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DYNAMO MAGNETIC FIELDS IN ACCRETION DISCS WITH FORCE-FREE CORONAE

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RESUMEN

Presentamos resultados del cálculo de la evolución y configuración de equilibrio del campo magnético de gran escala regenerado por un dinamo $\alpha\Omega$ que opera en el interior de un disco de acreción rodeado de una corona en un estado libre de fuerzas lineal. Para los modelos de disco y parámetros del mecanismo de dinamo utilizados, encontramos que la simetría del campo generado, con respecto al plano medio del disco, es cuadrupolar. Este resultado es consistente con cálculos anteriores suponiendo un vacío como ambiente exterior al disco. En contraste con dichos resultados, nuestro modelo es capaz de sostener una componente toroidal del campo magnético, además de la poloidal, permitiendo el escape de momento angular del material en el disco.

ABSTRACT

We calculate the evolution and equilibrium configuration of the large scale magnetic field regenerated by an $\alpha\Omega$-dynamo operating inside an accretion disc surrounded by a tenous corona in a linear force-free state. For all the disc and dynamo models studied, we find that the symmetry of the generated magnetic field is quadrupolar, as it is for the case of accretion discs surrounded by vacuum studied previously by other authors. In contrast to such calculations, a toroidal component of the magnetic field is sustained outside the disc allowing for angular momentum transport to escape from the disc material.

Key words: **ACCRETION, ACCRETION DISKS — ISM: JETS AND OUTFLOWS — ISM: MAGNETIC FIELDS**

1. INTRODUCTION

The presence of magnetic fields in accretion discs —in particular in protoplanetary disks— has been suggested among other reasons, in relation to the problems of angular momentum transport and outflow generation. While small scale magnetic fields, resulting from the magneto-rotational instability, are currently the most prominent candidate as the source of the anomalous viscosity driving accretion discs, most models of the generation of winds and jets from YSO's and AGN's assume the existence of **large-scale** (typical length-scale $\sim R$) magnetic fields threading the disc. However, the mechanism responsible for the generation of such magnetic field is not yet determined, although recent studies (see Reyes-Ruiz & Stepinski 1996) suggest that it cannot be advected from an externally generated field. Given the potentially important role that magnetic fields may play in accretion disc phenomena, we believe the study of their origin is well justified.

In the present work we summarize the results of our ongoing studies on the dynamo origin and dynamical effects of accretion disk magnetic fields. In our model, the differential rotation of the disk's keplerian flow, together with a postulated helical turbulence, regenerate and amplify a seed magnetic field by the standard $\alpha\Omega$ dynamo mechanism. We analyze the effect of an exterior disc corona, assumed in a linear force-free state, on the large scale magnetic field configuration of the dynamo magnetic field.

2. DISC, CORONA AND DYNAMO MODELS

We assume the structure of our "standard" disk model is given by a steady state, geometrically thin, optically thick axisymmetric accretion disk with mean Rosseland opacity given by Kramer's law. The standard Shakura & Sunyaev α_{ss} prescription for the turbulent viscosity is used and with this, physical conditions inside

