Publ. Astron. Soc. Aust., 1998, 15, 280–98

A Radio Survey of the SMC at 843 MHz with the MOST: I. The Survey

A. J. Turtle[1], Taisheng Ye[1], S. W. Amy[1] and Jennifer Nicholls[2]

[1]School of Physics, University of Sydney, NSW 2006, Australia
turtle@physics.usyd.edu.au, ye@physics.usyd.edu.au, s.amy@physics.usyd.edu.au

[2]Special Research Centre for Theoretical Astrophysics,
University of Sydney, NSW 2006, Australia
j.nicholls@physics.usyd.edu.au

Received 1998 August 3, accepted 1998 September 2

Abstract: A radio survey at a frequency of 843 MHz of 36 square degrees containing the Small Magellanic Cloud (SMC) has been made with the Molonglo Observatory Synthesis Telescope (MOST). The angular resolution is around 45 arcsec and the rms noise is about 1 mJy per beam. The radio image of the region is presented showing over a thousand sources with a variety of angular sizes from unresolved to 10 arcmin. Most of the sources are presumed to be background objects but about 70 of the more extended sources are H II regions or supernova remnants within the SMC.

Keywords: radio continuum: galaxies — galaxies: Magellanic Clouds — surveys

1 Introduction

The Magellanic Clouds have been studied in detail because they are close (50–75 kpc) and, unlike the Galactic Plane, there is little interstellar obscuration for much of the electromagnetic spectrum and most lines of sight intersect only one object. Consequently many southern surveys at radio wavelengths have included the Clouds. Though nearly all the detected sources are presumed to be background objects, each Cloud does contain a number of extended sources which are either supernova remnants (SNRs) or H II regions. Less luminous Cloud sources such as planetary nebulae and most pulsars are below the present limits of detection.

The history of star formation in the Clouds is known to be different from that in the Galaxy; in particular, far more SNRs (per unit mass) have been discovered in the Clouds. Observations which clearly separate SNRs from nearby H II regions and have sufficient sensitivity to reveal faint features will assist in the study of this anomaly. Similarly the comparison of detailed radio images of the H II regions with images made at other wavelengths may provide more accurate estimates of the recent rate of star formation.

The Molonglo Observatory Synthesis Telescope (MOST) is well suited for such observations. It operates at a frequency of 843 MHz with a resolution of about 45 arcsec and sensitivity of around 1 mJy ($1\ \text{mJy} = 10^{-29}\ \text{W Hz}^{-1}\ \text{m}^{-1}$). It has completed radio surveys of two areas, one of 36 square degrees containing the Small Magellanic Cloud (SMC) and the other of 65 square degrees containing the Large Magellanic Cloud (LMC). Here we report on the MOST survey of the SMC covering an area with a scalloped boundary (see Figure 1) which includes the region $00^{\rm h}\ 15^{\rm m}$ to $01^{\rm h}\ 44^{\rm m}$ in right ascension and $-75^\circ\ 13'$ to $-70^\circ\ 18'$ in declination (J2000). The survey area is similar to that used for continuum observations of the SMC by the Parkes 64 m telescope (Haynes et al. 1986, 1991). Various catalogues are in preparation.

Other radio surveys which include information on the discrete sources in the direction of the SMC are Clarke, Little & Mills (1976) at 408 MHz, McGee, Newton & Butler (1976) at 5 and 8·8 GHz, Mills et al. (1982) at 843 MHz and Loiseau et al. (1987) at 1·4 GHz. More recently, Filipović et al. (1997) have presented a catalogue of the flux densities of 224 sources at five frequencies between 1·42 and 8·55 GHz. The present survey has better sensitivity and angular resolution and the final image contains many more sources with over a thousand exceeding a flux density of 7 mJy at 843 MHz.

Only a few of these sources [63 H II regions, 15 supernova remnants (SNRs) and 3 new SNR candidates] are thought to lie within the SMC. These sources are discussed in detail in subsequent papers in this series (in preparation) and previously in Ye (1988) and Ye, Turtle & Kennicutt (1991). The remaining sources do not possess the radio morphologies or optical and x-ray counterparts that characterise typical H II regions or SNRs. A few may be members of an unrecognised class of object that occurs in galactic disks, but sources such as pulsars or counterparts of SS433 would be less than 10 mJy at the distance of the SMC. The majority of the detected sources have a larger flux density and

 1323-3580/98/030280$10.00

are likely to be background objects lying beyond the SMC. The number of these sources is not significantly in excess of those expected from a background population.

Though the sources in the SMC are our primary interest, the background sources do provide a valuable sample of distant extragalactic objects. At this frequency there is little general obscuration due to the SMC and so hardly any sources stronger than 10 mJy should have been missed because of this or overlap with the extended sources of the SMC (which occupy only 0·04 square degrees in total). A preliminary list of sources has already been used to subtract the smoothed background contribution of these sources from the large-scale non-thermal radio emission from the SMC (Ye & Turtle 1991). In addition, the spectra of the brightest background sources may be used in other investigations to study the interstellar medium of the SMC.

In Sections 2 and 3, we describe the observations and the data reduction and, in Section 4, we present the images of the survey.

2 Observations

The MOST is a synthesis radio telescope comprising two colinear, cylindrical–paraboloid reflectors each 11·6 m wide and 778 m long (Mills 1981; Robertson 1991). It operates at 843 MHz (a wavelength of 0·356 m) and measures right circular polarisation. At the declination of the SMC a typical 12 hour observation images a field of 70×73 arcmin^2 (right ascension by declination) with a full width half maximum (FWHM) beamwidth of 43×45 arcsec^2 and reaches a rms noise level of 1–2 mJy per beam area (the beam area is $3{\cdot}57 \times 10^{-8}$ sr). Additional observations with better sensitivity were also made of several smaller fields of 46×48 arcmin containing interesting H II regions or faint SNRs. A provisional calibration is provided by short measurements on a number of calibration sources before and after each 12 hour observation (Hunstead 1991).

The SMC has been gradually mapped over several years. The first observations were in 1981 (Mills et al. 1982). The performance of the MOST was improved in May 1983 and, over the next few years, observations covered an area containing almost all the emission nebulae in the SMC as catalogued by Davies, Elliott & Meaburn (1976). These data were used to study H II regions and SNRs (Ye 1988). A new survey was carried out between 1985 and 1992 (Turtle & Amy 1991; Ye & Turtle 1993). The partly overlapping fields were located on an array of pointing centres separated by 40 arcmin in declination and 10 minutes in right ascension, staggered by 5 minutes at adjacent declinations. Some additional fields were observed at non-standard centres where this improved the images of certain regions. All useful data acquired since mid-1983 have been included in the current data reduction. As a result the coverage of the survey area is not uniform; some central areas have been observed many times while peripheral regions may have been observed only once.

3 Data Reduction and Calibration

The survey contains 128 separate 12 hour observations. Each generated a data set (consisting usually of the responses from 384 fan beams sampled every 24 s) which was formed into an image using the method of back projection (Crawford 1984). Further procedures including CLEAN enhanced the quality of these images. The treatment was similar to that used for the First Epoch Molonglo Galactic Plane Survey (MGPS1) as described in detail in Green et al. (1999).

Calibration consisted of a series of steps. First a provisional adjustment to each data set was based on the contemporary short observations of standard calibration sources. Next, all the images contained unresolved sources which were also present in other overlapping images. Fits for the position and flux density of these sources were made on the final CLEANed images and the results were intercompared to produce mean gain, right ascension and declination corrections for each image. These corrections were then applied to bring the whole survey onto common intensity and position scales.

To improve the sensitivity and to get an overview of the SMC, all observations were then combined into a single image. All the 128 CLEANed images were mosaiced with a weight based on their quality and with the above corrections included.

The final step in the overall calibration involved two further sets of observations. Firstly, the calibration of position was carried out. Fifteen of the stronger background sources in the survey have been observed by us at 5 GHz using the Australia Telescope Compact Array (ATCA) with a beam (FWHM) of 4 arcsec. Seven of these sources were found to be still unresolved and their positions at 5 GHz were determined to better than 1 arcsec. The mean position of these sources in the 843 MHz mosaic agreed with the mean of the ATCA positions within 0·5 arcsec, showing that the positional scale had systematic errors of less than 1 arcsec.

