Investigating inner discs around Herbig Ae/Be stars

John Ilee

University of St Andrews

In collaboration with:
Peter Woitke (U. of St Andrews)
Rene Oudmaijer, John Fairlamb (U. of Leeds)
Stefan Kraus (U. of Exeter)
Hugh Wheelwright (MPIfR, Bonn)

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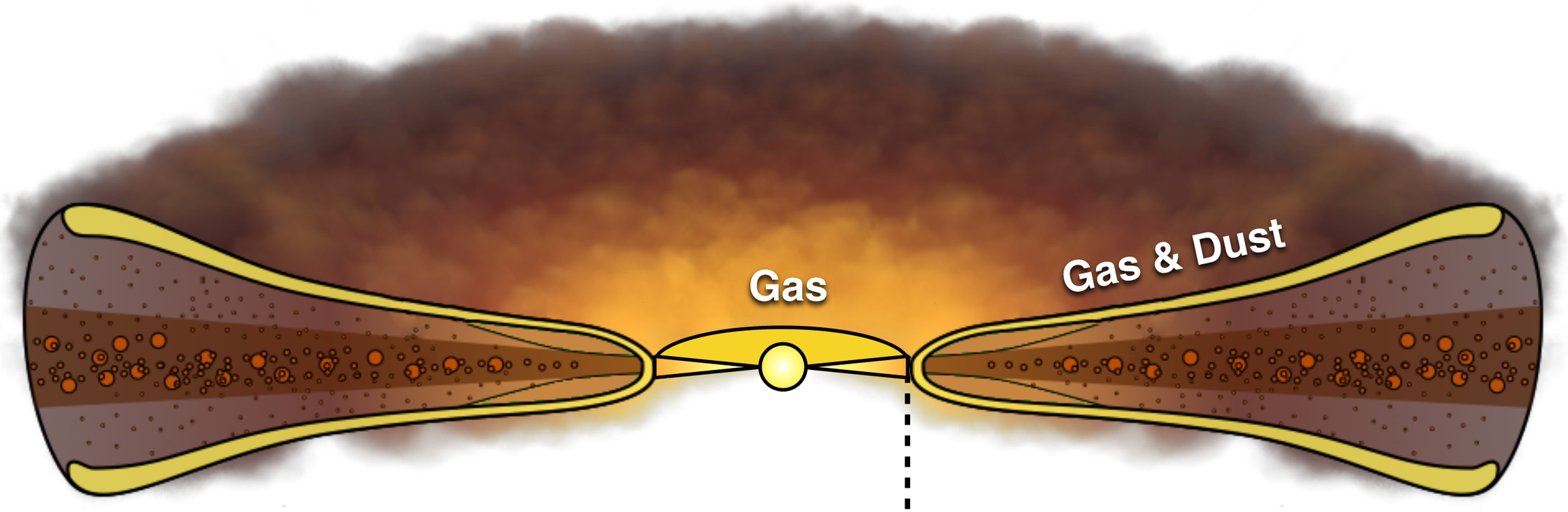
Why the inner disc?



$$R_{\rm sub} \sim \text{a few AU}$$
$$T_{\rm sub} \sim 1500\,{\rm K}$$

- Important for accretion
- But, difficult to observe
- Need ***indirect*** probes…

Adapted from Testi et al. (2014)

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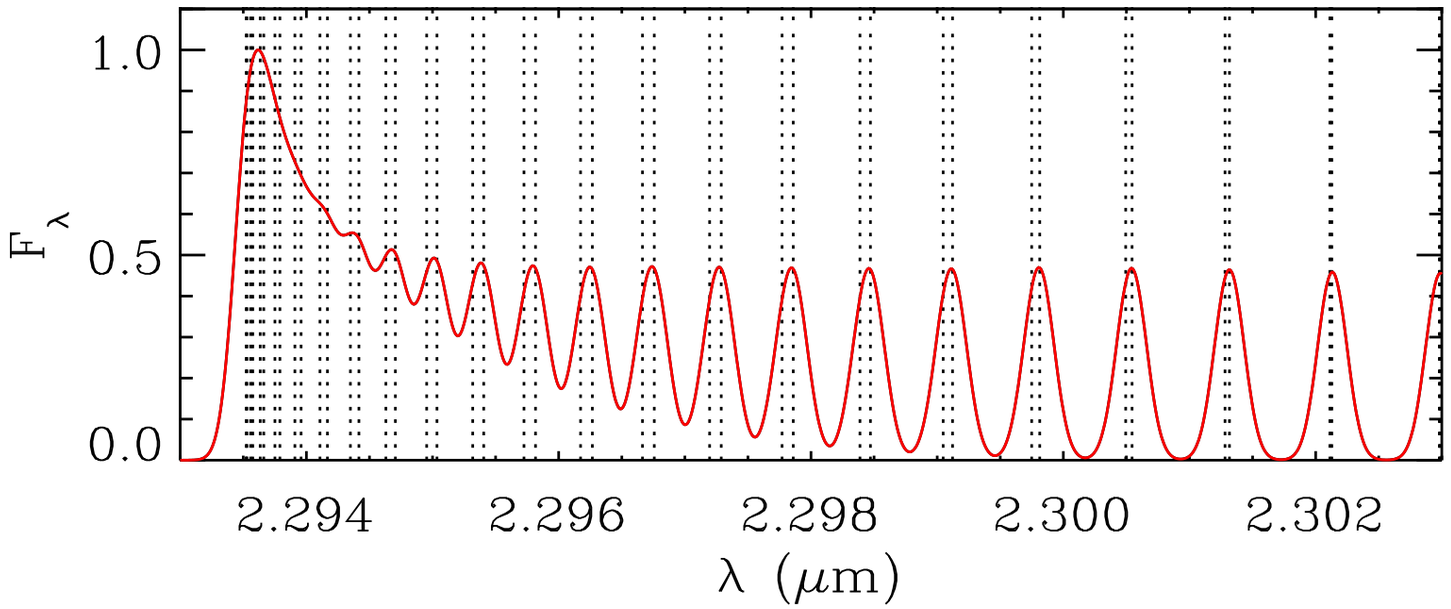
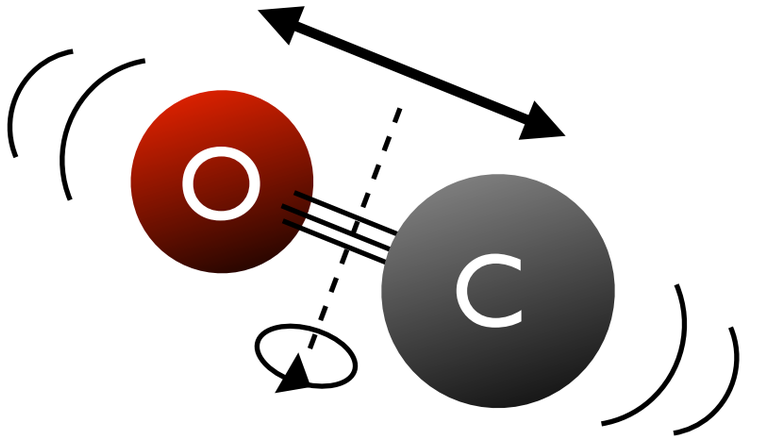
CO first overtone bandhead emission





- Excited in warm, dense gas

$$T = 1000 - 5000\,\mathrm{K}$$
$$n > 10^{15}\,\mathrm{cm}^{-2}$$

- The shape of the bandhead contains information about the origin of the emission (temperatures, densities, orientations)

(Carr 1989, Bik & Thi 2004, Berthoud 2007, Wheelwright et al. 2010, Ilee et al. 2013)

