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DYNAMO DOMINATED ACCRETION AND ENERGY FLOW: THE MECHANISM OF ACTIVE GALACTIC NUCLEI

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Abstract. An explanation of the magnetic fields of the universe, the central mass concentration of galaxies, the massive black hole of every galaxy, and the AGN phenomena has been an elusive goal. We suggest here the outlines of such a theoretical understanding and point out where the physical understanding is missing. We believe there is an imperative to the sequence of mass flow and hence energy flow in the collapse of a galactic mass starting from the first non-linearity appearing in structure formation following decoupling. This first non-linearity of a two to one density fluctuation, the Lyman-α clouds, ultimately leads to the emission spectra of the phenomenon of AGN, quasars, blazars etc. The over-arching physical principle is the various mechanisms for the transport of angular momentum. We believe we have now understood the new physics of two of these mechanisms that have previously been illusive and as a consequence they impose strong constraints on the initial conditions of the mechanisms for the subsequent emission of the gravitational binding energy. The new phenomena described are: 1) the Rossby vortex mechanism of the accretion disk α-viscosity, and 2) the mechanism of the $\alpha - \Omega$ dynamo in the accretion disk. The Rossby vortex mechanism leads to a prediction of the black hole mass and rate of energy release and the $\alpha - \Omega$ dynamo leads to the generation of the magnetic flux of the galaxy (and the far greater magnetic flux of clusters) and separately explains the primary flux of energy emission as force-free magnetic energy density. This magnetic flux and magnetic energy density separately are the necessary consequence of the saturation of a dynamo created by the accretion disk with a gain greater than unity.

The predicted form of the emission of both the flux and the magnetic energy density is a force-free magnetic helix extending axially from the disk a distance depending upon its winding number and radius of its flux surfaces, a distance of Mpc's. This Poynting flux of magnetic energy would be

invisible unless the currents bounding the magnetic field are dissipated. By definition of force-free, these currents are parallel to the field and throughout its volume. Therefore the dissipation must be throughout the volume as opposed to the conventional reconnection which takes place only at surface layers. This radically different interpretation of reconnection is supported by the observation of "interruption" events in fusion tokamak experiments. Here, and presumably in the galactic case as well, the parallel currents and their dissipation is mediated by run-away, high energy electrons and ions. It is then natural to seek an explanation for the emission spectrum of the dynamo-produced Poynting flux in the same synchrotron emission associated with the dissipation of these run-away currents. We propose the radically different view that these ultra high energy, run-away electrons directly produce the emission spectra as compared to the published models that assume an acceleration of bulk matter to a $\gamma \sim 10$ and then reconvert this kinetic energy by shock heating into a highly relativistic plasma, $\gamma \sim 10^6$.

1. Introduction

1.1. THE NEED FOR A GALACTIC DYNAMO

The mystery of the origin of matter can conveniently be buried in the arcane physics of inflation and symmetry breaking, but the question of the origin of the magnetic fields of galaxies and the still greater challenge of the interpreted magnetic field throughout galactic clusters is more difficult to comprehend. Magnetic fields comprise roughly equal energy density as the background radiation within galaxies, $\sim 3 \times 10^{-6}$ G and perhaps 10% of this energy density $\sim 10^{-6}$ G, in the space between galaxies within galactic clusters (). In both cases it is the magnetic flux that is the greatest challenge, although in the later case the total magnetic field energy is comparable to the binding energy of the cluster galaxies! Unless there is a dynamo, which creates magnetic flux, flux is at most conserved in the collapse or concentration to a galaxy or cluster. In the case of clusters, which are typically $\times 10^3$ the galaxy density of the surrounding space, the flux compression is at best $\propto 1/R^2 \sim \times 100$, implying $\sim 10^{-8}$ G for the IGM. This is a prohibitively large field for the IGM both according to observation ($\sim 10^{-9}$ G from measures of Faraday rotation) as well as theory. The only electrodynamic theory that predicts a pregalactic field is the Bierman battery ( ) where $\sim 10^{-28}$G may be created by thermoelectric currents at the time of decoupling due to the small structure fluctuations of pressure. (Kulsrud, Ostriker and — have suggested a very large multiplication of the

Bierman battery field by pre-galactic turbulence. However, all simulations of the evolution of the ISM from decoupling to galaxy formation, (Zurek et. al. 1994) suggest that turbulence is very small since $\lambda \sim 0.07$, the measure of rotation, is so very small. ($\lambda = v_{rotation}/v_{Keplerian}$). Thus no eddy would make a full revolution in the time from decoupling to the formation of the first large, two to one density fluctuation, or Damped Lyman-α cloud. If the interpretation of the galactic cluster field from rotation measures and x-ray flux were the only confrontation to primordial magnetic field formation, one might reasonably question these measurements and interpretation leaving open the question of the need for a galactic dynamo. However, and surprisingly the extrapolation of the galactic field to the IGM gives nearly the same result. The collapse of a galaxy should lead to an increase in field $B \propto 1/R^2$ provided no significant mass is left behind. However, as discussed in the next section, galaxy formation proceeds in a fashion such as to result in a "flat rotation curve" or $\rho \propto 1/R^2$ or $M \propto 1/R$ or mass density, thickness $\Sigma \propto 1/R$. However, the mass in this case is the dark matter and the baryonic matter that traps the magnetic flux collapses some what further. Therefore conserved flux leads to $B \propto \Sigma$ then $B \propto (1/R)^{-n}$ with $n \sim 3/2$. Since the galactic field extends out to at least 10 kpc and the collapse of the Lyman-α clouds initiates at 300 kpc with an initial radial collapse of a factor of $\times 3$ due to the small value of λ, then the implied initial field in the Lyman-α cloud with flux conservation would have had to have been $B_{cloud} \propto 3^{-2} \times (10pc/100pc)^{1.5} B_{galactic} \sim 10^{-8}$ G. This is so much larger than theory or observation would permit that the need for a galacitic dynamo is evident.

2. The Galaxy, Disk, Black Hole, and Dynamo

2.1. THE GALAXY

Galaxy formation is now reasonably well modeled (Navaro, Frank, & White, 1996, and Warren & Zurek, 19) as the progressive collapse of an initial mass or cloud of matter, a damped Lyman-α cloud, composed of dark and baryonic matter. The gravitational collapse leads to a rotating baryonic disk, the galaxy, with the striking signature of the "flat rotation curve". This constant rotational velocity of the inner major fraction of the mass of every galaxy demands a mass concentration such that the enclosed mass, M, at any radius R is $M_{inner} \propto R$, fig. 1.

