vided by cosmic rays and radioactive nuclei. For the purpose of our calculations we assume a solar protoplanetary disk to be an α disk with the opacity law taken from Ruden and Pollack [3] and the ionization state taken from Stepinski [4]. We choose $\alpha = 0.08$, and $\dot{M} = 10^{-6}\, M_\odot$ per year. We assume a disk surrounding a 1-$M_\odot$ star and extending from 0.2 AU up to 40 AU. Figure 2 shows the time evolution of the magnetic field from the initial field $Q(r) = 0.1$ in units of the equipartition value at r = 40 AU. At first the field increases sharply at the inner radii, decays at the middle radii, and remains unchanged at the outer radii. By the time t ≈ 10 yr, the magnetic field in the innermost portion of the disk achieves equilibrium. As time progresses the magnetic field achieves equilibrium at larger and larger portions of the inner disk. At the same time, the field continues to decay at the middle radii, but the decaying region shifts outward as a result of radial diffusion, and the magnetic field in the outer parts starts to show some growth. By the time t ≈ 100 yr the whole region within 3 AU has reached equilibrium. Radial diffusion from the regions of strong magnetic field stops the further decay of the field within the region where the local growth rate is negative, and the field is now actually growing there. The magnetic field in the outer parts of the disk continues to grow. By the time t ≈ 2000 yr, the magnetic field in almost the entire disk has reached equilibrium. Total equilibrium is achieved at roughly t = 4400 yr. The final configuration of the magnetic field follows closely the distribution of the equipartition value magnetic field, except at the middle radii.

Conclusions: The final configuration of a dynamo-generated magnetic field is independent of unknown initial conditions. However, initial conditions influence the way the magnetic field evolves toward its equilibrium, as well as the time needed to achieve such equilibrium. Evolution from initial conditions without field reversals (presented here) leads to an equilibrium field in a time that is very short in comparison with disk viscous time. Evolution from initial conditions with field reversals (not shown here) leads to an equilibrium in a time 10–10^2 times longer, as radial diffusion destroys field reversals. In equilibrium, the field has a magnitude of the order of the equipartition with the kinetic energy of turbulence.

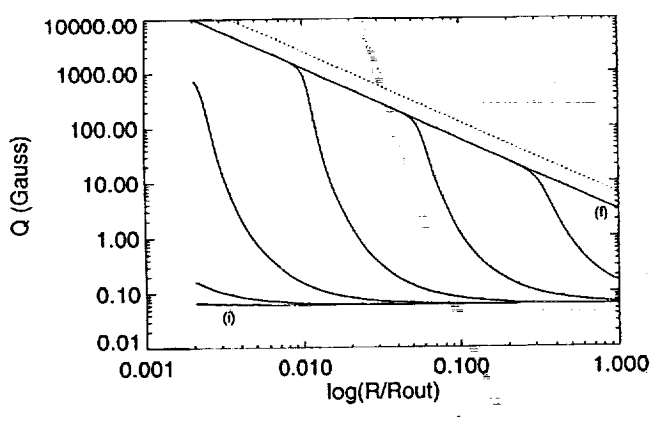

Fig. 1. Radial distribution of magnetic field Q is plotted against dimensionless radius r/r_{out} at various times for the case of an accretion disk around a compact star. The plots (i–f), in order of increasing time, correspond to t = 10, 10^2, 10^3, 10^4, 10^5, 10^6, and 10^7 s respectively. The dotted line shows the radial distribution of B_{eq}. After about t = 10^7 s the magnetic field equilibrates everywhere in a disk at about half the equipartition value.

