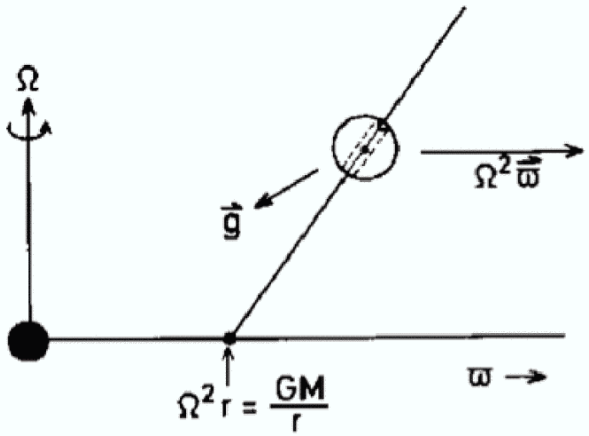
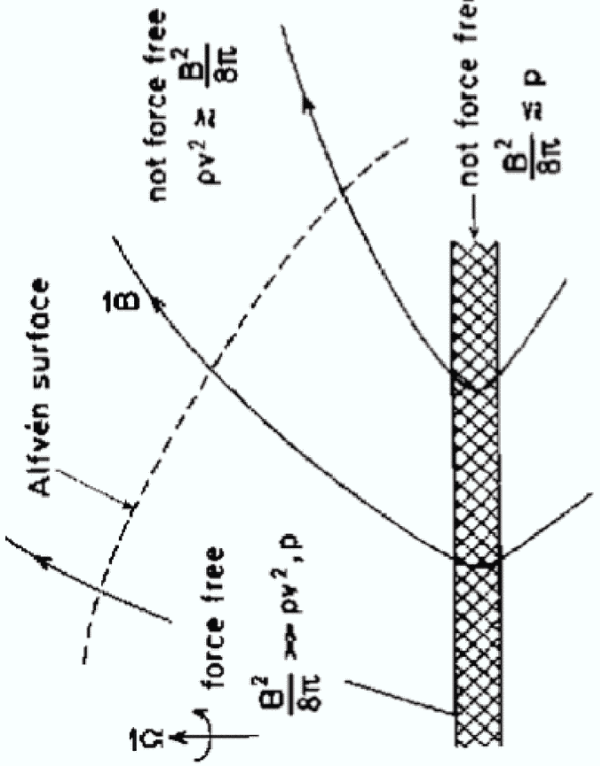
MHD at the interface between disk and outflow

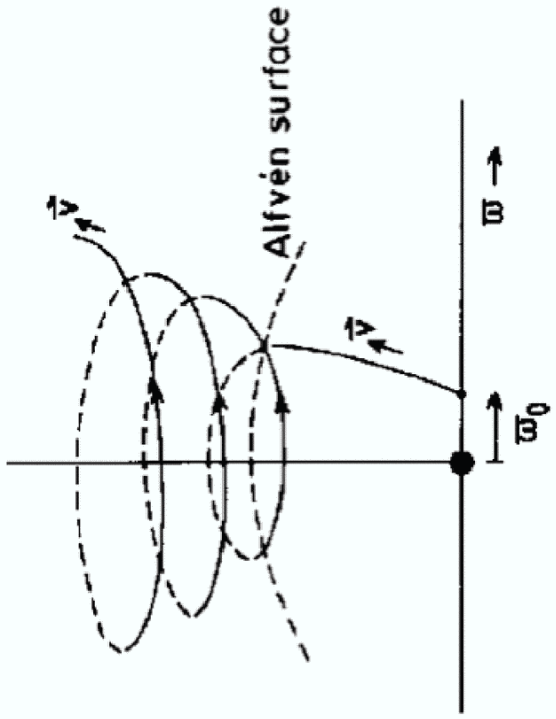
KITP 5/5/05

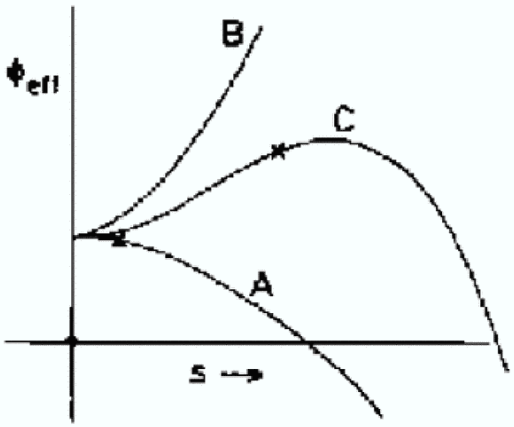
- MHD regimes in disk and outflow
- Launching, acceleration, collimation phases
- Kinds of field supported by the disk
- Stability of the disk/wind connection
- Launching conditions
  - multiple sonic points
- What happens at large mass loading?
- ADAF-jet connection
- Accretion of external flux ("dragging")
- Super-Eddington fluxes

