

Connecting Gas Dynamics and Star Formation Histories in Nearby Galaxies: The VLA-ANGST Survey

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Abstract. In recent years, HST revolutionized the field of star formation in nearby galaxies. Due to its high angular resolution it has now become possible to construct star formation histories of individual stellar populations on scales of a few arcseconds spanning a range of up to ~ 600 Myr. This method will be applied to the ANGST galaxies, a large *HST* volume limited survey to map galaxies up to distances of 3.5 – 4.0 Mpc (excluding the Local Group). The ANGST sample is currently followed-up by high, $\sim 6''$ resolution VLA observations of neutral, atomic hydrogen (HI) in the context of VLA-ANGST, an approved Large VLA Project. The VLA resolution is well matched to that of the spatially resolved star formation history maps. The combination of ANGST and VLA-ANGST data will provide a new, promising approach to study essential fields of galaxy evolution such as the triggering of star formation, the feedback of massive stars into the interstellar medium, and the structure and dynamics of the interstellar medium.

Keywords: ISM: kinematics and dynamics, ISM: Structure, Galaxies: evolution, Stars: formation, Galaxies: ISM, Radio Lines: ISM

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INTRODUCTION

Luminous matter in galaxies is being converted from the interstellar matter (ISM) phase into stars via the processes of star formation (SF). In turn, young, massive stars are short lived and release energy and matter back into the ISM in the form of strong stellar winds and supernova explosions, the so-called feedback processes. The detailed interactions of gas and stars are complex and it is not straight forward to predict the evolution of gas rich galaxies from any given state. The ISM must meet certain conditions to allow gravitational collapse of the material and eventually to form a star. But what exactly these conditions are and how they develop remains unclear. Many different models have been

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proposed to trigger star formation, e.g., stochastic modes [1, 2], where stars form out of gas density enhancements that are created by the random velocity structure of the gas, external triggers such a tidal interaction with companion galaxies or ram pressure effects due to the galaxy’s motion through an intergalactic medium [3, 4], turbulent SF [5, 6] where the turbulent ISM creates gas density enhancements suitable for gravitational collapse, episodic SF or ‘breathing’ modes [7, 8] where, after an initial starburst strong feedback from massive stars inhibit subsequent SF until the energy has dispersed and the gravitational pull of the galaxy accumulates material to start another episode of SF [7, 8], or propagating SF where energetic feedback from massive stars compresses the surrounding gas, leading to subsequent SF events propagating away from the origin [9, 10]. It remains unclear what the different SF mechanisms contribute to the overall SF history (SFH) of galaxies and for a full understanding is indispensable to observe both, the gaseous and stellar content of galaxies. This is the goal of our project. ANGST (ACS Nearby Galaxy Survey Treasury, see next section) is an ambitious program to determine the stellar content and spatially resolved SFHs in galaxies. VLA-ANGST is a Very Large Array (VLA) follow-up on the ANGST sample to map the neutral, atomic HI gas content at high spatial and high velocity resolution. Together, these surveys will provide well-matched, rich datasets which will be used to examine SF theories.

ANGST: ACS NEARBY GALAXY SURVEY TREASURY

ANGST (PI: J. Dalcanton, [11]) is a large project to obtain optical imaging in two bands (F814W, F475W) with the high resolution capabilities of the Advanced Camera for Surveys (ACS) on board of *HST*. It is a volume limited survey of all galaxies out to distances of ~ 3.5 Mpc, at Galactic latitudes $|b| > 20^\circ$. Due to their very large extent on the sky and the relatively small field of view of *HST*, Local Group galaxies are not part of the survey. To include most of the galaxies in the nearby M81 and Sculptor groups, however, cones out to 4 Mpc toward those regions have been added to the survey volume. ANGST contains 69 galaxies of all morphological types and spans a wide range of ~ 10 magnitudes in optical luminosity and ~ 4 magnitudes of SF rate.

One method to derive the SFH of a galaxy is based on the luminosity function of its main sequence. Every bin along the main sequence contains stellar populations of a given age but, unfortunately, it also contains younger stars which makes the interpretation less reliable and limits the look-back time to ~ 300 Myr. A better method to disentangle the different stellar ages is to use the blue loop of the stellar isochrones, occupied by helium burning stars – a method pioneered by [12, 13]. Not only can a *global* SFH up to ~ 600 Myr be derived with this method but the quality of the *HST* observations allows to pin down stars of a given age (time resolution up to ~ 30 Myr) and it is thus possible to create *maps* of the resolved SFH of galaxies [14].

