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High-resolution spectral imaging of SNR W44 and IC443 at 22 GHz with the Sardinia Radio Telescope

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Abstract. In the framework of the Astronomical Validation and Early Science activities of the Sardinia Radio Telescope (SRT, www.srt.inaf.it), we performed 22 GHz imaging observations of SNR W44 and IC443. Thanks to the single-dish imaging performances of SRT and innovative ad hoc imaging techniques, we obtained maps that provide a detailed view of the structure of the remnants. We are planning to exploit the high-frequency radio data of SNRs to better characterize the spatially-resolved spectra and search for possible spectral steepening or breaks in selected SNR regions, assessing the high-energy tail of the region-dependent electron distribution.

Keywords. (ISM:) supernova remnants, ISM: individual (IC443, W44), ISM: radio continuum

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1. Introduction

Galactic Supernova Remnants (SNRs) are commonly identified as extended radio sources with non-thermal spectra. To date, a multi-wavelength coverage (from radio to ultra-high energies) has been carried out for part of these SNRs. The nature of the high-energy emission is still debated. The co-spatial study of the radio and gamma-ray emissions may provide crucial information for disentangling the two basic possible scenarios represented by leptonic (Inverse Compton and bremsstrahlung emission) and hadronic models (π^0 mesons decay emission). Radio emission is expected up to $20-50$ GHz, but even for the most interesting and bright objects, high-resolution images at frequencies above 5 GHz in the confused regions of the Galactic Plane are lacking and not easily achievable (mostly due to the low flux densities in this range). In fact, interferometric imaging synthesis of large structures ($> 1°$) at high-frequencies becomes unfeasible. Radio continuum observations performed with single-dish telescopes allow us to obtain accurate flux density measurements of large SNR structures at high frequency ($\gtrsim 5$ GHz). Most of the features and details highlighted in high-resolution low-frequency interferometric images of SNRs (Castelletti *et al.* 2007 and 2011; Gao *et al.* 2011), can be also observed and studied in high-frequency single-dish images thanks to the very stable gaussian beam of SRT and to innovative ad hoc imaging techniques based on "On The Fly" (OTF) scans (Prandoni *et al.*, 2017). These characteristics are crucial to investigate both integrated and spatially-resolved spectral indexes of SNRs.

2. Data analysis and results

In the framework of Early Science activities (Egron *et al.* 2017), we performed observations at 21.4 GHz with the SRT K-band 7-feed receiver. By using the "Best Space Coverage configuration" (Bolli *et al.* 2015), we provided 7 simultaneous equally-spaced (OTF) scans, covering the whole area scanned by the multi-feed receiver (Fig.1). In this way, we obtained SNR maps characterized by about 14 scans per beam. This oversampling is fundamental to efficiently reject outlying measurements (due to radio-frequency interferences) and to optimize final image accuracy.

Thanks to its simple morphology and the availability of extensive flux density measurements up to high radio frequency (useful to cross-check calibrations), SNR 3C10 represents an ideal target for testing our data analysis tool (SRT Single Dish Imager; Egron *et al.*, 2016) on SRT K-band data. In Fig.2 we show a multi-feed image of 3C10 at 21.4 GHz with an angular resolution of $0.87'$, obtained by SRT on February 24 2016 (in the frameworks of the Early Science Program). This image is produced by merging the individual maps associated to each feed. We obtained a preliminary integrated flux density of ~ 8 Jy for 3C10 consistent with previous measurements at high radio frequency (observations at 14 to 18 GHz; N. Hurley-Walker *et al.* 2009).

After testing it on 3C10, we applied our K-band data analysis procedure on the larger and complex SNR W44 (Fig.3). This map will allow us to study for the first time the morphology and the flux density of W44 at high radio-frequencies. We used integrated flux density measurements obtained from SRT data at 21.4 GHz, 7.0 GHz and 1.5 GHz (see Egron *et al.* these proceedings) in order to provide a first radio continuum spectrum of W44 (Fig.3-6). Our preliminary result indicates a possible spectral curvature/break between around 5-10 GHz. This break in the spectrum of W44 would be consistent with a steepening of the primary particle spectrum at 10 GeV as suggested by gamma-ray observations of SNR W44 (Giuliani *et al.* 2011; Ackermann *et al.* 2013; Cardillo *et al.* 2014).