Secondly, the intensity calibration was carried out. The 843 MHz flux densities of the four strongest sources unresolved at this frequency were measured with the MOST in a special set of observations in 1992 September. Each source was observed in sequence for four minutes at each of several hour angles. Several standard calibration sources were included in the sequence and enabled the flux density of the four sources to be established on the standard MOST scale with an uncertainty of 2·0 per cent. The absolute scale itself, on which

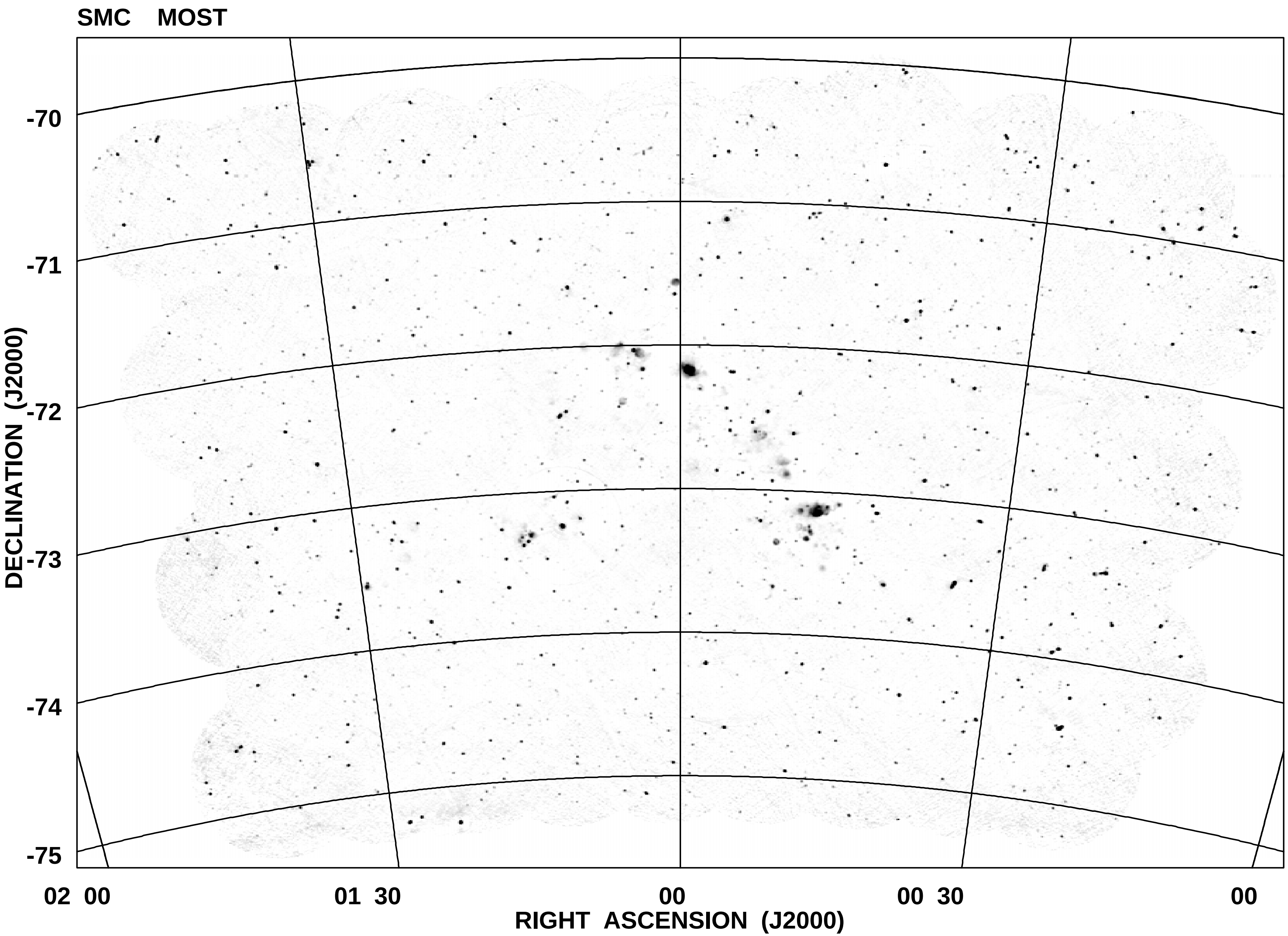

Figure 1—Grey scale version of the MOST 843 MHz image of the Small Magellanic Cloud. White corresponds to 0 mJy per beam and black to 25 mJy per beam.

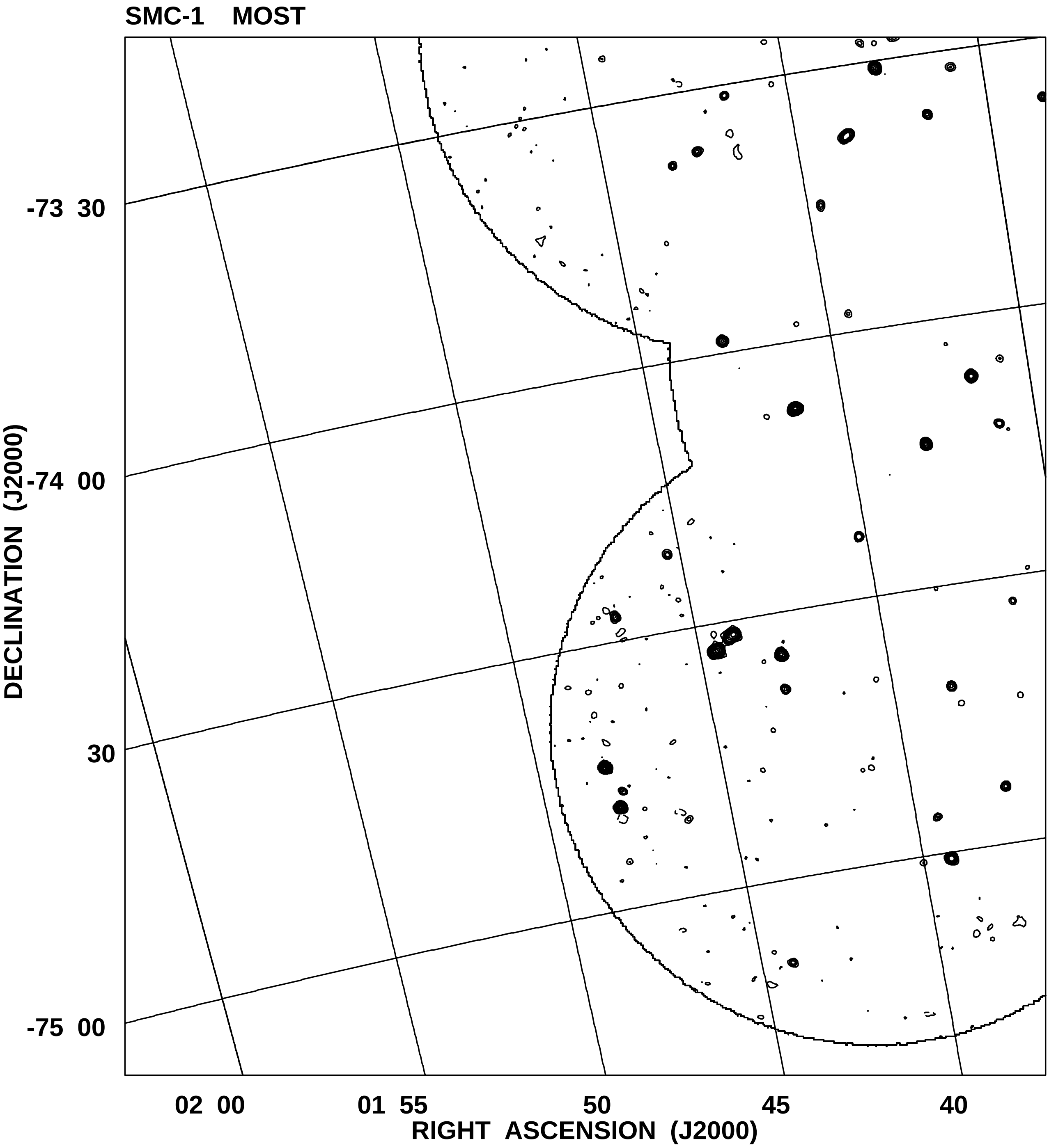

Figure 2—Fifteen plots of contiguous sections of the MOST 843 MHz image of the Small Magellanic Cloud. The contours shown are −4 (dashed), 4, 7, 10, 15, 20, 30, 40, 60, 80, 100, 200, 400, 600 and 800 mJy/beam.

