High-resolution Flux-accurate Radio Images of SN1006

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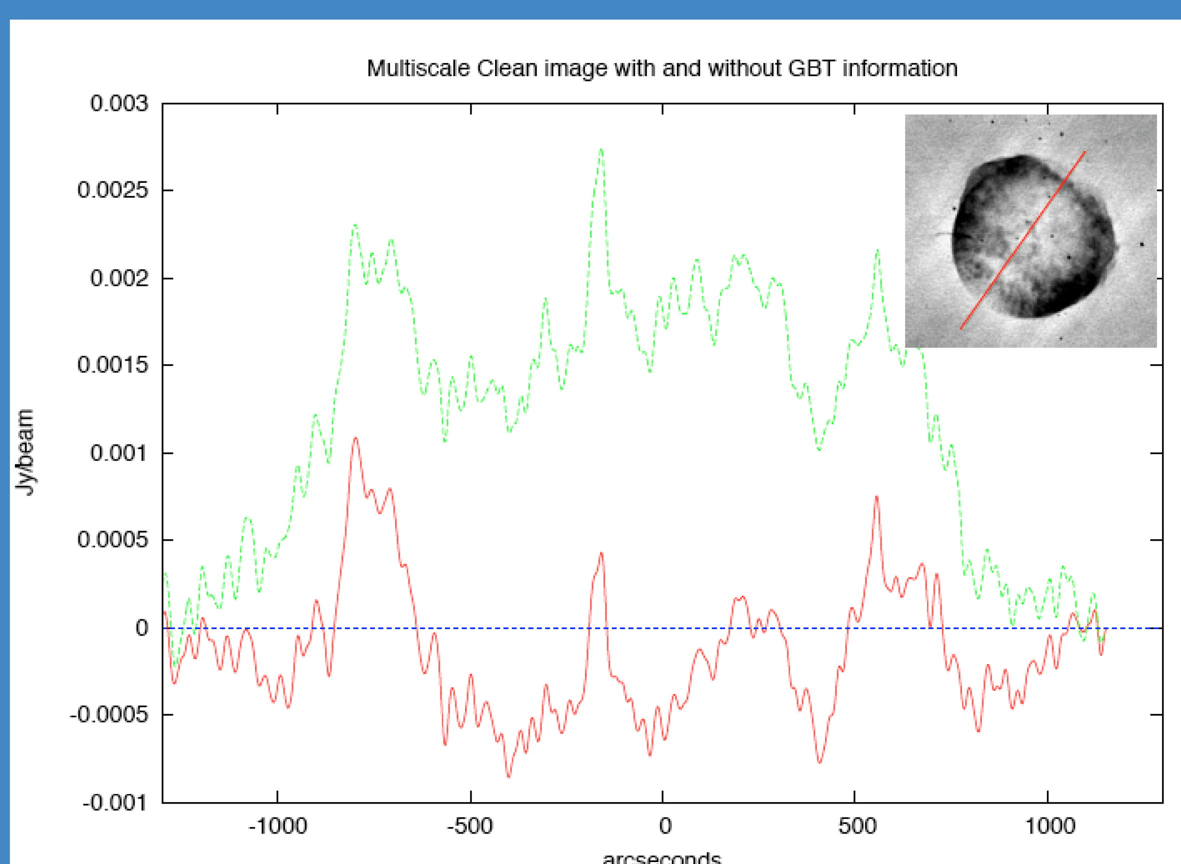
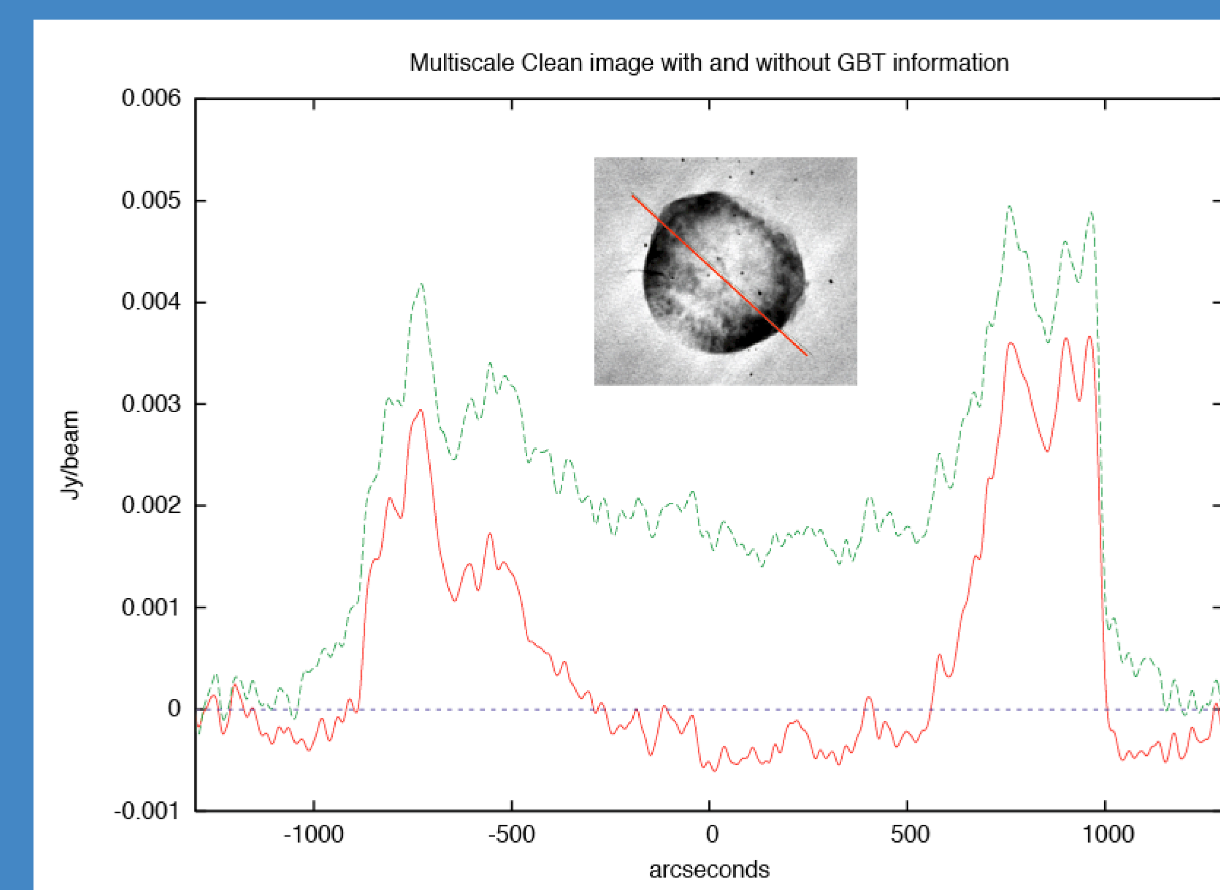


