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.

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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.

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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

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favored size for intense local flux tubes with $V_{At} \sim c_s$ is just $L(V_A/c_s)^2$ and we expect there to be roughly $(c_s/V_A)^2$ of them per turbulent cell. Each flux tube will be surrounded by a local turbulent wake of size r_t and a large-scale eddy velocity of V_T. This implies that different parts of the tube will tend to diffuse out to a radius at which the turbulent drift is just balanced by attractive effects due to the winding up of the magnetic flux tube. This radius turns out to be $L(V_A/c_s)^2$ so these flux tubes are relatively stable structures. A similar argument, applied to larger-scale, correlated assemblages of such flux tubes, implies that on a scale R one expects to find $(\bar{V}_A/V_A)^2$ flux tubes, of strength $\bar{V}_A \sim V_A(L/R)^{1/2}$.

How quickly will a single flux tube rise? Each flux tube will feel an upward acceleration of g, the local gravity, since each will be significantly underdense relative to the surrounding medium. They will tend to drift upward as fast as allowed by their coupling to the surrounding turbulent medium. Since each is embedded in a local wake with local eddy speed of V_T, and since the buoyant upward rise is slow compared to V_T, we have

$$V_b(V_T / r_t) \sim g$$

or

$$V_b \sim r_t g / V_T \sim \frac{L_g}{V_T}\left(\frac{V_A}{c_s}\right)^2$$

In other words, the tiny flux tubes rise at the speed one would have obtained for the diffuse field. For an accretion disk $L \sim V_A/\Omega$, $g \sim Hc_s$, $c_s \sim H\Omega$, and $V_T \sim V_A$, where H is the disk thickness and Ω is the local Keplerian frequency. Consequently one predicts that magnetic flux is lost from the disk at a rate of $V_A^2/(c_sH)$, in accord with previous estimates based on the assumption of a diffuse field.

In spite of this lack of obvious effect the existence of these small flux tubes turns out to be important for two reasons. First, the separation of magnetized and unmagnetized volumes in the plasma allows us to see how highly conducting dense plasmas can apparently violate the flux-freezing condition and allow nearly independent motion of the magnetic field and the bulk of the fluid. This in turn allows for the possibility of turbulent diffusion and effective dynamo action. This point is extremely important given that recent work in two-dimensional turbulence has cast doubt on the possibility of reconciling dynamo action with flux-freezing [3]. (We note in passing that in two dimensions the formation of flux tubes does not allow large-scale relative motions between the fluid and the magnetic field due to topological constraints.) Second, in radiation-pressure-dominated environments the diffusion of photons into flux tubes will prevent the magnetic field pressure from ever dominating even small volumes in the plasma. This implies large and weak flux tubes that, if effectively evacuated of matter, will be much more buoyant than a diffuse field would be. Consequently the magnetic dynamo in a radiation-pressure-dominated disk will saturate at a lower level, giving rise to a smaller effective viscosity.

References: [1] Kraichnan R. H. (1965) *Phys. Fluids, 8,* 1385. [2] Hawley J. and Balbus S. (1991) *Astrophys. J., 376,* 223. [3] Vainshtein S. I. and Cattaneo F. (1992) *Astrophys. J., 393,* 165.

THE PHYSICS OF BLACK HOLE X-RAY NOVAE.

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X-ray transients that are established or plausible black hole candidates have been discovered at a rate of about one per year in the galaxy for the last five years. There are now well over a dozen black hole candidates, most being in the category of X-ray novae with low-mass companions. There may be hundreds of such transient systems in the galaxy yet to be discovered. Classic black hole candidates like Cygnus X-1 with massive companions are in the minority and their census in the galaxy and magellanic clouds is likely to be complete.

The black hole X-ray novae (BHXN) do not represent only the most common environment in which to discover black holes. Their time dependence gives a major new probe with which to study the physics of accretion into black holes. The BHXN show both a soft X-ray flux from an optically thick disk and a hard power law tail that is reminiscent of AGN spectra. The result may be new insight into the classical systems like Cyg X-1 and LMC X-1 that show similar power law tails, but also to accretion into supermassive black holes and AGN.

The basic properties of the outbursts of the BHXN can be explained by the same accretion disk thermal limit cycle instability that accounts for dwarf novae. The large orbits and low-mass transfer rates qualitatively account for the longer recurrence and outburst timescales. Disk instability models give a good basic representation for the outburst light curves in both the optical and soft X-rays. The basic models do not account for secondary features such as the reflare that has been seen at 50–75 days after outburst in A0620-00, GS 2000+25, Nova Muscae 1991, and GRO J0422+32. These and other minor but systematic features may result from the effects of irradiation [1]. Other phenomena that require exploration are the unique light curve of V 404 Cyg that showed only the power law tail and rapid time variability and may indicate luminosity near the Eddington limit, resulting in disruption in the inner disk and the series of postoutburst flares displayed by GRO J0422+32.

The basic disk models do not account for the hard power law continuum. The fact that the apparent inner radius is fixed during the outburst of the soft X-ray BHXN, independent of the variation of the luminosity and hence the mass flow rate, strongly suggests that the optically thick, geometrically thin disk extends down to very near the last stable circular orbit. Thus models invoked for the hard power law in Cygnus X-1 that rely on an inner corona that subtends a substantial portion of the inner disk are not applicable to these systems. Observations show that the flux in the hard power law does not vary in simple proportion to the soft flux and hence is not simply powered by the mass flow rate through the inner disk. The power law can be approximated by emission from a Comptonized thermal plasma in some cases, but simple single-temperature models are inadequate in other cases. In addition, BHXN outbursts are commonly associated with radio outbursts requiring nonthermal particles and magnetic fields. There is thus a serious question as to whether nonthermal mechanisms contribute substantially to the observed power law spectra.

Two black hole candidates, the 1E Galactic Center source and Nova Muscae 1991, show transient narrow redshifted annihilation