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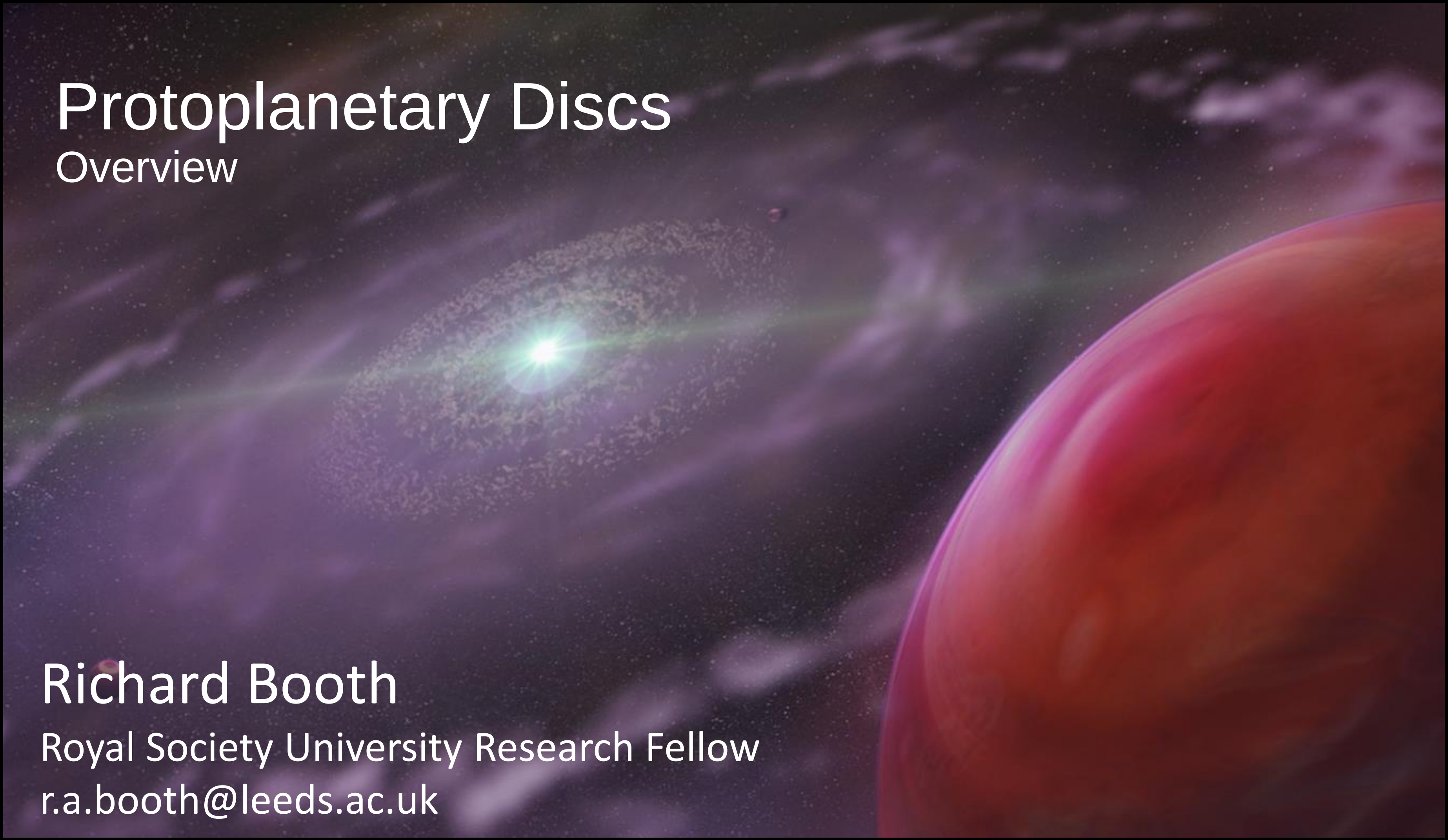

Protoplanetary Discs

Overview

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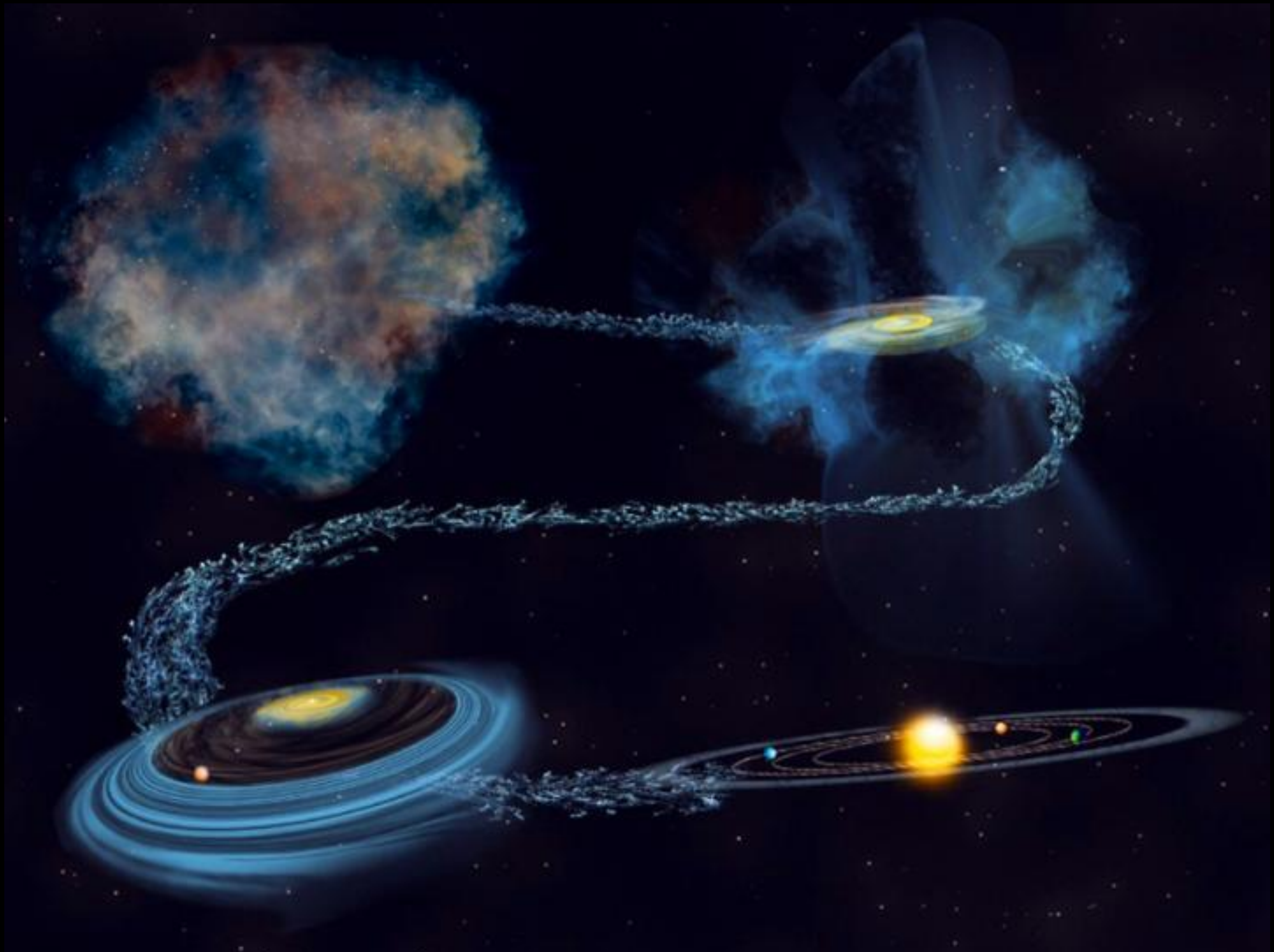
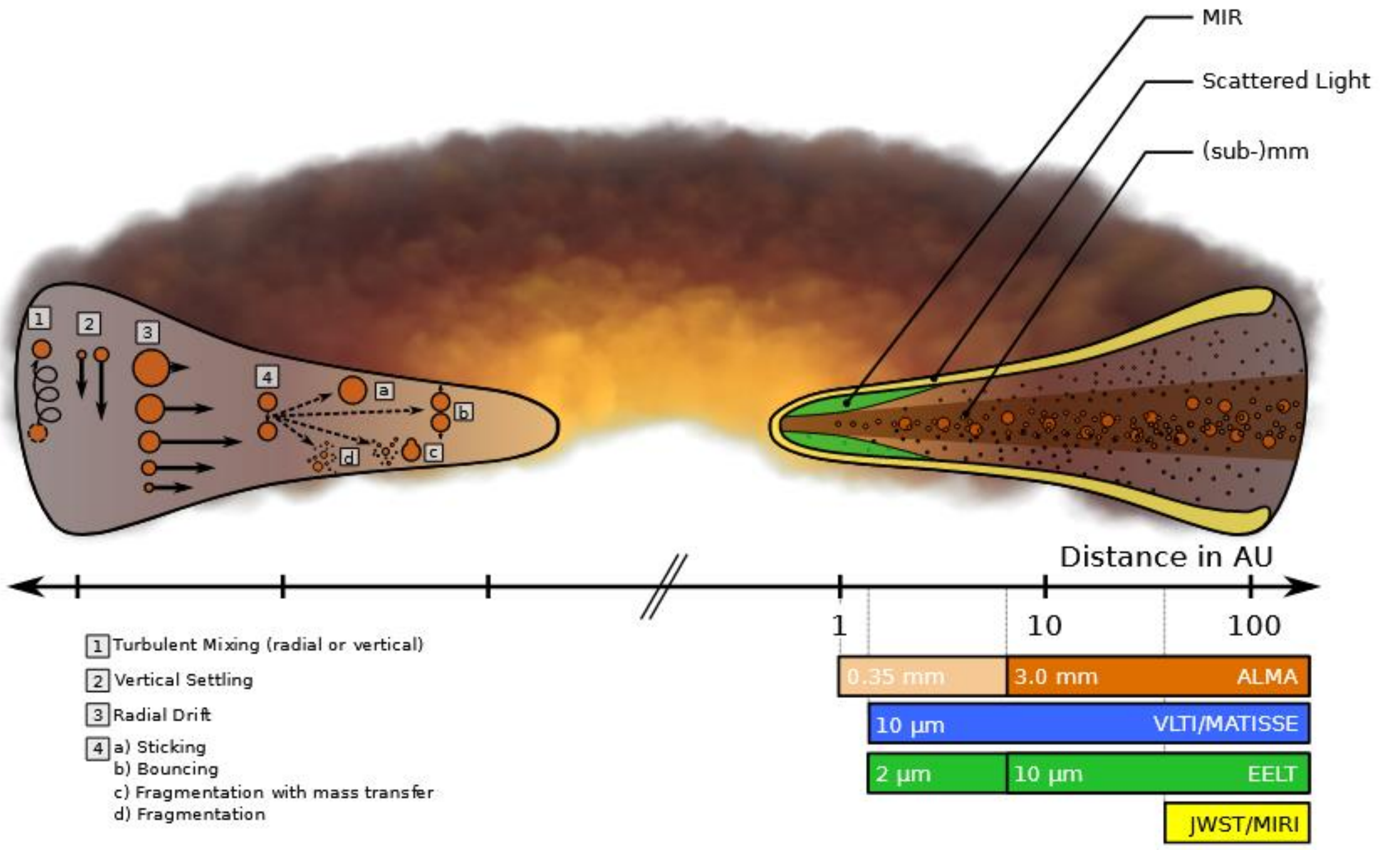
Overview