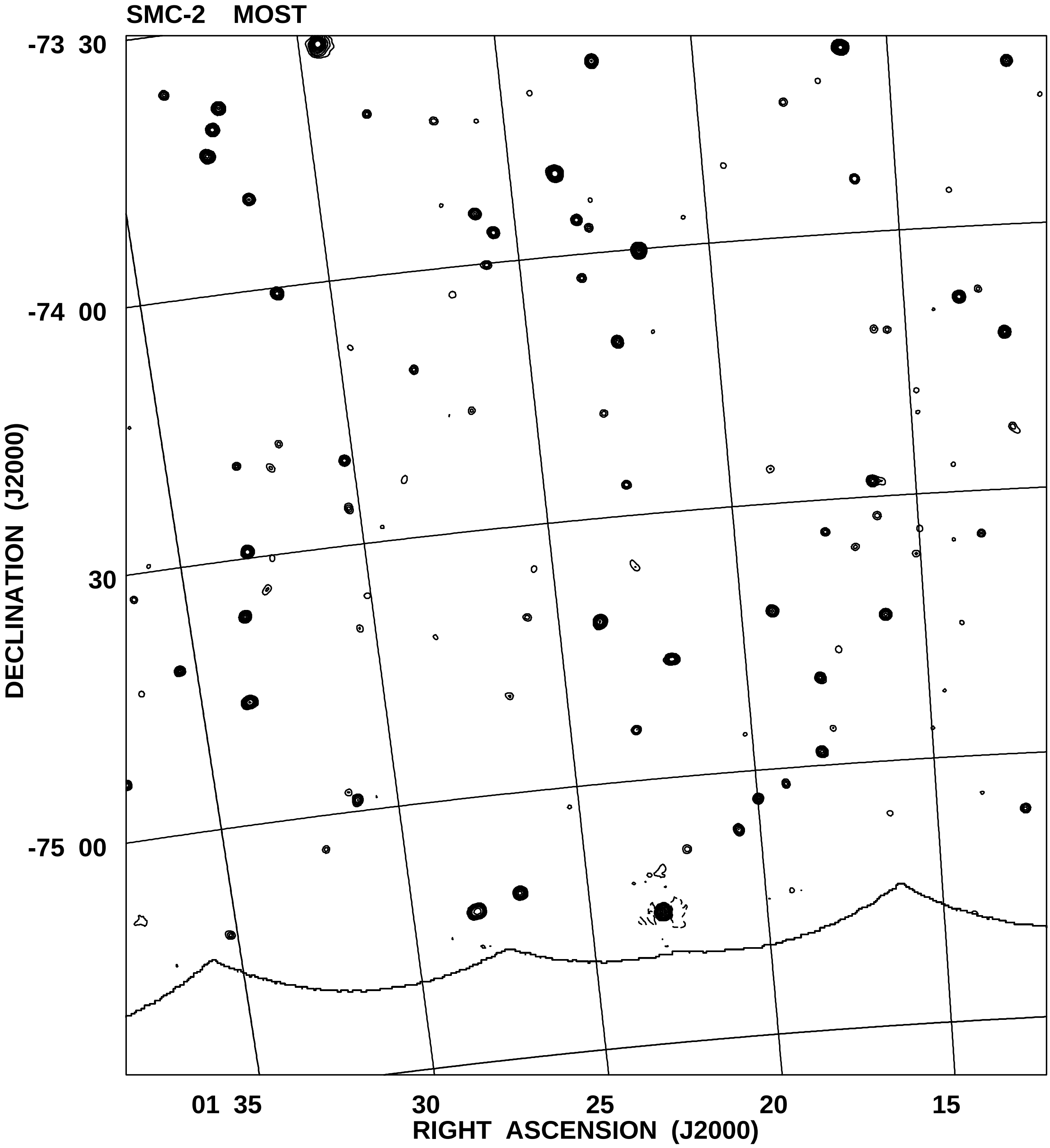

Figure 2—(*Continued*)

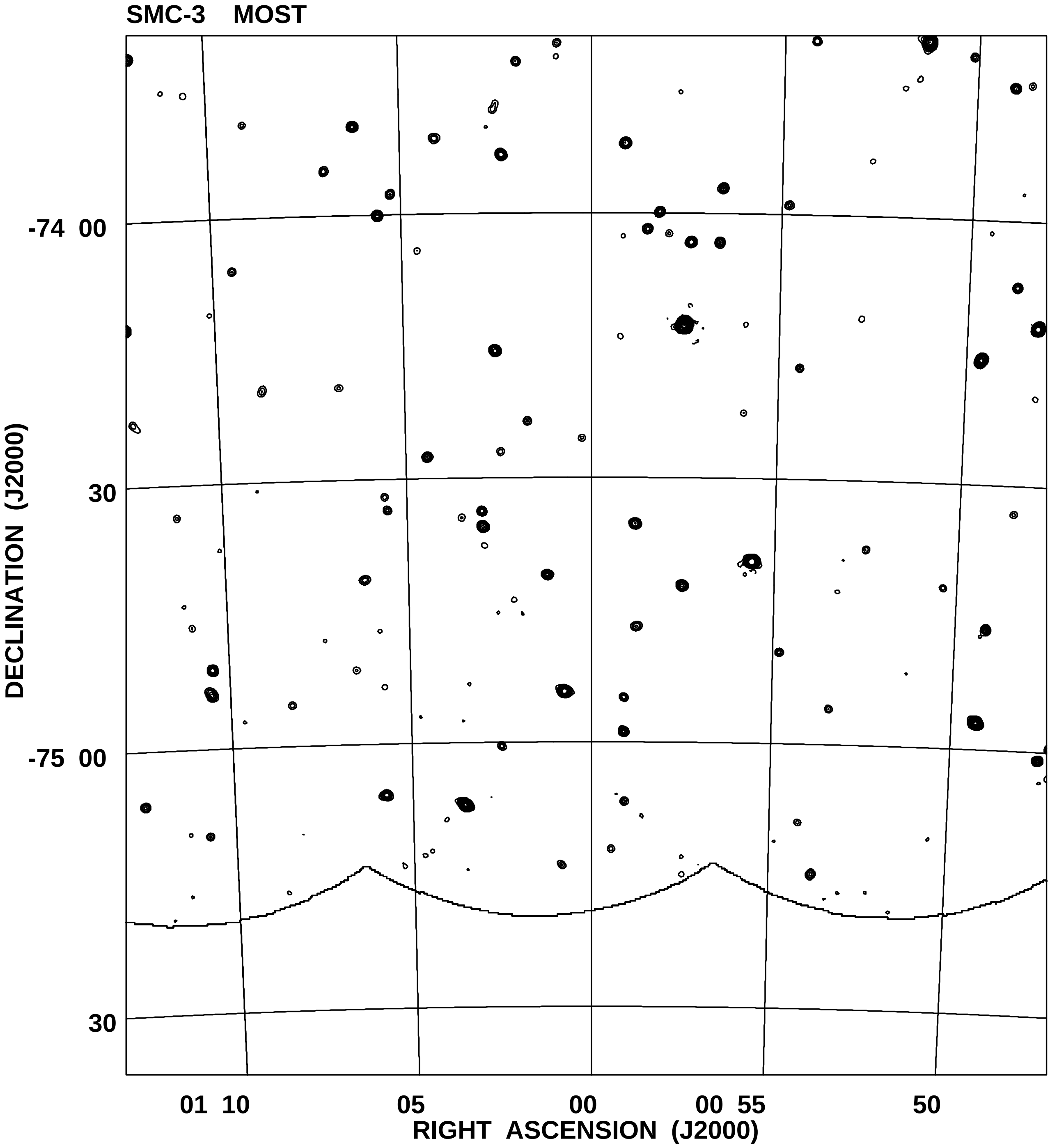

Figure 2—(*Continued*)

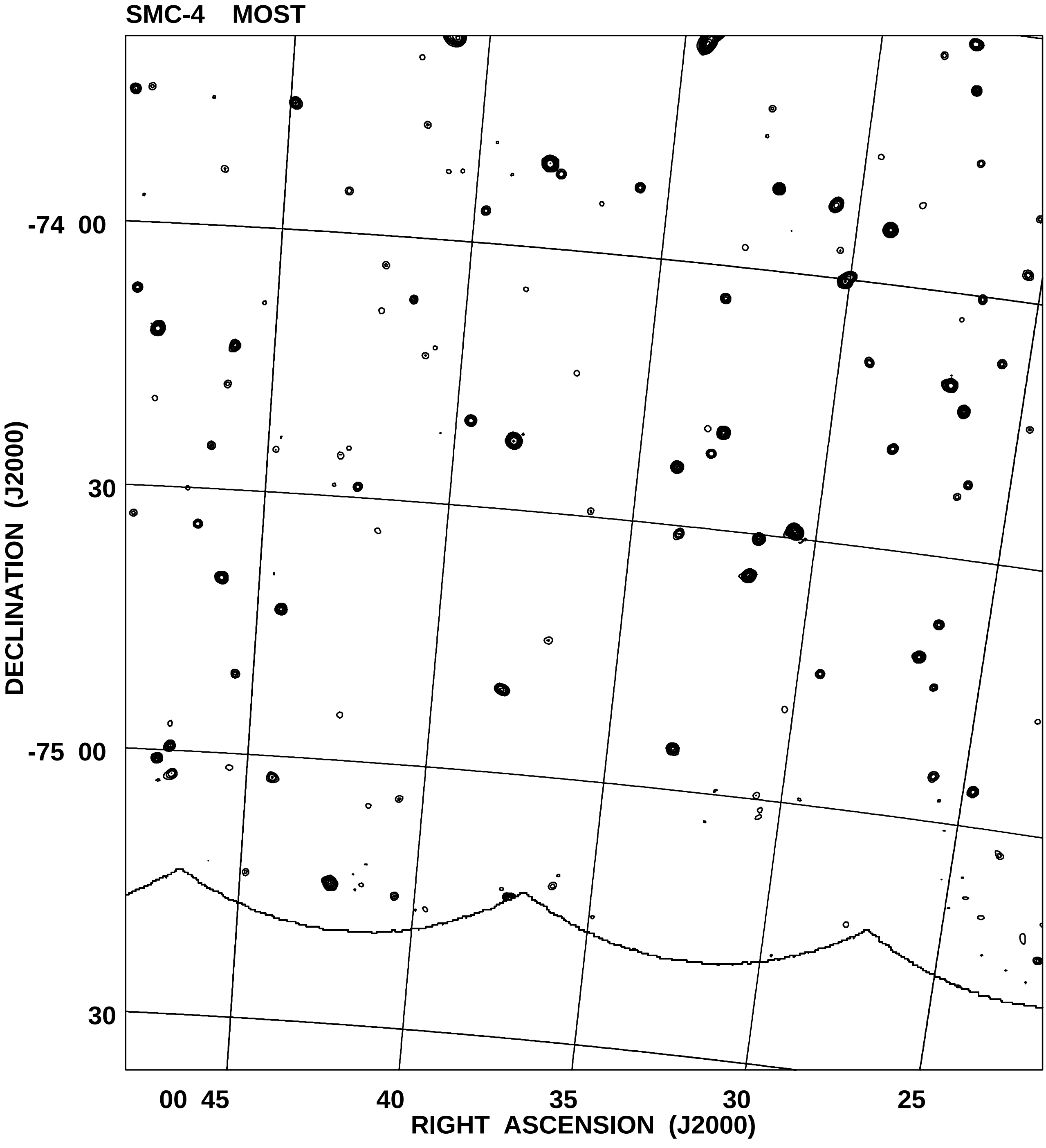

Figure 2—(*Continued*)

