Requirements for Accurate Galactic HI Observations with the GBT

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The GBT will have a major impact on Galactic HI studies. Its angular resolution and clean beam will make possible a number of experiments which cannot now be done. With its greatly reduced standing waves, spectral baselines should be superb. And perhaps most important, because the GBT optics are so clean, it should be possible to provide observers with spectra calibrated to an absolute standard, substantially free from stray radiation. No longer will one be required to be a black-belt radio observer to get an accurate HI spectrum – at the GBT it should be routine.

This memo gives an outline of some of the requirements necessary to move toward this happy state. Other requirements will no doubt be recognized as the telescope is commissioned.

1. *On-the-fly mapping capability.* General comments about on-the-fly techniques are given in the memo by Mangum (*On the Fly Observing at the 12 Meter* at the 12 meter web site www.tuc.nrao.edu/obsinfo.html), but for Galactic 21cm HI observing there are some special considerations. Perhaps the most important is that given the relative absence of atmospheric effects at 21cm, there will be little benefit in repeated scanning of a region to be mapped and the scan rate will thus be relatively slow, perhaps no faster than 0.2 arcmin per second. Frequency switching will probably be employed for most Galactic HI observations. The rate of switching should be no slower than 1 Hz, and for some experiments considerably more rapid.

During on-the-fly mapping, the beam will pass over radio continuum sources and the total system temperature will change. If the receiver temperature scale is calibrated with a switched noise source, the switching rate must be much faster than any change in system temperature. This will require a calibration cycle shorter than 1 second in many cases. It would be useful to have a rigorous review of issues arising from on-the-fly observing in the presence of a varying continuum background.

2. *Dynamic Range.* A single Galactic HI spectrum may have features of interest with antenna temperatures from a few mK to 100 K. The spectrometer must have a linear response over a range of 10^5.

3. *Calibration.* This is a complicated subject and has several aspects. We begin with the basic equation for the antenna temperature (assuming no atmospheric opacity):

$$T_a = \mathbf{a}\, \eta_R \left[\int\limits_{\Omega n} T_b\, P\, d\Omega \; + \int\limits_{\Omega > \Omega n} T_b\, P\, d\Omega \right].$$

The quantity $\mathbf{a}$ should be ~ 1, and reflects uncertainties in the calibration of the antenna temperature scale. The quantity η_R accounts for resistive losses, should also be ~ 1, and can be subsumed in the determination of $\mathbf{a}$. The quantity P is the power pattern of the antenna normalized to unit area, and T_b is the HI brightness temperature of the sky. We have split up the integration into two pieces: the first over the solid angle "near" the

main beam and the second over the remainder of the sky. In practical terms, the "near" pattern encompasses the first few Airy rings down to a level of 30 dB or so below the peak over an area ~ 1 square degree, while the "far" pattern is everything else.

For Galactic HI studies it is important to know how much of the power pattern is in each component. This can be determined by making a beam map to determine the shape of the near response, then scaling it by the peak gain (or effective area) of the telescope. Since the integral of the effective area is λ^2, this procedure will yield the fraction of the power patten outside the near area. In effect, to calibrate HI spectra on an absolute brightness scale we need to know the aperture efficiency and main beam efficiency. The telescope optics will change slightly with elevation to compensate for feed arm sag, so the calibration should be done at several elevations.

There are calculations of the beam amplitude and shape in GBT memos by Srikanth, and the calculations should be checked against the actual antenna performance. Once these quantities have been determined they should not change with time, and during routine HI observations the observer (or operator) would merely check the noise source against a known continuum source as often as necessary each day, then correct for the atmosphere by a simple model with constant coefficients.

In this way, the basic calibration done regularly at the telescope can yield absolutely calibrated HI measurements, i.e. the first integral in the equation, quickly and simply.