Combined Array for Research in Millimeter-wave Astronomy

Proposal Number

c0297

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)	2008-09-09	—	2

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 local galaxies characterized by the SDSS. STING uniformly samples a large range of star-formation activities, stellar masses, specific star-formation rates, and galaxy morphologies. Unlike previous interferometric surveys such as SONG, 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. STING is designed to enable 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. A key measurement that will come out of these observations is the spatially-resolved slope γ of the relation between H_2 and star formation rate. This project will produce a dataset of lasting archival value useful for the general community, and its observations deliver substantial improvements in sensitivity, coverage, fidelity, and range of properties spanned over existing surveys. The first observations were obtained in March, and the corresponding images (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	C	D	E	# Fields	Species	Imag/SNR	Flex.HA
1	NGC3147	10:17	73:24	115.27	0	8	6	19	CO 1-0	Imaging	—
2	NGC4254	12:19	14:24	115.27	8	0	6	19	CO 1-0	Imaging	—
3	NGC337	00:59	-07:34	115.27	8	0	0	19	CO 1-0	Imaging	—
4	NGC4536	12:34	02:11	115.27	8	0	0	19	CO 1-0	Imaging	—
5	NGC3198	10:19	45:32	115.27	8	16	0	19	CO 1-0	Imaging	—
6	NGC5713	14:40	-00:17	115.27	8	16	0	19	CO 1-0	Imaging	—
7	NGC772	01:59	19:00	115.27	8	16	0	19	CO 1-0	Imaging	—
8	NGC5371	13:55	40:27	115.27	8	16	0	19	CO 1-0	Imaging	—
9	NGC4501	12:31	14:25	115.27	8	16	0	19	CO 1-0	Imaging	—
10	NGC4654	12:43	13:07	115.27	8	16	0	19	CO 1-0	Imaging	—
11	NGC4568	12:36	11:14	115.27	8	16	0	19	CO 1-0	Imaging	—
Total Hours: 212.0											

Special Requirements

None

Status of Prior CARMA Observations

c0001 — Observations complete, reduced, and analysis underway
c0002 — Observations complete and fully reduced, SD data obtained, combination starting
c0004 — Observations complete, reduced, no detection
c0104 — Observations obtained and reduced, analysis underway
c0192 — Observations obtained and reduced, analysis underway

Introduction. A basic strength of CARMA is its capability to image the molecular gas distribution in other galaxies with a combination of good sensitivity, resolution, fidelity, and coverage. This project is an attempt by collaborators from *eight institutions* (five of them external) to seize this capability and use it to study the relation between gas and star formation (SF) in an efficient and systematic manner, maximizing science yield and creating a public data set of lasting value.

CARMA STING started observations in March 2008. Figure 1 shows the first integrated intensity images obtained (~ 180 hrs. of observations). Below we discuss the ongoing analysis, as well as the plans for zero-spacing and other ancillary observations. The CARMA STING dataset will be available to the community through our website: `http://www.astro.umd.edu/~bolatto/STING/`.

Goals of the survey. By contrast with existing interferometric CO surveys, CARMA STING is designed to uniformly sample the blue sequence of active star-forming galaxies in the local universe (Kauffmann et al. 2003, 2004). Our ultimate goal is to characterize the role of gas in the evolution of galaxy disks and the formation of the blue sequence. A key measurement that will come out of these observations is the spatially-resolved slope γ of the relation between H_2 and star formation rate, $\Sigma_{SFR} = (\Sigma_{H2})^{\gamma}$. STING will yield the data necessary to characterize the relations between HI, H_2, CO, and SFR throughout a significant range of galaxy masses and SF activities.

