Observational constraints on evolution of dust disc properties in Upper Scorpius

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Perspectives of Planet and Star Formation
Heidelberg, June 22-26/2026

Witnessing Different Stages of Planet Formation

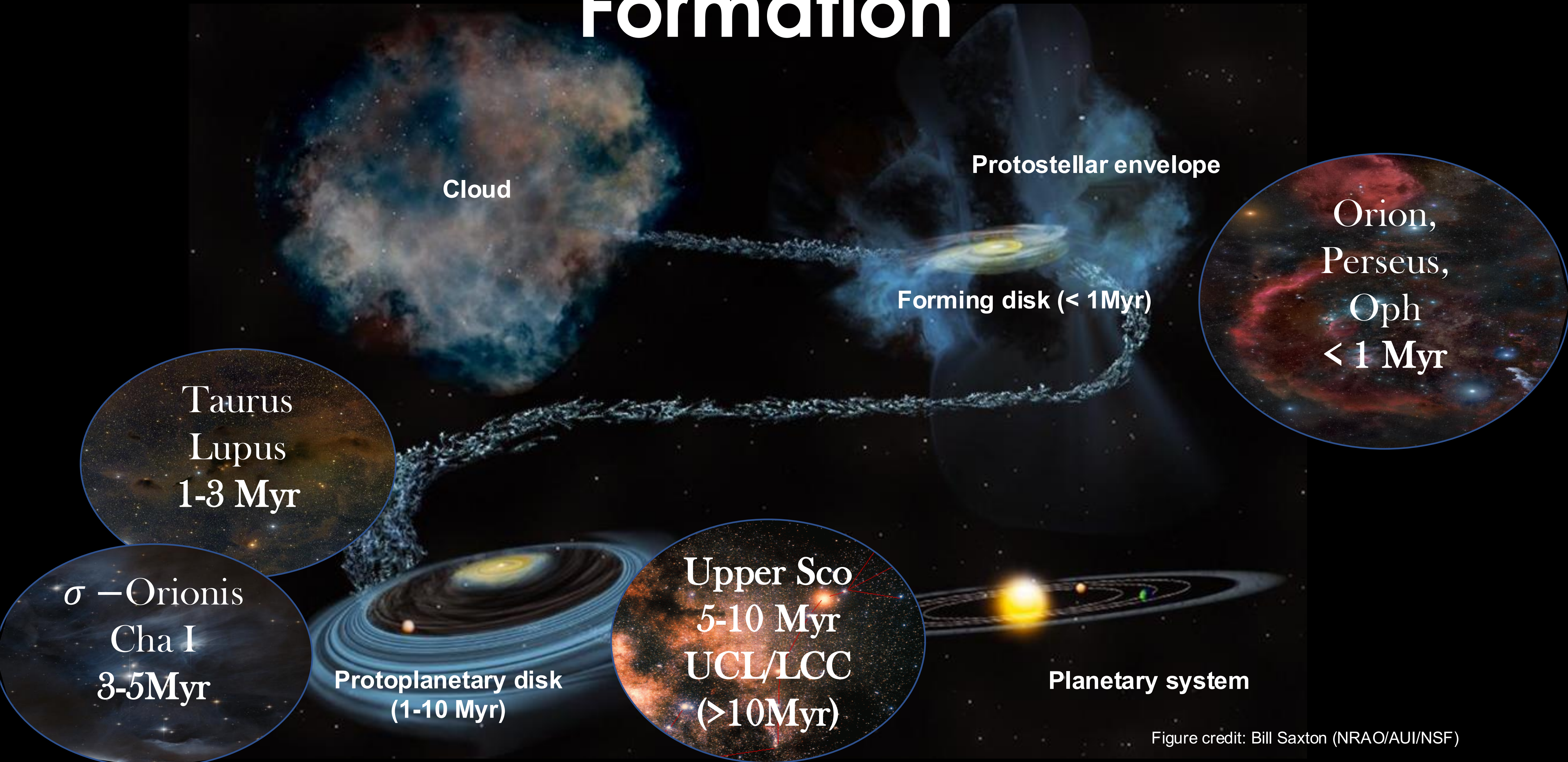


Figure credit: Bill Saxton (NRAO/AUI/NSF)

Witnessing Different Stages of Planet Formation

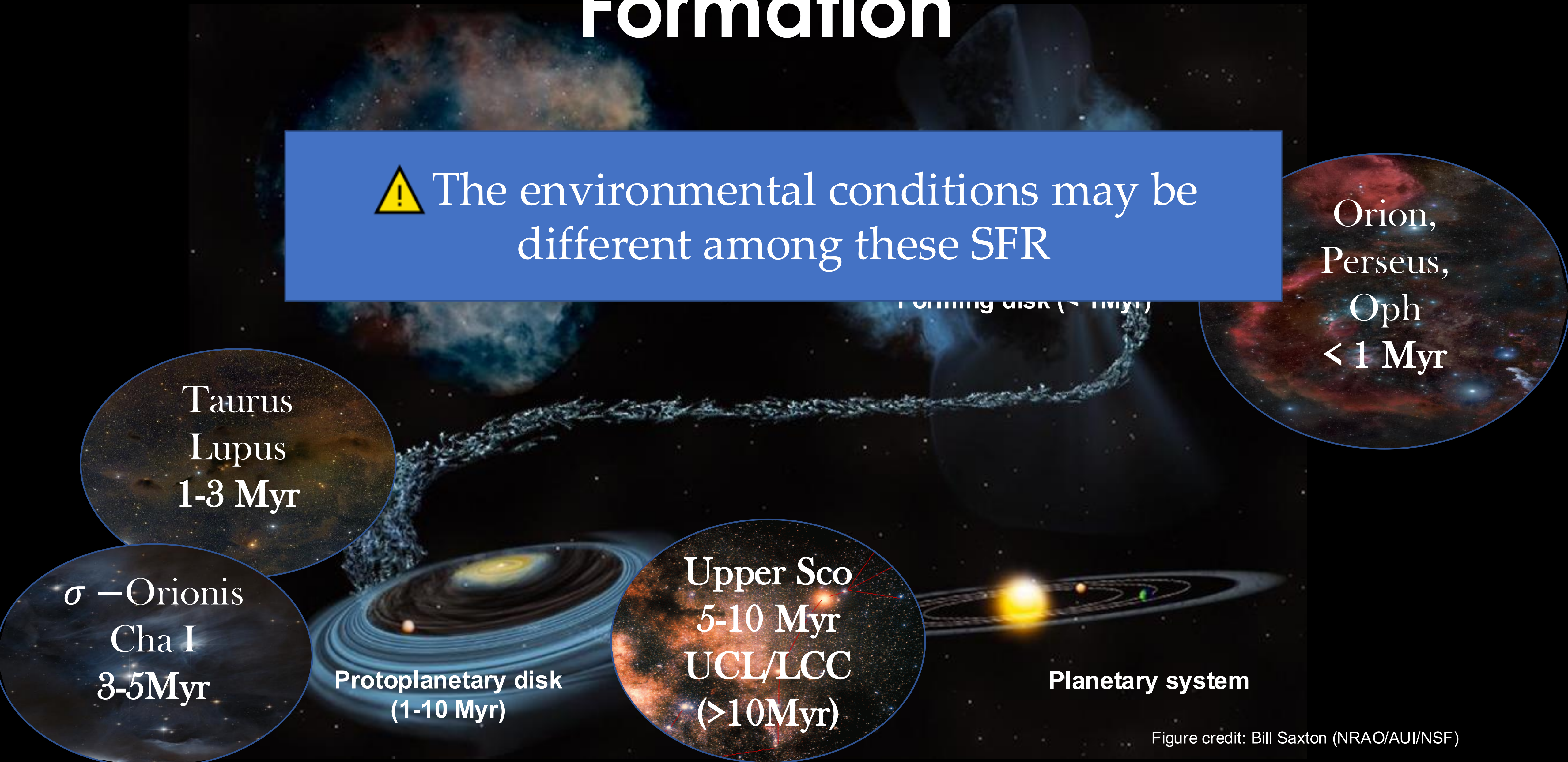


Figure credit: Bill Saxton (NRAO/AUI/NSF)

