Outflows and relativistic jets in AGNs

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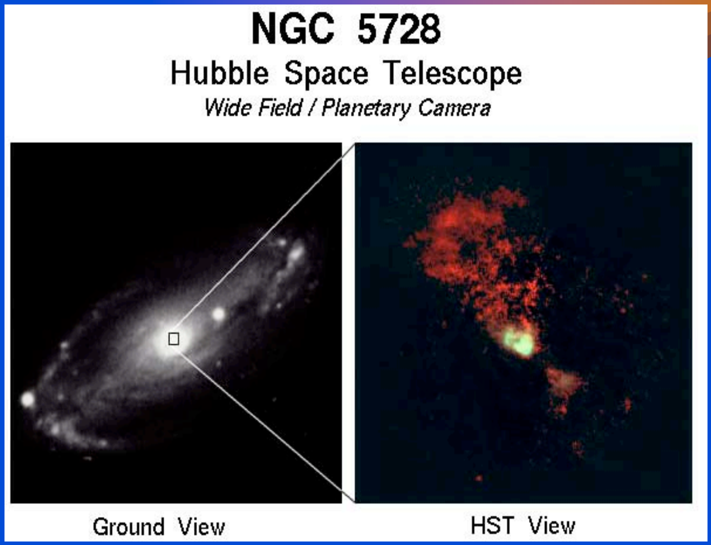
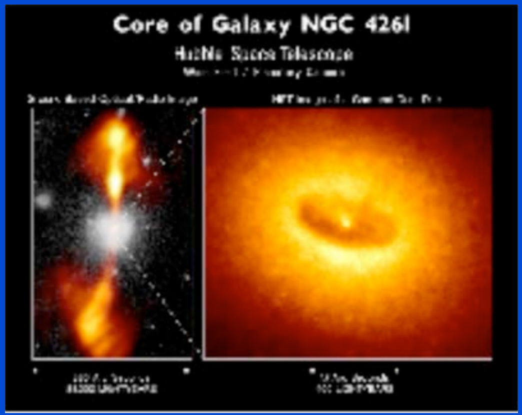
The two AGN classes

- Radio-quiet (Seyferts, QSO)
  - Relatively weak radio emission
    (but > normal galaxy)
  - No collimated jet
    (but bipolar flows, ionization cones)
  - No gamma-ray emission >MeV (Dermer &Gehrels '95)

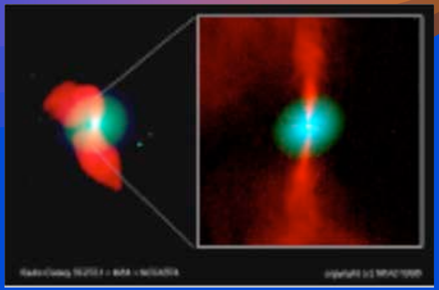




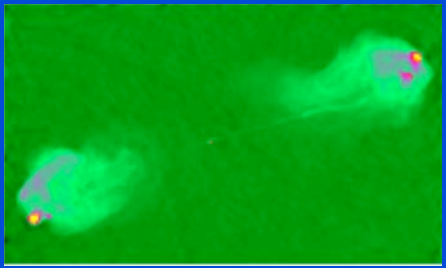
- Radio-loud (Radio galaxies, quasars)
  - Intense radio Emission (synchrotron)
  - Powerful jets
  - Gamma-ray emission >MeV, up to tens of TeV...

Jets in radio-loud AGNs

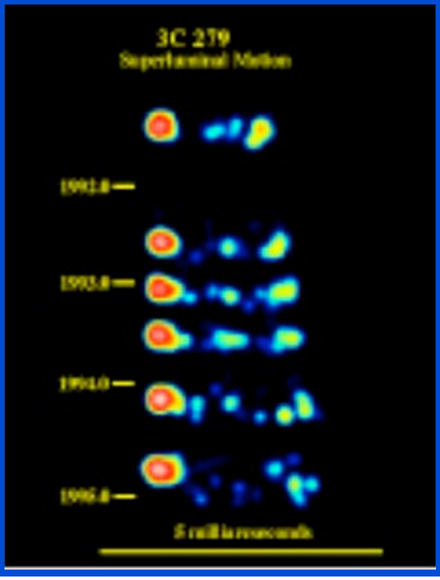
- Large scale (>kpc) one or two sided
  - FR I weak jets, not well collimated
    - Beamed counterparts : BL Lacs ?



