PRELIMINARY RADIO ANALYSIS FROM AN X-RAY/RADIO SURVEY OF NEARBY SPIRAL GALAXIES

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Abstract

We present a preliminary analysis of new VLA observations of the nearby spiral galaxies M51, M101 and NGC3184. As part of a larger Very Large Array (VLA)/*Chandra* survey of spiral galaxies, we obtained high resolution VLA observations of each galaxy. Observations were taken in the spring of 2002 (20 cm) in the VLA A-configuration, and in the winter of 2003–2004 (6 cm) in B-configuration. Many point sources have been detected in each galaxy. The results for a few of the sources will be presented here. With complementary *Chandra* observations we are for the first time able to definitively classify some sources. This type of analysis has been useful in identifying supernova remnants and also potential X-ray binaries in the galaxy M83. A more complex X-ray analysis is currently in progress and will be forthcoming in a later paper.

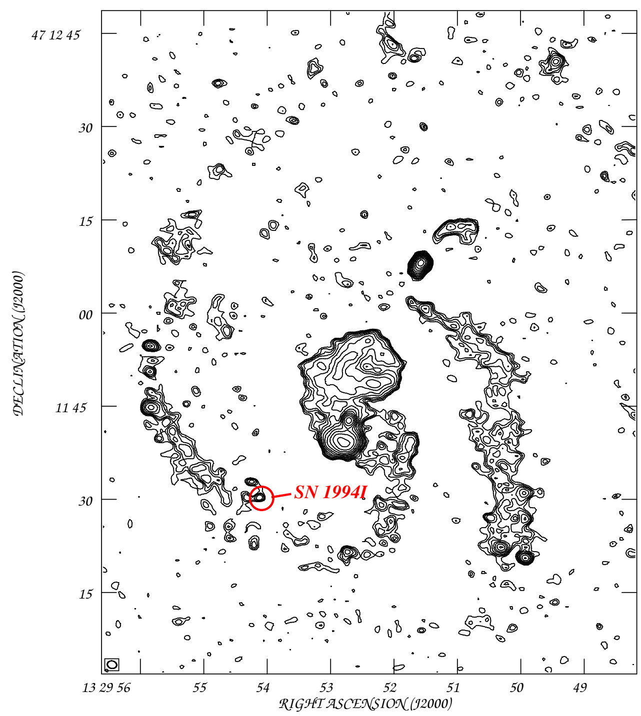

Figure 1: Central region of M51 in 20 cm contours. Spiral structure is very evident, as is the large lobe of emission just to the north of the nucleus.

1 Introduction

In the last few decades, astronomers have been monitoring supernovae using powerful radio telescopes. These observations give us clues to the post-main sequence evolution of massive stars, the progenitors of supernovae (Weiler et al., 2002). In particular nonthermal synchrotron radio emission from supernovae results from the interaction of the supernova shock with circumstellar material (CSM, Chevalier, 1982). The amount and duration of this radiation is related to the CSM density, and thus the mass-loss rate of the supernova progenitor. Radio observations over time (i.e., radio light curves) allow us to directly determine these progenitor mass-loss rates, as well as detect binary companions, or reveal episodes of enhanced wind activity. In addition the long-term monitoring of decades-old supernovae will allow us to examine the transition of a supernova into a supernova remnant, a phase that is not well understood. Much of the motivation for the work presented here comes from such long-term stud-

