Structure of magnetized transonic accretion disks

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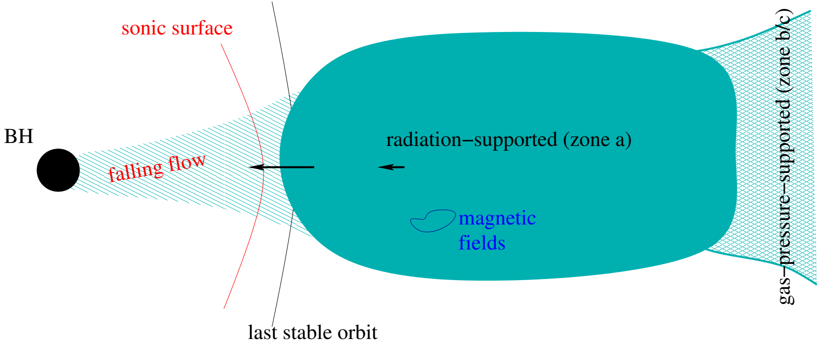
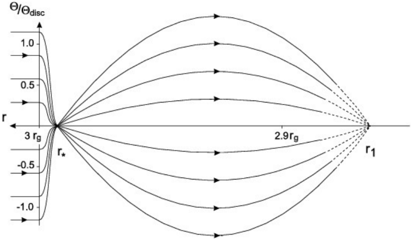
Accretion disc around a BH



standard disc and its inner boundary

Is there a “disk” beyond the disk?

Ballistic approximation:

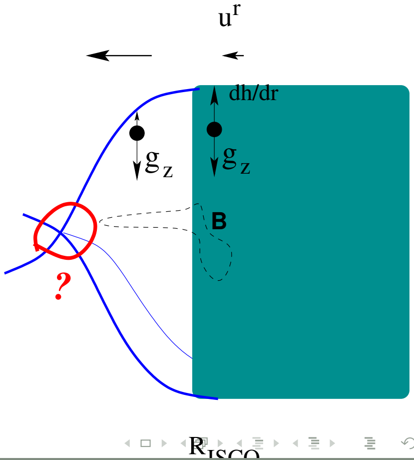


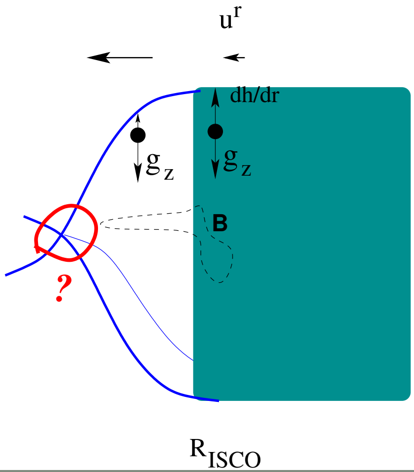
Beskin & Tchekhovskoy (2005)

$$\Omega_z > \Omega_K$$

still small radial velocity

The shock waves are smeared due to $\Omega_z(z)$





Density drops like

$$\rho_{in} \simeq \rho_{disc} \times \alpha \left(\frac{H}{R}\right)^2$$

Gas pressure

$$P_g \propto \rho^{5/3}$$

Radiation pressure

$$P_r \propto \rho^{4/3}$$

or stronger (radiated away)
Vertical magnetic field

$$B_z \propto \rho$$

Azimuthal mafnetic field

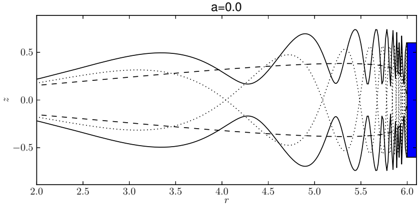
$$B_\varphi \propto \rho$$

Radial magnetic field (survives!)

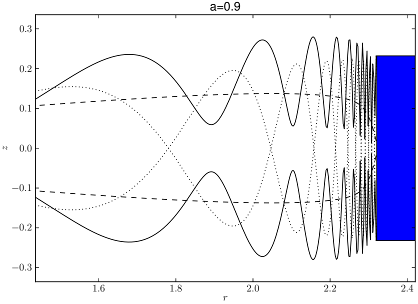
Magnetically-supported falling flow

Cauchy problem:

$$u^r \frac{d}{dr}\left(u^r \frac{dH}{dr}\right) = (\text{acceleration by MF}) - (\text{vertical gravity}) \qquad (1)$$



$a = 0$, $H/R = 0.1$
Abolmasov (2014)