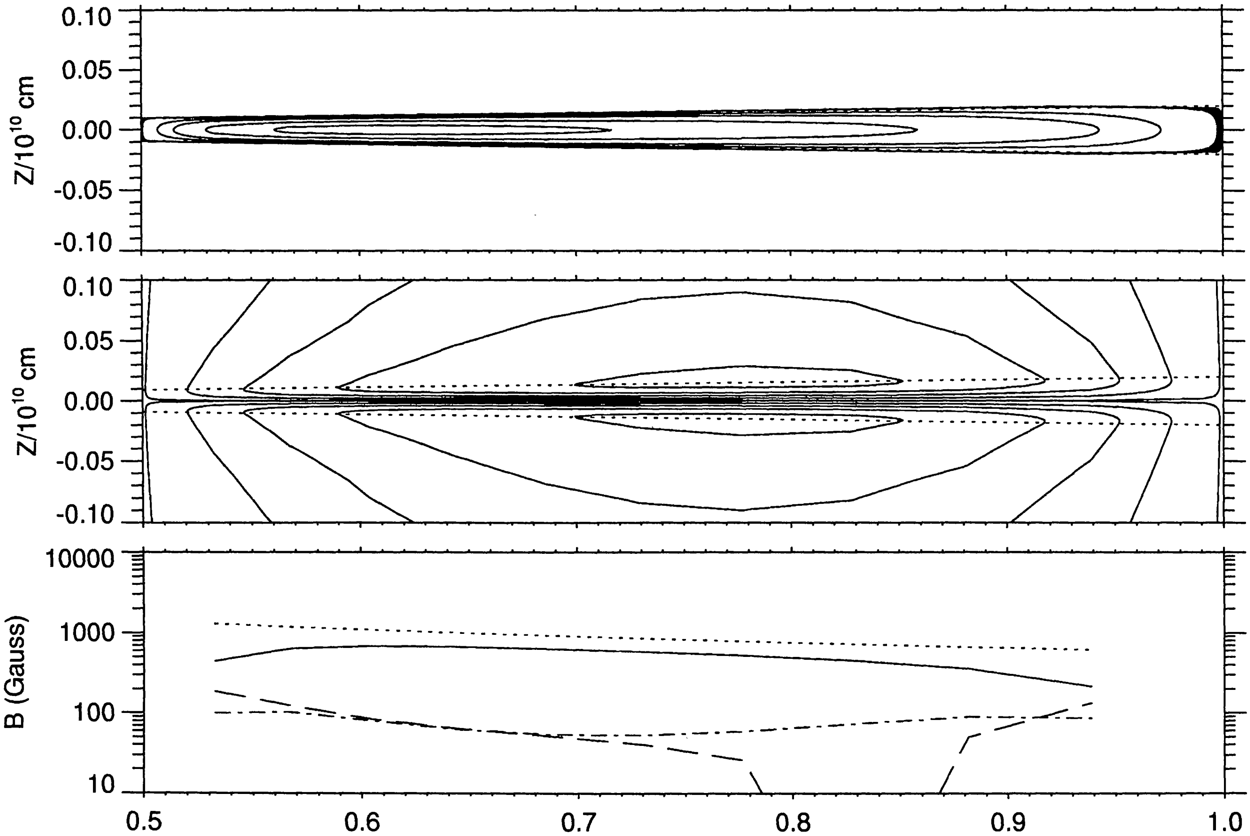

Fig. 1. Equilibrium magnetic field configuration for the case of a vacuum force-free exterior ($\mu = 0$). The top panel shows contours of equal toroidal field magnitude. The middle panel shows the poloidal magnetic field (the dashed line represents the surface of the disc). And the bottom panel shows radial profiles of the different field components,B_ϕ is solid, B_r is dash-dotted, B_z is dashed and the dotted line indicates, for reference, the magnitude of the magnetic field in equipartition with the turbulence.

the disc are given as in Frank, King, & Raine's book (1992) with parameters that roughly correspond to those in cataclysmic variables.

The disc is assumed to be perfectly ionized, with diffusivity due entirely to the so-called turbulent diffusivity which is proportional to the turbulent viscosity by a factor (the magnetic Prandtl number) believed to be of order unity.

The exterior of the disc (beyond $|Z| = H$) is assumed to be a tenuous plasma. The disc's magnetic field permeates the region giving rise to a solar corona like environment. Magnetic field lines in the corona are continuously stressed and relaxed as their foot-points move due to large scale and turbulent motions of disc material. We assume that such medium is always near a state of complete relaxation which is well represented by a so-called linear force free state. In axisymmetry, the poloidal magnetic field is determined from the solution of,

$$\left[\nabla^2 + \mu^2\right] A \;=\; 0 \;,$$

for the magnetic vector potential, with the toroidal field simply given by $B = \mu A$ where μ is a parameter related to the helicity content of the magnetic field.

We use a semi-dynamical (α-quenched) version of the dynamo process, where the back-reaction of the Lorentz force on the helicity of turbulent motions is simulated by "quenching" the α-effect. The quenching term is adopted from Rüdiger, Eltsner, & Stepinski (1995) using an equilibrium magnitude in equipartition with kinetic energy of the turbulent motions.

