TRACING THE DISK VERTICAL STRUCTURE WITH MULTIPLE MOLECULES

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GAS AS A TRACER OF THE VERTICAL STRUCTURE

- Different molecules are sensitive to different chemical/physical processes.
- Molecules trace vertical emission layers.
- Characterizing molecular emission allows us to determine disk properties.

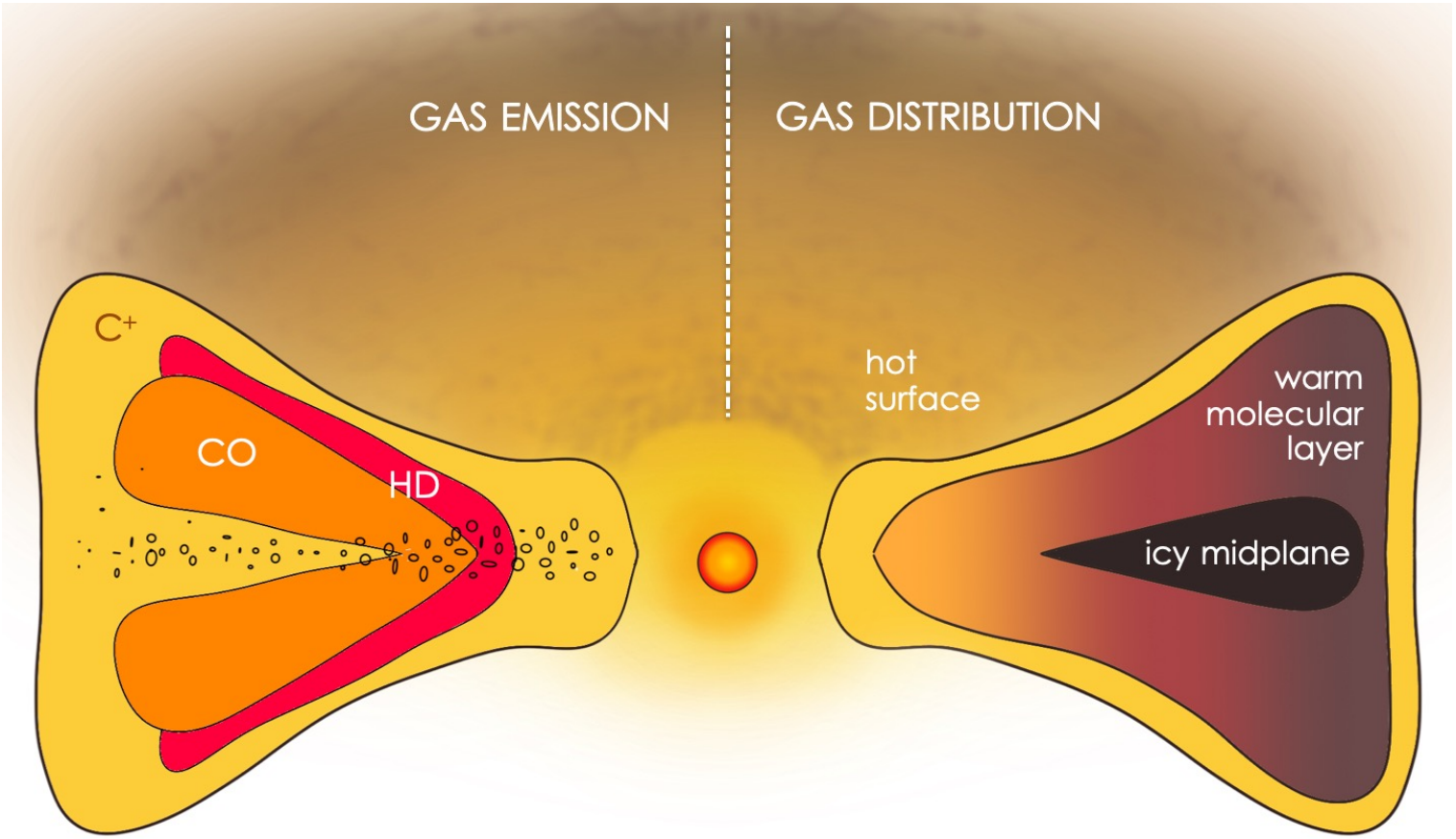
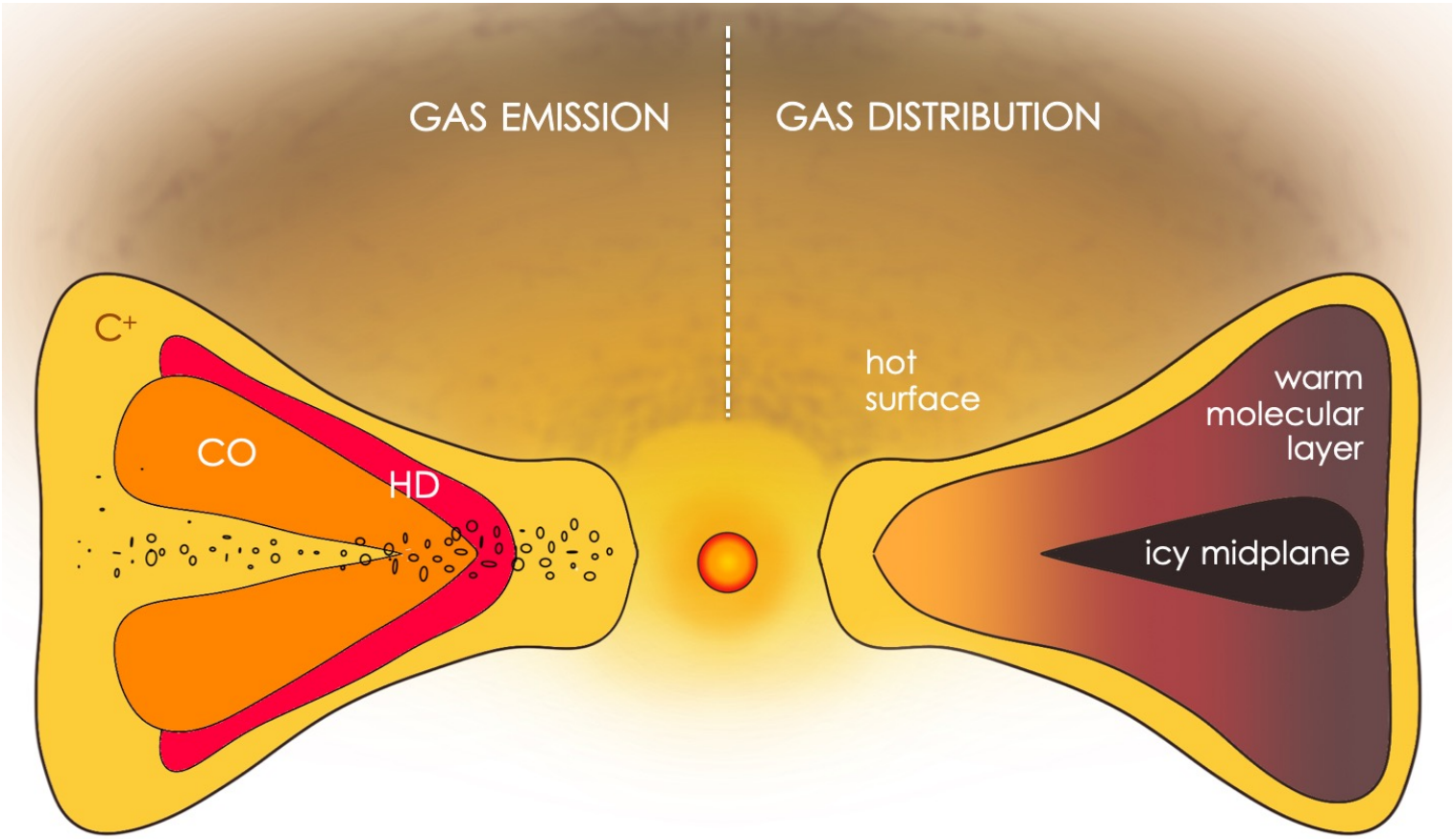


Image by Anna Miotello

GAS AS A TRACER OF THE VERTICAL STRUCTURE

How to measure the vertical profile?



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GAS AS A TRACER OF THE VERTICAL STRUCTURE

How to measure the vertical profile?

Indirect estimations **Direct tracing**

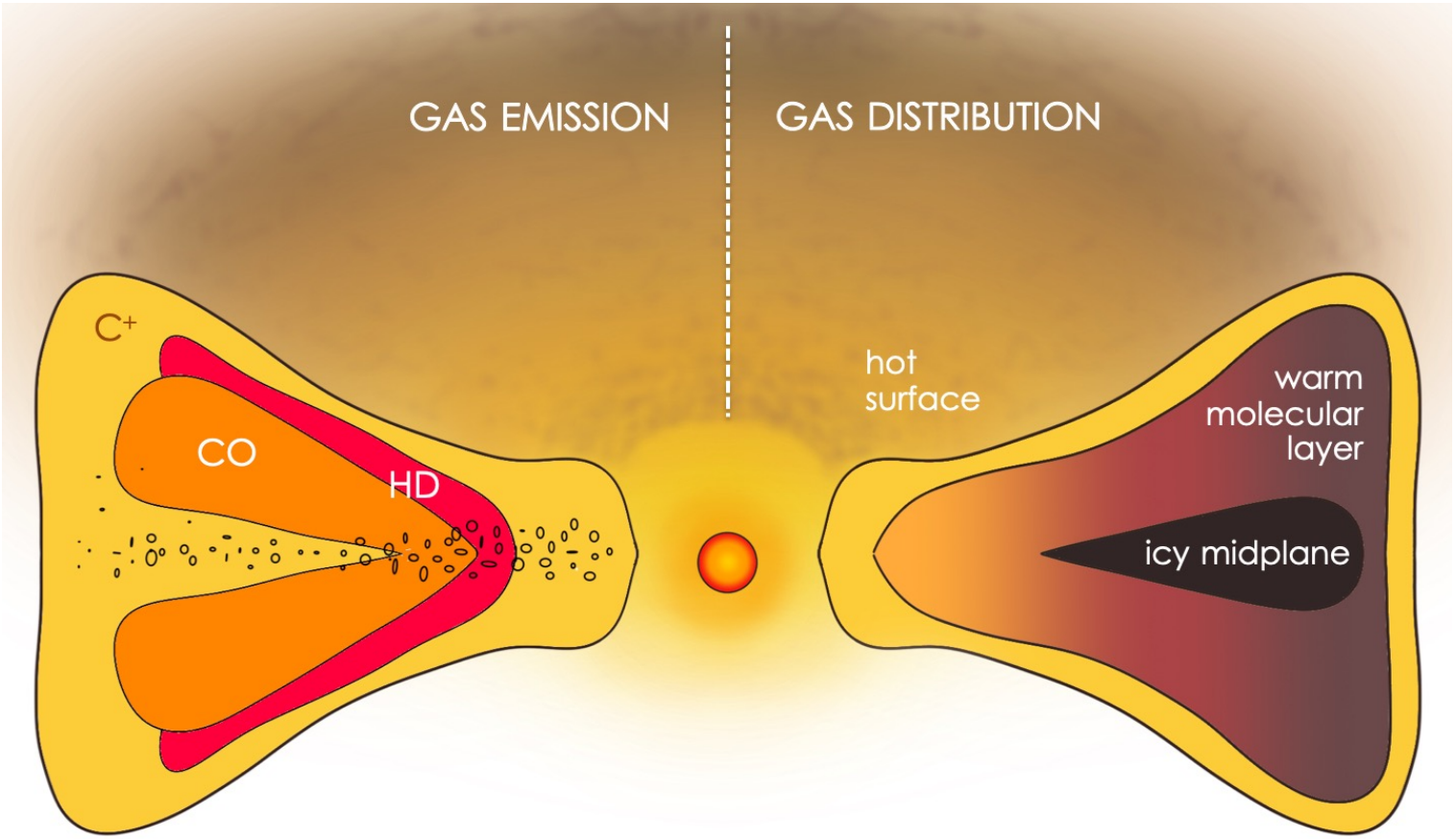


Image by Anna Miotello

GAS AS A TRACER OF THE VERTICAL STRUCTURE

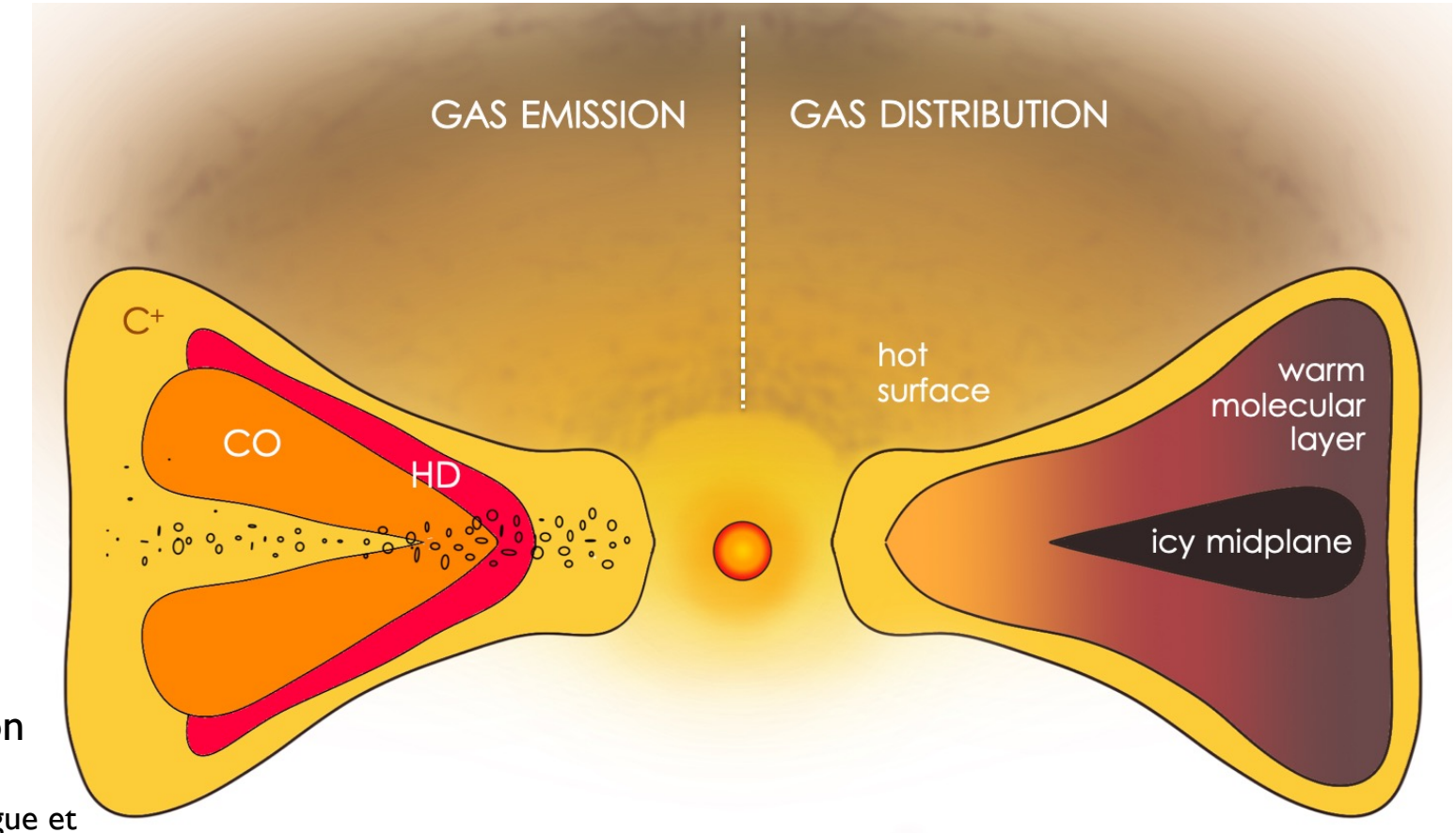
How to measure the vertical profile?

Indirect estimations
Temperature estimates/models

Teague & Loomis 2020, Bergner et al. 2021, Guzmán et al. 2021, Ilee et al. 2021

Direct tracing
From channel or integrated emission

Pinte et al. 2018, **Eddy** Teague et al. 2019, **Discminer** Izquierdo et al., 2021, **DiskSurf** (Teague)



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GAS AS A TRACER OF THE VERTICAL STRUCTURE

How to measure the vertical profile?

