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Sardinia Radio telescope (SRT) observations of Local Group dwarf galaxies

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Abstract. The dwarf galaxies in the Local Group (LG) reveal a surprising amount of spatial structuring. In particular, almost all non-satellite dwarfs belong to one of two planes that show a very pronounced symmetry. In order to determine if these structures in the LG are dynamically stable or, alternatively, if they only represent transient alignments, proper motions measurements of these galaxies are required. A viable method to derive proper motions is offered by VLBI studies of 22-GHz water (and 6.7-GHz methanol) maser lines in star-forming regions.

In 2016, in the framework of the Early Science Program of the Sardinia Radio telescope (SRT), we have conducted an extensive observational campaign to map the entire optical body of all the LG dwarf galaxies that belongs to the two planes, at C and K band, in a search for methanol and water maser emission.

Here, we outline the project and present its first results on 3 targets, NGC 6822, IC 1613, and WLM. While no luminous maser emission has been detected in these galaxies, a number of interesting weaker detections has been obtained, associated with particularly active star forming regions. In addition, we have produced deep radio continuum maps for these galaxies, aimed at investigating their star forming activity and providing an improved assessment of star formation rates in these galaxies.

Keywords. galaxies: dwarf, Local Group, telescopes, techniques: spectroscopic, radio lines: galaxies, masers, radio continuum: galaxies

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1. The SRT in (pea)nutshell

The Sardinia Radio Telescope (SRT, Bolli et al. 2015, Prandoni et al. 2017) is a 64-m antenna located at San Basilio (Sardinia, Italy). The shaped surface of the primary mirror minimize standing waves a the secondary focus, improving the quality of the baselines in spectroscopic measurements.

The SRT is equipped with three receivers: a K-band (18-26.5 GHz) 7-beam array in the Gregorian focus, provided with a mechanical derotator; a C-band (5.7-7.7 GHz) single feed in the Beam Wave Guide (BWG) focus; a coaxial dual-feed L&P in the primary focus. A number of additional packages, with different characteristics, are under construction and/or development aimed at covering also the S, Q, and W bands.

The SRT backend set offers: a broad-band ROACH 2-based digital backend, SARDARA, with bandwidths of up to 2 GHz, 16k channels, full Stokes information, for

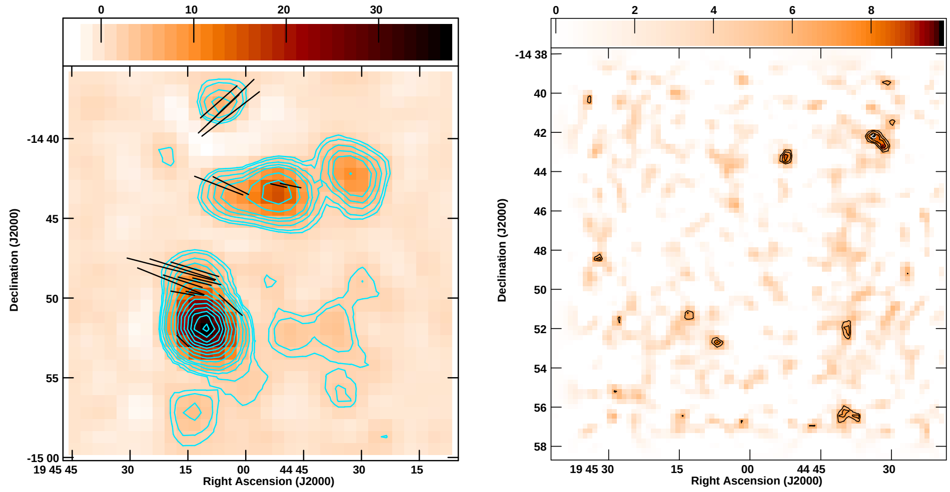

Figure 1. *Left:* SRT C-band total intensity $21' \times 21'$ image of NGC 6822 resulting from the spectral average of the bandwidth between 6000 and 7200 MHz. The FWHM beam is 2.9 arcmin. The noise level is 0.65 mJy/beam. Contour levels are $0.65 \times$ (3, 4, 6, 8, 10, 15, ... ,80). Electric field polarization vectors are overimposed. The length of the vectors is proportional to the polarization percentage (with 10% being a bar of ~ 2.1 arcmin), while their orientation represents the polarization angle. The error on the polarization angle is less than $10°$, and the fractional polarization is above $3\sigma_{FPOL}$. *Right:* SRT K-band total intensity $18' \times 18'$image of NGC 6822 resulting from the spectral average of the bandwidth between 21570 and 22770 MHz. The FWHM beam is 0.9 arcmin. The noise level is 2.0 mJy/beam. Contour levels are $2.0 \times$ (3 3.5 4 4.5 5 6 7).

which multi-feed capabilities and zoom modes are going to be available soon; a narrow-band digital spectrometer with bandwidths between 62.5 and 0.5 MHz, 2048 channel (yielding a maximum frequency resolution of 0.25 kHz), and full Stokes and 7-feed information provided. Additional backends are also available, including a Digital FilterBank (DFB) and a Digital BaseBand Converter (DBBC), mainly used for pulsar and VLBI measurements, respectively, and a Total Power analogue backend.

2. The SRT project ESP0003

2.1. *The SRT Early Science Program (ESP)*

After the completion of the Engineering Commissioning (Bolli et al. 2015) and Scientific Commissioning (Prandoni et al. 2017), in 2013 and 2016, respectively, and the participation of the SRT at the regular EVN sessions (see, e.g., Sanna et al. 2017, P. Castangia, in this book), regular single-dish operation were officially launched by an Early Science Program (ESP). The ESP lasted from February to August 2016 and comprised 13 large scientific projects, out of which four involved spectroscopic measurements, including the ESP project described in this contribution, labeled ESP0003 and titled 'Proper motions and star formation activity of Local Group dwarf galaxies'.

