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Molecular Outflows of Carma-7 in Serpens South

Casey Block[1] and Adele Plunkett[2]

[1] The Colorado College
[2] National Radio Astronomy Observatory

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ABSTRACT

In order to create more accurate models of star formation, we must know about the matter accretion rates onto the star, as mass values determine many properties of a star in its lifecycle. The best way of doing this is by studying the outflows of dust that are ejected from an evolving star. Measured over years, we are able to closely monitor the changes in velocity and momentum of the dust clouds, giving us insight into what is going on behind a thick envelope of matter of which we cannot see through. The carbon monoxide (CO) molecule is adept at tracking the movement of these clouds, and as such, we have focused on it in our studies of Carma-7, a protostar in the Serpens South cluster.

Keywords: Protostar, Outflow, Spectral Window, Gaussian Fitting, Carma-7, Serpens South

1. INTRODUCTION

We studied Carma-7, a protostar in the Serpens South Cluster. Specifically, we looked at the molecular outflows coming from this protostar, by observing the different transition lines of molecules that comprise the protostar and outflow system. The background on this process is as follows: Before a star can begin to form, it must exist within a cloud of matter whose density is greater than the average interstellar density. These clouds of matter are known as star-forming regions. Within these star-forming regions, the matter is gravitationally attracted to itself. This attraction creates protostars, which have three main components: (1) the envelope, (2) the disk and (3) the protostar itself. The outermost component is the stellar envelope, which surrounds the stellar disk, and inside the stellar disk is the protostar. As the protostar evolves, it must continually maintain hydrostatic equilibrium, in which the force of gravity attempting to have the matter collapse in on itself is balanced with the outward pressure exerted by the matter. The final stage for a protostar is the point at which it is generating this outward pressure by fusing hydrogen into heavier elements. Once this final stage is reached, the protostar is a fully-fledged star. To conduct this investigation, we'll need to measure outflows and identify tracer molecules.

2. TRACERS

The molecules that are used to track different parts of the protostellar system are known as tracers. While there may be more molecules than we observe in these outflows, they require specific temperature and density conditions to create their transition lines. Because of this, different molecules can trace different parts of a system. For example, the stellar disk has a different environment from the entrained material in the outflow. We have data on transition lines, and have focused on analysing the CO j=2-1 and DCN j=3-2 molecular lines, which correspond to spectral windows SPW-25 and SPW-33 respectively. Below we have a table of the different traces that we observed, along with their accompanying information.

Spectral Window	Channel Range	Central Velocity	File Name
25	352-593	13.2	*25a.png
25	375-475	13.9	*25b.png
25	476-511	4.4	*25c.png
25	511-562	1.76	*25d.png
27	210-290	8.03	*27.png
29	258-213	7.1	*29.png
31	1642-1693	-8.8	*31a.png
31	1418-1460	-5.93	*31b.png
31	580-620	4.5	*31c.png
31	140-184	10.1	*31d.png
33	169-294	7.55	*33.png
35	464-499	8.38	*35.png
37	159-287	7.49	*37.png
39	191-288	7.983	*39.png
41	225-256	7.56	*41.png
43	10-948	6.29	*43.png

3. OUTFLOWS

For this investigation, we focused on the outflows coming from Carma-7. Outflows are jets of material that are created as side effects of the matter-accretion process. Matter is accreted onto both the stellar disk and the protostar. It is difficult to directly observe the accretion process as this is an active area of research, but we do know how the matter loss and matter gain rates are related, so we can measure the accretion rates by observing the outflows from a given protostar. Outflows have two main components, the jet and the outflow. The jet is an extremely fast moving and thin spear of matter that, according to simulations, should come out of both faces of the stellar disk. The full outflow is created when these jets intersect with the surrounding material, entraining additional material which produces larger, more diffuse slow-moving clouds.

One of the many intricacies of outflows are their orientations. We are only able to observe the radial velocity (velocity perpendicular to the plane of the sky) when we take molecular line observations. However, the only way to get an accurate measurement of the transverse outflow velocity is by observing them over the course of decades. Without all of these measurements it is difficult to determine the orientation of the system, resulting in only being able to calculate projections of the outflow's total velocity, instead of the actual velocity with both radial and transverse components.

4. DATA ANALYSIS

Figure 1 is what is known as a "moment-zero map", and it shows the integrated intensity of light across a certain channel range, which corresponds to certain frequencies. The x- and y-axes are RA and Dec respectively. We use these maps to measure how much matter is in an area, as well as the velocity towards or away from the observer. The blue and cyan contour lines represent blue-shifted light, meaning light that is travelling towards us from the perspective of the protostar, and the red and magenta lines represent red-shifted light, that is moving away from the observer from the perspective of the protostar. To be clear, even if some emission is blue-shifted, the source still may be moving away from us, as the blue and red-shifts are calculated with respect to the central velocity of the source. This image is centered on 8.1km/s because that is the central velocity of the source, and to get correct red- and blue-shifted information, we compared the velocities to this central velocity. The red and blue contour lines are multiples of five times the background noise, while the cyan and magenta lines are three times the background noise, which is generally accepted as the lowest statistically valid measure of emission.

