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ARE SUPERNOVA REMNANTS QUASI-PARALLEL OR QUASI-PERPENDICULAR ACCELERATORS?

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ABSTRACT

Observations of shock waves in the solar system show a pronounced difference in the plasma wave and particle environment depending on whether the shock is propagating along or perpendicular to the interplanetary magnetic field. Quite different theories for particle acceleration have been developed for quasi-parallel and quasi-perpendicular shocks. Extension of these ideas to the interstellar medium would lead one to believe that the relativistic electrons in radio supernova remnants are accelerated by either the $Q_{\parallel}$ or $Q_{\perp}$ mechanism. If this is the case, the observed morphology of a remnant should depend on the angle Φ between the line of sight and the galactic magnetic field at the position of the remnant. The dependence of observed structure on this angle will be quite different for $Q_{\parallel}$ and $Q_{\perp}$ mechanisms. We have used a model for the galactic magnetic field and published maps of supernova remnants to search for a dependence of structure on the angle Φ. We did not find a tendency for the remnants as a whole to favor the relationship expected for either mechanism, although individual sources resembled model remnants of one or the other acceleration process. We will discuss a number of possible explanations for this result.

1. INTRODUCTION

Earlier in this meeting I spoke about radioastronomical observations of relevance to diffusive shock acceleration. I would like to return to this theme now and discuss radioastronomical observations which might illuminate the process by which supernova remnants accelerate charged particles. Once again, we will draw on analogies with phenomena in the solar wind.

Observations of shock waves in the solar wind show pronounced differences depending on the orientation of the shock normal to the interplanetary magnetic field. Shocks for which the shock normal is roughly parallel to the magnetic field are characterized by an extensive upstream layer of hydromagnetic turbulence termed a foreshock. Shocks for which the shock normal is roughly perpendicular have no such foreshock, and the plasma waves excited at the shock are electrostatic.

For both types of shocks, particle acceleration, primarily or exclusively of ions, is observed. The mechanisms proposed for acceleration are quite different in the two cases, being first-order Fermi acceleration for quasi-parallel shocks (Ref. 1), while for quasi-perpendicular shocks a shock-drift mechanism (Ref. 2) and acceleration via electrostatic waves (Ref. 3) have been proposed.

Now let us consider the situation for supernova remnant shocks. Radioastronomical observations show that supernova remnants are accelerating electrons to relativistic energies. It is also generally assumed that they are responsible for the cosmic ray ions. This being the case, they are vastly more effective accelerators of charged particles than are solar system shocks.

Given this, I will postulate that if these solar system mechanisms are operative in supernova remnants, then one or the other will dominate. It seems to me somewhat far-fetched, though obviously not out of the question, that *both* shock drift and first-order Fermi acceleration are active in supernova remnants. I will assume therefore that either quasi-parallel or quasi-perpendicular acceleration is occurring and that it would be interesting to determine the responsible mechanism. A possible way of making such a discrimination is indicated in Figure 1.

Supernova remnants will be expanding into a large-scale galactic magnetic field. The appearance of a supernova remnant should then depend on the angle between the line of sight and the magnetic field at the position of the remnant. If quasi-parallel acceleration is occurring, a remnant viewed across the field will appear limb brightened, while one viewed along the field will appear of uniform brightness. For the case of quasi-perpendicular acceleration, a remnant viewed across the field will appear of more uniform brightness, whereas one viewed along the field will appear highly limb brightened and annular. If, in addition, there is a large-scale systematic magnetic field in the galaxy, there will be a dependence of remnant appearance on position in the sky.

The purpose of this talk is to discuss an observational search for such an effect, which would tell us whether quasi-parallel or quasi-perpendicular acceleration is dominant in supernova remnants.

2. OBSERVATIONAL INVESTIGATIONS

There are three ingredients for such an investigation. First, we need a quantitative measure of the degree and nature

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of limb brightening as a function of the angle between the magnetic field and the line of sight, hereafter referred to as Φ. The dependence of limb brightening on Φ is obviously drastically different for quasi-parallel and quasi-perpendicular acceleration. Second, we need a model for the galactic magnetic field, so that we may obtain Φ given the remnant distance and position on the sky, and third, we need a sample of remnants with usable radio maps.

To fill the first of these needs, a model was chosen in which the volume emissivity is a simple function of spherical coordinates, specifically, an exponential decline behind the remnant shell, and a $\cos^2\theta$ or $\sin^2\theta$ dependence on angle with respect to the B field. We then numerically calculated the observed brightness distribution as a function of Φ. Examples of such model remnants are shown in Figure 2.

For the case of quasi-perpendicular acceleration, we see a gradual transition from an annular structure to two arcs parallel to the galactic magnetic field. In the case of quasi-parallel acceleration, there is a transition from uniform surface brightness to two arcs which are perpendicular to the field.

From model brightness distributions like this, we have extracted a single measure of the degree of limb brightening, taken to be simply the ratio of the rim-to-center brightness. This parameter was chosen because it may be easily measured from published maps of supernova remnants.

