Combined Array for Research in Millimeter-wave Astronomy

Proposal Number

c0494

Observing Proposal Cover Sheet

General Proposal Information

Title	Date	TOO/Time Critical
Completing the CARMA Survey Toward IR-bright Nearby Galaxies (CARMA STING)	2009-08-05	—

Scientific Category	1cm Project	3mm Project	1mm Project	Level of Help Required
Galaxies - Mapping	—	X	—	None

Authors List

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

Abstract

We propose to gather the final observations of the CARMA STING extragalactic CO survey. This survey targets 24 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 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 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 form 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 in advance draft form circulating among coauthors. The STING data will be released using the project website: `http://www.astro.umd.edu/STING`

Source Information

#	Source	RA	DEC	Freq	A[1]	B[1]	C	D	SH	# Fields	Species	Imag/SNR	Flex.HA
1	NGC4536	12:24	02:11	115.27	0	0	8	8	0	19	CO 1-0	Imaging	—
2	NGC3593	11:14	12:49	115.27	0	0	0	16	0	19	CO 1-0	Imaging	—
3	NGC5371	13:55	40:27	115.27	0	0	0	16	0	19	CO 1-0	Imaging	—
4	NGC1637	04:41	-02:51	115.27	0	0	0	16	0	19	CO 1-0	Imaging	—
5	NGC4273	12:19	05:20	115.27	0	0	8	16	0	19	CO 1-0	Imaging	—
6	NGC3486	11:00	28:58	115.27	0	0	0	16	0	19	CO 1-0	Imaging	—
7	NGC5713	14:40	-00:17	115.27	0	0	0	16	0	19	CO 1-0	Imaging	—
8	NGC4654	12:44	13:07	115.27	0	0	8	16	0	19	CO 1-0	Imaging	—
9	NGC3198	10:19	45:32	115.27	0	0	8	16	0	19	CO 1-0	Imaging	—
10	NGC3949	11:53	47:51	115.27	0	0	8	0	0	19	CO 1-0	Imaging	—
Total Hours: 176.0													

Special Requirements

Some of our targets are scheduled in the Fall 2009 C- and D-arrays with priority B (see magenta symbols in Fig. 1). If they end up being observed, we will not use the requested time (this will be known in advance of scheduling).

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%.

Status of Prior CARMA Observations

c0001 — Observations complete, reduced, and analysis complete. Student working on them (L. Lopez).
c0002 — Observations complete, reduced, SD data obtained. Source is weak and needs further integration.
c0004 — Observations complete, reduced. No detection. Will not publish.
c0104 — First STING proposal. Observations obtained and reduced. First publication forthcoming.
c0192 — Second STING proposal. Observations obtained and reduced.
c0297 — Third STING proposal. Observations obtained and reduced.
c0292 — One priority B track scheduled but never observed.
c0395 — Fourth STING proposal. Observations under way and reduced as they come.

Introduction and news. 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 external) to seize this capability and use it to study the relation between gas and star formation (SF) in a systematic manner, maximizing science yield and creating a public data set of lasting value.

CARMA STING started observations in March 2008. We are well on our way to completing the first paper, which is currently in advanced draft form circulating among the team members and we anticipate will be submitted within a month (N. Rahman is the lead author). Fig. 2 shows the survey images obtained ($\sim$ 250 hrs. total, mostly C and D). Only one D-array track was run for this project in the entire D09a semester. For the current semester, project c0395 has 16 D-array tracks schedule, only 2 of which are priority A, and a much smaller number of C tracks. For the timely completion of this project we have pared down the target list to the bare minimum necessary to properly sample the blue sequence of star forming galaxies (Fig. 1).

Since this is the fifth iteration of this proposal put through this panel, we have decided to expand a discussion of the status of the survey rather than to repeat the usual science and sample selection points. Once observations are completed, the reduced CARMA STING dataset will be made public and available to the community through our website: `http://www.astro.umd.edu/STING/`. Previous iterations of this proposal are available at the same site.

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). Our ultimate goal is to characterize the star formation law (SFL) in a systematic sampling of the blue sequence. A key measurement these observations enable is the spatially-resolved slope γ of the relation between H_2 and star formation rate, $\Sigma_{SFR} \propto (\Sigma_{H2})^{\gamma}$. STING will characterize the relations between HI, H_2, CO, and SFR throughout a significant range of galaxy masses and SF activities. The star formation law is the subject of much observational and theoretical (e.g., Gnedin et al. 2009; Krumholz et al. 2009) research, as was evident at the very recent SFR@50 meeting (`http://www.arcetri.astro.it/sfr50/`).

Science with STING. Figure 2 shows our study of the resolved star formation law in NGC4254 (Rahman et al., in prep.). We combined our CARMA observations with the IRAM 30m OTF map of CO $2-1$ (obtained as part of HERACLES; Leroy et al. 2009) under the assumption of thermalized emission to obtain a fully-corrected molecular map. The flux recovery from CARMA alone in the inner arcminute is excellent, giving us confidence in results derived from "CARMA only" observations (another 5 galaxies in our sample are part of HERACLES, and we will resubmit a proposal to obtain single-dish of 6 more. In the meantime we have secured JCMT time to complete observations of the sample in CO $3-2$).