5. SPW 25

Spectral window 25 (SPW-25) shows us the CO j=2-1 line. To more closely analyze the features shown in this map, we separated it into six additional moment-zero maps, each with its own channel range, depicted below. These more specific moment maps are the best example in our data set of what we think outflows should look like; it contains high and low velocity components, with one redshifted and one blueshifted outflow.

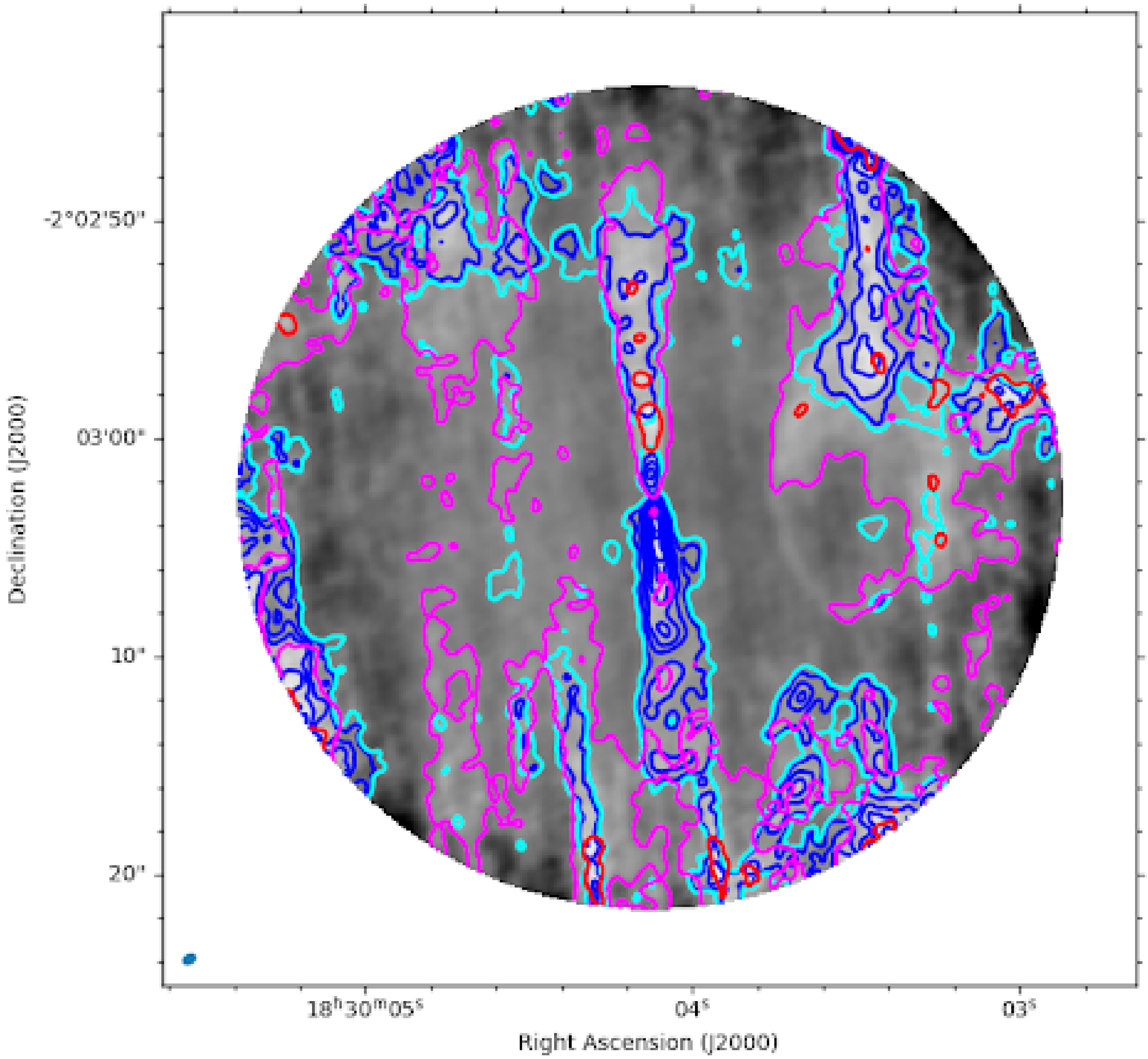

Figure 1. This moment map depicts the entirety of spectral window 25, the CO line, from channel 352 to channel 593

Because there is more low velocity material (velocities closer to the central velocity), the moment maps that border the central velocity depict more extended parts of the outflow. As the outflow progresses, it transfers some of its linear momentum to the surrounding environment, which is why high velocity moment maps mostly show emission from an area much closer to the stellar disk.

