Jet Formation in BH -disk systems

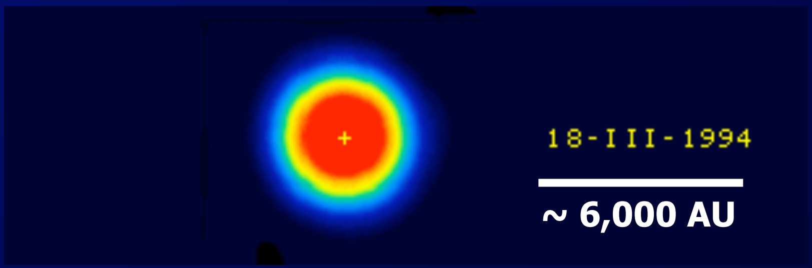
How do large-scale magnetic fields get there and what happens when they do?

Lovelace, Kronberg, Matt, Bellan, & Li

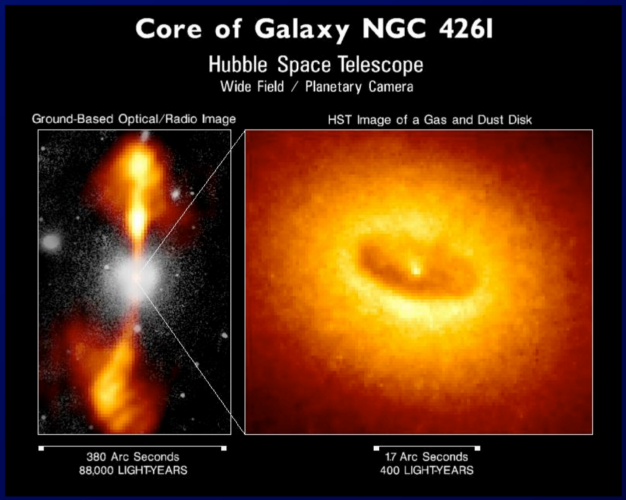
Workshop on Plasma Astrophysics, PPPL, January 2010

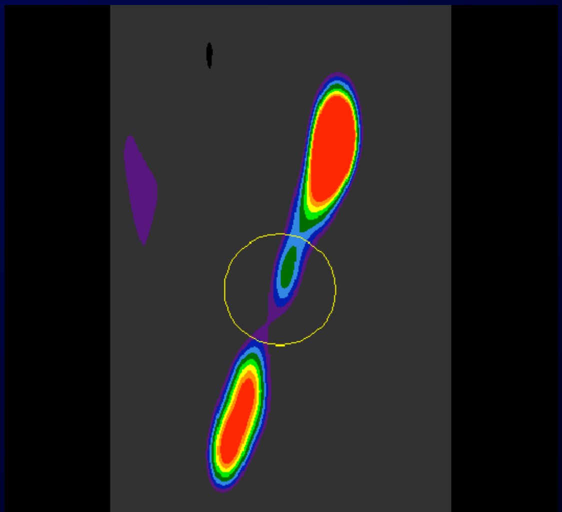
Observations of Jets
(a very concise summary)

There are a lot of them.



Mirabel & Rodríguez (1994)





Mirabel & Rodríguez (2002)

Astrophysical Jets and Winds

2. Accreting objects:

A) Winds $v_w > v_{esc}$

a. Radiatively,
b. Thermally,
c. Magnetically,
d. ν-driven winds (GRBs).

B) Jets (collimated winds) from:

a. BHs with accr. disks (AGNs, microquasars)

+

a'. Large-scale B field from disk dynamo or advection in disk.

b. Magnetized stars with accr. disks (protostars, neutron stars, white dwarfs, etc)

+

b'. Large-scale B field from the star, disk-dynamo, or advection in the disk.

C) Magnetically driven jets:

a. Magneto-centrifugal jets.

$$\left(\rho_j v_j^2 \sim B^2/4\pi\right)_{z\sim 10\ r\_S}$$

-- disk winds/jets (Bl.-P).
-- X-winds (Shu).
-- Conical winds (RUKL).

b. Magnetically-dominated jets.

$$\left(\rho_j v_j^2 << B^2/4\pi\right)_{z\sim 10\ r\_S}$$

-- Poynting-flux jets / Magnetic towers from disks.
-- Poynting-flux jets from disk/Kerr BH interface (Bl.-Z).
-- Poynting-flux jets from open polar field lines of rapidly rotating accreting stars.

Compelling Questions

1. If the jets are magnetically mediated, where do the large-scale fields come from in BH/disk systems?   What controls the advection, diffuison, and/or dynamo of ${\bf B}$ field in MRI disks ($\beta >1$) and the non-MRI disk corona ($\beta<1$).   What determines the small (VLBI) and large-scale ${\bf B}-$field structure of jets and is the Poynting-Robertson effect involved?

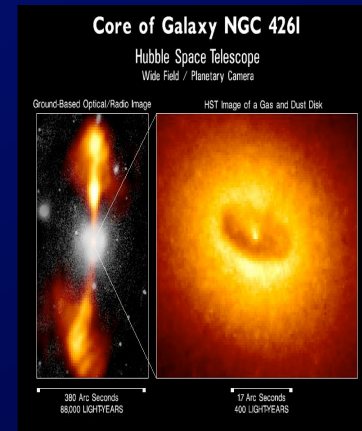
2. What is (are) the mechanism(s) for {\it efficiently} accelerating leptons {\it in situ} to energies sufficient to give TeV radiation (shock acceleration, reconnection, KH instability, ..)?   Do UHECRs come from BH/disk/jet/lobe systems?

