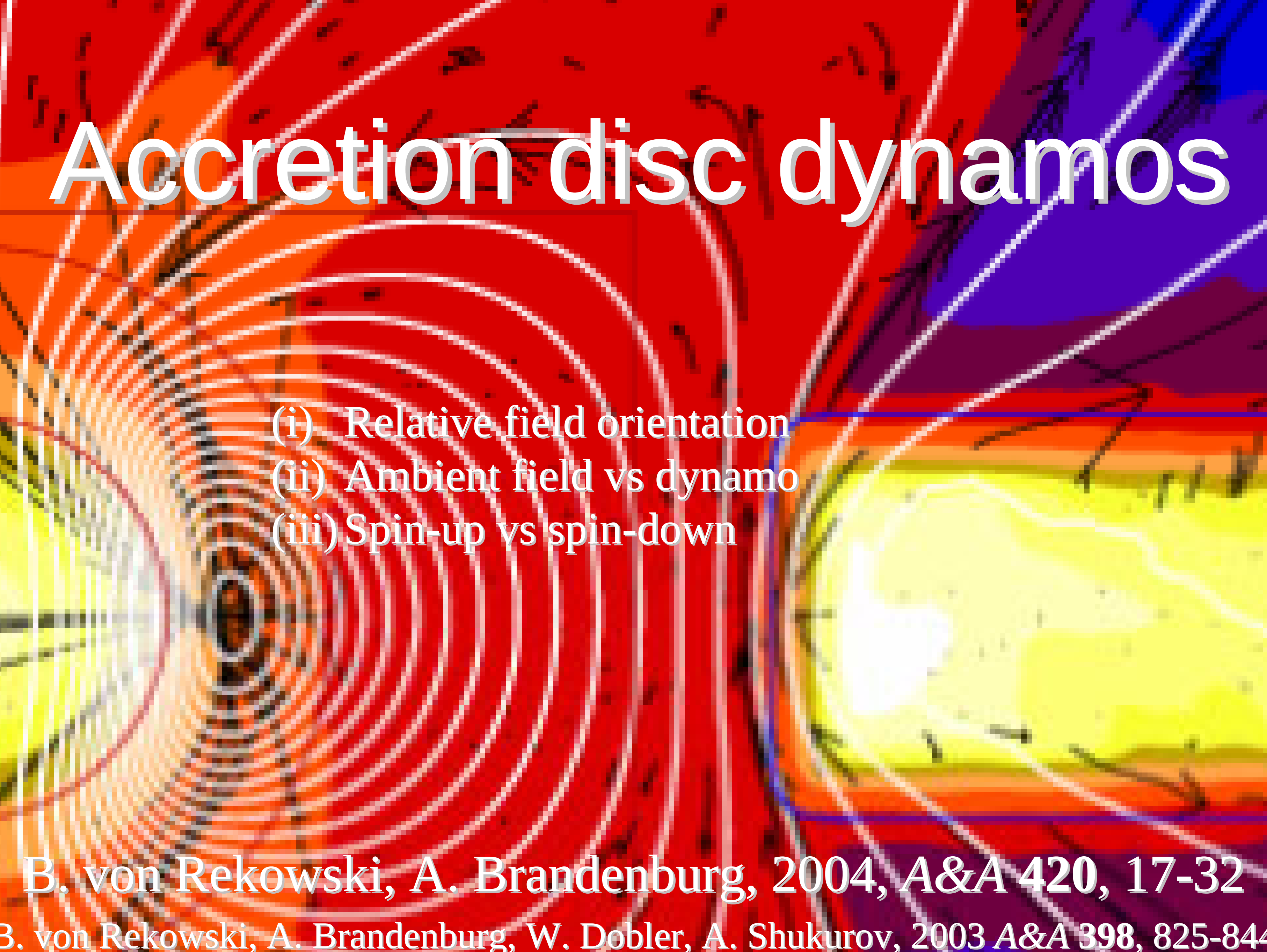


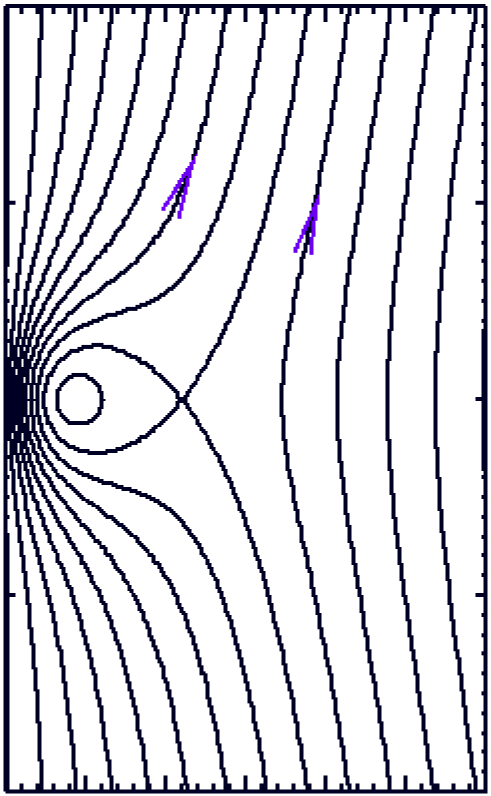
Accretion disc dynamos

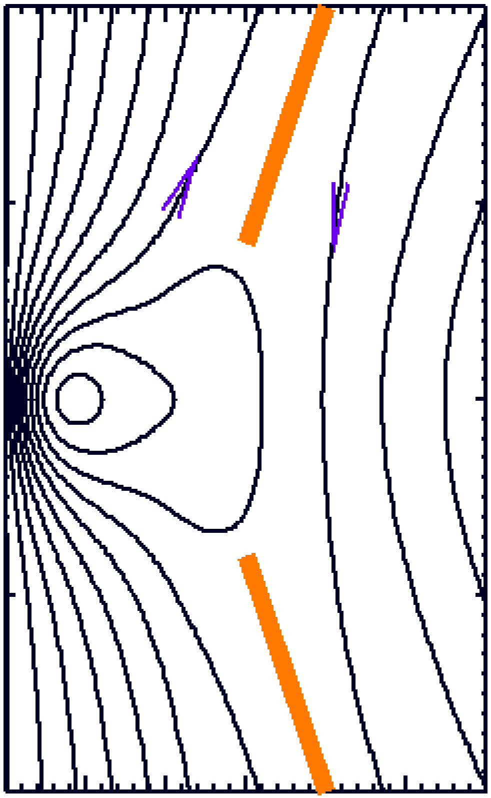
(i) Relative field orientation
(ii) Ambient field vs dynamo
(iii) Spin-up vs spin-down

B. von Rekowski, A. Brandenburg, 2004, *A&A* **420**, 17-32

B. von Rekowski, A. Brandenburg, W. Dobler, A. Shukurov, 2003 *A&A* **398**, 825-84

(i) Which way around does it go?





Stellar field aligned with ambient field

→ formation of X-point

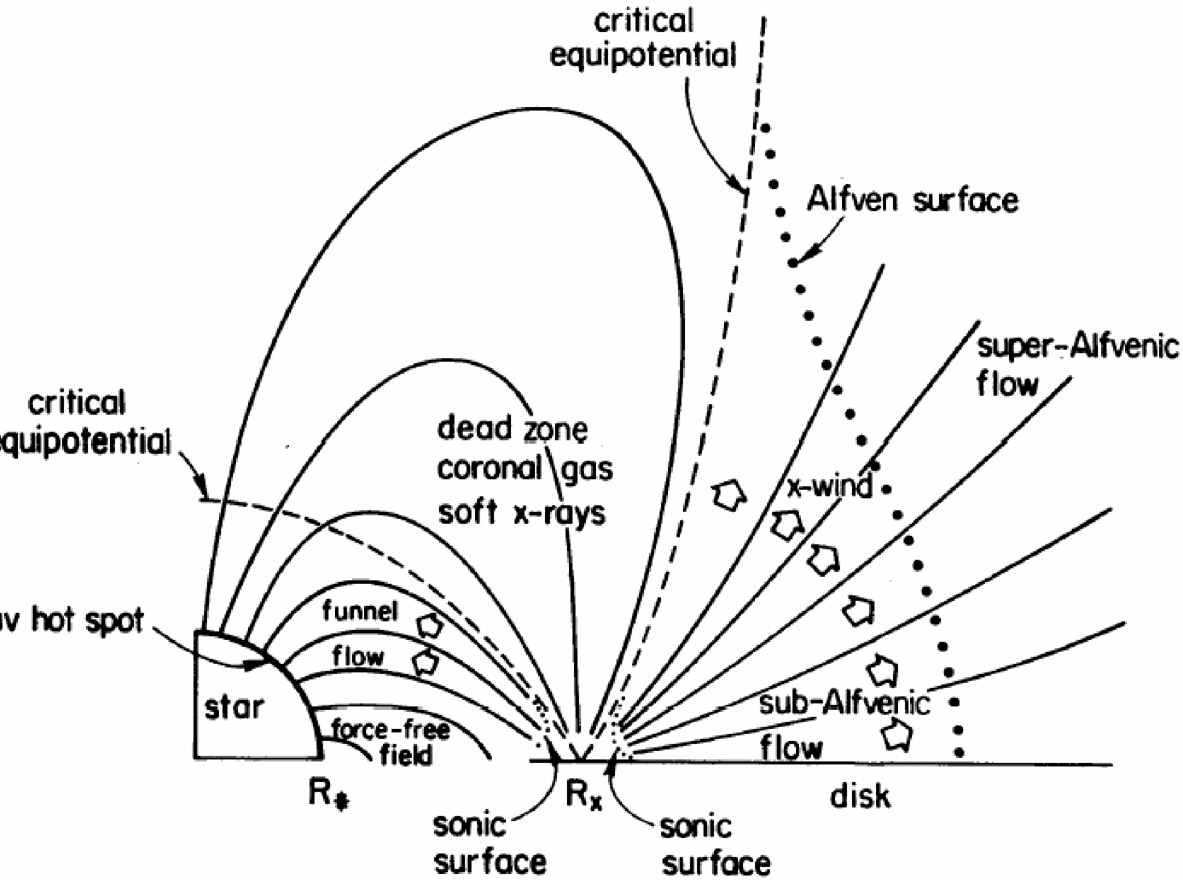
Stellar field anti-aligned

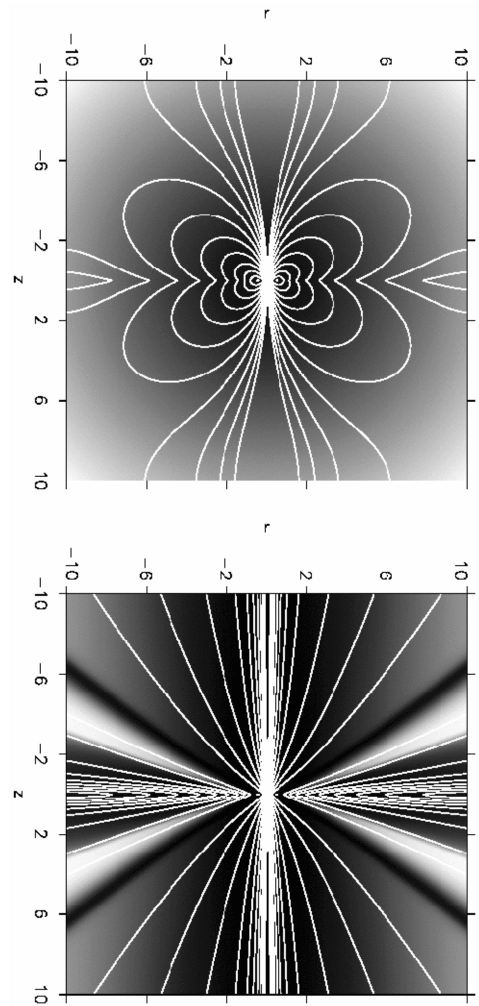
→ current sheet

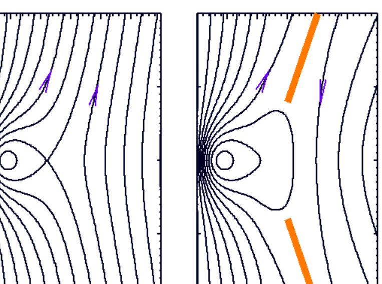
If external field is dragged in.
or if stellar field shows reversals

