Generation of Relativistic Jets

- How do they survive pair creation?
- Is relativistic reconnection an efficient converter of electro-magnetic into matter energy flow?

by Guy Pelletier. Grenoble. France

Unified view TeV Blazars-FR1

- δ governs 2 contraints:
  - ratio beamed/unbeamed luminosities
  - fraction of beamed sources

Statistics : unification TeV blazars-FR1.
both independent constraints => $\Gamma = 3\text{-}5$ (Chiaberge et al. 00)

- Statistical pb even with 2-component relat. Jet: $\Gamma = 15\text{-}25$ and $\Gamma_s = 3\text{-}5$!

Example: (Saugé & Henri 04)

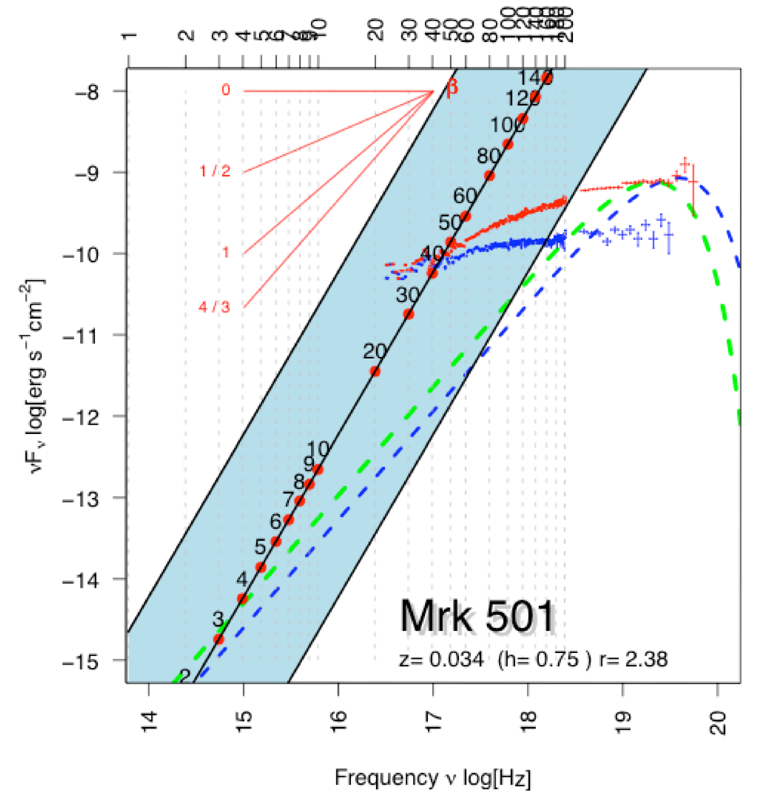
Proba for detecting a TeV-blazar among a BLLac population at $z \leq 0.13$:

6.35×10^{-6} for $\Gamma = 25$ (29 BLLac, 5-7 TeV-blazars)

- HESS TeV observation of M87 => $\Gamma \sim 3$
- R $\sim ct_{var}$ => $\Gamma \sim 3$

Pair creation in AGN jets

(according to Henri & Saugé 04, 05)



Opacity constraints on δ, from observation data only, seen on the low energy part of the synch. spectrum

δ ~ 30 or 3-5 : a crisis ?

- Remedy : (unavoidable package!)

i) Stratified emission

(SSC emission from a different place than synchrotron)

ii) Quasi monoenergetic distribution…

(in situ acceleration, reconnections)

iii) δ = 3-5 —> γγ-opacity important!

Pair creation catastrophe

Weak pair contribution usually expected

- Magnetisation : $\sigma \equiv \frac{Poynting\ flux}{matter\ energy\ flux}$

- Compactness : measures opacity and Compton drag

$$\tau_{\gamma\gamma} \simeq 0.2\ell_c\varepsilon^{\alpha} \text{ with } \ell_c(\mathrm{r}) \equiv \frac{\sigma_\mathrm{T}\mathrm{L}}{4\pi \mathrm{m_e c^3 r}} = \frac{\mathrm{m_p}}{\mathrm{m_e}}\frac{\mathrm{L}}{\mathrm{L_{Ed}}}\frac{\mathrm{r_g}}{\mathrm{r}}$$

- Braking length and Baryon load :

If e^+-e^- dominated

$$\frac{\ell_{rel}}{r} = \frac{1+\sigma}{\ell_c}\frac{<\gamma>}{<\gamma^2>}$$

If baryon dominated:

$$\frac{\ell_{rel}}{r} = \frac{m_p}{m_e}\frac{1+\sigma}{\ell_c}\frac{<\gamma_p>}{<\gamma^2>}$$

How to get efficient Poynting flux conversion?