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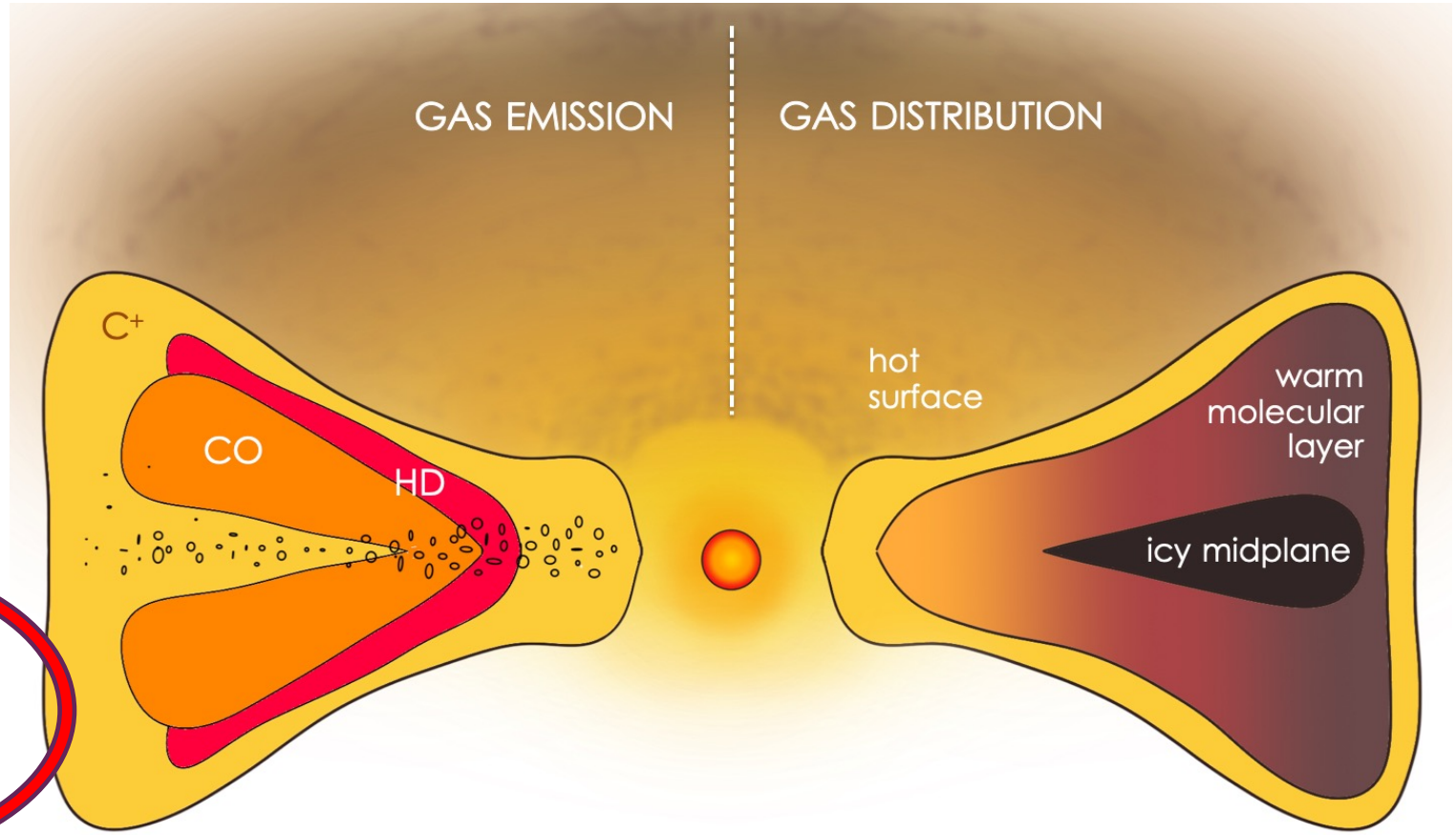
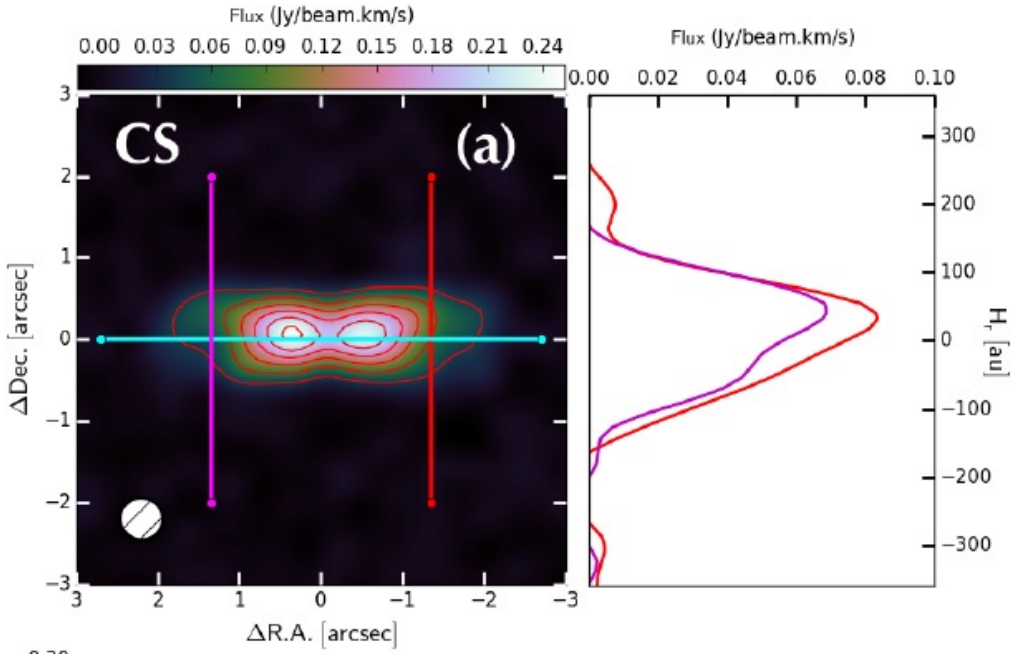


Image by Anna Miotello

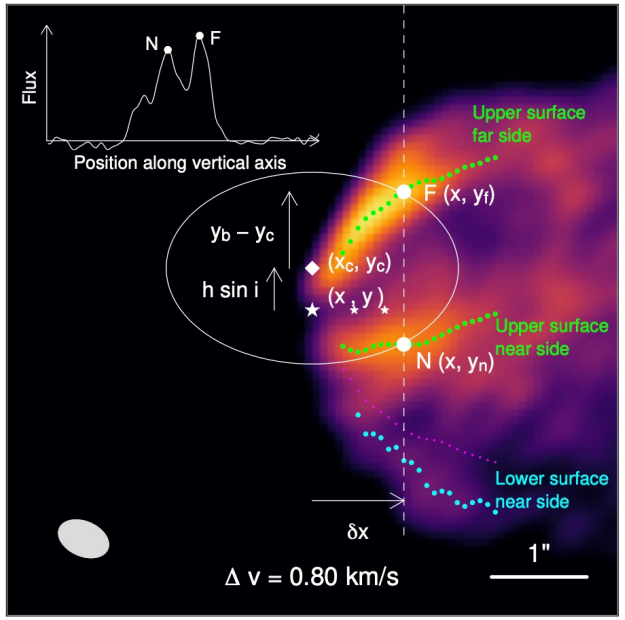
DIRECTLY TRACING THE VERTICAL STRUCTURE

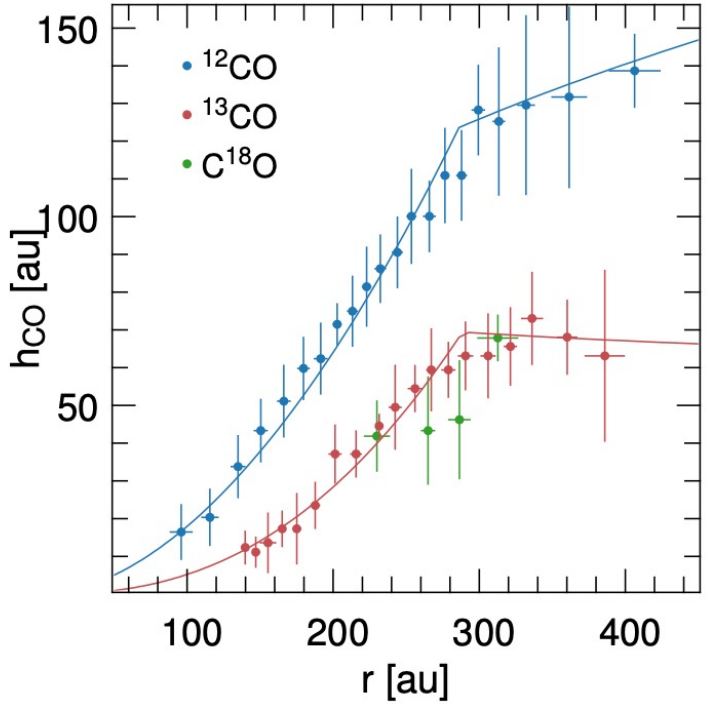
Edge on Disks



Flying Saucer, Ruíz-Rodríguez et al., 2021

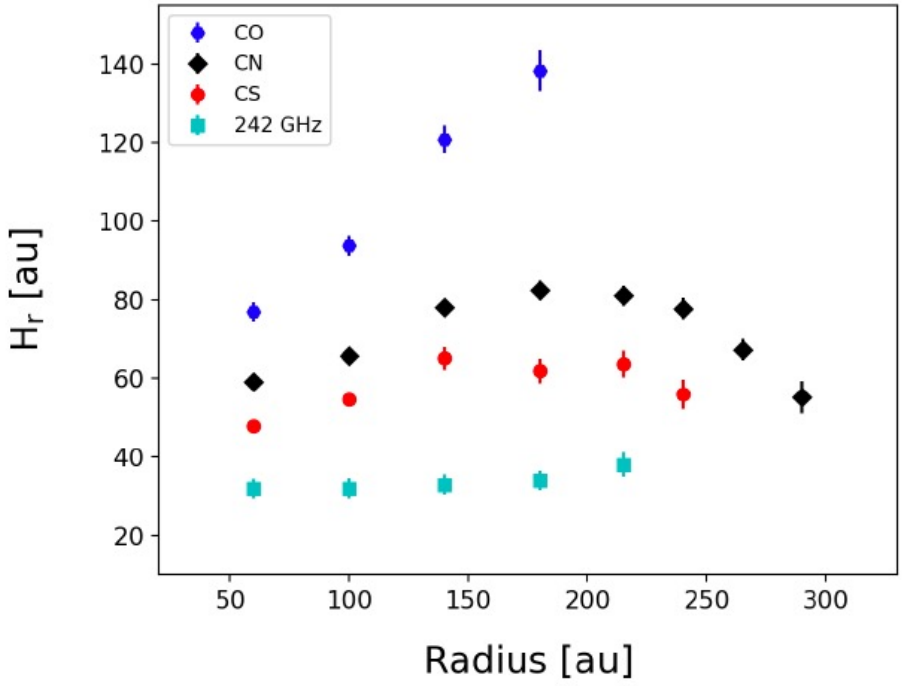
Inclined Disks



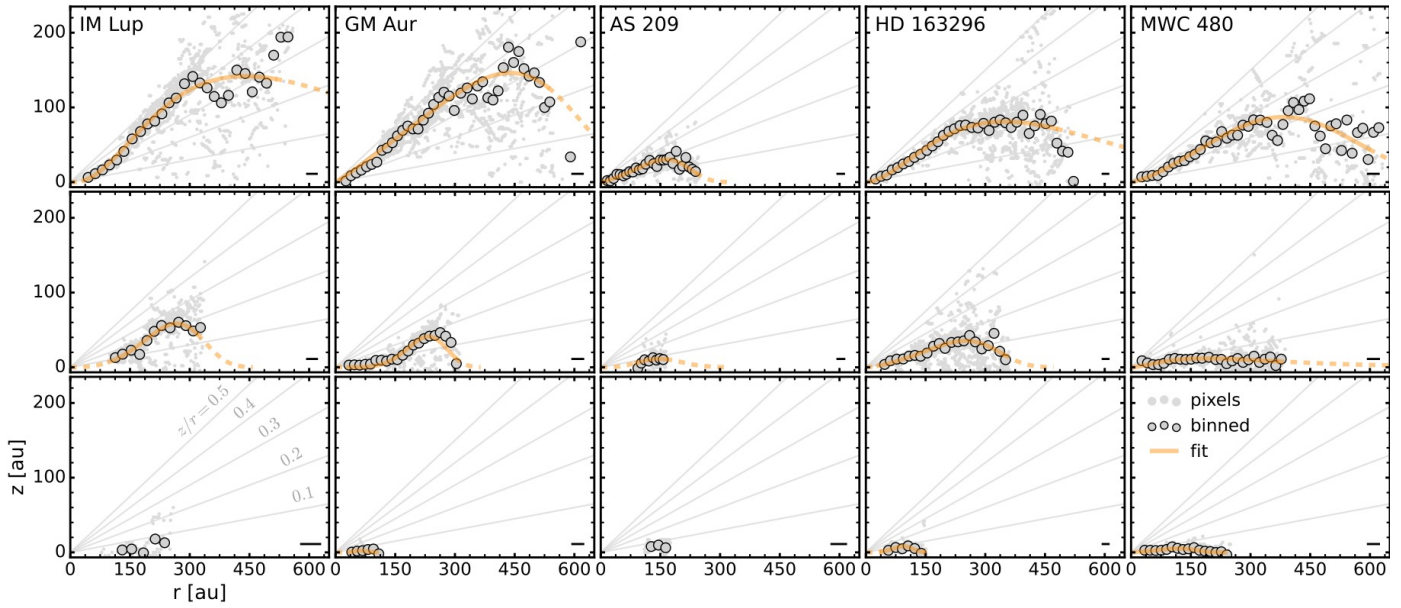


IM Lup, Pinte et al., 2018

WHICH MOLECULES?

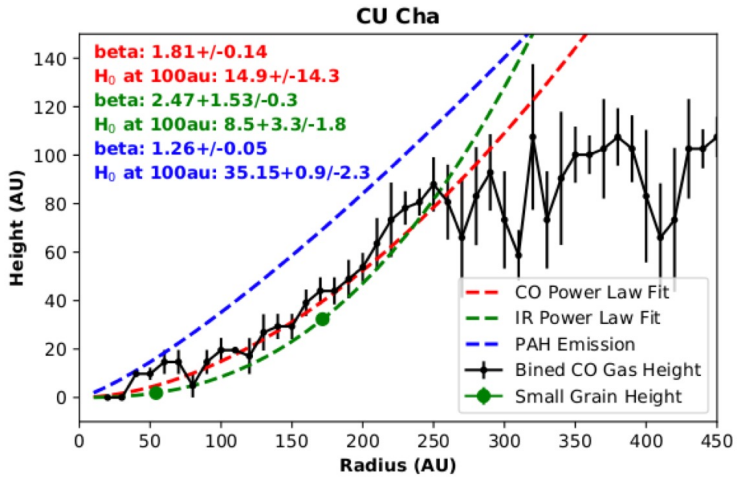


Flying Saucer, Ruíz-Rodríguez et al., 2021



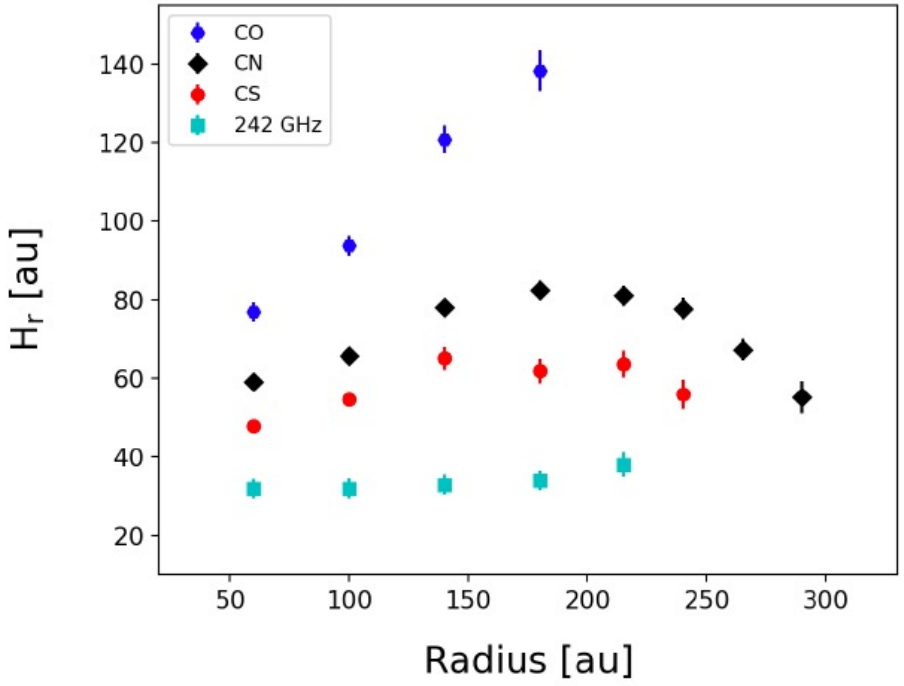
CO 2-1 ^{13}CO 2-1 C^{18}O 2-1

MAPS VI, Law et al., 2021

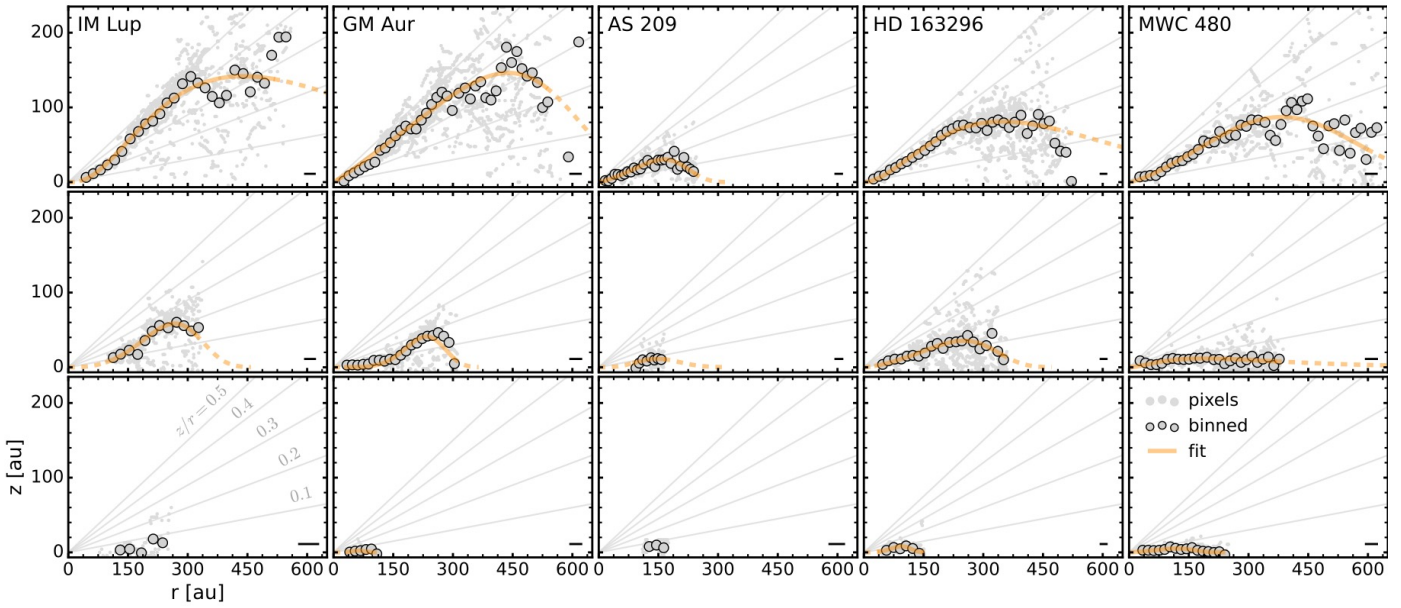


Rich et al., 2021

WHICH MOLECULES?