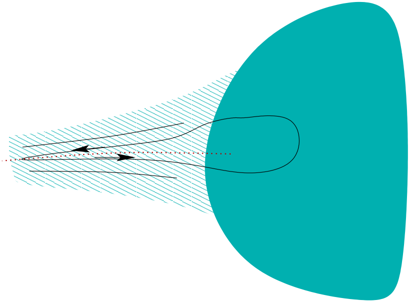


$a = 0.9$, $H/R = 0.1$

Equilibrium thickness

$$\frac{H}{R} \simeq (0.2..0.3)\left(\frac{1}{\alpha\beta}\left(\frac{H}{R}\right)_{\mathrm{disk}}\right)^{1/3}, \quad (2)$$

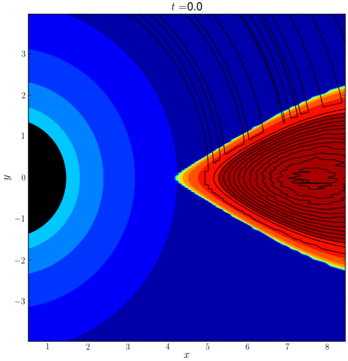
where $\beta = \left(\frac{p}{p_{mag}}\right)_{disk}$, $\alpha\beta \sim 1$



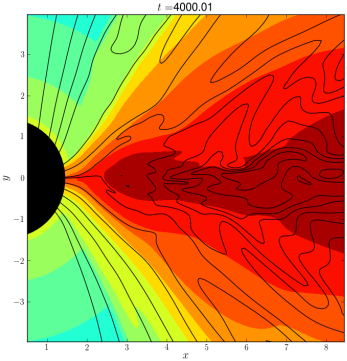
Should we trust this?

HARM2D simulations

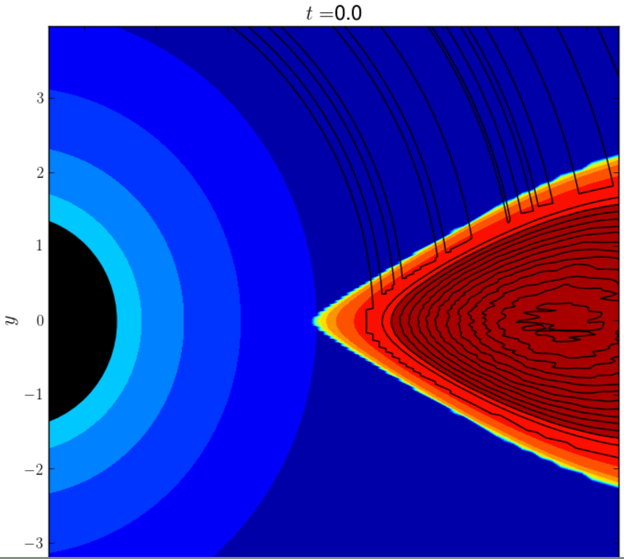
HARM: Gammie et al. (2003); Noble et al. (2006)

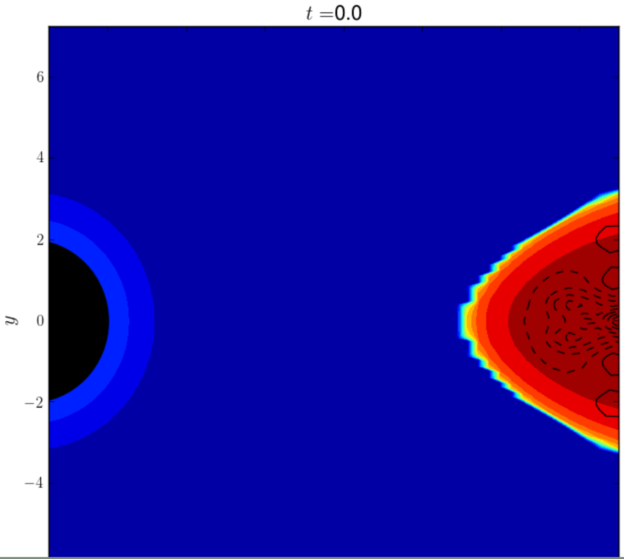


initial conditions



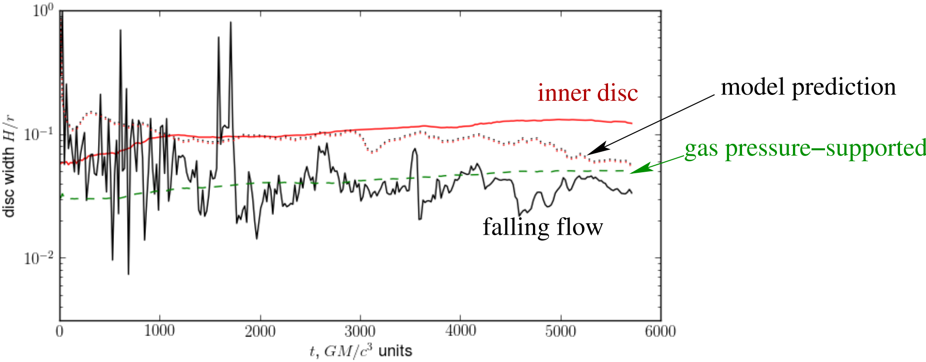
density (tones) and magnetic field (black contours) map


