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# ASTR 575: Final Project

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## 1. 50% OF PROJECT UPDATE

Analyzing the structures of protoplanetary/circumstellar disks with different observational tracers is essential for gaining a thorough understanding of these disks as well as the complex processes that shape the formation of planetary system. In this project, I am examining the first resolved millimeter observations of the nearly edge-on disk IRAS 05342+2744 (which I am calling Squid affectionately, and for simplification, for now).

Our observation of this source had coverage on the SMA (Submillimeter Array) from $\sim$ 209.2 GHz to 241.6 GHz. I first processed the MS set of this observed data, which is a format used in radio/millimeter interferometry that stores calibrated visibility data from our telescope. I wrote a Python script called *channel_subtraction_uvcontsub_function.py* that identifies spectral channels from the MS set that corresponds with emission from a given molecular transition. It defines a $\pm$100 MHz window around the rest frequency of an isotopologue of interest and the script determined the number of channels (each channel is 0.2793 MHz wide) that fall within this window, indicating where line emission was present. Thereafter, with the `casa` UVCONTSUB task, I isolated these channels that contain spectral line emission from underlying continuum emission (as continuum emission from dust for e.g. can obscure spectral features). UVCONTSUB estimates the continuum emission and fits a specified polynomial (I used a first-order polynomial) to the continuum and subtracts this from line-free channels (that I specified). Then, I imaged this continuum-subtracted MS-set with `casa`'s TCLEAN task, which reconstructs a 3D spectral cube from interferometric data by iteratively removing flux from the brightest pixel within a defined region (set by me) in a current "dirty" image and adds it to a model image (for more details of the algorithm, see here). I can convert the output image cube into a fits file which maps the isotopologue of interest in both position and velocity. I created spectral cubes for 3 isotopologues so far: $^{12}$CO (2-1), $^{13}$CO (2-1), and C$^{18}$O.

All the parameters I inputted for the `CASA` tasks can be found here.

Next, I made a Python script (*line_squid_library.py* to analyze these isotoplogues and I imported it into a jupyter notebook for easier visualization (*squid_line_analysis_fin.ipynb*). For all 3 cubes, I produced the following:

a) Channel maps: I produced a channel maps of each cube. A single channel map is a 2D image of the data cube at a specific velocity (channel), allowing me see how the gas is moving at different velocities (emission across multiple velocities). With my script, I can also apply a threshold mask to remove/smooth noise artifacts and a velocity mask to include only specific velocity ranges of emission that I am interested in (for instance, see the first plot in *squid_line_analysis_fin.ipynb* that includes all the channel maps of the $^{12}$CO (2-1) cube and the second plot of channel maps that only includes the velocity range I am interested in).

b) Moment maps: I then created Moment 0, 1, 2, and 8 maps on the smoothed/masked data. These moments provide summary statistics about the emission in different dimensions, such as intensity, velocity (to see a description of how I calculated these maps and what they are see here). I will described the Moment 0 and 1 maps as they are the most relevant. The Moment 0 is the the total emission across the spectral axis (the total intensity summed across all the channels) and traces gas distribution and structural features. For instance, in Figure 1, I overlaid $^{12}$CO (2-1) Moment 0 contours (which are certain percentages of the peak of the map) on the Panstarrs image of Squid, and we can discern outflow structure. I did this overlay on CARTA which is a data vizualization tool (like ds9), but working on producing similar plots in my code)

   In Figure 2, I overlaid C$^{18}$O Moment 0 contours on the Panstarrs image of Squid and (this is cool to me haha) we can see disk structure (perpendicular to the outflows)! C$^{18}$O is a more optically thin tracer compared to $^{12}$CO, which is why it better traces the material associated with the disk itself. Also, in extent, the gas disk seems massive (if you look at my Moment 0 plot in *squid_line_analysis_fin.ipynb*), $\sim 20''$ in $\Delta$ RA