2.2. *Project motivation*

The project takes motivation from the discovery that almost all non-satellites dwarf galaxies in the Local Group belong to either one of two planar, extremely symmetric, structures, termed LG plane 1 and LG plane 2 (Pawlowski et al. 2012, Ibata et al. 2013). If all these structures in the LG are dynamically stable then the galaxies will move within the associated plane, which allows to predict the expected proper motion of individual satellites in such structures (Pawlowski & Kroupa 2013, Pawlowski, McGaugh & Jerjen 2015); otherwise the structures would only represent transient alignments which would disperse as the dwarf galaxies continue their independent motions. In order to probe these two different scenarios, proper motions of these galaxies would be fundamental.

For nearby galaxies, a viable method to derive proper motions is offered by VLBI studies of 22-GHz water maser lines in star-forming regions. Indeed, VLBI observations in phase-referencing mode of water maser spots allow us to measure the 3D motions of the host galaxies with respect to distant quasars. In addition, distance measurements are possible by applying the rotational parallax method to the detected maser spots with relevant implications on the cosmological parameters and the total mass of matter (luminous and dark) of the LG. So far, such studies have been successfully performed on a limited number of maser spots detected in the galaxies M 33 and IC 10 (e.g. Greenhill et al. 1993; Brunthaler et al. 2005; 2007). Alternatively, also methanol maser lines can, in principle, be used for proper motion studies.

Within the aforementioned framework, it is particularly important to detect as many water/methanol maser sources as possible in any galaxy belonging to the LG and, in particular, in the LG dwarf galaxies belonging to the LG planar structures 1 and 2.

2.3. *Sample and data reduction*

For project ESP0003, we have thus mapped the full spatial extension of all non-satellite LG dwarf galaxies belonging to the two LG planes 1 and 2 in a search for new maser sources.

The sample is comprised of 14 Local Group dwarf galaxies associated with Planes 1 and 2 (Tarchi et al. in prep).

About 200 hours in total (C and K bands) were allocated to the project. The SRT was used in conjunction with the SARDARA backend (see previous section) with a bandwidth of 1.5 GHz and 16384 channels, yielding a channel spacing of 91 kHz ($\equiv$ 4 km/s@6.7-GHz and 1.2 Km/s@22-GHz). Full Polarization information were recorded. Maps were performed using On-the-Fly technique along RA and DEC. The data were reduced and analyzed using the proprietary Single-dish Spectral-polarimetry Sofware (SCUBE; Murgia et al. 2016).

2.4. *Preliminary results and discussion*

So far, we produced the epoch-averaged cubes at C and K band for three galaxies, NGC 6822, IC 1613, and WLM. Spectral cubes were also averaged in frequency to produce radio continuum maps for the three galaxies. Fig. 1 shows the total intensity radio continuum maps of NGC 6822 at C and K band. The maps reveal a number of compact sources at both frequencies, and extended emission at C-band. Polarized emission was also imaged at C-band (see Fig. 1, left panel). Spectral index studies are ongoing to assess the nature of these sources associated to either star formation activity or background objects (Tarchi et al. in prep). In the spectral line cubes, we searched for the 6.7-GHz methanol and 22-GHz water maser emission, using the maser finder method developed by S. Curiel and described in Surcis et al. 2011, with the following constraints: i) 5 sigma limit; ii) a channel range corresponding to 200 km/s, centered on the lines doppler shifted by the systemic velocity of the galaxy, that produced a list of maser candidates. For these, we derived the peak to noise ratio (SNR) in the spectrum at the position of the features found and considered detections those with SNR greater than 5 and tentative detections those with SNR between 3 and 5.

No maser emission above 5 sigma has been detected in the three targets analyzed.

For the water masers, this is consistent with the expectations. Using the equation by Brunthaler et al. (2006), that includes the water maser luminosity function, the number of expected (water) masers in a galaxy can be computed using, as inputs, the star formation rate (SFR) of the galaxy and the maser luminosity threshold of the image cube. The noise in the SRT cubes were of order 20 and 90 mJy/beam for C and K band, respectively. Thus, the number of expected water masers for our targets was smaller than 0.1. On the other side, while for IC 10 (also a LG dwarf galaxy) an expected number of 0.3 is derived as well using the same relation, the number of maser found in this galaxy is actually of 2, so far, indicating that possibly the SFR values are not always precise enough and/or maser flares may alter the computed expected maser numbers. Indeed, promisingly, a number of tentative maser features (with SNR between 3 and 4) have been detected in all three galaxies of our sample and await confirmation.

2.5. *Future steps*

The spectropolarimetric observations at C and K bands, presented in this study, of the full optical body of three targets of our sample of non-satellite Local Group dwarfs clearly shows the capabilities offered by the SRT to perform, along with maser surveys and monitoring programs, sensitive searches for masers in extended extragalactic (and Galactic) sources.

Indeed, the data reduction for the other eleven dwarf galaxies in the sample observed with the SRT has yet to be completed in order to derive a more statistically-relevant view of the presence/absence of water maser sources in these category of galaxies with relatively low star formation rates. In addition, from the radio continuum maps, spectral index and radio-emission based SFRs will be derived for all galaxies providing clues on the nature of the compact (and extended) emission.

Single-dish follow-ups are also planned of the tentative maser sources detected by us, for the first time, in the three galaxies studied so far, whose confirmation may provide promising targets for proper motion VLBI studies.

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