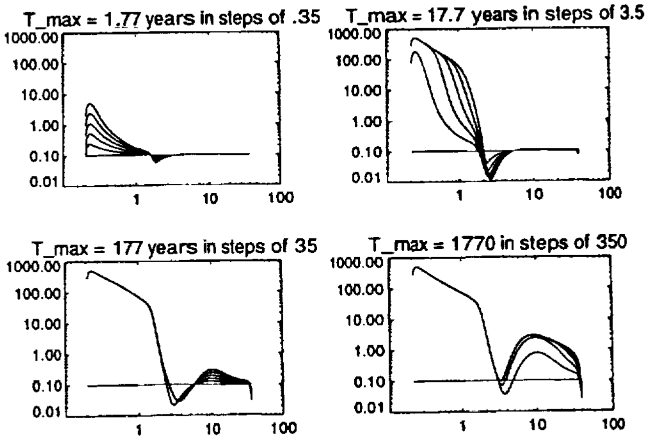

Fig. 2. Time evolution of the magnetic field in a protoplanetary disk from the initial condition Q = 0.1 at t = 0 represented by the horizontal solid line. Magnetic field Q is measured in units of $B_0 = B_{eq}$ (40 AU). Radial distance from the central star is measured in AU.

Such a field could have a substantial effect on the structure and dynamical evolution of thin disks. From an observational point of view, the magnetic field is concentrated close to the inner disk's radius, so it could be difficult to distinguish it from a stellar magnetic field, provided that a central star has a strong field.

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NONTHERMAL ACCRETION DISK MODELS AROUND NEUTRON STARS. M. Tavani[1] and E. Liang[2], [1]Princeton University, Princeton NJ 08544, USA, [2]Rice University, Houston TX 77251, USA.

We consider the structure and emission spectra of nonthermal accretion disks around both strongly and weakly magnetized neutron stars. Such disks may be dissipating their gravitational binding energy and transferring their angular momentum via semicontinuous magnetic reconnections. We consider specifically the structure of the disk-stellar magnetospheric boundary where magnetic pressure balances the disk pressure. We consider energy dissipation via reconnection of the stellar field and small-scale disk turbulent fields of opposite polarity. Constraints on the disk emission spectrum are discussed.

P. 2 S24-90 ABS. N94-31140

GRAVITATIONAL INSTABILITIES IN PROTOSTELLAR DISKS. J. E. Tohline, Department of Physics and Astronomy, Louisiana State University, Baton Rouge LA 70803, USA.

The nonaxisymmetric stability of self-gravitating, geometrically thick accretion disks has been studied for protostellar systems having a wide range of disk-to-central object mass ratios. Global eigenmodes with four distinctly different characters have been identified using numerical, nonlinear hydrodynamic techniques. The mode that appears most likely to arise in normal star formation settings, however, resembles the "eccentric instability" that has been identified earlier in thin, nearly Keplerian disks: It presents an open, one-armed spiral pattern that sweeps continuously in a trailing direction through more than 2-π radians, smoothly connecting the inner and outer edges of the disk, and *requires* cooperative motion of the point mass for effective amplification. This particular instability promotes the development of a single, self-gravitating clump of material in orbit about the point mass, so its routine appearance in our simulations supports the conjecture that the eccentric instability provides a primary route to the formation of short-period binaries in protostellar systems.

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THREE-DIMENSIONAL RADIATIVE TRANSFER CALCULATIONS ON AN SIMD MACHINE APPLIED TO ACCRETION DISKS. H. Vath, Department of Physics and Astronomy, Louisiana State University, Baton Rouge LA 70803, USA.

We have developed a tool to solve the radiative transfer equation for a three-dimensional astrophysical object on the SIMD computer MasPar MP-1. With this tool we can rapidly calculate the image of such an object as seen from an arbitrary direction and at an arbitrary wavelength. Such images and spectra can then be used to directly compare observations with the model. This tool can be applied to many different areas in astrophysics, e.g., HI disks of galaxies and polarized radiative transfer of accretion columns onto white dwarfs. Here we use this tool to calculate the image and spectrum of a simple model of an accretion disk.

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DYNAMICS OF FLUX TUBES IN ACCRETION DISKS. E. T. Vishniac and R. C. Duncan, Department of Astronomy, The University of Texas, Austin TX 78712, USA.