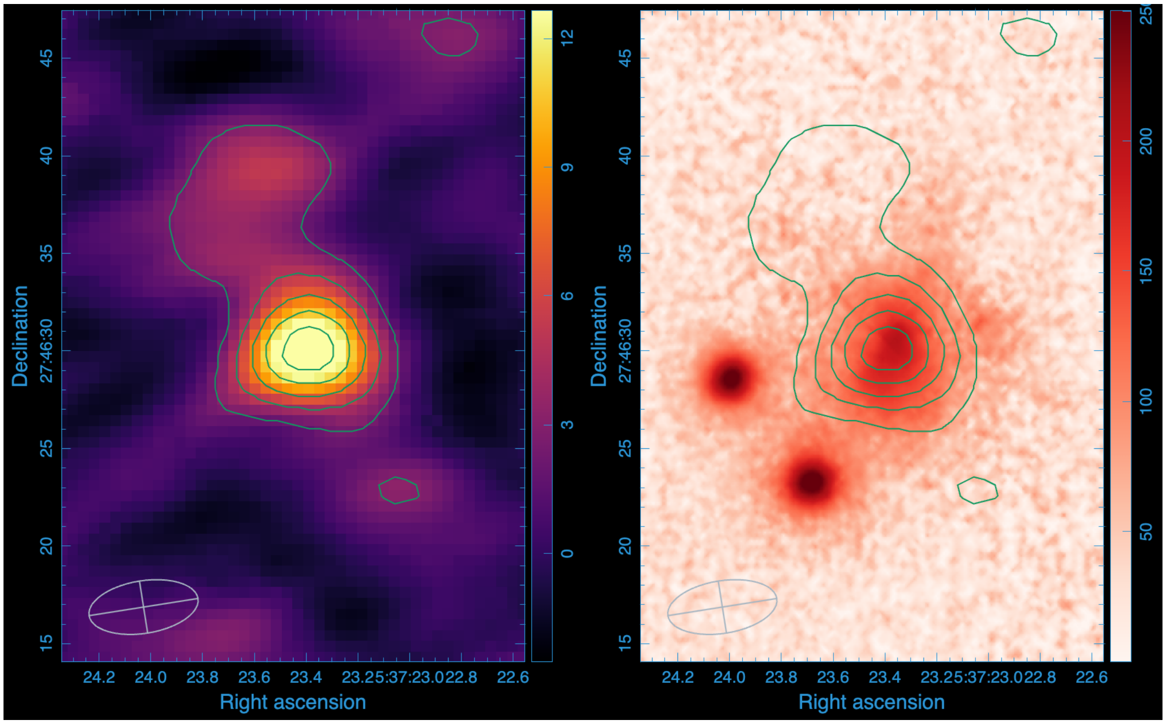


**Figure 1.** $^{12}$CO (2-1) moment 0 [left] with its contours overlaid on Panstarrs image of Squid [right]

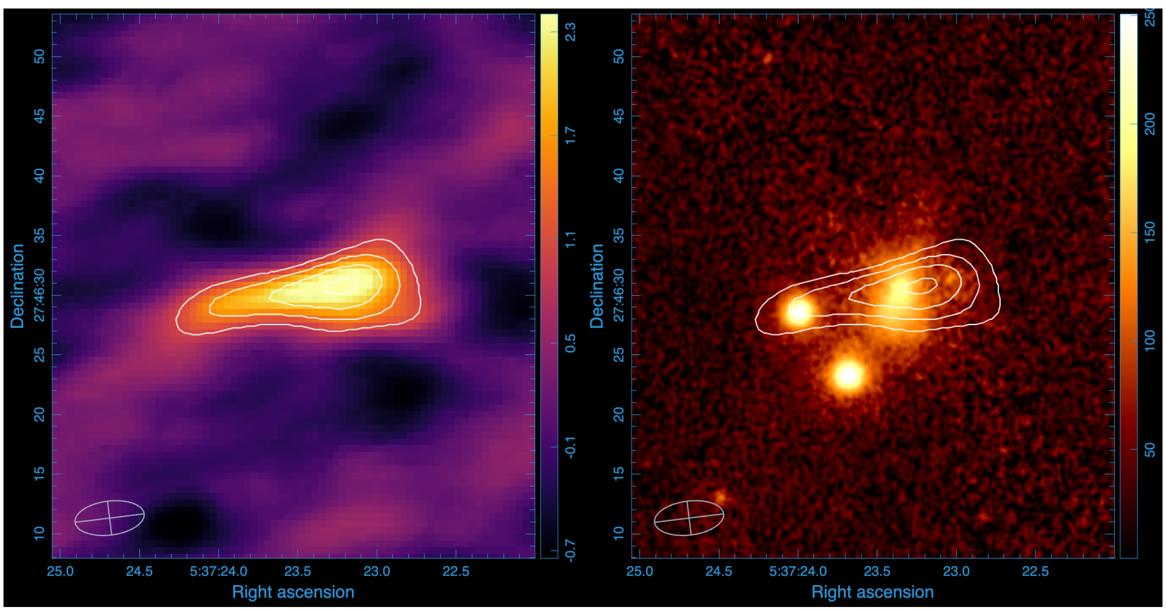


**Figure 2.** C$^{18}$O (2-1) moment 0 [left] with its contours overlaid on Panstarrs image of Squid [right]

The Moment 1 map is the total intensity-weighted velocity of the spectral line, which traces the kinematics of the gas. For instance, in the Moment 1 map of C$^{18}$O, we can see the red-shifted and blue-shifted sides of the disk, which is indicative that the disk may be in Keplerian rotation! Also, I set pixels in the Moment 1 map corresponding to pixels less than 3 times the rms of the Moment 0 map to nan.

Currently, I am working on producing spectral line profiles for the isotopologues. I produced one for C$^{18}$O (highlighting the region where the spectrum was extracted on the Moment 0), and calculated an integrated flux (using the trapezoidal integration function from `Numpy`) over the velocity range where I see emission. A double-peaked line profile is a classic signature of Keplerian rotation in a disk. Next, I will make position-velocity diagrams for each data cube with `pvextractor` (documentation here) along the major axis of the disk, which will better demonstrate the presence of Keplerian rotation (hopefully, they will reflect double-peaked emission morphology). Additionally, I will image continuum emission (which is the emission across all the frequencies in each frequency span [which are 2.29 GHz wide]in our MS-set). Getting the spectral slope of the continuum combined with analyzing the line profiles will give me insight into the grain size distribution in the disk (and so possibly whether planetesimals/planet-embryos are/not forming). Also, I can obtain publicly available 2MASS and WISE data and calculate the slope of the spectral energy distribution (SED).