The process by which this happens is the poorly understood, rather inefficient exchange of angular momentum by gravitational tidal torquing. It is inefficient in the sense that a fractional exchange of angular momentum is at a significant reduction of the enclosed mass and hence $M \propto R$. Nevertheless the baryonic mass thickness, Σ increases as $\Sigma \propto 1/R \propto 1/M$. When

Figure 1. Galaxy formation starts with the collapse of a Lyman-α cloud initially by a factor of $\sim \times 3$ until it reaches Keplerian support at $\sim \lambda \sim 0.4$ where a sequences of bar instabilities. bifurcations and tidal torquing results in the classic "flat rotation curve" or $\rho \propto 1/R^2$. $M \propto R$ and hence thickness. $\Sigma \propto 1/R$. At the critical thickness. $\Sigma \sim 100$ g cm^{-2}. $M_{disk} \sim 10^{7 to 8} M_{\odot}$ a Rossby vortex accretion disk commences.

this thickness becomes large enough to support a "Rossby vortex accretion disk", the transport of angular momentum becomes nearly 100% efficient and nearly all the enclosed baryonic mass evolves to the center, the black hole. A "Rossby vortex accretion disk" is, we believe, the physically consistent explanation of the hither to, parameterization (Shakura & Sunyaev 1973), called the $\alpha-$viscosity disk.

2.2. THE DISK

This critical thickness, for what we believe is the explanation of the fluid, hydrodynamic transport of angular momentum in an accretion disk, is the criterion for the formation of Rossby vortices, (Lovelace, Li, Colgate, & Nelson, 1998) which in turn, requires the confinement of heat or constant entropy in the disk for a period of several to ten rotation periods of the Keplerian orbits. The necessary limitation of the radiation cooling then requires that $\Sigma \sim 100$ g cm^{-2}, depending upon details of the opacity and specific heat. After the initial collapse of the Lyman-α cloud to Keplerian support, $\Sigma \simeq 10^{-2}$ g cm^{-2}, at 100 kpc. Then the enclosed baryonic mass in the disk when $\Sigma \sim 100$ g cm^{-2} is $M_{disk} \simeq M_{initial} \times (\Sigma_{initial}/\Sigma_{100g}) \simeq 10^{7to8} M_{\odot}$ at a radius of 3 to 10 pc. This is a mass typical of the likely mass of the central black hole of AGN.

2.3. THE BLACK HOLE

This mass of the accretion disk, the canonical value of $\sim 10^8 M_{\odot}$, then evolves to the black hole in a time, $\sim 10^8$ years, a time governed primarily by the gravitational condensation process of galaxy formation that feeds the disk. The energy released during this time is, of course, nearly all of the gravitational binding energy of the black hole, leading to the typical luminosity of $L_{AGN} \sim 10^{46}$ ergs/s. In addition to the major flow of gaseous and ionized matter in the disk, a few stars will be accreted in addition. We know that there is strong evidence for a small fraction of stars, $F_{stars} \sim 10^{-4}$, having formed prior to the Lyman$-\alpha$ cloud because of the small initial metallicity implied by the absorption lines. These stars must follow the evolution of the dark matter, because their trajectories are essentially collisionless relative to the other baryonic matter. Thus these pre-black hole stars will be distributed the same as the dark matter, $M_{enclosed} \propto R \propto \Sigma$. They will be orbiting and colliding with the disk in random orbits at a frequency $\nu_{collisions} \propto \Sigma \times v_{stars} \propto R^{-3/2}$. The evidence for this apparently minor phenomena, is the broad (high random Doppler velocity) emission lines of quasars or AGN. Without a major dynamic force such as a star disk collisions (Zurek, Siemiginowska, and Colgate, 1994) it is most unlikely for thermal energies to eject matter from the disk to high enough altitude and at low enough temperature to produce this emission. Despite this apparent minor role in the mass accretion of the formation of the black hole. these collisions provide a critical role in producing a dynamo from the black hole accretion disk.

2.4. STAR-DISK COLLISIONS AND THE α-DEFORMATION

The star-disk collisions produce an episodic, off-axis, large mass, deformation of the disk matter ejecting it to a high altitude. $\sim R$ above the disk exactly as needed to produce not only the broad emission lines, but also the critical $\alpha-$deformation of the $\alpha - \Omega$ dynamo. We can also estimate that the number of such collisions is sufficient for the $\alpha-$deformation necessary for the dynamo gain. The number of stars inside the outer radius. $R_{outer} \sim 10$ pc is $M_{disk} \times F_{stars} \simeq 10^4$. Each star with average thickness. $\rho_{star} R_{star} \simeq 10^{11}$ g cm^{-2} will make a number of collisions with the disk of $\rho_{star} R_{star} / \Sigma_{disk} \sim 10^9$ or a total number of collisions of stars with the disk of $\sim 10^{13}$ or one every 300 s for 10^8 y. Since, by gravitational concentration, the major fraction of these collisions will occur at small radius. close to the black hole. we estimate that for an innermost stable orbit period of $\sim 3 \times 10^3$ s at an average radius close to the black hole of twice the innermost stable orbit. later described as $R_{helix} \simeq 7 \times 10^{13}$ cm. that 5 to 10 collisions. $n_{collisions/turn}$. will take place per orbit period of the innermost fraction of the disk. The toroidal flux is $\Phi_{toroidal} \simeq B_{\phi} H R_{helix}$ G cm^2. and each collision will displace a flux $\Phi_{collision} \simeq 2(Mach_{\#})^{1/2} B_{\phi} H R_{star}$ G cm^2 where the Mach number of the collisions is $Mach_{\#} = H/R_{helix} \simeq 100$. (Zurek. et. al. 1996). Therefore the fraction of the toroidal flux displaced by star disk collisions into poloidal flux per turn will be $F_{\phi-toroidal-poloidal} \simeq n_{collisions/turn} \times Mach_{\#} \times R_{star}/R_{helix} \sim 0.15$. The dynamo gain. considering the very high, near infinite, magnetic Reynolds number of the the flow and the rotation of the collision plumes by expansion. will be $\sim (1 + F_{\phi-toroidal-poloidal})$, thereby ensuring positive dynamo gain in the region where the major fraction of the accretion energy is released.