The second ingredient we need is a model of the galactic magnetic field. The one we chose was from Sofue and Fujimoto (Ref. 4), who have made a fit to measurements of galactic Faraday rotation of extragalactic radio sources. This model also provides a good fit to the positions of galactic H II regions. Given this model, and the distance to a supernova remnant, we can calculate the angle Φ between the line of sight and the local magnetic field.

Finally, of course, one needs data on remnants. We searched the literature for suitable sources. The requirement was that the remnant have a good quality radio map and an estimate of the distance. We also excluded radiative supernova remnants, since it is generally thought that their radio emission arises from compression of the existing cosmic ray gas rather than acceleration *per se*.

We were disappointed in that this search yielded only 13 remnants. It is somewhat dismaying that after three decades of what one might call modern radio astronomy, so few good maps exist of a major type of radio source.

The analysis consisted of two phases. First, our single-parameter representation of the limb brightening was plotted as a function of Φ, and the measurements compared with model curves of the relationship for quasi-parallel and quasi-perpendicular acceleration. Our measurements were highly scattered on a plot of intensity ratio versus Φ, and showed no adherence to the model curve for either acceleration process.

A second form of analysis was a qualitative comparison of the observed maps with the model remnants shown in Figure 2. Although subjective, such an approach allowed consideration of more features of the remnants than simply a center-to-limb intensity ratio. The purpose of this deliberation was to see if there was a tendency for the remnants to more closely resemble the case of quasi-parallel or quasi-perpendicular acceleration. Again results were inconclusive, although specific remnants resembled the quasi-parallel or quasi-perpendicular model.

As discussed in Leckband et al (Ref. 5), the supernova remnant of 1006 AD shows a twin arc appearance, with the arcs perpendicular to the galactic plane. With our magnetic field model and the distance estimate employed, we obtain a value of $\Phi = 44°$. Such an appearance is consistent with that expected for a remnant radiating by quasi-parallel acceleration. On the other hand, Tycho's supernova remnant presents an almost perfect annular structure, and we estimate Φ to be about 35°. This is in accord with a remnant characterized by quasi-perpendicular acceleration. However, although individual remnants might resemble the models for one or the other acceleration process shown in Figure 1, there is no systematic tendency.

3. CONCLUSIONS AND RUMINATIONS

The results of this project were therefore negative. We were unable to find evidence for a galactic magnetic field modulation of the synchrotron emission in our sample of remnants.

We can think of four possible explanations for this negative result. First, it is possible that the notoriously uncertain distances to supernova remnants have produced large errors in our values of Φ. Second, the magnetic field model we have used might be incorrect, or describes a systematic component which is small in comparison with a superposed random component. Such an effect would also render our value of Φ in error.

In both of the above explanations, it is assumed that the galactic magnetic field does play a modulating function, but that other influences frustrate our ability to determine Φ. Alternatively, one can accept our results at face value, and conclude that true supernova remnants do not resemble either of the simple models discussed above. The third suggestion, therefore, is that the galactic magnetic field does not modulate the acceleration of electrons. Such a result would seem to invalidate both of the models discussed above, but would be compatible with others, such as second-order Fermi acceleration. The fourth and final possibility is that both quasi-parallel and quasi-perpendicular acceleration mechanisms are occurring, but that the operative acceleration mechanism varies from one remnant to another. Although this suggestion is at odds with a preference for simplicity in nature, it quite naturally accounts for the fact that remnants such as SN 1006 and Tycho's remnant so closely resemble the *exempla* of quasi-parallel and quasi-perpendicular acceleration, and yet that there is no systematic fealty to an acceleration model.

4. ACKNOWLEDGMENTS

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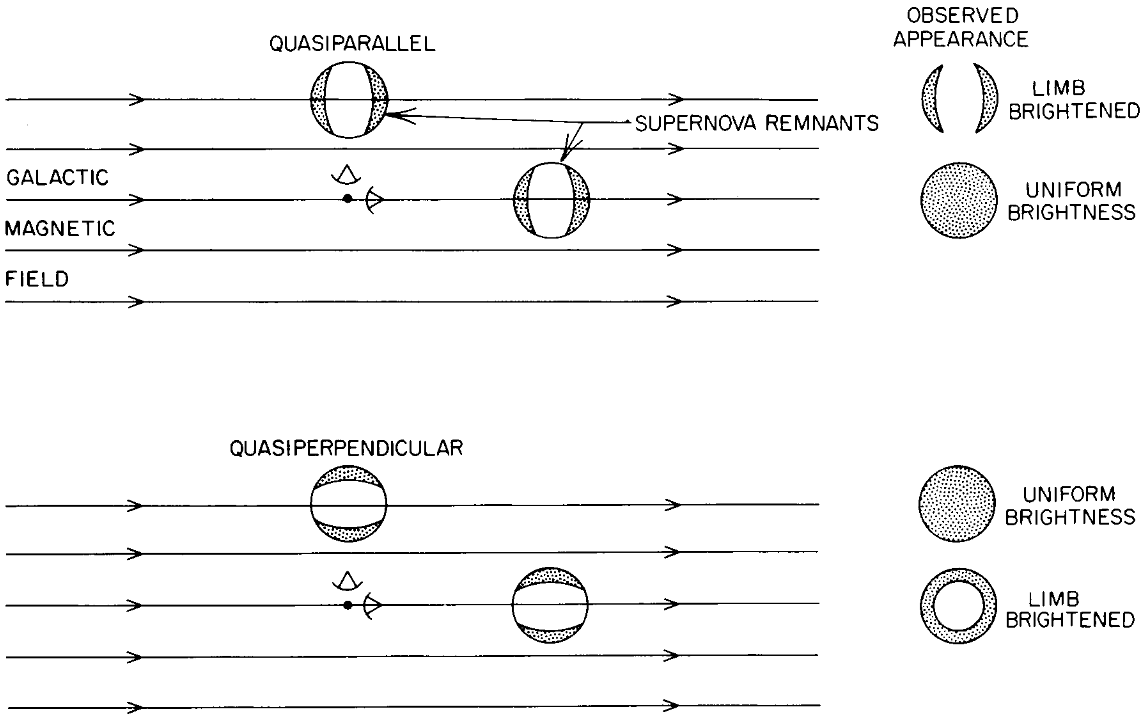