6. SPW 33

Next we have moment-zero map of SPW-33, which is the DCN line. This molecule is a good example of a tracer that is mostly showing us the stellar disk, but also some parts of the outflow that are not too extended. Because

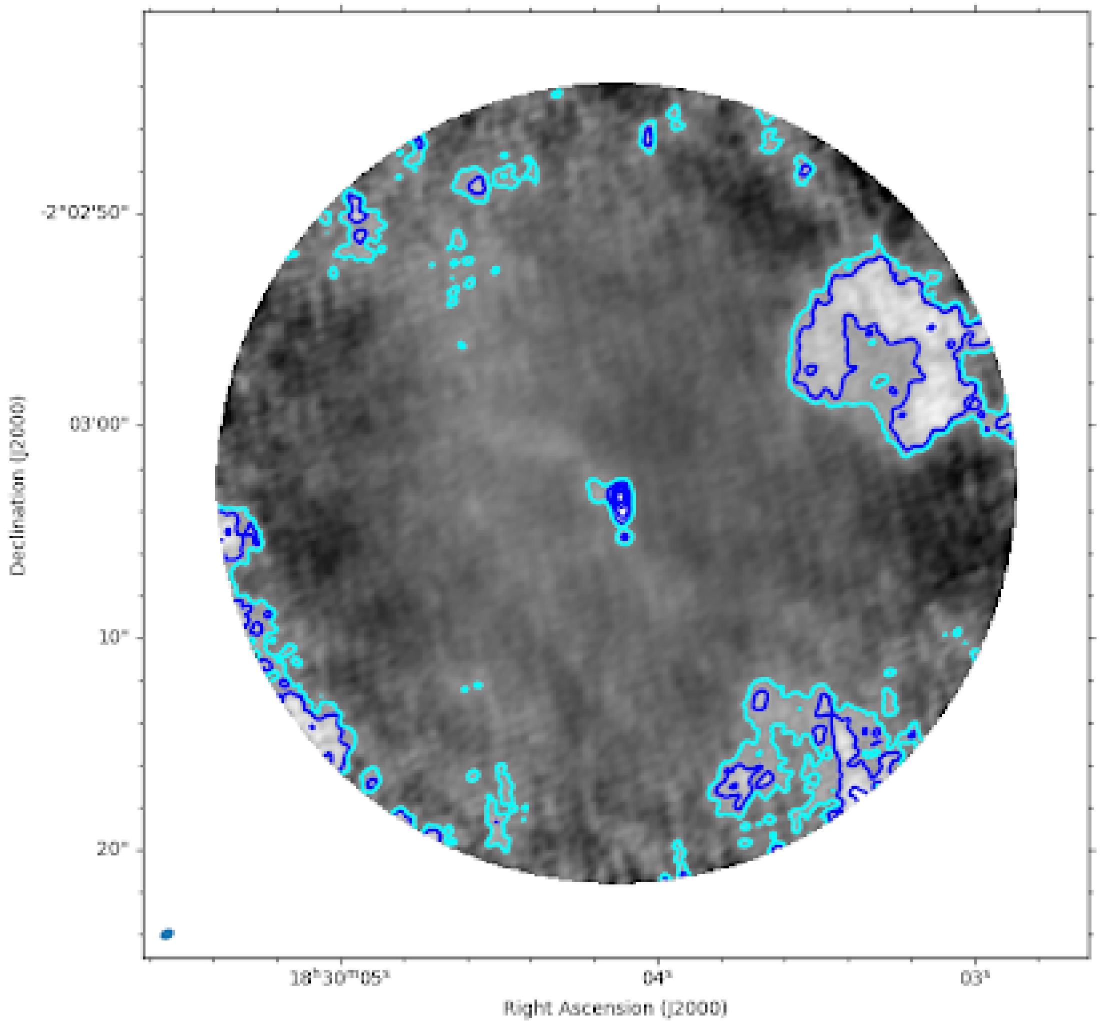

Figure 2. Moment map depicts the high velocity portion of the blushifted material of spectral window 25, the CO line. Cyan contours show the 3 σ noise level of the moment map. Blue contours begin at 5 σ and increment by 5 σ

the spectral profile of this spectral window shows most of the emission contained in one channel range, as opposed to separate peaks of emission, we decided not to split up the moment map into smaller channel range moment maps.

7. GAUSSIAN FITTING

The final step in the data analysis process is to fit 2-D Gaussians to the data. This step takes the tracking movements of the different parts of each outflow from a more qualitative and ad-hoc step to a more quantitative procedure. Every time we fit a Gaussian, we estimate mean and covariance parameters, so we can track how these parameters change over time for a given blob of matter. We started with Figure 8 because most of the emission was concentrated around the stellar disk, but it was still prominent enough to accurately fit a Gaussian to it, and ended with Figure 9 as our output.

