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CARMA Spectral Line Correlator Requirements

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ABSTRACT

We review the expected sensitivity and spatial dynamic range of the CARMA array during the next 10 years in comparison with the ALMA, ACA, SMA and IRAM arrays. The scientific capabilities of the CARMA array can be greatly enhanced at modest cost by adding a full polarization spectral line correlator.

1. Introduction

Many projects require observations of multiple spectral lines to analyze the structure and dynamics of star formation regions, galaxies and other sources.

E.g. for warm regions and outflows we need about 0.5 km/s resolution over 100 km/s in each spectral window, and for cold clouds $\sim$ 0.1 km/s over 20 km/s, i.e $\sim$ 256 channels per spectral window with bandwidths 100 MHz and 20 MHz at 230 GHz.

The CARMA correlator (Beasley etal 2003) is good for wideband, but does not have the spectral line capabilities we need, and currently have. On the other hand, it is expensive and risks delaying this correlator, to make it into a viable spectral line correlator.

We often want to observe both wideband (continuum, dust), AND multiple spectral lines. In this memo we propose to use the correlator being developed for the Allen Telescpe Array as a spectral line correlator for the CARMA array.

2. BIMA Correlator

Table 1 shows the correlator modes for the BIMA correlator. Modes 1-4 provide 1-4 spectral windows in each sideband of the 1st LO. Each spectral window has 256 to 1024 channels. Modes (5-8) provide various compromise solutions of combinations of wide and narrow spectral windows.

The mode determines the correlator configuration and number of spectral windows. The default is mode 8 with the maximum bandwidth. The following table gives the bandwidth and the number of channels in each correlator window. The four bandwidths bw1, bw2, bw3, bw4 may be one of

6.25/12.5/25/50/100 MHz. Multiplexing is used for a bandwidth 50 or 100 MHz, and reduces the number of channels in the window by a factor 2 or 4 respectively.

In mode=8, bw1 is restricted to 25, 50, or 100 MHz. These same windows are repeated in both sidebands of the first LO. There are double the number of channels in auto correlation mode but there is no sideband separation.

Figure 1 shows a typical correlator configuration for observing multiple spectral lines and continuum emission in a star formation region. There are 4 LSB and 4 USB spectral windows with bandwidths 25, 50, 100, 50 MHz. The quiescent DCN and ^{13}CO emission were observed with 0.13 km/s velocity resolution in window 1 and 5. The CH_3CN and $CH_3^{13}CN$ emission were observed with 0.53 km/s velocity resolution in windows 6 and 8. The 100 MHz windows were used to estimate the continuum emission.

Figure 2 shows the spectra of CH_3CN emission obtained from window 8.

3. Polarization, Mosaicing, and time multiplexing.

Polarization observations are required to understand many astrophysical situations. With a single polarization system we must use time multiplexing, with a switchable polarizer. The polarizer is frequency and polarization dependent (1/2 or 1/4 wave plates). BIMA has 4 sets of plates currently. Polarization observations are inefficient and more difficult to schedule.

Addition time multiplexing is required for mosaicing large fields. Polarization observations, mosaics, and multiple spectral lines all require time multiplexing and, in combination, are very inefficient.

Calibration of simultaneous observations of full polarization, or multiple spectral lines is more robust and reliable than time multiplexing or multiple tracks.

Dual polarization also improves the sensitivity for spectral line observations.

Table 1: BIMA Correlator Modes

baseband	LSB 1	USB 1	LSB 2	USB 2	LSB 3	USB 3	LSB 4	USB 4
mode 1	bw1/1024	-	-	-	-	-	-	-
mode 2	bw1/512	-	-	bw2/512	-	-	-	-
mode 3	bw1/512	-	-	bw2/256	-	-	-	bw4/256
mode 4	bw1/256	-	-	bw2/256	bw3/256	-	-	bw4/256
mode 5	bw1/512	-	100/32	100/32	-	-	100/32	100/32
mode 6	bw1/256	-	100/32	100/32	bw3/256	-	100/32	100/32
mode 7	25/256	-	100/32	100/32	100/32	100/32	100/32	100/32
mode 8	bw1/128	100/32	100/32	100/32	100/32	100/32	100/32	100/32

4. A Spectral line correlator for CARMA

The suggested solution for CARMA is to build a separate full polarization spectral line correlator so that we can have the full bandwidth and good spectral line capability at the same time.