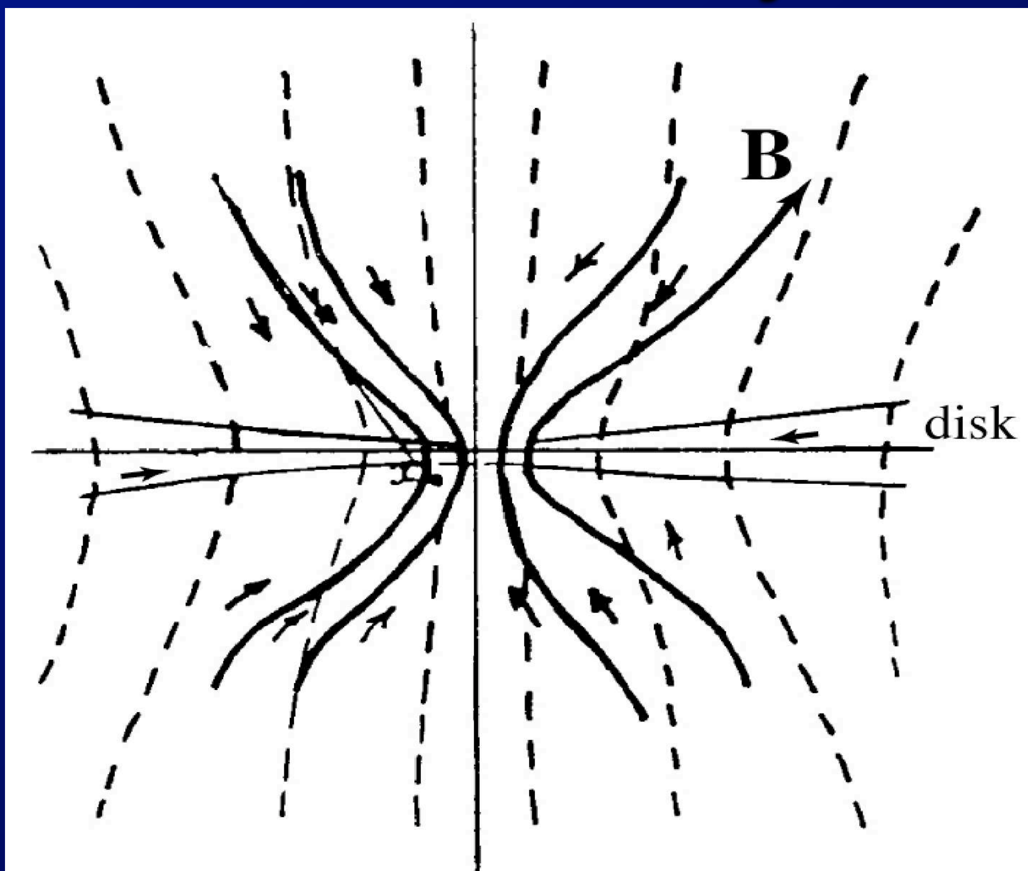
Theoretical Models of Jets

(a very concise summary)

They require large-scale magnetic fields.

The picture you might have in your head





Bisnovatyi-Kogan & Ruzmaikin 1976

Advection and compression of a weak field leads to a strong field in the inner disk.

Lovelace 1976

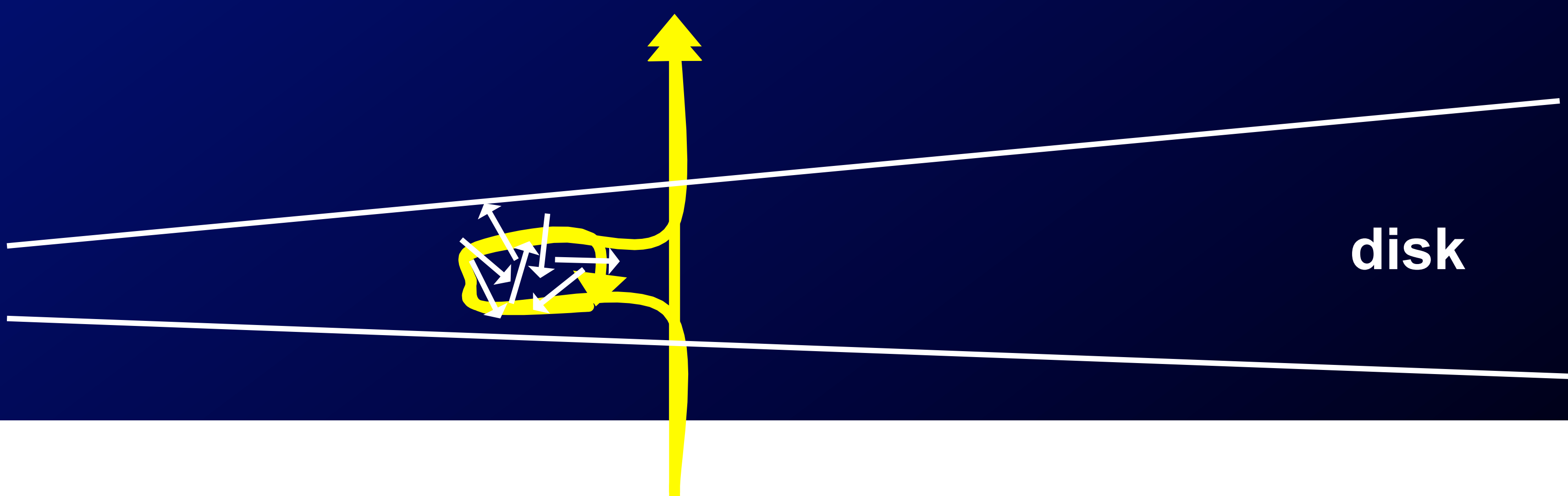
Blandford 1976;

Blandford & Znajek 1977

But problems with this idea were discovered in the 1990's

- Turbulence responsible for accretion also leads to enhanced reconnection (field diffusivity)
- A turbulent disk is a poor conductor
- Weak fields cannot advect inward in a thin disk

e.g., van Ballegooijen 1989; Lubow et al. 1994; Lovelace et al. 1994; Heyvaerts et al. 1996



