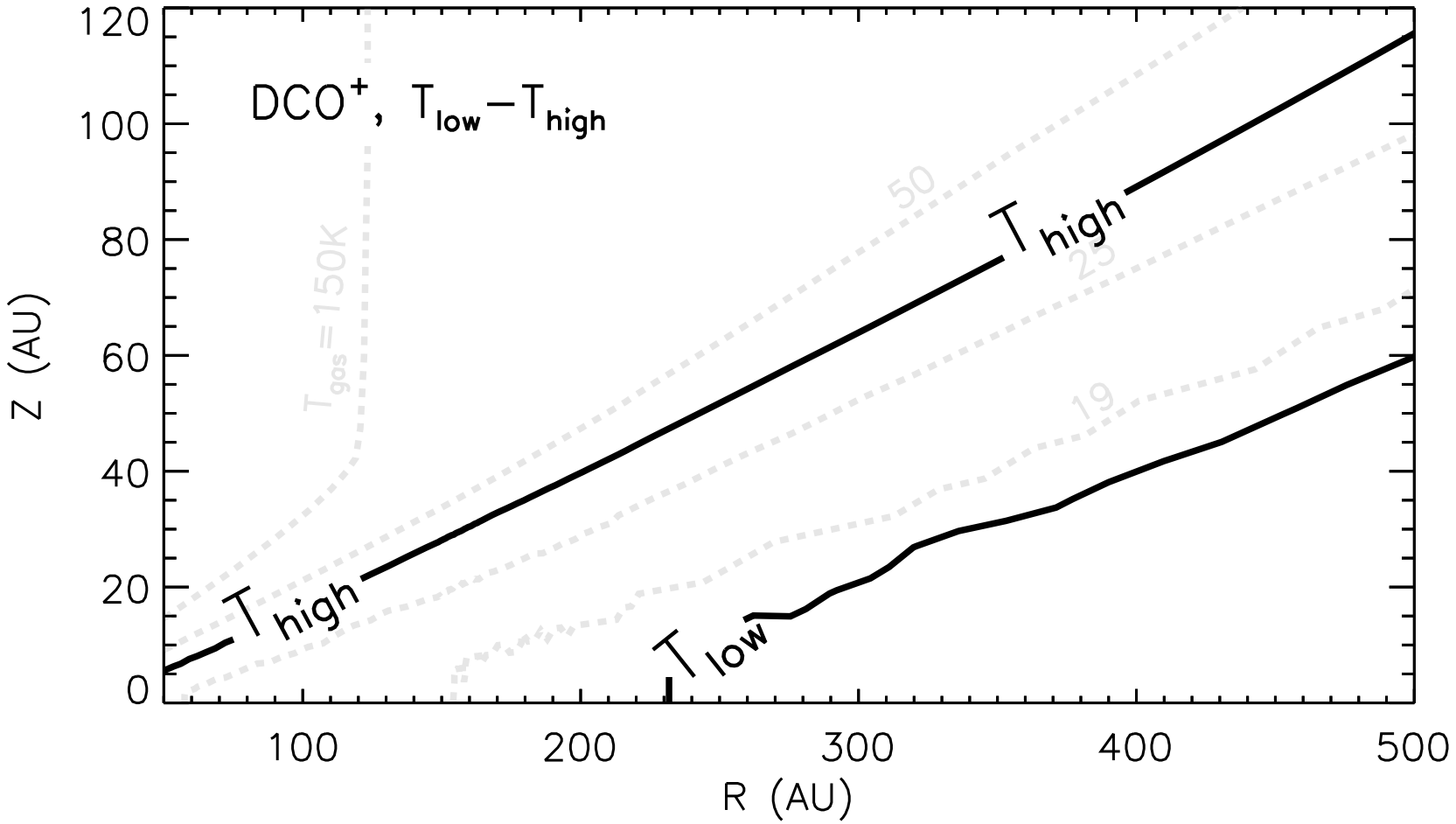
Physical model - parameterized approximation of Qi et al. 2011 best-fit model



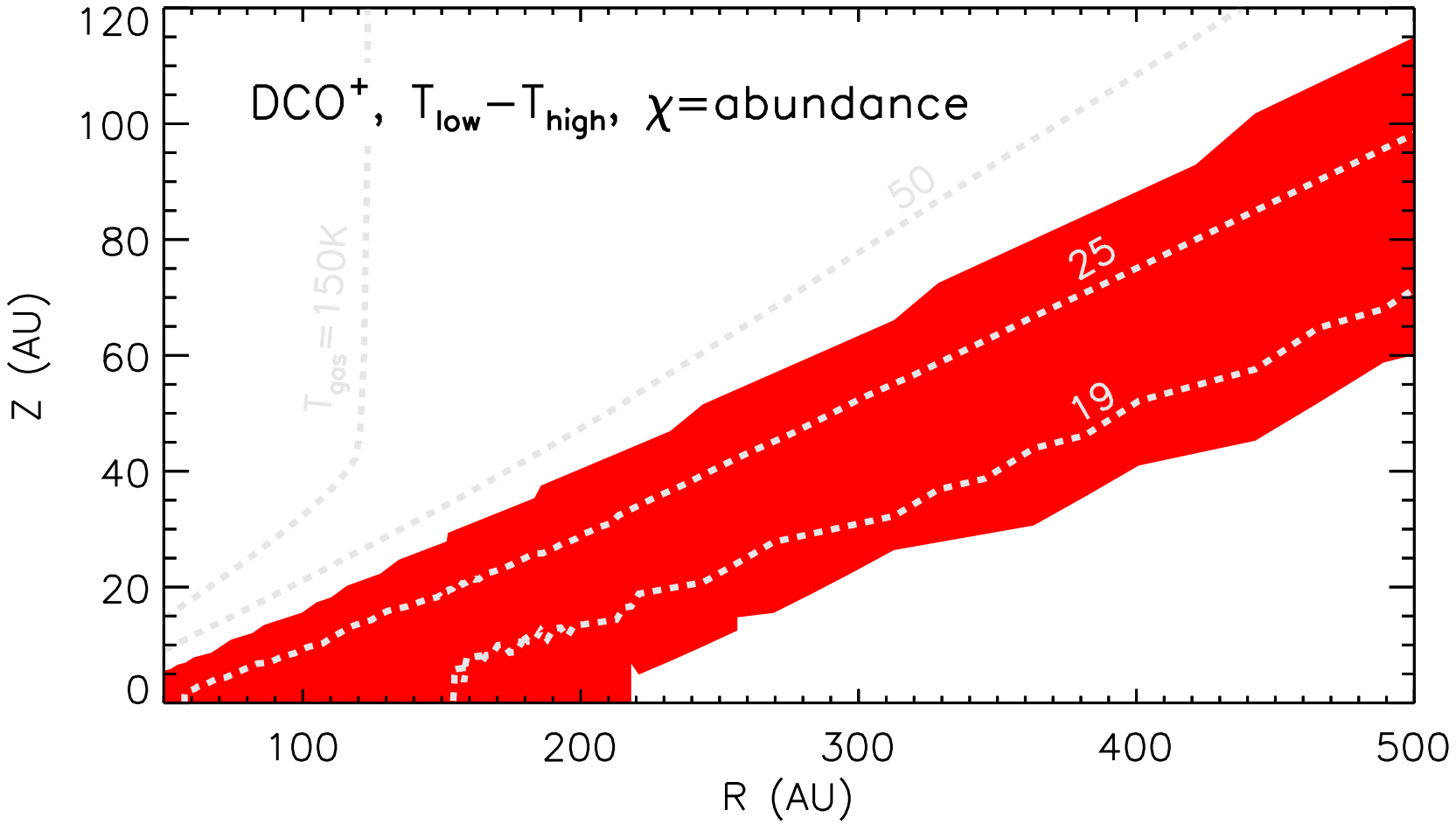
Transition	Model (Jy km/s)	Observed (Jy km/s)
CO 2-1	51	54.17±0.39[a]
^{13}CO 2-1	21	18.76±0.24[a]
C^{18}O 2-1	9	6.30±0.16[a]
CO 3-2	74	98.72±1.69[a]
C^{17}O 3-2	7	11.64±0.76[a]

