Supernova Remnants and Diffuse Ionized Gas in M31

René Walterbos, University of California, Berkeley

Robert Braun, NRAO, Socorro and NFRA, Dwingeloo

Through its proximity, M31 offers us an ideal opportunity to study in detail the basic physical properties of the interstellar medium on a galactic scale, providing us with information that is difficult to obtain in our own Galaxy. We have completed a large radio and optical survey of the interstellar medium and young stars in the NE half of this nearby spiral. The VLA was used to map the 21-cm HI (Braun, 1989a) and the 20-cm radio continuum emission (Braun, 1989b) at high sensitivity and spatial resolution, 5" to 10", corresponding to 17 to 34 pc. The No1 36-inch telescope at Kitt Peak was used to obtain deep CCD–images of the Hα and [SII] line emission, and broadband B and R exposures of the stellar associations in the main spiral arms. The line images reach emission measures of a few pc cm^{-6} and provide accurate absolute fluxes for about 1000 HII regions, supernova remnants (SNRs), and planetary nebulae (Walterbos and Braun, 1989). Here we will present new results on the SNRs in M31 and discuss the discovery of diffuse ionized gas with high [SII]- to Hα intensity ratio in the spiral arms.

We have compiled an initial list of radio/optical SNRs in M31, by searching for radio identifications of emission-line sources with a high [SII]/Hα ratio (> 0.60). (The [SII] filter included both sulfur lines and the Hα filter did not include [NII]).This search revealed 11 SNRs, of which only two were known. An example of a new detection is shown in Fig. 1. In addition, we detected radio emission from 3 SNRs that were identified in previous optical surveys (D'Odorico *et al.*, 1980), but that were outside our CCD fields. The 14 objects only include the most obvious candidates, but a full search is in progress and we expect to find several more SNRs. Also not all optical SNRs show detectable radio emission and a pure optical list of SNR candidates based only on the ratio of [SII]/Hα emission contains many more objects.

Two conclusions are apparent. First, the radio properties of the SNRs in M31 are quite similar to those of Galactic SNRs as can be seen from Fig. 2, where we show a surface brightness–diameter plot. The brightnesses are not systematically lower as has been suggested in the past (Dickel and D'Odorico, 1984). Second, the slope of the relation is close to –2; this slope is expected from the *intrinsic* dependence between surface brightness and diameter. Hence, as is shown in the right panel of Fig. 2., the radio lumininosity of the SNRs does not seem to depend strongly on diameter, or age, contrary to model predictions (see *e.g.* S. Reynolds, 1988 for a review). Selection effects, however, play an important role in these plots and a complete discussion that includes the upper limits for non-detections will be presented elsewhere (Braun and Walterbos, in prep.).

The CCD images show widespread diffuse ionized gas with a ratio of [SII]/Hα that is higher than that of discrete HII regions. This is illustrated in Fig. 3. Discrete HII regions typically show ratios between 0.2–0.3, while the diffuse gas in the arms consistently shows ratios of 0.5. We can trace this gas across the spiral arms to emission measures below 5 pc cm^{-6}. Its properties seem to be similar to that of the diffuse gas in the solar neighborhood (R. Reynolds, 1988 and references therein). The importance of diffuse ionized gas in the ISM has often been pointed out (*e.g.* Kulkarni and Heiles, 1988), but this is the first time it has so clearly been detected and measured on a global scale in an external galaxy. A point of debate is the origin of the ionization of this gas. The constancy of the ratio of [SII]/Hα in the diffuse medium displayed by our data, seems to favor photo ionization over shock ionization, since the ratio depends critically on shock