We have investigated the relation between SF and molecular gas using a variety of SFR tracers and algorithms. Fig. 3 shows our pixel-by-pixel results for the NGC 4254 analysis using different combinations of FUV, Hα, and 24 μm described in the literature. The different tracers have different systematics and limitations. Particularly striking is the difference in internal scatter between combinations that use Hα (very susceptible to extinction) and those that do not. We fit these data using a variety of linear and nonlinear bivariate techniques and weighting schemes. The slope of the SFL, γ, is steeper and sensitive to the fitting algorithm when based on Hα due to the internal scatter ($\gamma \approx 0.9-1.4$), while it becomes shallower and more robust for the other indicators

($\gamma \approx 0.7 - 0.9$). This latter result supports the linearity found by Leroy et al. (2008) using only $FUV + 24\ \mu$m as SFR tracer. Our preliminary studies in two other STING galaxies, NGC4536 and NGC3147 have also yielded $\gamma \leq 1$. Fig. 3 also shows our comparison with recently published SFL models. Krumholz et al. (2009) assumes that the SF per unit free-fall time in molecular gas is constant to predict the SFR in galaxies. The fraction of gas in molecular form is derived from the formation-destruction equilibrium under a number of assumptions. Their prediction for the molecular fraction at the metallicity of NGC4254 is show overlaid on the measurement from our combined CO and HI datasets. STING is testing the validity of the theory across the blue sequence.

Partnership and community outreach. The timely completion of STING requires a time contribution from the external observer pool. All external participants 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.

Technical Plan. This semester, which we hope is the last for STING, we aim to complete the sampling of the blue sequence. For that we target 3 galaxies for 24 hrs. each in two configurations (16D+8C) for optimal resolution and surface brightness sensitivity. Given how CARMA is scheduled, however, we also need to include in the target list priority-B galaxies that are not guaranteed to be observed (we expect half of them to be, and we will drop those). Targets 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 placing ^{13}CO in the LSB. Further details and graphics can be found at the project website.

• Calzetti, D., et al. 2007, ApJ, 666, 870 • Gnedin, N.Y., et al. 2009, ApJ, 697, 55 • Kauffmann, G., et al. 2003, MNRAS, 341, 54 • Krumholz, M.R., et al. 2009, ApJ 699, 850 • Leroy, A., et al. 2008, AJ, 136, 2782 • Leroy, A., et al. 2009, AJ, 137, 4670 • Prescott, M., et al. 2007, ApJ, 668, 182

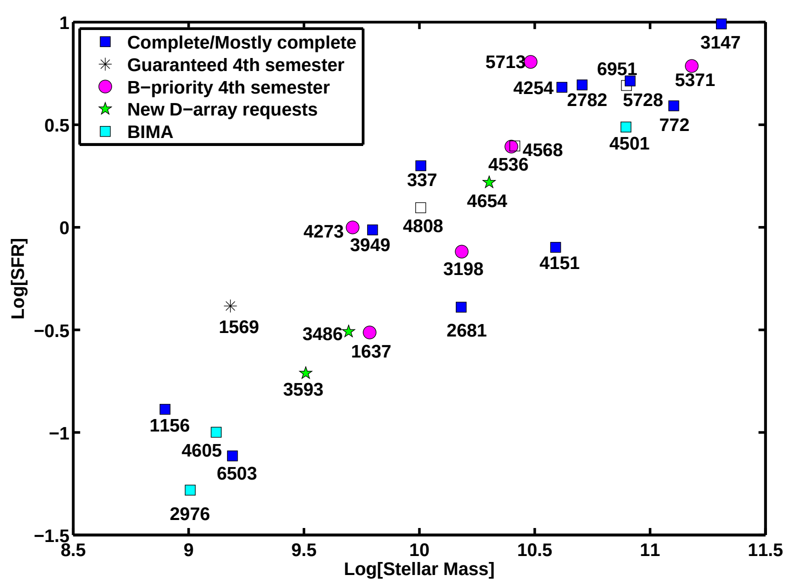

Fig. 1.— Status of STING and the sampling of the blue sequence. We have pared down the target list (3 galaxies with symbols not filled are dropped), and substituted 3 galaxies with substantial BIMA data (light blue) keeping the sample definition. Galaxies marked as mostly complete may need C and/or D array to attain the target sensitivity/resolution. The biggest coverage gap is at intermediate stellar masses $\log M_*/M_\odot = 9.5 - 10.5$ and we aim to close it. So, rank us highly and this will be the last time you have to read this proposal.