[a] Observed fluxes from Qi et al. 2011

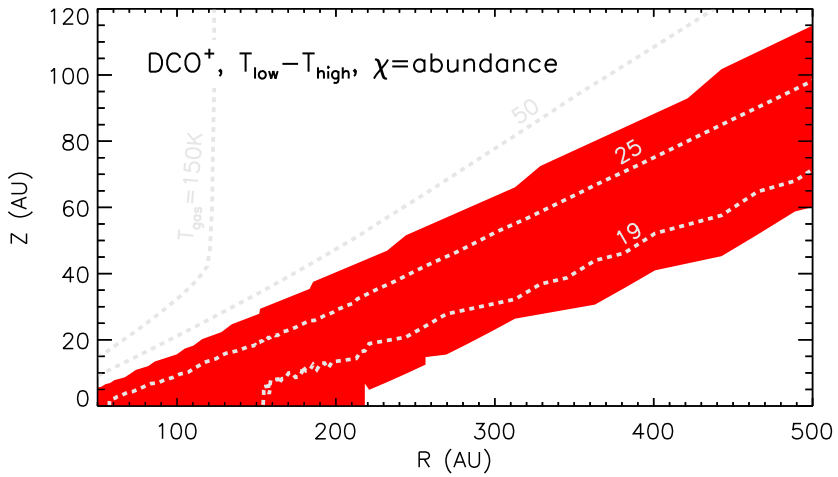
DCO^+ parameters - $T_{\rm high}$, $T_{\rm low}$, & abundance (χ)

