PULSED GALACTIC NUCLEI AND THE ORIGIN OF COSMIC RAYS

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Abstract. The possibility that a series of explosions of the galactic nuclei every $5 \times 10^6$ yr can cause a substantial flux of cosmic ray particles at the vicinity of the Earth is investigated. The steady flux of cosmic radiation forces the conclusion that there have been explosions back to $10^9$ yr if this is a dominant source of cosmic rays.

1. Introduction

Shortly after Fermi (1949) proposed his original idea for the origin of cosmic radiation, C-Y Fan (1951) suggested that the majority of protons originate from the nucleus of our Galaxy. The injection energy problem caused him to speculate:

On the other hand, if stars are unable to eject high energy particles, our result would mean that something corresponding to a series of explosions occurred in the nucleus of the Galaxy over an extended period of time many ages ago.

Because of difficulties associated with the Fermi mechanism in interstellar space, this article has generally been ignored. About ten years later, Burbidge and Hoyle (1963) suggested that the galactic halo is the result of a violent outburst in the nuclear region of our Galaxy. They pointed out that high energy particles could be produced by this outburst. They also suggested the possibility of recurrence of galactic nuclei explosions in some galaxies.

More recently the possibility of cosmic rays from violent events in the galactic center have been associated with long term quasi-steady state sources (Wayland, 1969). A different point of view on cosmic rays from the center of the Galaxy is that of Kulikov et al. (1969), who assume that the very high energy cosmic rays ($E \gtrsim 10^{17}$ eV) are a transient phenomenon resulting from an explosion of the galactic core.

Sanders et al. (1972) have reviewed the recent literature on the kinematics of gas near the galactic center. They present evidence for the existence of three expanding structures of gas at 250 pc and 2.5 kpc and the 3 kpc arm. The molecular ring at 250 pc and the 2.5 kpc ring have expansion energies of about $10^{53}$ to $54$ ergs at the present. There is the possibility that associated with the molecular ring are jet like structures indicating a relatively steady outflow of gas over the last $5 \times 10^5$ yr. The kinetic energy input rate required for this motion is about $10^{39}$ erg s$^{-1}$. The total energy for the event would be larger and could easily increase the input into energetic particles to $10^{40}$ erg s$^{-1}$, the level needed to maintain cosmic rays. The evidence is strong for the rings resulting from a series of explosions within tens of pcs of the galactic center separated in time by about $5 \times 10^6$ yr.

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2. A Model

The possibility that these explosions in the galactic nucleus produce cosmic rays is interesting to investigate. One of the main problems of acceleration of particles to cosmic ray energy is their confinement for sufficient periods of time within a turbulent region. This sets an upper limit of about $E_{\text{max}}^{(\text{E})} \approx 300 Z H l$, where $H$ is the magnetic field strength in gauss and $l$ the linear dimension of the turbulent region in cm. If the acceleration is mainly at the place of the explosions then $l \approx 10^{20} \text{ cm}$ and a reasonable value of $H$ is about $10^{-3} \text{ G}$. Thus protons could gain energies of $3 \times 10^{19} \text{ eV}$ and heavier nuclei even more. This would seem to indicate that the very highest energy cosmic rays would be of a heavy nuclear composition. As they would not pass through the large distances associated with extragalactic cosmic rays, the 3 K blackbody radiation cut off for primary protons and nuclei is avoided. This is consistent with the ideas of Kulikov et al. (1969). The acceleration process should be occurring on a more or less continuous basis to conform with the approximate consistency of the cosmic ray flux. This implies that the cosmic ray activity may be more vigorous at the time of an outburst and slowly fade. But also the constancy of cosmic radiation back to $10^9 \text{ yr}$ ago would require the pulsations at early galactic ages. This would place severe requirements on the total mass outflow from our Galaxy. To a certain extent this problem could be overcome by a return of part of the ejected mass to the galactic nucleus (perhaps helping to initiate a new explosion).

To estimate the consequences of a series of pulsations in a very simple way, let us construct a model for the particles produced. Assume that the particles are injected at a position $r_0 = 0$ at time $t_0$ (the start of an explosion) all with the same momentum $p_0$. We could also assume that the particles were injected with a power law spectrum with finite upper and lower bounds. The information obtained by such a complication would not be worth the resulting complexity in mathematics. Once the particles are injected, they will undergo scatterings in the expanding turbulent region which will result in changes in both momentum and direction. The spatial motion of particles outside of the turbulent region is very complex and will reflect to a large extent the shape of the galactic magnetic field. Because we are just testing the validity of a simple model, let us ignore this problem and just require spherical symmetry. The processes can be described by a Fokker-Planck equation in momentum with spatial diffusion and constant spatial diffusion coefficient $D$.

The particles will not be confined to the turbulent region, so we assume they radiate across the boundary of the turbulent region (I) and the surrounding medium (II). Thus for $t > t_0$ in region I we have

$$\frac{\partial M_1}{\partial t} - D_1 V^2 M_1 + \frac{\partial}{\partial p} \left( \frac{\langle \Delta p \rangle}{M_1} \right) \frac{\partial}{\partial t} M_1 - \frac{1}{2} \frac{\partial^2}{\partial p^2} \left( \frac{\langle (\Delta p)^2 \rangle}{M_1} \right) + \frac{M_1}{T_1} = 0, \quad (1)$$

where $M$ is the particle density, $\langle \Delta p \rangle$ and $\langle (\Delta p)^2 \rangle$ are the first and second moments of the momentum changing process, and $T$ is the effective lifetime against removal.