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What is the primary beam?

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This simulation is designed to illustrate the first order effects of the primary beam. It also introduces a the useful tricks that is making difference images in Tigger.

In radio astronomy you will generally hear people talking about two things that involve the word 'beam'.

i) The dirty beam: this is the point spread function (PSF) of an observation, i.e. when you Fourier transform your visibility measurements to obtain your image of the sky, it it convolved everywhere with the dirty beam pattern. Your image at this stage is known as the dirty image, i.e. it needs cleaning up with a deconvolution algorithm to remove the sidelobes of the dirty beam that are associated with each region of emission from the sky. The shape of this pattern is determined by how filled your aperture is, i.e. how good your uv plane coverage is. The Fourier transform of your uv coverage determines the shape of the dirty beam. Some people (myself included) prefer to refer to the dirty beam simply as the PSF as it (hopefully) avoids confusion with the other type of beam, namely...

ii) The primary beam: to first order the primary beam can be thought of as the sensitivity of your instrument as a function of direction. The receiving elements that make up the array are not uniformly sensitive to incoming radiation from all directions. For example, an array of parabolic dishes has maximum sensitivity in the direction which they are pointing (typically the phase centre), and the sensitivity drops off away from that direction. As a rule of thumb, the half power point in radians, i.e. the angular distance from the phase centre at which an intrinsic 1 Jy source has an apparent flux density of 0.5 Jy is roughly (wavelength / 2D) where D is the diameter of the dish.

Traditionally the primary beam pattern is assumed to be identical for every receptor in the array, with its effects removed from an observation by dividing the final deconvolved image by some assumed average primary beam pattern. The end effect of this is to correct the attenuated source fluxes, although this process also effectively results in increased image noise towards the map edge.

In reality the primary beam pattern is complicated business, and its inevitable presence in all observations can easily become a fly in your delicious bowl of radio astronomy soup. For example, the many sidelobes beyond the central main lobe that make the interferometer sensitive to sources in the far field. Bright sources can be particularly troublesome as we will see in a later simulation.

The assumption that beam patterns are the same for each receptor is also not a valid one. It is obviously the case for heterogeneous arrays such as e-MERLIN or some VLBI networks, and less obviously for aperture arrays such as LOFAR. However for observatories such as the VLA that ostensibly have identical elements making up the array, subtle effects like the finite pointing accuracy of the antennas result in each station having a slightly different effective primary beam.

Although the problem of bright sources limiting the dynamic range of an image are long familiar, subtle beam effects such as pointing error have only hitherto reared their head for the deepest observations. If your targets are faint enough though, these can prove limiting. But lest we forget: all these radio telescopes that are getting built or getting upgrades are expected to be able to routinely detect the faint radio sky.

Anyway, let's back up a little bit...