Number ________
Priority ________

FCRAO PROPOSAL SUMMARY

Title: A New Component of Molecular Outflows?
Investigators:

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	(1)	(2)	(3)	(4)
Molecule (Transition)	^{13}CO(J=1-0)	C^{18}O (J=1-0)	^{12}CO(J=1-0)	
Frequency (GHz)	110.201	109.782	115.271	
Days Requested	0.5	2.5	0.5	
LST Coverage	24 hrs	24 hrs	24 hrs	
Total Hours	12	60	12	

System Configuration:

Receiver:	SEQUOIA
Backends:	FAAS
Sideband Filter?:	yes
Polarizer?:	no

Special Scheduling Requirements:
None of the investigators can observe between October 6 and October 13.

Abstract

In the Spring of 1999, in what we thought was a straightfoward FCRAO project to study the effects of outflows from young stars on velocity dispersions in their host cores, we inadvertendly discovered a new component of molecular outflows. In ^{13}CO observations of the $\sim$1000 cm^{-3} gas in the vicinity of embedded young stars, we find *two components* in the velocity structure. One component is the "normal" ambient gas traditionally found in maps of ^{13}CO near these core regions, and the other, new, component appears to have a velocity offset that is consistent with it being momentum-conserving gas that is part of the flow itself. We explain in the proposal why this is *not* the usual "line-wing" outflow component. The proposal requests 3 days of 14-m time to follow up on this discovery. The time will be used to map ^{13}CO and C^{18}O in the $\sim$ 10 square arcmin around each of four cores known to contain outflowing young stellar objects.

Scientific Description

Summary In April of 1999, we undertook what we thought would be a straightforward FCRAO-based study of the interaction between outflows from young stellar objects and their surrounding high density cores. We began by observing just two star-forming cores with outflow sources, B5 and B335. As expected, the observations show that the outflows have an effect on the kinematics of the high-density core gas surrounding the source, and that the cores are rotating. But the *specific* interaction the outflows appear to be having with the cores was completely unexpected, and the rotation seen is clearly *differential*, to a degree not seen before in cloud cores. The observations we propose here are aimed primarily at studying the new core-outflow interaction, and will also be used to quantify rotational motions in the cores observed.

Spring 1999 Observations and Results In the Spring of 1999, we (Arce & Goodman) observed one Nyquist sampled footprint of the SEQUOIA 4 by 4 pixel array around two star-forming cores (B5 and B335), in the ^{13}CO(1-0) line. Each core was observed twice, once with velocity resolution (Δv) of 0.05 km/sec and once with $\Delta v = 0.026$ km/sec. Before adding the spectra with different Δv (with the same position offset), the spectra were resampled to have the same number of channels, reference channel and spectral resolution. After summing the spectra, they were then Hanning smoothed once, resulting in spectra of $\Delta v = 0.1$ km/sec.

The Figures in this proposal summarize our Spring 1999 results, and exhibit the oddities that cause us to suggest a previously uncategorized component of molecular outflows. Each of the first two pages of Figures (1a and 1b) shows: a summary of positions observed (upper left panel); three plots of gaussian-fit-derived line parameters as functions of each other; and one signal-to-noise histogram. In each of the three line-parameter plots, the circles and "×'s" mark points selected as shown in the position-position diagrams.

In each position-position diagram (upper left panels of Figures 1a and 1b), a background image is shown to guide the eye. For B5 (Figure 1a), the optical image in the background shows I-band continuum nebulosity in the vicinity of B5-IRS1 (0,0 on the grid). This I-band nebulosity is coincident with the blueshifted lobe of the wide-angle molecular outflow mapped in molecular lines at OVRO by Langer et al. (1996). For B335 (Figure 1b), the background image shows the redshifted lobe of the molecular outflow mapped in ^{12}CO at FCRAO by Moriarty-Schieven and Snell (1989).

