

NEW 20-CM RADIO-CONTINUUM STUDY OF THE SMALL MAGELLANIC CLOUD: PART I - IMAGES

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SUMMARY: We present and discuss new high-sensitivity and resolution radio-continuum images of the Small Magellanic Cloud (SMC) at $\lambda=20$ cm ($\nu=1.4$ GHz). The new images were created by merging 20-cm radio-continuum archival data, from the Australian Telescope Compact Array and the Parkes radio-telescope. Our images span from $\sim 10''$ to $\sim 150''$ in resolution and sensitivity of r.m.s. ≥ 0.5 mJy/beam. These images will be used in future studies of the SMC's intrinsic sources and its overall extended structure.

Key words. Magellanic Clouds – Radio Continuum: galaxies

1. INTRODUCTION

The well established proximity of the Small Magellanic Cloud (SMC; ~ 60 kpc; Hilditch et al. 2005) and its location in one of the coldest areas of the radio sky towards South Celestial Pole, allows observation of its radio emissions to be made without the interference of our own galaxy's dust, gas and stars (Galactic Foreground Radiation). This means that, not only the study of its intrinsic properties including its extended emission and polarisation are of great interest, but that it is an ideal location to study other objects such as supernova remnants (SNRs; Filipović et al. 2005, 2008), H II regions and Planetary Nebulae (PNe; Filipović et al. 2009a) which are difficult to study in our own galaxy and other galaxies that are further away.

Over the last 40 years extensive radio-continuum surveys of the Small Magellanic Cloud have been made including interferometric observations made using the Molonglo Synthesis Telescope

(MOST; Ye et al. 1995) and Australian Telescope Compact Array (ATCA; Filipović et al. 2002, Payne et al. 2004, Filipović et al. 2009b, Mao et al. 2008, Dickel et al. 2010), and single dish observations from the 64-m Parkes radio-telescope (Filipović et al. 1997, 1998). Most of these surveys, however, suffer from either low resolution, poor sensitivity and/or poor uv -coverage.

In this paper, we present and discuss a method of merging various radio-continuum observations of the SMC at $\lambda=20$ cm ($\nu=1.4$ GHz) in an attempt to make the best use of the currently available data prior to the next generation of radio-telescope surveys (such as ASKAP, MeerKAT and SKA). By combining a large amount of existing observational data of the SMC and with the latest generation of computer power we can create various new high-resolution and high-sensitivity images.

The newly constructed images are analysed and the difference between the various SMC images created at 20 cm are discussed. In Section 2 we describe the observational data and reduction techni-