Credit: Bill Saxton/NRAO/NSF/AUI

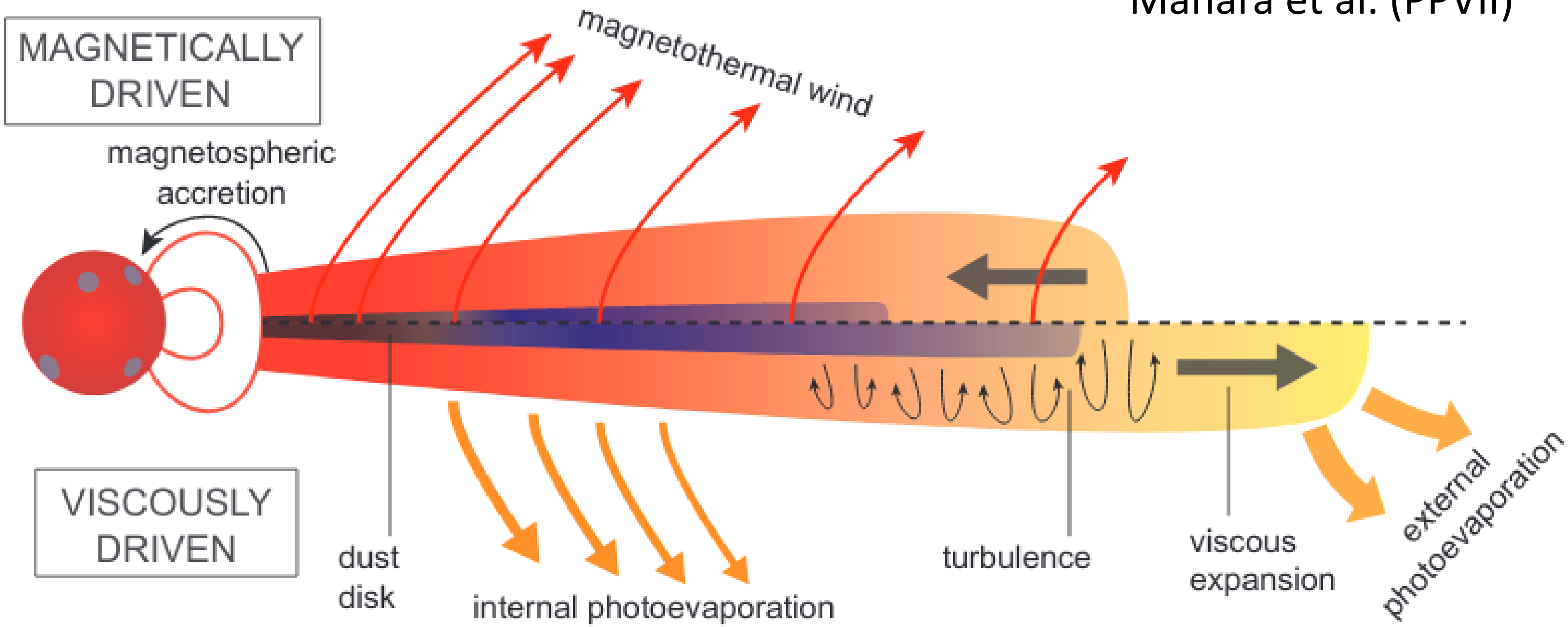
Structure of a Protoplanetary Disc



Testi et al. (2014)

Gas Evolution: Turbulent viscosity or Winds?

Manara et al. (PPVII)



Gas Evolution: Viscosity…

- Viscous discs spread
- Evolution slows as they age
- Produces a population of long-lived, weakly accreting discs
- Photoevaporation opens a gap and terminates accretion
- Clears the disc after a few Myr

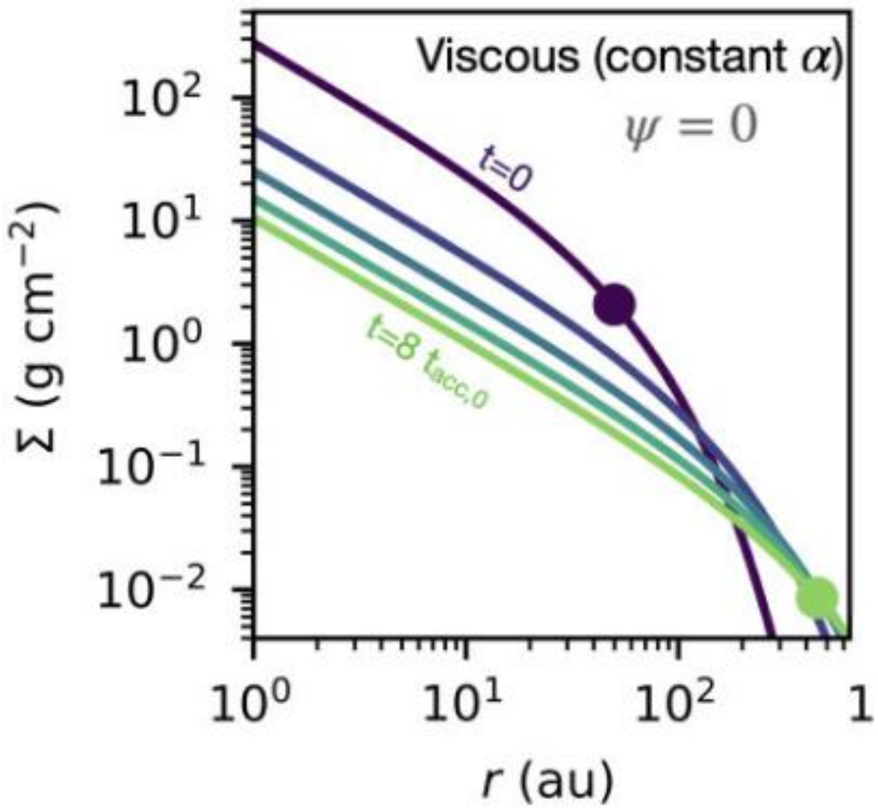


Fig Credit: Tabone+ (2022)

Gas Evolution: Viscosity and photoevaporation

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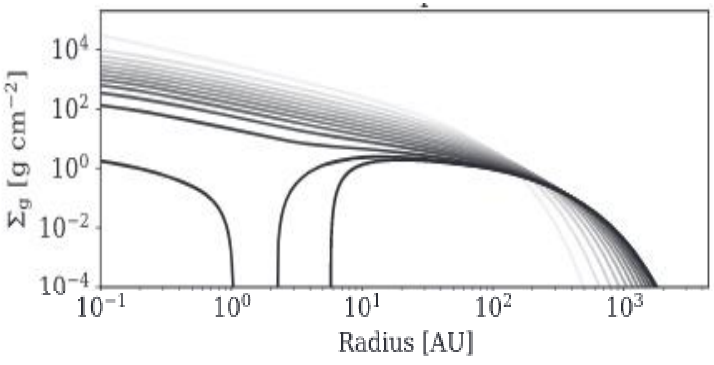

Owen et al. (2011)

Gas Evolution: Viscosity and photoevaporation

- Viscous discs spread
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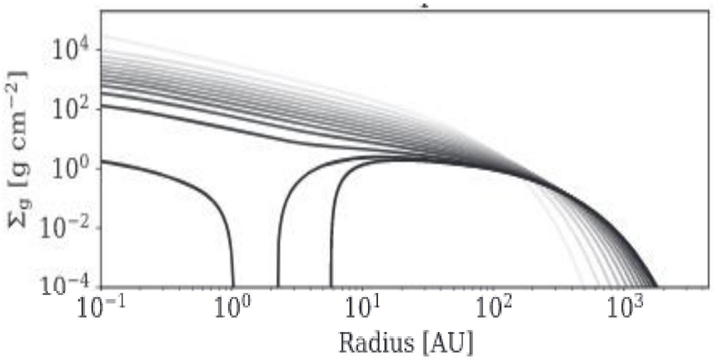

- Photoevaporation opens a gap and terminates accretion
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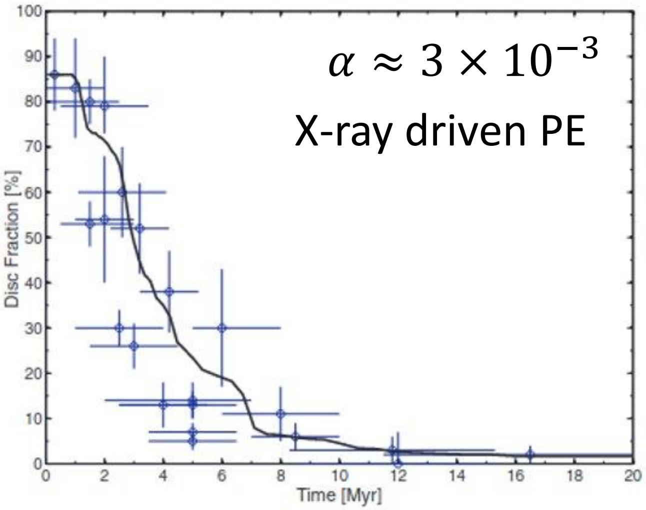
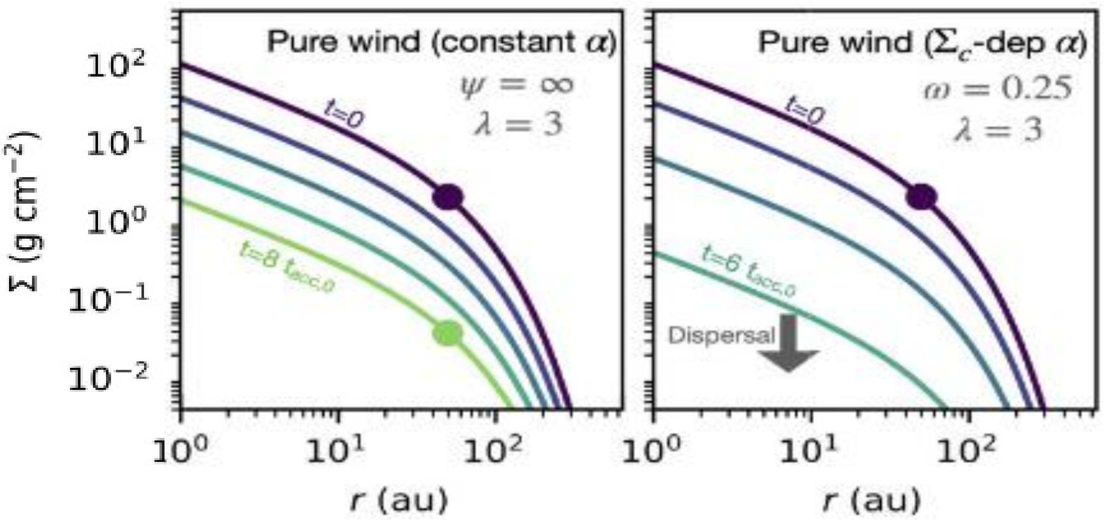
Reproduces disc lifetimes



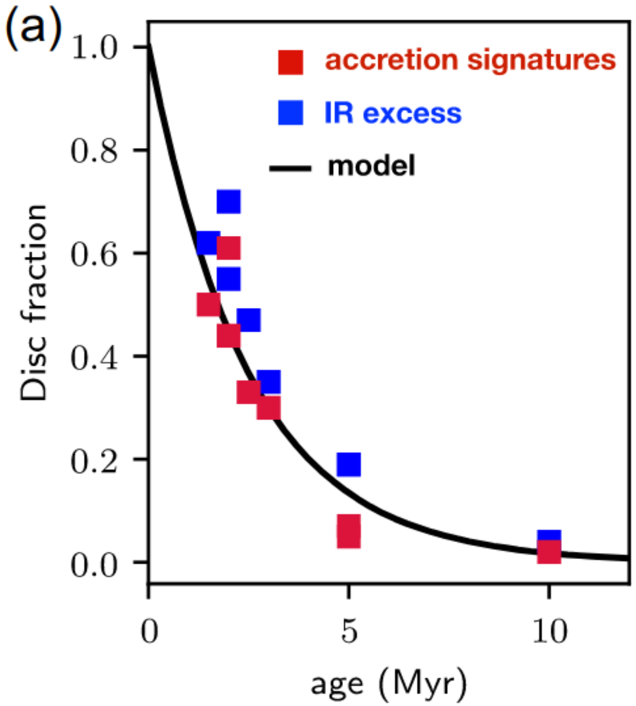
Owen et al. (2011)

