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avored 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 $(V_A/V_A)^2$ 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

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

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 $V_A^2/(c_s H)$, 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.

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THE PHYSICS OF BLACK HOLE X-RAY NOVAE. J. C. Wheeler¹, S.-W. Kim¹, M. D. Moscoso¹, and S. Mineshige², ¹Astronomy Department, University of Texas at Austin, RLM 15.308, Austin TX 78712, USA, ²Astronomy Department, Kyoto University, Sakyo-ku, Kyoto 606-01, Japan.

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

lines. These observations suggest that the annihilation region must be deep in the gravitational potential, but cannot be at the site of the positron production. This suggests that electron-positron pair winds may play a role in transporting the positrons from the site of production to that of annihilation [2]. The suggestion that there are quasi-steady-state flows from within the inner disk in turn suggests that the site of the origin of the hard power law radiation may be the same as that of the positrons, but that it is not a static corona, but rather associated with a steady flow from the inner disk.

Another special aspect of the BHKN is that two of them, V 404 Cyg and A0620-00, have revealed enhancements in Li in the atmosphere of the dwarf companion. This is also seen in Cen X-4, a neutron star transient, so the Li is not a unique signature of black hole systems. Nevertheless, the Li represents an important clue to the evolution of the system and to the physical processes that occur there. Two interesting possibilities are spallation in the disk or the companion star requiring energetic particles, or a precursor phase with a Thorne-Zytkow object, a buried neutron star in which the deep hot-bottom convective envelope may generate Li and mix it to the surface.

References: [1] Kim et al., this volume. [2] Moscoso and Wheeler, this volume.

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GAS DYNAMICS FOR ACCRETION DISK SIMULATIONS.
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The behavior of accretion disks can largely be understood in terms of the basic physical processes of mass, energy, and momentum conservation. Despite this, detailed modeling of these systems using modern computational techniques is challenging and controversial. Disturbing differences exist between methods used widely in astrophysics, namely Eulerian finite-difference techniques and particle codes such as SPH. Therefore neither technique is fully satisfactory for accretion disk simulations. This paper describes a new fully Lagrangian method designed to resolve these difficulties.