Revisiting Disk Masses with CO Isotopologues

Self-Consistent Models Reveal Sufficient Material for Planet Formation

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Artistic Illustration Credit: NSF/AUI/NSF NRAO/S.Dagnello

Why Measuring Disk Masses?

- Disk Mass
  - the total amount of **solids** and **volatiles** available for forming planets

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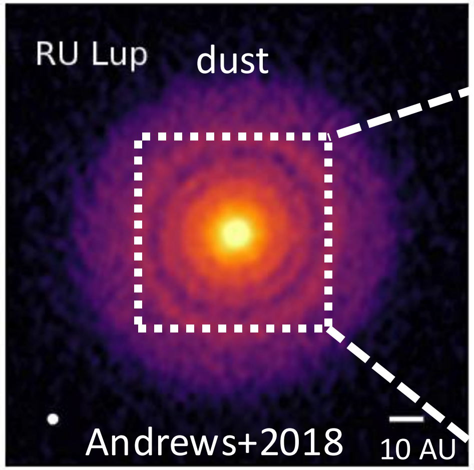

Artistic Illustration Credit: NSF/AUI/NSF NRAO/S.Dagnello

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Why Measuring Disk Masses?

- Disk Mass
  - – the total amount of **solids** and **volatiles** available for forming planets

- Set the dynamics of small and large grains
- Constrain the location and time for forming planets

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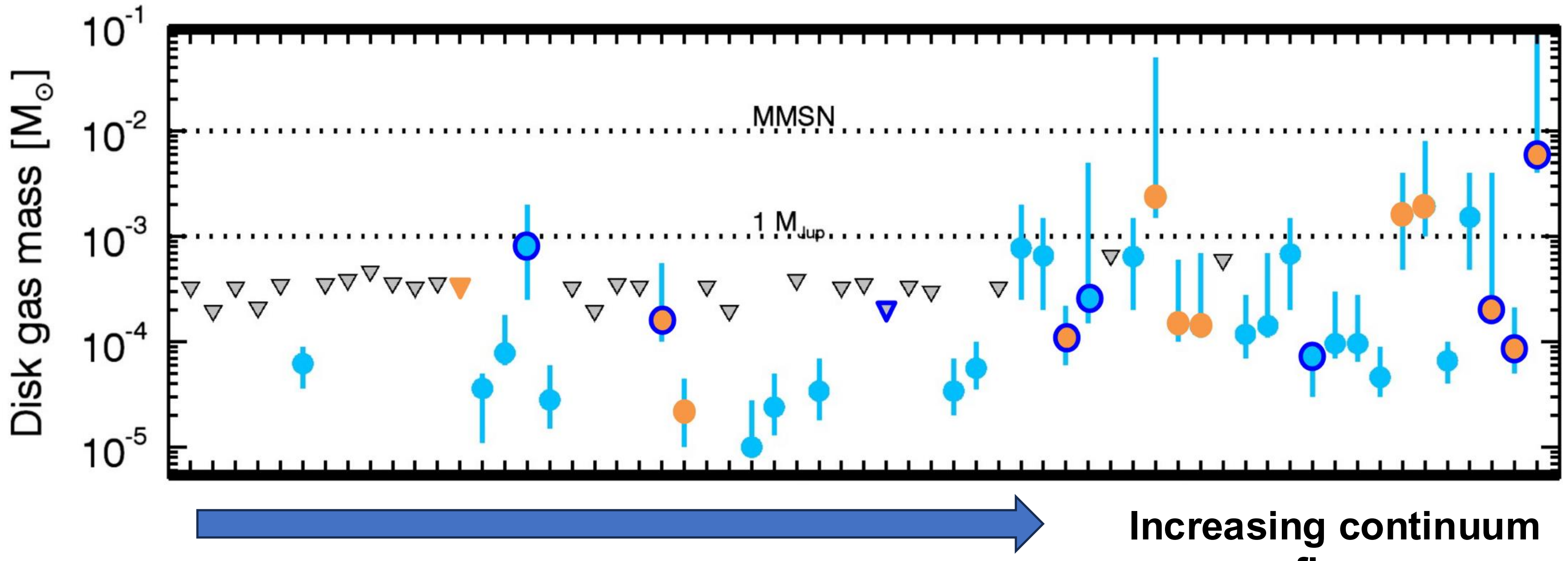
Disks were found to have low gas masses based on CO isotopologues
insufficient to form a solar system?



Increasing continuum flux

Lupus disks (Miotello+2017)

(also by other works such as *Ansdell*+2016; *Pascucci*+2016; *Long*+2017; *Manara*+2018)

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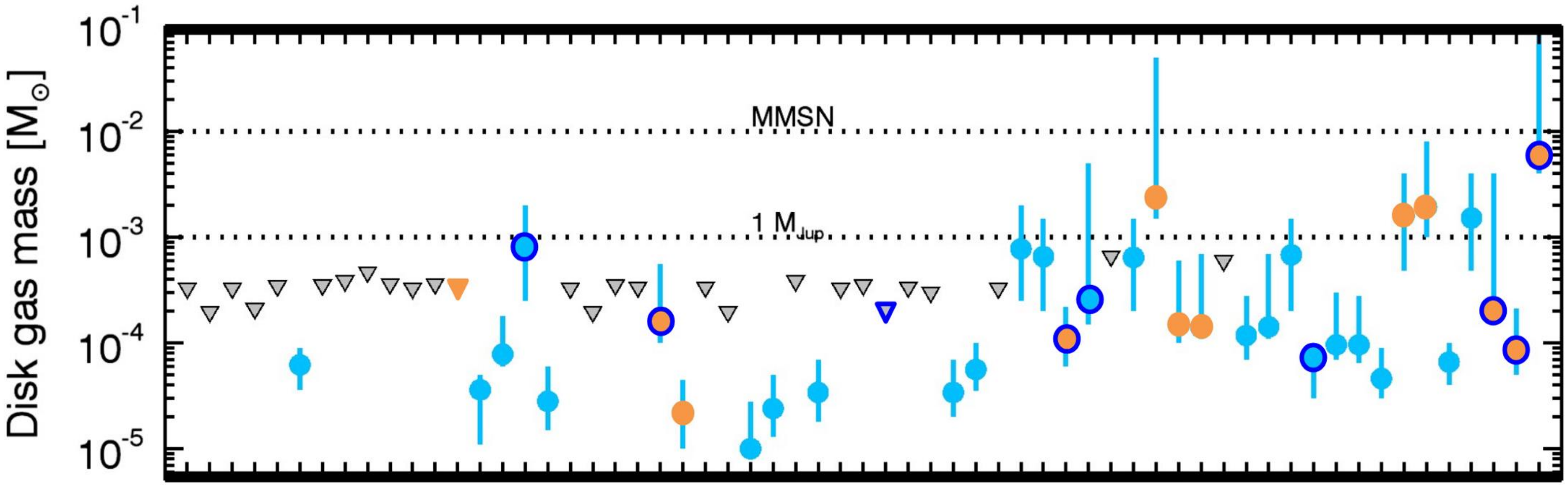

