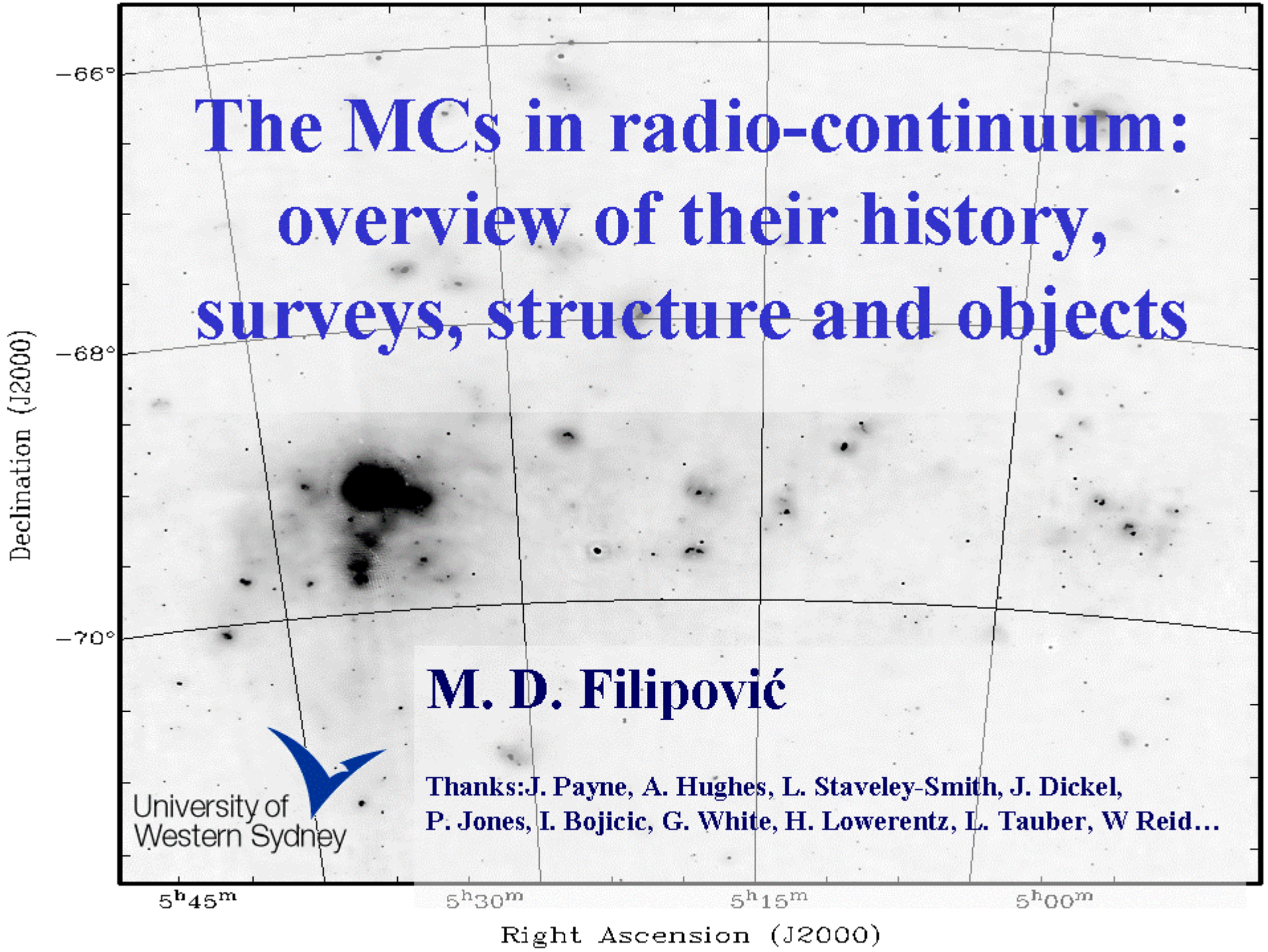


The MCs in radio-continuum: overview of their history, surveys, structure and objects

M. D. Filipović

University of Western Sydney

Thanks: J. Payne, A. Hughes, L. Staveley-Smith, J. Dickel, P. Jones, I. Bojicic, G. White, H. Lowerentz, L. Tauber, W Reid…

Outline

- **Brief history of two earlier generations of MC radio-continuum surveys.**
- **Current high frequency ATCA surveys combined with previous Parkes radio telescope data to enhance large scale structure.**
- **Radio-continuum objects: Supernova Remnants (SNRs), HII Regions, PNs, X-ray binaries, Bubbles, Super-Bubbles, Super - shells and Background Sources (e.g. AGN).**

Why MCs in RC

- 'Macro' scale:
  - Structure,
  - Magnetic Field(s), (see Gaensler et al 2005; Haynes et al 1991)
  - Emission type (Thermal vs Non-thermal) (see Hughes et al. 2006)
- 'Micro' scale:
  - objects: SNRs, HII Regions, PNs, X-ray binaries, Bubbles, Super-Bubbles, Super -shells and Background Sources (e.g. AGN).

Early History of Radio Observations of the MCs

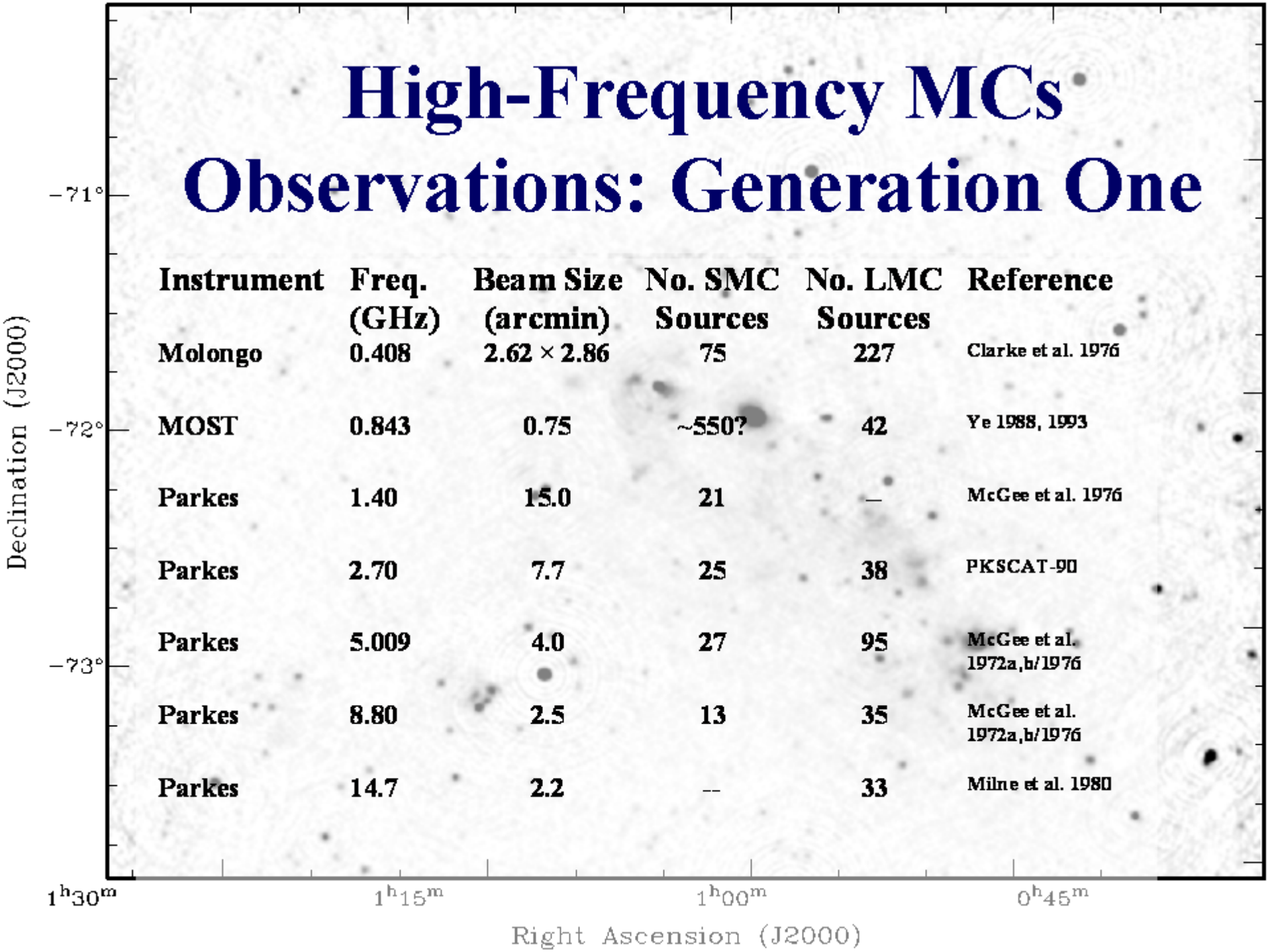
- MC's first detected by Mills & Little (1953).
- Pioneering work include: Mills (1955) at 85.5 MHz, Mills & Little (1959) at 96.8 and 158 MHz, Shain (1959) at 19.7 MHz, Mathewson & Healey (1964a) at 1400 MHz, Alvarez et al. (1987) at 45 MHz and Mountfort et al. (1987) at 2300 MHz.
- Low-resolution determines the large-scale structure and total radio spectrum.
  - α=-0.52±0.05 (Haynes 1991)
- High-resolution studies concentrate on discrete sources – SNRs, HII regions…

High-Frequency MC Observations: Generation One

- First catalogue of discrete LMC sources at 5.00 GHz (MC catalogue) by McGee et al. (1972a) using the Parkes radio telescope. McGee et al. (1976) presented a list of discrete sources toward the SMC at 5.00 GHz.
- MC4 Catalogue (Molonglo at 408 MHz) – Clarke et al. 1976
- McGee et al. (1972b) and Bolton & Butler (1975) observed the MCs at 2.70 GHz. This became part of the PKSCAT-90 (Otrupcek & Wright 1991).
- The PKSCAT-90 contains MC sources with fluxes at 1.40, 2.70, 5.00 and 8.40 GHz.