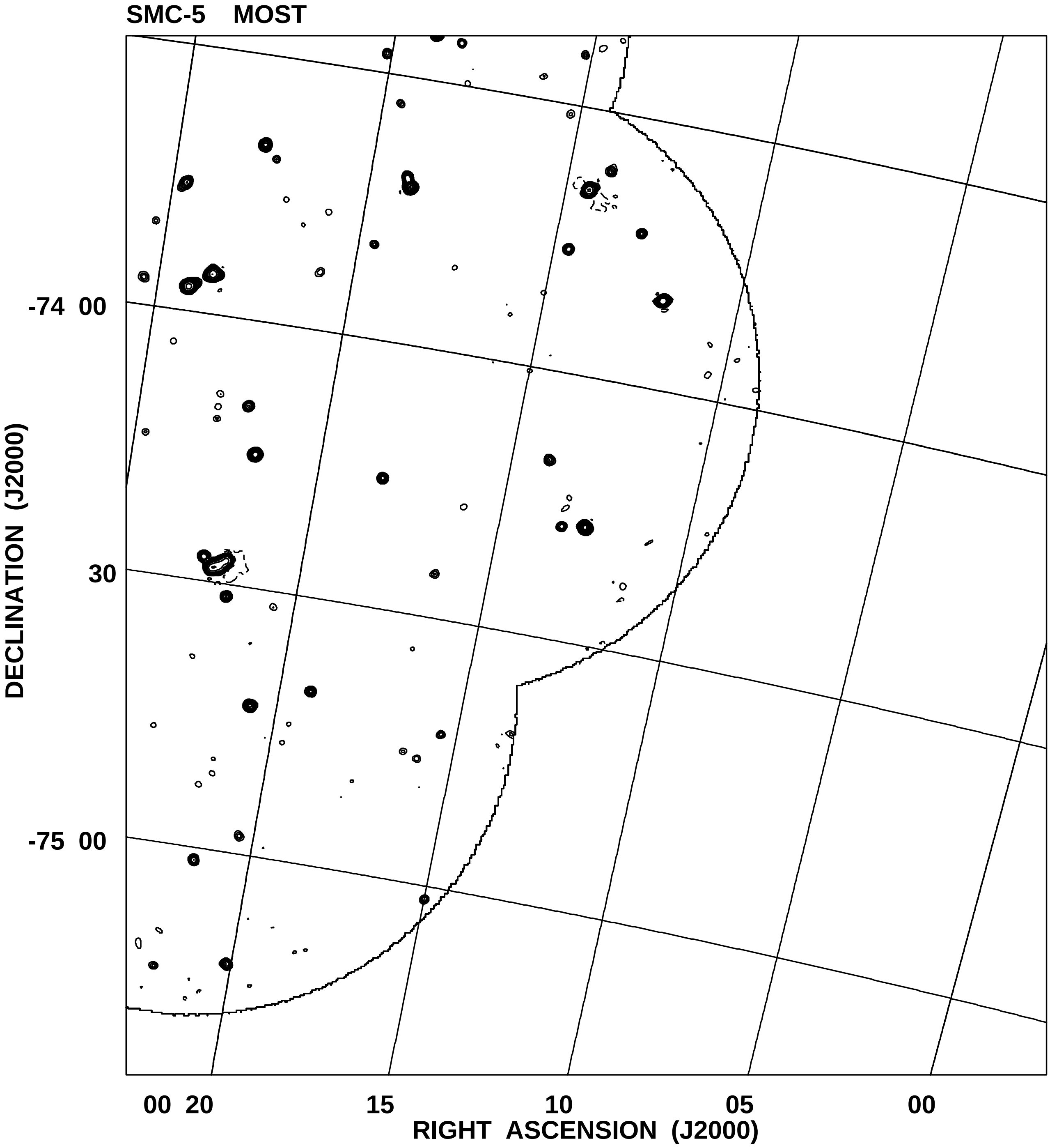

Figure 2—(*Continued*)

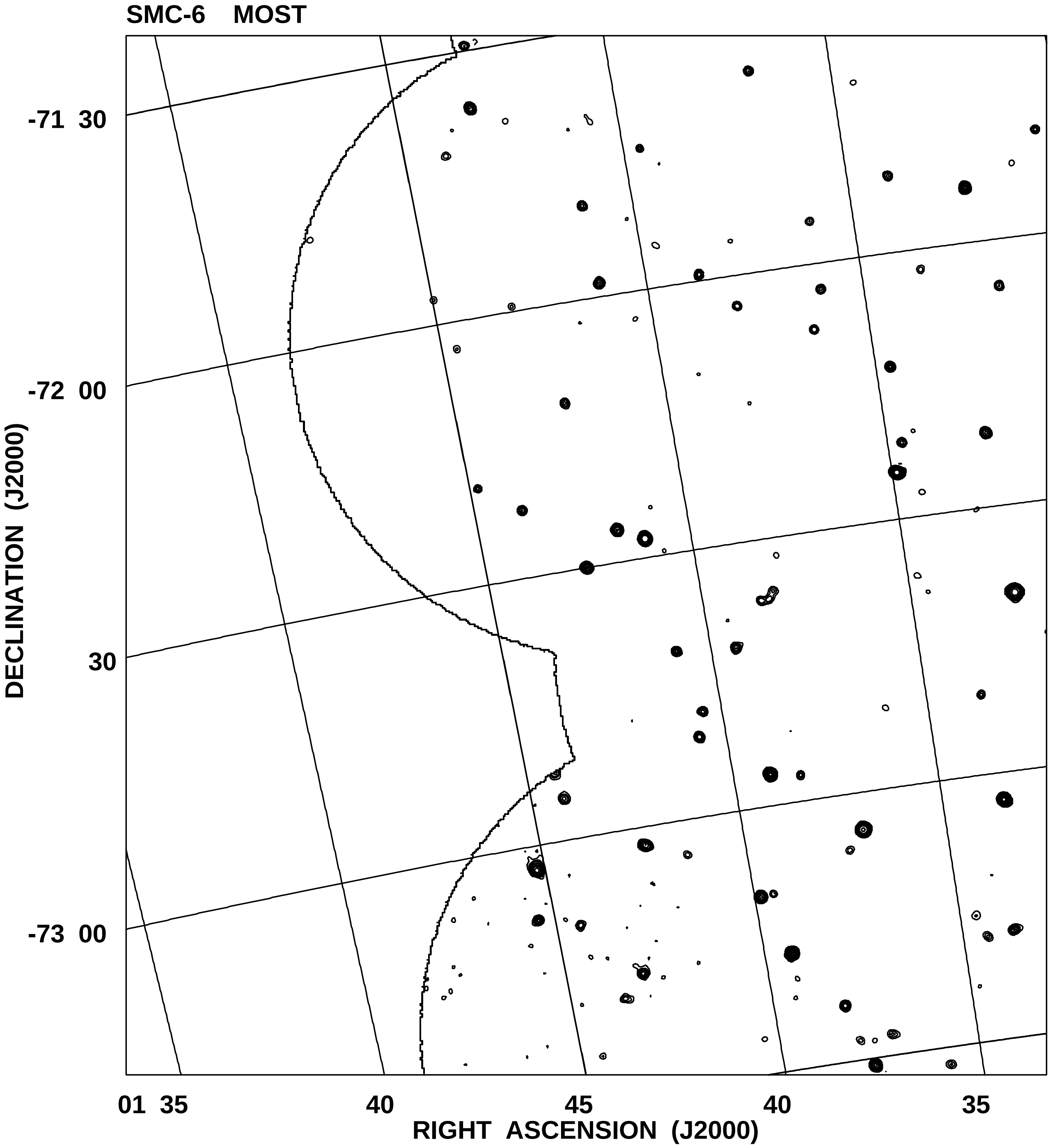

Figure 2—(*Continued*)

