JEDs and SADs in X-ray Binaries

Conditions for jet launching ?

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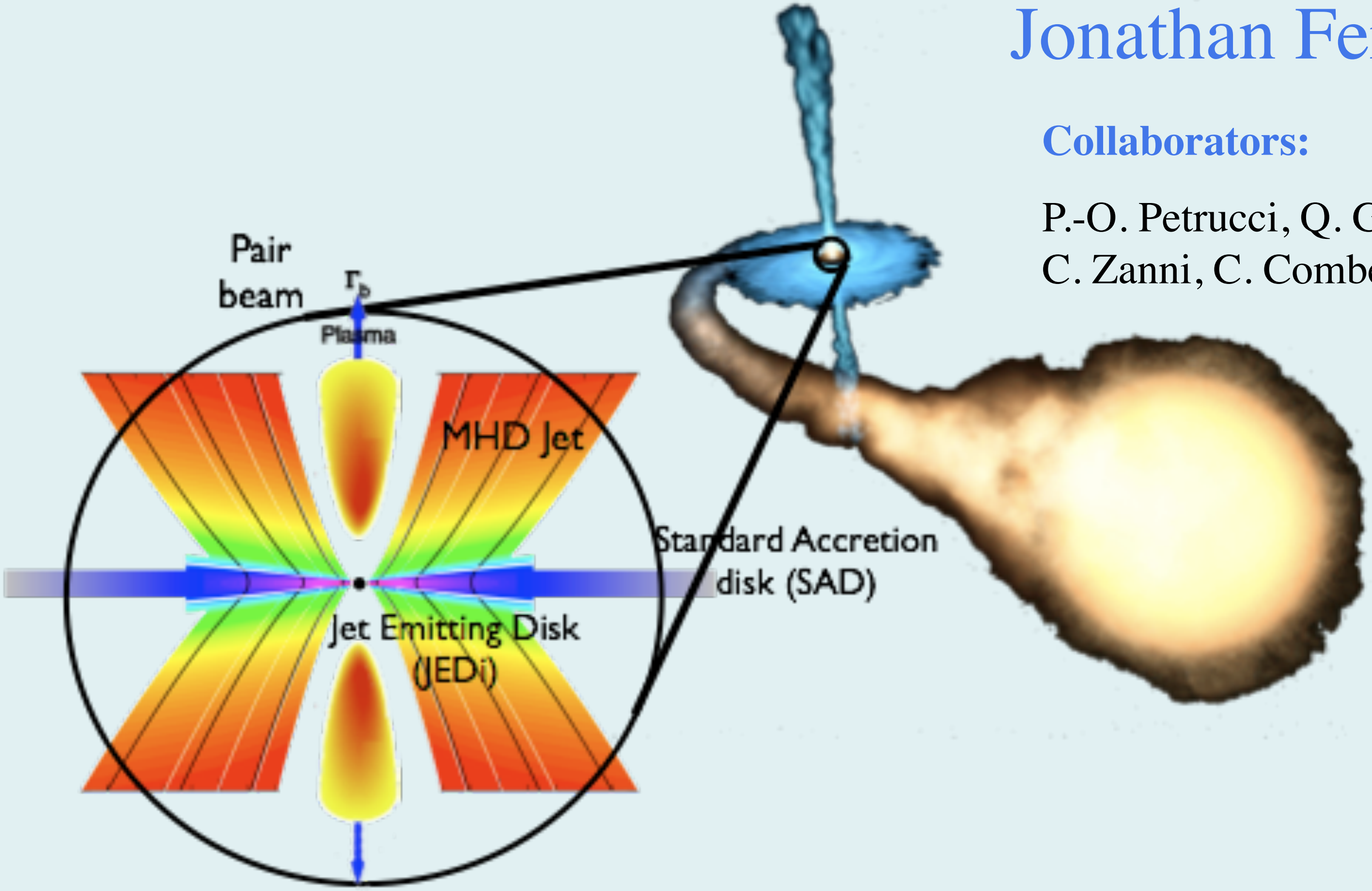

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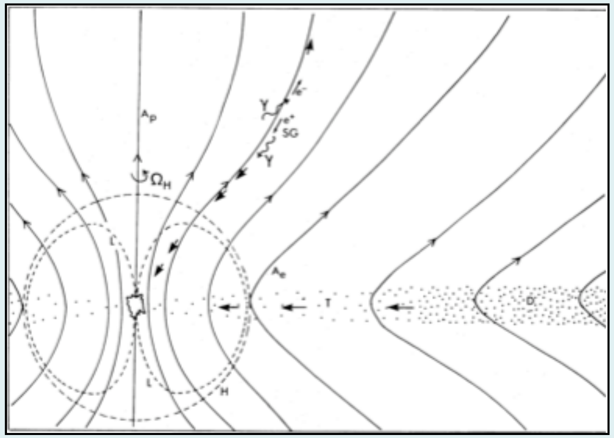
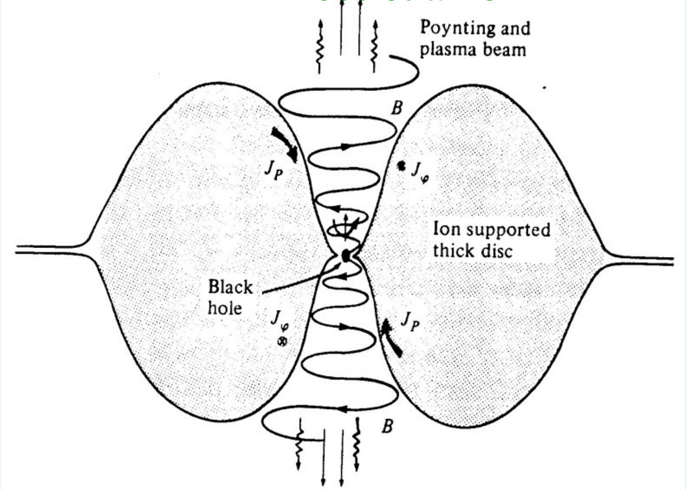
Self-confined jets: need of Bz field

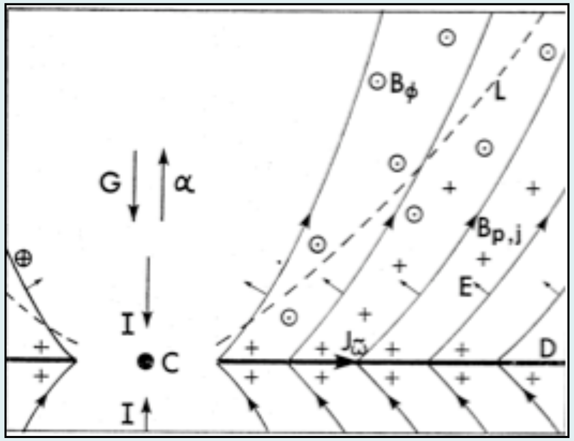
Important only near BH: extracting rotational energy