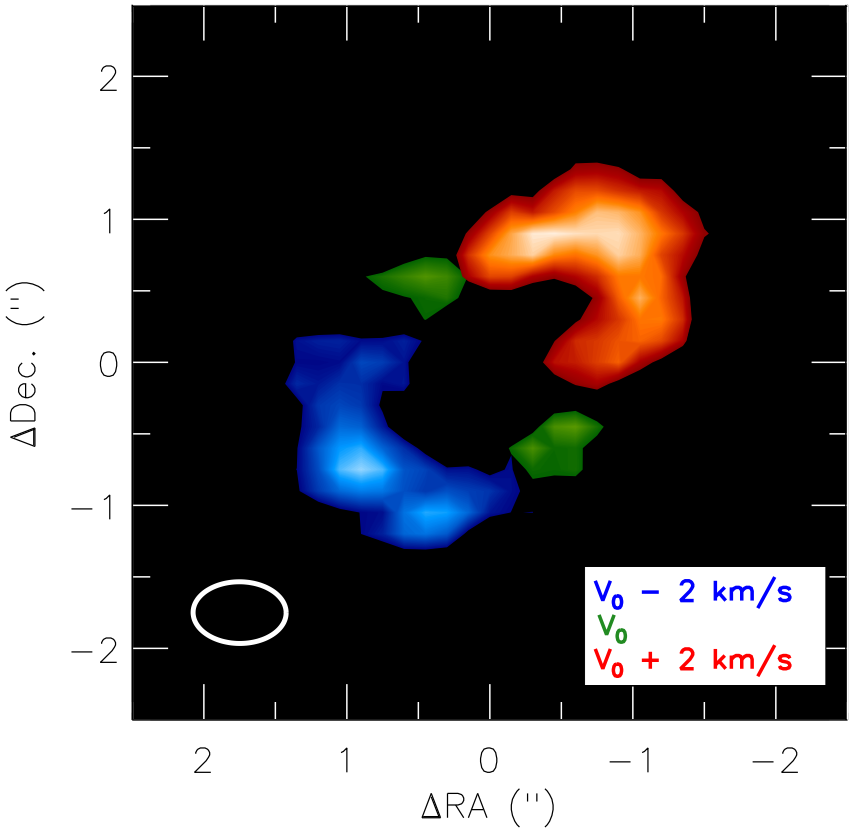


DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

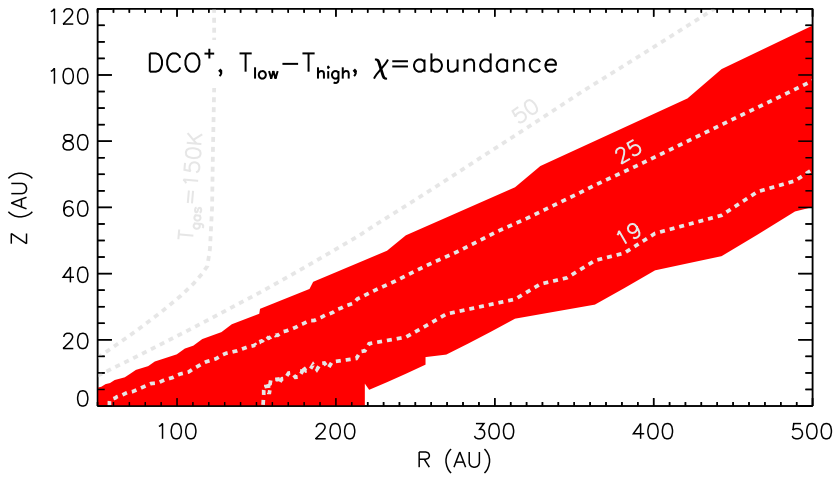


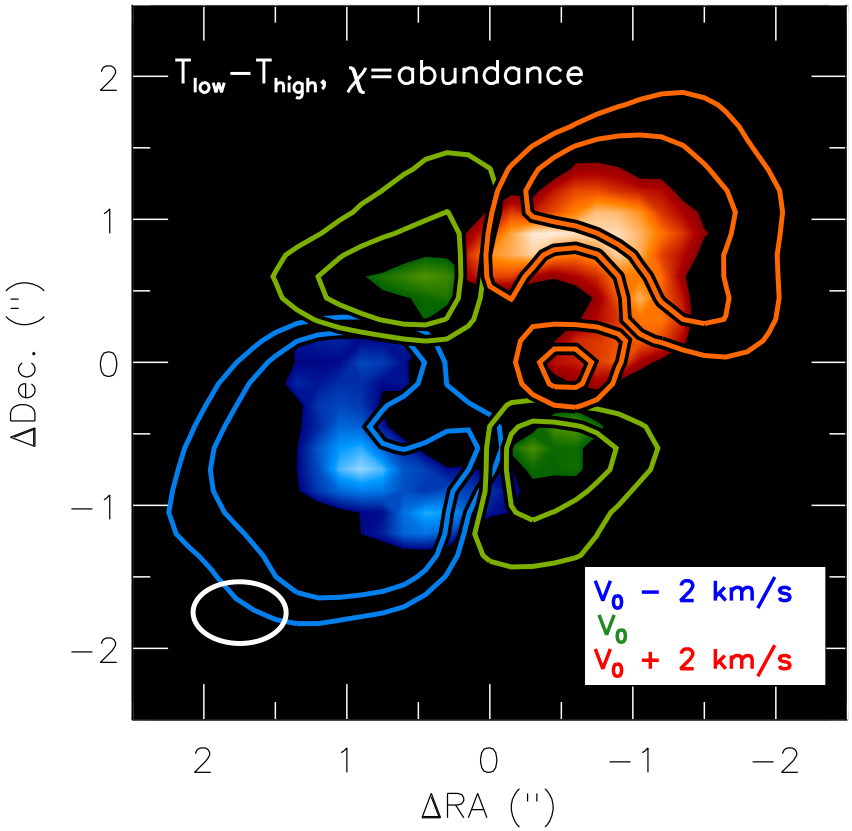
DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)





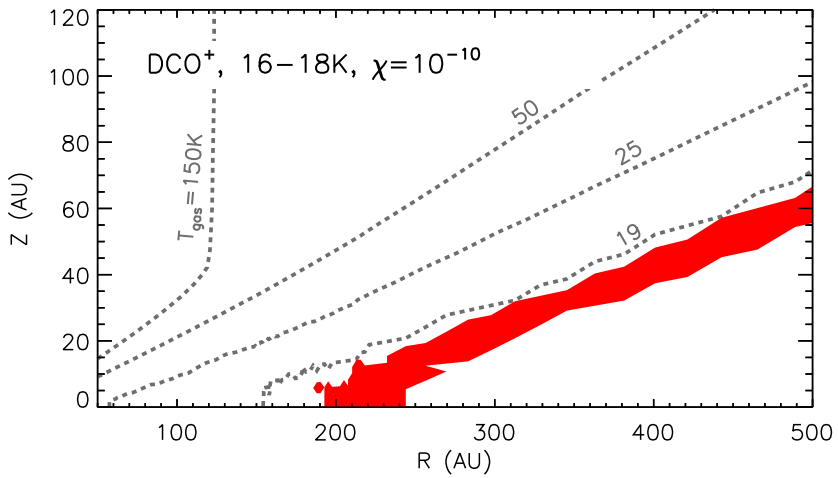
DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