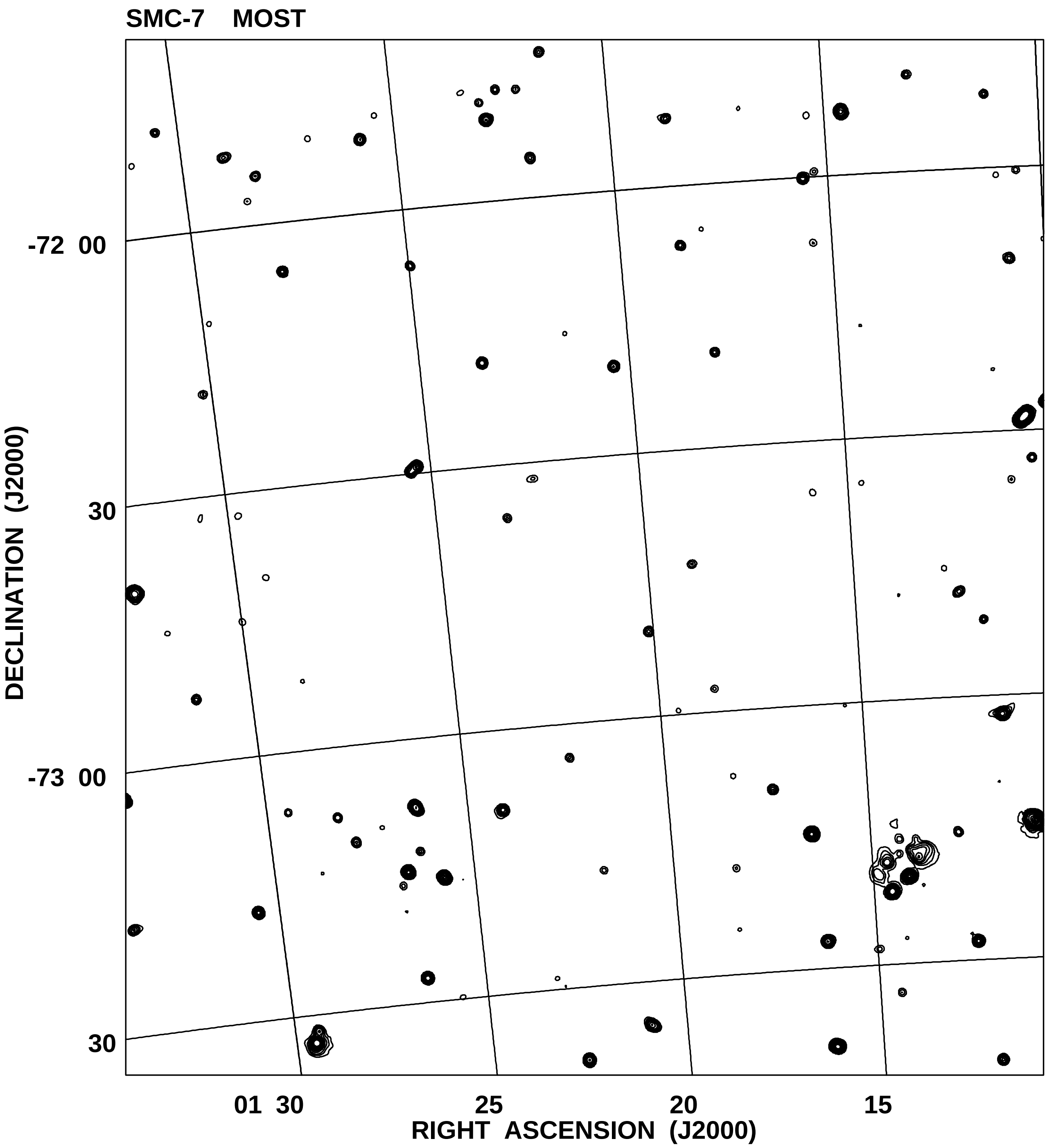

Figure 2—(*Continued*)

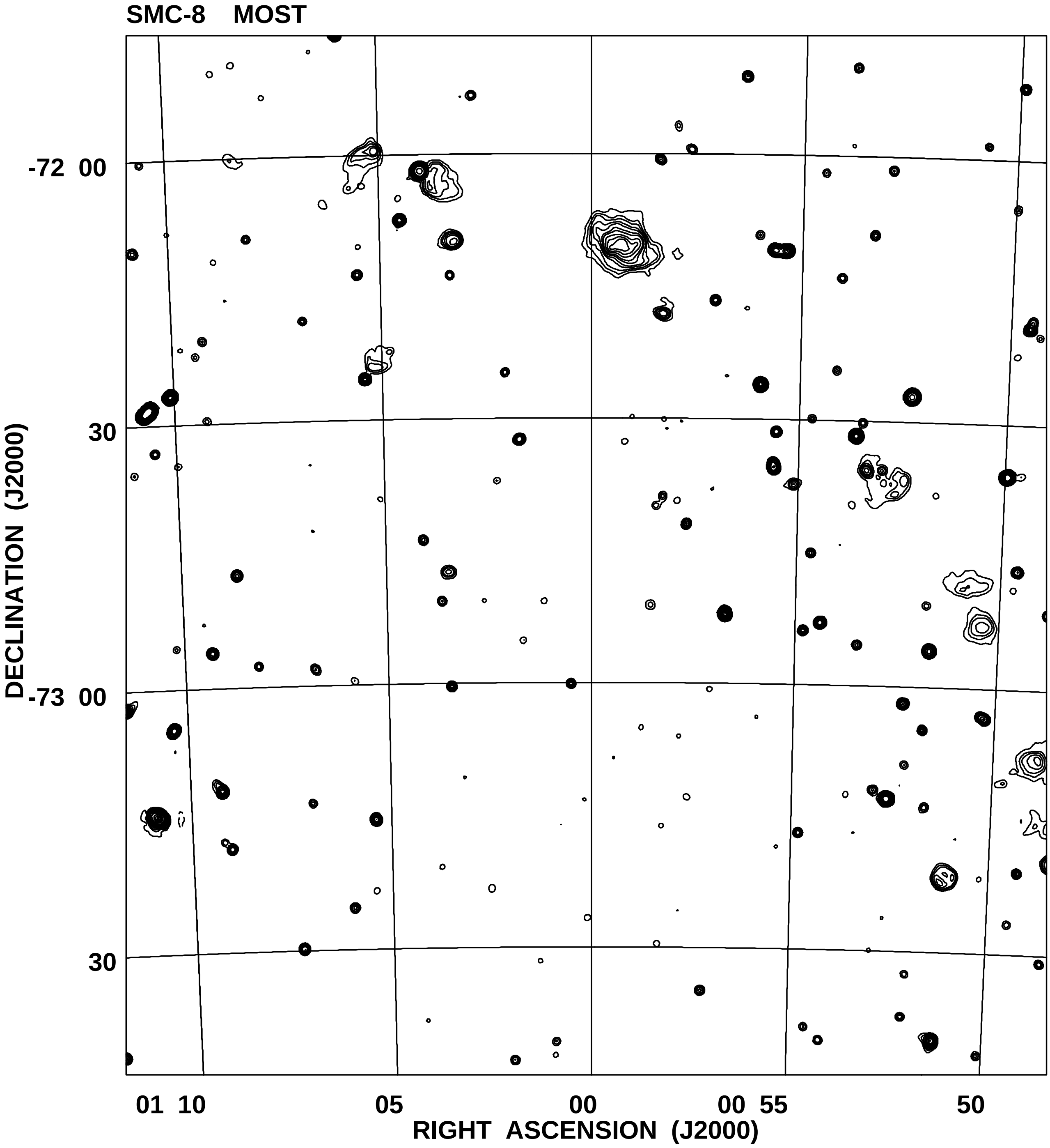

Figure 2—(*Continued*)

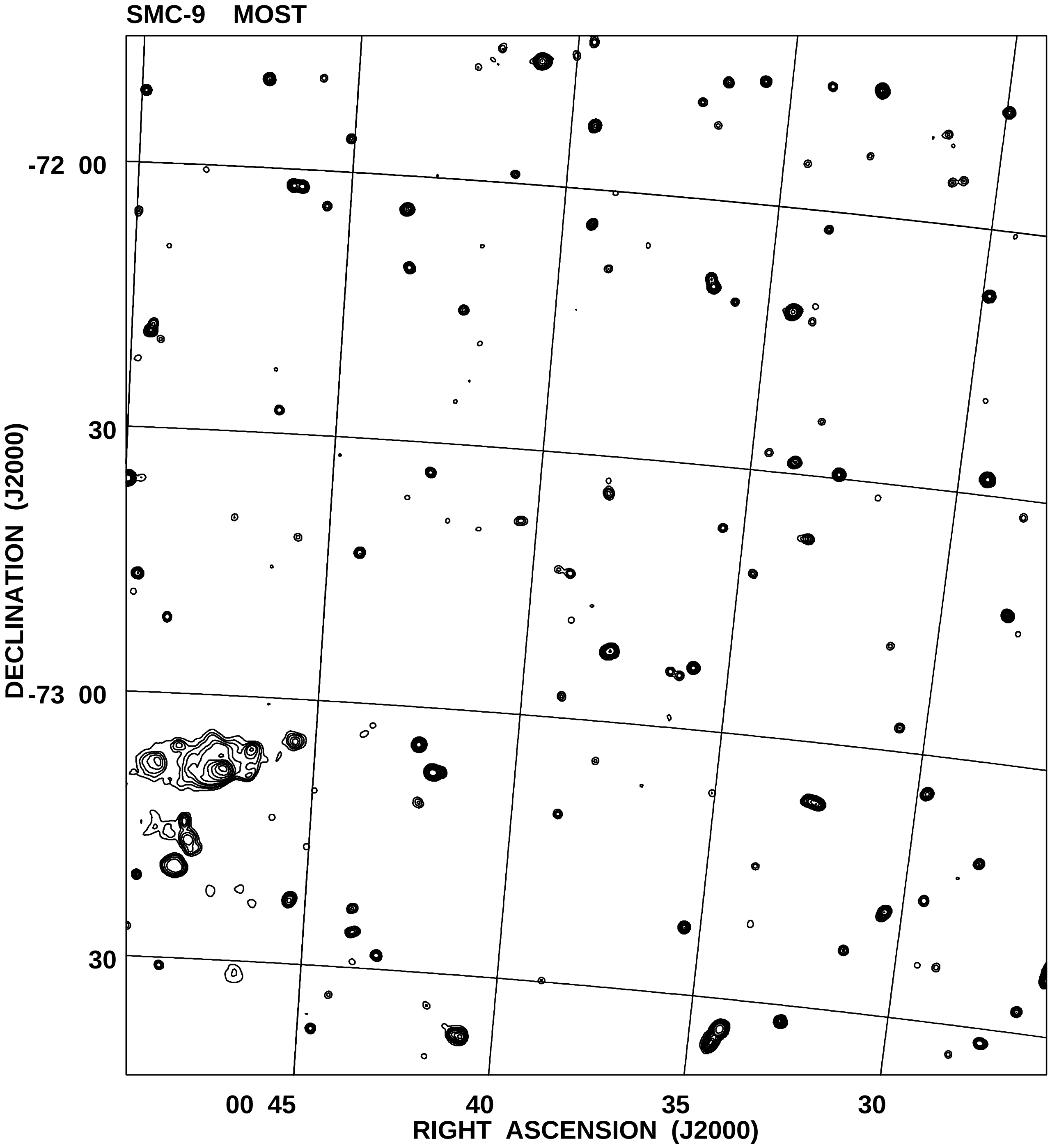

Figure 2—(*Continued*)

