

STUDY OF A GIANT LARGE MAGELLANIC CLOUD SUPERNOVA REMNANT, VELIKI (J0450.4–7050)

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SUMMARY: We present a high-resolution radio-continuum view and multi-frequency analysis of the Large Magellanic Cloud (LMC) Supernova Remnant (SNR) J0450.4–7050, which we nicknamed Veliki. These high-resolution observations reveal a larger extent than previously measured, making J0450.4–7050 one of the largest SNRs that we know of. Additionally, we observe a higher than expected radio surface brightness and an unusually flat spectral index ($\alpha = -0.26 \pm 0.02$), with little spectral variation over the remnant. We observe a bright $H\alpha$ shell indicating significant cooling over the remnant, but also an excess of [O III] on the eastern shock front. We investigate several theoretical scenarios to explain the emission and radio evolution of J0450.4–7050 in the context of the LMC environment, and determine that this is most likely an older, predominantly radiative, SNR with a higher shock compression ratio, which gives a flatter non-thermal spectrum in combination with thermal (bremsstrahlung) emission contribution.

Key words. ISM: supernova remnants - supernovae: general - supernovae: individual: J0450–7050 (Veliki) - Radio continuum: general

1. INTRODUCTION

Supernova Remnants (SNRs) have been extensively studied in terms of their evolution and impact on stellar and galactic evolution. Extensive studies have been conducted on the Galactic SNR population and on the SNR populations of nearby galaxies to understand their full evolution and physical properties. Several galaxies have had their SNR populations studied in detail, such as the Large Magellanic Cloud (LMC) (Filipović *et al.* 1996b, Filipović *et al.* 1998, Payne *et al.* 2008, Bozzetto *et al.* 2015, Maggi *et al.* 2016, Bozzetto *et al.* 2017, Yew *et al.* 2021, Bozzetto *et al.* 2023, Filipović *et al.* 2021, Zangrandi *et al.* 2024), the Small Magellanic Cloud (SMC) (Payne *et al.* 2007, Filipović *et al.* 2008, Maggi *et al.* 2019, Cotton *et al.* 2024b), M31 (Galvin and Filipović 2014, Kavanagh *et al.* 2020), as well as a number of nearby galaxies outside of the Local Group (Millar *et al.* 2011, Pannuti *et al.* 2011, Galvin *et al.* 2012, Millar *et al.* 2012, O’Brien *et al.* 2013, Galvin *et al.* 2014, Pannuti *et al.* 2015, Yew *et al.* 2018), which provides a unique opportunity to study entire galactic SNR populations in detail.

The newest generation of radio telescopes, such as Australian Square Kilometre Array Pathfinder (ASKAP) and MeerKAT, are ideal for analysing SNRs. With a higher resolution and sensitivity than previously available, they allow in-depth radio-continuum studies to be conducted. This has been demonstrated by the discovery of several new individual SNRs, such as J0624–6948 (Filipović *et al.* 2022), G288.8–6.3 (Ancora; Filipović *et al.* 2023, Burger-Scheidlin *et al.* 2024), G181.1–9.5 (Kothes *et al.* 2017), G121.1–1.9 (Khabibullin *et al.* 2023), G329.9–0.5 (Perun; Smeaton *et al.* 2024), and G305.4–2.2 (Teleios; Filipović *et al.* 2025) and SNR candidates, such as G308.73+1.38 (Raspberry; Lazarević *et al.* 2024) and G312.65+2.87 (Unicycle; Smeaton *et al.* 2024), as well as recent studies which uncover new details about previously known SNRs, such as G278.94+1.35 (Diprotodon; Filipović *et al.* 2024). It has also been demonstrated by the large-scale surveys conducted with these telescopes, which have resulted in several discoveries and analysis of several SNRs and SNR candidates (Ball *et al.* 2023, Cotton *et al.* 2024a,b, Goedhart *et al.* 2024, Anderson *et al.* 2025, Ball *et al.* 2025, in press). These highlight the importance of radio-continuum observations in discovering and analysing SNR populations.

Due to the LMC’s nearby location (~ 50 kpc; Pietrzyński *et al.* 2019) in an area with relatively weak Galactic emission interference, we are able to fully resolve the SNRs and study their physical properties in detail. Thus, we can map the evolution of an entire population and determine how the properties of the galaxy influence their evolution. To this end, we present a detailed study of one of the LMC SNRs, J0450.4–7050 (also known as J0450–709 and

MC 11), which we give the nickname Veliki¹. Veliki displays unusual properties which may be attributed, in part, to its location within the different environment of the LMC.

As one of the largest known SNRs in the LMC, Veliki has been extensively studied at multiple frequencies. It was discovered at radio frequencies as an unclassified radio source at 4800 MHz using the Parkes radio telescope (McGee *et al.* 1972), where it was named MC 11. It appears in several subsequent large-scale radio surveys with radio measurements ranging from 408 MHz to 8.85 GHz (Clarke *et al.* 1976, Wright *et al.* 1994, Filipović *et al.* 1995, 1996a, 1998). Mathewson *et al.* (1985) were the first to classify Veliki as an SNR using narrow-band optical observations to measure the [SII]/H α ratio of ~ 0.7 , which classified it as an evolved SNR using the criteria of Mathewson and Clarke (1973).

Veliki was then studied using X-ray and optical data by Williams *et al.* (2004). Their analysis revealed a complex filamentary optical structure with distinct inner and outer shell structure, with different expansion velocities; ~ 120 km s⁻¹ for the outer shell and ~ 220 km s⁻¹ for the inner. They detect interior X-ray emission and estimate a minimum age of $\sim 45,000$ years, making Veliki an evolved mixed-morphology (MM) remnant.

Veliki has also been observed in the Far ultraviolet (UV) (Blair *et al.* 2006), and also appears in the Infrared (IR) study of LMC SNRs by Lakićević *et al.* (2015). The most recent radio analysis was performed by Čajko *et al.* (2009). Their radio analysis showed a spectral index $\alpha = -0.43 \pm 0.06$, slightly flatter than expected and attributed to thermal contributions, as well as a physical size of $102 \times 75 \pm 1$ pc and a peak radio polarisation of $\sim 40\%$. Veliki also appears in several other LMC SNR analyses (Maggi *et al.* 2016, Bozzetto *et al.* 2017, Zangrandi *et al.* 2024). Maggi *et al.* (2016) gives X-ray properties of the 0.24 ± 0.02 keV plasma temperature and $33.6^{+36.8}_{-24.1} \times 10^{58}$ cm⁻³ emission measure, which are best fit by a one-component collisional ionisation equilibrium (CIE) model. This suggests that the inner plasma has reached thermal equilibrium between electrons and ions ($kTe = kTi$), consistent with an evolved SNR where sufficient time has passed to achieve electron-ion temperature equilibrium through Coulomb collisions (Vink 2012). The analysis of Bozzetto *et al.* (2017) also states a possible core-collapse (CC) origin for Veliki.

There have been γ -ray surveys conducted of the LMC, and there are currently only a handful of γ -ray emitting LMC SNRs known. Veliki is not detected in the current γ -ray studies, including the recent Fermi-LAT survey (Tramacere *et al.* 2025) which detected several γ -ray emitting SNRs, but did not cover Veliki’s location. These detections are expected to increase when Cherenkov Tele-

¹Veliki (Велики) meaning large in Serbian.

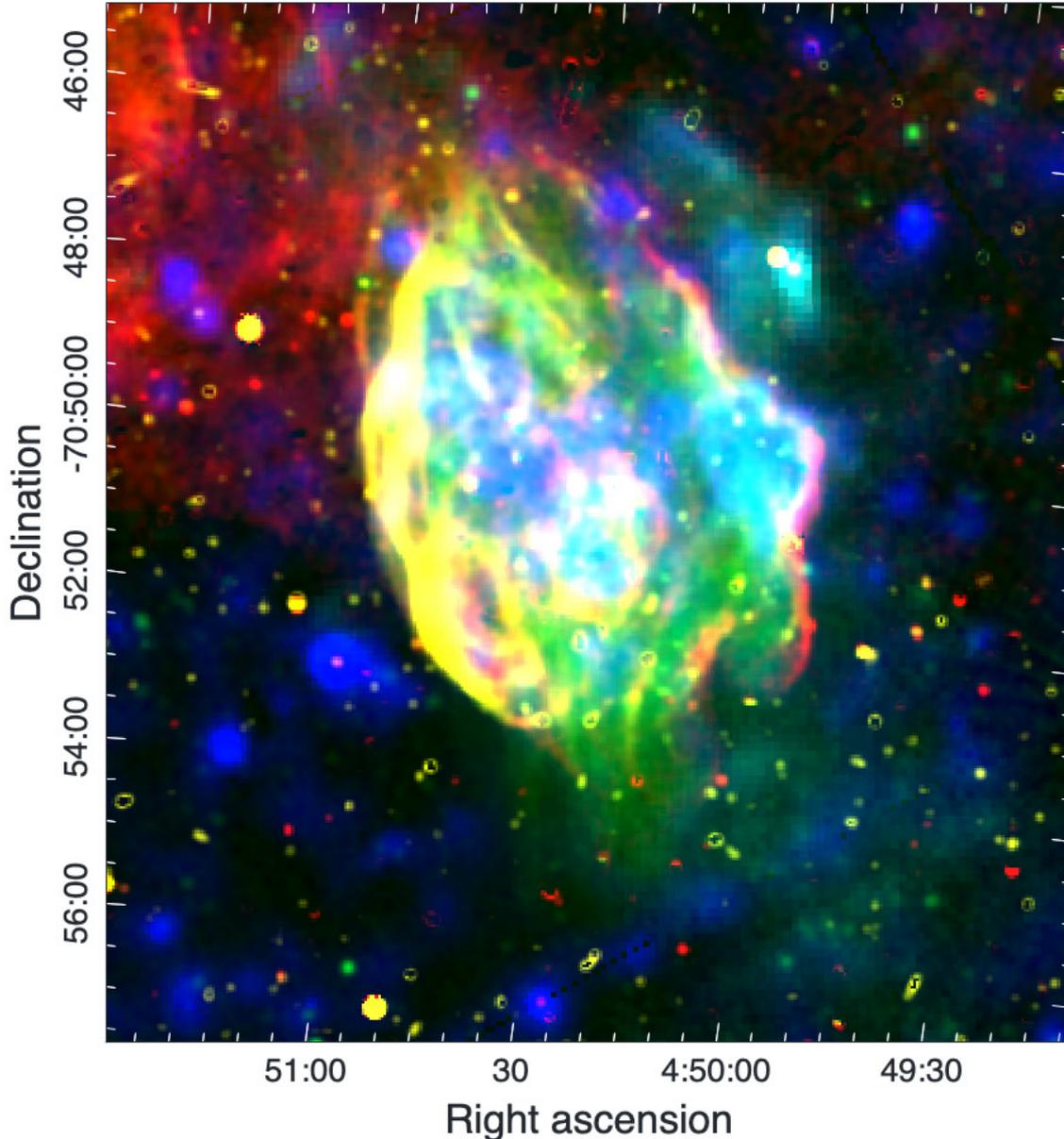


Fig. 1: Five colour multi-frequency image of Veliki. Red is optical MCELS $H\alpha$, green is 1.3 GHz MeerKAT radio, blue is *XMM-Newton* soft X-ray (0.3–1 keV), yellow is optical MCELS [OIII], and cyan is 250 μm *Herschel* IR.

scope Array (CTA) observations commence, which should achieve higher sensitivities than previously obtained (Acharyya et al. 2023).

In this paper, we present new radio observations of Veliki using data from the ASKAP and MeerKAT radio telescopes (see Section 2) with higher resolution and sensitivity than previous data. We also use archival data at other frequencies to perform a multi-frequency analysis of the properties. In Section 2 we detail the data used, in Section 3 we show results of the analysis, in Section 4 we discuss theoretical interpretations, and in Section 5 we present the final conclusions.

2. OBSERVATIONS AND DATA REDUCTION

The continuum data used consists of radio data from the ASKAP, MeerKAT, Murchison Widefield Array (MWA), and Molonglo Observatory Synthesis Telescope (MOST) radio telescopes, IR data from the *Herschel* telescope, optical data from the MCELS survey, and X-ray data from the *XMM-Newton* telescope. We also use spectral line data, specifically HI data from the Australia Telescope Compact Array (ATCA) and Parkes telescopes, and CO data from the Magellanic Mopra Assessment (MAGMA) survey.

2.1. Radio-continuum data

2.1.1. ASKAP

Veliki’s location in the LMC has been observed with the ASKAP telescope (Johnston *et al.* 2008, Hotan *et al.* 2021) as part of the large-scale Evolutionary Map of the Universe (EMU) survey (Norris *et al.* 2011, 2021, Hopkins *et al.* 2025). This area was covered at 888 MHz as part of the ASKAP commissioning and early science (ACES, project code AS033, scheduling block SB 8532) (Pennock *et al.* 2021, Bozzetto *et al.* 2023), and again in the subsequent main survey at 943 MHz (project code AS201).