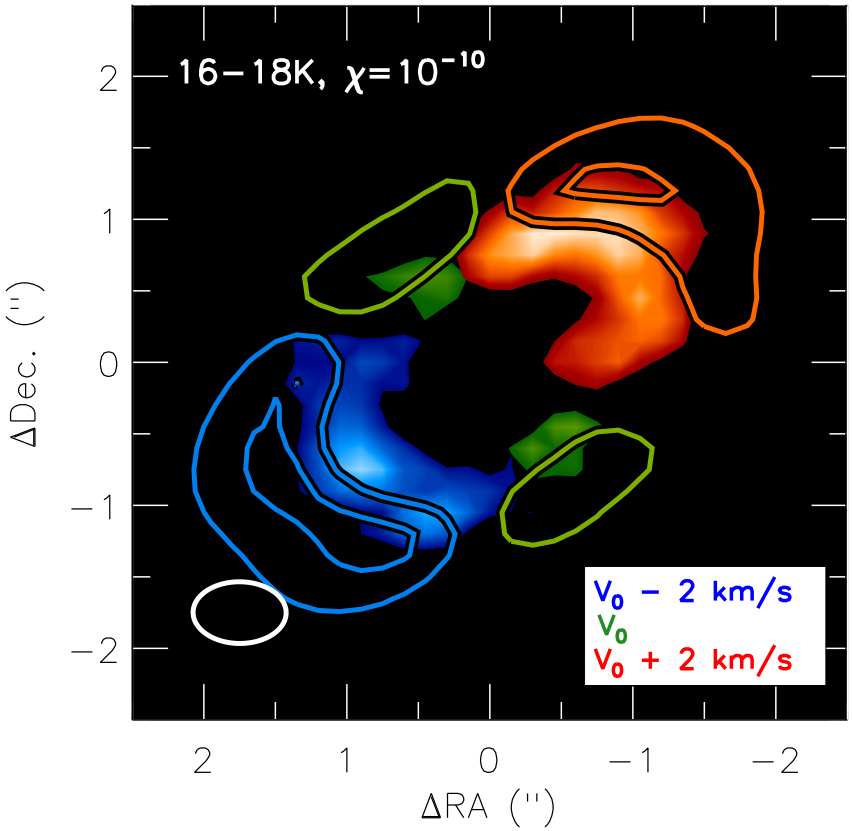




DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

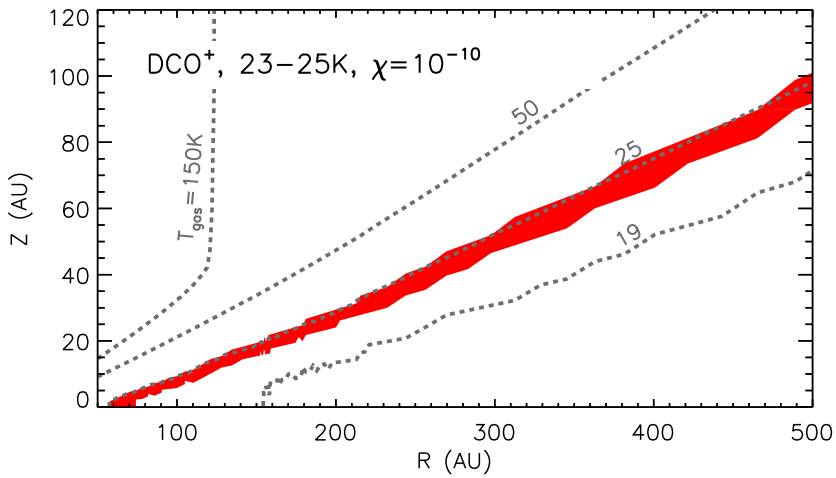
Too cool: -3 K

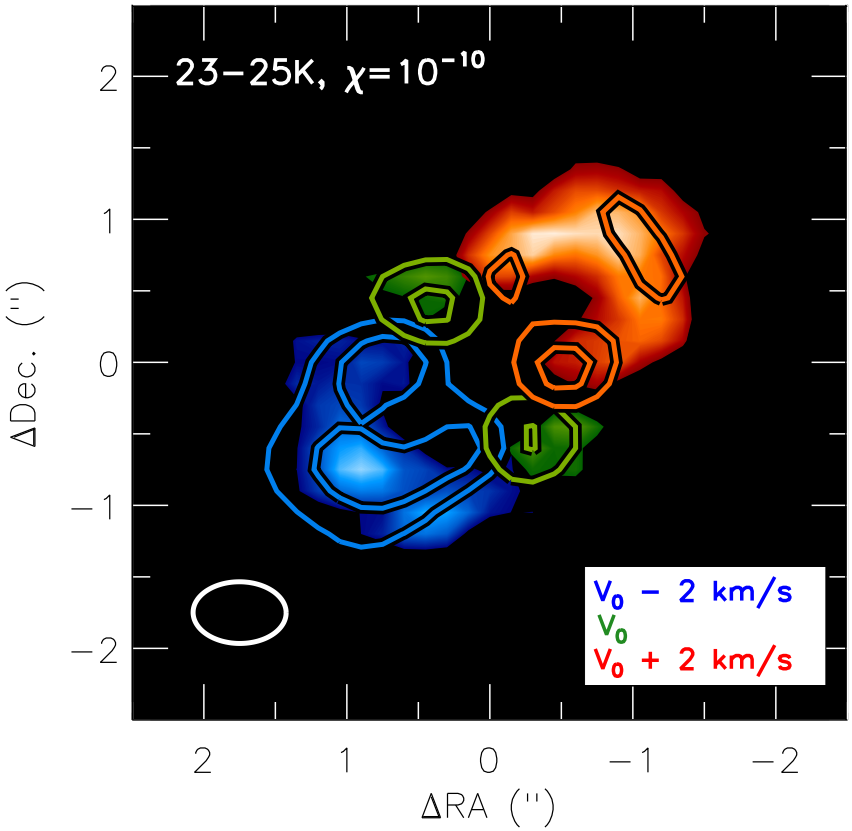




DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

Too warm: + 4 K

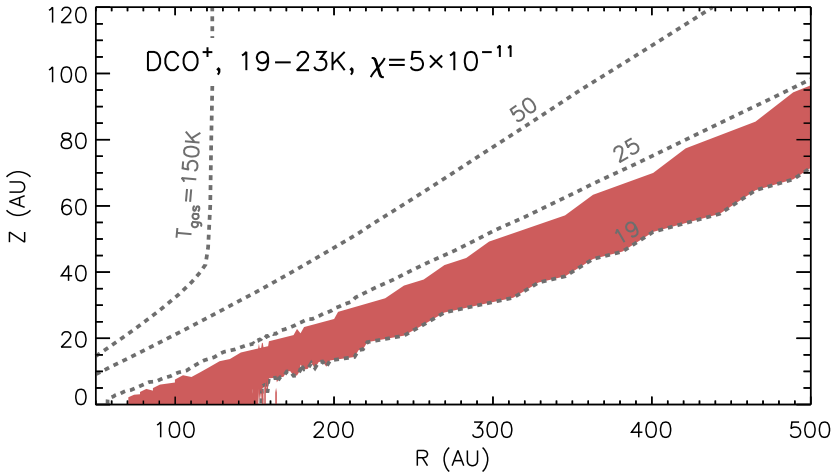


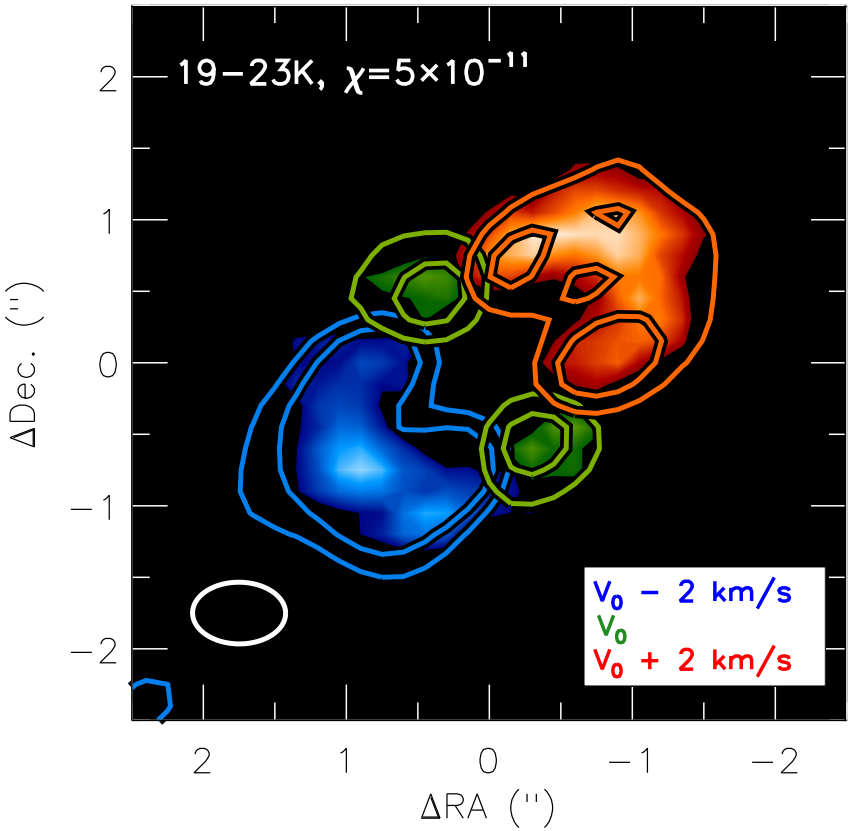


DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

Temperature range too broad:

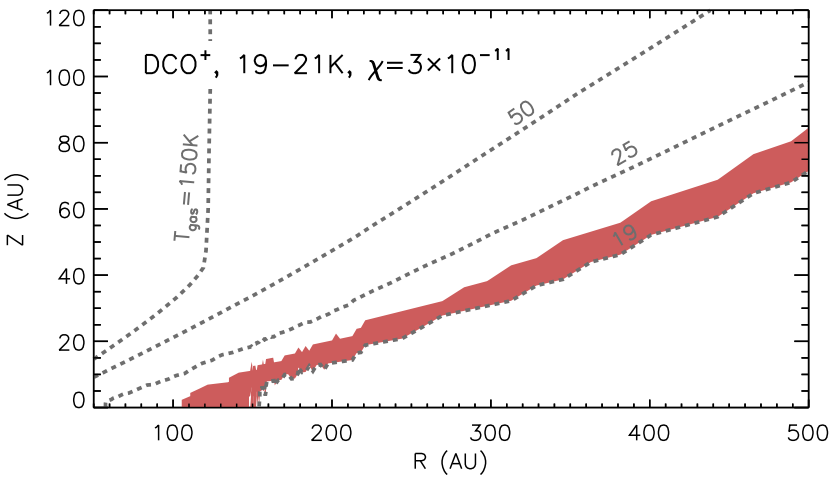
$\Delta T \times 2$

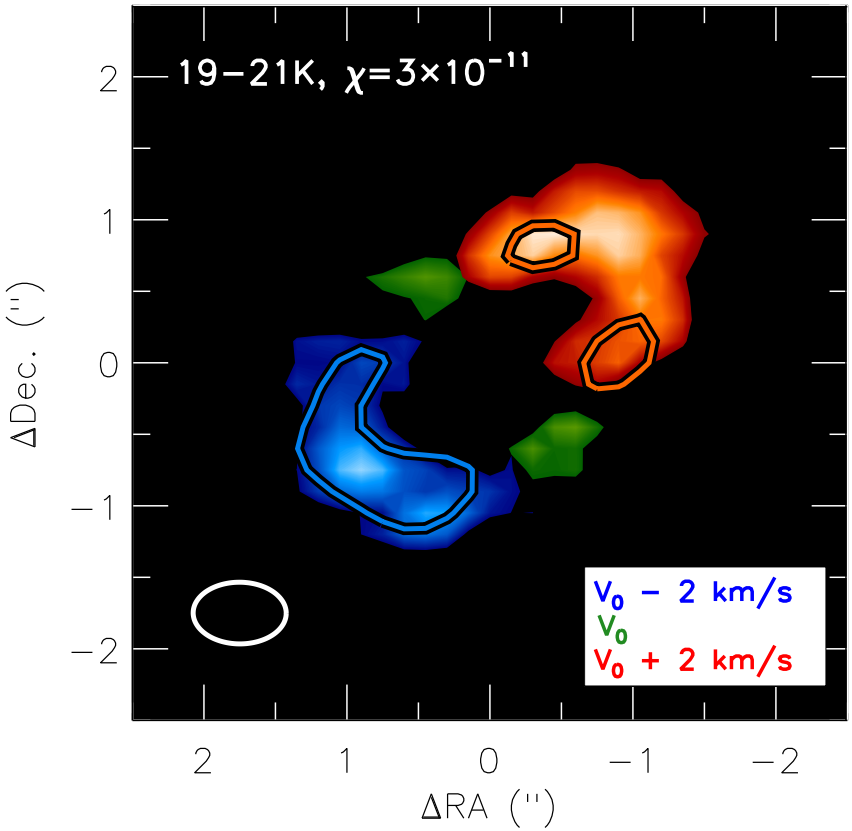




DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

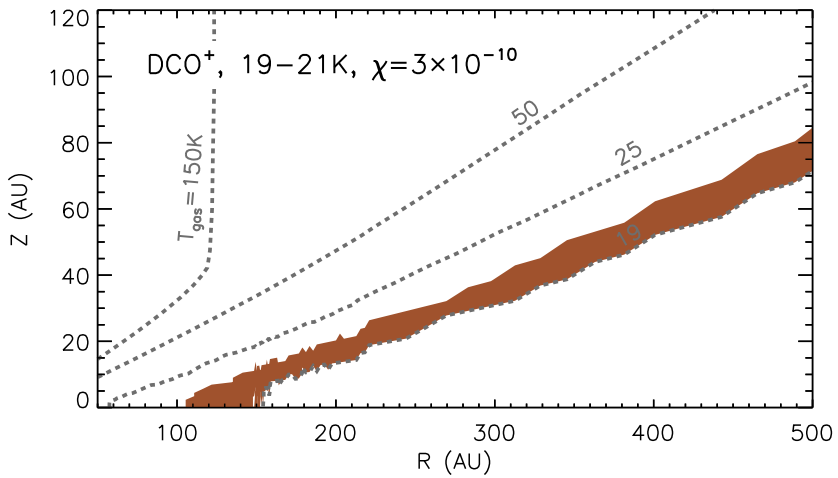
Low abundance: $\frac{1}{3}$

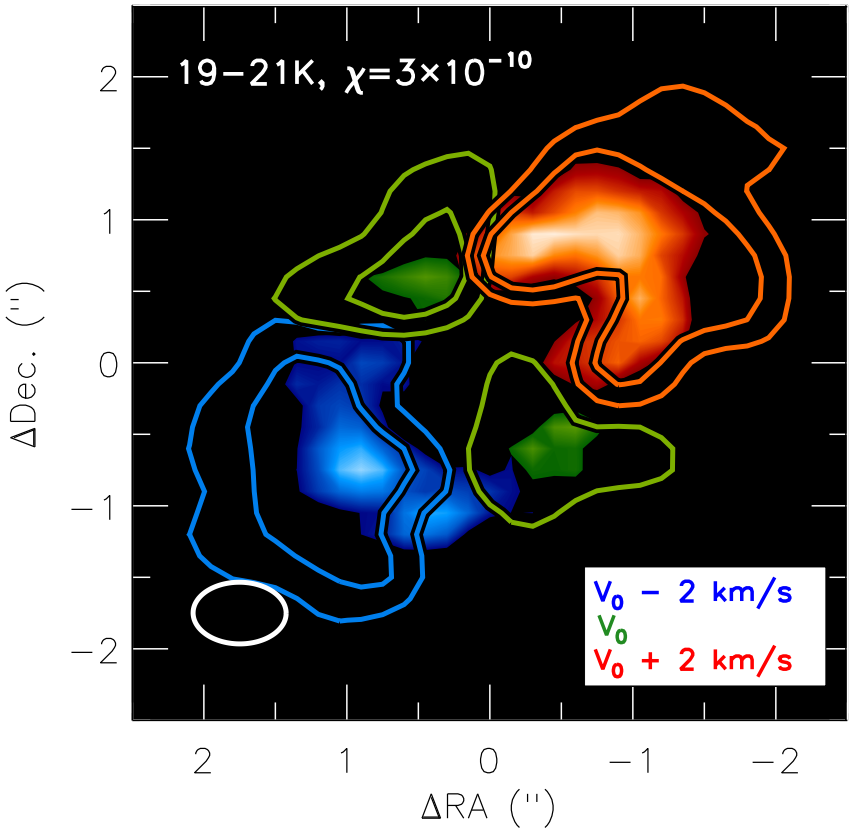




DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

High abundance: $\times 3$

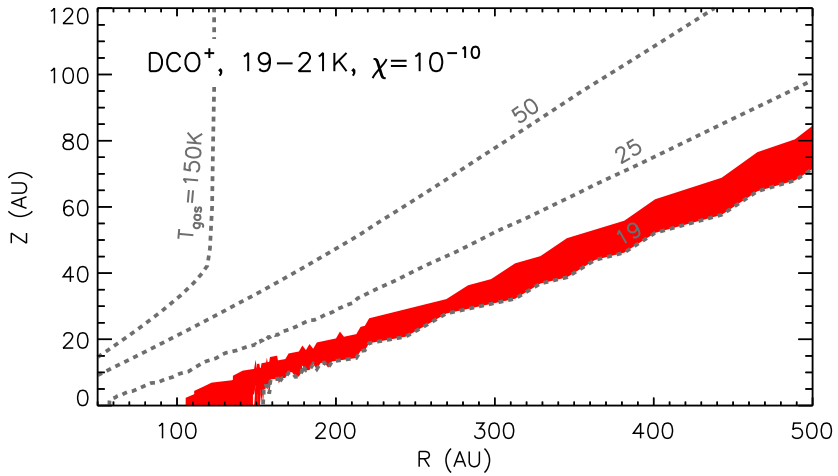


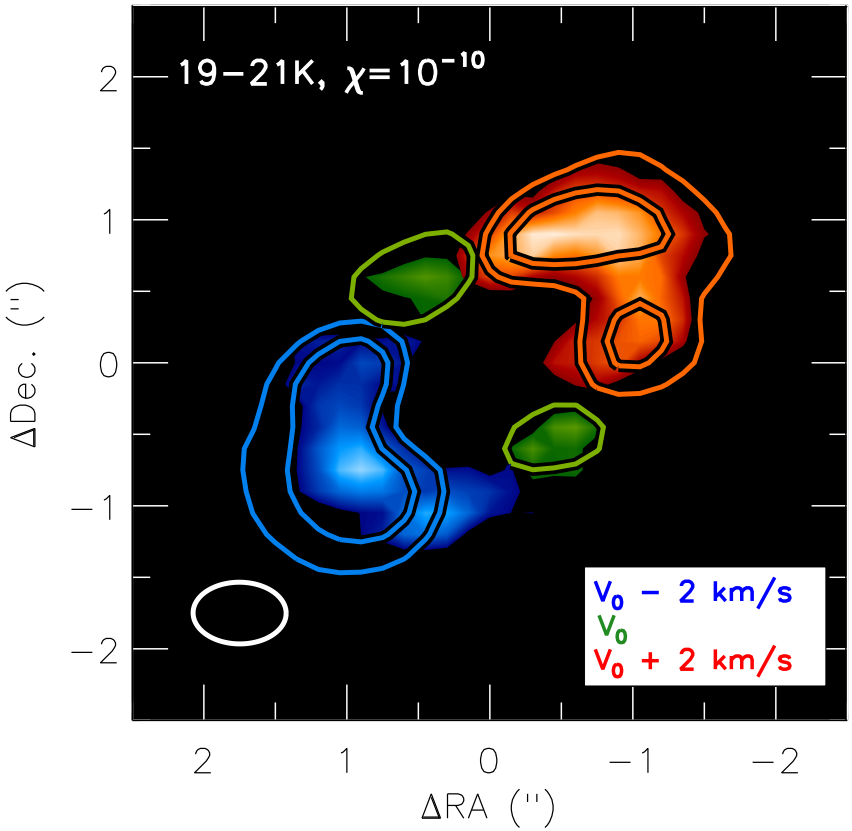


DCO^+ parameters - T_{high}, T_{low}, & abundance (χ)

