Supernova Remnants with LOFAR

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Contents

Discuss what are the possibilities that the LOFAR telescope allows for the study of SNRs.

- LOFAR: The LOw Frequency ARray
- SNR population at low frequencies
- Absorption processes: the case of Cassiopeia A
- Morphological variations: Mixed-Morphology Supernova Remnants

The LOw Frequency ARray

- Interferometer with stations in the Netherlands (24 *Core*, 14 *Remote*) and across Europe (12 *International*)
- Phased-array design
- 10-90 MHz (LBA);
 110-240 MHz (HBA)
- For 30 MHz on Full NL config., sensitivity of 5.7 mJy, angular resolution of ~20 arcsec



LOFAR Superterp, which houses six stations.

SNR Population at Low Frequencies ***

- Missing (young, small; old, faint) SNRs — LOFAR as a survey instrument.
- Confusion with HII regions —LOFAR is multifrequency (different values of α)

Right: HBA image of the W50 region. 48 MHz bandwidth; 115-163 MHz. Broderick *et al.,* in prep.



nJy/Beam

Physical Processes Operating at Low Frequencies

- Internal and external free-free absorption
- Synchrotron self-absorption
- Intrinsic spectral index variations —morphology

Cassiopeia A



LOFAR LBA broadband image of Cas A. 3 MHz BW at 30, 60, and 76 MHz. Angular resolution is 16.5'

Cas A

1MHz BW images at 30 (top),60 (bottom right) and 76 (bottom left) MHz







Absorption: Cas A



Preliminary spectral index map and three-colour image of Cas A at LOFAR LBA frequencies.

Mixed-Morphology Supernova Remnants

- A class of SNRs that are shell-type in the radio and are filled with thermal X-rays in the centre
- Older (~20,000 years)
- Associated with the denser parts of the ISM
- Often interacting with molecular clouds
- Some are GeV or even TeV γ-ray sources
- Flatter spectral indices

Background: HBA image of the W49B region —courtesy of Jess Broderick





MMSNRs —W49B

VLA L-Band (top) and LOFAR HBA (bottom) images of W49B, a MMSNR.

Angular size: 4'x3' Spectral index: 0.46

Note that the southwest region has a steeper spectral index than the rest of the remnant

Archival 1989 VLA image (<u>https://</u> <u>archive.nrao.edu/</u>), LOFAR image by P. Salas and the FACTOR team

MMSNRs —IC443



Image courtesy of G. White

IC443 at 30, 40, 50 and 60 MHz (LBA). The flattest spectral components (-0.25< α <0.0) coincide with the brightest parts of the SNR at the eastern edge. Steeper spectral index ($\alpha \sim -0.8$) towards centre/western edge.





VRO 42.05.01 at 133 MHz, 4.8 MHz BW (right) and at 1420 MHz (left —Leahy & Tian, 2005).

MMSNRs

- Continue studying spectral segregation
- Time granted for observations of W63 and HB9 in LOFAR Cycle 6



HB9 at 1420 MHz (Leahy & Tian, 2007).

Conclusions

- LOFAR opens the lowest radio frequency window at high sensitivity and angular resolution
- SNRs are brightest at LOFAR frequencies potential to detect missing SNRs, population studies
- LOFAR can spatially resolve the spectral properties of a source

Flux of Cas A



The radio spectrum of Cas A, Cyg A and Vir A Baars, *et al.*, 1977





MMSNRs ---3C397

VLA L-Band (top) and LOFAR HBA (bottom) images of 3C397, a MMSNR.

Angular size: 4.5'x2.5' Spectral index: 0.50

Note that some hotspots have a steeper spectral index than the rest of the remnant

Archival 1990 VLA image (<u>https://</u> <u>archive.nrao.edu/</u>), LOFAR image by P. Salas and the FACTOR team

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