Flying Saucer, Ruíz-Rodríguez et al., 2021



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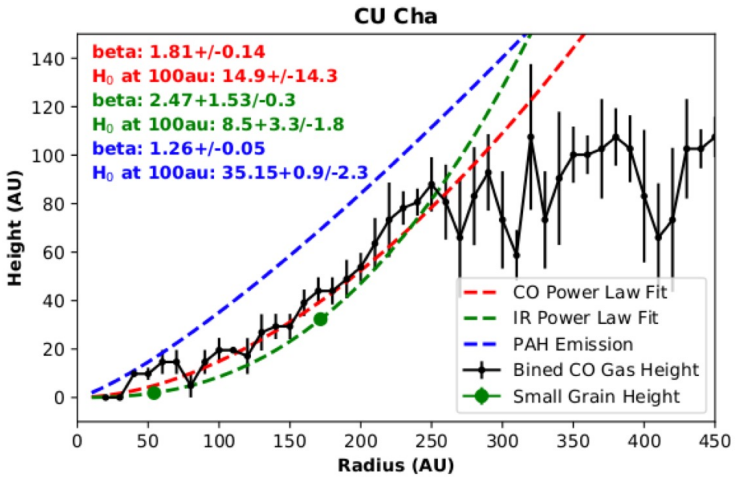
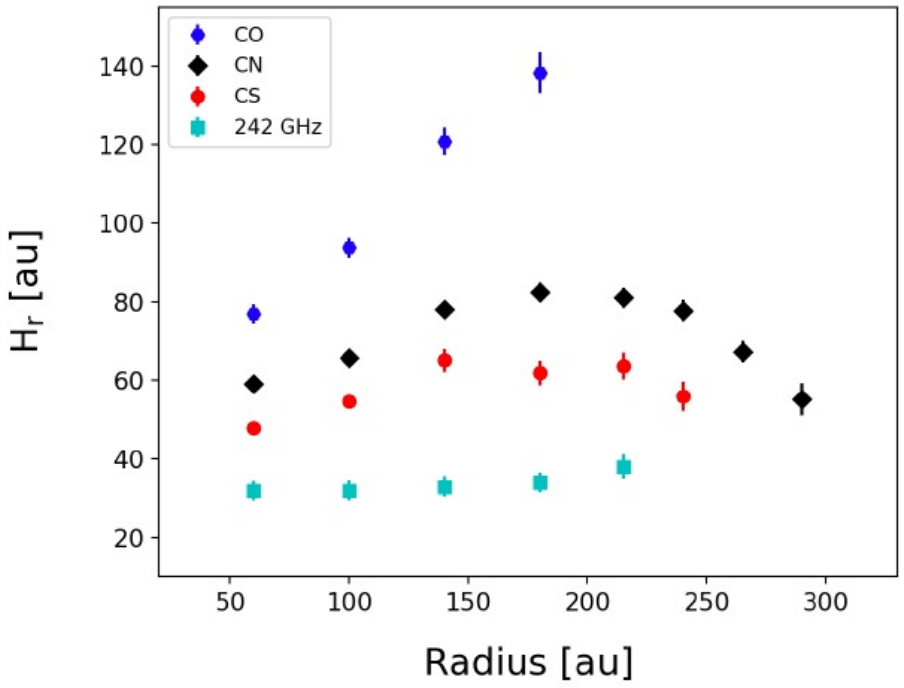


Rich et al., 2021

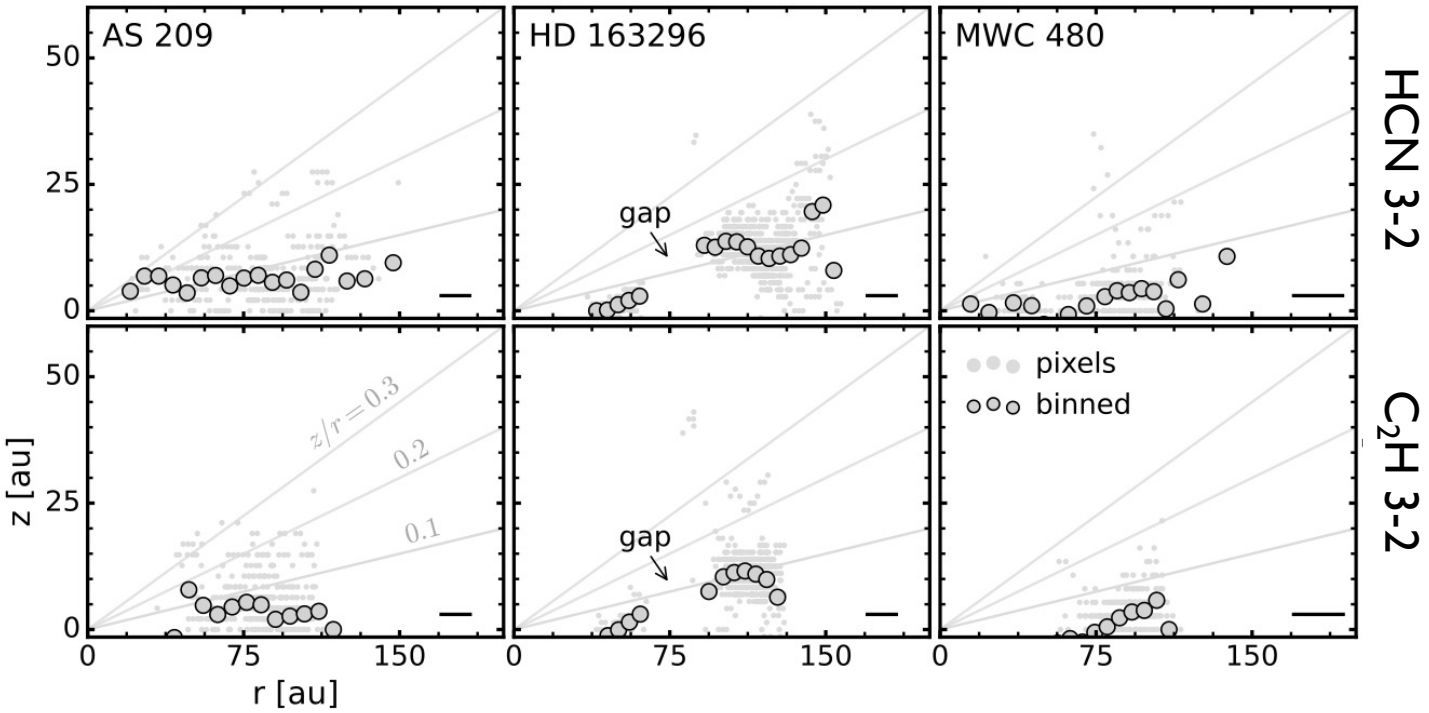
IM Lup (Pinte et al., 2018, Rich et al., 2021)

HD163296 (Teague et al., 2019, Rich et al., 2021)

WHICH MOLECULES?

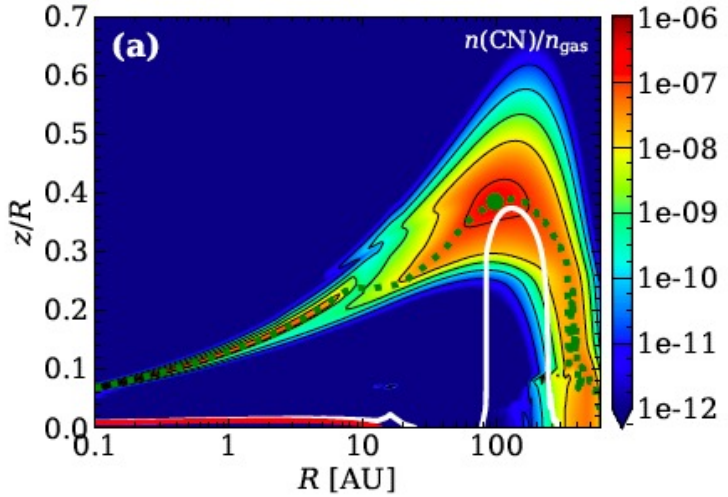


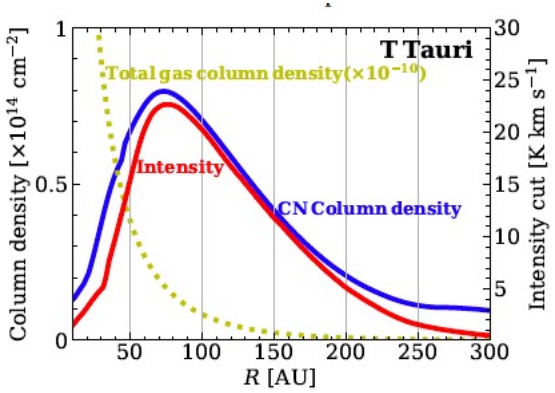
Flying Saucer, Ruíz-Rodríguez et al., 2021

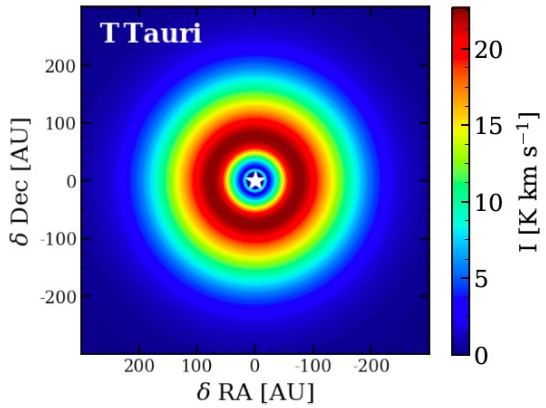


MAPS VI, Law et al. ,2021

CN AS A TRACER



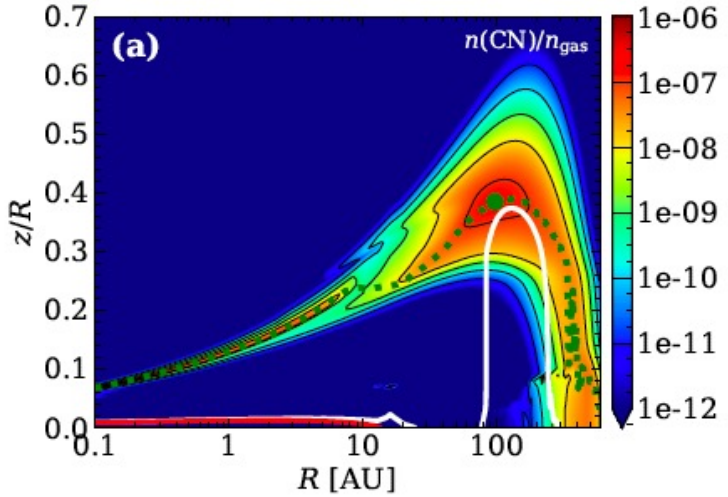


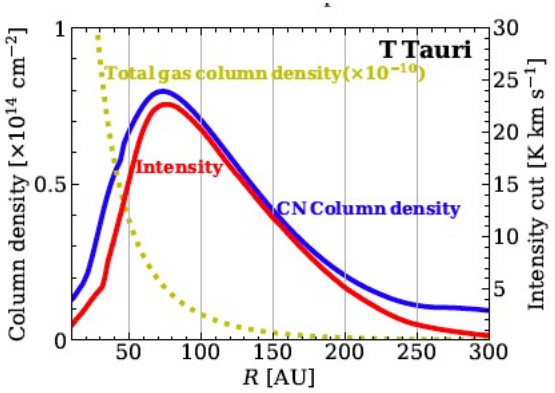


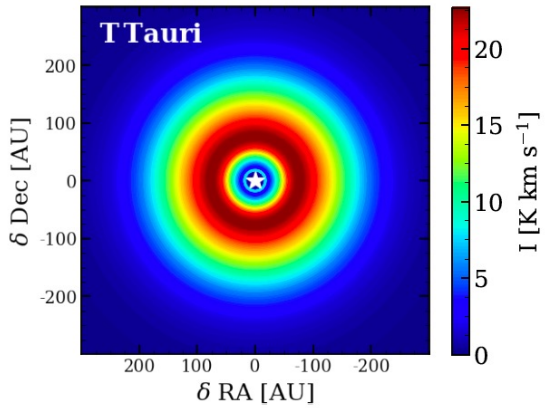
Cazzoletti et al., 2018

Teague et al. 2016, van Terwisga 2018, Teague & Loomis 2020

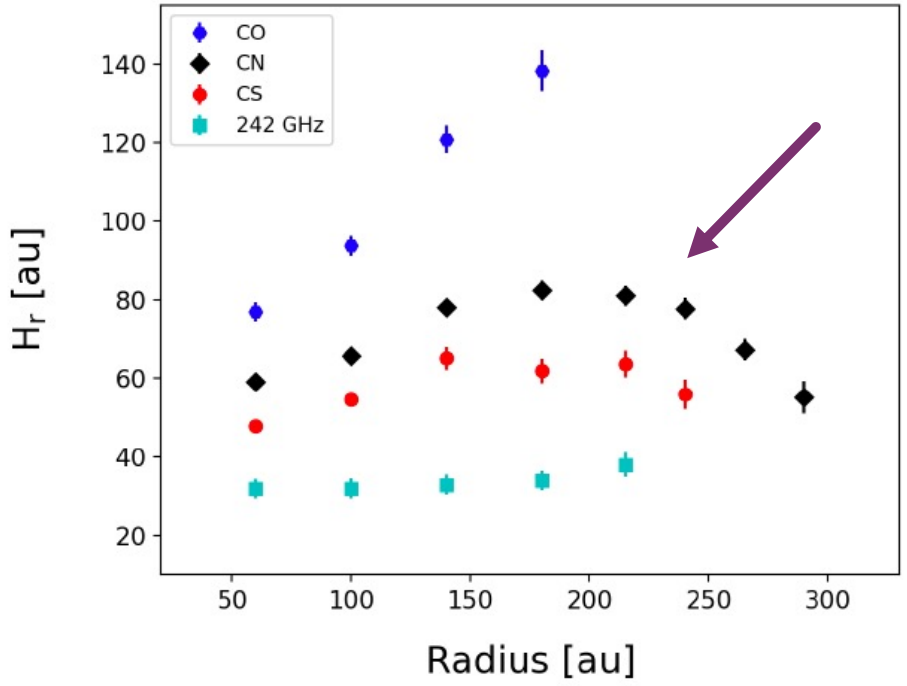
CN AS A TRACER







Cazzoletti et al., 2018



Flying Saucer, Ruíz-Rodríguez et al., 2021

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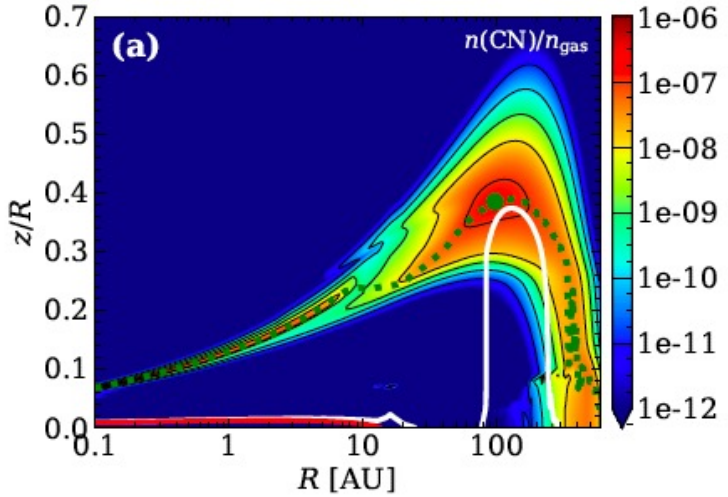