Bremsstrahlung and IC bumps observed in gamma-rays band are bounded to synchrotron spectral slope and cut-off in the radio domain. For this reason, a careful characterization of lepton contributions through high-frequency radio-observed parameters is necessary to disentangle hadron contributions in the high-energy spectra and better constrain SNRs as cosmic rays emitters. However, the assumption of a single electron population for the whole SNR is too simplistic. Indeed, a spread in the spectra slope distribution, through different SNR regions, has been highlighted by preliminary spatially-resolved spectral measurements obtained for SNR W44 and IC443 by using SRT data at 1.5 and 7.0 GHz (Pellizzoni *et al.*, these proceedings). Spatially-resolved high-frequency spectra measurements could be important to better disentangle different region-dependent physical processes in these SNRs.

3. Perspective for future SRT data analysis at high-frequencies

We plan to apply the same calibration procedure adopted for 3C10 and W44 to K-band images of SNR IC443, in order to look for a possible spectral steepening, as observed for W44. In Fig.7 we show a preliminary uncalibrated map of SNR IC443 obtained from SRT observations performed on March 23 2016. Furthermore, coupling K-band maps with L-band (1.5 GHz) and C-band (7.0 GHz) maps, we could obtain more accurate spectral index maps to search for possible spectral steepening or breaks in selected SNR regions, assessing the high energy tail of the region-dependent electron distribution.

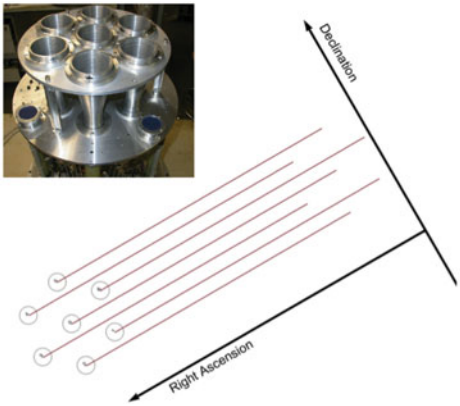

Figure 1. Schematic view of the "Best Space Coverage configuration" and SRT K-band 7-feed receiver (Upper left).

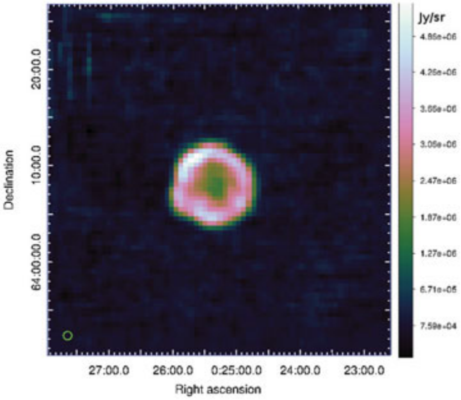

Figure 2. SRT radio continuum map of 3C10 at 21.4 GHz. The beam size is 0.87' FWHM (green circle).

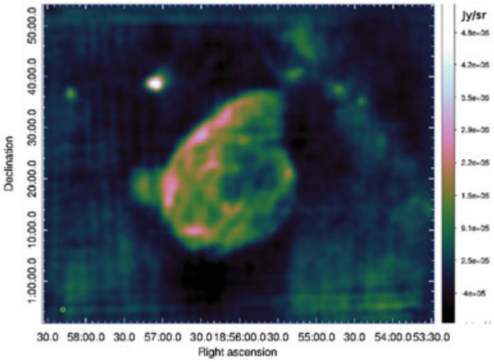

Figure 3. SRT radio continuum map of W44 at 21.4 GHz. The beam size is 0.87' FWHM (green circle on the bottom left). The Galactic plane and other nearby diffuse and point-like sources are clearly visible in this map.

