Jets and Plerions

Reviewer: David Eichler
Magnetic Collimation

by Hoop Stresses:

Benford (1976), Blandford, Konigl, Payne, Chan, Henriksen, Lovelace, Contopoulos ....

by polar poloidal field lines:

Blandford (1976), Spruit, Foglizzo, and Stehle 1997

But with disks and/or confining medium! (i.e. the magnetic fields provide transverse momentum but not energy during collimation and the disk holds the field in place). Not for plerions.

Does it work even with disks? maybe, (Spruit, Foglizzo, and Stehle 1997)

Does it work without disks?
by polar poloidal field lines: Does it Work?

Blandford (1976),
by polar poloidal field lines:
Blandford (1976),

Neutrons? (Eichler and Wiita, 1978)

Photo $\pi$ conversion
Magnetic Collimation

by Hoop Stresses:

Benford (1976).....Blandford, Konigl, Payne,. Henriksen, Lovelace,.......

Are self-similar solutions pyramid schemes?
1989: Heyvaerts and Norman get away from self-similar analysis and show that ANY AXISYMMETRIC magnetic outflow should be collimated

(see also Chiueh, Li and Begelman 1991)

( Spruit, Foglizzo and Stehle 1997 also non self-similar)
Kink Instabilities?

Second complaint: Collimation time exponentially long in Fast Magnetosonic Mach number $M_F$ (Eichler, 1993...) because each logarithmic increase in radius gives change in angle of order $1/M_F$

Because under no circumstances can the magnetosonic characteristic deviate from the flow line by more than $1/\Gamma$

$$B'_t = \frac{B_t}{\Gamma}$$

$$\rho' + B'^2/4\pi = \frac{\rho}{\Gamma} + \frac{B^2}{(4\pi \Gamma^2)} =$$

$$V'_t = \frac{V_t}{\Gamma}$$

$$V_m^2 = \frac{\sigma}{(\sigma+1)}$$

$$V_m \Gamma_{ms} = \sigma^{1/2}$$

$$M_f = \frac{V \Gamma}{V_m \Gamma_{ms}}$$
Chandra image of the Crab Nebula
Chandra image of the Crab Nebula
OK, suppose $\Gamma$ starts off small. There still remains the problem that it accelerates to $\Gamma = \sigma^{1/2}$ by the fast magnetosonic point, where hoop stresses set in.

This is true even at small polar angles. (Lyubarsky and Eichler 2001).

So why is there a polar jet in the Crab nebula???
Chandra image of the Crab Nebula

Rim shocks
Chandra image of the Crab Nebula
Chandra image of the Crab Nebula
Chandra image of the Crab Nebula
Crab’s jet

(a) Chandra

(b) HST difference image
The Komissarov-Lyubarsky model for plerions
Energy flux in the wind

\[ f_w = \frac{f_0}{r^2} (\sin^2 \theta + \frac{1}{\sigma_0}), \]
\[ B = \sqrt{\frac{4\pi f_0}{c}} \frac{\xi}{r} \sin \theta \left( 1 - \frac{2\theta}{\pi} \right) \]
Gas pressure and velocity field around the termination shock
Magnetic pressure/gas pressure
Simulated image, $\sigma=0.009$, with magnetic field at the axis
Chandra image of the Crab Nebula
Gas pressure and velocity field around the termination shock

- Sprite
- Rim shock
- Bright arch
- DISK
- Termination shock
- Mach belt
- Fluff
- Observer
Simulated image, $\sigma=0.009$, with magnetic field at the axis

- sprite
- sprite
- jet
- bright arch
- fluff
- rim shocks
Simulated image, $\sigma=0.004$
Simulated image, $\sigma=0.009$
Simulated image, $\sigma=0.025$
Simulated image, $\sigma = 0.009$, with magnetic field at the axis
Have we entered the age of precision plerionics?

Additional factor yet to be included:
Incomplete magnetic field annihilation post-Mach belt
Turbulence
Non-axisymmetry (kink instability,....)
Differential synchrotron cooling time
Play in the magnetization and angular profile parameters of the pulsar wind

Simulated nebulae can probably be made to appear more nebulous and better tuned to X-ray, optical images.
We are on the threshold of understanding plerions and their polar jets. (My opinion)

Surrounding medium and hoop stresses both play pivotal roles.