High-Frequency MCs Observations: Generation One

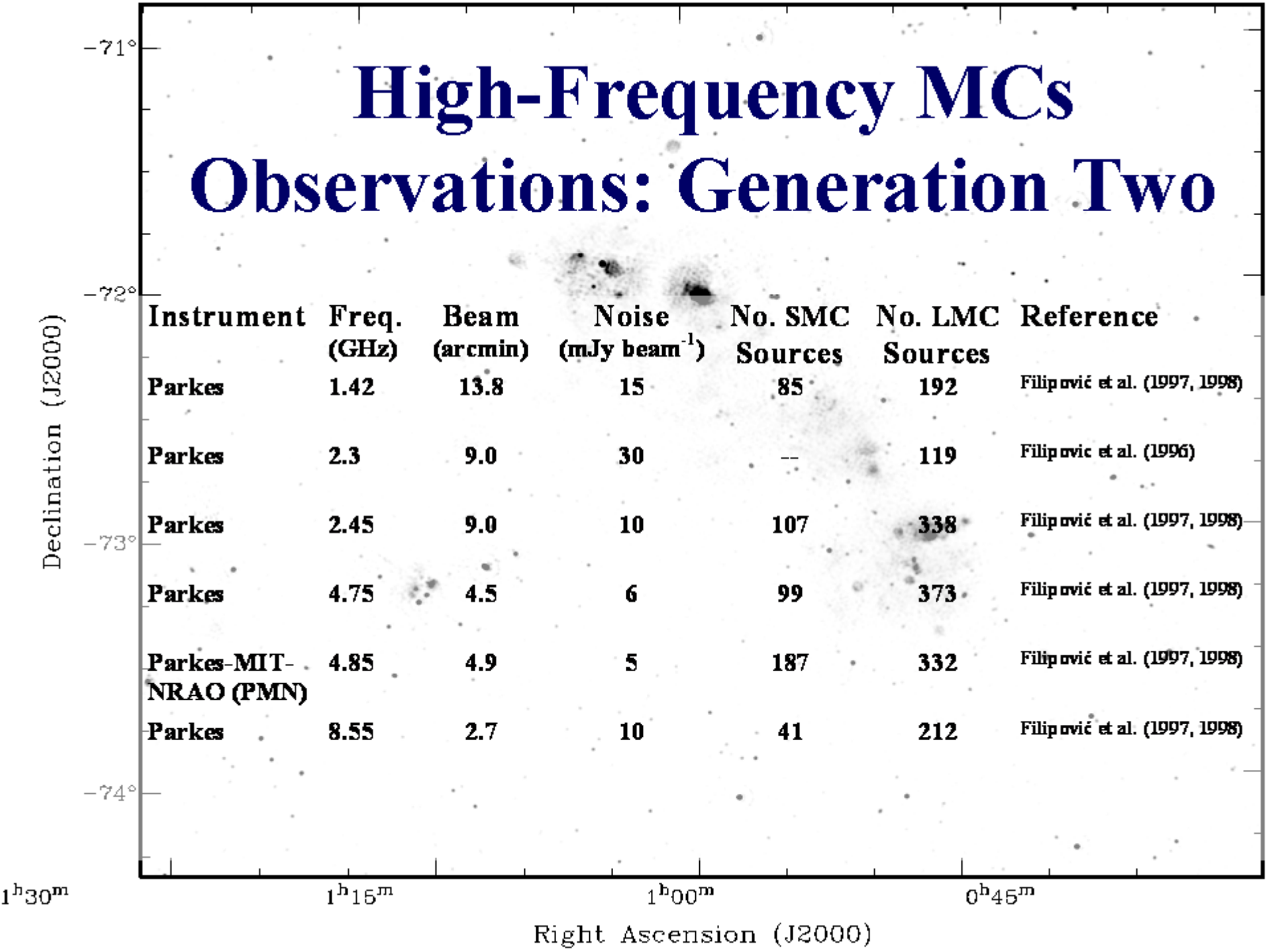
Instrument	Freq. (GHz)	Beam Size (arcmin)	No. SMC Sources	No. LMC Sources	Reference
Molongo	0.408	2.62 × 2.86	75	227	Clarke et al. 1976
MOST	0.843	0.75	~550?	42	Ye 1988, 1993
Parkes	1.40	15.0	21	—	McGee et al. 1976
Parkes	2.70	7.7	25	38	PKSCAT-90
Parkes	5.009	4.0	27	95	McGee et al. 1972a,b/1976
Parkes	8.80	2.5	13	35	McGee et al. 1972a,b/1976
Parkes	14.7	2.2	--	33	Milne et al. 1980



High-Frequency MC Observations: Generation Two

- International collaboration launched in 1986 to study the MCs using the Parkes radio telescope.
- Initial 1.4 GHz observations reported by Haynes et al. (1986) provided information about MC morphology, source spectra and magnetic fields.
- A series of eight articles began with Haynes et al. (1991) presented observations at 2.45, 4.75 and 8.55 GHz; Wright et al. (1994) added Parkes-MIT-NRAO (PMN) observations at 4.85 GHz and Filipović et al. (1996) included the LMC data with new 2.30 GHz observations.

High-Frequency MCs Observations: Generation Two



Instrument	Freq. (GHz)	Beam (arcmin)	Noise (mJy beam^{-1})	No. SMC Sources	No. LMC Sources	Reference
Parkes	1.42	13.8	15	85	192	Filipović et al. (1997, 1998)
Parkes	2.3	9.0	30	--	119	Filipovic et al. (1996)
Parkes	2.45	9.0	10	107	338	Filipović et al. (1997, 1998)
Parkes	4.75	4.5	6	99	373	Filipović et al. (1997, 1998)
Parkes-MIT-NRAO (PMN)	4.85	4.9	5	187	332	Filipović et al. (1997, 1998)
Parkes	8.55	2.7	10	41	212	Filipović et al. (1997, 1998)