Gas Evolution: Wind-driven evolution

- Evolution depends on how the magnetic field evolves

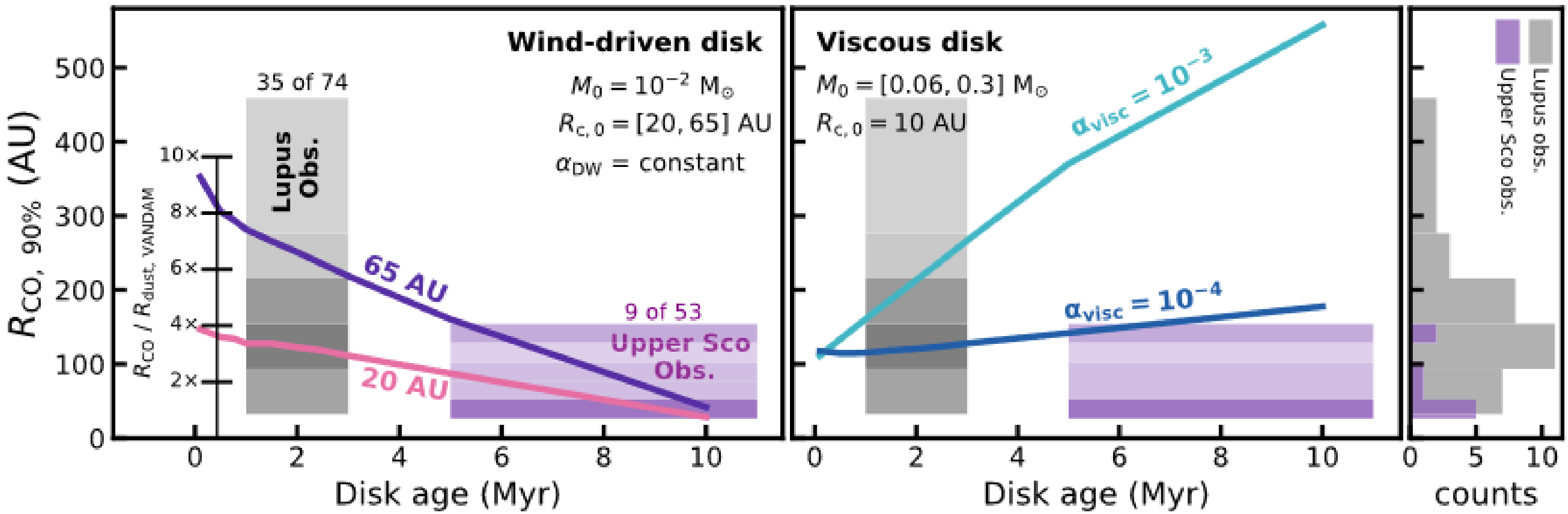


Purely wind driven models can also match disc lifetimes



Tabone et al. (2022); Data from Fedele+ (2010)

Disc Sizes: A distinguishing factor?



- Expansion of viscous discs is problematic
  - Discs have low viscosity?

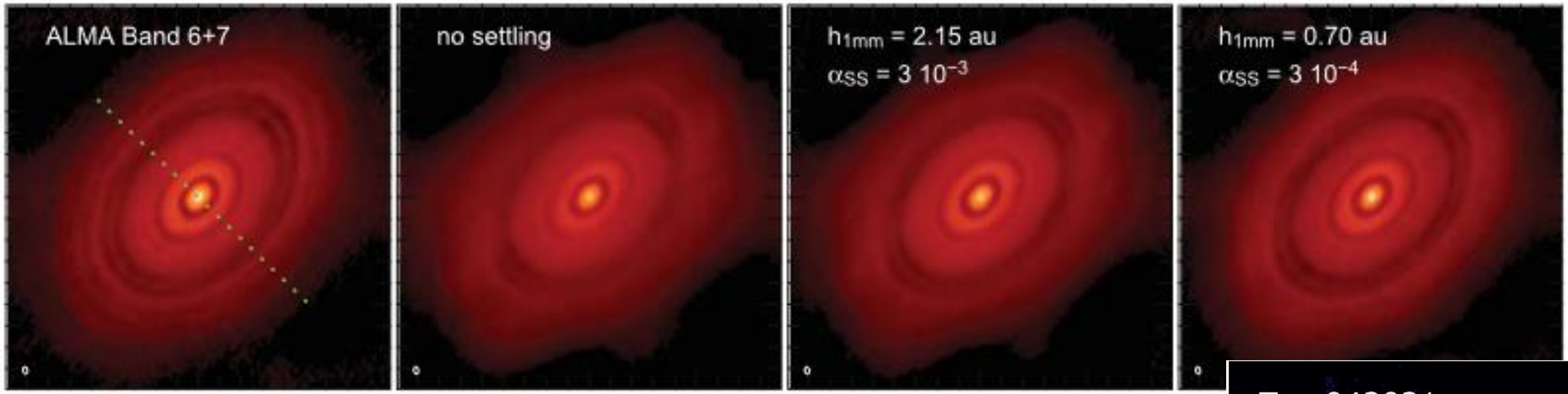
- Wind driven discs are a better match

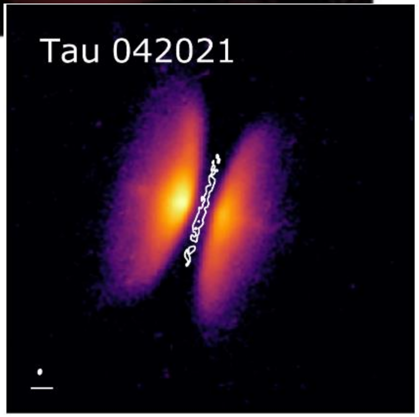
BUT:

U. Sco has as stronger radiation field.
Are the discs affected by external photoevaporation?

Trapman et al. (2022)

How turbulent are discs?





- Dust settling can be constrained via emission geometry
  - Favours weak turbulence ($\alpha \sim 10^{-4}$)

- Width of dust rings produces similar constraints

- CO lines in the sub-mm constrain turbulence in the upper layers of discs

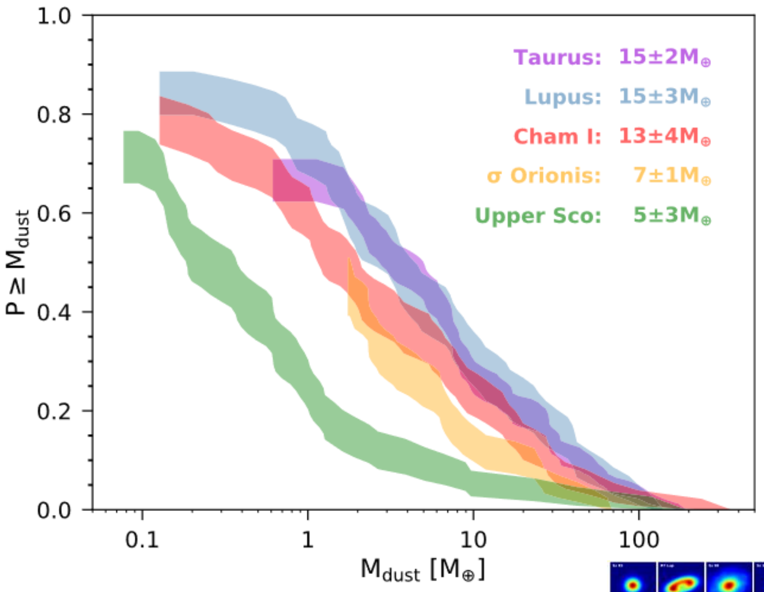
- See nice review **Rosotti** (2023) for more constraints

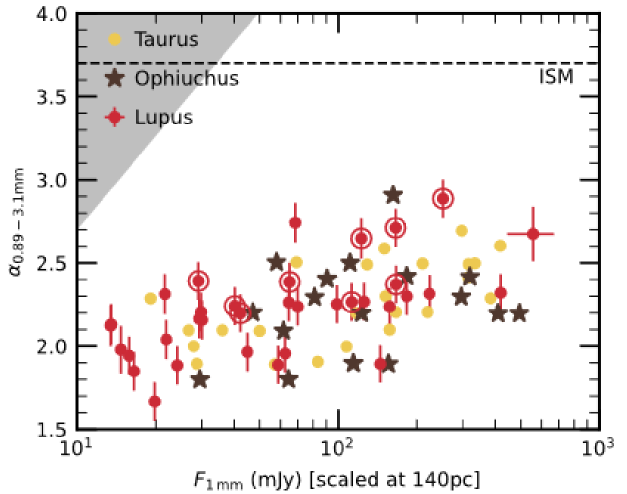
Pinte et al. (2016); Pizzati et al. (2023); Dullemond et al. (2020); Villenave et al. (2020)

Dust mass evolution

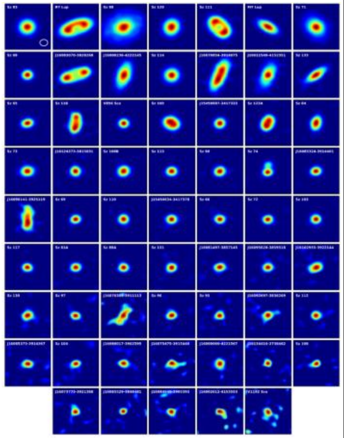
- Protoplanetary disc masses are well characterized by ALMA continuum observations

- Most discs are much smaller / less massive than the big, well-studied discs





Spectral index measurements point to ~mm sized grains

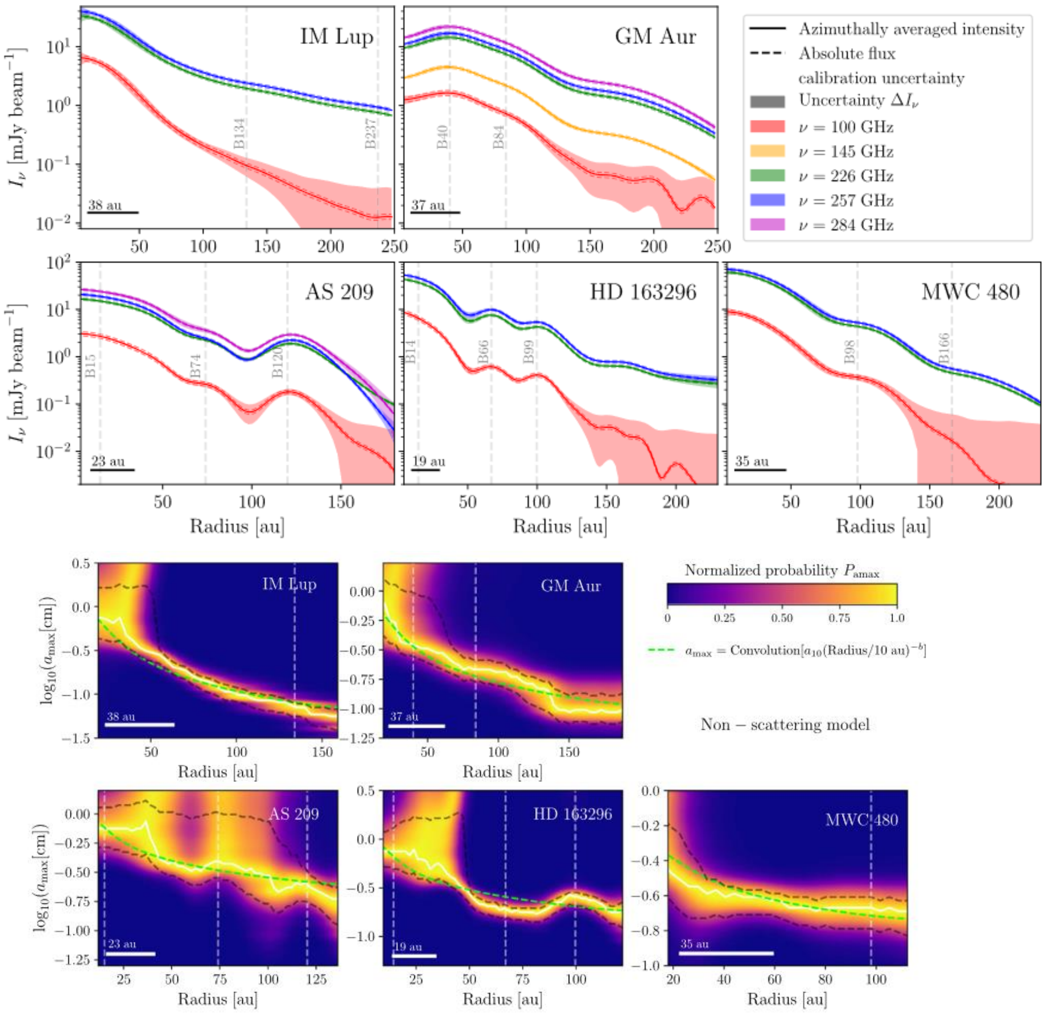


Ansdell et a. (2016;2017;2020); Barefeld et al. (2016); Williams et al. (2019); Ricci et al. (2010); Tazzari et al. (2021)