8. FUTURE WORK

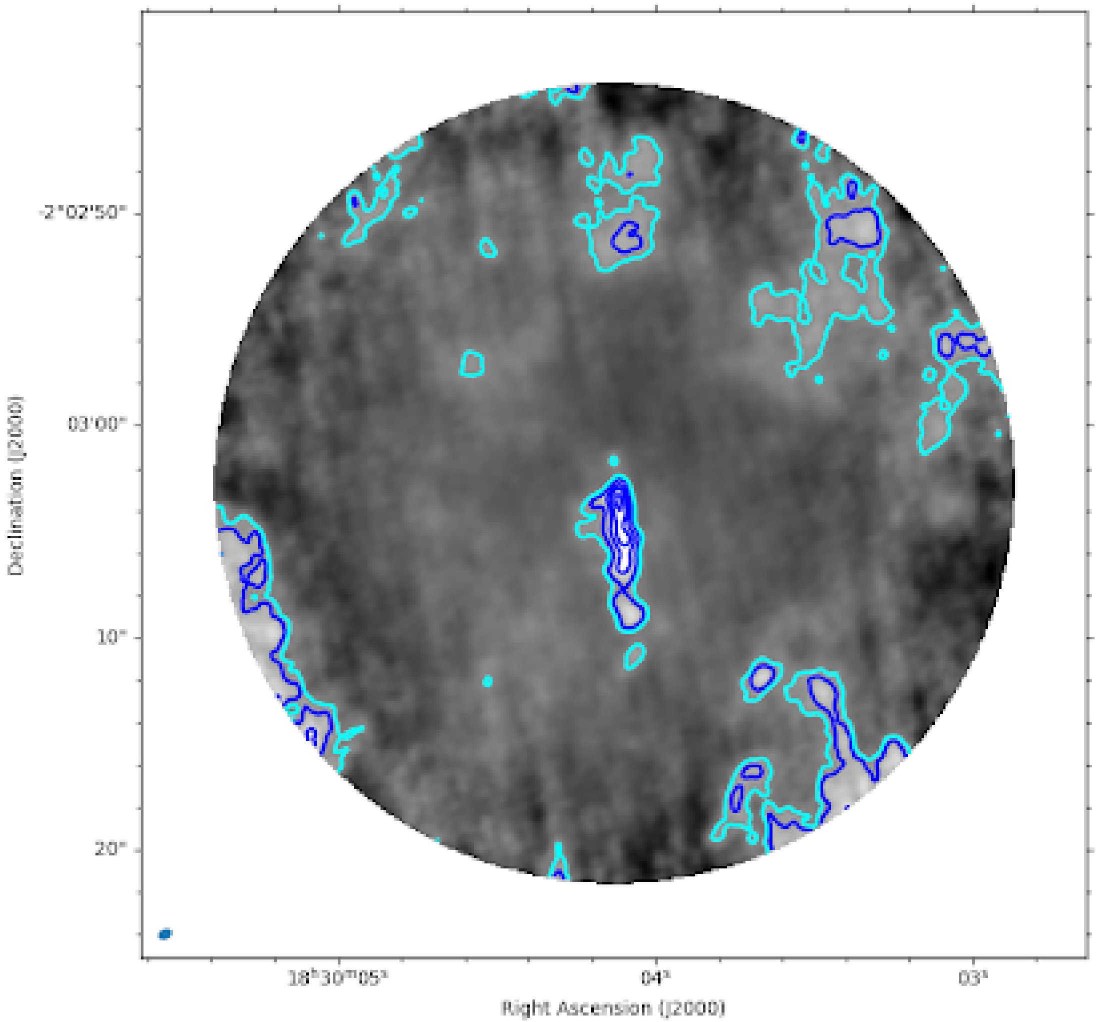

Figure 3. Moment map depicts the medium velocity portion of the blushifted material of spectral window 25, the CO line. Cyan contours show the 3 σ noise level of the moment map. Blue contours begin at 5 σ and increment by 5 σ

The remainder of this project consists of fitting Gaussians to the rest of the moment maps. Some of the moment maps require more than one Gaussian to fit to the data, to more fully and accurately capture the emission. Once the Gaussian fitting is done, we calculate the effective emitting region of each molecule. This measurement is then compared to the corresponding data taken in 2015 by Plunkett et al. At some point we may re-clean the images, to reduce the background noise and get more accurate measurements. This will help define what exactly is emission from the outflow – versus emission from surrounding protostars that happened to be in the field of view.

ACKNOWLEDGMENTS

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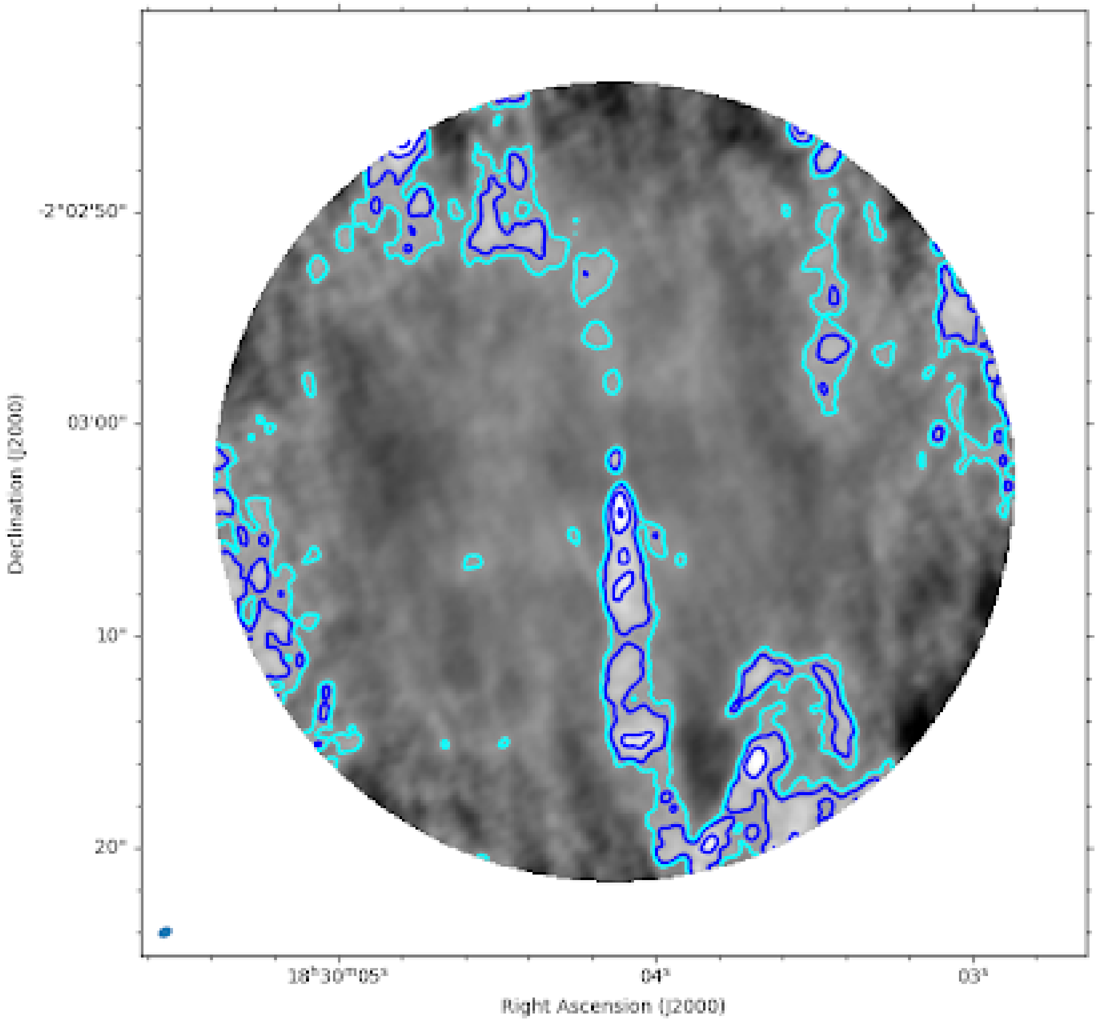