The Allen Telescope Array (ATA) is planning to have 32 antennas completed by September 2004. The ATA correlator for 32 antennas will provide 100 MHz bandwidth with 1024 spectral channels with full polarization correlations. This correlator could also be used for CARMA. For the 15-antenna CARMA array the 32 dual polarization inputs provide four 100 MHz bands each with 1024 channels. In this mode the cross polarized correlations are not used. When dual polarization receivers are installed, the ATA-32 correlator provides two 100 MHz bands including all cross polarizations. For the 23-antenna CARMA array, the ATA-32 correlator provides two 100 MHz bands in a single polarization or one 100 MHz band with all polarization correlations. The ATA-32 correlator is a prototype module for a 252-antenna ATA. Additional modules could also provide more spectral windows and bandwidth for the CARMA array.

This is one of the few things we can do to leverage the maximum science from our current instrument and development efforts at relatively low cost.

It is advantageous to have simultaneous wideband observations for dust, but we need sufficient resolution in order to subtract spectral emission within these wideband observations.

One of the selling points for CARMA is as a research and development array which is accessible to instrumentalists and students. Since it will be very difficult for outside users to bring their own backend to ALMA, it is essential to facilitate adding user instruments and software to CARMA. Providing a path for easy installation of a spectral line correlator which was not specifically built for CARMA will allow us to make CARMA more accessible to non-facility instrumentation.

5. CARMA's Role in next 5-10 years

Tables 2–5 compare the relative performance of CARMA with other arrays which are expected to be in use during the next 10 years. We included the ACA rather than the Nobeyama array in the tables as the ACA is a heterogeneous array with a similar number of antennas to CARMA. The Nobeyama array (6×10m + 45m antennas) is expected to be in operation for the next 5–10 years. The current status is available from http://www.nro.nao.ac.jp/index-e.html.

Table 2: The collecting area measures the sensitivity for single field observations. The number of antennas $\times$ antenna diameter measures the mosaicing sensitivity. The number of baselines measures the image fidelity for extended sources. The maximum baseline/antenna diameter measures the spatial dynamic range. These issues are discussed in more detail in BIMA memos 73 and 84.

Table 3: The SSB system temperatures, Tsys, are calculated using DSB receiver temperatures of

40K at 80-115 GHz and 80K at 230 or 345 GHz, or officially blessed values assuming 1.4 airmasses with precipitable water (mmh2o) as shown.

Tables 4–5 give the continuum and spectral line sensitivites in one sideband and one polarization. We used aperture efficiencies 78% at 100 and 230 GHz, 70% at 345 GHz for all telescopes except IRAM PdB for which we used aperture efficiencies 75, 55 and 35% corresponding to 21, 28, and 44 Jy/K (Guilloteau, Lucas, and Neri, 2002; Lucas private communication). The continuum bandwidth is given in table 2. No coherence or correlator loss factors were used; actual performance will vary, and may be much worse.

Tables 2–5 give some indication of the areas where CARMA is competitive in the next 5–10 years. The spatial dynamic range is excellent, even compared with ALMA. Together with the wide field imaging enabled with the heterogeneous array of 3.5, 6.1 and 10.4 m antennas, this is clearly an area in which CARMA can excell.

Many improvements can be expected in the next 5–10 years. Single sideband receivers will be in use at some frequencies. E.g. IRAM PdB is expected to have system temperatures 150, 230 and 350 K at 115, 230 and 345 GHz (SSB at 1.4 airmasses) in next 2–4 years (S.Guilloteau & R.Lucas, private communication). Dual polarization receivers will be in use at 345 GHz at the SMA. A dual polarization 4 GHz wideband correlator and longer baselines are planned for PdB. Dual polarization receivers improve spectral line sensitivity a factor sqrt(2), and full polarization observations by a factor 2 (factors of 2 and 4 in observing time), and will soon be standard on all arrays.

The spectral resolution with the CARMA wideband correlator is clearly lacking. Dual polarization and spectral resolution are two areas where the CARMA performance can be improved at modest cost.

6. Conclusion

The scientific capabilities of the CARMA array can be greatly enhanced by adding a full polarization spectral line correlator. The ATA correlator design enables CARMA to have simultaneous wideband and spectral line coverage, and full polarization capability for 23 antennas.

