Combined Array for Research in Millimeter-wave Astronomy

Proposal Number

c0395

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)	2009-03-17	—	1

Scientific Category	1cm Project	3mm Project	1mm Project	Level of Help Required
Extragalactic	—	X	—	None

Authors List

#	Name	E-mail	Phone	Institution	Thesis	Grad
PI	Alberto Bolatto	bolatto@astro.umd.edu	301 405 1521	UMD	—	—
2	Tony Wong	wongt@astro.uiuc.edu	NA	UIUC	—	—
3	Leo Blitz	blitz@astro.berkeley.edu	NA	UC Berkeley	—	—
4	Juergen Ott	jott@astro.caltech.edu	NA	NRAO	—	—
5	Daniela Calzetti	calzetti@astro.umass.edu	NA	UMASS	—	—
6	Fabian Walter	walter@mpia-hd.mpg.de	NA	MPIA-Heidelberg	—	—
7	Erik Rosolowsky	erik.rosolowsky@ubc.ca	NA	University of British Columbia	—	—
8	Andrew West	aaw@mit.edu	NA	MIT	—	—
9	Stuart Vogel	svogel@umd.edu	NA	UMD	—	—
10	Adam Leroy	leroy@mpia-hd.mpg.de	NA	MPIA-Heidelberg	—	—
11	Frank Bigiel	bigiel@astro.berkeley.edu	NA	UC Berkeley	—	—
12	Rui Xue	ruixue1@astro.uiuc.edu	NA	UIUC	—	X
13	Nurur Rahman	nurur@astro.umd.edu	NA	UMD	—	—

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 of the relation between H2 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 2008 and the first publication is underway. The corresponding images (as well as supplementary proposal and sample information) are available at the project website: `http://www.astro.umd.edu/STING`

Source Information

#	Source	RA	DEC	Freq	C	D	E	SH	# Fields	Species	Imag/SNR	Flex.HA
1	NGC4536	12:34	02:11	115.27	0	16	0	0	19	CO 1-0	Imaging	—
2	NGC3593	11:14	12:49	115.27	8	16	0	0	19	CO 1-0	Imaging	—
3	NGC1569	04:30	64:50	115.27	0	16	0	0	19	CO 1-0	Imaging	—
4	NGC5371	13:55	40:27	115.27	0	16	0	0	19	CO 1-0	Imaging	—
5	NGC3949	11:53	47:51	115.27	8	16	0	0	19	CO 1-0	Imaging	—
6	NGC1637	04:41	-02:51	115.27	8	16	0	0	19	CO 1-0	Imaging	—
7	NGC4273	12:19	05:20	115.27	8	16	0	0	19	CO 1-0	Imaging	—
8	NGC3486	11:00	28:58	115.27	8	16	0	0	19	CO 1-0	Imaging	—
9	NGC4536	12:34	02:11	115.27	0	0	6	0	19	CO 1-0	Imaging	—
10	NGC6951	20:37	66:06	115.27	0	0	6	0	19	CO 1-0	Imaging	—
11	NGC3147	10:16	73:24	115.27	0	0	6	0	19	CO 1-0	Imaging	—
12	NGC772	01:59	19:00	115.27	0	8	6	0	19	CO 1-0	Imaging	—
13	NGC2976	09:47	67:54	115.27	8	0	0	0	19	CO 1-0	Imaging	—
Total Hours: 208.0												

Special Requirements

None

Status of Prior CARMA Observations

c0001 — Observations complete, reduced, and analysis partially completed.
c0002 — Observations complete, reduced, SD data obtained.
c0004 — Observations complete, reduced. No detection.
c0104 — First STING proposal. Observations obtained and reduced. First publication forthcoming.
c0192 — Second STING proposal. Observations obtained and reduced.
c0297 — Third STING proposal. Observations underway and reduced as obtained.
c0292 — One track scheduled.

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 (~ 200 hrs. total of observations; NGC772 was just observed). 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/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 gas and star formation in the THINGS survey, finding that many models are degenerate for the existing CO data. The power to discriminate between models hinges on the availability of molecular data at or beyond the radius where galaxy disks cease to be molecule-dominated (typically $\sim 0.25\,R_{25} - 0.5\,R_{25}$, 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 (dotted ellipses in Fig. 1).