High-Frequency MC Observations: Generation Two

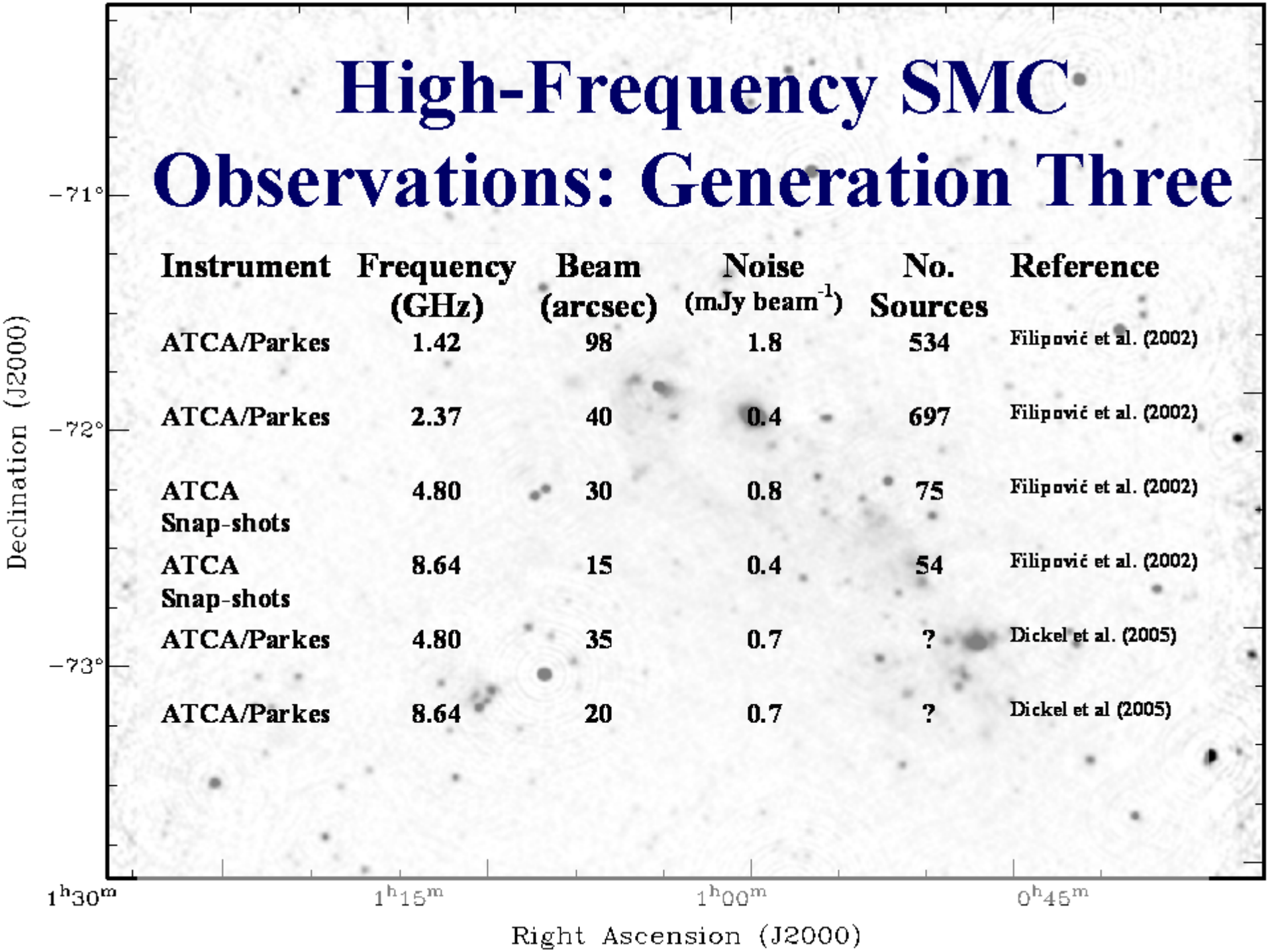
Paper	Important Findings	Reference
I	Ram pressure effects due to motion of LMC through Milky Way's halo affect radio morphology.	Haynes et al. (1991)
II	Far-infrared and 4.75 GHz LMC maps closely correlated; warm thermal components associated with HII regions containing young ionizing stars.	Xu et al (1992)
III	Distribution of linearly polarized radio emission form a loop outside the LMC plane towards the Milky Way.	Klein et al. (1993)
IV	New catalogue of LMC sources at 1.40, 2.45, 4.75, 4.85, and 8.55 GHz with a total of 469; 132 new.	Filipović et al. (1995)
IVa	2.30 GHz LMC Parkes observations found no significant discrepancies with previous observations.	Filipović et al. (1996)
V	New catalogue of SMC sources.	Filipović et al. (1997)
VI	Comparison of Parkes data with X-ray data (*ROSAT*).	Filipović et al (1998a)
VII	Further classification and analysis of discrete MC sources including SNRs and HII Regions.	Filipović et al. (1998b)
VIII	Comparison of Parkes surveys with *IRAS* surveys.	Filipović et al. (1998c)

High-Frequency MC Observations: Generation Three

- ATCA observations of the SMC in 1992 in mosaic mode with 320 pointings at 1.42 and 2.37 GHz; 33 selected 'snap shot' pointings at 4.80\8.64 GHz.
- Short-spacing at 1.42 and 2.37 GHz was filled in using similar Parkes data enhancing large scale structure to < 4 degrees.
- ATCA mosaic observations of the LMC taken in 1994 and 1995 (1.377 GHz) and 2001-2-3-4 (4.80 and 8.64 GHz); for the 1.377 MHz image the LMC was divided into 12 regions, each containing 112 pointing centers. 54 selected 'snap shot' pointings at 4.80 and 8.64 GHz.
- Parkes data added all four frequencies.

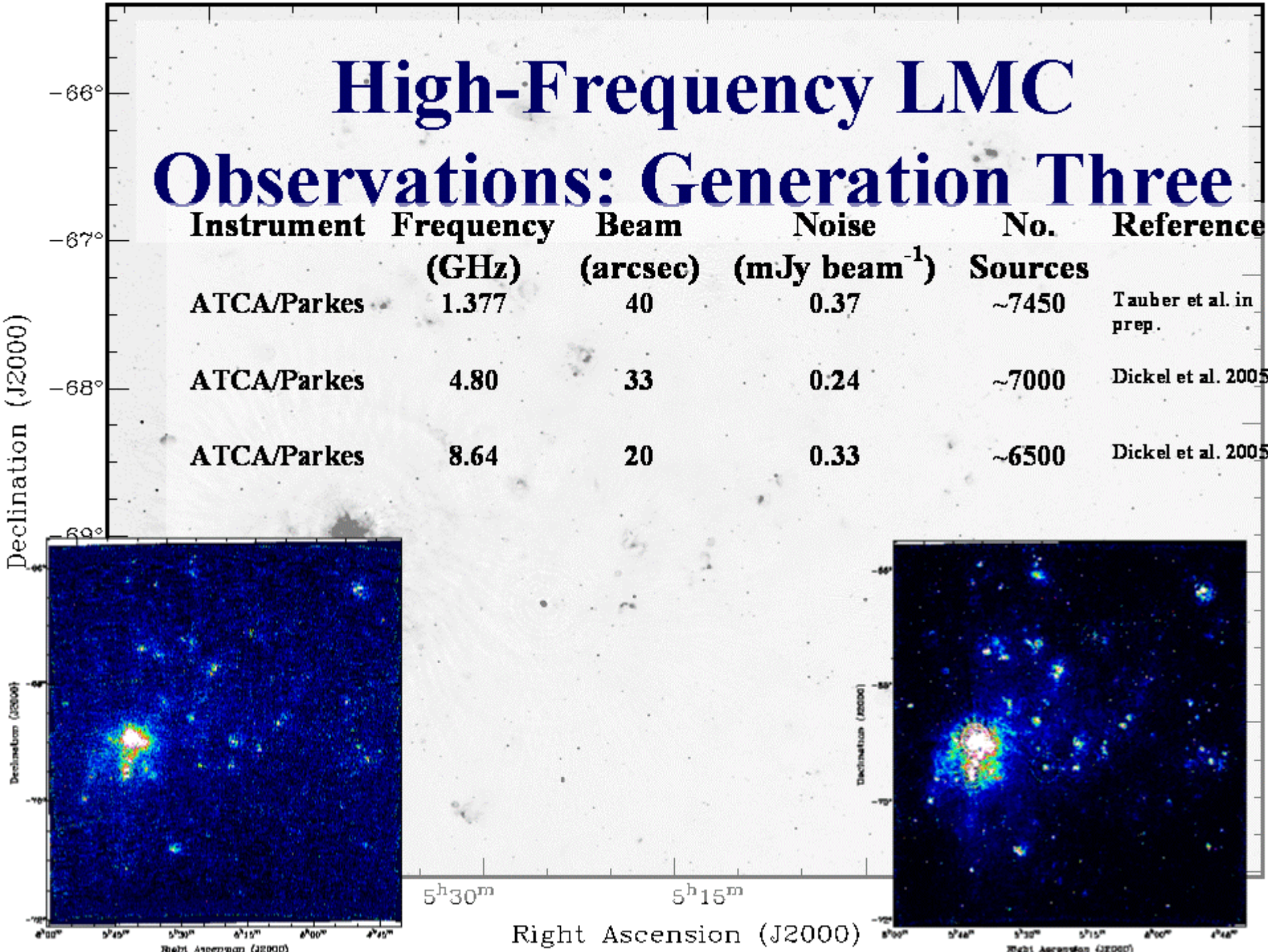
High-Frequency SMC Observations: Generation Three

Instrument	Frequency (GHz)	Beam (arcsec)	Noise (mJy beam^{-1})	No. Sources	Reference
ATCA/Parkes	1.42	98	1.8	534	Filipović et al. (2002)
ATCA/Parkes	2.37	40	0.4	697	Filipović et al. (2002)
ATCA Snap-shots	4.80	30	0.8	75	Filipović et al. (2002)
ATCA Snap-shots	8.64	15	0.4	54	Filipović et al. (2002)
ATCA/Parkes	4.80	35	0.7	?	Dickel et al. (2005)
ATCA/Parkes	8.64	20	0.7	?	Dickel et al (2005)