- Cold flow with $\sigma_0 \gg 1 \rightarrow \Gamma \sim \sigma_0^{1/3}$
- Significant deviation from cold monopolar flow necessary!
  (Vlahakis)

reconnections

- Warm when passing through the A-critical surface.

$$\sigma_0 \sim 10 \rightarrow \Gamma \sim \sigma_0 \sim 10$$

- No problem with external collimation.

Powerful non-relativistic jet needed for that.

Dynamical consequence of pair creation

Blazars

- $\Gamma = 3\text{-}5 \Rightarrow \tau_{\gamma\gamma}$ significant
- pair pressure grows to equipartition

- Pair creation and moderate field would kill the e.m. generation of a relativistic jet

$$\sigma_0 \sim 1 \rightarrow \Gamma \sim 1$$

- Strong Compton drag

Other problems: Collimation, Power

- Confinement pb of a relativistic flow

  -In non-relativistic flow B_ϕ insures self-confinement

  -In relativistic flow, $E \geq B_\phi$ —>

  no self-confinement ! (S. Bogovalov, K. Tsinganos)

- From a spinning BH : $P_{BZ} \sim 10^{-2} P_{accr}$
- From an accretion disk : $P_j \sim P_{accr}$

  But likely non-relativistic (matter outflow)

Interest of a “two-flow” model

(Sol, Pelletier, Asséo 89; Henri, Pelletier 91; Marcowith et al. 95, etc.)

- channeling : subrelat. jet confines the relat. jet
- power in the large scale jet (mildly or sub-relativistic)

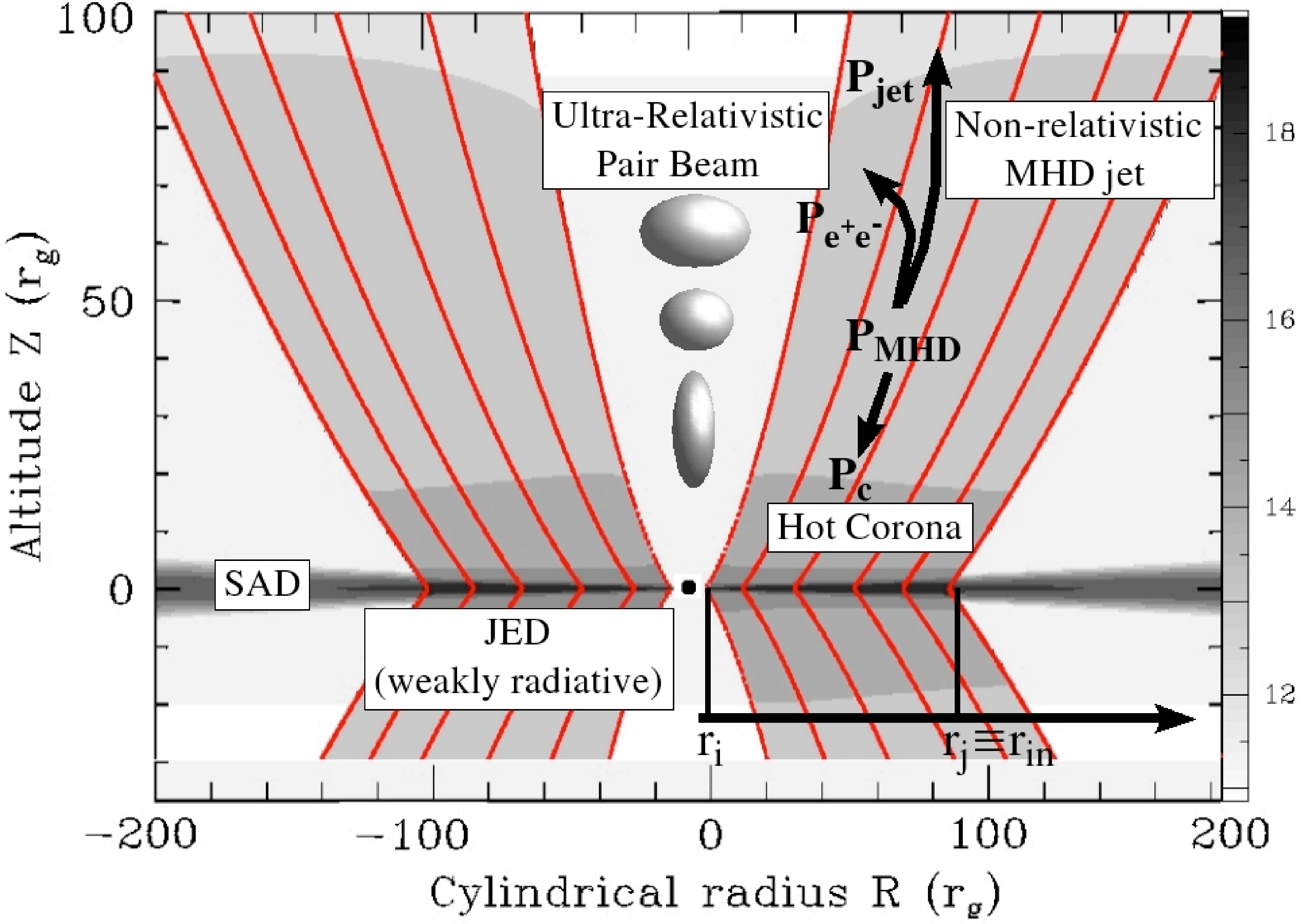
A sizable fraction of accretion power !