Figure 1. Illustration of how the appearance of supernova remnants changes with the angle between the line of sight and the galactic magnetic field for quasi-parallel (top) and quasi-perpendicular (bottom) remnants. Figure from Leckband et al (Ref. 5).

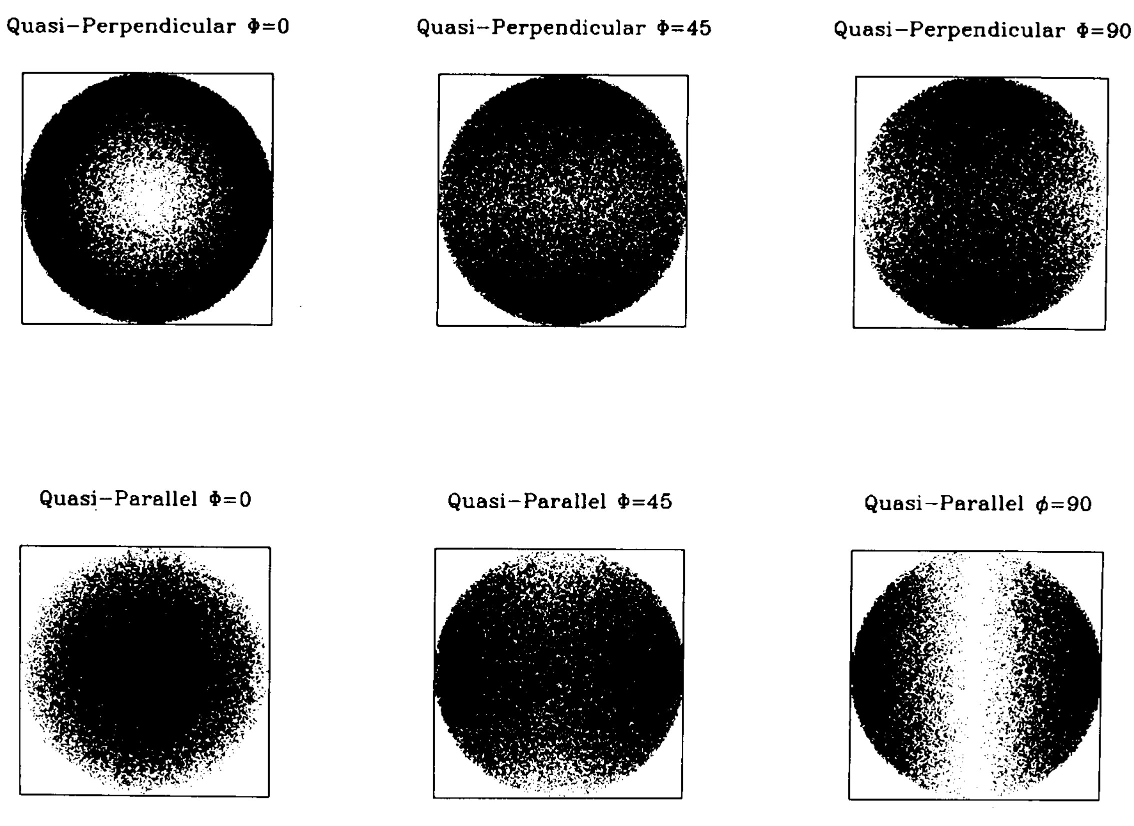

Figure 2. Appearance of model supernova remnants as a function of Φ, the angle between the line of sight and the galactic magnetic field. The top panels are for quasi-perpendicular remnants and the bottom ones for quasi-parallel remnants. The magnetic field is in the horizontal direction for all panels. Figure from Leckband et al (Ref. 5).

5. REFERENCES

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