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Theoretical Investigation of the Impact of Supernova Explosions on Dynamics of Particle

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Abstract: *Dynamics of cosmic ray proton within the supernova was considered by using the equation of the orbit described by the cosmic ray particle when it goes to infinity (at $u = 0$). We considered a certain direction when the cosmic ray proton moves at right angle. This helped us to determine the relationship between the field strength, B_0; the* density, *ρ of* cosmic rays *in a magnetic cloud and the distance of approach, b of an undeflected cosmic ray particle, using its Alfven speed, V_A.*
The field strength, B_0 within the supernova is directly proportional to the density, ρ *of* cosmic rays *in the magnetic cloud; and proportional to the velocity, v of the cosmic ray proton. Thus, attempting to give insight on the impact of supernova explosions on the dynamics of a particle.*
KEYWORDS: *Supernova explosions, Shockwave, Cosmic ray, Alfven speed.*

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I. Introduction

The remnants of self-destructing stars can accelerate particles to higher energies than world's most powerful accelerator. Cosmic ray sources are supernova remnants (SNRs) which are situated in the Galactic disk. Cosmic ray particles perform wandering in the tangled magnetic fields of the Galaxy (Ginzburg and Syrovatskii, 1969). The expanding stellar debris creates a shockwave when it slams into the surrounding gas, compressing and enhancing any magnetic fields present. Charged particles traveling through the shock front can get accelerated, and some also get deflected back by the magnetic fields (Kang *et al.*, 1996).

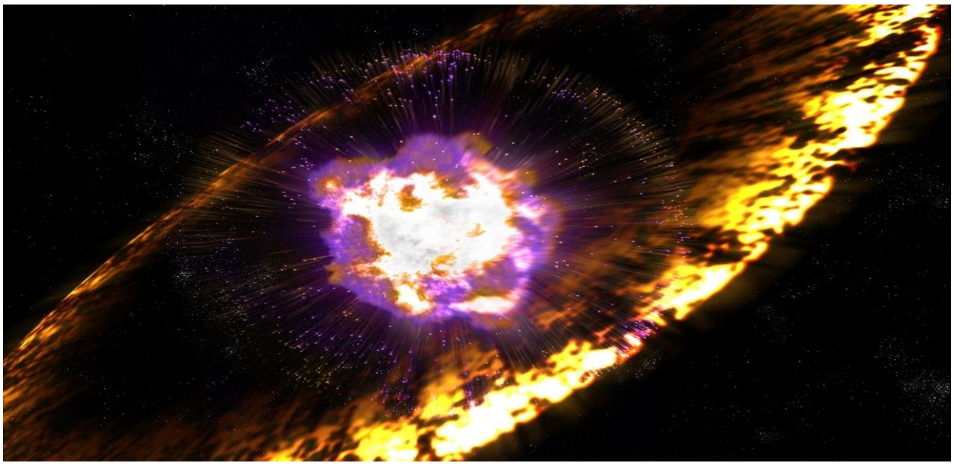

Figure 1: The shockwaves of supernova explosions accelerate charged particles such as protons, some of which end up raining on Earth as cosmic rays.
(**Source:** Greg Stewart, SLAC National Accelerator Laboratory).

In the cause of breaking down or simplifying the high energy equations, it was found that cosmic rays move with Alfven speed. The relative drift speed of the cosmic rays with respect to the plasma v_D occurs at the local Alfven speed, V_A (Kulsrud, 2005).

II. Materials And Method

This chapter contains fairy detailed descriptions of the mathematical instruments used/ assumptions made. Consideration was given to the field in which the cosmic ray proton operates or field due to the cosmic ray proton.

Dynamics of cosmic ray proton within the supernova was considered by using the equation of the orbit described by the cosmic ray particle when it goes to infinity (at $u = 0$):

$$\frac{1}{b} sin\theta = \frac{Zze^2}{\mu b^2 v^2}(1 + cos\theta) \qquad \text{\{Einar and Gordon, 1988\}}$$

where μ is the reduced mass of two ensemble (proton and electron) which constitute cosmic ray, v is the velocity of the cosmic ray particles and $Zze^2 = Ze.ze$ is the charge of the particles.