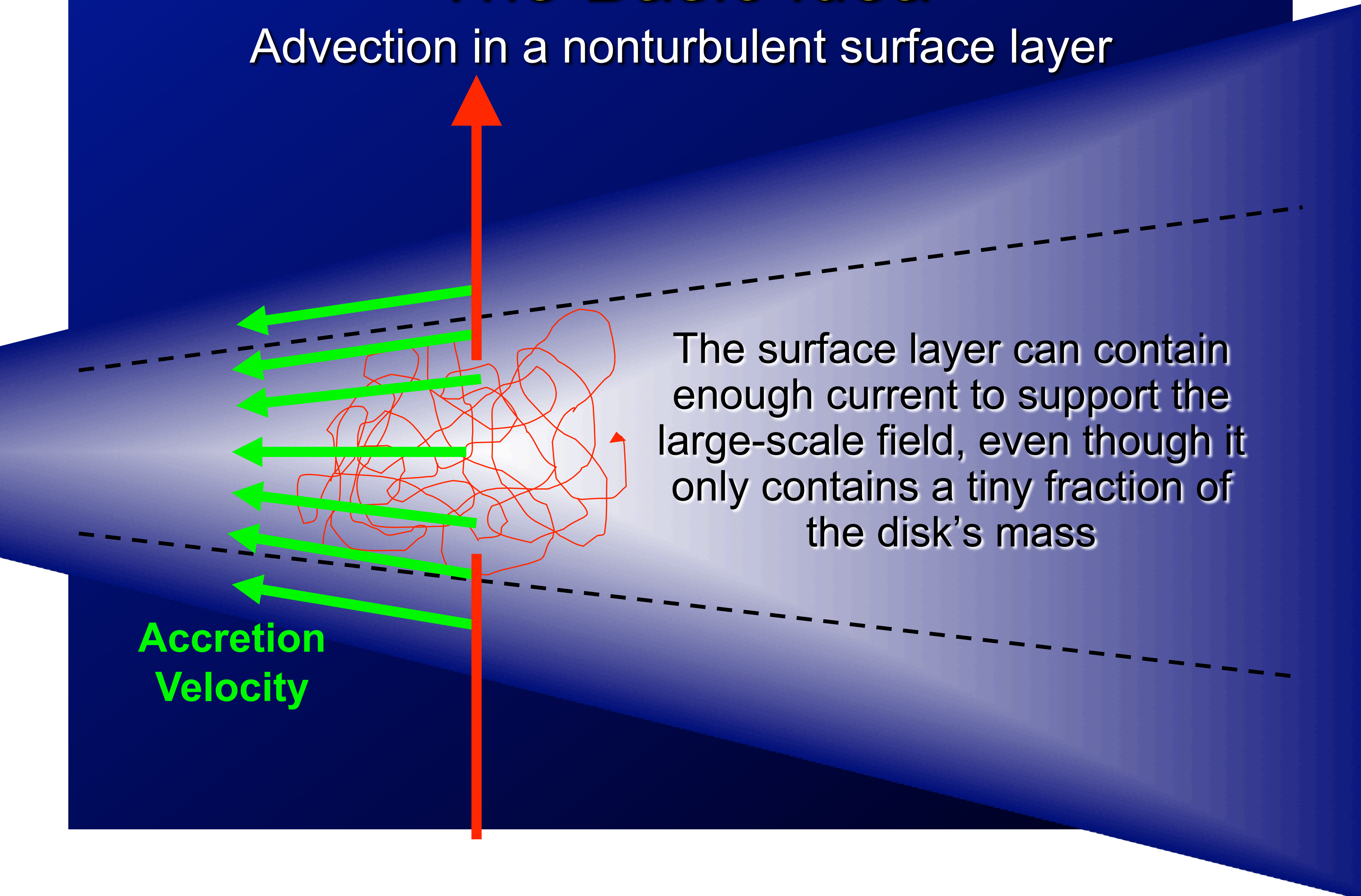
How might weak magnetic fields be able to advect inward?

Model 1: The surface layer of the disk is nonturbulent (i.e., highly conducting. It can support inward field advection (Bisnovatyi-Kogan & Lovelace 2007; Rothstein & Lovelace 2008; Lovelace, Rothstein,& Bisnovatyi-Kogan 2009

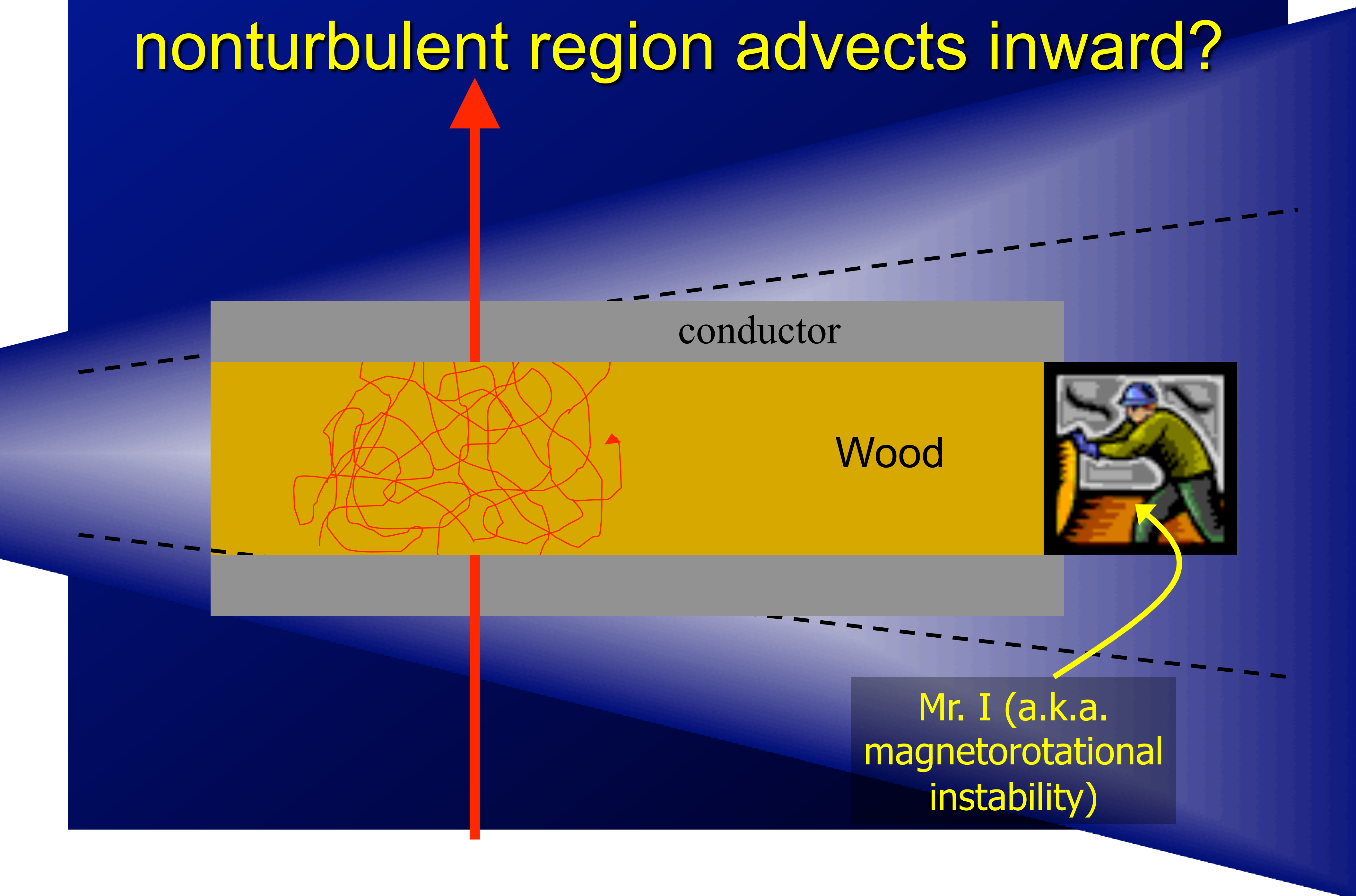
Model 2: Non-axisymmetric dbn of Bz (Spruit & Uzdensky 2005)

The Basic Idea

Advection in a nonturbulent surface layer



How do we determine if the nonturbulent region advects inward?