ALMA Large Program: AGE-PRO

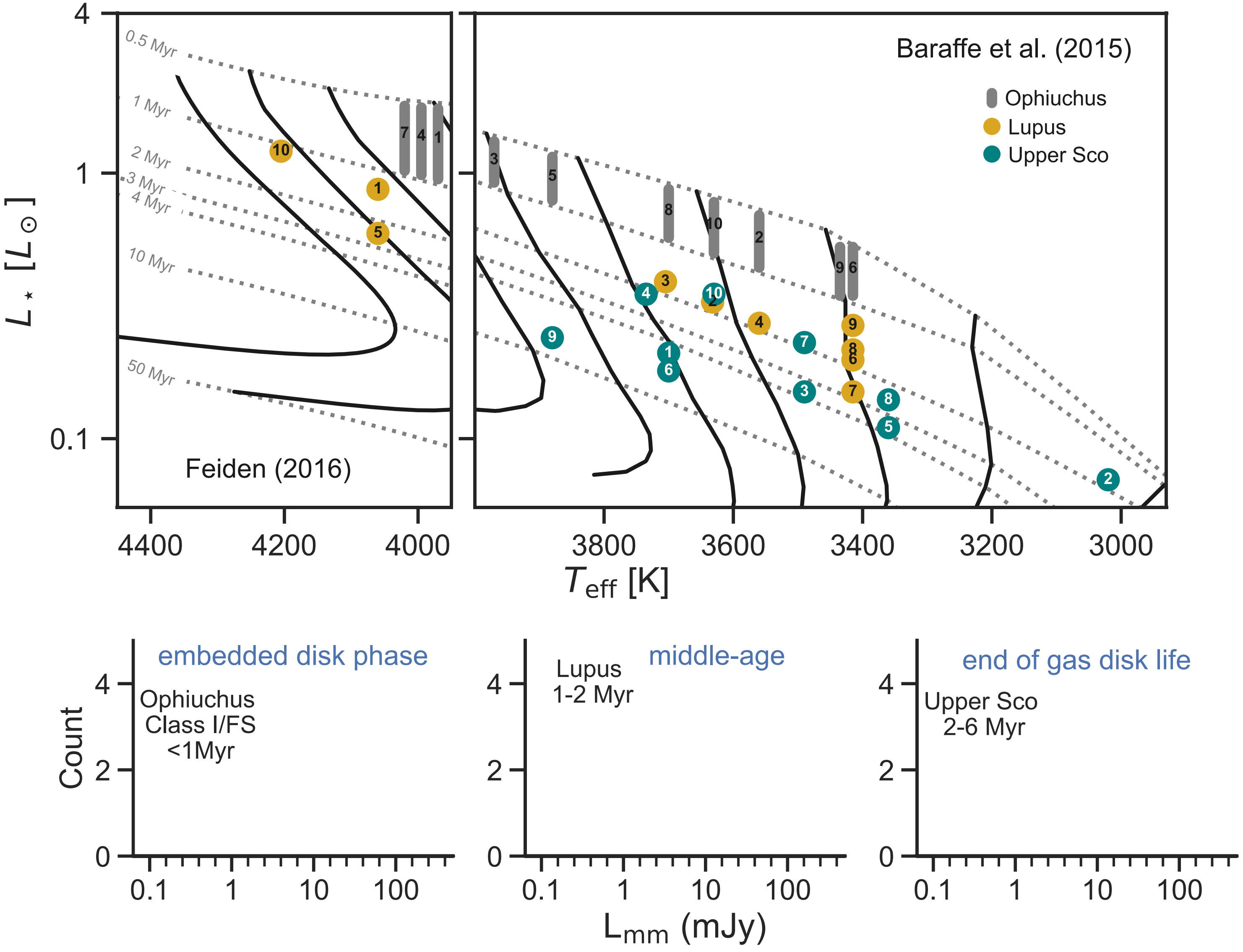
OUR GOAL

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

AGE PRO

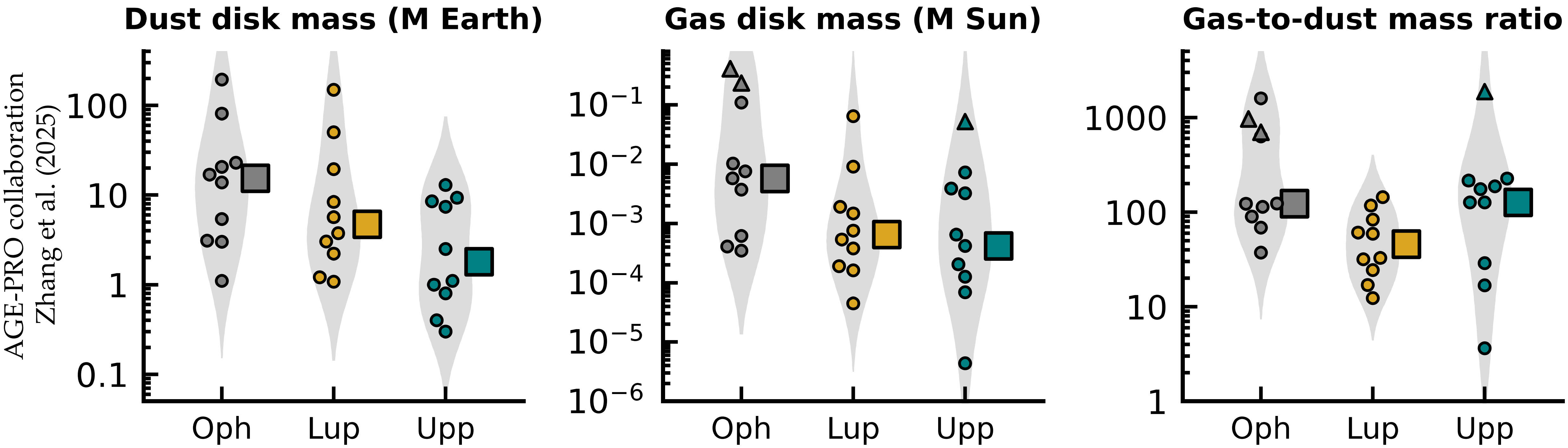
THE ALMA SURVEY OF GAS EVOLUTION IN PROTOPLANETARY DISKS

AGE-PRO Sample



- **30 disks to cover 0.1-6 Myr time-span**
  - Ophiuchus (<1 Myr)
  - Lupus (1-3 Myr)
  - Upper Sco (3-6 Myr)
- **Selection criteria**
  - Stellar spectral type: M3-K6 (0.3-0.8Msun)
  - Single or wide-separation binary (>600 au)
  - Sources with previous ^{12}CO detections
  - Closest to the region's median age

Key AGE-PRO Results

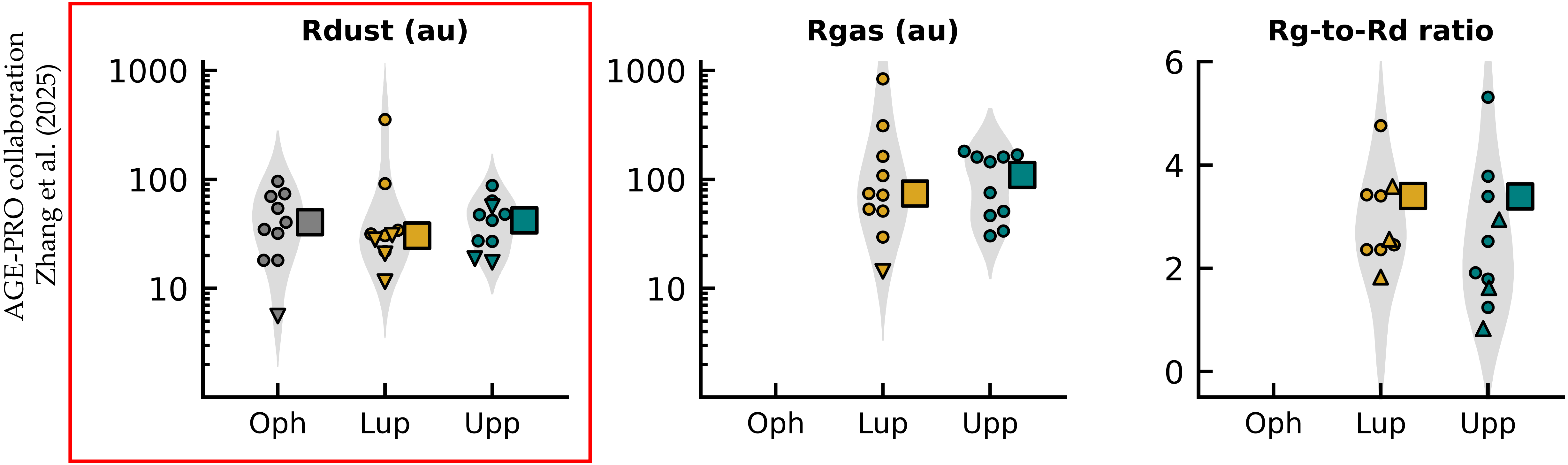


Ophiuchus (0.5-1 Myr): M_{gas} is high (~0.01 $M_\odot$) and g2d is ≳100

Lupus (1-3 Myr): Median disk mass drops by order of magnitude (~10^{-3} $M_\odot$), g2d ~ 40