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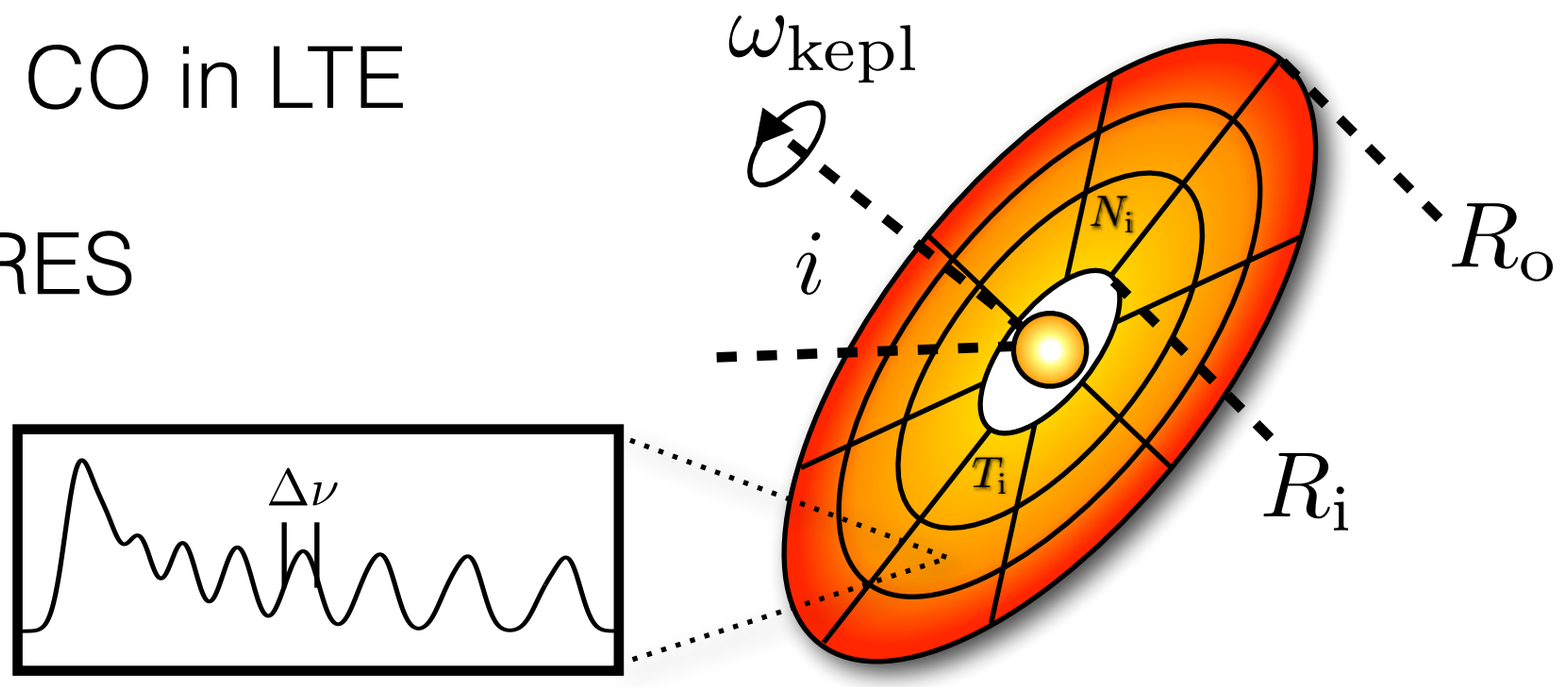
Analysing the overtones - a simple model

- Geometrically thin disc
- Temperature and density are described analytically
- Each element emits CO in LTE
- Applied to VLT/CRIRES spectra…

$$T(r) = T_{\rm i}\left(\frac{r}{R_{\rm i}}\right)^{p}$$

$$N(r) = N_{\rm i}\left(\frac{r}{R_{\rm i}}\right)^{q}$$



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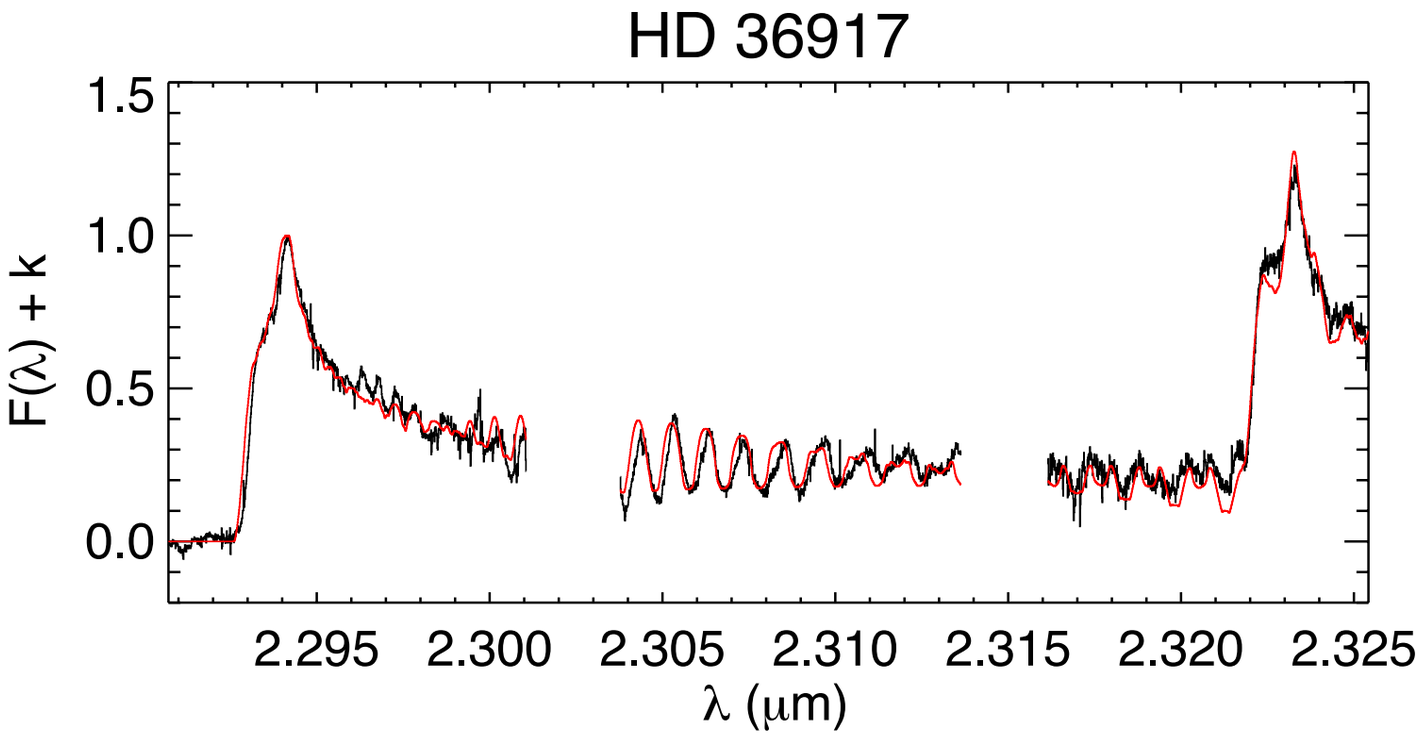
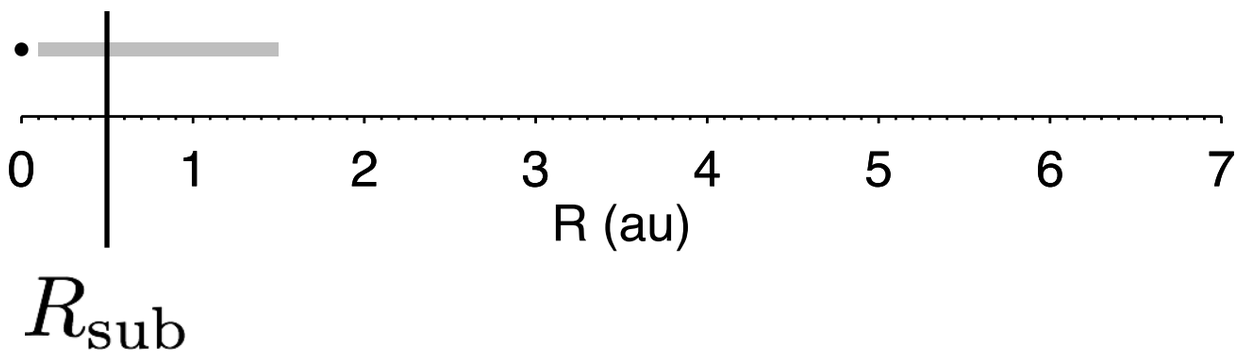
Analysing the overtones - a simple model





$R_{\rm sub}$

Herbig Be

$M_\star = 2.5\,{\rm M}_\odot$

Best fit:

$R_{\rm CO} = 0.1 - 1.5\,{\rm AU}$

$i = 51°$

$T_{\rm in} = 3400\,{\rm K}$

$N_{\rm in} = 6 \times 10^{20}\,{\rm cm}^{-2}$

(VLT/CRIRES 086.C-0684C - PI Kraus, Ilee et al. 2014a, in prep.)

Are the simple models appropriate?

- The thin disc models fit the data well.
- But, what about:
  - The disc vertical structure?
  - The effect of radiative transfer?
  - The chemistry occurring in these regions?