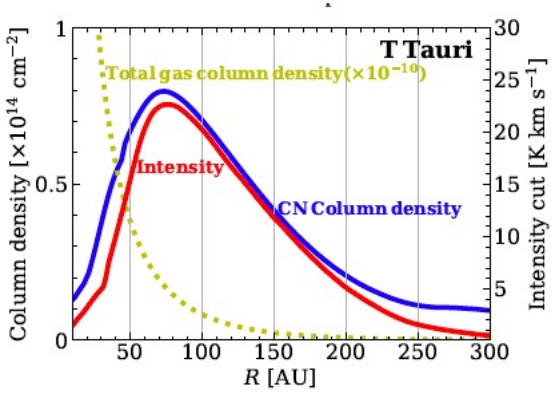

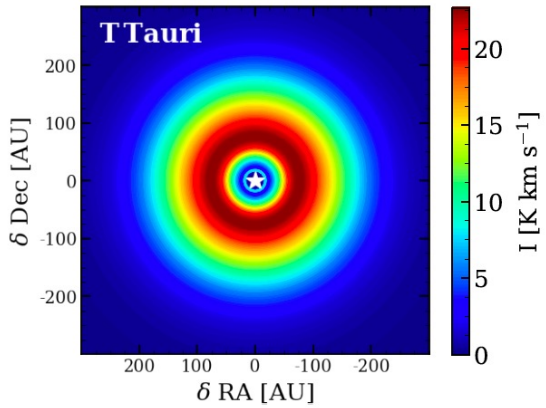

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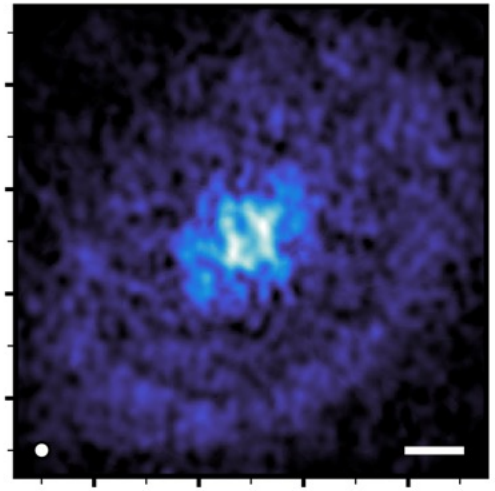
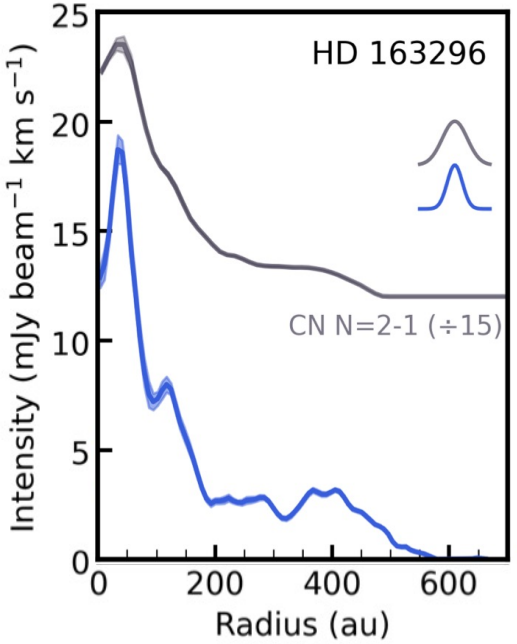
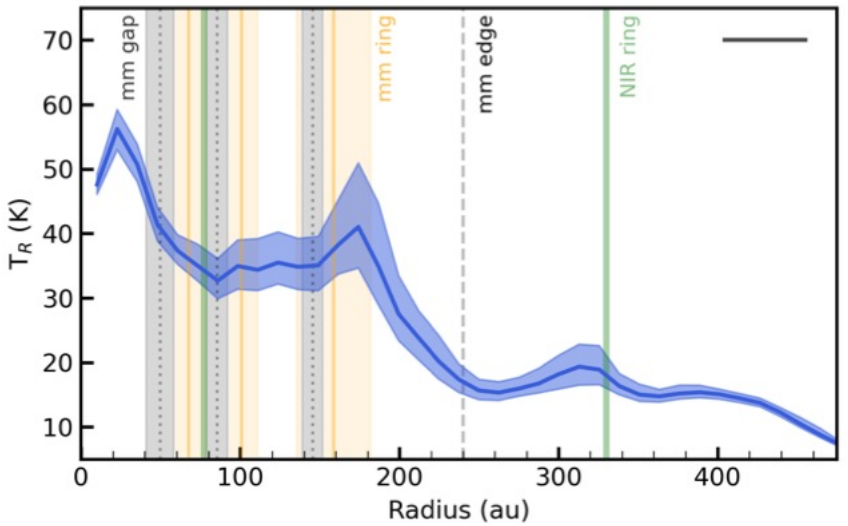
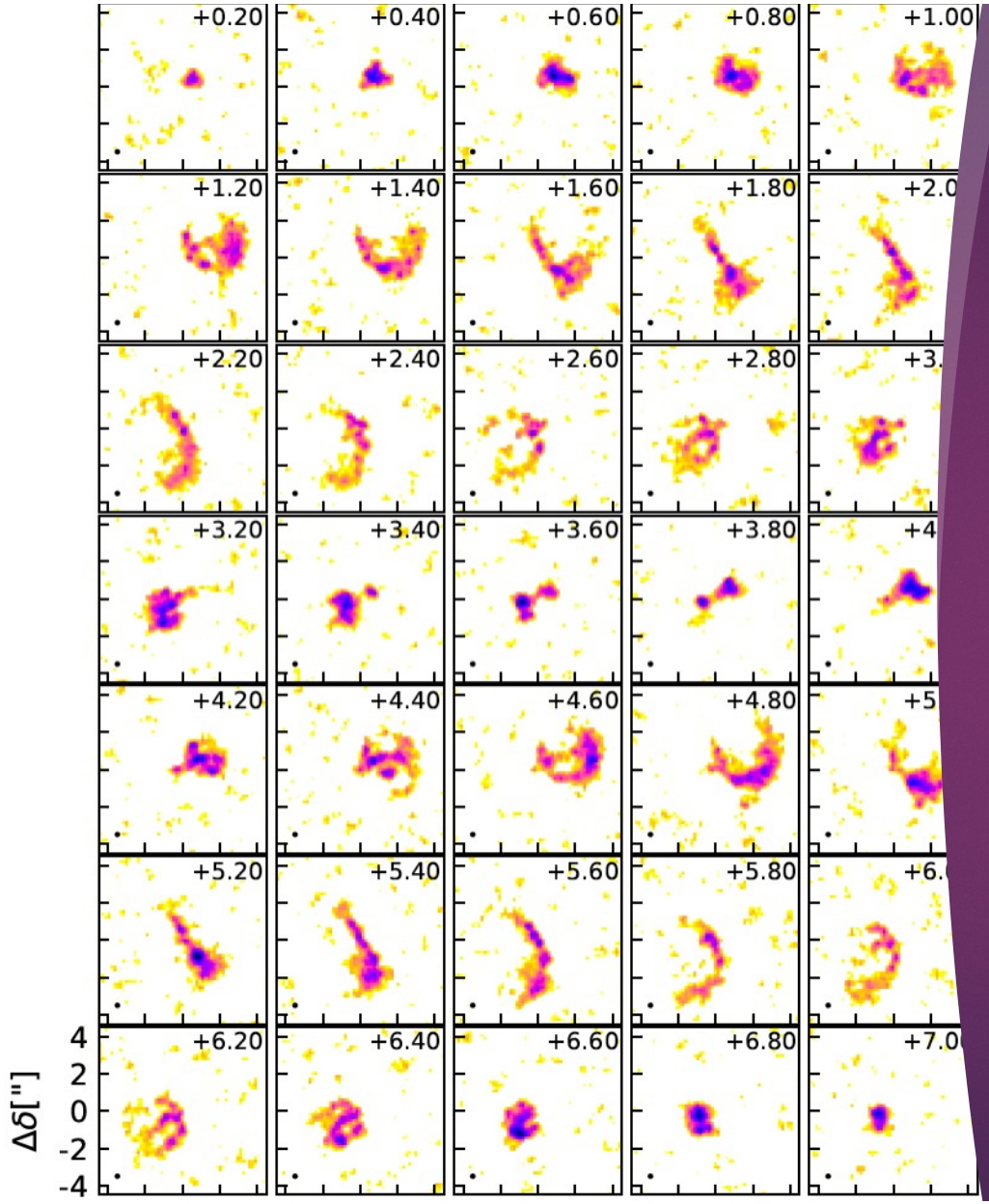






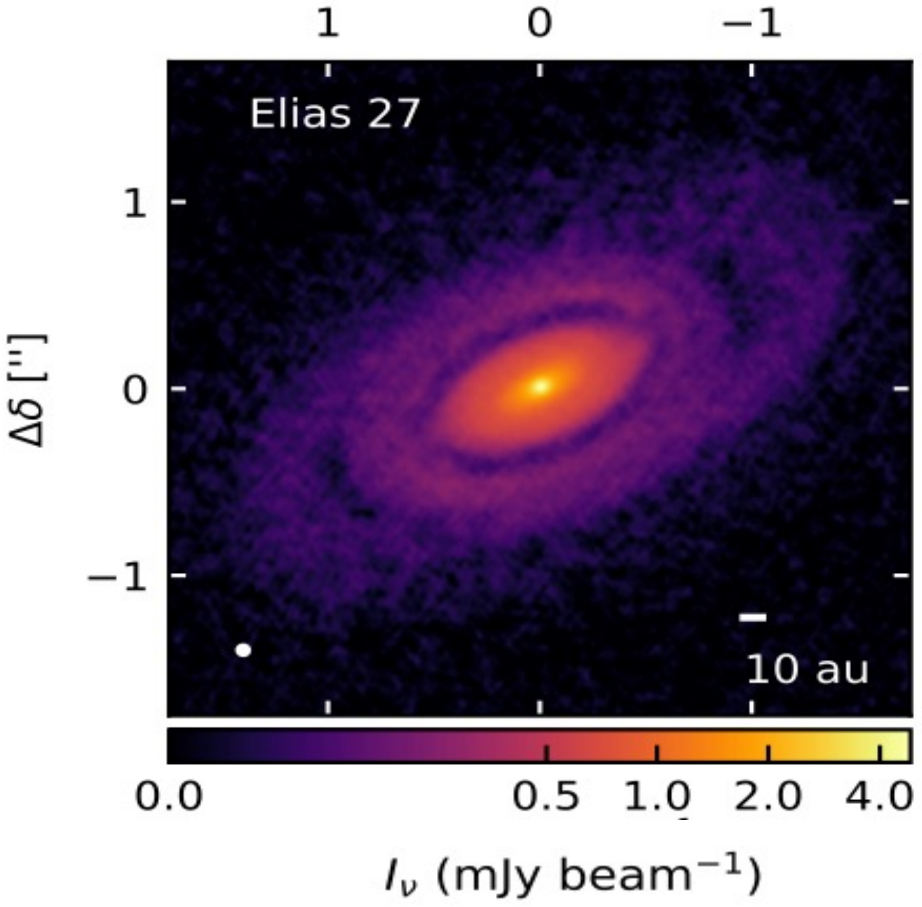
MAPS XI, Bergner et al., 2021



Directly Tracing the CN emitting surface in Elias 2-27

Paneque-Carreño et al., to be submitted

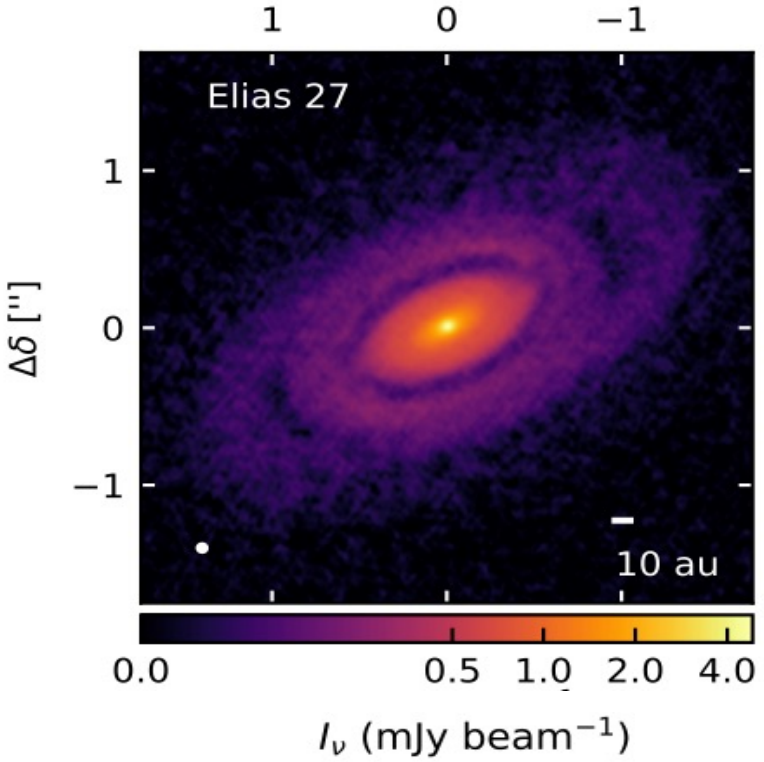
ELIAS 2-27

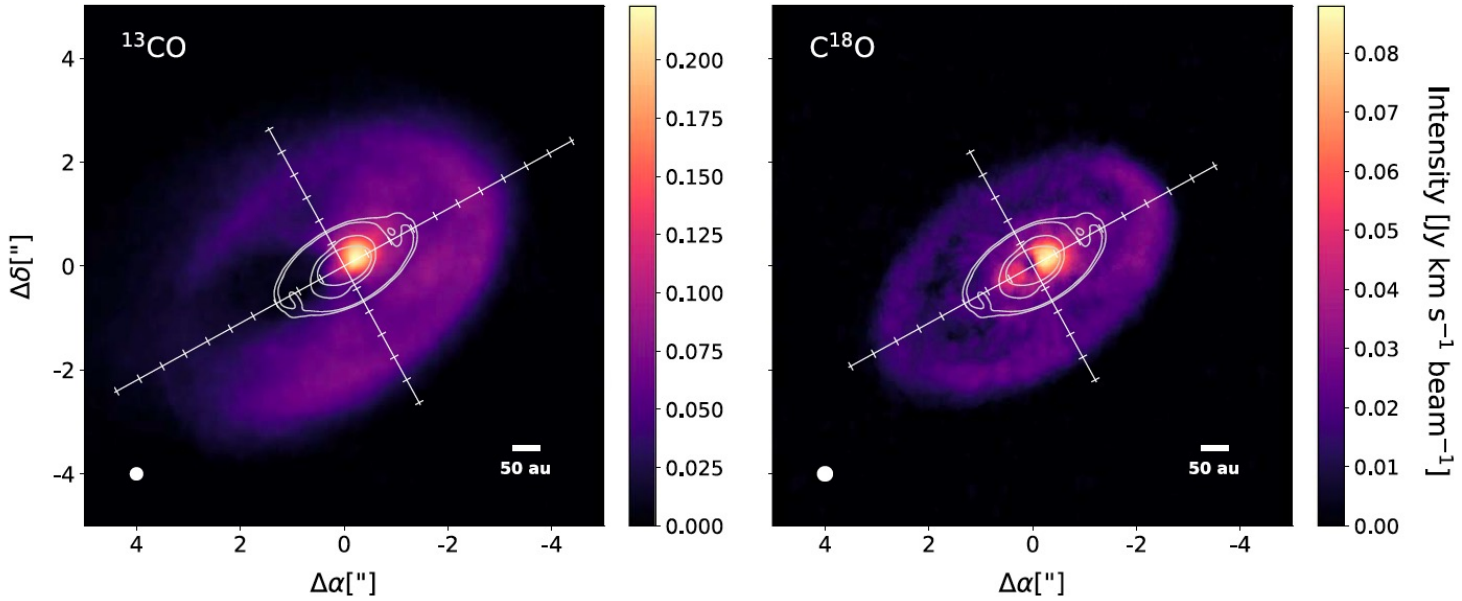


- Class II stellar object, ρ-Ophiuchus
- $M_* = 0.49\ M_\odot$
- disk-to-star mass ratio 0.3
- Large-scale spirals and dust gap

Perez et al., 2016, Huang et al., 2018c, Paneque-Carreño et al., 2021, Veronesi et al. 2021

ELIAS 2-27





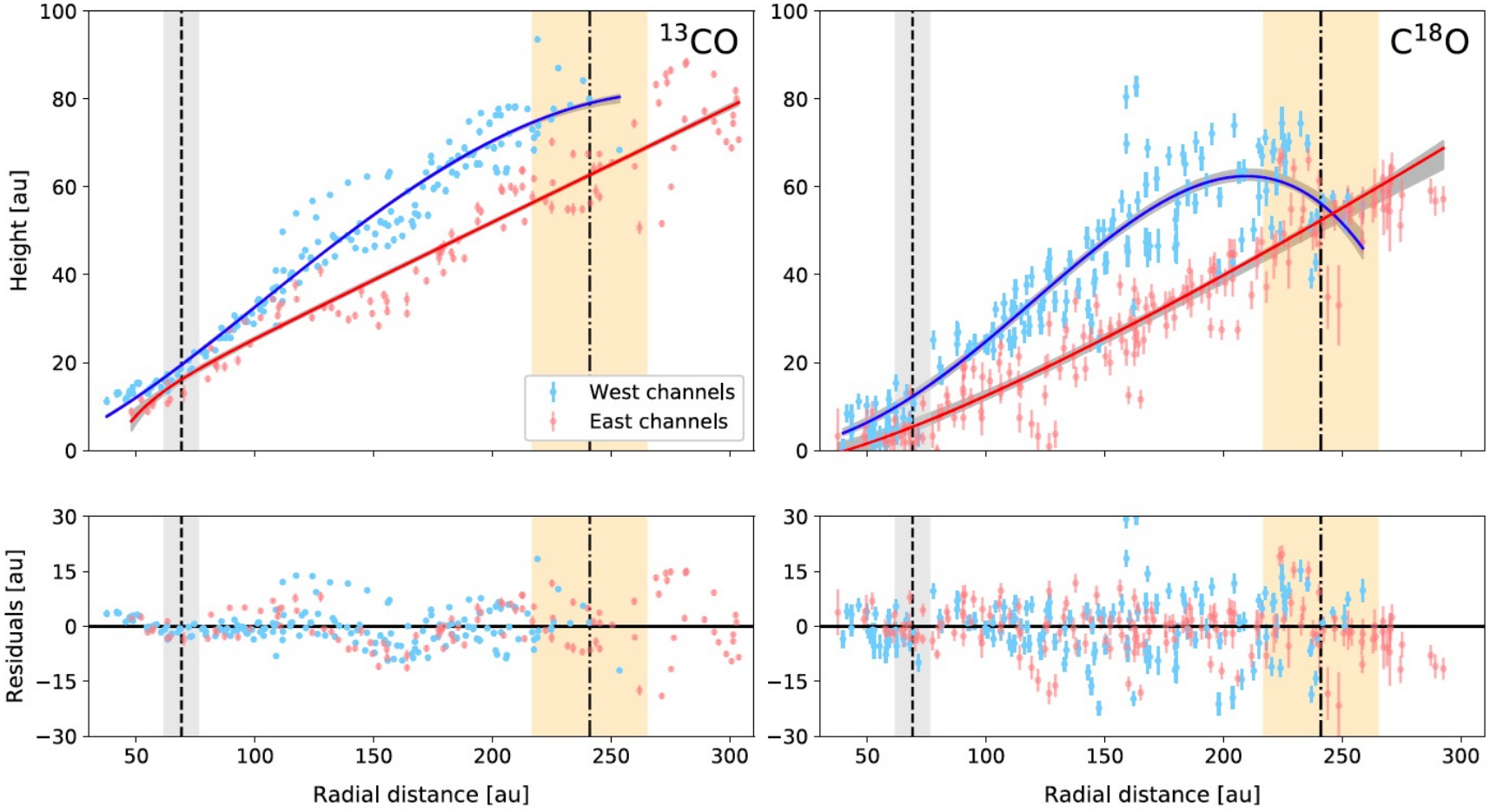
Paneque-Carreño et al., 2021

- Class II stellar object, ρ-Ophiuchus
- $M_* = 0.49\ M_\odot$
- disk-to-star mass ratio 0.3
- Large scale spirals and dust gap

- Heavy cloud absorption in East side
- Less contaminated B7 line emission from ALMA program #2016.1.00606.S and #2017.1.00069.S PI: L. Pérez.

