

## CARMA Memorandum Series #44

### CARMA SUMMER SCHOOL 2007

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May 9, 2008

### ABSTRACT

The first CARMA SUMMER SCHOOL was held at the observatory 2007 July 8-14 with 15 students from Berkeley, Caltech, Illinois, Maryland, NRAO, and Scotland. During the school each participant made observations, and analyzed the results. In this memo we collect together some of these results from the student projects.

*Change Record*

Revision	Date	Author	Sections/Pages Affected
			Remarks
1.0	2008-Jan-03	MCHW	1-6
			Draft memo
1.1	2008-Feb-08	MCHW	1-13
			added student contributions
1.2	2008-Mar-25	Megan	7,14
			added student contributions
1.3	2008-Mar-25	MCHW	1-14
			cleanup TeX
1.4	2008-Apr-02	MCHW	1-14
			added Danielle Lucero text and figures
1.5	2008-May-07	MCHW	1-14
			clean up.
1.5	2008-May-08	MWP	1-14
			Major cleanup, added Sid Kumar
1.6	2008-May-08	MCHW	1-22
			merge MCHW and MWP clean ups; added conclusion.

## 1. INTRODUCTION

The first CARMA SUMMER SCHOOL was held at the observatory near Big Pine CA, 2007 July 8-14 with 15 students from Berkeley, Caltech, Illinois, Maryland, NRAO, and Scotland. Students stay at the observatory for lectures, practical demonstrations, and observing projects. The lectures cover the basic theory and practice of interferometer observations, data reduction and imaging. During the school each participant makes observations and analyzes the results. We want the students coming to the school to be active users of CARMA, so there an expectation that they will come back as observers in the near future to put into practice what they have learned. The CARMA summer school continues the ‘hands-on’ traditions of the Hat Creek summer schools which we have run since 1989.

The CARMA telescope is designed as an aperture synthesis telescope. There are two receiver bands: 3 mm and 1 mm. A basic aperture synthesis observation makes an image the size of the primary beam ( $\lambda/\text{diameter} \sim 1$  arcmin at 100 GHz; 0.5 arcmin at 230 GHz) with a resolution corresponding to the maximum separations of the 15 antennas. Students learn how this works at the school. During the school the telescope was in the compact D-configuration, which gives an angular resolution of  $\sim 3$ -6 arcsec at 100 GHz, and 1.5-3 arcsec at 230 GHz. Each student gets about 4 hours observing time on source.

The most convenient source size is one which is smaller than the size of the primary beam. Larger sources can be imaged by time-sharing the pointing of the antennas (mosaicing), at the cost of lowered sensitivity.

The sensitivity is determined by the system noise (receivers plus atmosphere), the bandwidth (or velocity resolution), and the observing time. The atmosphere is usually not so good for 1 mm observations in the summer, or for sources which are at low declinations and must be observed through more of the atmosphere, so it’s best to select a bright source which is high in the sky and can be observed at 3 mm. Many CARMA projects do not satisfy all these conditions. However, during the school, it’s better to observe a strong source rather than a detection project. With a strong enough source you can investigate the effects of different calibration and imaging techniques.

For a TECHNICAL DESCRIPTION and a tool to calculate the RMS noise see:

[http://cedarflat.mmarray.org/observing/doc/instrument\\_desc.html](http://cedarflat.mmarray.org/observing/doc/instrument_desc.html)

<http://cedarflat.mmarray.org/observing/tools/rms.html>

## 2. LOGISTICS

Because this is a ‘hands-on’ school, we hold all lectures and demonstrations in the control building at Cedar Flat, adjacent to the telescopes. The students participate in all aspects of running the telescope, making observations, checking the data quality, archiving the data, etc. Breakfast and

lunch food were provided. Dinners from Mon-Fri were cooked communally in the control room kitchen by the staff and students.

Since the dorm and cottage at OVRO can accommodate at most 8, several students joined Mel, Dick, and Marc in camping out at the ‘Nelson’ group campground, about 1.5 miles from the control room. The campers avoid the hassle of driving up and down the mountain each day, and have a wonderful opportunity to star-gaze each night.

The school ran from 9am Monday to Friday night 13 July. Most students arrived on Sunday 8 July and departed on Saturday 14 July. We organized a hike to Bristlecone Pines on Saturday.

### 3. STUDENT PROJECTS

#### 3.1. Claudia Cyganowski (U. Wisconsin, Madison)

I observed HCO+(1-0), HCN(1-0), and N<sub>2</sub>H+ (1-0) (and continuum) towards G28.83 (a MYSO outflow candidate identified based on extended 4.5um emission in GLIMPSE images). The science goals were to investigate whether HCO+ traced an outflow coincident with the extended 4.5um emission (which has been hypothesized to trace shocked H<sub>2</sub> in outflows) seen in the GLIMPSE images, and to determine whether the 4.5um emission was associated with a single or multiple protostar(s) (using dense gas tracers and dust continuum emission). The HCO+ (1-0) velocity structure is complicated, apparently tracing multiple outflows from at least two protostars. A central compact core is observed in HCN and mm continuum (I also observed at 1mm in bad weather; the continuum was useable). The mass of this core (calculated from 1mm continuum) is consistent with it being a massive protostar.

#### 3.2. Ran Wang (NRAO)

The science goal is to detect DCO+, DCN, H<sub>2</sub>CO absorptions toward the gravitational lensing BL Lac object B0218+357. I observed 5.5 hours on source and detected H<sub>2</sub>CO (Figure 1). There is a recent published H<sub>2</sub>CO absorption result for the same target (the same line), which was observed in 1997. Compared to their result, I found that the continuum of the target increased by a factor of 2, and the optical depth of the line absorption also changed.

The original plan was to search the DCO+ and DCN absorptions in the z=0.68547 gravitational lens towards B0218+357 and study the D/H ratios. However the final rms was not good enough to get these two lines. The H<sub>2</sub>CO absorption was detected and the optical depth determined. I found the optical depth is about 2-3 times smaller compared to the published measurements ten years ago. I am thinking about high resolution observations of this source with the VLA to understand this change.