Science with STING. The missing datum to put together a complete picture of galaxy evolution is the behavior of the gas reservoir. Figure 2 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 Hα to trace both extincted and unextincted star formation, following Calzetti et al. (2007). This highlights one of the strengths of the sample: all galaxies have a variety of archival observations available. We find $\gamma \approx 1.0$ inside $0.25R_{25}$, steepening to $\gamma \approx 1.3$ outside. This inner slope is considerably shallower than the Kennicutt-Schmidt law ($\gamma = 1.4$; Kennicutt 1998, Kennicutt et al. 2007). We have obtained single-dish CO $2-1$ observations using HERA at the IRAM 30m as part of HERACLES (Leroy et al. 2009), an ongoing survey by MPIA-Heidelberg. Our tests show that we can use the HERA data to provide zero-spacing information. HERACLES will observe a further 5 STING galaxies. We have proposed to IRAM to image another 6 of our galaxies, and sample the $2-1/1-0$ ratio to remove excitation uncertainties (PI Nurur Rahman). We have proposed to complement these data with HARP-B CO $3-2$ observations at the JCMT (PI E. Rosolowsky), to study the excitation conditions in the molecular gas.

We have performed preliminary star formation law studies in two other STING galaxies, NGC4536 and NGC3147 (see figures in past proposals at website). We have also found $\gamma \leq 1$ in these objects.

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) tests of SF thresholds, 4) accurate mass modeling of galaxies, 5) tests of SF feedback theories, 6) high resolution analysis of the CO/FIR/RC correlations, 7) heating and cooling of the gas in combination with FIR and submm data, 8) relation between CO and extinction features, and 9) 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. STING has substantially **better angular resolution** (~ 3") than SONG ($\sim 6 - 7''$) and **better spatial resolution**, much **better sensitivity** (~ 25 mJy vs. ~ 60 mJy in 10 km s^{-1} in SONG), much **better image fidelity and calibration** owing to CARMA's 105 baselines, and **far superior galaxy coverage** ($\sim 30\%$ of the optical disk defined by R_{25}, compared to $\sim 6\%$ in SONG). Furthermore, SONG is 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. Why not just reobserve SONG galaxies? 1) SONG was an "ad hoc" sample, while STING tries to approach the question of gas and SF systematically. 2) SONG galaxies have large angular sizes, thus imaging them out to large radii represents a very big time commitment.

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. 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. Archival-quality images for STING will be released through the website after science validation, as in SONG.

We will attain a good level of coverage of the blue-sequence after the observations proposed here are performed, making the sample very exciting scientifically (we have already been contacted for follow up with VIRUS-P). STING was envisioned as taking 200-hour per semester for 3 semesters, possible only when awarded combined institutional and external time contributions. So far we have only received a grand total of 8 (w/makeup)+16 (wo/makeup) hours from the visitor time pool. This makes it impossible to sustain our level of effort. We would appreciate it if the panel expresses to the directors committee that, based on its community impact and the visitor participation, it warrants support from the visitor time pool at the requested level.

We request a 30% external contribution, commensurate with the CARMA external time share and the share 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%, Visitor—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 ~ 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. Further details can be found at the project website.

• 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., 1998, ApJ, 498, 541 • Kennicutt, R. C., et al. 2007, ApJ, 671, 333 • Leroy, A., et al. 2008, AJ, 136, 2782 • Leroy, A., et al. 2009, 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