It has become increasingly clear that the Schmidt Law as proposed by Kennicutt (1998) faces a number of challenges both locally (e.g., Wong & Blitz 2002), and in the cosmological context (e.g., Wolfe & Chen 2006). Leroy et al. (2008) recently explored several physically motivated prescriptions for tying gas to star formation in the THINGS survey, finding that while some models can be falsified with the existing data others are degenerate. The power to discriminate between models hinges on the availability of molecular data at or beyond the galactocentric radius where galaxy disks cease to be molecule-dominated (typically $\sim 0.25\,R_{25}$, where R_{25} is the radius of the $25^{\rm th}$ magnitude isophote). STING is designed to produce the data to discriminate among models, by spanning star formation rate (SFR) and specific SFR (SSFR, defined as SFR/M_*) ranges larger than previously probed, and by imaging CO in galaxies out to $0.25\,R_{25}$ and beyond.

Science with STING. The missing datum to put together a complete picture of galaxy evolution is the behavior of the gas reservoir. Figure 2a shows a preliminary study of the relation between the surface densities of SFR and molecular gas in NGC4254. The SFR is derived from the combination of *Spitzer* 24 μm and GALEX NUV to trace both extincted and unextincted star formation, following Boissier et al. (2007) and Leroy et al. (2008). This highlights one of the strengths of the sample: all galaxies have a variety of archival observations available. The analysis is carried out on 450 pc scales, limited by the $6''$ resolution of *Spitzer*. We find, in this first determination, a slope that is considerably shallower than the traditional Kennicutt-Schmidt law with $\gamma = 1.4$. A similar analysis for NGC3147 shows an even shallower slope and a lower normalization. We request short E array tracks for these objects to test whether spatial filtering may be a problem. We will obtain ancillary single-dish observations for NGC4254 in the next months using HERA at IRAM as part of an ongoing survey by MPIA-Heidelberg that we expect to use to provide zero-spacing information (HERA observes the $2-1$ transition, so we will have to make assumptions about line ratios). We intend to complement these data with CO $3-2$ observations led by E. Rosolowsky at the JCMT.

Figure 2b shows our preliminary results on the profiles of different tracers in another STING galaxy, NGC4536. We show here with arbitrary scalings the radial distribution of CO intensity, HI emission, SFR from *Spitzer* 24 μm using the prescription by Calzetti et al. (2007), 3.6 μm light (i.e., stellar surface density), and 8.0 μm light (PAH emission). The dashed line indicates the ratio of CO to SFR (i.e., the molecular star formation efficiency). This is essentially constant in the inner $30''$ of this object, pointing to $\gamma = 1$.

We are only beginning to tap these rich datasets on the matter of the relation between SF and H_2, but this is only one of the objectives of the survey. STING makes possible a range of science projects: 1) SFR and environment, 2) relation between H_2 and stellar and atomic components through the blue sequence, 3) accurate mass modeling of galaxies, 4) tests of SF feedback theories, 5) high resolution analysis of the CO/FIR/RC correlations, 6) heating and cooling of the gas in combination with FIR and submm data, 7) relation between CO and extinction features, and 8) comparison of H_2 masses obtained from CO and FIR modeling. The CARMA STING will provide a data set of 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 these problems 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 (see website). 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 heterogeneity of CO in galaxies (see Regan et al. 2001), we estimate that 10 mass bins and 3 galaxies per bin are needed for a fair sampling of galaxy properties. The resulting sample uniformly spans a large range of key properties, such as specific star formation rate.

Comparison with existing surveys. STING is geared toward the study of molecular disks, and is thus most directly compared to BIMA SONG. CARMA STING surpasses BIMA SONG by *every metric* except sheer number of galaxies, and even there the SONG sample is only 60% larger than the STING sample. STING has substantially **better angular resolution** (~ 3") than SONG ($\sim 6-7''$) and **better spatial resolution**, much **better sensitivity** ($\sim$ 25 mJy vs. $\sim$ 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). The SONG sample is unfortunately biased toward the inner regions of massive galaxies with low SSFR, thus by itself it is not useful for addressing many of the main goals of this proposal.