(Can even make the accretion flow weakly radiative!)

- powering the relativistic component : reconnections and disturbances in NR-jet heat e^+-e^- R-jet
- Compton pressure gradient (compton rocket):

Heated pairs strengthen coupling with radiation field

- Opacity effects. Pair creation catastrophe. Fast variability



100
50
0
Altitude Z (r_g)
−200
−100
0
100
200
Cylindrical radius R (r_g)
18
16
14
12
Ultra-Relativistic
Pair Beam
Non-relativistic
MHD jet
P_{jet}
$P_{e^+e^-}$
P_{MHD}
P_c
Hot Corona
SAD
JED
(weakly radiative)
r_i
$r_j \equiv r_{in}$

Dissipation through particle acceleration: Fermi processes and Reconnections

- Fermi processes (1st or 2nd order) in non-relativistic or in relativistic regime

- Magnetic reconnections (resistive or collisionless) in non-relativistic or in relativistic regime

Magnetic Reconnection
(dissipation of B)

Non-relativistic

- Conversion of

  magnetic energy flux ->

(1/2) Kinetic energy flux

$(u_{out} = V_A)$ +

(1/2) Heating -> radiation

- slow rate in resistive MHD.

Much faster in collisionless regime

- QME distribution

Relativistic

- Conversion of

electromagn energy flux ->

Kinetic energy flux <<

“Heating” (collisionless) ->

radiation

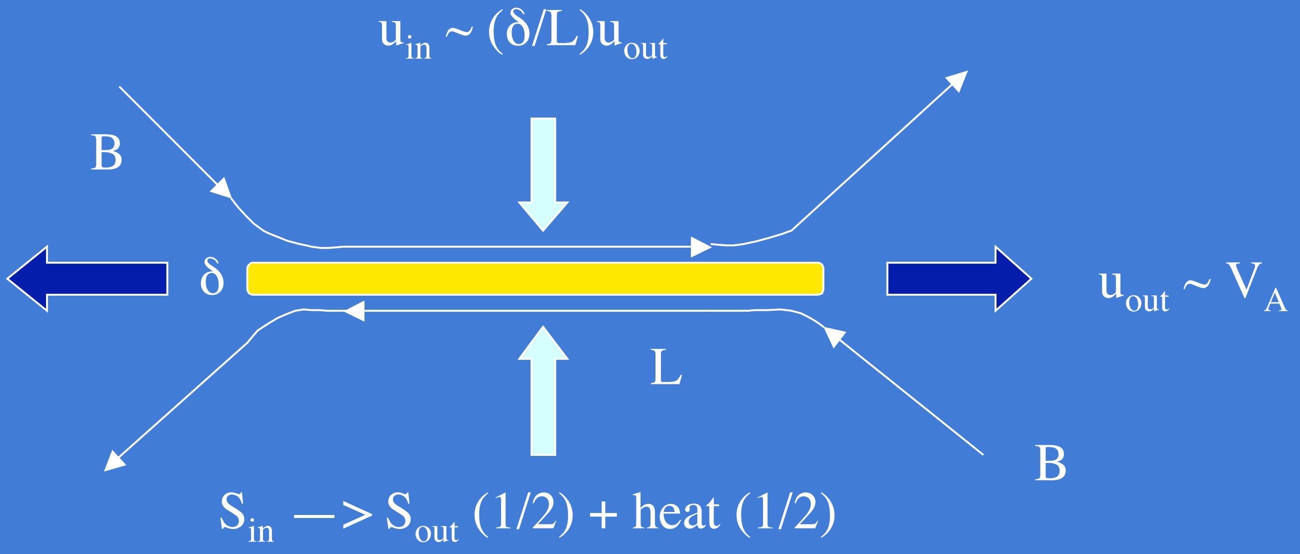
- high rate.