Constraints from resolved observations

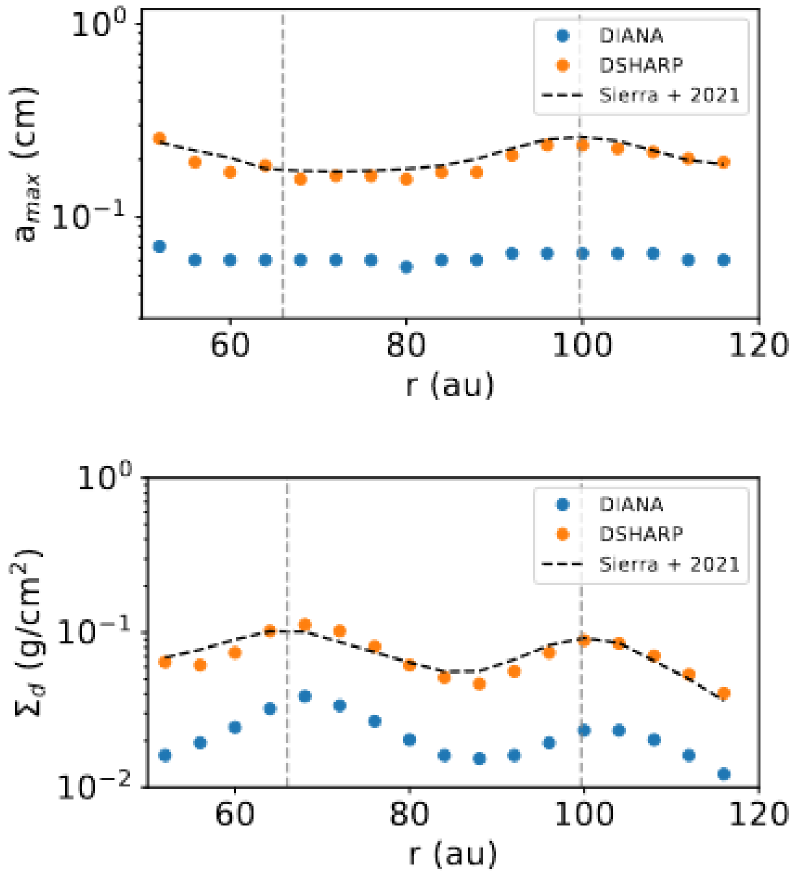
Good need high-angular resolution, multi-wavelength observations:

- Long wavelengths (optically thin) constrain grain sizes
- Short wavelengths (optically thick) constrain temperatures
- Must account for high optical depths and scattering

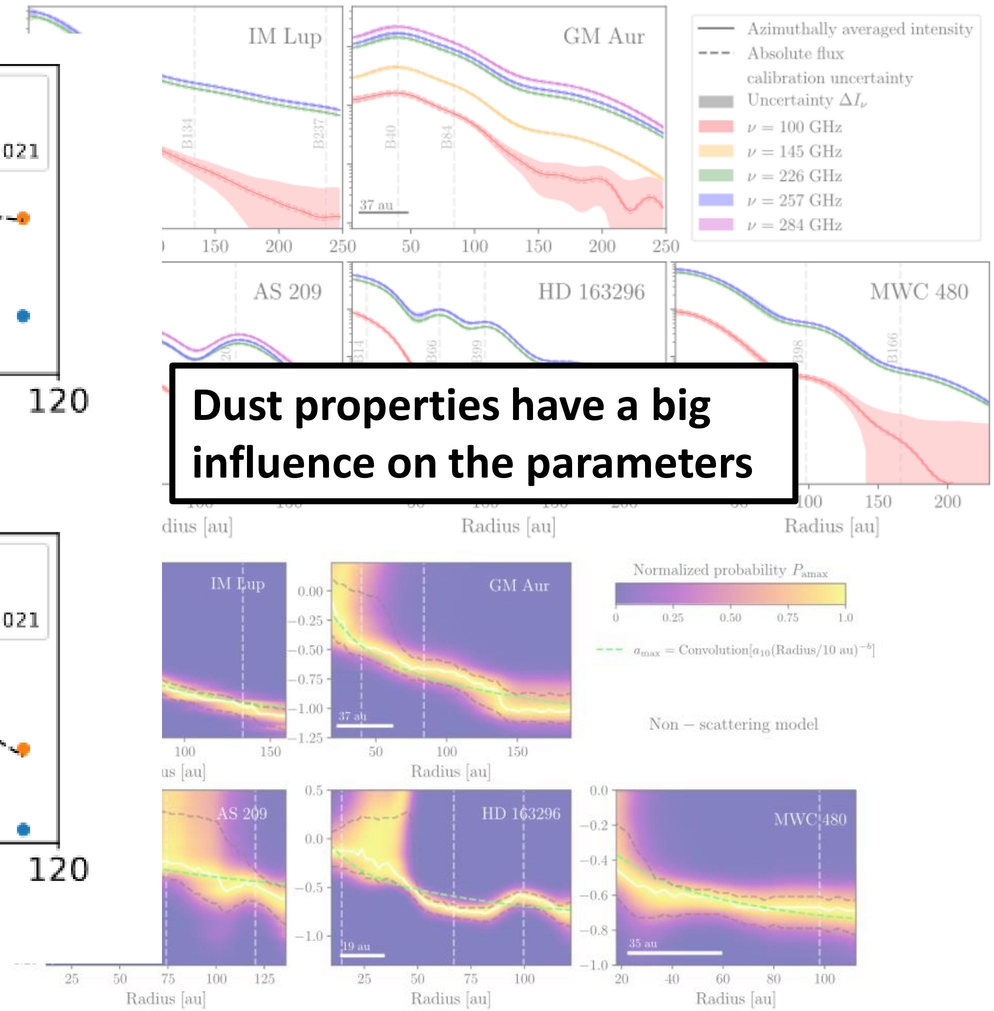


Sierra et al. (2021)

Constraints from resolved observations



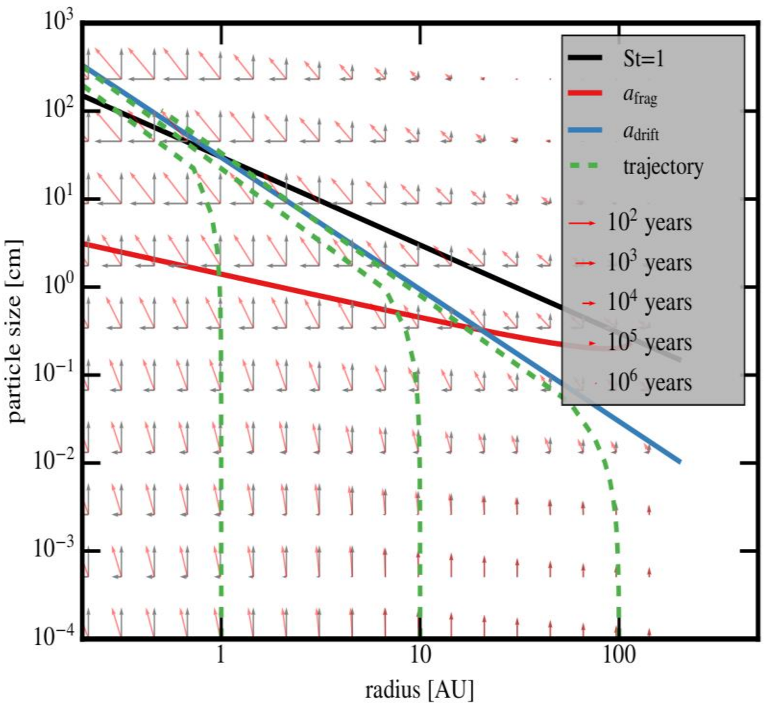
Sierra et al. (2021)



Dust properties have a big influence on the parameters

Dust evolution

- Dust grains grow until they reach one the '**barriers to growth**':
  Radial drift, bouncing, or fragmentation

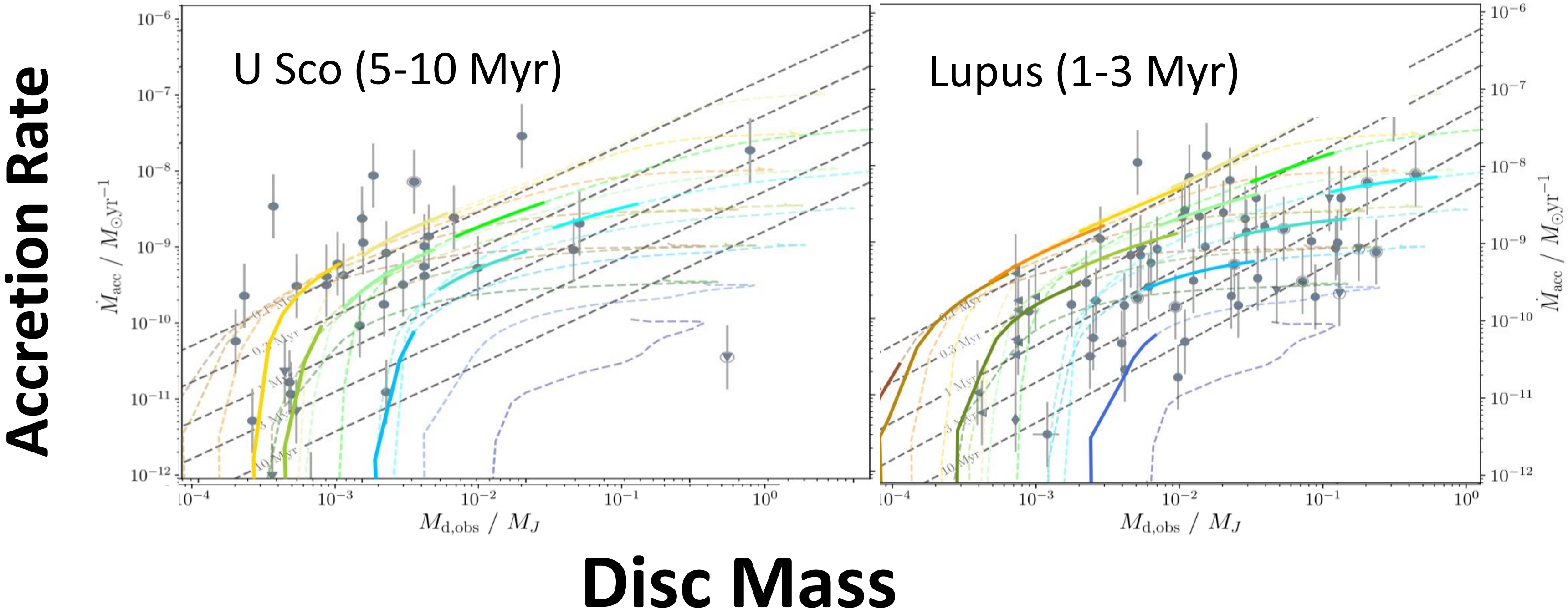


Credit: Birnstiel et al.