Increasing continuum flux

Lupus disks (Miotello+2017)

(also by other works such as *Ansdell*+2016; *Pascucci*+2016; *Long*+2017; *Manara*+2018)

However

- Lupus disks are only about ≈ 1 Myrs old;
- HD observations give large $\boldsymbol{M}_{\mathbf{gas}}$ (e.g., Bergin+2013, McClure+2016, Kama+2020)

Self-Consistent Thermochemical Models by **`DiskMINT`**

Disk Model For INdividual Targets

https://github.com/DingshanDeng/DiskMINT

Deng+2023, 2025a

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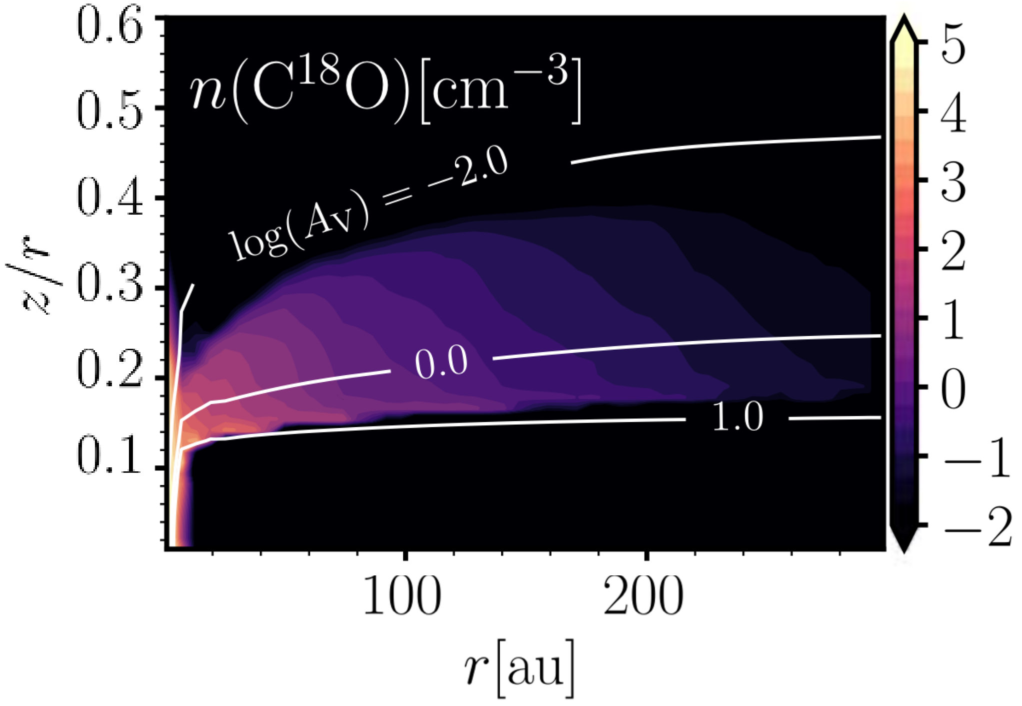
Physics and Chemistry are strongly coupled in disks, thus a self-consistent model is important



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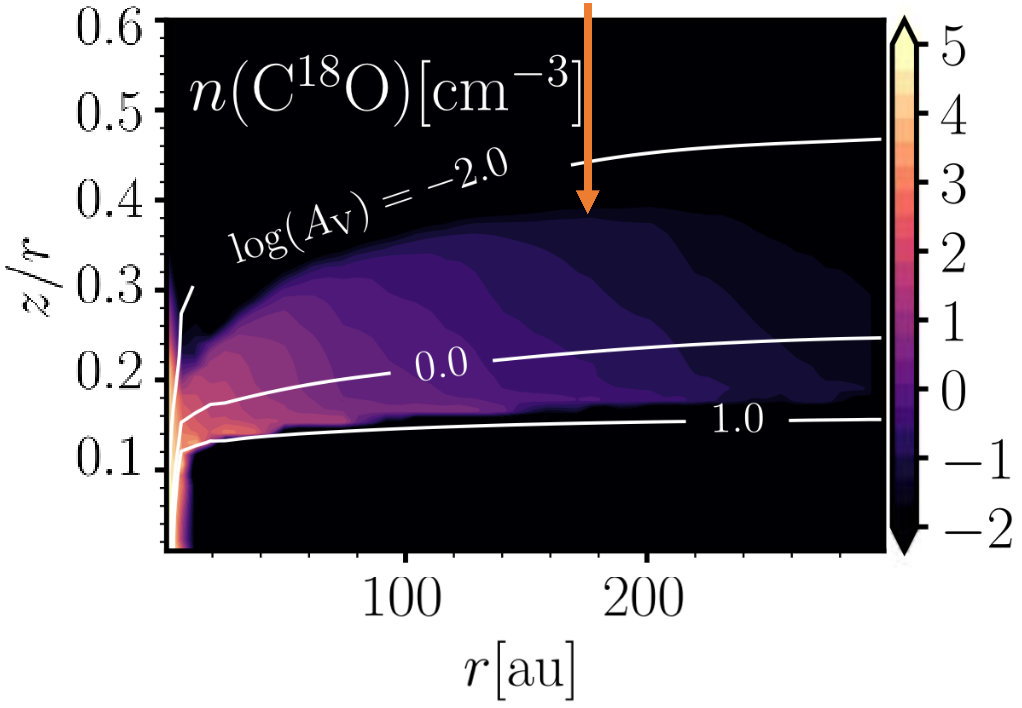