Perez et al., 2016, Huang et al., 2018c, Veronesi et al. 2021

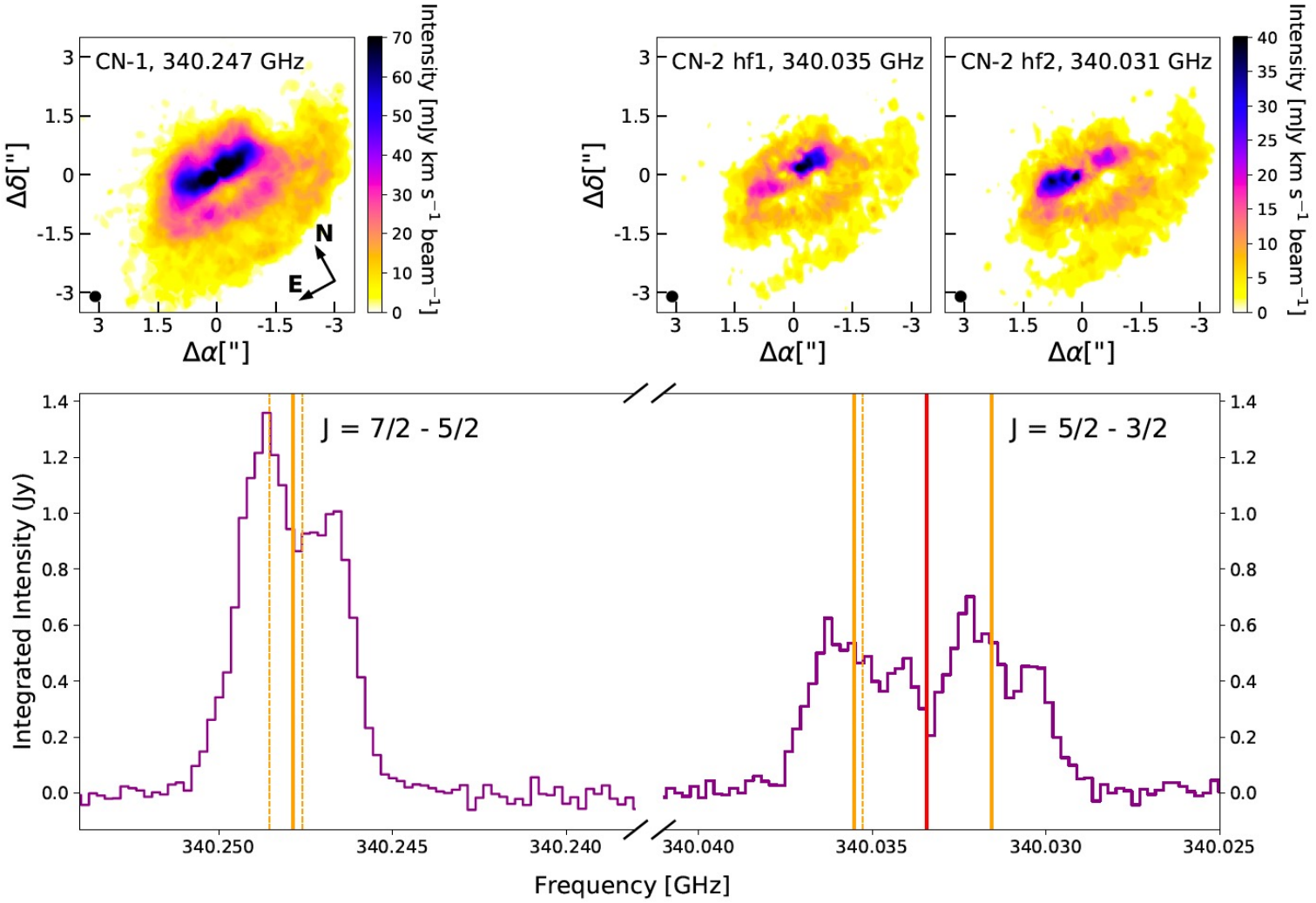
CO Emission Layer in Elias 2-27



Scale height asymmetry that distinguishes **between West and East**

Paneque-Carreño et al. 2021

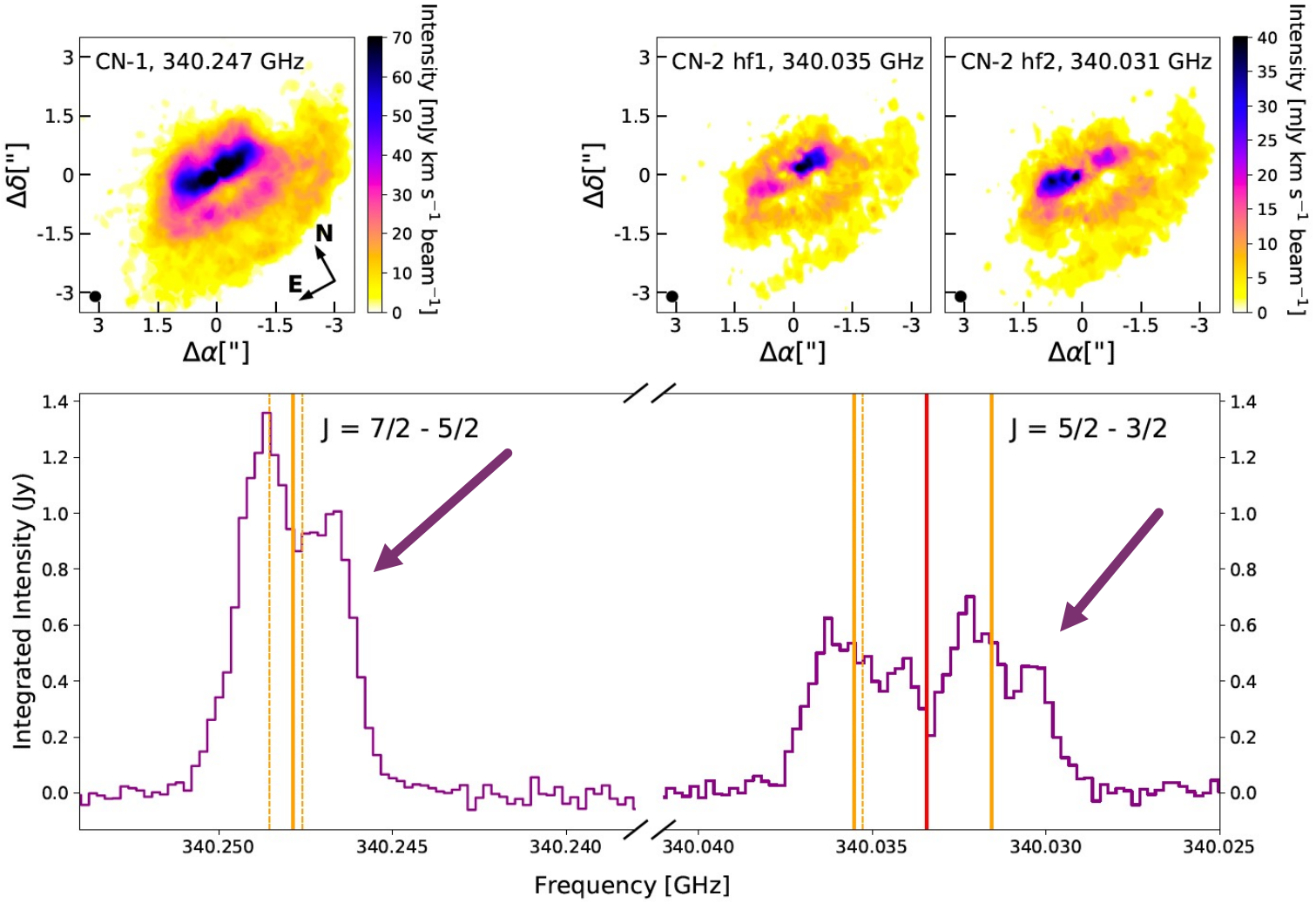
CN *N* = 3-2 emission



- Three emission features with similar morphology
- Blended line emission and possible absorption

Paneque-Carreño et al., to be submitted

CN N = 3-2 emission



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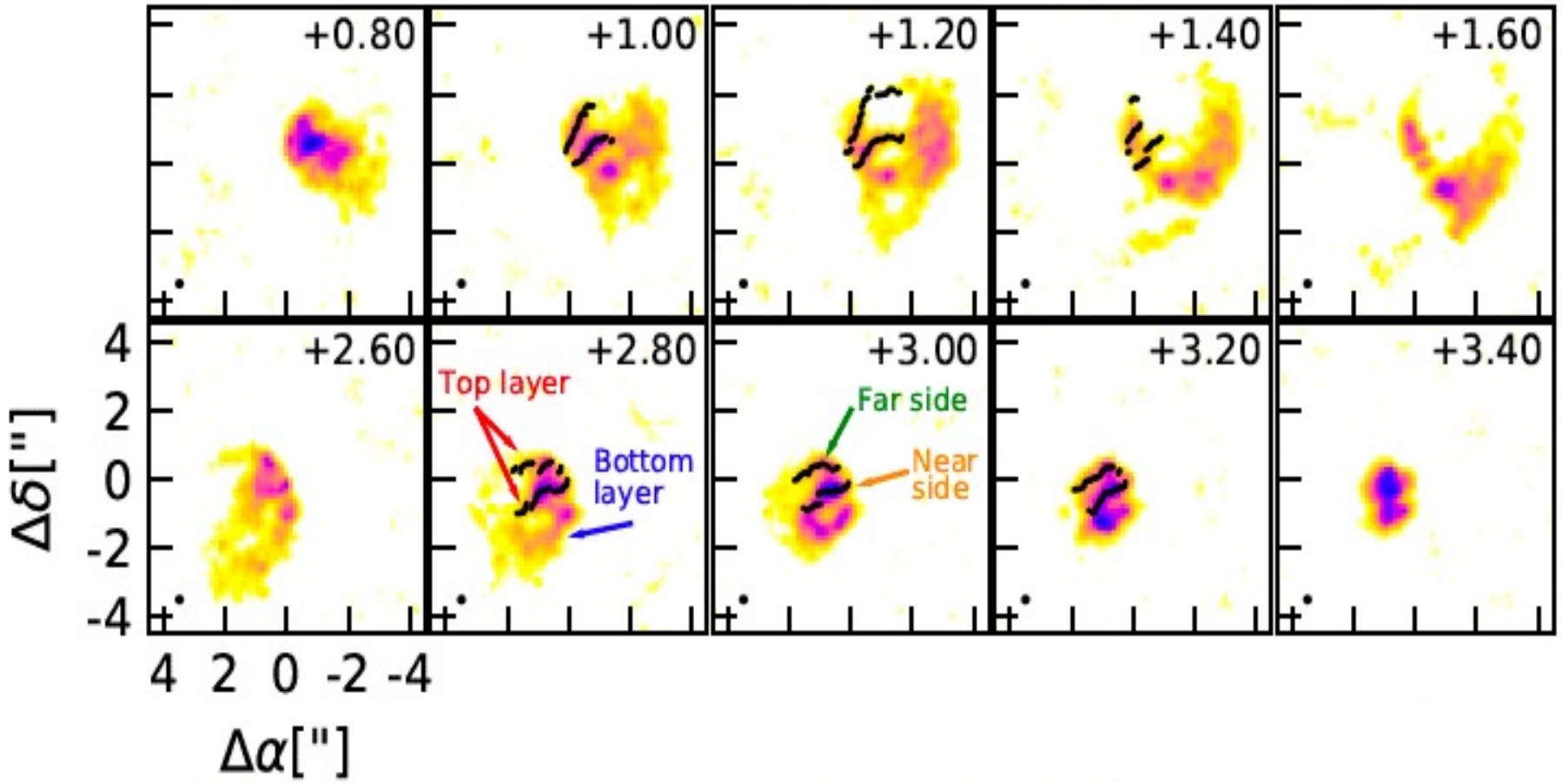
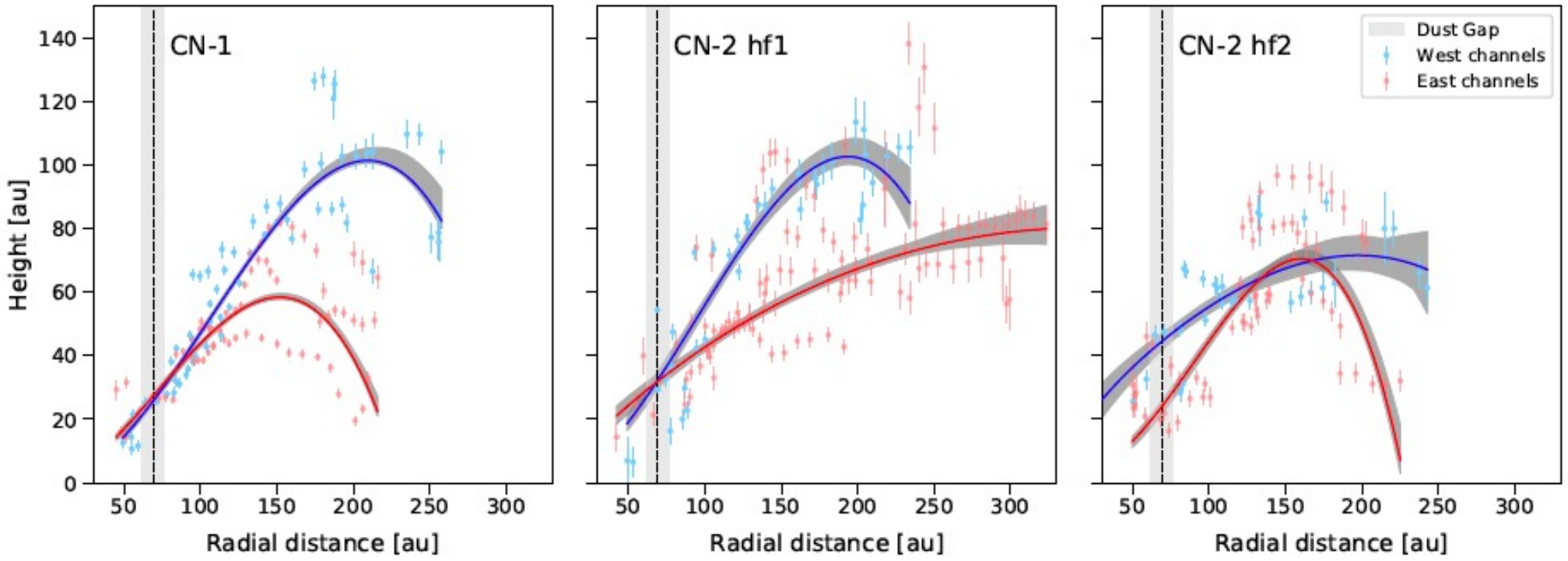
Paneque-Carreño et al., to be submitted

