Radio Interferometry: Theory, Techniques and Applications, IAU Coll. 131, ASP Conference Series, Vol. 19, 1991, T.J. Cornwell and R.A. Perley (eds.)

SPECKLES IN INTERSTELLAR RADIO-WAVE SCATTERING

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ABSTRACT Observations of speckles in the scattering disk of the Vela pulsar are presented and speckle techniques for studying and circumventing scattering of radio waves by the turbulent interstellar plasma are discussed. The speckle pattern contains, in a hologrammatic fashion, complete information on the structure of the radio source as well as the distribution of the scattering material. Speckle observations of interstellar scattering of radio waves are difficult because of their characteristically short timescales (≈seconds) and narrow bandwidths (≈kHz). Here, we present first observations, taken at 13 cm wavelength with elements of the SHEVE VLBI network, of speckles in interstellar scattering.

INTRODUCTION

Interference among ray paths in scattering can produce speckles. Density variations in the turbulent interstellar plasma "wrinkle" phase fronts of radio waves emitted from radio sources, so that they are scattered over a range of propagation directions, and arrive at an observer from a range of angles. Different rays follow paths of different lengths, so that they cancel or reinforce randomly at the observer. This results in varying phases and amplitudes as the line of sight moves through the scattering material.

Over a period of time and a range of frequencies, the angle of arrival of the phase fronts will vary over some range; the image on the sky so defined is known as the scattering disk. However, at any instant, only rays from a few directions may be observed, so that the image appears to consist of speckles. Averaged over time and frequency, these speckles will fill out the scattering disk.

Observations of speckles with an interferometer should show variations both in signal strength, as the interfering rays cancel or reinforce, and in phase, as the centroid of the image moves across the sky. Traditional single-dish observations of the scintillation of pulsars with time and frequency show related amplitude variations. Single-dish observations cannot show phase variations or, equivalently, the small position variations due to shift in the centroid of the instantaneous scattered image.

In interstellar scattering, the time and frequency scales for speckles are expected to be small. As an example we consider our observations of the Vela pulsar at a frequency of 2290 MHz. Single-dish observations show that the time scale of scintillations is about 12 seconds and their frequency scale is about 60 kHz. From the frequency scale and the estimated distance to the pulsar (500 pc), we can estimate a scattering disk diameter of $\approx$ 3.5 milliarcseconds (mas). The phase variations due to this position shift are $\approx$ 60 degrees (FWHM) on the Tidbinbilla-Hobart baseline and over 360 degrees (FWHM) on the Tidbinbilla-Hartebeesthoek baseline. This phase variation is in addition to that due to the finite signal-to-noise ratio.

OBSERVATIONAL PARAMETERS

Observations were made on 1 December 1989 with a subset of the Southern HEmisphere VEry long baseline interferometry (SHEVE) Network. Antennas included Tidbinbilla (34-m), Hobart (15-m), Culgoora (25-m), and Hartebeesthoek (25-m). Using the Mark II system, we recorded a 2 MHz bandwidth from 2290 to 2292 MHz. We primarily observed the Vela pulsar (0833-45) and a number of comparison sources including the quasars OJ287 and 0826-373. The data were correlated using the Caltech Block II correlator operating in fringe search mode. The correlator yielded 224 lags of the cross-correlation function every 2 seconds.

DYNAMIC SPECTRA

Figures 1 and 2 show dynamic spectra of the Vela pulsar and the quasar 0826-373 . The amplitudes and absolute values of the phases (0 to π) of their cross correlation functions are plotted on a linear greyscale versus time and frequency. Amplitude plots show zero amplitude as lightest and maximum amplitude (39.9 for Vela and 48.4 for the quasar) as darkest. Phase plots show 0 phase lightest and and π phase darkest. The best fitting phase, fringe rate (linear slope of phase with time), and delay (linear slope of phase with frequency) have been removed from each data set. The data have also been smoothed using a boxcar with dimensions 10 sec $\times$ 89 kHz. The residual phase variations seen in the quasar plots are due only to the finite SNR of the observation. For the Vela pulsar, speckles also contribute to the residual phase variations. Rolloff produces lower amplitudes and greater phase variations at the high-frequency band edge in both plots. The correlation amplitude is also low for the first ≈40 sec in the quasar plot because one antenna was still off source.

