MEM and CLEAN Imaging of VLBA polarisation observations of compact Active Galactic Nuclei

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Abstract

The imaging of Active Galactic Nuclei using VLBA polarisation observations is discussed. The CLEAN algorithm and Maximum Entropy Method are presented as examples of deconvolution techniques. A MEM with a form of entropy suitable for polarisation studies is outlined. Preliminary MEM images for 18-22cm VLBA polarisation observations of several AGNs are presented.

1. Imaging

There is a Fourier transform relationship between the intensity distribution as it appears in the sky and the visibility that is observed on the ground.

$$V(u,v) = F.T.(I(x,y))$$

$$V_s(u,v) = V(u,v)S(u,v)$$

Not all visibilities are sampled, however. Imaging is the process of deconvolving the sampled visibilities and attempting to re-create the original intensity distribution. This is a mathematically ill-posed problem.

2. Imaging Techniques

CLEAN Algorithm

The CLEAN algorithm is a standard technique to deconvolve the effects of the sampling function S(u,v) from the sampled visibilities. It involves breaking down the map into a series of CLEAN components (δ functions). These components are then convolved with a 2D Gaussian fit to the central lobe of the dirty beam (the F.T. of the sampling function) and the residual noise is added in to get the final "clean" image.

Maximum Entropy Method

Consider the function

$$J = H(I_m, P_m) - \alpha\chi^2(V_{Im}, V_d) - \beta\chi^2(V_{Pm}, V_d) - conditions$$

where H is the entropy of a model map of the source and χ^2 is a measure of the difference between the model and observed visibilities (there are two χ^2 terms, one for intensity and a second for polarisation). α and β are Lagrange parameters and other conditions are also included which represent additional constraints, such as positivity of the Stokes I component.

A model of the source is developed to maximise the function J above. This results in a balance between entropy (representing noise, and the effect of unsampled visibilities) and fidelity to observed data.

Multiple forms of entropy exist:

$$H = -\sum_k I_k (log(\frac{I_k}{IB_k}))$$ (Shannon)

$$H = -\sum_k I_k (log(\frac{I_k}{IB_k e}) - \frac{1+m_k}{2} log(\frac{1+m_k}{2}) - \frac{1-m_k}{2} log(\frac{1-m_k}{2}))$$ (Gull & Skilling)

where summation over k corresponds to summation over all the pixels, I_k is the intensity at pixel k and m_k is the fractional polarisation at that pixel. IB_k is the intensity of a bias map.

Shannon entropy is suitable for intensity-only imaging, whereas the Gull and Skilling form of entropy is a generalisation of Shannon entropy suitable for imaging with polarisation information.

3. Image Resolution – CLEAN vs. MEM

In general, the maximum resolution of an image is inversely proportional to the length of the longest baseline in the array, u_{max}. The resolution of a CLEAN image can be conservatively estimated as the full width at half maximum of the Gaussian clean beam.

MEM has a mathematically well based resolution of

$$x_{min} = \frac{1}{4u_{max}}$$

This is approximately a quarter of the conservative estimation of the CLEAN resolution.

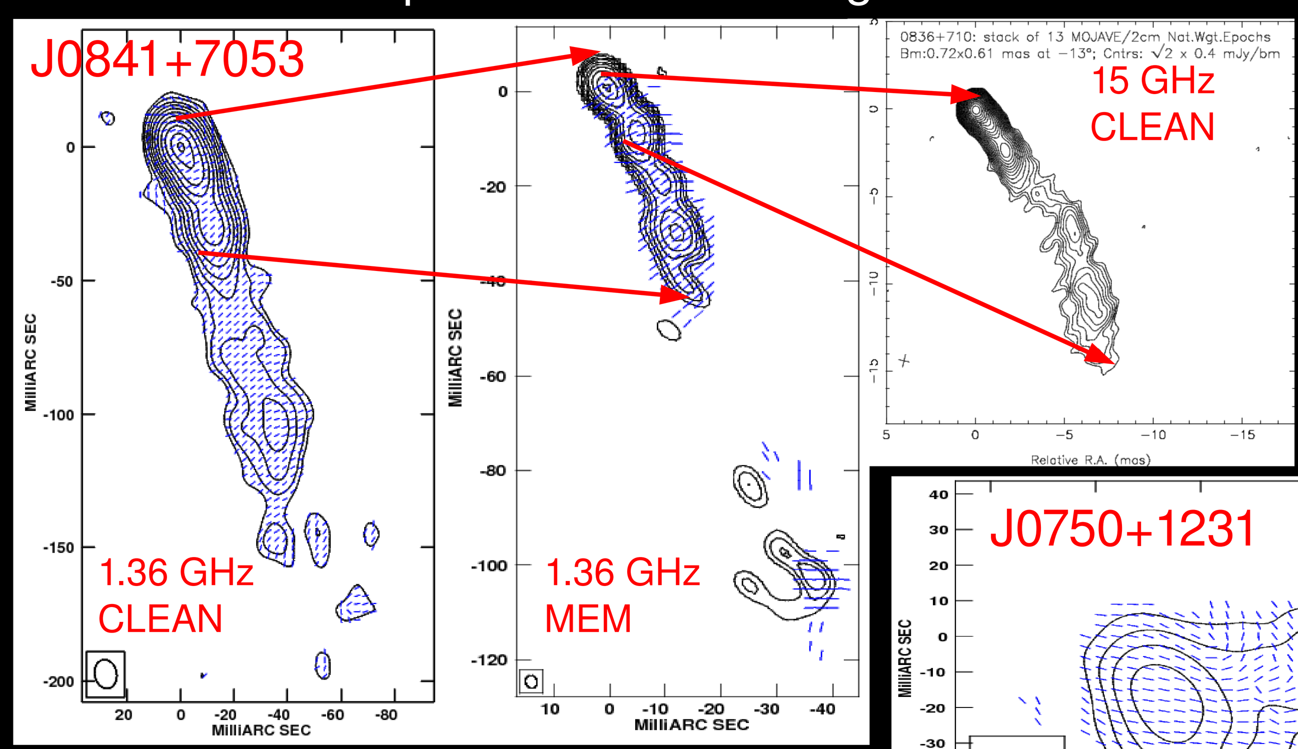
4. Implementation of Polarisation MEM to VLBI Data

