SMA Observations of Disks

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INTRODUCTION

The disks around young stars are the links between star and planet formation. They provide the raw material, determine conditions, and limit timescales for planet formation. Disk evolution proceeds from primordial, gas-rich "protoplanetary" disks composed of remnant material from the star formation, to tenuous, almost gas-free "debris" disks, whose dust must be replenished by the grinding of planetary embryos. Here we show a few examples of SMA observations of disks.

Protoplanetary ⟶ Debris

Protoplanetary	Debris
• Age~ 1 to 10 Myr	• Age up to Gyrs
• Gas rich and trace dust	• Dust rich and trace gas
• Sticking dust growing into planetesimals	• Colliding planetesimals creating new dust
• Mass 0.001 to 0.1 $M_\odot$	• Mass < 1 $M_☽$

DEBRIS-CONTINUUM: RESOLVING THE HR 8799 DISK

HR 8799, a 30 Myr old nearby A-type star, is the host of the first directly imaged multiple planet system. Wilner et al. (2018) observed the system with the SMA at 1.3 mm, complementing archival ALMA observations (see Fig 1). The 1.3 mm emission morphology imaged at 3".8 (150 AU) reveals a broad axisymmetric inclined belt centered on the star, with the inclination and position angle consistent with a coplanar configuration of the disk and planetary orbits within the mutual uncertainties.

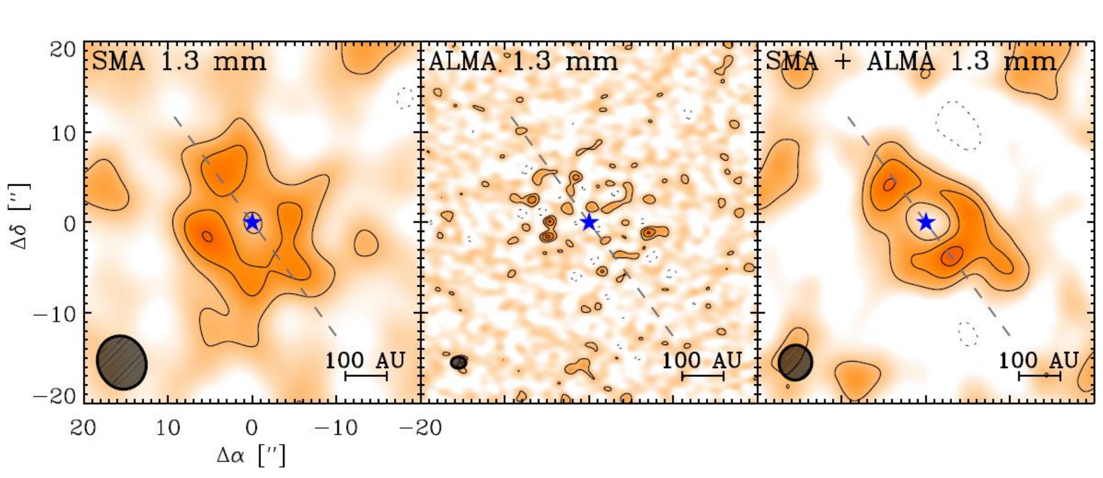


Figure 1. Images of 1.3 mm continuum emission from the HR 4799 Debris disk from the SMA (left), ALMA (center), and the SMA and ALMA combined (right).

[Reference: Wilner, MacGregor, Andrews et al. 2018, ApJ, 855,56]

PROTOPLANETARY-CONTINUUM: SIZE-LUMINOSITY

Disk size and luminosity encode crucial information about the mechanisms at play in planetesimal formation. Using new and archival SMA observations of continuum emission from 50 protoplanetary disks at 340 GHz (Fig. 2), Tripathi et al. (2017) quantified the correlation between disk size and luminosity, L∝ R^2, where brighter disks have their emission distributed to larger radii (Fig. 3). Dust evolution models can reproduce the disk size-luminosity relation (Fig. 4) with the presence of disk substructure, consistent with high resolution ALMA studies of such disks.