If field is due to dynamo

Wind and accretion



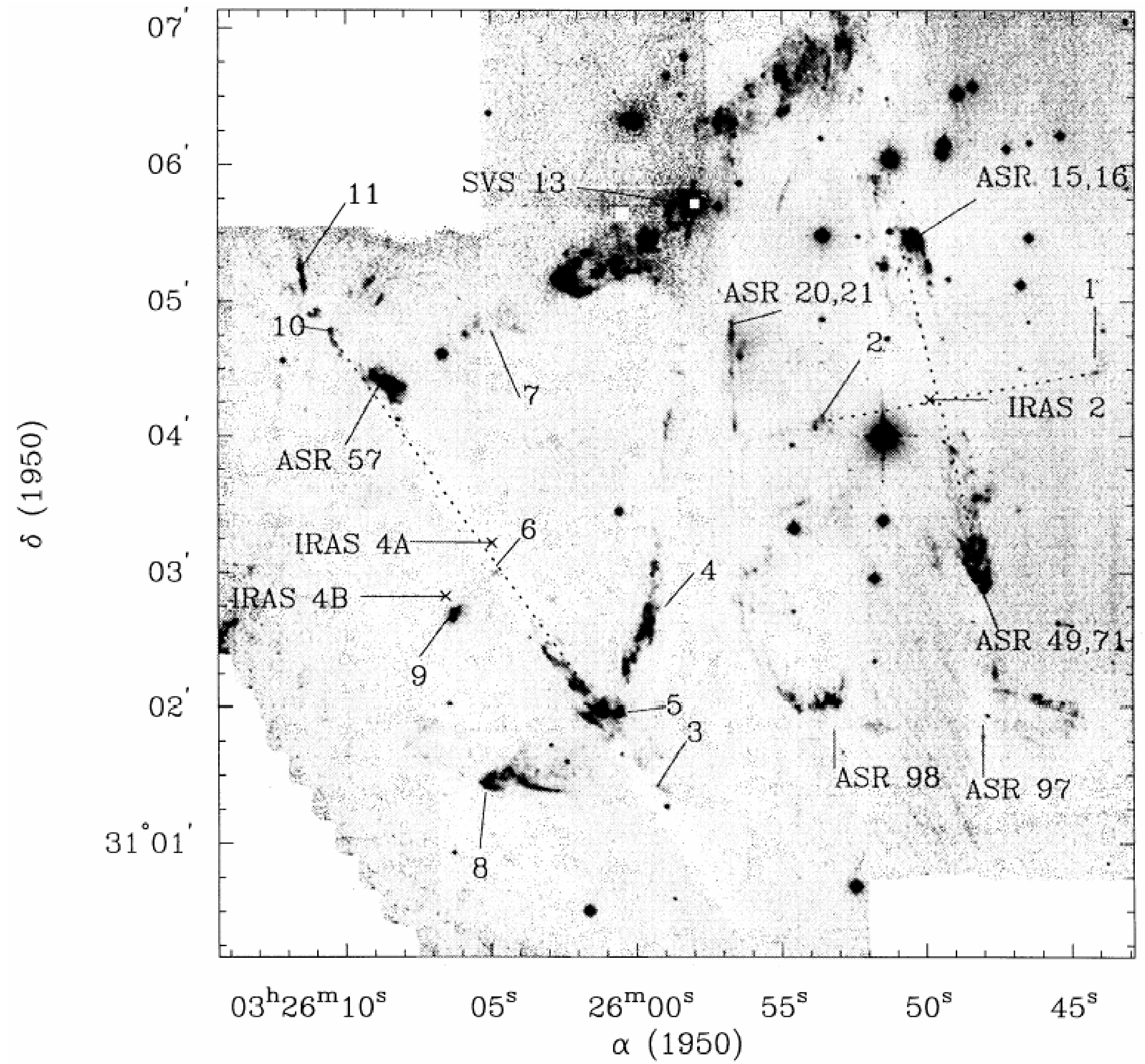




X-wind
(Shu et al. 1994)

Simulation
(Fendt & Elstner 2000)

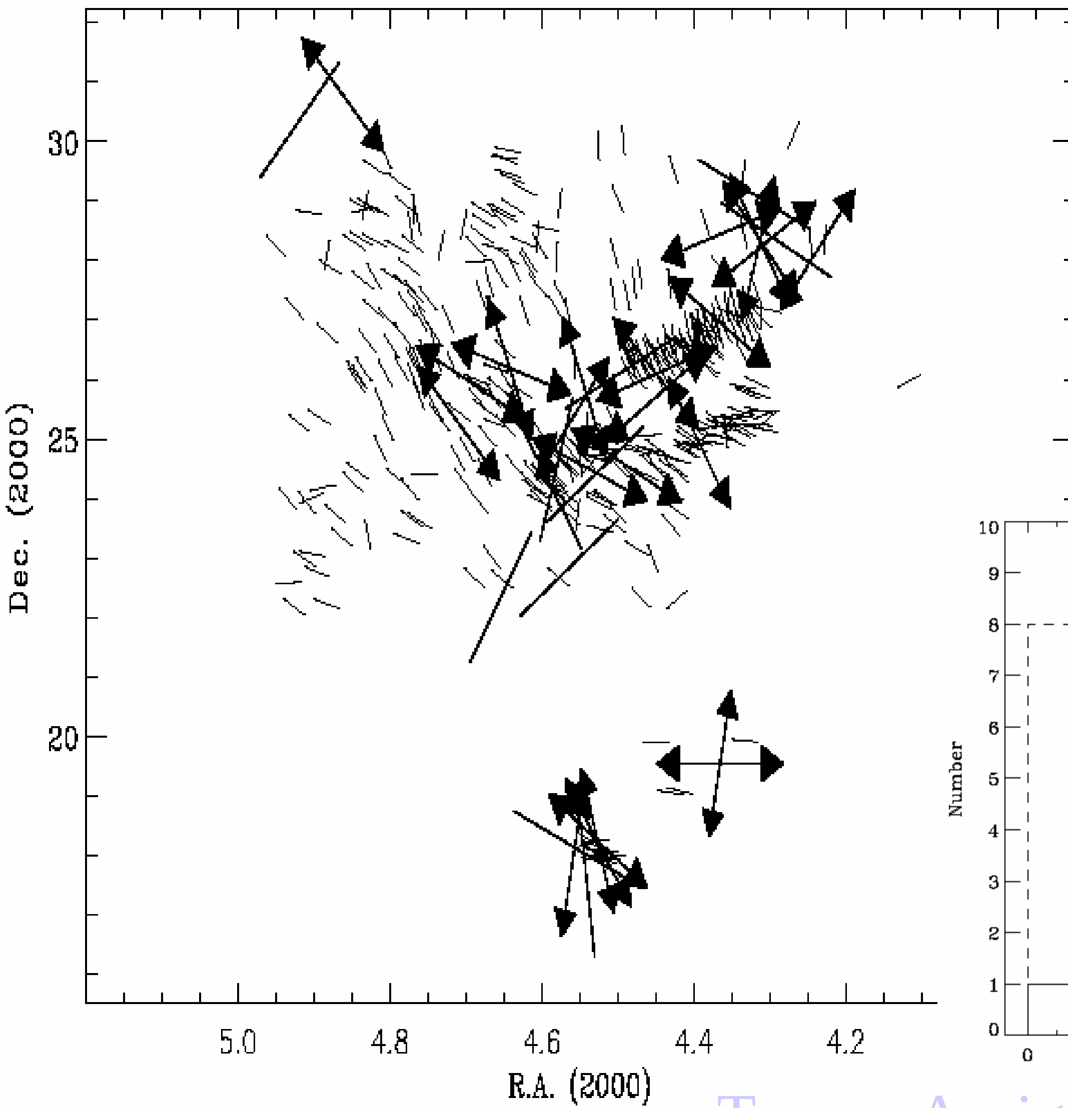
(ii) Ambient vs dynamo:
different jet directions



Hodapp & Ladd (1995)

Correlation with ambient field

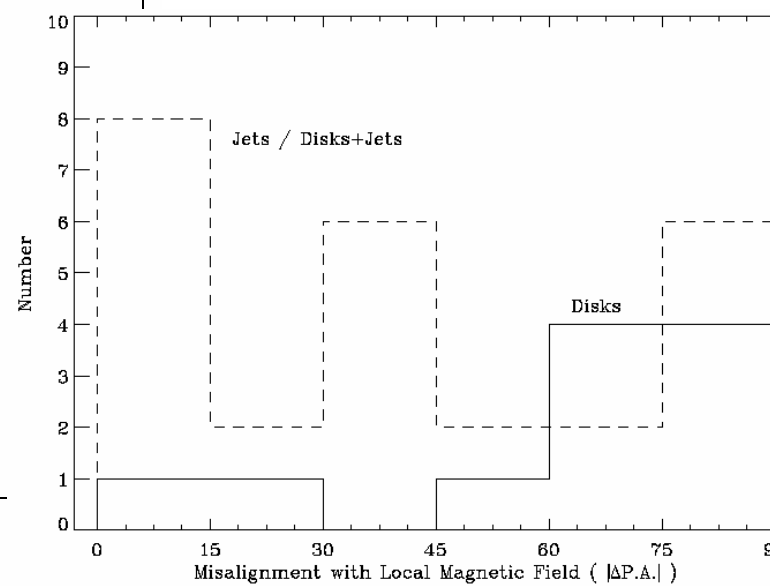
Menard & Duchene (2004)



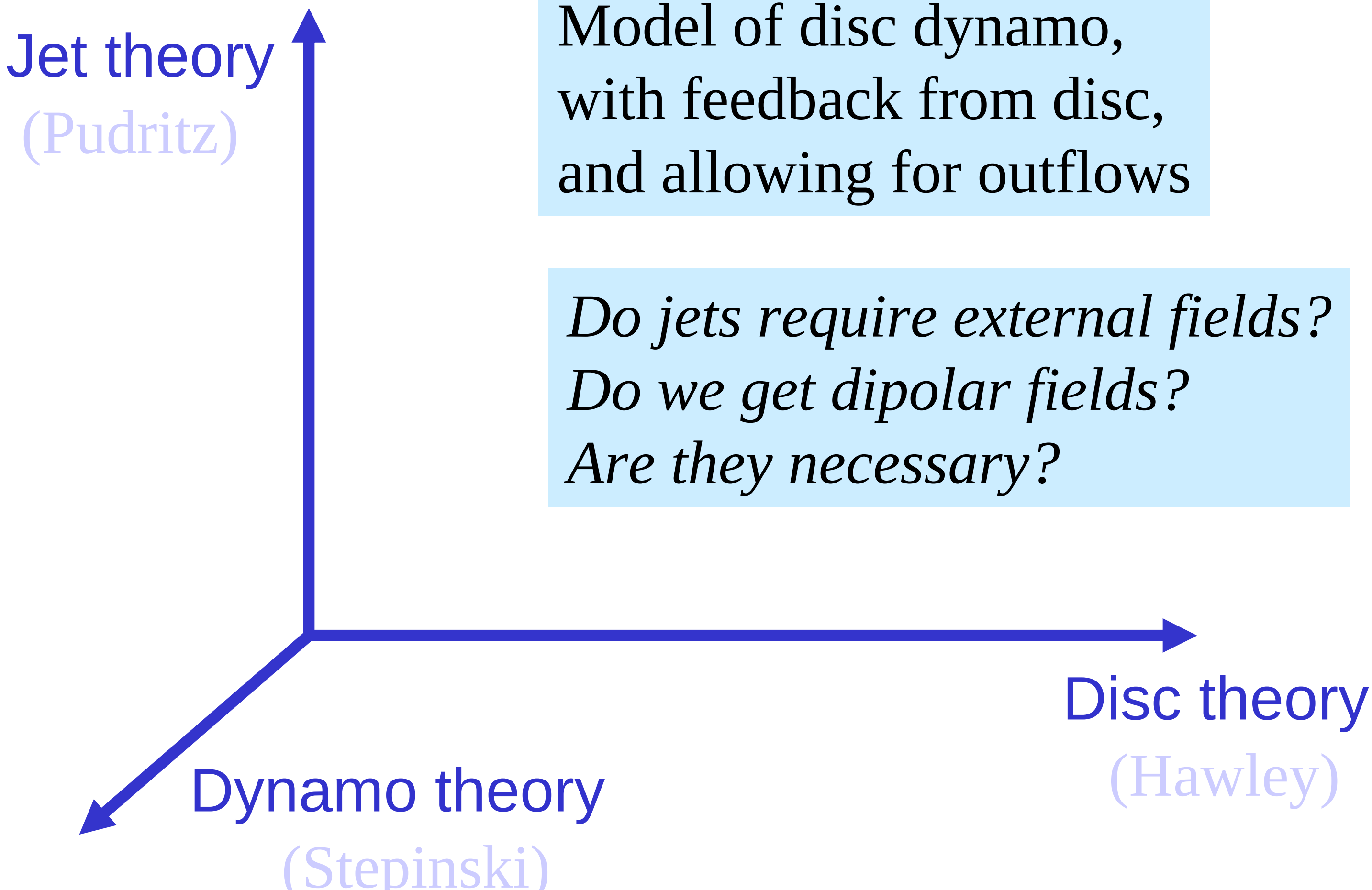
Taurus-Auriga

→ All objects have outflows

→Jets more pronouced when aligned



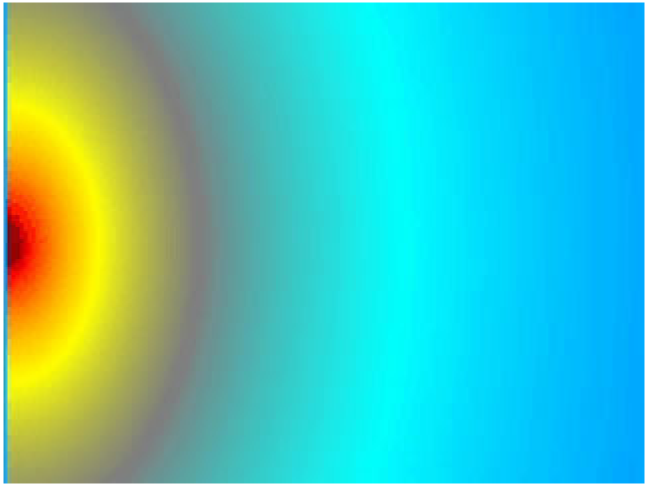
Bridging the gaps: jet-disc-dynamo



Model of disc dynamo,
with feedback from disc,
and allowing for outflows

Do jets require external fields?
Do we get dipolar fields?
Are they necessary?

