Calibrating ALMA Phases with WVR Data

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***Abstract*—This memo discusses the implementation in Obit of ALMA phase corrections based on the water vapor radiometers with which the antennas are outfitted. This implementation uses the libair software package developed by Bojan Nikolic. An example is given of the correction of large phase errors observed in ALMA data.**

***Index Terms*—Radio Interferometry, Calibration, ALMA**

I. INTRODUCTION

TROPOSPHERIC phase fluctuations at radio frequencies above 10 GHz are dominated by the variable electrical path experienced by a wavefront imposed by the clumpy distribution of water vapor in the atmosphere [1]. At frequencies below a few hundred GHz, the excess path is relatively constant with frequency but the phase effect on a given baseline is proportional the inverse of the wavelength being observed. Thus, at millimeter and sub-millimeter wavelengths, the phase disturbances can be severe.

Water vapor has a number of strong transition at centimeter through sub-millimeter wavelengths which can be used to infer the total column density of water vapor in a given path thought the atmosphere. The ALMA array has been outfitted with radiometers [2] to measure the water line at 183 GHz. A significant effort has gone into developing techniques for inferring the excess path from these measurements[3][4][5]. This memo describes the implementation of these techniques in the Obit package ([6], http://www.cv.nrao.edu/∼bcotton/Obit.html) and illustrates the corrections to ALMA observations.

II. ATMOSPHERIC PHASE VARIATIONS

The effects of water on millimeter wavelength observations are illustrated by the ALMA test data shown in Figure 1. These were observations near 90 GHz (3 mm) on a particularly bad day at the ALMA site ($>$ 2 mm precipitable water). The data illustrated were averaged in time and frequency and consist of three 10 min scans on a strong quasar. Over this period the phases are nearly incoherent and the amplitudes show the effects of the periods of large phase variations on the 20 second timescale of the averaging. Individual spectral samples are plotted separately and the small scatter shows that the data is of intrinsically high signal–to–noise ratio and the scatter in time is due almost entirely to fluctuations in the water vapor. Such data is of very limited scientific utility.

III. WATER VAPOR RADIOMETER (WVR) CORRECTION

The ALMA water vapor radiometers [2] make 4 double sideband measurements covering the 183 GHz water line. Due to the large optical depth and pressure broadening of this line, the relationship between the line profile and the excess electrical path imposed by the water vapor is highly nonlinear. Furthermore, the water vapor is poorly mixed in the atmosphere and is very clumpy. The excess path seen varies from antenna to antenna and the difference increases with antenna separation up to some "outer scale" of the variations. Thus, it is necessary to instrument each antenna with a WVR and derive independent corrections. Derivation of excess path lengths has been discussed in detail in [4][5].

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IV. OBIT IMPLEMENTATION OF WVR CORRECTIONS

The WVR correction method implemented in Obit uses the libair package developed by Bojan Nikolic [4] which produces linearized sensitivities to the four WVR measured brightness temperatures to the excess path $\frac{dL_ij}{dT_ij}$ where L_ij is the excess path estimate from radiometer channel j antenna i and T_{ij} is the measured brightness temperature in channel j antenna i. These sensitivities can be derived from scan averaged radiometer measurements and then applied to the individual, approximately one second samples to determine short time scale corrections from a weighted average of the four radiometer channels. Since the calculation of WVR sensitivities is rather expensive, its implementation is threaded.

This technique is implemented in Obit in task WVRCal which reads the WVR data obtained from the ASDM/BDF files using Obit task BDFIn and writes an AIPS SN table containing the phase corrections to a corresponding interferometer data set.

V. EXAMPLE WVR CORRECTION

Since the data shown in Figure 1 were taken on a strong, unresolved quasar, the short term phase fluctuations can be derived from a standard interferometric calibration. Figure 2 compares the phase corrections on a 1 second timescale derived from Obit/Calib (interferometric) and Obit/WVRCal (WVR) on the data shown in Figure 1. The strong variations in phase are highly correlated between these two, completely independent, measurements. The phase corrections determined from the WVR measurements were applied to the data shown in Figure 1 prior to averaging and the averaged results are shown in Figure 3. The expectation of flat amplitude and phase behavior is nearly achieved; the coherence loss in the averaged amplitudes is down to the level of the scatter in the data.

VI. DISCUSSION

The libair package of Bojan Nikolic has been successfully integrated into the Obit package. ALMA WVR data can be read into Obit and then this library used to generate phase corrections. In the example given, the uncorrected phases were nearly incoherent but the WVR derived corrections made a dramatic difference.