SUMMARY

Using long baselines, we are able to resolve speckles in the scattering disk of the Vela pulsar. Currently our analyses are limited by low SNR. Further observations are scheduled which should allow detailed statistical characterisation of the speckle effect. As VLBI baselines extend into space, angular accuracy will be diffraction-limited by scattering effects of the interstellar medium. Closure phase and self-calibration, for individual speckle elements, can remove these effects. This parallels the techniques presently used to compensate for atmospheric scattering effects.

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https://doi.org/10.1017/S0252921100013385 Published online by Cambridge University Press

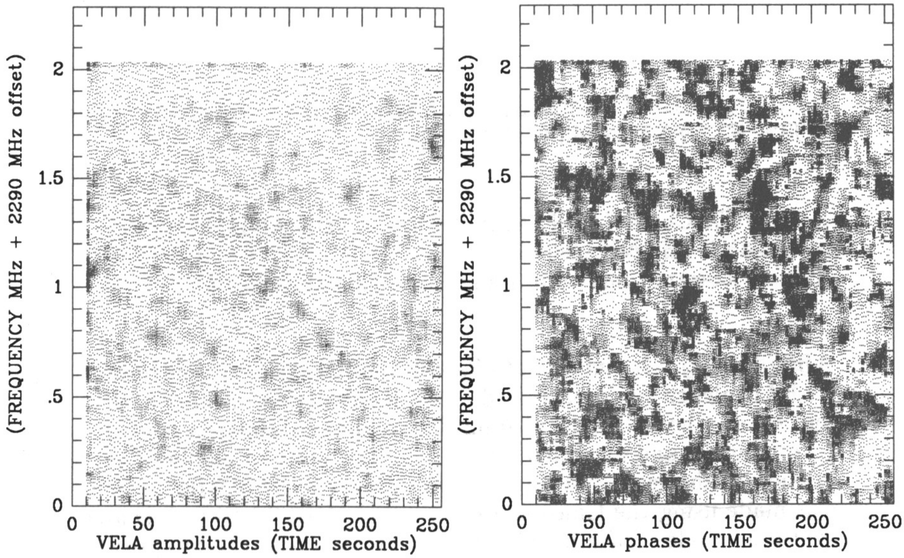

Fig. 1. Correlation amplitude and absolute value of correlation phase for the Vela pulsar. Data were collected on 335 1989 at 1530 UT on the Tidbinbilla-Hobart baseline. Data have been boxcar smoothed and represented by a linear greyscale as described in the text.

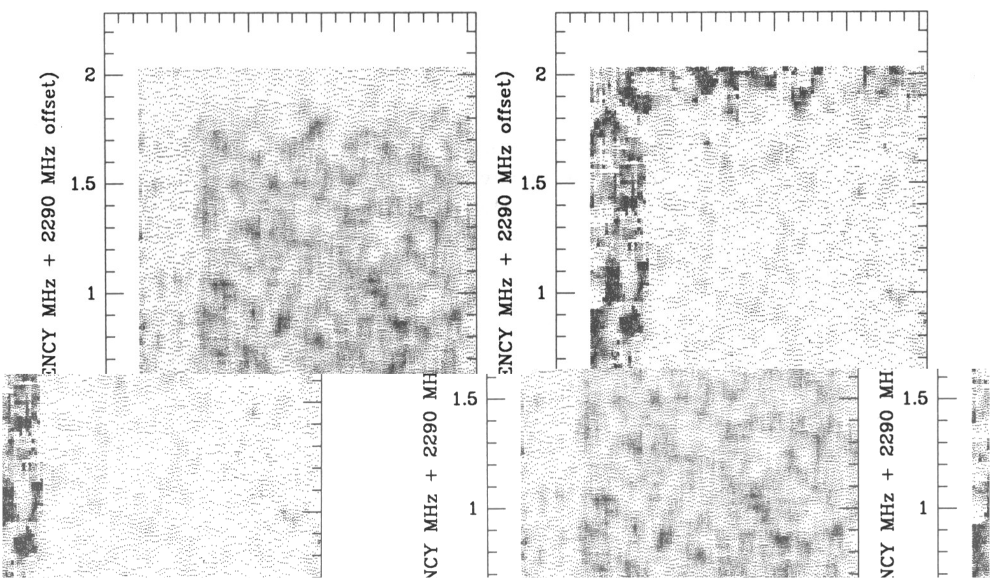

Fig 2. Correlation amplitude and absolute value of correlation phase for the quasar 0826-373. Data were collected on 335 1989 at 1200 UT on the Tidbinbilla-Hobart baseline. Data have been boxcar smoothed and represented by a linear greyscale as described in the text.

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