Figure 4. Moment map depicts the low velocity portion of the blushifted material of spectral window 25, the CO line. Cyan contours show the 3 σ noise level of the moment map. Blue contours begin at 5 σ and increment by 5 σ

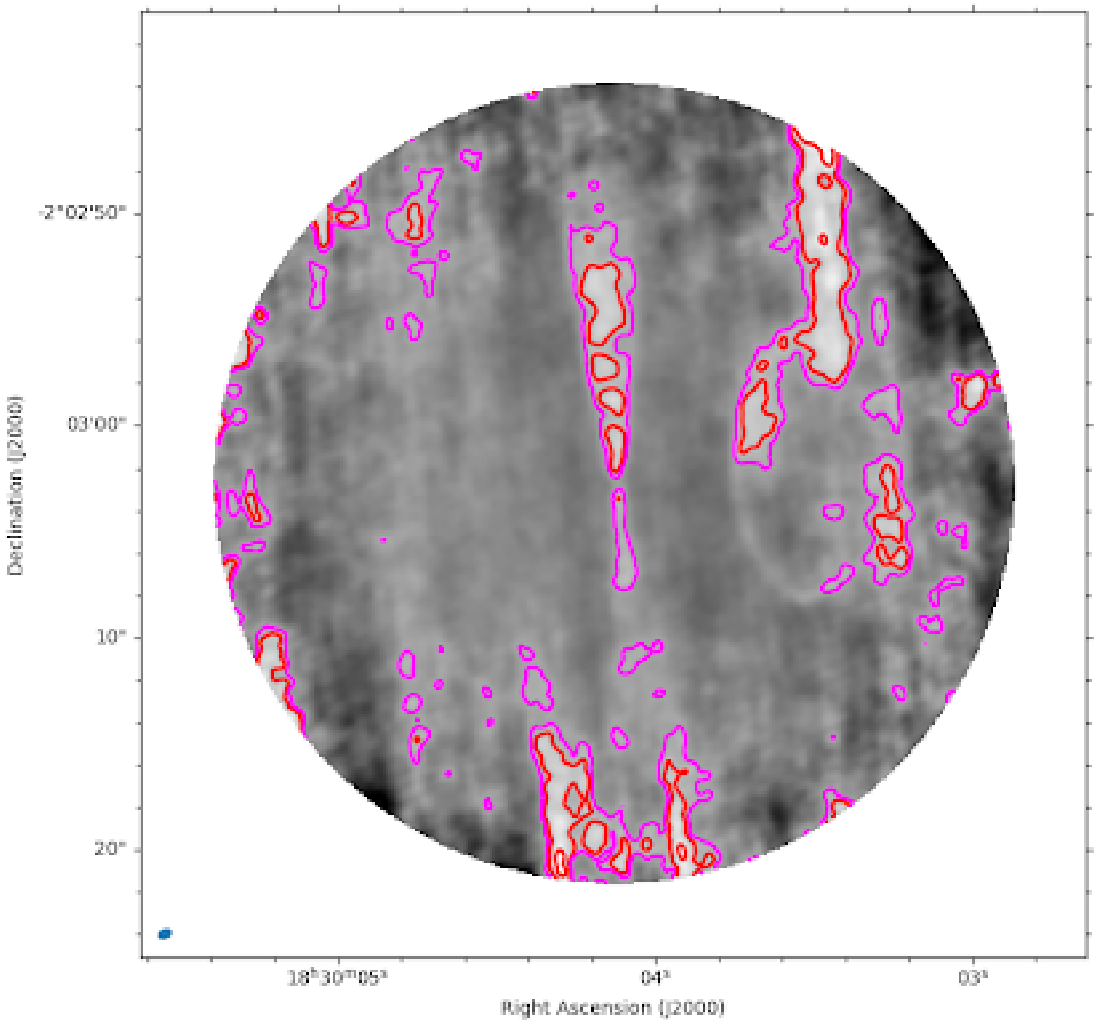

Figure 5. Moment map depicts the low velocity portion of the redshifted material of spectral window 25, the CO line. Magenta contours show the 3 σ noise level of the moment map. Red contours begin at 5 σ and increment by 5 σ