Dust evolution

Simple dust growth models can match many bulk properties of discs

Model:
- Grain growth
- Viscous evolution
- Photoevaporation



Sellek, Booth, & Clarke (2020)

Dust evolution

Simple dust growth models can match many bulk properties of discs

Model:

Grain growth
Viscous evolution
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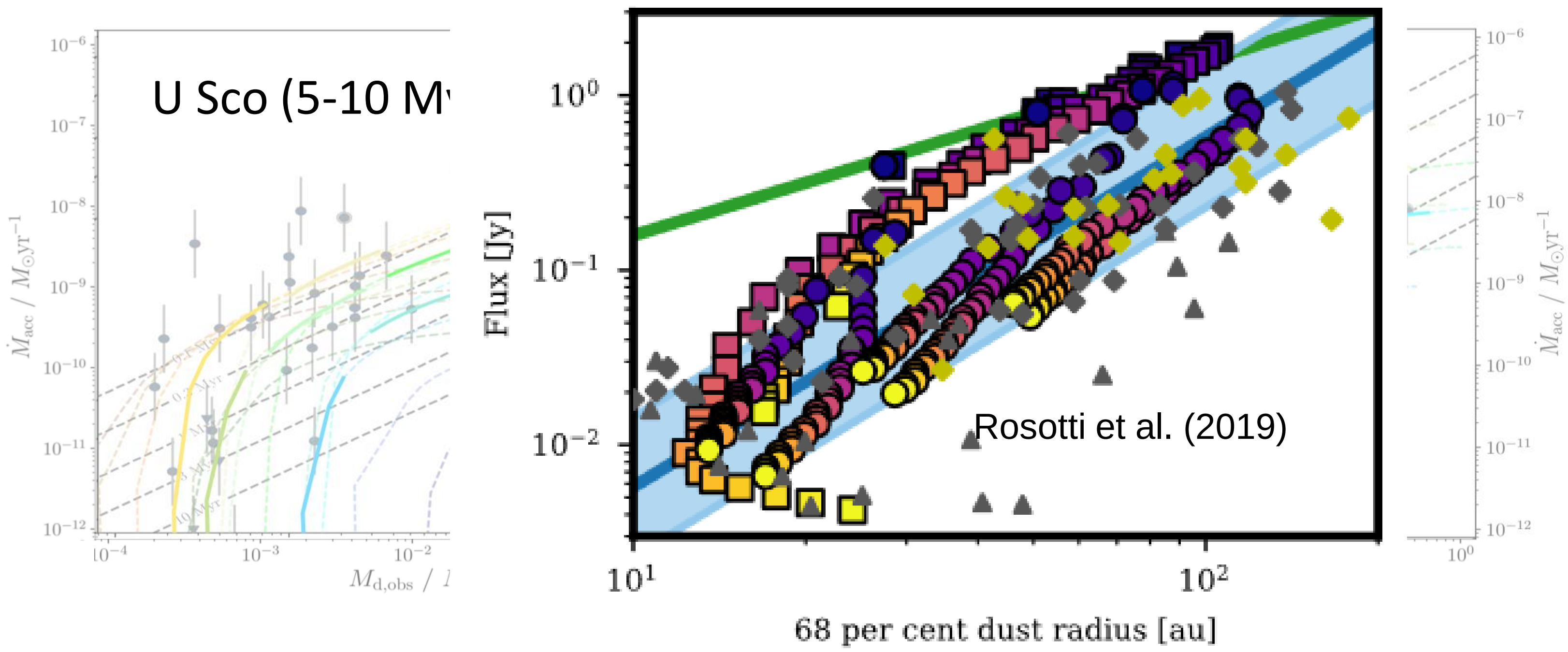
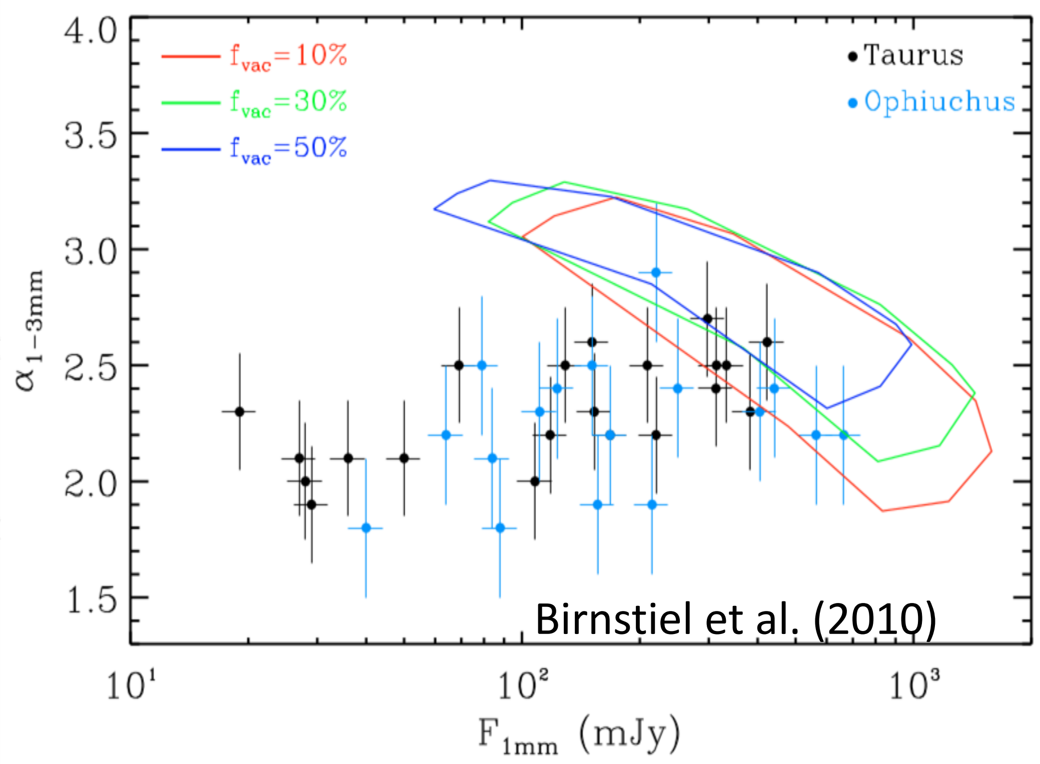


Sellek, Booth, & Clarke (2020)

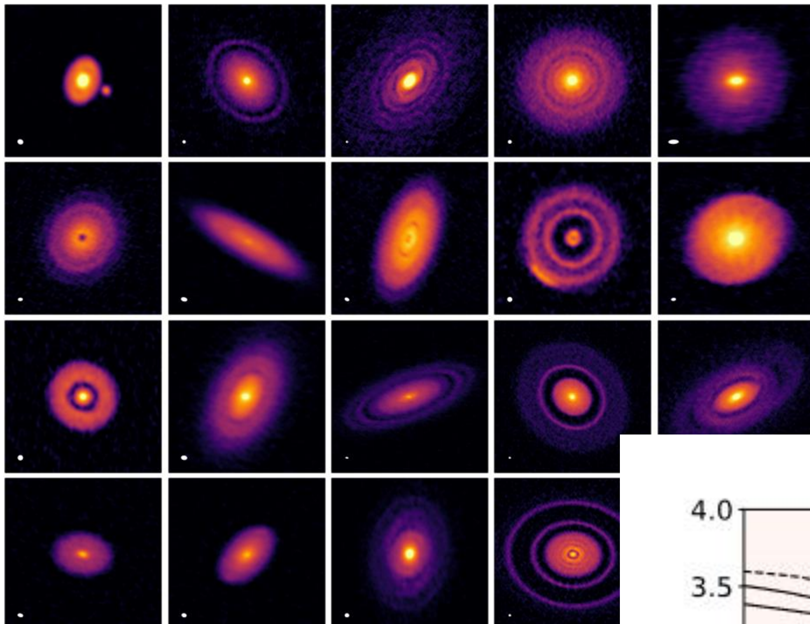
The problem with spectral indices

Spectral indices do not match:

- Large grains have been lost via radial drift
- Grains are too small
- Discs are too optically thin