Our inspiration



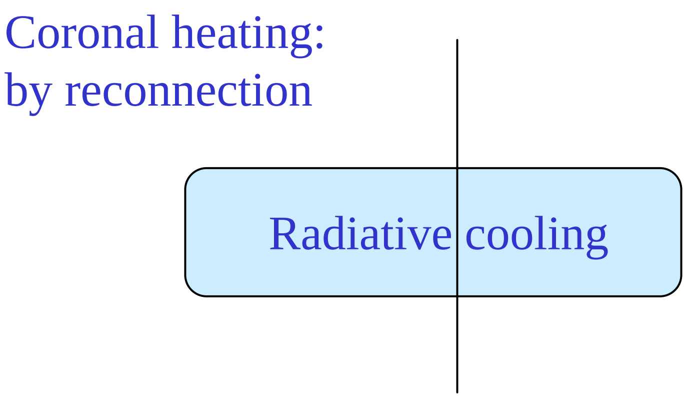
Ouyed & Pudritz (1997)

- Disc modeled as b.c.
- Adiabatic EOS
  - Virial temperature

$$c_p T = \frac{GM}{r}$$

- Need a cool disc
- Kepler rot. only for $T \approx 0$

Modeling a cool disc



Vertical cross-section through the disc

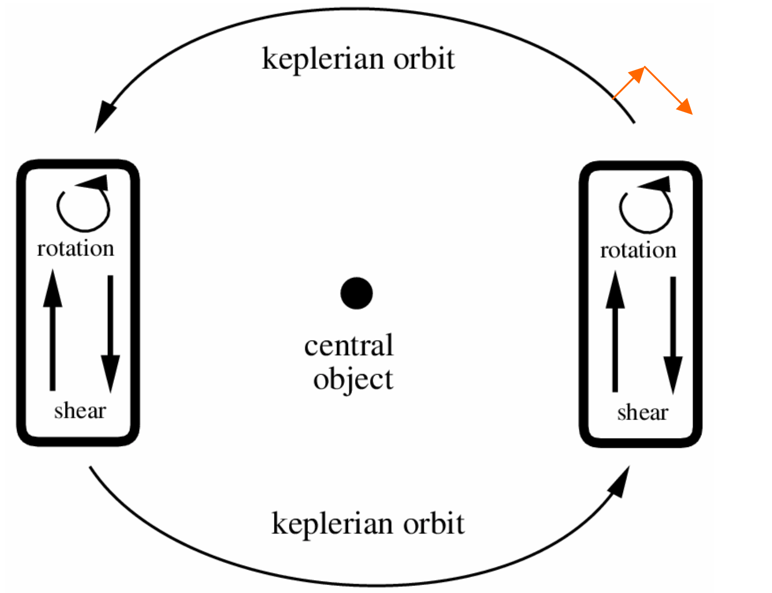
- vertical pressure eq.
- low T → high density
- Entropy lower in disc
  - bi-polytropic model

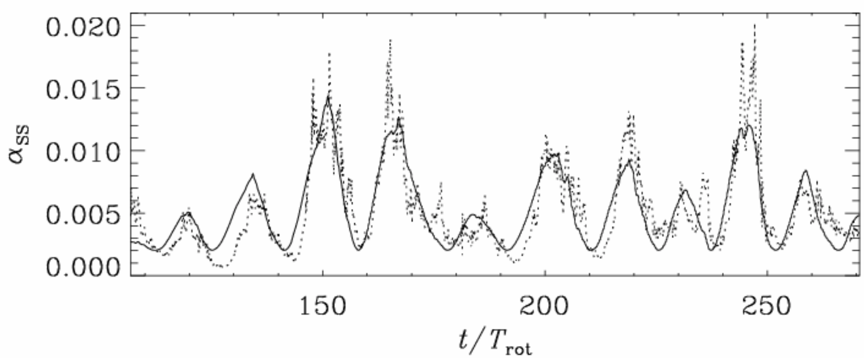
$$0 = -\frac{\partial}{\partial z}\left(h + \Phi\right) + T\frac{\partial s}{\partial z}$$

$$-\frac{u_\phi^2}{\varpi} = -\frac{\partial}{\partial \varpi}\left(h + \Phi\right) + T\frac{\partial s}{\partial \varpi}$$

Dynamo input: shearing sheet simulations

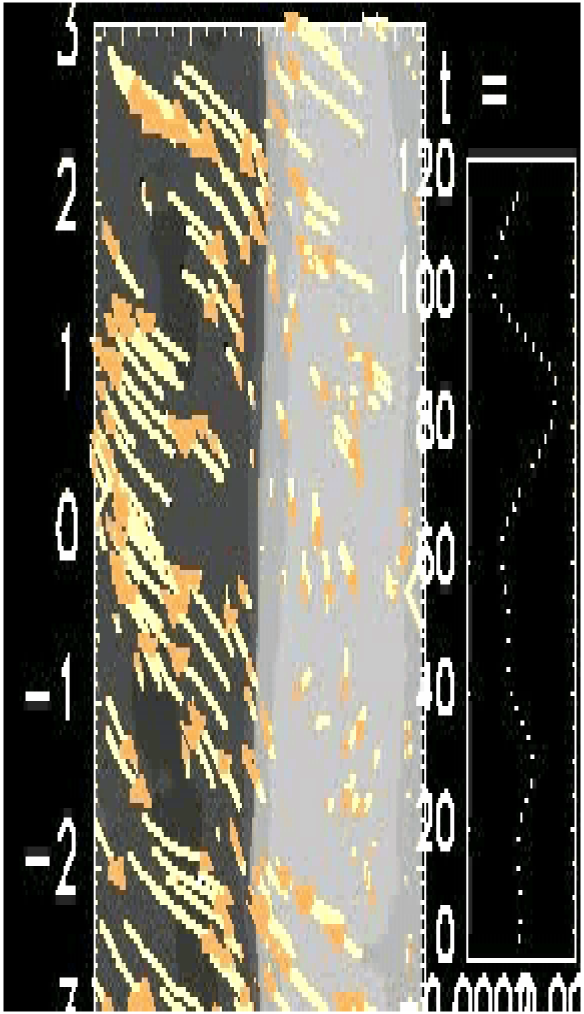
oscillatory mean fields





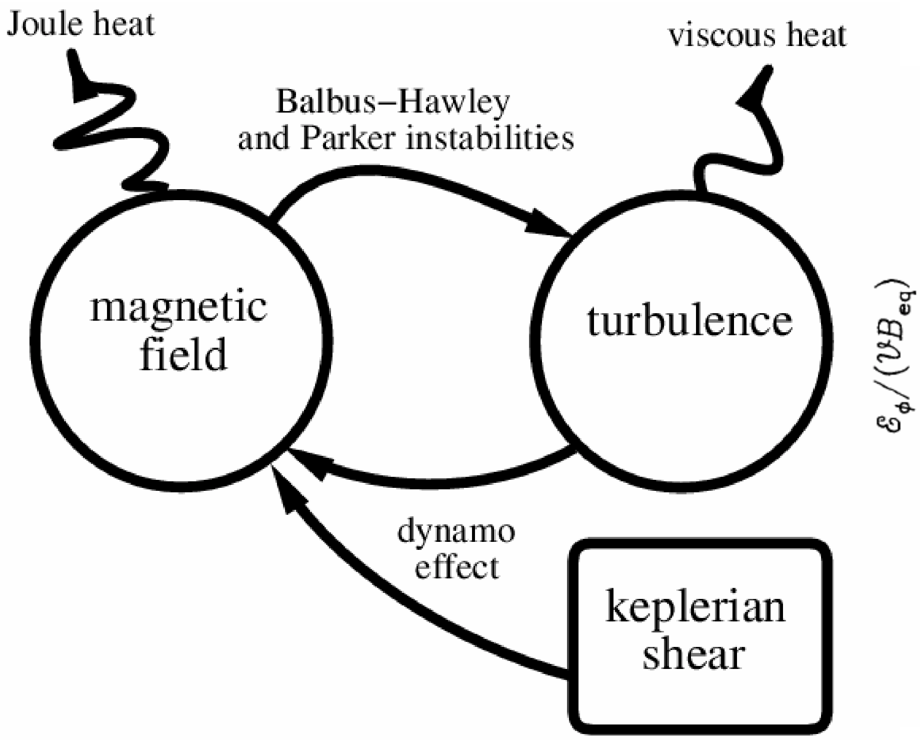
Dynamo cycle period: 30 orbits

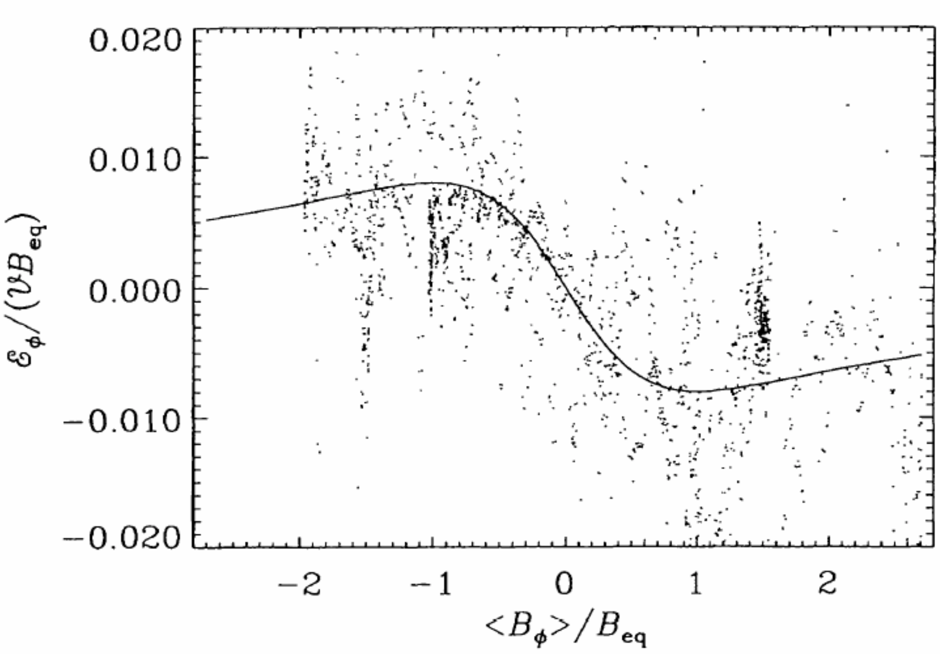
(=turbulent diffusion time)



B-vectors in midplane: reversals

New dynamo aspects





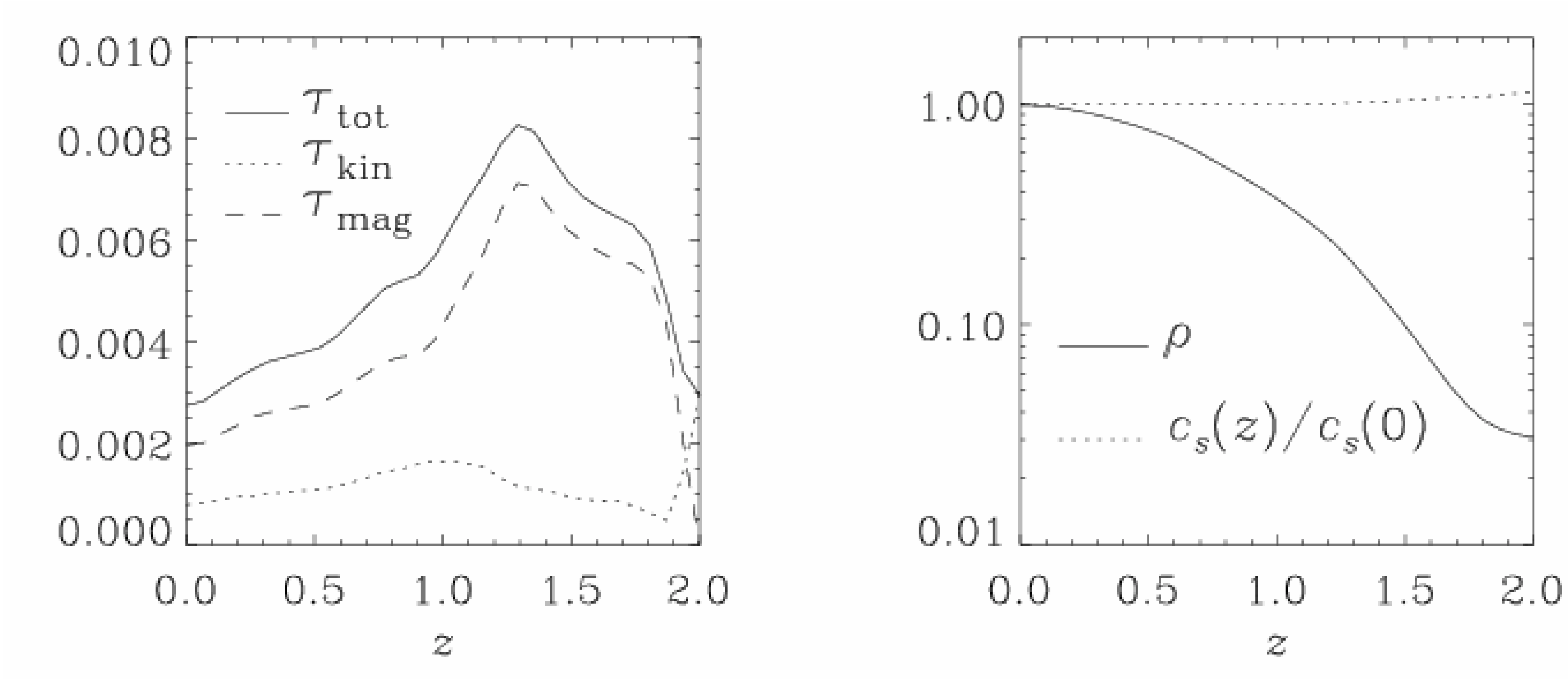
Magnetic field as catalyst

Negative alpha effect

Dynamo input (summary)