Partnership and community outreach. STING is a collaboration between eight different institutions, and its timely and successful completion requires a time contribution from the external observer pool. Six of the twelve 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 telescopes (see website). Neither the internal nor the external proposers can pursue a project of this scope on their own. *STING will make a key dataset available to the entire community, that would be otherwise impossible to obtain.* Moreover, this project has made an effort to reach out, by creating a web page to advertise the survey and by developing a data-reduction pipeline (due to Tony Wong at UIUC) that is general and available to the entire community of CARMA users.

STING was envisioned as taking 200-hour per semester for 3 semesters, possible only when awarded combined institutional and external time contributions. So far the observations have received no external time contribution. We request a 30% external contribution, commensurate with the CARMA external time share and smaller than the percentage of external members in this project. Accordingly, we request the time to be divided in the following proportions:
UMD—22.5%, UIUC—22.5%, UCB—25%, External—30%.

Technical Plan. This semester we aim to complete observations for 4 galaxies, and target 7 new galaxies for 24 hrs. each in two configurations (16D+8C) that maximize the combination of resolution and surface brightness sensitivity. Galaxies are mosaiced on a 19-point pattern optimally matched to their size, with expected sensitivity of $\sim$ 18 mJy in 10 km s^{-1} channels (so far a more typical sensitivity is $22 - 25$ mJy). The correlator is configured using 62 MHz windows with a resolution of 2.5 km s^{-1}, placing ^{13}CO in the LSB. Archival-quality images will be released after science validation, as in SONG. Further details can be found at the project website.

• Boissier, S., et al. 2007, ApJSS, 173, 524 • Calzetti, D., et al. 2007, ApJ, 666, 870 • Kauffmann, G., et al. 2003, MNRAS, 341, 54 • Kauffmann, G., et al. 2004, MNRAS, 353, 713 • Kennicutt, R. C., Jr. 1998, ApJ, 498, 541 • Leroy, A., et al. 2008, ApJ, in press • Regan, M., et al. 2001, ApJ, 561, 218 • Sanders, D., et al. 2003, AJ, 126, 1607 • Wolfe, A. M., & Chen, H.-W. 2006, ApJ, 652, 981 • Wong, T., & Blitz, L. 2002, ApJ, 569, 157

