NASSP Master's Project

VLBI imaging of the extraordinary supernova remnant in NGC 4449

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In the nearby Magellanic irregular galaxy, NGC 4449 ($D = 3.8 \pm 0.3$ Mpc) there is a remarkable object,SNR 4449-1 (also known as 1AXG J122810+4406), discovered in the radio (Seaquist & Bignell, 1978). Its non-thermal radio spectrum and observations of both broad and narrow optical lines identified it t as a young supernova remnant (SNR) of unusual luminosity. In the optical spectra, he highest velocities are seen in the forbidden lines, whose line-widths Milisavljevic & Fesen (2008) found to be ~6000 km s^{-1}. The supernova type is not known, although various arguments suggest a fairly massive progenitor, with a likely mass of ~25 $M_\odot$ (see Milisavljevic & Fesen, 2008, and references therein), implying that it was a core-collapse supernova (Type II or Ibc).

SNR 4449-1 is unusually luminous in the radio, having a total 1.4-GHz flux density in 2008 of $6.5^{+1.4}_{-0.7}$ mJy (Bietenholz et al., 2010), corresponding to a spectral luminosity of $\sim 10^{26}$ erg^{-1} s^{-1} Hz^{-1}, around three times higher than the radio-brightest remnant in our own galaxy, Cassiopeia A. In fact, the radio luminosity of SNR 4449-1 is near the upper envelope of those for any supernova or SNR. It is particularly interesting because it is between the ages of the oldest observed extra-galactic supernovae (~30 yr) and the youngest known Galactic supernova remnants (~300 yr), and it therefore represents one of the few observable links between supernovae and their remnants.

The remnant is only very marginally resolved with the Hubble Space Telescope, so its morphology was not well known from optical observations. However, it could be well resolved with Very Long Baseline Interferometry (VLBI). We made such observations in 2008 July, using the NRAO High Sensitivity VLBI array, consisting of antennas in the United states along with the Effelsberg antenna in Germany, and obtained the image shown in the left panel of Fig. 1. In 2009 June, independent VLBI observations were obtained with the European VLBI network (EVN), consisting of antennas in Europe, which led to the image shown in the right panel of Fig. 1 (Mezcua et al., 2013). Although the two different images show some similarities, they also show significant differences. Since SNR 4449-1 is present in images from 1961, it must have been at least ~50 yr old at the time of the VLBI observations, and is therefore not expected to evolve rapidly over the < 1 yr between the two sets of VLBI observations, so the difference in the images cannot be ascribed to evolution in time. Usually, young supernova remnants have a relatively circular shell shape, sometimes showing a mild bilateral enhancement. The parallel, almost straight ridges seen in the 2008 VLBI image are therefore unusual. It is important therefore to get a better idea of the morphology of this remnant.

Interferometric observations, such as VLBI, are made in the Fourier transform, or u-v plane, and must be Fourier transformed in order to make image. However, the sampling in the u-v plane is incomplete. Although so-called deconvolution techniques such as the commonly-used Clark CLEAN algorithm can substantially reduce the effects of the incomplete Fourier-plane sampling, it often remains a significant source of error and uncertainty in the final images, especially when the source is large compared to the resolution and the signal-to-noise is low, such as for SNR 4449-1. A way of improving the image, therefore is to acquire additional measurements to fill out the u-v plane.

However, in this case, the first step would be to combine both available data-sets to obtain a more reliable image than was possible with either data set on its own. This project is the combining of both the VLBI u-v plane data sets and then to image the combined data, and thereby hopefully to produce a better and more reliable image. The two VLBI data sets are close enough in frequency and time that it should be possible to combine them in this fashion.

This project would consist of re-reducing and calibrating the EVN data, now publicly available from the EVN archive, and then combining it with the (already calibrated) VLBA data, and the making an image of SNR 4449-1. It will therefore involve learning how to reduce VLBI data, done using AIPS. If the overall morphology or size of SNR 4449-1 can be more reliably determined than it was in either Bietenholz et al. (2010) or Mezcua et al. (2013), then a better estimate of its age could be made, which would certainly warrant publishing in a refereed journal.