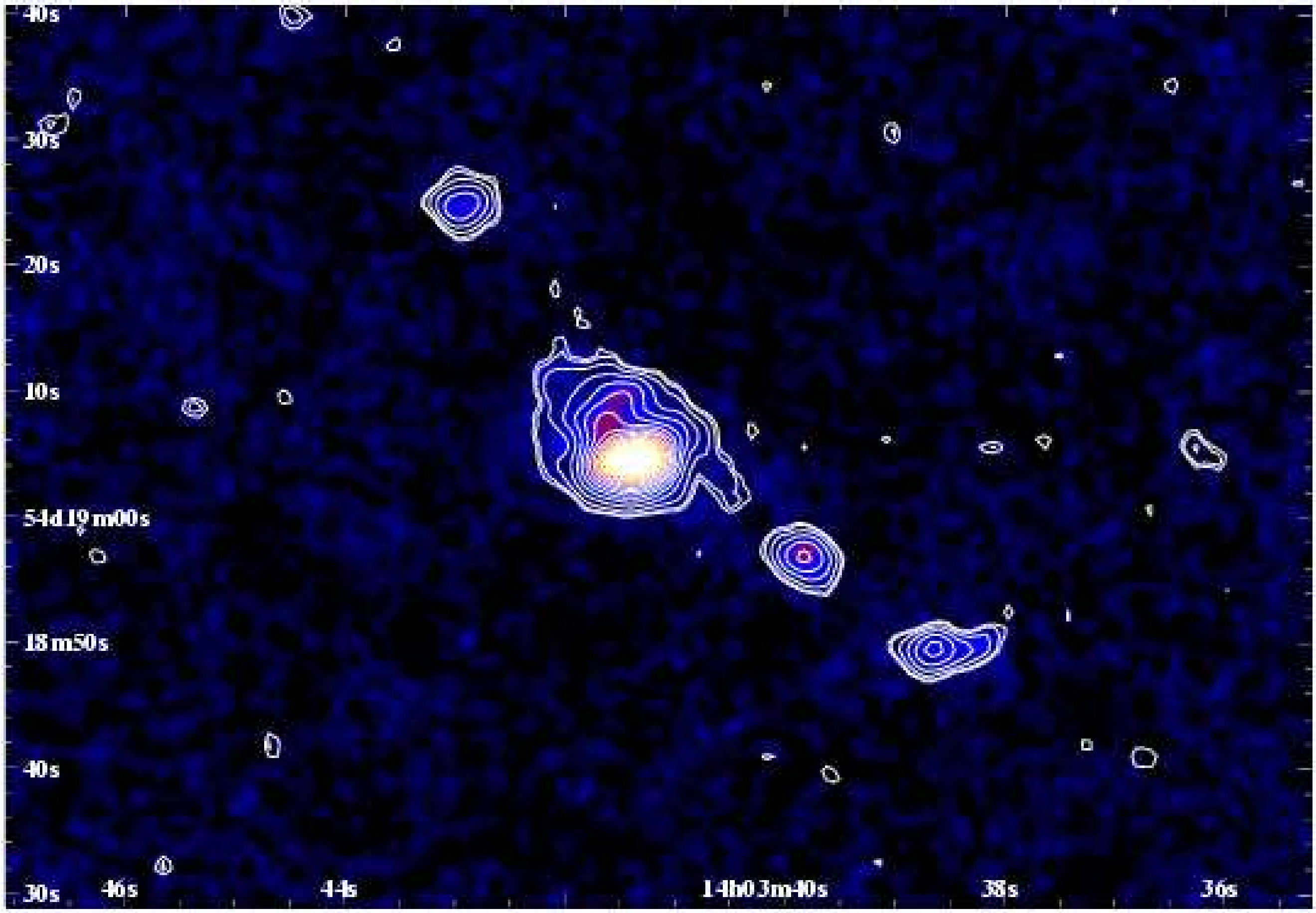

Figure 2: A close-up of NGC5461 at the end of spiral arm in M101. Colors show 6 cm emission while the contours are 20 cm emission.

ies of these radio supernovae.

We present here the first preliminary results from a large survey of nearby, face-on spiral galaxies. We have used the Very Large Array (VLA) to obtain deep observations of four galaxies: M51, M101, NGC3184, and M83. The last galaxy contains several sources that have been monitored since the early 1980's (Cowan & Branch, 1982, 1985; Cowan et al., 1994; Stockdale et al., 2001; Maddox et al., 2003). In the following sections we will describe each of the first three galaxies. We also will give the reasons for choosing the galaxies in the survey, as well as a qualitative description of the observations. We will then preview future work.

2 M51

We observed M51 (NGC5194) at 20 cm on 5 April 2002, using the VLA A-configuration (maximum baseline of 35 km). M51 is a large spiral galaxy that has been observed extensively at all wavelengths, and is the parent galaxy to one historical supernova. The spiral structure of the galaxy is very evident in the resulting continuum image. Figure 1 shows the nuclear region of the galaxy. We detect numerous radio point sources along the arms, including emission from the Type Ic supernova SN1994I.

The radio nuclear peak is coincident with the optical position as reported in NED (NASA Extragalactic Database). There is a complex region of diffuse emission to the north of the nucleus. While we cannot resolve individual sources in this region in the 20 cm image, *Chandra* detects several X-ray point sources. Future analysis of the X-ray data combined with complementary 6 cm radio data may reveal that the diffuse region contains several black holes and X-ray binaries.

3 M101

We observed M101 (NGC5457) on 7 March 2002 at 20 cm in A-configuration, and on 23 November 2003 at 6 cm in B-configuration (maximum baseline of 12km). M101 is the parent galaxy to three historical supernovae: SN1970G, SN1951H and SN1909A. It has been observed extensively in the radio to follow the evolution of SN1970G (e.g., Stockdale et al., 2001). The galaxy is also home to numerous cataloged supernova remnants (Matonick & Fesen, 1997; Pence et al., 2001; Di Stefano & Kong, 2003, etc). Our observations reveal several radio point sources, a few of which have X-ray coincidences.

