Magnetically powered GRB

- Magnetic field good for getting the E out of the engine

- Acceleration of the flow

- Prompt radiation

G. Drenkhahn & HCS 2002, A&A

Roles of magnetic field

Origin (Central engine)

- differential rotation (winding-up of field lines, MHD turbulence) *or*
- Intrinsic (ordered, stable) field in progenitor core

Poynting flux driven Outflow

I. Accelerates flow

II. Dissipation of B^2 => prompt radiation

Radiation produced in strong B-field: $B^2/8\pi > \rho c^2$

Types of magnetic outflow

1. 'isotropically tangled field': $P_{\rm mag} \sim \rho^{4/3}$
   - expansion like rad. pressure: $\Gamma \sim r$
   - complete conversion ME to KE

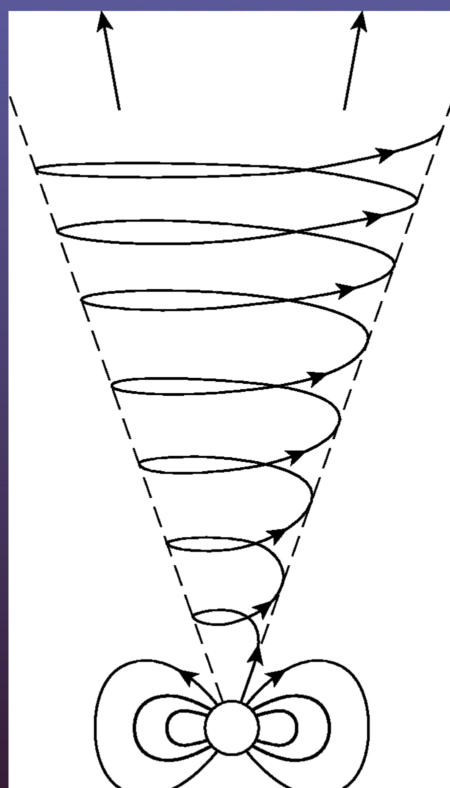
Fields produced by magnetic rotators:

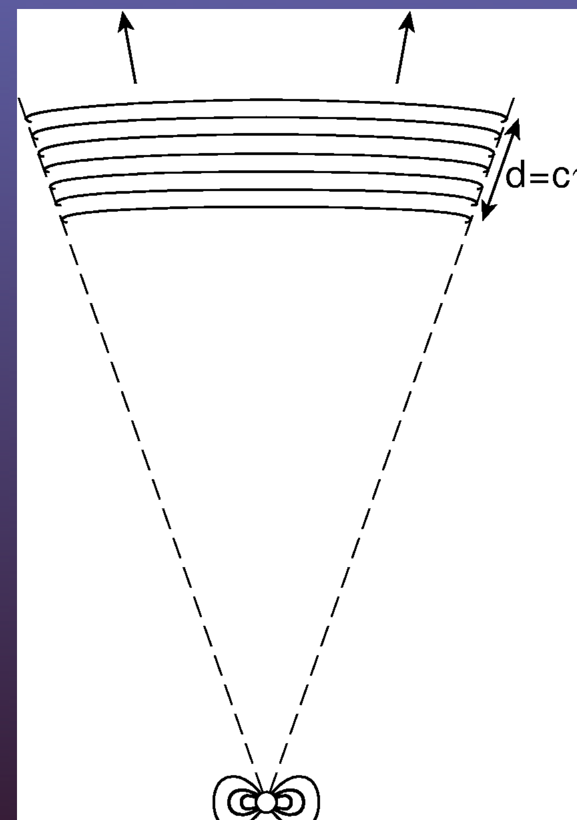
2. 'DC' field
   axisymmetric rotator (`aligned' case)

3. 'AC' case
   nonaxisymmetric rotator

‘DC’ outflow

Centrifugal jet model (AGN, □-QSO’s, proto**)





‘DC’ outflows

- Magneto-centrifugal acceleration
- AGN, protostars
- nonrelativistic: ~ 50% into KE