High-Frequency LMC Observations: Generation Three

Instrument	Frequency (GHz)	Beam (arcsec)	Noise (mJy beam^{-1})	No. Sources	Reference
ATCA/Parkes	1.377	40	0.37	~7450	Tauber et al. in prep.
ATCA/Parkes	4.80	33	0.24	~7000	Dickel et al. 2005
ATCA/Parkes	8.64	20	0.33	~6500	Dickel et al. 2005

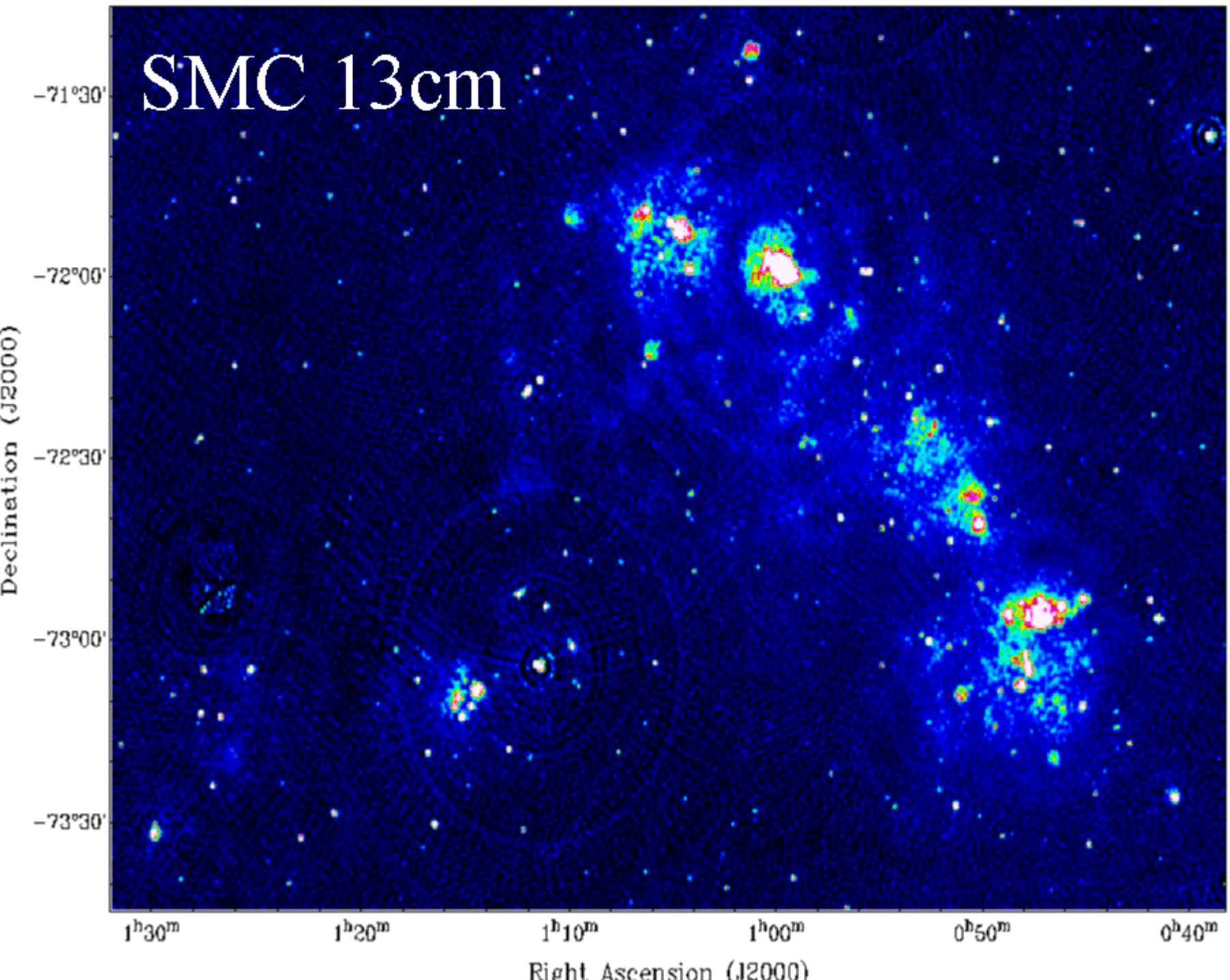


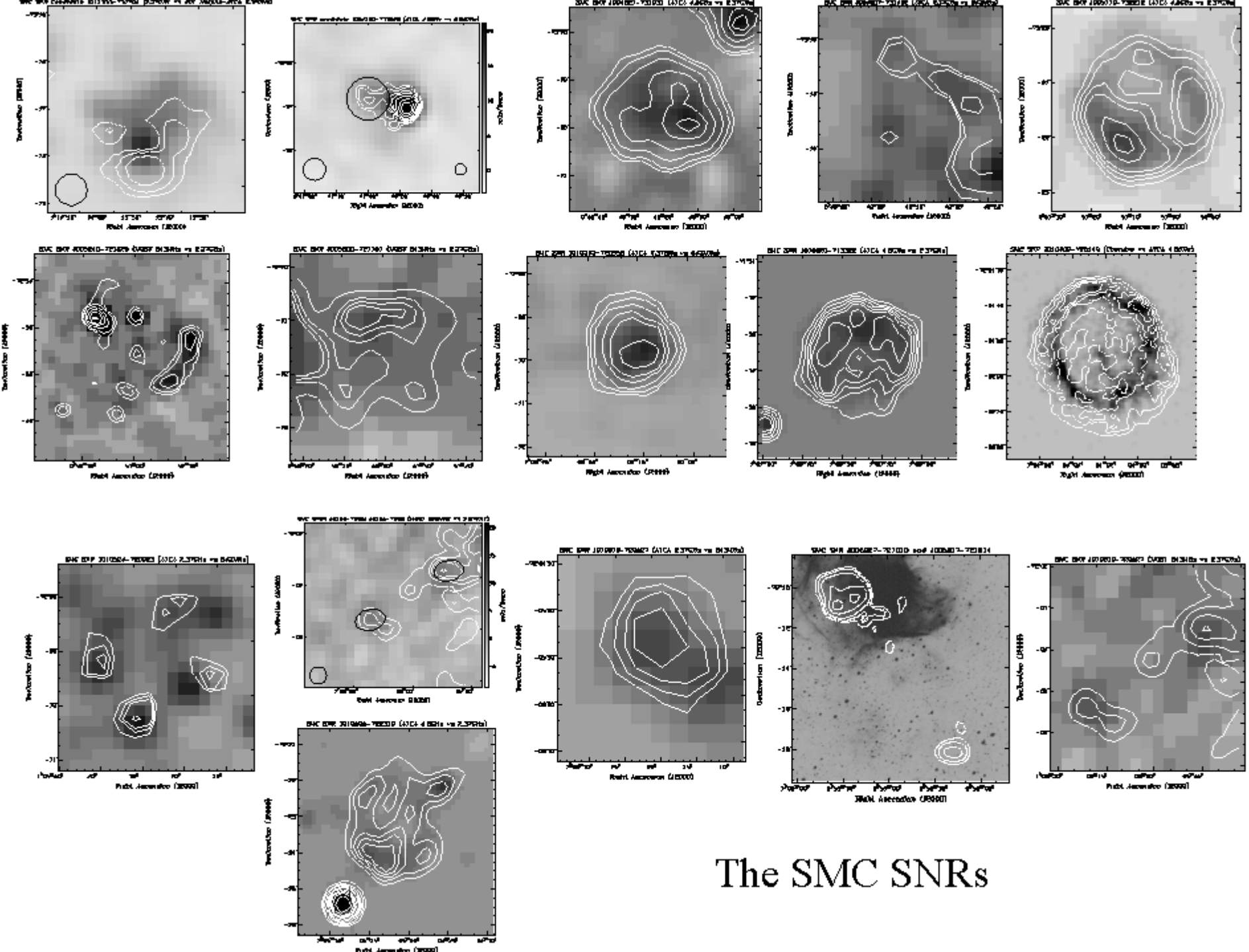
High-Frequency MC Observations: Generation Three

Paper	Important Findings	Reference
I	Catalogue of 717 radio sources toward the SMC at 1.42, 2.37, 4.80 and 8.64 GHz.	Filipović et al. (2002)
II	Classification of SMC sources into 71 HII regions (or candidates), 21 SNRs (or candidates) and 616 background sources.	Payne et al. (2004)
III	Detailed discussion and analysis of SNRs and HII regions within the SMC.	Filipović et al. (2005)
IV	Analysis of the N66 region within the SMC using radio-Hα subtraction images.	Reid et al. (2006)
V	Initial analysis of sources toward the LMC.	Payne et al. (2007.)
VI	Radio analysis of superbubbles within the LMC.	Pannuti et al. (in press)