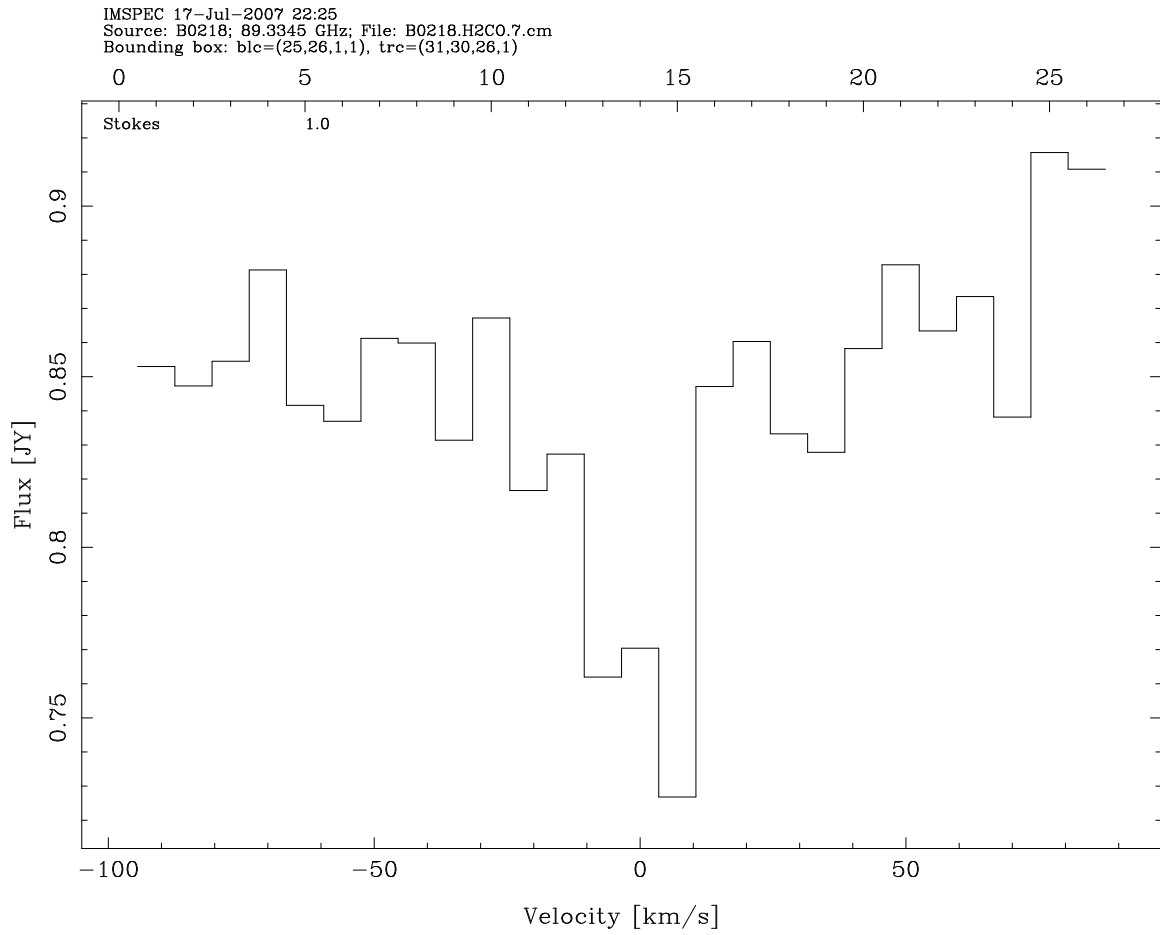


Fig. 1.— H<sub>2</sub>CO absorption spectra towards B0218+357 at 7 km/s resolution.

### 3.3. Hsin-Fang Chiang (UIUC)

The source I observed was the Class 0 young stellar object L1157-MM at RA 20:39 and DEC +68:02. The correlator configuration was 3mm continuum and 12CO(1-0) line at 115.271GHz. Bandwidths of both 8MHz and 2MHz were used, and coincided at the same frequency. Both 3mm continuum and 12CO(1-0) line emission were observed and well detected (Figure 2). The 3mm dust continuum shows the envelope structure and can help revealing the envelope’s collapsing mechanism, also may suggest the existence of embedded circumstellar disk after detailed modeling. The CO line emission traces the bipolar outflows driven by this young stellar object. The CO map as in the figure shows the morphology of the outflows. In the velocity space it can be seen that the northern lobe is redshifted and the southern lobe is blueshifted. What was observed in this track was only the central part of the long-extended outflows. A mosaic will be needed to see the whole outflow structure.

### 3.4. Amber Bauermeister & Katey Alatalo (UCB)

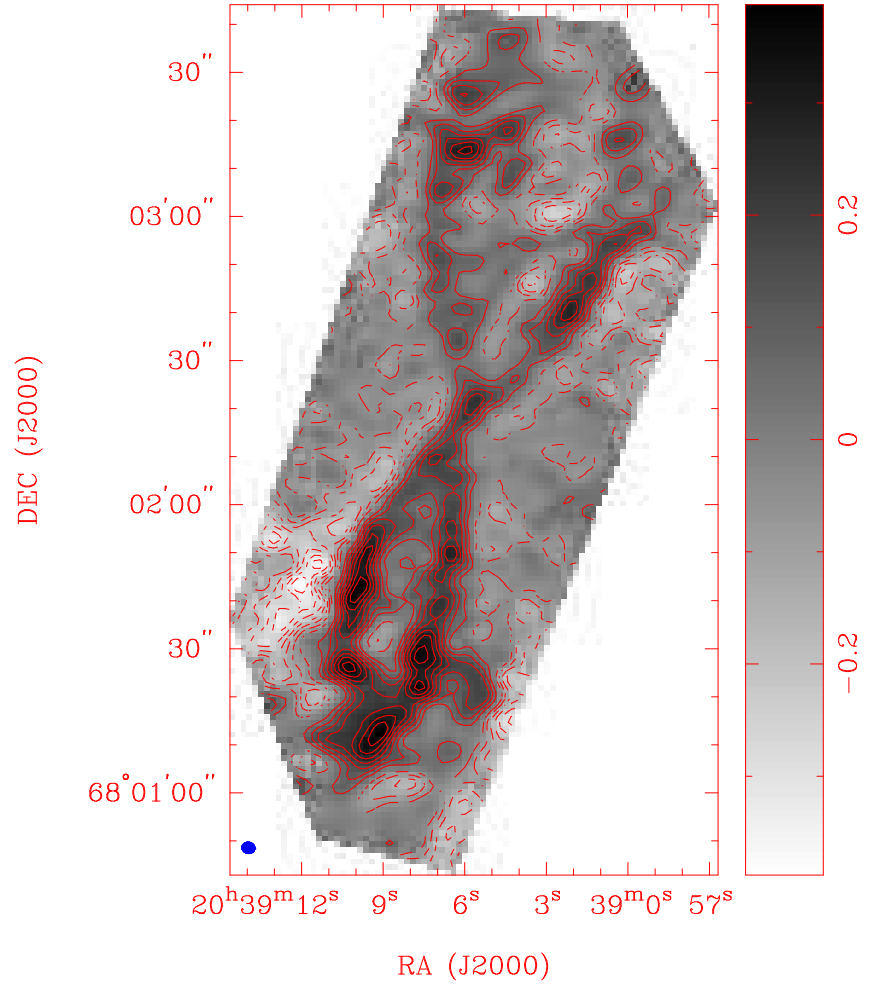
Amber Bauermeister observed NGC5005, one of the BIMA SONG galaxies with the highest CO surface brightness, in HCN. Katey Alatalo observed another BIMA SONG galaxy in HCN for the same purpose. We wanted to see if we could detect it in HCN, a tracer for high density gas in the inner region of the galaxy. Our observations did give a detection of HCN in the central region of the galaxy.

### 3.5. Kijeong Yim (UIUC)

The source was NGC 891 taken by 13CO(1-0). The science goals was study of vertically extended emission in the edge-on galaxy NGC 891. My observations were two mosaic tracks, along the major and minor axes of the galaxy (Figures 3, 4, 5, 6). While I did detect 13CO(1-0), I couldn’t see any extended vertical disk. The tracks have similar integration time. However since the major axis mosaic contained more pointings, the S/N in that track is lower.

### 3.6. Megan DeCesar (UMD)

My source was M82, a starburst galaxy in the nearby M81 group that has been studied extensively. The starburst is the result of an interaction between M81 and M82 that occurred  $\sim 200$  million years ago. Long tails of atomic hydrogen connect the galaxies today, providing concrete evidence of this past interaction that triggered star formation in the spiral arms of M81 and inner regions of M82. The violent deaths of massive stars in M82 have blown gas from its core, giving it its ragged appearance and classification as a starburst galaxy.