- Local disc simulations: cyclic fields
  - Quadrupolar for vacuum condition
  - Steady dipolar field for perfect conductor b.c.
- Dynamo alpha negative
  - Local mean-field models: similar results
- Global mean field models: always dipolar
  - Bardou et al. (2001), Campbell (2001)

Vertical stratification



Brandenburg et al. (1996)

z-dependence of $\quad \nu_{\text{turb}} = \alpha c_s H = \alpha(z)\, c_s H$

$$\rho \nu_{\text{turb}} = \rho\, \alpha c_s H = \alpha c_s \Sigma \approx \text{const}$$

Heating near disc boundary

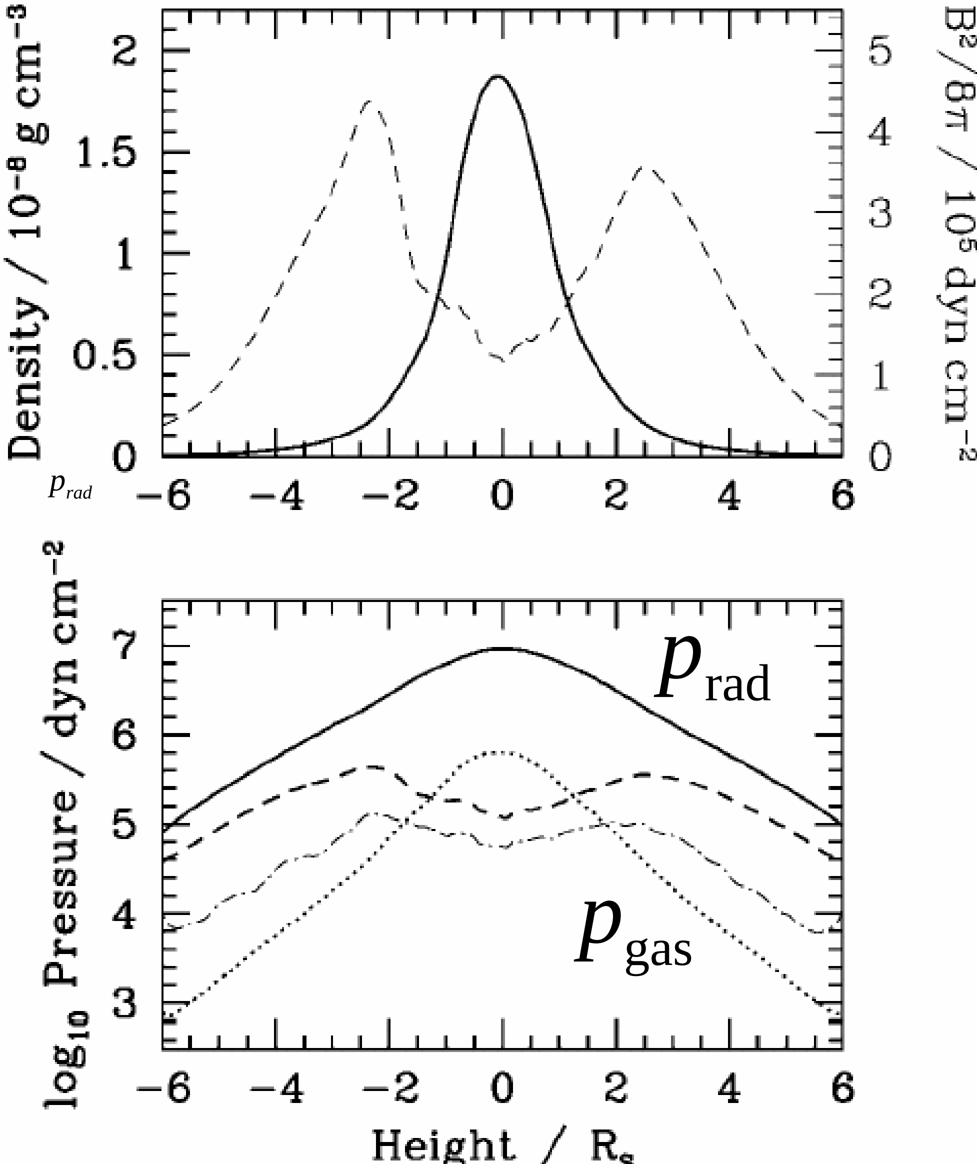
$$c_v \frac{\partial T}{\partial t} = \ldots + \nu(\nabla \mathbf{u})^2 + \frac{\mathbf{J}^2}{\rho\sigma}$$

weak z-dependence of energy density

$$\rho \mathbf{u}^2 \approx \mathbf{B}^2 / \mu_0$$

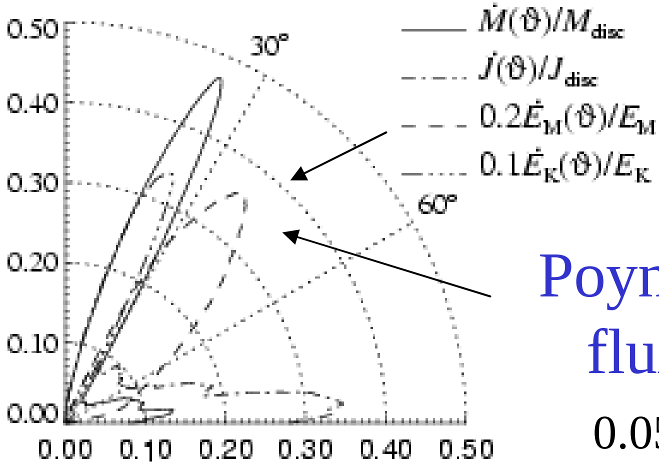
where

$$\mathbf{J} = \nabla \times \mathbf{B} / \mu_0$$



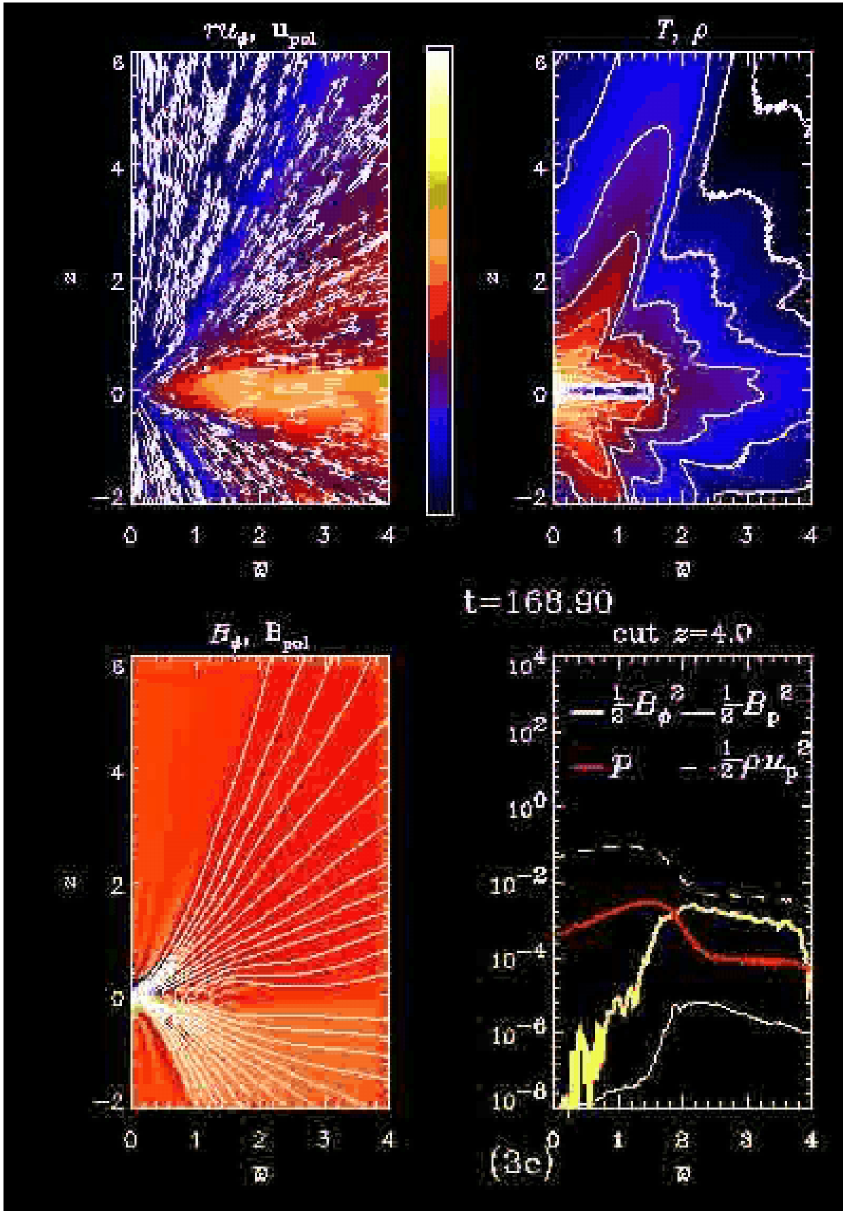
Turner (2004)

Alternative: Magnetisation from YSOs?



Poynting flux

$0.05\dot{M}c_s^2$



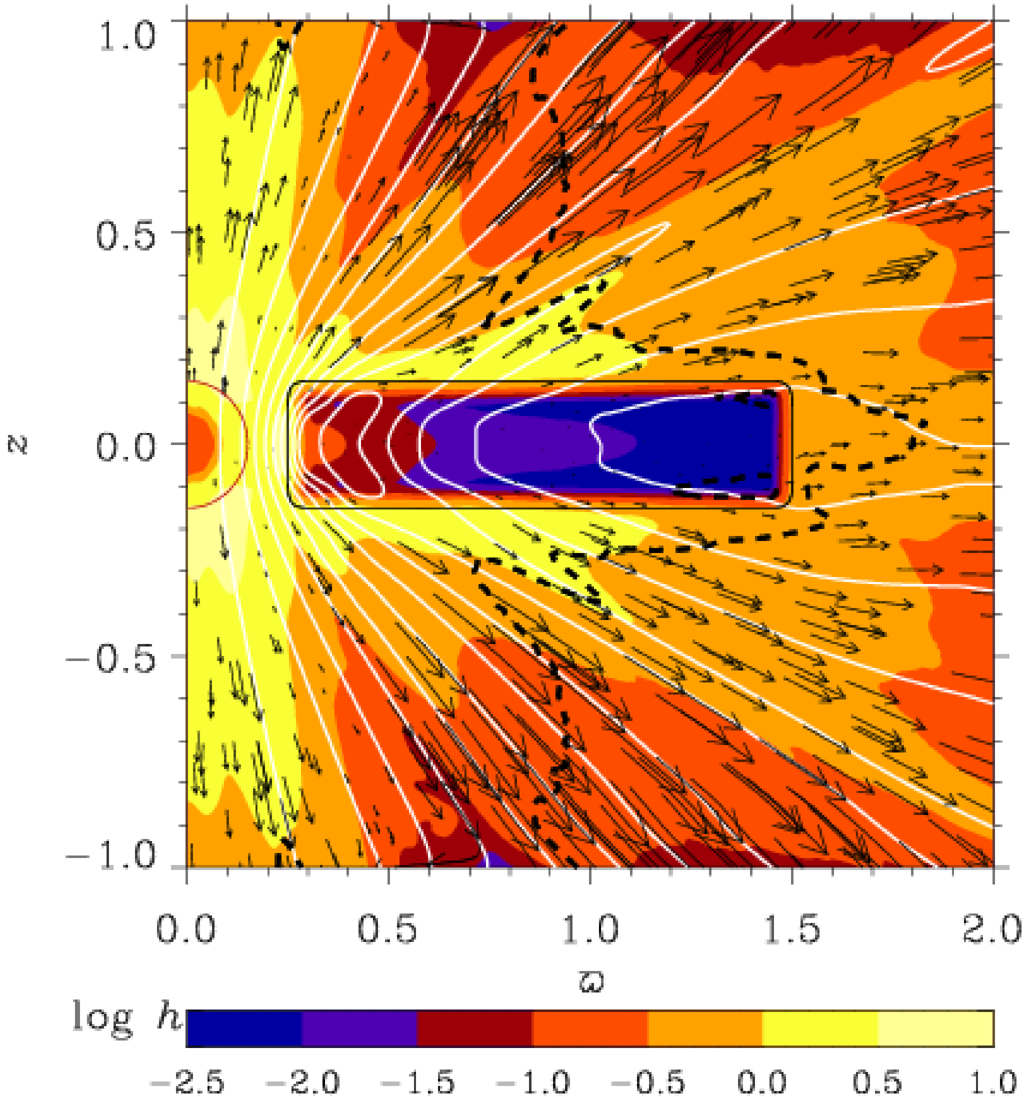
$$B_{rms} = \sqrt{8\pi \frac{F_{poynt}}{F_{kin}} \frac{N\dot{M}_w c_s^2}{V} \Delta t} \approx 1\mu G$$

