MAGNETIC VISCOSITY AS THE DOMINANT SHEAR FORCE IN ACCRETION DISKS

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ABSTRACT. Matter in accretion disks spirals inward because of angular-momentum losses due to intrinsic shear torques. For galactic disks, the accretion rates can be as high as $1M_{\odot}/yr$, corresponding to a value larger than unity of the dimensionless viscosity parameter α. The required torques exceed turbulent ones by at least an order of magnitude; they can, however, be the result of magnetic tensions.

In fast-revolving, clumpy disks, magnetic pressures can exceed static gas pressures and approach ram pressures. Suggestive candidates for such magnetic dominance are the inner, near-rigidly rotating parts of galactic disks.

There are three ways to estimate the present spiral-in mass-rate of our galactic disk, all consistent with $\dot{M} \lesssim M_{\odot}/yr$. They are:

(1) the typical mass rate required to power the quasar (AGN) phenomenon, if mass is converted to energy at an average rate of $\gtrsim 1\%$, see [1] ;

(2) the rate implied by an inward radial motion of the molecular-cloud complexes w.r.t. the local system of rest, at a speed of $\lesssim 5$ Km s^{-1}, [2] ; and

(3) the rate implied if the magnetic fields satisfy $B_r B_\varphi \approx B^2/3 \approx (8\pi/3)\, \rho\, v_s^2$, as observed for the disk, and thus exert a torque across cylinders of typical semi-height $h \lesssim 2r/3$, see figure 1. (A large magnetic scale height is indicated, among others, by slower revolution of the halo gas, [3,4]).

This mass rate is 10 times higher than the maximal rate achievable by turbulent viscosity, corresponding to a viscosity parameter $\alpha := |p_{r\varphi}|/p = 1$. As $\alpha \leq 1$ follows whenever the gas-pressure tensor $p_{\alpha\beta}$ is non-negative, I conclude that turbulent shear stresses in galactic disks are unimportant compared with magnetic tensions.

The importance of magnetic tensions in galactic disks can already be expected from the fact that intracluster

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magnetic fields of order 0.3 μG have been found (from radio and X-ray observations, [6]). Under collapse, a protogalaxy can thus inherit a dynamically significant seed flux.

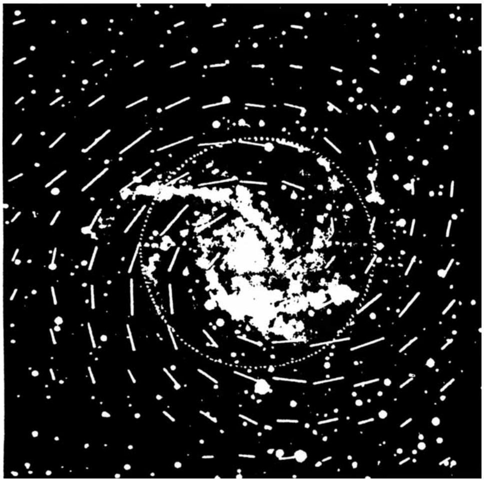

Figure 1: Measured average magnetic-field orientations in the face-on galaxy NGC 6946, [5]. In order to evaluate their torque around the symmetry axis, Maxwell's stresses are integrated along the circular cylinder indicated by white dots. The least known quantity is the scale height through which the field is oriented as drawn.

In principle, shear motions in gaseous disks can stretch the toroidal magnetic-field component until the magnetic pressure $B^2/8\pi$ approaches the ram pressure $\rho v_\varphi{}^2$ of the gas. In practice, the field tends to be expelled from the disk by buoyancy forces once $B^2/8\pi$ exceeds the static pressure $\rho v_s{}^2$. But buoyant escape of magnetic flux tubes is slow for tubes threading (heavy, sufficiently conducting) clouds. In the inner parts of galactic disks, the buoyant escape timescale of flux tubes can exceed the amplification timescale (via shear motions), leading to field strengths much in excess of static pressure balance. This is apparently happening in the inner, near-rigidly rotating part of our Galaxy, of radius r $\lesssim$0.5 Kpc, cf. figure 2. It is, moreover , indicated by the following facts:

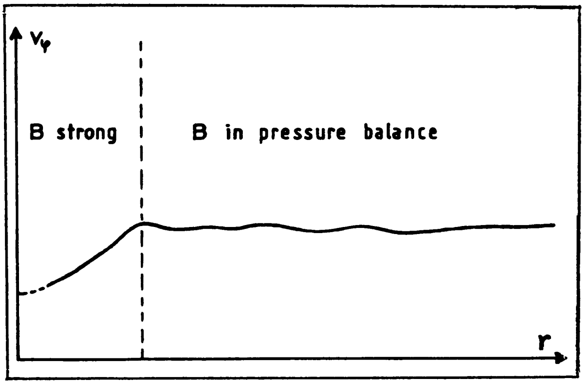

Figure 2: Symbolical galactic rotation curve, v_φ versus r. In the text , arguments are presented that $B_\varphi{}^2/8\pi\rho \approx v_s{}^2$ holds in the outer part ($v_\varphi \approx$ const) whereas $B_\varphi{}^2/8\pi\rho \lesssim v_\varphi{}^2$ holds in the inner part (v_φ/r $\approx$ const).

(1) Direct estimates of the magnetic field strength at various radii are consistent with $B(r) \approx 3$ mG $(pc/r)^{0.8}$ for 0.3 pc $\lesssim r \lesssim$ 10 Kpc, [7];

(2) it is known for over 15 years that the gas density scale height in the inner Galactic disk largely exceeds the pressure scale height, [8];

(3) the observed near-rigid rotation law would otherwise ask for a mass distribution $M(r) \sim r^3$ which is difficult to understand;

(4) the inner parts of the Galactic disk are clumpy and show various tilts, reminiscent of dynamic instabilities; and

(5) mass estimates of the central engine (Sgr A*) based on the motions of the gas lead to much higher values ($\approx 3 \cdot 10^6$ $M_\odot$) than those based on the motions of the stars ($\lesssim 10^3$ $M_\odot$), [9,7]. Apparently, gravity plays a minor role for the gas motions at $r \lesssim 1$ pc.

The possibility of dynamically important magnetic fields in thin disks has been found numerically by Shibata et al [10] who speak of "magnetically cataclysmic disks".

The three pages granted for this communication did not allow me to include detailed explanations and a sufficient number of references. I have therefore submitted a longer version to Astrophysics and Space Science which is expected to appear in print early in 1990.

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CAMENZIND: In AGN physics there is a feeding problem on the scale of a few kiloparsecs down to a few parsecs. Can magnetic stress solve this problem for accretion rates $M \gtrsim 10\ M_\odot$/yr?

KUNDT: In my mind, the answer is 'yes': Observed field strengths in neighbouring galaxies scale as the square root of the prevailing pressure (as expected), so that higher feeding rates (than for our Galaxy) result e.g. for higher gas densities at similar velocities.

BELVEDERE: You did assume energy equipartition between magnetic and velocity fields. Is there any observational evidence for that?

KUNDT: Yes, the high rotation measures near $r = 30$ pc, $RM \lesssim 10^4$ rad m^{-2} (at the edge of the Galactic chimney (Reich, this volume)), and the field measurements in Sgr A West ($r \lesssim 1$ pc), of $B \gtrsim= 3$ mG, correspond to magnetic tensions comparable to ram pressures.

KULSRUD: Is the vertical equilibrium condition satisfied in an accretion disk when B is large enough that $\rho\, v_\phi^2 \approx B^2$?

KUNDT: This was the last item of my talk which ran out of time: The strong field can be anchored by heavy clouds, but instabilities certainly develop, and are observed in the form of multiple tilts.

RUZMAIKIN: Why is the magnetic viscosity greater than the turbulent one? Is it compatible with a magnetic field evolution in the turbulent region?

KUNDT: Turbulent velocities are thought to be subsonic whereas Keplerian velocities tend to be 3 to 10 times faster than sound. Besides, magnetic tensions act through a larger vertical height.