  Unavoidably collisionless

- QME distribution

The Sweet-Parker model

δ vanishes with η!



$u_{in} \sim (\delta/L)u_{out}$

$u_{out} \sim V_A$

$S_{in} \longrightarrow S_{out}$ (1/2) + heat (1/2)

A relativistic version by M. Lyutikov and Uzdensky

Resistivity problem in MHD reconnection

- Reconnection thickness in MHD description
- Outflow and inflow (Sweet-Parker)

Matter and energy fluxes vanish with resistivity

Slow rate !

- Violation of MHD even with anomalous resistivity!

$$\frac{\delta}{\delta_0} = \sqrt{\frac{m_e}{m_i}\frac{c}{u_{in}}\frac{\nu_{ei}}{\omega_{pe}}}$$

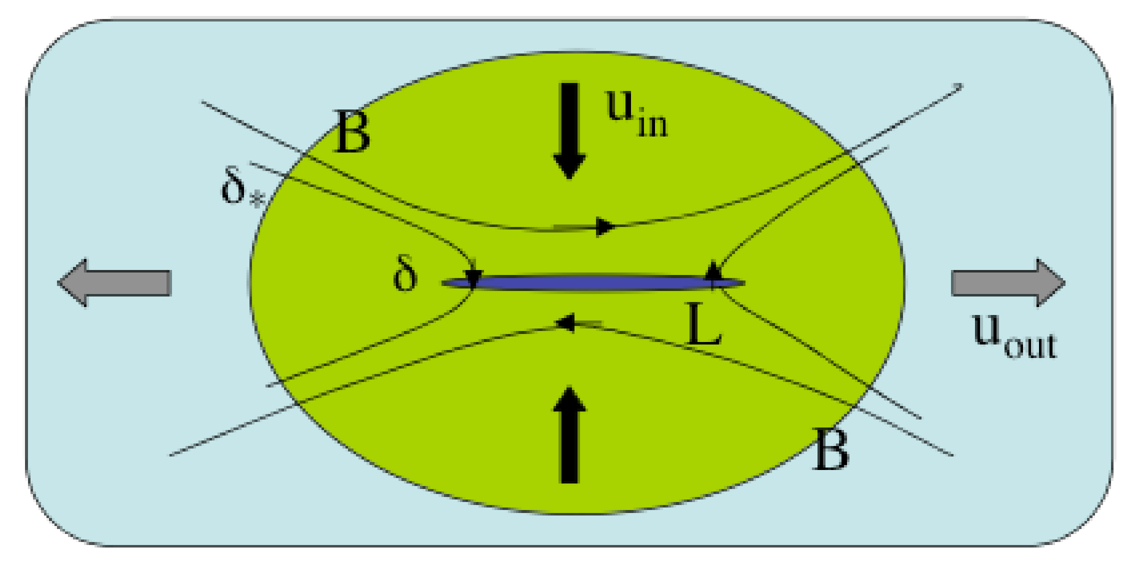
Reconnection mediated by whistler dynamics

2D1/2-reconnection with a baryon load

Sheet thickness $\delta \sim \delta_e << \delta_*$ (smallest MHD scale)