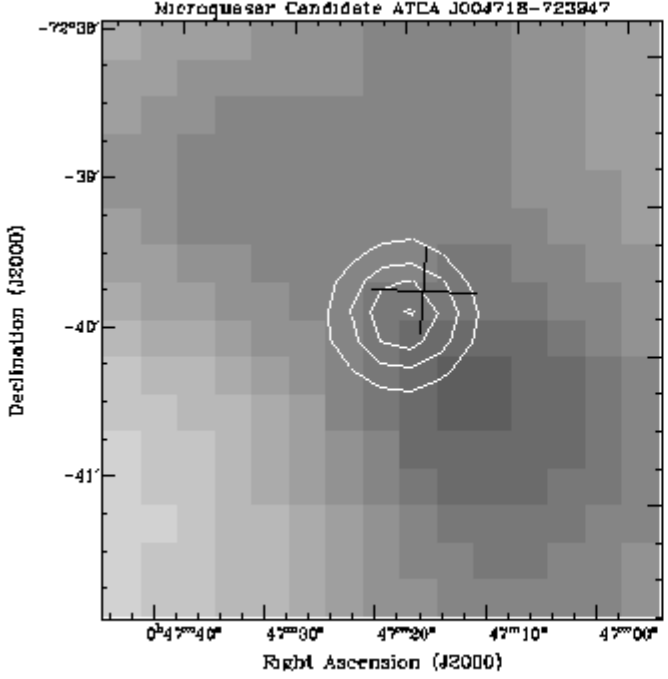
SMC Results

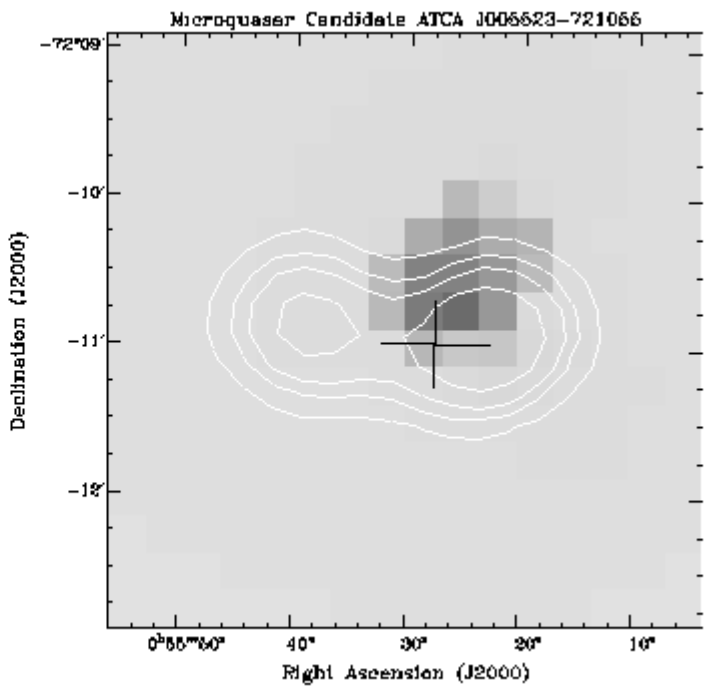
- **21 SNRs, 71 HII Regions, 616 Background objects (AGN), 4 candidate radio Planetary Nebulae and 2 candidate radio emitting X-ray Binaries; ATCA proposal submitted for deeper study of latter two.**
- **The SNR formation rate for Type II remnants is 0.087±0.01 per century.**
- **SNRs and HII Regions have similar luminosity (10^{16} W Hz^{-1}) suggesting a population of low-luminosity SNRs remain undiscovered.**

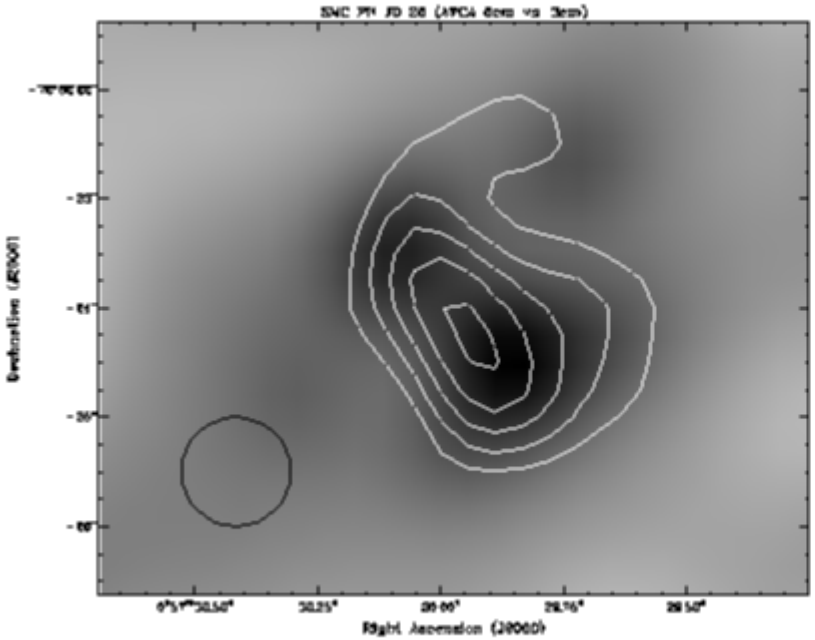

SMC 13cm
−71°30'
−72°00'
−72°30'
−73°00'
−73°30'
Declination (J2000)
1h30m
1h20m
1h10m
1h00m
0h50m
0h40m
Right Ascension (J2000)