- relativistic:

either $\Gamma_\infty < \text{a few}$

or $$\frac{\Gamma_\infty \rho c^2}{B^2} \ll 1 \quad (\Gamma_\infty \gg 1)$$

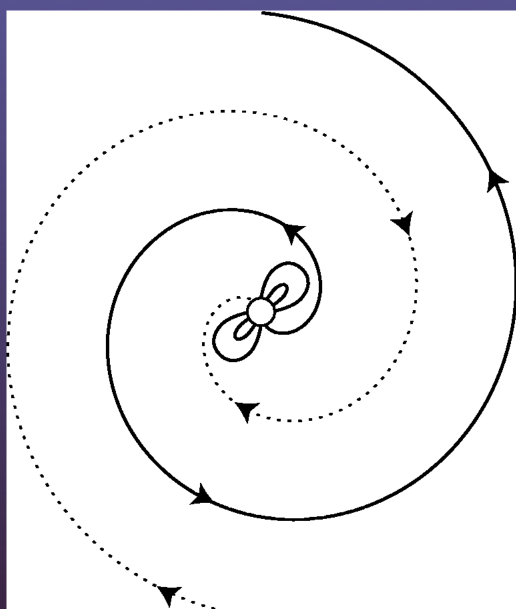
- inefficient conversion of B^2 to KE

cause: curvature force balances pressure gradient

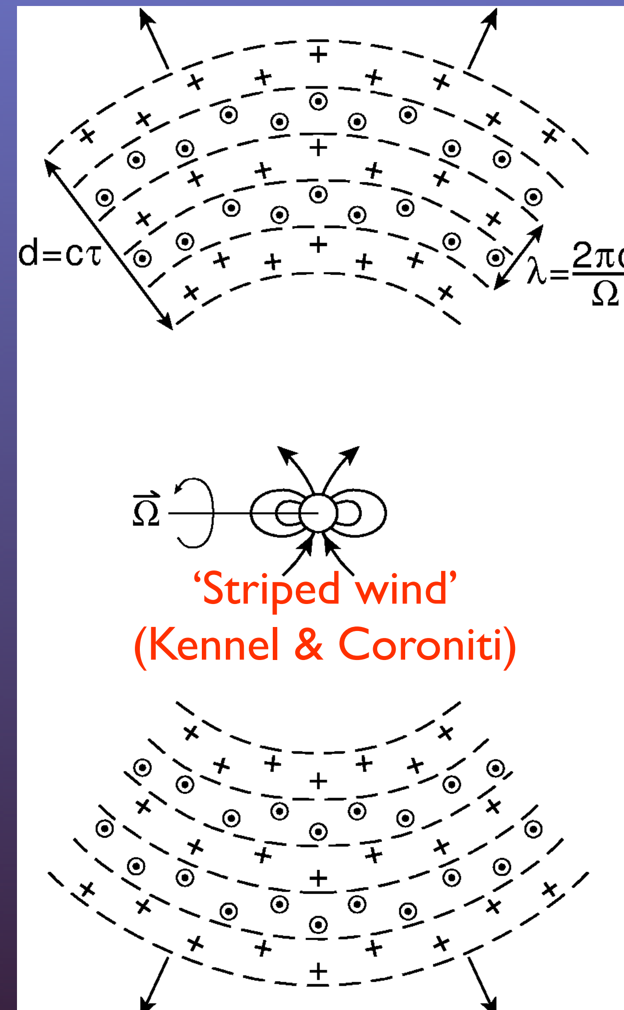
(F.C. Michel 1969; Daigne and Drenkhahn 2002)

‘AC’ outflow

Nonaxisymmetric rotator



(top view)



(side view)

Reconnection

- Wavelength of striped wind

$$\lambda \sim 2\pi v/\Omega \sim 2\pi r_{\rm L} \qquad \lambda' = \Gamma\lambda$$

- Reconnection speed $v'_{\rm rec} \sim \epsilon v'_{\rm A} \sim \epsilon c$ (ϵ = 0.1?)

