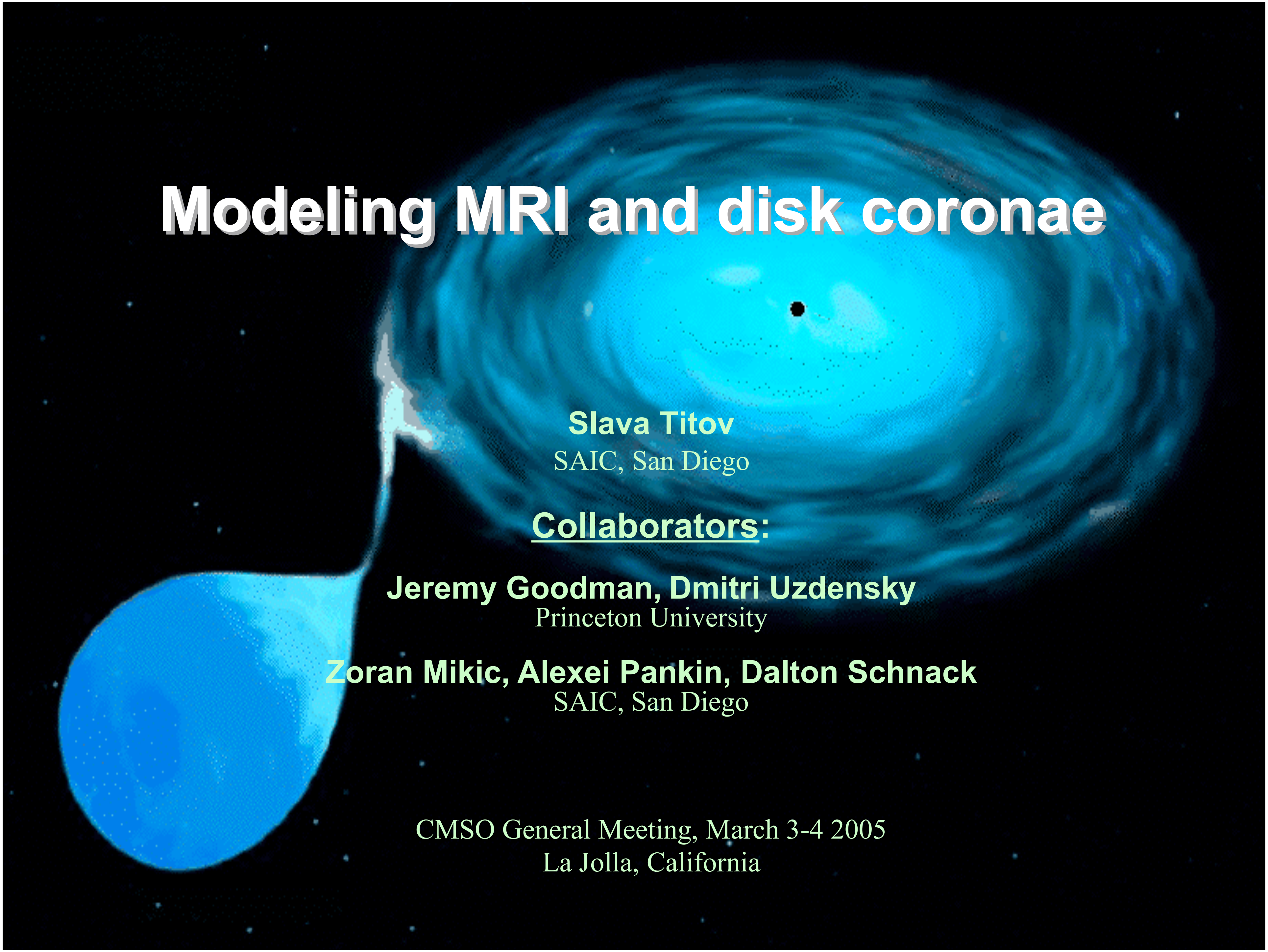


Modeling MRI and disk coronae

