MeerKAT S Band commissioning

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***Abstract*—Tests using a high dynamic range field show that direction independent only calibration results in unacceptably high levels of artifacts around bright sources. The use of direction dependent gain calibration (Peeling) is found to greatly reduce the level of artifacts. This is consistent with, but does not firmly establish, that antenna pointing errors are the dominant cause of the artifacts. A simple test of the polarimetry produces the expected results.**

***Index Terms*—imaging, dynamic range**

I. Introduction

THIS MEMO discusses an analysis of MeerKAT S band commissioning observations of a radio galaxy requiring high dynamic range. The target, called "The Corkscrew" (for obvious reasons) is the BL Lac galaxy MCG-07-47-031 which contains a bright (0.25 Jy), inverted spectrum core and very faint extended emission and shares the beam with several other relatively bright, extended sources. The region of the field of view containing these sources is shown in Figure 1. The "Corkscrew" galaxy appears in the upper left of this figure. This memo analyses the observations using the Obit package [1] [1].

II. Initial observation

The Corkscrew was initially observed with the antenna pointing position near the center of the extended emission (23 19 15.0, -42 06 00.0). Observations were under proposal SSV-20210906-WC-01 (now relabeled EXT-20210906-WC-01) with initial observations on 27 Sep. 2021, SBID 20210910-0009. The duration of the observations was 8 hours (including calibration) and were done at S-band with the S4 filter covering 2625-3500 MHz (center frequency 3062.50 MHz), using the 4k correlator mode.

A. Calibration

The data were calibrated in Tom Mauch's Obit based calibration pipeline as described in [2] with subsequent polarization calibration based on the noise diode calibration as described in [3]. Calibration included group delay, bandpass, amplitude, X-Y phase and on axis instrumental polarization. The delay, bandpass and flux density calibrators were 1934-638 and 0408-65. The gain calibrator was J2314-4455 and 3C48 and 3C138 were the polarization calibrators.

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

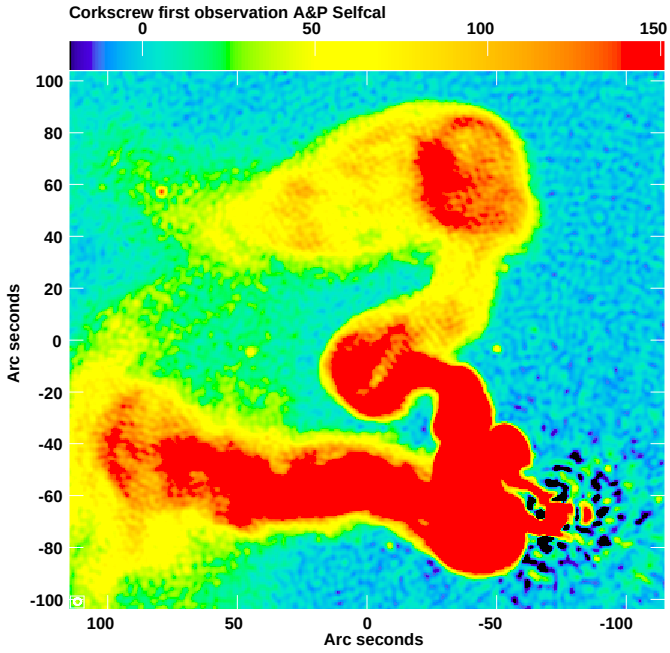

Fig. 2. First attempt on the "Corkscrew" with pointing center near center of extended source. Amplitude and phase self calibration has been applied but not DDEs. The scale ($\mu Jy\ bm^{-1}$) is given by the color bar at the top.

B. Imaging

Imaging used Obit task MFImage which uses faceting to address the noncoplanarity issues and multiple subbands which are imaged independently but deconvolved jointly as described in more detail in [4]. The initial test was done with subbands of 5% fractional bandwidth using 6 subbands to cover the full bandwidth (2625-3500 MHz). This led to currently undiagnosed imaging problems and subsequent imaging used 2% fractional bandwidth (14 subbands). Imaging consisted of a sequence of phase only self calibration (30 sec.) plus CLEAN deconvolution followed by an amplitude and phase (2 min.) self calibration.

