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Radio Synthesis Imaging of Scatter-broadening at Small Solar Elongations

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Abstract. When the lines of sight to distant radio sources pass close to the Sun, the radiation from the source undergoes scattering due to electron density irregularities in the outflowing solar wind plasma and phenomenon such as intensity scintillations and angular broadening can be observed. At small solar elongations ($\varepsilon < 4°$) the scattering is sufficiently strong that the scatter broadened image can be resolved using radio synthesis arrays such as the VLA[1]. The measured visibilities and the reconstructed image can be used to study the turbulence spectrum and anisotropy in the solar wind. We present here some results of observations of three strong radio sources at several elongations in the range 0.5°–4° using the A-configuration of the VLA (maximum baseline 35 km) at wavelengths of 2, 3.5, 6, and 20 cm.

Key words: Solar wind—synthesis imaging.

1. Observations and results

The radio sources 1430–155, 1437–153, and 1443–162 were observed during 2–6 Nov. 1988 when their lines of sight passed within about 4° of the Sun. Because of the steep gradient in the mean electron density of the solar wind ($n_e \sim R^{-2}$ or steeper at smaller solar distance), shorter wavelength (2 and 3.5 cm) observations were more suitable at small elongations and longer wavelengths (6 and 20 cm) at larger elongations.

Each source was observed at the chosen wavelength for about 10 minutes with an integration time of 10 seconds per visibility sample. The resulting visibility data were processed using the standard method to obtain 'clean' images of the sources observed at different elongations. Most of the images, where broadening could be seen, are elliptical in shape indicating anisotropic scattering in the solar wind and confirms the earlier findings of Armstrong *et al.* (1990). The axial ratio of the images varies between 1.5 – 7 depending on the elongation. Fig. 1 depicts the anisotropy and the orientation of the images observed at a wavelength of 6 cm. The magnitude of the broadening is generally larger at smaller elongations, although there are several exceptions. The variation of the scattering angle (i.e. the angular size of the major axis of the image) as a function of solar distance roughly follows a $R^{-1.6}$ law.

[1] VLA is part of NRAO, USA, operated by Associated Univ. Inc., under a cooperative agreement with NSF.

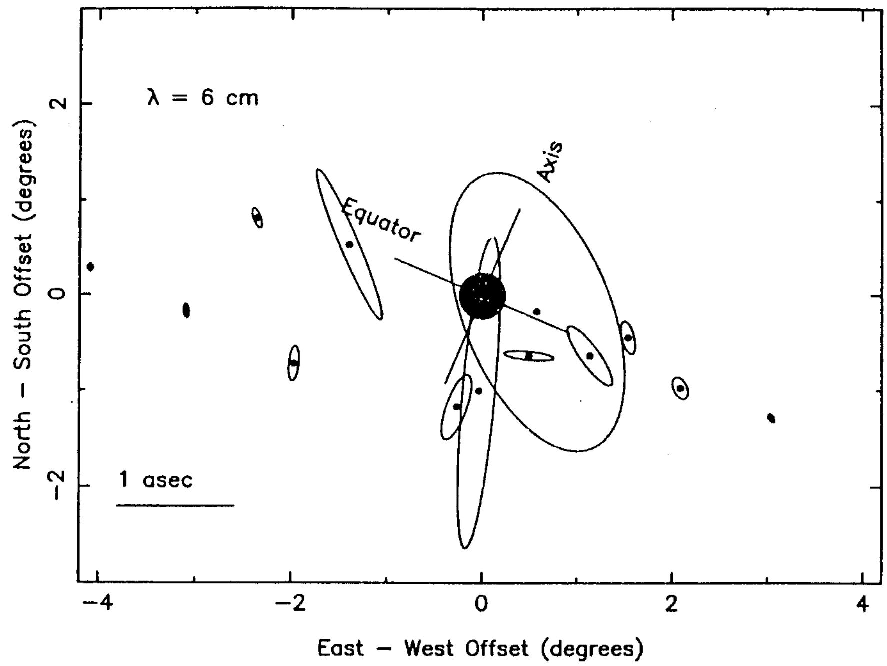

Figure 1. Shapes of scatter broadened images (ellipses) at different distances from the Sun (filled 0.5° circle at the centre). The scale for the images is indicated at the bottom left corner.

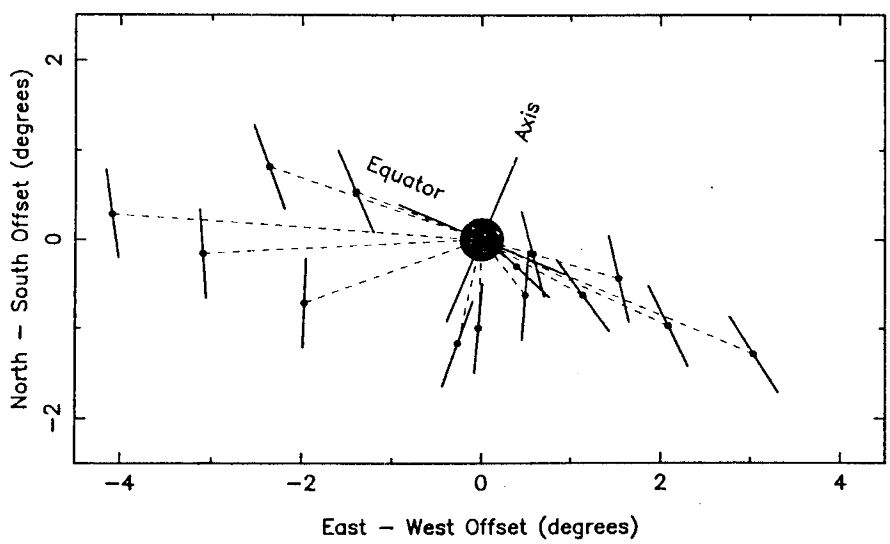

Figure 2. Orientation of the major axes (solid lines) of scatter broadened images with respect to the radial direction (dashed lines) from the Sun.

The anisotropy indicates that the scattering blobs are elongated in the direction perpendicular to the major axis of the image. This direction can be considered as the 'local' orientation of the magnetic field lines since density fluctuations are expected to be aligned along the field lines (Higdon 1984). Fig. 2 shows the observed orientation of the major axis at different elongations and position angles. Clearly, the orientation is not perpendicular to the radial everywhere. The deviations are seen to be the largest near the poles, which also suggest that magnetic field lines may indeed determine the direction of elongation of the scattering blobs.

The measured visibility $V(b)$, on a baseline b is related to the phase structure function $D(b)$ of the scattering screen by the simple relation $D(b) = -2\ln[V(b)]$. For a power-law spectrum of density fluctuations of the form $P(q) \propto q^{-\beta}$, where q is the spatial wavenumber, the phase structure function has the form $D(b) \propto b^{\beta-2}$. Through model fits to the measured visibilities we find that β is in the range 1.8 to 3.0 depending on solar distance, with a median value of ~ 2.0. This applies to scale lengths in the range 1–35 km sampled by the VLA baselines. The spectrum in this range appears to be shallower compared to Kolmogorov turbulence ($\beta = 11/3$) in agreement with earlier findings of Coles & Harmon (1989).

References

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