RA, DEC, FREQ = 20:39:06.198, 68:02:15.89, 1.15279709E+02 GHz at pixel (40.00, 78.00, 1.00)  
Spatial region : 1,1 to 84,151  
Pixel map image: L1157.usb.8M.mosaic.mask (L1157) Min/max=-0.3881/0.3874 Range = -0.3881 to 0.3874 JY/BEAM (lin)  
Contour image: L1157.usb.8M.mosaic.mask (L1157) Min/max=-0.3881/0.3874 JY/BEAM  
Contours : -0.3881, -0.3396, -0.2911, -0.2426, -0.1941, -0.1455, -0.09703, -0.04852, 0.04852, 0.09703, 0.1455, 0.1941, 0.2426, 0.2911, 0.3396

Fig. 2.— CO outflow in Class 0 young stellar object L1157-MM.

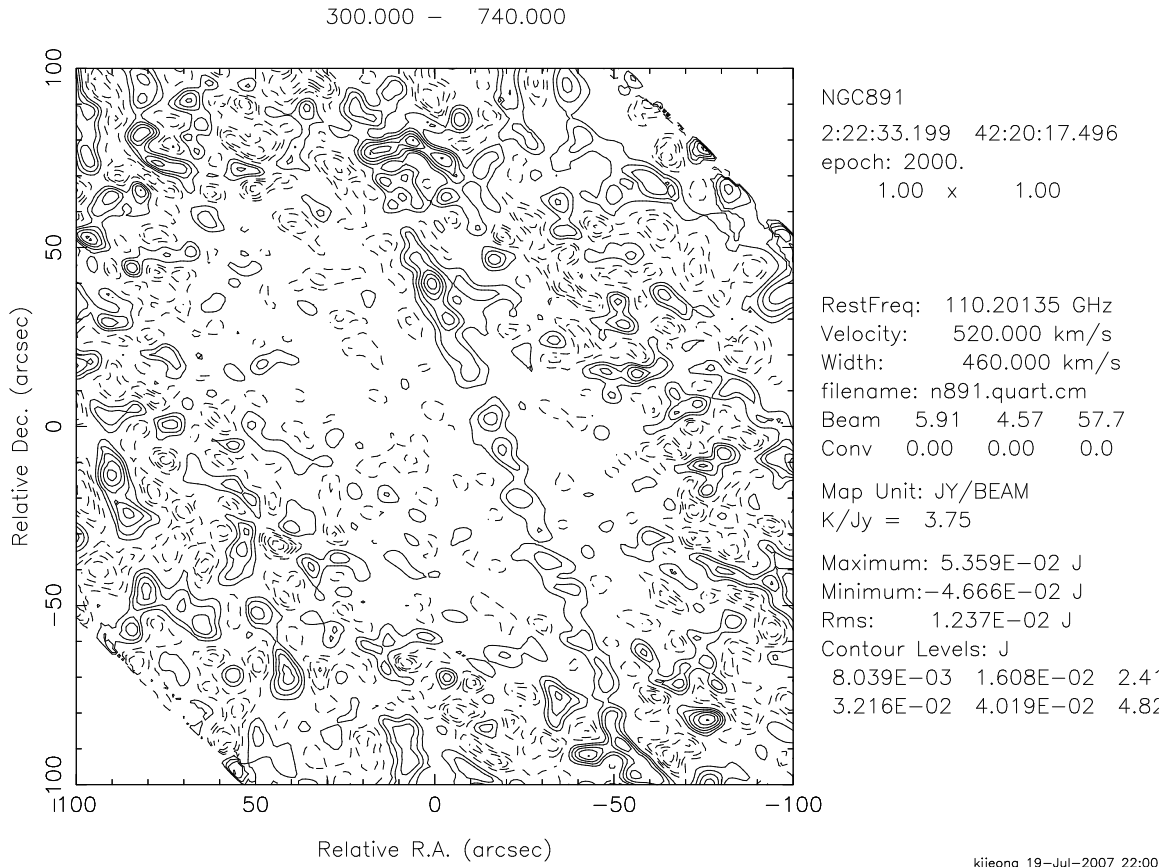


Fig. 3.— 13 CO (1-0) map of NGC 891 from 300 to 740 km/sec. Mosaic at five points along the disk major axis. (offsets: [0.667,0.667],[0.33,0.33],[0.0,0.0],[-0.33,-0.33],[-0.667,-0.667])



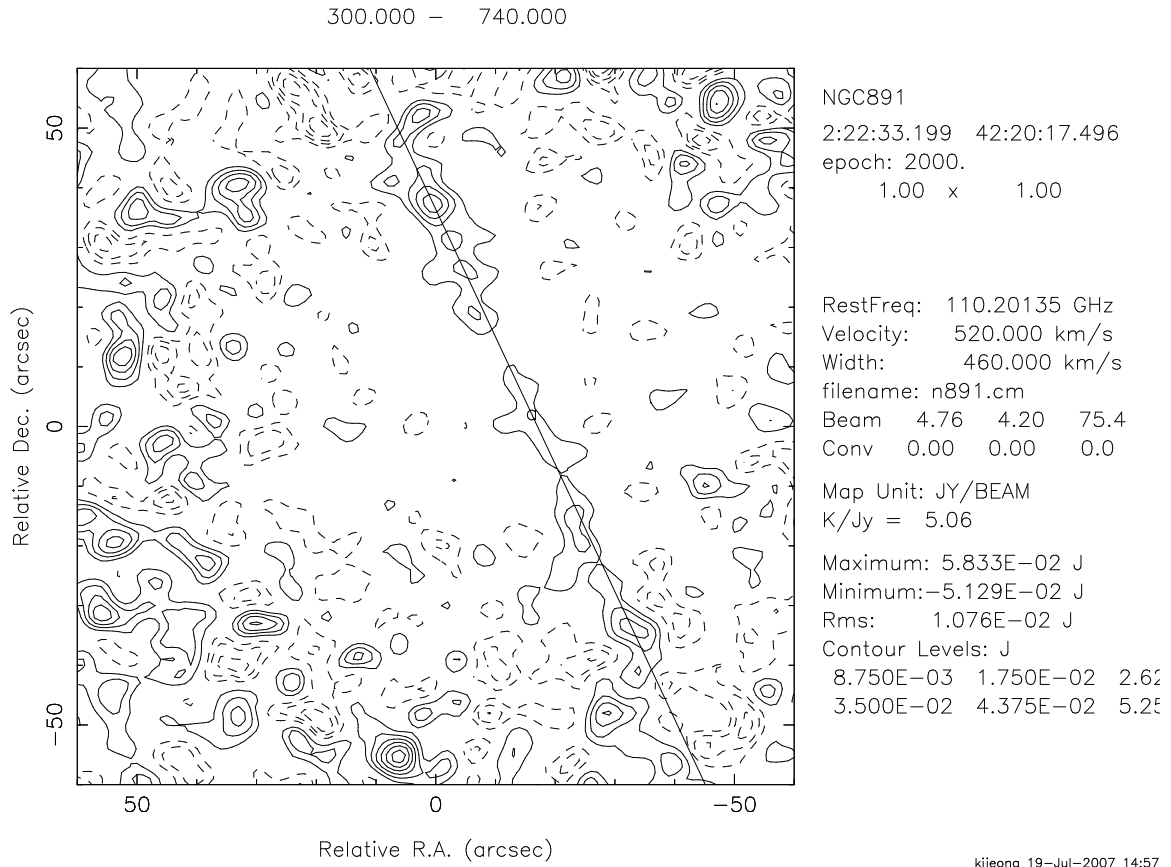


Fig. 4.— 13 CO (1-0) map of NGC 891 from 300 to 740 km/sec. Mosaic at two points along the axis perpendicular to disk. (offsets in mosaic options: [0.0,0.0],[-0.4,0.167])