C. Results

The resultant image contained strong artifacts near the bright, inverted spectrum core which would limit the scientific usability of the image. The central part of the image is shown in Figure 2

III. Reobservation

The bright core of the source was far enough removed from the antenna pointing position that the image might have been adversely affected by pointing errors. Several of the antennas had their pointing improved and the Corkscrew was reobserved with the antenna pointing center at the location of the core

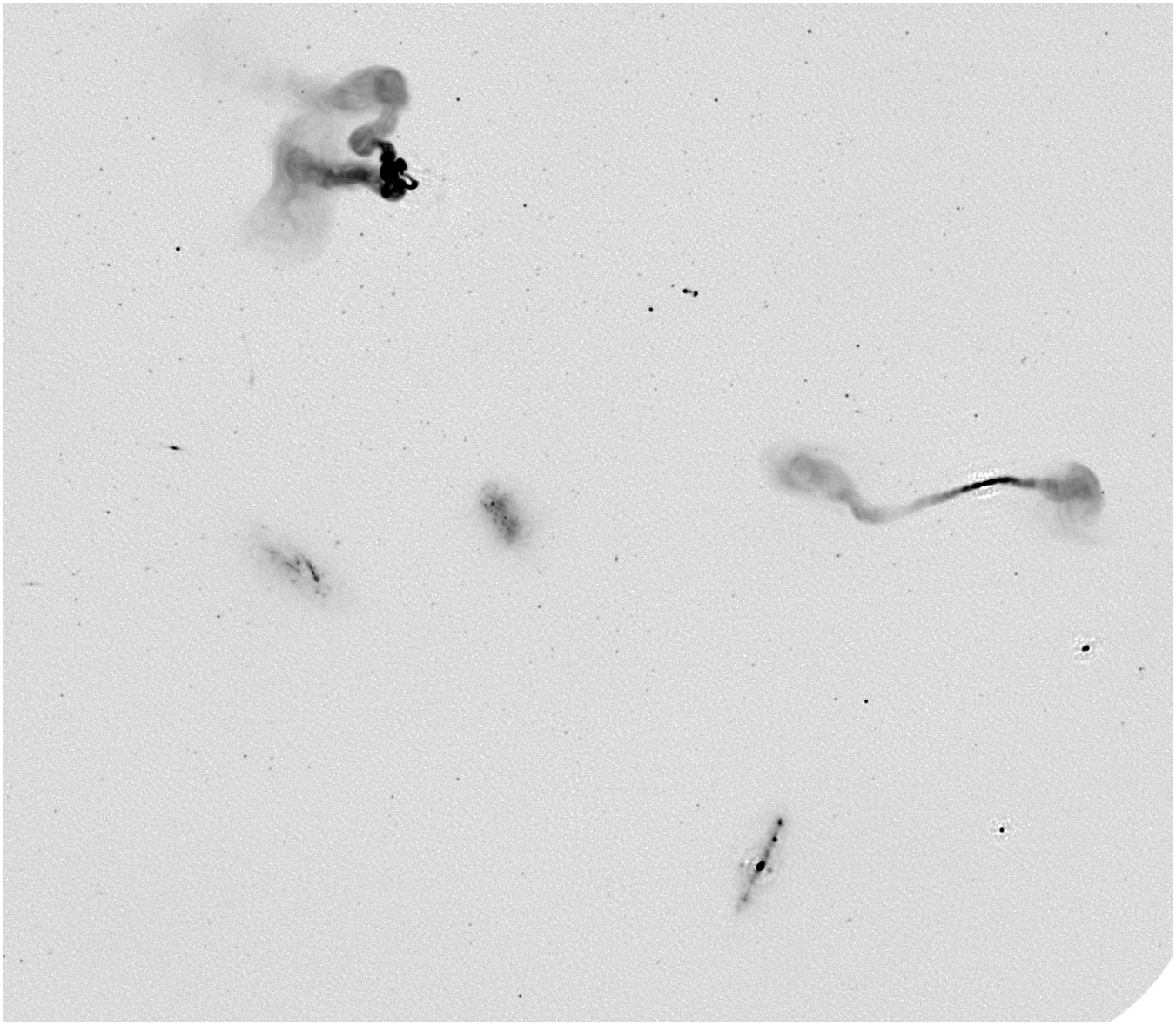

Fig. 1. Negative grayscale of central portion of a field observed with MeerKAT at S Band showing the several extended sources in the field. The "Corkscrew" is on the top left and the pointing center was on the compact source on the western side. The image has been amplitude and phase self calibrated and the bright sources in the upper left and lower right peeled to reduce the effects of DDEs. The stretch is $\sqrt{}$ -10 to 500 μJy/beam and the field shown is $37' \times 32'$.

(23 19 5.89 -42 06 48.4). The reobservations were on 8 Nov. 2021, SBID 20211101-0034 for a total duration of 8.5 hours including calibration. The data were calibrated and imaged as above and the resultant image of the Corkscrew is shown in Figure 3. The artifacts were somewhat reduced but still at a troublesome level.

