Ionospheric Faraday Rotation Correction

W. D. Cotton (NRAO), August 3, 2024

***Abstract*—At low radio frequencies the combination of the Earth's ionosphere and magnetic field introduce time and direction dependent Faraday rotation. This memo discusses using AIPS task TECOR to correct ionospheric Faraday rotation of MeerKAT UHF data in the Obit software environment. Application of TECOR largely removes the effects of ionospheric Faraday rotation in a test dataset.**

***Index Terms*—Ionospheric Faraday Rotation**

I. Introduction

A magnetized thermal plasma rotates the plane of a polarized signal passing through it by an amount, $\Delta\chi$ given by

$$\Delta\chi \;=\; \lambda^2\, 0.81 \int n_e B_{\|} dr, \tag{1}$$

where λ is the wavelength in m, n_e is the electron density in cm^{-3}, $B_{\|}$ is the strength of the component of the magnetic field along the line of sight in μGauss and r is distance in parsec. This effect is known as Faraday rotation. The Earth's ionosphere which is permeated by the Earth's magnetic field is such a magnetized plasma which can affect radio observations of magnetized emission from celestial objects. This is especially the case at long wavelength (λ^2) and daytimes during periods of enhanced solar activity. As is evident from Eq. (1), the amount of Faraday rotation depends on observing geometry, i.e. time and direction of the source. Variable ionospheric Faraday rotation (IFR) will corrupt measurements of the polarization angle and/or rotation measure of celestial sources. The ionosphere can disturb radio observations at L Band, even at night during solar minima [1].

Models of the magnetic field and monitoring of the ionosphere allow for at least crude corrections for IFR. Various aspects of such corrections in the context of radio astronomical interferometry are discussed in detail in [2].

This memo discusses the use of AIPS task TECOR in the Obit environment [3][1] to correct for IFR in MeerKAT UHF data. A specific example is given of a dataset including 3C286 and 3C138. The observation of 3C286 which was strongly affected by IFR is shown to have EVPA corrected to within a few degrees of the model given by [2]. Corrected, 3C138 agrees within a few degrees of [4] but the source has undergone an outburst since the data of [4].

II. Test Observation

An observation with MeerKAT at UHF (544 – 1088 MHz) was made on 2023-10-26 & 27 with 63 of the 54 antennas. The bandpass was divided into 4096 channels, 8 second integrations were used and all four correlations of the two orthogonal linear feeds were recorded. The observations included the unpolarized calibrators 0408-65 (photometric/bandpass/delay cal), 2 $\times$ 10 min. scans and J0538-4405 (gain cal) with many short scans. The polarized calibrators J0521+1638 (3C138), J1331+3030 (3C286) were observed with one 10 min. scan each. The Sun was in an unusually active sunspot maximum.

A. Calibration

The parallel hand calibration followed the general scheme used in [5] and [6]. For calibration purposes, the spectrum was divided into 8 spectral windows (IFs in AIPS).

B. X–Y phase and delay

Initial polarization calibration used the X–Y phase and delay calibration from the "noise diode" calibration run prior to the observation. The residuals to this X–Y calibration were determined using Obit task RLDly on the J1331+3030 scan. The cross hand data were poorly behaved at the bottom of the band and a number of channels were flagged. The solutions in RLDly averaged pairs of spectral windows.

C. Instrumental Polarization

The calibrators 0408-65 and J0538-4405 are very weakly linearly polarized and were modeled as unpolarized sources for use in Obit task PCal to determine the instrumental polarization parameters, ellipticity and orientation of the feeds. This calibration can be evaluated by examining the EVLA and fractional linear polarization as a function of wavelength squared for the polarized calibrators. For this purpose they were imaged by task MFImage [7] using a maximum fractional bandwidth (maxFBW) of 5% giving 14 subbands across the bandpass. The polarization of J1331+3030 is well modeled in [2] and the polarization of J0521+1638 at 1050 MHz is given in [4]. However, J0521+1638 has undergone an outburst (R. Perley private communication) since the data of [4] and its polarization may no longer be the same.

The measured polarization properties of J0521+1638 and J1331+3030 are shown in Figure 1. The EVPA shown in this figure is very discrepant for J1331+3030 from the model of [2] and J0521+1638 shows a difference as well. The linear difference of EVPA v. λ^2 seen for J1331+3030 seen in Figure 1 is characteristic of ionospheric Faraday rotation. These observation were made during a period of enhanced solar activity during which IFR is much higher plus this calibrator was observed at low elevation during the daytime; J0521+1638 was observed at night. IFR corrections are clearly required.

