COSMIC RAYS AND THE PARKER INSTABILITY

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Parker (1966, 1969, 1979) has shown that the magnetic buoyancy of a uniform horizontal magnetic field will destabilize the Galactic gas layer. Perturbations of the form shown in Fig. 1 will grow in time with the magnetic loops ballooning up into the Galactic halo, and the interstellar gas draining down the field lines to collect in the mid-plane. Parker also showed that if the dynamical effect of the cosmic ray component of the interstellar medium is included, using an isotropic cosmic ray pressure, then the instability is enhanced.

The instability has been regarded as significant for two reasons. Firstly it allows escape of magnetic field and cosmic rays out of the gas disc and into the Galactic halo (Parker 1967, 1969); and secondly it leads to condensations of the interstellar gas which may be the mechanism for the formation of the large molecular clouds observed in the Galaxy (Mouschovias, Shu, and Woodward 1974, Shu 1983), and hence the instability would represent an early stage in the process of star formation.

However it is possible to argue that the assumption that the cosmic ray pressure is always isotropic may not be valid. Since the only mechanism for isotropizing the collisionless cosmic rays is scattering by magnetic field fluctuations, it is necessary that fluctuations of the correct scale length and of sufficient amplitude should be present in the interstellar plasma; but under the assumptions that the field should be dominantly uniform, and that the cosmic ray pressure is isotropic in the unperturbed state, it may be difficult for the necessary fluctuations to arise. Consequently it is of interest to allow the cosmic ray pressure to become anisotropic, in order to ascertain how crucial the assumption of isotropy is for instability.

An appropriate approximation for the stress tensor of the cosmic rays P_{ij} is that due to Chew, Goldberger and Low (1956) in which we have

$$\underset{\approx}{P} = P_{ij} = P_{\parallel} b_i b_j + P_{\perp}(\delta_{ij} - b_i b_j)$$

where $\underset{\sim}{b}$ is a unit vector parallel to the field $\underset{\sim}{B}$, and $P_{\parallel}$ and $P_{\perp}$ are the pressures parallel and perpendicular to $\underset{\sim}{B}$ respectively. Equations governing $P_{\parallel}$ and $P_{\perp}$ can be derived under the assumptions that the Larmor radii and periods of the cosmic rays are respectively much smaller than

M. R. Kundu and G. D. Holman (eds.), Unstable Current Systems and Plasma Instabilities in Astrophysics, 361–363.

https://doi.org/10.1017/S0074180900075823 Published online by Cambridge University Press

the characteristic wavelength and timescale of the instability (Rossi and Olbert 1970). These are

$$\frac{d}{dt}\left(\frac{P_{\perp}}{n\ B}\right) = 0 \tag{1}$$

$$\frac{d}{dt}\left(\frac{P_{\parallel} B^2}{n^3}\right) = 0 \tag{2}$$

where n is the cosmic ray density, and d/dt is the cosmic ray comoving time derivative. These replace the equations $P_{\parallel} = P_{\perp} = P$ and $dP/dt = 0$ employed by Parker, otherwise the analysis is very similar to that of Parker, with the assumption of quasi-static cosmic rays, i.e.

$$\underset{\sim}{j}_{cr} \times \underset{\sim}{B} = \nabla . \underset{\approx}{P} \quad ,$$

together with equations (1) and (2) determining the time evolution of the cosmic rays.

Parker's analysis showed that for instability the wavelength of the perturbation must be greater than a certain critical wavelength given by

$$\lambda_c = 2\pi\ h_o \left[\frac{2\alpha\gamma\ (1 + \alpha + \beta)^2}{(1+\alpha)(1+\alpha-\gamma) - \frac{1}{2}\alpha\gamma + \beta(2+\beta+2\alpha-\gamma)}\right]^{\frac{1}{2}}$$

where γ is the polytropic exponent of the gas, α and β are respectively the unperturbed magnetic and cosmic ray pressures as a fraction of the gas pressure, and h_o is the characteristic scale height of the gas. For $\gamma = 1$ and $\alpha = 0.01$ we obtain $\lambda_c = 0.06\ h_o$ and $\lambda_c = 0.012\ h_o$ for $\beta = 0$ and $\beta = 1$ respectively, i.e. the cosmic rays decrease λ_c and hence destabilize the gas layer.

Using (1) and (2) however we obtain

$$\lambda_c = 2\pi\ h_o\sqrt{1 + \beta/\alpha} \left[\frac{2\alpha\gamma\ (1 + \alpha + \beta)^2}{(1+\alpha)(1+\alpha-\gamma) - \frac{1}{2}\alpha\gamma + \beta(2+\beta+2\alpha - 3\gamma/2)}\right]^{\frac{1}{2}}$$

which yields $\lambda_c = 0.18\ h_o$ for $\alpha = 0.01$, $\gamma = 1$, and $\beta = 1$, i.e. in this case the cosmic rays are stabilizing since λ_c is increased.

The physical reason for this is that the cosmic ray pressure is now largest in the troughs of the magnetic field lines in Fig. 1, due to the conserved magnetic moments, and their effect is to push the gas vertically out of the troughs. Whereas under the assumption that the cosmic ray stress is isotropic and constant along the field lines, the main effect of the cosmic rays comes from the horizontal component of the gradient of this stress which acts to push the gas into the troughs. The assumption of isotropic stress for the cosmic rays is therefore crucial for the enhancement of the Parker instability. Unless convincing arguments are found to justify this assumption it would seem likely that

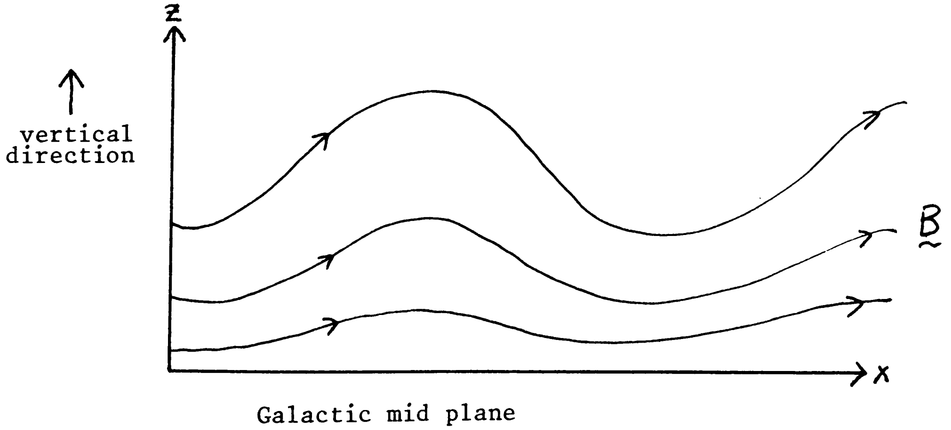

Fig. 1 Perturbation of the horizontal Galactic magnetic field lines.

the effect of cosmic rays helps to stabilize the Galactic gas layer, and makes the Parker instability less plausible as a mechanism for forming molecular clouds.

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