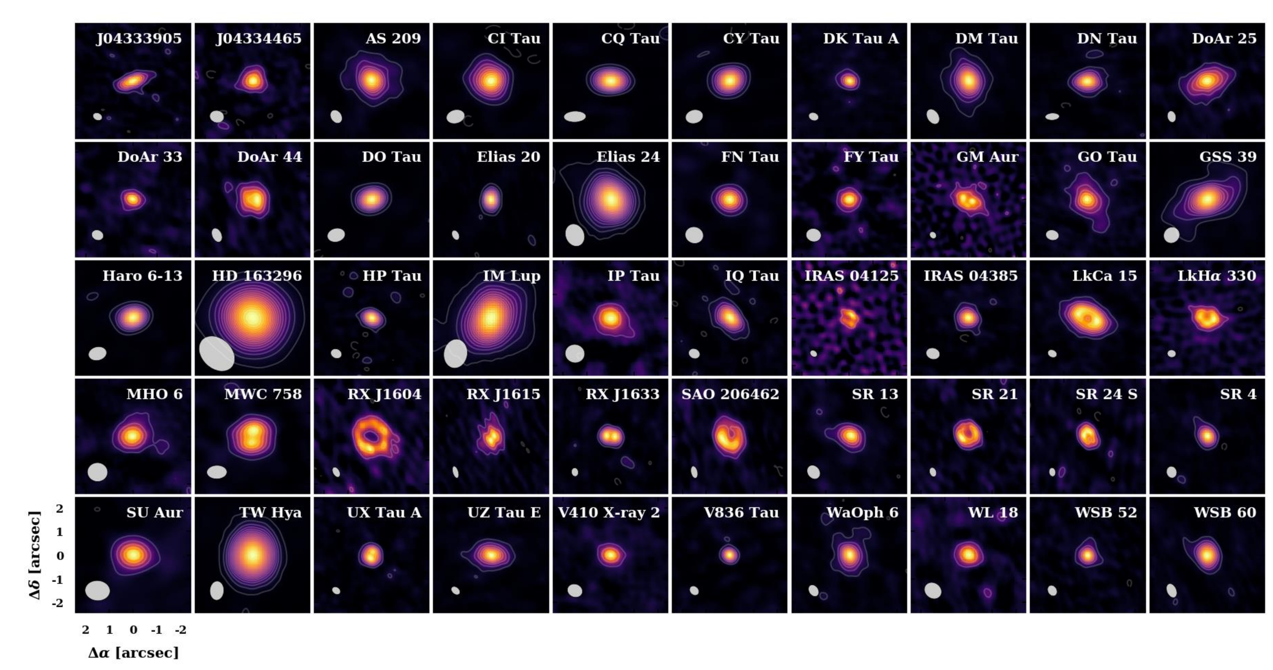


Figure 2. A gallery of 340 GHz continuum images of protoplanetary disks

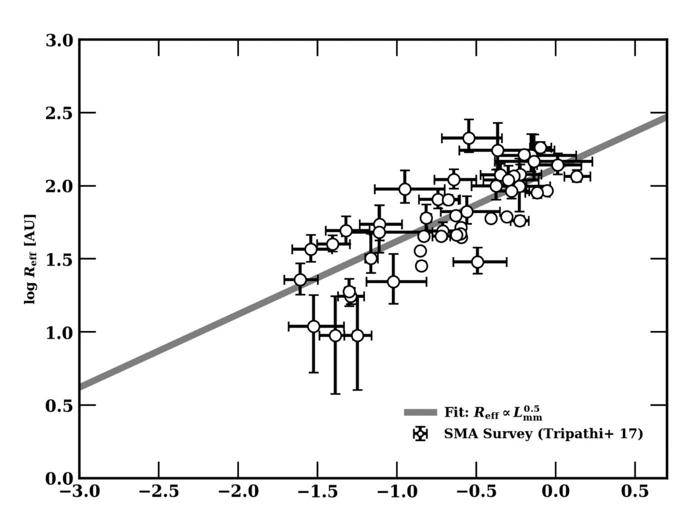
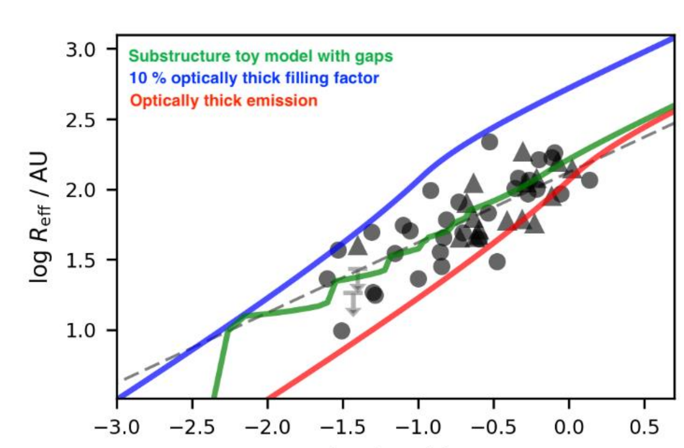