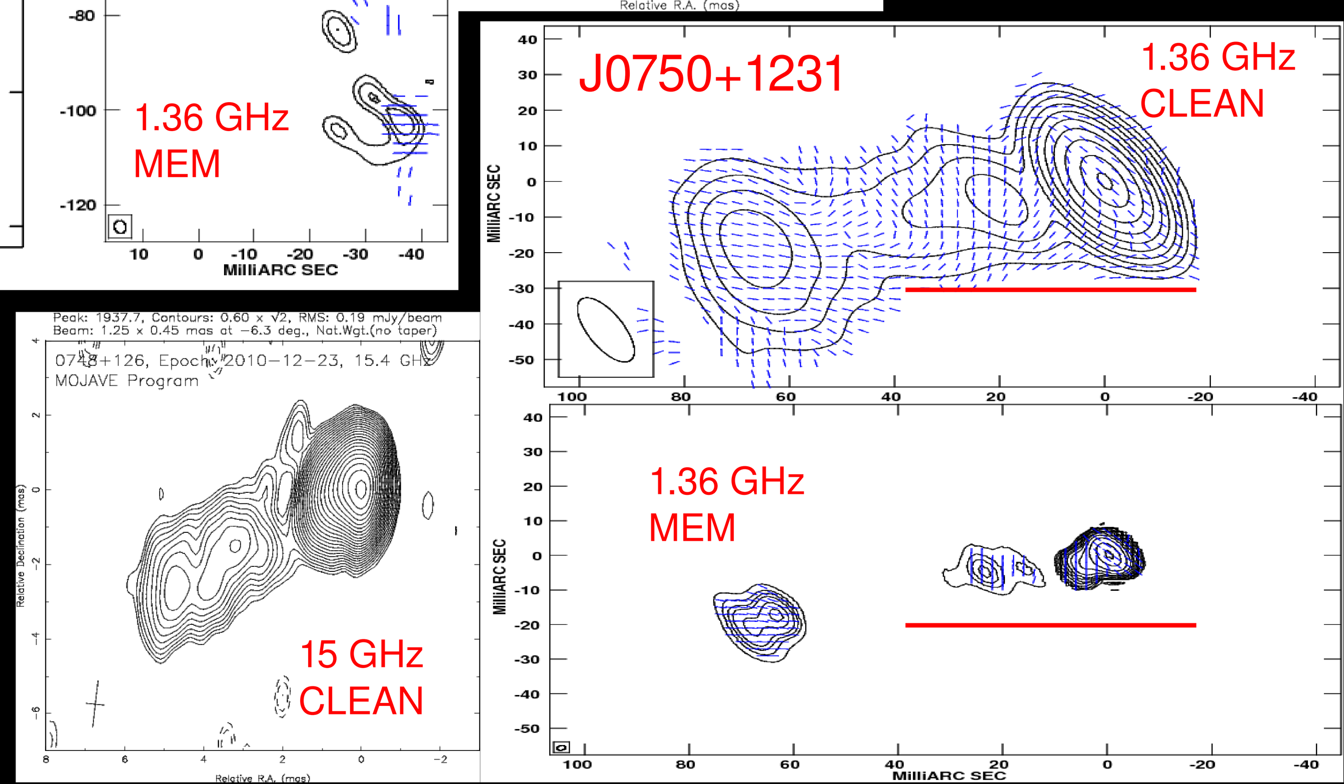
The standard Radio Astronomy software package Astronomy Image Processing System (AIPS) includes a task to conduct MEM deconvolution of intensity (Stokes I), but not polarisation (Stokes Q and U), images. We are accordingly writing polarised MEM software in C++.