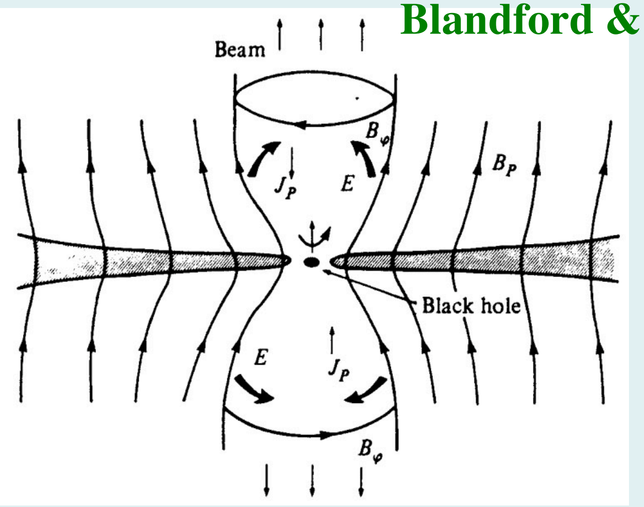
Blandford & Znajek 77
Rees et al 82



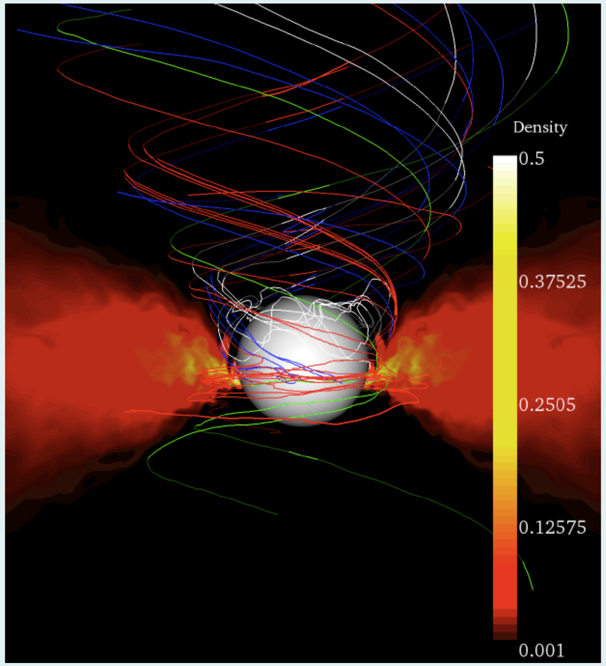
Distributed in the disc: extracting accretion energy

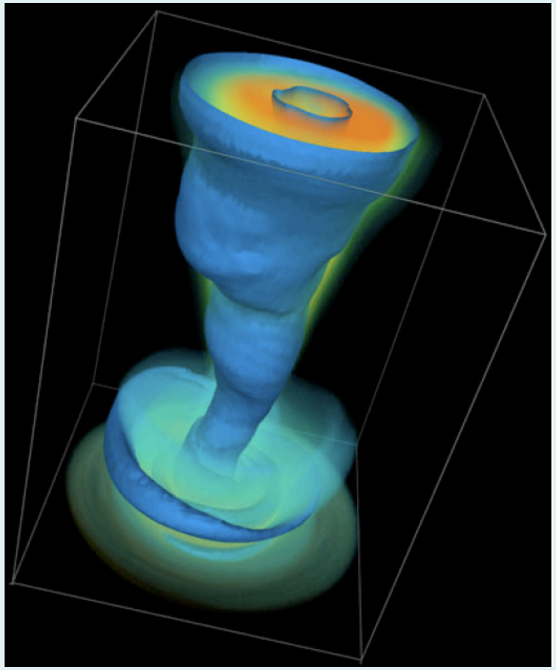


Blandford 76, Lovelace 76
Blandford & Payne 82



Global 3D MHD disc+jet simulations





Punsly, Igumenshchev & Hirose 09

McKinney & Blandford 09

Main results:

- Blandford-Znajek jets: a low power massive disc-wind but no Blandford-Payne jet
- BZ jets require a large scale B_z field (MRI does not generate it) @ t=0

Open issues:

- What determines/controls Bz field @ black hole vicinity?
- if BZ jets are THE jets, why similar jets from neutron stars (X-ray Binaries)?

SADs and JEDs: the impact of B_z… and h/r

When no large scale B_z magnetic field

Shakura & Suyaev 73
Narayan et al, Yuan et al

$$P_{acc} = 2P_{rad} \; + \; P_{adv}$$

- geometrically thin : $P_{acc} = 2P_{rad}$ (SAD)
- geometrically thick : $P_{acc} \simeq P_{adv}$ (ADAF, LHAF)

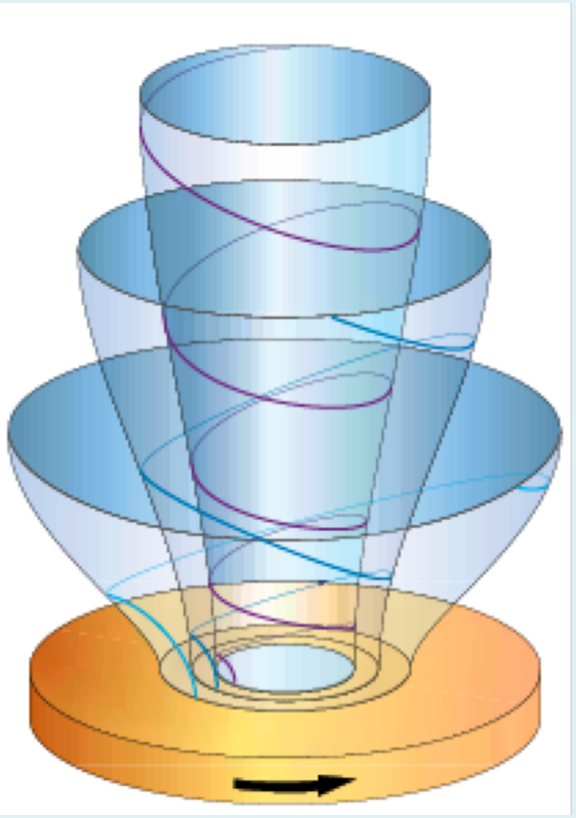
When large scale B_z magnetic field threads the disc
=> Jets from Jet Emitting Discs (JED)