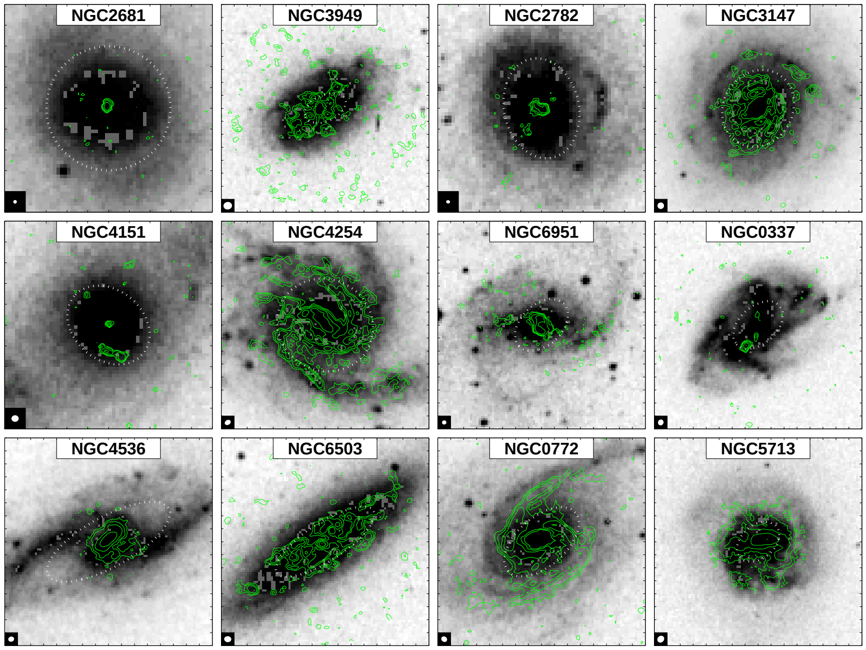

Fig. 2.— Integrated intensity CO contours overlaid on the DSS images of galaxies with a good degree of completion (NGC 1156 — undetected at 0.8 Jy km s^{-1} — is not included). Contours are log spaced (3σ to maximum). All targets were imaged in a 19-pointing mosaic pattern that produces a HPFOV of 120 arcsec. Tick-marks are every $10''$. The white dotted line indicates the area corresponding to $0.25R_{25}$, our CO mapping goal.

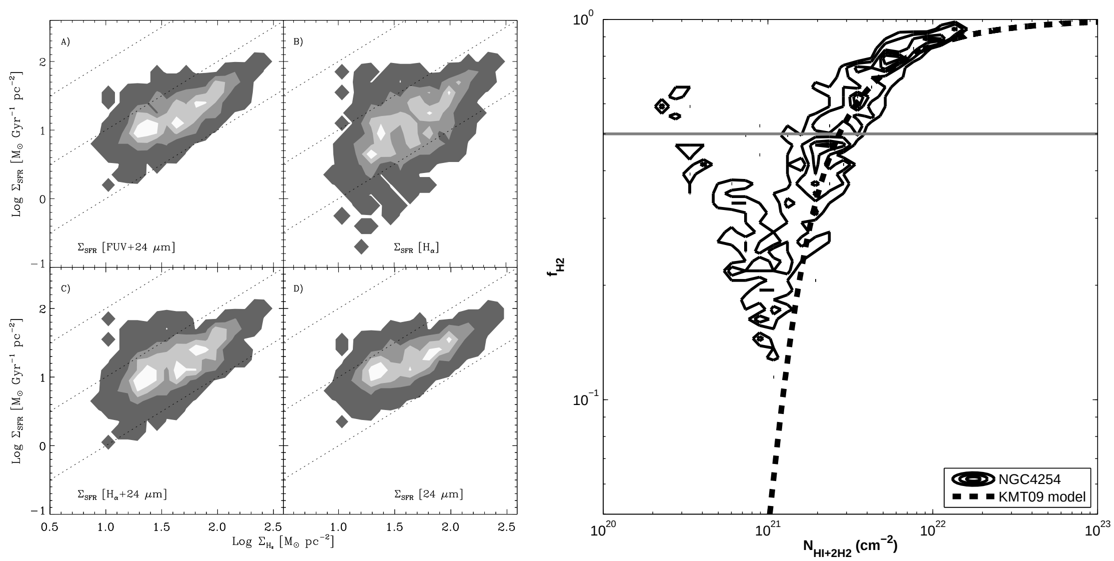

Fig. 3.— **(Left)** 2D histograms of the pixel-by-pixel molecular SF law in NGC4254. The different panels use different star formation tracers: FUV + 24 μm (Leroy et al. 2008), Hα with azimuthally-averaged extinction correction (Prescott et al. 2007), Hα+24 μm, equivalent to a local extinction correction (Calzetti et al. 2007), and nonlinear 24 μm (Calzetti et al. 2007). The dotted lines represent lines of constant star formation efficiency (SFE) or gas consumption lifetime (0.1, 1, and 10 Gyr). Our analysis independently supports the results of approximately constant SFE in the molecule-dominated region of galaxies (Leroy et al. 2008). **(Right)** Molecular fraction versus total gas column density, measured using the combined CARMA+30m CO and the archival VLA HI image. The dashed line shows the model by Krumholz et al. (2009) model corresponding to the metallicity of our source. In this model, the SFR is directly determined by the molecular fraction, which is controlled by the formation-destruction balance of H_2.