We have in the meantime produced a number of "proof-of-concept" MEM polarisation maps in AIPS by devising an algorithm to work around the limitations imposed by the AIPS MEM task (primarily the non-negativity requirement - whereas Stokes I must be positive, Stokes Q and U can be either positive or negative).

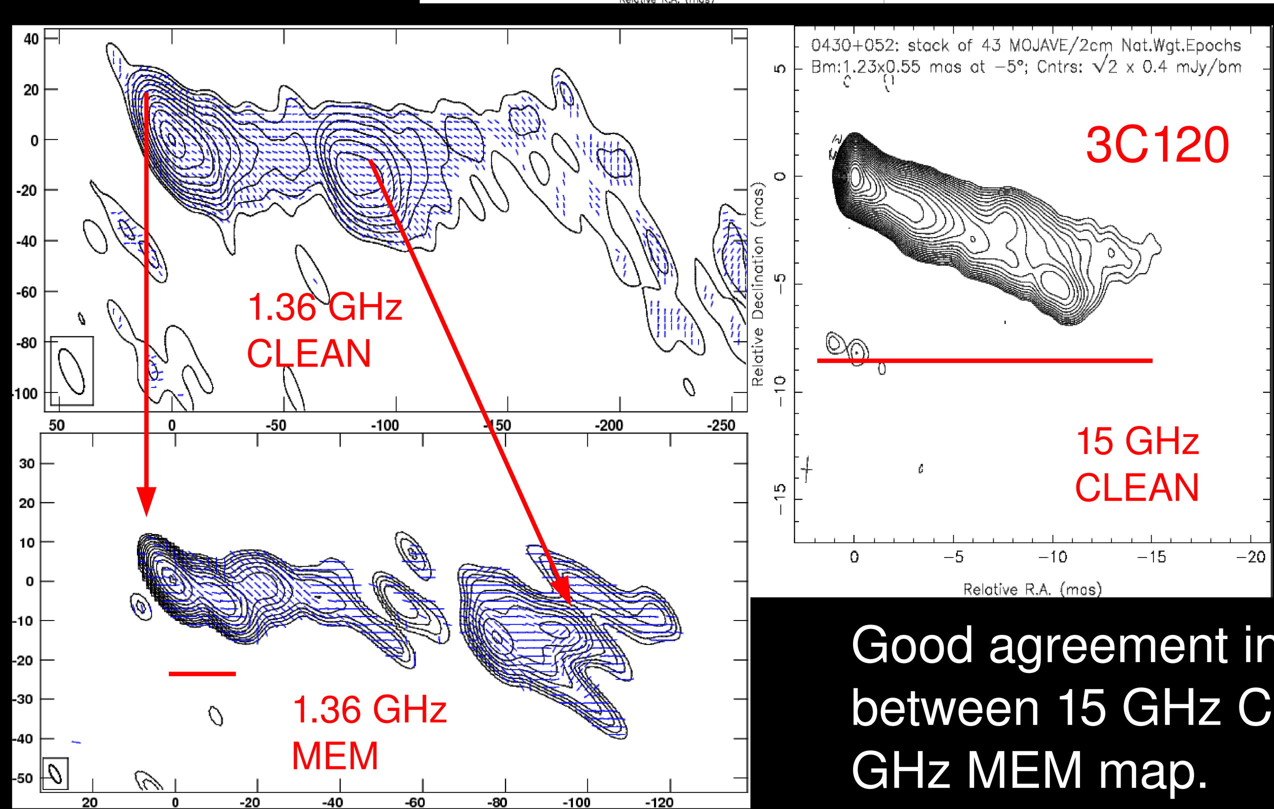
5. Preliminary MEM Intensity and Polarisation VLBA Images

The 1.36 GHz maps below were obtained with the Very Long Baseline Array (Coughlan et al. 2011). The blue sticks indicate the local polarisation angles. The MEM images provide increased resolution, but are less sensitive to extended emission. 15 GHz maps from the MOJAVE project are also shown for comparison. The horizontal lines on the corresponding 1.36 GHz MEM and 15 GHz maps are the same length in mas.





Good agreement between polarisation angles.



Good agreement in jet angle between 15 GHz CLEAN and 1.36 GHz MEM map.

6. References

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