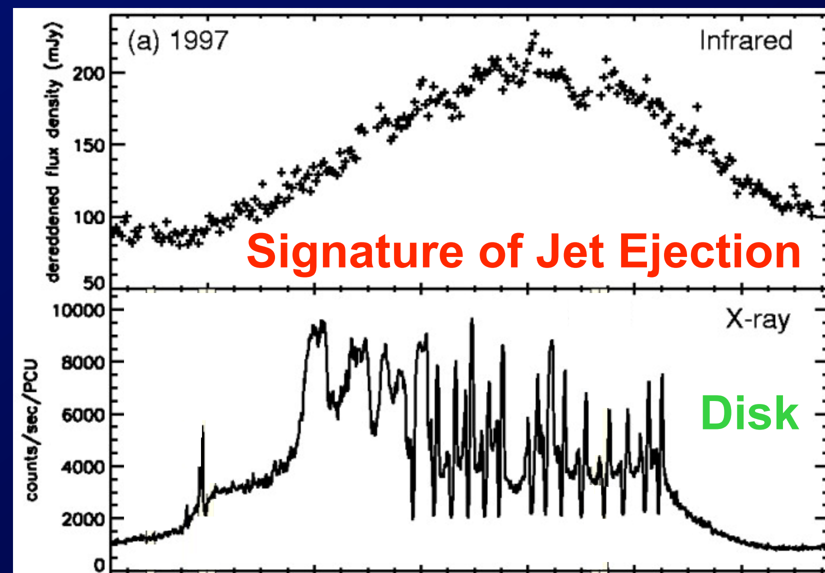
disk-jet connection

advected magnetic field

jet

turbulent disk timescales

(see also Tagger et al. 2004)



~ 20 min

Observations of GRS 1915+105

(Eikenberry et al. 1998; Rothstein et al. 2005)

Transport of Large Scale Poloidal Flux in Black Hole Accretion

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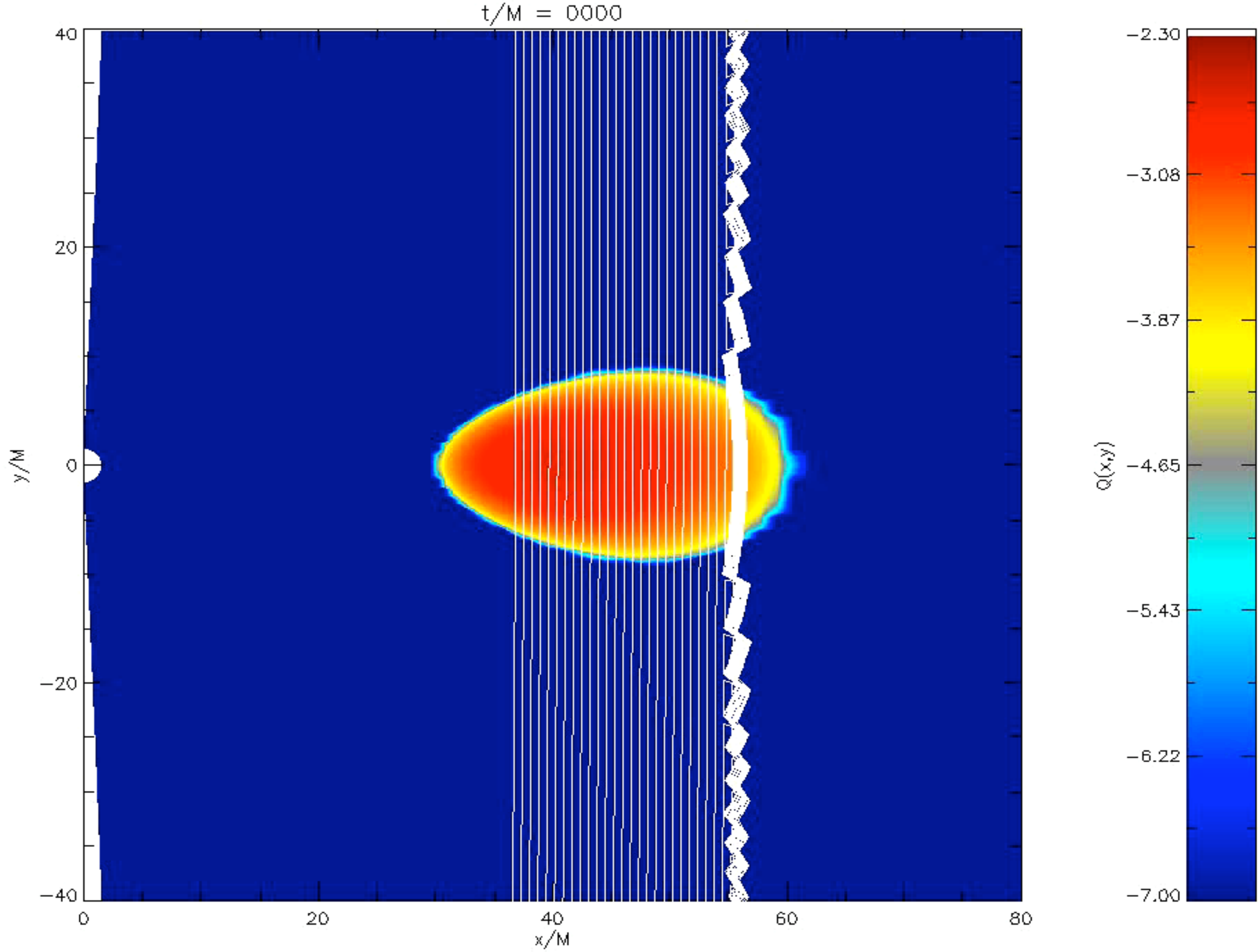
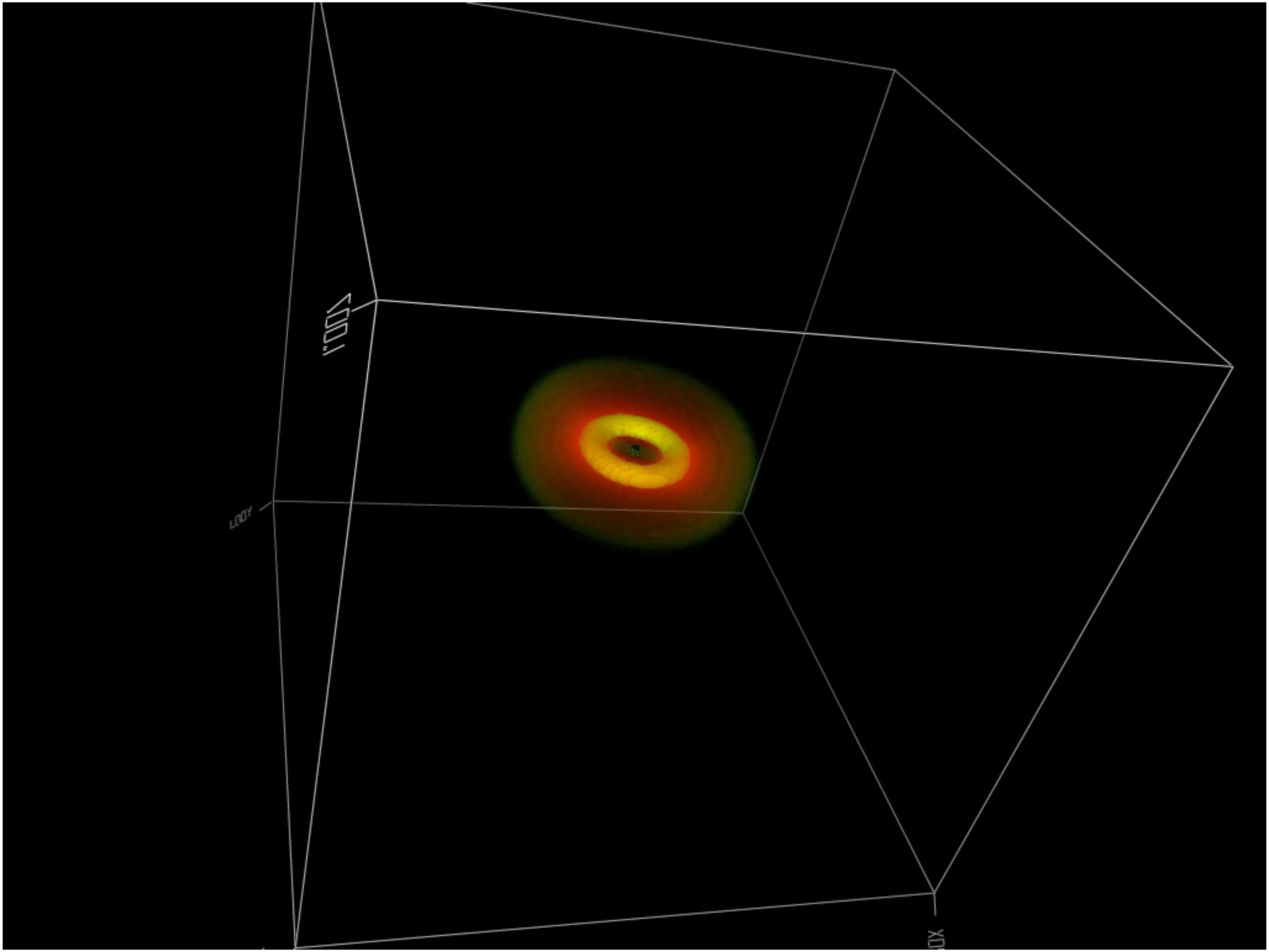
ABSTRACT

