High resolution imaging of nearby galaxies
for consideration of ATCA Legacy Projects

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1. Background

A complete sample of nearby galaxies was selected for 21 cm observations in the Local Volume HI Survey (LVHIS, Koribalski 2008), which provides both HI spectral line data and radio continuum images. Results are presented in Koribalski & Lopez-Sanchez (2009), van Eymeren et al. (2010), Kirby et al. (2012), Kamphuis et al. (2015), Johnson et al. (2015) and Wang et al. (2016). The LVHIS data were obtained with ATCA configurations 375 m, 750 m and 1.5 km. While the data includes numerous 6 km baselines, more sensitivity is needed to make maps at 10 arcsec resolution. Here we propose to push to much higher sensitivity and resolution allowing for (a) a more accurate multi-wavelength data analysis, (b) studies of the high density gas, and (c) a detailed understanding of the gas kinematics in galaxy disks.

We intend to take advantage of this valuable dataset and extend the LVHIS project with long baseline observations at ATCA for significant improvement in angular and velocity resolutions. This is based on the scientific motivations and technical considerations presented in the next two sections.

2. Scientific aims

The LVHIS data (82 galaxies) based on short baselines were very useful to detect the extended disks of those nearby gas-rich galaxies, as well as HI bridges between galaxy pairs and among groups. However, due to the relatively low resolution, the HI distributions in many dwarf galaxies are poorly resolved, and we only resolve the HI structure on scales of several kpc in massive galaxies.

Below we summarise the scientific investigations that have been achieved with the old data, most of which had to be limited to galaxies with relatively large HI disks.

- Star formation in tidal bridges of HI between merging galaxy pairs (Koribalski & Lopez-Sanchez 2009).
- Gas outflow driven by the feedback from massive stars in relatively large dwarf galaxies ($M_{\rm HI} > 10^8\ M_\odot$) (van Eymeren et al. 2010).
- HI tails in galaxies caused by tidal or ram pressure stripping (Johnson et al. 2015).
- Three dimensional-tilted ring modelling for the velocity field for 25 relatively large galaxies (Kamphuis et al. 2015, also see in Kirby et al. 2012 for 12 even larger galaxies).
- HI size-mass relation (HI radial distribution) for the 56 (41) relatively large galaxies (Wang et al. in prep).

Combining new data of high angular and velocity resolutions with the old LVHIS data, we will be able to learn unprecedented details of the HI distribution in the LVHIS galaxies. We will be able to push the science for the whole sample in the following new directions that are crucial for understanding galaxy evolution:

- Small ($<$ 500 pc) scale structures including HII regions, ISM super-bubbles, shells, etc.. A resolution of $10''$ at a distance of 10 Mpc corresponds to $\sim$500 pc.
- HI corresponding to the optical disk features like bars and spiral arms.
- The magnetic fields and the relation to star formation and the distribution of the HI gas.
- Kinematical analysis through tilted-ring modelling for $\sim$70 galaxies (in comparison to 37 measurable galaxies with LVHIS data, predicted in Kamphuis et al. 2015).The follow-up science including mass distributions, baryonic angular momentum, kinematical (de-)coupling to the stars, etc.
- HI radial distributions for the whole sample (in comparison to 41 measurable galaxies presented in Wang et al. in prep).

There are several existing high-resolution HI imaging data sets including THINGS (Walter et al. 2012), Little THINGS (Hunter et al. 2012), FIGGS (Begum et al. 2008), VLA ANGST (Ott et al. 2012). These samples highlight studies on individual galaxies or statistics for small-scale physics. Each of them (except for VLA ANGST) only includes certain types of galaxies: THINGS for late-type and a few irregular galaxies, FIGGS for irregular galaxies and Little THINGS for relatively isolated irregular galaxies. They achieved high resolution at the expense of large-scale structures, including the extended smooth disk component in spiral galaxies and tidal bridges between interacting groups. The LVHIS sample is a complete HI selected survey, including early-type disk galaxies, transition dwarf galaxies and interacting galaxies. Our sample benefits from the LVHIS dataset and is able to detect the extended HI. For these reasons we will be able to perform scientific investigations that were not achievable before, including

- A representative view of HI-star connection in general HI-rich galaxies.
- Environment dependence of resolved HI properties, including morphology, kinematics and gas-star connections.
- Combining galactic physics on hundreds of parsec scales with large-scale low surface density HI regions.