Both observations were conducted using the entire 36 antenna ASKAP array with a bandwidth of 288 MHz. The early science 888 MHz data has a restoring beam of $13.9'' \times 12.1''$ (position angle $PA = -84.4^\circ$) and the main survey 944 MHz data is convolved to a common beam size of $15'' \times 15''$. All EMU data was reduced using the standard ASKAP-Soft pipeline which involves multi-scale cleaning, self-calibration, and multi-frequency synthesis imaging (Guzman *et al.* 2019). Veliki appears in three separate EMU main scheduling blocks, SB 46957, SB 48589, and SB 46962, however, in SB 48589 and SB 46962, Veliki is located at the edge of the tile where sensitivity drops exponentially (Hopkins *et al.* 2025). Due to this, only SB 46957 is used in this analysis.

2.1.2. MeerKAT

The MeerKAT data used comes from the recent MeerKAT survey of the LMC under project code SSV-20180505-FC-02. The observations were conducted using the MeerKAT L-band split into 14 sub-band channels from 856–1712 MHz. Two sub-bands (centred at 1198.9 and 1255.8 MHz) were blanked due to Radio-Frequency Interference (RFI). Observations were conducted for all Stokes I, Q, U, and V parameters, and the data consists of all sub-bands as well as an additional broadband image centred at 1295 MHz across the whole bandwidth. Details of the image generation, calibration, data reduction, and final survey will be presented in Cotton *et al.* (in prep) and Rajabpour *et al.* (in prep). We use the Stokes I data products for our radio-continuum analysis, and the Stokes I, Q, and U products for our polarisation analysis.

2.1.3. MWA

We use radio data from the MWA telescope (Tingay *et al.* 2013). Specifically, we use the radio-continuum maps of the LMC from the GaLactic and Extragalactic All-sky MWA (GLEAM) (Wayth *et al.* 2015, Hurley-Walker *et al.* 2017) survey at 88, 118, 155, and 200 MHz as described in For *et al.* (2018).

2.1.4. MOST

We also use the more recent 843 MHz MOST radio survey of the LMC (Turtle and Amy 1991) to remeasure the prior MOST measurement of Mathewson and Clarke (1973). The Mathewson and Clarke (1973) 843 MHz measurement significantly differed from our new ASKAP 888 MHz measurement, and thus we remeasured from the more recent 843 MHz MOST survey data (see Section. 3.2 for more detail).

2.2. Optical data

We use optical data from the MCELS optical survey (Smith *et al.* 2000) of the Magellanic Clouds (MCs). The survey imaged the central $8^\circ \times 8^\circ$ of the LMC using the UM/CTIO Curtis Schmidt telescope and achieved a resolution of $3\text{--}4''$. We use the narrow-band observations of $H\alpha$ (centred at 656.3 nm with a bandwidth of 3 nm), $[SII]$ (centred at 672.4 nm with a bandwidth of 5 nm), and $[OIII]$ (centred at 500.7 nm with a bandwidth of 4 nm).

2.3. IR

We use Far Infrared (FIR) data from the Herschel Inventory of The Agents of Galaxy Evolution (HERITAGE) (Meixner *et al.* 2006) survey conducted using the *Herschel* Space telescope (Pilbratt *et al.* 2010). Specifically, we use the longest wavelengths from the Spectral and Photometric Imaging Receiver (SPIRE) instrument at 250, 350, and 500 μm .

2.4. X-ray

We use X-ray data from the *XMM-Newton* telescope. We use data from the MC *XMM-Newton* survey (Haberl 2014, Maggi *et al.* 2016, 2019), which surveyed the LMC and SMC with the full *XMM-Newton* bandwidth (0.2–10.0 keV) with a sensitivity of F_X (0.3–8 keV) $\approx 10^{-14}$ erg cm^{-2} s^{-1} . We use only the soft X-ray band (0.3–1 keV) in this analysis.

2.5. HI

We also used archival HI data published by Kim *et al.* (2003). The HI data were obtained by combining the Australia Telescope Compact Array and the Parkes 64-m radio telescope observations. The angular resolution of the HI data is $1''.0$, corresponding to the spatial resolution of ~ 15 pc at the distance of the LMC. The typical rms noise is ~ 2.5 K at the velocity resolution of ~ 1.6 km s^{-1} .

2.6. CO

The $^{12}\text{CO}(J = 1-0)$ data were obtained from the Magellanic Mopra Assessment (MAGMADR3, Wong *et al.* 2011, 2017). The angular resolution is $\sim 45''$, corresponding to spatial resolution of ~ 11 pc at the distance of the LMC. The typical rms noise is ~ 0.3 K at velocity resolution of ~ 0.5 km s^{-1} .

3. RESULTS

3.1. Morphology

We analyse the morphology of Veliki at several different frequencies (see Fig. 1). Veliki has a filamentary shell-like morphology at optical and radio frequencies, elongated along the north-south axis and with a brighter clump of emission on the western edge (see Fig. 2). From the MeerKAT data, we measure the centre of the remnant to be $\text{RA}(\text{J2000}) = 4^{\text{h}}50^{\text{m}}26.8^{\text{s}}$, $\text{Dec}(\text{J2000}) = -70^{\text{d}}50^{\text{m}}45.5^{\text{s}}$, with angular diameters $10.3' \times 5.6'$ and position angle 17.6° (measured counterclockwise from north axis), corresponding to a physical size of $150 \text{ pc} \times 81 \text{ pc}$ at the LMC (Pietrzyński et al. 2019). This size is significantly larger than previously reported in radio ($102 \text{ pc} \times 75 \text{ pc}$; Čajko et al. 2009), and this is due to the faint filamentary structure visible in the north and south, which was not visible in the previous radio images.

The $\text{H}\alpha$ and $[\text{SII}]$ emission are closely correlated and form an optical filamentary shell across the entire remnant (see Fig. 3, first, second, and third panels). The optical and radio emission are closely correlated with the optical leading the radio along the majority of the shell; the only exception being the southern filamentary structure which is only visible in radio. We note an excess of the $[\text{OIII}]$ emission in the eastern rim of the remnant, leading both the radio and $[\text{SII}]/\text{H}\alpha$ shell (see Fig. 3, fourth panel).

Veliki has interior soft X-ray ($0.3\text{--}1.0 \text{ keV}$) emission which is not visible at higher frequencies ($>1 \text{ keV}$ for *XMM-Newton*). This emission is confined to the interior of the SNR, with bright patches in the middle eastern section and in the western protruding clump. The exact X-ray properties of these clumps could be better determined with in-depth X-ray analysis, such as by *XMM-Newton* or *Chandra*, which could potentially reveal the chemical composition of the ejecta with X-ray spectroscopy. There is a complex filamentary $\text{H}\alpha$ structure near the eastern edge identified by Williams et al. (2004) and measured to be expanding faster ($\sim 220 \text{ km s}^{-1}$) than the outer shell ($\sim 120 \text{ km s}^{-1}$). There are no obvious radio or X-ray structures which correlate with this inner $\text{H}\alpha$ shell.

Veliki itself does not appear at IR frequencies (see Fig. 4). There is a bright patch of IR emission to the north-east of the shell, which appears to correspond with a catalogued molecular cloud PGCC G272.62-35.35 (Planck Collaboration et al. 2016). The cloud is not within the SNR extent, however, the IR emission closely traces the north-eastern radio and $[\text{SII}]/\text{H}\alpha$ rim, directly above the western bulge. The findings of Lakićević et al. (2015) conclude that interaction between Veliki and a surrounding cloud is in progress or imminent, (see Section 4.2).

Veliki itself does not appear in the HI and CO observations (see Fig. 5). The integrated HI covers the entire area, however, the CO observations

are restricted to a small portion of the north-western rim. We detect two distinct peaks in the CO emission corresponding with the observed IR patch and the molecular cloud. We also observe a possible HI cavity at the velocity range $231.2 \text{ km s}^{-1} < V_{\text{LSR}} < 242.8 \text{ km s}^{-1}$ which spatially corresponds with Veliki's location (see Fig. 5, panel (b)). The HI, CO, and IR observations are discussed in more detail in Section 4.2, in relation to Veliki's environment.

3.2. Radio flux densities

We fit a region around Veliki using the Cube Analysis and Rendering Tool for Astronomy (CARTA) imaging software (Comrie et al. 2021) to extract flux density measurements. We use an elliptical region based on the remnant centre and angular diameters as described in Section 3.1. We measure flux densities from the 88, 118, 155, and 200 MHz MWA data, the 888 and 944 MHz ASKAP data and the 1.3 GHz MeerKAT data (see Table 1). We also remeasured the 843 MHz flux density measurement from MOST. The previously measured value was 837 mJy from Mathewson et al. (1985); at odds with our most recent value of $696 \pm 70 \text{ mJy}$ at 888 MHz from ASKAP. We thus used the more recent MOST images of the LMC by Turtle and Amy (1991) to re-measure and verify this data point, and measured a value of $671 \pm 67 \text{ mJy}$, more consistent with expectations from ASKAP. We estimate a 10% error in our ASKAP, MeerKAT, and MOST flux density measurements, similar to the methodology used in Filipović et al. (2022, 2023, 2024), Smeaton et al. (2024) and Bradley et al. (2025). Due to the significantly poorer resolution of the MWA images caused by the lower frequency, we assume a 20% error for these measurements. We list these new measurements and previously catalogued flux density measurements for Veliki in Table 1.

3.3. Radio spectral index

We use the flux density values (see Table 1) to calculate the overall spectral index of Veliki, defined as $S \propto \nu^\alpha$, where S = integrated flux density, ν = observing frequency, and α = spectral index (Filipović and Tothill 2021). We use all available measurements to calculate the total spectral index, and the available high-resolution images to generate a spectral index map.

3.3.1. Total spectral index

The linear fit was conducted using the LINREGRESS² function in the Python library SCIPY (Virtanen et al. 2020) which uses a linear least-squares regression method to find the line of the best fit to the data. The quoted uncertainty is defined as the

²<https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.linregress.html>

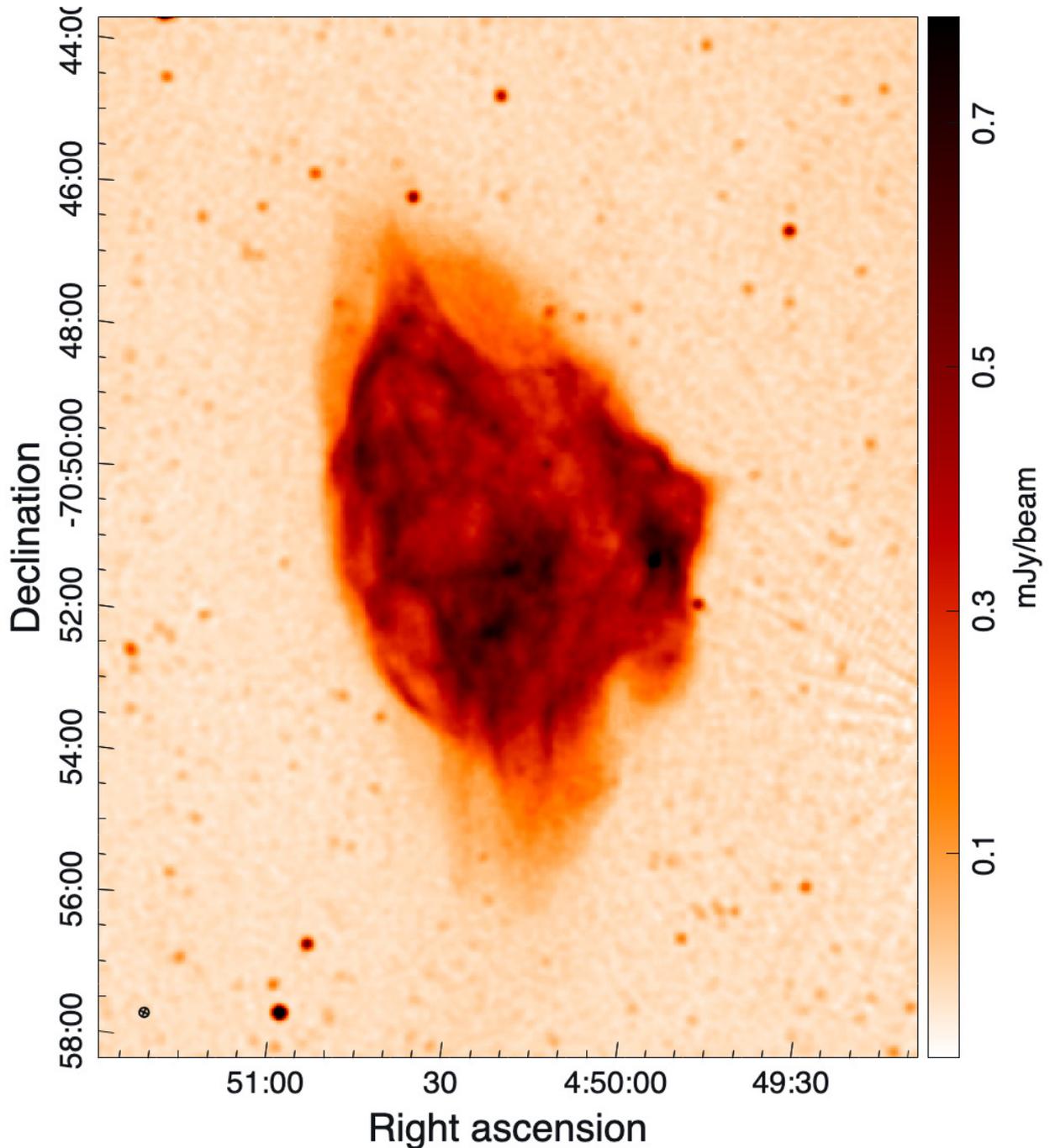


Fig. 2: MeerKAT 1.3 GHz view of LMC SNR J0450–709. The image is linearly scaled, has a synthesised beam of $8'' \times 8''$ shown in the bottom left corner and a measured local rms noise level of $10 \mu\text{Jy beam}^{-1}$.