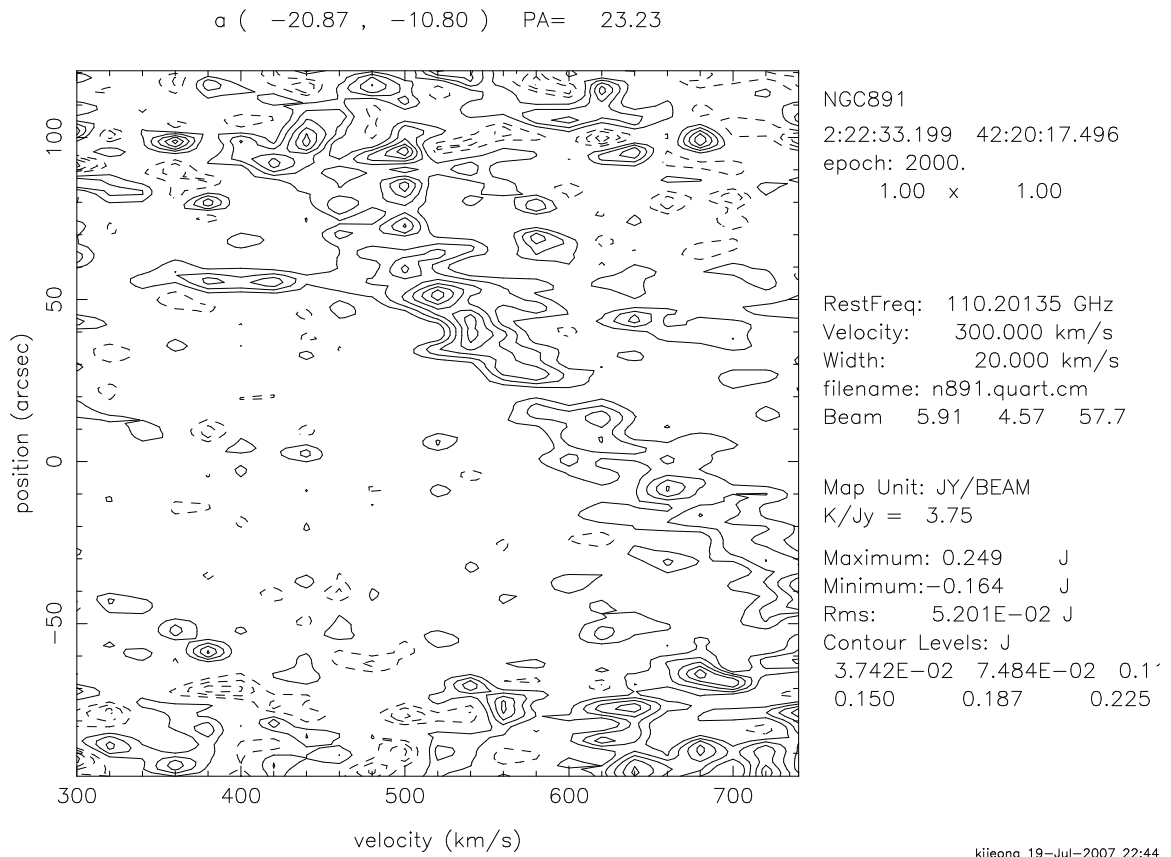


Fig. 5.— Position-velocity diagram of 13 CO (1-0) from major axis track. The velocity resolution is 20 km/sec.

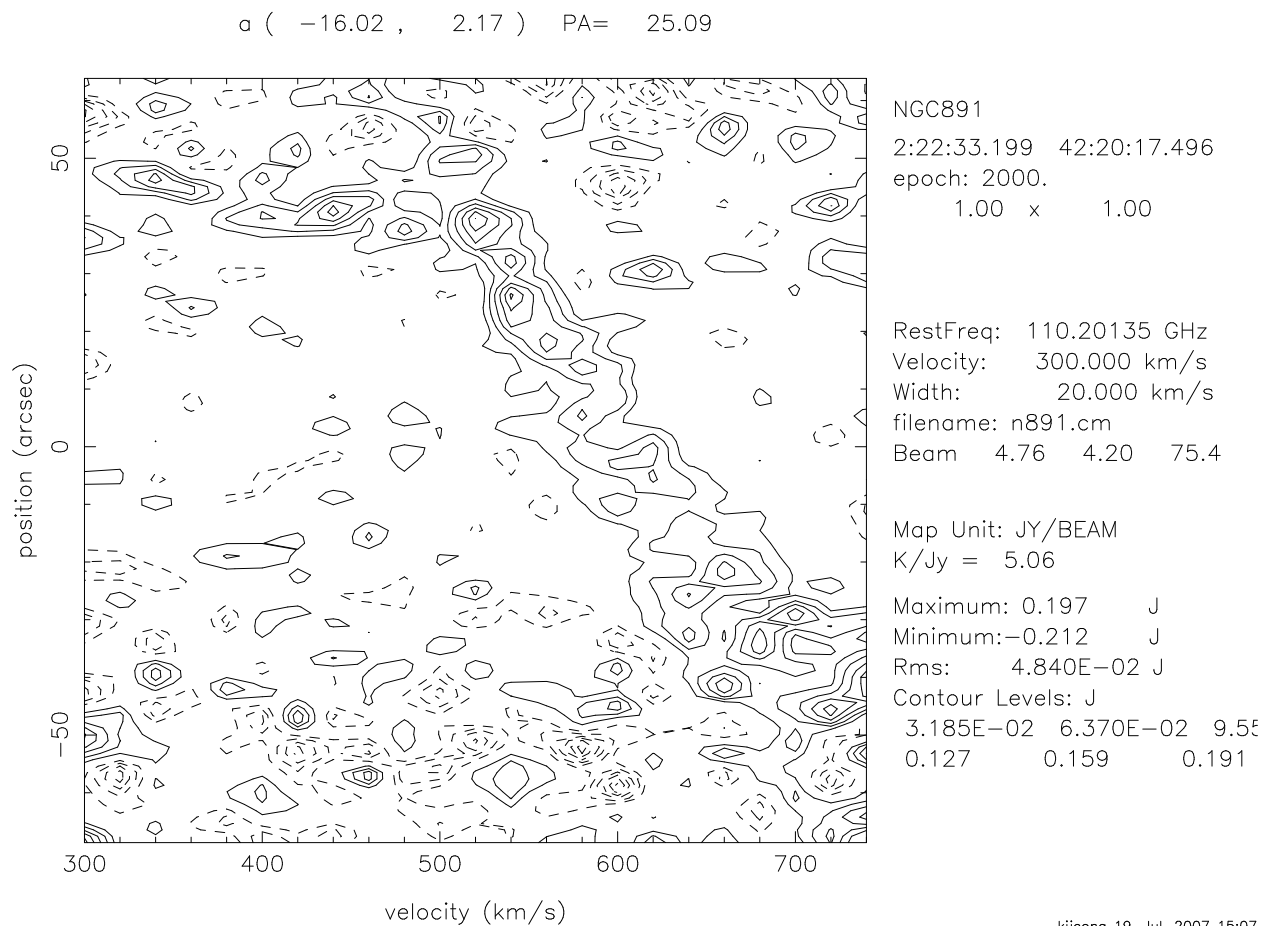


Fig. 6.— Position-velocity diagram of 13 CO (1-0) from minor axis track. The velocity resolution is 20 km/sec.

