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MAGNETIC FIELDS IN MOLECULAR CLOUD CORES: LIMITS ON FIELD STRENGTHS AND LINEWIDTHS

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Summary: *Preliminary observations by others indicate that the magnetic field strength in dense molecular cloud cores is on the order of 30 μG, much closer to the background field strength than to the flux-freezing prediction for this density. This result implies that some process must exist to decrease the magnetic field strength in these regions to much less than its flux-frozen value, e.g. ambipolar diffusion. At these moderate field strengths, magnetohydrodynamic waves in the cores provide a good explanation of observed supra-thermal molecular linewidths.*

ABSTRACT

Magnetohydrodynamic waves may be the source of the supra-thermal molecular linewidths observed in molecular cloud cores. If so, a substantial fraction of the non-thermal portion of the linewidth is the result of magnetohydrodynamic turbulence, which gives rise to the shear Alfvèn waves in the cloud core (Zweibel and Josafatsson 1983).

New data on core properties (Myers and Benson 1983; Benson and Myers 1983; Myers 1983,1984,1985; Myers, Goodman and Benson 1986) enable us to place limits on the field strength in a region if one assumes that the linewidth observed is comparable to the Alfvèn speed in that same region. Energy considerations give further constraints on field strength. All techniques of estimation used in this paper, as well as available direct (Zeeman-splitting) observations (Troland and Heiles 1986; Heiles and Stevens 1986) indicate field strengths substantially weaker than a 'flux-frozen' value.

Assuming an energy source exists to maintain dynamical turbulence, the field strengths required to sustain MHD turbulence and waves are an order of magnitude weaker than field strengths calculated using a flux-freezing analysis. In the flux-freezing scenario $(B/B_o) \approx (n/n_o)^k$, where n and B are the local density and magnetic field strength, respectively, n_o and B_o are ambient values, and $1/3 \leq k \leq 1/2$. If we consider a generalized cloud core with density $n = 10^{4.4}$ cm^{-3} in a medium with ambient density $n_o = 100$ cm^{-3} and magnetic field $B_o = 20$ μG, flux-freezing predicts $B \approx 200$ μG. (See Table I.) If, however, we make the order-of-magnitude assumption that the non-thermal portion of the observed linewidth, Δv_{nt}, is approximtely equal to the Alfvèn speed, v_A, we calculate $B \approx 33$ μG.

We have also considered the energy balance in cloud cores, in order to estimate the field strength from another point of view. Pressure balance gives values similar to $B_{v_A=\Delta v_{nt}}$, as one would expect, owing to the similarity of the equations involved. (See Table I.) And, the magnetic pressure for $B \approx 30$ μG is either comparable to or less than the gravitational pressure in these cores, wheras the magnetic pressure for $B \approx 200$ μG is far too great to permit gravitational collapse.

This idea—that flux-freezing is unlikely in dense star-forming molecular cloud cores—almost certainly means that ambipolar diffusion is important in these regions (Shu 1983, Mestel 1985). At core densities, and higher, only the (increasingly small) ionized component of the plasma is coupled

to the field lines, and the neutral particles may stream through relatively easily, potentially leading to the formation of a star.

The field strengths required to explain linewidths with MHD turbulence and waves, and those for stars to be able to form are self-consistent. Important remaining considerations are: [1] what could be an appropriate energy source for the Alfvèn waves; [2] what is the lifetime of the waves, given a finite energy source; and [3] what is the field strength, observationally?

TABLE 1: COMPARISON OF MAGNETIC FIELD STRENGTHS [1]

$B_{flux-freezing}$ (k=1/3)	124 μG [2]
$B_{flux-freezing}$ (k=1/2)	317 μG
$B_{Zeemansplitting}$	50 μG $\geq 3\sigma$ [3]
$B_{equalpressure}$	36 μG [4]
$B_{virialequilibrium}$	57 μG [5]
$B_{v_A=\Delta v_{nt}}$	33 μG [6]

Notes: (1) for a "mean" cloud where log(n) = 4.40; FWHM linewidth = 0.32 km s^{-1}; T = 11K; radius = 0.12 pc (Myers and Benson 1983) (2) (B/20 μG) = (n/100 $cm^{-3})^k$ (3) probably an underestimate due to beam-dilution effects; value from Heiles and Stevens (1985) (4) $B^2/8\pi = \rho\sigma_{nt}^2 + \rho kT/\mu$ (σ_{nt} = non-thermal portion of linewidth) (5) virial equilibrium for a spherical cloud (6) $v_A = \Delta v = B/(4\pi\rho)^{1/2}$ (will automatically be of order $B_{equalpressure}$)

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