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Weather Conditions at Green Bank Relevant to Observing at mm-Wavelengths

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There are now enough data to characterize the Green Bank site for mm-wavelength observing. The most important factors are atmospheric opacity and wind. The atmospheric opacity provides a fundamental limit, while the effects of wind are more complex and in some cases can be corrected. The opacity and wind speed are essentially uncorrelated. This document is a summary. The references should be consulted for a more thorough discussion of the issues.

We will consider only the high-frequency observing season between 1 October and 1 May -- just over 5,000 hours each year -- although experience has shown that there are periods of good mm-wavelength observing conditions in every month of the year.

With data from the National Weather Service and realistic models of the atmosphere, the opacity at the GBT can now be estimated with high accuracy (Maddalena 2009). Results for the winter observing season over the years 2004-2008 are shown in in the upper panel of Figure 1. The opacity at zenith is <0.1 for 2800 h at 22 GHz and 1300 h at 86 GHz, and <0.2 for 4300 h, 3300 h and 2800 h at 22, 45 and 86 GHz respectively. Opacities at 86 GHz derived from tipper measurements (http://www.gb.nrao.edu/mustang/wx.shtml) are consistent with these numbers. At the GBT site an atmospheric opacity τ=0.1 produces a sky brightness temperature of 27 K at the zenith.

The opacity rises dramatically above 110 GHz, and at the ^{12}CO(1-0) transition at 115 GHz is never below 0.4. However, major surveys in ^{12}CO(1-0) have been made from poorer sites than Green Bank (elev. 807m): for example, at the FCRAO at Quabbin, MA (elev. 314m), Bell Labs at Holmdel, NJ (elev. 114m) and the CfA mini in Cambridge, MA (elev. 24m). In fact, because the dominant source of opacity at 115 GHz is O_2 with a scale height of 8 km, in good weather the GBT would be only a factor of two slower than the IRAM 30m in reaching the same S/N ratio on an extended source. For point sources the large area of the GBT more than compensates for this factor, and the GBT is 10x faster than the 30m at 115 GHz and 25x faster at 86 GHz.

The lower panel of Figure 1 shows the distribution of precipitable water vapor (pwv) for comparison with other sites. There are typically 1000 winter hours with pwv< 5mm and 2000 hr with pwv < 10mm.

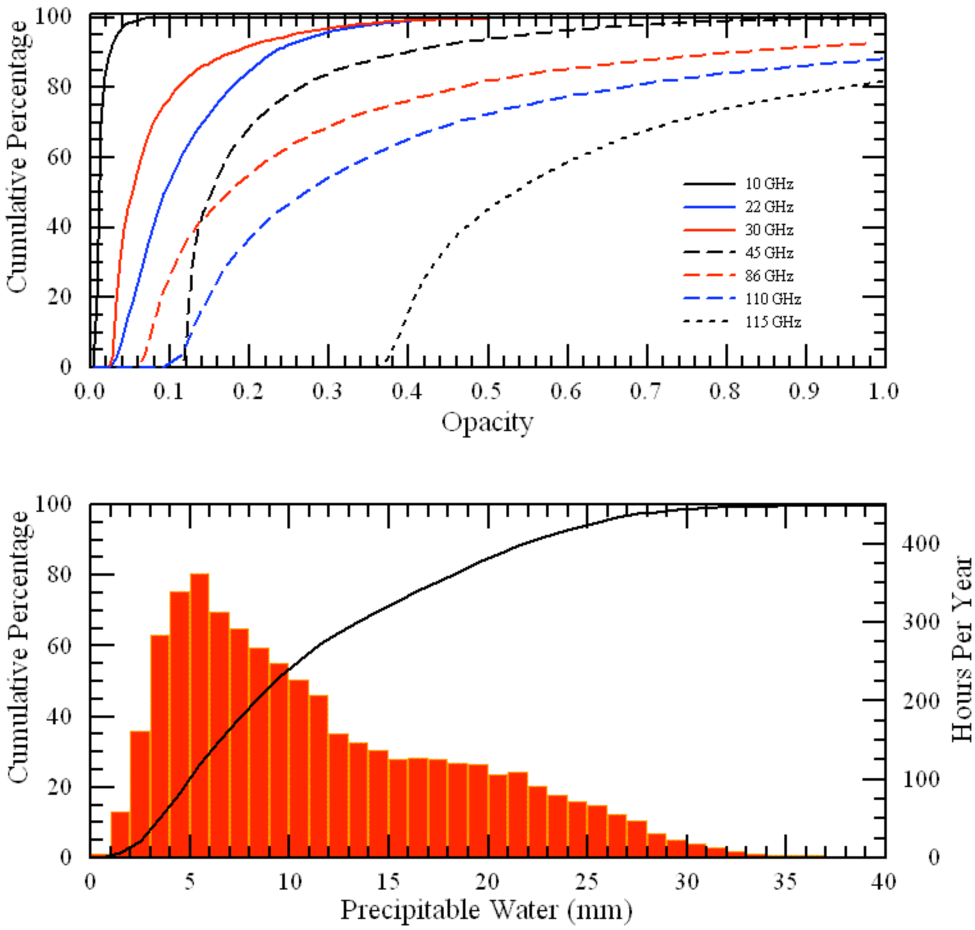

Figure 1: Top: The cumulative zenith opacity at Green Bank during the winter observing season (1 October - 1 May) as a function of frequency over 2004-2008. The bottom panel shows the cumulative distribution of precipitable water vapor over the same interval.

