Identifying and filtering RFI based on its polarised nature

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Abstract

The experience in the GMRT EoR experiment has been that RFI sources tend to be strongly polarised. One could therefore consider schemes in which the data is separated into an unpolarised part and a fully polarised part. This is worked out analytically for a single dish and numerically for more baselines in this note, which summarises the current state (Sept 2009) of ongoing discussions with Ue-Li Pen.

1 Introduction

RFI sources studied in the GMRT EoR experiment, and hence presumably at 150 MHz at GMRT in general, tend to be very strongly polarised, whereas the astronomical signal is nearly unpolarised. One very simple flagging scheme which has been tried is to delete data sets which show a large difference between RR and LL visibilities. This may miss cases when the RFI is linearly polarised at the feed. When the RFI is not too strong, one could also consider, as an alternative to flagging, a separation of the data into the sum of a fully polarised part and an unpolarised part, the latter representing the astronomical signal. We first illustrate this in the simplest possible case - a single dish with a dual polarisation feed used in the full Stokes mode. The data for a single spectral channel after a short integration (long enough to get decent signal to noise, but not so long that the RFI source has varied) will then be a 2x2 correlation matrix M, between the two feed voltages. This is to be decomposed into a sum $\alpha I + P$, where the first term is the unpolarised astronomical signal and the second the fully polarised RFI emission. P is of rank one, being of the form $I_P v v^\dagger$ where v is a complex unit column vector containing the two fully coherent (by assumption of non-variation in the integration time) components of the RFI electric field. I_P is the polarised intensity. Rank one implies $\det(P) = 0$. This statement is equivalent to the more familiar one that for a fully polarised source, $I_P^2 - Q^2 - V^2 - U^2 = 0$.

Since $\det(P) = \det(M - \alpha I = 0$, this means that to find α, all that we have to do is to get the eignevalues of the matrix M. It can be shown that only one of the two solutions gives positive intensity I_P of the polarised source and that is the solution which we want since the intensity is positive. To give a numerical example, we can decompose the matrix

$$\begin{bmatrix} 1 & 0.5 \\ 0.5 & 1 \end{bmatrix}$$

either as

$$\begin{bmatrix} 0.5 & 0 \\ 0 & 0.5 \end{bmatrix} + \begin{bmatrix} 0.5 & 0.5 \\ 0.5 & 0.5 \end{bmatrix}$$

or as

$$\begin{bmatrix} 1.5 & 0 \\ 0 & 1.5 \end{bmatrix} + \begin{bmatrix} -0.5 & 0.5 \\ 0.5 & -0.5 \end{bmatrix}$$

While the second matrix in both the decompositions above is of rank one, it corresponds to a polarised souce of negative intensity when we use the eignevalue 1.5, as can be seen by taking its trace.

2 Multiantenna case

We now look at the more interesting case, possibly relevant the the GMRT central square, where we have many antennas, say a in number, all looking at the same set of r RFI sources, each one of which is perfectly, but of course differently polarised. In this case, there does not seem to be a simple way to proceed analytically, except to count equations and unknowns. The data now consists of $4a(a-1)/2$ Stokes visibilities between the a antennas - notice we have not included the self terms, i.e products of feeds on the same antenna with themselves or each other, in this since these are more sensitive to systematic errors. Notice also we are counting complex degrees of freedom, each equal to two real degrees of freedom. The model has $a(a-1)/2$ astronomical visibilities, but also $r(4a-1)$ real parameters describing the coupling of the r RFI sources to the a antennas. This results from thinking of two complex voltages reaching the two feeds of a given antenna from a given source, giving $4ar$ real parameters, but also removing one overall phase per source which does not enter into measured correlations. Notionally, these are $r(4a-1)/2$ complex parameters. Clearly, there is an upper limit to r, the number of RFI sources which can be solved for with a given number of antennas, and this is given by

$$r_{max} = 3a(a-1)/(4a-1)$$

. This is not wildly exciting - it allows only one source to be removed for three antennas, and two from four, but it is better than nothing. For one baseline, i.e just two antennas, it seems to allow only six seventh of a source. The reader with a taste for the arcane (others may not have got this far) may enjoy working out that this case has an additional symmetry which disappears for $a \geq 3$. viz. we can scale up the RFI in one antenna and down in the other without affecting the measurements. This provides the extra one seventh and allows one source to be removed from one baseline as well.

3 Numerics

Going slightly beyond the above counting exercise, a small simulation was carried out, for a case with five antennas and three RFI sources, which ought to work. The iterative scheme was to take an SVD of the full data, and use the top three singular values as an estimate of the RFI contribution to the visibilities, and subract from the total. If the rest were unpolarised, the required decomposition has been achieved - in practice, the estimate is not unpolarised, so its diagonal components were made equal by averaging and the off diagonal components forced to zero. This was now subtracted from the full visibility to get the input for the next round of SVD. for the polarised component. This iteration scheme assumes that the RFI is strong, but an alternative iteration based on the opposite assumption was also constructed. In either case, the result was that the schemes did converge to the input, indicating that the above counting argument was not misleading or flawed. The actual algorithm turned out to be far too slow to to have practical utility, clearly, if the method is worth implementing, a better scheme is needed.

4 Caveats

. Any RFI removal scheme assumes a model for the source, and this one assumes full coherence between the two polarisations -we can call this the 'single mode' or 'rank one' condition. Fluctuations in the strength of the source do not affect this, but any fluctuation within the averaging time (which cannot be too short) which affects the relative amplitude and phase of the signals in the two feeds will violate the basic assumption. For example if the RFI enters through far sidelobes of the main dish (s distinct from spillover from the feed), this can occur as the antenna rotates by more than a beamwidth.

The other caveat to keep in mind is the condition on reasonable signal to noise. Clearly, one would not want to introduce more variance in removing RFI than was caused by the RFI itself. The standard formal mechanism for implementing this is the Wiener filter, so the above derivation would have to be 'Wienerised' in order to be practical - but this requies at least crude estimates of the statistics of the RFI and the astronomical source. This is left as an elementary exercise to the reader.