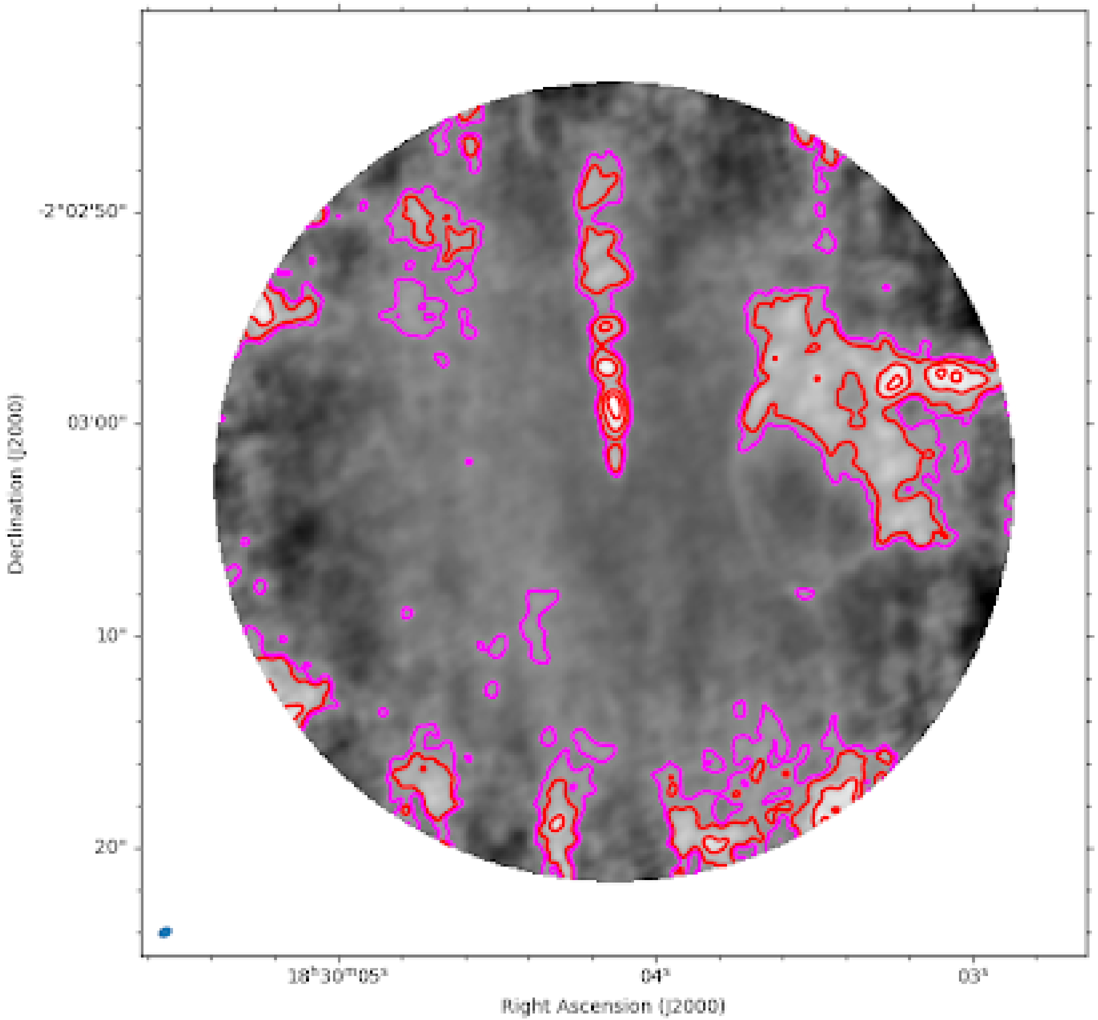

Figure 6. Moment map depicts the medium velocity portion of the redshifted material of spectral window 25, the CO line. Magenta contours show the 3 σ noise level of the moment map. Red contours begin at 5 σ and increment by 5 σ