Slava Titov
SAIC, San Diego

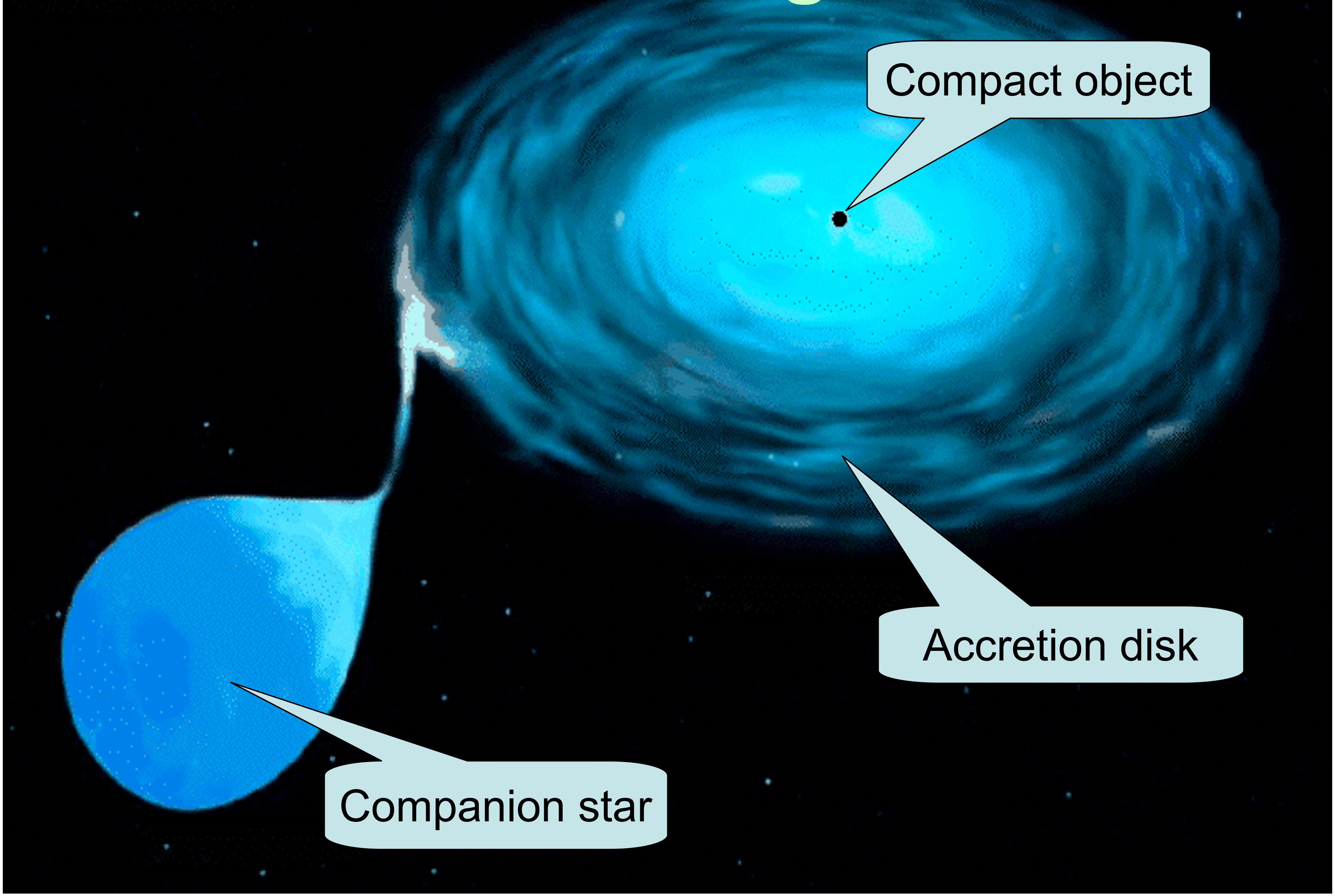
Collaborators:

Jeremy Goodman, Dmitri Uzdensky
Princeton University

Zoran Mikic, Alexei Pankin, Dalton Schnack
SAIC, San Diego

CMSO General Meeting, March 3-4 2005
La Jolla, California

Possible configuration



Conservation of angular momentum

In cylindrical coordinates *(r, ϕ, z)*

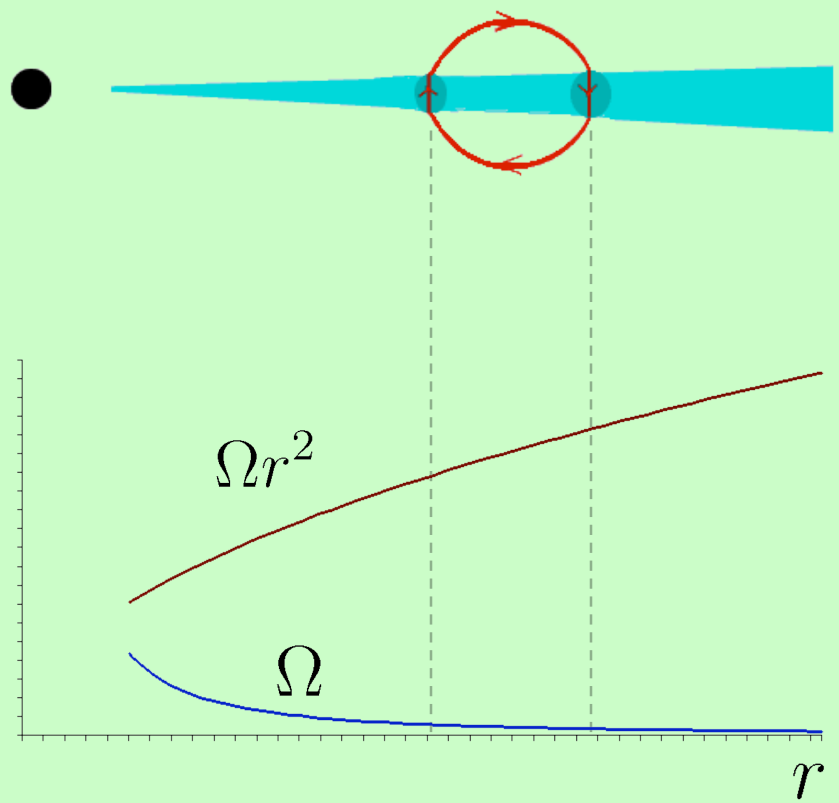
(disk rotation is around *z*-axis)

$$\frac{\partial}{\partial t}\rho v_\phi r + \boldsymbol{\nabla}\cdot\left[\rho v_\phi r \boldsymbol{v} - r\frac{B_\phi}{4\pi}\boldsymbol{B}_p + r\left(P + \frac{B_p^2}{8\pi}\right)\hat{\boldsymbol{\phi}}\right]$$
$$-\boldsymbol{\nabla}\cdot\left[\frac{\eta_{\rm v}}{3} r\left(\boldsymbol{\nabla}\cdot\boldsymbol{v}\right)\hat{\boldsymbol{\phi}} + \eta_{\rm v} r^2 \boldsymbol{\nabla}\frac{v_\phi}{r}\right] = 0$$

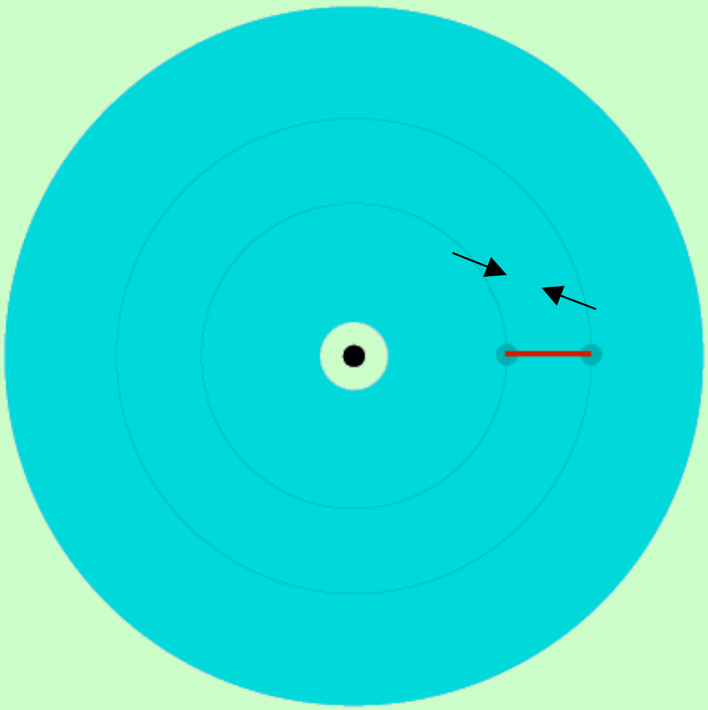
- the microscopic viscosity $\eta_{\rm V}$ is too small to sustain the accretion
- ➔ a turbulent viscosity ?
- magnetic field helps to make differential-rotation flows unstable
    - MRI in the disk
    - coronal MRI