10^{11} YSOs for 1 Gyr, 10^{44} erg/s each

Similar figure also for outflows from protostellar disc

B. von Rekowski, A. Brandenburg, W. Dobler, & A. Shukurov, 2003 *A&A* **398**, 825-844

Structured outflow

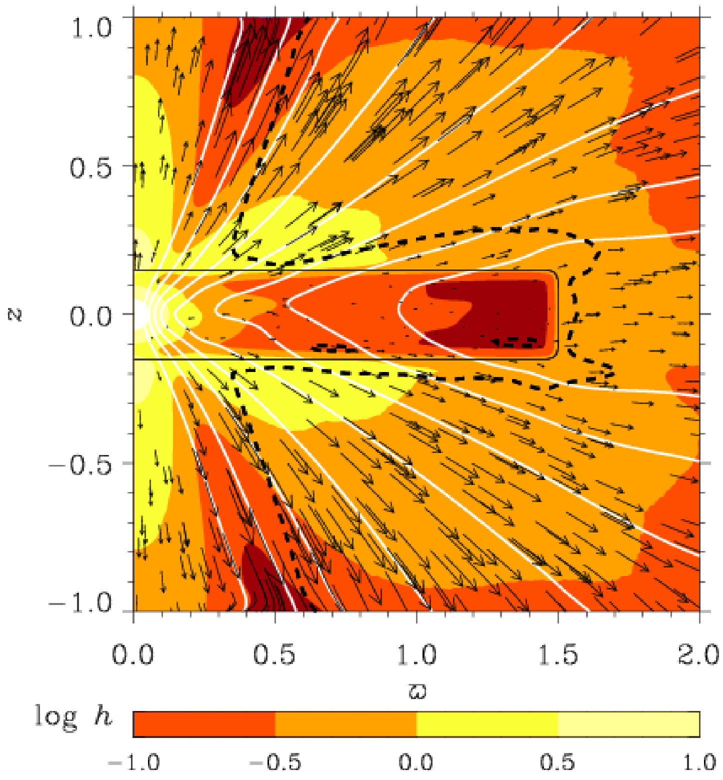


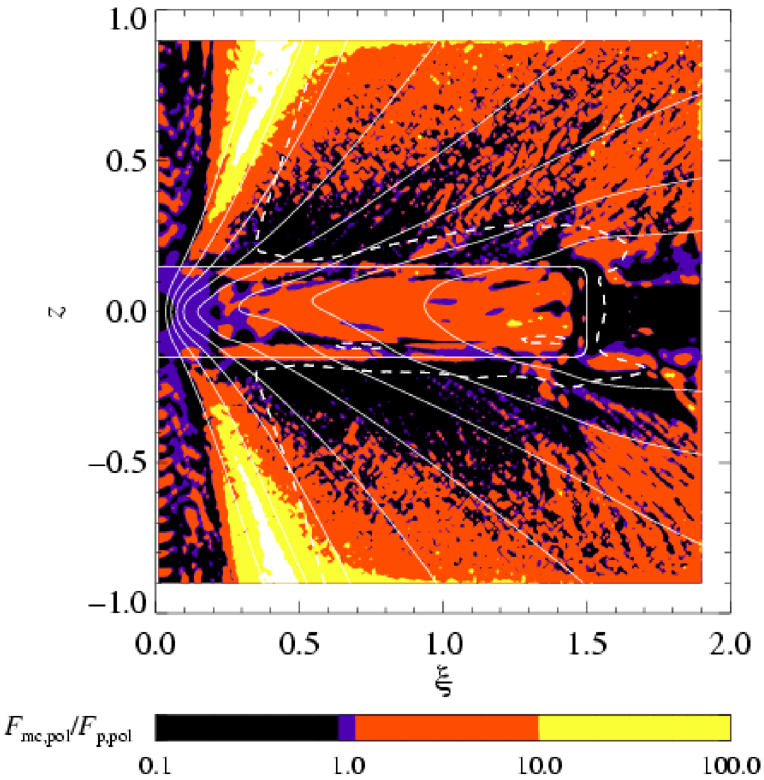
Disc temperature relative to halo is free parameter: Here about 3000K

Cooler disc: more vigorous evolution

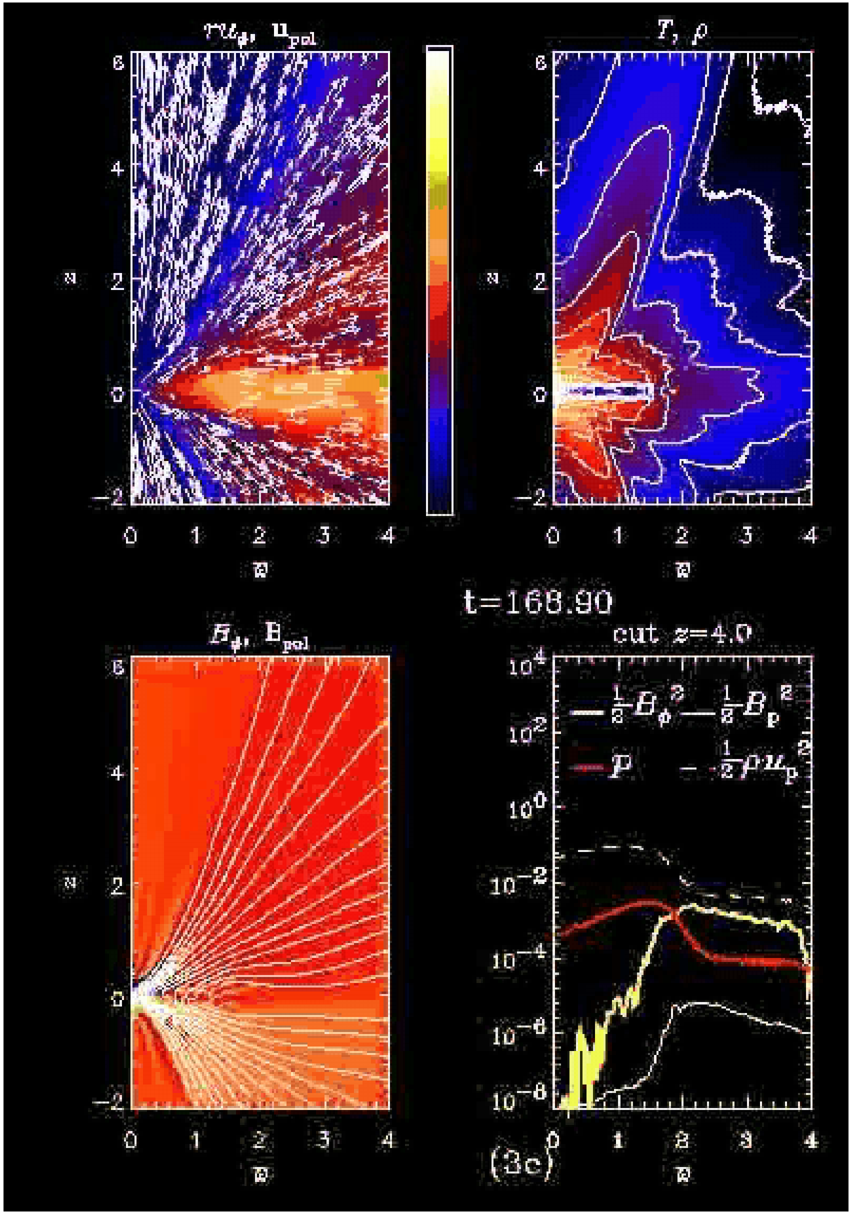
Acceleration mechanism

Disc temperature about 3000 K





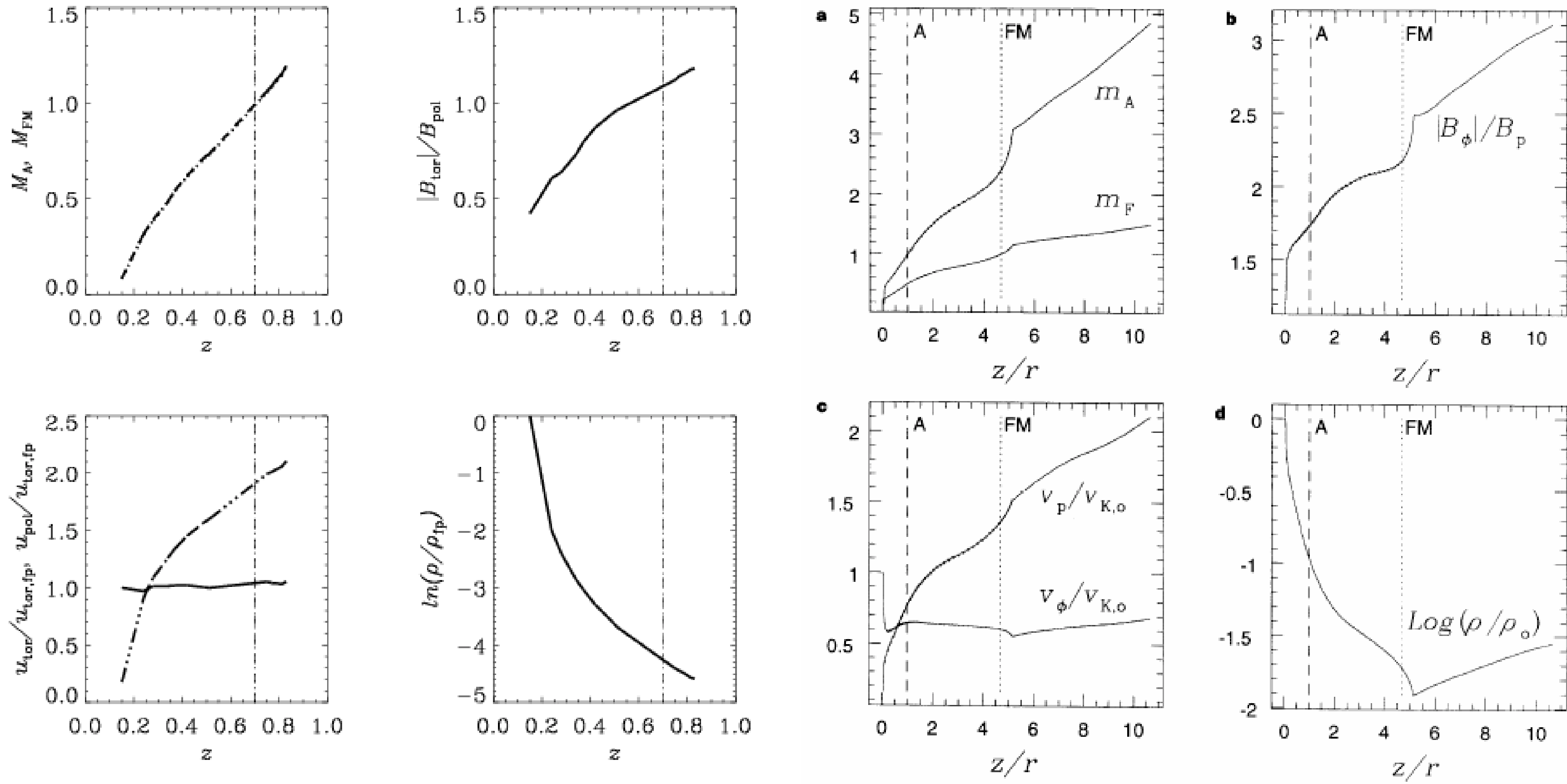
Ratio of magneto-centrifugal force to pressure force



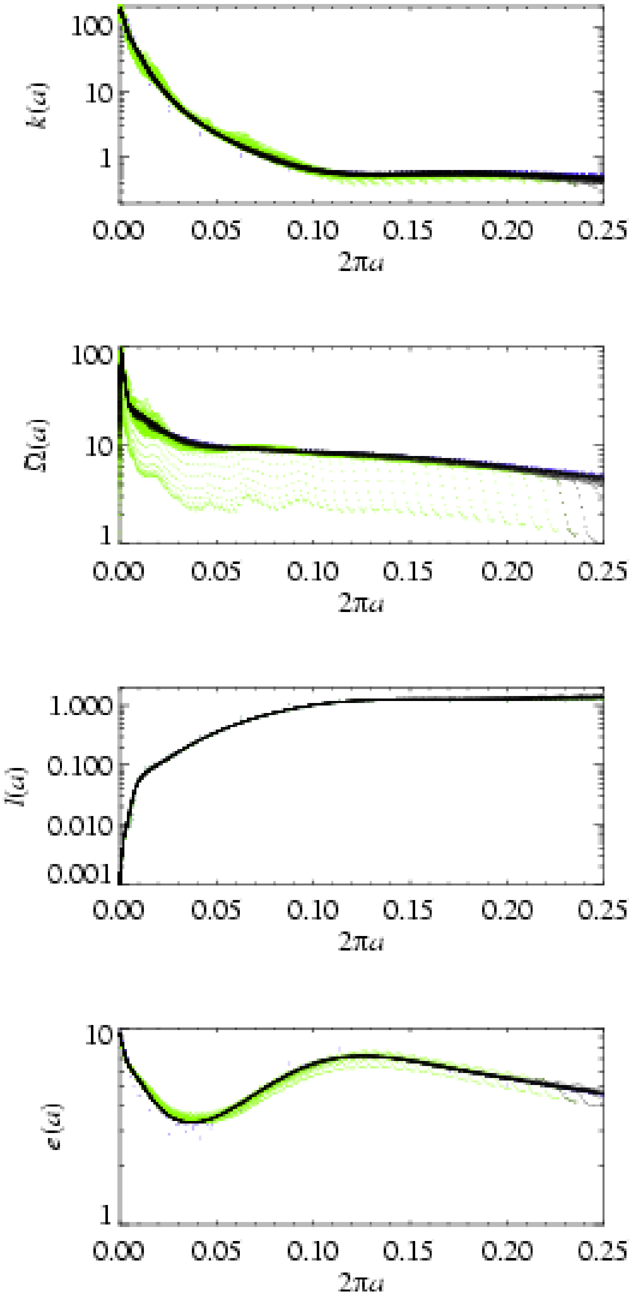
Unsteady outflow is the rule

Momentum transport from the disc into the wind

Comparison with Ouyed & Pudritz (1997)



