# NEW SUPERNOVA REMNANTS IN M33

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**Abstract:** Existing catalogues of supernova remnants (SNRs) in external galaxies are very incomplete. Potentially however, such samples are of great importance in understanding SNRs, since the distances to objects in a given sample are essentially the same and since absorption is small (compared to galactic SNRs). We have recently obtained H$\alpha$+[NII], H$\beta$, [SII], [OIII], and 6100 Å continuum CCD images of nine selected areas in M33 using the KPNO 4m. In addition to the six SNRs already known to exist in the fields we have surveyed, we have identified 21 other nebulae with [SII]:H$\alpha$+[NII] ratios which may be SNRs. Spectra of seven of these nebulae were obtained subsequently and show that the majority are indeed SNRs. A more detailed analysis of regions containing significant HII region contamination and a search for very small diameter remnants is currently underway.

## I. Introduction

SNRs are difficult to identify in nearby galaxies because they are faint and hard to distinguish from H II regions. Although X-ray (Long *et al.* 1981) and radio (D'Odorico *et al.* 1982, Cowan and Branch 1985) searches may eventually be more effective at identifying extragalactic SNRs, most known SNRs have been found optically. The most successful searches have been based upon interference filter imagery with follow-up spectroscopy. Emission nebulae with [S II]:H$\alpha$ ratios exceeding 0.4 are generally confirmed to be SNRs when spectroscopic observations are carried out (Dopita *et al.* 1980, Blair *et al.* 1981). Such ratios are expected for radiative shocks ($\sim$100 km s$^{-1}$) propagating through cloudlets in the ISM.

In M33, 19 SNRs have been identified by this technique previously (see D'Odorico, Dopita and Benvenuti 1980). They range in diameter from 3.5 to 70 pc and have H$\alpha$ luminosities of order $10^{36}$ to $10^{37}$ergs s$^{-1}$ (Blair and Kirshner 1985). The previous surveys, conducted primarily with photographic plates, are very incomplete. The SNRs that have been found obey a number-diameter (N(<D)) relationship that is consistent with free expansion to large diameter. The thermal energy content of the remnants appears to grow with diameter. Both of these results conflict with our conventional understanding of supernova remnant theory. However, both may be associated with the lack of a complete sample to any radius (as well as inaccurate diameter estimates). A larger sample of SNRs with well-defined sensitivity limits will help resolve these problems.

M33 is an ideal galaxy for pursuing such questions because it is nearby (1 arcsec = 3.5 pc), relatively face on (i$\sim$50°), and not very affected by Galactic absorption. As a result we have begun an interference filter CCD survey of M33. CCDs are ideal for extending traditional identification techniques for SNRs because they are linear and have large dynamic range and high quantum efficiency. In addition, CCD images can be used to provide the first set of integrated optical line fluxes for a significant sample of SNRs. This is information which has not been available previously since spectroscopic observations are usually made only of an isolated portion of a SNR. We are following up our imaging with spectroscopy which will permit a study of the structure and abundances of the ISM in M33.

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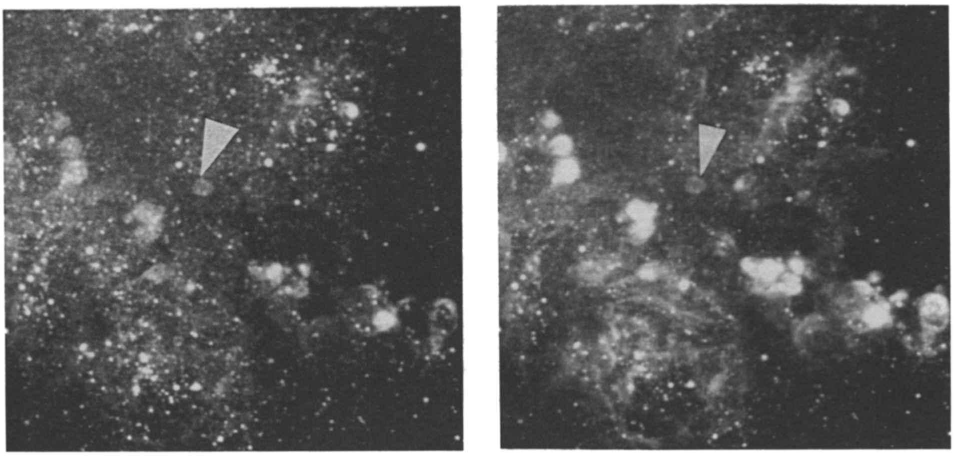

Figure 1: The raw [S II] and H$\alpha$+[N II] images of field 'h'. Notice how much brighter most of the emission nebulae are in H$\alpha$+[N II] compared with [S II]. An exception is the SNR candidate near the center of the field (indicated with an arrow).