I chose this object because it has been observed successfully by BIMA and would be an easy target for CARMA. This almost guaranteed that I would get good data that could be used to learn the data reduction tools in MIRIAD.

My data turned out well, as expected. We did have a calibration issue – we had not observed a calibration source other than at the beginning and end of the observation. In spite of this, M82 showed up clearly in both the image and the spectra, so although we cannot obtain a flux measurement we can still glean information like rotational velocity from the data.

Figure 7 shows the CO(1-0) transition in the central  $\sim 400$  pc of M82, assuming a distance of  $\sim 3.7$  Mpc. We have deconvolved the data using a point source clean routine (blue) and a maximum entropy routine (red). The two methods are consistent in their reproduction of the source structure, and match well with images made previously of this region of the galaxy.

### 3.7. Sidharth Kumar (UMD)

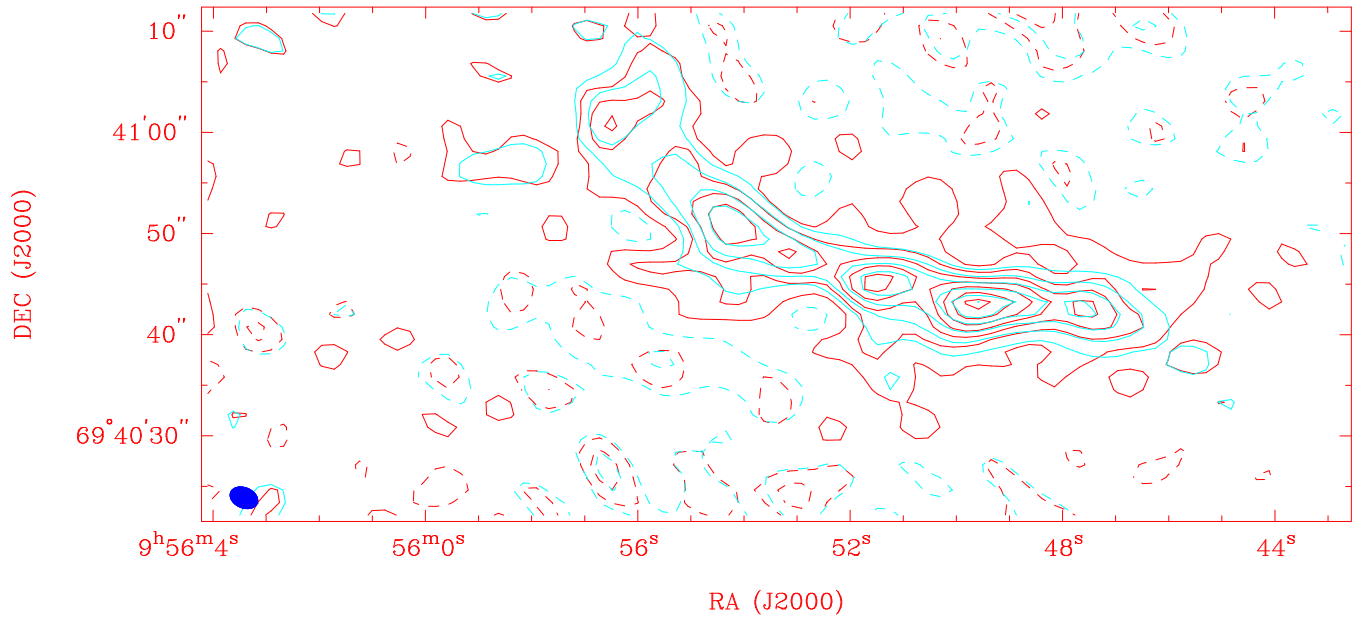
The Eagle Nebula (RA,DEC) = 18:18,-13:47) was observed in  $^{13}\text{CO}(1-0)$  (110.2GHz),  $^{12}\text{C}^{18}\text{O}(1-0)$  (109.78GHz) and in the continuum. The bandwidths for the set line frequencies and the continuum were 8MHz, 8MHz and 500MHz respectively. The pillars of the nebula were mapped out in a 19 point mosaic. The signal to noise was highest in the  $^{13}\text{CO}(1-0)$  maps as expected. Fig. 8 shows the velocity integrated image obtained in the  $^{13}\text{CO}(1-0)$ .

### 3.8. Danielle Lucero (New Mexico Tech)

My summer school project is a continuation of a project that I started that aims to map the CO emission in a sample of nine elliptical galaxies. Our goal is to measure the direction of rotation of the gas and to compare that to stellar kinematics. The results should reveal how much of the molecular gas is may have come from internal stellar mass loss and how much must have been acquired from outside. The key is the angular momenta: if the gas and stars have misaligned angular momenta, then an internal origin can be ruled out (for galaxies which are not strongly triaxial).

At the summer school I observed the E/S0 galaxy NGC 6524 in the  $^{12}\text{CO} 1-0$  line which was previously detected with the CSO 10m telescope. I used a hybrid mode: I used a correlator setup with three 62MHz bands slightly overlapped to give a total coverage of 440 km/s.

To date the results are: I detected the CO as expected (Figures 9, 10, 11). The CO emission resides in a disk in regular rotation about the center. There may be some indication that the line was wider than what the literature quoted so I observed the source again using a different correlator setup so that I could get any line that may have been missed. I have not yet reduced this extra data set. It may not be necessary since it seems that I got enough of the line to determine the



RA, DEC, FREQ = 9:55:52.199, 69:40:46.99, 1.15209892E+02 GHz at pixel (132.00, 125.00, 1.00)  
Spatial region : 82,105 to 172,145  
Contour image: m82.memcm (M82) Min/max=-0.05047/0.1415 JY/BEAM  
Contours : -0.1354, -0.116, -0.0967, -0.07736, -0.05802, -0.03868, -0.01934, 0.01934, 0.03868, 0.05802, 0.07736, 0.0967, 0.116, 0.1354, 0.1547  
Contour image: m82.sdicm (M82) Min/max=10<sup>30</sup>/-10<sup>30</sup> JY/BEAM  
Contours : -0.1827, -0.1462, -0.1096, -0.0731, -0.03655, 0.03655, 0.0731, 0.1096, 0.1462, 0.1827, 0.2193, 0.2558, 0.2924

Fig. 7.— CARMA map of the CO J=1-0 transition in M82's center. The blue contours were derived from a point source deconvolution, the red from maximum entropy.