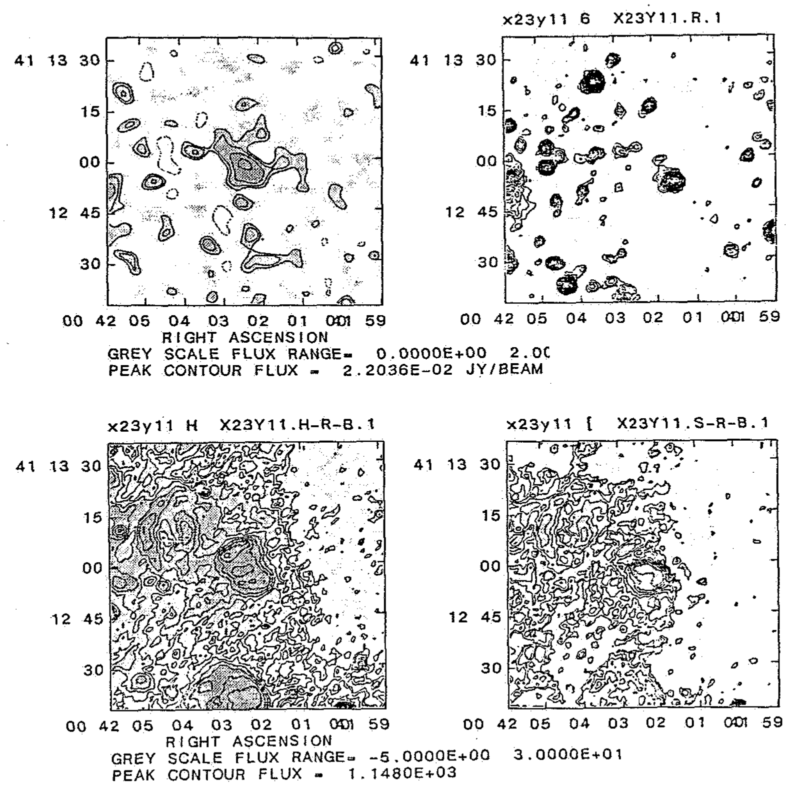

Fig. 1. One of the new SNRs in M31 that was detected in our survey. The sequence of images (from top left, in clockwise direction) shows the 20-cm radio continuum map, the R-band optical continuum, the [SII] emission-line image and the Hα image. The field measures 250 by 250 pc. The SNR is in the center and is blended with a neighboring HII region. It stands out as a source of relatively strong [SII] and radio continuum emission.

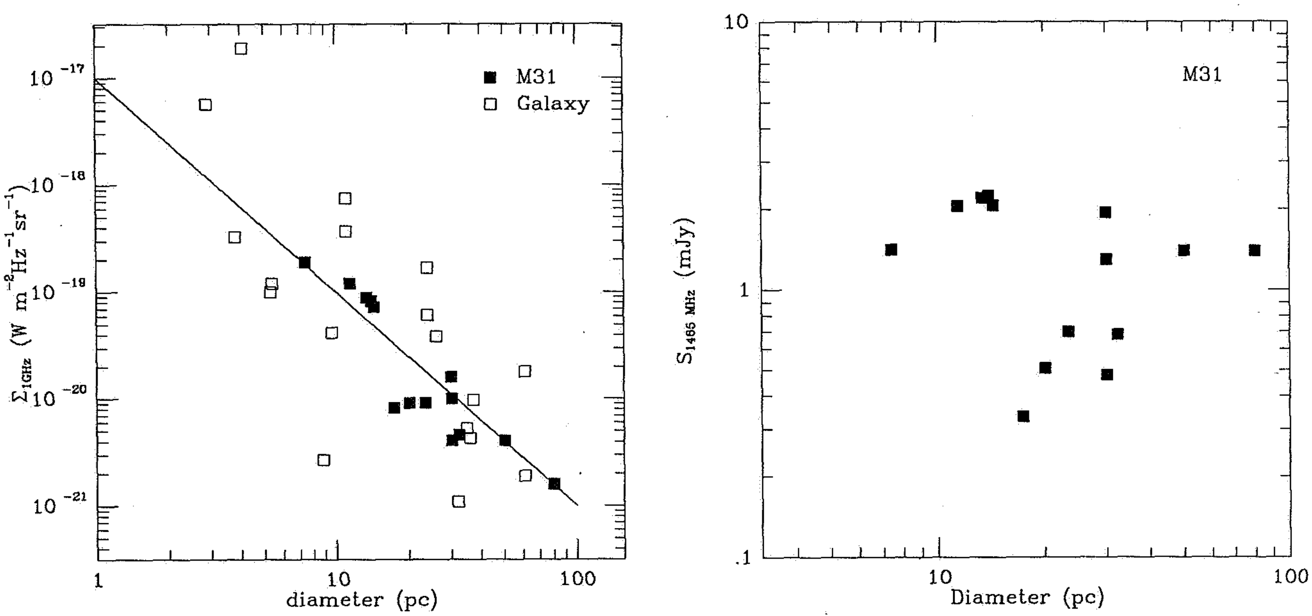

Fig. 2. The left diagram shows the (in)famous Σ-D relation for the new, as yet uncomplete, sample of SNRs in M31 and for Galactic SNRs with reliable distances (Green, 1984). Most of the M31 objects are new detections. The radio properties of the M31 SNRs are quite similar to those in our Galaxy. The line is *not* a fit, but a line with slope −2, corresponding to the *intrinsic* dependency between the surface brightness and the diameter. Most of the correlation in this figure is due to the fact that the two quantities are related to each other, as is apparent from the diagram on the right, which plots the flux (which is proportional to luminosity since all remnants are at the same distance) as a function of diameter.

