SHOCK-ASSOCIATED PLASMA DENSITY FLUCTUATIONS IN THE INTERSTELLAR MEDIUM

S R Spangler

Dept. of Physics & Astronomy, Univ. of Iowa, Iowa, USA

ABSTRACT

Theories of diffusive shock acceleration of the cosmic rays predict that there should be regions of intense Alfvén waves both upstream and downstream of the shock front. Observations of similar waves near solar system shock waves show that they produce substantial density fluctuations. Such density fluctuations might produce observable scattering of radio waves. We discuss observations which have searched for angular broadening or "blurring" of radio sources whose lines of sight pass close to or through supernova remnants. No definite cases of remnant-associated scattering have been detected. However, the source CL 4, which is viewed through the Cygnus Loop supernova remnant, may be such an object and merits further observation.

1. INTRODUCTION

One of the more interesting topics in plasma astrophysics is that of shock acceleration of charged particles. In "diffusive" shock acceleration (Ref. 1), charged particles reflect from a shock wave and generate magnetohydrodynamic waves. These waves in turn cause pitch-angle scattering of the particles, thus isotropizing and confining them to the vicinity of the shock where they can be repeatedly overtaken and accelerated. The excited hydromagnetic waves form the key ingredient to the operation of this mechanism. This theory has been given observational support by observations of shock waves in the solar system, which show reflected particles, the excited hydromagnetic waves, and ions accelerated to a few hundred kilovolts.

It is widely speculated that a magnified version of this process is responsible for production of the cosmic ray ions and electrons. The generative shocks in this case would be supernova remnants. If our speculations are correct, ahead of a supernova remnant there should be a foreshock with reflected ions and electrons, excited magnetohydrodynamic waves, and particles being accelerated to relativistic energies. It would be a tremendous success for these theories if observational evidence for this upstream wave layer, or the equally important downstream region of magnetic fluctuations, could be found.

At first, it would seem that any attempt to detect these waves would be doomed to failure. They should have wavelengths comparable to and somewhat larger than the ion inertial length, which for the interstellar medium is a few thousand kilometers, or perhaps smaller. The detection of objects of this size near a supernova remnant a kiloparsec away would appear nigh-on impossible.

The purpose of this talk is to discuss a technique which, in principal, is capable of detecting interstellar MHD waves. To the best of my knowledge, it is the only such technique, and relies on the measurement of radio wave scattering due to density fluctuations in the interstellar medium. Radio waves from objects such as pulsars and extragalactic radio sources at low galactic latitudes are observed to be distorted by a number of propagation effects. These distortions are interpreted as the result of propagation through an interstellar medium with random density fluctuations, which engender a random refractive index. The simplest such effect to interpret is angular broadening, or the "blurring" of a radio source viewed through the turbulent interstellar medium. This phenomenon is physically analogous to the blurred appearance of objects viewed through the turbulent exhaust of a jet engine.

How is this observational technique relevant to the question of shock acceleration of charged particles? Spacecraft observations of shock waves in the solar system reveal that large-amplitude density fluctuations accompany these magnetohydrodynamic waves (Ref. 2). Analyses indicate that the density fluctuations are due to (1) slightly oblique propagation with wave normal angles of a few degrees, and (2) ponderomotive effects. At any rate, the density perturbations are large, being about 15% or so of the mean plasma density. By analogy, we may assume that similar density fluctuations exist in front of supernova shock waves.

Having introduced the requisite background in space plasma physics and radio astronomy, we now present the idea of our experiment in Figure 1. We choose to observe extragalactic radio sources whose lines of sight pass close to the edge of a supernova remnant. There are also objects for which the line of sight passes through the post-shock region.

If the foreshock is sufficiently extensive so that the line of sight traverses a substantial distance through the foreshock, angular broadening of the source may be observable. I should mention that there is a host of observational astronomy questions which must be considered when trying

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to determine if the radio source is affected by interstellar scattering. We spend a good deal of time on these deliberations, but they are beyond the scope of this article.

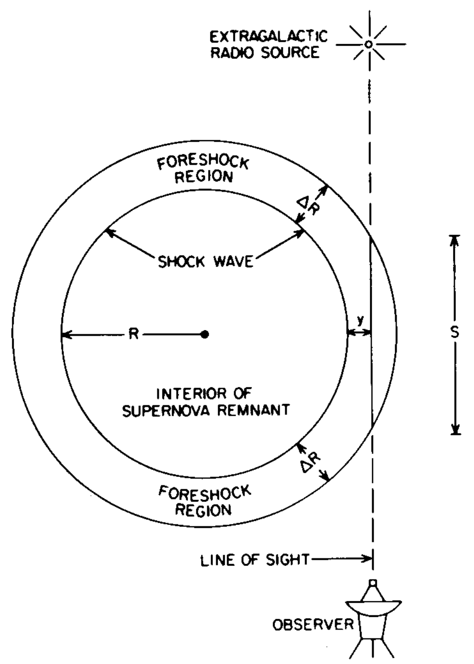

Figure 1. Illustration of how radioastronomical observations can be used to search for foreshocks of supernova remnants. We observe (with multifrequency VLBI) sources whose lines of sight pass close to supernova remnants. If the line of sight passes through a pre-shock region of enhanced turbulence, angular broadening or blurring of the source may be observed.

