EXTREME SCATTERING EVENTS: AN OBSERVATIONAL SUMMARY

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Abstract. We review observational constraints on the structures responsible for extreme scattering events, focussing on a series of observations of the quasar PKS 1741–038. VLA observations were conducted to search for changes in the rotation measure and HI absorption during the ESE, while VLBI observations sought ESE-induced changes in the source's image. No RM changes were found implying $B_\parallel < 12$ mG, and no HI opacity changes were found implying $N(\text{HI}) < 6.4 \times 10^{17}$ cm^{-2}. No multiple imaging was observed, but the diameter of the source *increased* by 0.7 mas, contrary to what is predicted by simple refractive lens modeling of ESEs. We summarize what these limits imply about the structure responsible for this ESE.

1. Introduction

Extreme scattering events (ESE) are a class of dramatic decreases $\gtrsim 50\%$) in the flux density of radio sources near 1 GHz for several weeks bracketed by substantial increases (Fiedler *et al.*, 1994; Figure 1). Because of their simultaneity at different wavelengths and light travel time arguments, ESEs are likely a propagation effect (Fiedler *et al.*, 1987). First identified toward extragalactic sources, ESEs have since been observed toward pulsars (Cognard *et al.*, 1993; Maitia *et al.*, 1998).

To date, the only other observational constraints on the structures responsible for ESEs – besides the light curves – are the lack of pulse broadening and the variation in the pulse times of arrival during the pulsar ESEs. This paper summarizes constraints obtained during the ESE toward the quasar 1741–038. We discuss Faraday rotation measurements by Clegg *et al.* (1996) in §2, VLBI imaging by Lazio *et al.* (2000a) in §3, and HI absorption measurements by Lazio *et al.* (2000b) in §4. We present our conclusions in §5. Figure 1 shows the ESE of 1741–038 with the epochs of the various observations indicated.

2. Faraday Rotation Measure Observations

At each epoch, the polarization position angle ϕ was measured at 6 to 10 frequencies and then fit, by minimizing χ^2 and accounting for $n\pi$ ambiguities, as
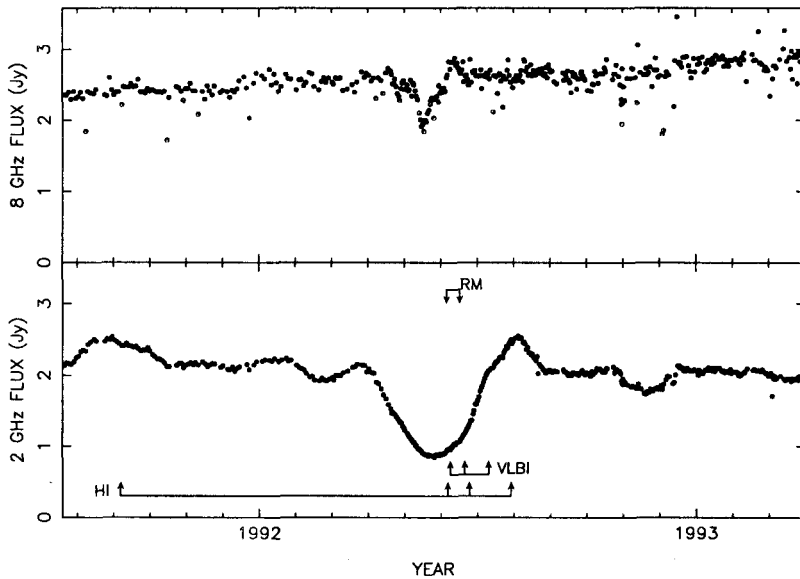
Figure 1. The light curves of 1741–038 at 2 and 8 GHz showing the extreme scattering event and the epochs of the various observations.

a function of the observing wavelength, λ^2. The same procedure was used for 1741–038 and for the parallactic angle calibrator 1725+044.

Based on the relative invariability of RM toward 1725+044 and 1741–038, Clegg *et al.* (1996) conclude $\Delta\text{RM} < 10.1$ rad m^{-2} during the ESE. This upper limit implies an upper limit on the mean magnetic field parallel to the line of sight of $B_\| < 12$ mG for a typical value of the free electron column density through the structure, $N_0 \sim 10^{-4}$ cm^{-3} (Clegg *et al.*, 1998).