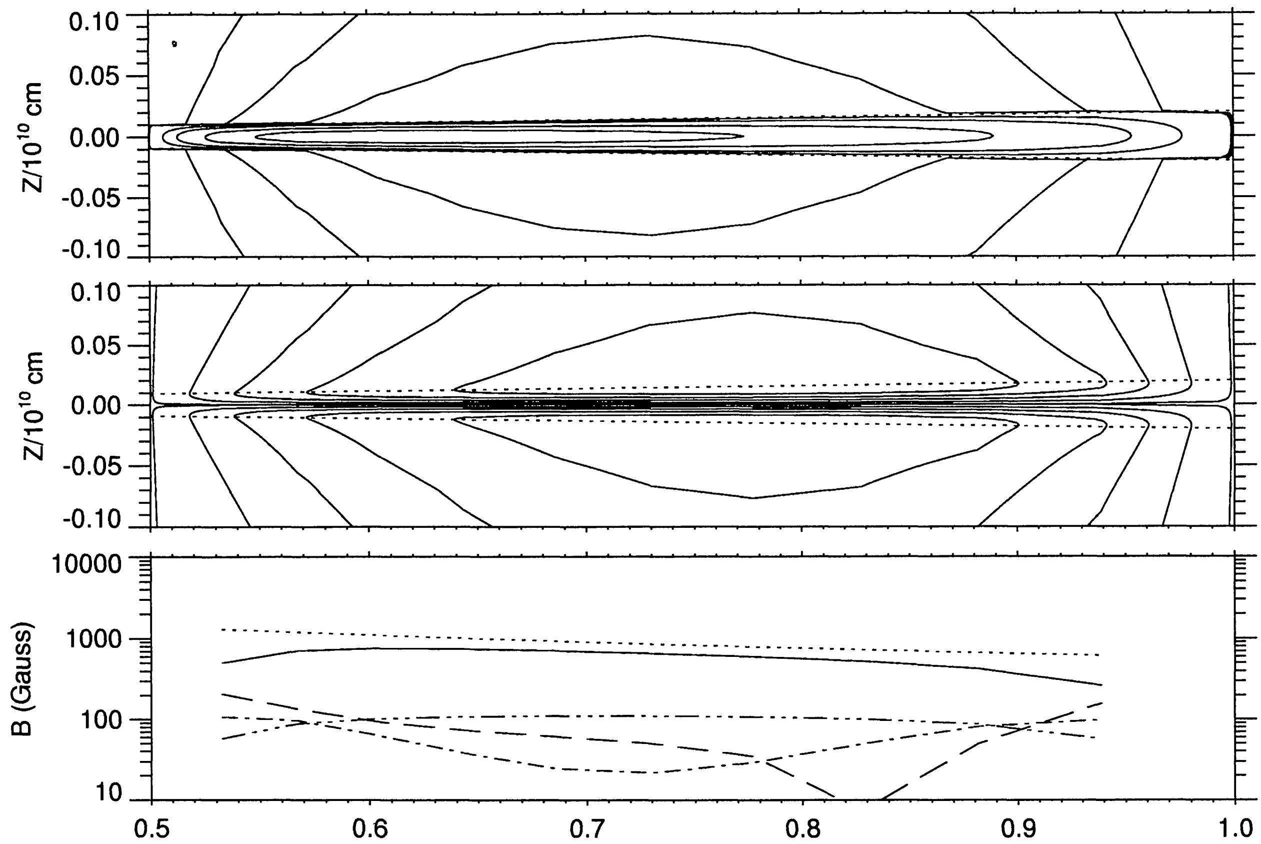

Fig. 2. Same as Figure 1 but for a Corona characterized by $\mu = 0.5\mu_{crit}$. In the bottom panel we have added a dash-triple-dot line showing the radial profile of B_ϕ at the surface of the disk.

3. RESULTS

The system of coupled $\alpha\Omega$ dynamo equations is solved numerically using explicit finite differences. An analytic solution of the equation for the exterior magnetic field can be obtained as a series of Bessel functions of order 1. Cutting the series to a number of terms equal to the number of grid points in the radial coordinate we can match the exterior solution to the dynamo magnetic field assuming the continuity of all magnetic field components. For mathematical simplicity the field and potential are made to vanish at R_{in}, R_{out} and, assuming the disc and corona to be an isolated system, they also vanish as $|Z| \to \infty$.

Results are shown for a fiducial disc having $\alpha_{ss} = 0.1$, $R_{in} = 5 \times 10^9$ cm, $R_{out} = 10^{10}$ cm, $\dot{M} = 10^{16}$ gm s^{-1}, and $M_* = M_\odot$. The magnetic field is rapidly (on timescales < 100 dynamical timescales) regenerated and amplified from a seed magnetic field orders of magnitude weaker that the equipartition strength. After this, the magnetic field achieves an equilibrium value near the equipartition strength which is shown in the figures.

4. SUMMARY AND CONCLUSIONS

We have calculated the configuration of the large-scale magnetic field resulting from an $\alpha\Omega$ dynamo operating inside an accretion disc surrounded by a linear force-free corona.