IV. DDEs, Peeling

The suspected culprit is antenna pointing errors which will introduce direction dependent gains (AKA DDEs) largely in amplitude. The amplitude self calibration solves for a direction independent gain and in the presence of multiple sources of significant flux density may not be correct for any of them. To test this, the two brightest sources in the field, the core of the Corkscrew and NGC7582, the edge on spiral in the lower right of Figure 1 were "Peeled" [5]. Peeling allows a limited range of direction dependent corrections which should correct for antenna mispointing gains. The result is shown in Figure 4. In addition to self calibration and peeling, this image also includes a multiresolution CLEAN and the larger field is that shown in Figure 1.

V. Polarization

In order to test the polarization calibration, the inner jet in the FR I radio galaxy, 2MASXJ23175633-4213335 at z=0.056, appearing in the center right of Figure 1, was imaged in Stokes I, Q and U and is displayed in Figure 5. The inner jets of FR I galaxies typically show transverse magnetic fields as is seen in Figure 5.

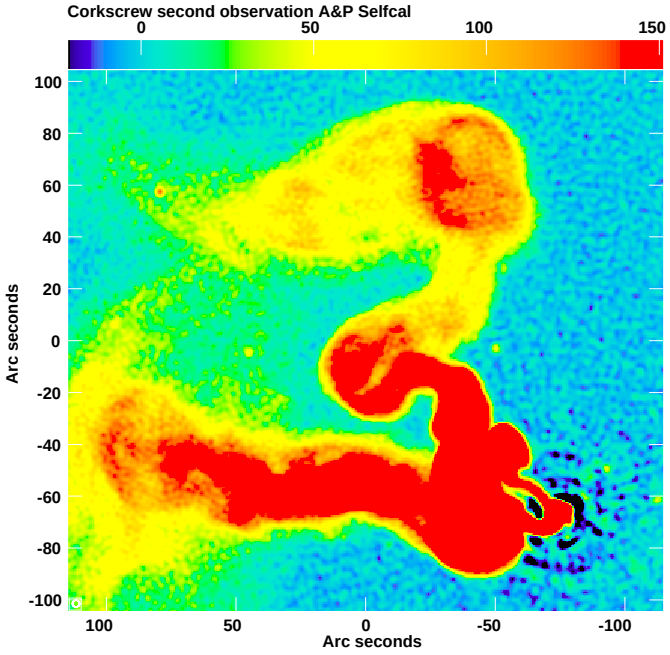

Fig. 3. Like Figure 2 but the reobservation of the "Corkscrew" with pointing center on the bright core.

