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PHASE CALIBRATION OF THE PROPOSED MILLIMETER ARRAY

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ABSTRACT The phase structure function can be estimated from water vapor radiometer data. We present typical phase structure functions and indicate how residual calibration errors are related to the phase structure function and the calibration parameters. From this, we can estimate the amount of time the array can be used and compare different calibration methods.

INTRODUCTION

The Millimeter Array (MMA) is proposed to operate on baselines of up to 3 km at frequencies up to 350 GHz. Since no operating interferometer can indicate the expected phase stability on such baselines on high, dry sites, NRAO has undertaken a site survey, measuring the opacity and estimating the phase stability on baselines ranging from about 100 m to 5 km.

ESTIMATING THE PHASE STRUCTURE FUNCTION

Every five hours, the survey radiometer looked at the zenith for one hour, recording the emission at 225 GHz from atmospheric water vapor. Assuming that inhomogeneously distributed water vapor dominates interferometric phase errors, the fluctuations recorded by the radiometer lead to the phase structure function (Holdaway, 1991). The most stable atmospheres are characterized by a single power law phase structure function:

$$D_\phi(\rho) = \left(8.3 ASD_{56}\, \rho^{0.54}\right)^2, \qquad (1)$$

where ρ is the baseline in meters, ASD_{56} is the Allan standard deviation of the radiometer fluctuations at 56 s averaging time, which varies from 0.03 K to 0.30 K for the best half of the winter months on the potential MMA sites, and D_ϕ is in units of degrees squared at 230 GHz. More commonly the phase structure function is a two part power law, consistent with Kolmogorov turbulence:

$$D_\phi(\rho) = \left(4 ASD_{56}\, \rho^{0.76}\right)^2 \qquad \rho < 150m \qquad (2)$$

$$D_\phi(\rho) = \left(28 ASD_{56}\, \rho^{0.36}\right)^2 \qquad \rho > 150m. \qquad (3)$$

ESTIMATING RESIDUAL CALIBRATION ERRORS

Since the calibrator and the target source are observed through different paths in the atmosphere, and since the atmosphere is traveling with velocity v across the array, errors will be made applying the calibrator phase to the target source. Assuming a thin phase screen, the residual phase error after calibration will be independent of baseline for long baselines and is given by

$$\sigma_\phi = \sqrt{2D_\phi(vt + d)} \tag{4}$$

where D_ϕ is the phase structure function, t is the time required for the calibrator/target source observation cycle, and d is the distance between the lines of site to the calibrator and the target source in the thin phase screen. Typical winds aloft on the potential MMA sites are about 12 m/s during the winter months (Schwab, 1992).

An interferometer's phase is usually calibrated by observing a nearby point source on timescales of tens of minutes. Equation 3 indicates the rms phase on 3 km baselines will usually be more than a radian if calibration is performed only once every 10 minutes. The more frequently the array can be calibrated, the more often the array can be used on long baselines at high frequencies. To determine how frequently the array should be calibrated, we refer to Equation 4. Since D_ϕ is a monotonically increasing function, we simply minimize the quantity $vt + d$ as a function of calibrator strength, slew rate, and array setup time and sensitivity for any particular calibration method. This optimization is carried out for several calibration techniques in Holdaway (1992a, 1992b). The MMA will be sensitive enough to get accurate phases on a 0.20 Jy calibrator in under 3 s, and source counts of flat spectrum quasars (Kühr, 1979) indicate that there will usually be a 0.20 Jy calibrator within 2° of the target source. Hence, it should be possible for the MMA to perform phase calibration with a cycle time of 10 s or less.

We are considering some novel phase calibration schemes: determining the atmospheric phase from total power fluctuations, frequent beam switching onto a nearby calibrator, and spatially pairing the antennas in the 3 km array such that one antenna is observing the calibrator while the other antenna is observing the target source. Any of these techniques will greatly increase the amount of time which the MMA will be able to observe on 3 km baselines at high frequencies. See Holdaway (1992b) for estimates of the 3 km array's usability with each of these calibration schemes.

REFERENCES

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