Figure 3. The Disk Size-Luminosity Relation at 340 GHz. The mean relation from the SMA survey of Tripathi et al. (2017) is shown as the solid line. Errorbars represent the 68% confidence interval.

Figure 4. The presence of disk substructure or optically thick emission, with a filling factor of few tens of percent, could explain the mean size-luminosity relation.



[Reference: Tripathi, Andrews, Tilman & Wilner 2017, ApJ, 845,44]

PROTOPLANETARY-SPECTRA: X-RAY DRIVEN CHEMISTRY

Protoplanetary disk chemistry is expected to evolve slowly, over timescales spanning~ 0.01 - 1 Myr. However, Cleeves et al. (2017) discovered a short-term (within a year) variability in the $H^{13}CO^+$ J=3-2 line in the IM Lup disk, probably due to the stellar X-ray activity perturbing the chemical "steady state" of the disk. Cleeves et al. (in prep) followed up this discovery with a moderate-sized SMA program to measure the pattern of variability in both $H^{13}CO^+$ 3-2 line and the X-ray luminosity toward the DM Tau disk through repeated SMA, Chandra and Swift observations spanning two months.

The initial results indicate significant $H^{13}CO^+$ variability across the SMA observations while other molecular lines (neutrals and optical thick lines) do not change (Fig. 5) . Cleeves et al. (in prep) creates synthetic X-ray light curves based upon the statistical behavior of young stars and computes the expected abundance variations of HCO^+ over time (Cleeves et al. 2017). Preliminary results suggest that indeed the distribution of variability seen in the data and that seen in the models are similar, consistent with the X-ray driven chemistry hypothesis.