## II. Observations

The survey consists of observations in the light of H$\alpha$+[N II], [S II], [O III], H$\beta$ and the 6100 Å continuum. The [S II], H$\alpha$+[N II] and 6100 Å continuum filter images are used to distinguish ISM-dominated SNRs, H II regions and stars. The [O III] and H$\beta$ images are useful in searching for ejecta-dominated SNRs and in measuring the reddening of individual nebulae. In an initial observing run in 1986 Sept 12-14 using the prime focus CCD on the KPNO 4m, we observed nine fields, each 3.7 arc minutes square, covering the nucleus and a portion of the inner spiral arms of M33 to the south and west of the nucleus. The field centers are listed in Table 1.

**Table 1: Field Centers**

| Field | RA (1950) | DEC (1950) | No. of New Candidates | No. of Known SNRs |
|---|---|---|---|---|
| a | 01 30 13.0 | +30 24 13 | 3 | 3 |
| b† | 01 31 01.7 | 30 24 15 | 3 | 0 |
| c | 01 31 01.7 | 30 17 18 | 2 | 1 |
| d | 01 31 01.6 | 30 20 45 | 4 | 0 |
| e | 01 30 45.4 | 30 24 11 | 4 | 0 |
| f | 01 30 29.2 | 30 24 17 | 3 | 0 |
| g | 01 30 45.4 | 30 20 46 | 0 | 1 |
| h | 01 30 46.0 | 30 17 13 | 2 | 1 |
| i | 01 30 29.0 | 30 13 45 | 0 | 0 |

†galactic nucleus

Until our analysis is complete we cannot quantify the sensitivity of the survey in detail. However, the faintest nebulae in our images have surface brightnesses less than $10^{-16}$ ergs cm$^{-2}$ s$^{-1}$ arcsec$^{-2}$. Our survey region contained six SNRs in the list of D'Odorico *et al.* (1980). All were easily detectable in all of the emission line images. As illustrated in

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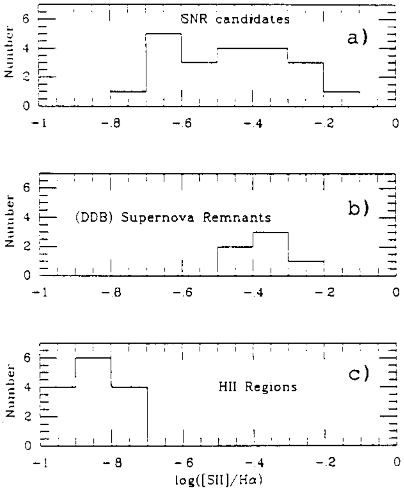
Figure 2b, [S II]:Hα+[N II] ratios through our filters for previously identified SNRs range from 0.36 to 0.52, averaging 0.45. Bright H II regions have [S II]:Hα+[N II] ratios which cluster near 0.14 (Figure 2c).



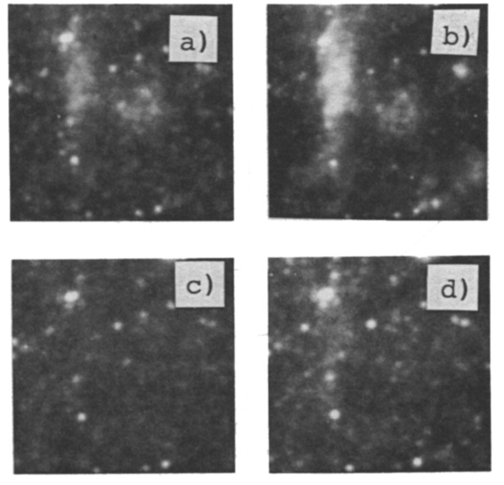




Figure 2: [S II]:Hα+[N II] ratios through our filters for (a) new candidates, (b) previously identified SNRs and (c) H II regions in M33. Figure 3: (a) [S II], (b) Hα+[N II], (c) 6100 Å, and (d) [O III] images of a one arcminute region in field 'c' containing a diffuse patch of emission selected as a candidate SNR as a result of its strong [S II] emission.