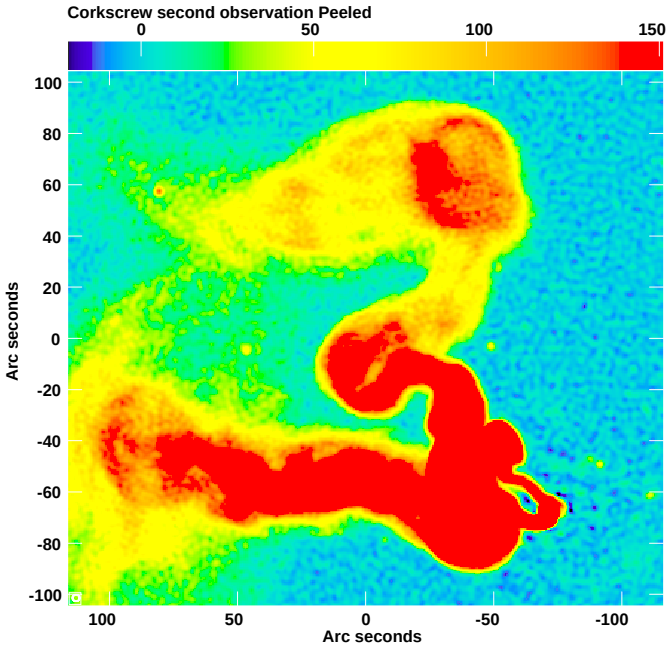

Fig. 4. Like Figure 3 but with the two brightest sources in the field Peeled.

VI. Discussion

The scientific usability of the derived image of the Corkscrew was compromised when the array was pointed at the center of the extended part of the source (see Fig 2). This is true in spite of amplitude and phase, direction independent self calibration. Clear artifacts near the 0.25 Jy core are up to 250 $\mu Jy\ bm^{-1}$ or a dynamic range of less than 1000:1. The RMS in the source free region near this source is 5.9 $\mu Jy\ bm^{-1}$.

One of the potential causes of these artifacts is direction dependent gain effects (DDEs) caused by mispointing of the antennas. As the bright core was some distance from the pointing center, a potential improvement is centering the observation on the core, this will minimize the effects of mispointing. In addition, the pointing of several of the antennas was improved. The result of the reobservation (see Fig 3) was that the extent of the negative artifacts was reduced and the maximum artifact was -120 $\mu Jy\ bm^{-1}$, still far above the local noise.

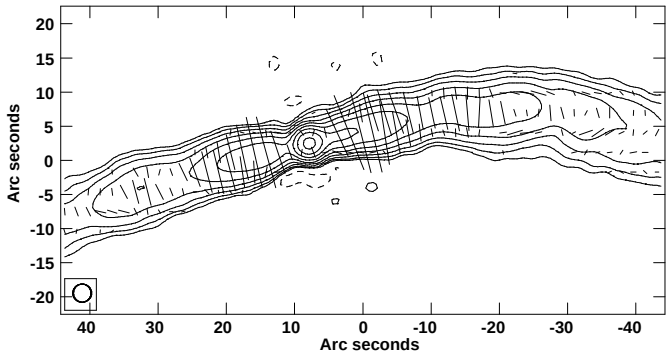

Fig. 5. Stokes I contours with superposed polarization "B" vectors of the inner jet in the FR I galaxy, 2MASXJ23175633-4213335 at z=0.056. Contours are Stokes I with levels powers of 2 times 30 $\mu Jy\ bm^{-1}$. Polarization "B" vectors indicate the orientation of the dominant magnetic field in the emitting region. The restoring beam size is shown in the box in the lower left corner.

The previous tests only used direction independent gain calibration and antenna pointing errors are expected to produce direction dependent gain errors. This possibility was tested using Peeling to derive the gain corrections in the directions of the core of the Corkscrew and NGC 7582, the edge on spiral in the lower right of Figure 1. These resulted in the image shown in Figure 4 which greatly reduces the extent and level of artifacts; the largest negative is -20 $\mu Jy\ bm^{-1}$. This is consistent with DDEs caused by antenna mispointing but does not prove it. However, there are known to be problems in the antenna pointing. A simple polarization imaging test does not reveal any problems with the polarimetry.

References

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