  - FR II powerful jets, well collimated, (hot spots)
    - Beamed counterparts : FSRQ ?



- Superluminal motion observed at pc scale (VLBI/VLBA), always one-sided

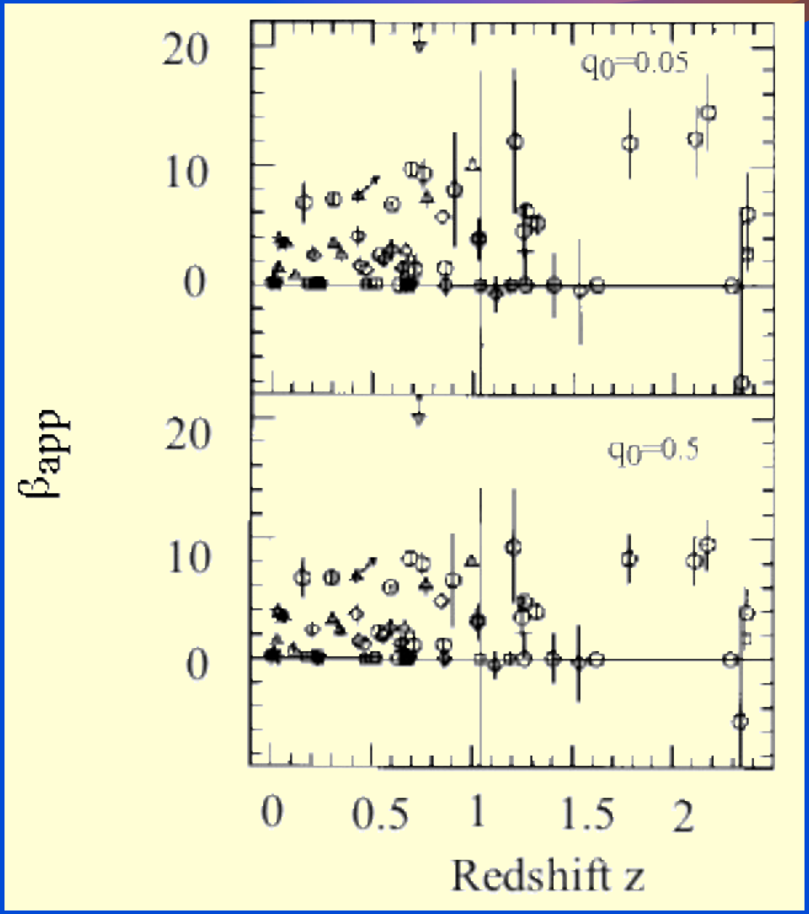


Apparent V between 5 and 10 c

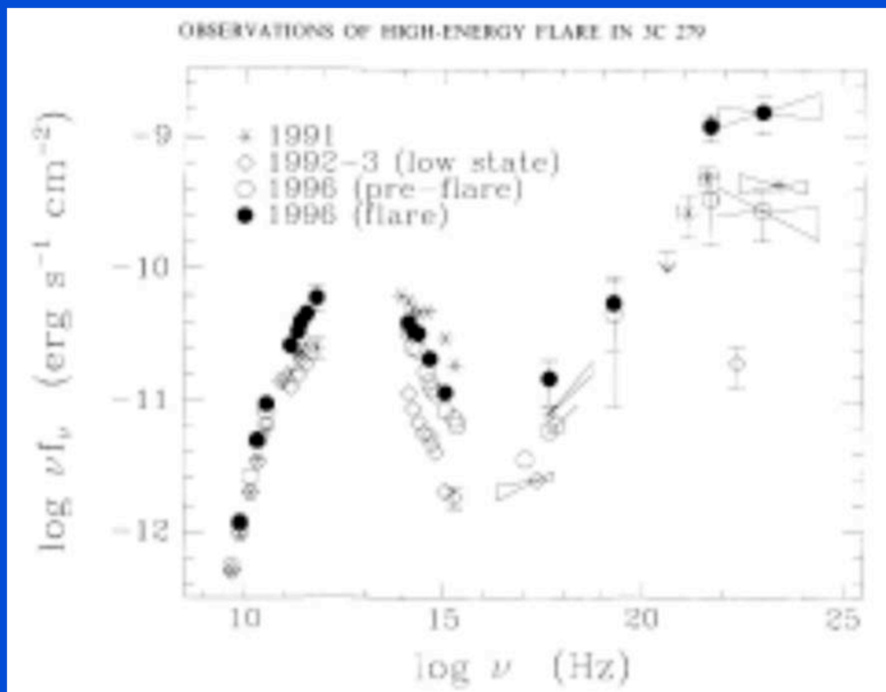
No clear difference between BL Lacs and FSRQ !