2.5. THE SATURATED DYNAMO AND DYNAMO DOMINATED ACCRETION

The combination of differential rotation within the disk and the energetic collisions of a few, $\sim 10^{-4}$ mass fraction, of stars in orbits nearly orthogonal to the disk leads to conditions that are ideal for the formation of an $\alpha - \Omega$ dynamo. Any dynamo, by definition, implies a gain greater than unity. and thus the magnitude of a seed field will exponentiate in time depending upon this gain. Since the characteristic unit of time is the period of the inner most stable orbit around the black hole, or $\tau \sim 10^4$ s, then during the above evolution time of 10^8 y, the smallest marginal gain, $\epsilon << 1$ will amplify, $\exp \epsilon(t/\tau)$, even the smallest seed field, e.g. that of the Bierman battery of $\sim 10^{-23}$ gauss in less than a few years, $t \sim 10^8$ s, to macroscopic fields of sufficient strength, $\sim 10^{4 to 5}$ G, to alter the fluid dynamics of accretion. We call this accretion condition Dynamo Dominated Accretion, or DDA. The characteristic of DDA is that the magnetic fields of the dynamo build up to sufficient strength so as to alter the fluid flow in the disk in such a fashion as to reduce the gain of the dynamo and thus lead to a limiting (mean) field value, the "saturation field". We believe that this resulting saturated dynamo leads to the phenomena associated with AGN: the AGN (Quasars, Blazars, BL-Lac objects) emission spectra, the collimated radio and optical sources, the superluminal velocities, the ultra high energy cosmic rays, and the magnetic flux of the galaxy and meta-galaxy.

3. The Galactic Dynamo

The mechanism of an $\alpha - \Omega$ dynamo in the disk is that a poloidal bias field is wrapped up by a differential torque of Keplerian orbits into an enhanced toroidal field, the Ω-deformation, where this toroidal field is initially contained within the disk. The torque necessary to wind this magnetic field is derived from the flux of angular momentum in the accretion disk, flowing away from the black hole. Hence, the work done by this torque appears either directly as heat in the standard α-viscosity accretion disk (The α-viscosity of accretion disks is not to be confused with the α-deformation of the $\alpha - \Omega$ dynamo.) or as magnetic energy if the torque does work primarily against the magnetic field. The poloidal field is augmented by the α-deformation, driven by star - disk collisions, which displaces axially a fraction of the toroidal flux and rotates it into the poloidal plane. These deformations are shown in fig. 1. Thus DDA describes the case when the major fraction of the potential energy of accretion appears initially as energy of magnetic field. This magnetic energy then fulfills several observable functions in the formation of AGN and galaxies.

1) First the dissipation of a major fraction of this magnetic energy gives rise to the emission spectrum characteristic of AGN, quasars, blazars, and BL Lac objects.

2) An additional fraction illuminates and delineates the striking topology of the collimated radio sources and radio lobes with their dramatic superluminal velocities.

3) The magnetic flux generated by the dynamo is partly conserved and fills both the galactic volume with the observed magnetic field of the galaxy as well as a much larger volume, $\sim \times 10^3$ of the galactic flux, of meta-galactic

Figure 2. The mechanism of an $\alpha - \Omega$ dynamo in the disk is that a poloidal bias field, a quadrapole field, is wrapped up by a differential torque of Keplerian orbits into an enhanced toroidal field, the Ω-deformation. The poloidal field is augmented by the α-deformation, driven by star - disk collisions, which displaces axially a fraction of the toroidal flux and rotates it into the poloidal plane. This rotated loop of flux must reconnect and then add to the original poloidal, quadrupole flux to create dynamo gain.

space.

4) The very large scale coherent magnetic and electric fields are the natural conditions for accelerating the ultra high energy cosmic rays.

Here we will concentrate on the spectrum of the dissipation of the bulk of the magnetic energy. but first we must consider the topology of the saturated dynamo.

3.1. THE TOPOLOGY OF THE SATURATED DYNAMO

Saturation occurs because the field strength builds to a value large enough to alter the hydrodynamic flows that produce the dynamo in the first place. This may be either the α or the Ω deformations. Since the α deformation is driven by star - disk collisions. the relative high matter density of the stars relative to that of the disk implies that the α deformation will not be affected by a value of the magnetic stress that would otherwise seriously perturb the Keplerian flow within the disk. (This is opposite to the case of a stellar or planetary dynamo where we expect that the α deformation is produced by convection, which is relatively weak compared to the stress of differential rotation within the body.) Therefore, in DDA, saturation will first occur by limiting the $\Omega-$ deformation or the differential rotation of Keplerian orbits. and so we expect the dynamo toroidal and poloidal field strengths to increase to values that reduce the differential Keplerian flow. This requires a torque whose value is the angular momentum flux within the disk. By the virial theorem this torque times the angular velocity is the potential energy flux of accretion. Therefore the full energy flux of accretion must flow through magnetic fields in the case of DDA.

The toroidal and poloidal fields that can produce this torque are limited by the fluid stresses within the disk. The maximum toroidal field within the disk is limited by the confining gravitational pressure within the disk, or $(B_{toroidal}^2/8\pi) \sim \Sigma g(H/R)$ where Σ is the mass per unit area of the the disk, g is the local gravity due to the black hole at radius R. and H is the vertical height of the disk. This field will be bounded by a radial current density, J_R, at the surface of the disk. The torque on the fluid within the disk is then $\mathbf{R} \times \mathbf{J_R} \times \mathbf{B_{poloidal}}$. External to the disk, by definition of "external", the pressure and density is small. The vertical gravity of the disk, $g(H/R)$, and modest temperatures ensure a small thermal scale height and hence an exponentially small density vertically from the disk. However, in spite of an infinitesimally small matter density, the plasma conductivity can be effectively infinite (high magnetic Reynolds number) and so external to the disk. flux and flux lines will be conserved in a force-free configuration. This force free configuration depends upon the winding of the poloidal field.

The poloidal field that results in maximum gain of an accretion disk dynamo will be quadrapole in order that the radial component in the midplane of the disk will be in one radial direction only. The toroidal field wrapped up from this single direction radial flux will therefore also be in a single toroidal direction (as opposed to a counter direction across the midplane as would occur for a dipole poloidal field). The star - disk collisions entrap and axially displace flux from an entire cross section of the disk. and therefore the single direction flux from the quadrapole field will be strongly favored for dynamo gain compared to a dipole - produced. counter direction poloidal flux.