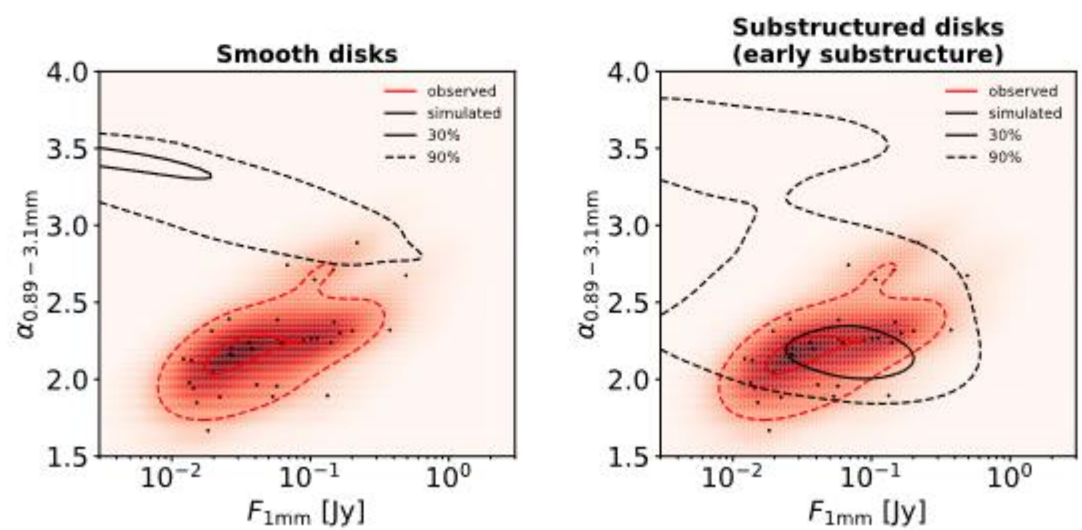


Role of dust trapping



… But Discs are not smooth

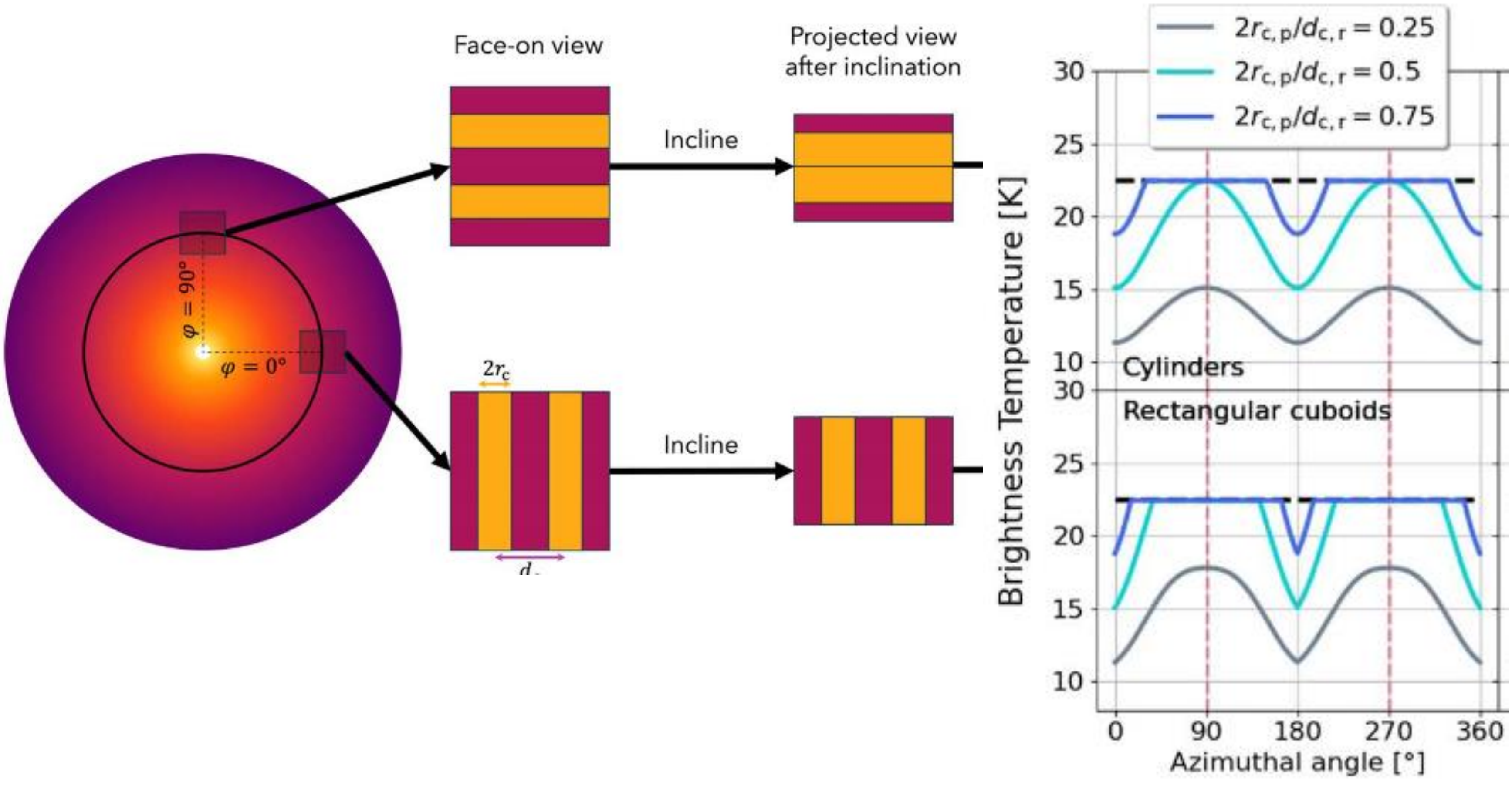
Population synthesis models with with and without substructures



Sub-structures help retain grains, keeping spectral indices low

Pinilla et al. (2012); Zormpas et al. (2022); Delussu et al. (2024)

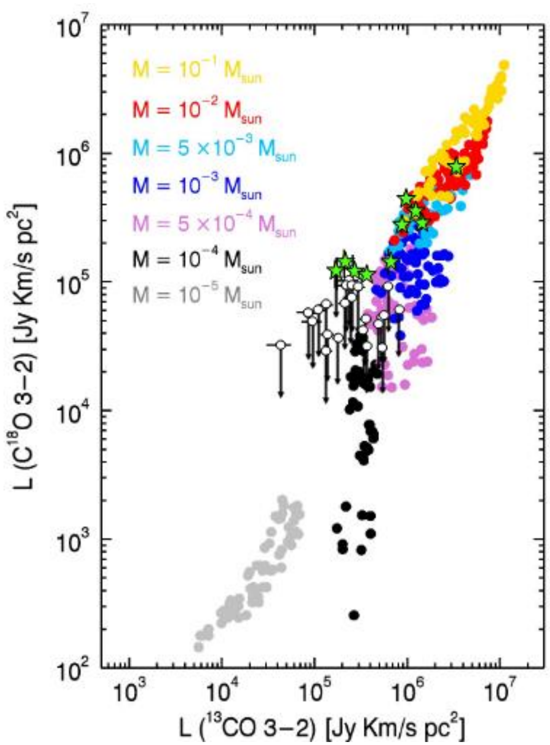
Signatures of unseen traps

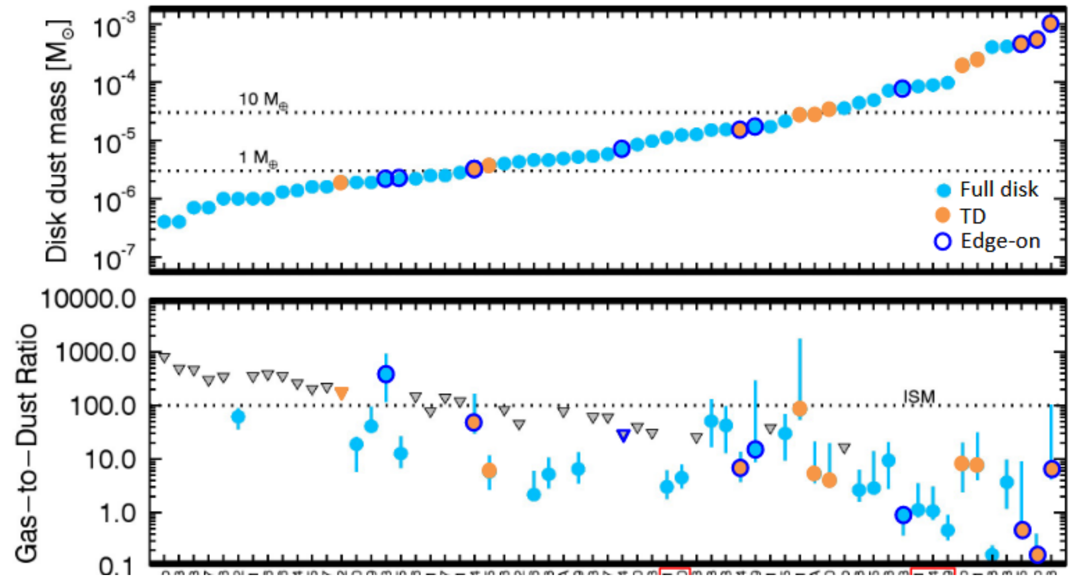


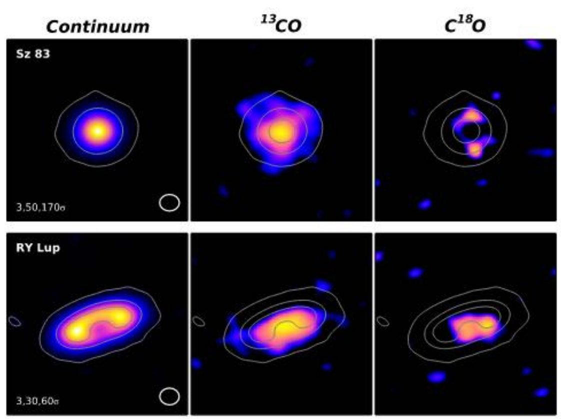
Scardoni et al. (2024)

Gas Masses: Carbon depletion in discs

CO masses are lower than expected from the dust masses







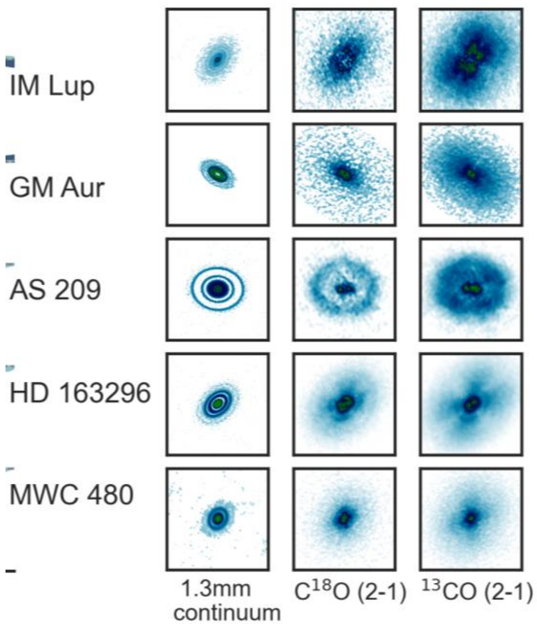
CO emission in shallow surveys was much weaker than expected

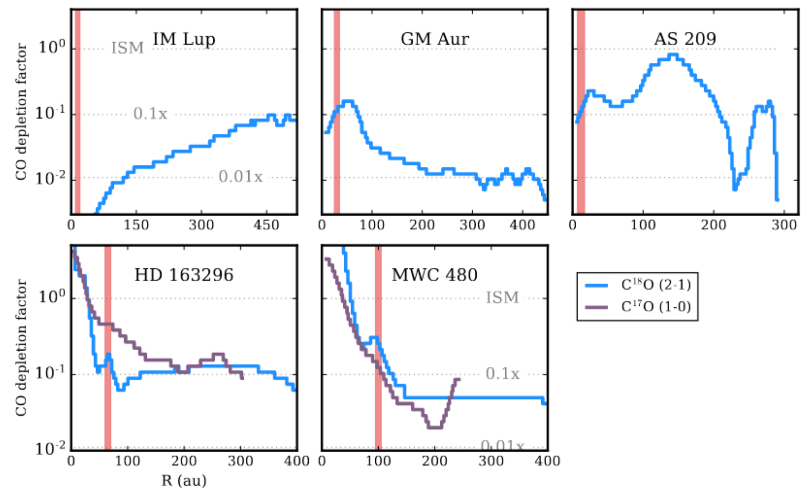
Andell et al. (2016)
Miotello et al. (2016,2017)

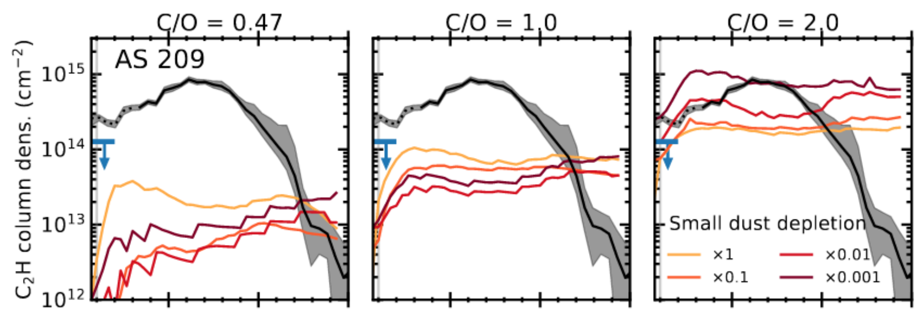
CO depletion and C/O enhancement

ALMA MAPS:
Observed many lines at high angular resolution

- Radial profiles of CO depletion (factor 10-100)
- Enhanced emission from hydrocarbons: high C/O ratios in the gas



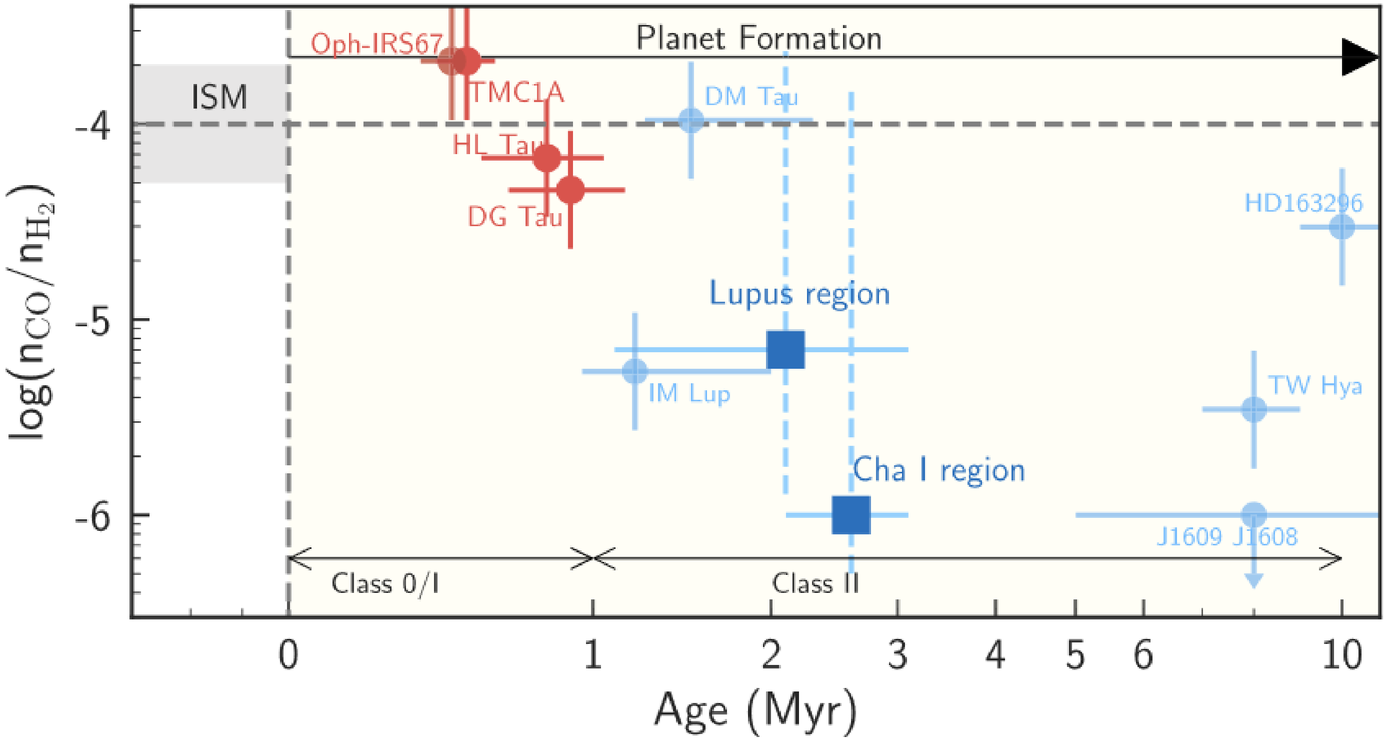




Zhang et al. (2021)
Bosman et al. (2021)