t =0.0
y
3
2
1
0
−1
−2
−3

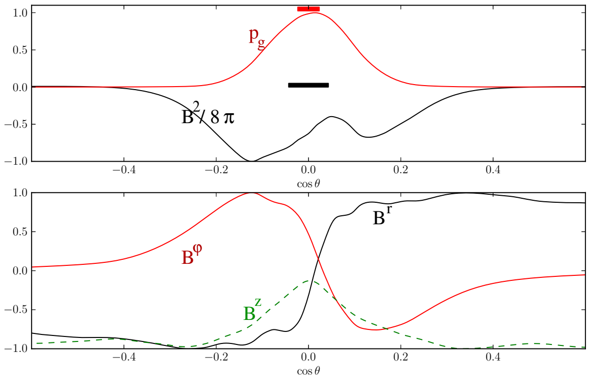


t =0.0
6
4
2
0
−2
−4
y

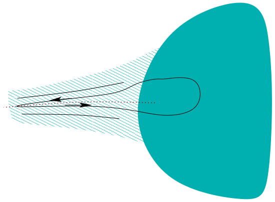
Thicknesses



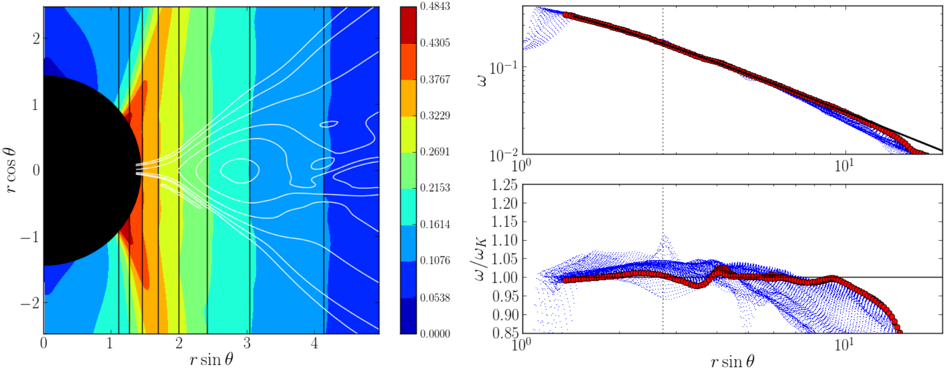
what's going on?



Driven current sheet!



Cylindrical and Keplerian rotation near the ISCO



$$\omega_K = \frac{1}{r^{3/2} + a}$$

Why?

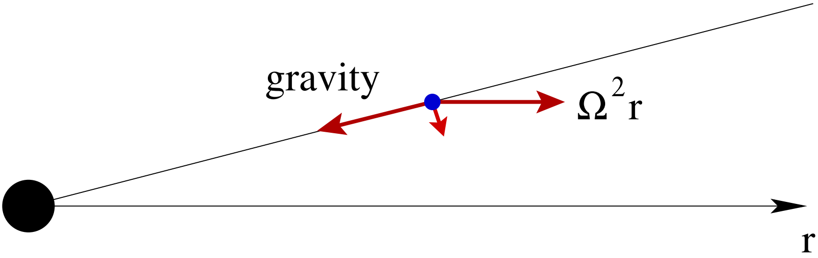
- cylindrical isostrophes naturally occur in a pseudo-barotropic case: $\nabla p || \nabla \rho \Leftrightarrow \nabla j || \nabla \Omega$, where $j = \Omega \varpi^2$ (Poincaré-Wavre theorem, aka as von Zeipel's)
- nearly Keplerian rotation is expected near the sonic surface: $\left(v - \frac{c_s^2}{v} \right) v' = \Omega^2 R - \frac{GM}{R} + c_s^2 \frac{d}{dR} (RH)$ [should it hold for GR?]
- magnetic fields do not spoil everything unless there is a dynamically important regular MF

Isostrophes!