We report on a global, three-dimensional GRMHD simulation of an accretion


t/M = 0000
y/M
x/M
Q(x,y)
40
20
0
−20
−40
0
20
40
60
80
−2.30
−3.08
−3.87
−4.65
−5.43
−6.22
−7.00

3D GRMHD Jet Simulations

Jonathan McKinney
Stanford/Kipac



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doi:10.1088/0004-637X/702/2/L148

THE INVARIANT TWIST OF MAGNETIC FIELDS IN THE RELATIVISTIC JETS OF ACTIVE GALACTIC NUCLEI

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ABSTRACT

The origin of cosmic magnetic (B) fields remains an open question. It is generally believed that very weak primordial B fields are amplified by dynamo processes, but it appears unlikely that the amplification proceeds fast enough to account for the fields presently observed in galaxies and galaxy clusters. In an alternative scenario, cosmic B fields are generated near the inner edges of accretion disks in active galactic nuclei (AGNs) by azimuthal electric currents due to the difference between the plasma electron and ion velocities that arises when the electrons are retarded by interactions with photons. While dynamo processes show no preference for the polarity of the (presumably random) seed field that they amplify, this alternative mechanism uniquely relates the polarity of the poloidal B field to the angular velocity of the accretion disk, resulting in a unique direction for the toroidal B field induced by disk rotation. Observations of the toroidal fields of 29 AGN jets revealed by parsec-scale Faraday rotation measurements show a clear asymmetry that is consistent with this model, with the probability that this asymmetry came about by chance being less than 1%. This lends support to the hypothesis that the universe is seeded by B fields that are generated in AGNs via this mechanism and subsequently injected into intergalactic space by the jet outflows.

Key words: accretion, accretion disks – galaxies: active – galaxies: jets – galaxies: magnetic fields – magnetic fields