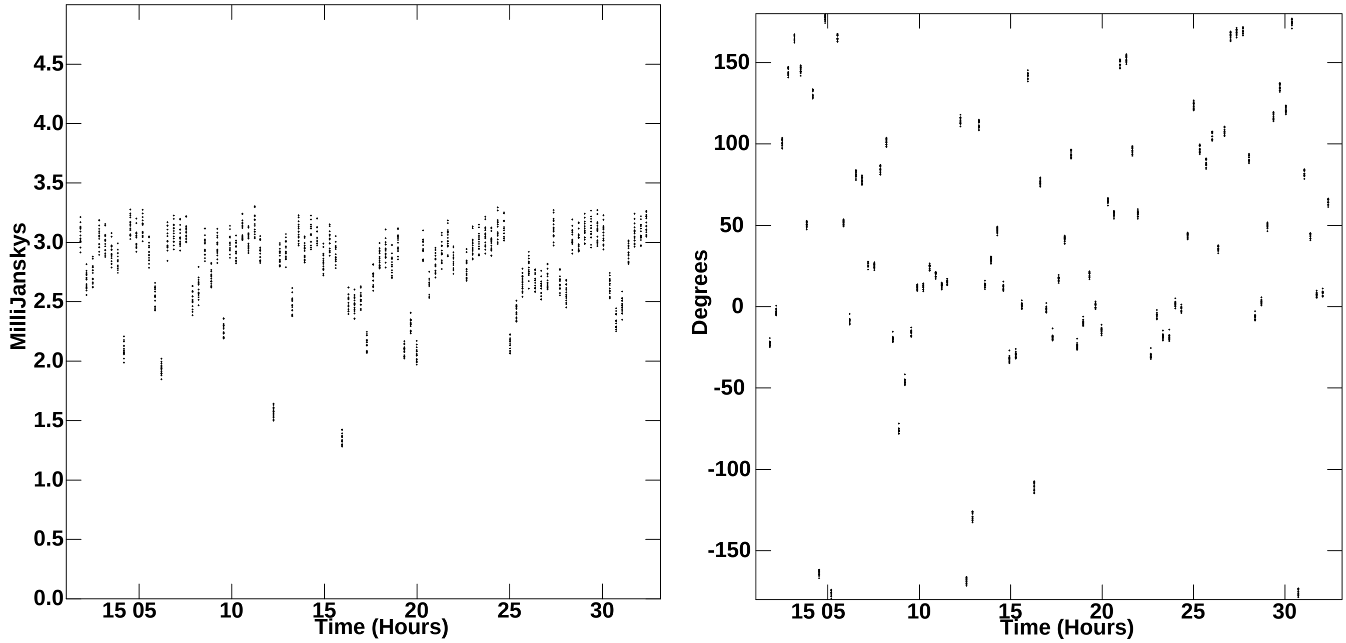

Fig. 1. Baseline 3–5 data without WVR corrections. Data are averaged to 20 sec and 15 channels. Amplitudes are shown on the left, phases on the right.