Ferreira & Pelletier 95
Ferreira, Petrucci, Garnier in prep

$$P_{acc} = 2P_{rad} \; + \; P_{adv} + \; 2P_{jet}$$

Energy budget depends on disc thickness $\varepsilon = \frac{h}{r}$

BP jets from Jet Emitting Discs (JEDs)



$$\dot{M}_a \propto r^\xi$$

- Steady-state
- Axisymmetric jets : nested magnetic surfaces of constant magnetic flux

Blandford 76, Lovelace 76
Blandford & Payne 82

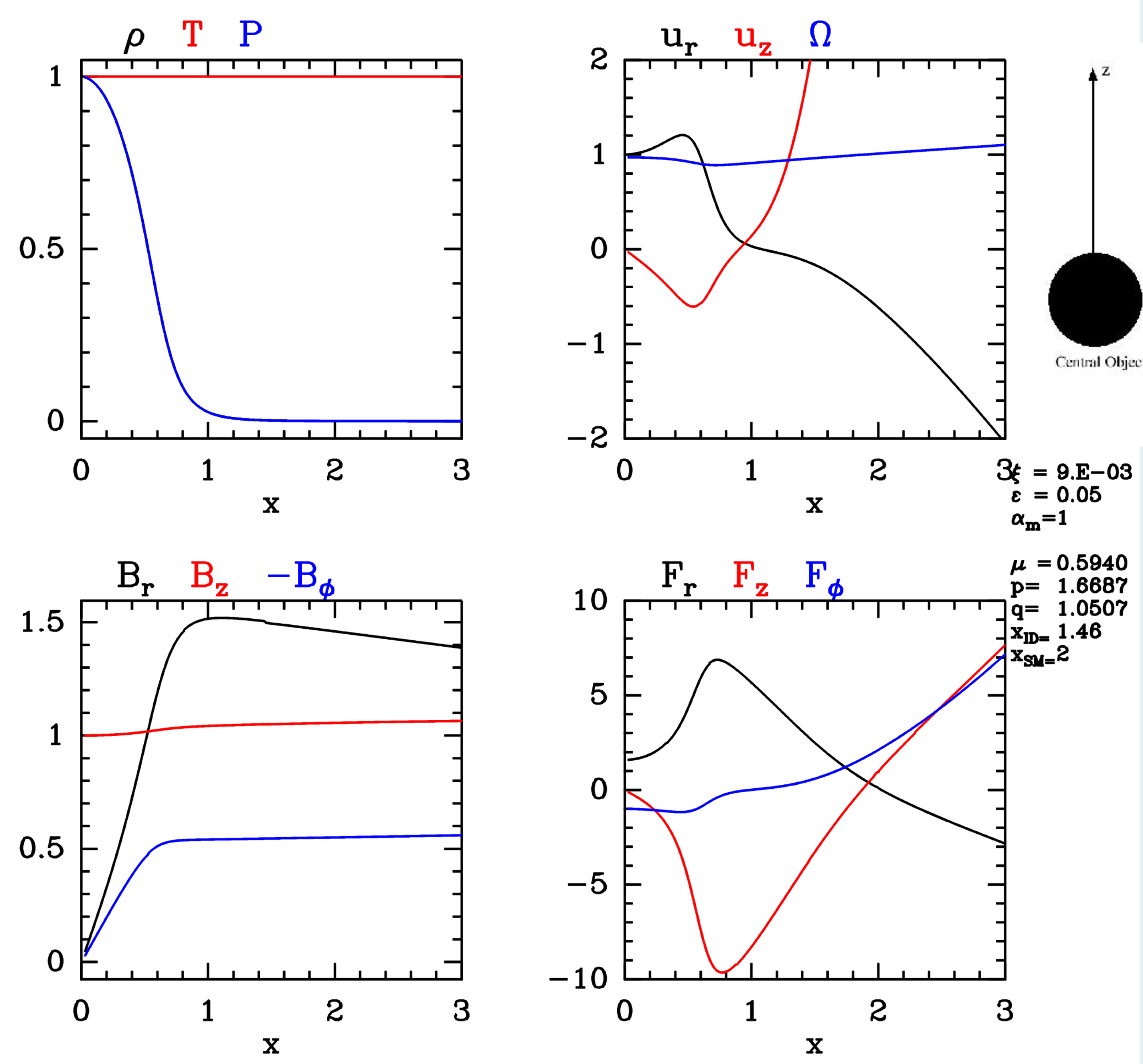
- Single fluid MHD description
- Non-relativistic equations
- Transition from resistive & viscous disc to ideal MHD jet: local a prescriptions for MHD turbulence

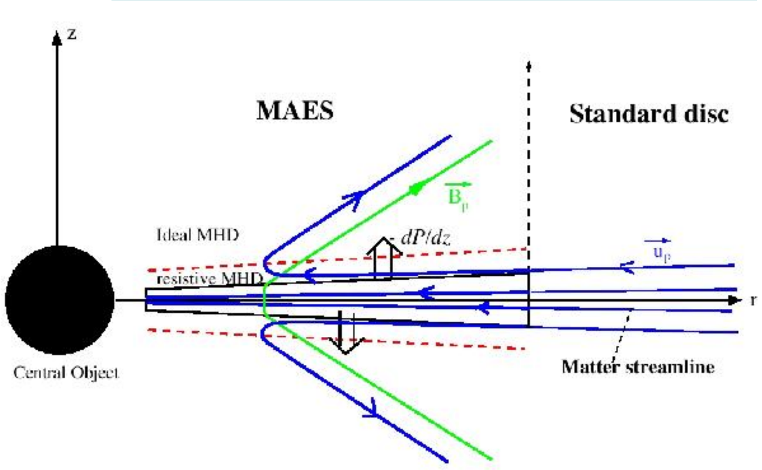
A complex interplay between disc and jets determines the disc ejection efficiency x

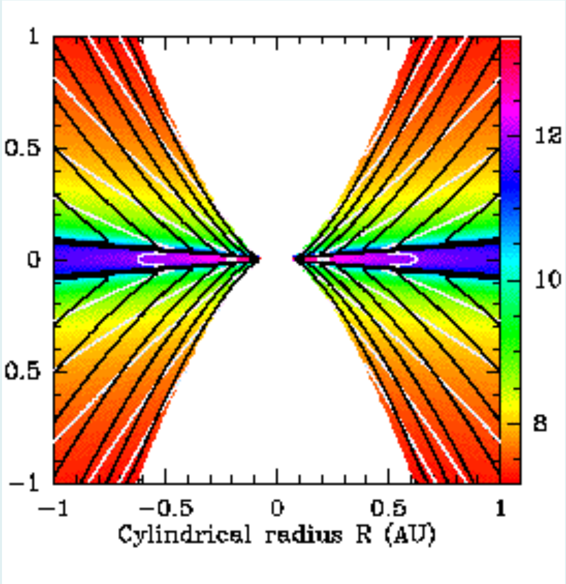
=> Well-defined MHD model whose parameter space is constrained by smooth crossing of critical points