The SMC SNRs



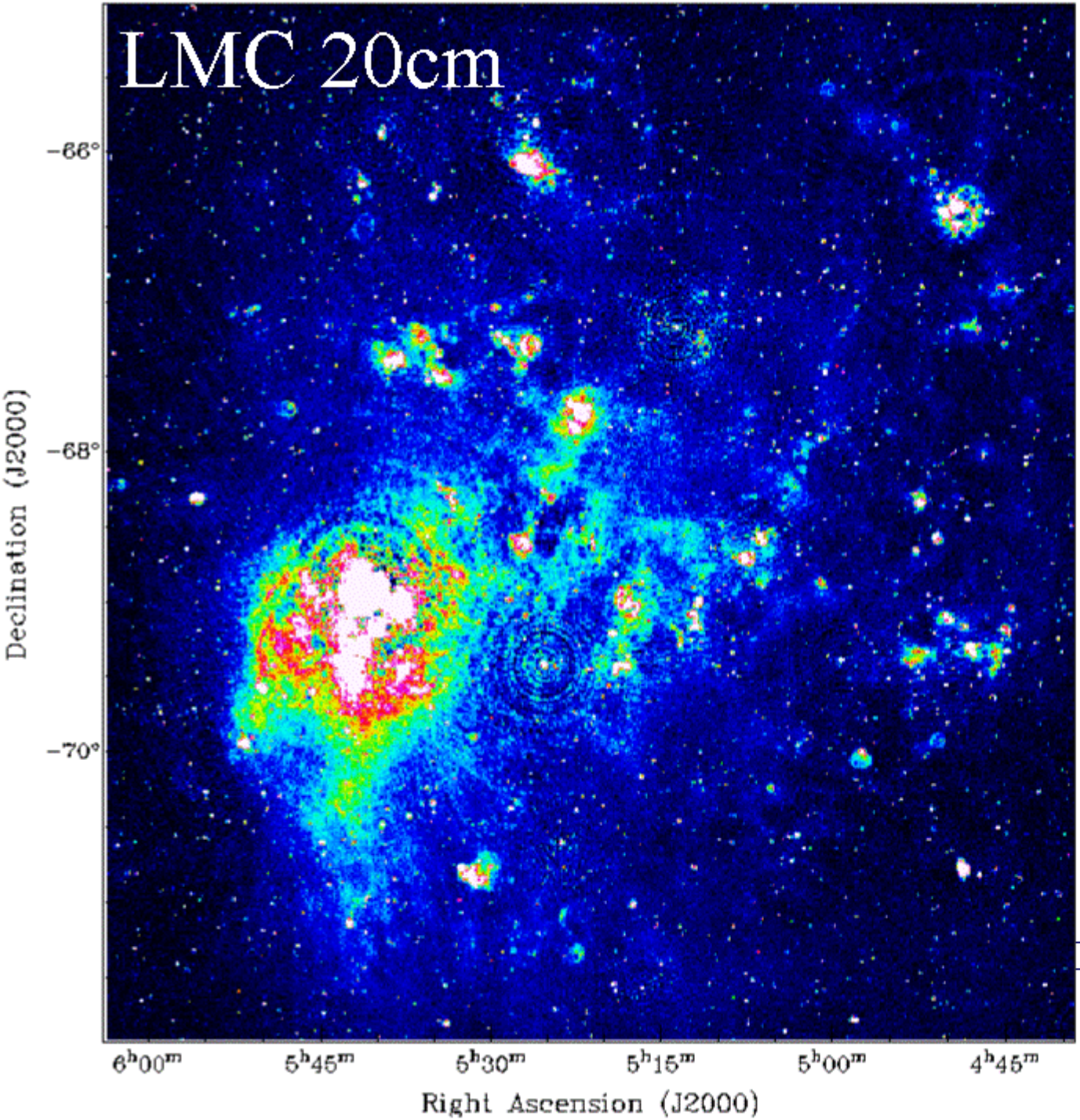




SMC
2 Microquasars
4 PNe

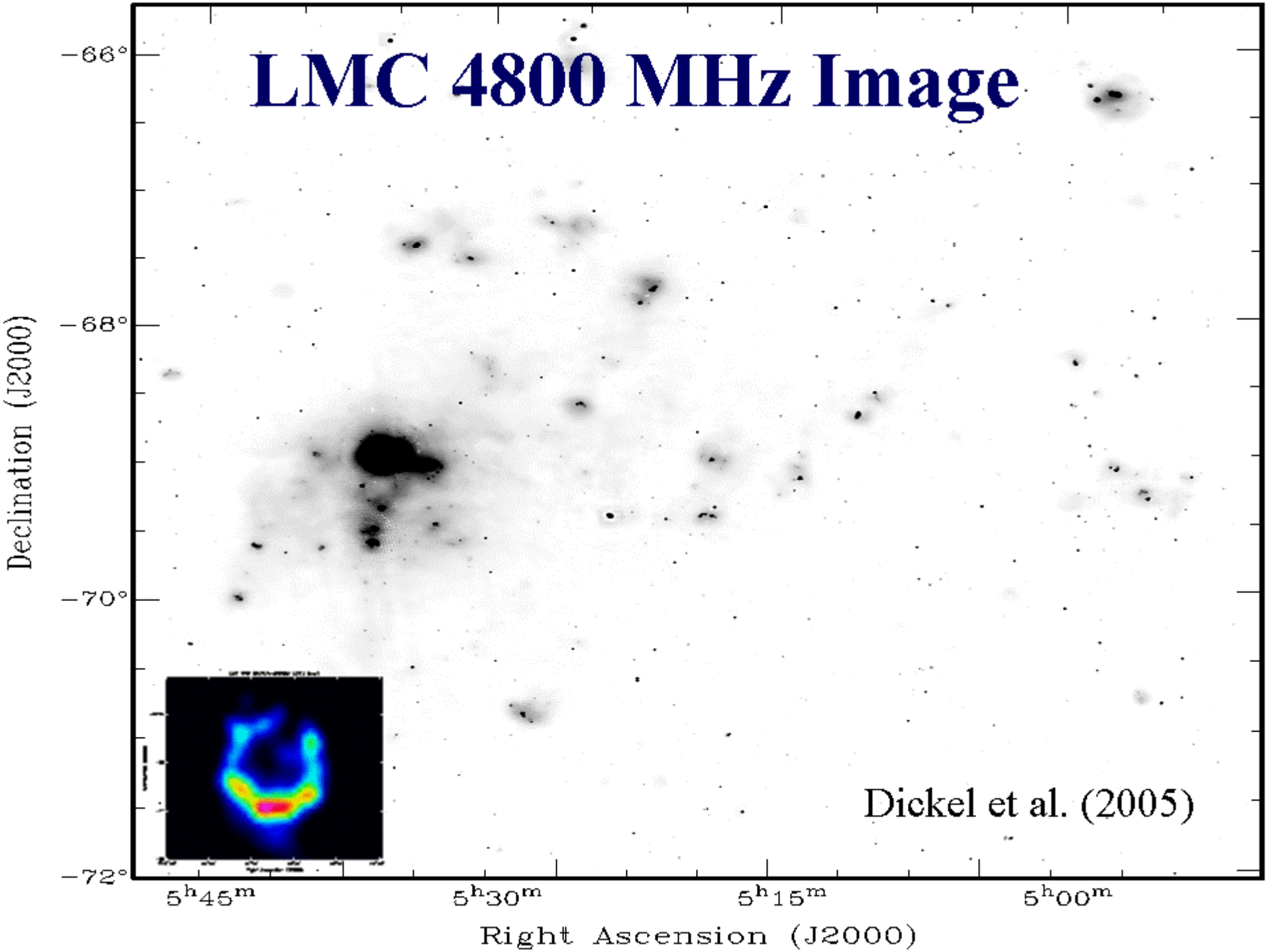
LMC MOSAIC Results

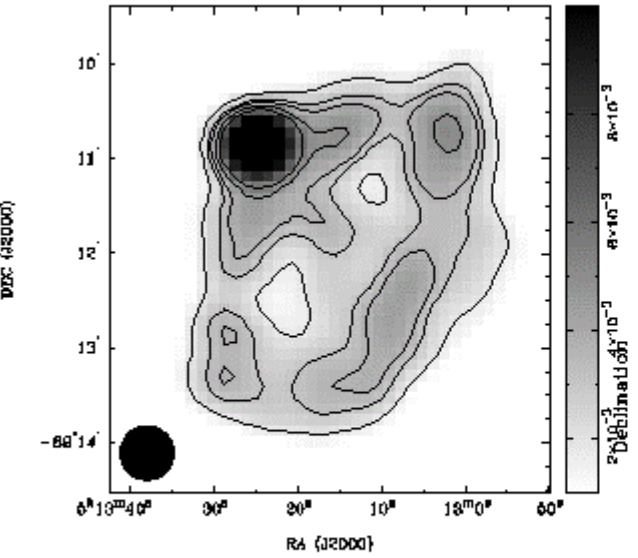
- 7,500 sources (at least 95% Background)
- 76 known or suspected SNRs.
- 17 radio superbubbles
- Some 150 HII regions
- 23 PNe

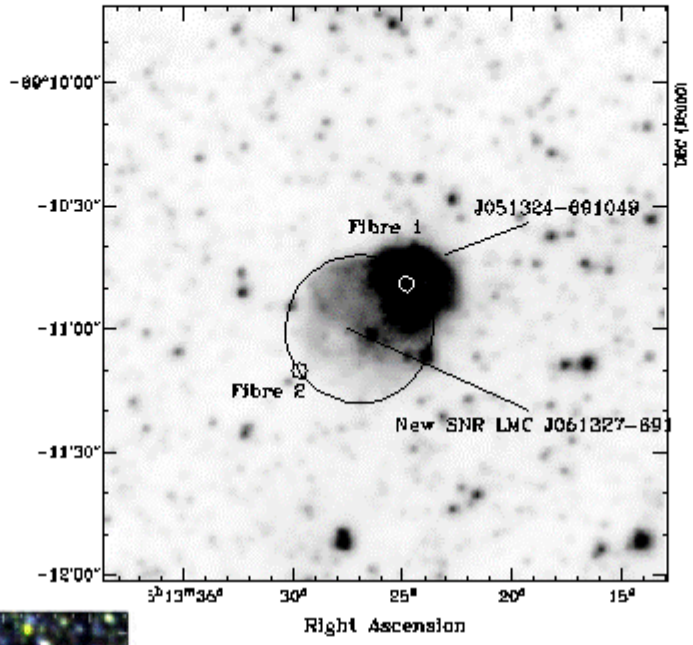


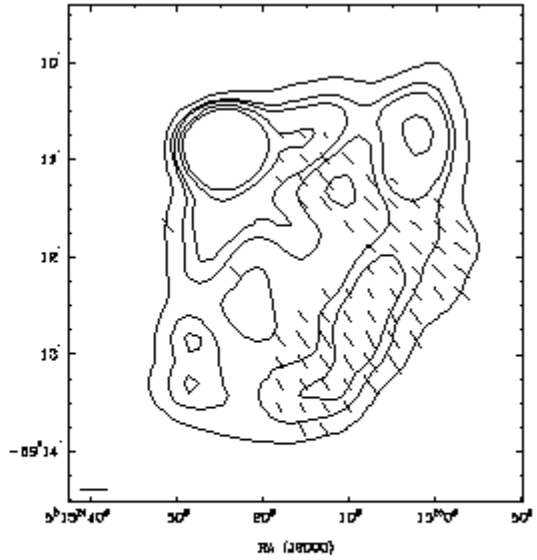
Hughes et al. in prep.