In both Figures 1a and 1b, there exist two populations of spectra in each ^{13}CO(1-0) core map. The division into two populations is most striking in the plot of line width versus peak antenna temperature in B5 (see Figure 1a). One group of spectra shows a clear increase of line width with antenna temperature, whilst the other group is clustered in a blob with mean line width substantially below the first group's and showing no line width-antenna temperature trend. The same kind of separation is also present in the other line-parameter plots shown in Figure 1a. Remarkably, when we investigated the spatial distribution of these two components, we found that the component whose line width is anti-correlated with antenna temperature (circle symbols in Figure 1a) is roughly *coincident with the blueshifted outflow lobe* in B5. For B335 (Figure 1b), the division into components is also clear, but the *redshifted* lobe, rather than the blueshifted one, exhibits the interesting behavior. Since the sample of outflow points in B335 is currently so small, for now we will claim B5 as the best example of the new outflow component we claim to have uncovered.

We have thoroughly checked to make sure that the oddities apparent in Figure 1 are not caused by instrumental effects. Each core was observed in two sessions, and a different spectral resolution was used in each session. We find that both data sets, for both cores, show the same strange behavior. We have eliminated spectra with signal-to-noise less than 3 (see histograms in Figures 1a and 1b), so all the spectra remaining in our analysis are of medium to very high quality (see Figure 2 for examples).

As far as we, and the experts we have shown these data to know, this is the first time that this has effect been identified in dense cores. We suspect that either the combination of spectral and spatial resolution in previous observations was too low to be able to detect these "strange" features, or that making line width-antenna temerature diagrams is so unusual that these features just were not noticed before.

A New Component of Molecular Outflows? When we began our Spring 1999 project, we expected that we might see an enhancement in ^{13}CO line width coincident with outflow positions, and our plan was to estimate how much energy and momentum had been deposited in the core by the outflow. Never did we imagine we would find the trends apparent in Figure 1a.

At this moment, our best guess is that the "odd" spectra at positions coincident with the outflow consist of two components: one associated with ambient (core) gas, and another associated with emission *from the outflow itself.* This guess is motivated by two facts: 1) the odd spectra look like a superposition of two gaussians (see Spectrum *c* in Figure 2); and 2) our own recent IRAM 30-m observations of pc-scale flows show spectra with highly separated multiple components, only one of which is associated with ambient gas. If this guess is right, then the "width" of a single gaussian fit to these intrinsically bi-component spectra is actually a measure of the separation between components, rather than a true width (assuming each component's width similar to or less than their separation). Assuming then, that width measures separation of "outflow" from "core" gas, the line width-antenna temperature inverse correlation in Figure 1a implies that gas of higher density (higher peak antenna temperature) is displaced less from the core than gas of lower density. This anti-correlation between density and velocity would be entirely consistent with a momentum-conserving outflow, where lower density gas is accelerated to higher velocity.

New Observations Before we can publish the tantalizingly spectacular results of Figure 1a in a refereed Journal, we need to investigate this "new outflow component" hypothesis/phenomenon further. We propose to observe a larger area of B5 and B335 in ^{13}CO, in order measure the extent of the odd spectra, and to check just how associated with the outflow they really are. We expect that observing two more footprints in B5 and two more in B335 will be enough to map the region of interest for those cores. In addition, we will choose two more outflow sources from our Spring 1999 source list to map (3 footprints per source) in ^{13}CO. The sources will be selected so as to make round-the-clock observing optimal.

We plan to observe the $\sim$ 10 ^{13}CO-footprints in frequency switching mode, with a spectral resolution of 24 kHz. In order to achieve an rms of $\sim$ 0.1 K (similar to the previous data) for each spectrum, and assuming a "typical" system temperature of 230 K, we would need 220 seconds per pointing. Thus, it would take 1 hour to do a Nyquist sampled map. Half an hour should be provided for pointing and focusing, and another 30 minutes for miscellaneous overhead (moving from source to source, etc.). Thus, we can complete the ^{13}CO observations in about one half-day.