Superluminal motions

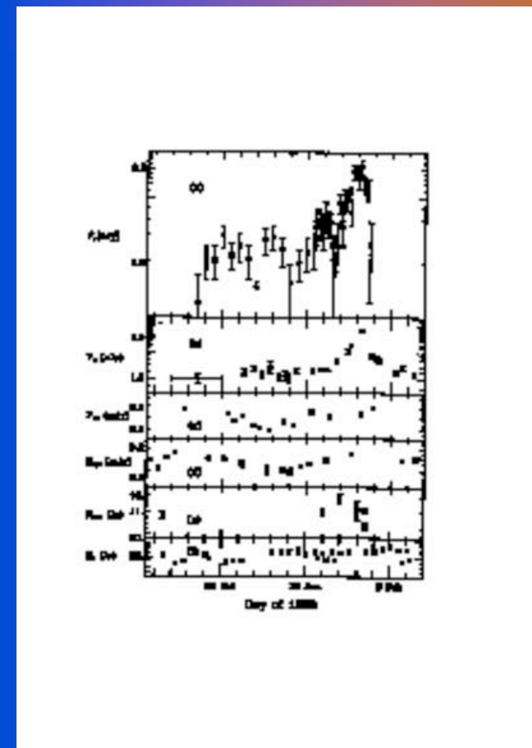
- Statistics on known sources (Vermeulen & Cohen '95)
- Compatible with a constant $\Gamma_b \sim 10$
- Some larger values discovered?
- Responsible also for Doppler boosting, enhanced variability...



Gamma-ray emitting blazars (grazars)



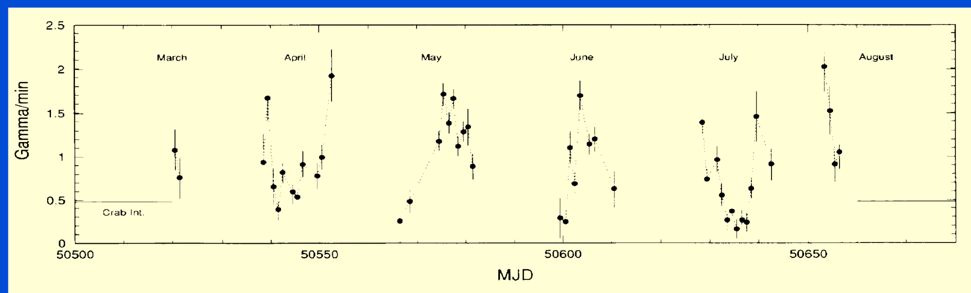
Gamma-ray luminosity can dominate the e.m.spectrum (10^{48} erg.s^{-1})



Strongly variable, often correlated with other wavelengths, but not in a simple way

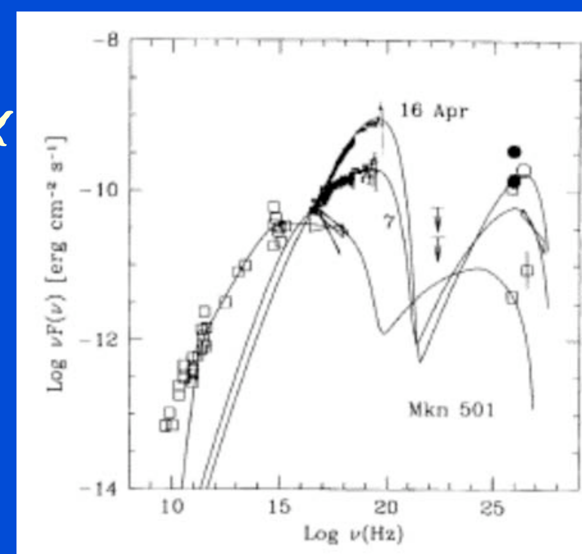
Extreme blazars (>100 GeV)