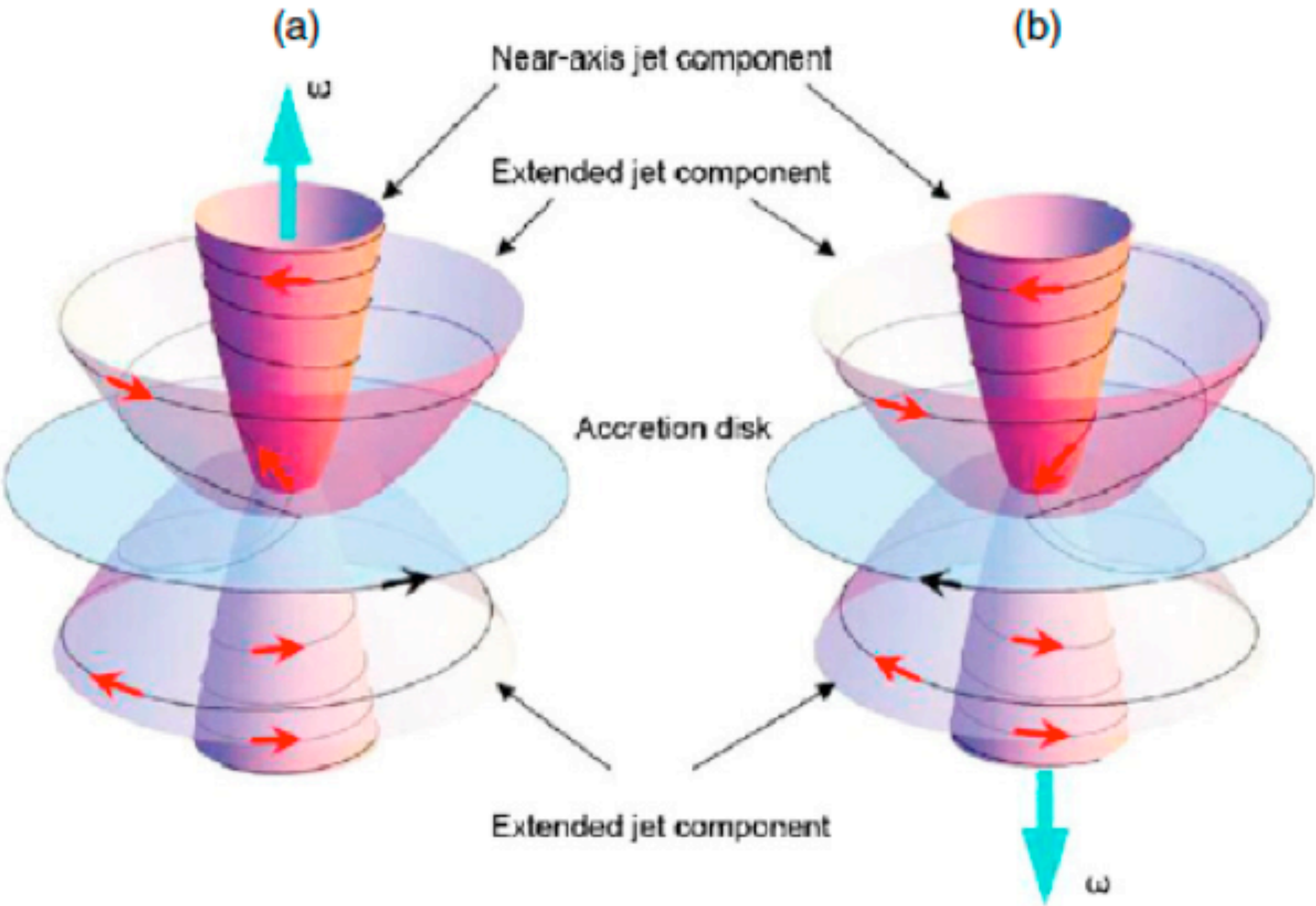
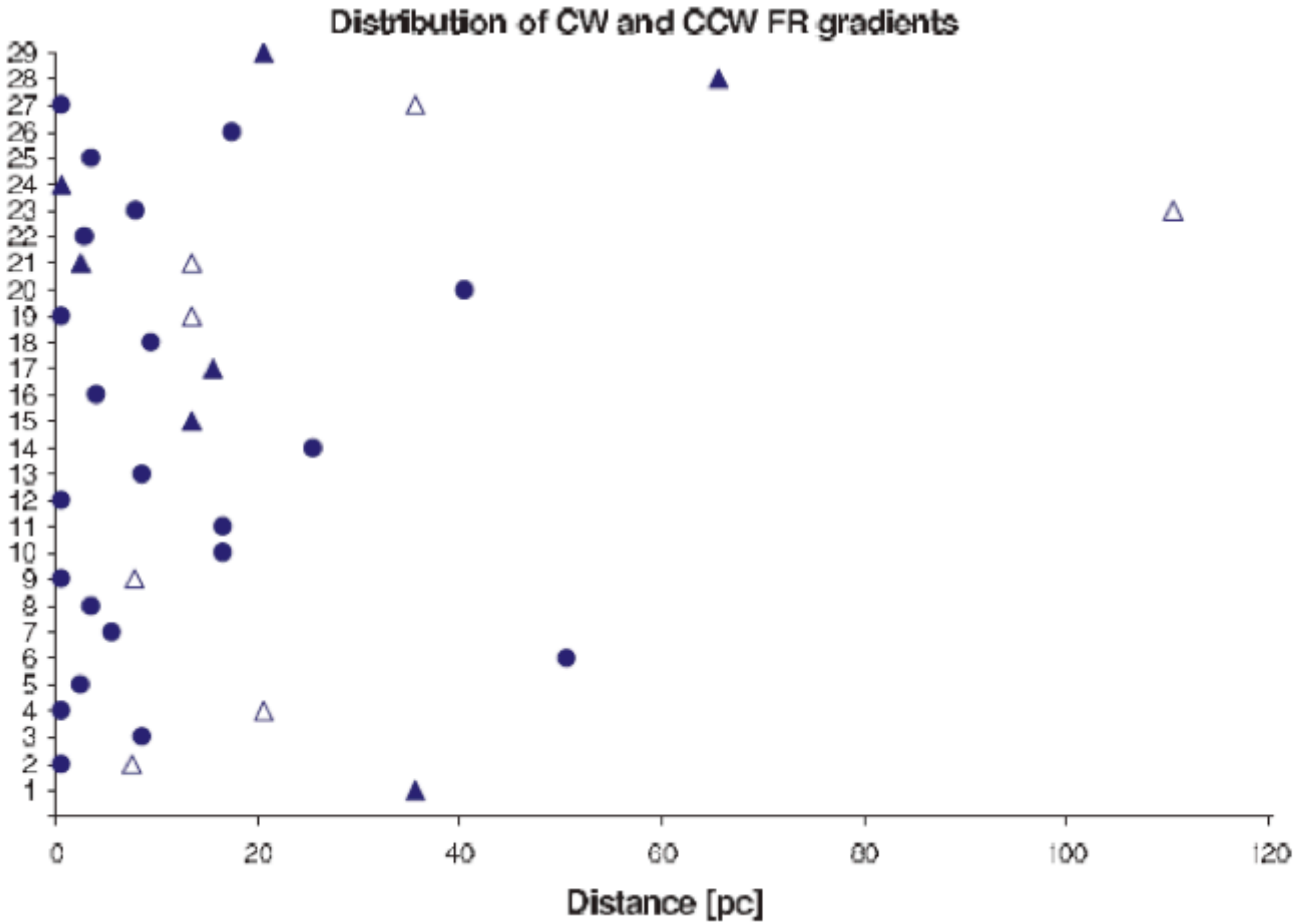


Figure 1. Sketch of an AGN jet B field generated by the PR battery (black lines with red arrows) near the axis and periphery of the jet. The direction of disk rotation is shown by the black arrows in the disk and the corresponding angular velocity vector by the cyan arrows. The observer is located in the (a) northern and (b) southern hemispheres of the disk.