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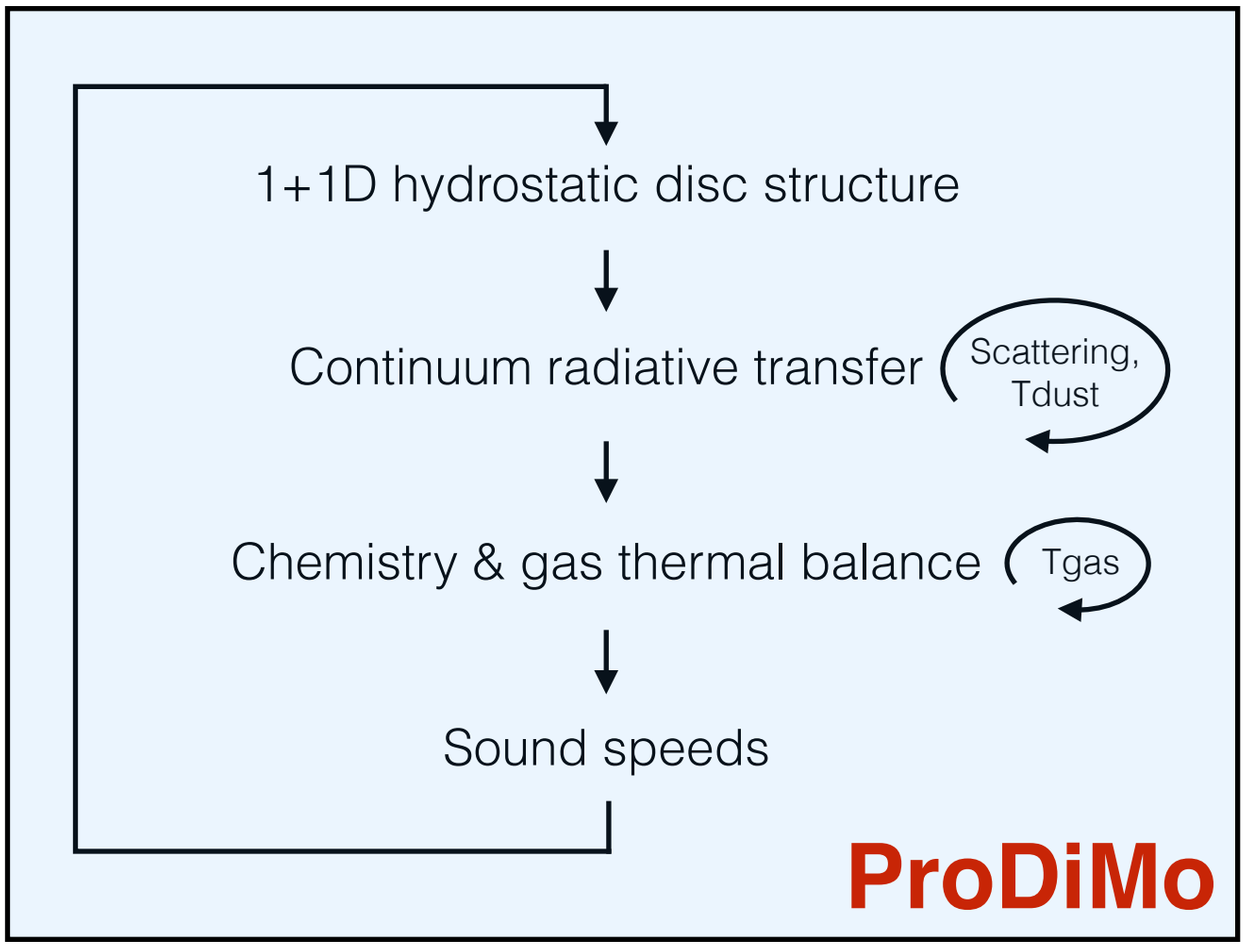
The next step - ProDiMo

- Protoplanetary Disc Model (Woitke, Kamp & Thi 2009)
- Self consistent modelling of **physics**, **chemistry** and **radiation transport** in circumstellar discs
- Can apply this to the inner disc…



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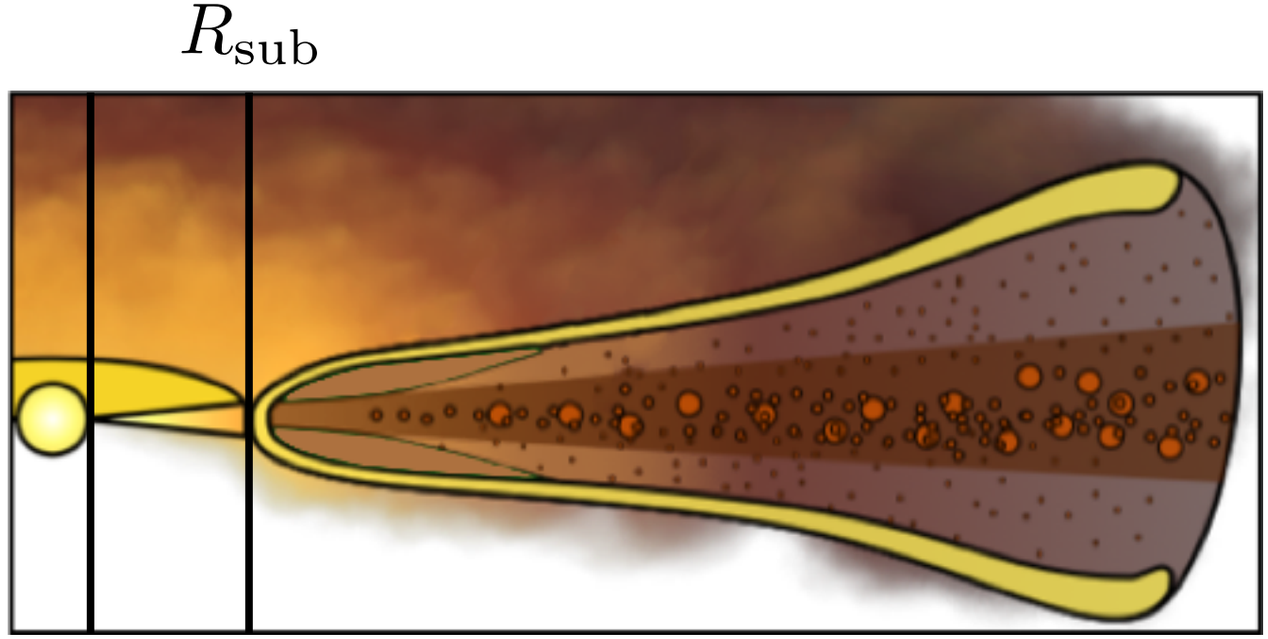
The ‘Herbig Ae’ inner disc model

- Hydrostatic disc model with two radial zones

- A ‘typical’ Herbig Ae object:

$$M_\star = 2.2\,\mathrm{M}_\odot$$
$$L_\star = 32\,\mathrm{L}_\odot$$
$$T_\mathrm{eff} = 8600\,\mathrm{K}$$
$$M_\mathrm{disc} = 0.02\,\mathrm{M}_\odot$$



Dust-to-gas ratio → 0

Adapted from Testi et al. (2014)

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Structure

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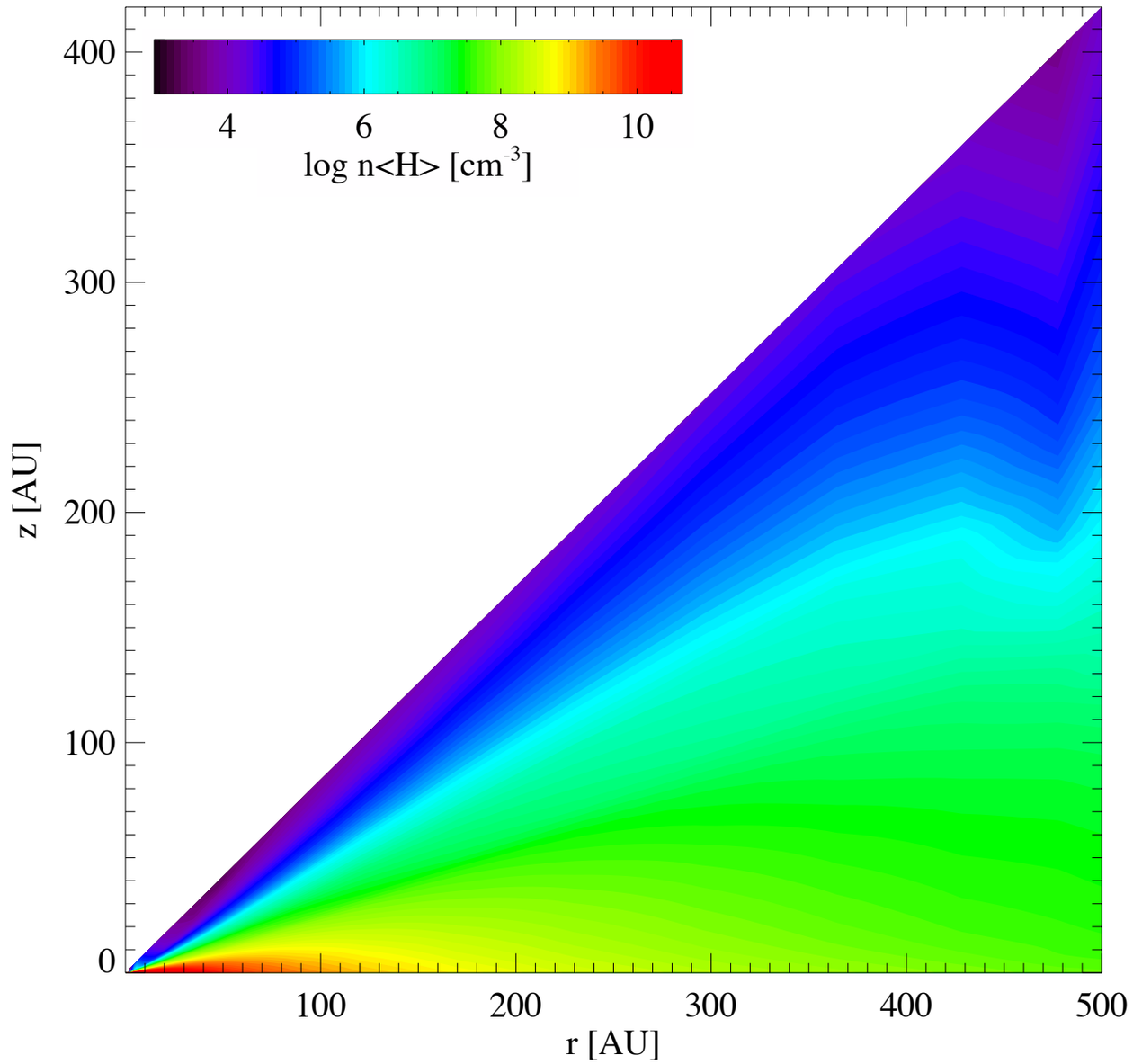
Disc structure



(Ilee et al. 2014b, in prep.)