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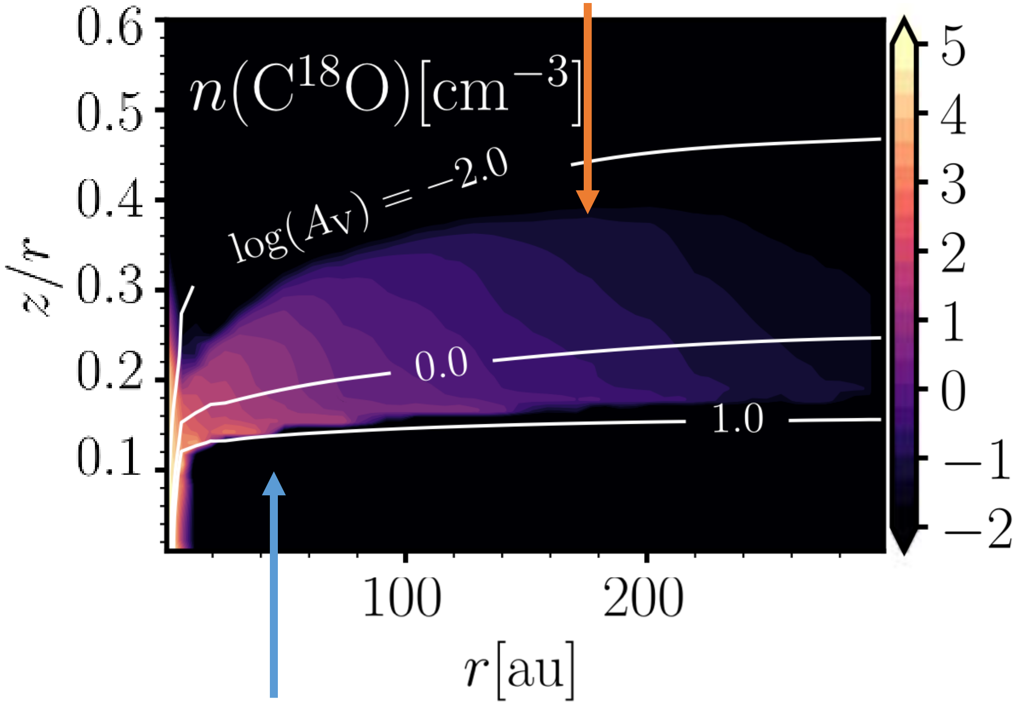

2. Freeze Out
With grain-surface chemistry

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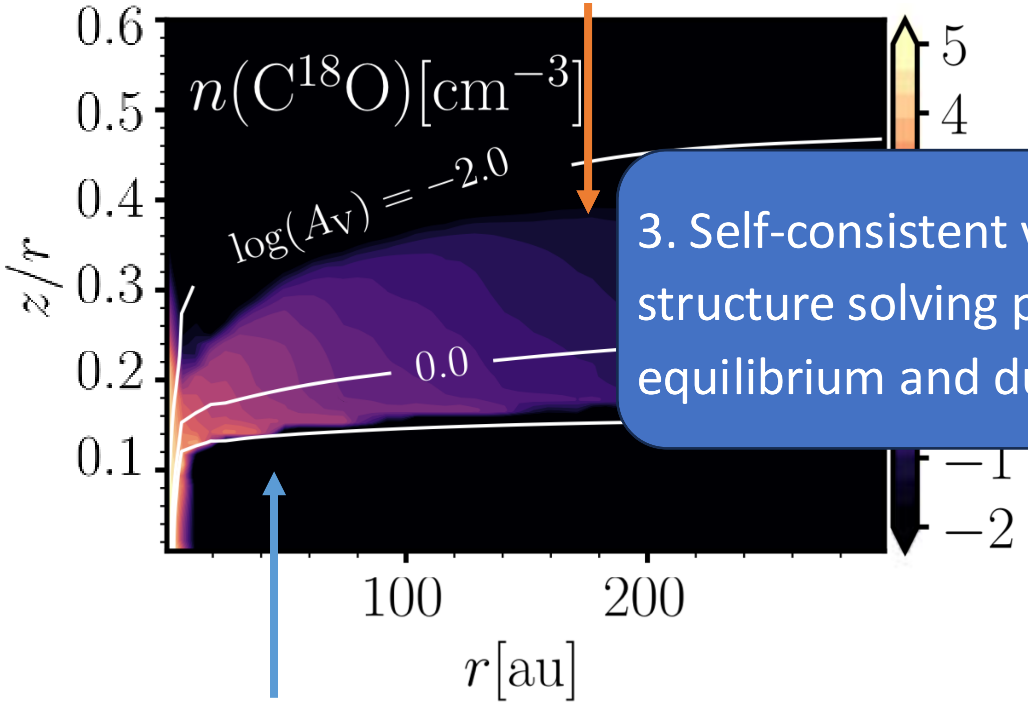


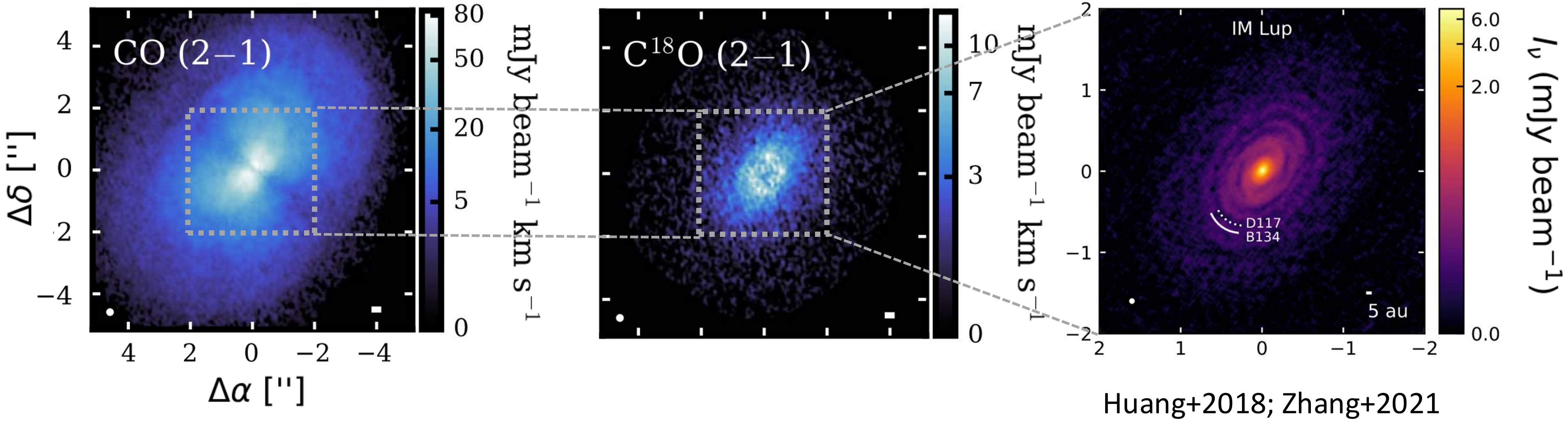
3. Self-consistent vertical structure solving pressure equilibrium and dust settling

2. Freeze Out
With grain-surface chemistry

Application to the Large disk around IM Lup Disk

IM Lup is one of the largest disks that has in-depth observations

- R_{CO} ≈ 500 AU (MAPS)
- R_{dust} ≈ 300 AU (DSHARP)



