VLA Test Memo 236

How close to the Sun should we observe with the VLA?

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Introduction

VLA users often ask what the effect of observing close to the Sun will be in their data. *jobserve* spits out warnings if within 10° of the Sun, and users have difficulty interpreting what this means. This note gives a quick summary of the effects, and crude guidelines on what warnings should be provided to users.

Overview

The solar wind is a turbulent plasma and as such modifies radio waves as they propagate through it. The main effect of interest to VLA observers is the random fluctuation in the interferometer phase. There is a long history of study of this phenomenon (see, e.g., Spangler & Sakurai 1995; Armstrong et al. 1990; among many others). The expected magnitude of the phase fluctuation can be calculated, given observing parameters.

Expected Phase Fluctuation

Taking the equations and results from Spangler & Sakurai (1995) and Armstrong et al. (1990), write the structure function of the phase as:

$$D_\phi = \alpha \; \lambda^2 \; B^\beta \; R_o^\gamma \quad , \tag{1}$$

where α is a proportionality constant, λ is the wavelength, B is the baseline length, R_o is the distance from the Sun, and β and γ are derived observationally. Armstrong et al. (1990) derive $\beta \sim 0.57$, and Spangler & Sakurai (1995) derive $\alpha \sim -2.7$. The structure function is the square of the phase fluctuations:

$$\phi = \alpha' \; \lambda \; B^{\beta/2} \; R_o^{\gamma/2} \quad , \tag{2}$$

To find the proportionality constant, take results from the above referenced papers. Armstrong et al. (1990) give $D_\phi \sim 1$ rad^2 for $R_o \sim 7.6$ solar radii, $B = 10$ km, $\lambda = 20$ cm. This would give $\alpha' = 0.44$. Spangler & Sakurai (1995) give $D_\phi \sim 15$ rad^2 for $R_o \sim 10$ solar radii, $B = 500$ km, $\lambda = 12.6$ cm. This would give $\alpha' = 1.3$. These are obtained using the wavelength in cm, the baseline in km, and the distance from the Sun in solar radii. Take the average of these two, giving $\alpha' = 0.86$.

Now, for convenience convert from radians of phase error to degrees, and from solar radii to degrees from the sun:

$$\phi_{\rm deg} \sim 7\ \lambda_{\rm cm}\ B_{\rm km}^{0.29}\ R_{\rm deg}^{-1.4} \quad . \tag{3}$$

Inverting this gives the distance from the Sun which yields a given phase error:

$$R_{\rm deg} \sim \left(\frac{7\ \lambda_{\rm cm}\ B_{\rm km}^{0.29}}{\phi_{\rm deg}}\right)^{0.71} \quad . \tag{4}$$

Results and Discussion

Assume that a fluctuation of 10° on the longest baseline can be tolerated, then it is possible to calculate the distance from the Sun at which this occurs for all VLA bands in all configurations. However, at very close distances, there are two additional effects which can start to become significant: there may be correlated signal from the Sun which is strong enough to corrupt the visibilities (which is worse for lower frequencies and the smaller configurations); and the Sun will start to contribute to elevated system temperatures. Note also that solar conditions will affect the calculated distance, since the total amount of plasma in the solar wind will vary with solar activity. The results of Spangler & Sakurai (1995) were obtained from data taken in 1991 - near solar maximum. The results of Armstrong *et al.* (1990) were obtained from data taken in 1983 and 1985 - near solar minimum (of course this is why α' differs for the two). By using the average, the effect at solar maximum has been underestimated (the distances would be larger by about 30%) and the effect at solar minimum has been overestimated (the distances would be smaller by about 40%). Because of these other effects, distances less than $\sim 3°$ should always cause concern. Table 1 shows the calculated distance for the VLA bands (at wavelengths shorter than P-band - for P- and 4-bands there are many other considerations which factor into the discussion) and configurations, substituting 3° if that distance is less than 3°.

A more complete analysis would balance the phase error from this effect with that from the atmosphere and from the VLA electronics.

One final note - users are also often confused about warnings about being close to the planets (and the Moon). These warnings should be ignored unless the planet (or the Moon) is extremely close - certainly anything further than 1° should present no problems (the Moon is potentially still a nuisance out to slightly larger distances [a few degrees] at L- and P-bands, at 4-band it is cooler than the background anyway).

Table 1: Minimum distance from the Sun for 10° phase errors at the VLA

		R_{deg}			
Band	λ_{cm}	A	B	C	D
Q	0.7	3	3	3	3
K	1.3	3	3	3	3
U	2.0	3	3	3	3
X	3.5	4	3	3	3
C	6.2	6	5	4	3
L	21	14	11	8	7

References

Spangler, S.R., & T. Sakurai 1995, ApJ, 445, 999

Armstrong, J.W., W.A. Coles, M. Kojima, & B.J. Rickett 1990, AJ, 358, 685