The study of magnetized plasmas in astrophysics is complicated by a number of factors, not the least of which is that in considering magnetic fields in stars or accretion disks, we are considering plasmas with densities well above those we can study in the laboratory. In particular, whereas laboratory plasmas are dominated by the confining magnetic field pressure, stars, and probably accretion disks, have magnetic fields whose β (ratio of gas pressure to magnetic field pressure) is much greater than 1. Observations of the Sun suggest that under such circumstances the magnetic field breaks apart into discrete flux tubes with a small filling factor. On the other hand, theoretical treatments of MHD turbulence in high-β plasmas tend to assume that the field is more or less homogeneously distributed throughout the plasma [1].

Here we consider a simple model for the distribution of magnetic flux tubes in a turbulent medium. We discuss the mechanism by which small inhomogeneities evolve into discrete flux tubes and the size and distribution of such flux tubes. We then apply the model to accretion disks. We find that the fibrilation of the magnetic field does not enhance magnetic buoyancy. We also note that the evolution of an initially diffuse field in a turbulent medium, e.g., any uniform field in a shearing flow, will initially show exponential growth as the flux tubes form. This growth saturates when the flux tube formation is complete and cannot be used as the basis for a self-sustaining dynamo effect. Since the typical state of the magnetic field is a collection of intense flux tubes, this effect is of limited interest. However, it may be important early in the evolution of the galactic magnetic field, and it will play a large role in numerical simulations. Finally, we note that the formation of flux tubes is an essential ingredient in any successful dynamo model for stars or accretion disks.

We will consider an idealized situation in which there exists a turbulent cascade with a scale L and a turbulent velocity, on the scale of V_T. We will assume that the magnetic field has an rms Alfvèn speed V_A where $V_A \sim V_T$. We will also assume that the typical scale of curvature for the field lines is L. These assumptions are less restrictive than they may appear. If the turbulent cascade actually extends to larger length scales and higher velocities, then the magnetic field is dynamically insignificant on these larger scales and we can still confine our attention to scales of size L or smaller. If the magnetic field is in a shearing flow, surrounded by turbulence of its own creation, then the near equality of V_T and V_A is guaranteed, as well as the curvature of the magnetic field lines on the scale L.

The field lines will tend to stretch at a rate $\sim V_T/L$. If the plasma is highly conducting then the same amount of matter will be entrained on a progressively longer and longer flux tube. In a stationary state this stretching will be balanced by the pinching off of closed loops. These loops will have a radius ~L and a longitudinal compressive force $\sim \rho V_A^2/L$. This tension will be opposed, usually by turbulent stretching with a force of $\sim V_T^2/L$. Some large fraction of the time the loops will collapse. Regardless whether the internal pressure of the loop is dominated by the magnetic field or gas pressure the magnetic tension will decrease more slowly than the turbulent stretching force and the loop will collapse to a plasmoid ball, whose energy is slowly lost to microscopic dissipation. This process will tend to remove matter from the flux tubes at a rate of $\sim V_T/L$, which is rapid and will produce largely evacuated flux tubes under almost any circumstances. If we start from a uniform or nearly uniform field, this process will end when the same amount of flux is divided into some number of intense flux tubes with a magnetic pressure equal to the ambient pressure and a local β of order unity or less. The final rms Alfvèn velocity will be the geometric mean between its initial value and the local sound speed. This increase will occur at a rate comparable to V_T/L, in agreement with the results of numerical experiments [2,3].

What will be the typical radius of the individual flux tubes? A single flux tube with an internal Alfvèn speed of $V_{At} \sim c_s$, and exposed to an ambient turbulent velocity of V_T, will remain coupled to the fluid provided that $r_t < (V_T/V_{At})^2 L$. On the other hand, these tubes will impede the flow, and thereby reduce the ambient fluid velocity below V_T, if the total number N is large enough that Nr_t/L is greater than 1. The requirement that the magnetic energy be divided into N flux tubes is just the requirement that $Nr_t^2 V_{At}^2 \sim V_A^2 L^2$, which implies that the flux tubes will not impede the flow if r_t is comparable to, or greater than, $L(V_A/V_{At})^2$. We conclude that the