Solar interference on short baselines in the UHF band

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CAM	Control and Monitoring
SKA	Square Kilometer Array

1 Introduction

Inspection of two UHF (544 to 1088 MHz) datasets taken on MeerKAT calibrators showed amplitude and phase ripples a few times stronger than those due to the structure in the field, which are due to the Sun. These ripples were present when the Sun was low in elevation, and disappeared at sunset. Further analysis shows that only those baselines which are aligned towards the setting Sun are affected, much like another famous prehistoric observatory in England. Based on reasonable thresholds, we can identify these baselines with those whose effective projection length towards the Sun correspond to a fringe spacing larger than the size of the radio Sun (and being more important for lower frequencies). This implies that a identification of such baselines and flagging them before calibration would be adequate. A field-subtracted dataset is currently being computed in order to arrive at a robust flagging scheme.

2 Datasets used

Table 1: Data sets

	Dataset 1	Dataset 2
CB ID	1583247661	1569150359
Date	3 March 2020	22 Sept 2019
Duration	17:01 to 25:12 SAST	13:05 to 28:27 SAST
Band	UHF, 32K channels	UHF, 4K channels
Source used	Long track on J0408	Long track on J1939

3 Analysis

The data were converted to Measurement Sets and analysed in CASA. Many of the short baselines exhibit strong ripples in amplitude and phase as a function of time during the first part of the observation, and is more pronounced for lower end of the band. Some examples are given below.

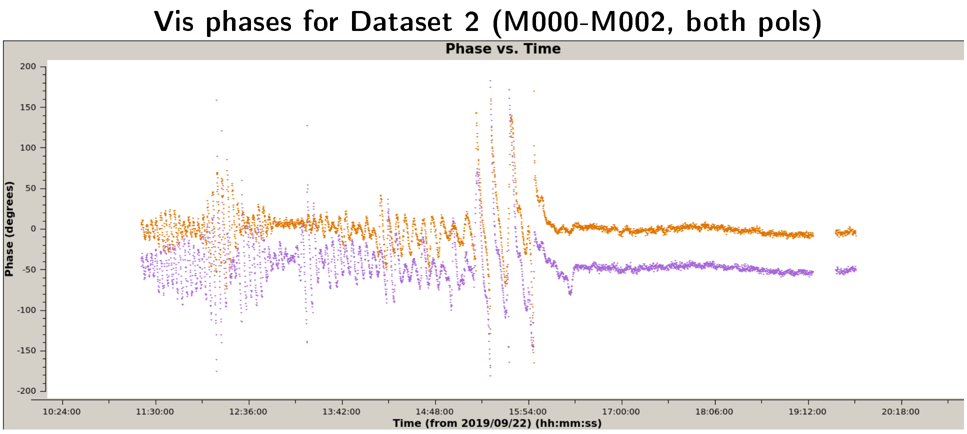

Figure 1: Visibility phase of M000-M002 for Dataset 2

The ripples end abruptly at some point for both datasets. The ripples that follow, with much less amplitude, are due to structure in the field.

Vis phases for Dataset 1 (channel number vs dumps)

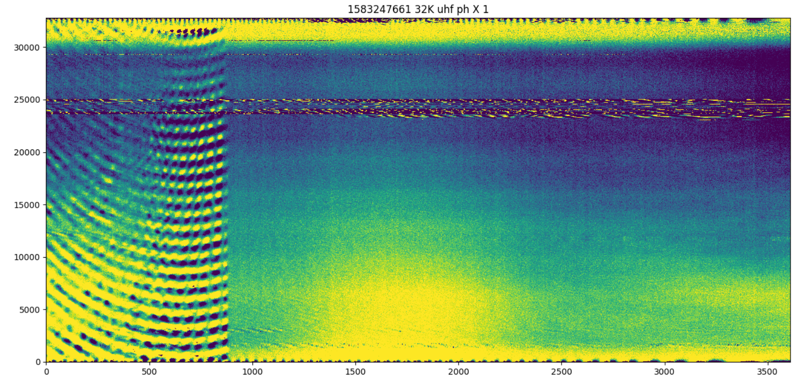

Figure 2: Visibility phase of M000-M001 of X pol

This time when the ripples disappear corresponds exactly to sunset. In figure 3, we plot the RMS of the ripples over a set of initial channels, as a function of time, only for the baselines which are dominated by these ripples. Note the time of sunset.