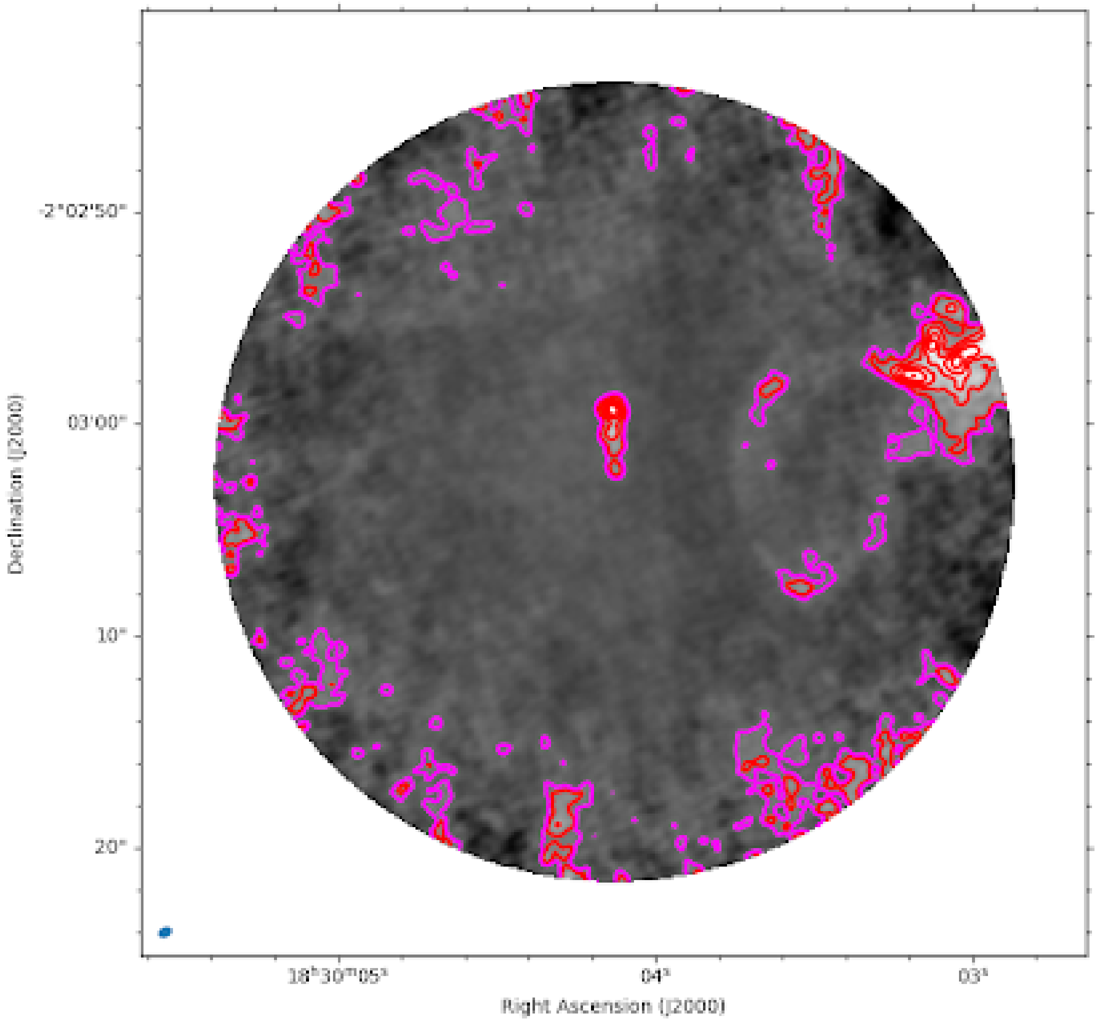

Figure 7. Moment map depicts the high velocity portion of the redshifted material of spectral window 25, the CO line. Magenta contours show the 3 σ noise level of the moment map. Red contours begin at 5 σ and increment by 5 σ