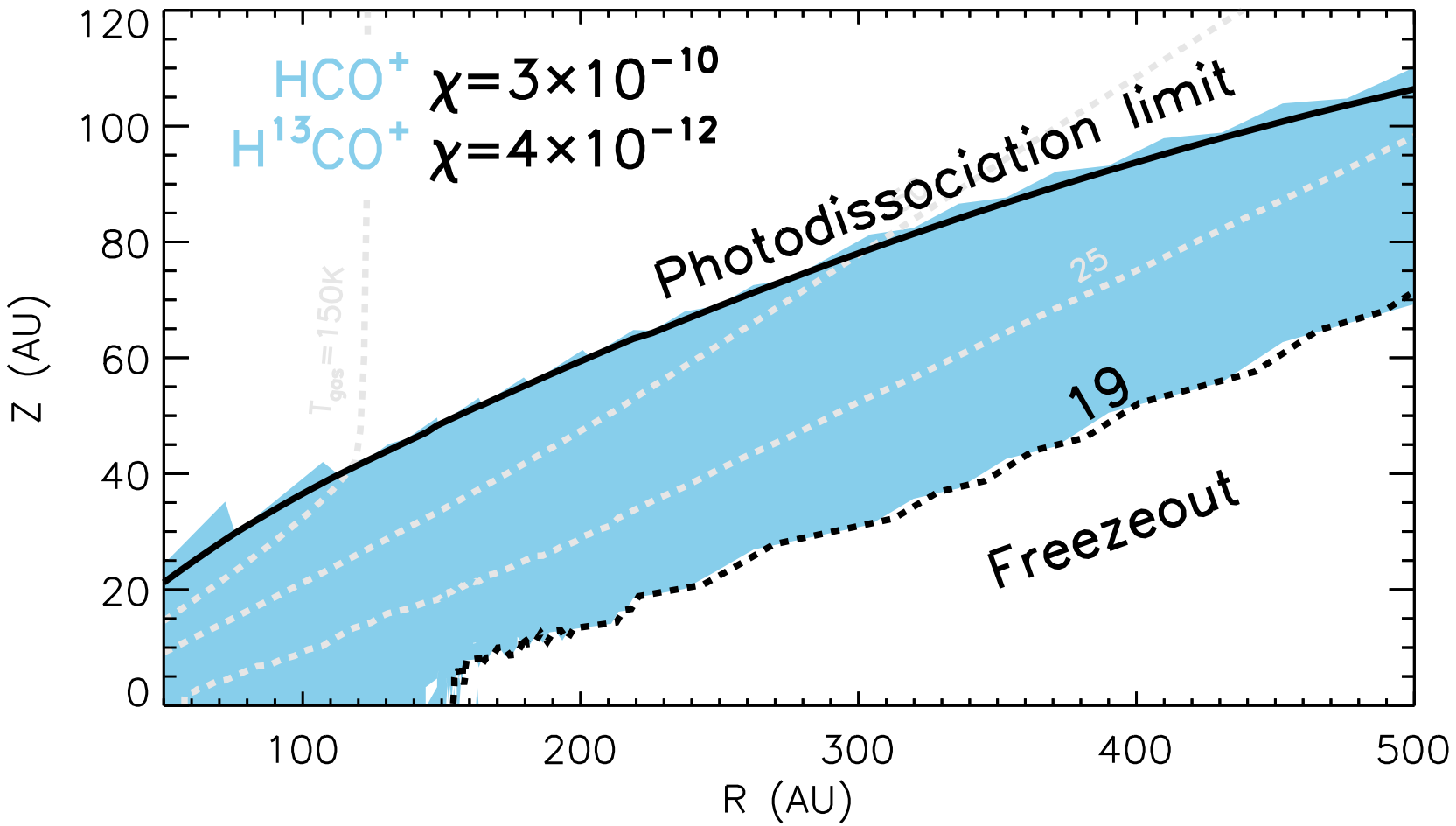
Temperature: 19 - 21 K

Abundance: 10^{-10}



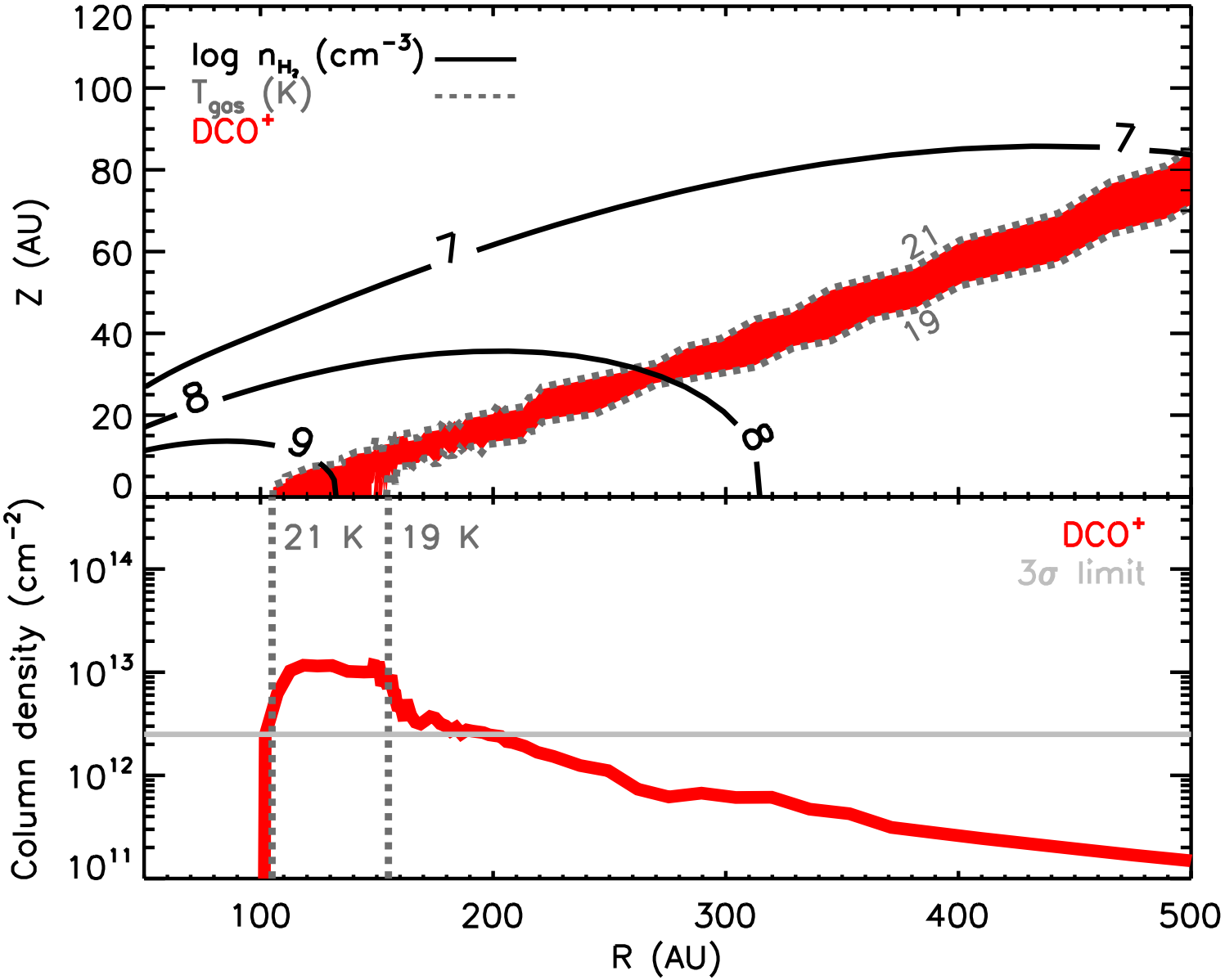


HCO^+ & $H^{13}CO^+$