standard error of the fit (Theil 1950), and thus likely underestimates the true uncertainty. We calculate a spectral index value of $\alpha = -0.26 \pm 0.02$, with a reduced χ^2 value of 0.53 and 17 degrees of freedom (see Fig. 6). In order to verify this value, we also fit the data points with a weighted fit using the `CURVEFIT` function in the `SCIPY` library, and get similar results of $\alpha = -0.27 \pm 0.03$, and a reduced χ^2 value of 0.50

with the same degrees of freedom. These reduced χ^2 values and the consistency between the two methods indicate a good fit for the data and provide confidence for the measured spectral index value.

We note the largest outlier is the 408 MHz measurement from Clarke *et al.* (1976). They note that Veliki appears extended in their observations and this may have caused erroneous measurements due to the

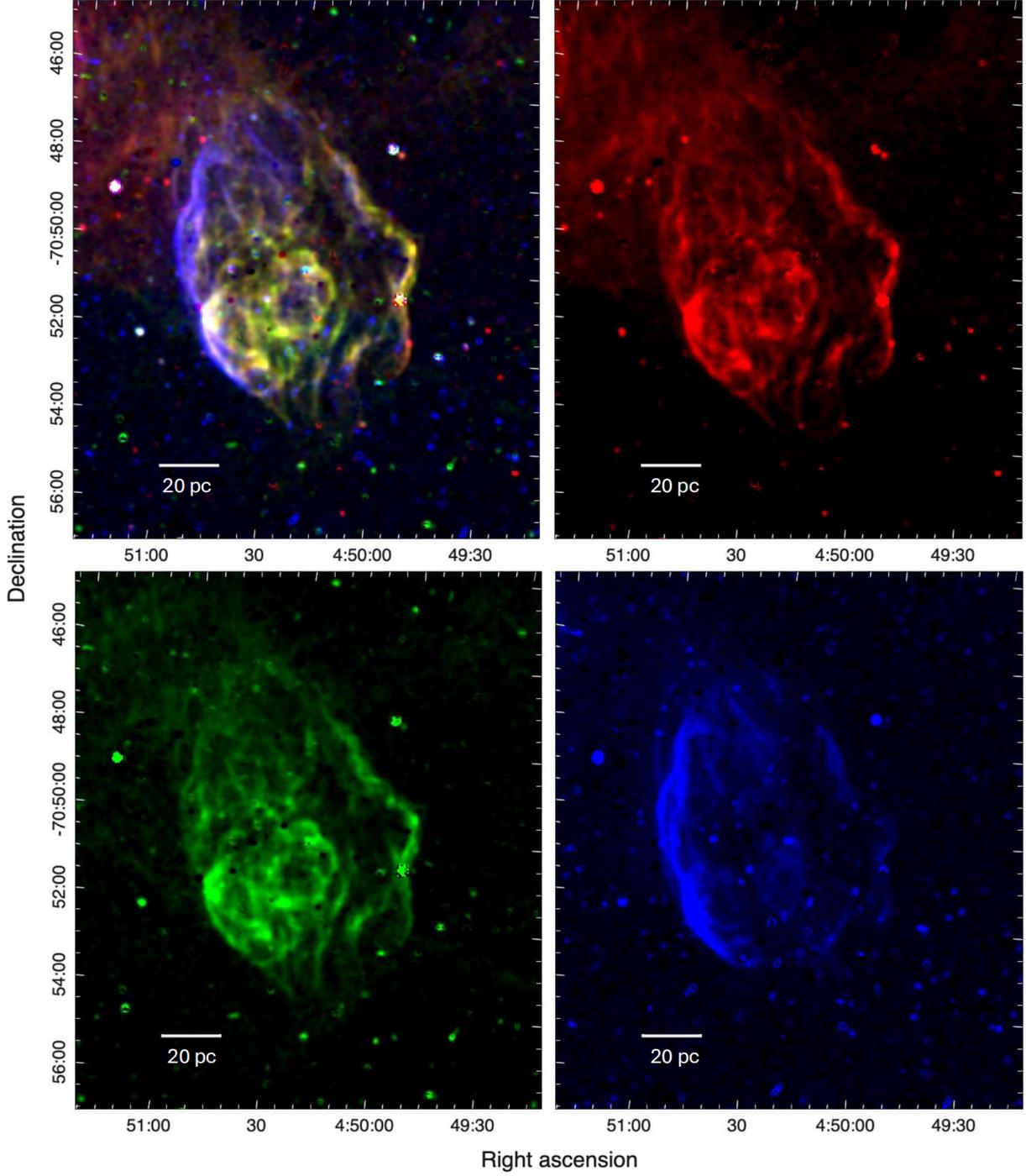


Fig. 3: 4-panel image of Veliki at optical wavelengths using MCELS data. **Top left:** Optical RGB using three MCELS filters. The other three panels show the individual filters in their respective colours which make up the RGB. Red is $H\alpha$ (**top right**), green is $[SII]$ (**bottom left**), and blue is $[OIII]$ (**bottom right**). All images are linearly scaled and have a 20 pc scale bar shown in the bottom left corner.

older telescope’s insensitivity to extended emission. While this outlier could indicate spectral curvature, its inconsistency with recent measurements and high uncertainty prevents us from claiming spectral curva-

ture based solely on this point. Even excluding this point, we calculate similar spectral index values as above, with $\alpha = -0.27 \pm 0.01$ (reduced $\chi^2 = 0.42$, degrees of freedom = 16) for linear least-squared regres-

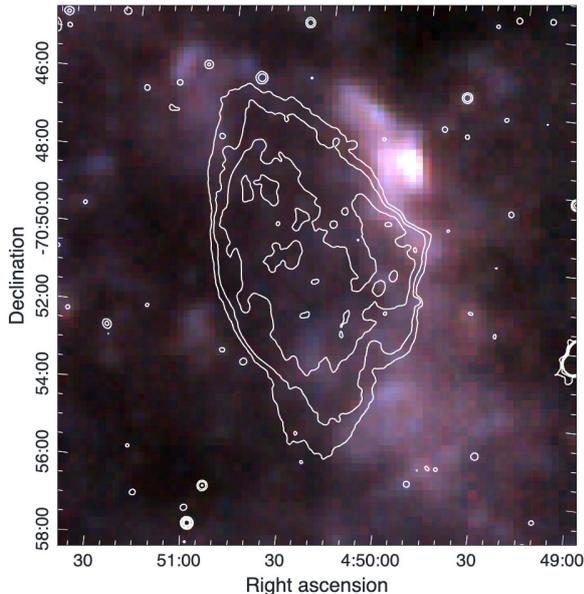


Fig. 4: FIR RGB of Veliki and surrounding area using *Herschel* FIR data. Red is 500 μm , green is 350 μm , and blue is 250 μm . All images are linearly scaled. The contours are from the 1.3 GHz MeerKAT radio image at levels of 0.05, 0.15, 0.40, and 0.70 mJy beam^{-1} .

sion, and $\alpha = -0.27 \pm 0.03$ (reduced $\chi^2 = 0.41$, degrees of freedom = 16) for the weighted fit. We therefore determine that this point of higher uncertainty is not significantly impacting the results, and that a linear fit is accurate with no obvious curvature in the spectrum.

We use this total spectral index value to scale the flux to 1 GHz, and obtain $S_{1\text{GHz}} = 664 \text{ mJy}$. We calculate surface brightness, defined as $\Sigma_{1\text{GHz}} = S_{1\text{GHz}}/\Omega$ where $\Omega = \text{angular area}$. Using the region defined in Section 3.1 as $10.3' \times 5.6'$, we calculate the angular size of $\Omega = \pi ab = 163086 \text{ arcsec}^2$ and $\Sigma_{1\text{GHz}} = 1.7 \times 10^{-21} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1}$. We calculate radio luminosity defined as $L_{1\text{GHz}} = 4\pi d^2 S$, where $d = \text{distance to the object}$. Using the distance of 50 kpc, we calculate $L_{1\text{GHz}} = 1.9 \times 10^{17} \text{ W Hz}^{-1}$.

3.3.2. Spectral index map

We use the high resolution ASKAP and MeerKAT radio data to generate a spectral index map. All images are convolved to the lowest resolution (ASKAP 944 MHz beam size = $15''$, pixel size = $2''$) before calculation. The images are then input into the MATHS function in the MIRIAD software which calculates the line of best fit through the data points for each pixel, which are then used to generate the final image (see Fig. 7, left). We estimate a spectral index error map using standard error propagation. For each frequency pair (ν_1, ν_2) , the spectral index error is calculated as $\sigma_\alpha = 1/\ln(\nu_1/\nu_2) \times \sqrt{(\sigma_1/S_1)^2 + (\sigma_2/S_2)^2}$

Table 1: Measured and catalogued flux densities for Veliki. Uncertainties for ASKAP, MeerKAT, and MOST are taken as 10% and uncertainties for MWA fluxes are taken as 20%. Other uncertainties are taken as listed in the catalogue, or are assumed to be 10% if a value is not given (indicated by \dagger). The \ddagger indicates values where an uncertainty was not listed in the catalogue, but an uncertainty equation was given in the listed reference, and this was used to calculate the uncertainty.

ν (MHz)	$S \pm \Delta S$ (mJy)	Reference
88	1580 ± 316	This work
118	1159 ± 232	This work
155	1082 ± 216	This work
200	918 ± 184	This work
408	610 ± 150	(Clarke et al. 1976)
843	671 ± 67	This work
888	696 ± 70	This work
944	779 ± 78	This work
1295	615 ± 62	This work
1400	$644 \pm 64^\dagger$	(Čajko et al. 2009)
2300	$540 \pm 47^\ddagger$	(Filipović et al. 1996a)
2450	$514 \pm 55^\ddagger$	(Filipović et al. 1995)
2700	$470 \pm 47^\dagger$	(Filipović et al. 1998)
4750	$496 \pm 52^\ddagger$	(Filipović et al. 1995)
4800	$448 \pm 45^\dagger$	(Čajko et al. 2009)
4850	$479 \pm 47^\ddagger$	(Filipović et al. 1995)
5010	410 ± 150	(McGee et al. 1972)
8640	$360 \pm 36^\dagger$	(Čajko et al. 2009)
8850	367 ± 57	(Filipović et al. 1995)

where σ_i is the rms noise in each image and S_i is the flux density. We calculated the errors for all frequency pairs and averaged them to obtain the final uncertainty map. Both images were then cut to remove values with uncertainties > 1.0 . We measure an average value of $\alpha = -0.46 \pm 0.36$. The spectral index is mostly uniform with $\alpha \sim -0.4$ to -0.5 , but there are two areas of slightly steeper spectral index in the western bulge and on the south-eastern edge which extent to $\alpha \sim -0.6$ to -0.7 .

These values are significantly steeper than the overall value obtained from the full set of flux measurements (see Fig. 6), and the estimated errors are quite high. This is likely due to the smaller frequency range used (888–1300 MHz) when compared with the total range (88–8850 MHz). Therefore, the map values likely overestimate the spectral index steepness and the total value $\alpha = -0.26$ is more accurate. The images had similar native resolutions and were convolved to the same resolution before map generation, and thus the uniformity of the spectral index is likely accurate. Both the spectral index map and spectral index error map show a uniform distribution, indicating that there are no areas of significant spectral variability, such as a central Pulsar Wind Nebulae (PWN).