3.2. CONSEQUENCES OF THE DYNAMO AND WRAPPING UP THE POLOIDAL FLUX

Each loop of quadrapole flux. produced by star-disk collisions. is tied.within the disk. at two radii. R_{inner} and R_{outer}. and because of the Keplerian orbits will have angular velocities ω_{inner} and ω_{outer}. The difference in number of turns in a finite time. Δt. results in a winding number of turns $n_{differential} = \Delta t(\omega_{inner} - \omega_{outer})$. which is manifested as a winding of the quadrapole flux both inside and outside the disk. If the toroidal field resulting from this winding were confined axially either inside or outside the disk. then the resulting toroidal field would become infinite as more turns of flux are added. Thus the energy density and the axial stress would become infinite. As a consequence long before infinite stress. the increasing toroidal field expands axially by an amount sufficient to maintain the pressure balance condition within the disk as well as the force - free condition outside the disk. The pressure balance within the disk is maintained by a constant number of differential turns. $\simeq B_{toroidal}/B_{quadrapole}$ within the disk. which in turn is maintained. despite $n_{differential}$. by matter sliding along the quadrapole field line as the toroidal flux exits the disk at both R_{inner} and R_{outer}. The radial component of the helical field is small because the hoop stress of the azimuthal field is in balance with the compression of the axial component of the field and thus maintains the force-free helix at near constant radius as a function of length. Therefore the centrifugal force from the Keplerian rotation is orthogonal to the field lines. and so any consequential motion of the matter along the field lines is small. In addition there is no stress due to the field alone on conducting matter moving along uniform field lines without instabilities Therefore. since the thermal scale height for an equilibrium temperature atmosphere above the disk is small. $< 1\%$ compared to the radius. the matter density on force-free field lines becomes infinitesimally small. because the matter will always fall back to the disk. (The residual matter density is determined by a balance between charge separation electric field and the electric field due to current carrier starvation of the current.) Therefore nearly all the winding of the quadrapole flux occurs external to the disk. This wound flux must, by definition, take on a force free configuration of minimum energy. This occurs at constant flux when the two components, $B_z^2 \simeq B_\phi^2$, resulting in a helix of ~ 45 deg. (The force free condition actually results in a changing angle or ratio of B_z/B_ϕ as a function of R, but 45 degrees is a sufficient approximation for present purposes.) The winding of the helix extends axially a distance Z_{max} depending upon time and the number of turns, and a similar helix of larger radius, fewer turns and weaker field describes the return flux line intersecting the surface of the disk at R_{outer}.

4. The Helix

Since the mass and therefore kinetic energy of matter on the field lines is so small, the torque and accretion energy appear entirely as magnetic stress. This is compared to Blandford and Payne (1982), where the torque is derived from the radial flow of matter along co-rotating field lines even though the helices extend far from the disk. In this case of DDA the torque is created by $\mathbf{J} \times \mathbf{B}$ forces within the disk and is transmitted from inner to outer radii through the tension in the extended, helical field lines that connect matter in the disk at inner radii to matter in the disk at outer radii. This is possible when $\rho \sim 0$ on field lines. Thus the magnetic energy is ejected quasi-statically, or sub-Alfven, from the disk in the form of a continuously wound helix. One end of a flux line of the helix is anchored in the rapidly rotating inner orbit of the disk. The return of this flux line occurs first radially at some large axial distance from the disk (the limiting extent of the helix) and then returns towards the disk, intersecting the disk at R_{outer}. The inner radius is where the major fraction of the potential gravitational energy is released. The magnetic energy produced per turn will be $W_{magnetic} \simeq 2\pi^2 R_{inner}^3[(B_z^2 + B_\phi^2)/8\pi]$ in a time of $2\pi R_{inner}/v_\phi$; or a luminosity of $L \simeq v_\phi R_{inner}[(B_z^2 + B_\phi^2)/8\pi]$. This describes a helical, force free flux tube that is extending axially from the disk at a velocity $v_z \simeq v_\phi$. Thus in the time, $t_{blackhole} \sim 10^8$ y, the maximum extent of the helix would be $Z_{max} \leq 10$ Mpc. We expect both dissipation of the magnetic energy as well as the mass of the IGM to truncate this length, fig. 3.

Since the winding of each flux surface depends upon the matter velocity in the disk at its respective Keplerian orbit, the velocity of axial extension of each flux surface or "tube" decreases as $R^{-1/2}$ and therefore describes a cone of flux surfaces surrounding the most energetic helix, or the R_{helix} flux surface. In addition the axial velocity of all these flux surfaces, i.e. the cone, is always large compared to thermal velocities of the ISM through which the flux surfaces are proceeding. The dynamic pressure of this interaction is the most likely origin of the external boundary pressure and hence outer

Figure 3. The quadrapole poloidal flux of the dynamo is tied at two radii. The differential Keplerian rotation of the disk winds this flux surface into a force-free magnetic helix of many turns, $\sim 10^{12}$, and extending Mpc's. It is force-free because the matter falls back gravitationally to the disk. It extends at the velocity of the inner most orbit, because $B_Z \sim B_\phi$ at minimum energy and force free. The binding energy of the formation of the black hole is emitted as magnetic energy, the Poynting flux, of the force-free helix.

boundary condition of the helix. We expect this pressure to decrease as a function of the axial distance from the disk because of decreasing density with axial distance in the galaxy and we therefore expect the helices to expand (moderately) as a function of axial distance. This same external weak dynamic pressure undoubtedly plays a significant role in maintaining the rectilinear progression of the helix without major kink instabilities.

4.1. EXPANSION OF THE HELIX AND GENERATION OF B_Z FLUX

The consequential rearrangement of the force-free field can not take place with both hydromagnetic stability and flux conservation (Taylor) and so a complicated resistive instability creates additional axial flux at the expense of a fraction of the azimuthal flux. This process in "the reversed field pinch" has sometimes been misleadingly called a "dynamo" because it seems to generate axial magnetic flux without any obvious "engine". Instead a topological rearrangement of azimuthal to axial flux takes place by a "suspected" resistive tearing mode. Regardless of the details of this poorly understood rearrangement of flux, a minimum energy configuration is preserved, and the near-45 degree helix is maintained.

(One can understand intuitively the need for such a rearrangement of flux when one considers the consequence of a presumed conservation of each orthogonal flux separately. Then $B_\phi \propto 1/R$ and $B_z \propto 1/R^2$. Consequently an expansion in R will enforce $B_\phi >> B_z$ and either a kink instability due to the small pitch angle of the flux or a violation of the minimum energy condition will occur. Nature evidently prefers a solution that reestablishes both minimum energy and a stable equilibrium.)

The problem is now to describe the emission spectrum from the dissipation of this magnetic energy.

