GETTING THE BASICS RIGHT: FINDING THE FLUX DENSITY FROM INTERFEROMETRIC IMAGES

One might think that the process of determining a basic characteristic of a radio source such as its flux density from a radio-astronomical image is well established. However, that is not quite the case, and this project aims to answer the question: how do we most accurately determine the flux density of an unresolved source from images made from interferometric data. Much of radio astronomy involves working with images obtained from interferometers: for example, the new South African radio telescope, MeerKAT, will be an interferometer. An interferometer measures in the Fourier transform plane, rather than the image plane we are perhaps more used to dealing with. In consequence, interpreting the images made from interferometric data, and extracting reliable measures of the properties of astronomical sources presents some unique challenges. This project addresses a rather basic question: What is the flux density of a source? Surprisingly, there are different ways of measuring the flux density which do not necessarily agree, and we do not know which method produces the most accurate results.

In the case of a resolved source, the issue of the source flux density is intrinsically complicated. However, unresolved sources are common in astronomy. For example, there are many sources which will be essentially point-like when observed with MeerKAT even at its highest resolution. For an unresolved source, the flux density should be single-valued.

There exist several commonly-used methods to obtain the flux density of a source on an interferometric image, which for real images do not necessarily produce the same result. The aim of this project is to determine which of these methods produces the most accurate and un-biased results. This knowledge will particularly useful for the many large surveys that MeerKAT will undoubtedly carry out, but will be applicable to data from any interferometric array, including the NRAO Very Large Array, ASKAP, ALMA and VLBI including the proposed African VLBI Network.

In an ideal interferometric image, an unresolved source should have exactly the form of the “CLEAN beam”, also called the restoring function, which is usually an elliptical Gaussian. The width of this Gaussian represents the interferometer’s resolution, or its response to a point source after de-convolution. The brightness in the images is usually expressed in units of flux density per CLEAN beam area, such as Jy beam$^{-1}$. An unresolved source with a flux density of 1 Jy would thus have a peak brightness of 1 Jy per beam.

The common methods for obtaining the brightness of a source from an interferometric image are 1) taking the peak brightness 2) fitting an elliptical Gaussian to the image, and then calculating the total flux density of that fitted Gaussian 3) integrating the brightness in the image over a small region around the source. In a perfect image, all three methods would return exactly the same value, which would be the flux density of the source.
However, in real images, the three values will not be identical, due to the presence of noise and residual deconvolution errors. For example, even for a completely unresolved source, the brightness profile may not correspond precisely to the ideal Gaussian “CLEAN beam” - see Figure 1 for an example. We do not know which of the three methods returns the most accurate and unbiased values of the flux density.

The approach to determining the best method will be to simulate visibility measurements for a collection of model sources for a given interferometer (e.g., MeerKAT) including realistic noise and then to image and deconvolve this simulated data in the same way that real interferometer would be. Since we know true flux density of the model sources by construction, we can then compare the flux density measurements obtained from the images to the known values and assess the accuracy of the different methods of measuring flux densities from interferometric images.

What needs to be done: the student needs to acquire some familiarity with either the CASA or AIPS radio astronomy software. Then, using that software, the student should develop the tools to simulate visibility data, generate images, and then analyze the images. A large sample of flux densities obtained from the images should then be compared to the model values, and the accuracy and biases of the different methods of obtaining flux densities evaluated statistically. Finally, the project should also be written up and published in the astronomical literature.

This project is suitable as an advanced Honours project, or with some expansion as an Master’s project. There is certainly scope for a PhD. within the large, and as yet not well explored field of image accuracy and deconvolution errors. Understanding deconvolution errors and image accuracy will be crucial to achieving usable high dynamic range in images of future interferometers such as MeerKAT and SKA.
Figure 1: Example profiles through a source in an interferometric image. For clarity, we show one-dimensional “slices” only in Right Ascension (R.A.) through the source, but slices in declination would be of a similar nature. The units on the horizontal axis are arbitrary measures of angle, typical units for MeerKAT would be arcseconds. The red line shows the true point-source profile. The black line shows the observed interferometric image including noise. The green line shows the true source convolved with the ideal “CLEAN” beam, while the blue line shows the image noise. For the green curve, the peak brightness (in units of e.g., Jy per beam) is exactly equal to the area underneath the curve (in Jy), which is also the flux density of the real point source (also Jy). For the observed black curve, this equality is only approximate.