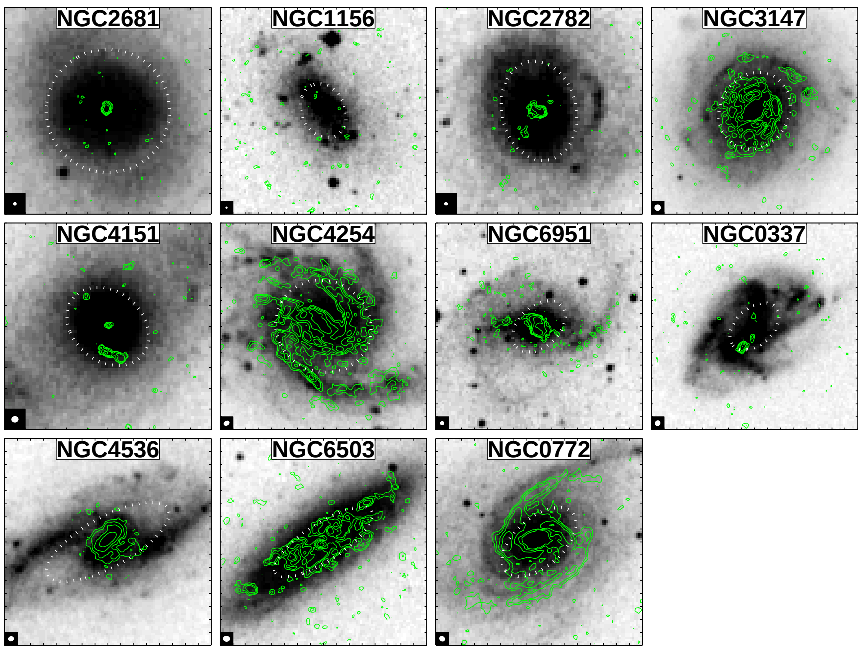

Fig. 1.— Integrated intensity CO contours overlaid on the DSS images of the galaxies for which we have a good degree of completion. Contours are logarithmically spaced, starting at 3σ to the maximum intensity value in each case. NGC 1156 was not detected down to 0.8 Jy km s^{-1}. All targets were imaged in a 19-pointing mosaic pattern that produces a HPFOV of 120 arcsec. Tickmarcks are every 10″. The white dotted line indicates the area corresponding to $0.25 R_{25}$.

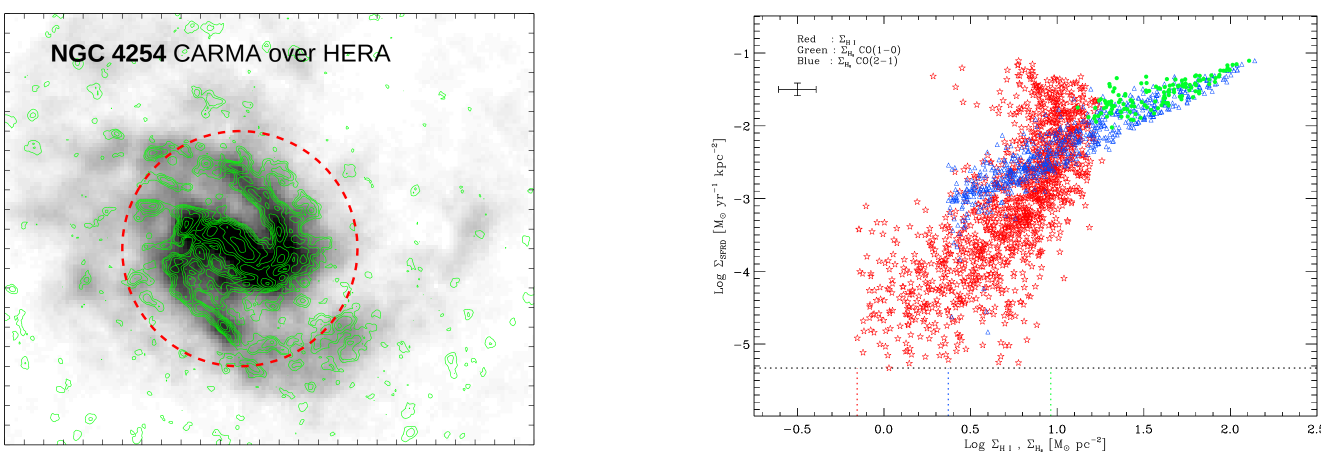

Fig. 2.— *(Left, a)* CARMA mosaic of NGC4254 overlaid on HERA CO $2-1$ SD OTF map. The HERA data have a resolution of 12.5″. The agreement is excellent, and we have been able to produce a zero-spacing flux corrected image. Under the assumption of thermalized emission, CARMA recovers 100% of the flux in the inner quarter of the mosaic, decreasing to $\sim 70\%$ at the edges (dashed line). Six of our galaxies are included in the approved project HERACLES (PI. Adam Leroy) and will have similar SD observations. We have proposed HERA observations for other 6 galaxies (PI. Nurur Rahman). *(Right, b)* The resolved star formation law in NGC 4254 at 14″ resolution (1 kpc). The green circles indicate CARMA data, the blue triangles HERA data, and the red stars VLA HI data. The vertical lines illustrate the sensitivity of each dataset. We have used a combination of Hα and 24 μm imaging to obtain the SFR, possible because of the wealth of existing ancillary observations for STING galaxies.