Combined Array for Research in Millimeter-wave Astronomy

Proposal Number

c0192

Observing Proposal Cover Sheet

General Proposal Information

Title	Date	TOO/Time Critical	Priority
The Continuation of the CARMA Survey Toward IR-bright Nearby Galaxies (CARMA STING)	2008-03-04	—	1

Scientific Category	Frequency Band	Level of Help Required
Extragalactic	3mm	None

Authors List

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Advisor must send a supporting letter if Thesis is checked. See Instructions.

Abstract

We propose to continue the CARMA STING extragalactic CO survey. This survey targets 27 FIR-bright galaxy disks selected to fully span the blue sequence of active star-forming galaxies found by the SDSS. The STING uniformly samples a large range of star-formation activities, stellar masses, specific star-formation rates (SSFR), and galaxy morphologies. Unlike previous interferometric surveys such as SONG, the STING is designed to image galaxies disks out to one-quarter to one-half of their optical radii, thus beginning to sample the transition between the molecule-dominated and the atomic-dominated galactic regions. Molecular observations of this regime are key to distinguish between the different mechanisms that may regulate star formation in galaxies. The STING will enable us to address the systematic study of star-formation in relation to the atomic gas, molecular gas, dust, and stellar components of galaxies in a manner that is not currently possible, with the ultimate goal of understanding the impact of the gas reservoirs on the evolution of galaxies. This project is designed to produce a dataset of lasting archival value, and its observations will deliver substantial improvements in sensitivity, coverage, fidelity, and range of properties spanned over existing surveys. The first observations are being obtained, and the corresponding maps (as well as supplementary proposal and sample information) are available at the project website: `http://www.astro.umd.edu/~bolatto/STING`.

Source Information

#	Source	RA	DEC	Freq	B	C	D	E	# Fields	Species	Imag/SNR	Flex.HA
1	NGC337	00:59	-07:34	115.27	0	8	16	0	19	CO 1-0	Imaging	—
2	NGC3198	10:19	45:32	115.27	0	8	16	0	19	CO 1-0	Imaging	—
3	NGC4254	12:18	14:24	115.27	0	8	16	0	19	CO 1-0	Imaging	—
4	NGC4273	12:19	05:20	115.27	0	8	16	0	19	CO 1-0	Imaging	—
5	NGC4536	12:34	02:11	115.27	0	8	16	0	19	CO 1-0	Imaging	—
6	NGC3949	11:53	47:51	115.27	0	8	16	0	19	CO 1-0	Imaging	—
7	NGC4654	12:47	13:07	115.27	0	8	16	0	19	CO 1-0	Imaging	—
8	NGC5713	14:40	-00:17	115.27	0	8	16	0	19	CO 1-0	Imaging	—
9	NGC4605	12:39	61:36	115.27	0	8	0	0	19	CO 1-0	Imaging	—

Total Hours: 200.0

Special Requirements

None

Status of Prior CARMA Observations

c0001 — Observations complete, reduced, and analysis starting
c0002 — Observations complete, preliminary reduction, SD data obtained
c0004 — Observations complete, reduced, no detection
c0104 — D-array scheduled, C-array pending, first observations obtained and reduced
c0113 — Not yet scheduled

Introduction. The missing datum to put together a complete picture of galaxy evolution is the behavior of the gas reservoir. Characterizing the mechanisms by which atomic gas turns into molecular gas and ultimately into stars on galactic scales is a crucial step to understand the shaping of galaxies. The CARMA STING brings together a team from *eight institutions* with the goal of efficiently and systematically imaging CO in galaxies, and does so in a manner designed to maximize the impact and legacy value of the observations.

The need for a new survey. Most of the existing surveys of extragalactic molecular gas used single-dish telescopes with the consequent handicap in angular resolution (e.g., Young et al. 1995 with FCRAO; Kuno et al. 2007 with NRO). Only a few sizable CO surveys have used interferometers: NUGA with PdBI (28 galaxies; García-Burillo et al. 2003), BIMA SONG (44; Helfer et al. 2003), OVRO MAIN (15; Baker et al. 2003), and NMA/OVRO (20; Sakamoto et al. 1999). With the exception of SONG, which targeted optically luminous sources, the goal of these surveys was the study of the central regions of galaxies.