- Reconnection time (in lab frame) $\tau_{\rm rec} \sim \frac{\Gamma^2}{\epsilon\Omega}$

- → dissipation at `interesting' distances
  (near photosphere for $\Gamma = 100$ *)*

Flow acceleration by dissipation

plane flow: $v(x), \quad B^2(x)$

dissipation: $\partial_x B^2(x) < 0$

→ pressure gradient accelerates in flow direction

faster dissipation → steeper gradient

hydro: Bernoulli: $\frac{1}{2}v^2 + w = E\,, \;\; w = p + e$

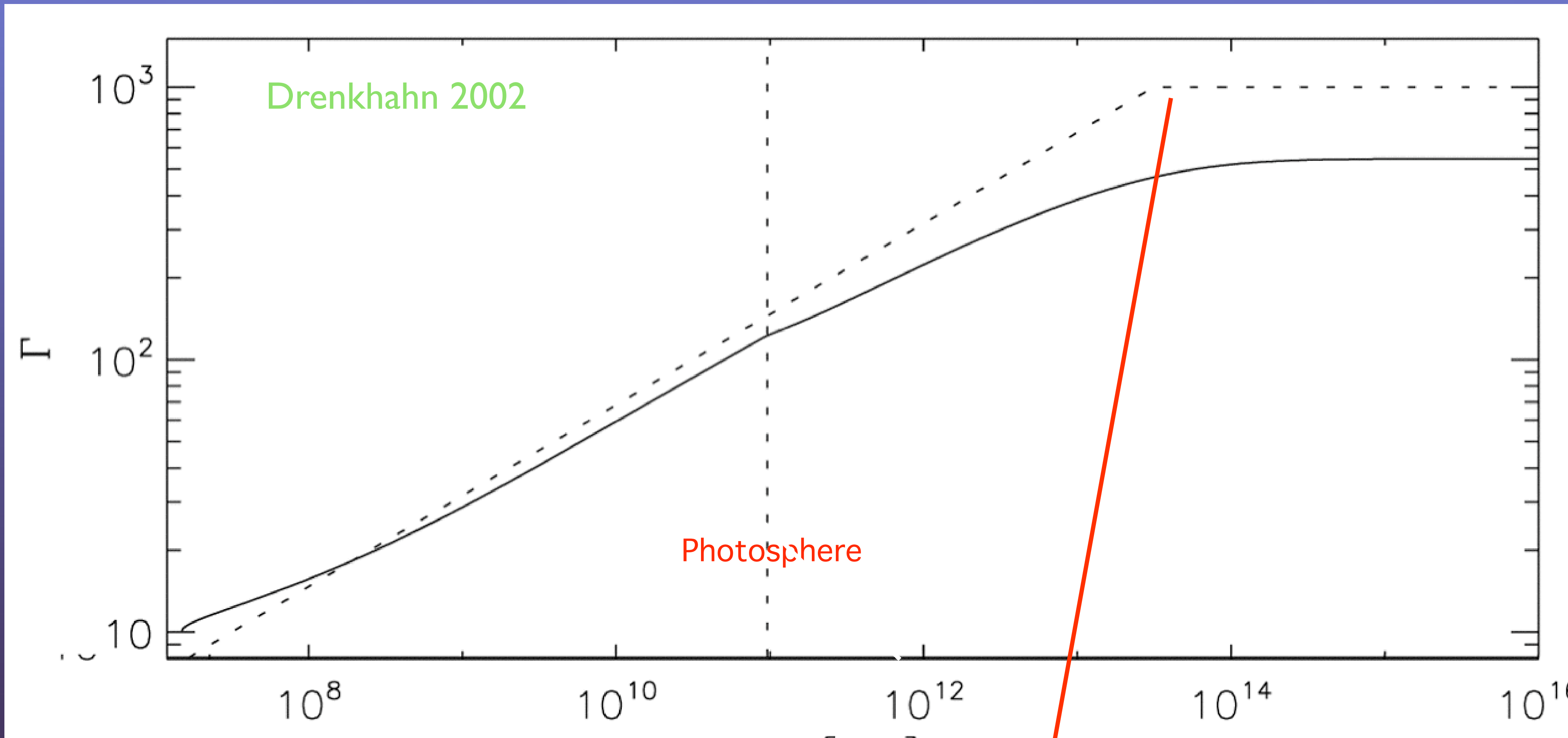
Flow acceleration in AC outflow

Optically thick:

$B^2 \longrightarrow$ radiation $\longrightarrow$ 100% KE (as classical fireball)