Huang+2018; Zhang+2021

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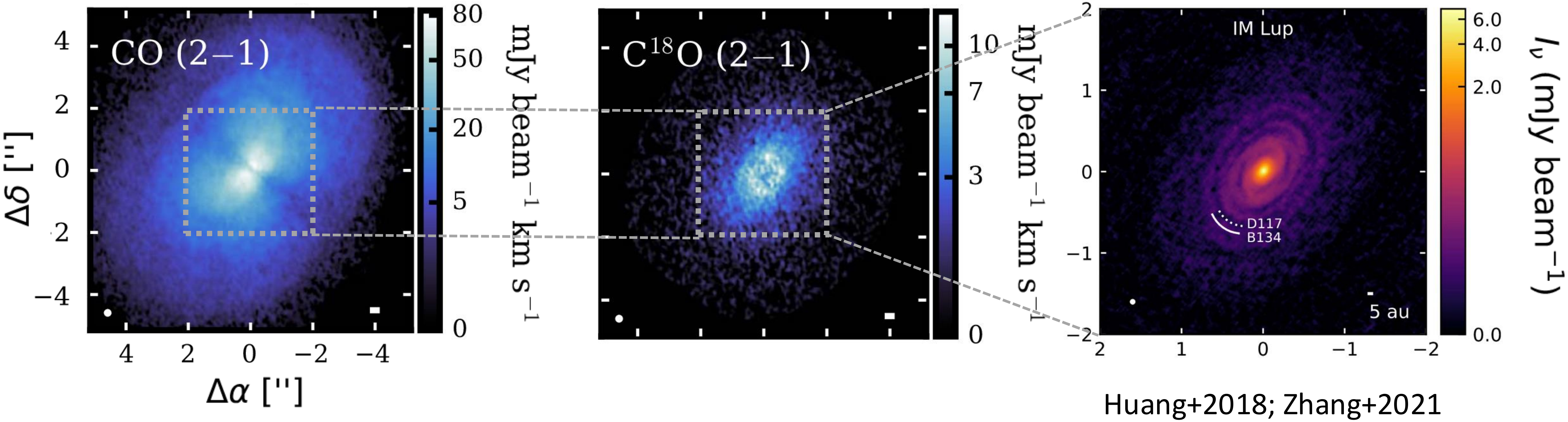
However, it was inferred with a gas-to-dust mass ratio of ≈ 1 or a CO depletion with a factor of ≈ 100 from thermochemical disk models



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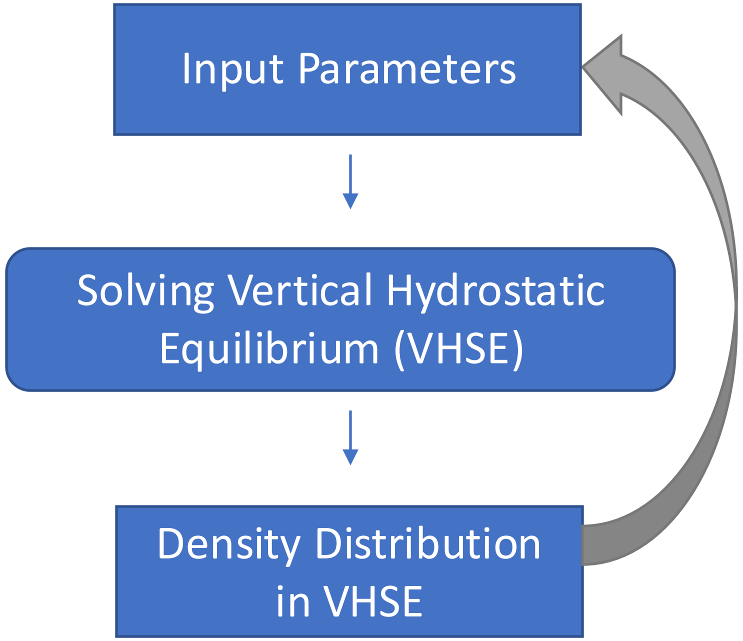
Application to the Large disk around IM Lup

DiskMINT builds models that consider dust and gas simultaneously with self-consistent thermal-density distribution



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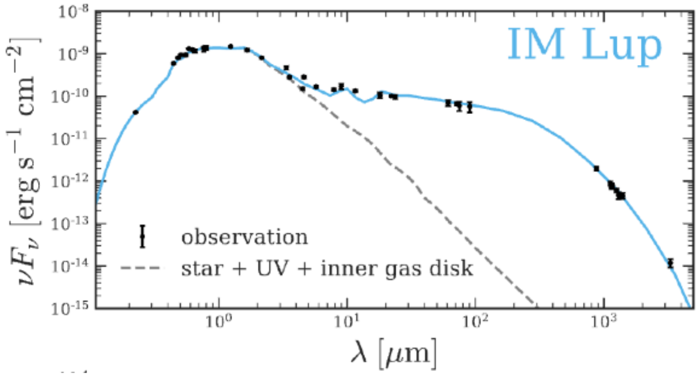