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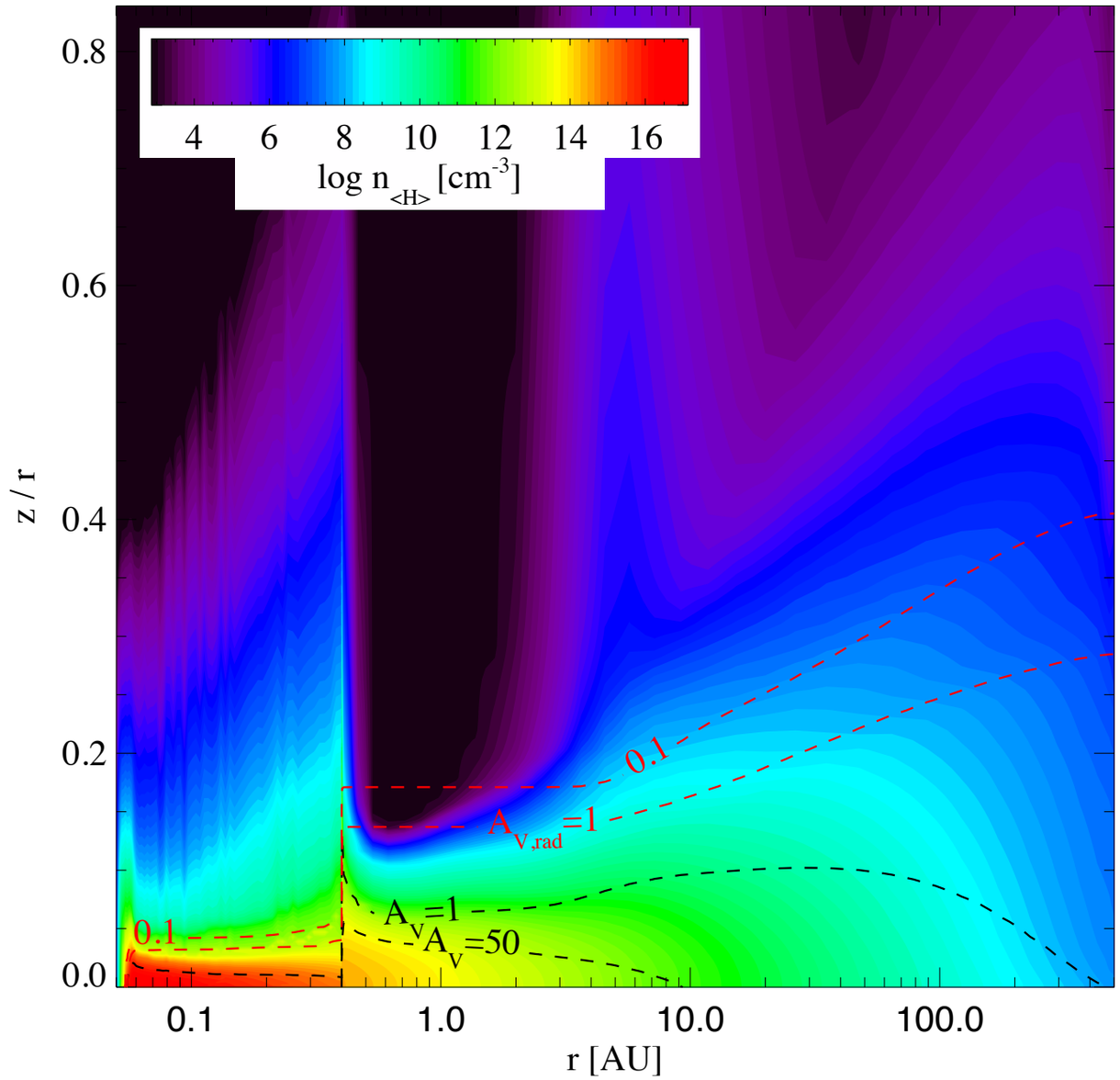
Disc structure



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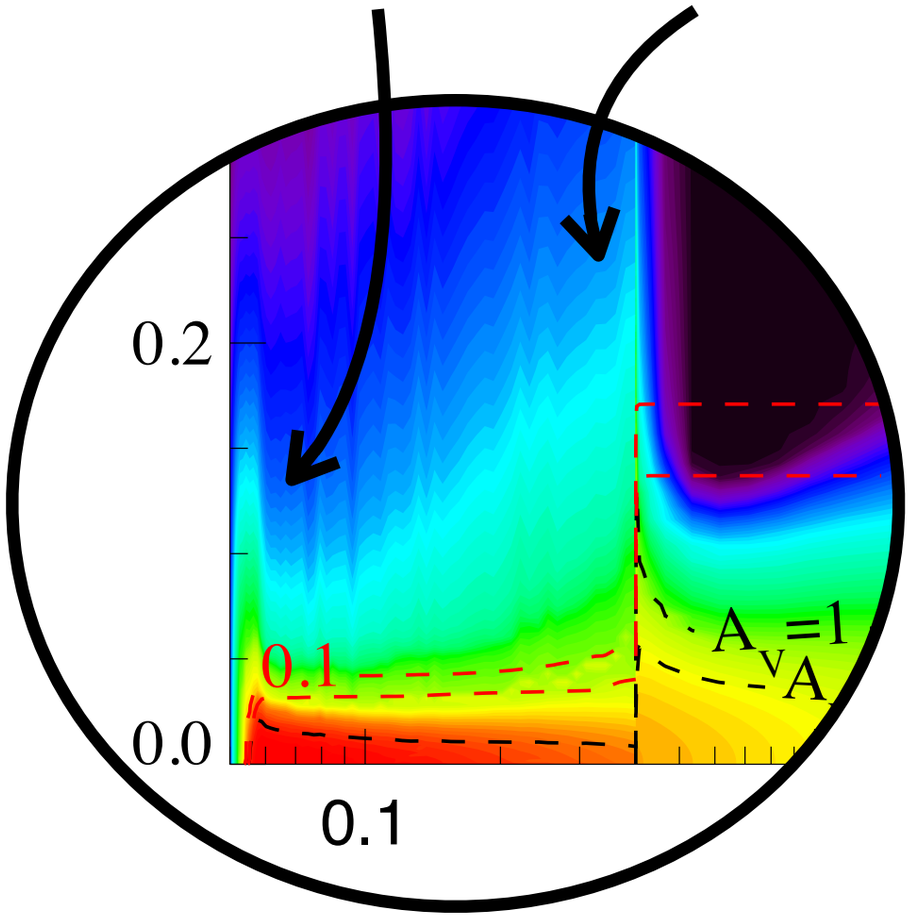
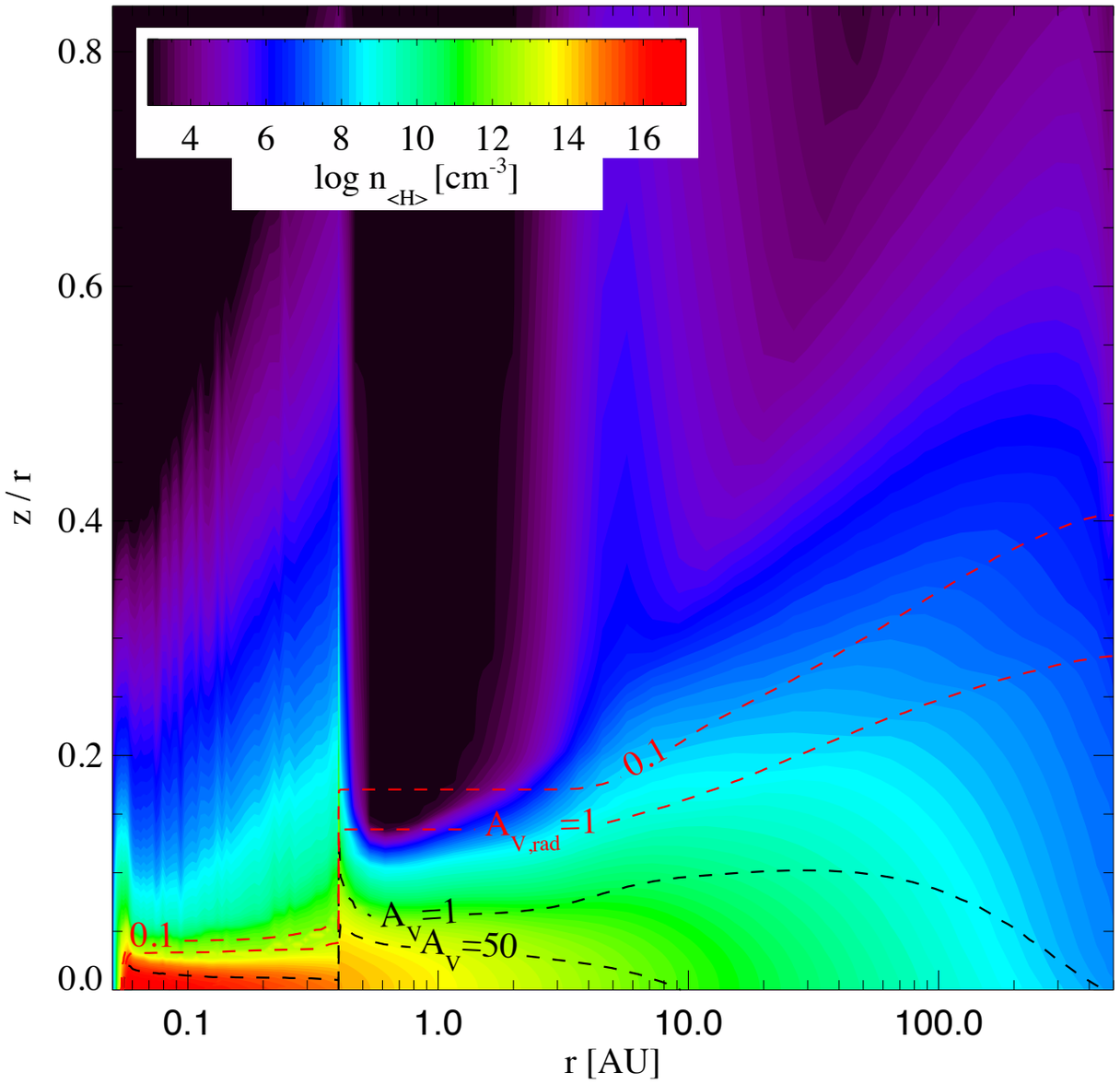
Disc structure