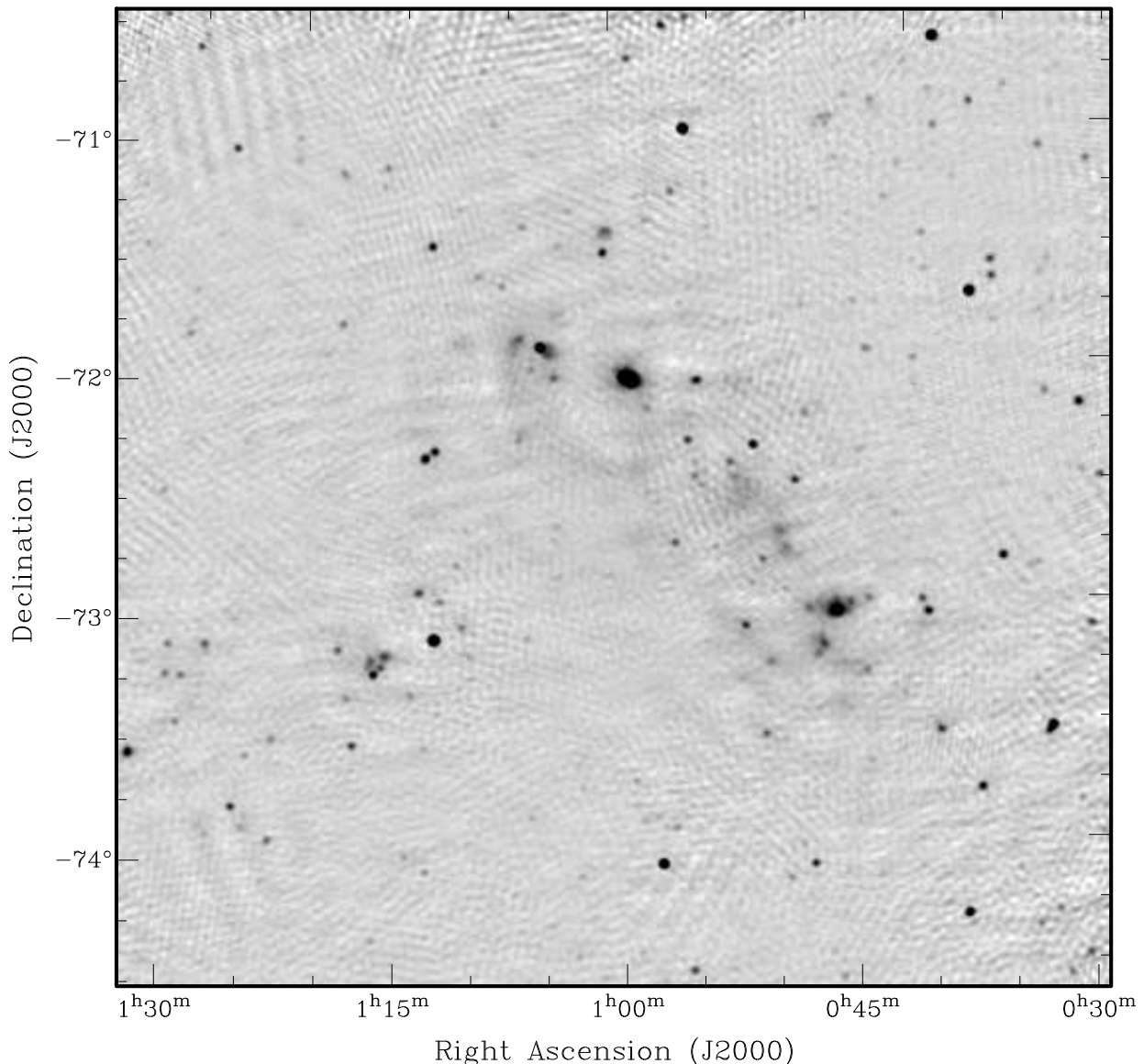


Fig. 1. ATCA project C159 radio-continuum total intensity image of the SMC merged with Parkes. The synthesised beam is $98''$ and the $r.m.s.=1.5$ mJy/beam.

ques. In Section 3 we present our new maps with a brief discussion and in Section 4 is the conclusion. The astrophysical interpretation of sources found in the surveys will be presented in subsequent papers.

2. OBSERVATIONAL DATA

2.1. Observational Data Details

To create the highest fidelity and resolution image to date of the SMC at 20 cm, we looked for mosaic observations that covered the SMC region. After an extensive search in the Australian Telescope Online Archive¹ (ATOA), we retrieved three

projects C159, C1197 and C1288 that observed the whole SMC.

All these three projects taken from the ATOA were ATCA mosaic observations of the SMC. Used as part of a survey of neutral hydrogen emission in the SMC by Staveley-Smith *et al.* (1997; see paper for observation details), project C159 (Fig. 1) provided the first large scale image using a mosaic mode. The ATCA project C1197 (Fig. 3) contained two sets of observations using different array configurations (H214 and H75). Observations of the H75 array configurations were part of a study into the cool gas in the Magellanic Stream (see Matthews *et al.* 2009 for observation details). The ATCA project

¹<http://atoa.atnf.csiro.au>

C1288 (Fig. 2) was used as part of a study of magnetic fields of the SMC, carrying out radio Faraday rotation and optical starlight polarisation data (see Mao et al. (2008) for observation details). The Parkes data was obtained from a radio-continuum

study (Fig. 4) of the SMC (Filipović et al. 1997). The source 1934-638 was used for the primary calibration and the source 0252-712 as the secondary calibrator for all ATCA images. A brief summary of the three ATCA projects can be found in Table 1.

Table 1. ATOA mosaic observational data used in imaging of SMC.

<i>ATCA Project</i>	<i>Date Observed</i>	<i>Array</i>	<i>Bandwidth(MHz)</i>
C159	06-10-1992 to 07-10-1992	375	4
	09-10-1992 to 14-10-1992	375	4
C1288	10-07-2004 to 18-07-2004	6A	128
C1197	20-10-2003 to 01-11-2003	H214	128
	31-07-2005 to 02-08-2005	H75	128
	09-09-2006 to 10-09-2006	H75	128
	12-09-2006 to 15-09-2006	H75	128
	19-09-2006 to 22-09-2006	H75	128