In addition to the ^{13}CO observations, we plan to map C^{18}O in each of the four sources that will be part of this study. The C^{18}O maps will allow us to estimate optical depth in ^{13}CO, and to estimate density. The C^{18}O setup will be similar to the one we plan for ^{13}CO. Past experience has shown that a C^{18}O map of one of these regions takes roughly five times as long as a ^{13}CO map (see also Fuller et al. 1991). Thus, we request 2.5 days for C^{18}O observations.

Finally, a literature search has revealed that the existing ^{12}CO observations of the lower-density gas associated with these outflow sources are often of lower spectral resolution than the ^{13}CO observations we propose here. Thus, in order so that we might better test various outflow theories (e.g. that the higher-density gas is less disturbed by the outflow than the low-density gas), we plan to spend a just a few hours making ^{12}CO maps of the regions we observe in ^{13}CO and C^{18}O.

References

Fuller, G. A., Myers, P. C., Welch, W. J., Goldsmith, P. F., Langer, W. D., Campbell, B. G., Guilloteau, S. & Wilson, R. W. 1991, ApJ, 376, 135

Heyer, M. H., Ladd, E. F., Myers, P. C. & Campbell, B. 1990, AJ, 99, 1585

Langer, W. D., Velusamy, T. & Xie, T. 1996, ApJL, 468, L41

Moriarty-Schieven, G. H. & Snell, R. L. 1989, ApJ, 338, 952

Figure 1a: ^{13}CO(1-0) FCRAO Data for B5-IRS1 Core

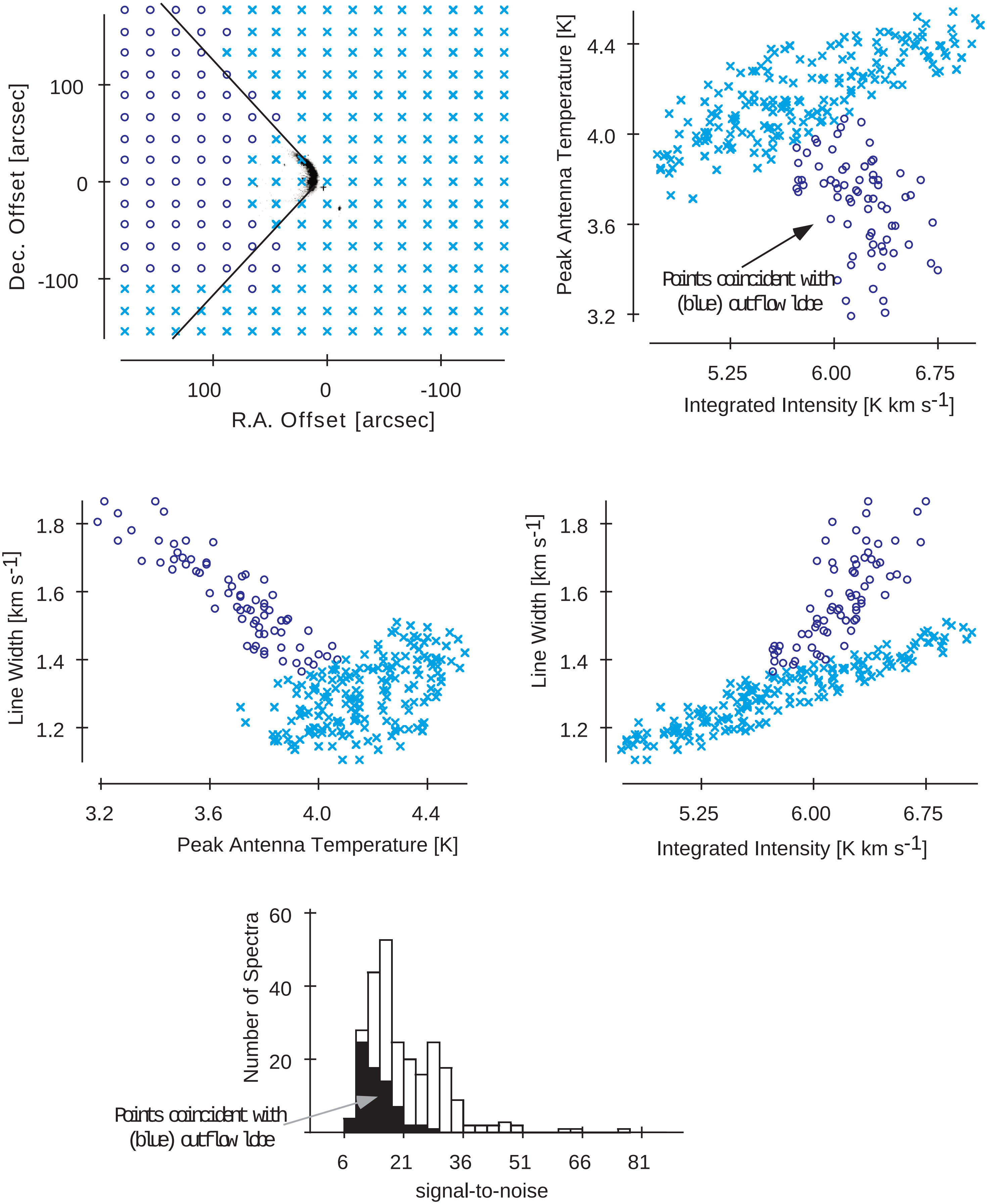
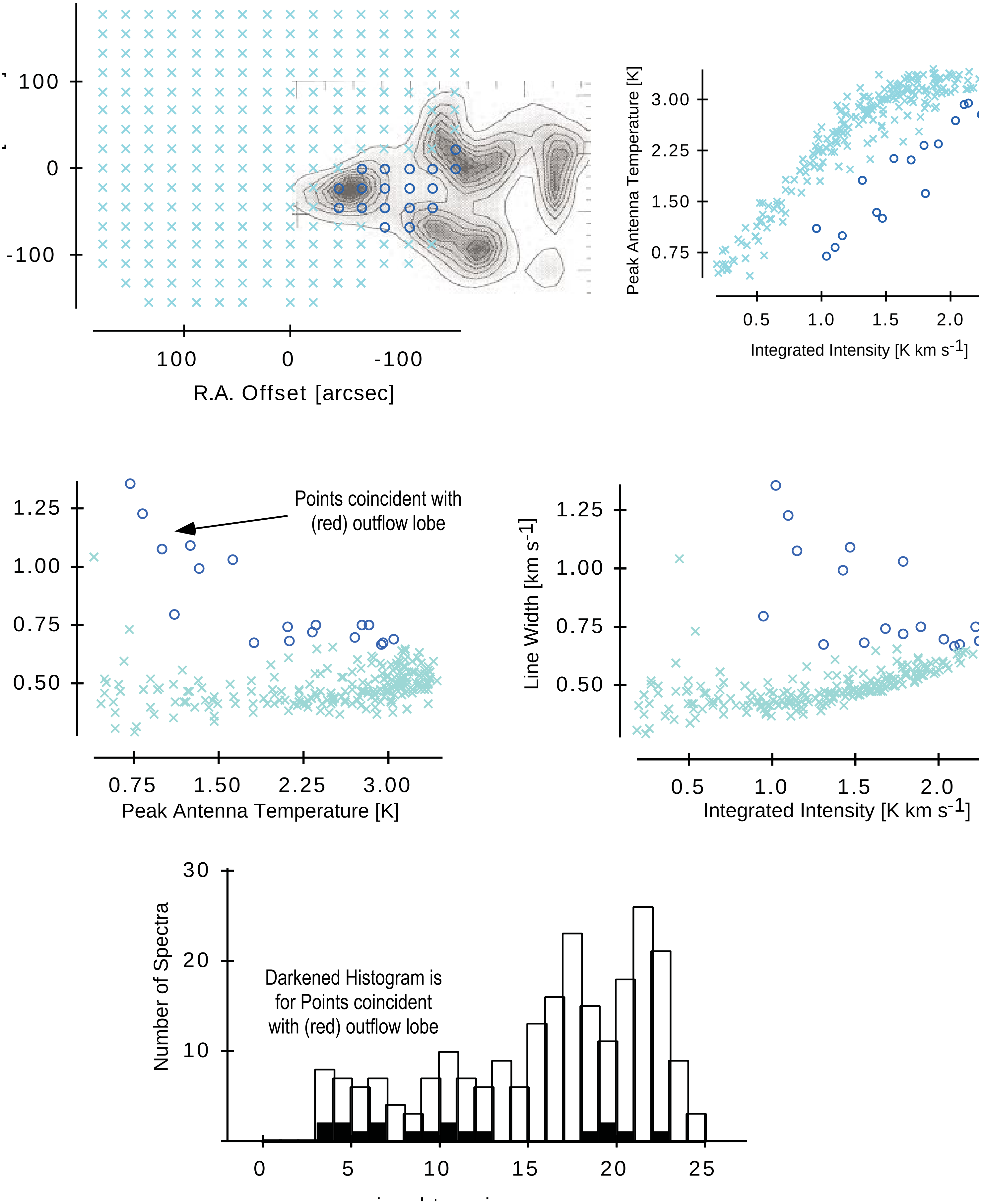