Very similar: Alfven Mach >1
Toroidal/poloidal field ratio increases



Lagrangian invariants

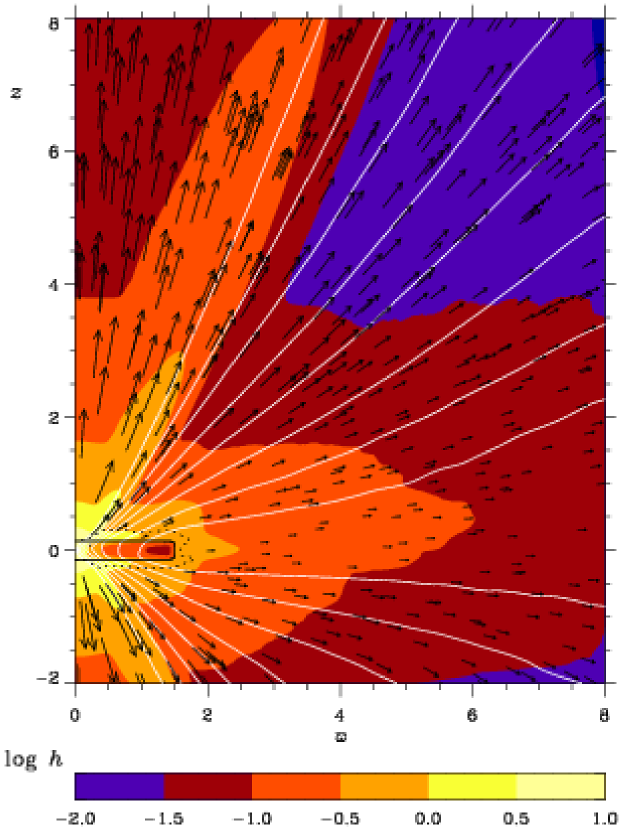
$$k(a) = \rho u_i / B_i$$

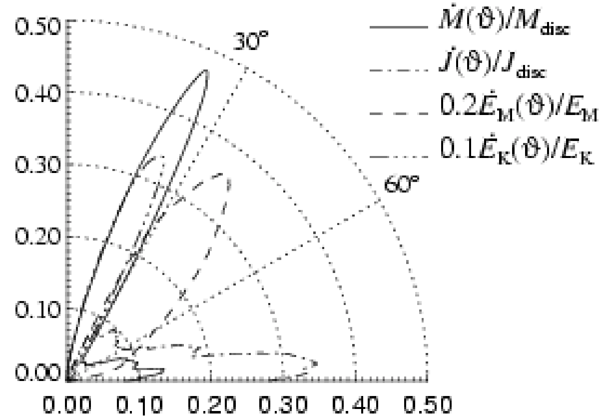
$$\tilde{\Omega}(a) = \varpi^{-1}\left(u_\phi - B_\phi / \rho\right)$$

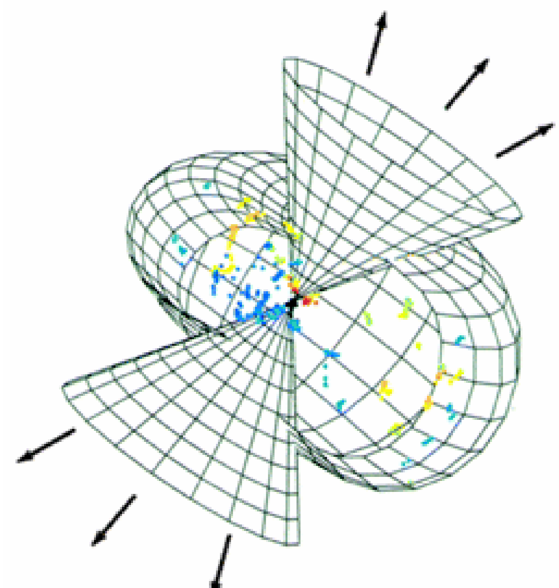
$$l(a) = \varpi u_\phi - \varpi B_\phi / \left(\mu k\right)$$

$$e(a) = \tfrac{1}{2}\mathbf{u}^2 + h + \Phi - \varpi\tilde{\Omega} B_\phi / \left(\mu k\right)$$

Conical outflows (similar to BN/KL)

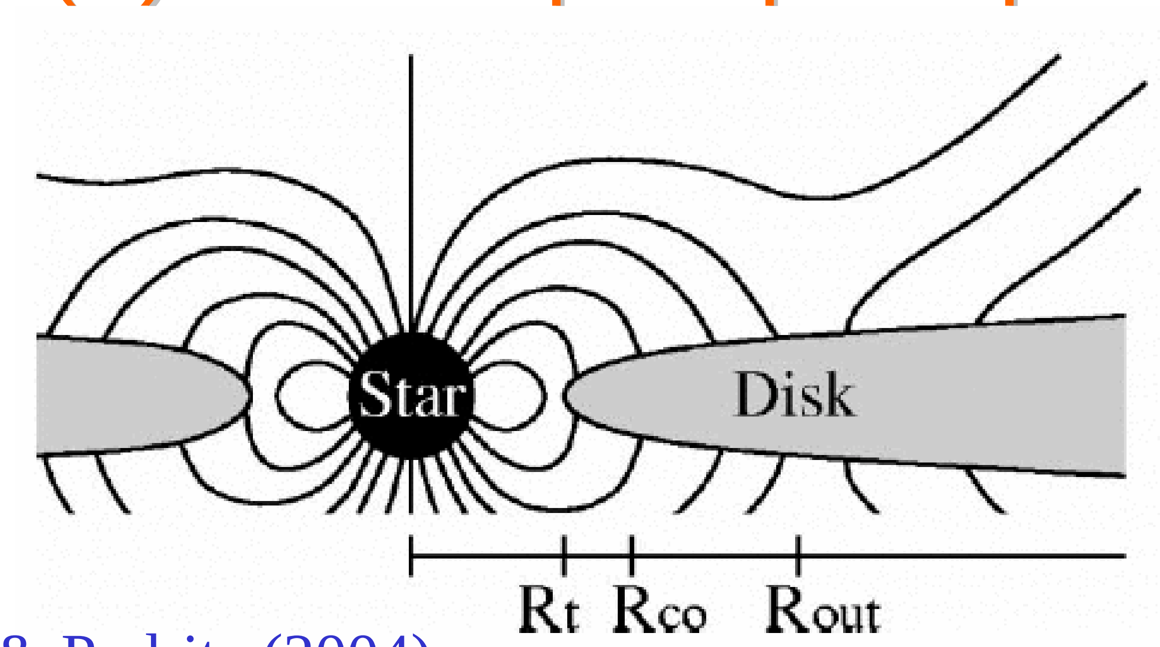


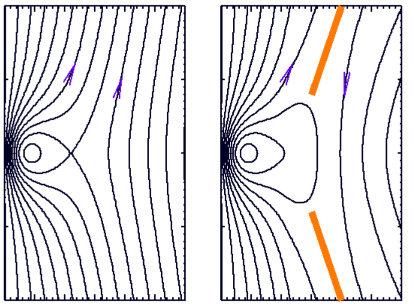




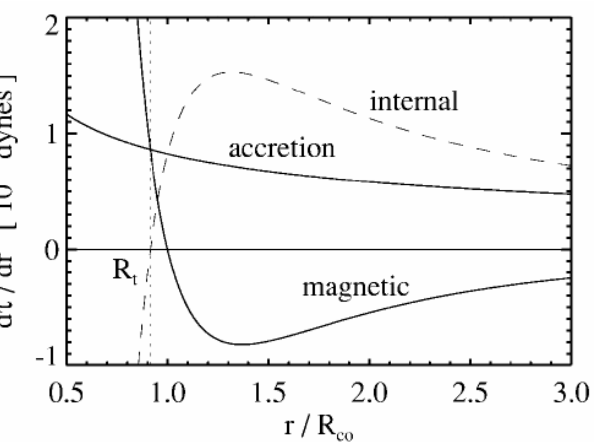
Greenhill et al (1998)

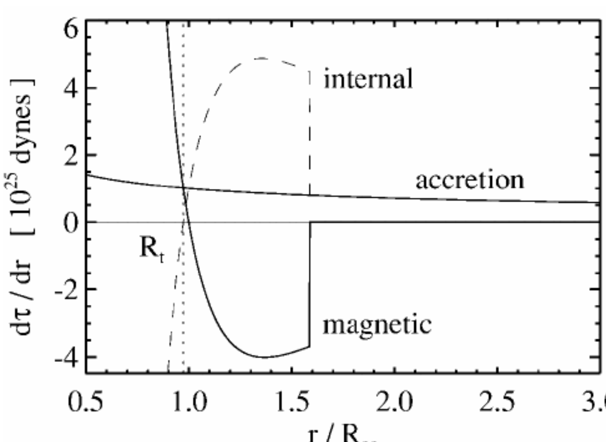
(iii) Stellar spin-up or spin-down?

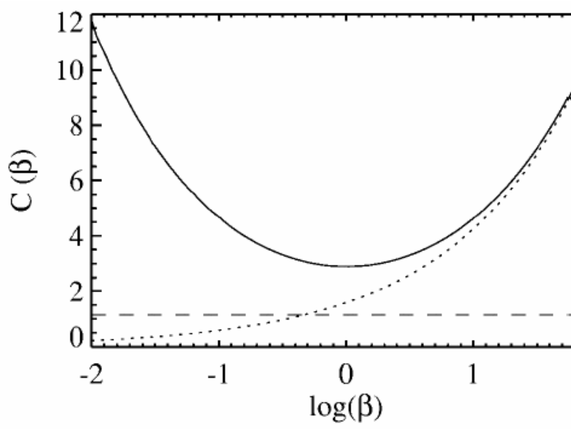




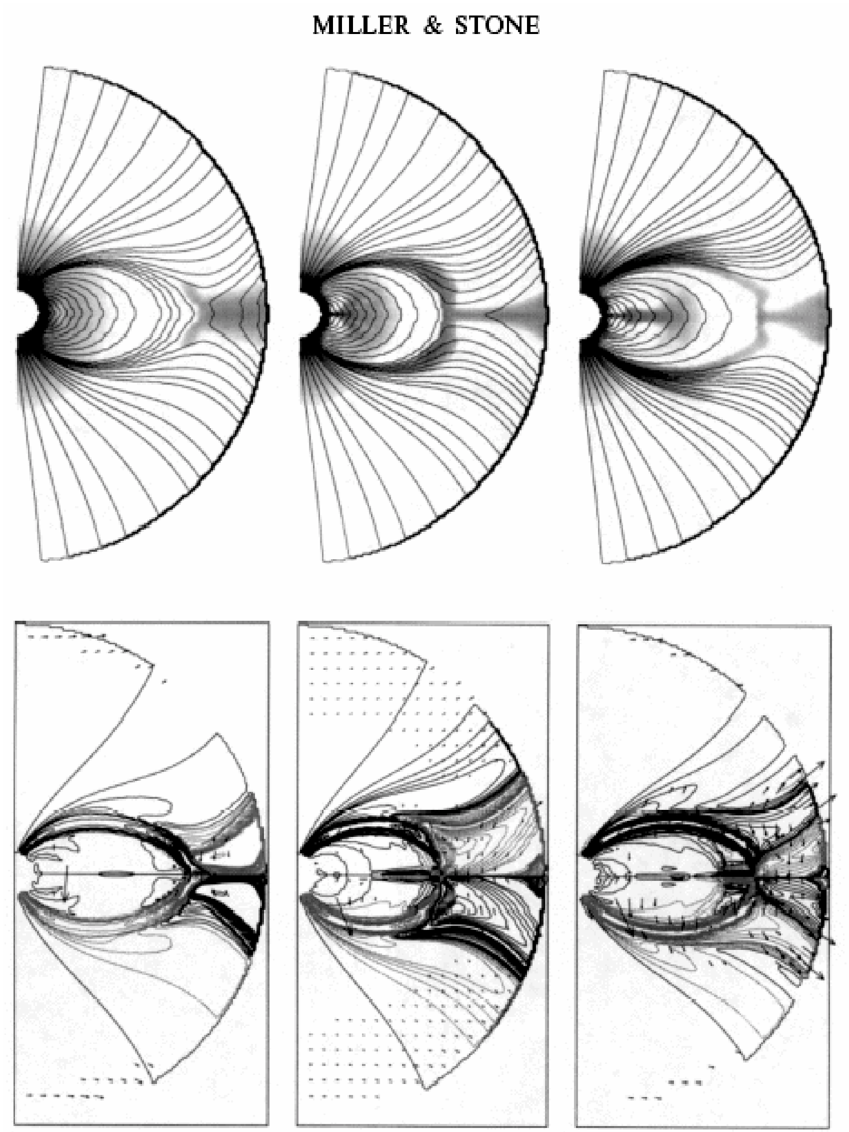
Matt & Pudritz (2004)