Effects of the wind are more complex. The wind moves the GBT feed arm relative to the dish, changing the pointing by an amount that depends on the wind speed and direction. Pointing changes have typical periods of 30 seconds. The feed arm displacement can be measured using the Quadrant Detector, which is in continuous operation. This allows the true GBT pointing to be recovered, and for observations that involve mapping, the effects of moderate wind might be small (Ries et al 2009). The most severe constraint on wind-induced pointing errors is for measurement of point sources, where wind-induced gain fluctuations no larger than 15% are desired.

Ries (2010) has measured wind speeds and pointing errors for the GBT and Figure 2 summarizes this work. The vertical dashed lines are the 15% gain-error limits for various frequencies, and the curves show the cumulative distribution of hourly average wind speeds for one year. Peak wind speeds in a given hour are typically twice the average. Most of the time (>70% during winter nights) the mean wind speed is low enough to permit accurate measurement of point sources throughout the 3mm band. In

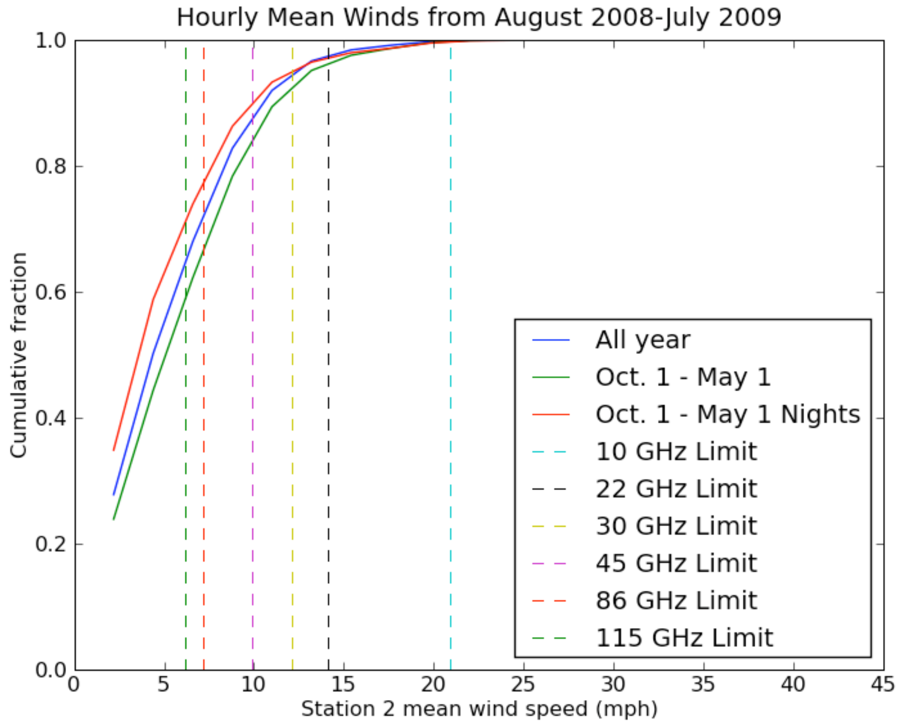

Figure 2: Cumulative distribution of hourly mean wind speed for one year. Vertical dashed lines mark speeds above which pointing errors cause a 15% reduction in point-source gain (from Reis 2010).

practice, data from the Quadrant Detector will be needed to characterize the detailed pointing as wind speeds tend to be quite variable about the mean.

SUMMARY

The following table summarizes our current estimates of the time available in the winter season between 1 October and 1 May for GBT "photometric" quality observations at zenith, i.e. with the lowest wind-induced pointing errors (from Fig. 2).

Frequency	tau < 0.1	tau < 0.2
22 GHz	2600 h	4000 h
45 GHz	---	2800 h
86 GHz	975 h	2100 h

REFERENCES

Maddalena R.J. 2009, [*http://www.gb.nrao.edu/~rmaddale/Research/AccurateWeatherForecastingOct2009.pdf*](http://www.gb.nrao.edu/~rmaddale/Research/AccurateWeatherForecastingOct2009.pdf)

Ries, P. 2010, PTCS Project Note 68.1, "Winds and their effect on the GBT"

Ries, P., Hunter, T., and Ghigo, F. 2009, PTCS Project Note 64.4, "Quadrant Detector Practical Application"