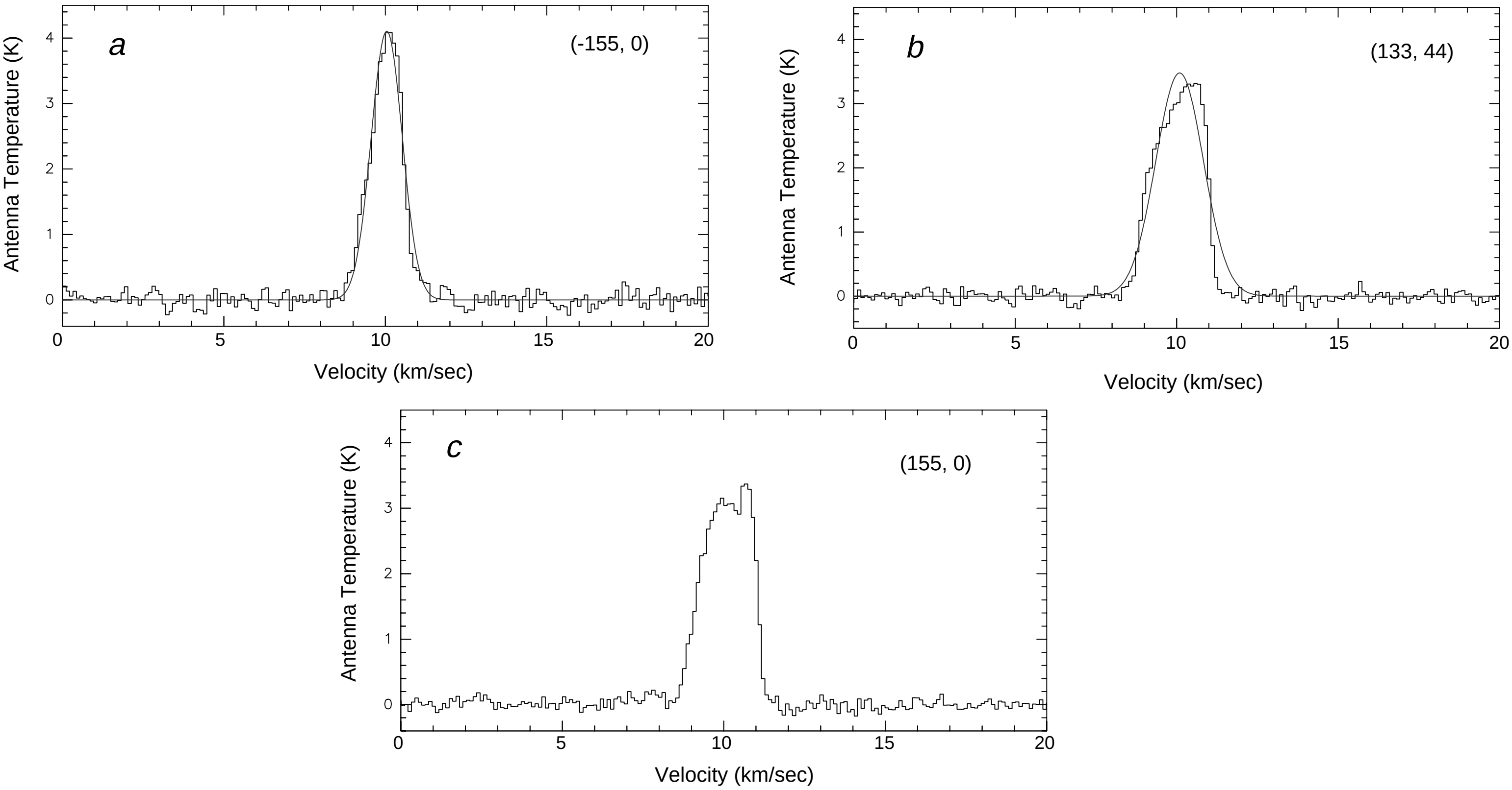
Figure 1b: ^{13}CO(1-0) FCRAO Data for B335 Core