4.2. ANALOGOUS MAGNETIC HELICES: THE TOKAMAK, SOLAR FLARES AND THE RADIO LOBES

We first list the approximate, or gross magnetic and plasma properties of the AGN helix necessary for an estimate of its emission properties. We will make analogies to the major, extensive experimental and theoretical plasma physics of the tokamak confinement fusion research. We first note that such a force free magnetic helix is similar to the familiar magnetic confinement topology of the tokamak and also to the presumed topology of solar flares, but, however, with one major difference: Both the tokamak and solar flares are force free magnetic helices that are limited in length, the tokamak by the circumference of the toroidal confinement vessel, and the solar flare by the length of the loop between its ends, tied in the solar surface. In contrast one end of the AGN magnetic helix can expand in length to a minimum energy equilibrium independent of the imposed winding number of the boundary condition at one end. In the tokamak and solar flare, a change in winding number necessarily imposes a new or different topology and thus new or different stability conditions. Thus the zoo of instabilities that these two configurations are subject to, may not necessarily apply to the AGN helix. However, when the AGN helix extends axially and expands radially sufficiently that the dynamic pressure of the IGM exceeds that of the helical magnetic field, the free axial expansion will be impeded and the AGN helix topology will be altered and the pitch or the winding increased. The above "zoo" of instabilities will presumably then take place and are the probable explanation of the luminosity of the "radio lobes". With this caveat in mind we summarize the properties of the AGN helix when its axial extension is not limited by dynamic pressure.

4.3. THE APPROXIMATE HELICAL FIELD

A helical force free field is maintained by a current density, $\mathbf{curl} \times \mathbf{B}$, which, by definition of force free, must be along field lines and thus is a current density $J_{||}$. In the case of a helical field, this current both maintains the axial component of the field, B_z, by the azimuthal component of the current, J_ϕ, and visa versa for B_ϕ and J_z. The topological difference of the axial component of the current is that the integral of J_z over the cross section of the helix results in a total current, I_{helix}, that extends axially and rectilinearly with the helix. If this current, I_{helix}, were confined to just the axis, then we know, by Maxwell's equations, that $B_\phi \propto 1/R$. However, we know that current will be carried by flux surfaces of sequentially larger radii consistent with the boundary conditions of both Keplerian winding and dynamic pressure of the the ISM, and in addition modified by the force free condition, $\mathbf{curl} \times \mathbf{B} \times \mathbf{B} = \mathbf{0}$ as well as by the poloidal flux distribution produced by the saturated disk dynamo. This will be a computational problem for the future, but for now we need to find a sufficient approximation in order to estimate the gross properties of the luminosity from the helix.

The magnetic energy carried from the saturated dynamo by the helix is $L_{helix} \simeq (B^2/8\pi) \times (area) \times v_z$ or the Poynting flux of magnetic energy density. Since $B_\phi = I_z/5R$ where I_z is the axial current included inside R in amperes, then $L_{helix}(R) \propto I_z^2$. Since the major fraction of the gravitational energy of accretion must be released close to the black hole, then the major fraction of I_z will be concentrated at small radius. Thus as an approximation we assume that the current leading to the luminosity of the AGN is uniformly distributed in an area corresponding to twice that of the the minimum stable orbit around the black hole, R_{min}. For a Schwarzschild black hole, i.e., without rotation, $R_{min} = 6R_{BH}$, but because of the accretion of some, perhaps half, of the residual angular momentum at R_{min}, we expect the black hole to be partially, perhaps half way, towards a limiting Kerr black hole and so $R_{min} = 3R_{BH}$. With this approximation we choose $R_{helix} = 6R_{BH}$. Then since for a $10^8 M_\odot$ black hole, $R_{BH} = 1.2 \times 10^{13}$ cm, we have $R_{helix} = 7.2 \times 10^{13}$ cm. For a canonical DDA AGN where $L_{helix} = L_{46} = 10^{46}$ ergs/s and a mean velocity of the helix of c/3, then within this radius $< B > \sim 4 \times 10^4$ G and $B_\phi = B_z = 3 \times 10^4$ G and so $I_{helix} = 10^{19}$ amperes or a flux of electrons of $\Phi_e = 6 \times 10^{37}$ electrons s^{-1}.

4.4. ELECTRICAL ENGINEERING DESCRIPTION OF THE HELIX

The current carrying helix can be described as an inductance.

$L_{inductance} \simeq ln(R_{outer}/R_{inner})L_{helix} \times 10^{-8}$ henries. Thus the stored energy of the helix is $W_{helix} = L_{inductance} I^2_{helix}/2$, or for $I_{helix} = 10^{19}$ amperes, $\simeq 2 \times 10^{29}$ joules/cm. At an axial extension velocity of c/3, this results in the AGN luminosity of 2×10^{46} ergs/s. If the current in an inductance is interrupted in a time Δt_I, then a voltage is developed across the inductance. This voltage times the current times the time is just the stored energy. Thus to reduce or dissipate this stored energy requires either a change in the inductance or a resistive dissipation of the current. The topology of the helix and hence its inductance, is determined by the force free condition and winding number. We presume, by the observed extraordinary extension of the helix or "jet", that the helix is stable to the kink, $(m = 0, 1, l = 1)$, instability. Presumably this is due to the minimum energy condition. Thus any dissipation of the magnetic energy must be resistive, $\eta J^2_{||}$, in nature. We will later derive the consequences of assuming that the resistivity, η, is due to the synchrotron and Comptonized synchrotron radiation drag on relativistic run-away electrons carrying the current. However, whatever the origin of the resistivity, there will necessarily be an electric field, $E_{||} = \eta J_{||}$, and this electric field will reduce the current as well as accelerate some particles not affected by η.

4.5. TORQUES

If the current of the helix is reduced along its length by dissipation, then by conservation of current around a circuit, a fraction of the total I_{helix}, must return radially from the inner helix to the outer boundary helix. This radial current $\mathbf{I_{radial}} \times \mathbf{B_{radial}}$ is an increment of the torque supplied by the accretion disk between R_{outer} and R_{inner}. The total torque is accounted for by $\mathbf{I_{helix}} \times \mathbf{B_{helix}} \times (\mathbf{R_{outer}} - \mathbf{R_{inner}})$.

4.6. THE MAGNETIC FLUX OF THE GALAXY AND METAGALAXY

The total magnetic flux generated by the saturated dynamo is concentrated towards the inner more energetic regions. To the extent that $B \propto 1/R$, then the flux generated, $\mathbf{B} \times \mathbf{R} \times \mathbf{v} \propto R^{-1/2}$, and we can approximate the flux generation by considering only the innermost helix. Then in 10^8 y. the total flux becomes 6×10^{43} G cm^2. The flux of the galaxy using a mean field $B_{glaxy} \sim 3 \times 10^{-6}$ G for a galaxy height of 1 kpc and radius of 30 kpc is 10^{39} G cm^2, or 10^{-4} of the generated flux and $\sim 10^{-3}$ of the escaping residual flux. This extra flux can escape the originating galaxy and fill the meta galaxy. The rotation measures and x-ray luminosity of the intergalactic region within galaxy clusters indicate possibly $\times 10^3$ the flux between galaxies as within each galaxy, and so the saturated dynamo of DDA forming the black hole is sufficient to explain the flux of magnetic field of the galaxies as well as the larger flux within galactic clusters.