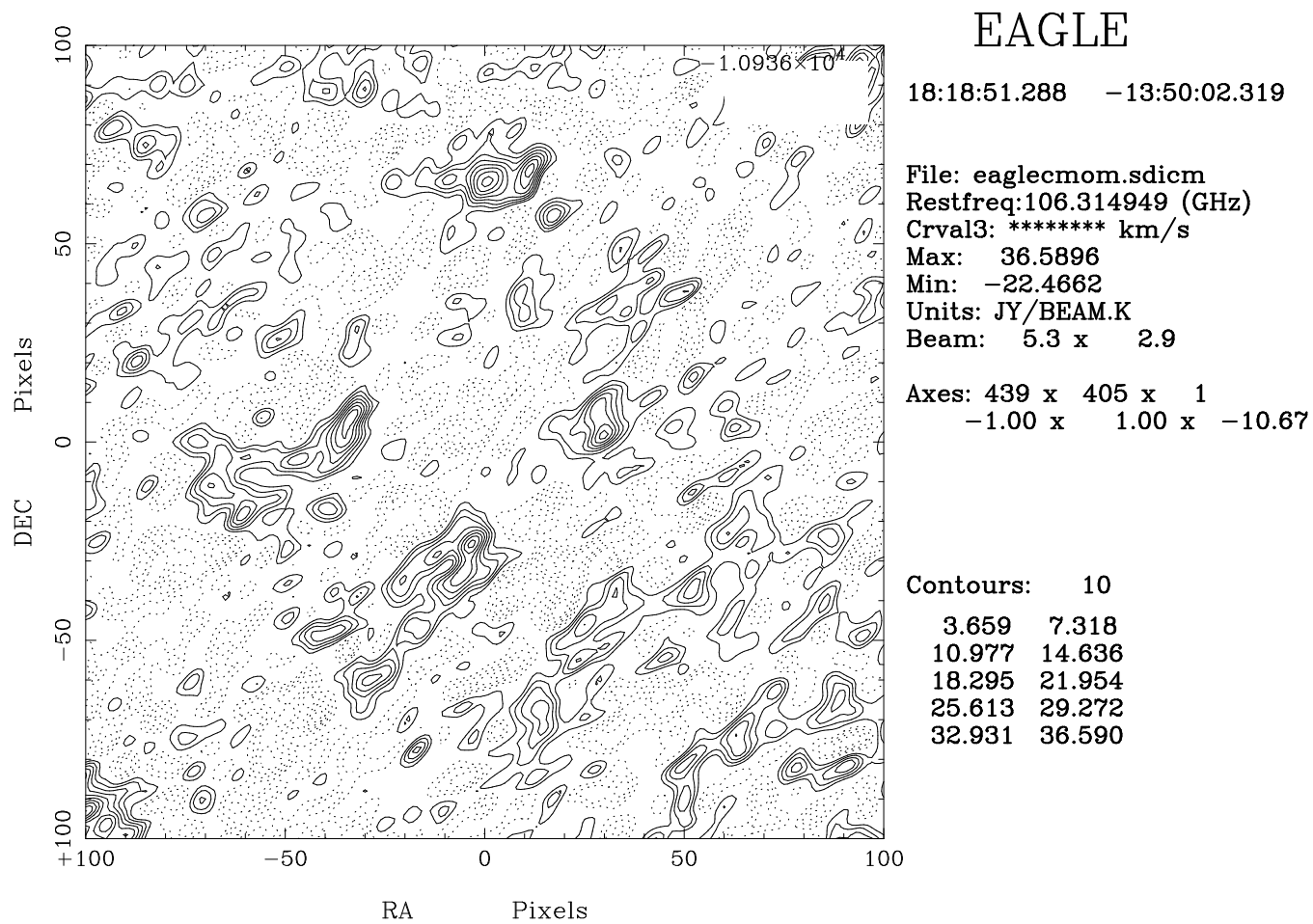


Fig. 8.—  $^{13}\text{CO}(1-0)$  Eagle Nebula image integrated between  $V_{LSR} = 20$  and 27 km/s

science goals.

The total flux is:  $\sim 78.8$  Jy km/s which is very close to the single dish detection (82 Jy km/s) The total H<sub>2</sub> mass is then:  $6.3 \times 10^9 M_{\odot}$ .

I have not yet finished reducing the optical data for this particular source.

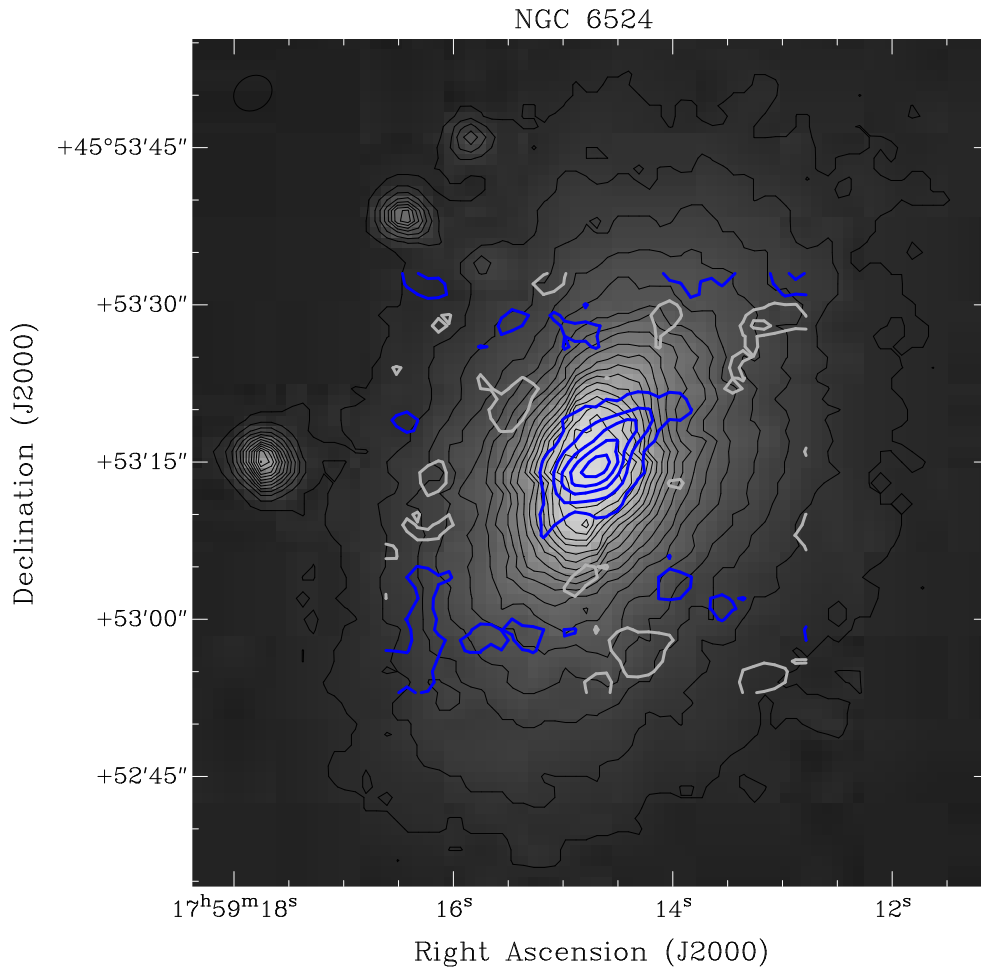


Fig. 9.— An CO integrated intensity map of NGC 6524 overlaid on an SDSS2 Red optical image. contours are in increments of -15%, -10%, 10%, 15% 30% 50% 90% of the peak 32.35 Jy/beam km/s the beam size is: 3.8" x 3.2"