7. References

The CARMA First-light Correlator–Revised Performance Estimates , A.J. Beasley, D.W. Hawkins, K.P. Rauch, D. Woody, April 2003 (http://www.mmarray.org)

An Introduction to the IRAM Plateau de Bure Interferometer, S.Guilloteau, R.Lucas, and R.Neri, July 2002 (http://www.iram.fr/IRAMFR/PDB/bure/bure.html)

Table 2: Relative performance of CARMA and other millimeter wavelength arrays

Telescope	CARMA	CARMA+3.5	SMA	ALMA	ACA	IRAM PdB.
nants	6x10.4 + 9x6.1	+ 8x3.5	8x6.1	64x12	4x12 + 12x7	6x15
collecting area [m^2]	773	850	230	7238	914	1060
average diameter [m]	8.1	6.9	6.1	12	8.5	15
nants x diameter	122	158	49	768	136	90
number of baselines	105	253	28	2016	120	15
max baseline/antdiam	328	571	82	375	8	58
polarizations	1	1	2	2	2	2
continuum BW /pol [GHz]	4	4	2	8	8	4
spectral windows /pol	8	8	6x4	8	8	8
window bandwidths [MHz]	2–500	2–500	82	31–2000	31–2000	20–320
spectral channels/window	64	64	64–2048	2048	8192	64–512
total spectral channels/pol	512	512	3072x2	16384	65536	4096

Table 3: Assumed System Temperatures

Telescope	CARMA	SMA	ALMA & ACA	IRAM PdB.
altitude [km]	2.4	4.1	5.0	2.7
mmh2o	4	1	1	2
100 GHz	126	98	95	100
230 GHz	367	202	197	250
345 GHz	1110	298	284	350

Table 4: Continuum Sensitivity [mJy/sqrt(min)]

Telescope	CARMA	CARMA+3.5	SMA	ALMA	ACA	IRAM PdB.
100 GHz	1.4	1.3	5	0.08	0.6	0.9
230 GHz	4	3.6	11	0.16	1.3	2.8
345 GHz	14	12	18	0.26	2.0	6.2

Table 5: Spectral Line Sensitivity [K x 1 km/s / 1 arcsec / sqrt(min)]

Telescope	CARMA	CARMA+3.5	SMA	ALMA	ACA	IRAM PdB.
100 GHz	19	17	49	1.4	12	12
230 GHz	7	6	13	0.4	3	5
345 GHz	8	7	8	0.2	2	4

