Multi-frequency-synthesis and wide-field imaging with the EVLA

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Abstract

Broad-band receivers are used on radio interferometers to increase their continuum-imaging sensitivity. However, the interferometer sampling function, the sky brightness distribution, and the array-element response functions change with frequency. Imaging algorithms need to account for all these effects to reconstruct both the spatial and spectral structure of the sky brightness distribution over the wide fields-of-view allowed by the element response functions, while also achieving the full sensitivity offered by the large instantaneous bandwidths. In this talk, we will describe the algorithms used for wide-field wide-band imaging with the EVLA (Expanded Very Large Array), and show imaging results that demonstrate our current capabilities.

1 Introduction

The large instantaneous bandwidths offered by most new radio interferometers increases the raw continuum-imaging sensitivity of the instrument, while also allowing measurements of the spectral structure of the incident radiation across large continuous frequency ranges. To take full advantage of such instruments, we need algorithms that model and reconstruct both spatial and spectral structure simultaneously, while accounting for various effects of combining measurements from a large range of frequencies (namely varying ranges of sampled spatial scales and varying array-element response functions).

The technique of multi-frequency-synthesis accounts for the changes in the sampling function with frequency, and when coupled with a multi-scale and multi-frequency image model, can be used to reconstruct both spatial and spectral structure of the sky brightness often at the angular resolution offered by the instrument at the highest sampled frequency. Such an algorithm also increases the achievable dynamic range in the image by reducing image artifacts that appear above the noise level when the frequency-dependence of the sky brightness is not properly accounted for. With wide bandwidths, the frequency dependence of the element response function is also important. For 2:1 bandwidth, it leads to increased sensitivity over a field-of-view of almost twice the half-power beam-width at the lowest frequency in the sampled range. Also, the spectral response of the instrument's direction-dependent gain shows increasing variation as a function of distance from the pointing direction. Wide-field imaging algorithms that correct for frequency-dependent instrumental effects are therefore required, and serve the dual purposes of accurately reconstructing the sky brightness and its spectrum over a wide field of view, as well as reducing imaging artifacts from sources far from the pointing center.

2 Methods and Results

Several recently-developed algorithms can be used in conjunction to perform imaging and deconvolution across wide fields of view, using wide-band data from instruments such as the EVLA (Expanded Very Large Array).

For wide-band imaging, we use the MS-MFS (Multi-scale multi-frequency synthesis) algorithm [1,2], a combination and extension of multi-scale and multi-frequency deconvolution techniques [3,4]. The sky brightness distribution is modeled as a series of multi-scale basis functions whose amplitudes follow a polynomial in frequency, and a χ^2 minimization is performed to solve for lists of coefficients. For wide-field imaging, we use the W-projection [5] algorithm to account for the non-coplanar baseline effect via spatial-frequency-domain convolutions using functions derived from Fresnel diffraction kernels that describe the propagation

of EM radiation across a distance given by the w-coordinate for each baseline. For the correction of time and frequency-dependent primary-beams, we use the A-Projection [6] algorithm that uses models of the antenna aperture-illumination functions for each timestep and frequency to correct for its effects during the imaging step. Both projection methods can be naturally extended to form mosaics by augmenting gridding-convolution functions with phase-gradients corresponding to the angular distance between the image center and the various pointing centers of the mosaic observation. The generic formulation of the measurement equation and how the above algorithms work together within the same framework is described in [7].

This framework has been implemented within the CASA (Common Astronomy Software Applications) package, and is being tested on wideband EVLA data. In this talk, we will show examples that illustrate our current wide-field wide-band imaging capabilities with the EVLA.

3 Conclusion

The large instantaneous bandwidths of instruments like the EVLA offer significant increases in the continuum imaging sensitivity, as well as sufficient spectral coverage to reconstruct the sky spectrum to an accuracy sufficient for astrophysical use, all from a single observation. The overlap of array-element response functions from individual frequencies leads to sufficient sensitivity over a wide field-of-view, making the instrument sensitive to far-out sources as well as those that may fall within the nulls of the primary beam at any one frequency. Algorithms that reconstruct both spatial and spectral structure of the sky brightness, and also apply time, frequency and direction-dependent instrumental corrections across wide-fields of view have been developed and are in advanced stages of integration and testing with wide-band data from the EVLA.

4 References

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