Mining the ALMA Archive: Building a Catalog of Structured Young Protostellar Disks

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Introduction

Protostellar disks are rotating disks of gas and dust around pre-fusion ignition young stellar objects (YSOs). YSOs are divided into classes from 0 to III based on age and structure, and we are examining the youngest YSOs, Classes 0 and I, to find signs of axisymmetric structure in the form of rings, which may indicate potential future planet formation (Miotello et al, 2022).

Most studies of structure in disks have focused on very high-resolution images (e.g., Ohashi et al. 2023). Data at this resolution is expensive and hard to achieve. To do a broader survey, we need to be able to work with lower resolution data. At lower resolutions, we can use the raw visibility data to gain additional detail. Complex UV visibilities represent the spatial frequency components of the observed signal as measured by antenna pairs and contain more information than the image (Jennings et al. 2020).

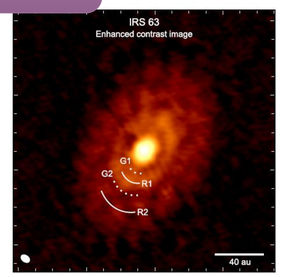


Figure 1: Enhanced image of IRS 63 (Segura-Cox et al., 2020), showing ring structures.

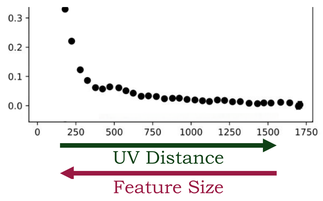
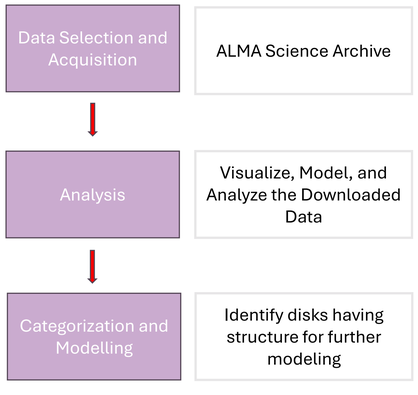


Figure 2: Example visibilities for a disk, where large UV distances are small scale features and short UV distances are large scale.

Methods



We draw on publicly available ALMA Archive data. Our process begins by downloading the raw data from the archive and processing them courtesy of the Arcade virtual machine maintained by CANFAR. We then analyze the data using specialized Python packages (e.g., Galario; Tazzari et al. 2018) to identify and model disk substructure.

Results

A Smooth Object: IRS 37A

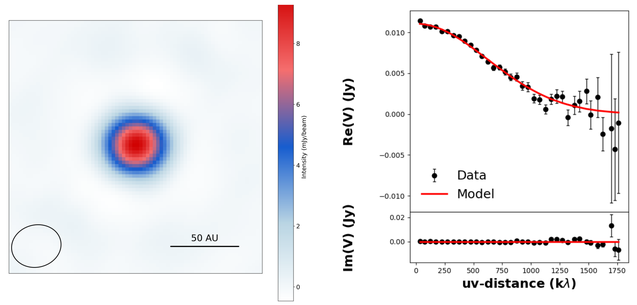


Figure 4: Intensity map and UV profile for IRS 37A, previously known to be a Smooth object (Michel et al., 2023). The red line shows a simple Gaussian model fitting.

A Disk with Structure: IRS 63

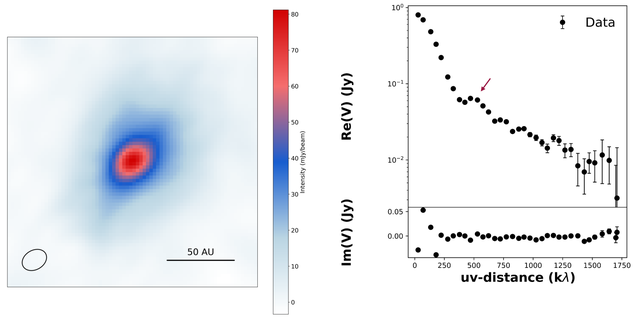


Figure 5: Intensity map and log-scale UV profile for IRS 63. The lack of visible structure in the image is countered by departures from a smooth decrease in the UV profile, a verification of structure as shown in Fig. 1.

New Potential Structure: C4-033

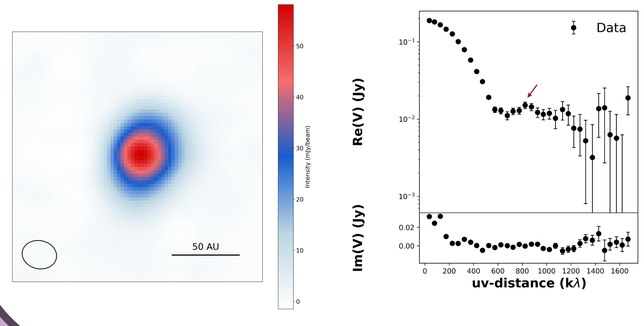


Figure 6: Intensity map and log-scale UV profile for C4-033. This is a new detection of potential disk structure in an object not previously known to have it.

Discussion

Further Study Needed: IRS 47

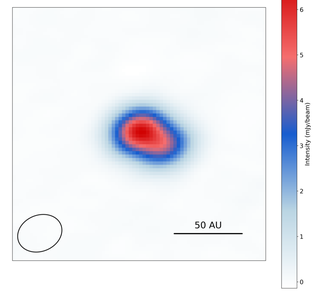


Figure 7: Intensity map (top), UV profile (left), and residuals (right) for IRS 47.

We only select individual or easily separable objects meeting Signal-to-Noise thresholds from projects with resolution, sensitivity, and angular resolution to provide the required observation quality. Additionally, not every object is easy to examine (e.g. tight binaries, extended structure). IRS 47, for example, has a visually distended structure but a UV profile suggestive of underlying structure. Subtracting a simple 2D Gaussian from the overall image leaves us residuals showing a close binary, which we have verified looking at higher resolution data.

Future Work

Having examined 115 objects to date, the current journey is a quest to build a catalog of categorized younger YSOs, noting that there are more than 10,000 YSO observations in publicly available data in the ALMA archive. With a sufficiently large sample, we hope to apply population statistics to better understand when disk structure begins to form and what that structure looks like.

# Projects Examined	6
# Available Objects	257
# Class 0/I	115
Usable Targets	41
Structure Present	17
Smooth Disk	10
Further Study Needed	14

The structures we have seen so far are essentially those we are specifically looking for, axisymmetric ring structures. Spirals, non-symmetric emissions, and warped disks have all been observed in disks and are possibilities for exploration in future work, in addition to more complex and varied modeling.

REFERENCES

Jennings et al. 2020, MNRAS, 495(3), 3209 ■ Michel et al. 2023, AJ, 166(5), 184 ■ Ohashi et al. 2023, AJ, 951(1), 8 ■ Segura-Cox et al. 2020, Nature, 586(7828), 228 ■ Tazzari et al. 2018, RAS, 476(4), 4527