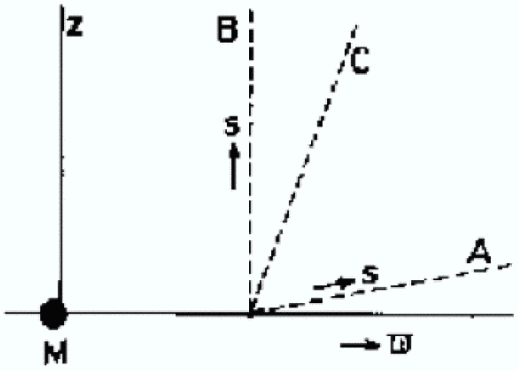
'Tutorial': Spruit, 1996, NATO ASI Series C., vol.477, p.249-286
www.mpa-garching.mpg.de/~henk/pub/jetrevl.ps.gz



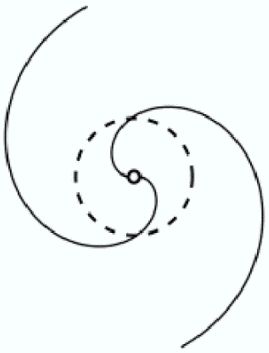

not force free
$\rho v^2 \approx \frac{B^2}{8\pi}$
not force free
$\frac{B^2}{8\pi} \approx p$
Alfvén surface
$\vec{B}$
force free
$\frac{B^2}{8\pi} \gg \rho v^2, p$
Ω