If you want thick discs, you should consider 2D-rotation laws.
Because rotation is gravity/inertia (see Abramowicz et al. (1997))

$$\Omega_c/\Omega_s \sim \sin^{3/2}\theta \sim 2^{-3/4}$$

$$g_c/g_s \sim \sin^3\theta \sim 2^{-3/2} \sim 3$$

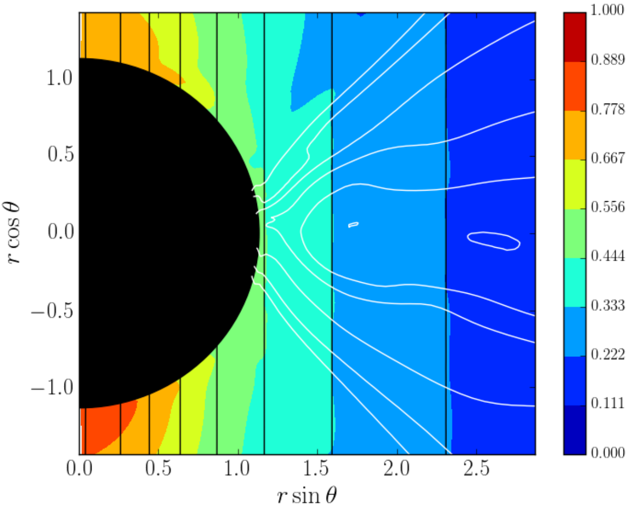


Details in Abolmasov & Chashkina (2015)

Summary:

- falling flow has a magnetically-supported component with thickness $\propto \left(\frac{h_0}{\alpha\beta}\right)^{1/3}$
- gas accretes through neutral magnetic lines in current sheets
- rotation in a thick disk is close to Keplerian and pseudo-barotropic (single barotropic gas + MF; everything can change if energy release is present!)
- everything changes when the cumulative magnetic flux becomes large

In more details: Abolmasov (2014); Abolmasov & Chashkina (2015)



Thank you for attention!

Magnetic fields

Magnetic flux conservation expressed in terms of comoving-frame-measured magnetic fields:

$$4\pi Hr\left(u^i B^r - u^r B^i\right) = \Phi^{ri} \tag{3}$$

Poloidal magnetic fields in the disc:

$$B^r(r) = \frac{H_0 r_0}{Hr} B_0^r$$

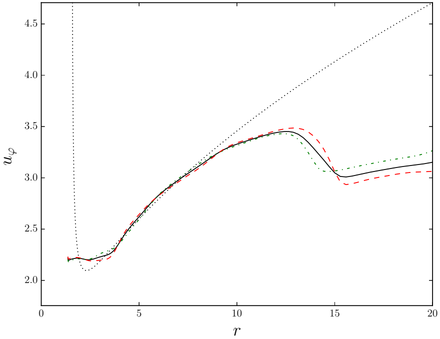
$$B^\varphi(r) = \frac{H_0 r_0}{Hr} \times \frac{u^\varphi - u_0^\varphi}{u^r} B_0^r$$

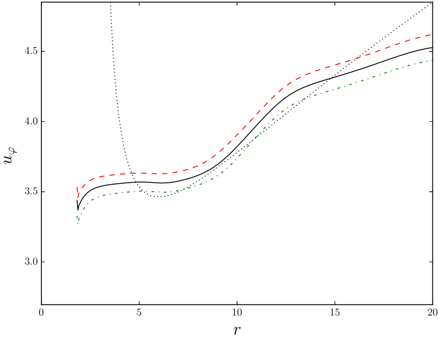
$$B^z(r) = \frac{H_0 r_0 u_0^r}{Hru^r} \times B_0^z$$

Toroidal field in the disk:

$$B_{tor}^\varphi = \frac{H_0 r_0}{Hr} \frac{u_0^r}{u^r} B_0^\varphi$$

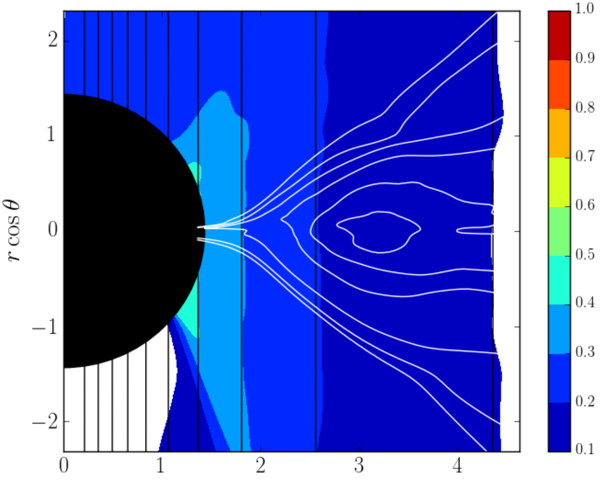
Angular momenta





$a = 0.9$+regular seed field (left) and $a = 0$ + multi-loop mode (right)
first and second halves of the integration time domain shown separately

Two-dimensional rotation law



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