ABSTRACT

Since radio interferometers, like the Very Large Array or the Australian Compact Array, act like a high-pass spatial filter, images of large, diffuse sources -- such as most galactic supernova remnants -- contain information about only small scale structures. Historically, researchers have had to choose between single dish measurements, with accurate total flux but low resolution, and interferometric measurements, with much higher resolutions but which might miss 20-80% of the flux. This shortcoming has several serious implications for science. First, optical, x-ray and infrared images have information on all scales, making radio comparisons with other wavelengths problematic. Second, spectral index images between radio frequencies demand specialized and poorly tested methods to overcome differences in spatial sensitivity. Here, we present high resolution 20cm images of supernova remnant SN1006 that combined single-dish measurements, taken by the Green Bank Telescope, with Very Large Array observations. The images contain flux information that is accurate on all relevant spatial scales.



THE ZERO SPACING PROBLEM

Interferometers work by combining signals between antennas. Long baselines provide high resolution -- they sample small scale structure. Short baselines measure large scale flux. Every interferometer has a minimum spacing which sets the largest angular scale. Structures larger than this scale are simply invisible -- no matter how bright.

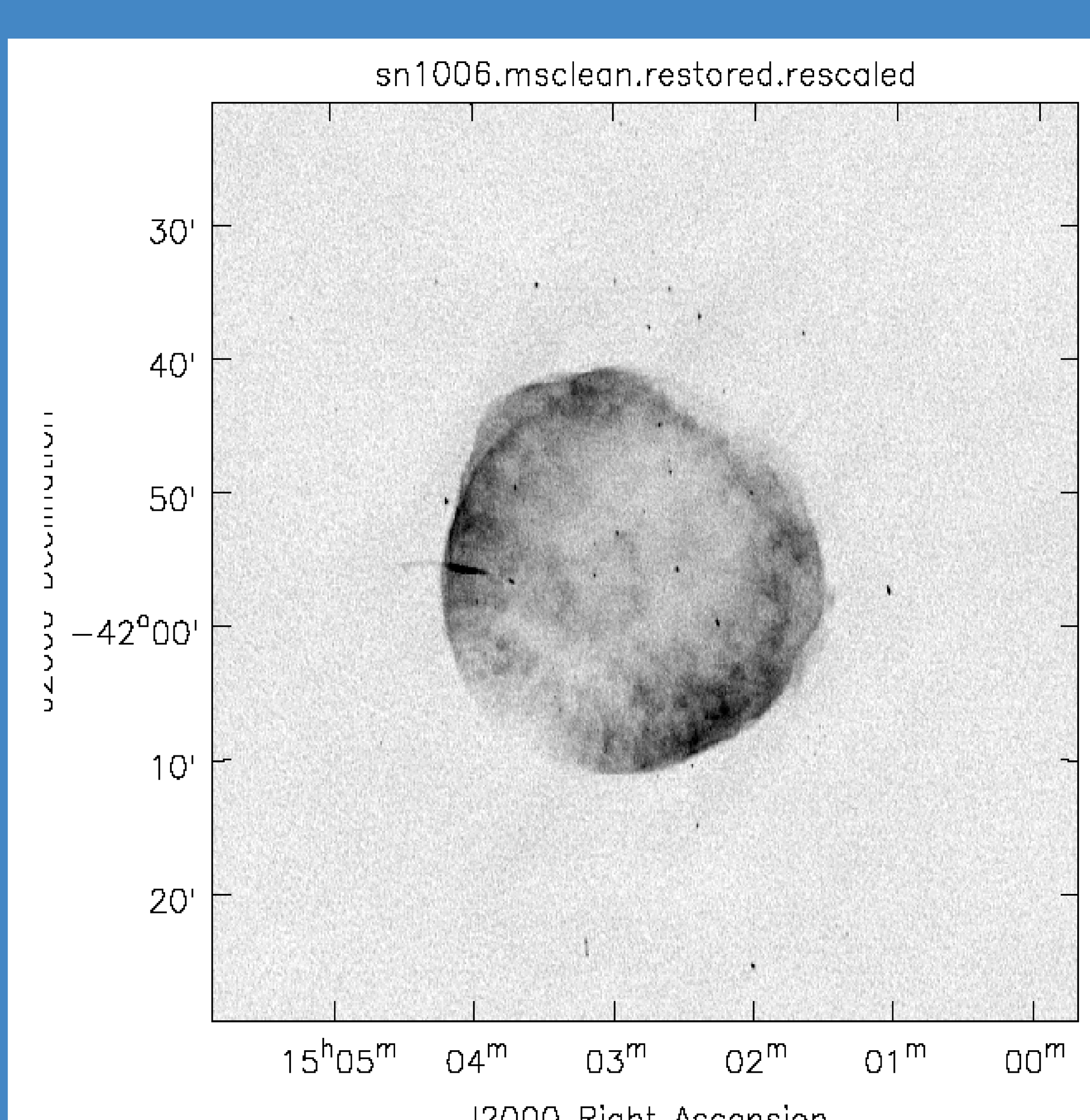
SNR SCIENCE AFFECTED BY ZERO SPACING

Zero spacing issues affect all of the following:

•Any comparison to optical (HST), x-ray (Chandra) or infrared (Spitzer) images

•Any calculations based on knowing the full radio emission (equipartition calculations)

•Any comparison between radio observations with dissimilar Fourier sampling, ESPECIALLY spectral index measurements



TECHNICAL DETAILS

• This image was created using two hours of single dish data from the Green Bank Telescope, in conjunction with eight hours of VLA observations in BnA, CnB & DnC, all at 1370 MHz.