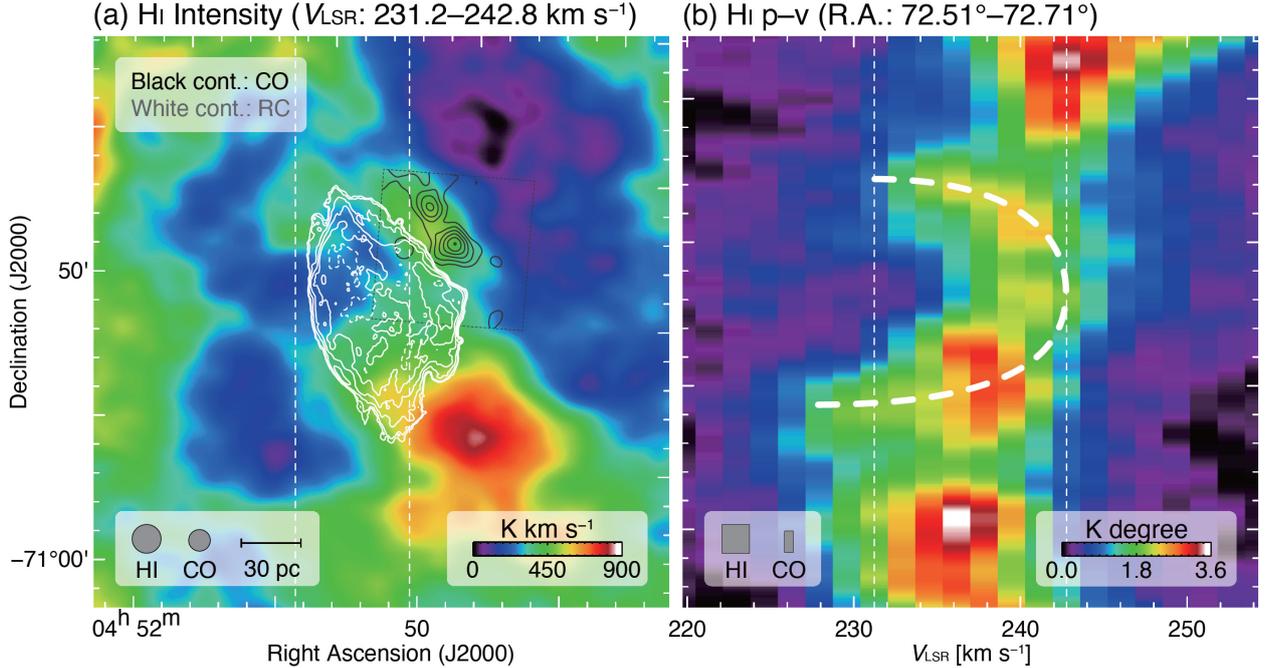


Fig. 5: HI and CO maps of Veliki and surrounding environment. Panel (a): HI intensity map of Veliki and surrounding environment. HI intensity is integrated over the V_{LSR} velocity range of 231.2–242.8 km s⁻¹. White contours are from MeerKAT 1.3 GHz radio-continuum map and black contours are from Mopra CO map. The contour levels are 0.10, 0.12, 0.18, 0.28, 0.42, and 0.60 mJy beam⁻¹ for radio-continuum, and 1.2, 2.1, 3.0, 3.9, 4.8 and 5.7 K km s⁻¹ for CO. The dashed black square shows the extent of the CO image which the contours are taken from as it covers only a portion of the north-western shell. The vertical dashed white lines correspond with panel (b) and show the extent of the possible HI cavity. The beam sizes are shown in the bottom left corner along with a scale bar. Panel (b): HI p - v diagram, integrated over Veliki’s RA location (72°51–72°71). The beam sizes are shown in the bottom left corner. The thin white dashed correspond with panel (a) showing the location relative to Veliki, and the thick dashed white line traces the possible HI cavity.

3.4. Polarisation

We conduct a polarisation and rotation measure (RM) analysis using the MeerKAT radio data. This analysis was done using the Python PYRMSYNTH program³, which uses the RMCLEAN method as described in Heald (2009). The total polarised intensity is calculated as the magnitude of polarisation, $PI = \sqrt{Q^2 + U^2}$, where PI = polarised intensity, and Q and U are the flux density measurements of the respective Stokes parameters (Fig. 8, top left). The fractional polarisation is calculated as PI/I , where I is the measured Stokes I flux density (Fig. 8, top right). The RM measurement follows the method of Heald (2009), which decomposes the complex polarisation function $PI = Q + iU$ as a function of λ^2 into components at different Faraday depths (Fig. 8, bottom left). This RM is then used to de-rotate the polarisation vectors to measure the intrinsic electric field direction, which we then rotate by 90° to map the intrinsic magnetic field (Fig. 8, bottom right).

³<https://mrbell.github.io/pyrmsynth/>

The results show relatively uniform polarisation values predominantly located in the southern half of the shell. We measure the average PI of 0.05 ± 0.01 mJy beam⁻¹ and average fractional polarisation of $9 \pm 2\%$. We measure the average RM of -16 ± 11 rad m⁻², ranging from ~ -200 to $+100$ rad m⁻². The RM differs across the SNR, with positive RM values seen predominantly along the western edge with a smaller patch on the north-eastern side, and negative values observed predominantly in the centre, slightly offset to the east.

The magnetic field structure we observe appears highly disorganised. This is consistent with the low fractional polarisation ($\sim 10\%$) (Reynolds et al. 2012) and the broad range of RM values (-200 to $+100$ rad m⁻²) seen across the remnant. Such characteristics suggest either an intrinsically complex magnetic field structure, potentially indicating magnetic turbulence, or possible depolarisation effects along our line of sight. We note that at the MeerKAT observing frequency, there may be significant uncertainties in these magnetic field orientations due to the high absolute RM values observed. Therefore, the in-

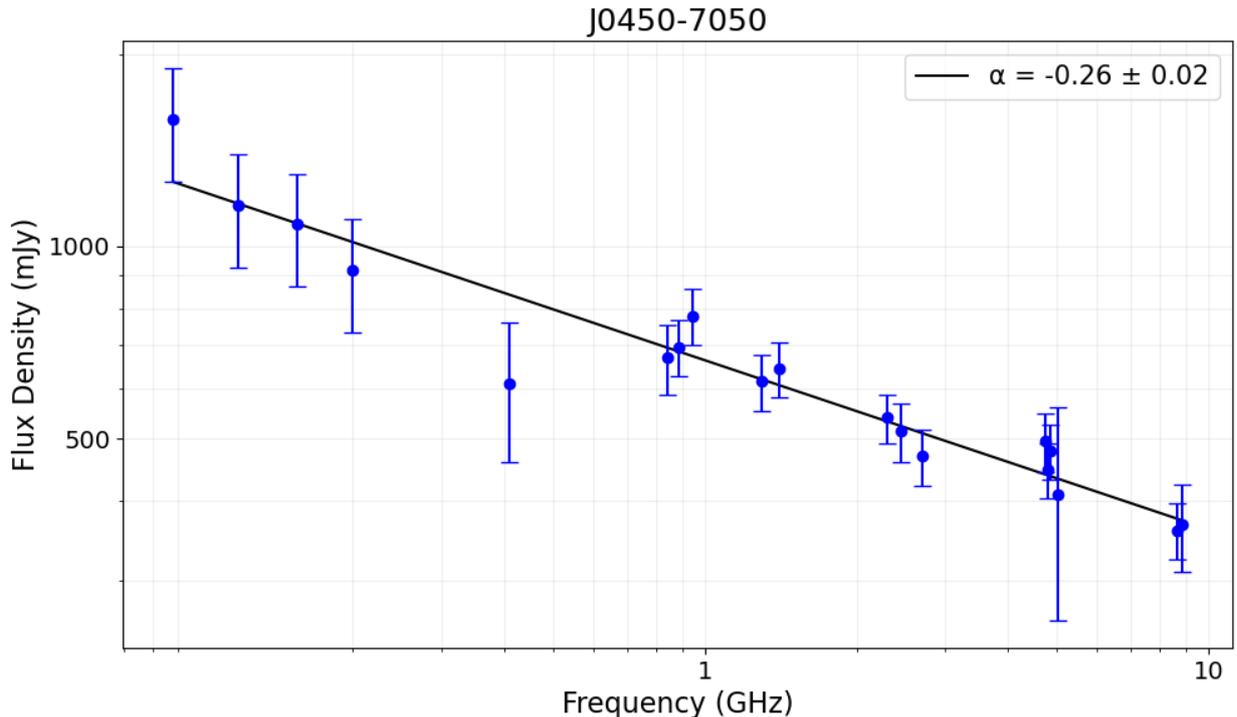


Fig. 6: Spectral index graph of Veliki using flux density values from Table 1. A linear power law is fit and the slope is taken as the spectral index. The quoted error only includes the statistical error of the fit.

terpretation of this magnetic field structure should be taken with caution.

3.5. Magnetic field

We can estimate the strength of the magnetic field in Veliki using an adapted equipartition calculation, following the method outlined in Filipović *et al.* (2023). We use the calculated values of spectral index $\alpha = 0.26^4$ and flux density at 1 GHz $S_{1\text{ GHz}} = 0.66\text{ Jy}$, and assume values of shock velocity $v = 170\text{ km s}^{-1}$, speed of sound in the interstellar medium (ISM) $c_s = 10\text{ km s}^{-1}$, filling factor $f = 0.25$, compression ratio $r \approx 4$ and injection parameter $\xi \approx 4$, for strong non-modified shocks, and equal proton and electron temperatures $T_p = T_e$. The value of $\xi \approx 4$ assumes a non-modified shock, and the assumed shock velocity in the ambient medium will give a compression ratio $r \approx 4$, consistent with a strong shock. Assuming electron equipartition, we find $B = 20.0\text{ }\mu\text{G}$ in an ambient field of $6.1\text{ }\mu\text{G}$, and assuming proton equipartition we find $B = 68.9\text{ }\mu\text{G}$ in an ambient field of $21.0\text{ }\mu\text{G}$.

⁴This paper primarily uses the notation of $S \propto \nu^\alpha$ which gives a spectral index value of $\alpha = -0.26$. This equation uses the opposite, equally correct, notation of $S \propto \nu^{-\alpha}$, therefore flipping the sign of the radio spectral index value.

4. DISCUSSION

4.1. Veliki’s size

Veliki was already one of the largest SNRs in the LMC, and the newly visible filamentary structure extends its size even further to $150 \times 81\text{ pc}$. There is the possibility that these blowout structures may not represent the SNR shell, but could potentially be leaked ionising radiation rather than physical matter. We observe a web-like or patchy structure in the radio emission over the SNR (see Fig. 2) which may indicate a porous ISM, expected in lower metallicity environments such as the LMC (Dimaratos *et al.* 2015). This porosity could facilitate the leakage of ionising radiation through channels of lower density material, naturally creating features that resemble physical blowouts. The spectral index appears to be flatter at the edges (see Fig. 7), however, it is difficult to say this with certainty due to the cut used to generate the map, as the uncertainties were significantly higher in the filamentary areas. This leakage is a more likely scenario for the southern filaments, as the optical [SII]/H α shell does not extend to the outermost radio emission in this direction. Therefore, the southern filamentary structure may not be part of the physical structure.