Upper Sco (5-11 Myr): Median disk mass stays ~constant, g2d ~ 100

Key AGE-PRO Results

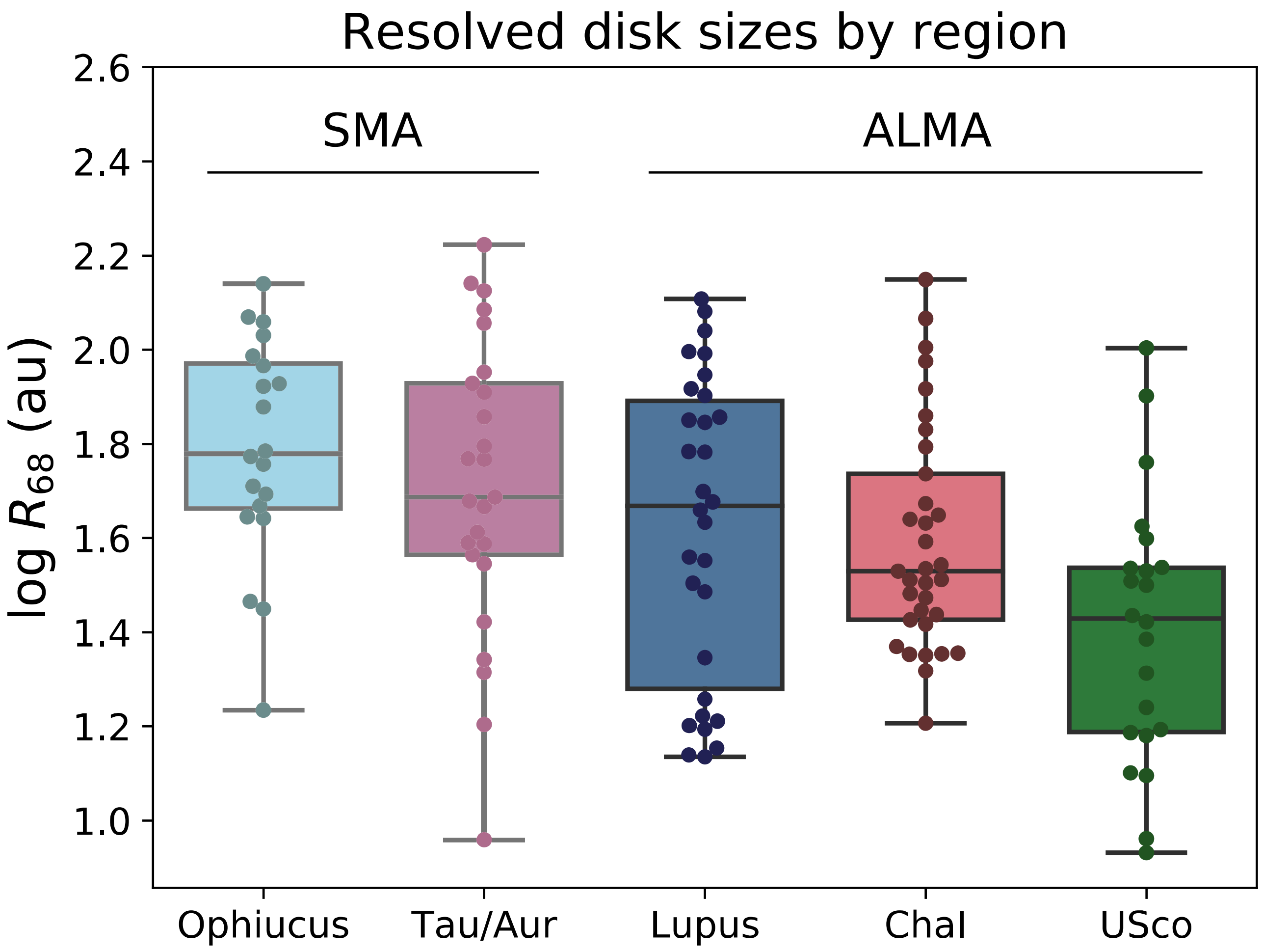


Dust disk size: remains <u>similar</u> within the three star forming regions.

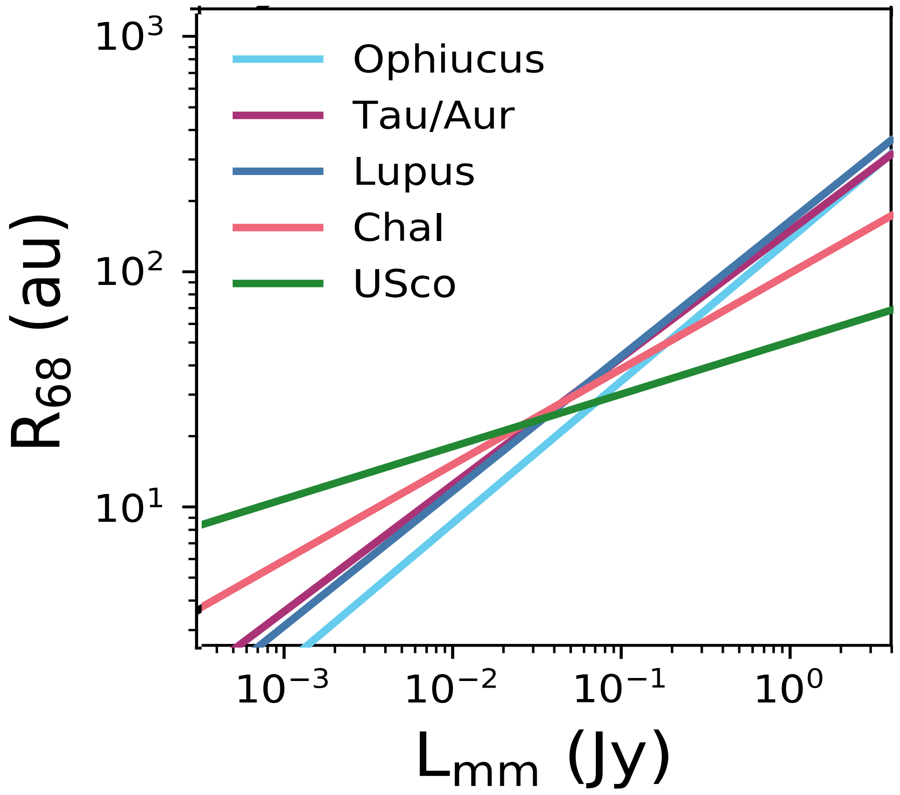
What does R_{dust} evolution tell us about the disk properties?

Are the observations biased?

Observational Results Previous to AGE-PRO



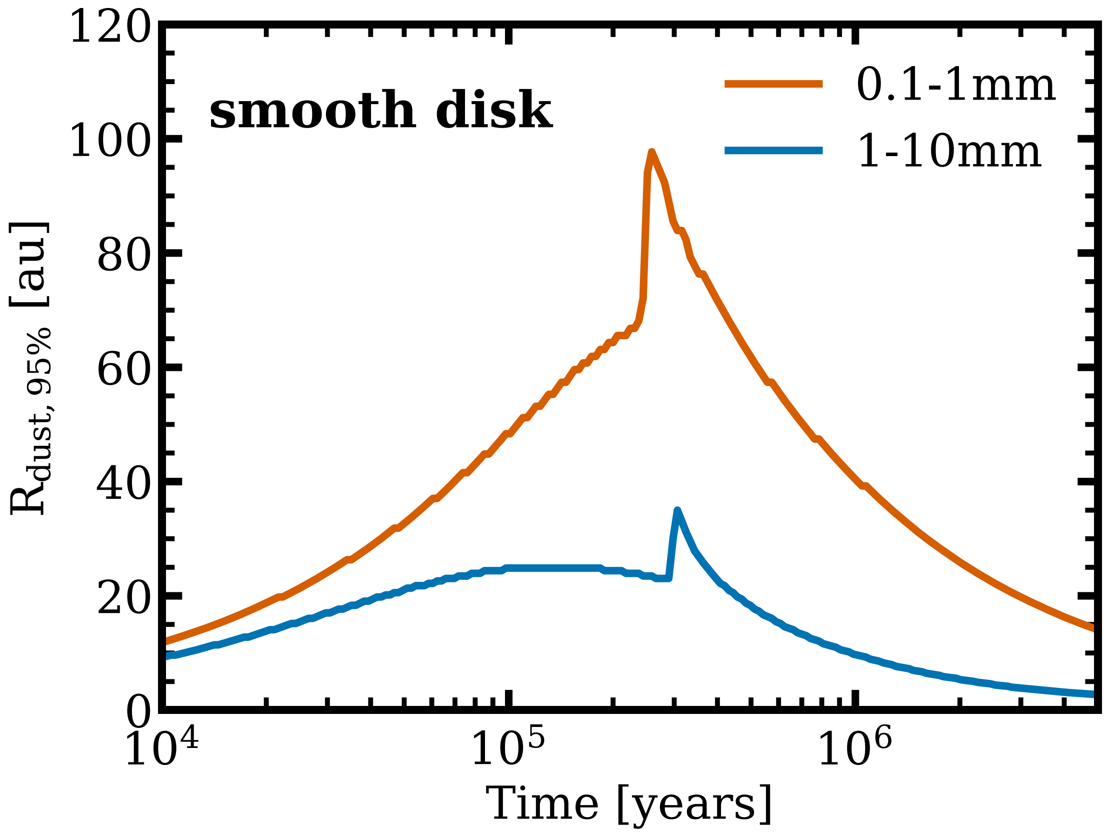
Hendler et al. (2020, incl. Pinilla)

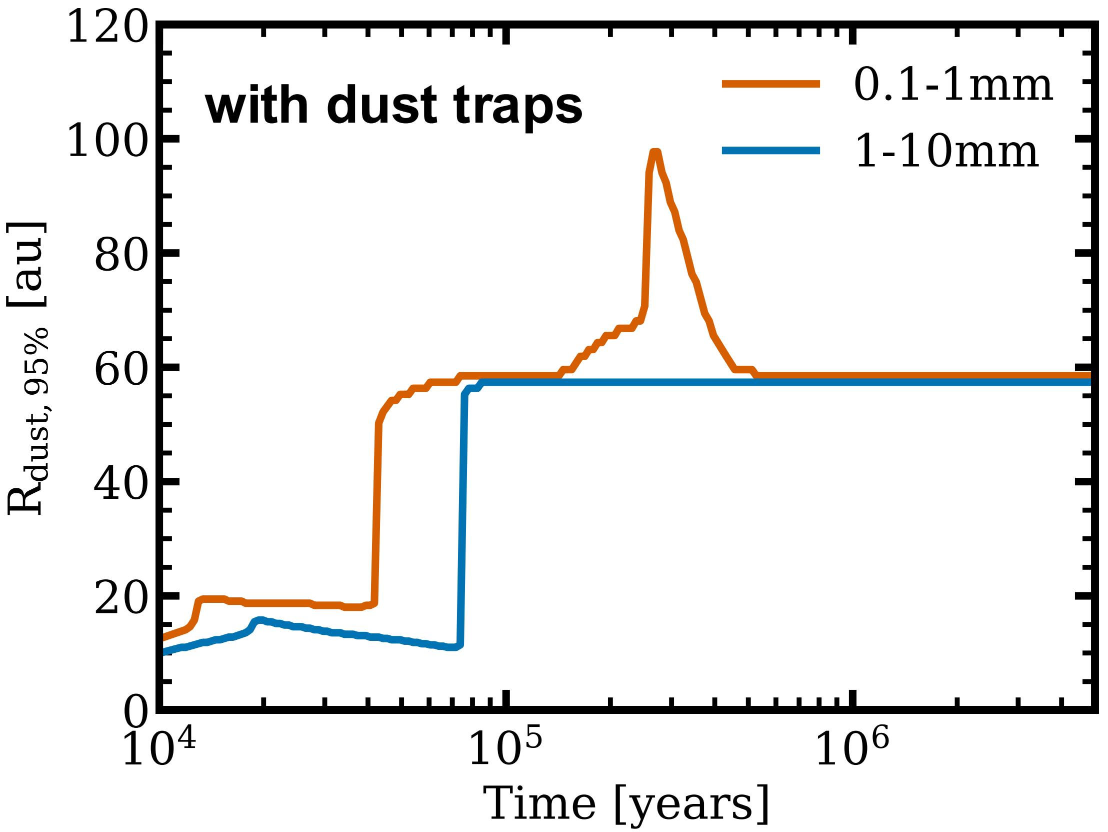


Continuum flux - dust disk radii correlation: **is not the same in all regions,** it becomes flatter for Upper Sco (5-10 Myr old)