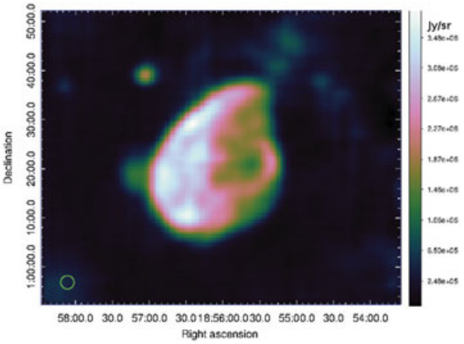

Figure 4. SRT radio continuum map of W44 at 7.0 GHz. The beam size is 2.71' FWHM (green circle on the bottom left).

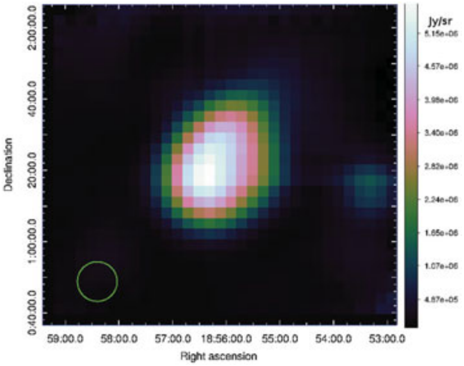

Figure 5. SRT radio continuum map of W44 at 1.5 GHz. The beam size is 11.1' FWHM (green circle on the bottom left).

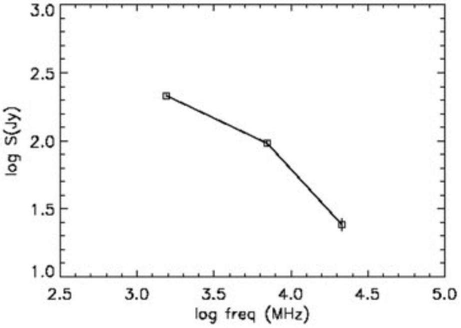

Figure 6. Integrated radio continuum spectrum of W44 obtained by using the flux density measurements related to the maps at 21.4, 7.0 and 1.5 GHz shown in Fig. 3, 4 and 5.

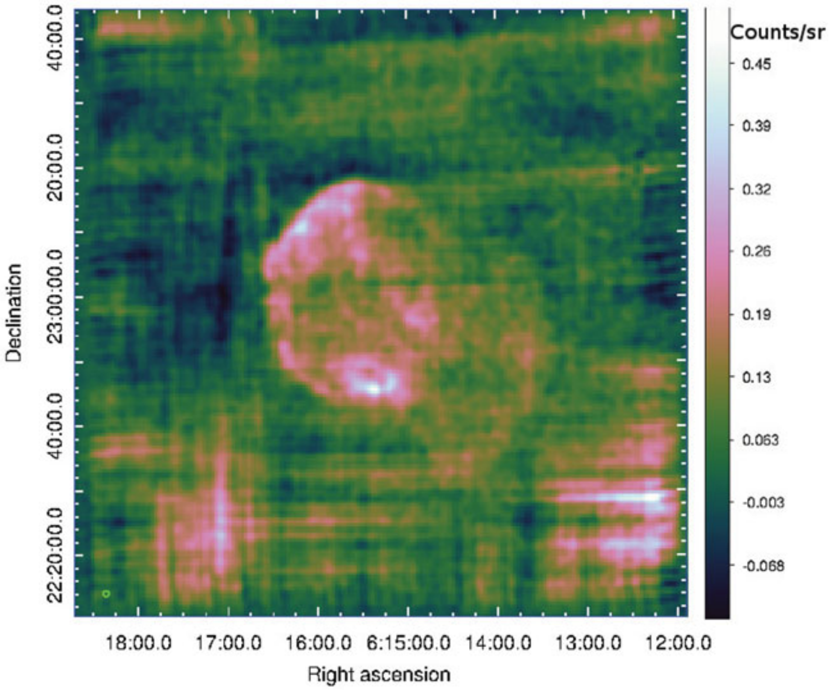

Figure 7. Preliminary SRT radio continuum map of IC443 (uncalibrated) at 21.4 GHz. The beam size is 0.87' FWHM (green circle on the bottom left).

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