As in the case of a disc surrounded by vacuum, the magnetic field has quadrupolar symmetry with respect to the disc mid-plane. This has been verified with an eigenmode analysis of the linear dynamo equations where we find that in general (independent of disc and force-free parameters) the largest growth rate, as well as the lowest critical dynamo number, corresponds to quadrupolar modes (Reyes-Ruiz 1998, in preparation).

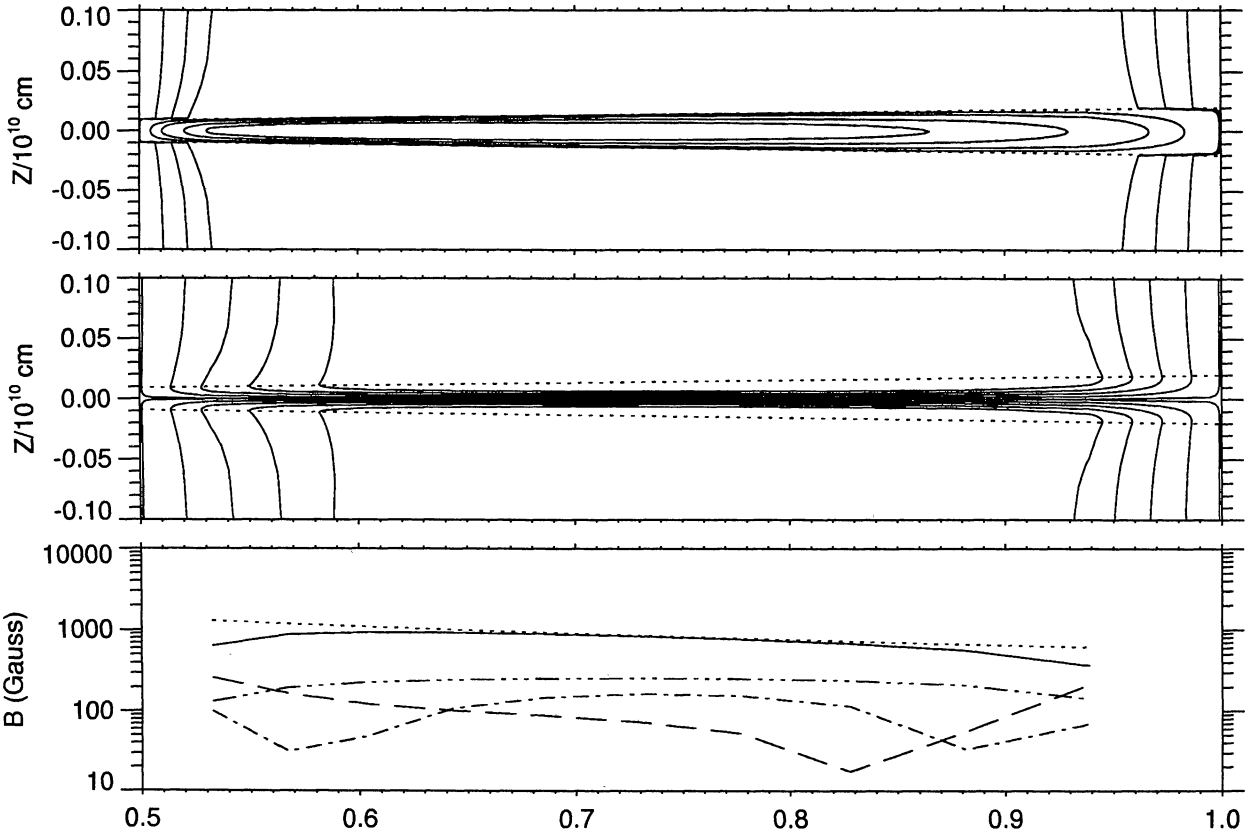

Fig. 3. Same as Figure 1 but for a corona characterized by $\mu = 0.99\mu_{crit}$.

The *interior* magnetic field, its magnitude, radial distribution and ratio between components, varies only slightly as the properties of the corona (force-free parameter μ) are changed. In general the field is strongly dominated by the toroidal component with $B_z, B_r \sim 10^{-2} B_\phi$ typically (the poloidal components calculated near the surface).

Marked differences in the magnetic field configuration, with respect to the dynamo solution with vacuum outside the disc (Reyes-Ruiz & Stepinski 1997), appear only near the surface and outside the disc, and only for values of the force-free parameter near a critical maximum set by the requirement of field convergence as $|Z| \to \infty$. For such values of μ, the toroidal field has similar magnitude to the other 2 components at the surface of the disc.

The effects of such magnetic field on the disc dynamics, as well as their potential importance in driving outflows will be the subject of future investigations.

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