• The single dish data were flux calibrated by comparing overlapping spacings between the VLA D configuration and the GBT (35-100m) .

• The single dish image was used as a "Starting Model" in AIPS++ for the deconvolution of the synthesis data. While this is not the only method for combining single dish and interferometric data, it has two advantages.

  •1) Methods that combine data in the Fourier plane require the single dish to map a much larger area to prevent ringing.

  • 2) The "Starting Model" method can be carried out in AIPS++, AIPS & Myriad -- making it widely available to the astronomical community.

• The image was created with Multi-Scale CLEAN in AIPS++ (Cornwell & Holdaway, 2005). Traditional CLEAN represents emission as a sum of point sources, a poor assumption for extended emission. Multi-Scale CLEAN in AIPS++ represents extended emission by compact blobs at a range of scale sizes, searching for scale sizes which reduce the maximum residual.

• The GBT map (integration of 0.1 seconds per sample and 20 MHz bandwidth) achieved a noise level of 30 mJy beam^{-1}, a factor of 1.4 above the confusion limit.

• The images have been adjusted for the expansion of the supernova remnant to optical images taken in 1998 (Winkler et al.).

• The final image (corrected for the primary beam) has an integrated flux of 18.68 Jy, with a background noise of 77μJy beam^{-1}.

• The noise in the final image is dominated by uncertainties in the VLA data. The GBT adds only 4 μJy beam^{-1}.

THE CONSTANT NOISE FALLACY

Many experienced radio astronomers believe adding single dish to interferometric data is infeasible, since the time required to achieve the same rms noise is prohibitively expensive. For our SN1006 field it would take nine years of GBT observing time to integrate to the VLA A-configuration point source sensitivity. However, this assumes that the goal is to achieve the same nominal point source sensitivity.

For any measure of image quality, the correct goal is to equalize the signal to noise across the Fourier spacings (Crowell, Holdaway & Uson 1993). This makes intrinsic sense: equalizing the noise across the Fourier spacings would produce extremely high signal to noise on only the shortest spacings.

The rule of thumb used at the VLA to determine observation duration at the next smallest configuration actually equalizes signal to noise -- a factor of four reduction in time for every factor of three reduction in angular resolution. Using this rule of thumb, the GBT observations should dwell for 20 seconds per beam.

In fact, these GBT observations have used 1 second per beam, and the final image is not limited by uncertainty in the GBT data (4 μJy beam^{-1}), but uncertainties in the VLA data (70 μJy beam^{-1}).