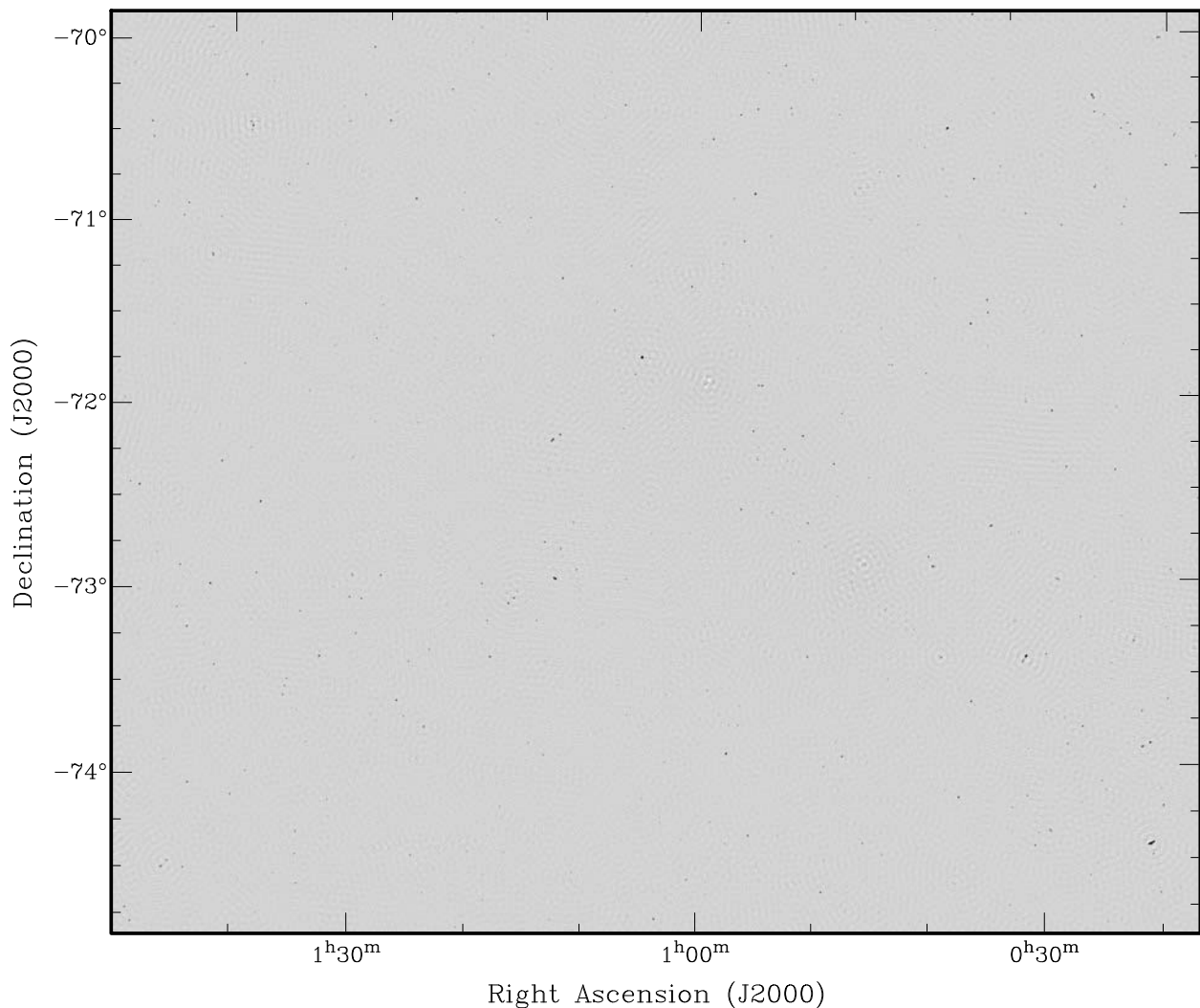


Fig. 2. ATCA Project C1288 radio-continuum total intensity image of the SMC merged with Parkes. The synthesised beam is $17.8'' \times 12.2''$ and the $r.m.s=0.7$ mJy/beam.