- "Puffed up inner rim" for both gas ***and*** dust





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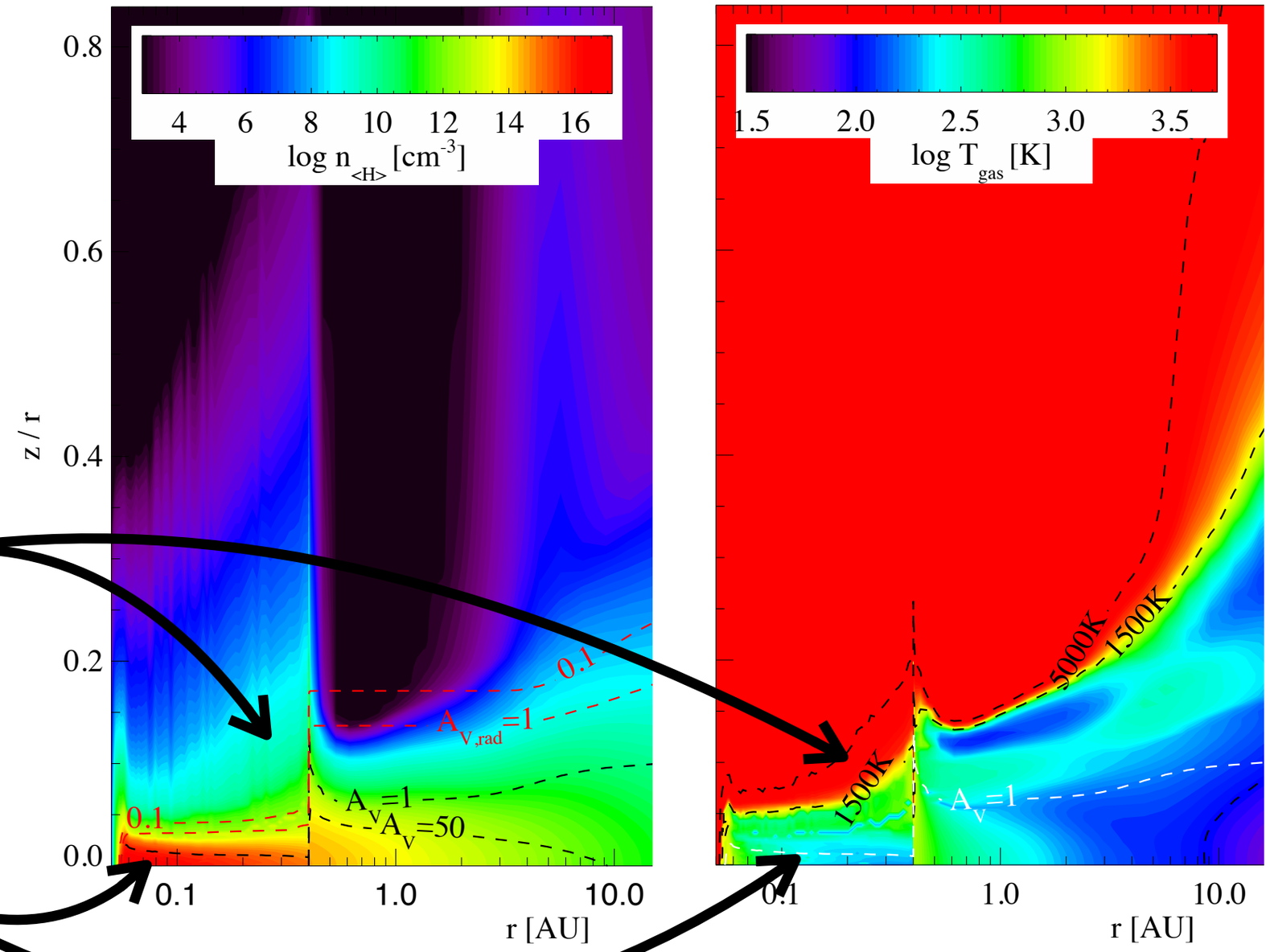
Disc structure

- Inner gas highly irradiated
- Two regimes:
  1. Extended, hot, atomic upper layers
  2. Cold, thin, molecular midplane



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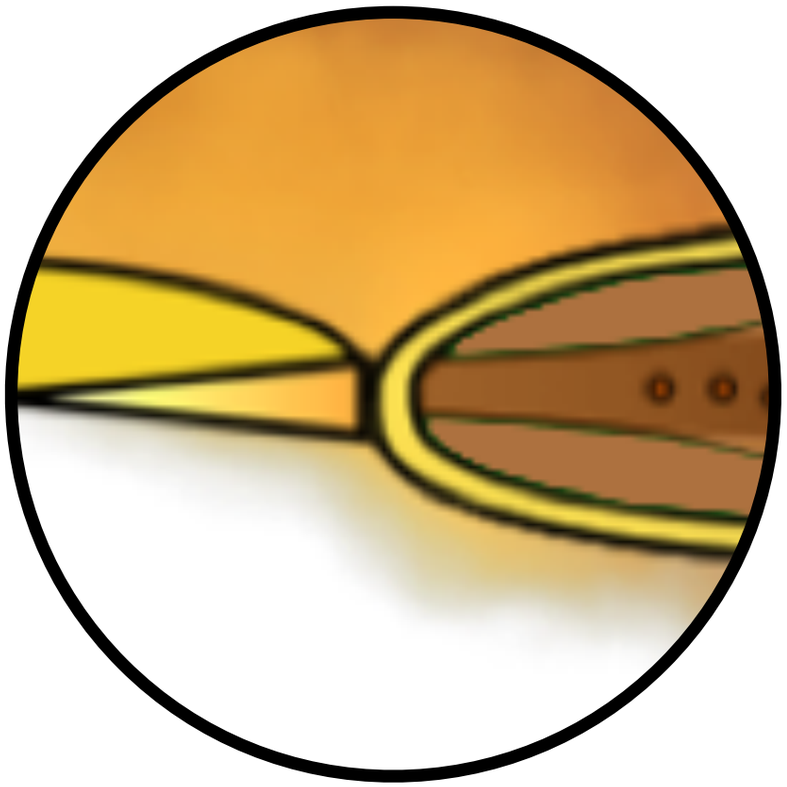