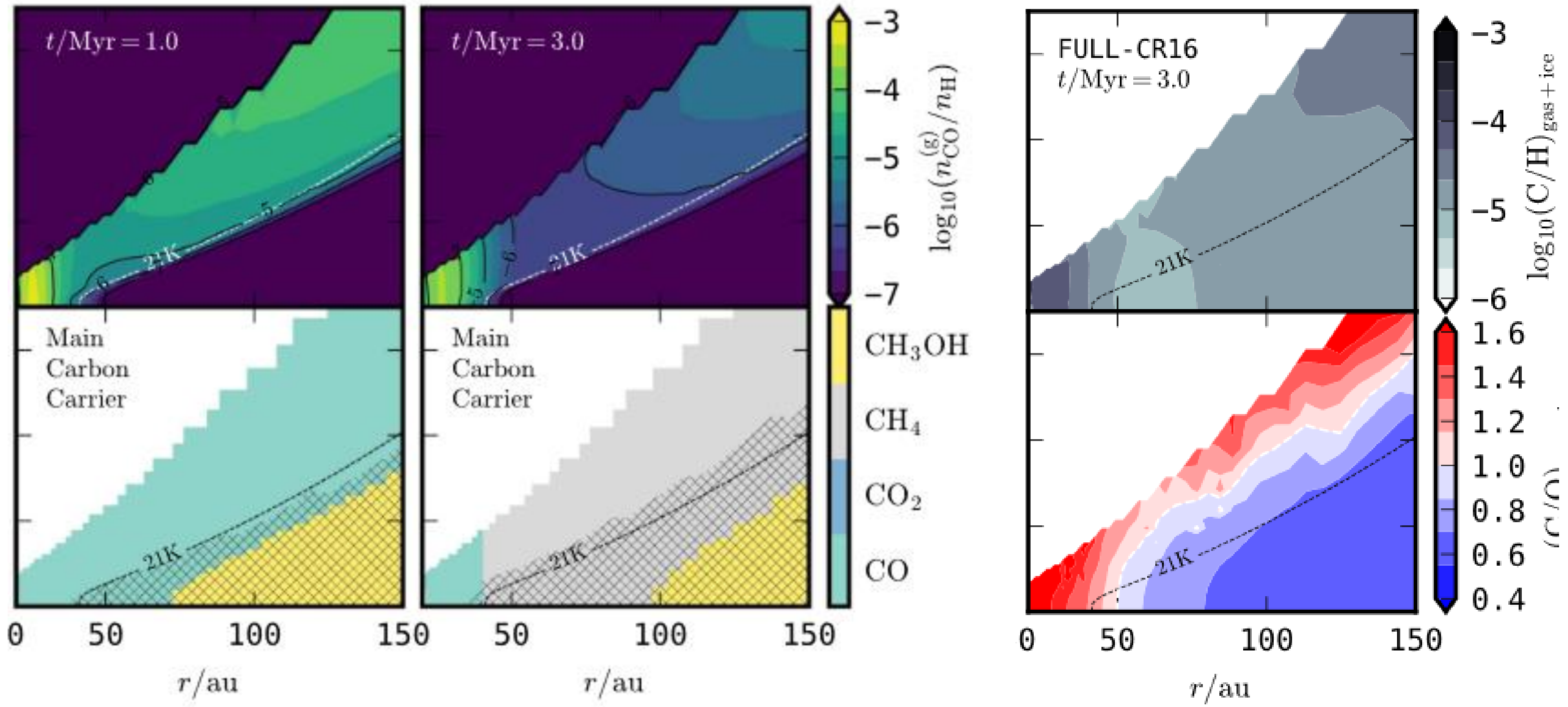
Time-scale of CO depletion

CO depletion appears after ~1 Myr



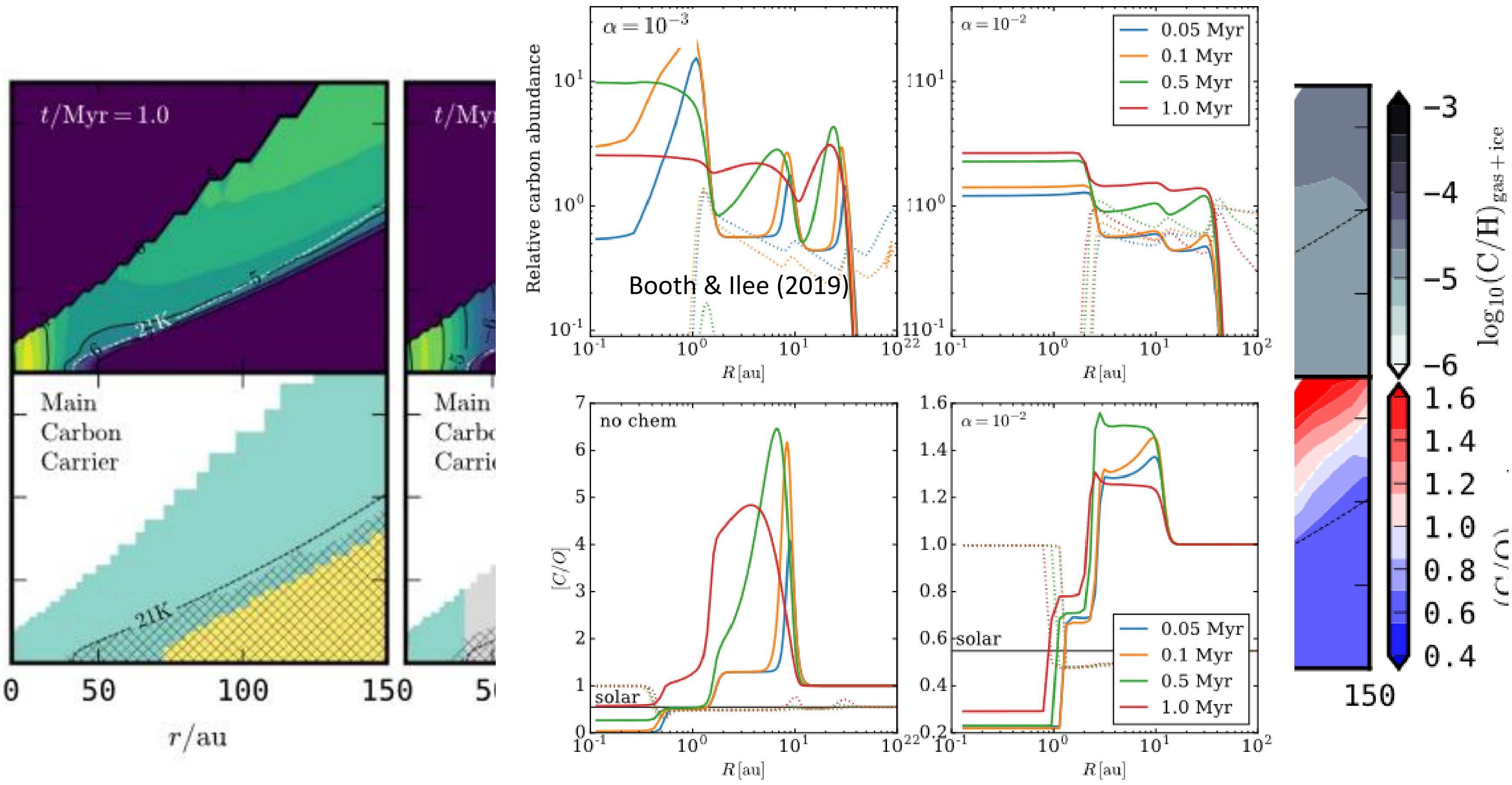
Zhang et al. (2020)

Coupled chemistry + transport



Krijt et al. (2020);

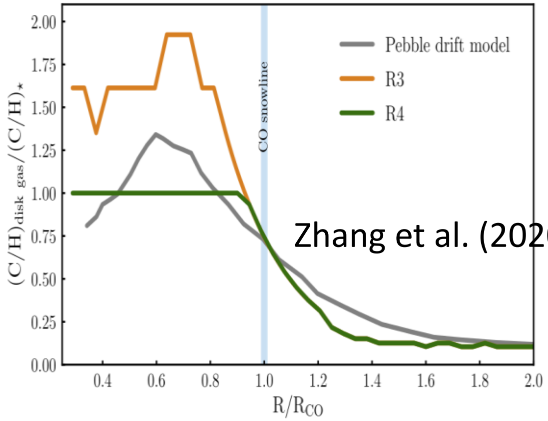
Coupled chemistry + transport



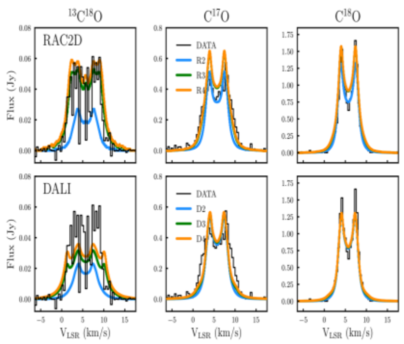
Krijt et al. (2020);

Evidence for volatile transport

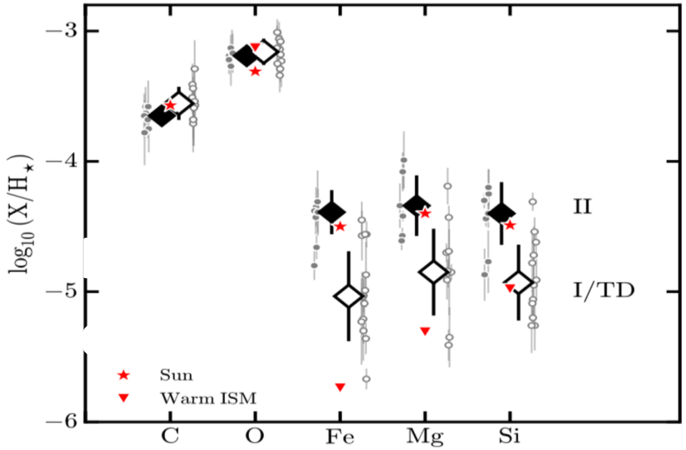
HD163296: Enhancement of CO inside the snow line
Due to pebble drift?