Model Predictions for R_{dust}

Long, Pinilla et al. (2020), Pinilla et al. (2020)

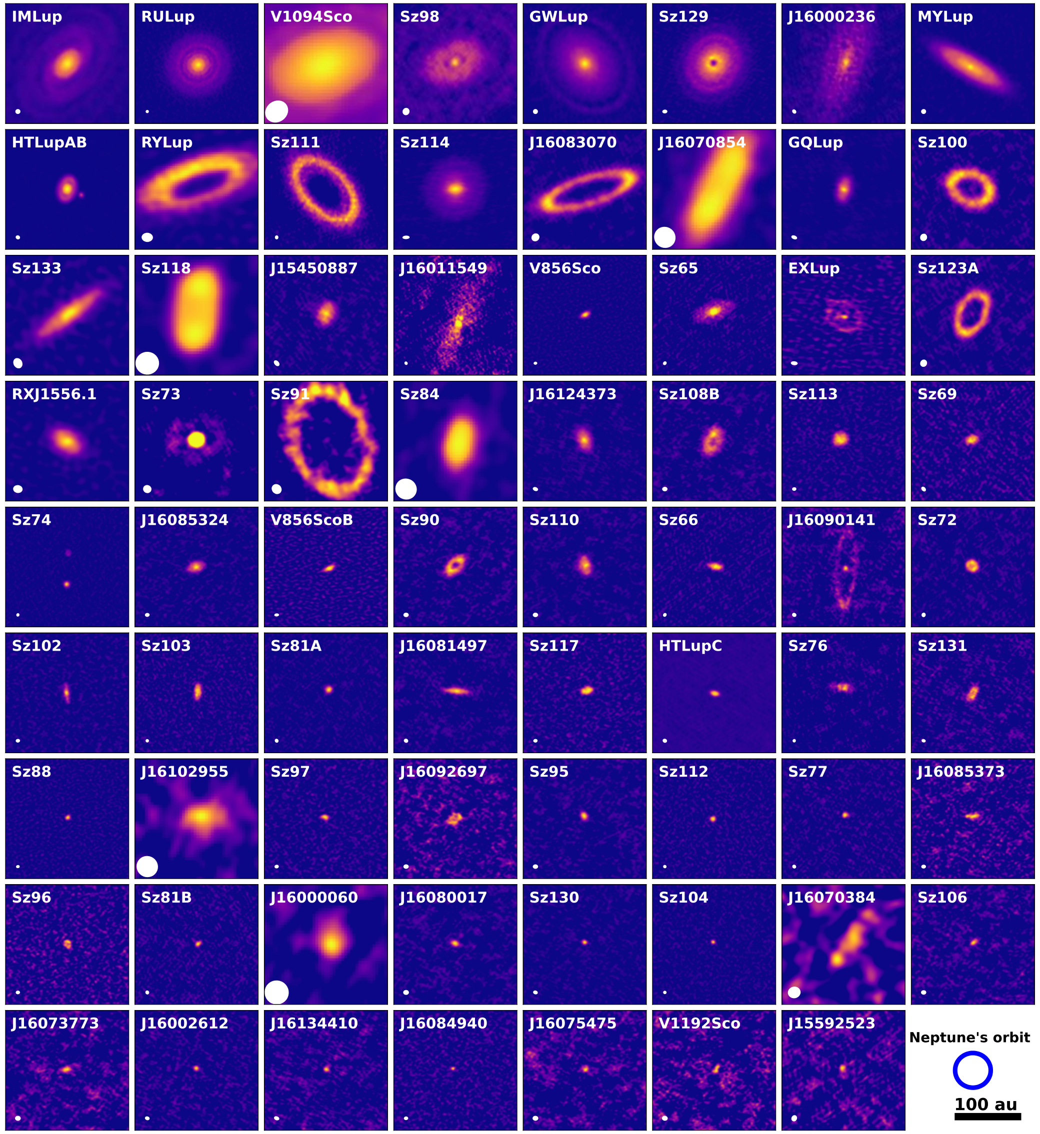


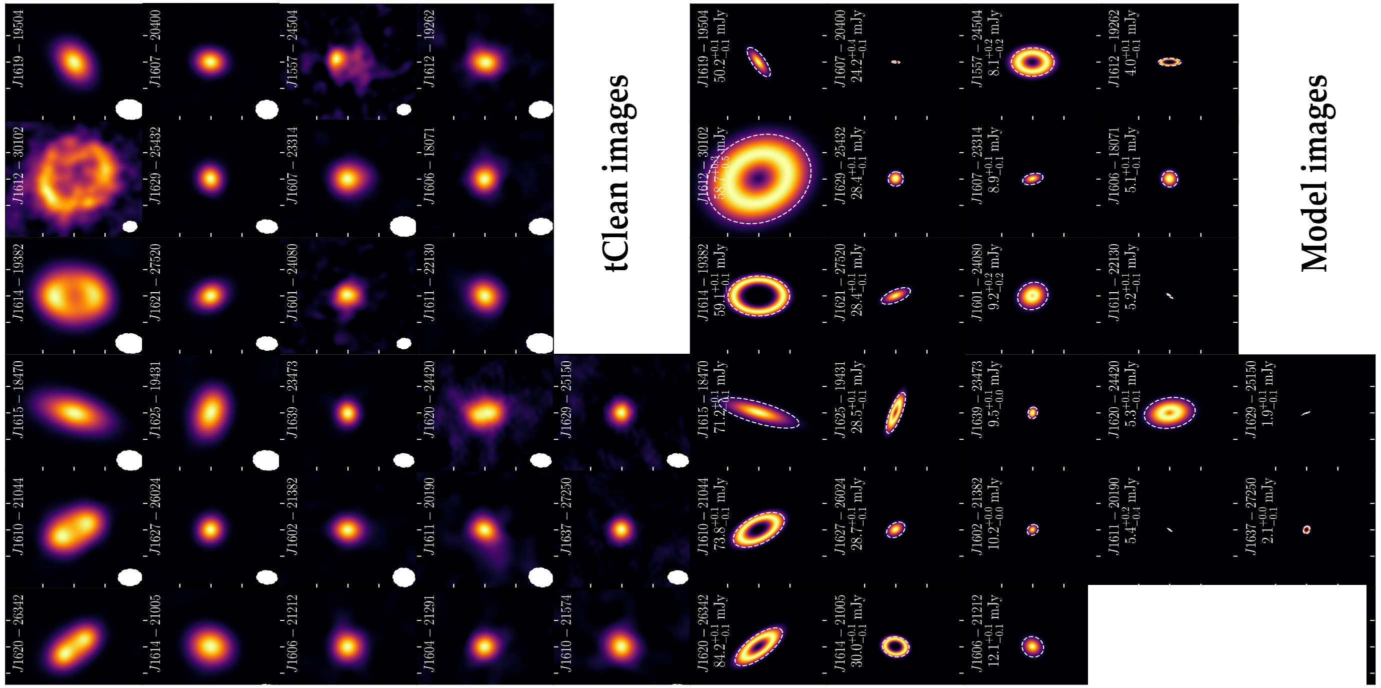


In a smooth disk: Rdust decreases with time due to radial drift, and disks are expected to be smaller when observed at longer wavelength

In a disk with pressure bump(s): Rdust remain constant over time after ~0.5 Myr (usually tracing the location of the furthest pressure bump), and this is independent of wavelength.

Recent ALMA Large Sample Observations

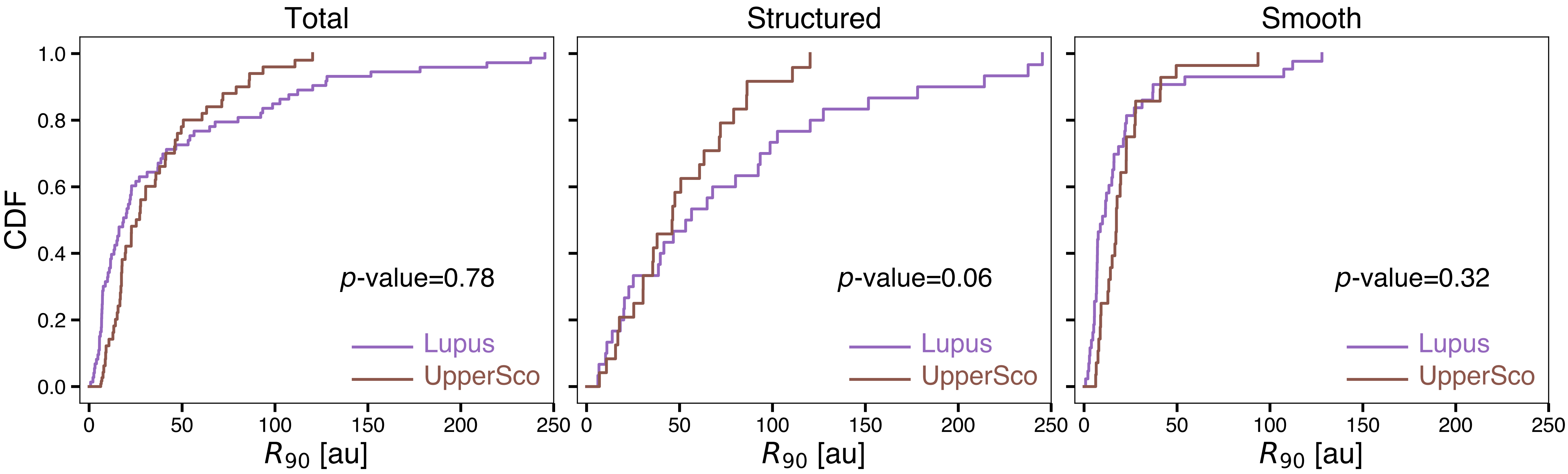




Left: Lupus disks – 73 disks, covering a spectral type between M5-K2, at a resolution of 0.03-0.04'' (Guerra-Alvarado et al., 2025, incl. Pinilla). Compact disks are common ~67% are smaller than 30 au.