Distribution of CW and CCW FR gradients
29
28
27
26
25
24
23
22
21
20
19
18
17
16
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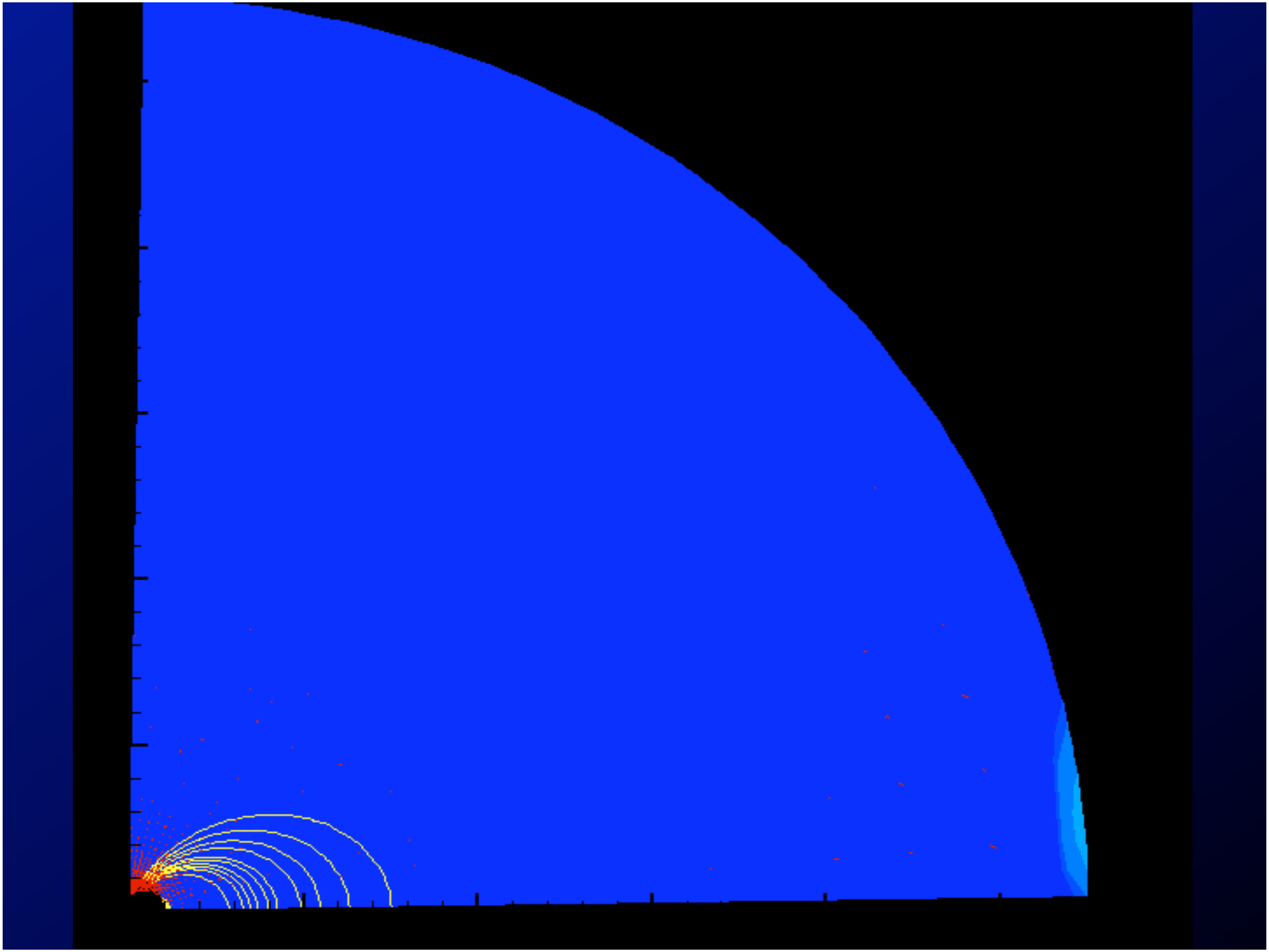
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
Distance [pc]