3. Technical goals

It will be the largest sample of galaxies to date with HI data of such high resolution (6-10 arcsec and 1-4 km/s).

The new data will enable a comparison to several image surveys in other bands. The existing datasets include ultraviolet images from GALEX with a PSF$\sim 5''$, mid-infrared images from WISE with a PSF$\sim 10''$, and optical images provided by our CI Luis Ho from his CGS survey with a PSF$\sim 1''$. We also plan to obtain CO mapping (e.g. from APEX) and wide-field IFU optical spectroscopy (e.g. from KOALA at the AAT) data for this sample.

We will combine the new HI images with multi-wavelength data for a resolution-matched analysis after slightly smoothing the data. This kind of analysis has been adopted by several large HI projects (e.g. THINGS, VLA ANGST) and has been highly useful in connecting the properties of stars and HI gas. We will be able to analyse the kinematics of dwarf galaxies in the sample with the high velocity resolution HI mom 1 maps. We will also obtain deep continuum and polarisation maps at high angular resolution, which will be very useful for studying the star formation rate, AGN activities and magnetic fields. If we combine the data with LVHIS data and future WALLABY data, we further enhance the uv-coverage and sensitivity (at a velocity resolution of 4 km/s.

In the context of up-coming new radio facilities and HI surveys, the proposed resolution (angular and spectral) is much higher than the WALLABY data planned at ASKAP. MeerKat will be able to achieve comparable resolution and sensitivity. Considering the timeline of MeerKat (telescope commissioning and planned legacy surveys), we wish to finish the proposed observation in 3 years time.

4. Program details

In order to obtain high resolution HI data for the 82 LVHIS galaxies we propose to observe them with the three ATCA 6-km configures (with CABB) and to combine these new observations with the existing LVHIS data. These galaxies all have $dec \leq 30°$. We will use the 16-cm band (the L band), and the 1 MHz zoom modes (16×1MHz concatenated for HI) of ATCA. Each galaxy will be observed for in total 36h, 12h for each of the three different 6-km configurations (6A, 6B and 6C). In total the project requires ∼2400 h, and observations will be performed in an unattended mode.

Combining the data to be obtained in this project with existing LVHIS data, we will reach an HI sensitivity of ∼1 mJy/beam with a 4 km/s channel width and $\sim 6'' \times 6''/\sin\delta$ resolution. Assuming a 100 km/s velocity width and 3 σ detection, we are able to detect point sources with HI masses down to $M_{\rm HI}\ 1.4\times10^4 ({\rm dis/Mpc})^2 M_\odot$. Assuming a declination δ of $-40°$ and two-channel detection at 3σ significance, we are able to reach a column density of $3.3\times10^{20}\ cm^{-2}$. These are comparable to the resolution and depth of the THINGS and LITTLE THINGS surveys ($6''$ angular resolution and $3.2\times10^{20}\ cm^{-2}$ column density limit, estimated in the same way as we do for the proposed observations). At the same time, we will also obtain 21-cm continuum images with a sensitivity of ∼10 μJy.

We have gathered a team with strong track record and great expertise in both the scientific and technical areas covered by this proposal.

5. Reference

•Ott et al. 2012, ApJ, 144, 123 •Walter et al. 2012, ApJ, 136, 2563 •Hunter et al. 2012, AJ, 144, 134 •Begum et al. 2008, MNRAS, 386, 1667 •Johnson et al. 2015, MNRAS, 451, 3192 •Kamphuis et al. 2015, MNRAS, 452, 3139 •Kirby et al. 2012, MNRAS, 402, 2924 •Koribalski &López-Sánchez, 2009, MNRAS, 400, 1749 •van Eymeren et al. 2010, MNRAS, 407, 113