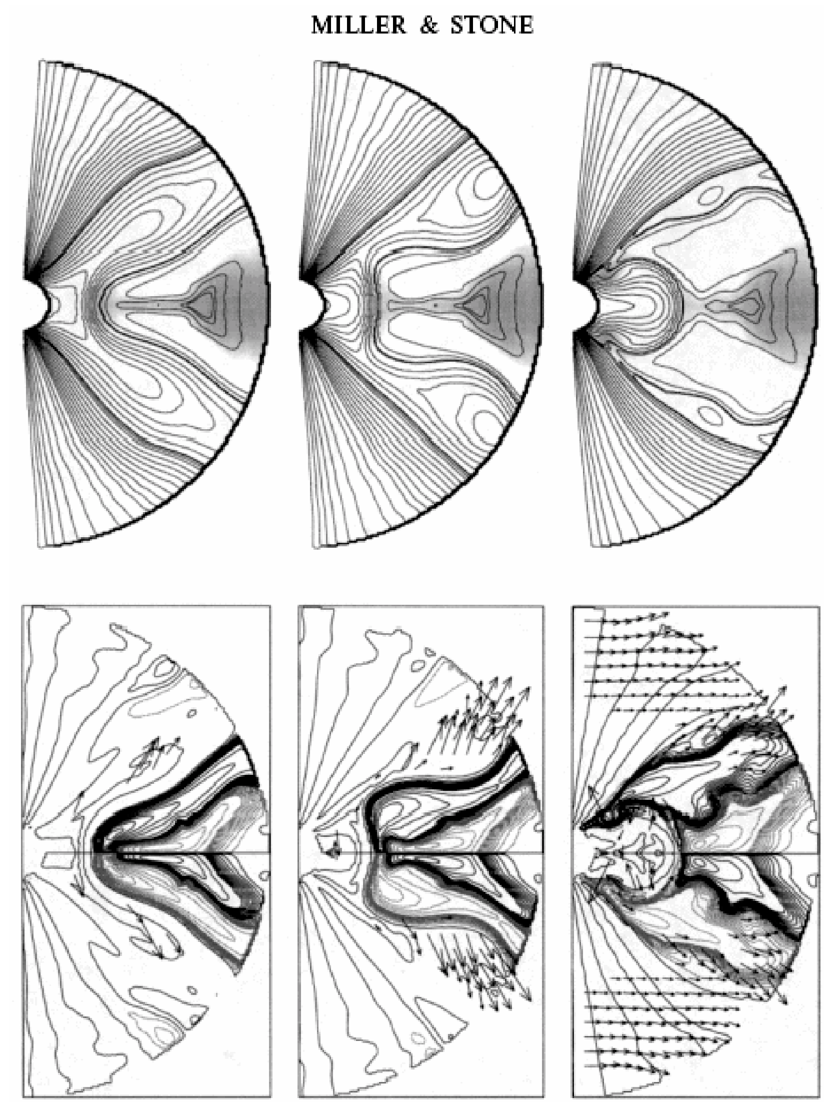






Simulations by Miller & Stone (1997)

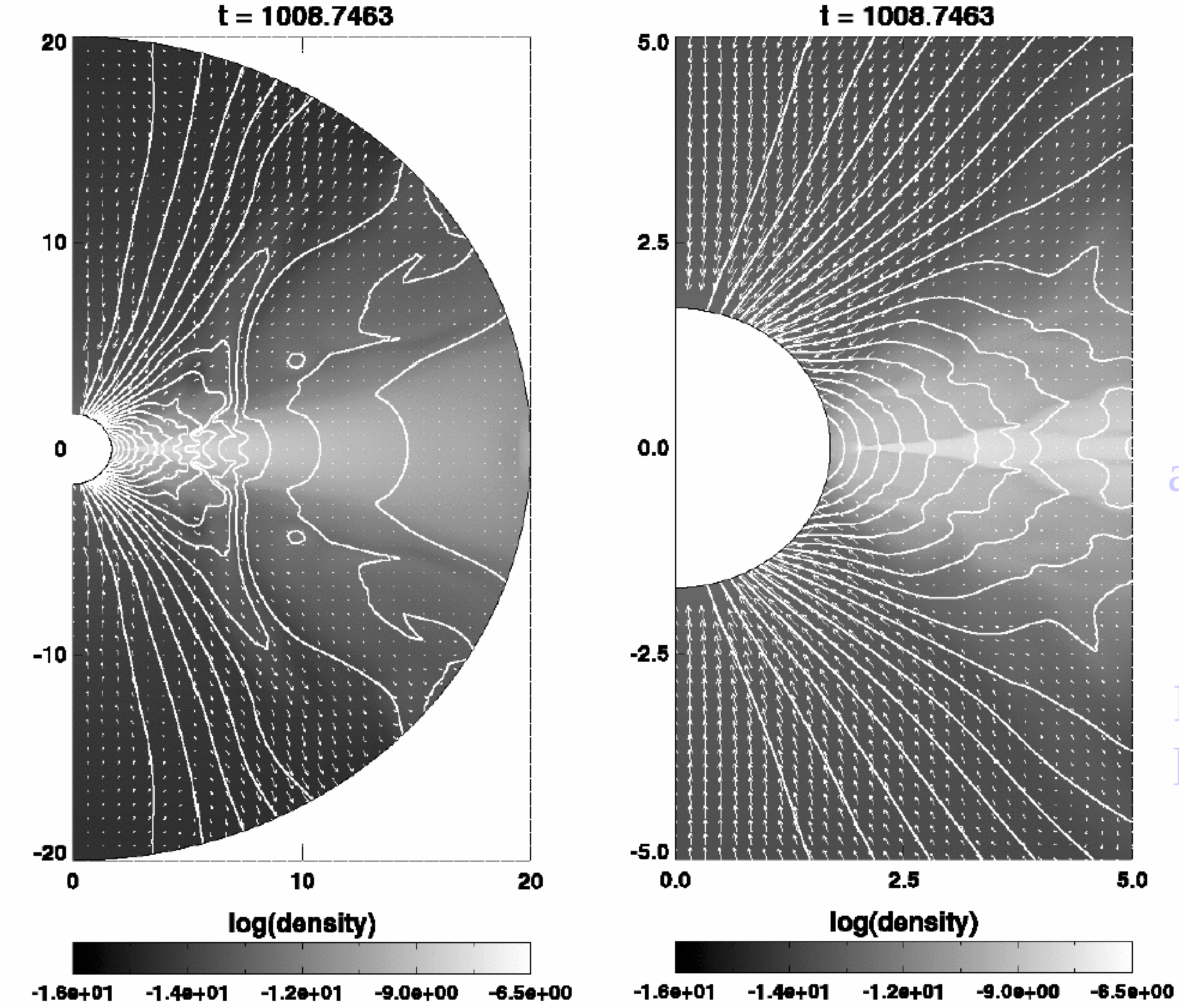




Simulation time: several days

Stellar spin-up or spin-down?

Küker. Henning, & Rüdiger (2003)



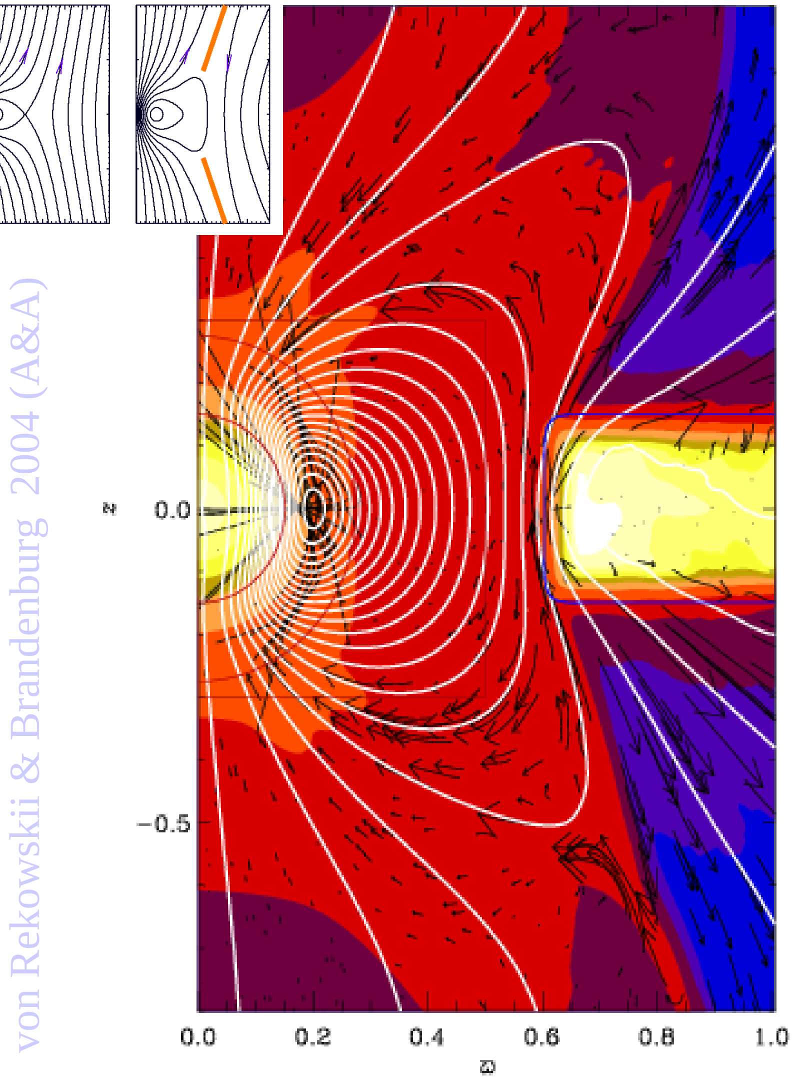
Strong accretion flow

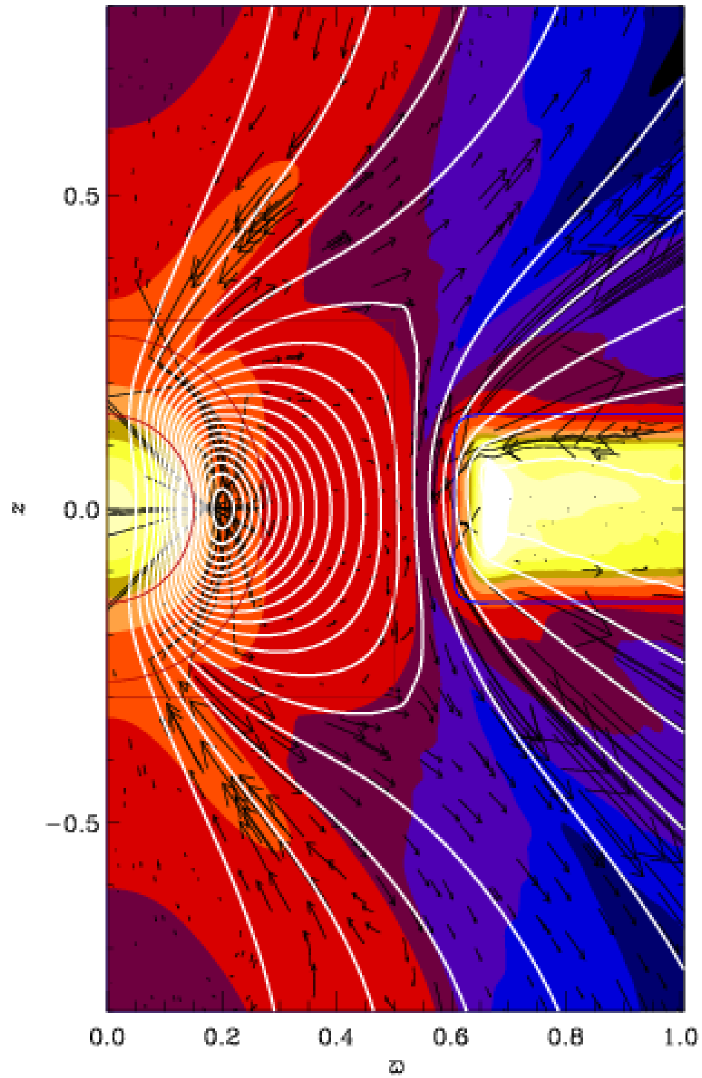
Fieldline loading?