Figure 2 shows the H II region complex NGC5461, located within one of the spiral arms of M101. The central source is the brightest source in both radio observations. It has 20 cm and 6 cm peak fluxes of 1.43 mJy and 1.66 mJy, respectively. This gives a spectral index of +0.12. In an analysis of a *XMM-Newton* observation of M101, Jenkins et al. (2004) report a potential X-ray binary and possible intermediate mass black hole candidate. More complete analysis of the VLA and *Chandra* observations will be presented in Kilgard, et al (in preparation) and Maddox, et al (in preparation).

4 NGC3184

We observed NGC3184 at 20 cm in two runs on 7 March and 5 April 2002 in the VLA A-configuration. We then observed at 6 cm on 28 November 2003 in B-configuration. Due to a severe pointing error (observer mistake) we re-observed the galaxy on 16 January 2004.

NGC3184 is the parent galaxy to three historical supernovae: SN1921B, SN1921C, and SN1937F. For this reason, the galaxy has been observed several times since 1983 for emission from the historical supernovae. Eck et al. (2002) reported only upper limits to the flux from each supernova.

Our observation detected several weak point sources, including the nucleus. Nuclear emission shows a marginally non-thermal spectral index. We also detected emission from an area near the position of SN1921C (see Fig. 3). The emission is present in all observations since 1983.

The emission near SN1921C was previously cataloged as a single source in the FIRST Survey. In a search for optical counterparts to FIRST sources, McMahon et al. (2002) detected a faint, red, non-stellar object at the radio position. In our observations, at much higher resolution than FIRST, we clearly see two sources. It is likely that the radio emission is unrelated to the supernova. It is more likely a background source. This would not be unusual based on the common presence of background sources in all of our observations.

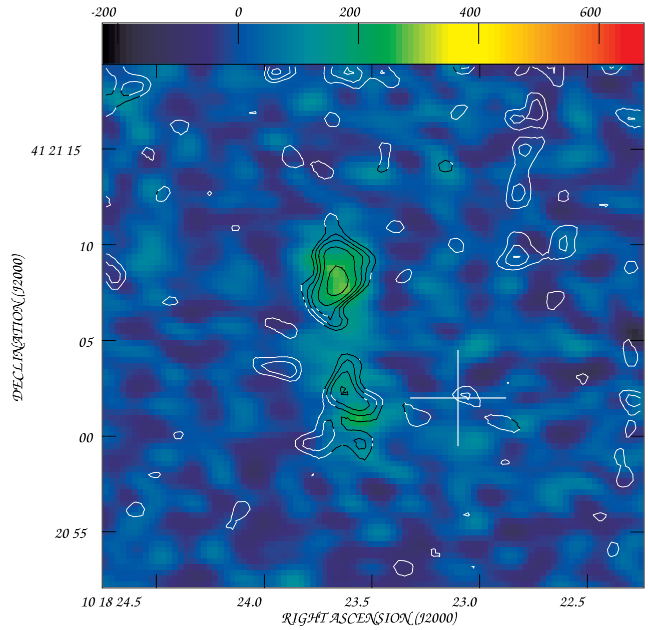

Figure 3: Blow-up of small region near NGC3184. Colors are the 20 cm emission and the contours show 6 cm emission. The cross indicates the reported optical position of Type I SN1921C. The size of the cross reflects a 5″ positional uncertainty in the optical position.

Due to the orientation of the *Chandra* CCD and the large distance from the nucleus, we were unable to perform X-ray analysis on the sources.

5 Conclusion

In the last several years, deep radio searches have led to the discovery of many new and interesting sources in the Universe. While some were previously known objects like supernovae and H II regions, others cannot be classified without detection in other wavelengths. Deep X-ray observations also detect interesting sources and can help to classify radio sources when there is a coincidence.

The use of complementary radio and X-ray observations has been a key aspect of our study of M83. While several sources were known to be supernovae and H II regions, as well as a background radio galaxy (Stockdale, et al in preparation), others could only be classified by adding *Chandra* observations. These include unknown supernova remnants and a radio counterpart to an X-ray binary.

Utilizing this multi-wavelength ability, we were motivated to search for and to identify new sources in a number of other nearby spiral galaxies. We have detected numerous radio point sources in these galaxies and *Chandra* has obtained equally numerous X-ray sources. The overlap between the two lists is $\sim 10\%$. While this is a relatively small number of coincidences, in many cases we are able to confidently classify objects based on their properties in each band.

What is presented here is just a very small part of the larger project. The first set of radio observations is complete and analysis is in progress. In the future we will be attempting new observations on a different set of galaxies.

Acknowledgments

The Very Large Array of the National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement with Associated Universities, Inc.

Special thanks to the scheduling committee of the VLA for their generosity in allowing us to recover data for NGC3184 after an erroneous observation. Financial support for this research was provided by the National Science Foundation grants AST-9986974 and AST-037279. Funding was also provided by Marquette University College of Arts and Sciences. Thanks also to Roy Kilgard and Andrea Prestwich for providing source lists and some analysis of the *Chandra* observations.

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