4.7. THE BLACK BODY DISK

We now summarize the physical properties of the helix as well as calculate some of its plasma properties, but first we point out what the standard α-viscosity accretion disk would have looked like without the DDA. We start by assuming a standard α-viscosity disk with the α-viscosity parameter $\sim 1/10$. Although we believe this enhanced viscosity is produced by Rossby vortices, the actual mechanism makes no difference. For an accretion rate corresponding to $L_{helix} = 10^{46}$ ergs/s and an efficiency of 0.3 corresponding to the inner orbit of $3M$ we require a mass flow rate of $(1/2)M_{\odot}\ y^{-1}$. Then $\Sigma = dM/dt/(2\pi R_{min} \alpha c/3) = 70$ g cm^{-2}. This is thick enough to establish black body radiation even for Compton opacity, but we next determine that the emission temperature will be low enough and consequently the opacity great enough to ensure not only black body, but sufficient thickness, $\tau \sim 10 to 100$, to satisfy the Rossby vortex confinement criterion. Thus if the luminosity is emitted black body from both sides of the disk, then at the radius, R_{helix}, the surface temperature becomes $T_{surface} \simeq [L_{AGN}/(2\pi R^2_{helix} ac/4)]^{1/4} \simeq 30$ eV. This is in the euv part of the spectrum where opacities are increased by both helium and small fractions of metals thus substantiating the larger opacity. The height of the disk, H, is determined by the pressure and gravity, or $(aT^4_{midplane} + nkT) \simeq \Sigma g(H/R_{helix})$ giving $H/R \sim 0.06$ where we estimate $T_{midplane} \sim T_{surface}$, because the radiation cooling time is shorter than the heating time. Thus without a dynamo, we have a standard thin disk of modest thickness and surprisingly low temperature, 30 eV, compared to the high energy emissions of quasars and blazars. Furthermore the energy density within the disk, $aT^4 = B^2_{helix}/8\pi$ of the dynamo, since in either case the energy flows through photons or magnetic energy. However, only in the case of the dissipation of the magnetic energy can we expect the very much higher energies of the typical AGN emission.

4.8. SUMMARY OF DISK AND HELIX PLASMA CONDITIONS

If a major fraction of the energy of accretion is emitted in magnetic energy, $\sim 80\%$, then we expect the surface emission temperature due to the residual heating, 20%, to be ~ 20 eV. Then the disk height becomes $H \sim 0.012R$. The DDA disk then is described by:

Mass of black hole:

$$M_{blackhole} = 10^8 M_{\odot}$$

Time to accret this mass:

$$t_{accret} = 10^8 years$$

Schwarzschild radius of the black hole:

$$R_{blackhole} = 1.2 \times 10^{13} cm$$

Radius of innermost stable orbit:

$$R_{innermost} = 3M = 3.6 \times 10^{13} cm$$

Radius inside of which half the energy is emitted:

$$R_{helix} = 2R_{innermost} = 7 \times 10^{13} cm$$

Outer radius of $\alpha-$accretion disk:

$$R_{outer} \sim 3pc$$

Surface density or thickness of the disk at R_{helix}:

$$\Sigma = 70 gcm^{-2}$$

Luminosity of the disk in black body radiation assuming 80% is emitted in magnetic energy:

$$L_{blackbody} = 2 \times 10^{45} ergs/s$$

Surface temperature of the inner disk assuming 80% is emitted in magnetic energy:

$$T_{blackbody} = 20ev$$

Height of disk in units of its radius:

$$H_{disk}/R_{helix} = 0.012$$

Density within the disk:

$$\rho_{disk} = \Sigma/H_{disk} = 10^{-10} gcm^{-3}, n_e = 6 \times 10^{13} ecm^{-3}$$

Ion electron thermal relaxation rate

$$n_e \sigma_{coulomb} (m_e/m_i) v_e \simeq 2.4 \times 10^6 s^{-1}$$

Mass fraction of stars:

$$F_{stars} = 10^{-4}$$

Number of collisions per star:

$$\rho_{star} R_{star}/\Sigma_{disk} \simeq 10^9$$

Fraction of toroidal flux transformed to poloidal flux per turn:

$$F_{\phi-toroidal-poloidal} \simeq 2(Mach\#)^{1/2} \times R_{star}/R_{helix} \simeq 0.015$$

Dynamo Gain per turn at R_{helix}:

$$\sim (1 + F_{\phi-toroidal-poloidal}) \simeq 1.15$$

The magnetic flux generated in 10^8 y:

$$B \times R \times v \simeq 6 \times 10^{43} Gcm^2$$

Luminosity of the disk as magnetic energy of the helix:

$$L_{Helix} = (v_\phi/2) \times (\pi R_{helix}^2) \times B_{helix}^2/8\pi \simeq 10^{46} ergs/s$$

Mean magnetic field of inner disk and inner helix:

$$B_{helix} \simeq 4 \times 10^4 G$$

Axial velocity of the helix at R_{helix}:

$$v_{z,helix} = v_\phi = v_{Keplerian} \simeq c/3$$

Length per turn:

$$z_{turn} = 2\pi R_{helix} = 4.5 \times 10^{14} cm$$

Free length of helix without truncation by dissipation or matter:

$$Z_{max} = v_{z,helix} t_{blackhole} \simeq 10 Mpc$$

Axial current or electron flux of the helix:

$$I_{helix} = \mu R_{helix} B_{helix} \simeq 10^{19} amperes = 6 \times 10^{37} e/s$$

Number density of current carriers at velocity c:

$$n_{eq} = I_{helix}/(\pi R_{helix}^2 c) \simeq 0.12 cm^{-3}$$

Fractional energy density, $F_{runaway}$ of current carriers at a relativistic γ compared to the magnetic energy:

$$F_{runaway} = n_e \gamma mc^2/(B_{helix}^2/8\pi) \simeq 1.3 \times 10^{-15} \gamma$$

Distance of charge separation necessary to result in a potential of γmc^2 of relativistic current carriers:

$$F_{chargeseparation} \simeq [\gamma mc^2/(4\pi n_e e^2)]^{1/2} \simeq 5 \times 10^5 \gamma^{1/2} cm$$

These last two conditions describe the current carrying charges as a low β, charge neutral plasma nearly regardless of the run-away relativistic energy, γmc^2.