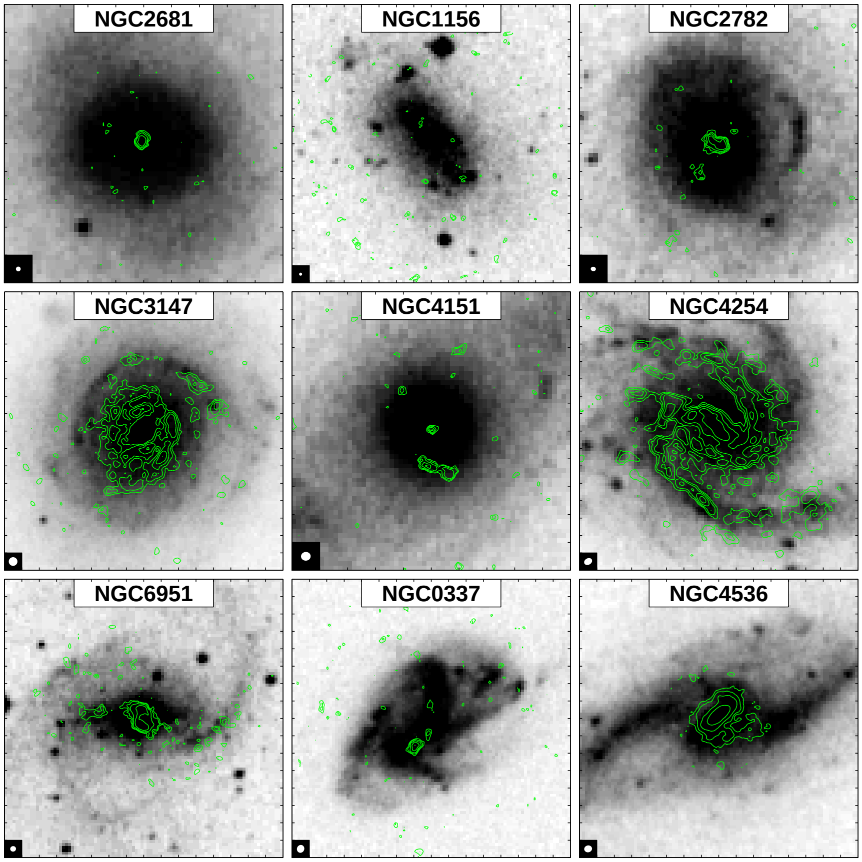

Fig. 1.— Integrated intensity CO contours overlaid on the DSS images of the galaxies for which we have a good degree of completion. Contours are logarithmically spaced, starting at 3σ to the maximum intensity value in each case. NGC 1156 was not detected down to 0.8 Jy km s^{-1}. All targets were imaged in a 19-pointing mosaic pattern that produces a HPFOV of 120 arcsec. Tick-marks are every $10''$. These targets were chosen among the proposed sample to accommodate the bandwidth limitations of the existing CARMA correlator, as well as the schedule constraints.

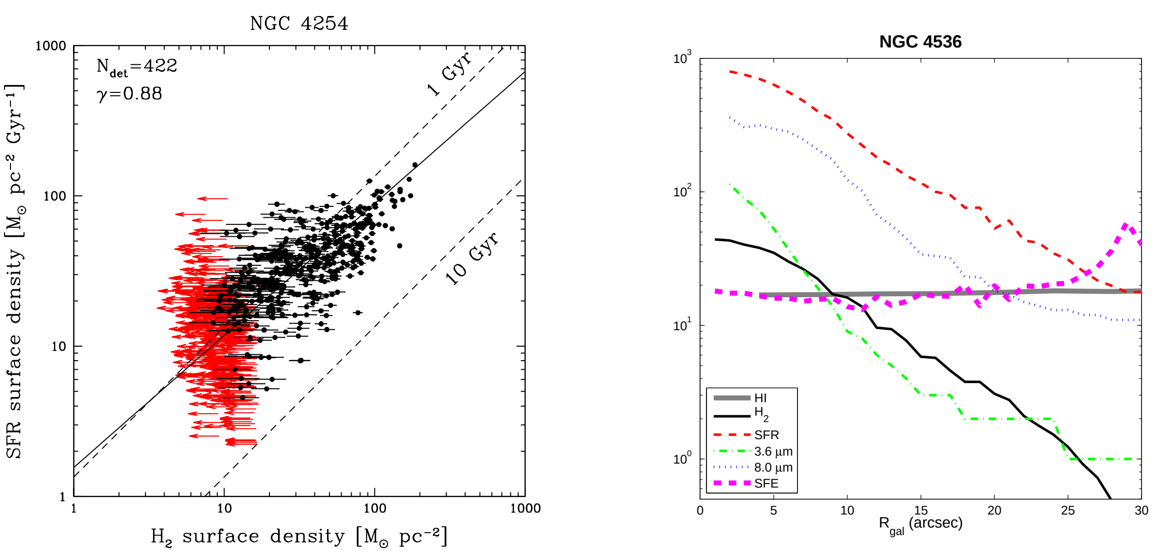

Fig. 2.— *(Left, a)* The spatially-resolved star formation law in NGC4254. The dashed lines indicate gas consumption times of 1 and 10 Gyr. The solid line indicates the fit to the data, with a power-law slope $\gamma \approx 0.88$. The number of significant points is 422 using Nyquist sampling. *(Right, b)* Radial profiles of atomic and molecular gas, SFR, stellar light, and PAHs in NGC 4536. The dashed line indicates the resulting purely molecular SFE. The constancy of the molecular SFE indicates $\gamma = 1$ in the inner regions of this galaxy.