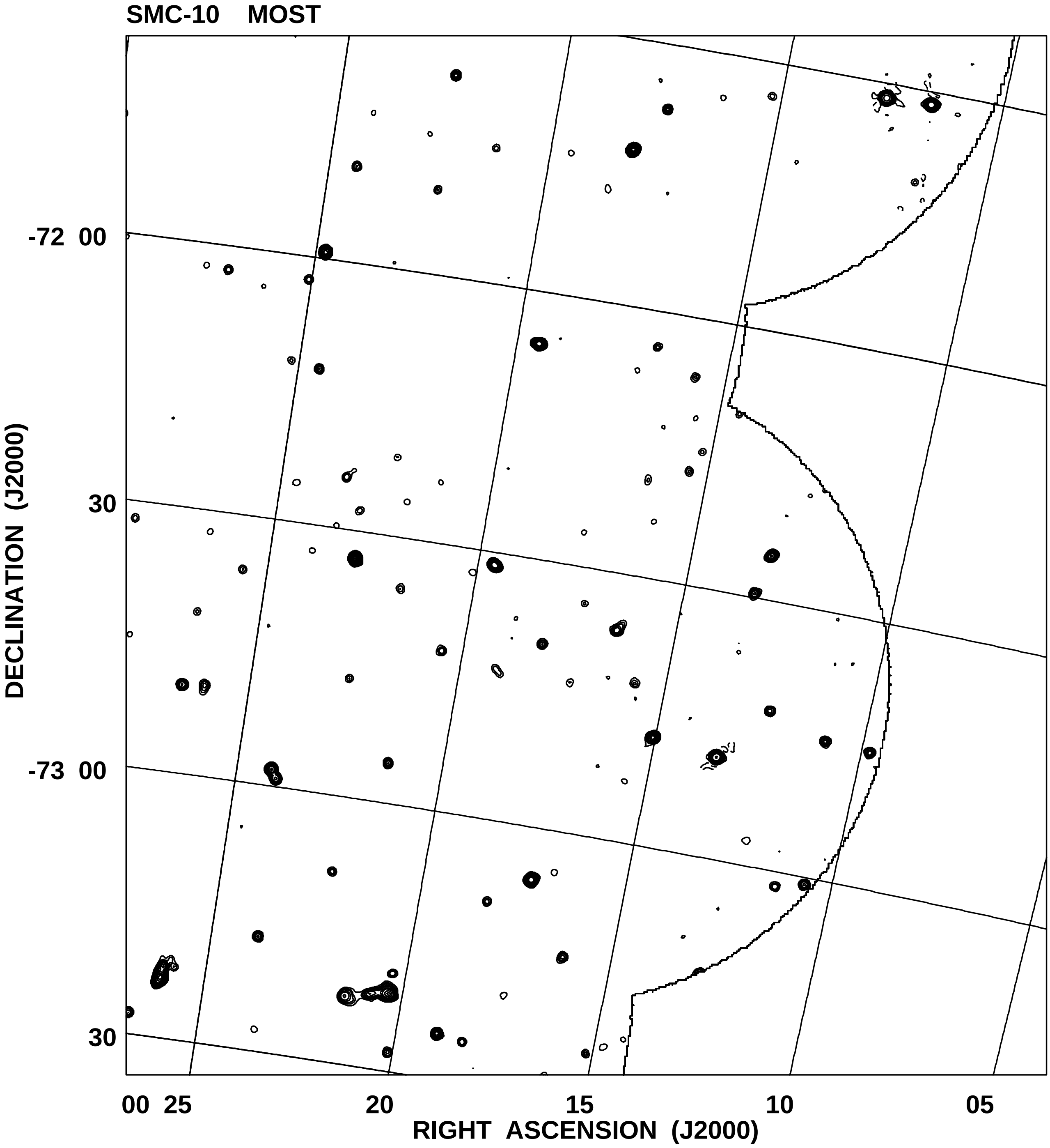

Figure 2—(*Continued*)

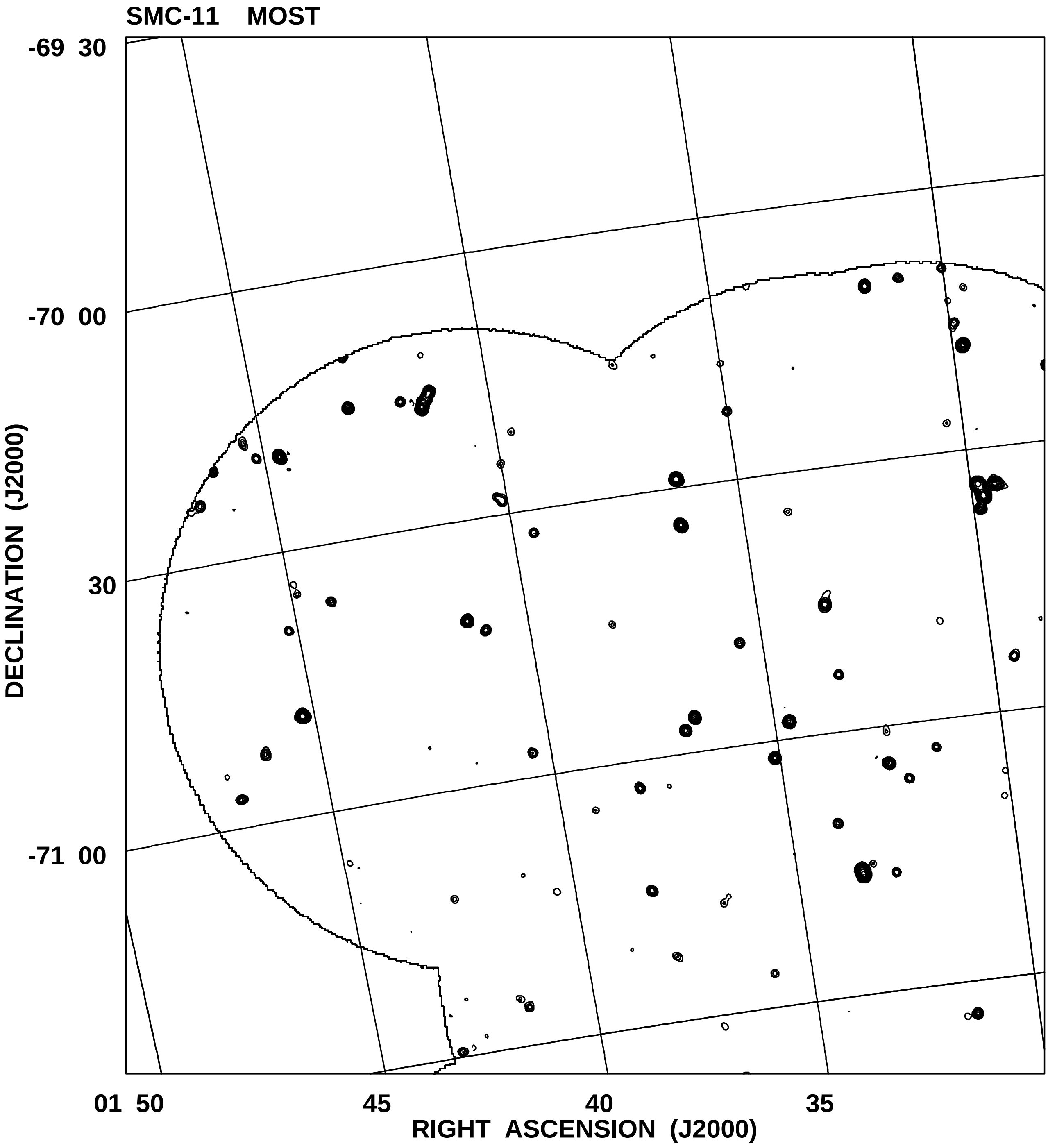

Figure 2—(*Continued*)