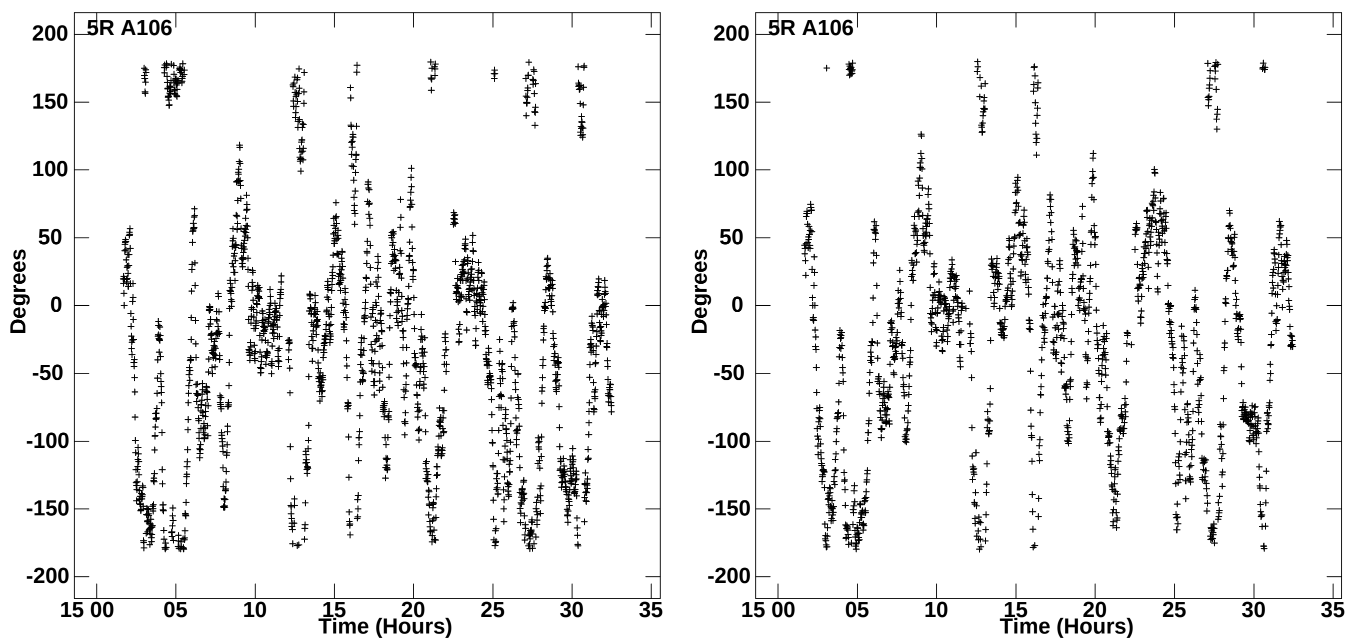

Fig. 2. One second relative phase corrections determined from interferometric calibration (left) and WVR (right) with the same reference antenna.

ACKNOWLEDGMENT

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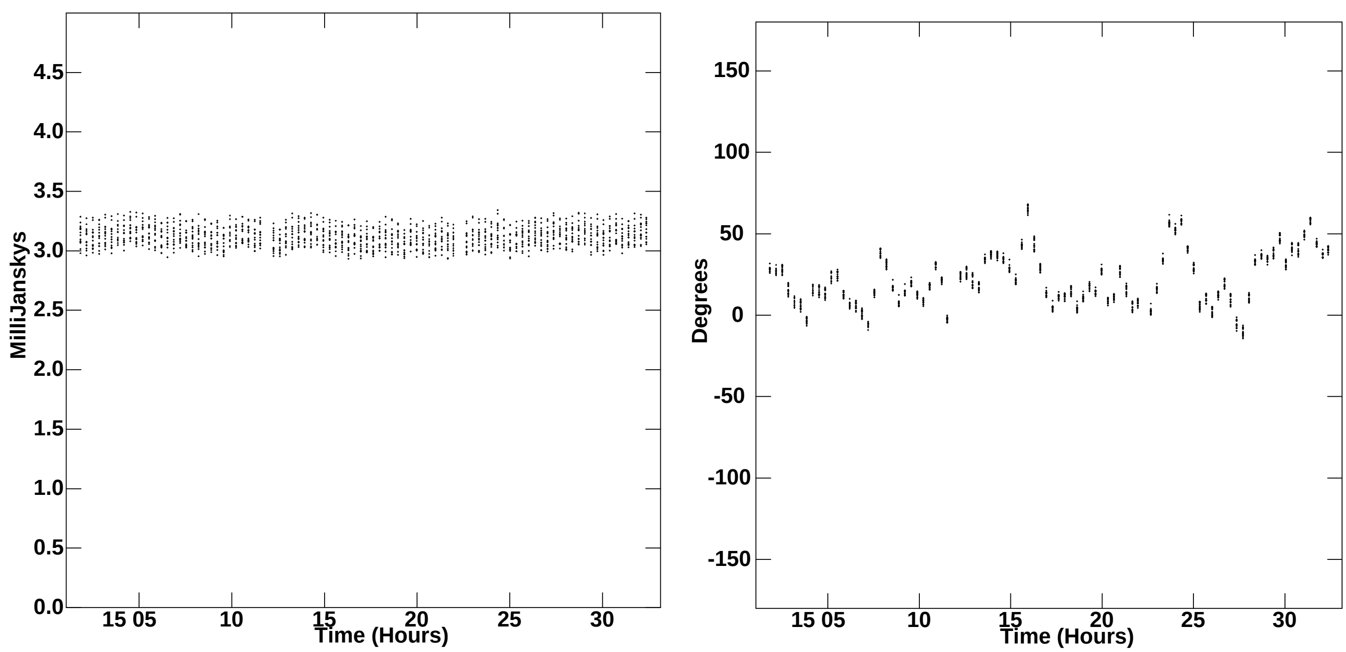

Fig. 3. Like Figure 1 but applying corrections derived from WVR data.