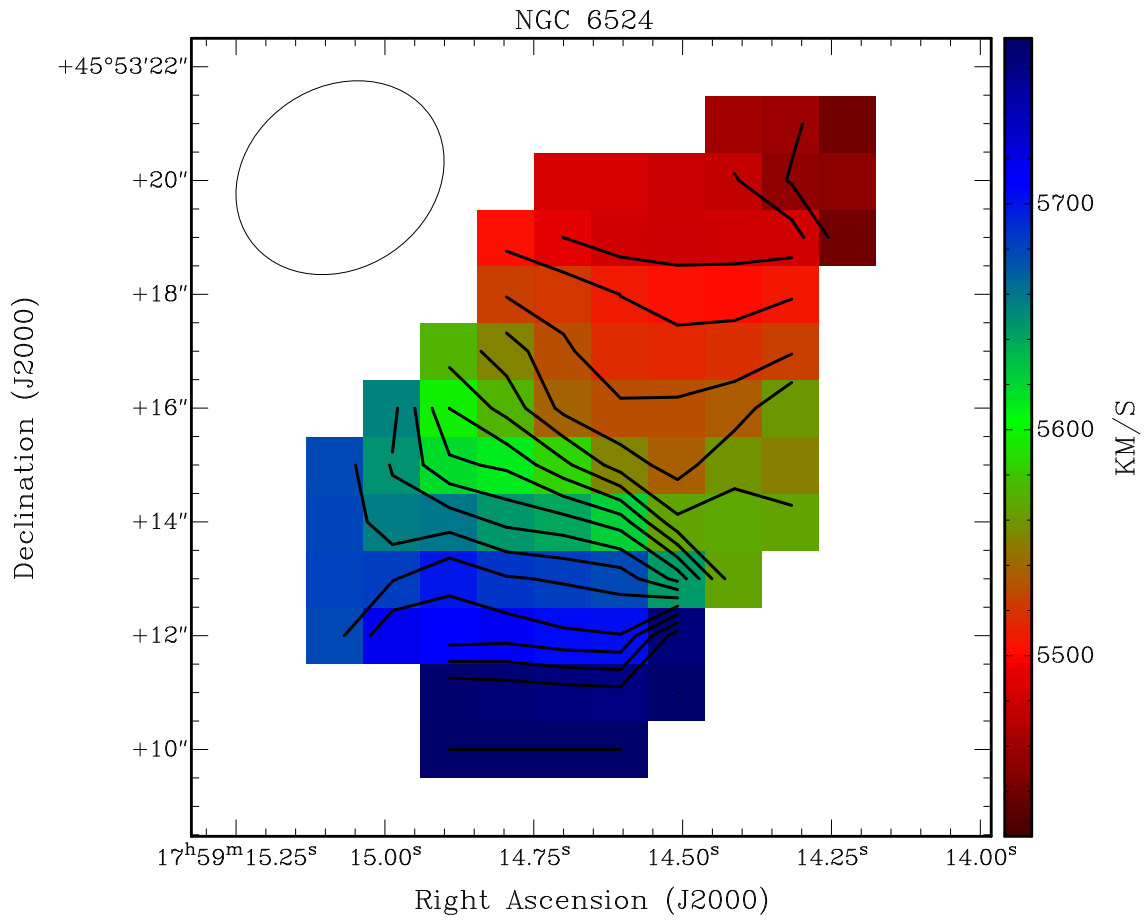


Fig. 10.— An 1st moment map of NGC 6524 Contours are in increments of 5% of the peak.

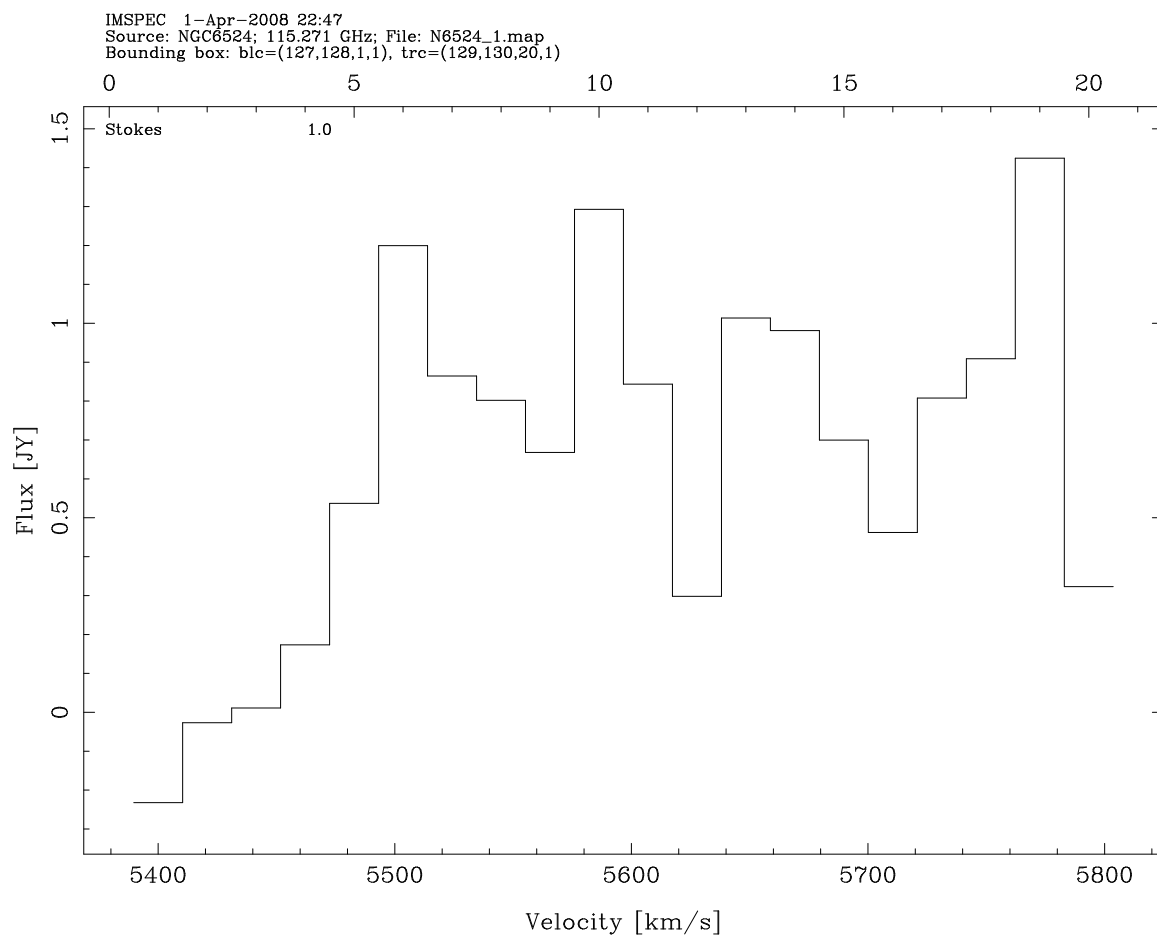


Fig. 11.— The CO spectrum of NGC 6524 calculated for the central brightest pixel.

#### 4. CONCLUSION

The students participated in all aspects of running the telescope. The students organized the observing schedule and took turns in shifts as the duty observers running the telescope 24 hours a day. The students design and make the observations, analyze the data and make astronomical images. Some of these summer school projects become thesis projects and published papers. Many of the students from the previous Hat Creek summer schools are now the interferometry experts at major universities and observatories. In addition to the lectures, demonstrations and student observing projects, the students have a unique opportunity to participate in the commissioning of the CARMA telescope. Many of the observing procedures and data processing techniques are still under development and the students were better able to understand what is needed and how the problems might be solved by directly working with a new instrument. For example, several of the students noticed that the bandpass calibration of the 32 and 8 MHz bands was inadequate, and were able to improve on the calibration technique. Figure (12 and 13, produced by Ran Wang, show that the bandpass obtained from observations of the noise source and 3C273 are significantly different. Richard Barvainis from the National Science Foundation visited the site on the Wednesday, and was, we hope, duly impressed by the diligent hum of activity and learning.