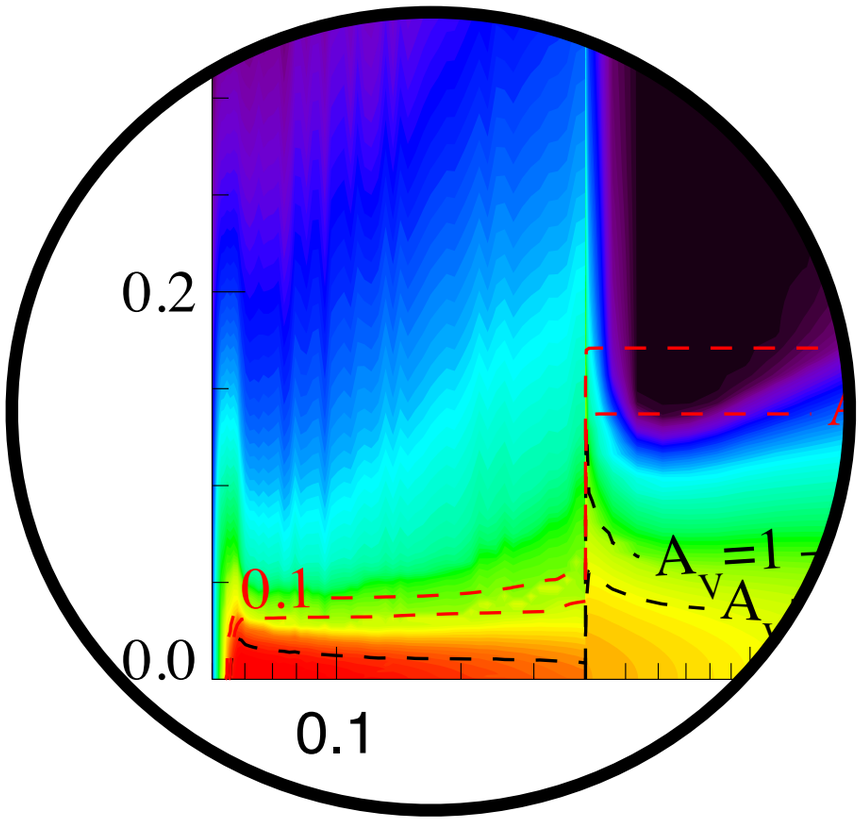

Do we need to rethink our cartoon?

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Line Emission

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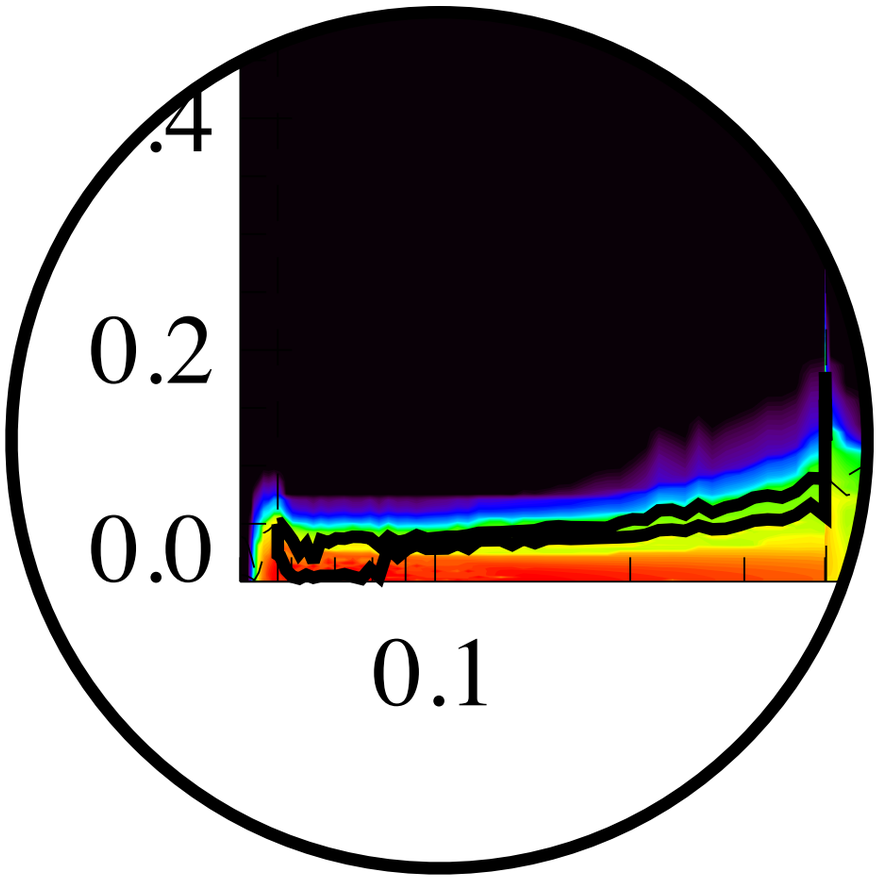
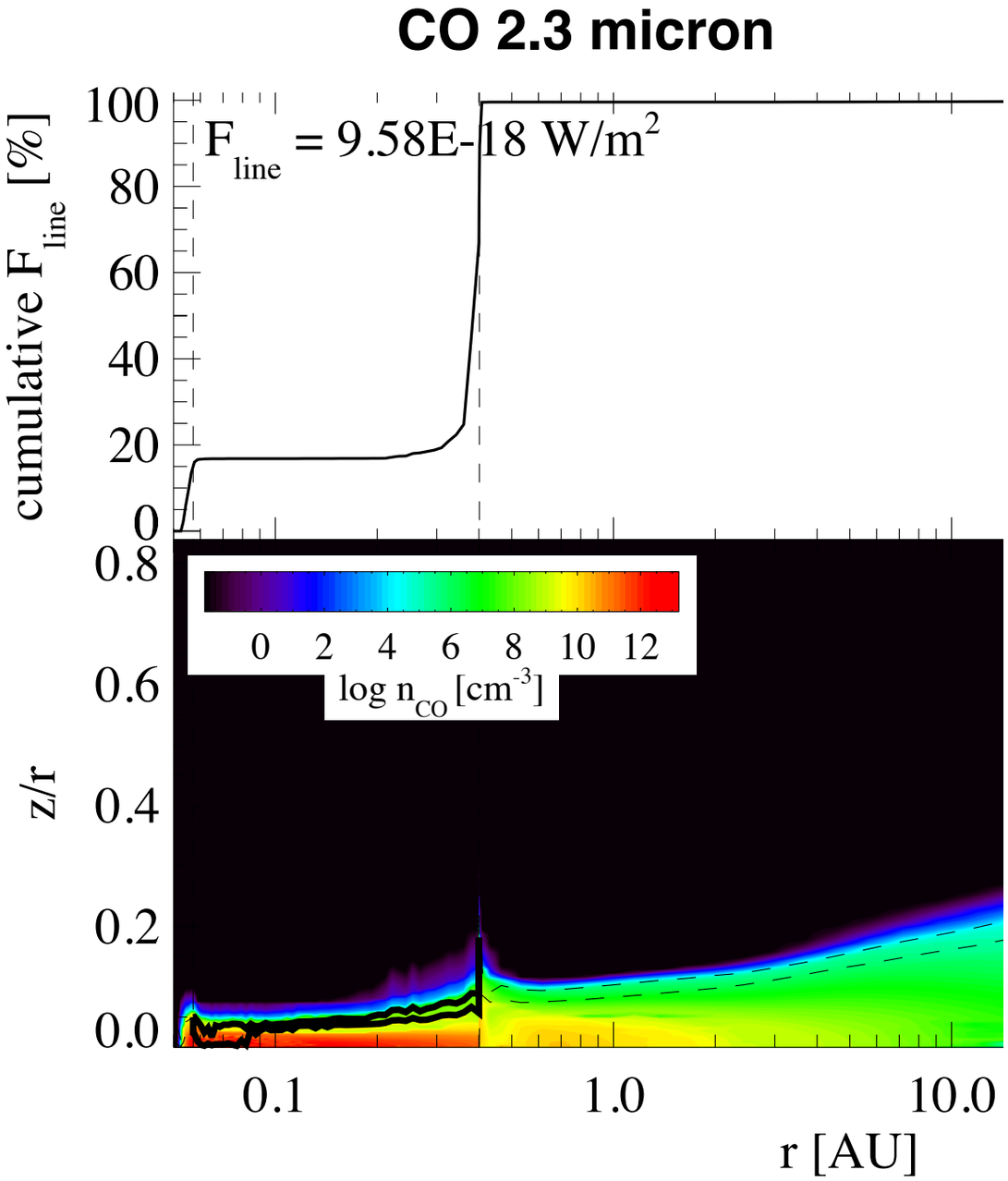
Line Emission