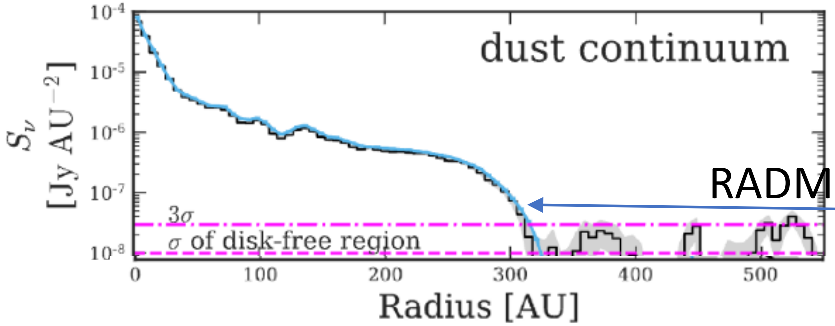

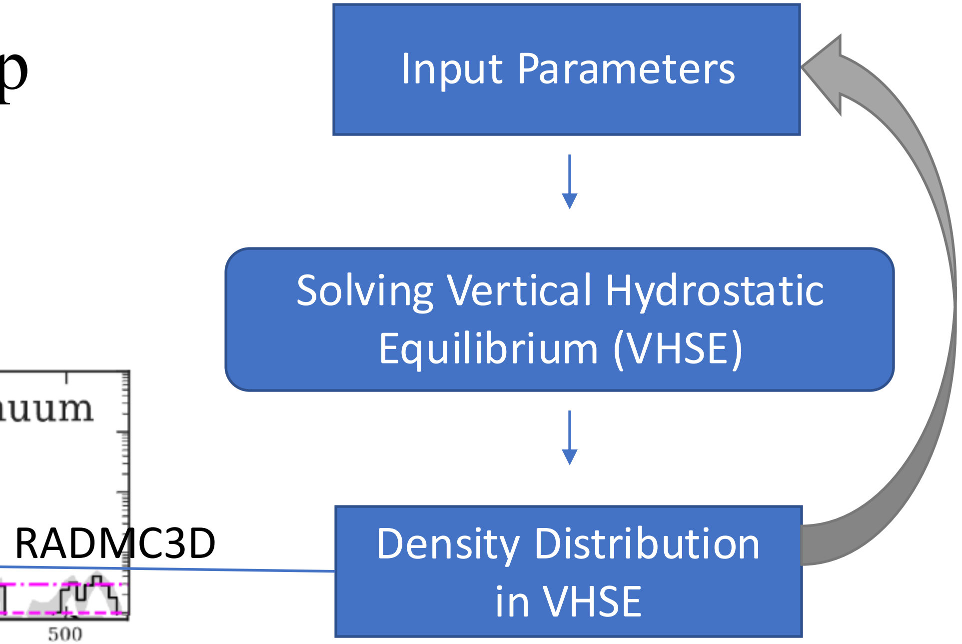

Deng+2023, 2025a

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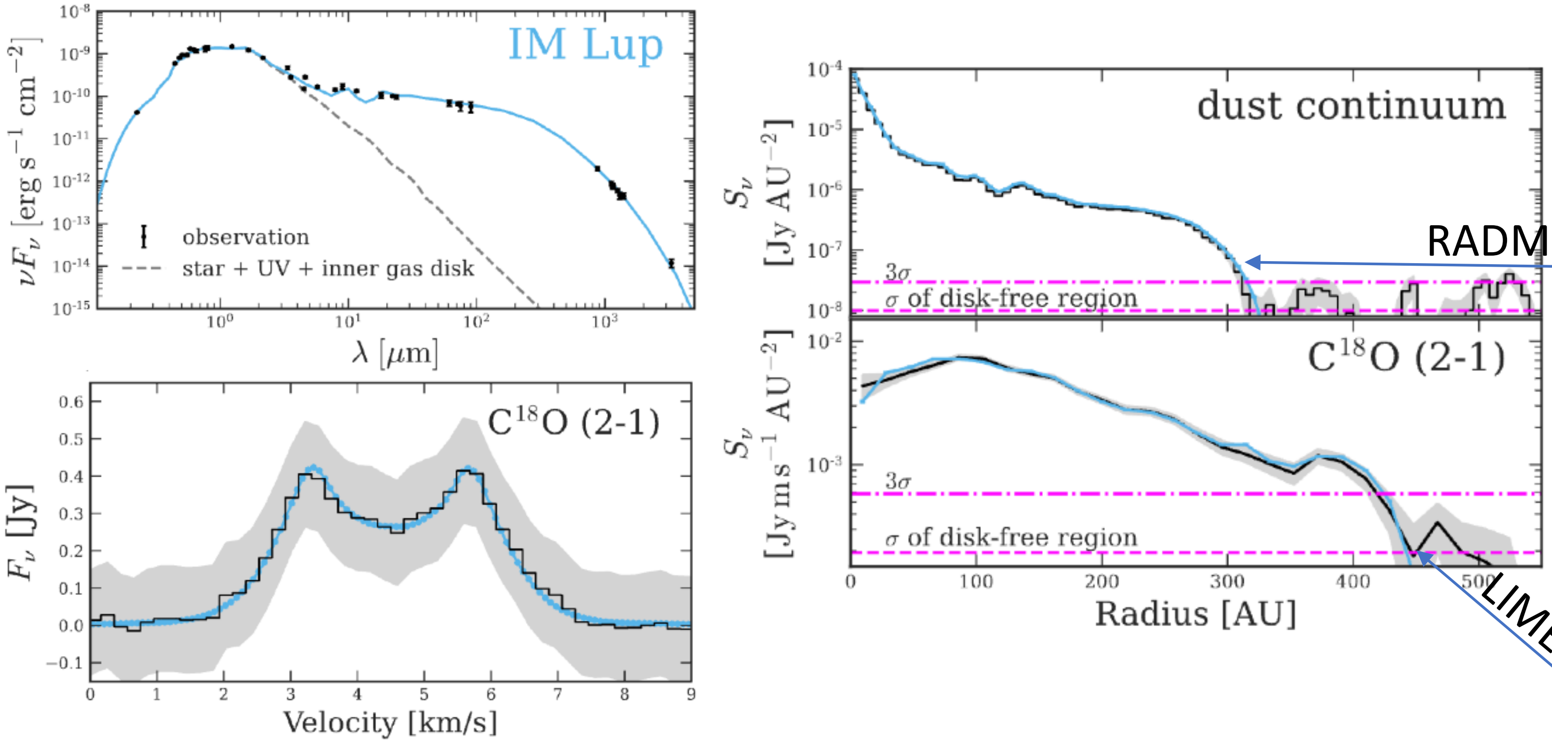