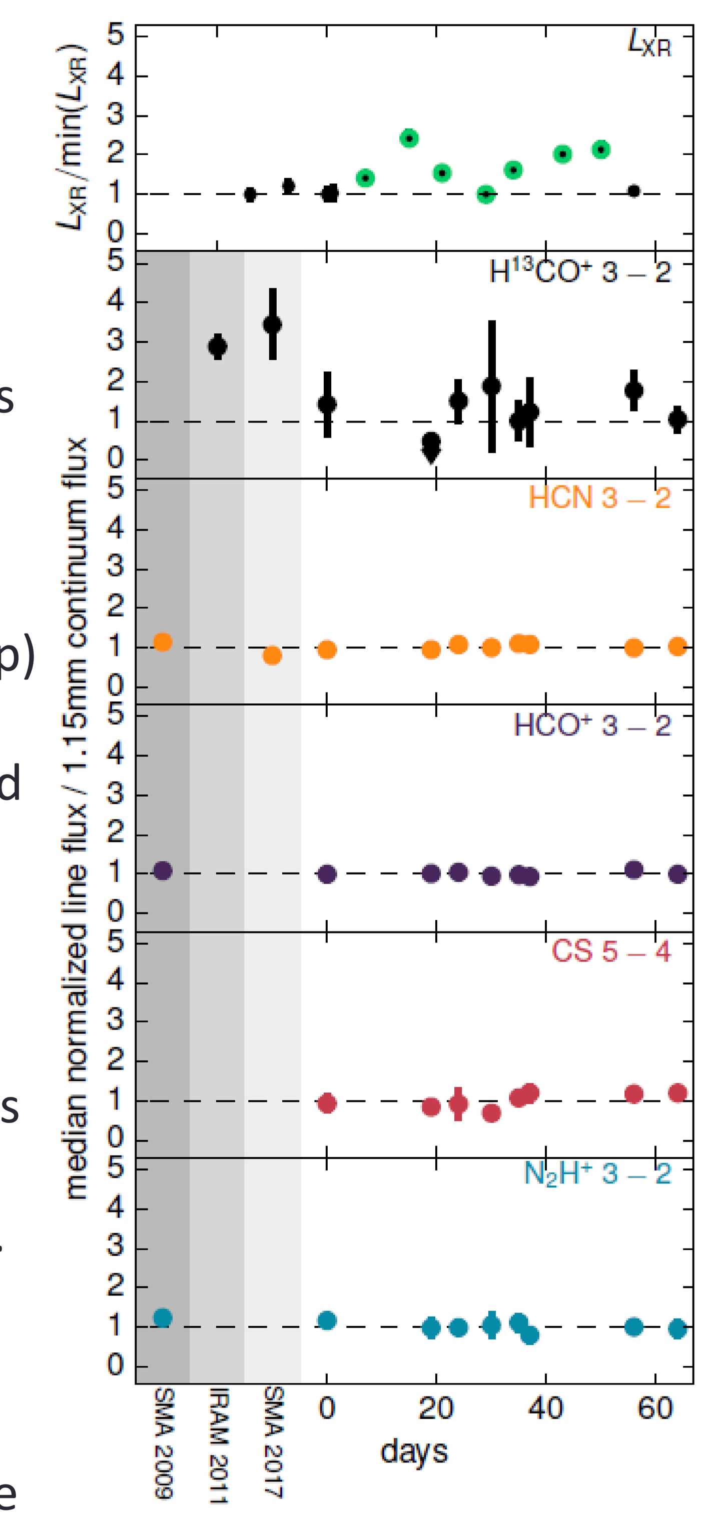
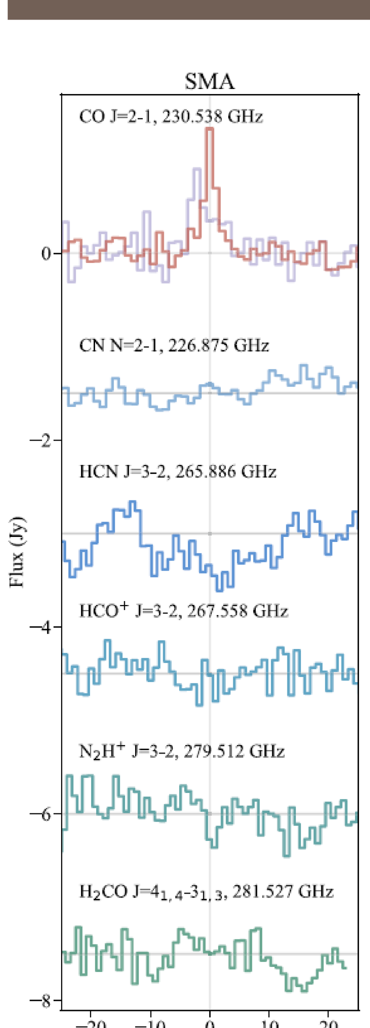


Figure 5. DM Tau SMA observations. Top: Chandra and swift X-ray observations. Bottom panels: disk-integrated line fluxes as labeled.