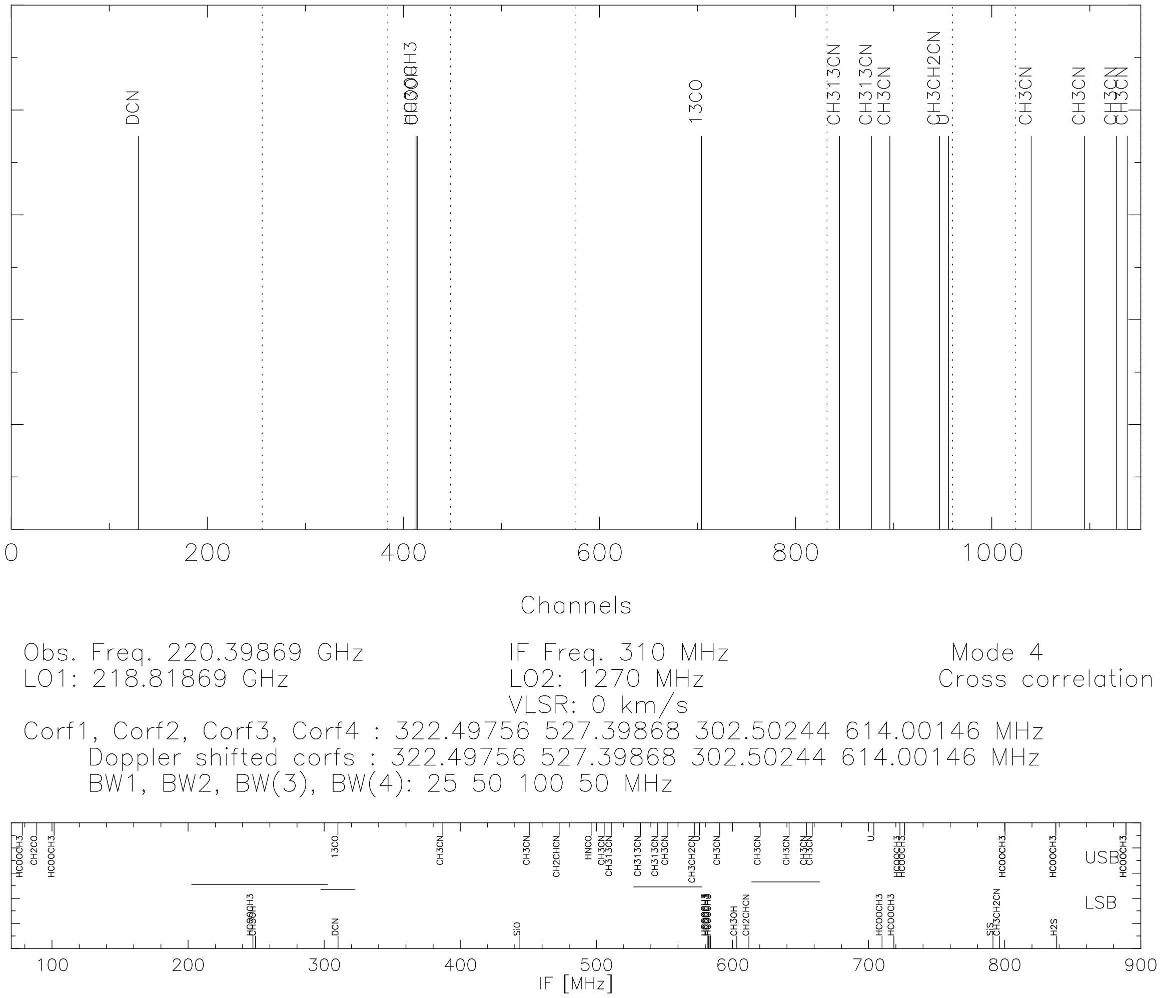

Fig. 1.— BIMA correlator in mode 4 showing spectral lines in 4 LSB and 4 USB spectral windows with bandwidths 25, 50, 100, 50 MHz.

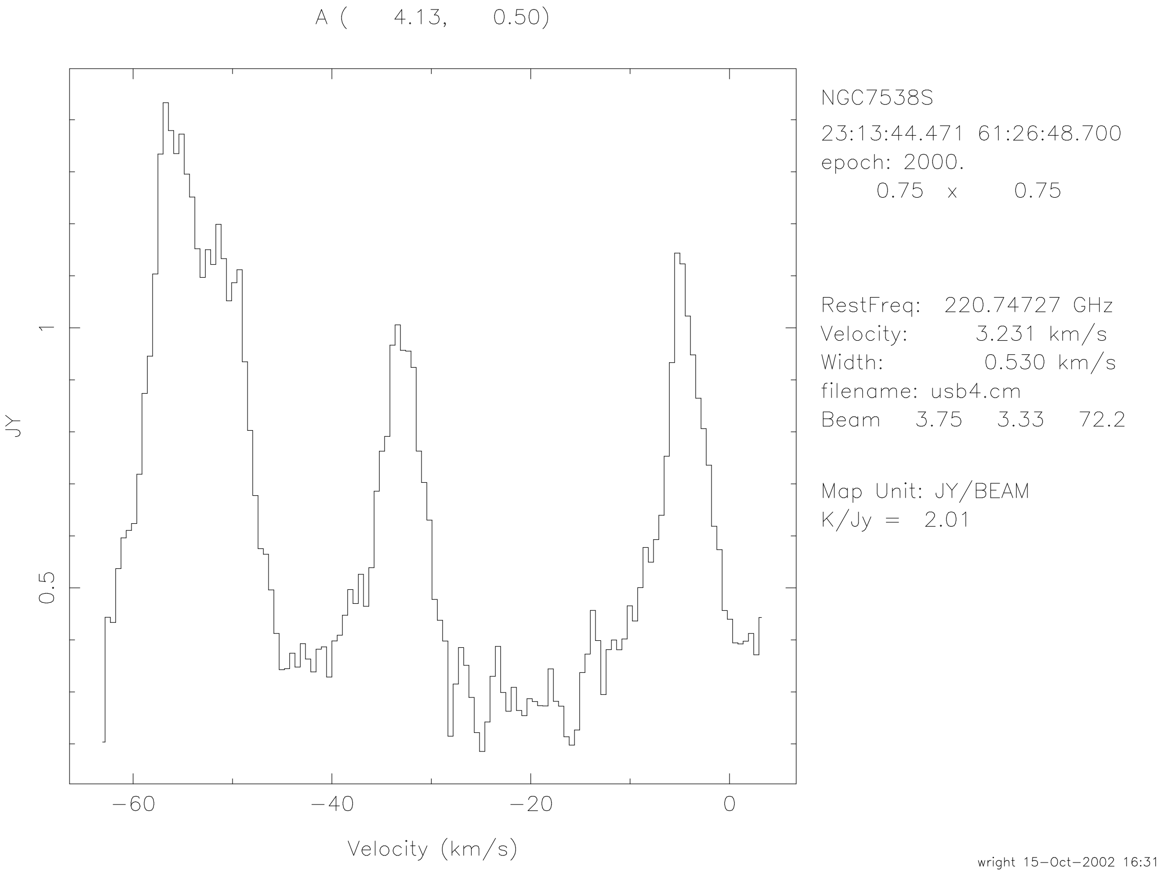

Fig. 2.— Spectra of CH_3CN emission in one spectral window