Ferreira & Pelletier 93, 95
Ferreira 97, Casse & Ferreira 00
Ferreira & Casse 04

Disc physics: resistive to ideal MHD, super-FM flow



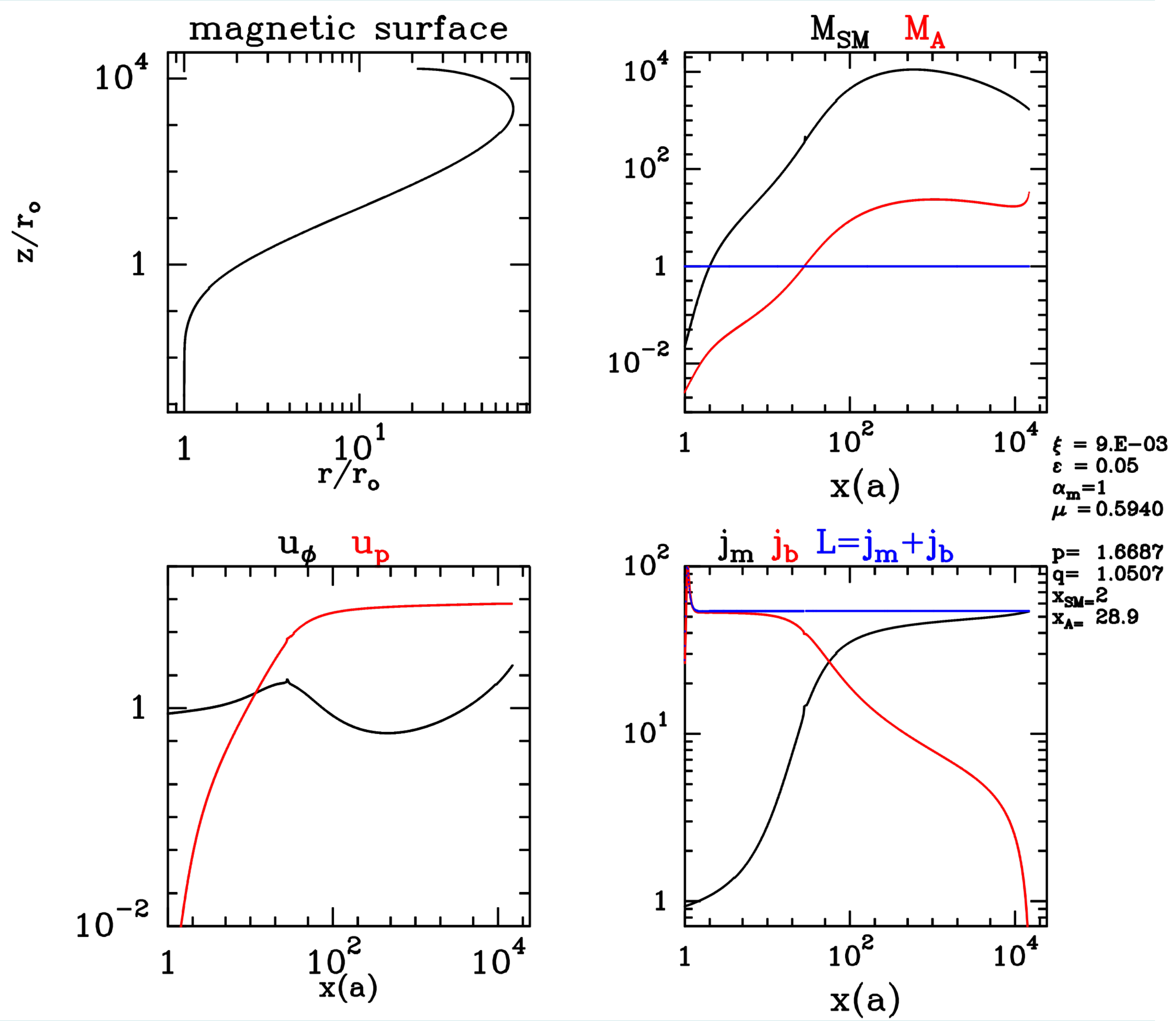


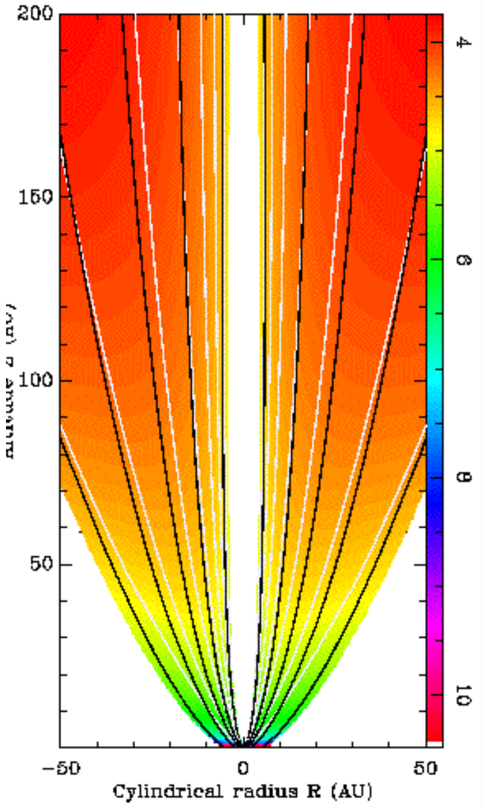


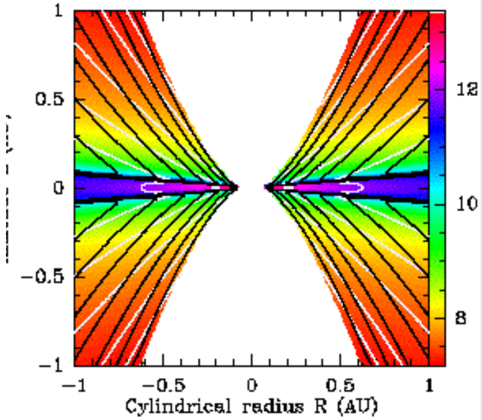
x=z/h(r)