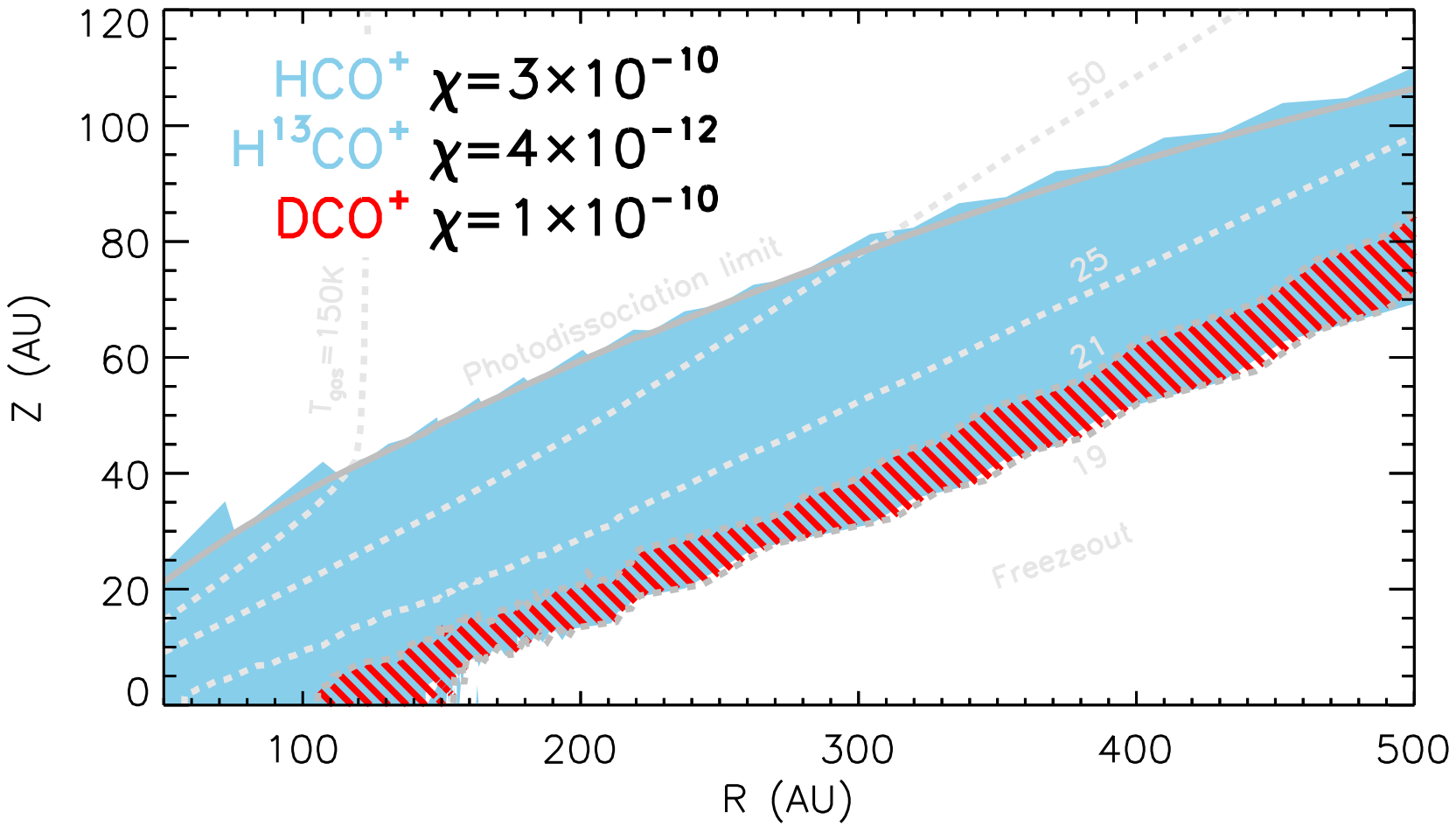

HCO+ χ=3×10−10
H13CO+ χ=4×10−12
Photodissociation limit
25
19
Freezeout
Tgas=150K
Z (AU)
R (AU)
0
20
40
60
80
100
120
100
200
300
400
500