## III. Results

A detailed analysis of these images is in progress. However, based upon an initial visual inspection of the images, we have selected 21 relatively isolated nebulae exhibiting relatively strong [S II] emission which we suspect are SNRs. A typical example of one of the candidates appears in Figure 3. These objects exhibit a wide range of morphologies from diffuse spots (such as the object in Figure 3) to limb-brightened emission regions (see Figure 1). The majority but certainly not all of the objects are located in regions where there is substantial confusion with nearby stars or H II regions. As one might expect, the candidates are on average fainter than the previously identified SNRs. They range in size from 10 to 80 pc.

Accurately determining line fluxes from faint nebulae is difficult because there are so many sources of background, many of which vary on about the same scale as the nebulae whose line fluxes one is trying to measure. Sources of "unwanted" background include individual stars and star clusters, a diffuse stellar continuum, diffuse emission line gas, and in some cases moonlight. Ultimately we intend to subtract stars individually from the images and model the diffuse contribution in the emission line images using the 6100 Å continuum images as a template and then extract accurate line fluxes from the reduced line images. It is important to analyze the images in this way because we need a quantitative detection criterion in order to estimate the completeness of the survey. Here however we have adopted a rough approach to estimate the line fluxes and ratios. We have simply found the excess flux associated with a nebula in the raw image by subtracting the average flux in an adjacent visually selected background region. We have then corrected the emission line fluxes for stellar contamination by scaling from the observed excess (or deficit) in the continuum image using scaling ratios obtained from moderately bright stars in the image. The [S II]:Hα+[N II] ratios we obtain for all these nebulae are shown in Figure 2a. All of these nebulae have ra-

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tios which are higher than typical H II regions, although it is not clear, on the basis of this plot alone, that all are SNRs.

In an attempt to verify that we are in fact detecting new SNRs we have obtained spectra of seven of the 21 objects. Two examples, obtained with the IDS on the 2.5m Isaac Newton telescope at La Palma are shown in Figure 4. These particular objects are certainly SNRs. The total [S II] flux exceeds that in Hα. In fact, five of the seven candidates for which we have spectra appear to be SNRs, on the basis of their [S II]:Hα ratios.

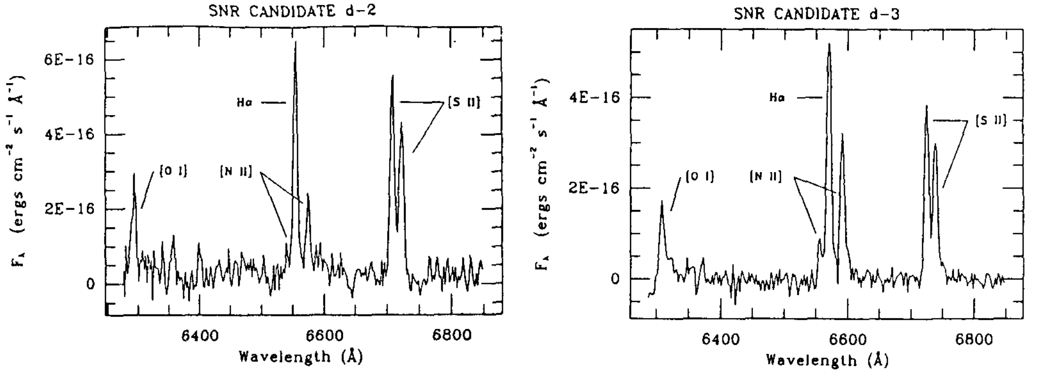


Figure 4: Spectra of two candidates in field 'd'. Both show strong [S II] emission relative to Hα which is characteristic of radiative shocks found in SNRs.

In conclusion, although the analysis of these data is not complete, it is apparent that SNRs can be discovered efficiently in this manner in M33. If the survey is extended to include all of M33, the number of known SNRs will be doubled or even tripled. This will lead to a more accurate estimate of the SN rate in M33 and enable us to determine the relative numbers of SNRs in the spiral arms and interarm regions. It will be important to investigate the fainter SNRs to insure that we understand "typical" M33 SNRs. Most of the previously known SNRs are very high surface brightness objects (reminiscent of N49 in the Large Magellanic Cloud); echelle observations indicate surprisingly high shock velocities in many of these SNRs (Blair *et al.*, this conference). This new sample should provide SNRs with a wider range of shock velocities for comparison with models and lead to more reliable interpretation of chemical abundances than is possible currently.

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