Even with this caveat, however, Veliki is still one of the largest in the LMC. The only confirmed larger LMC SNR is MCSNR J0507–6847 with a physical diameter of $\sim 150\text{ pc}$ (Chu *et al.* 2000, Maitra

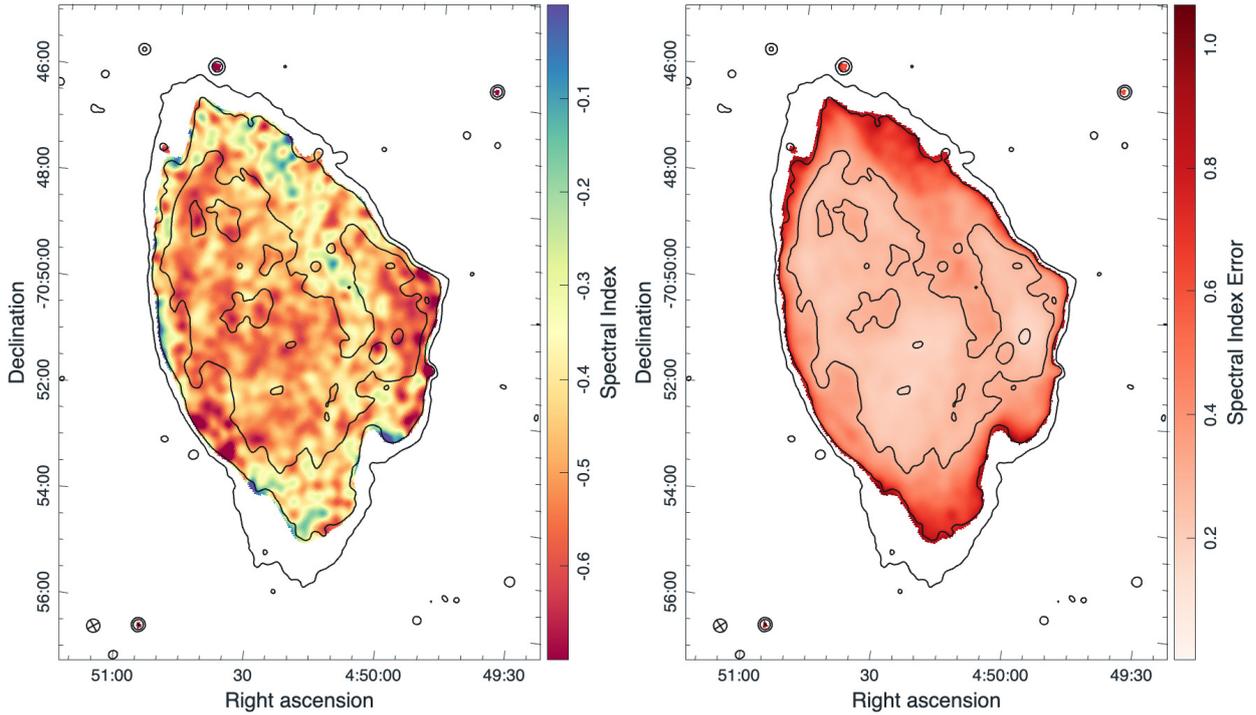


Fig. 7: Spectral index map and error map of Veliki created using the ASKAP EMU data at 888 and 944 MHz, and MeerKAT data at 1.3 GHz. Final images have synthesised beam sizes of $15'' \times 15''$ shown in the bottom left corners. The contours are radio-continuum contours from the MeerKAT 1.3 GHz image at levels of 0.05, 0.15, 0.40, and 0.70 mJy beam^{-1} . **Left** is spectral index map and **right** is spectral index map error, generated as described in text.

et al. 2021, Zangrandi et al. 2024), which is exclusively seen at X-ray frequencies. Veliki’s size is large when compared with other galaxies as well. The largest confirmed SMC SNR is J0056–7209 (Haberl et al. 2012, Maggi et al. 2019) with a physical size of $99 \times 65 \text{ pc}$ (Maggi et al. 2019).

A physical size comparison is more difficult with the Galactic SNR population due to distance uncertainties. There are some Galactic SNRs that may reach the physical size of Veliki, depending on which distance estimate is used. These include G278.94+1.35 (Diprotodon) which may reach up to $157 \times 154 \text{ pc}$ (Filipović et al. 2024), G65.1+0.6 which may reach up to $179.5 \times 179.5 \text{ pc}$ (Vukotić et al. 2019), and G312.4–0.4 which may reach up to $154.8 \times 154.8 \text{ pc}$ (Vukotić et al. 2019). The distances to these Galactic SNRs are debated in the literature, however, and thus their physical sizes may be significantly smaller.

We also compare Veliki’s radio surface brightness with these similarly sized SNRs. We measure Veliki as having $\Sigma = 1.7 \times 10^{-21} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1}$. Of these compared SNRs, only G312.4–0.4 is brighter at $\Sigma = 4.7 \times 10^{-21} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1}$ (Vukotić et al. 2019). The other SNRs compared are approximately an order of magnitude dimmer, with G278.94+1.35 (Diprotodon) having $\Sigma = 1.3 \times 10^{-22} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1}$ (Filipović

et al. 2024), and G65.1+0.6 having $\Sigma = 2 \times 10^{-22} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1}$ (Vukotić et al. 2019). We also use the Σ -D relationship of Pavlović et al. (2018) to compare Veliki’s properties with those of a larger SNR sample (see Fig. 9, from their Fig. 3). Veliki falls outside of the predicted SNR evolutionary tracks, demonstrating that its combination of larger size and brighter radio emission is an outlier in the typical SNR sample.

The compared SNRs are likely expanding in a rarefied environment, for example, in the case of MC-SNR J0507–6847 (Chu et al. 2000, Maitra et al. 2021) and Diprotodon (Filipović et al. 2024), whose larger size is attributed to this rarefied ambient density and their older age. Conversely, Veliki is predicted to be expanding into an ambient density of $\sim 0.3 - 0.5 \text{ cm}^{-3}$ (Williams et al. 2004), and this higher density environment may help to explain the brighter radio emission.

4.2. Environment

The LMC environment has a lower metallicity than the Milky Way (MW) (Rolleston et al. 2002), which is theoretically expected to impact the radiative cooling efficiency of SNRs. As radiative cooling is typically dominated by metal line emission, lower metallicity environments have reduced cooling efficiency (Thornton et al. 1998). Thus, it would

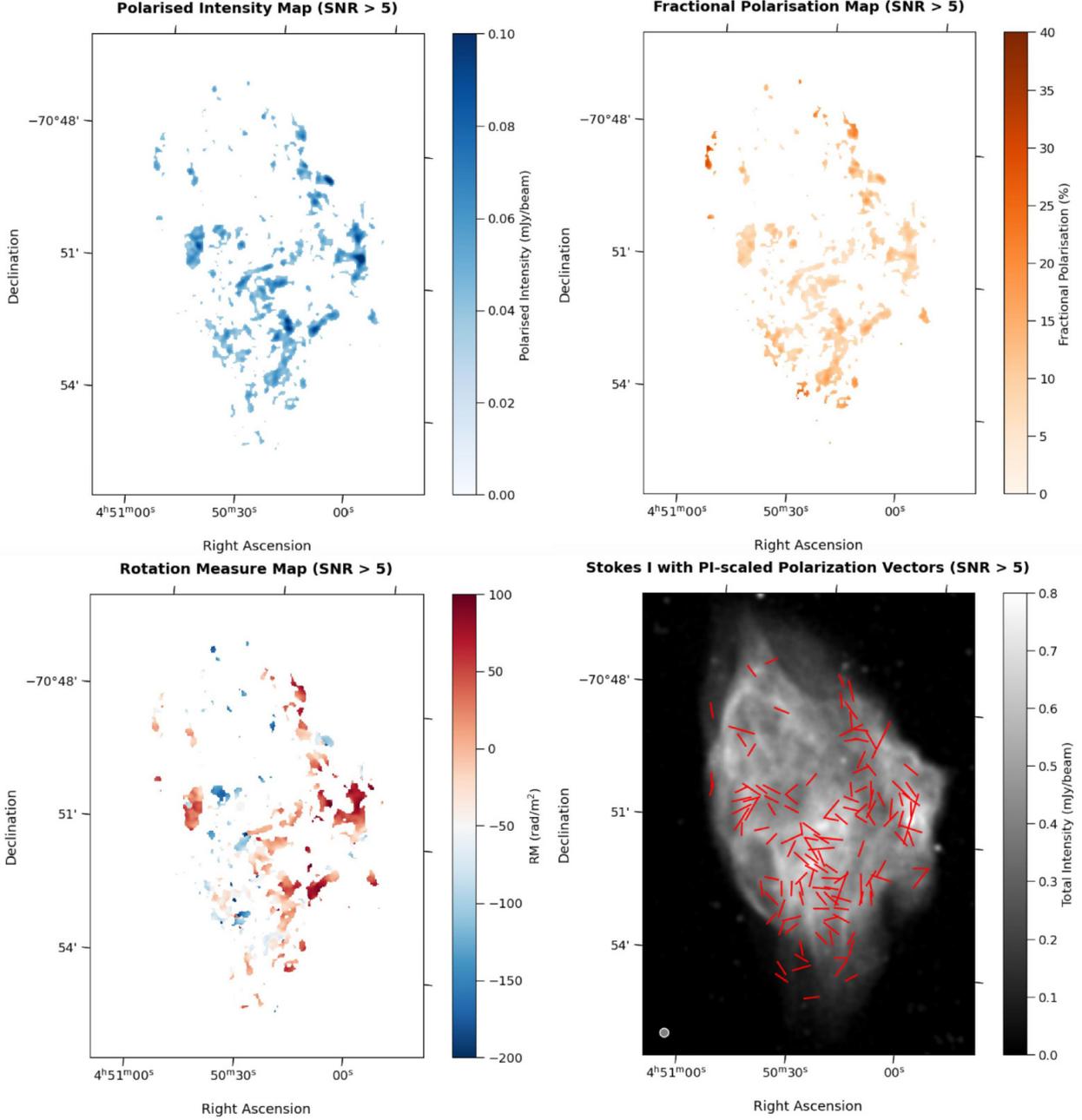


Fig. 8: Polarisation and RM output from the RM synthesis analysis described in text. All images have been cut at a signal to noise ratio of 5σ . **Top left** is polarised intensity, **top right** is fractional polarisation, **bottom left** is rotation measure (RM), and **bottom right** is magnetic field vectors overlaid over the Stokes I total intensity image. Background Stokes I image is linearly scaled and has a beam size of $8'' \times 8''$ shown in the bottom left corner.

be expected for LMC SNRs to remain in the adiabatic phase for longer than their respective Galactic counterparts. More recent LMC surveys have also detected metallicity gradients within the LMC, with the lowest metallicities observed in the southwest (Choudhury *et al.* 2021), corresponding with Veliki's location. Veliki's properties display that it is now dominated by the swept-up ISM rather than the inner ejecta, meaning that this delayed cooling

may have a significant impact on the observed morphology. Thus, this environment may explain Veliki's size and radio brightness if the onset of cooling were delayed.

We also note a molecular cloud PGCC G282.62-35.35 with IR and CO emission detected to the west-north-west of Veliki, located just outside of the shell. We see no obvious radio-continuum signs that the SNR is significantly interacting, such as

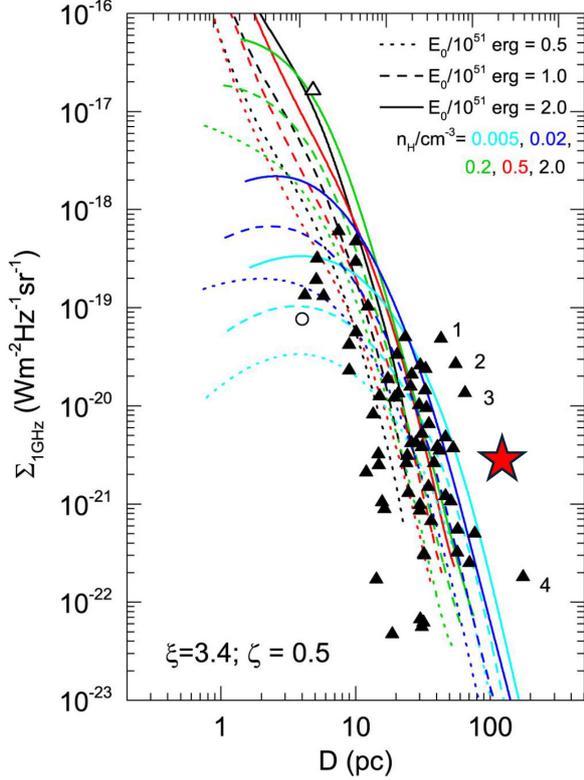


Fig. 9: Radio surface brightness to diameter diagram for SNRs at frequency $\nu = 1$ GHz, adopted from Pavlović et al. (2018, their Fig. 3), shown as black triangles. Different line colours represent different ambient densities, while different line types represent different explosion energies. The open circle is young Galactic SNR G1.9+0.3 (Luken et al. 2020), and the open triangle represents Cassiopeia A. The numbers represent SNRs (1): CTB 37A, (2): Kes 97, (3): CTB 37B, and (4): G65.1+0.6. The red star represents Veliki at estimated surface brightness of $1.7 \times 10^{-21} \text{ W m}^{-2} \text{ Hz}^{-2} \text{ sr}^{-1}$ and diameter of 150 pc (the diameter is taken as the major axis). The image shows evolutionary tracks for representative cases with injection parameter $\xi = 3.4$ and nonlinear magnetic field damping parameter $\zeta = 0.5$.

limb brightening or distinct changes in morphology at this location, as seen in other SNRs with molecular cloud interaction (e.g. G166.0+4.3 (Landecker et al. 1989); Puppis A (Dubner et al. 1991); G119.5+10.3 (Pineault et al. 1997); G18.8+0.3 (Dubner et al. 1999); N63A (Sano et al. 2019); G46.8-0.3 (Supan et al. 2022); N49 (Sano et al. 2023, Ghavam et al. 2024)). Veliki also appears in the analysis of IR properties of SNRs in the LMC of Lakićević et al. (2015), where it is concluded that it is interacting, or about to interact, with the surrounding clouds. Using ratios of different *Herschel* IR data, they show that the dust temperatures and hydrogen column densities are consistent inside and outside of the SNR, indicating that there is no current signif-

icant dust heating or sputtering. It is possible that their spatial correlation is due to a projection effect, the objects are simply in the same line of sight but at different physical locations within the LMC. Conversely, it is possible that there is a current interaction but it is not resulting in significant heating and sputtering, due to slower radiative shocks. Once Veliki’s shocks have significantly slowed down and entered the radiative phase, it is possible that the interacting cloud material has settled down and entered into equilibrium inside and outside the SNR, resulting in the observed IR ratios (Lakićević et al. 2015). This scenario would also be consistent with the [OIII] excess observed on the opposite rim compared to the molecular cloud, as this interaction may have caused the western edge to cool down faster due to the interaction.