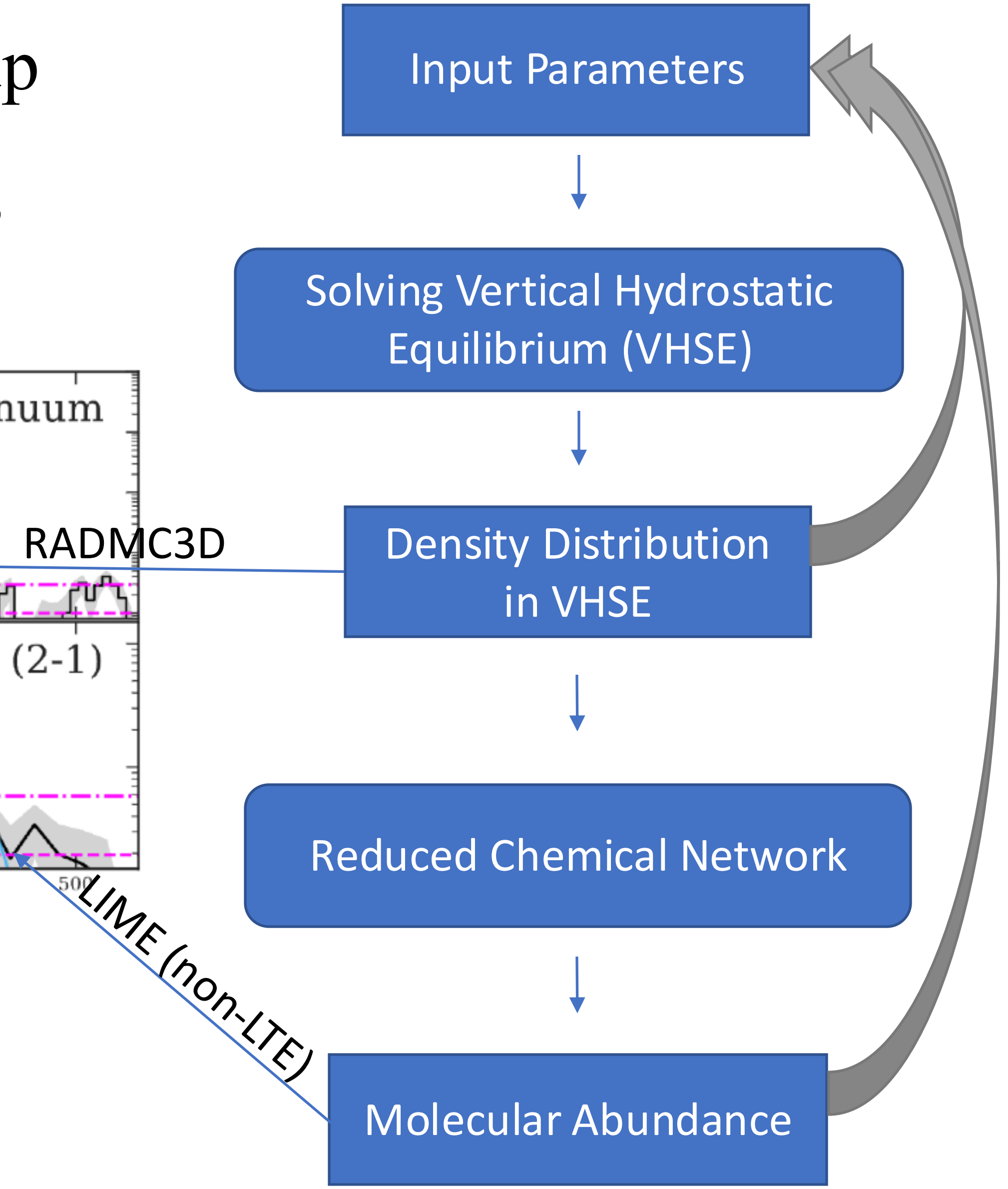
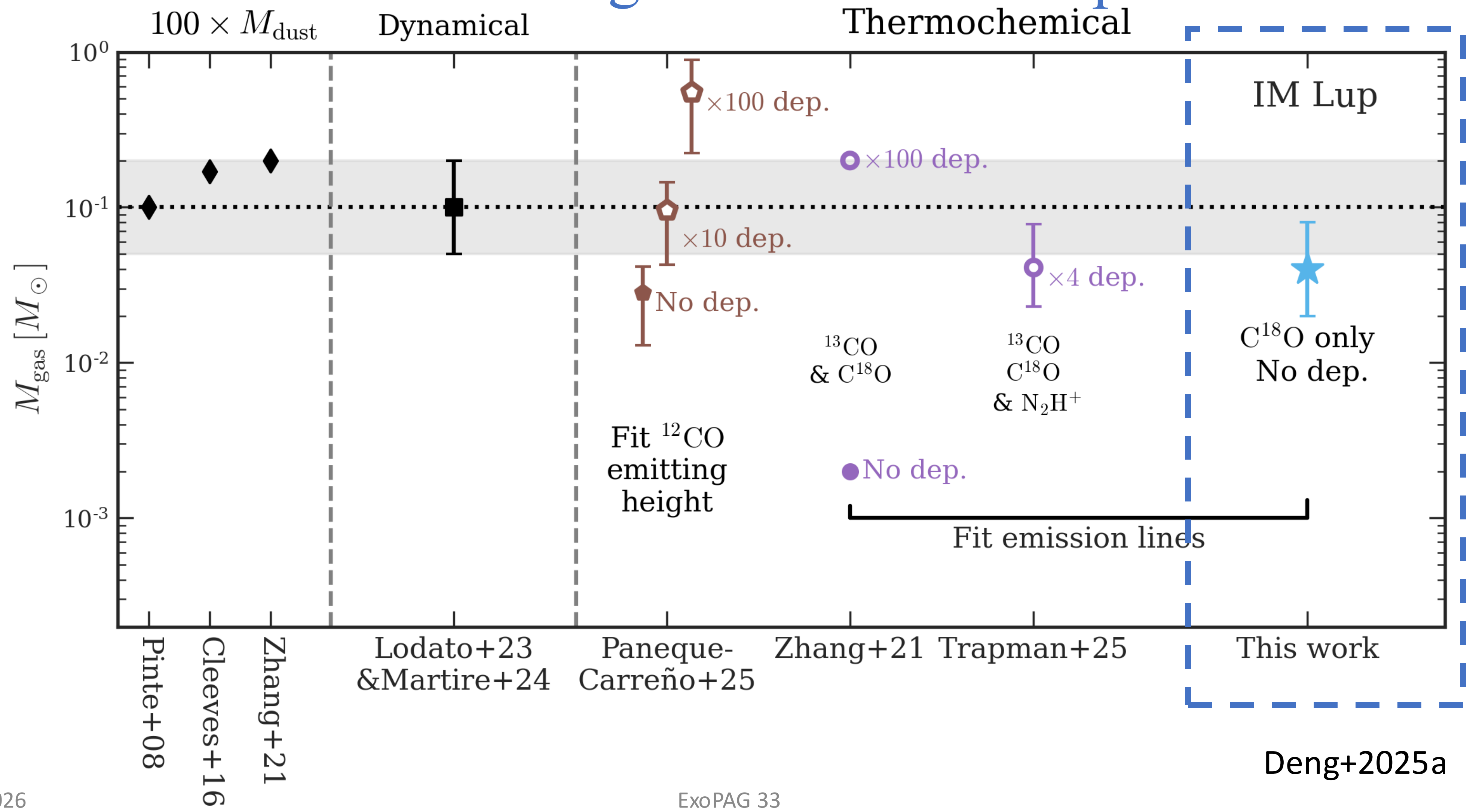




Deng+2023, 2025a

DiskMINT infers Mgas, Mdust, and radial distribution of gas and dust surface densities!