Ferreira, Petrucci, Garnier in prep

Jet physics: super-A, self-confined flow







$x(a)=z/h$ along magnetic surface

Ferreira, Petrucci, Garnier in prep

2.5D Numerical experiments

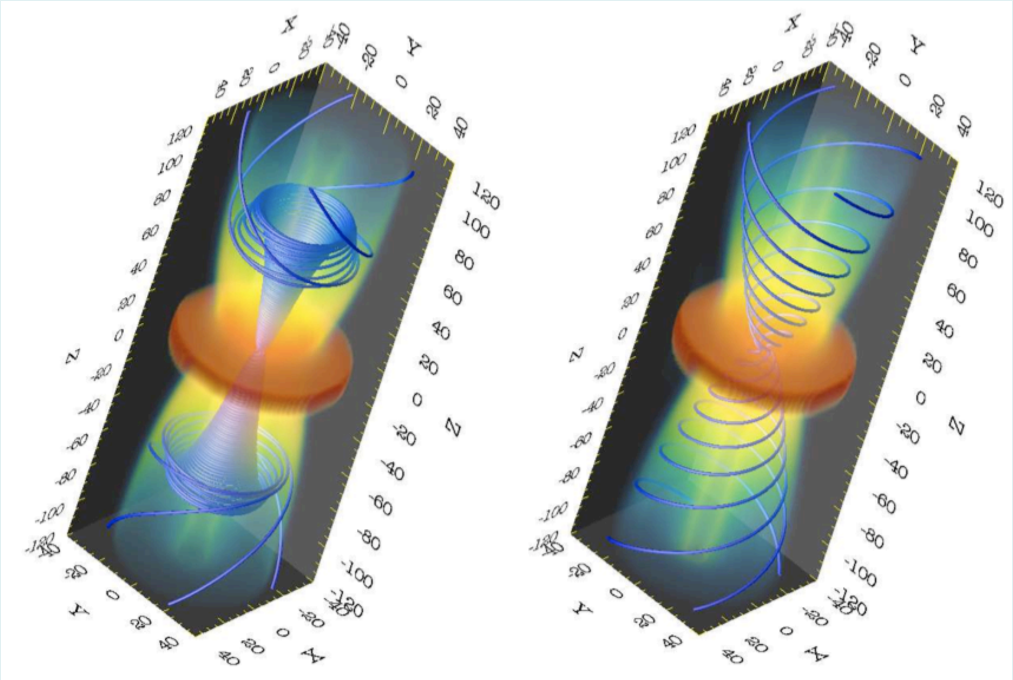
Main self-similar results have been confirmed with several MHD codes, using alpha-prescriptions:

1.Steady ejection **only for near equipartition B_z field** # Tzeferacos et al 09

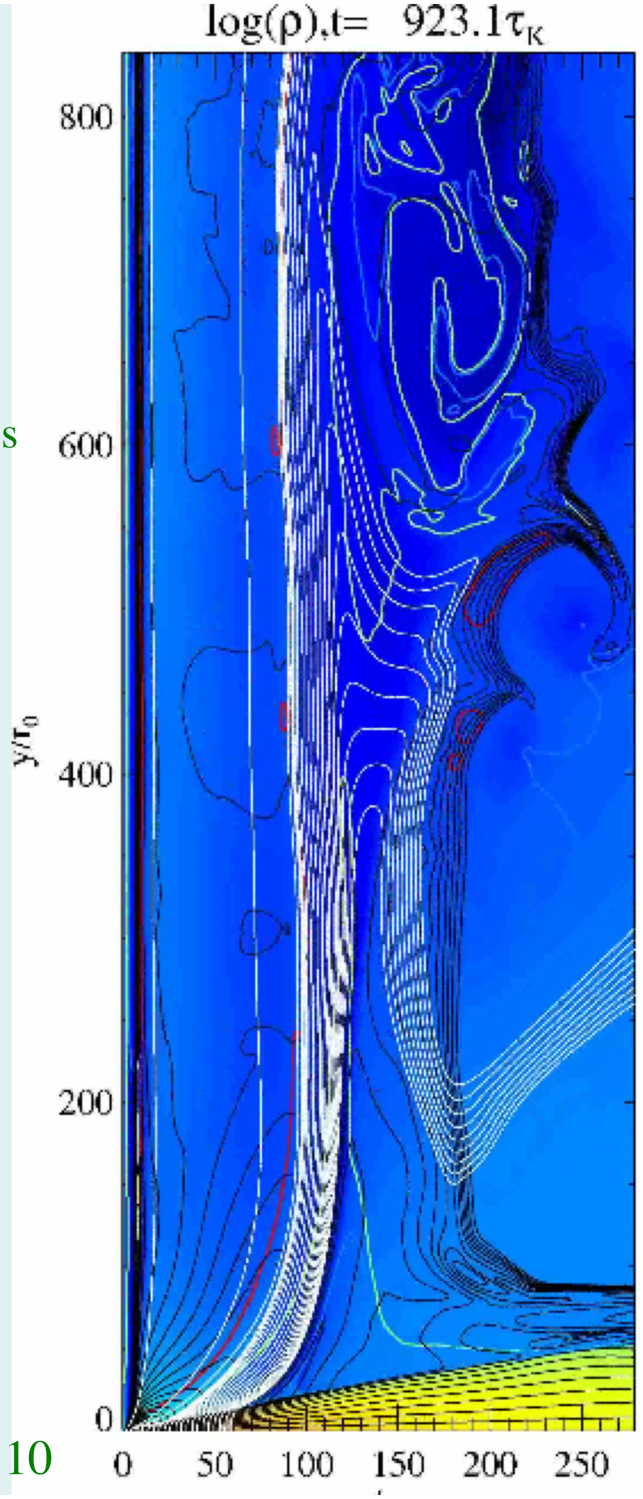
2.Viscous torque negligible # Meliani et al 06

3.Large diffusivity ($n_m \sim V_A h$) required with some anisotropy # Zanni et al 07, Tzeferacos et al 09

4.BUT disc mass loss NOT reliable (Murphy, Ferreira, Zanni 10)