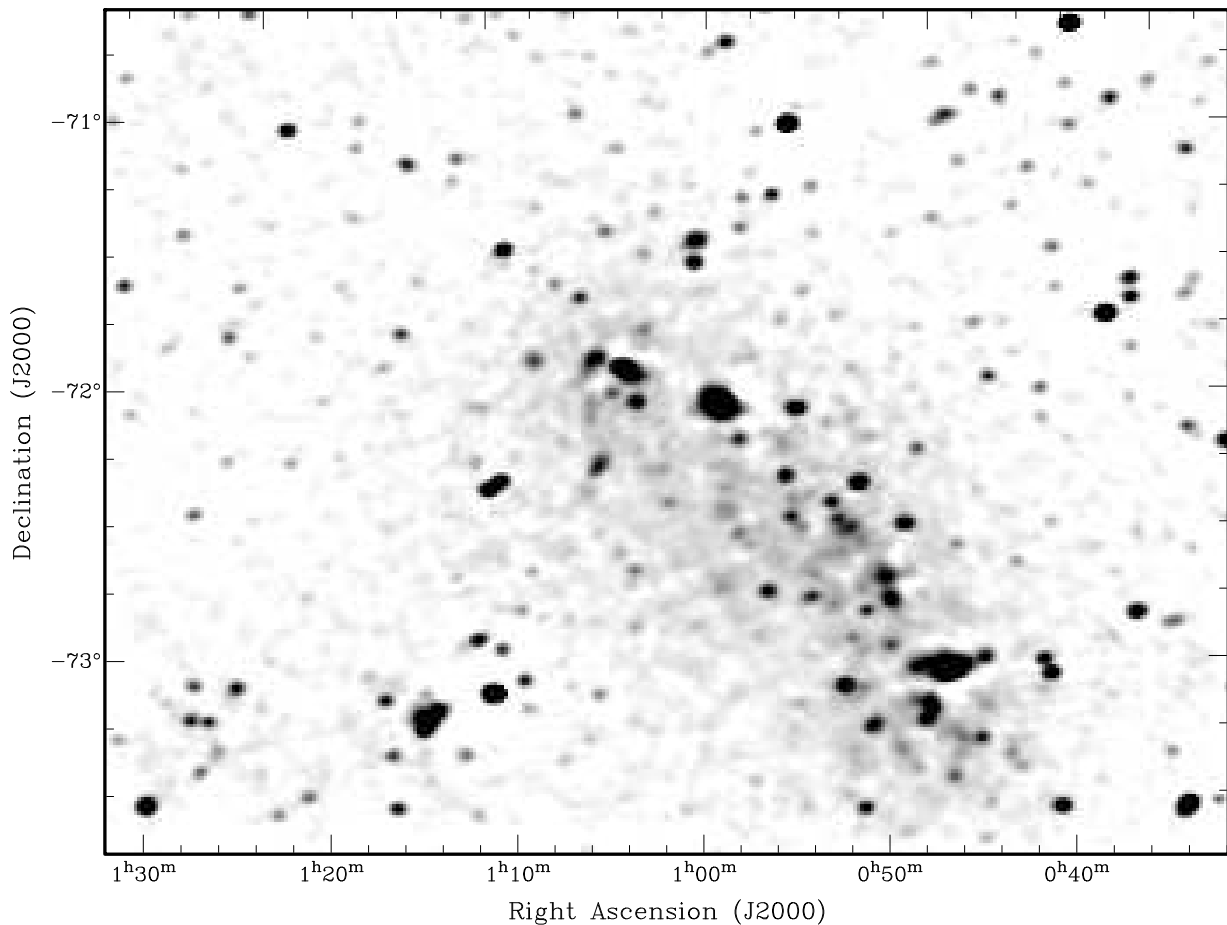


Fig. 3. ATCA Project C1197 radio-continuum total intensity image of the SMC. The synthesised beam is $158.2'' \times 124.8''$ and the $r.m.s.=1.0$ mJy/beam.

2.2. Image Creation

The software packages MIRIAD (Sault and Killeen 2010) and KARMA (Gooch 2006) were used for the data reduction and analysis. Initial high-resolution images were produced from the full dataset using the MIRIAD multi-frequency synthesis (Sault and Wieringa 1994) with natural weighting.

The joint-deconvolution method (Cornwell 1988) was used in the imaging process to give better uv -coverage from the different pointings that were overlapping each other.

The deconvolution process employed MIRIAD tasks MOSSDI and MOSMEM (or combination of both). Ideal for the deconvolution of point source emissions, MOSSDI is an SDI variance of the clean algorithm that is designed for Mosaics (Steer *et al.* 1984). The map created from ATCA project C1288 (Fig. 2), consisted mostly of point sources due to the long baselines, therefore MOSSDI was used to deconvolve it.

While on the other hand, MOSMEM is a method that uses maximum entropy (Cornwell 1989) and is suited for extended objects. This task was used for ATCA projects C159 (Fig. 1) and C1197 (Fig. 3) where the short baseline was used and ex-

tended emission dominates.

The various resolution maps were created by restricting the radial distance in the uv -plane of the three ATCA projects. The combined maps with various resolutions (with the exception of the highest resolution map), were created using a combination of both the MIRIAD task MOSSDI and MOSMEM. This method struck the balance between the two deconvolution tasks and its effects on point source emission and extended emission. Using MOSSDI to clean the mosaic with a low number of iterations till the side lobes of strong point sources are no longer present, removed any interference. Then using MOSMEM to complete the deconvolution process allowed the extended emissions from the data of the short baselines to remain.

To create the best possible SMC mosaic image at 20 cm, we examined the radial distance in the uv -plane of all three ATCA projects combined (Fig. 5), and identified where significant gaps between baselines existed. The first significant gap was found at $3k\lambda$ (see this image in Fig. 6). Using this as a starting point we were able to process and successfully create an image. Subsequently we increased the radial distance from $3k\lambda$ to $6k\lambda$ (Fig. 7) and later $16k\lambda$ (Fig. 8).