[Reference: Cleeves et al. 2017, ApJL, 843L, 3; Cleeves et al. in prep]

DEBRIS-SPECTRA: LINES IN THE B PICTORIES DISK

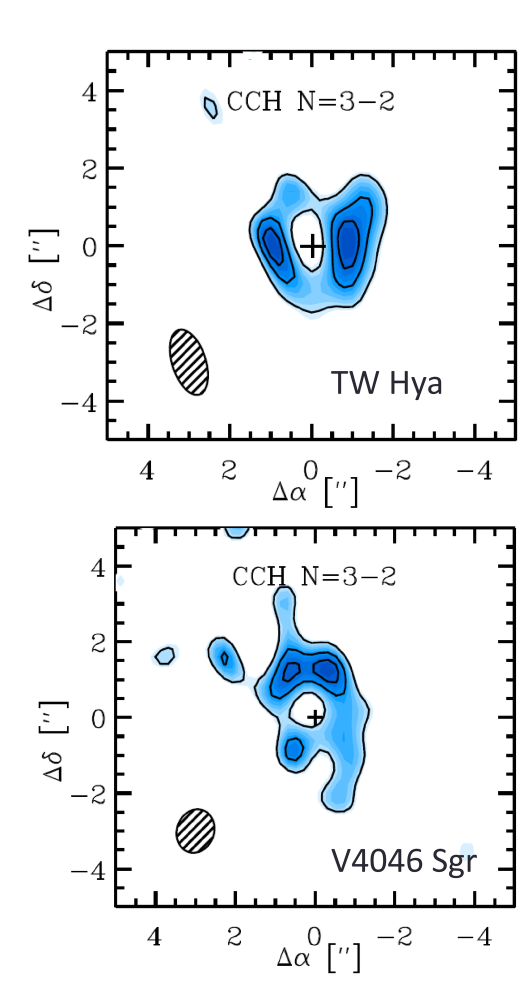


Molecular survey of the β Pictoris belt with the SMA (Matra et al. 2018)

- Upper limits for non-CO species reported, attributed to rapid molecular photodissociation due to the A-star's strong UV flux
- An Upper limit of < 2.5% on the HCN/(CO+CO2) ratio of outgassing rates, consistent with those observed in Solar System Comets.

[Reference: Matra, Wilner, Öberg et al. 2018, ApJ, 853,147]

PROTOPLANETARY-SPECTRA: CCH IN TW HYA AND V4046 SGR

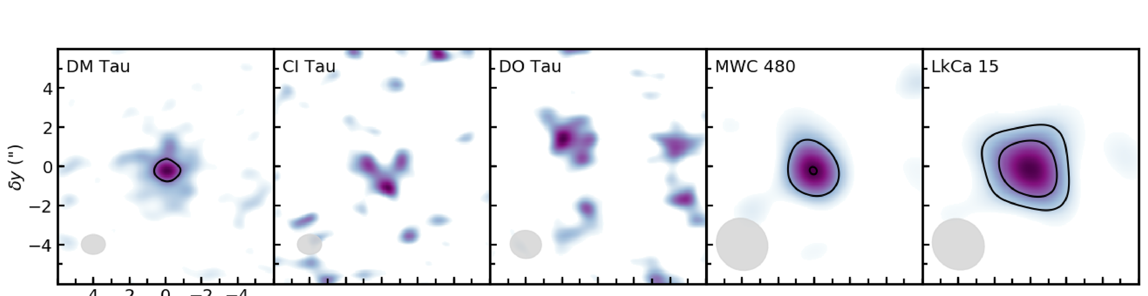


CCH(3-2) emission towards the disks around the nearby classical T Tauri star systems TW Hya and V4046 Sgr (Kastner et al. 2015, 2016).

- Ring-like morphology within each disk.
- Likely tracing irradiation of the tenuous surface layers of the outer disks by high-energy photons from the central stars.

[Reference: Kastner et al. 2015, ApJ, 806,75; 2016, IAUS, 314, 193]

PROTOPLANETARY-SPECTRA: HCN EMISSION IN 5 DISKS



It is expected the lock-up of elements into solids (Öberg et al. 2011) results in an increasing N/C ratios in the gas as the disk evolves. Bergner et al. (in prep) have carried out the SMA observations of the HCN 3-2 in five disks in Taurus that cover a range of stellar and disk properties, to determine the radial emission profiles of HCN 3-2 in the disks (complementing ALMA observations), which should help addressing the prevalence of volatile depletion during planet formation.

[Reference: Öberg et al. 2011, ApJL, 743, L16; Bergner et al. in prep]