Further experiments: interaction with magnetosphere

Alternating fieldline uploading and downloading

von Rekowskii & Brandenburg 2004 (A&A)



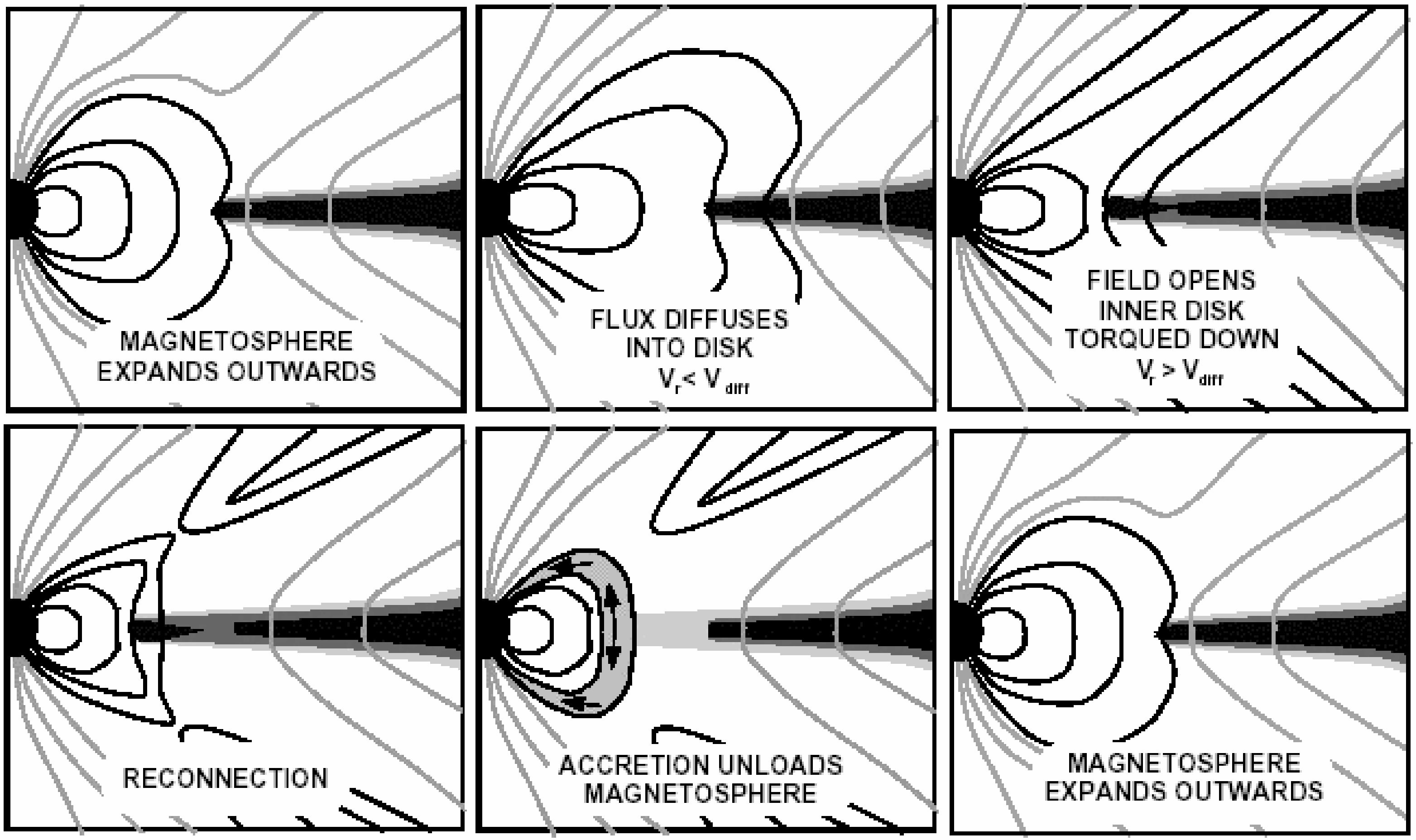


Similar behavior found by Goodson & Winglee (1999)

Star connected with the disc

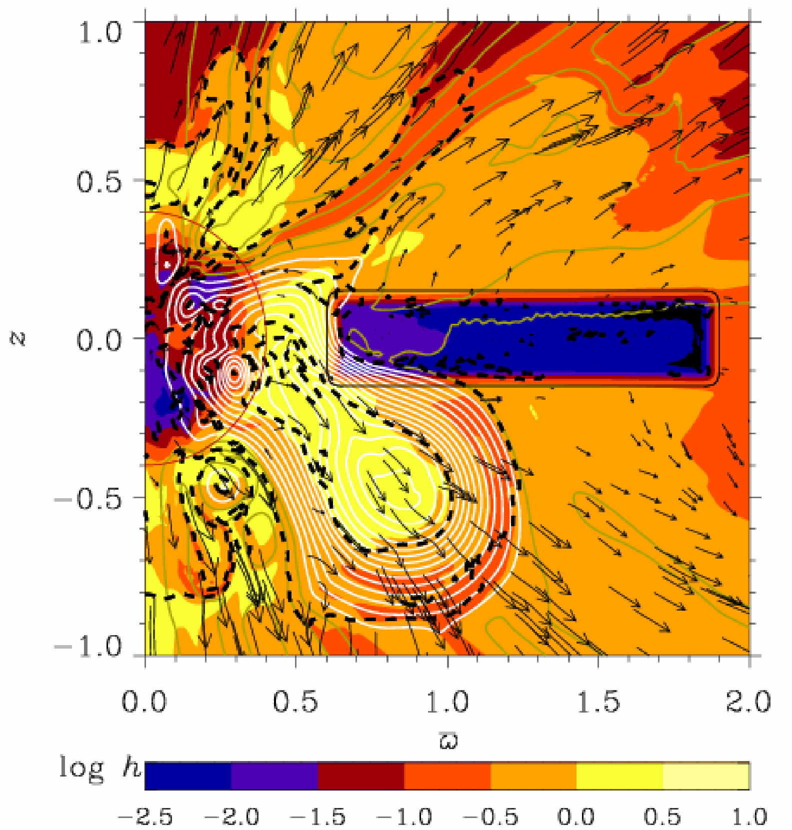
Star disconnected from disc

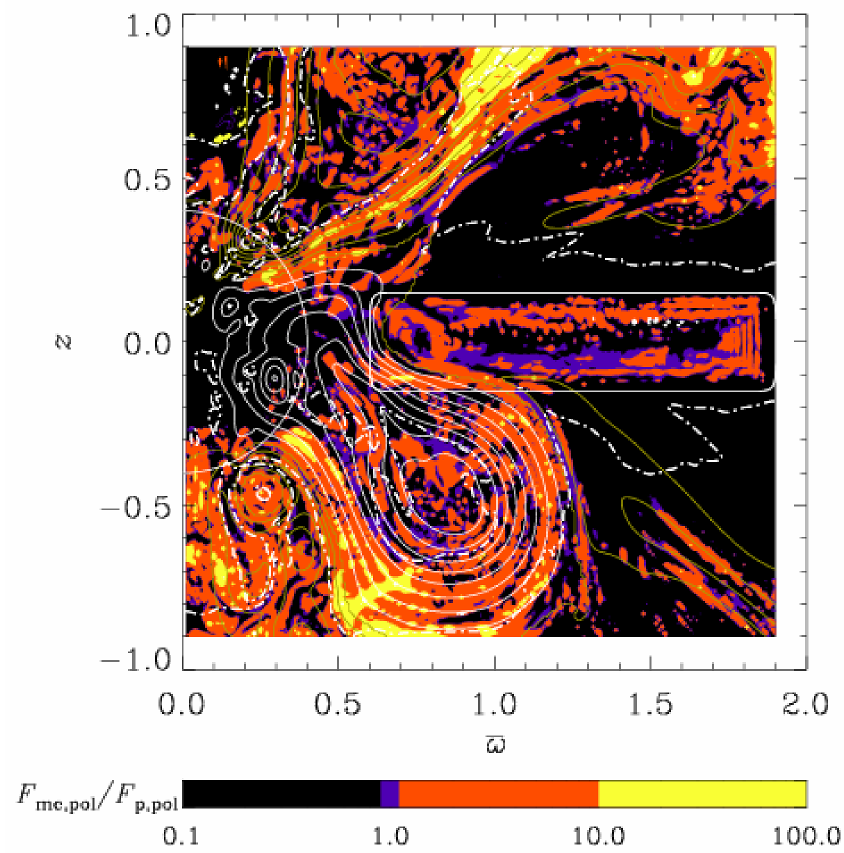
Similar behavior found by Goodson & Winglee



cf. field line opening: Uzdensky (2002), Pudritz & Matt (2004)

Stellar breaking: winds from stellar dynamo

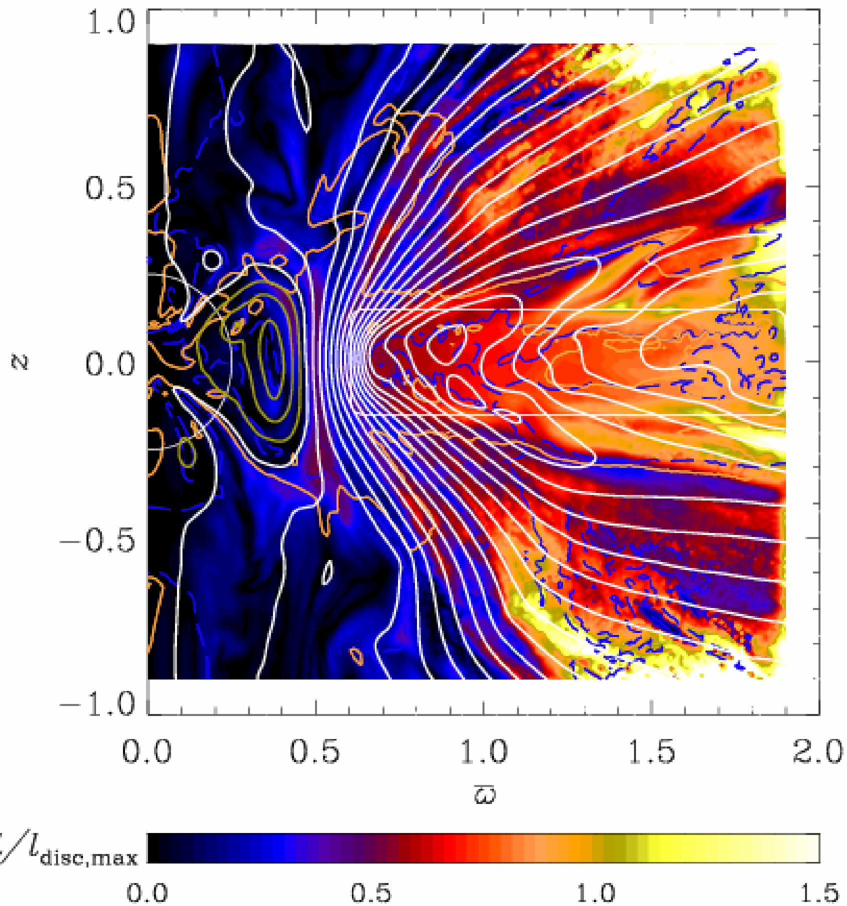


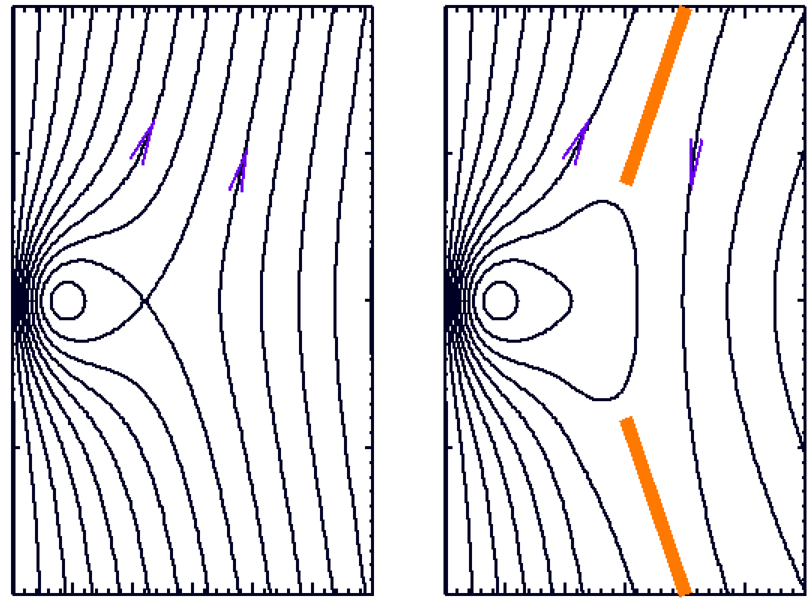


Speed: 300 km/s
Highly time-dependent;
Switch dipole/quadrupole

Magneto-centrifugal acceleration

Winds from stellar dynamo



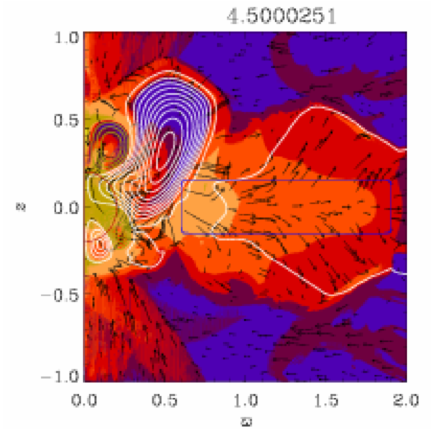


Current sheet configuration
as a result of the simulations

Pencil Code

- Started in Sept. 2001 with Wolfgang Dobler
- High order (6th order in space, 3rd order in time)
- Cache & memory efficient
- MPI, can run PacxMPI (across countries!)
- Maintained/developed by many people (CVS!)
- Automatic validation (over night or any time)
- Max resolution so far 1024^3

Conclusions



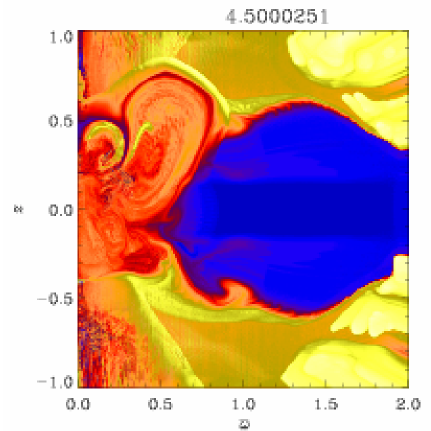
(i) Stellar field anti-aligned against exterior

– Current sheet, not X-point configuration

(ii) Conical outflow

– Collimation: external field required

– Larger distances? Mass loading?



(iii) Disc field opens up: magnetic spin-up

– Spin-down by stellar wind (depends on strength)

Future work: entropy gradient self-maintained

– Requires radiative cooling of disc surface

– See poster by Ramsey & Clarke for non-polytropic models