Upper right: UpperSco disks – 121 disks (Carpenter et al., 2025), M5-K2 at a resolution of 0.1'' (Pinilla et al., 2025). Both analysis are in the visibility plane

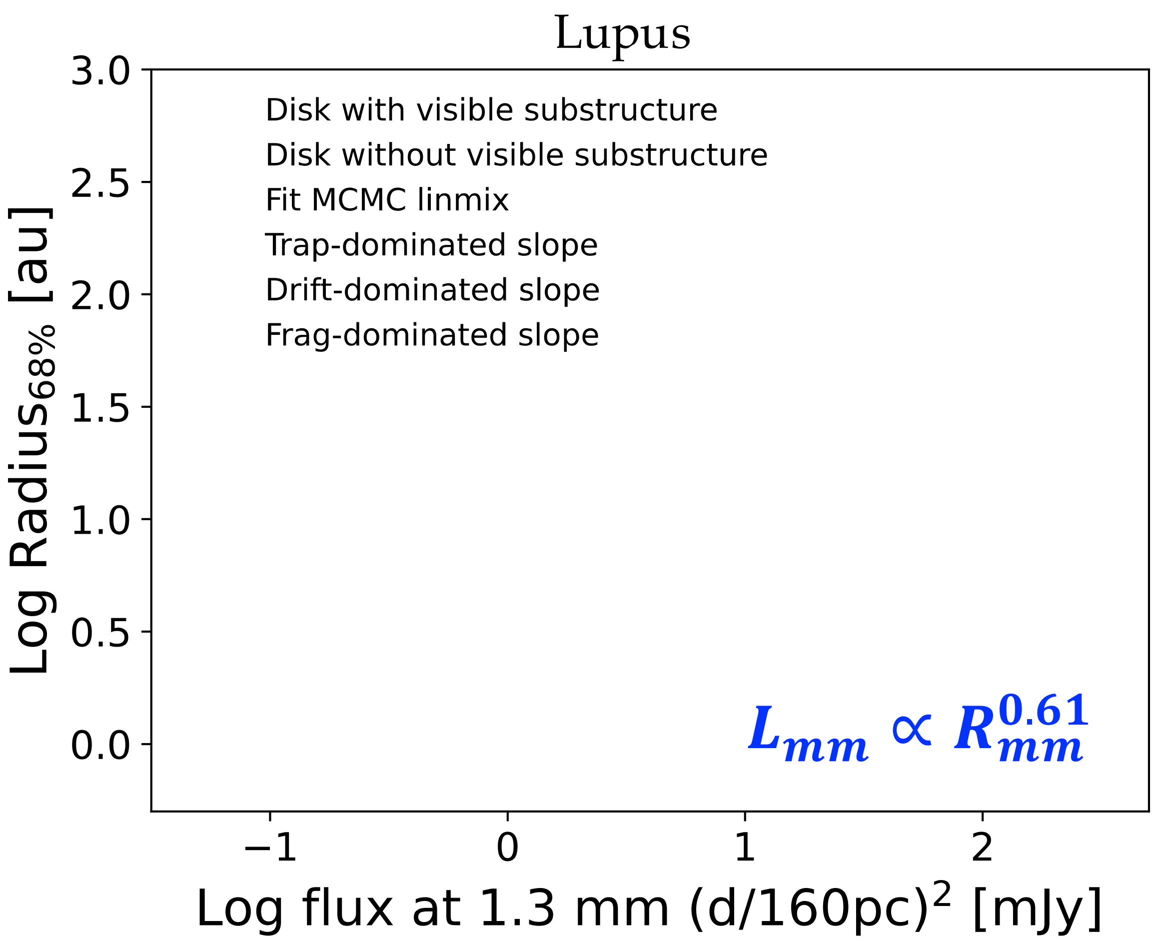
Analysis of the UpperSco Disks and Comparison with Lupus

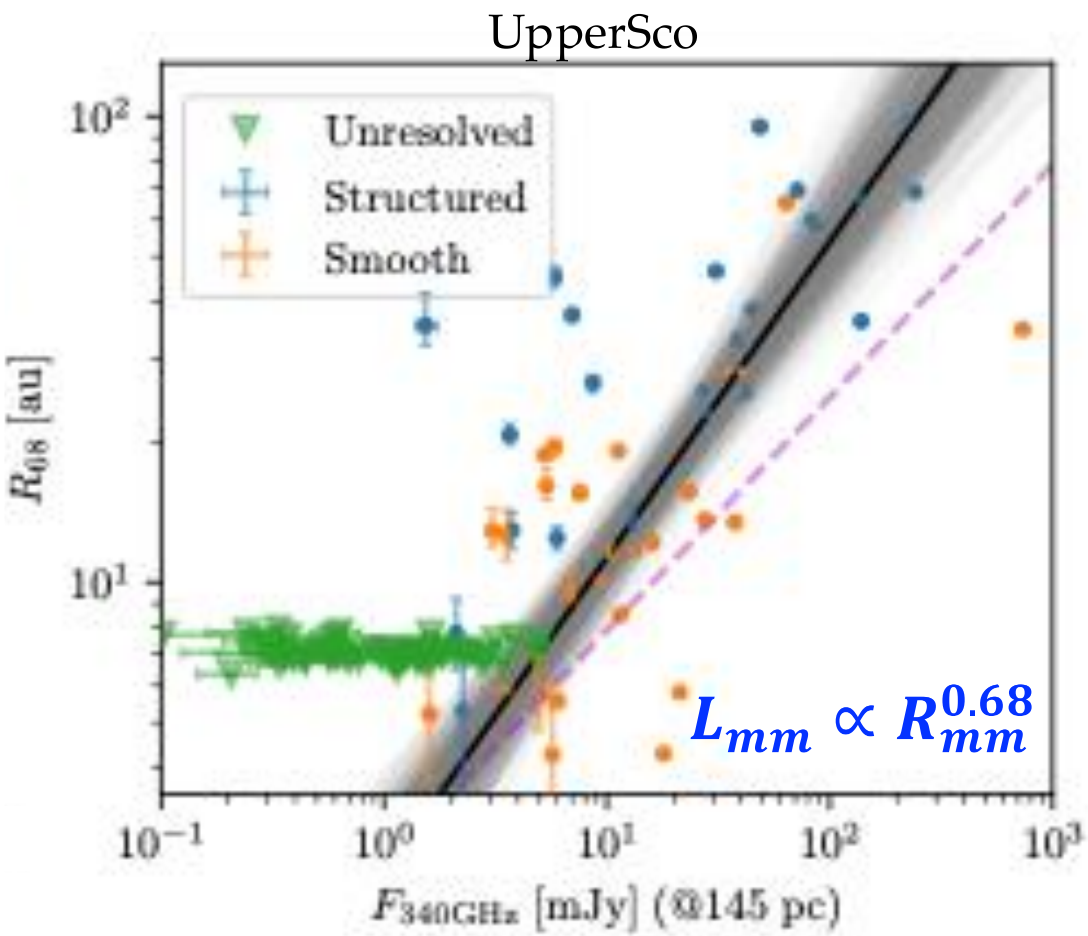


Pinilla et al. (2025)

There is **no a significant difference** of R_{dust} among the disks in Lupus and the surviving disks in UpperSco

Continuum flux - Dust Disk Radii Correlation





$R_{dust} - L_{mm}$ relation is similar in both regions, and in agreement with radial drift models (Zormpas+2022). This means that if in most of these disks traps are present, they need to be **leaky traps**