5. The Dissipation of Magnetic Energy and the AGN Luminosity

We have described the conversion of gravitational energy to magnetic energy in the form of an extended force free minimum energy helix. In order to convert this energy to photons and thus become visible, requires that the bounding currents of the magnetic field be dissipated. These can be dissipated either resistively or hydromagnetically. Next to the black hole the strength of the field relative to the density of matter or equivalently the assumption of force free precludes hydromagnetic dissipation. At the "radio lobes" the mass and density of matter is presumably great enough at 100's of kpc that hydromagnetic phenomena become important and then presumably the remaining fraction of the magnetic energy is dissipated both hydromagnetically as well as resistively, and presumably, potentially by hydromagnetic instabilities. Here, however, we are concerned with the far more demanding explanation of the bulk of the energy emission with short time variations (hours) and therefore close to the black hole and the extraordinary spectral distribution over 17 orders of magnitude of photon energy. The most demanding of these spectra, that of Markarian 421 requires emission extending from the radio to TeV and so we use this example for comparison to theory.

5.1. THE DIRECT EMISSION BY THE ELECTRON CURRENT

We strongly believe that it is far simpler to produce this spectra directly by the current carrying electrons themselves whose dissipation is the dissipation of the magnetic energy, rather than producing the spectra through a sequence of phenomena currently described as hydromagnetic acceleration, collisionless shock interaction, turbulent heating to relativistic temperatures, and finally synchrotron and Compton emission from this relativistic plasma.

Instead we believe that the current carrying electrons are directly accelerated as a run away distribution of electrons by the dissipation itself. This leads to the circular or self-consistent description where the dissipation of the magnetic energy creates the parallel electric fields that produce the acceleration that in turn produces the dissipation. This dissipation is then directly the spectra of AGN. As proof of principle of this process we first describe laboratory measurements in Tokamaks where exactly this phenomenon is described. The run away parallel current of electrons dissipates the magnetic energy by synchrotron radiation and this dissipation or synchrotron emission in turn self regulates the electron acceleration. Next we describe this process and derive the special conditions required for a consistent theory to produce the spectra of Markarian 421. These conditions will include the self excitation of a very small degree of plasma turbulence, $\Delta B/B = 3 \times 10^{-3}$, too small and at too low a frequency, (the lower hybrid mode) to heat the plasma, and furthermore quasi-coherent over $B/\Delta B \simeq 10^3$ wave lengths. Although these conditions may seem special, they are surprisingly close to those produced in the laboratory, but on a far larger scale.

5.2. THE RUN AWAY CURRENT

In tokamak plasmas the plasma current, primarily $J_{||}$, because $\beta = nkT/B^2/8\pi$ is small, is carried by current carriers whose drift velocity, $v_{drift} << (kT/m_e)^{1/2}$. Occasionally an "interruption" event occurs where the current, initially carried benignly by electrons of modest drift velocity, suddenly transforms into a run away current of relativistic energy. The initial (free) magnetic energy $B^2_{\phi initial}/8\pi$ is divided between kinetic energy, $n_e \gamma mc^2$ and final magnetic free energy, $B^2_{\phi final}/8\pi$. The "free" magnetic energy, $W_{free} = \int B^2_\phi/8\pi d(vol)$, is the energy associated with the toroidal plasma current and would appear as "heat" if the current were interrupted. (In a tokamak, since the vacuum vessel is a torus, the convention of axial and azimuthal is reversed from the accretion disk. The **z** direction is toroidal, the direction of the initial bias field, and that of the major plasma current, and the azimuthal direction, ϕ, is the direction of the field lines surrounding this current. The sum of these two field components describes a helix confined within the vacuum vessel and is the direct analogy to the helix produced by DDA.) This division of energy between kinetic and potential is then sometimes referred to as the conservation of canonical angular momentum. Regardless, the total kinetic energy in the $\sim 10^6$ ampere beam at $\gamma \sim 10 to 100$ of a typical large experimental apparatus is sufficient at times to seriously damage the equipment. As a consequence, experimentally, an interruption event is to be avoided at any cost in major tokamaks and is researched only with great care. Nevertheless the general outline of the plasma physics is understood whereby plasma is initially lost to the walls, typically by a *ballooning mode instability*. When a "ballooned" flux surface carrying hot plasma touches the cold wall, plasma is lost to the wall, thereby depleting the interior of sufficient electrons to carry the current at low drift velocities. This condition, $J_{\|}/n_e \sim> (kT/m_e)^{1/2}$ is known as the Driecer condition for run away acceleration of the current carriers. The cure for experimental conditions is to inject a large number of electrons and ions, initially as a neutral gas, which are then subsequently ionized by the plasma whenever such an instability occurs.

5.3. AN EXPERIMENTALLY OBSERVED SELF-LIMITED, RUN AWAY CURRENT BY ITS OWN SYNCHROTRON RADIATION

At times, and with care, the properties of the run away relativistic beam can be investigated as at Garching (Kurzan, Steuer, & Fussmann, 1995, & 1997) where the run away beam current of an interruption are accelerated to a monoenergetic, self limited value at an energy of $\gamma \sim 20$. This self-limiting energy is very much less than the flux limited acceleration where $\gamma = ceB_\phi \times area/mc^2 \simeq 10^{3 to 4}$. The beam was observed to radiate by synchrotron radiation stimulated at a high, 17^{th}! harmonic, of the small perturbations, $\Delta B/B \sim 10^{-3}$ of the periodic toroidal field coils. This radiation in this case is an experimental curiosity but at the scale of the AGN helix it becomes a basic radiation mechanism of the AGN.

5.4. THE PROBABLE AND NECESSARY PLASMA TURBULENCE

The interpretation of the cause of interruptions in tokamaks and the effectiveness of the cure seem simplistic, but the hard question is: why doesn't the electric field accelerating the run away current draw the necessary plasma back into the current beam? If the hot plasma is lost to the walls, the thermal gradient generates electric field potentials of only a few kT where as the run away acceleration requires potentials many orders of magnitude greater. These electric fields are along field lines and so there should be no impedance to plasma flow. The plasma loss occurs in the first place presumably because a flux surface is distorted "ballooned" from inside to outside the plasma current carrying column, and so the flow of plasma and hence current carrying electrons should be reversible regardless of the slow, hydromagnetic, ballooning instability. The fact that it is evidently not reversible implies a large impedance for electron flow along lines of force.

5.5. THE LIKELY INSTABILITY LEADING TO THE PLASMA TURBULENCE

This instability is most likely an oscillation of the field lines at a finite amplitude, driven at the lower hybrid frequency as a lower hybrid mode. The field itself by definition of force free is absolutely stable, and only an external source of energy, the current, can power a finite oscillation. The effective non-linear impudence, η_{wave} extracts energy from the current, $\eta_{wave} J^2_{parallel}$, that drives the wave or mode parametrically. The lower hybrid mode is suspected because "current drive" of a tokamak current is created by a forced, non-linear amplitude of the lower hybrid waves by an external source of radio frequency power at the lower hybrid frequency. The excitation of the mode by $J_{||}$ is then just the inverse of the "current drive". The closest mechanical analogue is the violin where the bow, $J^2_{||}$, excites a finite oscillation of the strings, $B^2_{||}/8\pi\rho$.