National Radio Astronomy Observatory, 520 Edgemont Rd., Charlottesville, VA, 22903 USA email: bcotton@nrao.edu

[1] http://www.cv.nrao.edu/~bcotton/Obit.html

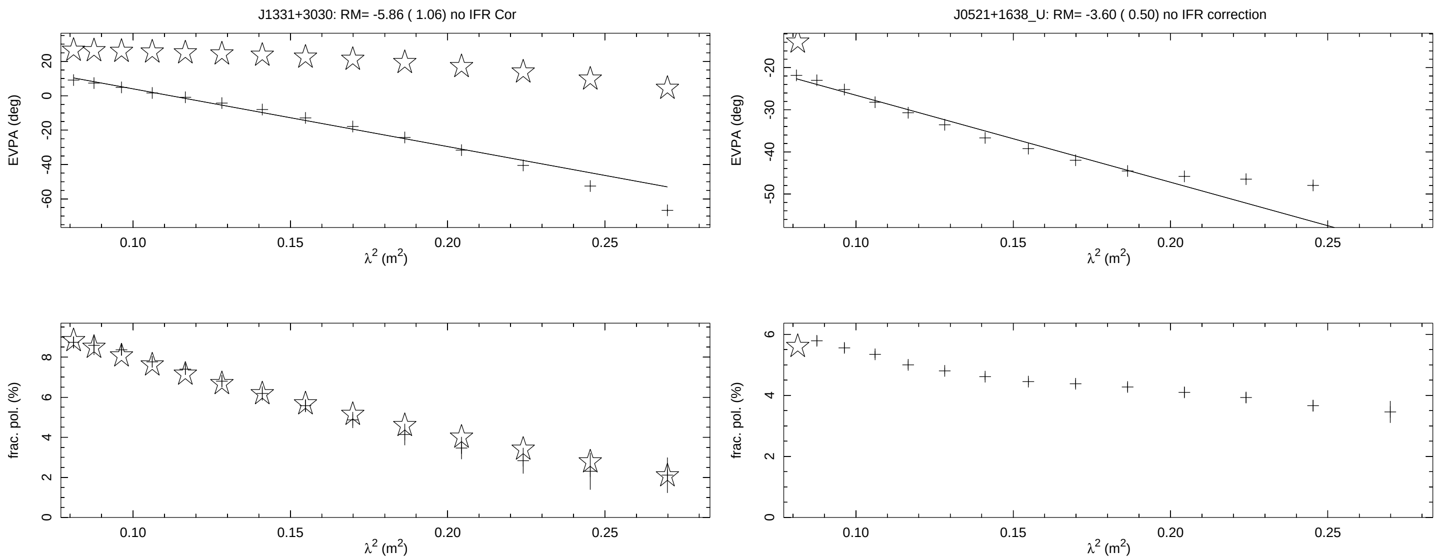

Fig. 1. **Left:**Sub band EVPA and fractional polarization in UHF for J1331+3030 (3C286) without correction for ionospheric Faraday rotation. Upper plot is EVPA and the lower plot fractional linear polarization. Stars are the model values from [2]. The solid line is a rotation measure fit to the data with fitted RM given in the title. **Right:** Like **Left** but for J0521+1638 (3C138) and the star is from [4].

D. Ionospheric Faraday Rotation Correction

AIPS Task TECOR can be used to determine the ionospheric Faraday rotation and the times and directions of the source observations and generate a calibration (AIPS CL) to correct the effect. TECOR uses the IGRF version 13 model of the Earth's magnetic field and ionospheric zenith Total Electron Content (TEC) values in IONEX from any of a number of sources, see TECOR's Explain section for details.

TECOR was run using the jplg IONEX files available as ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex/YYYY/DDD where YYY is the year number and DDD is the day of year number The approach suggested in https://iopscience.iop.org/article/10.3847/1538-3881/acc174 was basically followed. A Scale TEC Factor=0.85 (APARM(4)), elevation offset=56.7 (APARM(5) or perhaps 7) and scale elevation=0.978 (APARM(6) or perhaps 8). The derived AIPS CL table was applied to complete the calibration. After IFR corrections the measured polarization properties of J0521+1638 and J1331+3030 are shown in Figure 2. The corrected results for J1331+3030 are significantly closer to the model of [2]. The EVPA of J0521+1638 at 1050 MHz more nearly reproduces the value of [4] and the overall RM is reduced.

III. Conclusion

Use of AIPS task TECOR largely corrected the ionospheric Faraday rotation in a scan on 3C286 in MeerKAT UHF data taken during daytime during a very active solar maximum.