RMS of phases over initial channels as a function of time for affected baselines

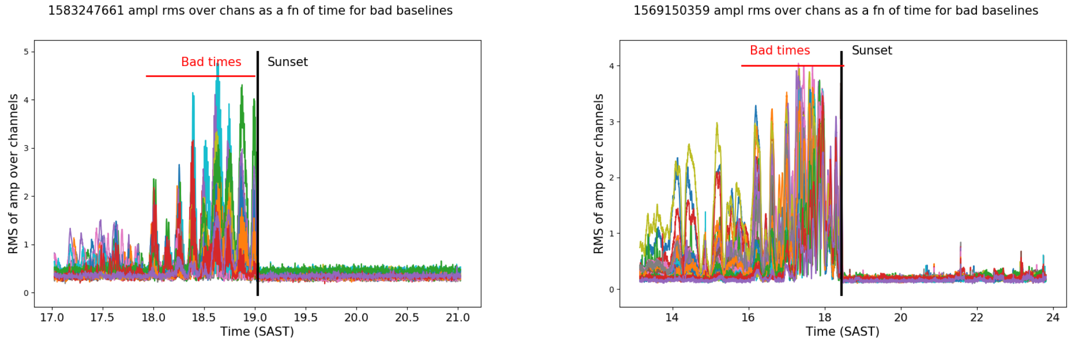

Figure 3: RMS of vis phases versus time for affected baselines for Datasets 1 and 2

Examples of the ripples are shown in figure 4, where we plot the vis phases of X pol for Dataset 1 for the worst 25 baselines where blue corresponds to a time range before sunset, and orange to a time range after sunset. Plots for both datasets for the affected time ranges are similar. Bad baselines are identified as those with a large RMS over the time when the Sun is above the horizon, taken at some fiducial channel in the initial part of the band.

Table 2: Locations of the target and Sun

	Dataset 1	**Dataset 2**
CB ID	1583247661	1569150359
Target	J0408-65	J1939-63
Sun	2258-01	1156+00
Separation	79 deg	101 deg