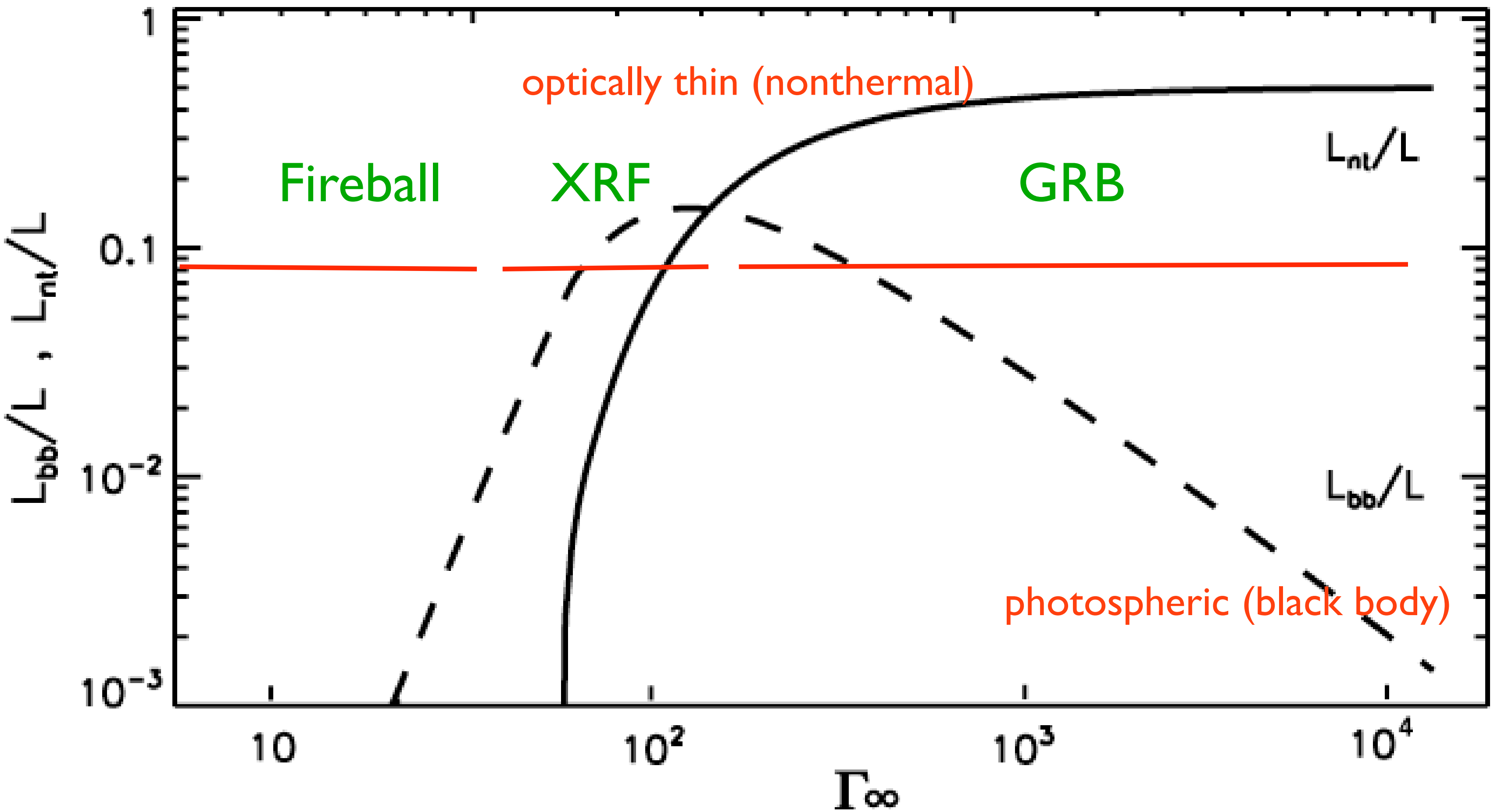
Optically thin:

$B^2 \longrightarrow$ radiation (escapes) $\longrightarrow$ 50% KE, 50% radiation



$$\left.\begin{array}{ll}\Gamma \sim r^{1/3} & r < r_s \\ \Gamma_\infty & r > r_s\end{array}\right\}$$