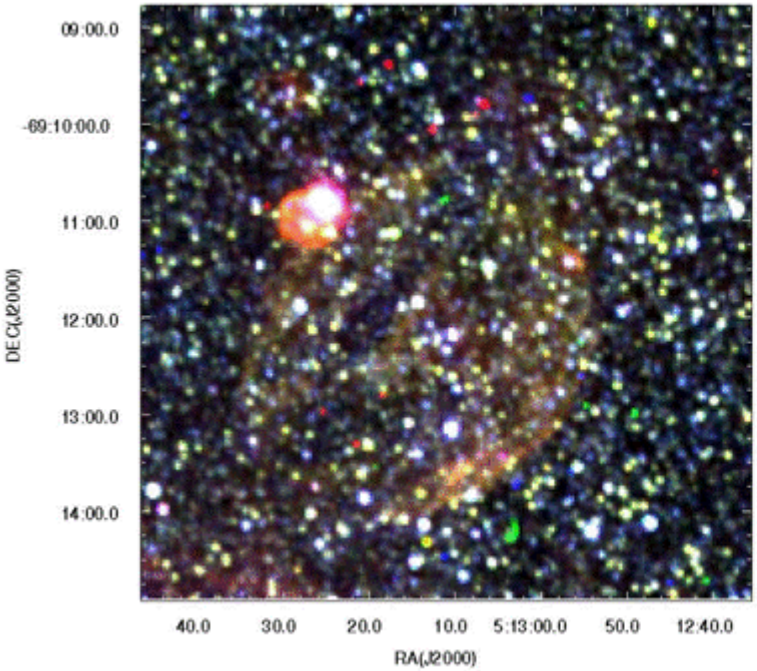
LMC 4800 MHz Image





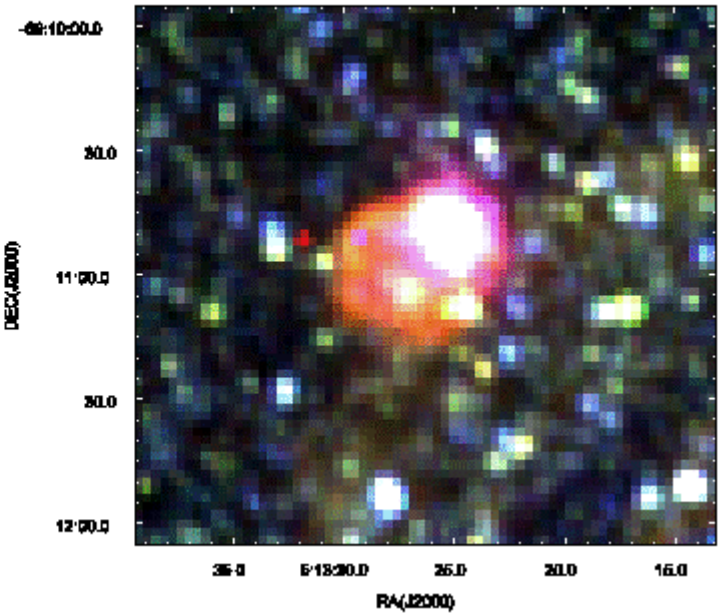






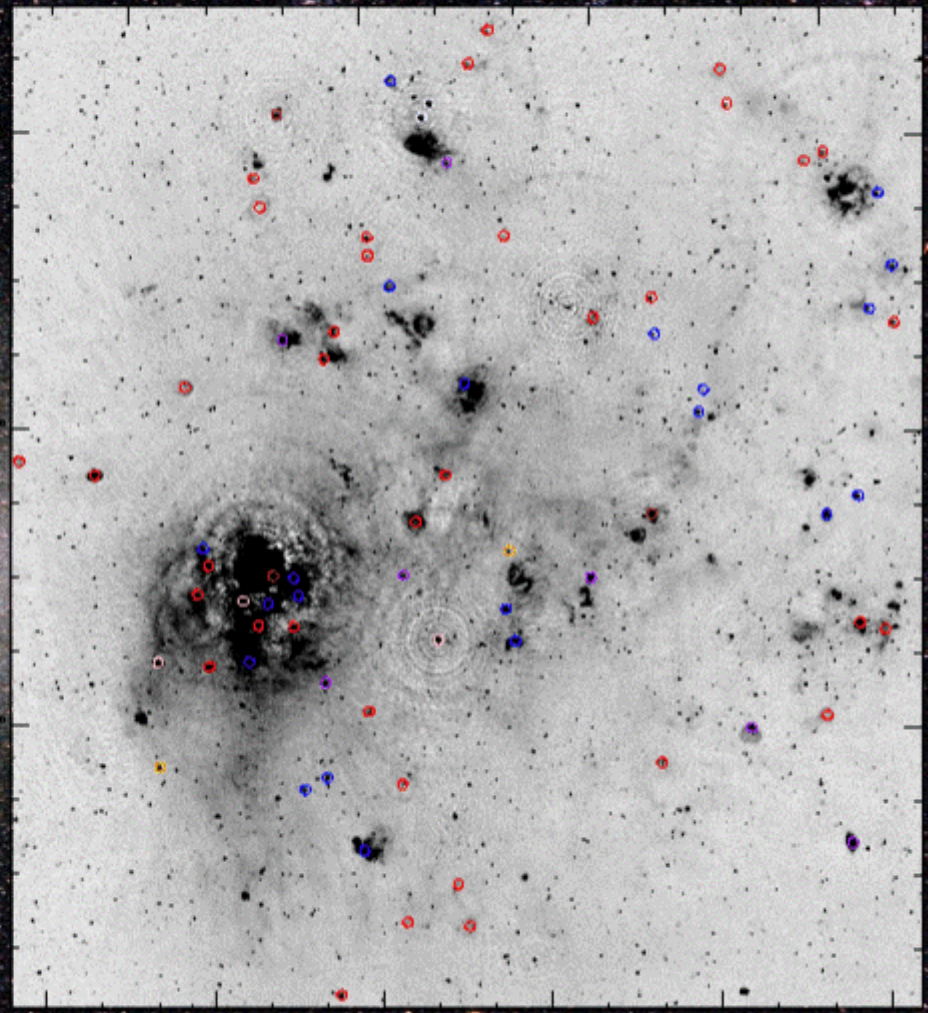
LMC SNRs
→B0513-692
→J051324-691

Bojicic et al. (2007)