Overview

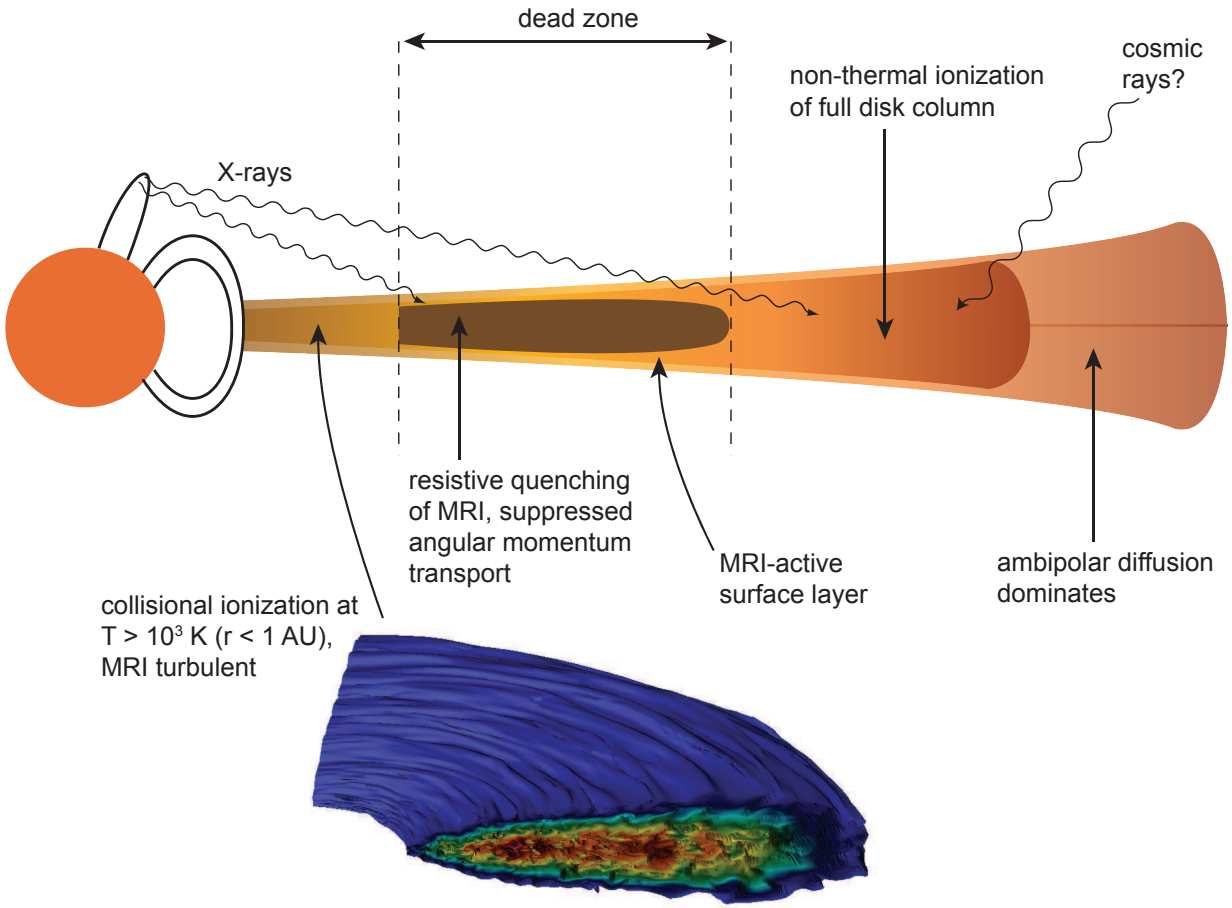
Ring morphology explained, and a localized probe



Local $[DCO^+] / [HCO^+] \sim 0.3 \sim 10^4 \times [D/H]_{ISM}$



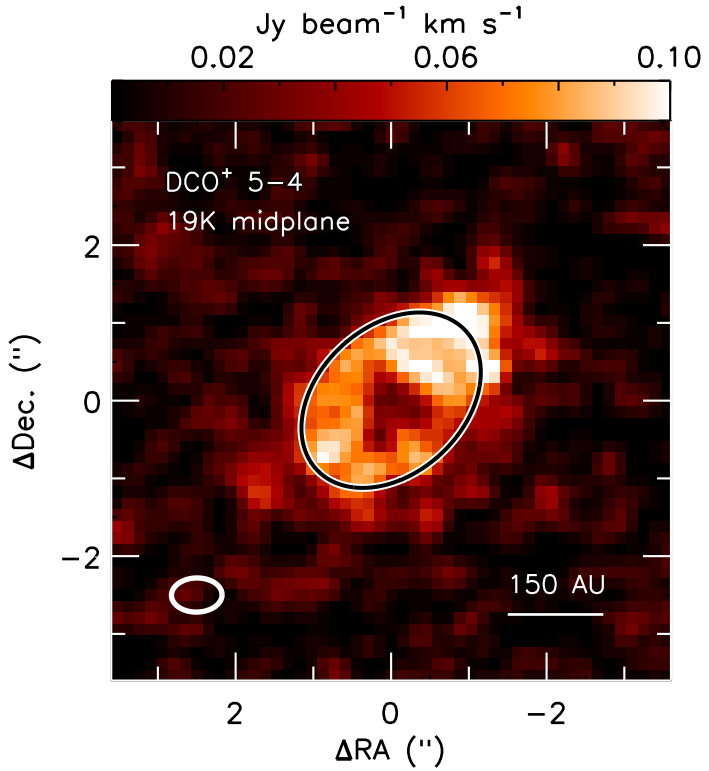
Ionization fraction $\gtrsim 10^{-10} \gg 10^{-13} \rightarrow$ no 'dead zones' just inside CO snowline

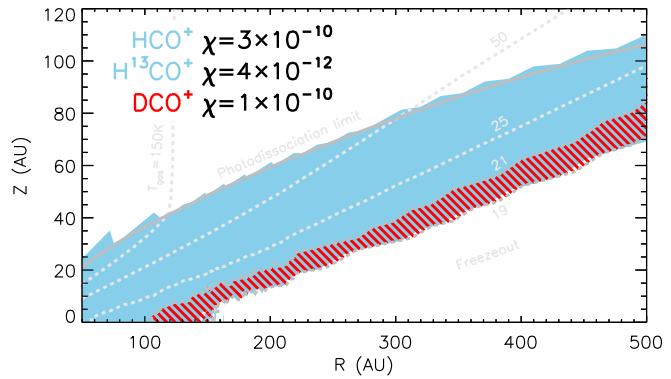


Gammie 1996, Armitage 2011

Summary

- High resolution and sensitivity ALMA images reveal a ring of DCO^+ J=5-4 emission
- DCO^+ emission from a narrow temperature range, 19–21 K
- Local [DCO^+] / [HCO^+] $\sim$ 0.3, $\approx 10^4$ times the ISM [D] / [H]
- DCO^+ probes a highly specific disk layer - one component of "disk tomography"





Model comparison