UpperSco is Subject of Mild-External Photoevaporation

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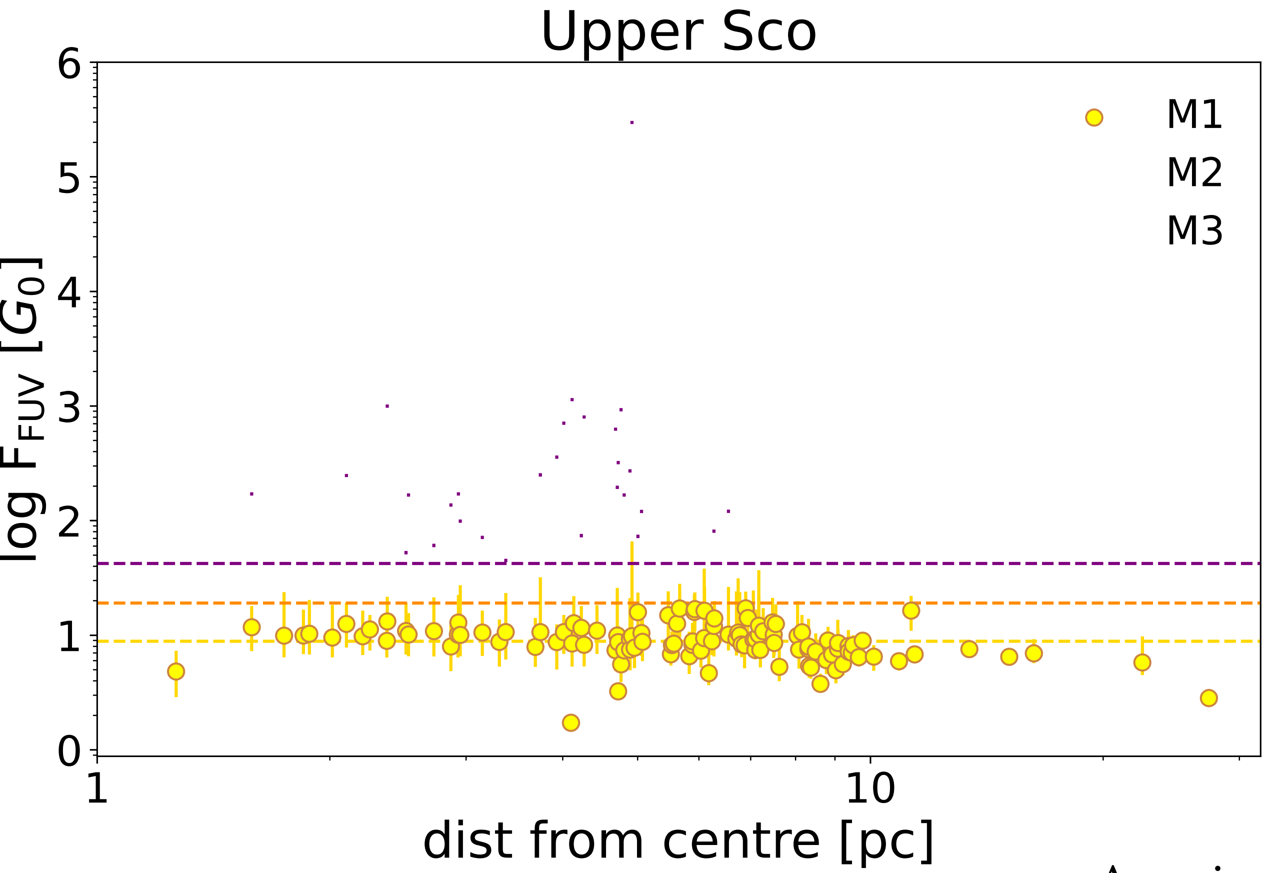
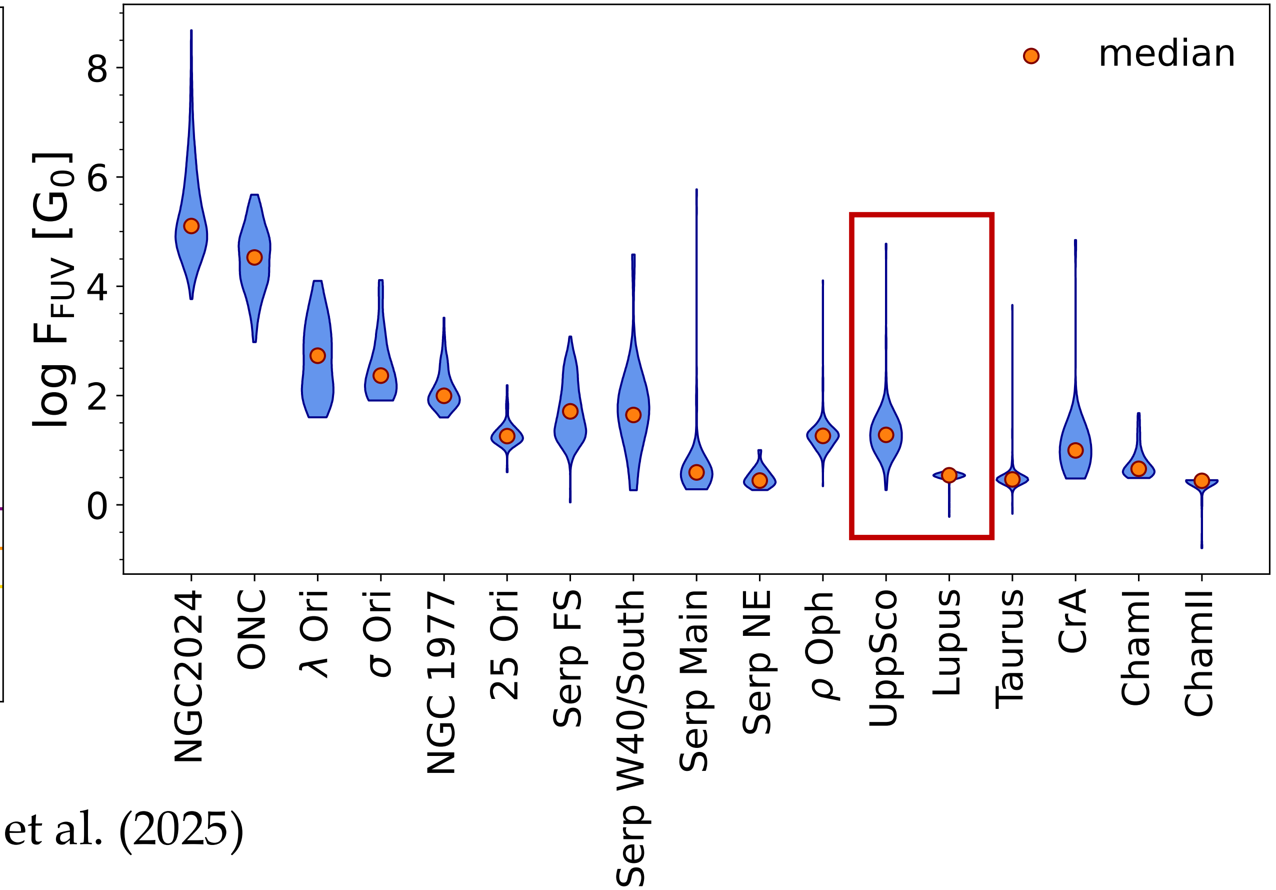
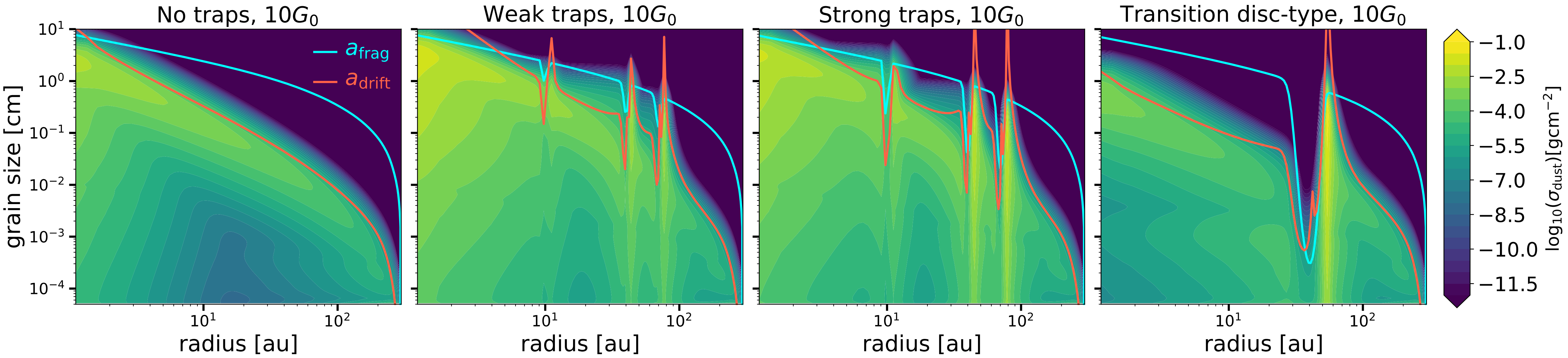




Anania et al. (2025)

Upper Sco is not an older version of Lupus/Taurus, as the environment is different

Comparison with dust evolution models that include external photoevaporation



Pinilla et al. (2025)
See also Garate et al. (2024)

Dust Evolution Models (Dustpy):

- $F_{UV} = 1, 10, 20, 40\ G_O$
- $0.3, 1.0\ M_{sun}$
- $\alpha = 10^{-3}$
- No traps, weak-, strong, transition disk type traps.