CN N = 3-2, tracing emission layer



Paneque-Carreño et al., to be submitted

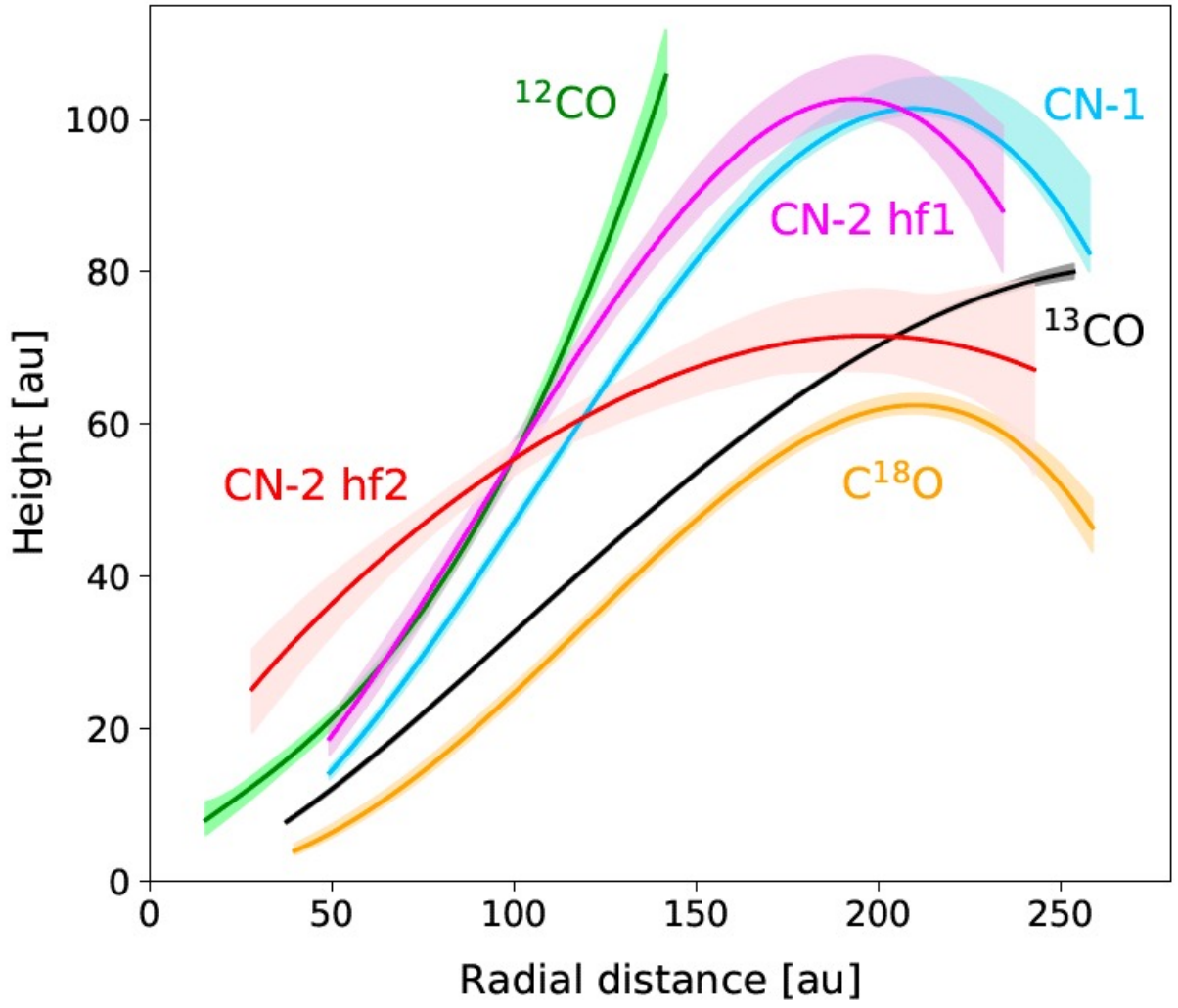
CN N = 3-2, tracing emission layer



East/West **scale height asymmetry** is recovered **in CN**

Paneque-Carreño et al., to be submitted

Emission layers in Elias 2-27

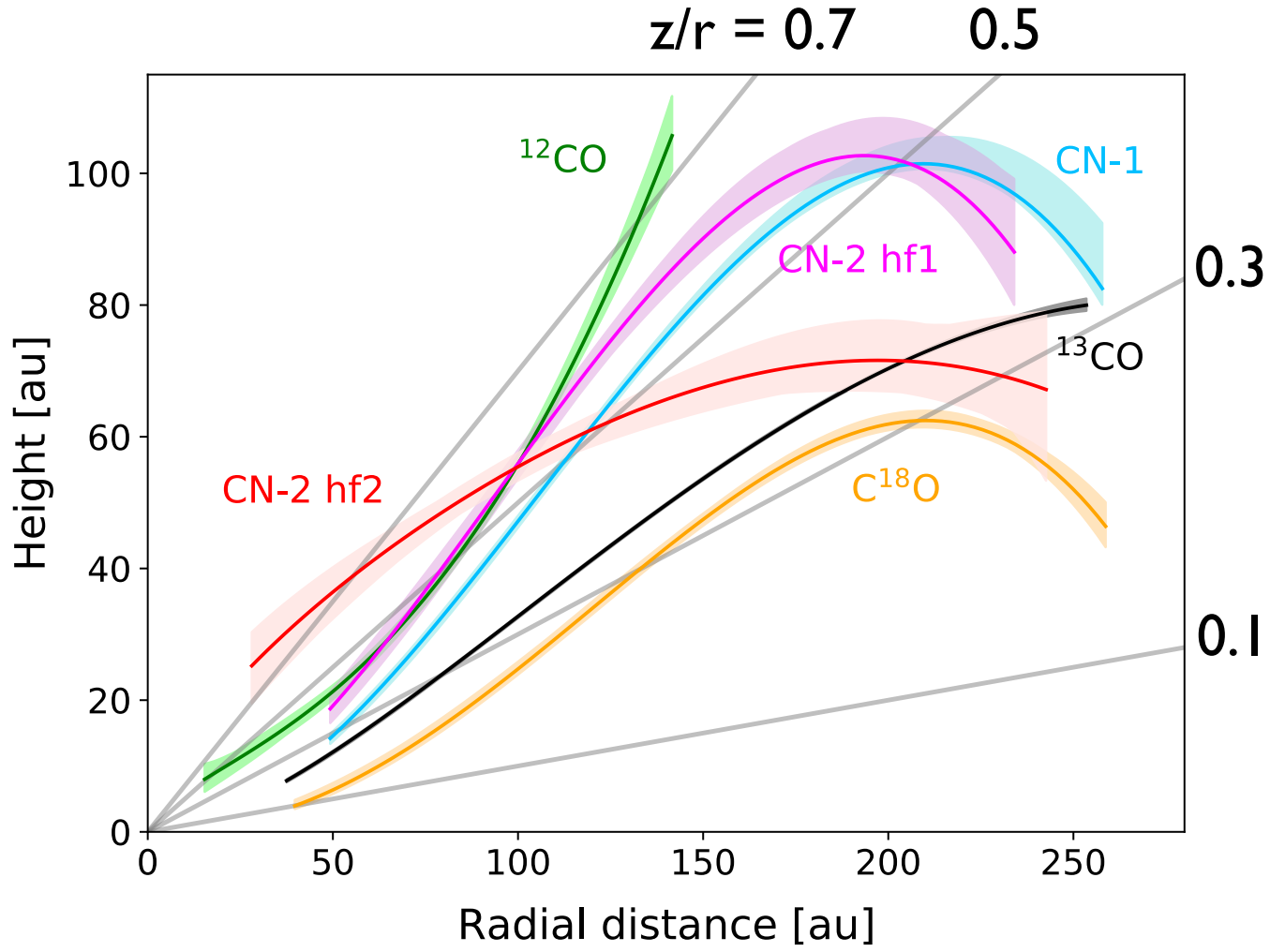


- Data from West side of the disk only
- CN traces a layer **co-located with ^{12}CO**

^{12}CO data from DSHARP, Andrews et al. 2018

Paneque-Carreño et al., to be submitted

Emission layers in Elias 2-27

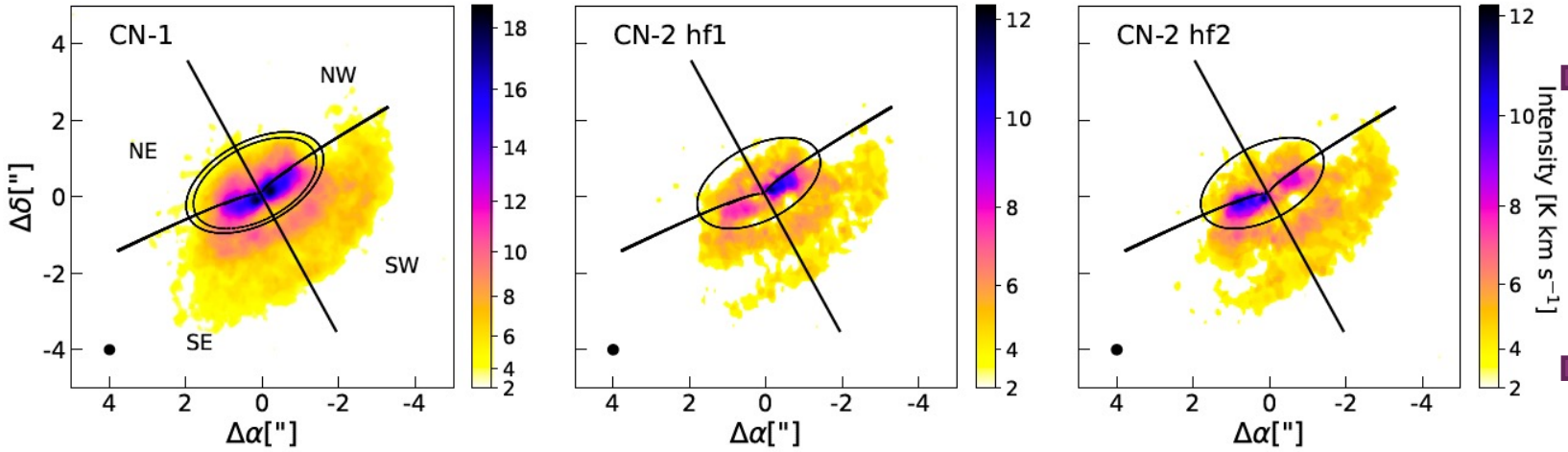


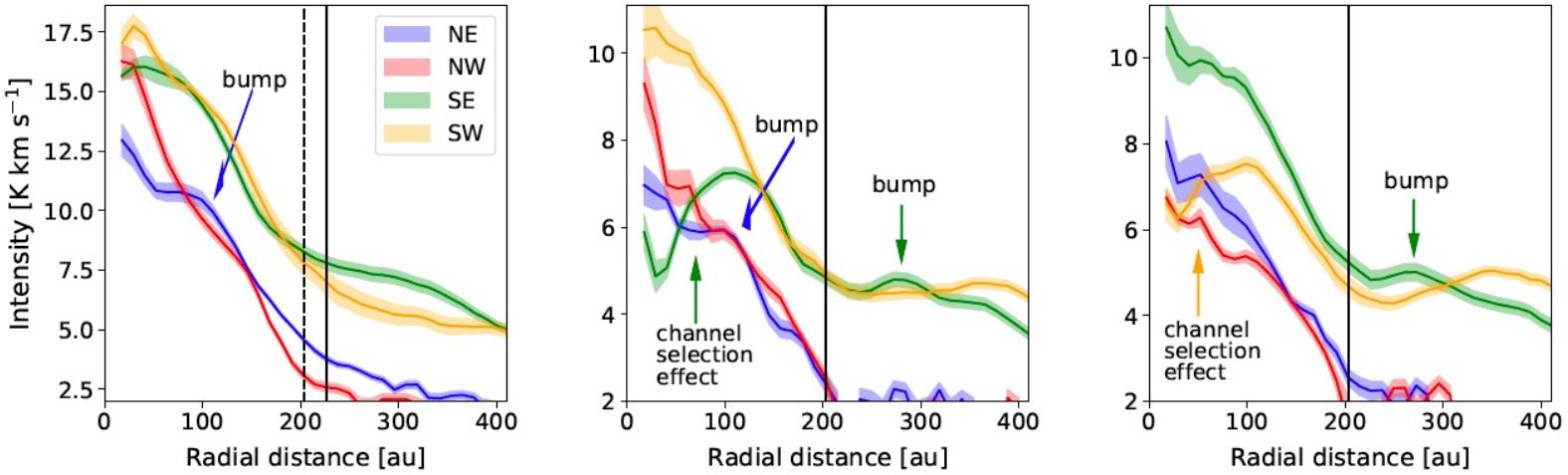
Average z/r of 0.5 for CN emitting layer

^{12}CO data from DSHARP, Andrews et al. 2018

Paneque-Carreño et al., to be submitted

CN N = 3-2, deprojected emission





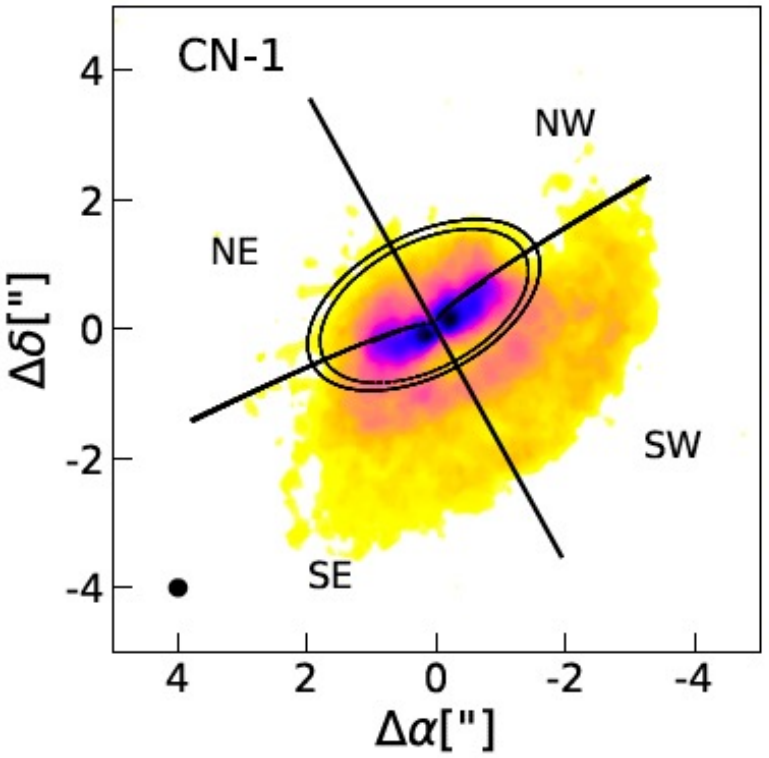
Accurate deprojection is possible due to constrained vertical emitting layer.

Asymmetry between **North and South** emission

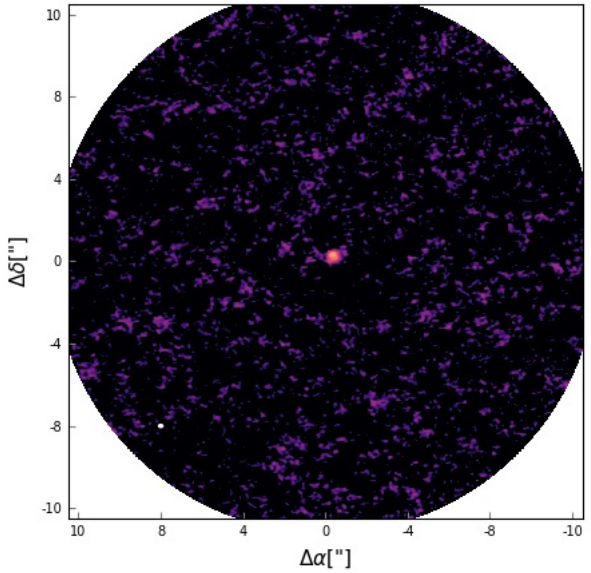
No clear CN ring is recovered

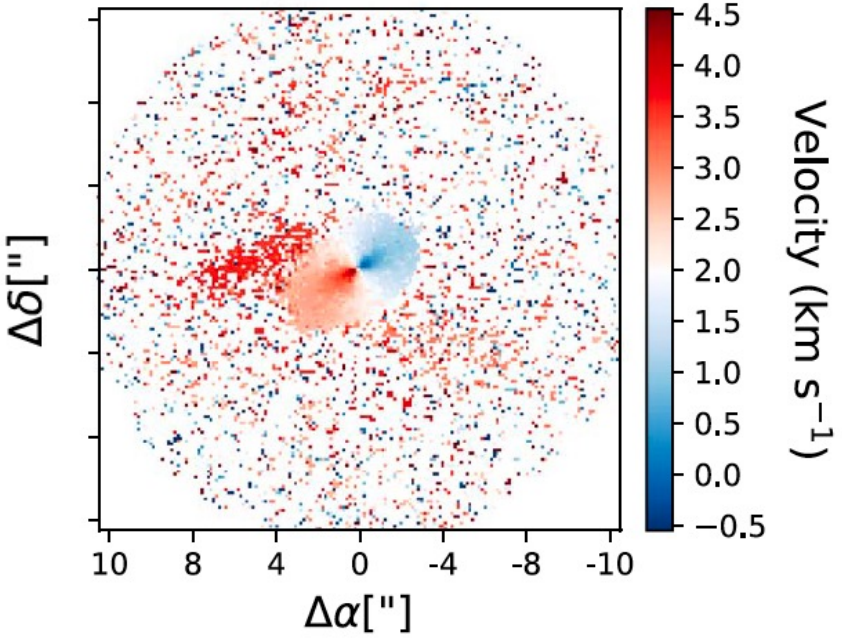
Paneque-Carreño et al., to be submitted

What causes the asymmetry?