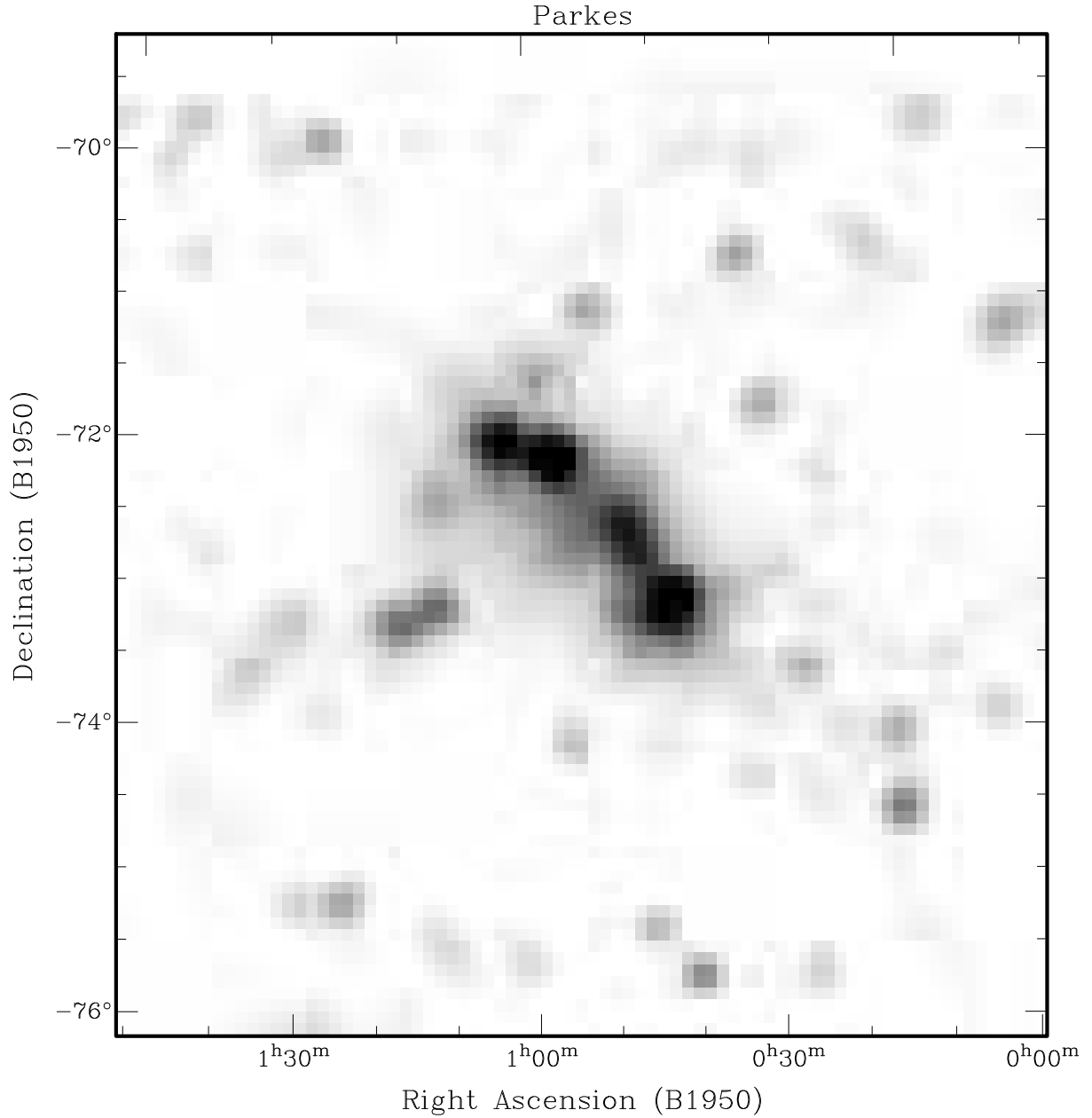


Fig. 4. A radio-continuum total intensity of SMC taken from Parkes retrieved from Filipović et al. (1997). The synthesised beam is $13.8'$ and $r.m.s.=15$ mJy/beam.

We also merged all mosaics with the Parkes observations to provide the essential and important short spacing data (Stanimirović 2002).

The new images presented in this paper show the individual maps (from all ATCA projects; Tab-

Table 2. The details of ATCA projects of SMC mosaics at 20-cm.

ATCA Project	Beam Size (arcsec)	PA (degree)	$r.m.s.$ (mJy/beam)
C159	98.0×98.0	0	1.5
C1288	17.8×12.2	26	0.7
C1197	158.2×124.8	85	1.0

le 2) and combined maps that are merged with Parkes data. Table 3. lists the details of the various combined images.

Table 3. The details of three SMC merged mosaics at 20-cm.

uv distance (k λ)	Beam Size (arcsec)	PA (degree)	$r.m.s.$ (mJy/beam)
3	48.4 × 33.6	26	0.5
6	30.1 × 20.1	27	0.5
16	16.3 × 9.5	22	0.5