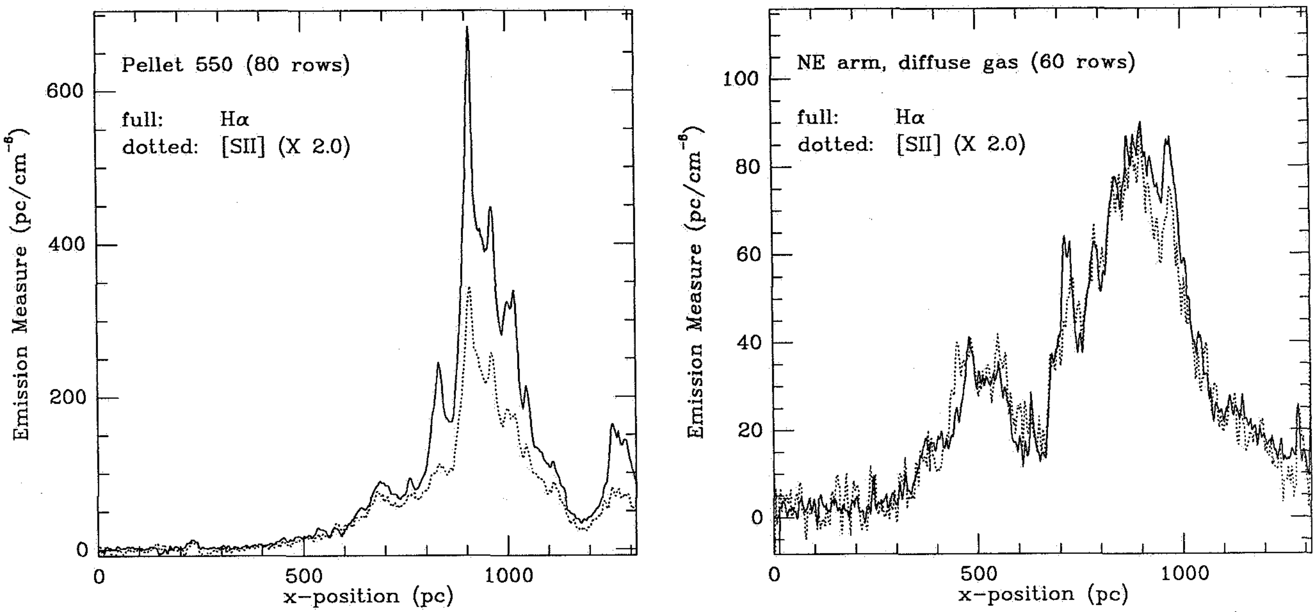

Fig. 3. Cross-cuts in Hα and [SII] emission lines through the 10-kpc spiral arm on the NE side of M31. The plots were obtained by averaging the indicated number of rows in the continuum-subtracted CCD images. The [SII] intensities have been multiplied by two. The left diagram includes the large HII region complex Pellet 550, while the right diagram was obtained for a region with mainly diffuse ionized gas. The ratio of [SII]/Hα intensities is typically about 0.2–0.3 in discrete HII regions but reaches a constant value of 0.5 in the diffuse medium.

velocities whereas it can be successfully reproduced by photo ionization models (*e.g.* Mathis, 1986). The gas is spatially correlated with the neighboring star forming regions in that it is more widespread around the larger HII complexes. This is to be expected in both shock and photo ionization models. Correlation of the diffuse gas distribution with the distribution of O and B stars, derived from the B and R frames, will establish if the photons responsible for the ionization have leaked out from the HII complexes, or if they come from older stars that have already dispersed the clouds in which they were formed. This study is in progress (Walterbos and Braun, in prep.).

We are currently extending our study of the interstellar medium to a sample of nearby galaxies of different Hubble types.

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