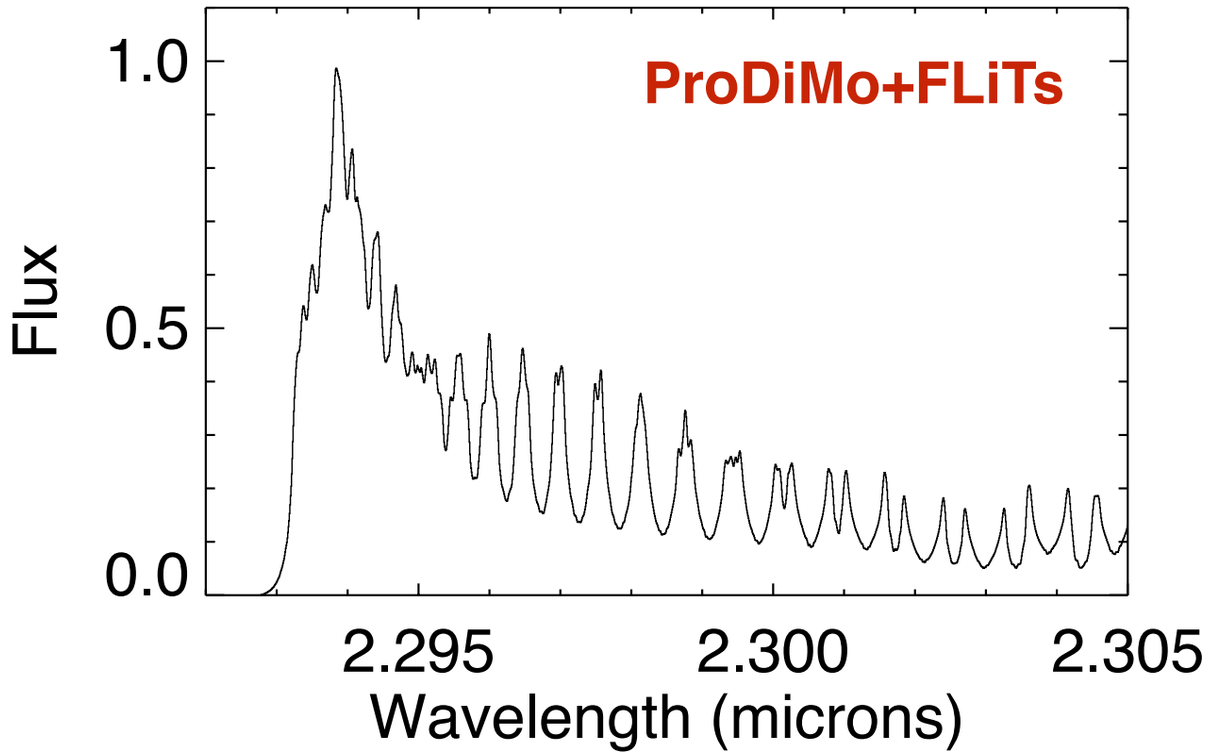
- Can determine origin of line emission in this model

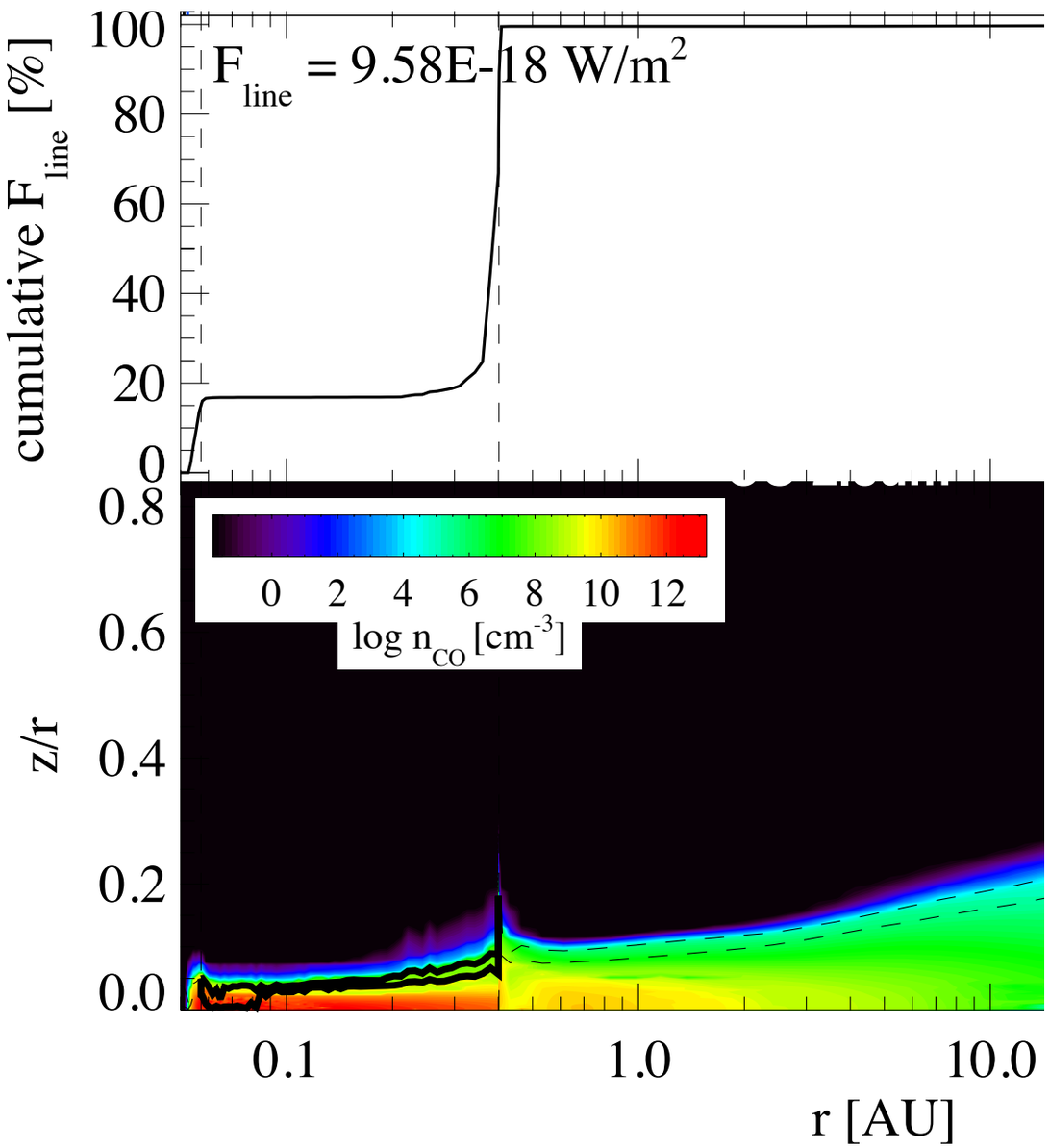




Line Emission

- …and produce observables





(Min et al. 2014, in prep.)

