Accretion disc dynamos

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

(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)

→ All objects have outflows
→ Jets more pronounced when aligned

Taurus-Auriga
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

- Disc modeled as b.c.
- Adiabatic EOS
  - Virial temperature
    \[ c_p T = \frac{GM}{r} \]
- Need a cool disc
- Kepler rot. only for \( T \approx 0 \)

Ouyed & Pudritz (1997)
Modeling a cool disc

- Vertical pressure eq.
- Low T → high density
- Entropy lower in disc
  - Bi-polytropic model

\[ 0 = -\frac{\partial}{\partial z} (h + \Phi) + T \frac{\partial s}{\partial z} \]

\[ -\frac{u_\phi^2}{\omega} = -\frac{\partial}{\partial \omega} (h + \Phi) + T \frac{\partial s}{\partial \omega} \]
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 $\nu_{\text{turb}} = \alpha c_s H = \alpha(z) c_s H$

$\rho \nu_{\text{turb}} = \rho \alpha c_s H = \alpha c_s \Sigma \approx \text{const}$
Heating near disc boundary

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

weak z-dependence of energy density

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

where

\[ J = \nabla \times \mathbf{B} / \mu_0 \]

Alternative: Magnetisation from YSOs?

Poynting flux

$$0.05\dot{M}c_s^2$$

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

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

Similar figure also for outflows from protostellar disc

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

\[ k(a) = \frac{\rho u_i}{B_i} \]

\[ \tilde{\Omega}(a) = \sigma^{-1}\left(\frac{u_\phi - B_\phi}{\rho}\right) \]

\[ l(a) = \sigma u_\phi - \sigma B_\phi \left/ \left(\mu k\right)\right. \]

\[ e(a) = \frac{1}{2} u^2 + h + \Phi - \sigma \tilde{\Omega} B_\phi \left/ \left(\mu k\right)\right. \]
Conical outflows (similar to BN/KL)

(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?


Strong accretion flow
Fieldline loading?
Further experiments: interaction with magnetosphere

Alternating fieldline uploading and downloading

Similar behavior found by Goodson & Winglee (1999)

von Rekowski & Brandenburg 2004 (A&A)

Star connected with the disc

Star disconnected from disc
Similar behavior found by Goodson & Winglee

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 (6\textsuperscript{th} order in space, 3\textsuperscript{rd} 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\textsuperscript{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