VLA-ANGST

Using the Very Large Array in B, C, and D configuration, VLA-ANGST maps the HI content at high linear ($\sim 6''$) and velocity resolution (a few km s^{-1}). This is well matched

to the spatial resolution that can be achieved in the construction of the resolved SFH for the ANGST targets. Not all of the ANGST galaxies are observed in VLA-ANGST. Objects too far south for the VLA as well as galaxies with known HI non-detections are excluded. A few of the ANGST targets have already been mapped by the 'The HI Nearby Galaxy Survey' (THINGS, PI: F. Walter [15]), an HI survey with the exact same observational setup as VLA-ANGST, and the data is shared. In total, VLA-ANGST has an allocated time of ~ 480 hours of VLA time and the data collection is expected to be finished by the end of 2008.

The VLA-ANGST sample is listed in Table 1 and histograms of the number of galaxies as functions of galaxy parameters are shown in Fig. 1. Most of the galaxies are at a distance of ~ 3 Mpc, where the M 81 and the Sculptor groups reside. The size distribution peaks at small diameters; most galaxies exhibit rather faint absolute blue magnitudes of ~ -13 mag. Together with their morphological classification (Fig. 1(e)) it becomes obvious that the sample is dominated by gas rich dwarf irregular galaxies (dIrrs). This is expected for a volume limited survey, because dwarfs are the most numerous type of galaxy, and because dwarf spheroidals and ellipticals are mostly excluded from VLA-ANGST due to the criterion to discard ANGST galaxies with HI non-detections. The dominance of dIrrs is not unwelcome. As shown in Fig. 1(f), most of the galaxies in our sample are rather slow rotators and are expected to be largely governed by solid body motion. Shearing forces that may mix stellar populations and smear out HI structures are therefore much less dominant and are usually found at the outskirts of dIrrs. The comparison of stars and gas features are thus much more accurate and can be traced back to older populations.

VLA-ANGST Science Goals

The combination of ANGST and VLA-ANGST will provide new tools to understand the interplay between stars and gas in galaxies. In particular, the surveys will contribute to answer the following questions:

What causes gas to collapse into stars? What are the triggers of star formation?

The HI data will be compared to maps of resolved SFH. Both the distribution as well as the dynamics of the gas are expected to play key roles in defining the actual sites where star formation can occur. Different star formation models (see Introduction) lead to different properties of the gas in their relation to stellar contents and ages. SF efficiencies will be derived which may depend on the SFH of a galaxy, on its morphology, and/or on its metallicity. The high resolution of our data will be reflected in precision rotation curves, which is indispensable in understanding how shearing influences SF, and to identify regions where the galaxies spin like solid bodies. Those areas are the most promising ones to test stochastic and propagating SF modes in galaxies.

What is the role, efficiency, and impact of stellar feedback on the ISM?

With the stellar population age and mass distribution at any given position in a galaxy, the kinematic properties of the HI gas can be used to estimate what fraction of the en-

TABLE 1. VLA-ANGST targets. D: distance, d: diameter, M_B : absolute blue magnitude, Type: galaxy type with $< 0 =$ elliptical, Sb=3, Sc=5, $> 7=$ Sd or later, V_c : circular velocity defined as $W_{50,c}/2$.