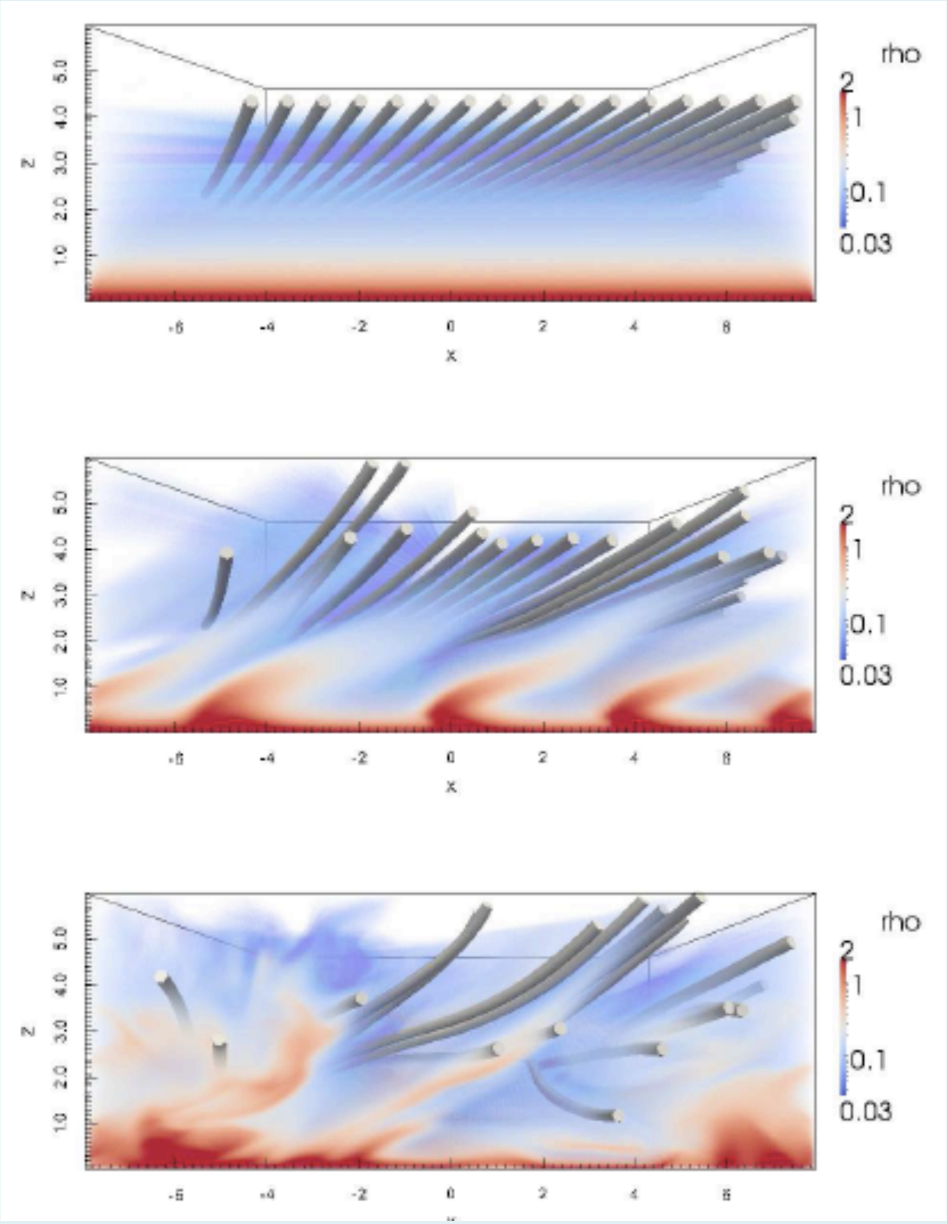


Zanni et al 07, Tzeferacos et al 09



Murphy et al 10

MRI @ m~ 0.1



Lesur, Ferreira, Ogilvie 2013

Shearing-box simulations of stratified disc with Alfven surface within computational domain

=>At large Bz, the non linear stage of MRI is jet production

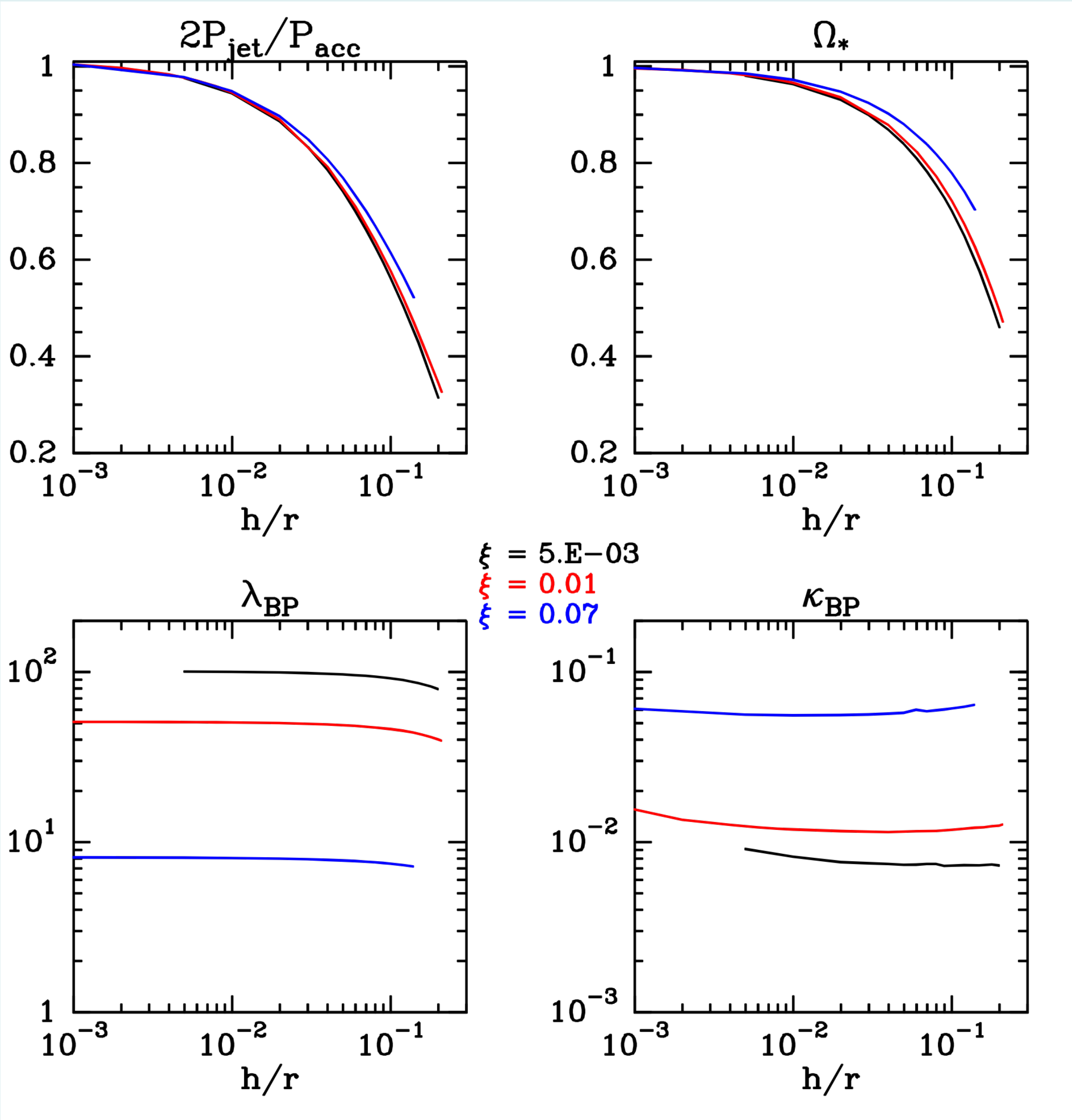
- Local mechanism identical to Ferreira & Pelletier 95 solutions

$$0.1 < \mu = \frac{B_z^2}{P} < 1$$

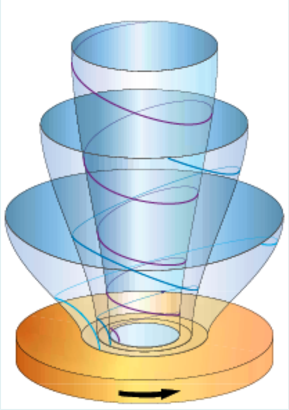
- Radial instability, requiring global simulations