THE FUTURE

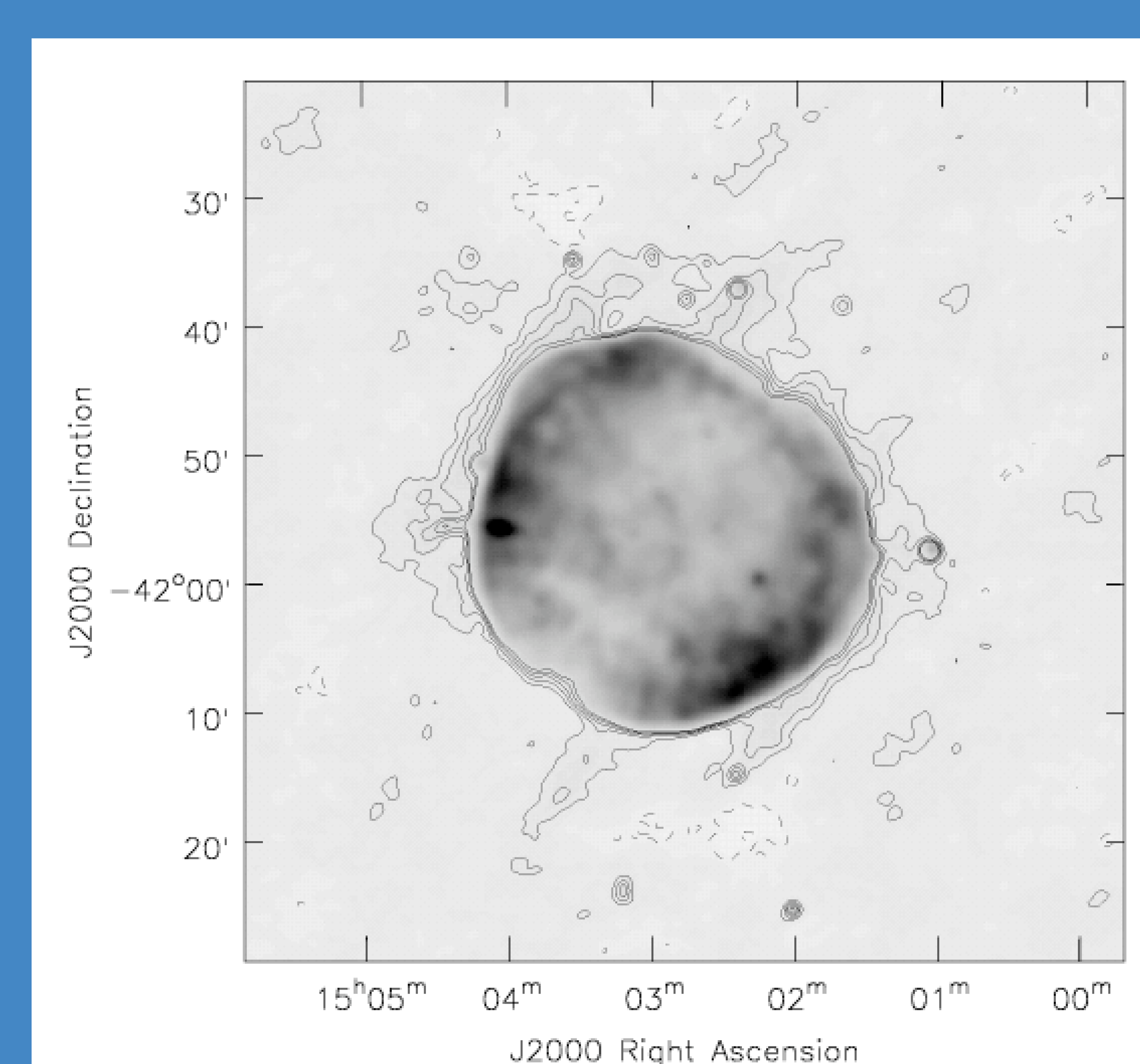
What kind of objects are zero spacing issues relevant to?

At centimeter wavelength at the VLA:

•Nearby galaxies (SNRs, HII regions, HI)
•Galaxy clusters: Coma, Virgo
•Supernova remnants
•Planetary nebulae & HII regions
•Galactic plane (HII)

At millimeter wavelengths the effect is even more pronounced:

For CARMA
•12 meters, 90 GHz = scales beyond 1 arcminute will be unobservable
For ALMA
•15.4 meters, 490 GHz = scales beyond 10 arcseconds will be unobservable.



References

Stay tuned for our Science paper on SN1006: Dyer, Winkler, Long & Hughes ~2006.

Cornwell, Holdaway & Uson 1993

Cornwell & Holdaway, 2005

Winkler, P.F., Gupta, G., & Long, K.S. 2003, ApJ, 585, 324

Image of the GBT courtesy of NRAO (AUI). The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. While working on this paper K.K.D. was supported by a National Science Foundation Astronomy and Astrophysics Postdoctoral Fellowship ***http://www.aoc.nrao.edu/NSFfellows/*** *under award AST 01-03879 and by the National Academy of Sciences through a National Research Council Fellowship at the Naval Research Laboratory. Basic Research in Radio Interferometry at the Naval Research Laboratory is supported by the Office of Naval Research.* Currently at the Australia Telescope National Facility.*