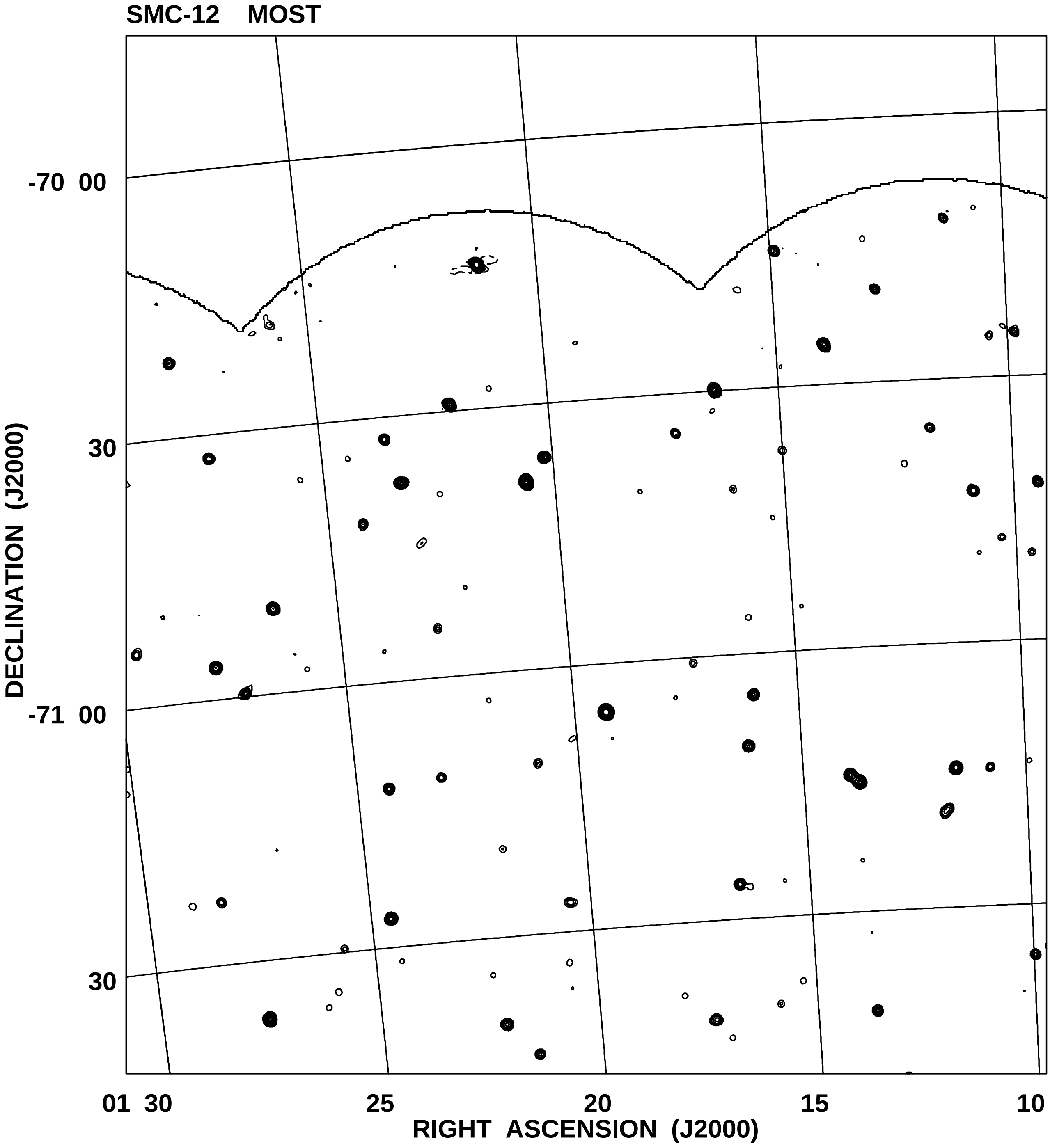

Figure 2—(*Continued*)

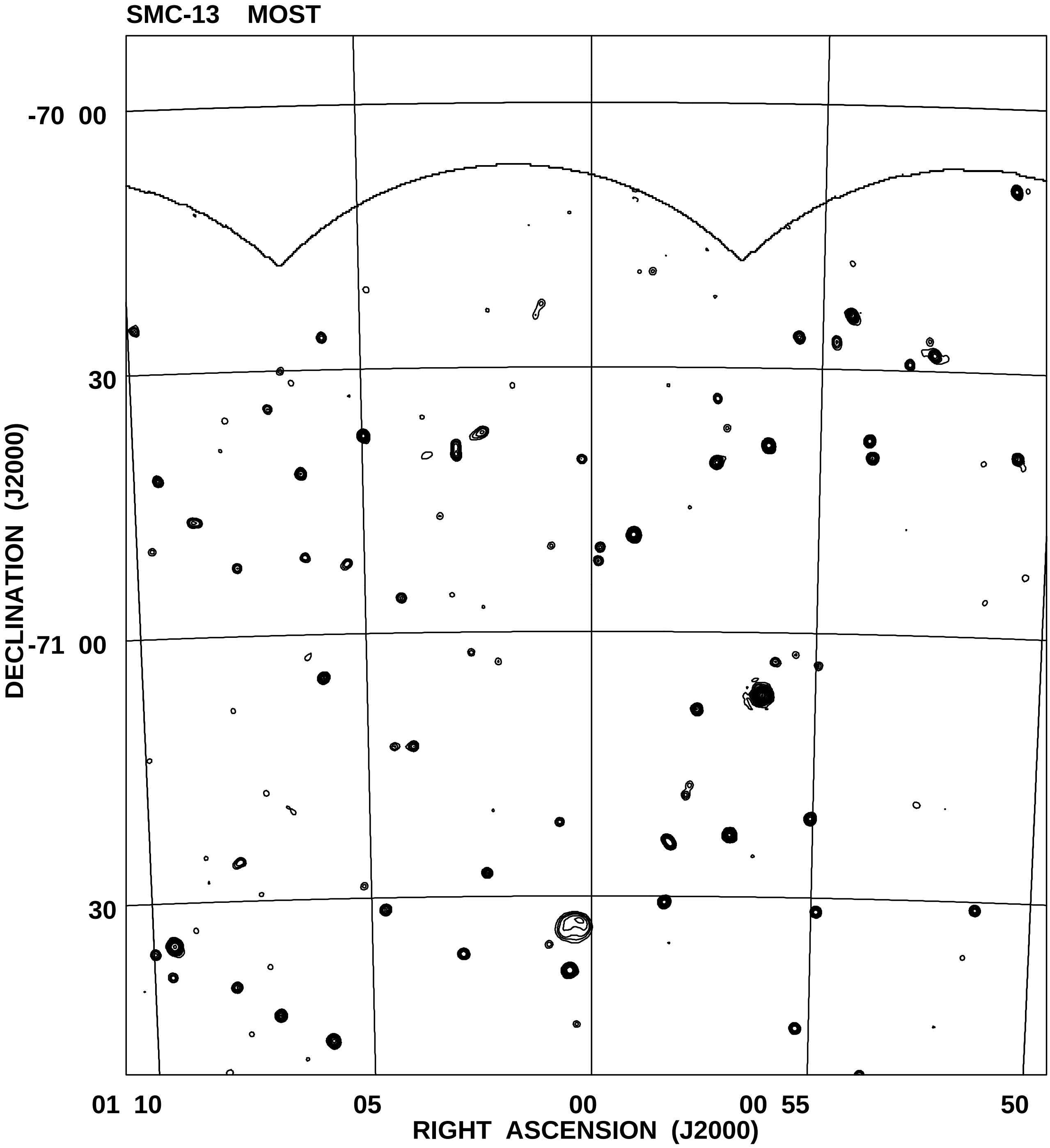

Figure 2—(*Continued*)

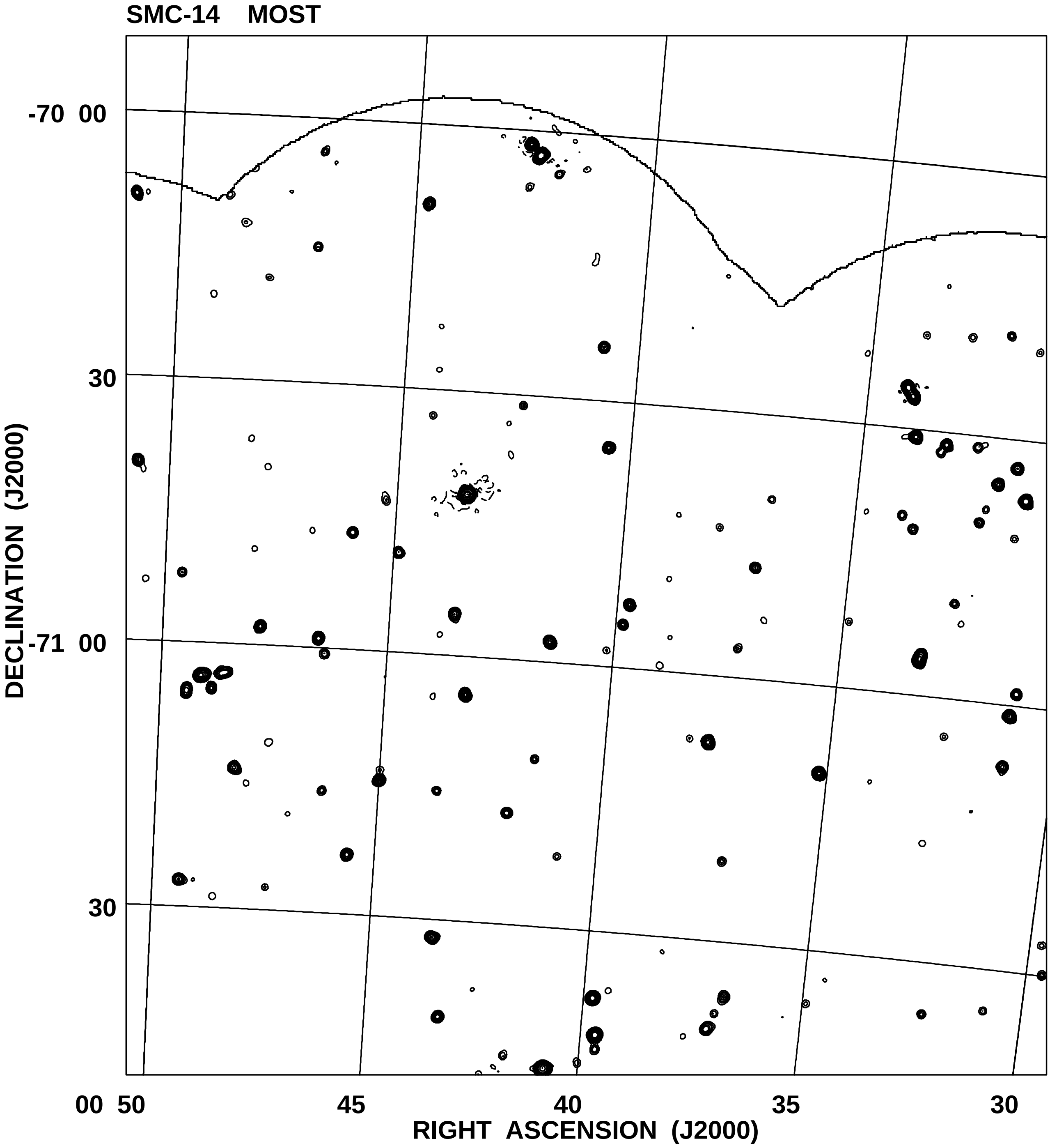

Figure 2—(*Continued*)

