Astronomical Imaging with the One Hectare Telescope

Melvyn Wright, December 1998

1) array configuration

Depends on the science target what sort of array you want to build.
- filled array gives the best brightness sensitivity
- skeleton array gives more resolution.

Best may be a compromise of a high antenna density compact array with a sparse more extended array. For a large number of antennas, a random Gaussian distribution of antennas provides excellent uv-coverage with low sidelobes. The maximum central density is set by the antenna size and the width of the Gaussian can be chosen to optimize the science for which the array is intended.

2) resolution

The resolution is 1 arcmin per GHz per km. e.g. 20" at 1.4 GHz with 2 km array.
- A 1HT filled array with diameter ~100m has 10' resolution at 1 GHz;
  not too exciting for any kind of discrete source imaging.

- 2 km array with 500 x 5m antennas has spacing 12.5m = 2.5 dish diameters;
  gives well sampled uv-coverage which avoids shadowing.

3) sensitivity

Assuming T_{sys}=40 K, BW=100 MHz, N_{ants}=500, D_{ant}=5.65, f=1.4 GHz, θ=20"

Continuum mapping: assuming that interference will be a problem, some sort of spectrometer will be required for continuum mapping.
- Rms Flux density: 0.25 mJy/beam; Rms Brightness: 0.4 K, in 1 minute

Galactic: 1 MHz bandwidth; 1 kHz resolution (0.2 km/s at HI) in 1000 channels
or 0.03 km/s for mapping cold molecular cores around 10 GHz.
- Rms Brightness: 5 K in 10 hours at 20" resolution.

Extragalactic HI: 100 MHz bandwidth; 100 kHz resolution (20 km/s) in 1000 channels
- Rms Brightness: 0.5 K in 10 hours at 20" resolution.

4) confusion

For continuum mapping, the 1HT will be confusion limited. Number of sources in 1' beam > rms noise (T_{sys}=40, τ=1min, BW=800MHz)

Alternative estimates:
- Kellerman gives $N(S) = 60\ S^{-1.5}\ Sr^{-1}$
  => '$60/0.00025^{1.5}/3400/3400$' = 1.3
- Subramanya & Mills at 843 GHz => '0.1/0.00025/57/57' = 0.1
- Greenbank with 1.3 power => '$6.5/0.00025^{1.3}/3400/3400$' = 0.03
- Greenbank with 1.5 power => '$6.5/0.00025^{1.5}/3400/3400$' = 0.14

the 1HT is confusion limited in 1 - 100 minutes with 1 arcmin resolution at 5 GHz.

For continuum mapping, additional high resolution observations with an equally sensitive telescope will be required to subtract the confusing sources. This requirement will limit the usefulness of the 1HT for continuum mapping, and suggests that the primary use will be for spectral line imaging.

5) Data Flow

Assuming 500 antennas and 100 MHz bandwidth, the input bandwidth is 5 10^{10} Hz. For interference suppression we may need to sample 8 bits/Hz (4 x Nyquist).

With a 2 km array, the maximum delay is 2 km/3 10^5 km/s = 7 microsecs this requires 7 10^{-6} x 100 MHz x 8 bits/Hz = 6000 bits per delay line.

Correlator: conventional processing requires a 125000 baseline correlator with 1000 channels per baseline.

- Nyquist sample rate for 2 km array is 12*3600/(pi*2000)*2.5 = 17 secs.
- correlator output = 125000 x 32 bits x 1000 channels / 17 secs = 2.4 10^8 bits/s = 2 10^13 bits/day.

Images: Full field = 2 km / 5m x 2.5 pixels/sample = 1000 x 1000 pixels.

- suppose that we make 3 images per day with 1000 spectral channels = 3 x 1000 x 1000 x 1000 x 32 bits/word = 10^{11} bits/day.

Direct Imaging: an alternative to a correlator is direct beam formation.

- The sampled IF for each antenna is summed with a phase shift appropriate for each of 1000 x 1000 pixels and 1000 channels using FFT processing. This requires 3 x 1000 x log2(1000) x 0.1 MHz = 3 Giga ops/s for the FFT part and some more for the summing and squaring of each pixel.
- a possible architecture is a separate processor for each antenna/IF data stream, summing the processed output (freq channels, and phase shifted) into a common image matrix.
- an advantage is avoiding storing the correlation data.

6) array calibration.

i) phase array = find delay0 which maximizes central pixel on strong point source
   - this suggests a minimum correlator with at least 500 baselines, or alternatively, a software correlation, which might phase up the antennas whose phases have been determined in order to determine the unknown antenna gains. So perhaps we don't need to build a hardware correlator.

ii) set delay0 + geometric delay into delay register

iii) sample lags 0 - 1024 at 1 to 100 MHz bandwidth; FFT to 1000 frequency channels.

iv) either cross correlate, or weighted sum of antennas for each channel.

v) use planets and quasars to calibrate without additional gizmos on antennas.

7) Image processing.

The high data rate lends support to the idea of direct imaging, and not storing correlation data. One can still make an image of the instrumental response (the synthesised beam) and do image deconvolution. The images can be written out at some reasonable data rate for evolving sources such as comets. Not storing correlation data precludes the conventional selfcalibration. The tropospheric path fluctuation at cm wavelengths is around 1mm on a 2 km baseline in 5 min. This is only 1/30 wavelength at 10 GHz and is probably not the limiting the image quality. At meter wavelength ionospheric fluctuations may limit the image quality.

Conclusions.

1. Build a 2 km array with a high antenna density core to provide high brightness sensitivity to large scale structure.

2. Continuum imaging is confusion limited; most imaging will be spectroscopy. A 1000 channel, 100 MHz maximum bandwidth is good for spectroscopic imaging. These are wide field images; both bandwidth and 3D synthesis are required for the full field of view. Multiple frequency channels are also required for interference filtering and continuum imaging.

3. Direct imaging is an attractive possibility; we avoid building a correlator, and do not have to store correlation data. This route allows us to re-use software with available hardware.