$C^{18}O$

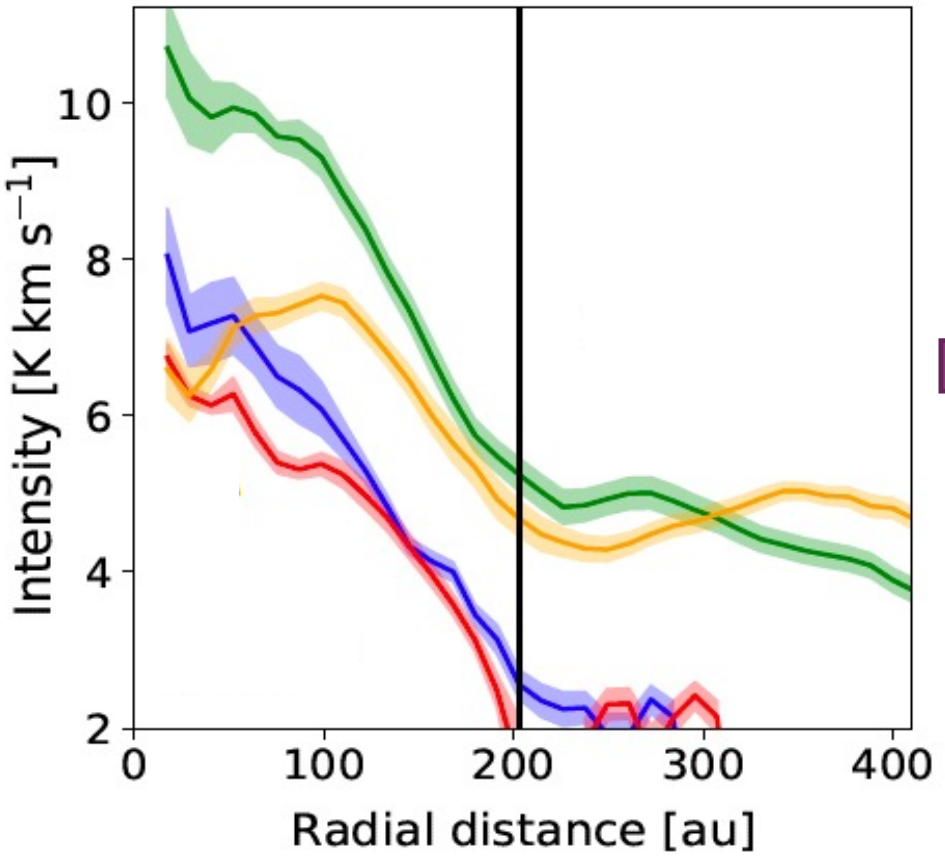




Paneque-Carreño et al., 2021

- Large-scale emission traced in ^{13}CO and $C^{18}O$ data, possibly on-going infall.
- CN sensitive to UV flux, if small grains are infalling they would be shielding the gas from energetic photons

CN N = 3-2, physical properties

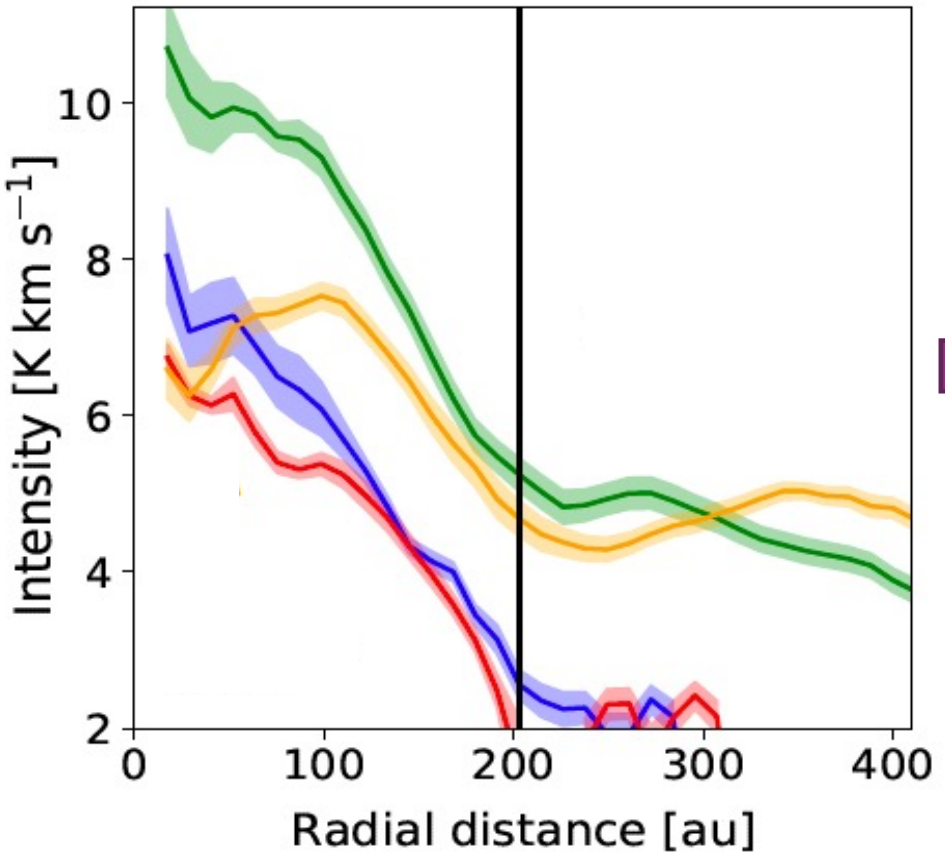


$$N_u = \frac{4\pi S_\nu \Delta v}{A_{ul}\Omega hc}$$

Analysis divided in quadrants!

Paneque-Carreño et al., to be submitted

CN N = 3-2, physical properties

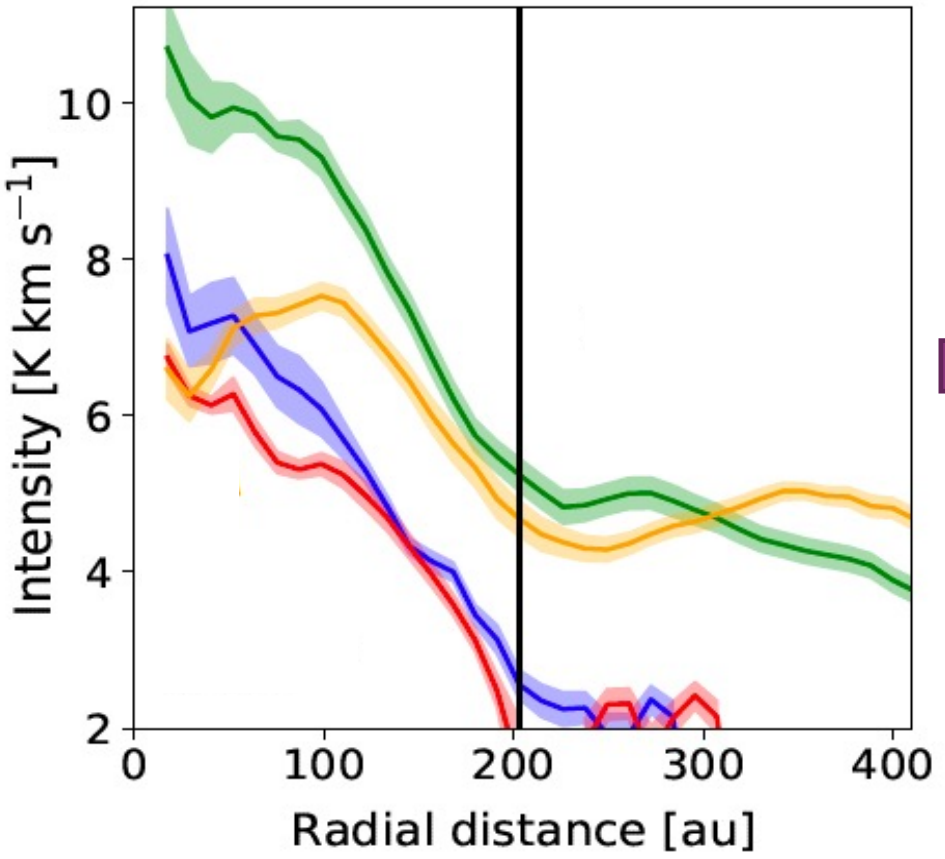


$$N_u = \frac{4\pi S_\nu \Delta v}{A_{ul}\Omega hc}$$

$$\frac{N_u}{g_u} = \frac{N_T}{Q(T_{rot})} e^{-E_u/kT_{rot}}$$

Paneque-Carreño et al., to be submitted

CN N = 3-2, physical properties



$$N_u = \frac{4\pi S_\nu \Delta v}{A_{ul}\Omega hc}$$

$$\frac{N_u}{g_u} = \frac{N_T}{Q(T_{rot})} e^{-E_u/kT_{rot}}$$

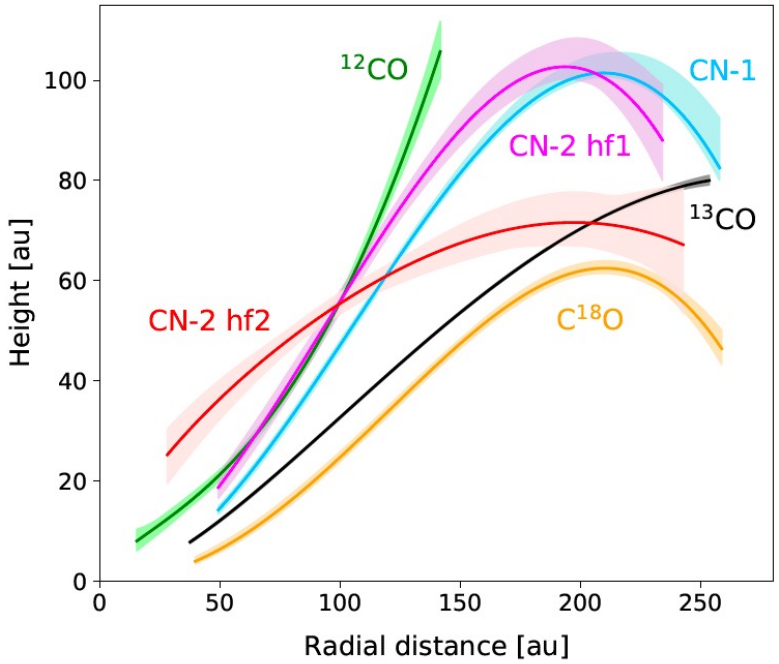
?

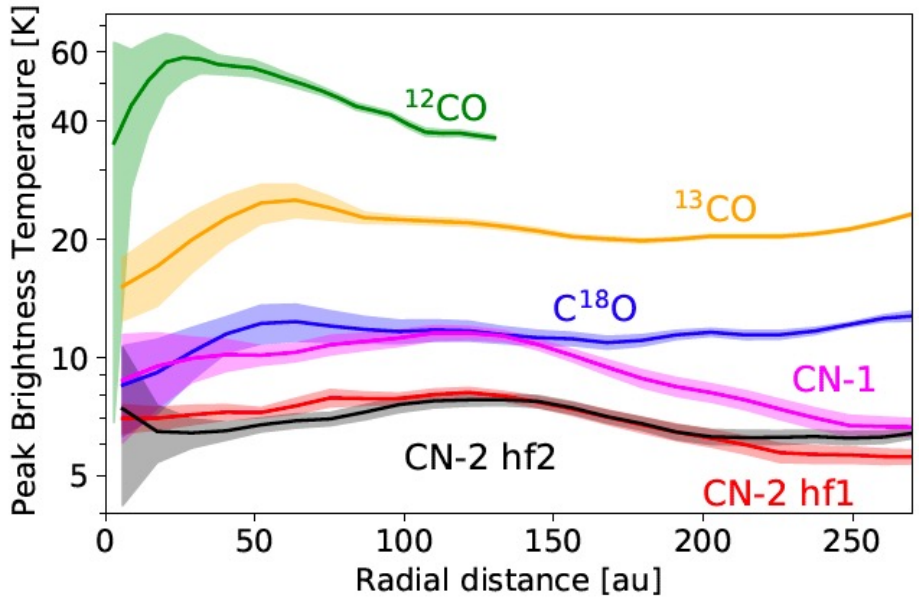
Paneque-Carreño et al., to be submitted

Estimation of T_{rot}

$$\frac{N_u}{g_u} = \frac{N_T}{Q(T_{rot})} e^{-E_u/kT_{rot}}$$

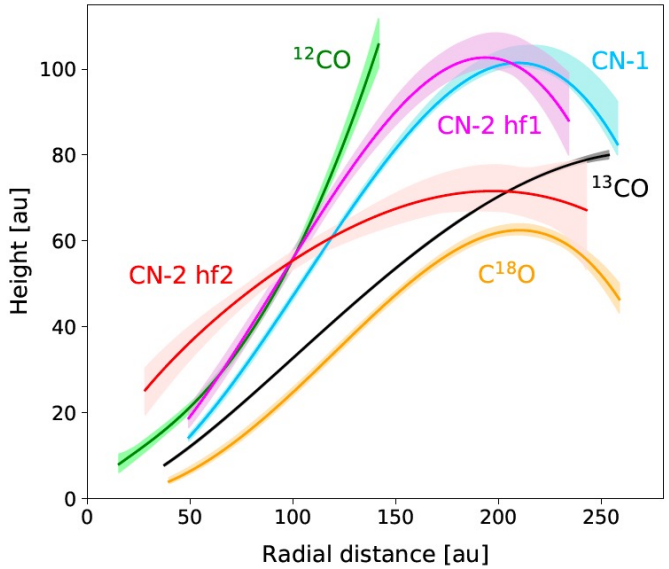
Temperature profile of CN is estimated from the brightness temperature of optically thick **CO emission.**





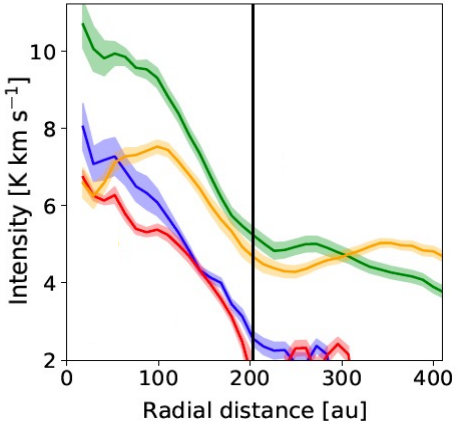
Paneque-Carreño et al., to be submitted

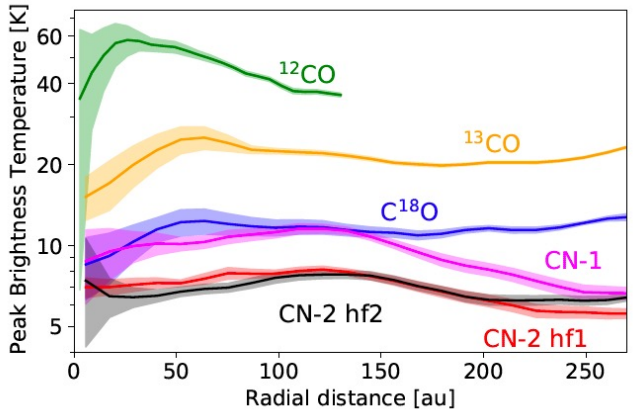
CN N = 3-2, physical properties



$$N_u = \frac{4\pi S_\nu \Delta v}{A_{ul}\Omega hc}$$

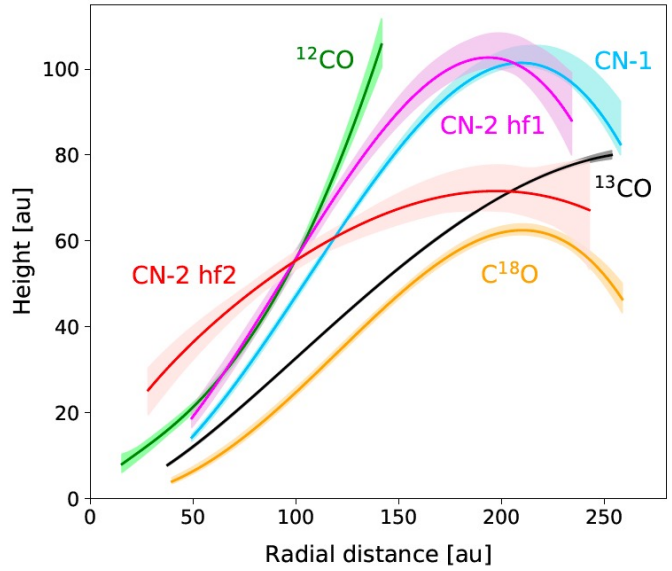
$$\frac{N_u}{g_u} = \frac{N_T}{Q(T_{rot})} e^{-E_u/kT_{rot}}$$

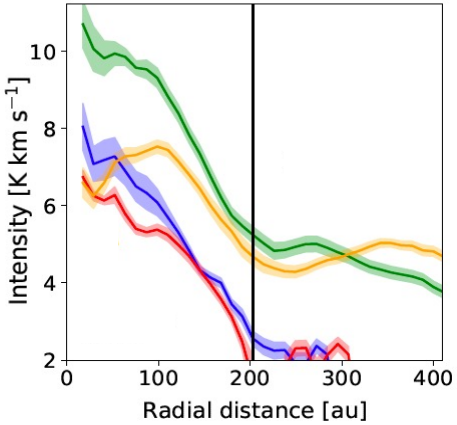


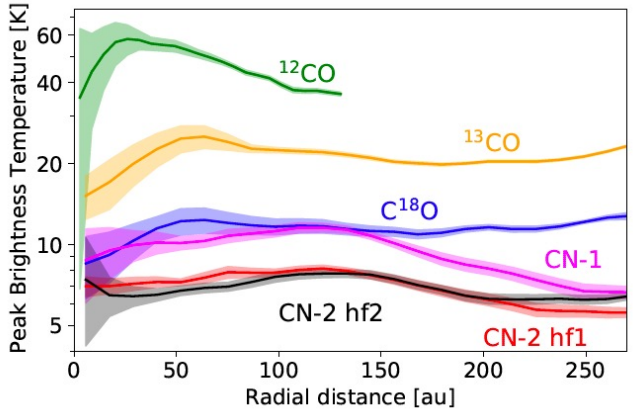


Paneque-Carreño et al., to be submitted

CN N = 3-2, physical properties







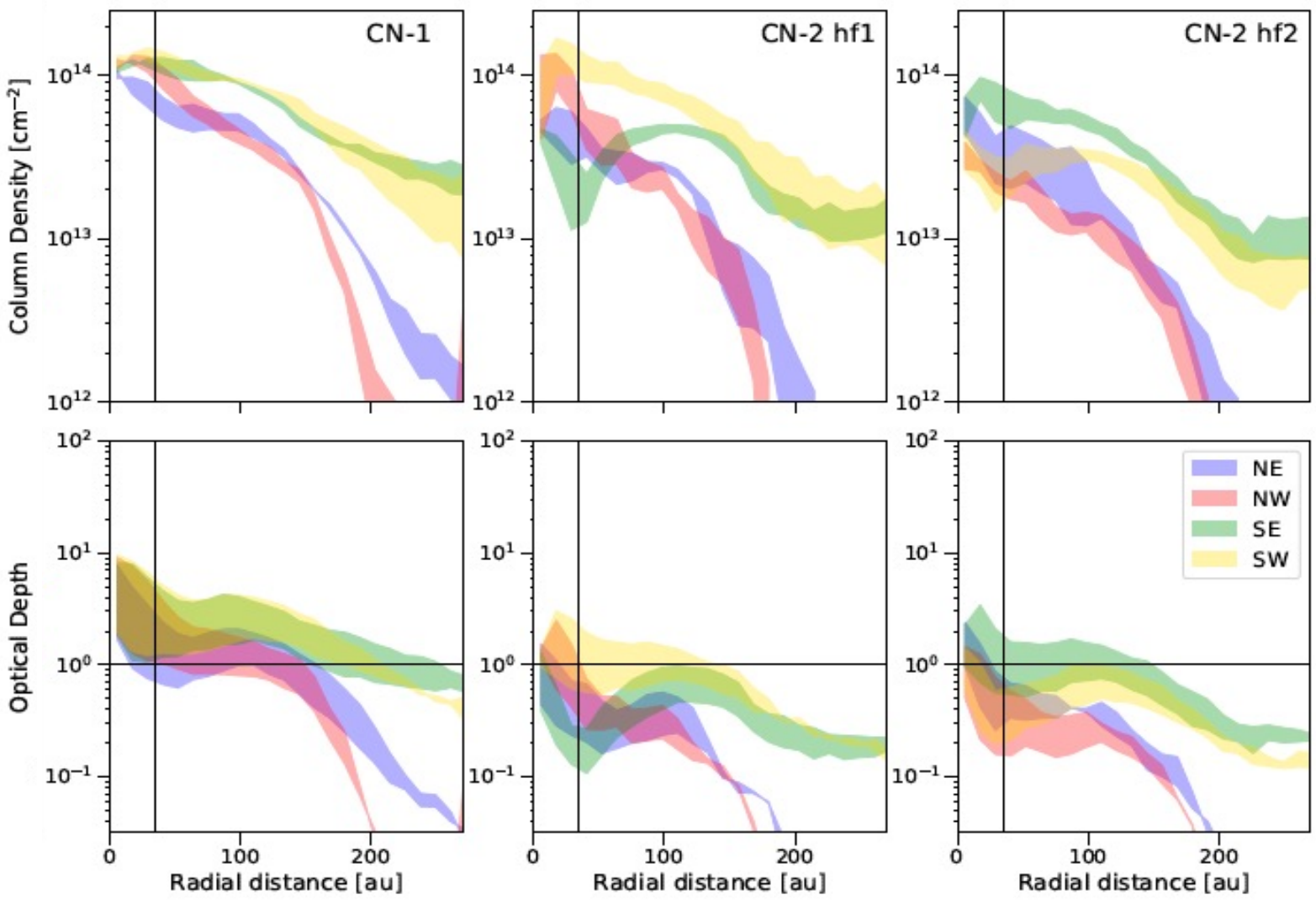
$$N_u = \frac{4\pi S_\nu \Delta v}{A_{ul}\Omega h c}$$