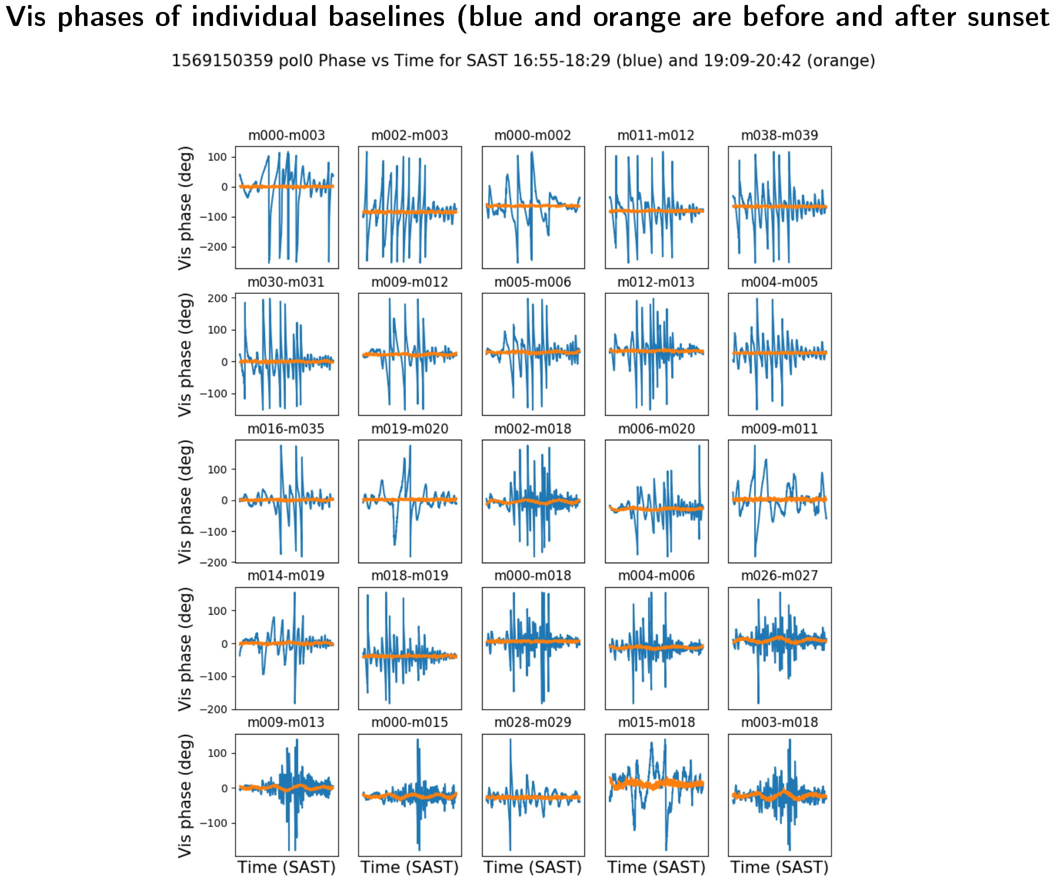

Figure 4: Visibility phases of individual affected baselines in Dataset 1

4 Affected baselines in the uv-plane

In figures 5 and 6, we plot the affected baselines on the uv-map (note, these uv are in units of metres) for the two datasets. Clearly, MeerKAT is a good stonehenge since observatories have to be backwards compatible!

In the two figures below, only X pol is shown, and the plots for Y pol are similar. The top panel corresponds to the time range when the Sun is above the horizon and the bottom panel corresponds to the time range after the Sun has set. The affected baselines are marked in orange and the unaffected baselines are marked in blue. The left panels shows all the uv points (for the middle of the time range) and the middle panekl is a zoomed in version, where the entire uv-track is shown, with the mid point marked with a symbol.

The right panel shows the RMS as a function of the initial baselines. This RMS is of the phases over the correspondingtime ranges for each baseline index. These phases are first made median zero, adjusted for phase wraps and detrended by fitting a 4th order polynomial over the entire time range under consideration.

The line of orange dots point towards the Sun. A further zoomed in version is shown in figure 7 for dataset 1 On the right is a plot of histogram of the position angles of the bad baselines (marked in red on the left). The thick black line is the range of PA of the Sun till it sets.

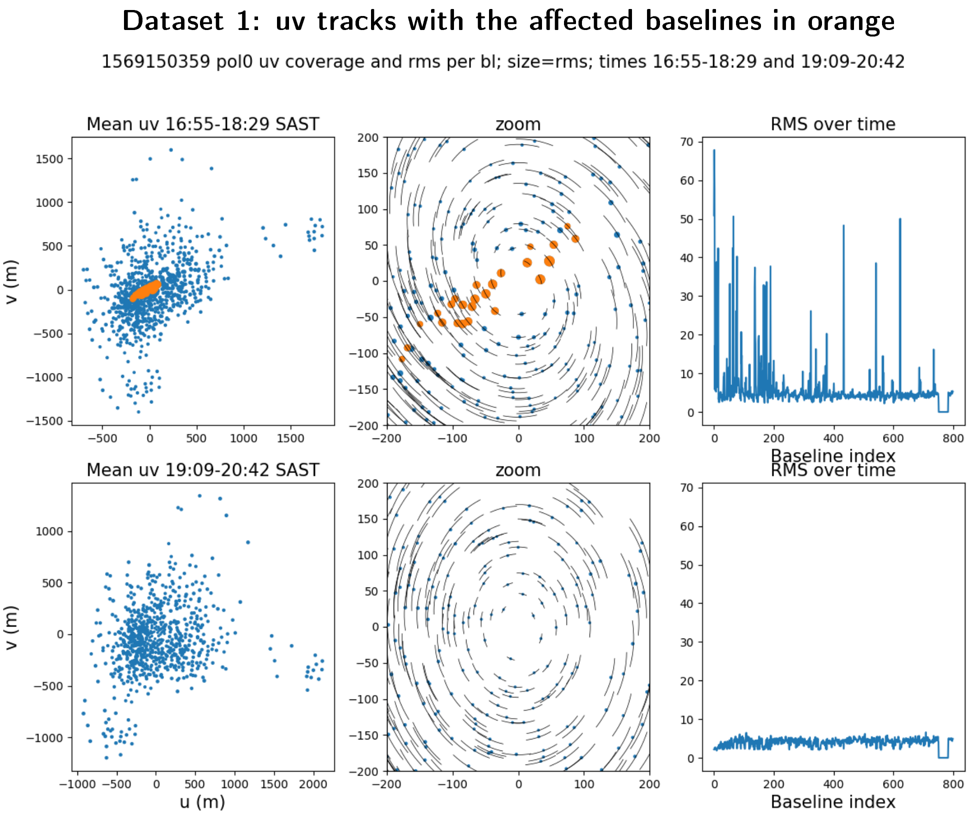

Figure 5: uv-tracks showing the affected baselines lining up towards the Sun for dataset 1