Name	D Mpc	RA (J2000) h : m : s	DEC(J2000) ° : ' : "	d arcmin	M_B mag	Type	V_c km s ⁻¹
Galaxies with HI detections and recent SF, brighter than -13							
N3109	1.3	10:03:07.2	-26:09:36	17.0	-15.18	9	116
SexA	1.3	10:11:00.8	-04:41:34	5.5	-13.71	10	63
SexB	1.4	10:00:00.1	05:19:56	5.1	-13.88	10	38
DDO125	2.5	12:27:41.8	43:29:38	4.3	-14.04	10	30
DDO99	2.6	11:50:53.0	38:52:50	4.1	-13.37	10	37
DDO190	2.8	14:24:43.5	44:31:33	1.8	-14.14	10	45
N3741	3.0	11:36:06.4	45:17:07	2.0	-13.01	10	81
N4163	3.0	12:12:08.9	36:10:10	1.9	-13.76	10	18
N4190	3.5	12:13:44.6	36:38:00	1.7	-14.20	10	46
N247	3.6	00:47:08.3	-20:45:36	15.4	-17.92	7	210
N253	3.9	00:47:34.3	-25:17:32	26.7	-20.04	5	410
Galaxies with HI detections and recent SF, fainter than -13 mag							
Antlia	1.3	10:04:04.0	-27:19:55	2.0	-9.38	10	22
KK230	1.9	14:07:10.7	35:03:37	0.6	-8.49	10	21
GR8	2.1	12:58:40.4	14:13:03	1.1	-12.00	10	26
DDO187	2.3	14:15:56.5	23:03:19	1.7	-12.43	10	34
KKH98	2.5	23:45:34.0	38:43:04	1.1	-10.29	10	22
U8508	2.6	13:30:44.4	54:54:36	1.7	-12.95	10	49
DDO181	3.0	13:39:53.8	40:44:21	2.3	-12.94	10	39
UA292	3.1	12:38:40.0	32:46:00	1.0	-11.36	10	27
U8833	3.1	13:54:48.7	35:50:15	0.9	-12.31	10	28
U4483	3.2	08:37:03.0	69:46:31	1.2	-12.58	10	33
DDO6	3.3	00:49:49.3	-21:00:58	1.7	-12.40	10	22
KKH37	3.4	06:47:45.8	80:07:26	1.2	-11.26	10	20
KDG73	3.7	10:52:55.3	69:32:45	0.6	-10.75	10	18
HS117	4.0	10:21:25.2	71:06:58	1.5	-11.51	10	13
BK3N	4.0	09:53:48.5	68:58:09	0.5	-9.23	10	15
Galaxies with HI detections but little evidence for recent SF							
KKR25	1.9	16:13:47.6	54:22:16	1.1	-9.94	10	15
KKH86	2.6	13:54:33.6	04:14:35	0.7	-10.19	10	14
Galaxies with HI detections and dE morphology							
N404	3.1	01:09:26.9	35:43:03	2.5	-16.25	-1	78
KDG63	3.5	10:05:07.3	66:33:18	1.7	-11.71	-3	19
		y	y	y			
Galaxies with no reported single-dish detection/observation, but dIrr/Sm morphology							
DDO113	2.9	12:14:57.9	36:13:08	1.5	-11.61	10	?
DDO183	3.2	13:50:51.1	38:01:16	2.2	-13.08	9	?
MCG9-20-131	3.4	12:15:46.7	52:23:15	1.2	-12.36	10	?
A0952+69	3.9	09:57:29.0	69:16:20	1.8	-11.16	10	?
DDO82	4.0	10:30:35.0	70:37:10	3.4	-14.44	9	?
Galaxies with no reported single-dish detection/observation and dE morphology, but recent SF							
KK77	3.5	09:50:10.0	67:30:24	2.4	-11.42	-3	?

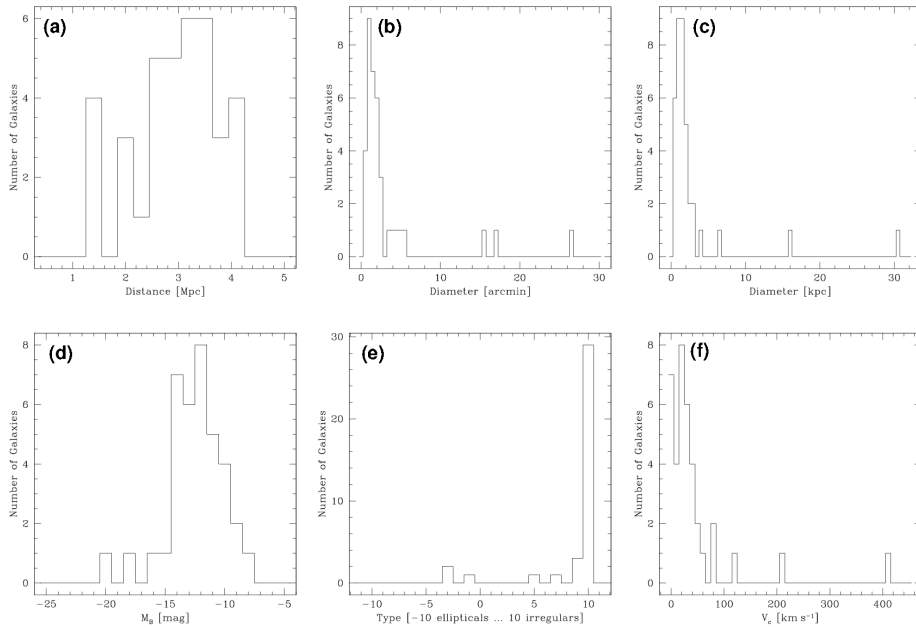


FIGURE 1. Properties of the VLA-ANGST sample: Histograms of (a) distance, (b) apparent diameter, (c) physical diameter, (d) absolute blue magnitude, (e) galaxy type (see Table 1 for nomenclature), and (f) circular velocity.

ergy released by strong stellar winds and supernova explosions is dumped into the ISM. This will also help to better understand the mechanism of expanding HI supershells, which are thought to be a signature of feedback from entire stellar clusters [16], but for many of the shells the search for such a cluster has failed [17]. When regions with and without strong shear are compared, it will be possible to determine how much of the HI turbulence is caused by external, galaxy wide dynamics and what fraction originates from more localized SF events. The energetic input from massive stars can have two very different effects, it can either compress the surrounding gas, causing it to collapse and to expedite further SF, or it can stir up the surrounding ISM in a way such that SF is suppressed. Our data will make it possible to derive which of the processes is more dominant.

