VRI: Virtual Radio Interferometer

ASTR 240: In-class activity, March 25, 2013

Open the virtual radio interferometer (Google "virtual radio interferometer" if necessary – there are several mirror sites).

Orientation

This section provides a walk-through of how to use the VRI
(We will go through this in class, so you can probably skip most of this section unless you were confused and/or asleep.)

- First, choose an observatory in the upper left. This will set you up with a default latitude, number of antennas, and antenna properties (diameter, elevation limit); you can read these values from the boxes along the top of the VRI applet. You can change any of these quantities as desired (in fact, I recommend it!). The antennas will also appear in a default configuration in the upper right panel of the four main VRI panels – you can drag the antennas into any configuration you like.
- Next, choose a source to observe from the drop-down menu immediately below the observatory menu. It might be helpful to start with a point source, but I recommend that you try out several different sources using different antenna configurations. Sometimes it is difficult to select the same source twice in a row; to reset your observation using the same source, you might have to select a different source before re-selecting your original source.
- To prepare to observe your source, take the Fourier transform using the "FFT" button to the left of the four main panels. The FT of your source will appear in the lower left panel. Note that by default only the amplitude is displayed. You can toggle between amplitude, phase, real, and imaginary components using the drop-down menu immediately below the bottom left panel.
- Next, consider how you want to observe your source. These options are at the bottom of the applet frame. You can change things like the frequency and bandwidth of the observation, the hour angle range over which you observe the source (start hour angle is above end hour angle), and the declination of the source.
- Once you have decided how to observe your source, generate the "tracks" of your (u,v) plane sampling by pressing the "plot" button at the right of the screen. The bottom right panel of the applet will now show the points in the (u,v) plane sampled by your observation, which depends only on the array configuration (antenna locations, latitude) and observing options (source declination, hour angle range, frequency).
- Now, observe your source! Press the "Apply" button at the bottom of the applet frames to sample the FFT of the source (bottom left panel) at the (u,v) plane locations defined by the array configuration and observing options (bottom right panel).

- Finally, take the inverse FT of the sampled visibilities to find out what the reconstructed "dirty" image of your source will look like. Press the "FFT-1" button to the left of the applet frames to take the inverse FFT of the sampled data in the bottom left panel; the "dirty image," i.e., the inverse FFT of the sampled data, will appear in the top left panel of the applet. If you were observing a point source, this image also reflects the "dirty beam" of your observation.

Play!

I'd like you to play around and try to get a sense of how different array configurations, source declinations, observatory longitudes, hour angle ranges, frequencies, etc., affect how you observe the source. If you want to play on your own, go for it! If you want a little more direction, I've made some suggestions for activities/challenges below.

1. Design your own array

Start with the MERLIN array (only because it has six antennas, which is a convenient number for playing with). Plot the (u,v) spacings for the default settings (by pressing "plot" at the right of the applet frames). Note how the (u,v) spacing shows some short baselines and some long baselines, with a slight gap in between, but without too much redundancy in baseline length. Why is this desirable? Now, try moving the six antennas into an evenly-spaced ring (err, regular hexagon). What do you think the (u,v) coverage will look like? Check, by pressing the "plot" button. What advantages/disadvantages does this (u,v) coverage have over the original MERLIN array? Try observing a point source with the default Merlin array and then with a hexagon to find out. Try moving the antennas around into different configurations, and try to find the best balance you can between a good range of long/short baselines, without too much redundancy, and with fairly good coverage between the extremes (i.e., not too many gaps in baseline length). Try observing a point source to check what your beam looks like. Notice the similarities and differences between your (u,v) coverage and the beam shape. Can you figure out which features of the (u,v) coverage correspond to features in the beam (particularly the sidelobes)?

2. Fun with beam shapes

Start with the ATCA array (you may have to zoom in from the MERLIN configuration, since the baselines are much shorter). Keeping everything else at its default value, plot the (u,v) coverage. Check what the beam looks like by imaging a point source. Looks kind of like a round point, right?

Now, vary the declination of the source. Pay attention to the declination of the source compared to the latitude of your observatory. What happens to the beam if your source is at a declination equal to your latitude? What if it is on the celestial equator? What if it is in the opposite hemisphere? (Don't make your source declination >90 degrees away from your latitude, or you won't be able to see it! Well, you shouldn't, anyway… I don't think the VRI knows that the earth is opaque…) Think about why the beam gets more strongly elongated to the N-S as the source moves to the opposite hemisphere in declination.

Now try varying the hour angle over which you observe the source. Try observing it for a short period of time when it is on the eastern horizon, the western horizon, or overhead. Try observing it for just the first half of the night. Pay attention to how these parameters affect the beam shape.

See if you can figure out how to manipulate the beam to look the way you want. Just by moving around the antennas (not changing the source declination or hour angle coverage), can you make the beam elongated in the East-West direction? How about the North-South direction? Go ahead and vary everything… can you make it look like an x? A + sign? An unladen European swallow?

3. Resolving sources

Start with an antenna configuration that resolves a point source to your satisfaction (small beam, not too many wacky sidelobes); you can use the default MERLIN configuration, for example.

Try observing a double source. Note how the two point sources are convolved with the beam so that the amplitudes just look like two beams, side by side. What do you think the phases should look like? Make a prediction, then check. Next, try moving the antennas so that they are very close together (as close to on top of each other as you can get). Will you still be able to resolve the two point sources? Gradually move the antennas apart until the two point sources are resolved. Which direction requires long baselines to resolve the point sources? What is the longest baseline length you can make **without** resolving the two point sources? (Hint: try aligning your antennas in the direction perpendicular to the direction between the two point sources and restricting the length of time over which the observation takes place.)

Try observing a narrow Gaussian. Start with the antennas very close together, then gradually move them apart. How can you tell the difference between an observation that just has a large Gaussian beam, and an observation of a Gaussian source? (i.e., how can you tell that the Gaussian is spatially resolved?)

Try observing some of the other sources and play around with making the best array configuration to observe each of the sources. Some things to think about:

- What is the shortest baseline you need to pick up all the extended flux? (Try observing a wide Gaussian to help you think about this one – what happens if all the baselines are long? What do you need to do to keep the source looking big and fluffy?)
- What is the longest baseline you need to pick up the important details? (A double point source or narrow Gaussian might be good for this.)
- How does the uniformity of the (u,v) coverage affect your observation when the source is a little bit complex? Try playing around with the radio galaxy or disc

for this part of the exercise. For the radio galaxy, what baseline lengths do you need to (1) resolve the source into two different radio lobes and (2) resolve each individual lobe into a fluffy elongated structure?

- For sources that have a preferred orientation, try short observations with the antennas at different orientations. Are north-south or east-west baselines more useful? Why? Does this change as you make the observations longer?
- The disc is a medium-size source but it has sharp edges (and little corners). Play around with making the "best" image possible of this source. Can you suppress the sidelobes?