DiskMINT finds IM Lup has a large disk mass without assuming additional CO depletion



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DiskMINT also finds RU Lup has a large disk mass

Highest accretor in Lupus star-forming region

Deng+2023

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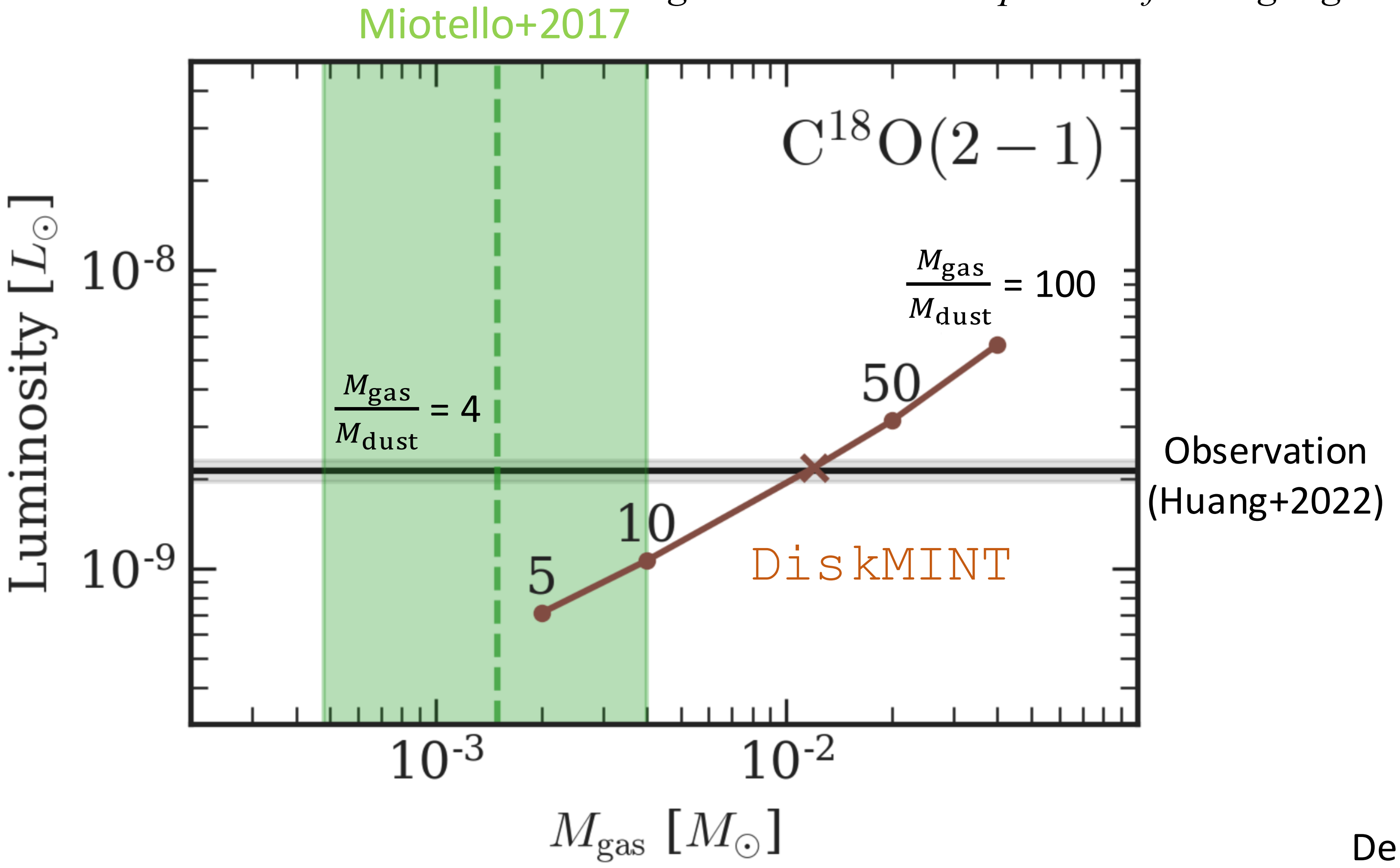