6. THE ESTABLISHMENT OF THE RUN AWAY CONDITION IN THE AGN HELIX

As noted in the summary conditions above, the electron density for the relativistic run away condition of the helix is $n_e \simeq 0.1\ cm^{-3}$ compared to an electron density in the disk of $n_e \simeq 6 \times 10^{13}\ cm^{-3}$. At the modest temperature of the radiation dominate disk of 20 to 30 eV, the Debye length, $\simeq 10^4$ cm even at the run away condition, $n_e \simeq 0.1\ cm^{-3}$, and so is always small compare to the scale height, $\sim 10^{11}$ cm. Therefore neutral plasma conditions persist and so gravity determines equally the electron and ion densities. As pointed out before, the radial component of the helical field lines as they enter or leave the disk is negligible so that vertical gravity determines the density along field lines above the disk. The vertical component of gravity a distance z_{atm} above the disk is $g_z \simeq g z_{atm}/R$ and so the scale height for a constant temperature atmosphere becomes $H_{scale} = H_{disk}(R/z_{atm})$. Therefore the height above the disk where the plasma atmosphere density should decrease to the run away condition is $z_{atm,runaway} \simeq H_{disk}[\ln(n_{eq,disk}/n_{eq,runaway})]^{1/2} \simeq 6H_{disk}$, or very close to the disk surface. Therefore even without some form of $J_{||}$ instability, the relativistic run away condition should be met. However, as pointed out above, consistency with the assumption of only gravitational forces acting along the magnetic field lines, the electric field of run away acceleration must be small compared to the Debye field. For this picture to be consistent with actual run away acceleration. some additional turbulence must be present to confine or immobilize the thermal electrons.

7. THE EMISSION SPECTRUM FROM THE AGN HELIX

There are two possible conditions for the emission spectrum of the AGN helix.

1) There are no $J_{||}$ instabilities and the entire radiation from the AGN helix is by curvature synchrotron radiation and Comptonized synchrotron radiation. However, in order to reach the necessary luminosity the required electron $\gamma \sim 10^{10}$ is too large to be realistic.

2) This required level of plasma turbulence is maintained, $\Delta B/B$, by $J_{||}$ instabilities due to the run away current. This relativistic run away current radiates the helix magnetic energy by synchrotron and Comptonized synchrotron radiation from the curvature due to the ΔB perturbation field alone.

As opposed to the usual fully tangled magnetic field in isotropic turbulence. we look for a small finite level of turbulence on top of the highly organized force free, minimum energy helix. The objective is to find the conditions for producing the broad band emission of Markarian 421 from radio to TeV. We assume that $F_{\Delta B} = \Delta B/B$ is excited by $J_{||}$. We must then satisfy the following criteria:

1) The electron energy, $\gamma mc^2 > Tev$ or $\gamma > 2 \times 10^6$.

2) In order for the second peak in the spectra at TeV energy to have comparable total energy flux as the first or synchrotron peak, the thickness to Compton up-scattering,

$$\tau = n_e \sigma_{Klein Nishina} R = [I_{helix}/(\pi R^2 ec)]\sigma_{KN} R = 1/\gamma^2$$

or $R_{Compton} = 21 R_{helix}(\sigma_{KN}/\sigma_{Compton})$. Here we have used the current and field of the helix.

3) The first synchrotron peak should be at 2 keV or $2 \times 10^{17} Hz$ so that:

$$\omega_{cyclotron}\gamma^2 \simeq 2 \times 10^{17} Hz$$

or $B_{effective} = 0.05G$ for $\gamma = 2 \times 10^6$.

4) The total total synchrotron and Comptonized synchrotron radiation should be of order $L_{helix} \simeq 10^{46} ergs/s$ or :

$$L_{helix} = \gamma^2 [I_{helix}/(\pi R^2)] \sigma_{Compton} (B^2_{effective}/8\pi) \pi R^3 l$$

or

$$\gamma^2(B^2_{effective}/8\pi)lR = 3\times 10^{32}/L_{46}$$

or

$$B^2_{effective}l = 10^7/L_{46}G^2cm$$

or for a maximum $l = 10^2$, or $lR = 0.03pc$ and $L_{46} = 0.1$ because of beaming, then $B_{effective} \simeq 100G$, in which case $F_{\Delta B} = \Delta B/B = 3\times 10^{-3}$. This is in strong contrast to the condition for the first peak where $B_{effective} \simeq 0.05G$. The only solution to these conflicting values without producing a separate or additional hot plasma of similar energy, γ is to arrange that the synchrotron emission is semi-coherant as if the relativistic electrons were emitting in a "wiggler" field of coherent length $\lambda_{coherent} = R_{Larmorelec.}(B_{effectiveemission}/B_{effectivefrequency}) \simeq 2\times 10^3$. Such a structure of field perturbations is not unlikely if the mechanism of generating the perturbations is the excitation of the lower hybrid modes at a level $(B_{effectiveemission}/B_{helix})^2 \simeq 10^{-5}$ corresponding to the above conditions. Whether such a mode and emission mechanism is a result of the run away conditions in the helix is, of course, uncertain. However, the model produces the central black hole during galaxy formation, produces the magnetic field of galaxies and the meta galaxy, produces the inherantly collimated source of magnetic energy to illuminate the collimated radio jets, the force free helical magnetic field, produces a run away current of highly relativistic electrons that carries the energy of formation of the black hole, and finally does so in a circumstance where instabilities are expected.

On the other hand there may be geometric solutions to the fundamental problem kof creating the emission spectra from the run away electrons of the current alone. We have not yet explored all these possibilities.

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References

Zurek, W.H., Siemiginowska, and Colgate, S.A., 1994, Ap.J., 434, 46. & Addendum ibid. 470, 652

Blanford and Payne (1982

Sturrock, 1971 ApJ., 164, 529

Kurzan, B., Steuer, K.H, & Fussmann, G., 1995, Phys. Rev. Let.; 75, 4626

Kurzan, B. Steuer, K.H., 1997; Rev.Sci.Inst., 68,.423

Kurzan, B., Steuer, K.H.1997, Phys Rev., 55, 4608.

Navaro,J.F., Frank, C.S., & White, S.M., 1996, Ap.J, 462, 563.

Lovelace, R.V.E., Li, H., Colgate, S.A., & Nelson, A.F., 1998, "Rossby wave instability of Keplerian accretion disks", submitted.

Shakura, N.I. & Sunyaev, R.A., 1973, A&A, 24, 337