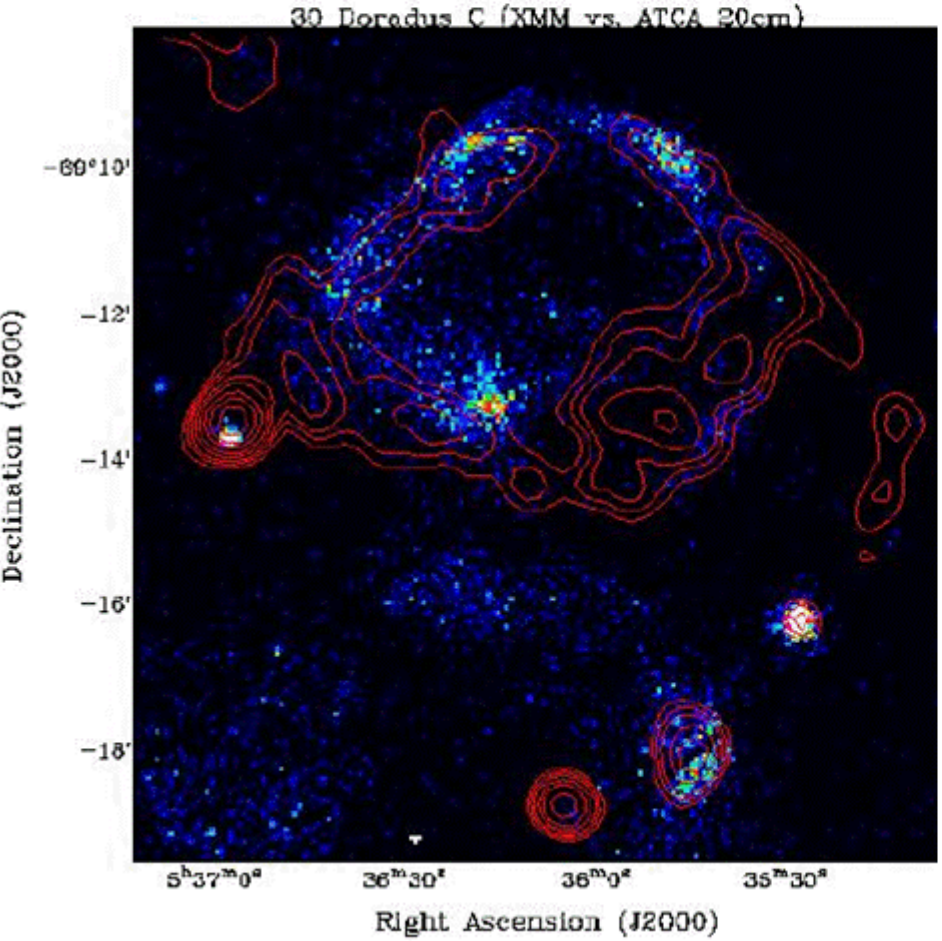


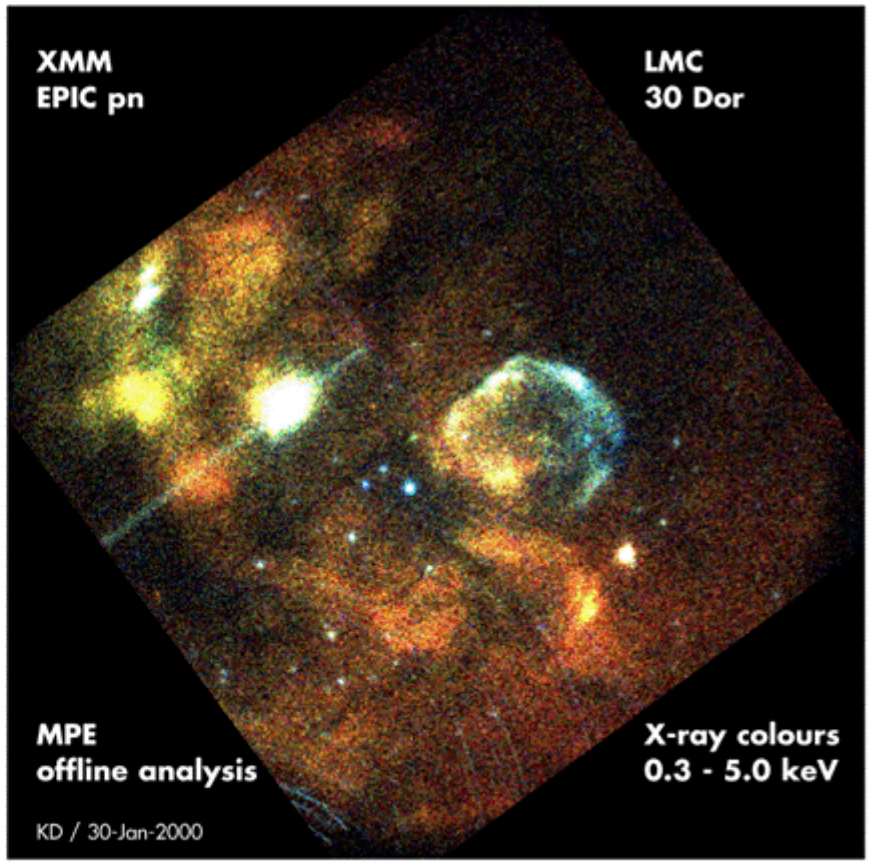
MCs SNRs

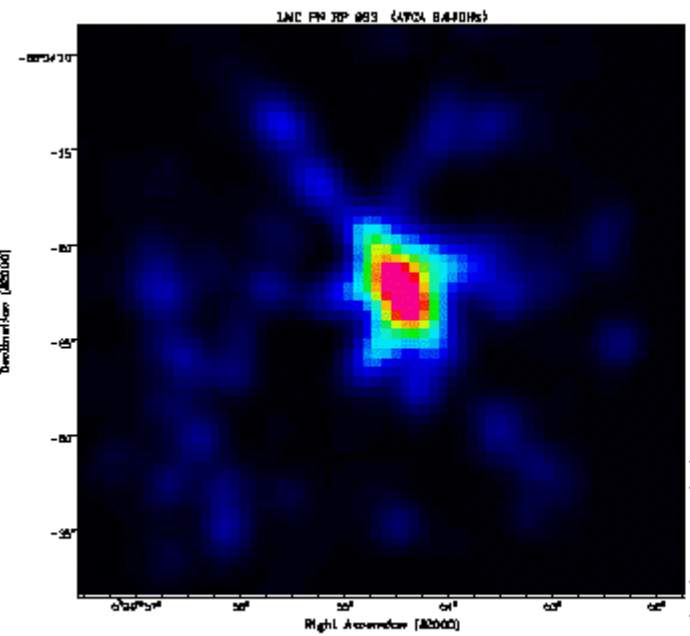
- SMC – 21(16) and LMC 76(41)
- Nothing(?) unusual/unexpected
- Embedded in HII regions (75%)
- Need for more comprehensive multi-frequency study:



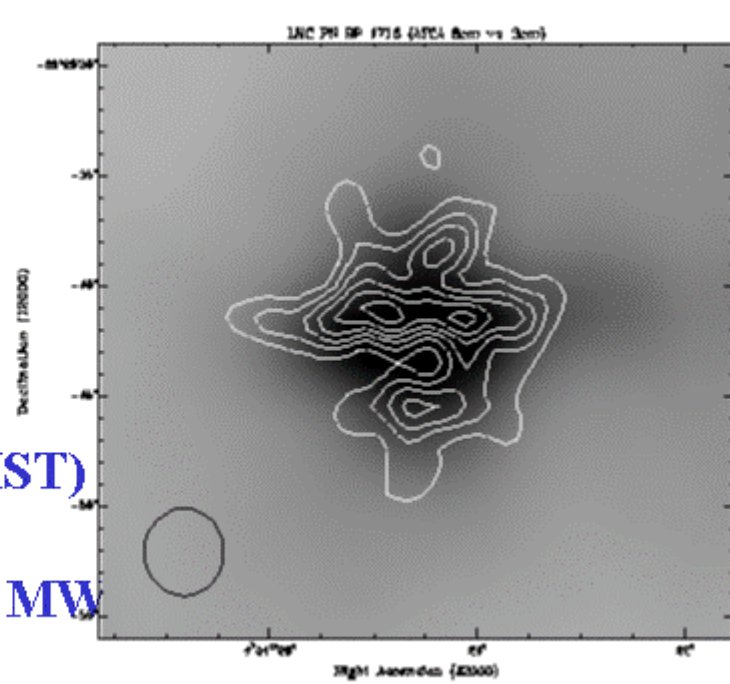
SNR or Bubble or Super Bubble or Shell or HII complex or Supershell?







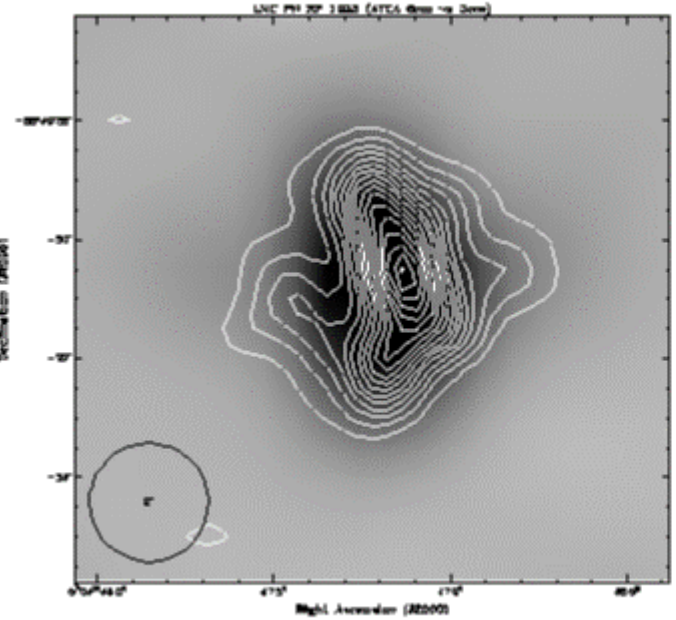
LMC PNe



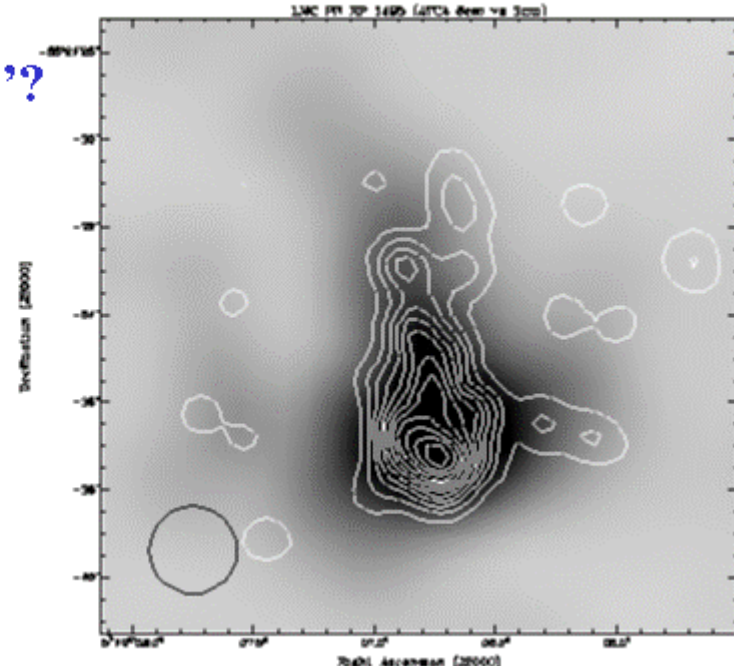
23 (14 confirmed in HST)

More (RC) Lum then MW

Much bigger then MW



New class – ‘subNova’?



Future directions

- MIRA => SKA
  - Wider frequency coverage (especially low end)
  - More resolution
  - More sensitivity
- More comprehensive polarisation and magnetic field study
- Multi-frequency comparison