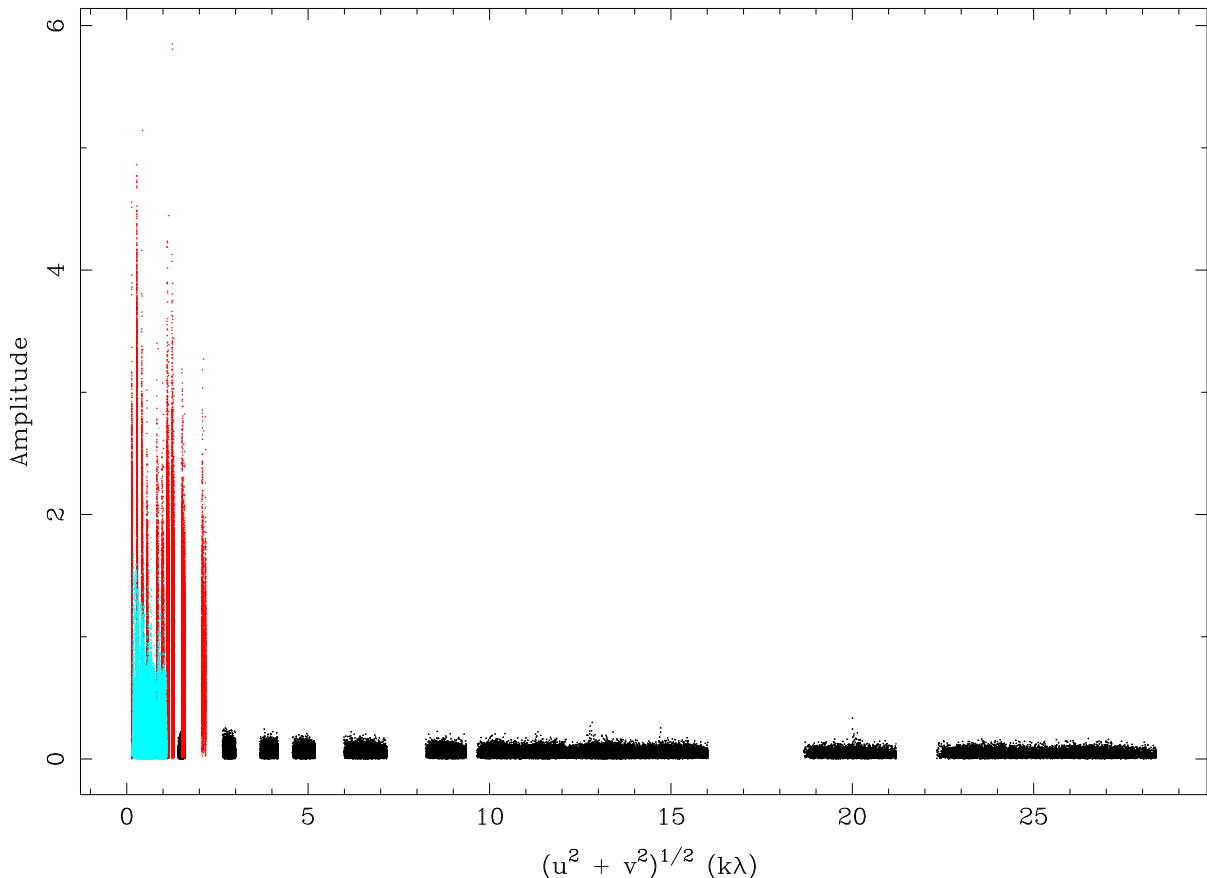


Fig. 5. *Amplitude vs. uv -distance graph of the three projects overlapping with each other. Blue colour represents observational data from ATCA project C1197, red from C159 and black from C1288. (See the electronic edition of the Journal for a color version of this figure).*

3. RESULTS AND DISCUSSION

In Figs. 1 to 3, we show the individual intensity mosaic maps of the SMC from ATCA projects C159, C1288 and C1197 respectively and in Fig. 4 we reproduce the Parkes (single-dish) image from Filipović *et al.* (1997). The Figs. 6, 7 and 8 are images at uv distance of 3, 6 and 16 $k\lambda$ respectively (Table 3).

All these images can be downloaded from the Astronomy Digital Image Library (ADIL) at <http://adil.nsa.uiuc.edu/>.

3.1. Individual SMC Mosaics at $\lambda=20$ cm

Comparing the individual images of the SMC at 20 cm created from the ATCA projects, we can see the effects of the different array configurations. While shorter baseline images such as C159 (Fig. 1) and C1197 (Fig. 3) show much intensive extended emission, compared to C1288 image (Fig. 2; 6A array) which contains point sources at higher resolution.

Fig. 1 was imaged from the C159 observations and later merged with the data from Parkes single-dish radio-telescope. It contains a combination of

extended emission and point source emission. From the individual images (Figs. 1 to 4), Fig. 1 has a balanced combination of the different types of emission and resolution.

Using an array configuration of 6A, image in Fig. 2 (ATCA project C1288) has the longest baseline and only point sources can be seen. However, Fig. 2 has the highest resolution compared to the other individual images presented in this paper and is dominated by the radio point source population.

Created from ATCA project C1197, in Fig. 3 the most prominent feature is extended emission. Although this image suffers from poor resolution due to the dominance of shorter baselines, which upon closer examination means a lack of detail of individual objects.

In Fig. 4 we show observation taken from single dish telescope (Parkes). As a result, this image has the lowest resolution compared to Figs. 1 to 3 which are observations taken from an array interferometer. The main characteristic of Fig. 4 is the extended emission and the shape of the SMC galaxy.

We note that the area coverage of these three mosaics is different. Therefore, when combining the mosaics we only used the individual observations that overlapped with each other.