2. OBSERVATIONAL RESULTS

Since 1984, we have been carrying out VLBI observations of radio sources near supernova remnants, looking for enhanced scattering which might be attributable to MHD waves near the shocks. It should be mentioned that from the outset we realized that the probability of success was not high. Extensive, wave-dominated foreshocks will occur only at portions of the shock where the shock normal is parallel to the galactic magnetic field. For a given radio source, the line of sight may pass through a region where this condition is not satisfied. Alternatively, the density in the region into which a given shock is expanding may be too low to host detectable perturbations. There can easily be other agents for frustrating this experiment.

I will now proceed to discuss the results to date, which I would describe as mixed. In other words, we have not detected what I would describe as categorical or even strong evidence for MHD wave-associated turbulence. However, in spite of the relatively small number of lines of sight investigated, we already have a case which at the very least encourages us to continue these types of observations.

In Spangler et al (Ref. 3), we presented three frequency VLBI observations of five radio sources whose lines of sight pass close to supernova remnants. In four of the remnants the radio structure is shell-like, whereas one (the remnant G74.9+1.2) allegedly resembles the Crab Nebula. In each case, there is a juxtaposed radio source which can act as a probe of the interstellar medium in the vicinity of the remnant.

For three of the sources we were not able to detect interstellar scattering; only upper limits to the intensity of turbulence along the line of sight could be set. For two of the objects, scattering was detected. Our observations of 2013+370 were sufficiently detailed to allow a measurement of the spectrum of interstellar turbulence (Ref. 4). As we shall see shortly, the source is not particularly scattered for this part of the sky. The line of sight to the radio source 1849+005 is one of the most heavily scattered known; our measurement of a high degree of scattering is confirmed by the discovery by Clifton and Lyne of a highly scattered pulsar a few arcminutes from 1849+005. At the present time we are carrying out supplemental observations to see if the observed degree of scattering is abnormal for this part of the sky, and if the enhancement can be attributed to this supernova remnant.

For the remaining remnants, the upper limits are perhaps a little disappointing. For two of the sources (near the remnants CTA 1 and HB 21) the "impact parameters" were many parsecs, so the results are perhaps not surprising. For the source near the remnant HB 9, however, the upper limits were more interesting. Either the thickness of the SNR foreshock is less than about 3–4% of the remnant radius, or the foreshock turbulence does not have the properties we would have expected from studies of the Earth's foreshock.

In contrast to these ambiguous or disappointing results, an additional project has yielded an intriguing result. We have measured the scattering along the lines of sight to eleven sources in the constellation Cygnus (Ref. 5). The results are presented in graphical fashion in Figure 2. Here the

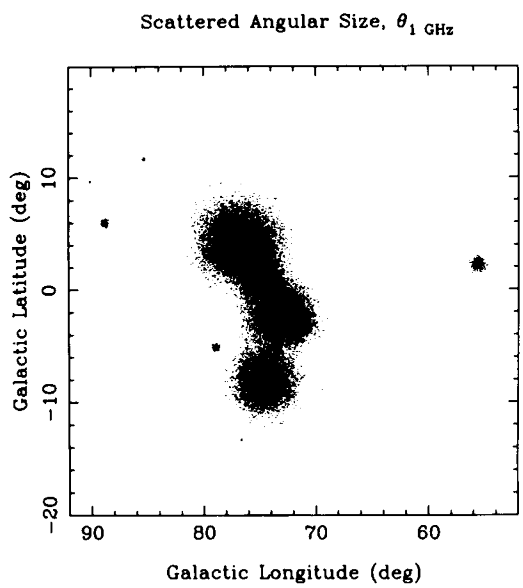

Figure 2. Graphical representation of interstellar scattering in the Cygnus region of the sky. The width of the blur is proportional to the scattering size at 1 GHz. The heavily scattered source at longitude 75° and latitude −8° is 2048+313.

size of the blurred image is proportional to the interstellar scattering size at 1 GHz.

We can see that the scattering of 2013+370 (at galactic coordinates $\ell_{II} = 74.9$, $b_{II} = 1.2$) is not conspicuously large for this part of the sky. The simplest description of this figure might be that strong scattering is restricted to within a couple of degrees of the galactic plane. What obviously prevents us from making such a statement is the highly scattered source 2048+313 (at galactic longitude 75°, latitude −8°), which is the second most heavily scattered source in our sample, despite its angular distance from the galactic plane. The other remarkable feature of this source is that it is viewed through the Cygnus Loop supernova remnant. Although future observations are necessary to confirm our notions, it is inviting to speculate that this enhanced scattering is due to foreshock or post-shock turbulence associated with this remnant.

3. EPITOME

Research projects in progress should clarify the role of supernova remnants in generating high levels of density turbulence. Such radioastronomy experiments hold the promise of valuable experimental input to theories of cosmic ray acceleration by supernova shock waves. Scattering measurements should be able to give the amplitude and spatial spectrum of density fluctuations both upstream and downstream of the shock front. A knowledge of the relationship between the magnetic field and the density perturbation in an MHD wave would then permit us to deduce the wave spectrum on both sides of the shock. Observational and theoretical research in space plasmas are progressing towards a good understanding of this relationship. Finally, knowledge of the shock velocity (known for many remnants) would complete the set of the principal parameters in the theory of shock acceleration.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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