This upper limit is much larger than the typical interstellar field strength but enhancement of the ambient field to $B \sim 1$ mG is possible within a shock front (Clegg *et al.*, 1988). Alternately, ΔRM may be small if the field is disordered or if the ionized region is not magnetized.

3. VLBI Imaging

Comparison of the visibility data from the ESE epochs to those obtained after the ESE (1994 July 8) show the source to be more resolved during the ESE. The excess angular broadening is $\Delta\theta_d \lesssim 0.7$ mas, implying that the ESE structure had a scattering measure $\text{SM}_{\text{ESE}} = 10^{-2.5}$ kpc m$^{-20/3}$. The pulse broadening of a background pulsar should be $\tau_d \leq 1.1 D_{\text{kpc}}$ μs at 1 GHz, consistent with the observed lack of broadening during pulsar ESEs (Cognard *et al.*, 1993; Maitia *et al.*, 1998). The refractive models commonly used to explain ESEs predict that the source's flux

density and angular diameter should be highly correlated. We observe an *anti-correlation*. Simple stochastic broadening models require much more scattering (2 mas) than is observed. We consider it likely that both refractive defocussing and stochastic broadening are occurring.

We were unable to test a key prediction of refractive models – angular position wander of the background source – because these observations had no absolute position information. A second prediction is multiple imaging. During this ESE, any secondary image(s) must have been extremely faint; multiple imaging, with the secondary image slightly offset from the primary, is unlikely to explain the increase in angular diameter because no other effects of strong refraction are seen (cf. Clegg *et al.*, 1998). We also observe little, if any, ESE-induced anisotropy in the VLBI images. If ESE lenses are filamentary structures (Romani *et al.*, 1987), they must be extended *along* the line of sight, a possibility also suggested by Lestrade *et al.* (1998).

4. HI Absorption

At all epochs the HI opacity spectra show the presence of a strong absorption feature near 5 km s^{-1} and a typical rms determined outside the HI line of $\sigma_\tau \approx 0.015$. There is no gross change in the absorption line during the ESE nor do any additional absorption components appear. Between any two epochs $\Delta\tau \leq 0.049$ ($< 2.3\sigma_\tau$). This upper limit implies a neutral column density change of $\Delta N_H < 6.4 \times 10^{17}$ cm^{-2} ($T_s/10$ K) for a structure with a spin temperature $T_s = 10$ K.

Heiles (1997) proposes interstellar tiny (AU)-scale atomic structures (TSAS) in order to explain small (angular) scale changes in HI opacity. TSAS would have $N_H \sim 3 \times 10^{18}$ cm^{-2} and $T_s \sim 15$ K. Our $\Delta\tau$ limit marginally excludes a connection between TSAS and ESEs.

Walker and Wardle (1998) propose AU-scale molecular clouds in the Galactic halo precisely to explain ESEs. The clouds would be cold, $T_s \gtrsim 3$ K, and dense enough to be opaque in the HI line. ESEs would result from the photoionized skins of the clouds. We see no $\tau \sim 1$ features (Walker, 2000, private communication, has since suggested $\tau \sim 0.1$). However, the clouds could have velocities approaching 500 km s^{-1}, while the observed velocity range is no more than 250 km s^{-1} – significant HI absorption could have been present outside of our velocity range.

5. Summary

Salient aspects of this observational program are
- ΔRM < 10.1 rad m^{-2} implying a magnetic field $B_\parallel < 12$ mG within the ESE structure.

– No change in the VLBI structure, except a 0.7 mas *increase* in the angular diameter. This increase is *not* consistent with that expected from a purely refractive model: ESEs must result from both broadening and defocussing within the ionized structures.

– $\Delta \tau_{HI} < 0.05$ implying that the HI column density associated with the ESE structure is $N_H < 6.4 \times 10^{17}$ cm^{-2}. Tiny-scale atomic structures are marginally ruled out; HI -opaque, halo molecular clouds would be excluded, but the observed velocity range covers only 25% of the allowed range.

The major impediment to improved observational constraints is the lack of a monitoring program that could find additional ESEs.

Acknowledgements

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