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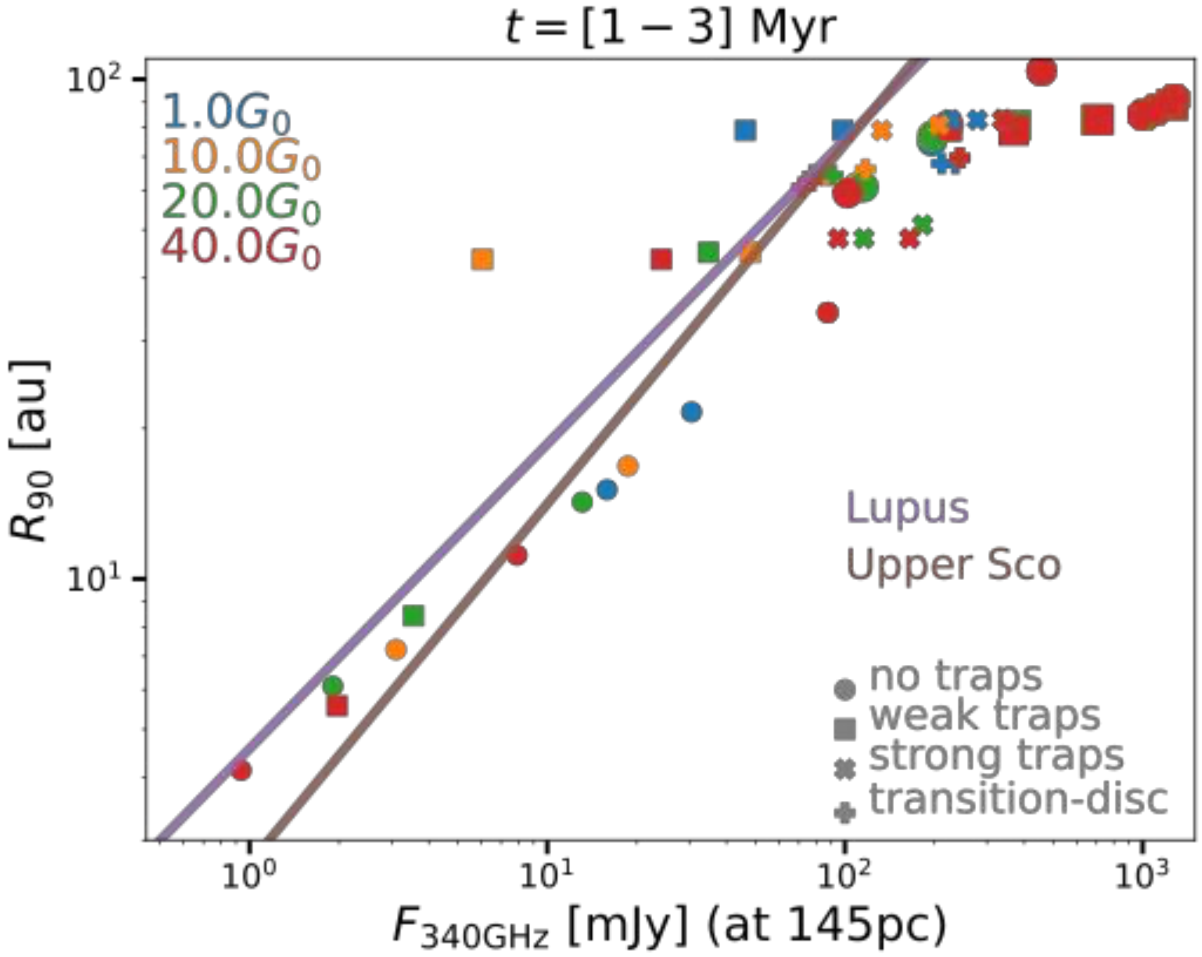
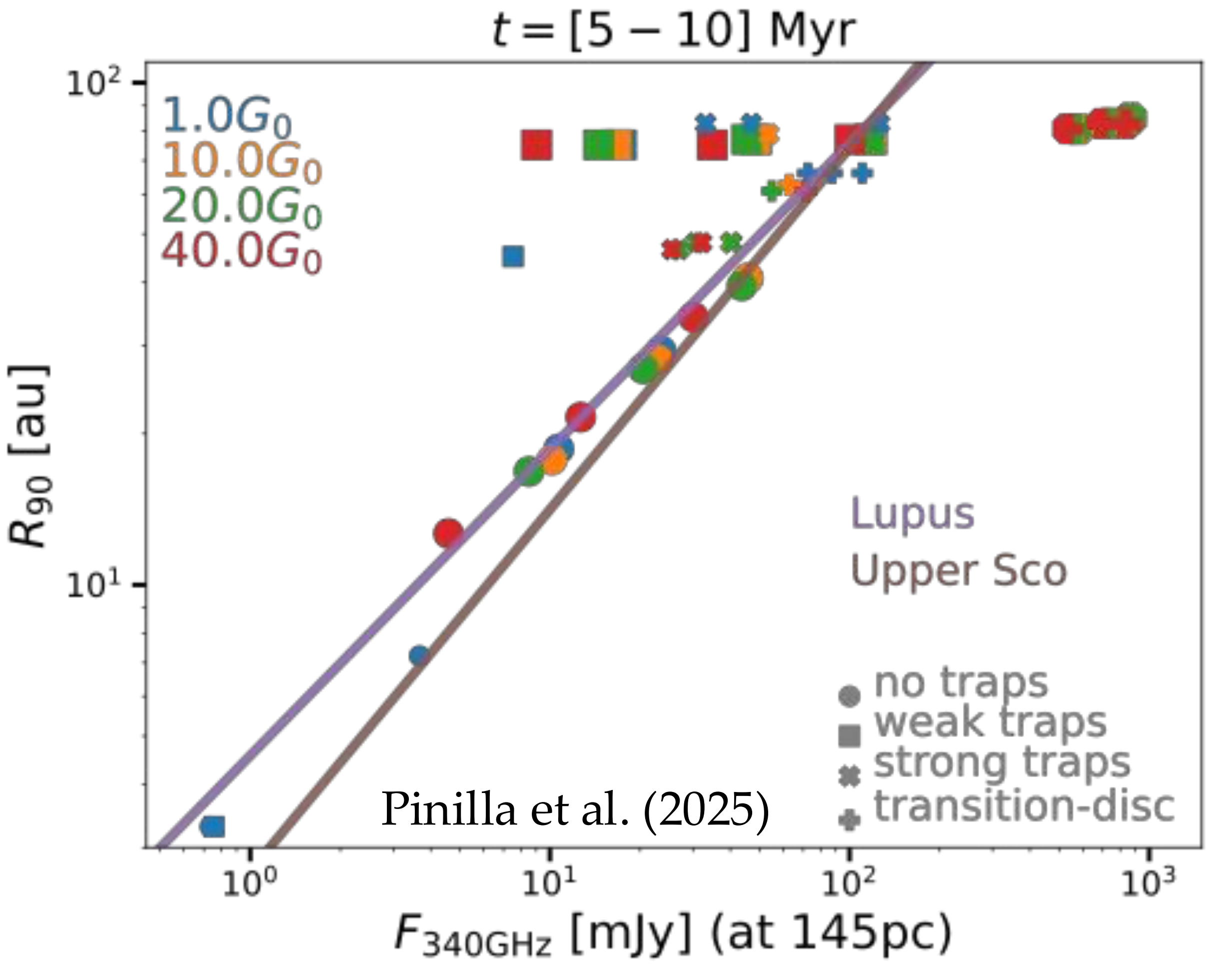
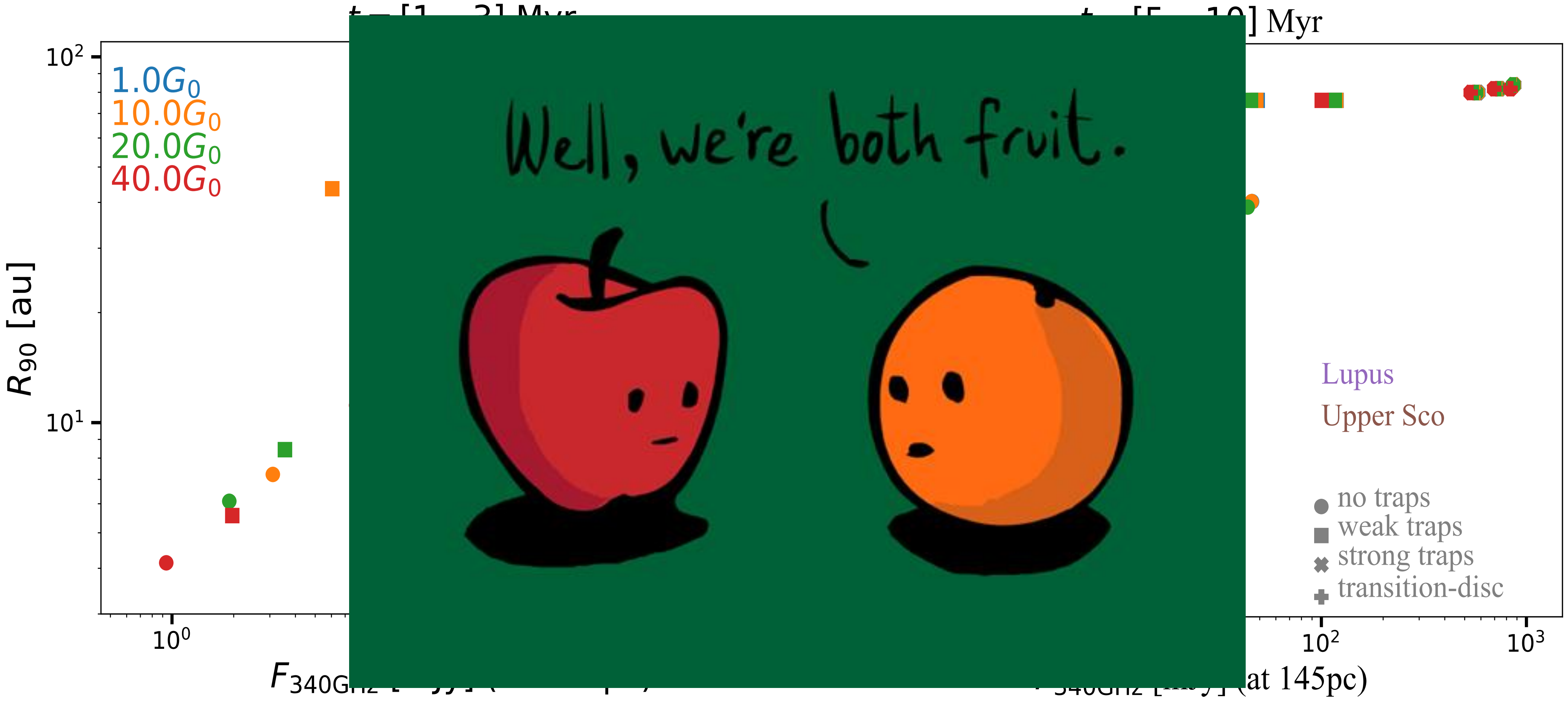




Mild values of external photoevaporation do not have a strong influence on this correlation. The presence or absence of traps (that controls the level of drift) has the highest impact