Alfvén surface
$\vec{v}$
$\vec{v}$
ϖ
ϖ_0

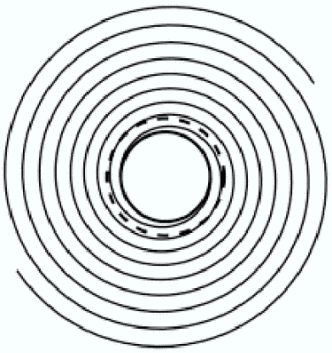




Field line shape in the cold radial field model



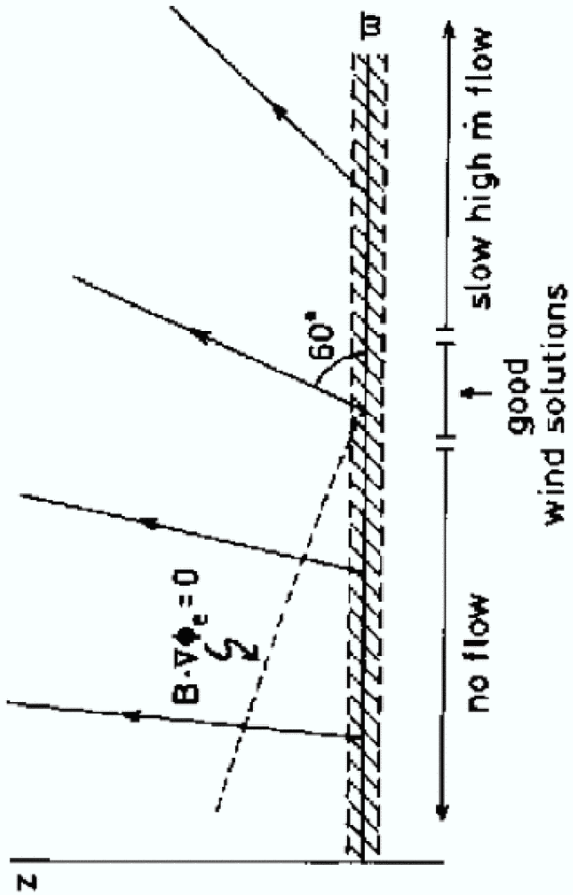
$\log\mu = -3$

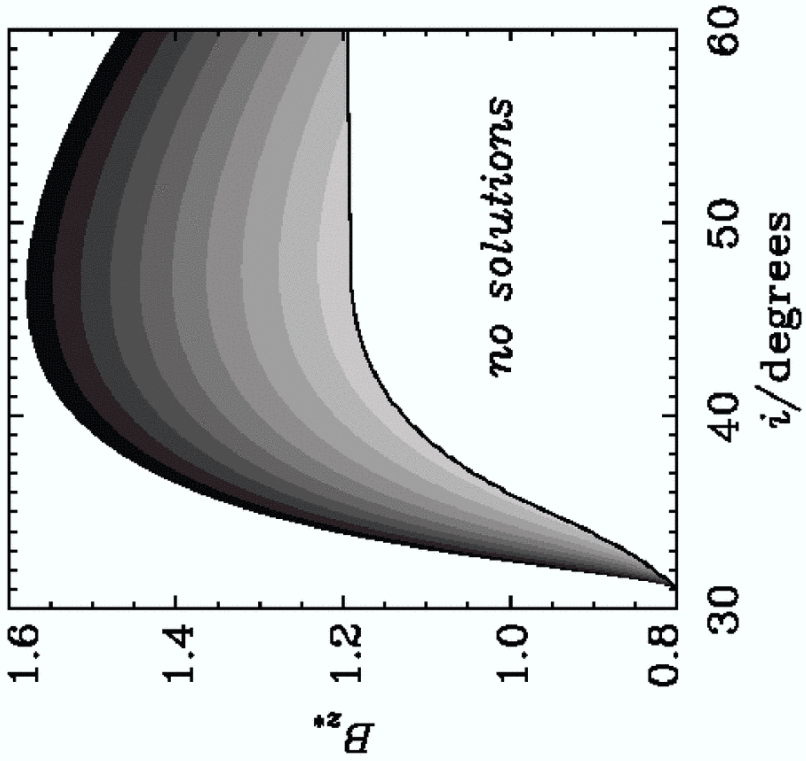


$\log\mu = 1$

'centrifugal' case
low loading
high asymptotic speed

'slow push' case
high loading
low outflow speed
instabilities!!


z
B·∇Φe=0
60°
no flow
good
wind solutions
slow high ṁ flow

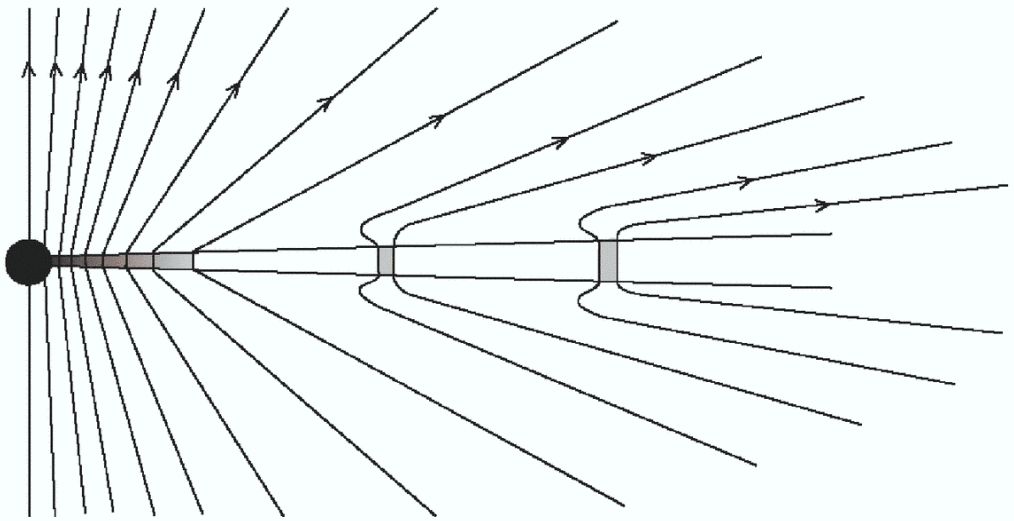

1.6
1.4
1.2
1.0
0.8
Bz*
30
40
50
60
i/degrees
no solutions

Erroneous disk-wind connections

- Steady state between advection and magnetic diffusion inside disk (OK)
- --> B_r and B_phi at disk surface --> outflow (wrong)
  - C. Campbell 1999 -- 2003
  - Rüdiger, Shalybkov etal 2000 --
  - Ferreira etal 1997 --
  - Wardle & Königl 1993
- Right: Ogilvie and Livio 2001, ApJ 553, 158

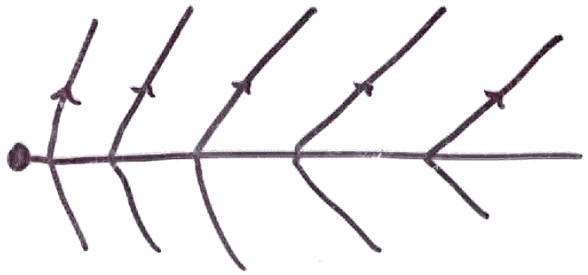
'Accretion' of external fields

Spruit and Uzdensky 2005, astro-ph



Spruit 5 May 2005 1

ordered field — Outflows?