Previous results also suggest expansion into an ambient density $\sim 0.3\text{--}0.5 \text{ cm}^{-3}$ (Williams et al. 2004) which is well below molecular cloud densities (Fukui et al. 2009). Therefore, it is possible that Veliki is interacting with the molecular cloud, however, the current data is not conclusive in this regard. Further observations, particularly in the γ -ray domain, would be useful for detecting and constraining any molecular cloud interaction.

The integrated HI data (see Fig. 5, panel (a)), shows a density gradient across the SNR. Denser HI material is seen on the western rim compared to the eastern, and the eastern rim shows a smoother radio-continuum structure. This density gradient is supported by Veliki’s elliptical morphology which is more constrained on the east and west edges with an observed blowout structure in the north and south. Such blowout structures are observed in other SNRs with such density gradients (e.g. SNR J0455-6838 (Crawford et al. 2008); SNR S147 (Xiao et al. 2008); G309.2-00.6 (Gaensler et al. 1998)). We also observe an excess of [OIII] emission on the eastern edge, corresponding with the lower density medium. This emission may be due to a faster, more energetic shock in this area, or it may be due to this rim cooling slower than the rest of the SNR, both scenarios which are consistent with expansion into a lower density. These results strongly support a density gradient in the surrounding medium.

We also detect an expanding HI shell in the p - v HI diagram at the LMC velocity range (see Fig. 5, panel (b)). Such a cavity can be caused if the progenitor star’s stellar winds shaped the surrounding environment. In the case of Veliki, this may have formed an axialsymmetric cavity into which the expansion occurred, explaining the barrel-like morphology and observed north-south outflows. This has been observed in some SNRs such as G290.1-0.8 (Slane et al. 2002), G166.0+4.3 (Bocchino et al. 2009), and W49B (Zhu et al. 2014). For an SNR as evolved as Veliki, the expansion likely would have already reached the boundary of the initial cavity, as shown by the spatial correlation within Veliki’s shell, and thus the expanding

HI may be a combination of the initial progenitor's stellar wind and the expanding shockfront.

4.3. Evolutionary phase

Veliki's optical properties are consistent with an almost fully radiative SNR, with the [SII]/H α emission forming a filamentary shell across the entire SNR. The H α emission indicates areas where the post-shock gas has cooled sufficiently to enable recombination (Raymond 1979, Vink 2020). The [SII] emission acts as a tracer of radiative shocks (Vučićić *et al.* 2023), and the strong [SII]/H α correlation indicates predominantly radiative shocks.

One possible exception to this is the strong [OIII] emission observed in the eastern shell. This emission may be caused by faster, more energetic shocks in this region (Dopita and Sutherland 1996). This faster expansion would likely be due to the external density gradient, and may indicate a region of non-radiative expansion. Older SNRs can display both radiative and non-radiative shock fronts due to their complex morphology (Vink 2020), even when the whole SNR is predominantly radiative. This phenomenon has been studied in detail for some SNRs, such as RCW 86 (Vink *et al.* 2006, Yamaguchi *et al.* 2016) and Cygnus Loop (Salvesen *et al.* 2009, Vučićić *et al.* 2023).

Conversely, the observed [OIII] emission may be due to different cooling rates over the SNR. Due to the lower density on this side of the SNR, this scenario may be more likely than the stronger shock scenario. While the shell may expand faster within a lower density medium, if there is not a sufficient ambient material present, then strong shocks capable of producing [OIII] emission are less likely. On the other hand, expansion into a lower density will reduce the cooling rate, and thus this edge may be cooling more slowly than the rest of the SNR. In this case, the [OIII] emission would be due to higher temperatures in this area, and would not necessarily indicate non-radiative shocks.

Thus, the optical morphology indicates that Veliki is either fully radiative with an area of higher temperatures on the eastern side, or predominantly radiative with a small area of non-radiative expansion. It should be noted that the previous X-ray models (Williams *et al.* 2004) indicate that the interior X-ray emission still has sufficient thermal pressure to drive expansion, suggesting that Veliki may not be solely momentum-driven, and thus could potentially support areas of non-radiative expansion.

4.3.1. Evolutionary modelling

We also apply the SNR evolution model of Leahy and Williams (2017) and Leahy *et al.* (2019) using the measured X-ray temperature and emission measure from Maggi *et al.* (2016) with the new mean radius measured from the high-resolution MeerKAT data. Standard forward shock models, with various

ejecta power-law indices, and the cloudy ISM model, appropriate to MM SNRs, were explored. All models yielded explosion energies of $\simeq 8.6 \times 10^{51}$ ergs, ages of $\simeq 43000$ yr, and ISM densities of $7 \times 10^{-2} \text{ cm}^{-3}$ (standard models) or 2 to $5 \times 10^{-2} \text{ cm}^{-3}$ (cloudy models). The estimated age ranges are in agreement with the previous results of Williams *et al.* (2004), however, the modelled ambient densities are approximately an order of magnitude lower. The previous measurements relied on measuring the H α emission measure in the filamentary optical shell, while the model results give the intercloud density of the ISM as described in (White and Long 1991). This may explain the difference in density estimates if the H α filaments are representing radiative shocks as they propagate through the denser intercloud medium.

The high explosion energy is required to reproduce Veliki's larger size with the measured high emission measure. This higher explosion energy scenario is also supported by Veliki's location on the Σ -D evolutionary diagram (see Fig. 9). While Veliki is an outlier in this distribution, it is offset to the higher explosion energy side. Such high explosion energies are not uncommon, e.g. based on chemical evolution models of the Galaxy (Kobayashi *et al.* 2006), and models of SNR populations (Leahy 2017, Leahy *et al.* 2020, Leahy and Filipović 2022). The models also yield the transition times to the radiative phase, which are $\simeq 95,000$ yr. This would suggest that Veliki is not fully radiative despite the observed radiative shell. This discrepancy can be explained in the cloudy model if the shocks are propagating within the clouds. Propagation through this denser material could cause these shocks to become radiative before the intercloud shocks, and thus could explain how we can see a filamentary radiative shell prior to the transition time.

This scenario would result in a higher compression ratio in the clouds and would explain the optical filamentary structure as well as the higher-than-expected radio surface brightness. An issue with this scenario is the absence of non-radiative filaments over the SNR. If these radiative shocks were attributed only to the propagation through the clouds, we would still expect to see the non-radiative filaments from the intercloud regions. This would likely result in a scenario where we see both the radiative and non-radiative shocks anti-correlating with each other, a scenario not observed in Veliki. The absence of any observed non-radiative shocks may argue against this scenario but does not rule it out.

4.4. Spectral Index

The measured spectral index value of $\alpha = -0.26 \pm 0.02$ is flatter than expected for an SNR. This value is flatter than the previously measured value of $\alpha = -0.43 \pm 0.06$ (Čajko *et al.* 2009), as well as flatter than the observed average for the LMC population (Maggi *et al.* 2016, Bozzetto *et al.* 2017) and the theoretical value of $\alpha = -0.5$ (Bell 1978).

The observed spectral index values of SNRs are typically attributed to the diffuse shock acceleration (DSA) theory (Bell 1978, Reynolds and Ellison 1992, Urošević 2014). The standard DSA theory predicts that the spectral index should steepen as an SNR ages, as the particle acceleration becomes less efficient and thus the corresponding shock and compression ratio becomes weaker (Onić 2013, Urošević 2014). This is observed in the majority of evolved SNRs which exhibit a spectral index $-0.6 < \alpha < -0.5$ (Ferrand and Safi-Harb 2012, Ranasinghe and Leahy 2023, Green 2025). However, there are several possible mechanisms that can act to flatten an SNR's spectral index.

4.4.1. Morphology types with flatter indices

Some SNR morphology types are naturally expected to have flatter spectral indices and this is observed in numerous SNRs (Ferrand and Safi-Harb 2012, Ranasinghe and Leahy 2023, Green 2025). For example, composite SNRs host a central PWN, and are expected to have a flatter overall spectral index due to the PWN contribution (average $\alpha = -0.41$ for Galactic population (Ranasinghe and Leahy 2023)). We observe no obvious PWN within the radio images (see Fig. 2) nor any spectral variation (see Fig. 7) that may indicate this possibility. There is also no observed radio or X-ray point source that may indicate a central pulsar. Veliki appears as a typical shell-type SNR, and thus we deem this scenario unlikely.

Another class of SNRs with theoretically predicted flatter spectral indices are the MM (or filled-centre or thermal composite) remnants (Rho and Petre 1998). While Veliki is classified as a MM SNR, their flatter spectral index (average $\alpha = -0.34$ for Galactic population (Ranasinghe and Leahy 2023)) is generally attributed to environmental interactions (Rho and Petre 1998). γ -ray observations could help constrain this possibility, particularly as they could determine a potential molecular cloud interaction. For example, γ -ray observations consistent with hadronic emission from neutral pion decay would give support to the molecular cloud interaction scenario (Uchiyama et al. 2010), but this data are not currently available. Future γ -ray observations could help constrain this scenario. As there is not sufficient evidence to determine interaction with a denser environment (see Section 4.2), and so this scenario is left as a possibility.

4.4.2. Second-order Fermi acceleration

One suggested mechanism that may cause radio spectral index flattening is the combination of DSA with the second-order Fermi acceleration (Onić 2013, Urošević 2014). In this scenario, particles initially accelerated by the shock front undergo further stochastic acceleration through interactions with magnetic turbulence in the post-shock region (Liu et al. 2008, Cho and Lazarian 2006, Petrosian and Liu 2004). This mechanism depends on magnetic field strengths

and orientations, and is thus highly sensitive to magnetic field variations (Cho and Lazarian 2006, Fan et al. 2010).

Thus, we would expect the magnetic field turbulence and varying shock conditions to correlate with spectral index variations, which is not observed in Veliki. If the second-order Fermi acceleration were the dominant mechanism, then we would expect to see variations in the spectral index map (see Fig. 7) which correlate with the magnetic field turbulence (the rotation measure and fractional polarisation maps, see Fig. 8). If the [OIII] emission does represent non-radiative shocks, then we would also expect to see correlation with these varying shock conditions. As no such correlations are seen, this argues against the second-order Fermi acceleration as a dominant mechanism.

4.4.3. Thermal contribution

Some evolved SNRs can have a significant thermal bremsstrahlung contribution which flattens the spectral index as they sweep up significant amounts of interstellar material (Urošević and Pannuti 2005, Onić et al. 2012, Onić 2013, Urošević 2014). Additionally, MM SNRs can have a significant thermal bremsstrahlung contribution, either attributed to denser environment interactions which is typical for MM SNRs, or contribution from the X-ray filled interior (Onić et al. 2012, Vink 2012). There is no evidence for sufficiently dense environmental interactions following the arguments from previous sections (see Sections 4.2 for prior discussion). It is also unlikely that any significant thermal contribution is attributed to the thermal X-ray emission, as this would cause spectral variation to correlate with the interior X-ray emission, which is not observed.

Thermal bremsstrahlung contribution is theoretically expected for evolutionarily old SNRs, particularly SNRs in the radiative phase of evolution. Radiative SNRs with a high compression ratio can have sufficient amounts of high density ionised material in the downstream region to generate significant thermal bremsstrahlung contribution.

To test this scenario, we model the spectral index of Veliki as a combination of thermal and non-thermal components using a two-component model similar to the method of Onić et al. (2012), where we define $\alpha_{\text{total}} = \alpha_{\text{thermal}} + \alpha_{\text{non-thermal}}$. For a rough estimate, we restrict the expected values to $\alpha_{\text{thermal}} = -0.1$ and $\alpha_{\text{non-thermal}} = -0.5$. This model required a thermal contribution of 58.6% at 1 GHz and achieves a reduced χ^2 value of 0.664, representing a relatively good fit for the data. This is a significant thermal contribution, but is still possible from older SNRs. For example, the analysis of Onić et al. (2012) show a thermal contribution for IC 443 of 3–57% (Onić et al. 2012).