Points coincident with (red) outflow lobe

Darkened Histogram is for Points coincident with (red) outflow lobe

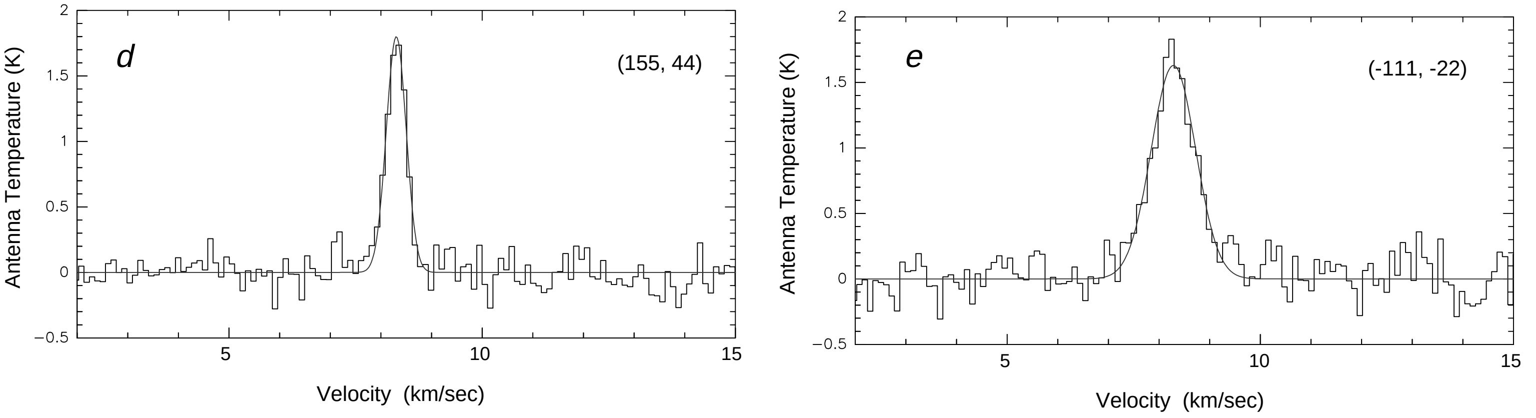
Figure 2: Sample spectra

B5-IRS1 core



Sample spectra from the B5-IRS1 ^{13}CO(1-0) map. Superimposed on the spectra is the gaussian fit to the line. The position of the spectrum, given in coordinate offset from the source (in arceseconds), is shown on the upper right corner of each spectrum. Spectrum *a* comes from the "normal" set of spectra, spectra *b* and *c* come from the "strange" set of spectra. Notice how wide and "ungaussian" spectra *b* and *c* are. Notice how spectrum *c* could be fit by two gaussians very close to each other in velocity space.

B335 core



The same as above, but for the B335 core. Here, even though the "strange" spectrum (*e*) has a more or less gaussian shape, the line is much wider than a "normal" line (spectrum *d*) with the same peak temperature. Unlike the B5-IRS1 data, none of the spectra from B335 show a "double gaussian" shape.