Still more variable (<30′)



Extreme spectrum :
- synchrotron peak in X rays dans les X
- Compton peak at TeV

Correlated variability



« Standard » model for gamma-ray emission

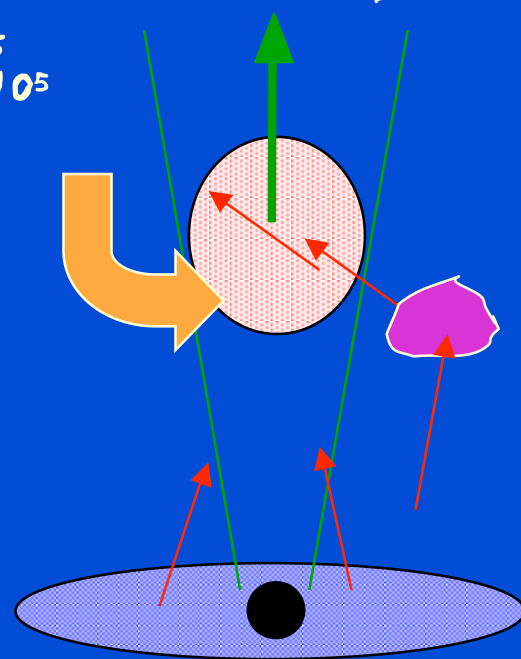
Gamma-ray opacity constraint : lower value of Bulk Lorentz factor, need for relativistic bulk motion

Leptonic processes favoured : Inverse Compton on synchrotron or external photons e- (γmc2) + hν $\rightarrow$ e- (γ'mc2) + hν'

Relativistic jet Γ_b = 10

Relativistic particles
injection @γ ≈ 10^3 - 10^5
Internal Shocks ?

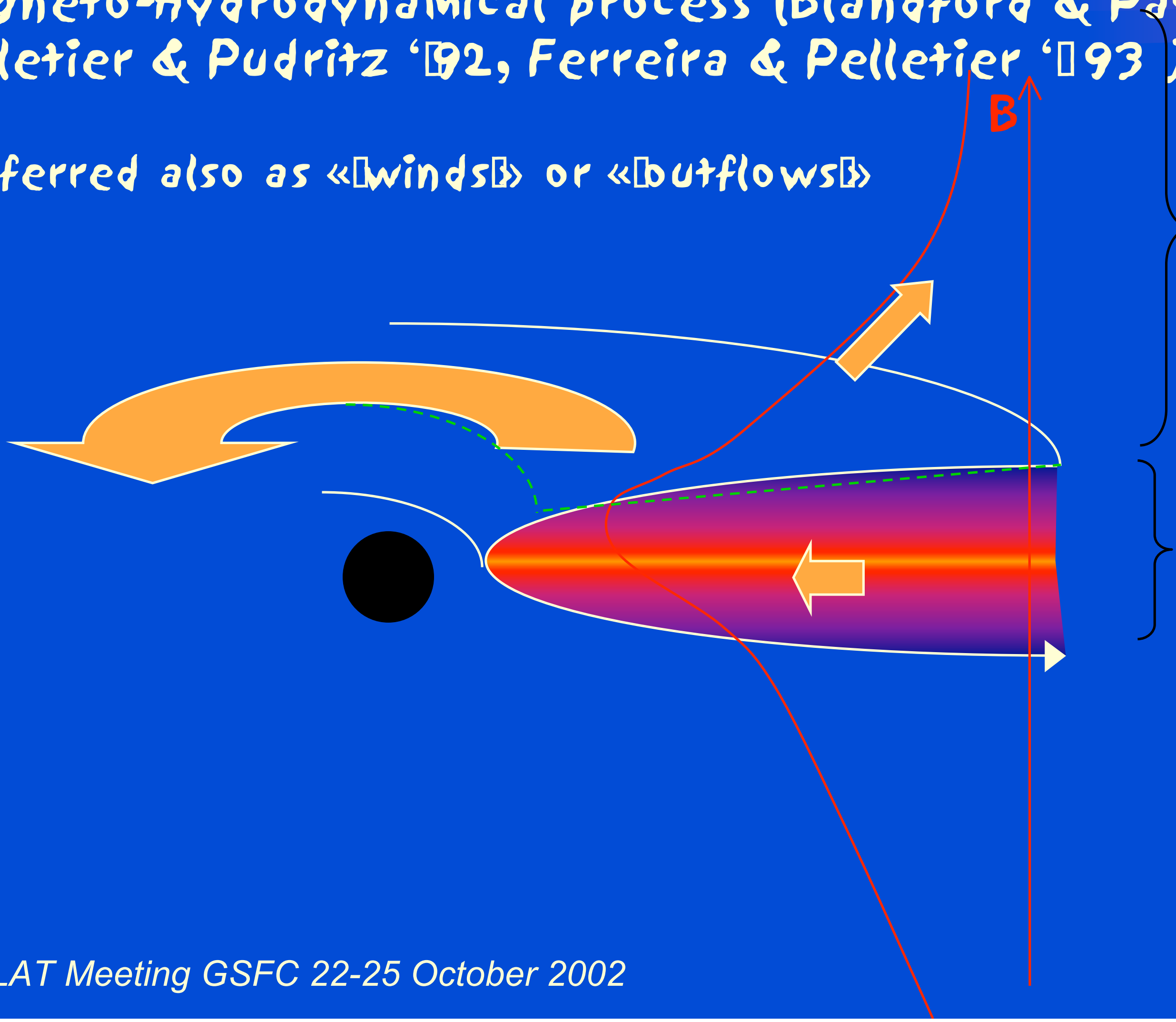
Sources of soft photons
- accretion disk
- optical lines
- synchrotron (SSC)