A certain direction was considered, when the cosmic ray proton moves at an angle $\theta = \frac{\pi}{2} rad. = 90^0$. This helped us to determine the relationship between the field strength, B_0; the density, ρ *of* cosmic rays in a magnetic cloud and the distance of approach, b of an undeflected cosmic ray particle, using its Alfven speed: $U = \left(\frac{B_o^2}{4\pi\rho}\right)^{1/2} = V_A$.

III. Results

Considering the equation of the orbit described by the cosmic ray particle when it goes to infinity (at $u = 0$):

$$\frac{1}{b} sin\theta = \frac{Zze^2}{\mu b^2 v^2}(1 + cos\theta) \tag{1}$$

At $\theta = \frac{\pi}{2} rad. = 90^0$, equation (1) become: $\frac{1}{b} = \frac{Zze^2}{\mu b^2 v^2}$ and

$$b = \frac{Zze^2}{\mu v^2} \tag{2}$$

But $Zze^2 = Ze.ze = (1.60\ X\ 10^{-19})^2 = 2.56\ X\ 10^{-38}C$; and the reduced mass of the two ensemble (CR proton and atmospheric electron) μ is:

$$\mu = \frac{mM}{(m+M)} = \frac{9.11\ X\ 10^{-31} X\ 1.67 X\ 10^{-27}}{\{(9.11\ X\ 10^{-31}) + (1.67 X\ 10^{-27})\}} = 9.1 X 10^{-31} Kg.$$

Substituting into equation (2), it gives: $b = \frac{2.56\ X\ 10^{-38}}{9.1 X 10^{-31} v^2}$.

Then, $v^2 = \frac{2.56\ X\ 10^{-38}}{9.1 X 10^{-31}.b}$

$$v = \frac{1.68\ X\ 10^{-4}}{\sqrt{b}} \tag{3}$$

Equating equation (3) to the Alfven velocity which denoted the final velocity of cosmic ray particle, it gives: $\frac{1.68\ X\ 10^{-4}}{\sqrt{b}} = \left(\frac{B_o^2}{4\pi\rho}\right)^{1/2}$ and

$$B_o^2 = \frac{2.81\ X\ 10^{-8} X\ 4\pi\rho}{b} \tag{4}$$

Substituting $\pi = 3.142$ into equation (4), it gives: $B_o^2 = \frac{3.53\ X\ 10^{-7}\rho}{b}$ and

$$B_0 = 5.94\ X\ 10^{-4}.\left(\frac{\rho}{b}\right)^{1/2} \tag{5}$$

$$B_0\ \alpha\ (\rho)^{1/2} \tag{6i}$$

$$B_0 \,\alpha\, \frac{1}{(b)^{1/2}} \tag{6ii}$$

IV. Discussion

The equation (3) above shows that the velocity, v of the cosmic ray proton is inversely proportional to the distance of approach, b of an undeflected cosmic ray particle. Equation (6i) shows that the field strength, B_0 is directly proportional to the density, ρ *of* cosmic rays in a magnetic cloud. From equation (6ii), the field strength B_0 is inversely proportional to the distance of approach b of an undeflected CR particle.

Looking closely at equations (3) and (6ii), the magnetic field strength B_0 within the supernova is proportional to the velocity, v of the cosmic ray proton. This coincided with what Fleming, 1902 said: “a magnetic field exerts a force on a moving charge, where the force is proportional not only to the field strength but also to the speed of the charged particle”. Thus, this gives insight on the impact of supernova explosions on the dynamics of a particle.

V. Conclusion

In this paper, we investigated theoretically the dynamics of cosmic ray particle at supernova remnant (SNR) shocks in order to provide evidence on the impact of supernova explosions. This has helped in showing how some physical parameters vary or relate with each other. Thus, giving insight on the dynamics of cosmic ray particle.

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