References

[1] W. D. Cotton, J. J. Condon, and T. Mauch, "The Ionosphere at L Band: MeerKAT," *Obit Development Memo Series*, vol. 59, pp. 1–6, 2018. [Online]. Available: https://www.cv.nrao.edu/∼bcotton/ObitDoc/MeerKATIon.pdf

[2] B. Hugo and R. Perley, "Absolute linear polarization angle calibration using planetary bodies for MeerKAT and JVLA at cm wavelengths," *SARAO documents*, vol. SSA-0004E-001, pp. 1–70, 2024.

[3] W. D. Cotton, "Obit: A Development Environment for Astronomical Algorithms," *PASP*, vol. 120, pp. 439–448, 2008.

[4] R. A. Perley and B. J. Butler, "Integrated Polarization Properties of 3C48, 3C138, 3C147 and 3C286," *ApJS*, vol. 206, p. 16, 2013.

[5] T. Mauch, W. D. Cotton, J. J. Condon, and et al., "The 1.28 GHz MeerKAT DEEP2 Image," *ApJ*, vol. 888, p. 61, 2020.

[6] W. D. Cotton, K. Thorat, J. J. Condon, B. S. Frank, G. I. G. Jzsa, S. V. White, R. Deane, N. Oozeer, M. Atemkeng, L. Bester, B. Fanaroff, R. S. Kupa, O. M. Smirnov, T. Mauch, V. Krishnan, and F. Camilo, "Hydrodynamical Backflow in X-shaped Radio Galaxy PKS 2014-55," *MNRAS*, vol. 495, p. 1271, 2020.

[7] W. D. Cotton, J. J. Condon, K. I. Kellermann, M. Lacy, R. A. Perley, A. M. Matthews, T. Vernstrom, D. Scott, and J. V. Wall, "“The Angular Size Distribution of μjy Radio S”ources”," *ApJ*, vol. 856, p. 67, 2018.

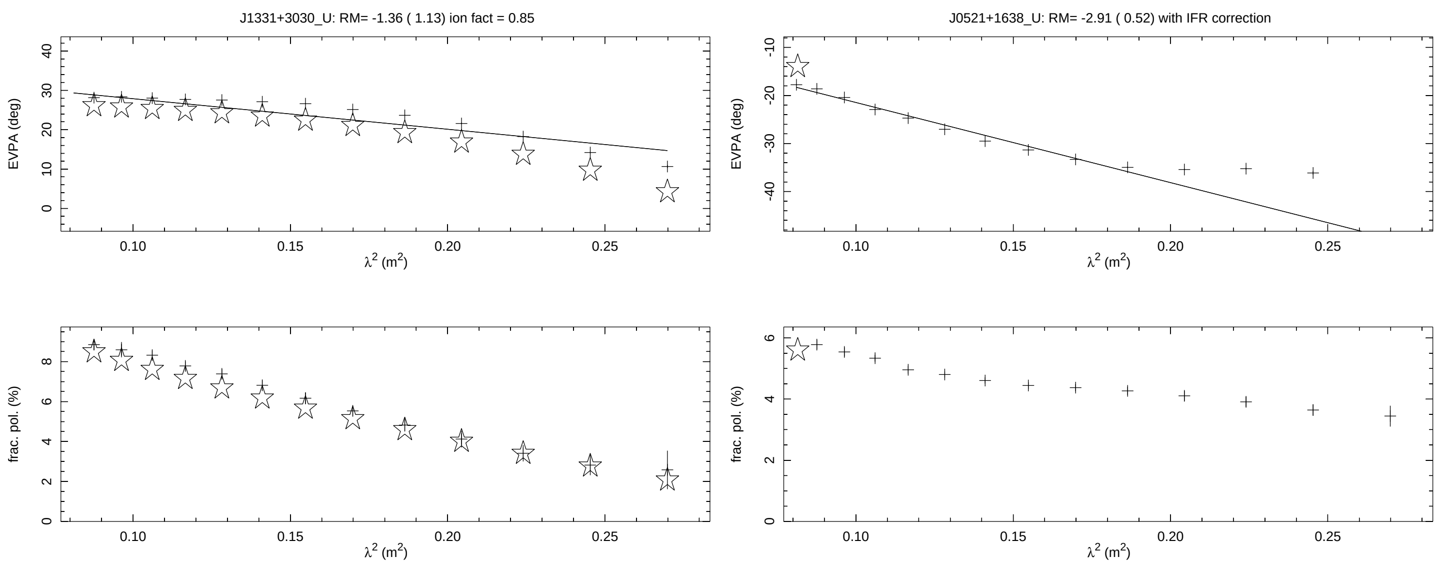

Fig. 2. Like Figure 1 but applying IFR corrections.