Whistler dynamics at scales $<< \delta_*$

Break down of "frozen in" at e^- inertial scale δ_e



$m_e \longrightarrow 0$
$m_p \longrightarrow \infty$

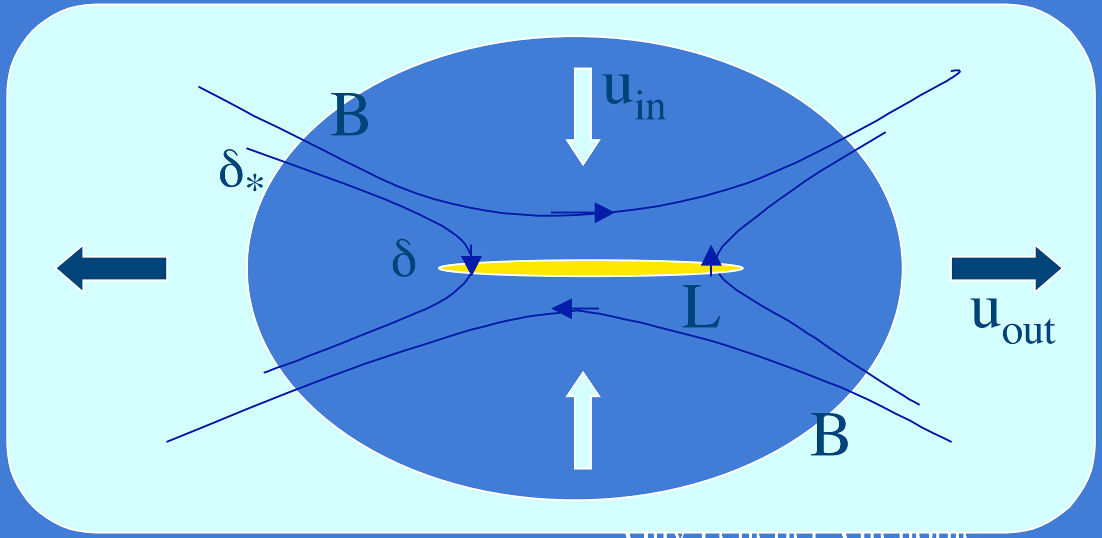
Collisionless Relativistic Reconnection

Universal laws independent of the small scale dissipation process

(extension to the relativistic case of the approach of J. Drake 2001 + co.)

Modified Relativistic MHD :
covariant generalised Ohm's law

$$u_{out} \sim \frac{\delta_*}{\delta}\gamma_A u_A \;\; and \;\; u_{in} \sim \frac{\delta_*}{L}\gamma_A u_A$$



$\delta = \delta_e$, $L = 10\delta_e$

Fast reconnection with
electron acceleration

G.P. & P.Y. Longaretti 2005

Energetic of relativistic reconnection
(with a baryon load)

- Flux of e.m. energy converted mostly in electron energization and thus radiation. Otherwise non-relativistic!

- With a baryon load (whistler dynamics), for $B^2/4\pi > 0.2\ (e+P)$, Fully relativistic e.m. influx (by electrons) i.e. $cB^2/4\pi$ in a current sheet of $\delta = \delta_e$
- balanced by synchrotron loss -> QME distrib that peaks at

$$\gamma_{max} \sim 2.4 \times 10^7 \left(\frac{n_0}{1\, cm^{-3}}\right)^{-1/5}$$

Energetics of relativistic reconnection

(for a purely e^+e^--plasma)

- Fully relativistic e.m. influx for $B^2/4\pi > e+P$
- In a current sheet of thickness $\delta = \delta_e(\gamma_0)$ ($> r_L(\gamma_0)$ in relat regime)

  (break down of “frozen in” at this scale)
- Balanced by synchrotron loss in radiative regime =>

  QME distribution that peaks at the same energy estimate as before!
- In advective regime (midly relat.) $u_A \sim 1$ i.e. equipartition B_{in} with P_{out}

- simple phenomenology: B, n => γ_0 and $\delta = \delta_e(\gamma_0)$

- Advection, diffusion and cooling outside the reconnection site

Prospect

- Progress in 3D-reconnection (when baryon loaded, mediation by whistler dynamics confirmed already).

- Physics of reconnection in pair plasmas (Lyubarsky).

  Relativistic regime => radiative reconnection for strong B

  OK for magnetar and pulsar winds
- In Blazars advective reconnections only (midly relativistic)

- Getting control of the formation of reconnection sites.
- Relevance of these physics for the interpretation of the spectra of H.E. sources.