Acknowledgements: We want to thank the many people who were involved in making the first CARMA school a success. In particular we thank Debbie Juliff and Janet Kutulas for administrative help ( we note that both have moved on to new jobs and hope that the summer school was beneficial experience (!) and wish them well in their future careers), Cecil Patrick for excellent lunches and shopping to buy the food each day which the school participants wanted to cook for our dinners, Terry Sepsey for keeping the observatory well supplied and clean, and many thanks to CARMA and OVRO staff for engineering, technical and local support at the CARMA summer school.

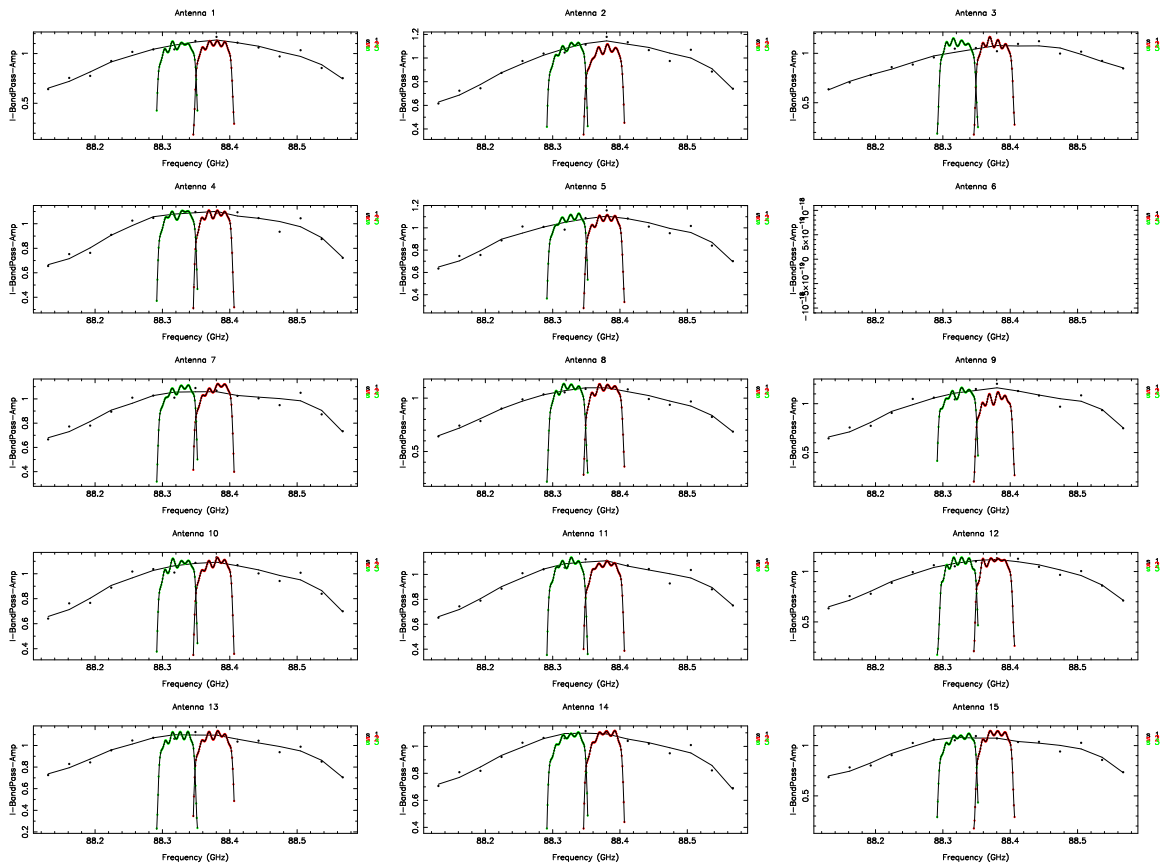


Fig. 12.— Bandpass obtained from observations of the noise source in 32 and 500 MHz bands.

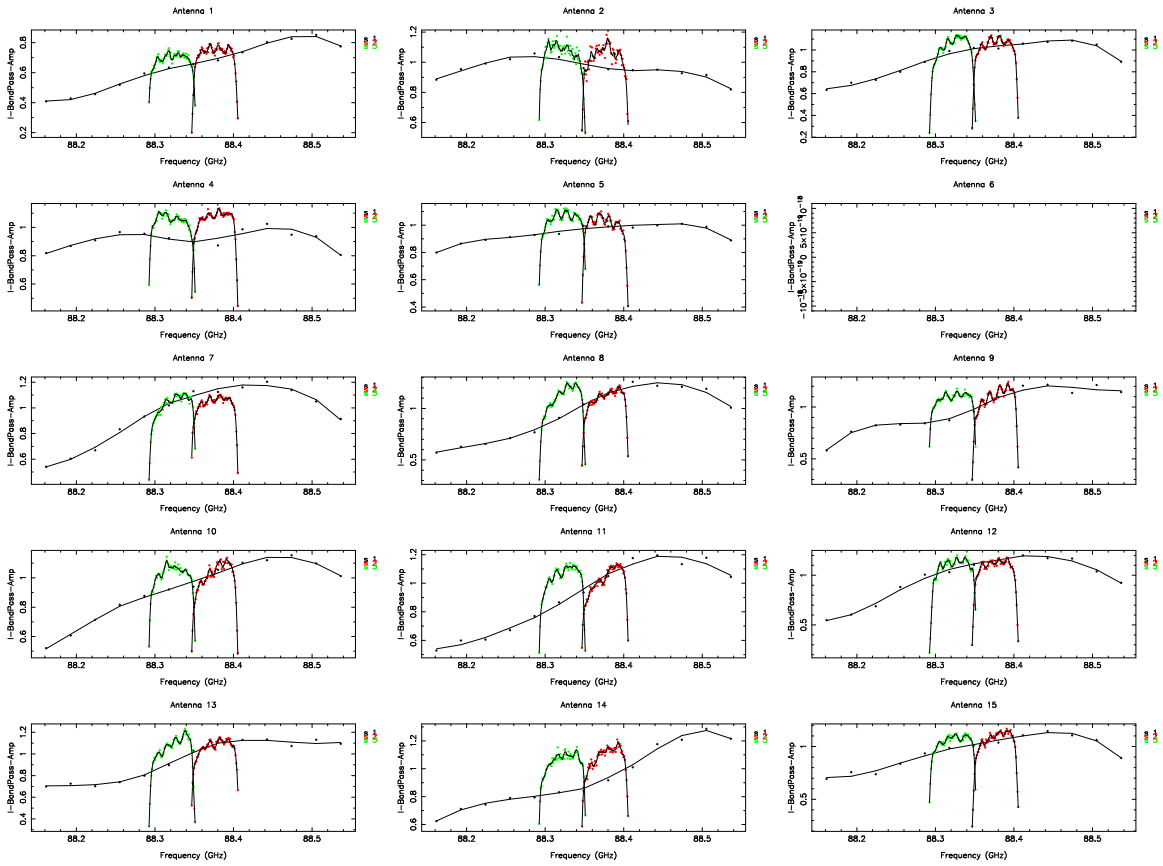


Fig. 13.— Bandpass obtained from observations of 3c273 in 32 and 500 MHz bands.

## 5. Email Addresses of Participants

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