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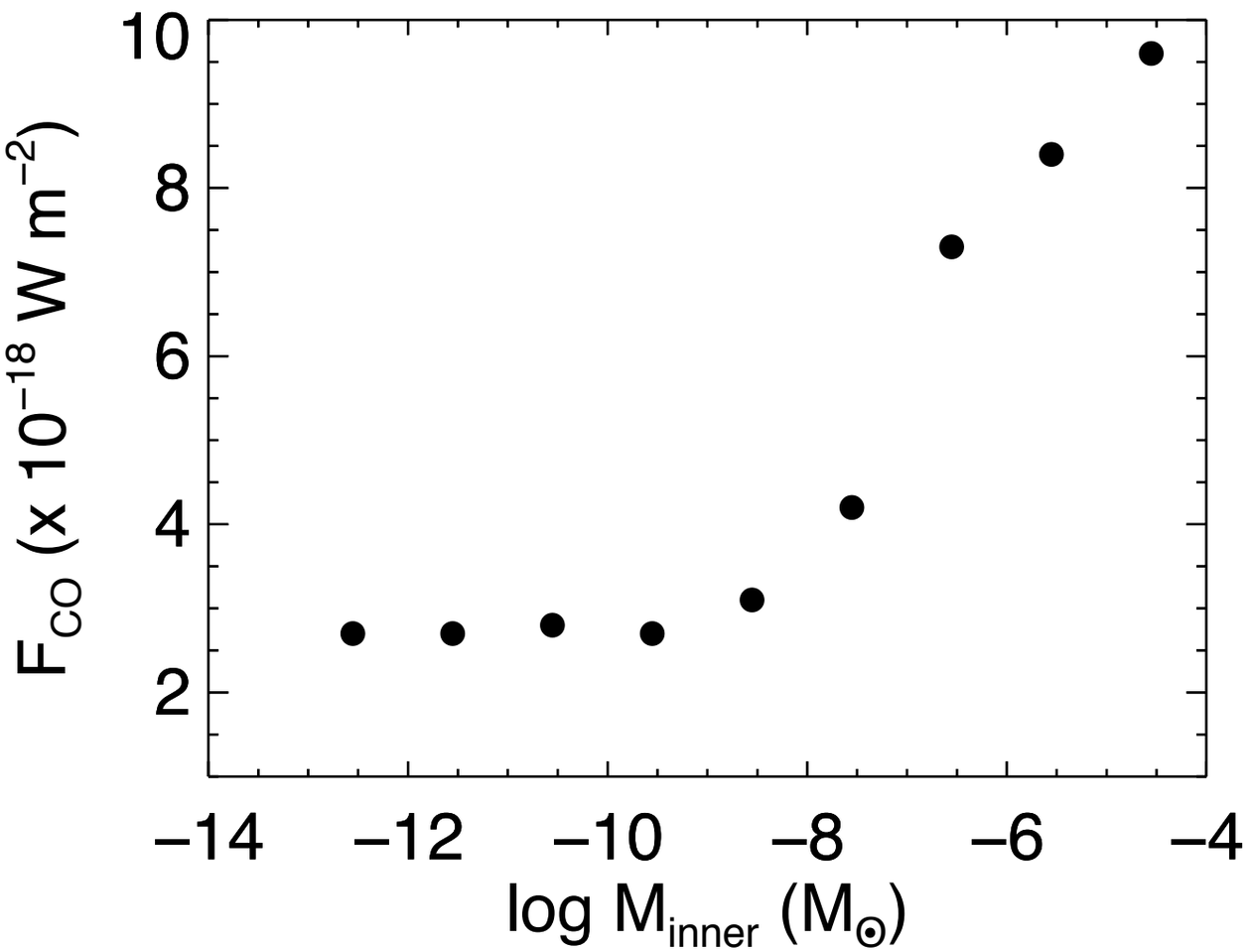
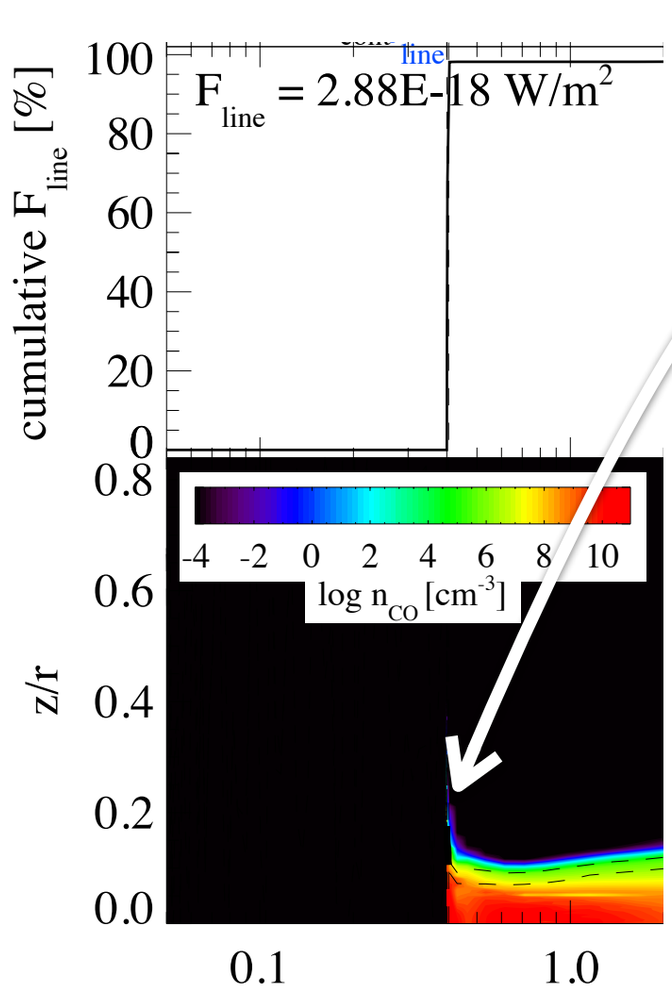
Line Emission

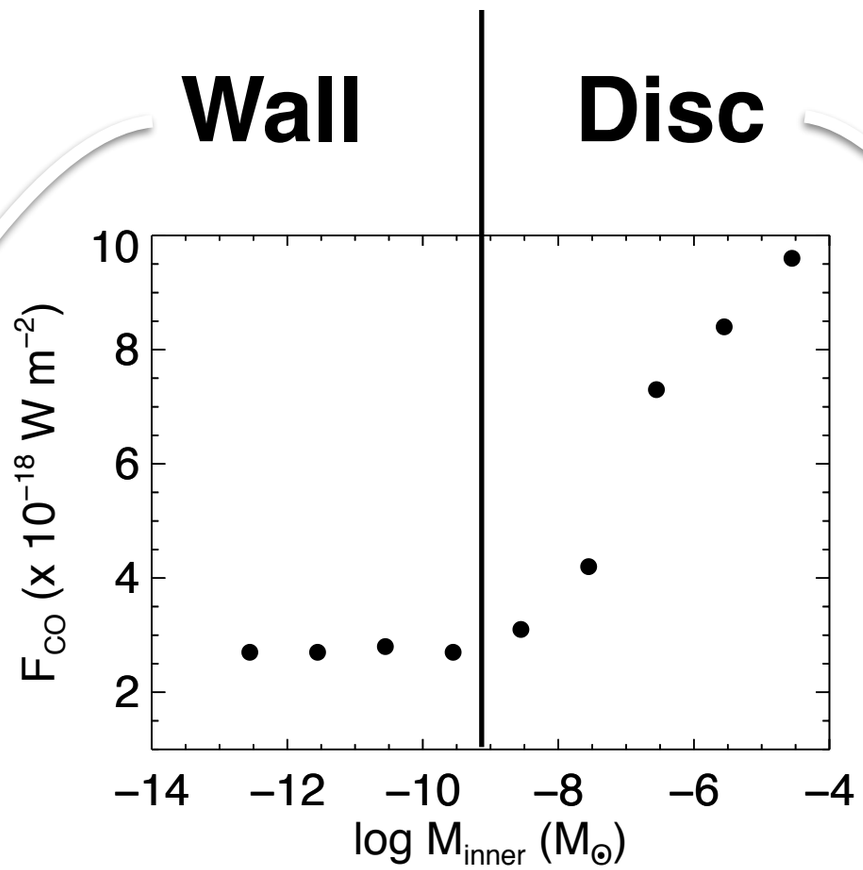
- Inner mass determines strength of CO bandhead emission:

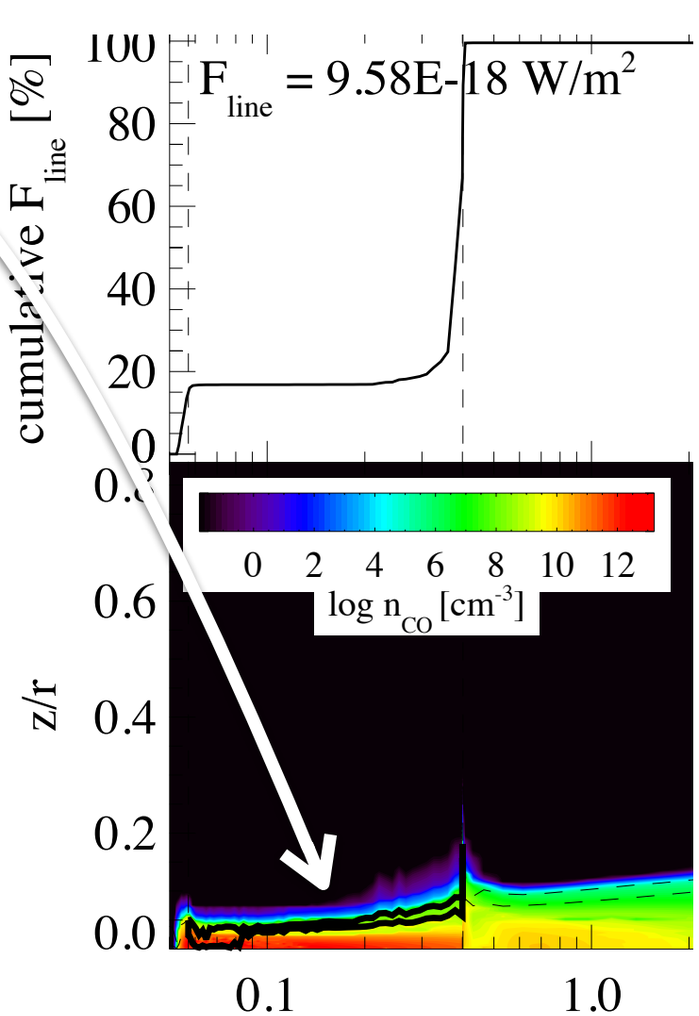


Line Emission

- …and location of CO bandhead emission







What next?

- Determine other line tracers for these disc regions & collect potential observables
- Look at earlier spectral types - a ‘Herbig Be’ model?
- Concentrate on individual objects, adapt these models to them, and fit multi-wavelength datasets

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Summary

- Simple thin disc models can fit CO bandhead emission well, and suggest inner disc origin

- Modelling physics, chemistry & RT of these regions also suggests a disc origin, but the structure of the disc is not ‘thin’

- The inner disc must contain sufficient mass before the CO originates from there - a possible hint at why some YSOs exhibit this emission while others do not