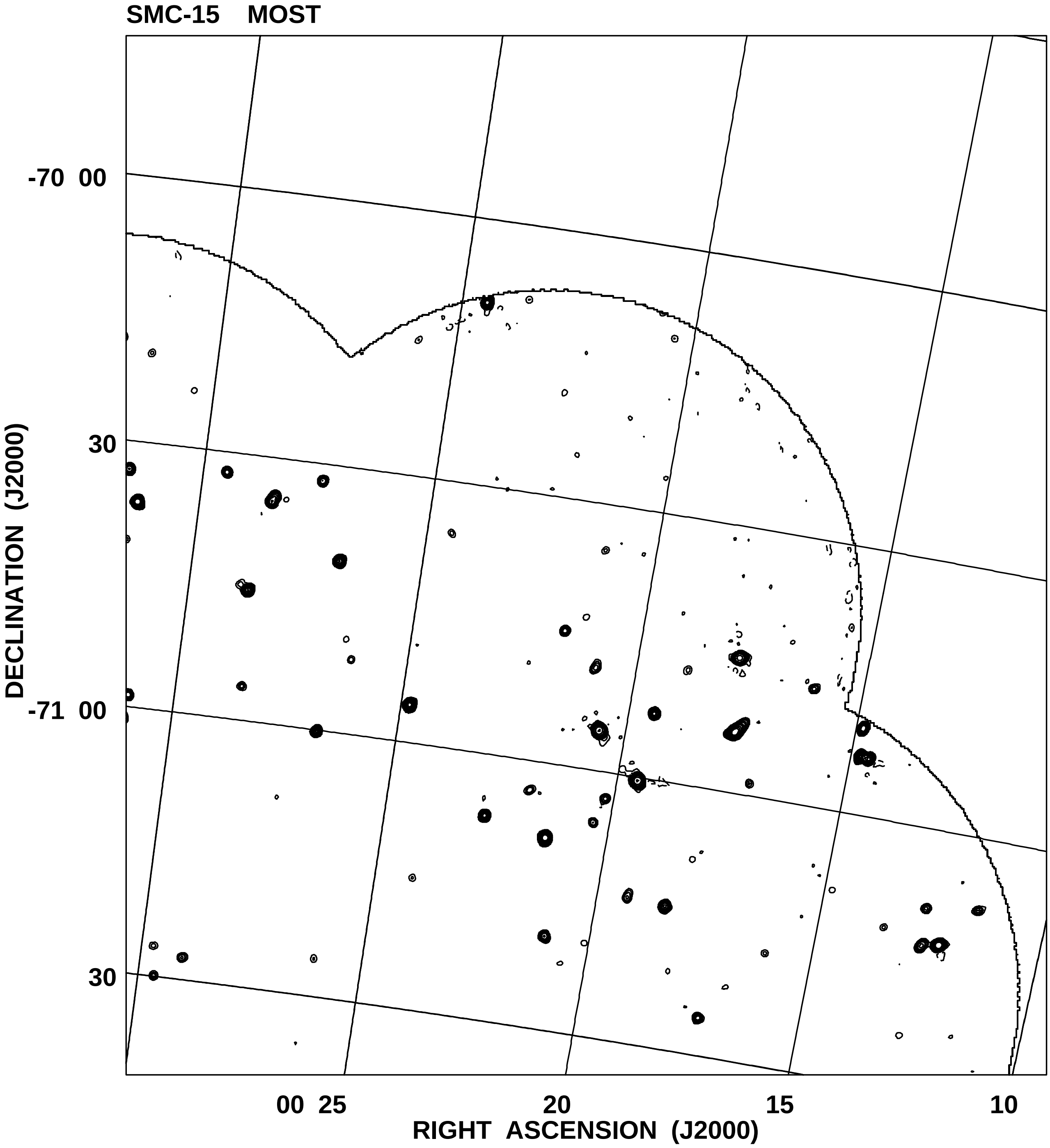

Figure 2—(*Continued*)

the sources 0409–752 and 1934–638 are 19·8 and 13·65 Jy respectively, is believed to be correct to within 5% (Hunstead 1991). After applying a single empirically derived factor to the mosaic, the fitted flux densities of the four sources agreed with the results of the special observations to within 2%. Hence the overall flux density calibration should be correct to better than 6%.

For individual sources, the random errors due to noise and other effects are likely to exceed the systematic uncertainties in position and flux density.

4 The Images

A grey scale image of the whole survey is shown in Figure 1. To provide more detail of the sources, the mosaiced image has been divided into the fifteen smaller images presented in Figure 2. Each small image covers a 2×2 degree^2 area with slight overlaps.

As explained earlier, the noise level is not constant across the mosaic image. It depends on the number and quality of the individual images which contribute to a given region. The rms noise is typically 0·5 mJy per beam area in the central areas and 1·5 mJy per beam area near the edge. The noise is not entirely random as can be seen in Figure 1. Some artifacts are still present at a low level; for instance elliptical grating rings (with an RA radius of 1·12°) or other sidelobes of the strongest sources may not be completely removed. However, these features are very weak and do not reduce the value of the images.

The mosaiced image contains no information on the broad features of the radio emission from the SMC because the MOST is an interferometer with a minimum separation of 42·9 wavelengths and so low spatial frequencies are attenuated or not recorded. The broad features of the SMC at 843 MHz measured with a beam of 24 arcmin are presented in Ye & Turtle (1991) which includes a separation into thermal and nonthermal components.

Catalogues including larger images of the relevant extended sources are in preparation separately for the SNRs, the H II regions and the background sources.

Acknowledgments

The MOST is supported by the Australian Research Council and the Science Foundation for Physics within the University of Sydney. The SMC survey would have been impossible without encouragement and technical support from all members of the Astrophysics Department of the School of Physics. TY acknowledges the receipt of a Harry Messel Research Fellowship.

References

Clarke, J. N., Little, A. G., & Mills, B. Y. 1976, Aust. J. Phys. Astrophys. Suppl., 40, 1
Crawford, D. F. 1984, in URSI/IAU Symp. Indirect Imaging, ed. J. A. Roberts (Cambridge Univ. Press), p. 373
Davies, R. D., Elliott, K. H., & Meaburn, J. 1976, MNRAS, 81, 89
Filipović, M. D., Jones, P. A., White, G. L., Haynes, R. F., Klein, U., & Wielebinski, R. 1997, A&AS, 121, 321
Green, A. J., Cram, L. E., Large, M. I., & Ye, T. 1999, ApJ, submitted
Haynes, R. F., Klein, U., Wielebinski, R., & Murray, J. D. 1986, A&A, 159, 22
Haynes, R. F., Klein, U., Wielebinski, R., Murray, J. D., Bajaja, E., Meinert, D., Buczilowski, U. R., Harnett, J. I., Hunt, A. J., Wark, R., & Sciacca, L. 1991, A&A, 252, 475
Hunstead, R. W. 1991, Aust. J. Phys., 44, 743
Loiseau, N., Klein, U., Greybe, A., Wielebinski, R., & Haynes, R. F. 1987, A&A, 178, 62
McGee, R. X., Newton, L. M., & Butler, P. W. 1976, Aust. J. Phys., 29, 329
Mills, B. Y. 1981, PASA, 4, 156
Mills, B. Y., Little, A. G., Durdin, J. M., & Kesteven, M. J. 1982, MNRAS, 200, 1007
Robertson, J. G. 1991, Aust. J. Phys., 44, 729
Turtle, A. J., & Amy, S. W. 1991 in IAU Symp. 148, The Magellanic Clouds, ed. R. Haynes & D. Milne (Dordrecht: Kluwer), p. 114
Ye, T. 1988, PhD Thesis, University of Sydney
Ye, T., & Turtle, A. J. 1991, MNRAS, 249, 693
Ye, T., & Turtle, A. J. 1993, in Lecture Notes in Physics: New Aspects of Magellanic Cloud Research, ed. B. Baschek, G. Klare & J. Lequeux (New York: Springer), p. 167
Ye, T., Turtle, A. J., & Kennicutt, R. C. 1991, MNRAS, 249, 722