Deng+2023





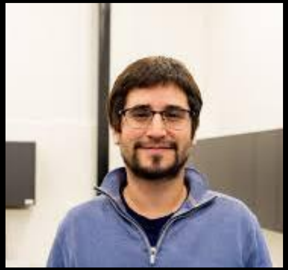




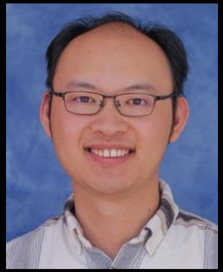

AGE PRO

THE ALMA SURVEY OF GAS EVOLUTION IN PROTOPLANETARY DISKS













AGE-PRO ALMA Large Program

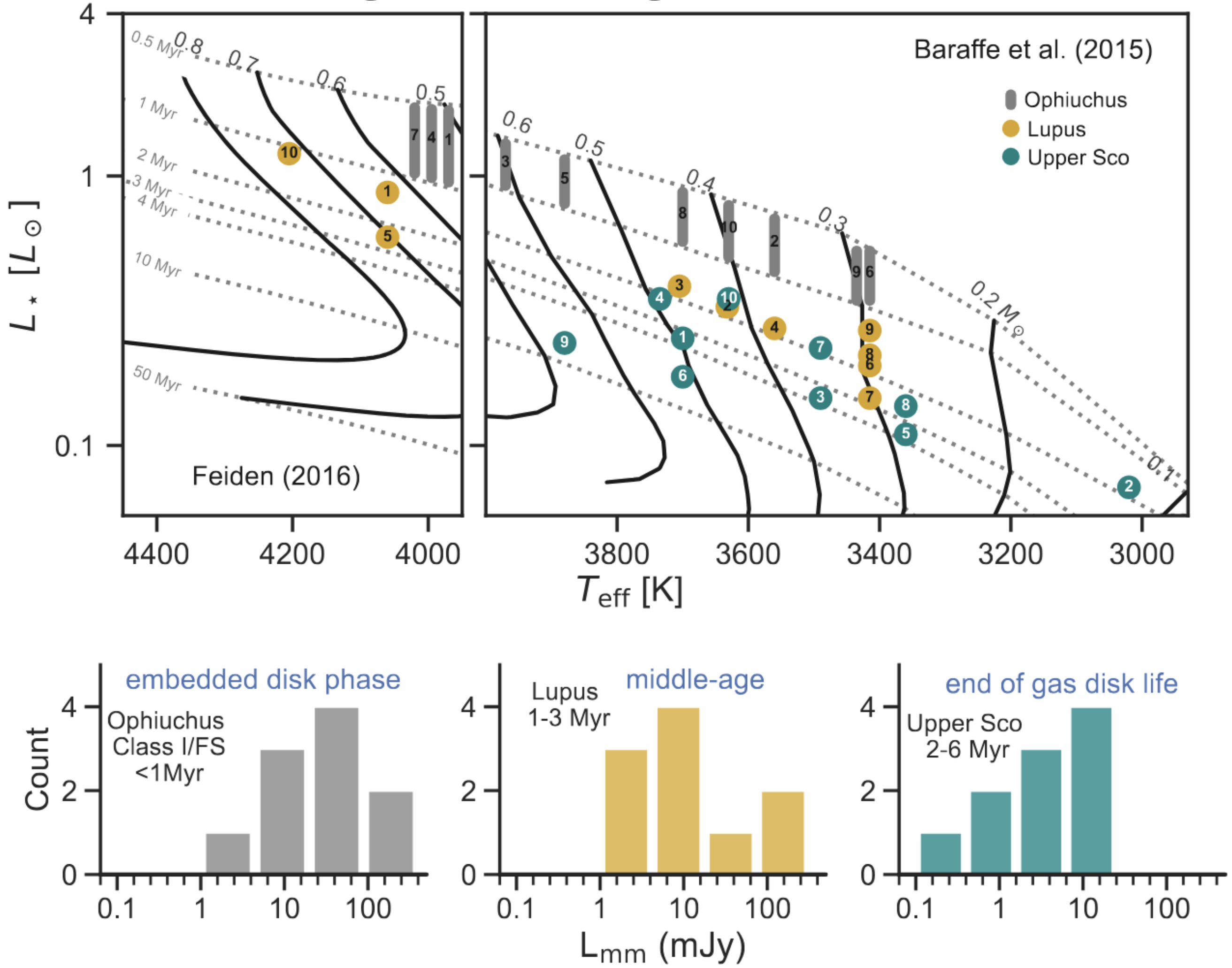
THE ALMA SURVEY OF GAS EVOLUTION IN PROTOPLANETARY DISKS

Goal

To systematically trace the evolution of gas disk **mass** and **size** throughout the lifetime of protoplanetary disks

Sample

30 disks to cover 0.1-10 Myrs gas disk lifetime.



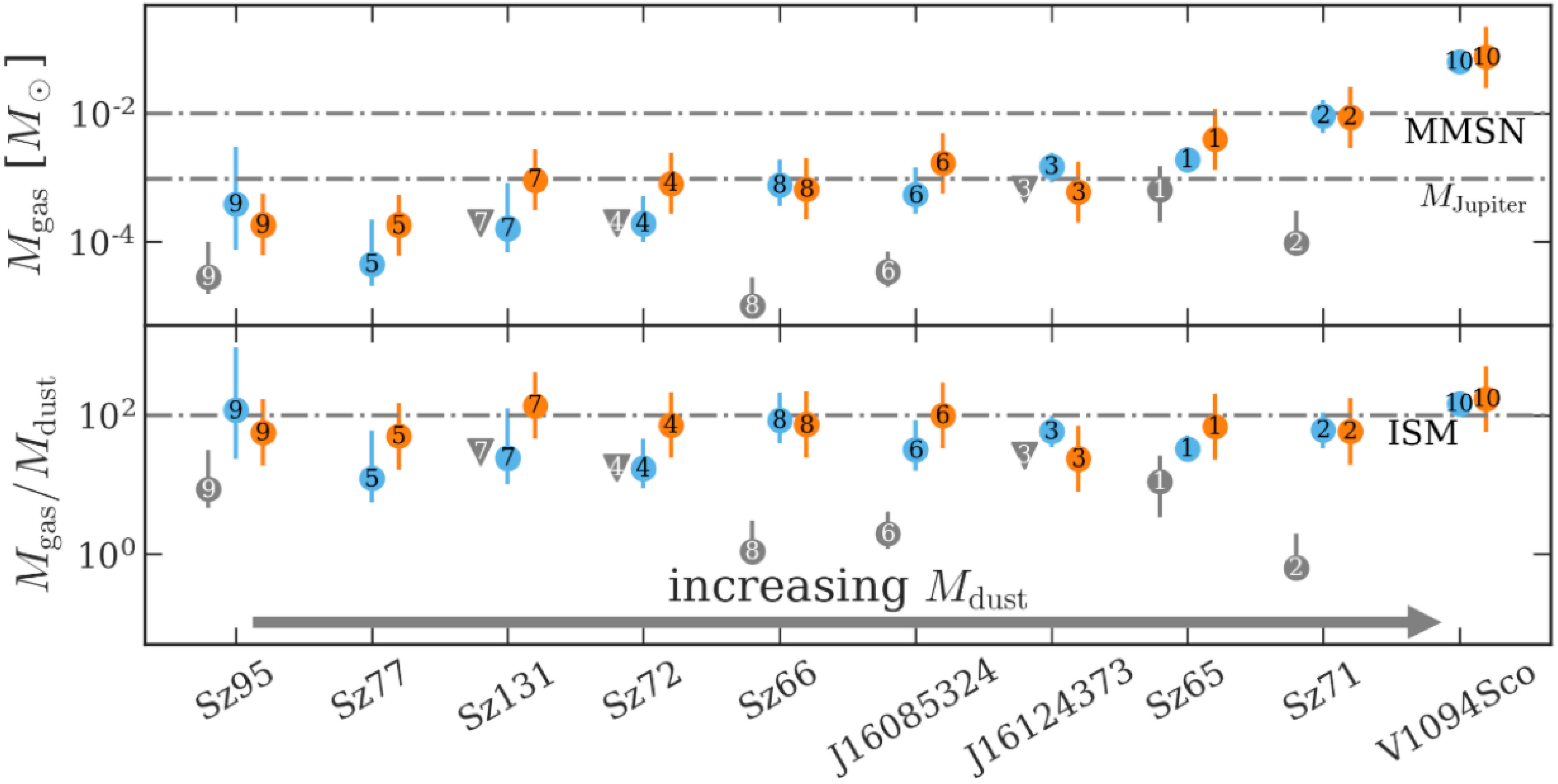
Zhang+(AGE-PRO collaboration) 2025

Application to the AGE-PRO Lupus disks

fits ^{13}CO — Miotello+2017

^{13}CO, $C^{18}O$, N_2H^+ lines — Trapman+(AGE-PRO, 2025)

only fits $C^{18}O$ — This work Deng+(AGE-PRO, 2025)



Conclusion and Future

- `DiskMINT` enables the use of $C^{18}O$ to reliably estimate gas disk masses.
- For RU Lup and IM Lup, the model **explains the total $C^{18}O$ line luminosity, line spectrum and radial profile with a higher M_{gas} (about a MMSN gas disk),** an order of magnitude higher than previous estimates.
- We find AGE-PRO disk masses **are large and with gas-to-dust mass ratios that are close to ISM**.
- `DiskMINT` is open-source and published now. A model grid will be made accessible on GitHub in January.
  - First-order estimates of CO-based Mgas from grids easily
  - Users can perform **detailed analyses of individual targets** by refining models from the best-fit grid point.

Star the Git Repo and Use DiskMINT NOW!

DiskMINT

Disk Model For INdividual Targets

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