By contrast, the CARMA STING is the first CO survey specifically designed to sample the blue galactic sequence in the local universe and gain understanding of the evolution of gas in galaxy disks. SDSS made apparent that there is a very well-defined sequence relating stellar mass to star-formation activity, so that SFR is primarily dependent on stellar mass (Kauffmann et al. 2003, 2004). In the SFR vs. M_* plane galaxies separate into two well defined branches: the red branch of "dead" galaxies prevalent in high density environments, and the blue branch of "star-forming" galaxies, spanning a range of masses and star-formation activities.

It has become increasingly clear that the Schmidt Law as proposed by Kennicutt (1998) is intimately tied to the formation of bound molecular clouds. Pushing the analysis further, however, has been hindered by the scarcity of high-resolution CO data and by the fact that *the available interferometric observations do not go out far enough in the disk.* Leroy et al. (2008, submitted) find that the radial profiles of the star formation per unit gas (SFE) and the ratio of molecular to atomic gas both have an exponential decay with a typical scale length of $0.25\,R_{25}$. They also find that the power to discriminate between the different alternatives proposed for the molecular cloud formation process (e.g., global instabilities, galactic shear, formation of a cold phase, etc) hinges critically on the availability of molecular data at or beyond this radius. The STING is specifically designed to provide the data necessary to discriminate among models, by spanning the entire SFR range probed by Kennicutt (1998), and by imaging galaxies out to $0.25\,R_{25}$ and beyond. *These characteristics are unique to the STING* (c.f., Fig. 1c, 1e, 1f).

Science with the STING. We will use the STING observations to analyze the relation between gas and star formation through a significant span of galaxy masses. A major goal of this survey is to help link star formation and the ISM to our understanding of galaxy evolution by answering "What sets the rate of star formation in galaxies?" The resolution of CARMA will allow us to probe conditions on sub-kpc scales. The ancillary data will yield maps of star formation rate, stellar, dust, and gas mass. With rotation curves derived from the CO and HI, and molecular gas surface densities from FIR and CO, we will model the predicted SFR and compare it to observations. In a nutshell, the first science that we will pursue with the proposed observations includes:

• Model the SFR predicted by theories of galactic-scale star formation and compare it to the observations • Address the relation between SF activity and molecular and atomic gas • Study the SF efficiency in a variety of environments • Quantify the distribution of H_2 in relation to the stellar and atomic components • Perform accurate mass modeling of galaxies • Test feedback theories • Study the transport of gas in galaxy disks • Clarify how the FIR/radio correlation differs between "normal" and "starburst" galaxies • Study the heating and cooling equilibrium of gas in disks in combination with Spitzer, Herschel, and JCMT data • Model the FIR dust continuum in relation to the molecular gas distribution in combination with Spitzer, Herschel, and submm imaging.

Where the variety of topics reflects the breadth of interests represented among the proposers, and the succinctness reflects the lack of space to develop them. The CARMA STING will provide a key data set of lasting archival value to quantitatively explore the relation between the gas reservoirs and the star formation in galaxies, with the ultimate goal of understanding and characterizing the major processes that determine galaxy evolution.

Sample definition. In order to study this problem, we have designed a sample that reflects the current understanding of galaxy evolution, is well supported by ancillary data, and is matched to the capabilities of CARMA. Our selection criteria include the availability of midIR and FIR photometry, HI data, and SDSS observations. The sample is composed of northern ($\delta > -20°$), moderately inclined ($i < 75$ deg) galaxies from the IRAS Revised Bright Galaxy Sample (RBGS) within 45 Mpc (Sanders et al. 2003). The galaxies were selected to uniformly sample 10 mass bins distributed between $M_* = 10^9$ and 3×10^{11} $M_\odot$. Within each bin the galaxies were ranked according to criteria designed to emphasize coverage and ancillary observations. Because of the heterogeneous nature of CO distributions in galaxies (c.f., Regan et al. 2001), fewer than 10 mass bins and 3 galaxies per bin would result in too coarse a sampling of galaxy properties. The resulting sample uniformly spans a range of key properties (Fig. 1).

Comparison with existing surveys. The STING is geared toward the study of molecular disks, and is thus most directly comparable to BIMA SONG. The STING will have substantially **better angular resolution** (~ 3") than SONG ($\sim 6-7''$) and **better spatial resolution** (Fig. 1b), much **better sensitivity** (~ 18 mJy vs. ~ 60 mJy in 10 km s^{-1} in SONG), much **better image fidelity and calibration** owing to CARMA's 105 baselines (vs. 45 baselines in SONG), and **far superior galaxy coverage** ($\sim 30\%$ of the optical disk defined by D_{25}, compared to $\sim 6\%$ in SONG; Fig. 1c). Figure 1 graphically describes the sample and compares it to SONG. We envision these surveys as complementary, thus *we have purposefully avoided overlap with SONG*. Nonetheless, the CARMA STING will surpass BIMA SONG by *every metric* except sheer number of galaxies, and even there the SONG sample is only 60% larger than the STING sample.