- Current global simulations with m<<1 dot not allow confined ejection

Power of « Blandford & Payne » jets

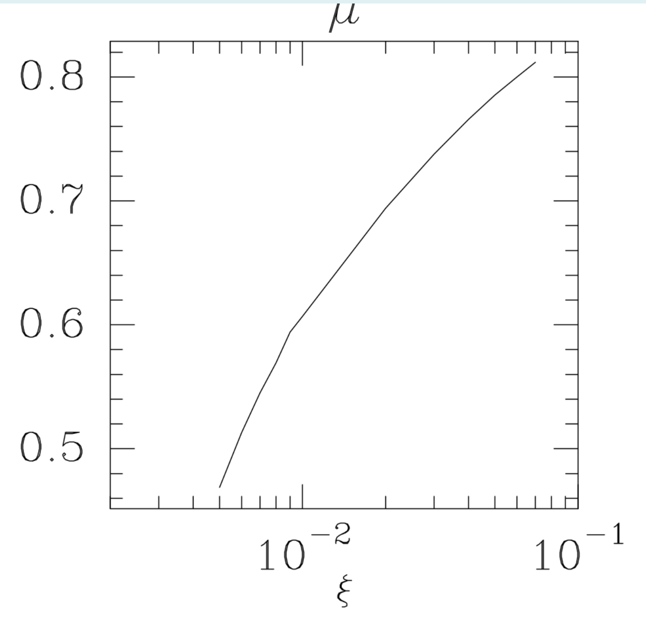


Ferreira, Petrucci, Garnier, in prep



$$\dot{M}_a \propto r^{\xi}$$

Isothermal solutions

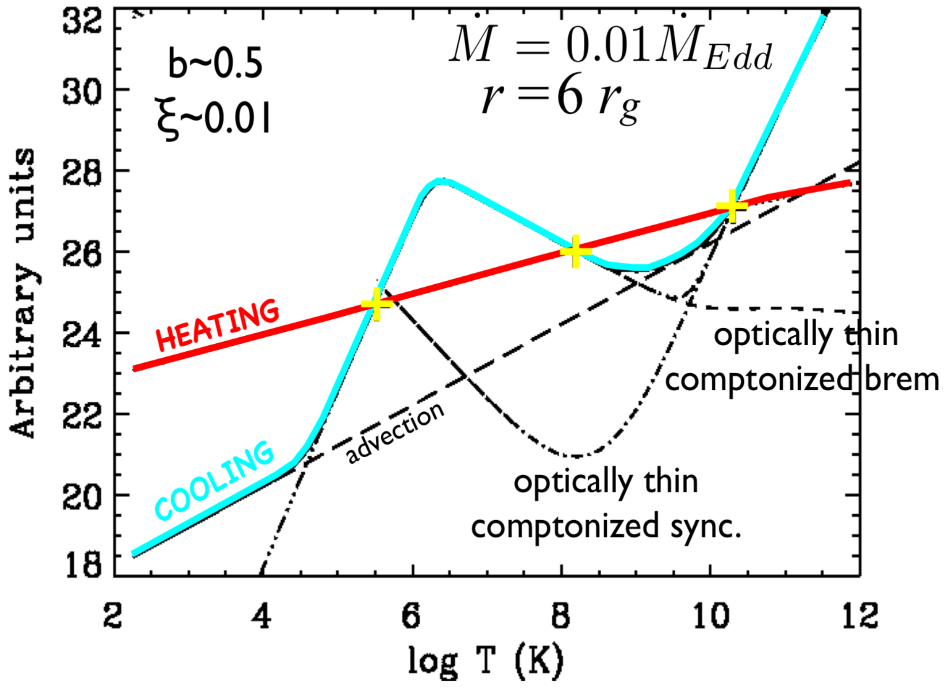


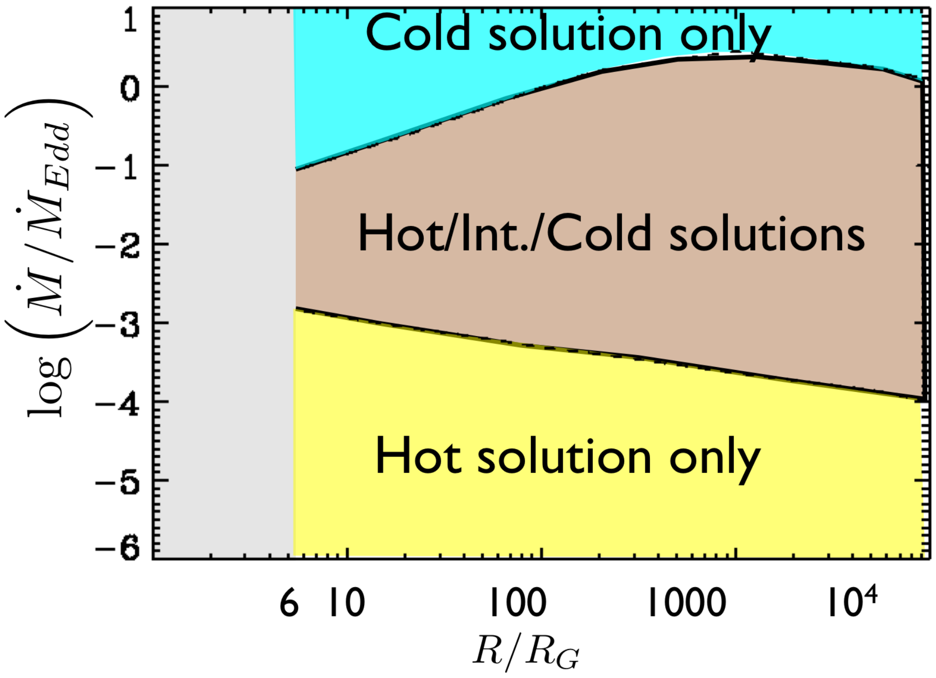
The thicker (hotter) the disc, the less powerful the jets