Some potential problems with this scenario are the lack of spectral curvature and the absence of a low-frequency spectral turnover in our observed spec-

trum (see Fig. 6). Thermal bremsstrahlung contribution is expected to begin to dominate at higher frequencies, and can result in a flattening at higher frequencies and thus a curved spectrum (Reynolds 2008, Onić *et al.* 2012, Urošević 2014), as observed in other SNRs (e.g. IC 443, 3C 391, 3C 396 (Onić *et al.* 2012); HB3 (Tian and Leahy 2005, Urošević *et al.* 2007, Onić and Urošević 2008)). We measure the flux densities over a broad frequency range (88–8850 GHz) and observe no such spectral curvature. The absence of spectral curvature does not preclude thermal bremsstrahlung contribution, however, as the amount of curvature can be very low and can easily be lost in the scatter of the data points.

Low-frequency spectral turnovers are observed in some SNRs, and can be a sign of possible thermal bremsstrahlung emission at higher frequencies, such as in the cases of 3C 391 and IC 443 (Brogan *et al.* 2005, Onić *et al.* 2012). The absence of such a turnover in Veliki’s spectrum does not preclude thermal bremsstrahlung contribution, however. In evolved SNRs, the thermal plasma can be more diffuse, thus having a lower optical depth and potentially shifting the absorption turnover to frequencies below our observational range (<88 MHz). This thermal emission can still contribute at higher radio frequencies where bremsstrahlung dominates over absorption effects, thus resulting in an overall flatter spectral index with no observed spectral turnover. This is consistent with a more evolved SNR such as Veliki, where the plasma may be more diffuse than in younger SNRs such as 3C 391 and IC 443. Additional spectral index data points in the microwave and infrared domain would significantly help to constrain the integrated radio spectral index and thus help to distinguish between synchrotron and thermal bremsstrahlung emission components.

Both spectral curvature and a low-frequency spectral turnover are seen in some SNRs with thermal contribution, however, their absence does not preclude this possibility, particularly for an evolved SNR. Therefore, thermal contribution is likely a contributing factor to the spectral index flattening.

4.4.4. Higher compression ratio

The final mechanism we consider is that of spectral index flattening caused by a high compression ratio. In standard DSA theory, the energy spectrum of accelerated particles is affected by the shock compression ratio (Onić 2013, Urošević 2014). Typically, the relationship between the radio spectral index α and compression ratio r is given by $\alpha = 3/(2(r-1))$. Our measured spectral index of $\alpha = 0.26 \pm 0.02^5$ corresponds to a compression ratio of $r \sim 6.8$, thus exceeding the standard limit of $r = 4$ for strong adiabatic

⁵This paper primarily uses the notation of $S \propto \nu^\alpha$ which gives a spectral index value of $\alpha = -0.26$. This compression ratio equation is derived from the DSA theory and thus uses the opposite, equally correct, notation of $S \propto \nu^{-\alpha}$, therefore flipping the sign of the radio spectral index value.

shocks in an ideal gas. Higher compression ratios are theoretically expected in fully radiative shocks, with $r = M_T^2$, where M_T is the isothermal Mach number (Urošević 2014). For example, for radiative shocks of $\sim 100\text{--}200 \text{ km s}^{-1}$, the compression ratio can reach values as high as $\sim 100\text{--}400$ (assuming a typical speed of sound in the ISM of $v_c \sim 10 \text{ km s}^{-1}$). Therefore, if the DSA theory is still accurate for fully radiative shocks, this is expected to significantly flatten the particle spectrum and, naturally, produce a flatter radio spectral index. See the studies of Onić (2013) and Urošević (2014) and references therein for more theoretical details.

Multiple lines of evidence support this scenario for Veliki. Older SNRs such as Veliki are expected to naturally have higher compression ratios as the shocks become radiative and the expansion slows down. Therefore, Veliki’s prominent radiative shell may indicate a significant deceleration in the shell and a higher compression. The derived magnetic field is slightly higher than expected for older SNRs. For example, the Galactic SNRs Ancora and Diprotodon have predicted values of $7.7 \mu\text{G}$ (for electron equipartition) or $41.7 \mu\text{G}$ (for proton equipartition), and $13.7\text{--}19.6 \mu\text{G}$ (depending on the distance estimate used), respectively. The higher magnetic field observed in Veliki can be explained by a higher compression ratio, as this compression would also compress, and thus strengthen, the swept-up magnetic field.

This scenario is also supported by the uniform spectral index. As the compression ratio increase is due to the radiative shell which encompasses the entire remnant, it would naturally result in a roughly equal flattening over the entire SNR.

4.5. What is Veliki?

Several mechanisms can be responsible for Veliki’s observed properties, particularly the bright radio surface brightness and flat spectral index. With the evidence available we determine that the most likely scenario is that of a fully radiative SNR, with spectral flattening due to thermal bremsstrahlung contribution and a higher compression ratio.

This scenario is the simplest model to explain the observed properties. It posits that Veliki is fully within the radiative phase, and these radiative shocks have sufficiently cooled and decelerated to increase compression. This higher compression ratio would provide the high density ionised material in the downstream region, resulting in thermal bremsstrahlung contribution. It would also compress the swept-up magnetic field, increasing the magnetic field strength and synchrotron emission in the shell. This combination would result in the high radio surface brightness.

Veliki’s larger size can be attributed to its expansion into the lower metallicity environment of the LMC, where the cooling would likely have been delayed. Thus, Veliki would remain in the adiabatic phase for longer and expand to a larger size. The asymmetric morphology indicates that there is an ex-

ternal density gradient, with denser material along the east-west axis and less dense material in the north-south, resulting in the blowout and barrel-shaped structure. It is possible that Veliki is also the result of a higher energy explosion, as predicted by the previous models (see Section. 4.3), which would help explain the brighter radio surface brightness and larger size.

5. CONCLUSIONS

The new high-resolution radio observations of the LMC SNR Veliki show previously unseen faint filamentary structures extending out of the north and south of the remnant. This increases the extent of Veliki to 150×81 pc, making it one of the largest SNRs in the LMC. Additionally, it has an unusually high radio surface-brightness, approximately an order of magnitude brighter than other SNRs or comparable size, and has one of the lowest average radio spectral indices ($\alpha = -0.26 \pm 0.02$). We observe a bright [SiII]/H α shell over the remnant indicating predominantly radiative shocks, as well as higher temperatures or faster, possibly non-radiative, shocks on the eastern rim shown by an excess of the [OIII] emission.

We investigate several theoretical scenarios to explain these unusual properties. We determine that Veliki is most likely a fully radiative SNR and the flatter spectral index and brighter surface brightness are attributed to a higher compression ratio and possible thermal bremsstrahlung contamination. We also consider the alternative scenario of the observed properties resulting from expansion into a cloudy ISM, resulting in a variable compression ratio and causing the shocks to become radiative and flattening the spectral index.

Veliki may also have had a higher explosion energy ($\sim 8.6 \times 10^{51}$ ergs), explaining the brighter radio surface brightness and larger size. The larger size can also be explained by expansion into a lower metallicity LMC environment. Both the listed scenarios can potentially explain Veliki's properties, and more observations are required to fully differentiate between them. In particular, observations that can better constrain Veliki's environment, are vital to fully determine Veliki's nature.

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REFERENCES

- Acharyya, A., Adam, R., Aguasca-Cabot, A., et al. 2023, *MNRAS*, **523**, 5353
- Anderson, L. D., Camilo, F., Faerber, T., et al. 2025, *A&A*, **693**, A247
- Ball, B. D., Kothes, R., Rosolowsky, E., et al. 2023, *MNRAS*, **524**, 1396
- Bell, A. R. 1978, *MNRAS*, **182**, 147
- Blair, W. P., Ghavamian, P., Sankrit, R. and Danforth, C. W. 2006, *ApJS*, **165**, 480
- Bocchino, F., Miceli, M. and Troja, E. 2009, *A&A*, **498**, 139
- Bozzetto, L. M., Filipovic, M. D., Haberl, F., et al. 2015, *Publication of Korean Astronomical Society*, **30**, 149
- Bozzetto, L. M., Filipović, M. D., Vukotić, B., et al. 2017, *ApJS*, **230**, 2
- Bozzetto, L. M., Filipović, M. D., Sano, H., et al. 2023, *MNRAS*, **518**, 2574

⁶<http://www.atnf.csiro.au>

- Bradley, A. C., Smeaton, Z. J., Tothill, N. F. H., et al. 2025, *PASA*, **42**, e032
- Brogan, C. L., Lazio, T. J., Kassim, N. E. and Dyer, K. K. 2005, *AJ*, **130**, 148
- Burger-Scheidlin, C., Brose, R., Mackey, J., et al. 2024, *A&A*, **684**, A150
- Čajko, K. O., Crawford, E. J. and Filipović, M. D. 2009, *SerAJ*, **179**, 55
- Cho, J. and Lazarian, A. 2006, *ApJ*, **638**, 811
- Choudhury, S., de Grijs, R., Bekki, K., et al. 2021, *MNRAS*, **507**, 4752
- Chu, Y.-H., Kim, S., Points, S. D., Petre, R. and Snowden, S. L. 2000, *AJ*, **119**, 2242
- Clarke, J. N., Little, A. G. and Mills, B. Y. 1976, *Australian Journal of Physics Astrophysical Supplement*, **40**, 1
- Comrie, A., Wang, K.-S., Hsu, S.-C., et al. 2021, *CARTA: Cube Analysis and Rendering Tool for Astronomy*, Astrophysics Source Code Library, record ascl:2103.031
- Cotton, W. D., Filipović, M. D., Camilo, F., et al. 2024a, *MNRAS*, **529**, 2443
- Cotton, W. D., Kothes, R., Camilo, F., et al. 2024b, *ApJS*, **270**, 21
- Crawford, E. J., Filipović, M. D., de Horta, A. Y., Stootman, F. H. and Payne, J. L. 2008, *SerAJ*, **177**, 61
- Dimaratos, A., Cormier, D., Bigiel, F. and Madden, S. C. 2015, *A&A*, **580**, A135
- Dopita, M. A. and Sutherland, R. S. 1996, *ApJS*, **102**, 161
- Dubner, G., Giacani, E., Reynoso, E., et al. 1999, *AJ*, **118**, 930
- Dubner, G. M., Braun, R., Winkler, P. F. and Goss, W. M. 1991, *AJ*, **101**, 1466
- Fan, Z., Liu, S. and Fryer, C. L. 2010, *MNRAS*, **406**, 1337
- Ferrand, G. and Safi-Harb, S. 2012, *AdSpR*, **49**, 1313
- Filipović, M. D. and Tothill, N. F. H. 2021, *Principles of Multimessenger Astronomy*, 2514 (Bristol: IOP Publishing)
- Filipović, M. D., Haynes, R. F., White, G. L., et al. 1995, *A&AS*, **111**, 311
- Filipović, M. D., White, G. L., Haynes, R. F., et al. 1996a, *A&AS*, **120**, 77
- Filipovic, M. D., White, G. L., Jones, P. A., et al. 1996b, in *Astronomical Society of the Pacific Conference Series*, Vol. 112, *The History of the Milky Way and Its Satellite System*, ed. A. Burkert, D. H. Hartmann, and S. A. Majewski, 91
- Filipović, M. D., Haynes, R. F., White, G. L. and Jones, P. A. 1998, *A&AS*, **130**, 421
- Filipović, M. D., Haberl, F., Winkler, P. F., et al. 2008, *A&A*, **485**, 63
- Filipović, M. D., Bojičić, I. S., Grieve, K. R., et al. 2021, *MNRAS*, **507**, 2885
- Filipović, M. D., Payne, J. L., Alsaberi, R. Z. E., et al. 2022, *MNRAS*, **512**, 265
- Filipović, M. D., Dai, S., Arbutina, B., et al. 2023, *AJ*, **166**, 149
- Filipović, M. D., Lazarević, S., Araya, M., et al. 2024, *PASA*, **41**, e112
- Filipovic, M. D., Smeaton, Z. J., Kothes, R., et al. 2025, [arXiv:2505.04041](https://arxiv.org/abs/2505.04041), (DOI: 10.48550/arXiv.2505.04041)
- For, B. -Q., Staveley-Smith, L., Hurley-Walker, N., et al. 2018, *MNRAS*, **480**, 2743
- Fukui, Y., Kawamura, A., Wong, T., et al. 2009, *ApJ*, **705**, 144
- Gaensler, B. M., Green, A. J. and Manchester, R. N. 1998, *MNRAS*, **299**, 812
- Galvin, T. J. and Filipović, M. D. 2014, *SerAJ*, **189**, 15
- Galvin, T. J., Filipović, M. D., Crawford, E. J., et al. 2012, *Ap&SS*, **340**, 133
- Galvin, T. J., Filipović, M. D., Tothill, N. F. H., et al. 2014, *Ap&SS*, **353**, 603
- Ghavam, M., Filipović, M. D., Alsaberi, R., et al. 2024, *PASA*, **41**, e089
- Goedhart, S., Cotton, W. D., Camilo, F., et al. 2024, *MNRAS*, **531**, 649
- Green, D. A. 2025, *JApA*, **46**, 14
- Guzman, J., Whiting, M., Voronkov, M., et al. 2019, *ASKAPsoft: ASKAP science data processor software*, Astrophysics Source Code Library, record ascl:1912.003
- Haberl, F. 2014, in *The X-ray Universe 2014*, ed. J.-U. Ness, 4
- Haberl, F., Sturm, R., Filipović, M. D., Pietsch, W. and Crawford, E. J. 2012, *A&A*, **537**, L1
- Heald, G. 2009, in *IAU Symposium*, Vol. 259, *Cosmic Magnetic Fields: From Planets, to Stars and Galaxies*, ed. K. G. Strassmeier, A. G. Kosovichev, and J. E. Beckman, 591
- Hopkins, A. M., Kapinska, A., Marvil, J., et al. 2025, [arXiv:2505.08271](https://arxiv.org/abs/2505.08271), (DOI: 10.48550/arXiv.2505.08271)
- Hotan, A. W., Bunton, J. D., Chippendale, A. P., et al. 2021, *PASA*, **38**, e009
- Hurley-Walker, N., Callingham, J. R., Hancock, P. J., et al. 2017, *MNRAS*, **464**, 1146
- Johnston, S., Taylor, R., Bailes, M., et al. 2008, *ExA*, **22**, 151
- Kavanagh, P. J., Sasaki, M., Breitschwerdt, D., et al. 2020, *A&A*, **637**, A12
- Khabibullin, I. I., Churazov, E. M., Bykov, A. M., Chugai, N. N. and Sunyaev, R. A. 2023, *MNRAS*, **521**, 5536
- Kim, S., Staveley-Smith, L., Dopita, M. A., et al. 2003, *ApJS*, **148**, 473
- Kobayashi, C., Umeda, H., Nomoto, K., Tominaga, N. and Ohkubo, T. 2006, *ApJ*, **653**, 1145
- Kothes, R., Reich, P., Foster, T. J. and Reich, W. 2017, *A&A*, **597**, A116
- Lakićević, M., van Loon, J. Th., Meixner, M., et al. 2015, *ApJ*, **799**, 50
- Landecker, T. L., Pineault, S., Routledge, D. and Vanelidik, J. F. 1989, *MNRAS*, **237**, 277
- Lazarević, S., Filipović, M. D., Koribalski, B. S., et al. 2024, *Research Notes of the American Astronomical Society*, **8**, 107
- Leahy, D. A. 2017, *ApJ*, **837**, 36
- Leahy, D. A. and Filipović, M. D. 2022, *ApJ*, **931**, 20
- Leahy, D. A. and Williams, J. E. 2017, *AJ*, **153**, 239
- Leahy, D., Wang, Y., Lawton, B., Ranasinghe, S. and Filipović, M. 2019, *AJ*, **158**, 149