Coronal MRI

Side view



Top view



The flux tube stretches ➔

- leading/lower spot loses Ωr^2 to the trailing/upper one,
- ➔ the lower spot sinks, while the upper spot rises;➔
- the difference in their Ω increases

Disk

In cylindrical coordinates *(r, ϕ, z)*, integrated over *z*

Eqs. of motion

$$-2\Omega\,\tilde{v}_\phi \;=\; -c_s^2\frac{\partial \ln\Sigma}{\partial r} + \frac{B_r}{2\pi}\,\frac{B_z}{\Sigma}, \qquad (1)$$

$$\left(\Omega r^2\right)' v_r \;=\; -c_s^2\frac{\partial \ln\Sigma}{\partial \phi} + r\frac{B_\phi}{2\pi}\,\frac{B_z}{\Sigma}, \qquad (2)$$

cont. eq.

$$\left[\frac{\partial}{\partial t} + \left(\Omega + \frac{\tilde{v}_\phi}{r}\right)\frac{\partial}{\partial \phi} + v_r\frac{\partial}{\partial r}\right]\ln\Sigma \;=\; -\frac{1}{r}\left[\frac{\partial (r v_r)}{\partial r} + \frac{\partial \tilde{v}_\phi}{\partial \phi}\right], \qquad (3)$$

induct. eq.

$$\left[\frac{\partial}{\partial t} + \left(\Omega + \frac{\tilde{v}_\phi}{r}\right)\frac{\partial}{\partial \phi} + v_r\frac{\partial}{\partial r}\right]\frac{B_z}{\Sigma} \;=\; \frac{1}{\Sigma}\left(\dot{B}_z + \eta\boldsymbol{\nabla}_{\rm h}^2 B_z\right), \qquad (4)$$

input **(from corona)**

$B_r(r,\phi,t),\ B_\phi(r,\phi,t)$

output **(for corona)**

$v_r(r,\phi,t),\ v_\phi(r,\phi,t),\ B_z(r,\phi,t)$

Corona

Resistive MHD eqs. (zero beta limit)

$$\nabla \times \boldsymbol{B} = \frac{4\pi}{c}\boldsymbol{J}, \tag{5}$$

$$\nabla \times \boldsymbol{E} = -\frac{1}{c}\frac{\partial \boldsymbol{B}}{\partial t}, \tag{6}$$

$$\boldsymbol{E} + \frac{1}{c}\boldsymbol{v} \times \boldsymbol{B} = \eta \boldsymbol{J}, \tag{7}$$

$$\rho\left(\frac{\partial \boldsymbol{v}}{\partial t} + \boldsymbol{v} \cdot \nabla\, \boldsymbol{v}\right) = \frac{1}{c}\boldsymbol{J} \times \boldsymbol{B} + \nabla \cdot (\nu \rho \nabla \boldsymbol{v}), \tag{8}$$

$$\rho = \rho_0 \ \text{(constant)}. \tag{9}$$

at $z = 0$

input (from disk)

$v_r(r, \phi, t),\ v_\phi(r, \phi, t),\ B_z(r, \phi, t)$

output (for disk)

$B_r(r, \phi, t),\ B_\phi(r, \phi, t)$

Initial state

Two possibilities

1 Only a single flux tube, no large scale magnetic field is present

- $B_z = 0$, emerge flux tube adiabatically slow by rising B_z in two lagrangian elements/footprints through the source term in the induction eq. ➔
  - natural emergence of the flux tube into the corona
  - natural behavior both in the disk (no initial jerk) and in the corona (sequence of force-free equilibria)
- Other values: $v_r = \tilde{v}_\phi = 0, \quad \Sigma = \mathrm{const}$

2 Large scale magnetic field is also present

- Accretor is a black hole ➔
  - steady magnetosphere is possible
- Accretor is a star ➔
  - steady magnetosphere is questionable