References

Bietenholz, M. F., Bartel, N., Milisavljevic, D., Fesen, R. A., Challis, P., & Kirshner, R. P. 2010, MNRAS, 409, 1594, ADS, 1007.3953

Mezcua, M., Lobanov, A. P., & Martí-Vidal, I. 2013, MNRAS, 436, 2454, ADS, 1309.4013

Milisavljevic, D., & Fesen, R. A. 2008, ApJ, 677, 306, ADS, 0709.0181

Seaquist, E. R., & Bignell, R. C. 1978, ApJL, 226, L5, ADS

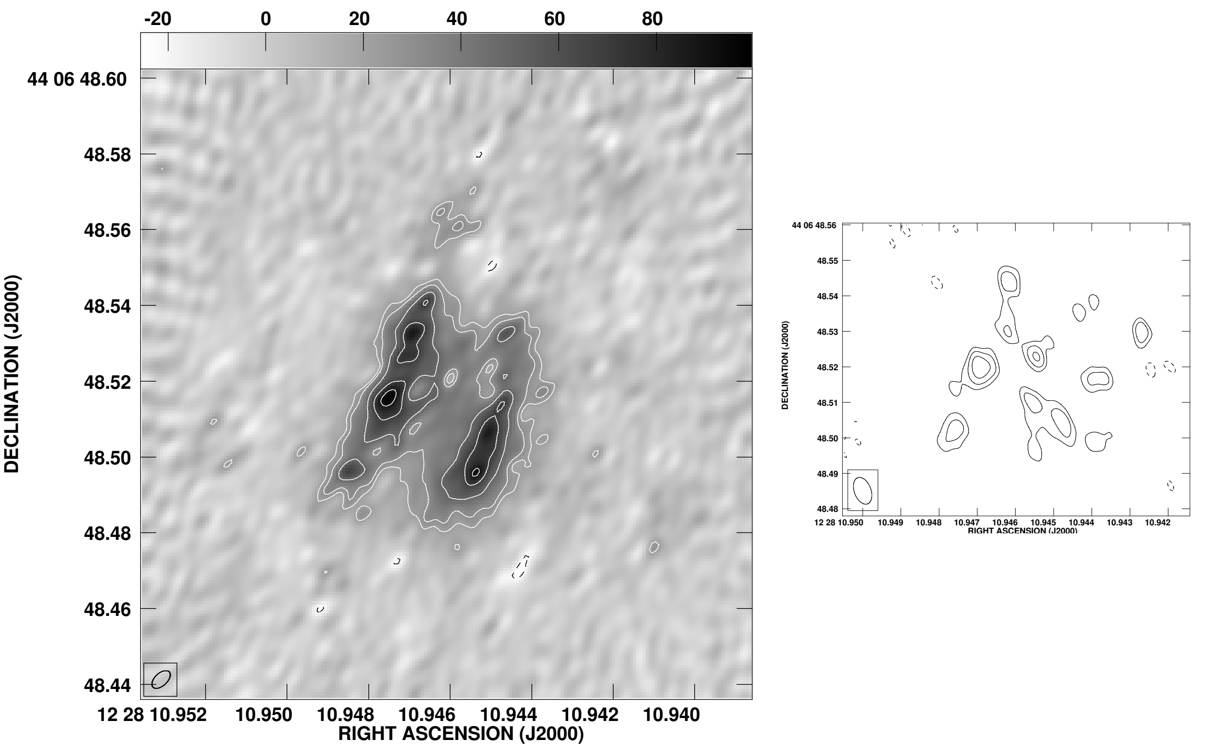

Figure 1: Two VLBI Images of SNR 4449-1, shown at approximately the same scale. In both panels, the FWHM resolution is indicated at lower left. **Left:** At 1.4 GHz using the NRAO high-sensitivity array. The contours are drawn at −22, 22, 30, 50, 70 and 90% of the peak brightness, which was 98 μJy beam^{-1}. **Right:** At 1.7-GHz using the European VLBI Network. Contours drawn at 39, 55, 78 μJy beam^{-1}(from Mezcua et al., 2013).