- Leahy, D. A., Ranasinghe, S. and Gelowitz, M. 2020, *ApJS*, **248**, 16
- Liu, S., Fan, Z.-H., Fryer, C. L., Wang, J.-M. and Li, H. 2008, *ApJL*, **683**, L163
- Luken, K. J., Filipović, M. D., Maxted, N. I., et al. 2020, *MNRAS*, **492**, 2606
- Maggi, P., Haberl, F., Kavanagh, P. J., et al. 2016, *A&A*, **585**, A162
- Maggi, P., Filipović, M. D., Vukotić, B., et al. 2019, *A&A*, **631**, A127
- Maitra, C., Haberl, F., Maggi, P., et al. 2021, *MNRAS*, **504**, 326
- Mathewson, D. S. and Clarke, J. N. 1973, *ApJ*, **180**, 725
- Mathewson, D. S., Ford, V. L., Tuohy, I. R., et al. 1985, *ApJS*, **58**, 197
- McGee, R. X., Brooks, J. W. and Batchelor, R. A. 1972, *Australian Journal of Physics*, **25**, 581
- Meixner, M., Gordon, K. D., Indebetouw, R., et al. 2006, *AJ*, **132**, 2268
- Millar, W. C., White, G. L., Filipović, M. D., et al. 2011, *Ap&SS*, **332**, 221
- Millar, W. C., White, G. L. and Filipović, M. D. 2012, *SerAJ*, **184**, 19
- Norris, R. P., Hopkins, A. M., Afonso, J., et al. 2011, *PASA*, **28**, 215
- Norris, R. P., Marvil, J., Collier, J. D., et al. 2021, *PASA*, **38**, e046
- O'Brien, A. N., Filipović, M. D., Crawford, E. J., et al. 2013, *Ap&SS*, **347**, 159
- Onić, D. 2013, *Ap&SS*, **346**, 3
- Onić, D. and Urošević, D. 2008, *SerAJ*, **177**, 67
- Onić, D., Urošević, D., Arbutina, B. and Leahy, D. 2012, *ApJ*, **756**, 61
- Pannuti, T. G., Schlegel, E. M., Filipović, M. D., et al. 2011, *AJ*, **142**, 20
- Pannuti, T. G., Swartz, D. A., Laine, S., et al. 2015, *AJ*, **150**, 91
- Pavlović, M. Z., Urošević, D., Arbutina, B., et al. 2018, *ApJ*, **852**, 84
- Payne, J. L., White, G. L., Filipović, M. D. and Pannuti, T. G. 2007, *MNRAS*, **376**, 1793
- Payne, J. L., White, G. L. and Filipović, M. D. 2008, *MNRAS*, **383**, 1175
- Pennock, C. M., van Loon, J. Th., Filipović, M. D., et al. 2021, *MNRAS*, **506**, 3540
- Petrosian, V. and Liu, S. 2004, *ApJ*, **610**, 550
- Pietrzyński, G., Graczyk, D., Gallenne, A., et al. 2019, *Natur*, **567**, 200
- Pilbratt, G. L., Riedinger, J. R., Passvogel, T., et al. 2010, *A&A*, **518**, L1
- Pineault, S., Landecker, T. L., Swerdlyk, C. M. and Reich, W. 1997, *A&A*, **324**, 1152
- Planck Collaboration, Ade, P. A. R., Aghanim, N., et al. 2016, *A&A*, **594**, A28
- Ranasinghe, S. and Leahy, D. 2023, *ApJS*, **265**, 53
- Raymond, J. C. 1979, *ApJS*, **39**, 1
- Reynolds, S. P. 2008, *ARA&A*, **46**, 89
- Reynolds, S. P. and Ellison, D. C. 1992, *ApJL*, **399**, L75
- Reynolds, S. P., Gaensler, B. M. and Bocchino, F. 2012, *SSRv*, **166**, 231
- Rho, J. and Petre, R. 1998, *ApJL*, **503**, L167
- Rolleston, W. R. J., Trundle, C. and Dufton, P. L. 2002, *A&A*, **396**, 53
- Salvesen, G., Raymond, J. C. and Edgar, R. J. 2009, *ApJ*, **702**, 327
- Sano, H., Matsumura, H., Nagaya, T., et al. 2019, *ApJ*, **873**, 40
- Sano, H., Yamane, Y., van Loon, J. Th., et al. 2023, *ApJ*, **958**, 53
- Slane, P., Smith, R. K., Hughes, J. P. and Petre, R. 2002, *ApJ*, **564**, 284
- Smeaton, Z. J., Filipović, M. D., Koribalski, B. S., et al. 2024, *Research Notes of the American Astronomical Society*, **8**, 158
- Smith, C., Leiton, R. and Pizarro, S. 2000, in *Astronomical Society of the Pacific Conference Series*, Vol. 221, *Stars, Gas and Dust in Galaxies: Exploring the Links*, ed. D. Alloin, K. Olsen and G. Galaz, 83
- Supan, L., Fischetto, G. and Castelletti, G. 2022, *A&A*, **664**, A89
- Theil, H. 1950, *Indagationes mathematicae*, **12**, 173
- Thornton, K., Gaudlitz, M., Janka, H. -Th. and Steinmetz, M. 1998, *ApJ*, **500**, 95
- Tian, W. W. and Leahy, D. 2005, *A&A*, **436**, 187
- Tingay, S. J., Goeke, R., Bowman, J. D., et al. 2013, *PASA*, **30**, e007
- Tramacere, A., Campana, R., Massaro, E., et al. 2025, *A&A*, **697**, A200
- Turtle, A. J. and Amy, S. W. 1991, in *IAU Symposium*, Vol. 148, *The Magellanic Clouds*, ed. R. Haynes and D. Milne, 114
- Uchiyama, Y., Blandford, R. D., Funk, S., Tajima, H. and Tanaka, T. 2010, *ApJL*, **723**, L122
- Urošević, D. 2014, *Ap&SS*, **354**, 541
- Urošević, D. and Pannuti, T. G. 2005, *APh*, **23**, 577
- Urošević, D., Pannuti, T. G. and Leahy, D. 2007, *ApJL*, **655**, L41
- Vink, J. 2012, *A&ARv*, **20**, 49
- Vink, J. 2020, *Physics and Evolution of Supernova Remnants* (Cham: Springer Nature)
- Vink, J., Bleeker, J., van der Heyden, K., et al. 2006, *ApJL*, **648**, L33
- Virtanen, P., Gommers, R., Oliphant, T. E., et al. 2020, *Nature Methods*, **17**, 261
- Vučetić, M., Milanović, N., Urošević, D., et al. 2023, *SerAJ*, **207**, 9
- Vukotić, B., Čiprijanović, A., Vučetić, M. M., Onić, D. and Urošević, D. 2019, *SerAJ*, **199**, 23
- Wayth, R. B., Lenc, E., Bell, M. E., et al. 2015, *PASA*, **32**, e025
- White, R. L. and Long, K. S. 1991, *ApJ*, **373**, 543
- Williams, R. M., Chu, Y. -H., Dickel, J. R., et al. 2004, *ApJ*, **613**, 948
- Wong, T., Hughes, A., Ott, J., et al. 2011, *ApJS*, **197**, 16
- Wong, T., Hughes, A., Tokuda, K., et al. 2017, *ApJ*, **850**, 139
- Wright, A. E., Griffith, M. R., Burke, B. F. and Ekers, R. D. 1994, *ApJS*, **91**, 111

- Xiao, L., Fürst, E., Reich, W. and Han, J. L. 2008, *A&A*, 482, 783
- Yamaguchi, H., Katsuda, S., Castro, D., et al. 2016, *ApJL*, 820, L3
- Yew, M., Filipović, M. D., Roper, Q., et al. 2018, *PASA*, 35, e015
- Yew, M., Filipović, M. D., Stupar, M., et al. 2021, *MNRAS*, 500, 2336
- Zangrandi, F., Jurk, K., Sasaki, M., et al. 2024, *A&A*, 692, A237
- Zhu, H., Tian, W. W. and Zuo, P. 2014, *ApJ*, 793, 95

ИСТРАЖИВАЊЕ ЦИНОВСКОГ ОСТАТКА СУПЕРНОВЕ У ВЕЛИКОМ МАГЕЛАНОВОМ ОБЛАКУ: ВЕЛИКИ (J0450.4–7050)

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Оригинални научни рад

Представљамо преглед високе резолуције у радио-континууму и мултифреквенцијску анализу остатка супернове (ОСН) J0450.4–7050 у Великом Магелановом облаку (ВМО) коме смо дали надимак Велики. Ова посматрања високе резолуције откривају да је остатак већих димензија у односу на претходна мерења, што чини J0450–7050 једним од највећих познатих ОСН. Додатно, детектовали смо површински сјај већи од очекиваног и необично благ спектрални индекс ($\alpha = -0.26 \pm 0.02$), са врло мало варијација дуж остатка. Посматрана је сјај-

на љуска у линији $\text{H}\alpha$ што указује на значајно хлађење, али и ексцес емисије у линији [OIII] на источном делу удара, сугеришући већу брзину делова ударног таласа. Размотрили смо неколико теоријских сценарија емисије и радио-еволуције J0450–7050 у типичном окружењу ВМО и закључили да се вероватно ради о старом ОСН са већом компресијом на ударном таласу која даје блажи нетермални спектар, у комбинацији са термалним (закочним) зрачењем које има одређени допринос.