Conical Winds and Axial Jets From the Disk Magnetosphere Boundary

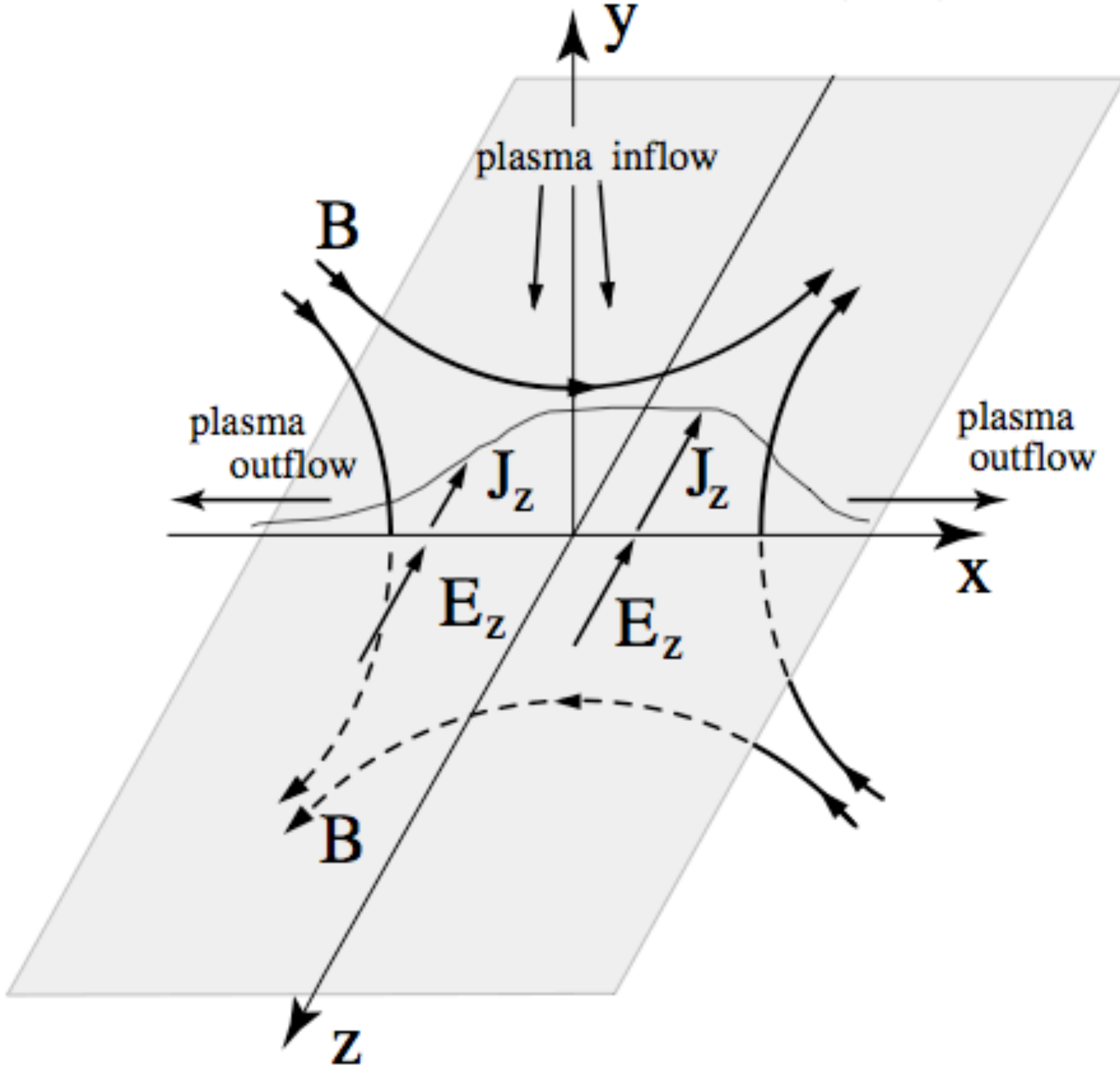
Romanova, Ustyugova, Koldoba, & Lovelace

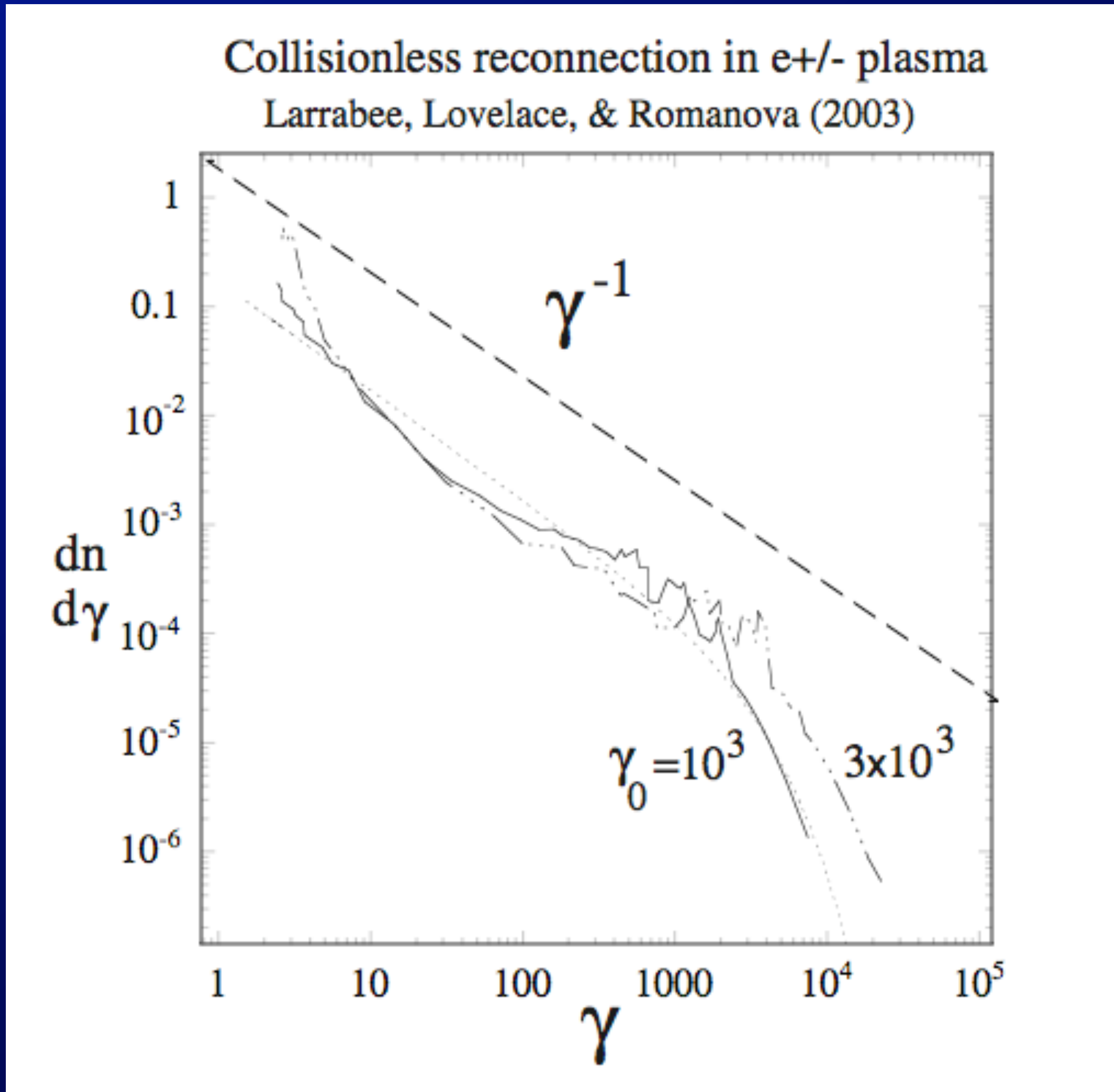
MNRAS 2009



Collisionless reconnection in e+/- plasma

Larrabee, Lovelace, & Romanova (2003)




Collisionless reconnection in e+/- plasma
Larrabee, Lovelace, & Romanova (2003)
1
0.1
10-2
10-3
10-4
10-5
10-6
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dγ
γ -1
γ0 =10 3
3x10 3
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10
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1000
10 4
10 5
γ

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