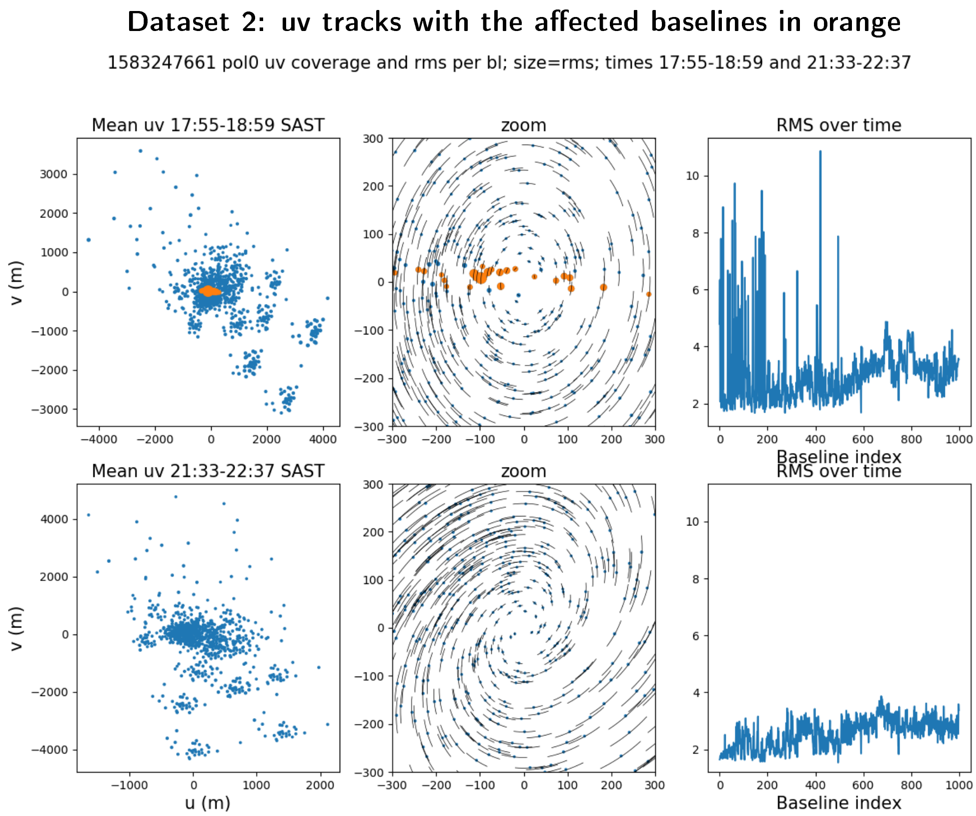

Figure 6: uv-tracks showing the affected baselines lining up towards the Sun for dataset 2