What is the structure and dynamics of the ISM?

For many nearby galaxies, a wealth of data across all wavelengths will become available in the very near future. Surveys, e.g., the 11HUGS (“The 11 Mpc H α UV Galaxy Survey”, PI: J. Lee [18]), SINGS (“*Spitzer* Nearby Galaxy Survey”, PI: R. Kennicutt [19]), LVL (“*Spitzer* Local Volume Legacy”, PI: R. Kennicutt [20]), or STING (“Survey Toward Infrared-bright Nearby Galaxies”, CARMA CO maps, PI: A. Bolatto) add observations of star formation tracers such as H α , UV, FIR, and CO. The combination of

the multi-wavelength information will eventually lead to the detailed understanding of the energy balance between the different phases of the ISM, e.g., at which HI densities and dispersions the different SF tracers appear and how this bootstraps on SF processes. In addition, the fractal properties of HI, e.g., the fractal dimension can be studied over a large number of different galaxies with unified data quality.

How do galaxies evolve?

Gas is consumed by SF and feedback processes of massive stars are replenishing part of the ISM. The knowledge of the global SFH of the galaxies in our sample will allow us to derive the HI to stellar mass ratio as a function the cumulative SF rate over the galaxies' lifetimes. Even better, the spatial resolution of the SF rate maps enables us to derive variations of this ratio over the bodies of the galaxies, e.g, in the cores and the outer disks. This will provide a measure for the efficiency with which gas is turned into stars. In addition, properties of the ISM will be brought in relation to the type of their hosts. Large scale dynamics, e.g., bars and density waves, will have an effect on the gas and SF properties. This influences the evolution of a galaxy as a whole and the timing between gaseous features (via kinematics) and stellar ages will be derived. Rotation curves, which are needed for such a study and which will be a product of VLA-ANGST, are also a gold mine to test Λ cold dark matter (Λ CDM) models. The spatial resolution of the data is good enough to derive the shape of the dark matter halo down to the very cores of the galaxies. Whereas theoretical Λ CDM models predict a cuspy profile, observations so far show a flat density distribution in contradiction to Λ CDM [21]. The VLA-ANGST survey, in particular combined with the THINGS and 'Little THINGS' surveys will provide a large, high spatial and velocity resolution database of HI in galaxies with very similar data quality. Λ CDM tests on the shape of dark matter density profiles will therefore have the excellent statistics of a 100+ nearby galaxy sample.

OUTLOOK

At this moment in time, a large number of interferometric HI surveys of nearby galaxies are underway or have just been finished. In the south, the "Local Volume HI Survey" (LVHIS², PI: B. Koribalski) is covering all galaxies with HI out to ~ 10 Mpc, with a spatial resolution of $\sim 20''$, the highest economically feasible resolution of the Australia Telescope Compact Array³. In the northern hemisphere, there is the Giant Meterwave Radio Telescope "Faint Irregular Galaxies GMRT Survey" (FIGGS, PI: A. Begum) as well as three major high resolution ($\sim 6''$) VLA HI surveys, THINGS⁴ ("The HI Nearby Galaxies Survey", PI: F. Walter), VLA-ANGST⁵ (PI: J. Ott), and 'Little THINGS'⁶ (PI:

² <http://www.atnf.csiro.au/research/LVHIS>

³ The Australia Telescope Compact Array is part of the Australia Telescope which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

⁴ <http://www.mpia.de/THINGS>

⁵ <http://www.cv.nrao.edu/~jott/VLA-ANGST>

⁶ <http://www.lowell.edu/users/dah/littlethings>

D. Hunter), ongoing or have recently been completed. All of the three VLA surveys are designed to provide data very similar in spatial resolution (VLA B, C, and D array configurations), velocity resolution (a few km s^{-1}), and sensitivity (HI column density limit $\sim 10^{19} \text{ cm}^{-2}$). In addition, the data reduction of the three surveys will be very similar. This will provide almost equally high fidelity imaging for a total of more than a hundred galaxies. Extragalactic high resolution HI studies will therefore enter a new era with statistically meaningful results. Together with surveys at other wavelengths that are currently underway (ANGST, LVL, 11HUGS, STING, etc.), we will have all the tracers at hand to understand the interplay of gas and stars on scales of galaxies and galaxy groups. This will lead to hard tests for SF and galaxy evolution theories and substantially further our understanding of the processes involved.

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