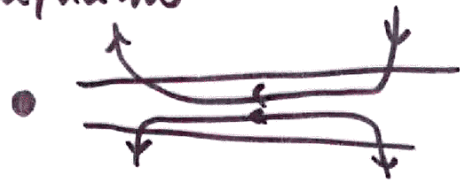


good

small scale "turbulent"

not so good

Large scale dynamo



unlikely

2

High and low mass loading

Measure of mass loading

$$\mu = 4\pi \dot{m}\, \Omega\, \varpi_0 / B_0$$

$$\dot{m} = \rho v / B_p = \text{cst} \;//\; \text{field line}$$

a) Base of the flow: $v_p = v_{p0}$, $\rho = \rho_0$:

$$\mu = \rho_0 v_{p0}\, 4\pi\, \Omega\, \varpi_0 / B_0^2$$

$$\mu = \frac{v_{p0}\, v_{k0}}{v_{A0}^2} \quad \leftarrow \text{Keplerian velocity}$$

"starting velocity"

Angular momentum loss (per cm^3)

$$\dot{j} = \frac{B_0^2}{4\pi} f(\mu)$$

$$f(\mu) = \tfrac{3}{2}\mu\left(1+\mu^{-2/3}\right)$$

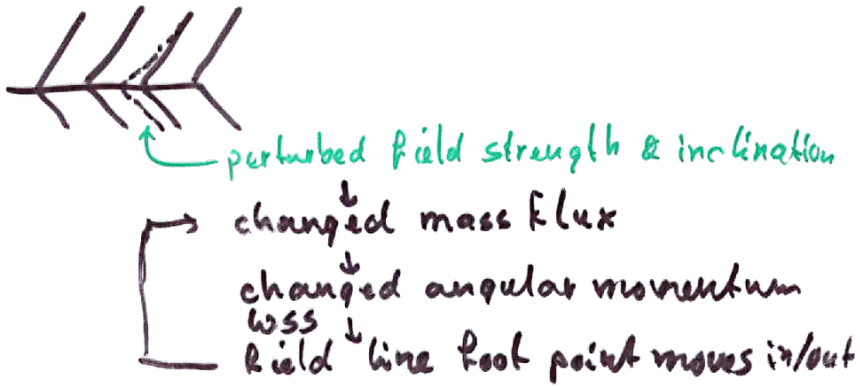
3

stability of disk-wind connection.

Lubow, Papaloizou & Pringle
1994 MN 268, 1010 L
"unstable, does not work"

Agapitou & Papaloizou (unpub. 2000)
↑ thesis

Instability:



Cao & Spruit 2002 A&A 385, 289:
unstable, inward propagating waves

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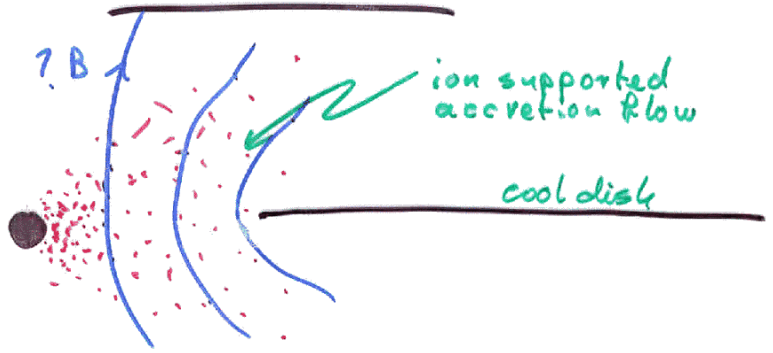
ADAF (ISAF) - outflow connection



Model for the hard X-ray spectra of X-ray binaries

Obs: - hard states produce jets (but not always ....)
- soft states don't

suggested connection: thick disk is better for launching jet flow

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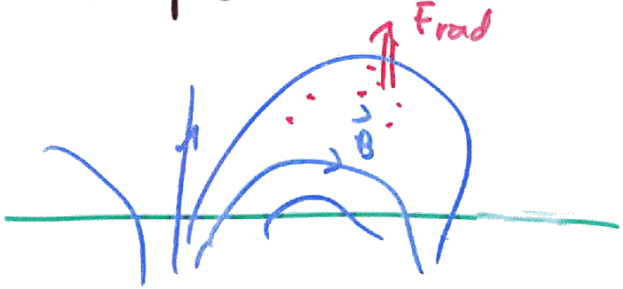
Super-Eddington fluxes from a magnetic disk atmosphere



Frad due to scattering balances magnetic stress when

$$\frac{F_{rad}}{c} \sim \frac{B^2}{8\pi}$$

$$\rightarrow F_{max} = \frac{B^2}{8\pi} c$$

B_{max} determined by conditions deep inside disk