Comparison with dust evolution models that include external photoevaporation



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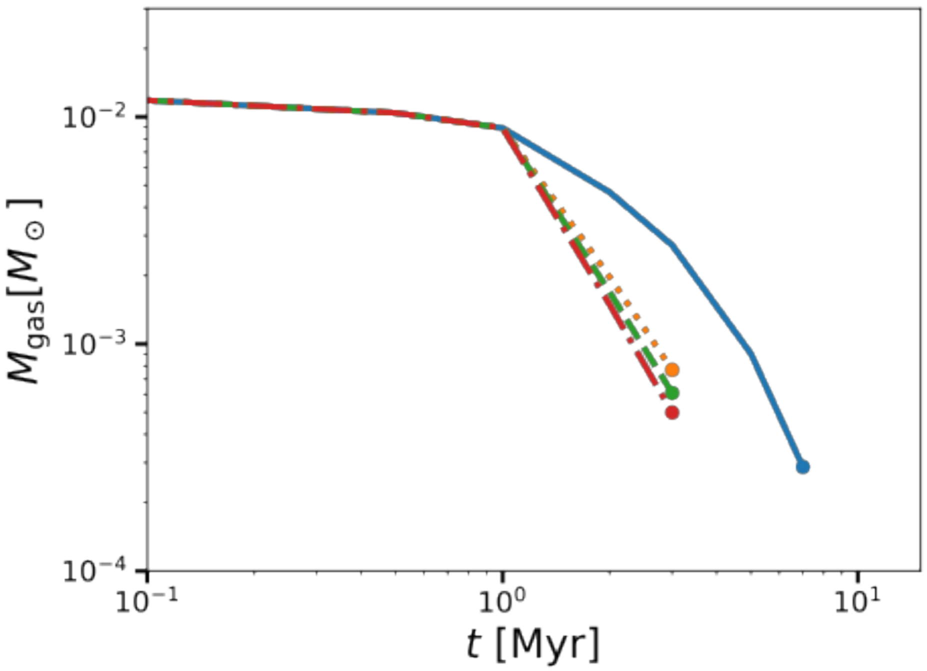
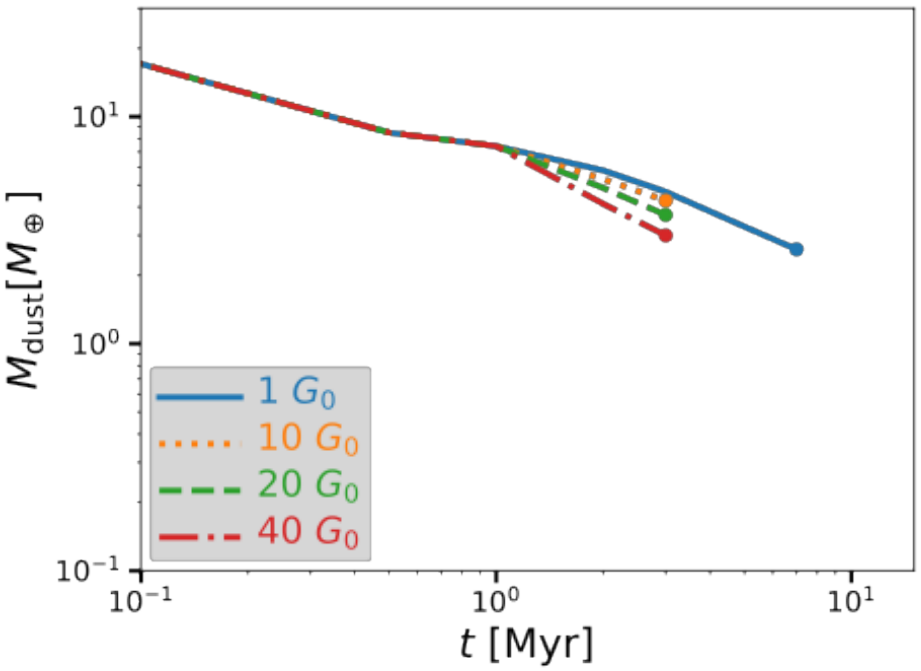
Disks around a low mass stars should have already dispersed by the age of UpperSco



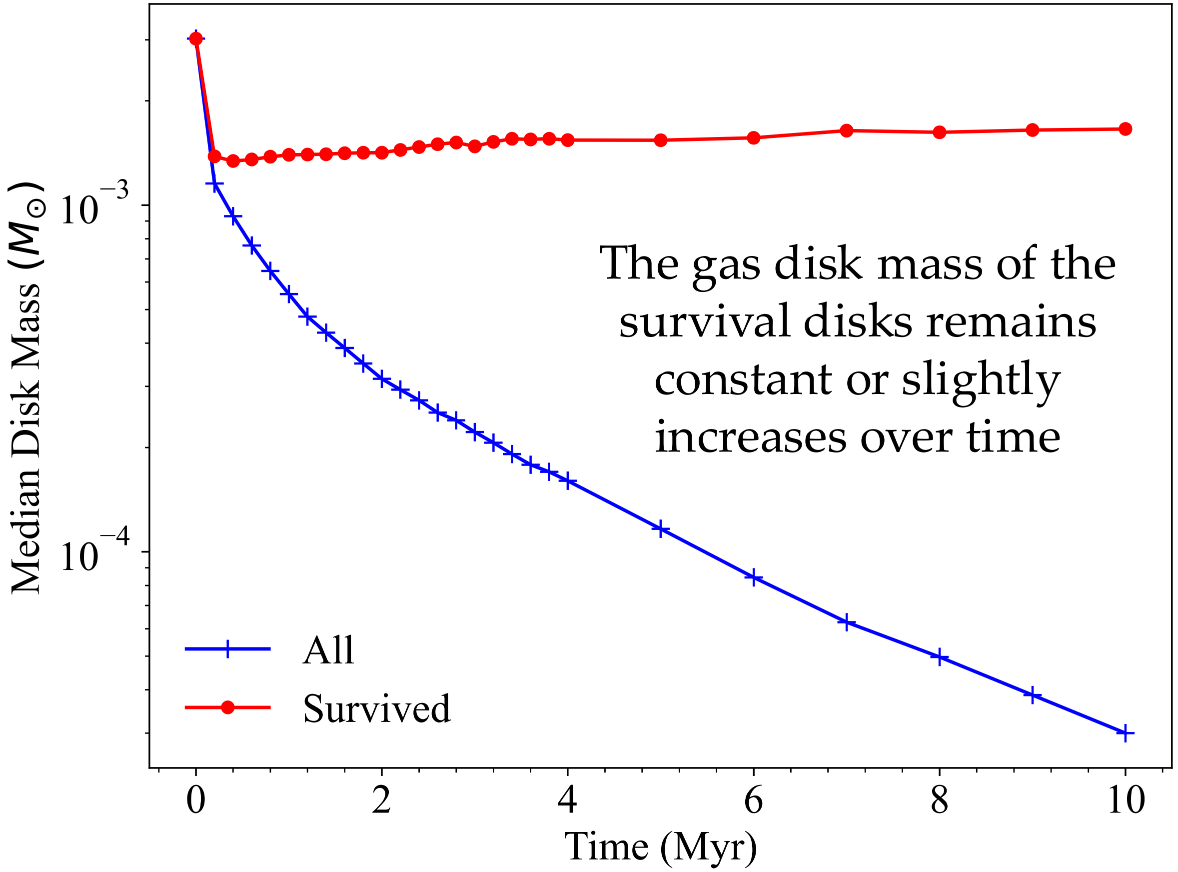


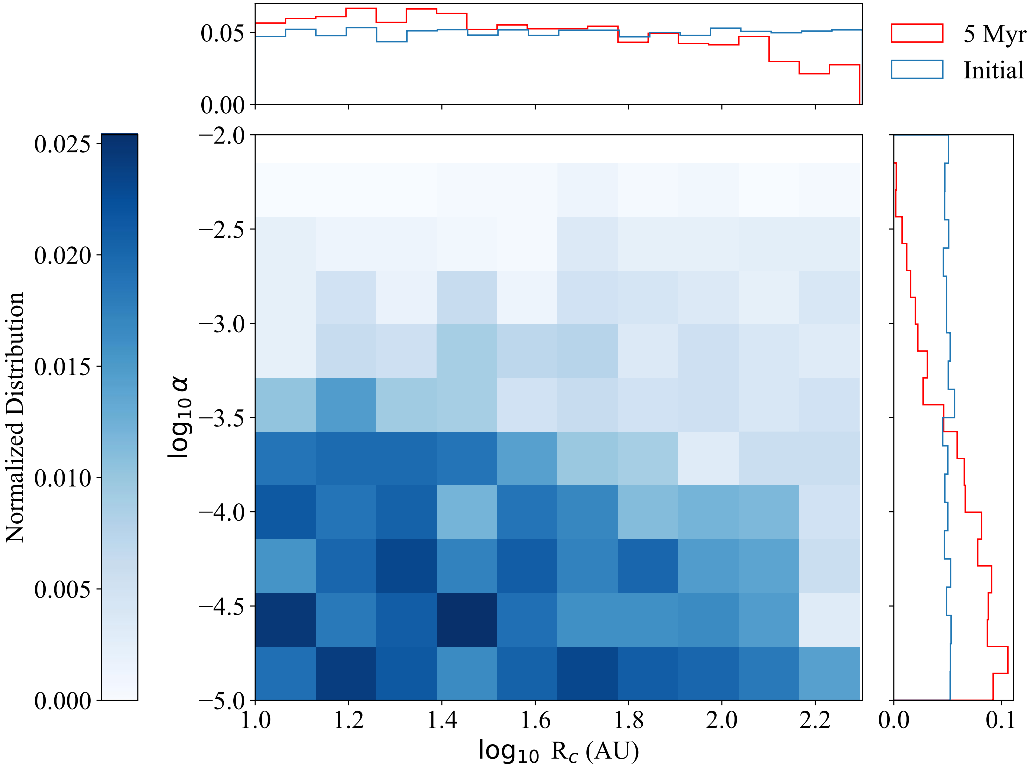
Models for 0.3 M_{sun}

Example with strong traps

What physical conditions are needed for these disks to survive?

External Photoevaporation: Population Synthesis Approach





Ping et al. (2026)

> 10,000 simulations to text what disks survive in UpperSco star forming region

Conclusions

1. Recent analysis of ALMA observations of different star forming regions show that R_{dust} **does not evolve with time**, suggesting the presence of dust traps in most disks

2. $R_{dust} - L_{mm}$ **relation is similar** in Lupus and UpperSco star forming regions, **in agreement with radial drift models**. If dust traps are present, they need to be **leaky traps. Similar conclusion for M_{dust}-M_{star} relationship (no shown here)**

3. Mild values of external photoevaporation **do not have a strong influence on the observed $R_{dust} - L_{mm}$ relation.** Radial drift and the presence of dust traps have the highest impact.

4. Disks in Upper Sco are less optically thick at mm-emission, we recover R_{90} vs. M_{star} relationship **(no shown here)**

Future Perspectives

- Mild values of FUV should have a high impact in the **gas properties** of UpperSco. → Future high sensitivity and angular resolution of molecular lines in UpperSco (and even older disks)

- We are trying to measure disk turbulence **directly from the gas (Teresa's talk)**, and **indirectly from the dust (e.g., Kiyoaki's work).** Can we test if we detect evidence of different levels of turbulence for the old vs. young disks?

- Let's find more protoplanets!