Partnership. This project is a collaboration between eight different institutions, and its timely and successful completion necessitates of a time contribution from the external observer pool. Five of the eleven participants in this proposal are external to the CARMA consortium, and they all bring something unique and crucial to the table in the way of expertise and access to datasets and telescopes (the tasks and contributions by each one of the members can be seen in the project website). Neither the internal nor the external proposers can pursue the project on their own: *this proposal will make a key dataset available to the entire community, that would be otherwise impossible to obtain*. We request a 30% external contribution, commensurate with the CARMA external time share and with the percentage of external members in this project. Accordingly, we request the time to be divided in the following proportions:
UMD—17.5%, UIUC—17.5%, UCB—20%,CIT—15%, External—30%.

Technical and Management Plan. Last semester we were allocated ~ 140 hrs. of internal time, which allows us to pursue $5-6$ galaxies. This semester we will target 8 galaxies for 24 hrs. each in two configurations (16D+8C) that maximize surface brightness sensitivity. Galaxies will be mosaiced on a 19-point pattern optimally matched to their size, with expected sensitivity of ~ 18 mJy in 10 km s^{-1} channels. The correlator will be configured using 62 MHz windows, with a native resolution of 2.5 km s^{-1}. Archival-quality images will be released after science validation, as in SONG. Further details can be found at the project website — `http://www.astro.umd.edu/~bolatto/STING`.

• Baker, A. J., et al. 2003, ASPCS 290, 479 • García-Burillo, S., et al. 2003, A&A, 407, 485 • Helfer, T. T., et al. 2003, ApJS, 145, 259 • Ho, L. C., et al. 1997, ApJS, 112, 315 • Kauffmann, G., et al. 2003, MNRAS, 341, 54 • Kauffmann, G., et al. 2004, MNRAS, 353, 713 • Kennicutt, R. C., Jr. 1998, ApJ, 498, 541 • Kuno, N., et al. 2007, PASJ, 59, 117 • Sakamoto, K., et al. 1999, ApJS, 124, 403 • Young, J. S., et al. 1995, ApJS, 98, 219

Table 1

Name	Morph	RA (h)	Dec (deg)	Dist (Mpc)	Incl (deg)	D_{25} (")	M_* ($M_\odot$)	SFR ($M_\odot$ yr^{-1})	Sl	Sp	He	VLA	Class	Tracks
NGC 1156	IB	3.00	25.2	7.0	43.1	173	8.9	-0.9	N	Y		DCB	H	2D
NGC 1569	IB	4.51	64.9	4.6	64.7	238	9.2	-0.4	N	Y	G	DCB	H	2D
NGC 1637	Sc	4.69	-2.9	10.2	31.1	191	9.8	-0.5	N	Y		DC		2D
NGC 3147	Sbc	10.28	73.4	41.4	29.5	243	11.3	1.0	N	Y		DC	S2	2D
NGC 4151	SABa	12.18	39.4	19.0	21.0	173	10.6	-0.1	Y	Y	G	CB	S1.5	2D
NGC 6951	SABb	20.62	66.1	24.0	52.5	193	10.9	0.7	N	Y		DCB	S2	2D
NGC 0337	SBcd	1.00	-7.6	21.6	50.6	175	10.0	0.3	N	YY	K	DC		
NGC 3198	Sc	10.33	45.5	13.8	70.0	388	10.2	-0.1	Y	YY	K	DCB	H	
NGC 3949	Sbc	11.90	47.9	13.6	56.5	136	9.8	-0.0	Y	Y		B	H	
NGC 4254	Sc	12.31	14.4	15.3	32.0	302	10.6	0.7	Y	YY	G	DCB	H	
NGC 4273	Sc	12.33	5.3	15.3	48.5	131	9.7	0.0	Y	Y		CB	H	
NGC 4536	SABb	12.57	2.2	14.9	58.9	425	10.4	0.4	Y	YY	G	DCB	H	
NGC 4654	SABcd	12.73	2.2	15.1	56	283	10.3	0.2	Y	Y		DC	H	
NGC 5713	SABb	14.67	-0.3	26.7	48.2	148	10.5	0.8	Y	YY	K	DCB		
NGC 0772	Sb	1.99	19.0	28.7	48.5	274	11.1	0.6	N	Y		DC	H:T2	
NGC 2681	S0-a	8.89	51.3	12.5	15.9	235	10.2	-0.4	Y	Y		B	L1.9	
NGC 2782	SABa	9.23	40.1	39.5	45.1	195	10.7	0.7	Y	Y		DCB	H	
NGC 3486	Sc	11.01	29.0	9.2	46.0	349	9.7	-0.5	Y	Y		DB	S2	
NGC 3593	S0-a	11.24	12.8	5.0	74.6	281	9.5	-0.7	Y	Y		DCB	H	
NGC 4214	I	12.26	36.3	3.7	43.7	408	9.0	-1.0	Y	Y	G	DCB	H	
NGC 4501	Sb	12.53	14.4	15.3	61.0	519	10.9	0.5	Y	Y	G	C	S2	
NGC 4568/7	Sbc	12.61	11.2	15.3	66.0	258	10.4	0.4	Y	Y	G	DCB	H	
NGC 4605	SBc	12.67	61.6	3.9	70.4	354	9.1	-1.0	Y	Y		DCB		
NGC 4808	Sc	12.93	4.3	19.7	69.2	142	10.0	0.1	Y	Y	G	DCB		
NGC 5371	Sbc	13.93	40.5	41.1	54.0	239	11.2	0.8	Y	Y		DB	L2	
NGC 5728	Sa	14.71	-17.3	38.3	59.0	192	10.9	0.7	N	Y		C		
NGC 6503	Sc	17.82	70.1	3.8	73.7	371	9.2	-1.1	N	Y		DCB	T2/S2	