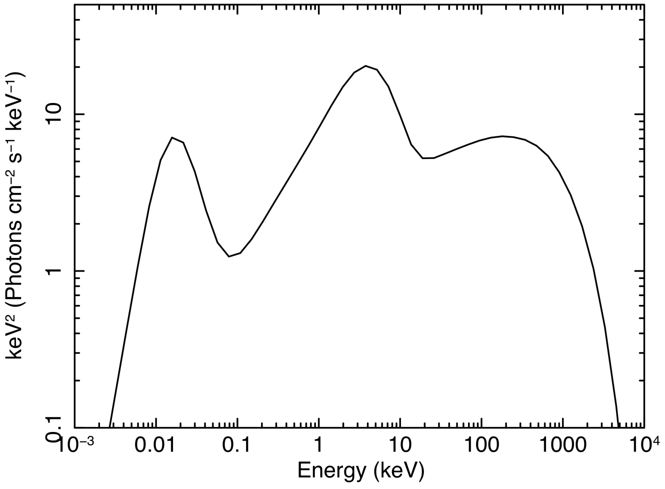
- **Thick discs (h/r > 0.2) cannot drive powerful jets.**
- **Thermal driving can help/supersede magnetic but jet power decreases**

Three branches of JED solutions

Petrucci et al 10







Existence of a hot, thermally stable branch consistent with powerful ejection as in Low/Hard states of XrBs

BZ versus BP ejection mechanism

Power carried by Blandford & Znajek jets (Livio et al 99, Pelletier 04 (astro-ph/0405113) :

$$P_{BZ} \simeq 10^{42}\mathbf{a}^2 \left(\frac{B_z}{10^4 G}\right)^2 M_8^2 \text{ erg }/\text{s}$$

Power carried by Blandford & Payne jets (Ferreira 97, Petrucci et al 10):

$$P_{BP} = \mathbf{b}\, P_{acc} = \mathbf{b}\, \frac{GM\dot{M}}{2r_i}$$

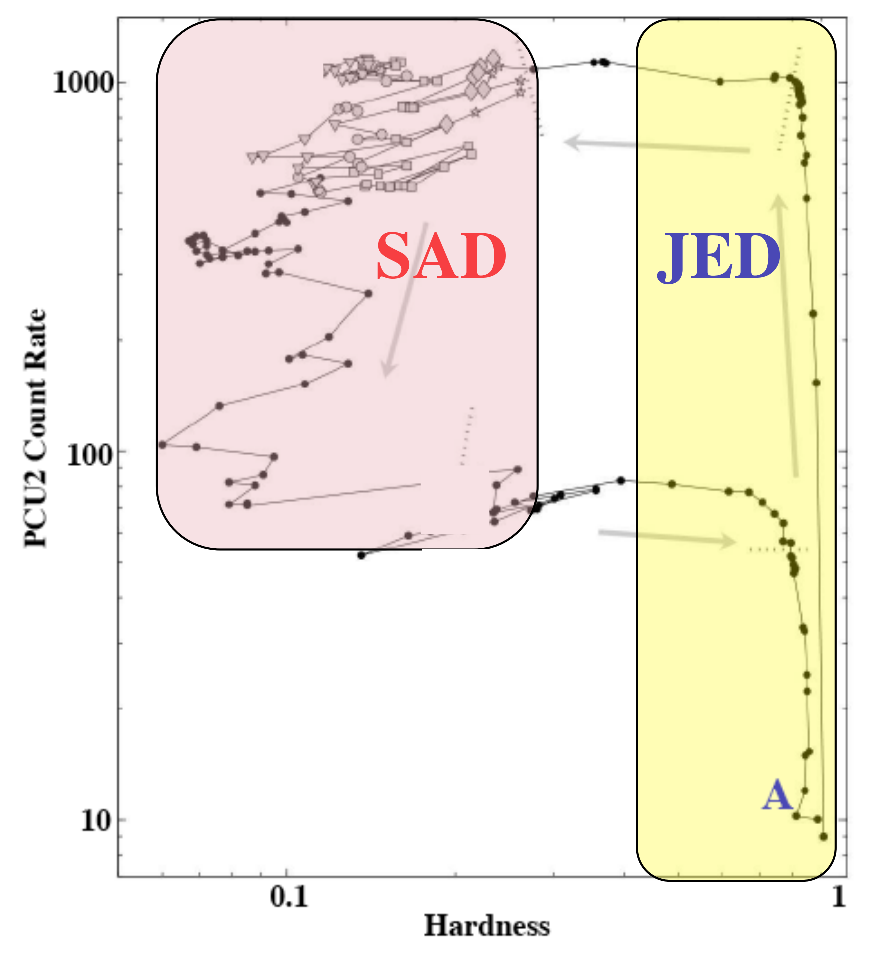
Introducing *disc magnetization* μ and *sonic Mach number* m_s

$$\frac{B_z^2}{\mu_o} = \mu P = \frac{\mu}{\mathbf{m_s}} \frac{\dot{M}\Omega_K}{4\pi r} \qquad \frac{P_{BZ}}{P_{BP}} \simeq 3\,10^{-3}\, \frac{a^2}{b}\, \frac{\mu}{m_s} \left(\frac{r_i}{r_g}\right)^{-3/2}$$

For a=1, $r_i=r_g$ and JED with b ~ 0.5 (hot, opt thin branch), μ ~ m_s ~ 1

P_{BZ} a few percent only of P_{BP}

LMXrB hysteresis: magnetic tides & floods ?



Possible mechanism for LMXrBs **long term** variability = B field is second independent variable (Ferreira et al 06)

- accretion rate M(t)
- available magnetic flux F(t)

$$\mu = \frac{B_z^2/\mu_o}{P} \propto \frac{\Phi^2}{\dot{M}}$$

JED in its hot, optically thin branch (Petrucci et al 10)

JED-to-SAD and SAD-to-JED transitions triggered by variations in local disc magnetization m (Petrucci et al 08)

Concluding remarks

(1) JEDs (accretion power released in jets) provide universal explanation for **powerful** self-confined jets (YSO, AGN and XrBs)

(2) To date, most complete models + analytical arguments favor **near equipartition B_z fields distributed in discs**.
Un-observed in 3D global MRI simulations around black holes but
- no large scale Bz or far too low
- discs too thick

(3) BZ jets probably present (though affected by radiative effects) but dynamically **an epiphenomenon** whenever BP jets launched from disc

(4) $B_z(r,t)$ is a key ingredient in long term LMXrB variability: depends on field advection (BC) and object history (IC)
radial extent of JEDs may differ from
- one object to another
- one outburst to another

Challenge for observers: compare Pjet Vs Pacc
Cf Petrucci et al 2010 for Cygnus X-1 case