$$\frac{N_u}{g_u} = \frac{N_T}{Q(T_{rot})} e^{-E_u/kT_{rot}}$$

$$\tau_{ul} = \frac{A_{ul}c^3}{8\pi\nu^3\Delta v} N_u (e^{h\nu/kT_{rot}} - 1)$$

Paneque-Carreño et al., to be submitted

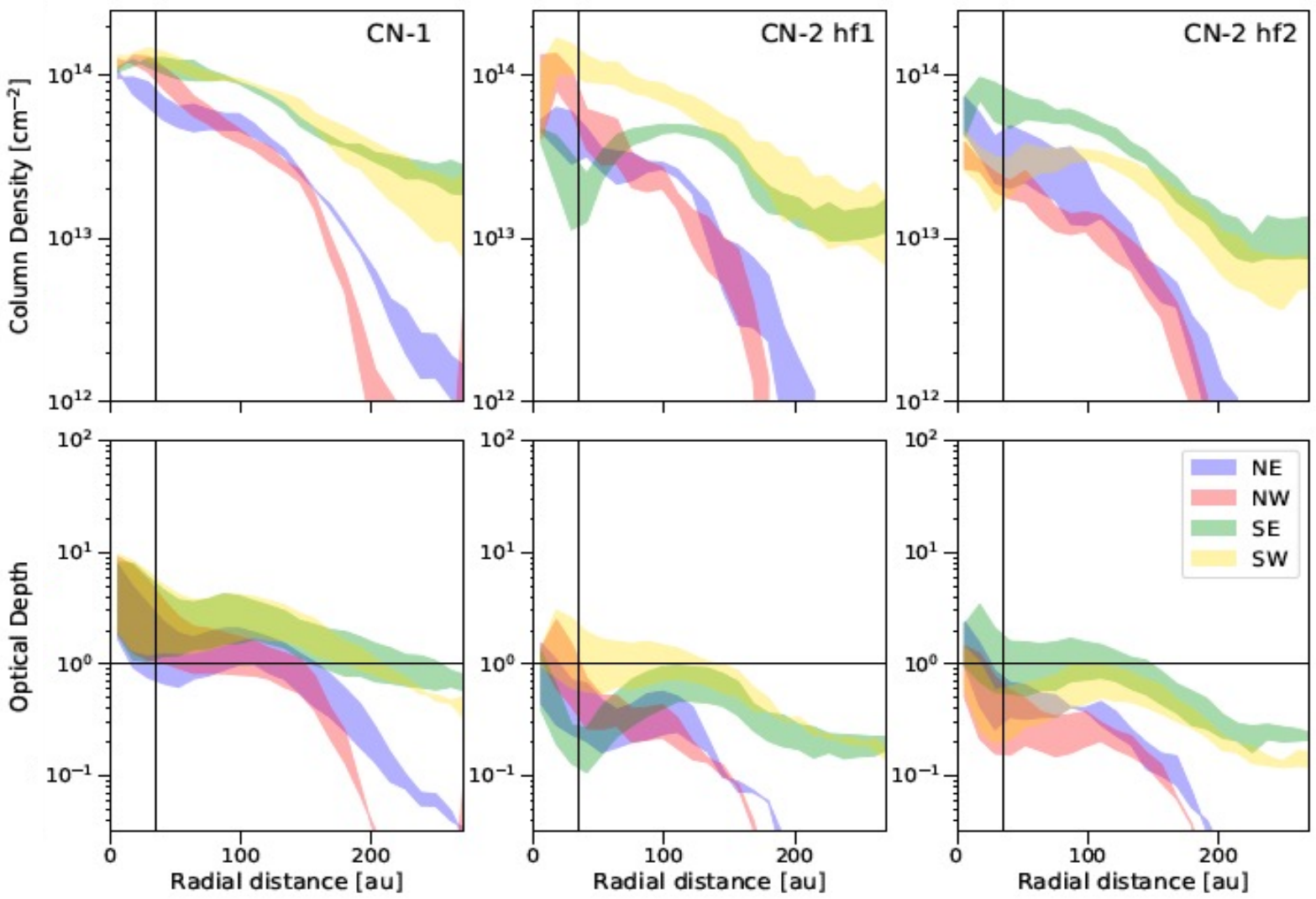
CN N = 3-2, physical properties

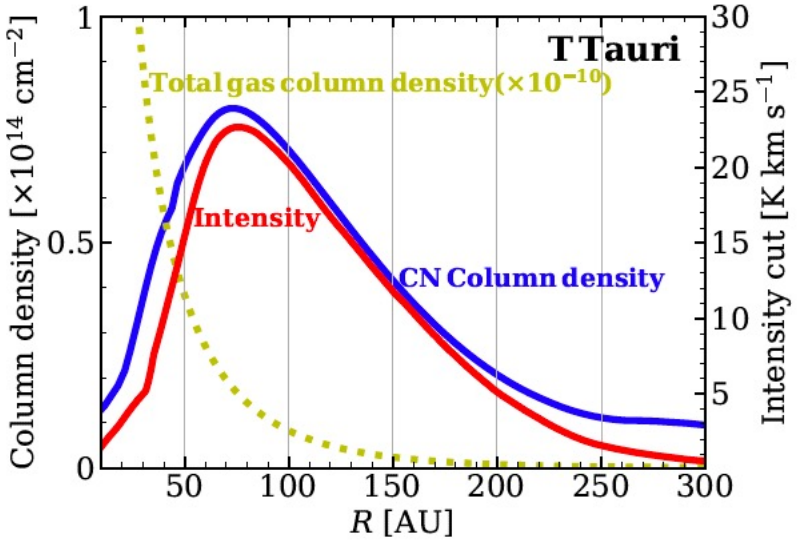


- Column density 10^{14}–10^{13}cm^{-2} in South side
- Steep decrease in North side column density
- Optically thin emission beyond 100au

Paneque-Carreño et al., to be submitted

CN N = 3-2, physical properties

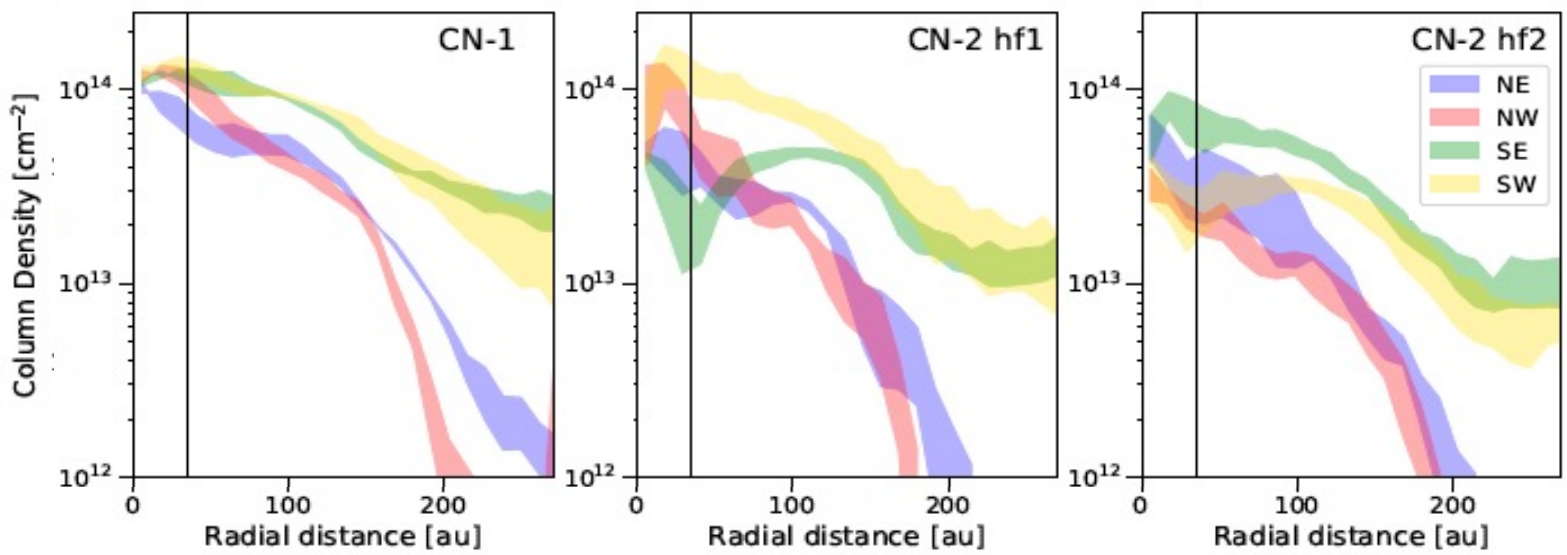


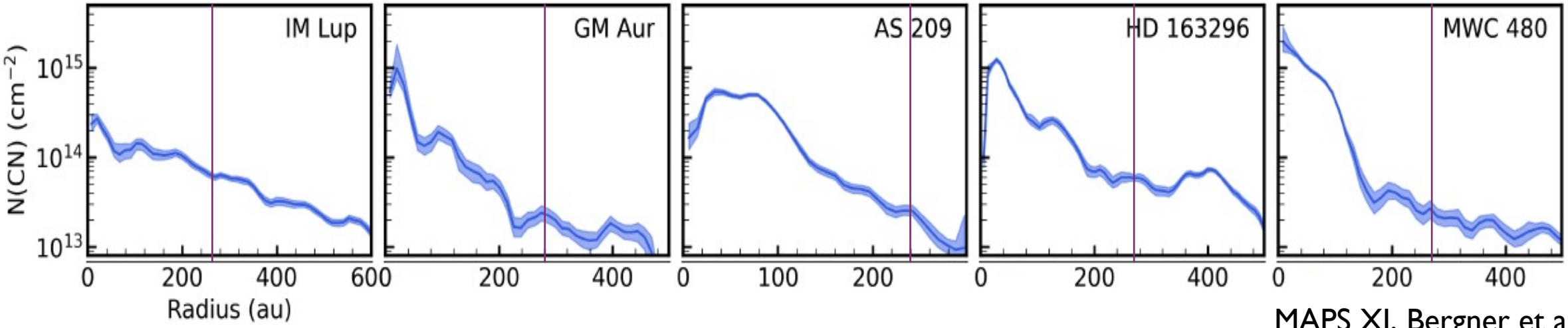


Cazzoletti et al., 2018

Paneque-Carreño et al., to be submitted

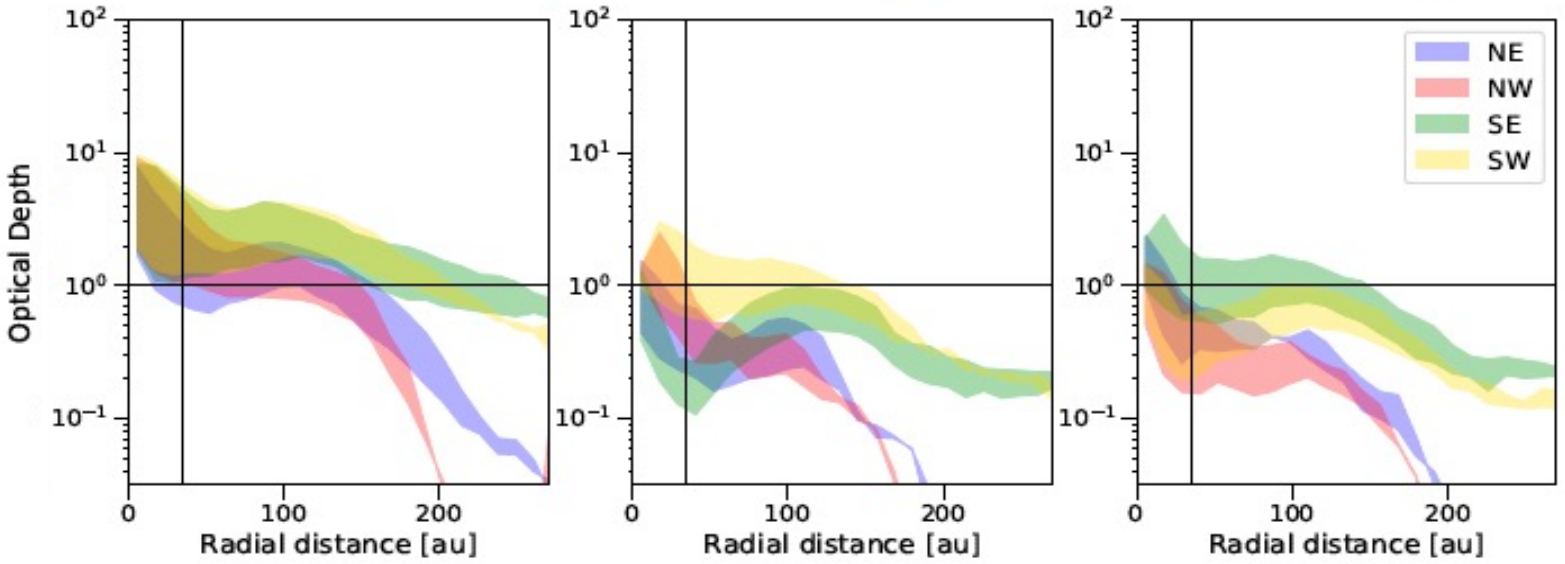
CN N = 3-2, physical properties

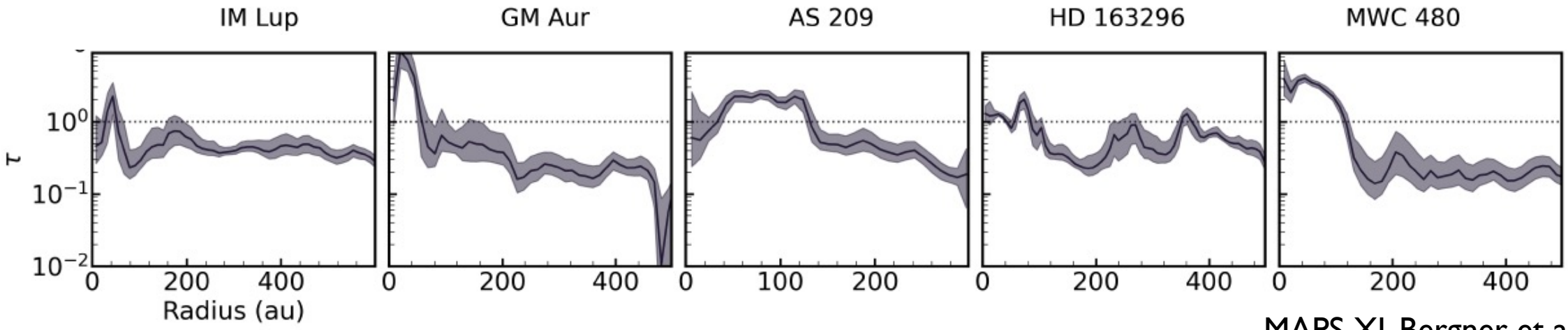




MAPS XI, Bergner et al., 2021

CN N = 3-2, physical properties





MAPS XI, Bergner et al., 2021

SUMMARY

- In Elias 2-27 **CN emission comes from a high vertical region**, co-located with CO. It is **optically thin and constrained spatially.**
- The **East/West vertical asymmetry** in Elias 2-27 seems to be a **global phenomena. CN additionally traces** a strong **North/South brightness asymmetry,** which **could be** an additional **indicator of infall.**
- CN emission properties are consistent with predictions for **FUV pumping origin.**
- **Direct tracing of the emitting surface is needed** for correct deprojection and for directly deriving physical properties.

TRACING THE DISK VERTICAL STRUCTURE WITH MULTIPLE MOLECULES

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