Radiation from Poynting flux in AC model



Drenkhahn and HCS 2002

Summary

- Magnetic extraction of rotational/gravitational energy

- AC vs DC models,

  Poynting flux conversion problem DC model

- Efficient dissipation in AC model

  - 50% prompt radiation. - Smooth bursts -

- Flow acceleration by dissipation of B^2

- Uncertainty: reconnection physics

‘

-

Poynting flux

$$S = \frac{c}{4\pi} E \times B$$

$$|S| = c(\frac{E^2}{8\pi} + \frac{B^2}{8\pi})$$

in MHD: $E = v \times B/c \, , \quad S = v_\perp \frac{B^2}{4\pi}$

magnetic energy flux: $F_{\rm m} = v_\perp \frac{B^2}{8\pi}$

$$S = 2F_{\rm m}$$

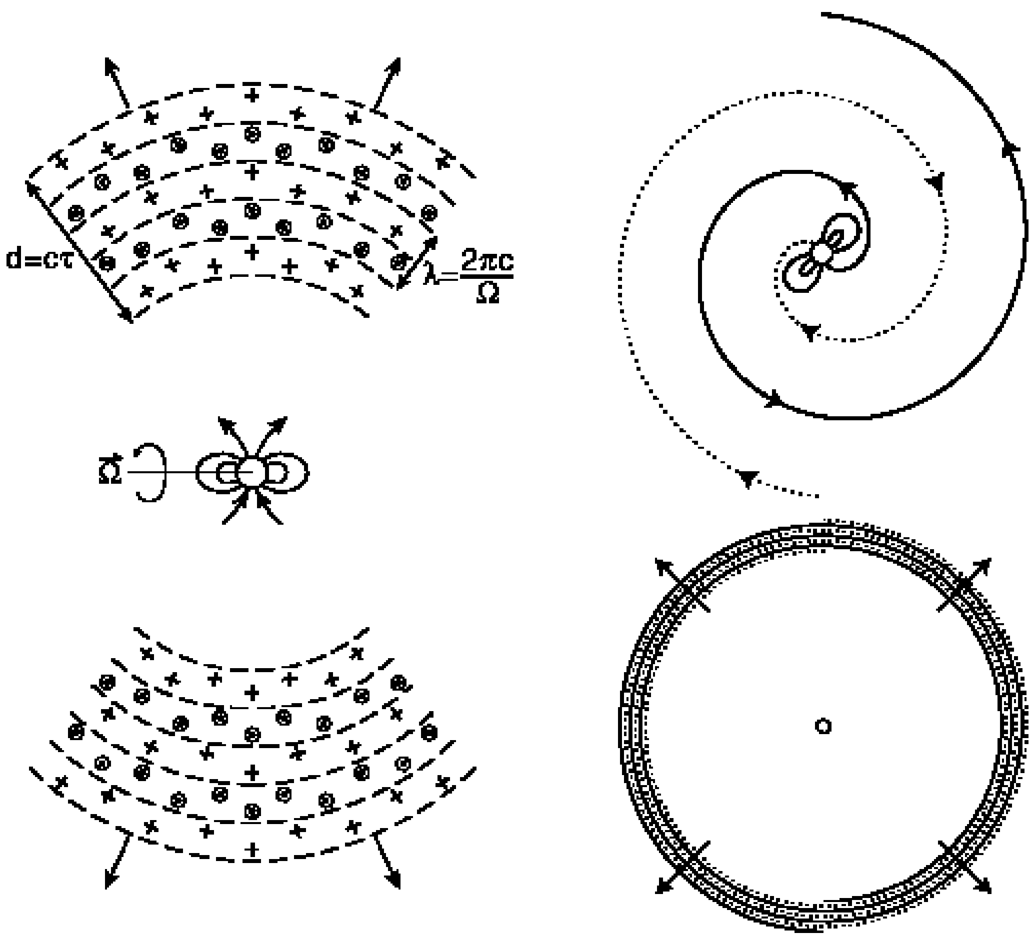


Fig. 2. Field configuration in quasi-spherical magnetic outflow driven by a perpendicular rotator ('pulsar-like' case) (schematic). Left: view in the equatorial plane, with dots and plusses indicating field lines into and out of the plane of the drawing. Right: top view from the rotational pole. Bottom right: same view on larger scale, at a later time $t \gg \tau$.

'AC' outflow

(nonaxisymmetric rotator)