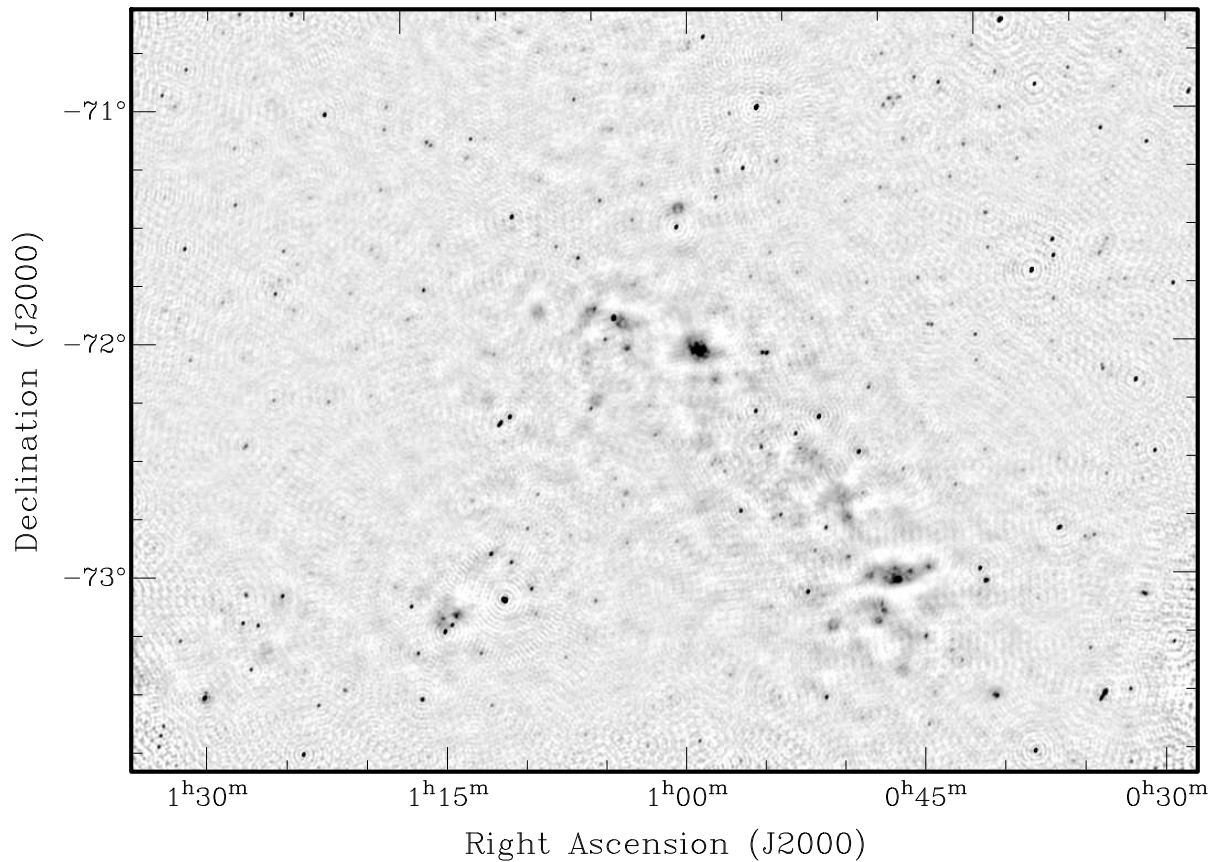


Fig. 6. A radio-continuum total intensity images of the SMC at $3k\lambda$. The synthesised beam is $48.4'' \times 33.6''$ and the $r.m.s=0.5$ mJy/beam.

3.2. New Combined SMC Mosaics at $\lambda=20$ cm

Figs. 6-8 are combination images with various resolutions, the features of the images have a combination of point source emission and extended emission.

We also point out that some differences between various images can be attributed to slightly different deconvolution techniques and careful flagging of highly noisy observational data. Our new high-resolution and high-sensitive analysis of these images will be presented in future papers.

4. CONCLUSION

In this paper we present and discuss new high-sensitivity and resolution radio-continuum images of the SMC at 20 cm. The new images were created by merging sensitive 20-cm mosaic radio surveys, from the ATOA, and later the data from Parkes 64-m radio-telescope. These images will be used in future studies of the SMC's intrinsic sources and overall structure.

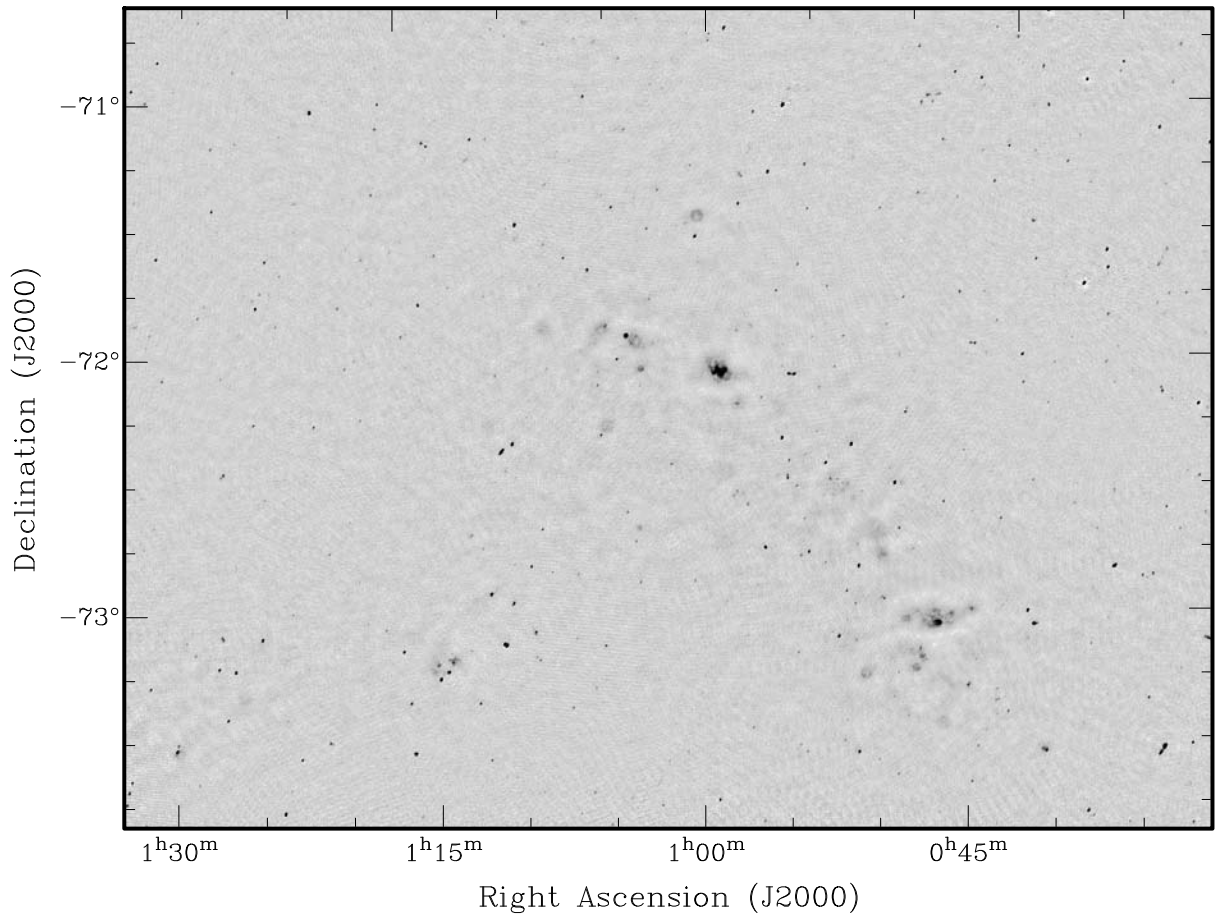


Fig. 7. A radio-continuum total intensity images of the SMC at $6k\lambda$. The synthesised beam is $30.1'' \times 20.1''$ and the $r.m.s=0.5$ mJy/beam.