Table of the sample detailing galaxy name, morphology, J2000 coordinates, inclination, major axis extent (D_{25}), log of the stellar mass based on K-band magnitude (M_*), log of the star formation rate based on FIR luminosity (SFR), existing SDSS photometry (Sl), existing Spitzer IRAC *and* MIPS photometry (Sp; YY indicates is part of the SINGS project with a wealth of other ancillary observations), Herschel observations (He, G denotes guarantee time observation, K denotes in KINGFISH sample), configurations for archival VLA HI observations, Ho et al. (1997) nuclear classification (Class; H denotes HII galaxy, T for Transition type, L for Liner, S for Seyfert), and planned D-array tracks for the ongoing semester 1 observations. The Table is separated in 3 sections: pending, proposed, and future.

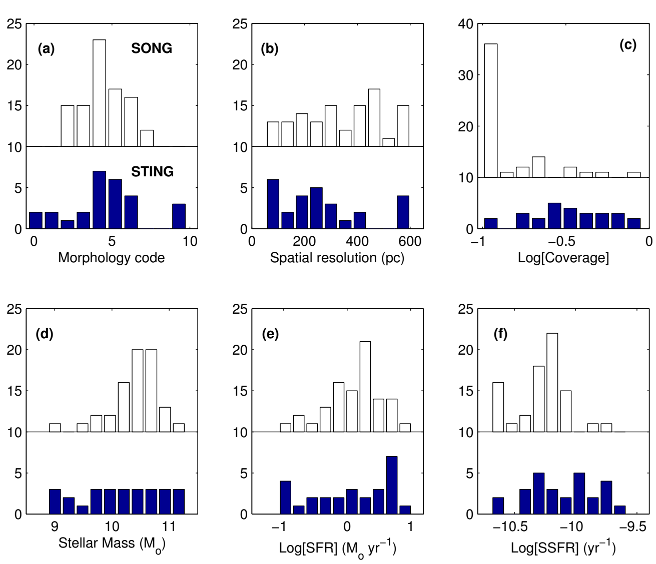

Figure 1: Histograms contrasting the distribution of several parameters for the STING and SONG samples. The panels indicate the distributions of: a) morphological types from LEDA. b) Spatial resolution on source. c) Log of the fraction of the source area (measured by D_{25}) covered. d) Stellar mass, M_*, as measured by K-band light. e) Log of SFR. f) Log of specific SFR, or the inverse time to form M_* at current SFR. The CARMA STING is designed to uniformly sample the stellar mass range of 10^9 to 3×10^{11} $M_\odot$, probing a wider range of SFRs, SSFRs, FIR luminosities, and morphologies than SONG. The STING is also designed to cover a larger fraction of galaxy disks than SONG (median of 30% versus 6%), with no loss of spatial resolution and a factor of three better sensitivity ($\sim$ 18 vs. $\sim$ 60 mJy beam^{-1}.