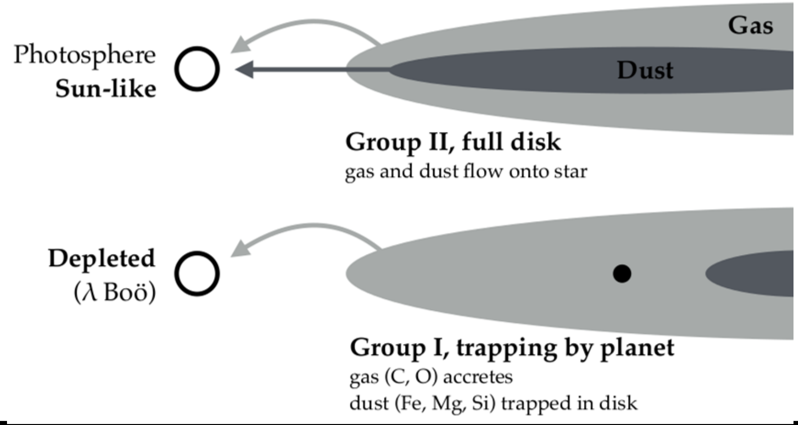


Zhang et al. (2020)



Missing refractories accreting onto stars
in discs with deep gaps

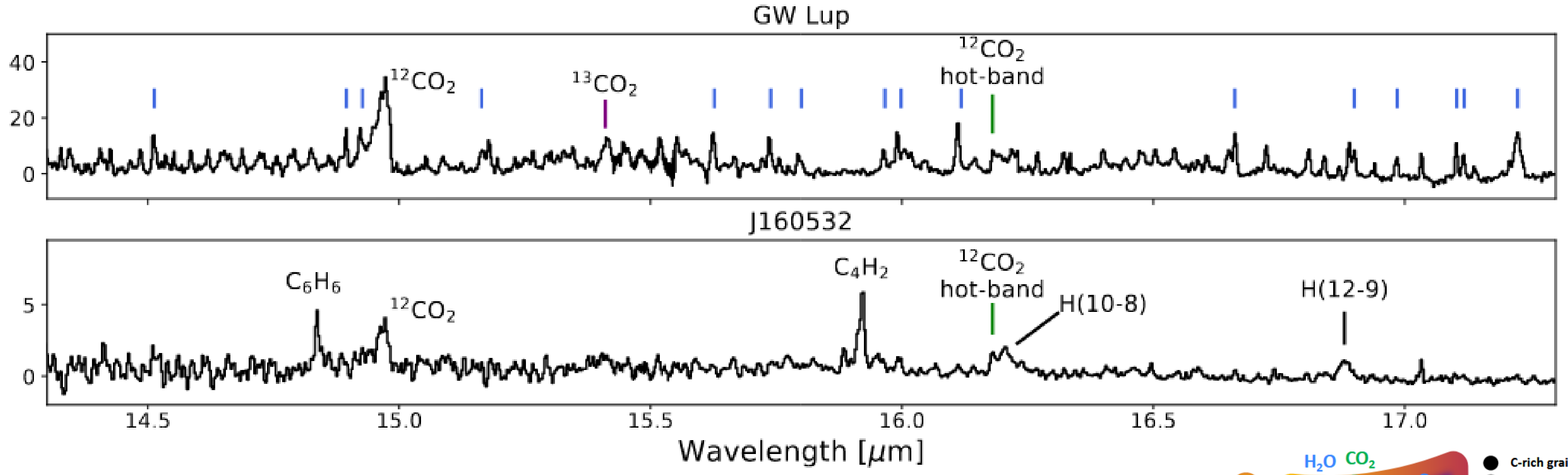


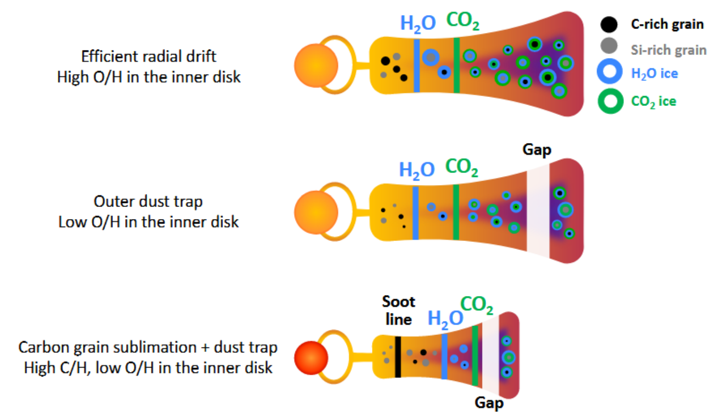


Kama et al. (2016)

Diverse inner disc chemistry with JWST

JWST MINDS programme





GW Lup: H_2O and CO_2 rich; hydrocarbon poor

J120532: Hydrocarbon rich; H_2O poor

- Due different conditions in the disc?
- Or different disc compositions?

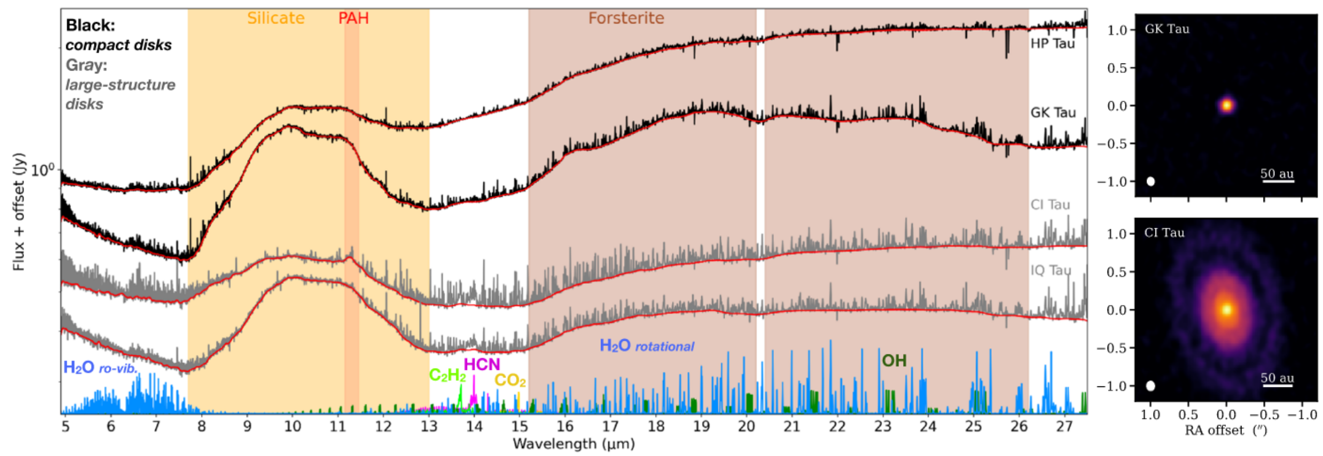
Tabone et al. (2023), van Dishoeck et al. (2023)

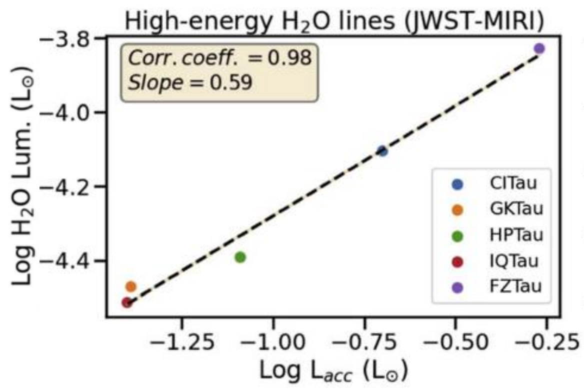
Linking inner disc chemistry to disc properties

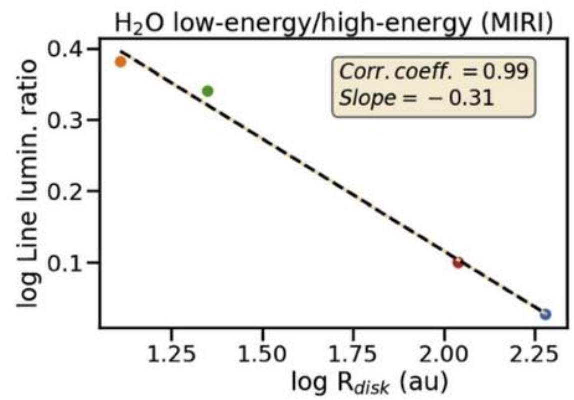
H_2O emission in discs is sensitive to disc properties:

- High-temperature emission traces disc accretion
- Lower-temperature emission correlates with disc size

Do small discs have excess water associated with radial drift?



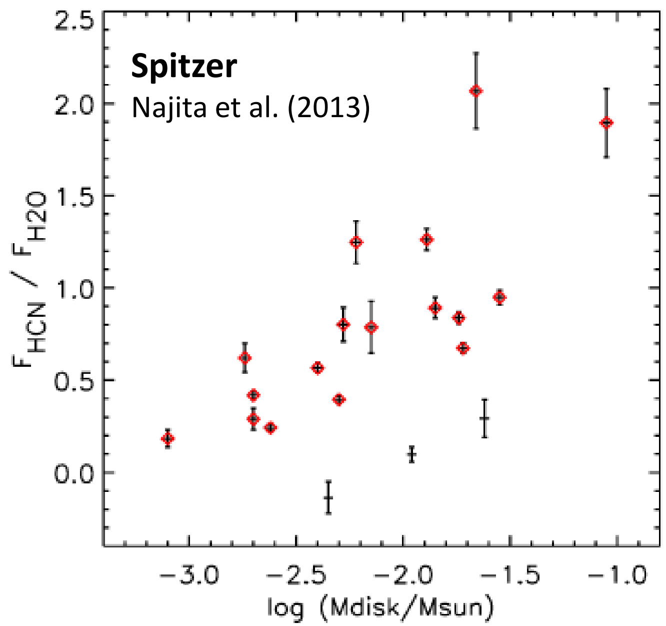


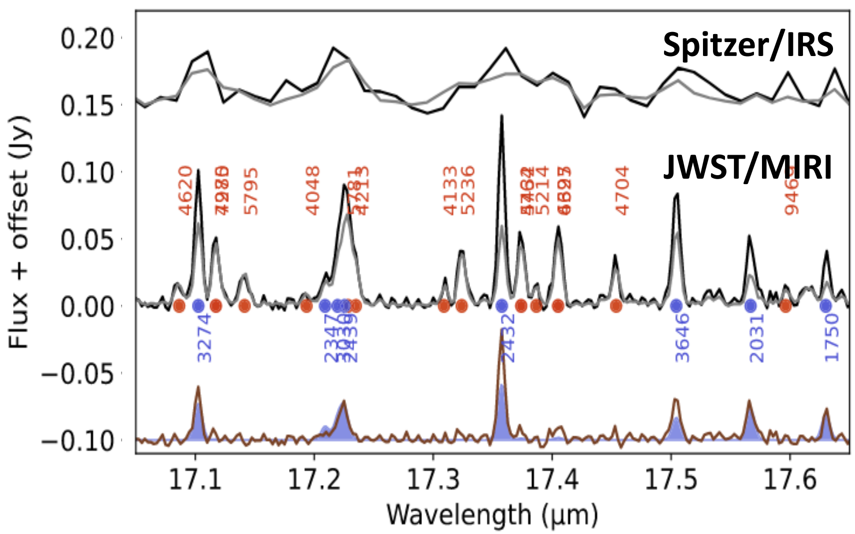


Banzatti et al. (2023)

Linking inner disc chemistry to disc properties

Similar results were already seen by Spitzer…





… but the sensitivity and resolution of JWST leads to more precise and robust measurements.

Banzatti et al. (2023)

Summary

Topics covered:

- Protoplanetary disc evolution:
  - Do discs evolve viscously or are they driven by MHD-winds?
    MHD wind models maybe currently favoured
  - How dust evolves
    How efficient is radial drift?
- Carbon depletion in protoplanetary discs
  - A mix of chemical conversion and formation of ices on large grains
- What role does radial transport play in the composition?
  Combining JWST and ALMA observations will help pin down gas and dust evolution