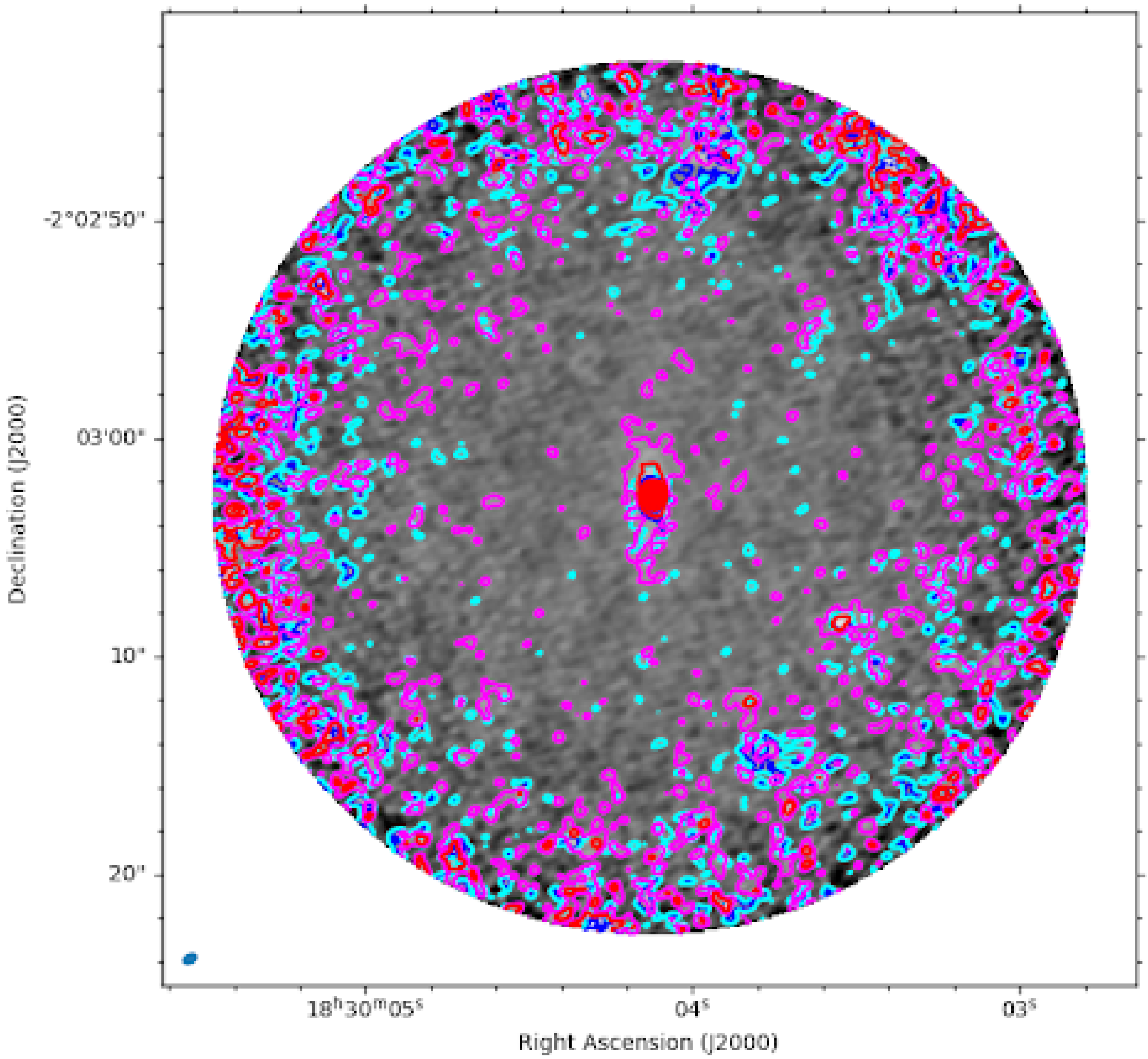
-2°02'50"
03'00"
10"
20"
Declination (J2000)
18h30m05s
04s
03s
Right Ascension (J2000)

Figure 8.

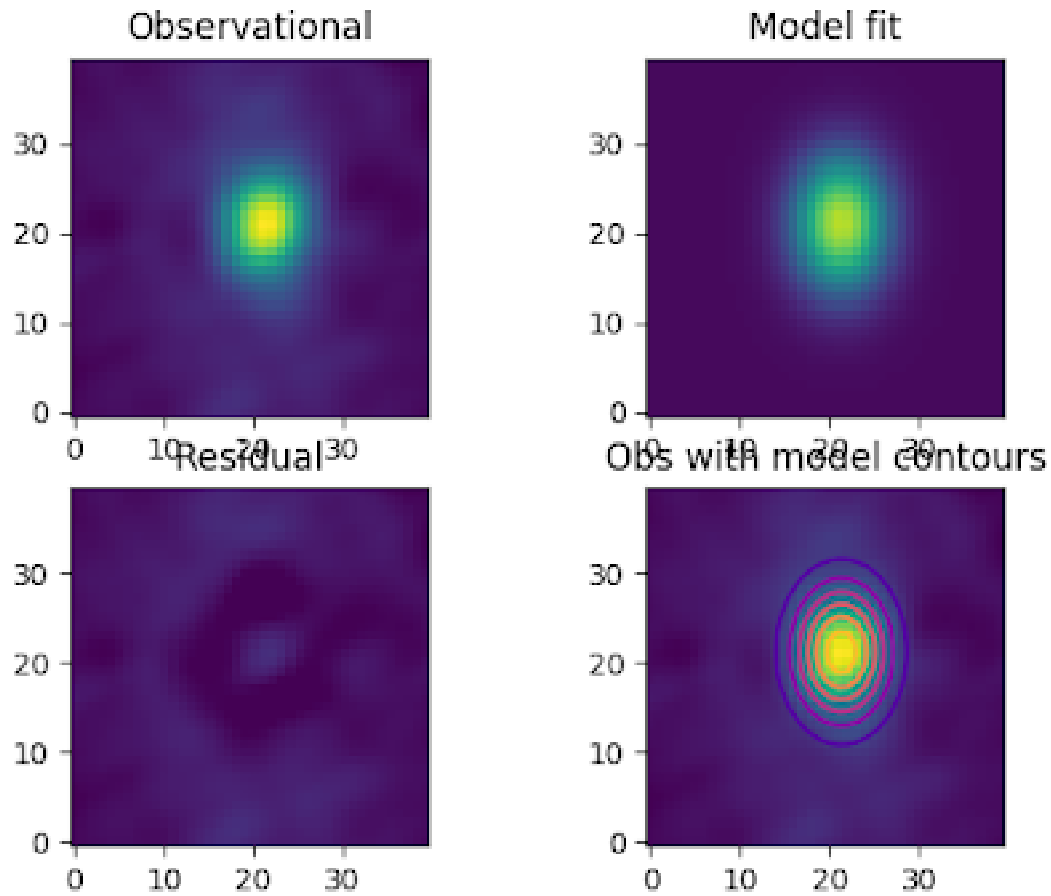
Observational
Model fit
Residual
Obs with model contours
0
10
20
30

Figure 9.