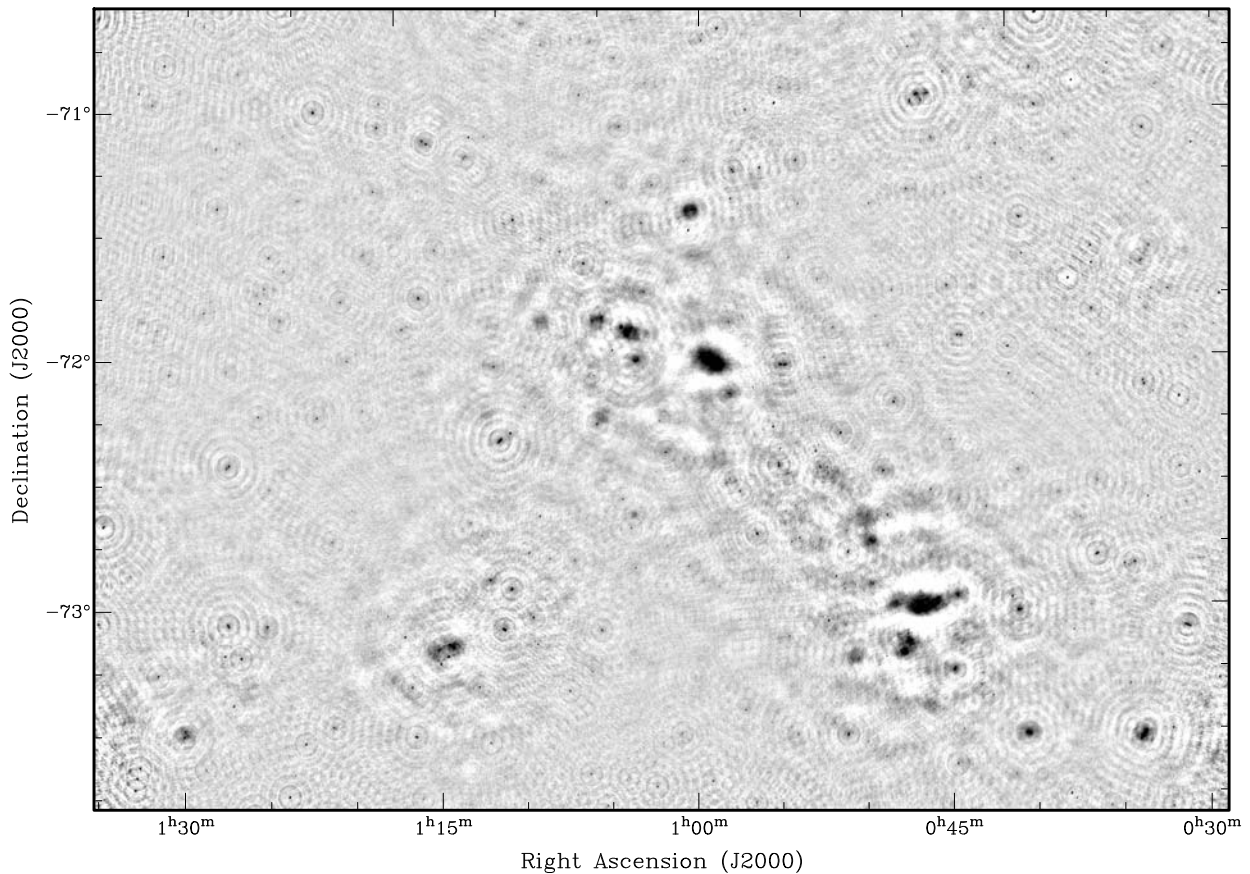


Fig. 8. A radio-continuum total intensity images of the SMC at $16k\lambda$. The synthesised beam is $16.3' \times 9.5''$ and the $r.m.s=0.5$ mJy/beam.

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**НОВО ПРОУЧАВАЊЕ МАЛОГ МАГЕЛАНОВОГ ОБЛАКА У
РАДИО-КОНТИНУУМУ НА 20 ЦМ: ДЕО I - СНИМЦИ**

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Стручни чланак

У овој студији представљамо нове АТСА резултате посматрања високе резолуције и осетљивости у радио-континууму Малог Магелановог Облака (ММО) на $\lambda=20$ cm ($\nu=1.4$ GHz). Нове радио-мапе настале су спајањем архивских мозаик посматрања на 20 cm са Аустралија Телескоп Онлајн Архива и по-

датака са Паркс радио-телескопа (отвор антене 64 m). Наши нови снимци су резолуције од $\sim 10''$ до $\sim 150''$ и осетљивости од $\text{g.m.s.} \geq 0.5$ mJy/beam. Ови снимци ће бити коришћени у будућим истраживањима како објеката тако и укупне структуре ММО-а.