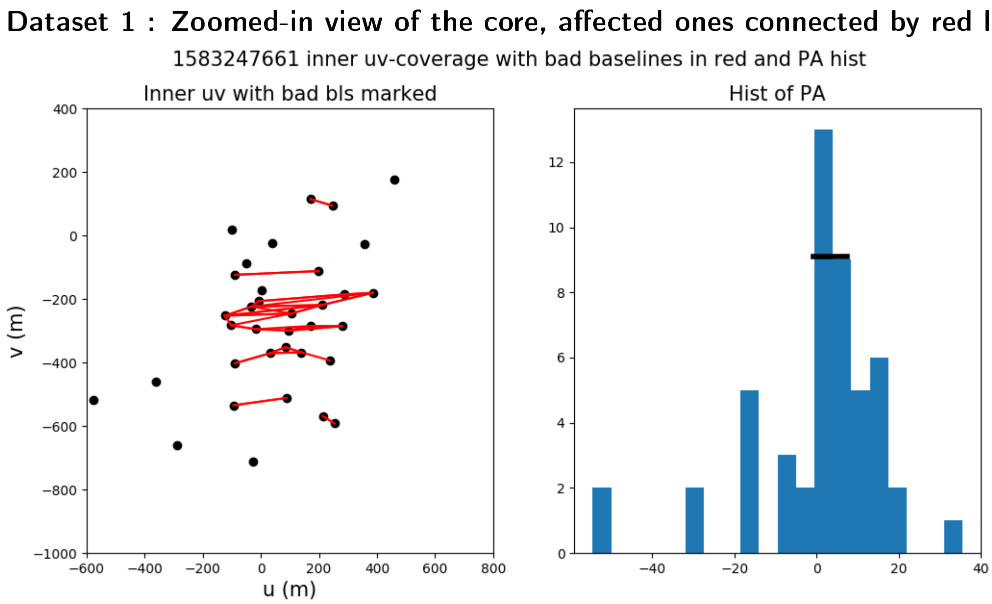

Figure 7: Inner core with affected baselines and histogram of their position angles

5 Identifying the affected baselines

Hence, we need to either

- Identify and flag affected baselines for all UHF observations when the Sun is rising or setting, especially for the lower part of the band or
- Model the Sun and subtract it, which is much more painful.

We can identify the affected baselines reasonably easily. Plotted below are the zoomed-in uv-coverage of the baselines computed towards the Sun, with each point marking the value for the mid point of the time range before sunset. The colours are proportional to the rms of the phases as described earlier (increasing from blue to red). The circle marks the first null of the *jinc* function corrrsponding to 1.3 times the solar diameter (appropriate at this frequency - 645 MHz). We can see, as expected, that those baselines pointing towards the Sun, which would have the minimum baseline length projected towards the Sun near sunset, are the ones affected. The ones with shorter spacings in this projection are also more affected. That the plotted positions are those of the mid point of the time range explains why the colours do not seem to b radially decreasing from the exact centre. Comparing with the fourier transform of the Sun, it is clear that flagging all baselines whose fringe spacing is larger than about the optical solar diameter should be sufficient.

uv coverage towards the Sun, colour is rms, circle is 1.3 visible Sun

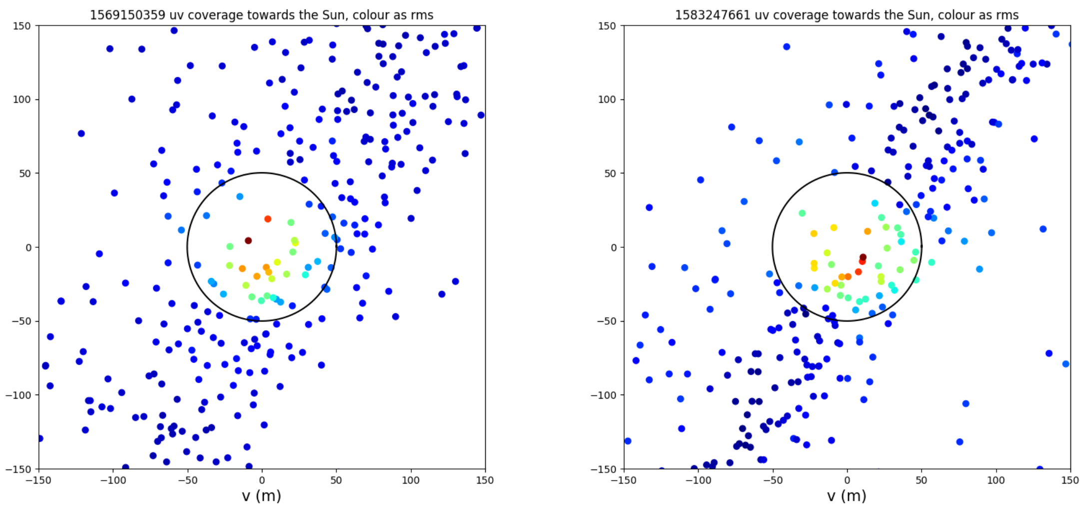

Figure 8: uv-coverage towards the Sun, showing the rms per baseline

6 Future work

- Determine the baselines affected, and for how long before sunset (or after sunrise) robustly. Work is ongoing to image the calibrator field after sunset, subtract from daytime observation and examine residuals for this purpose.
- Use the result above to determine a heuristic to automatically identify affected baselines for a given date and time (based on the declination of the Sun and time of observations) for flagging.
- If the effect of the Sun can be seen for longer than 2-3 hours before sunset (or after sunrise), then make new observation covering a full track of the Sun