Generation of relativistic jet ?

Powerful jets can be extracted from accretion disks through Magneto-Hydrodynamical process (Blandford & Payne '82, Pelletier & Pudritz '92, Ferreira & Pelletier '93)

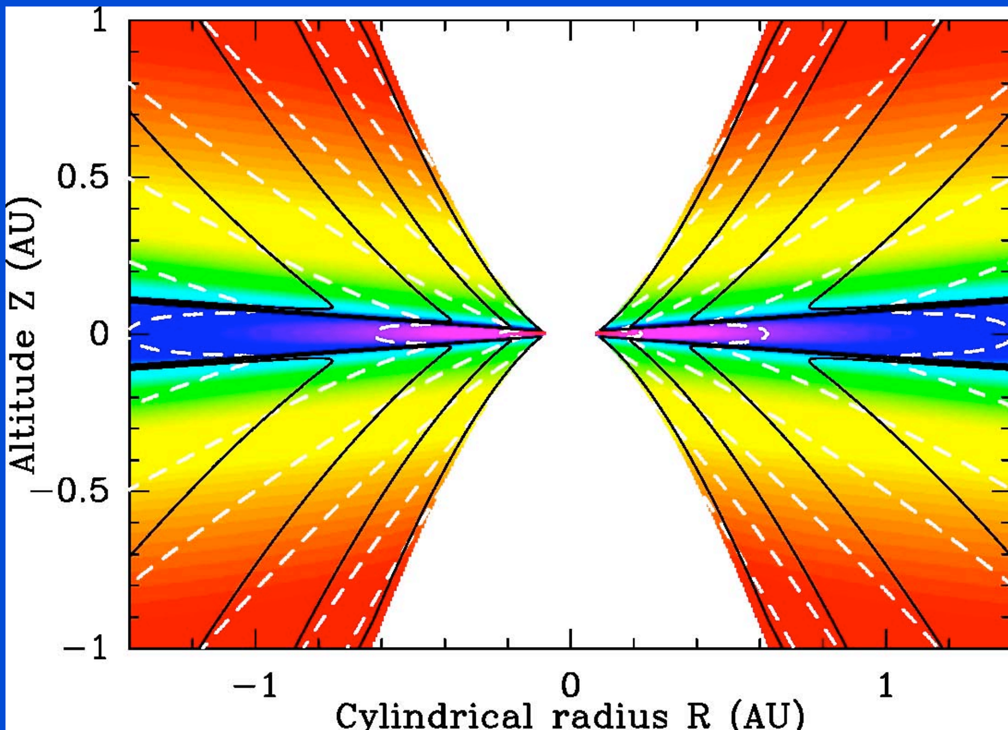
Referred also as « winds » or « outflows »

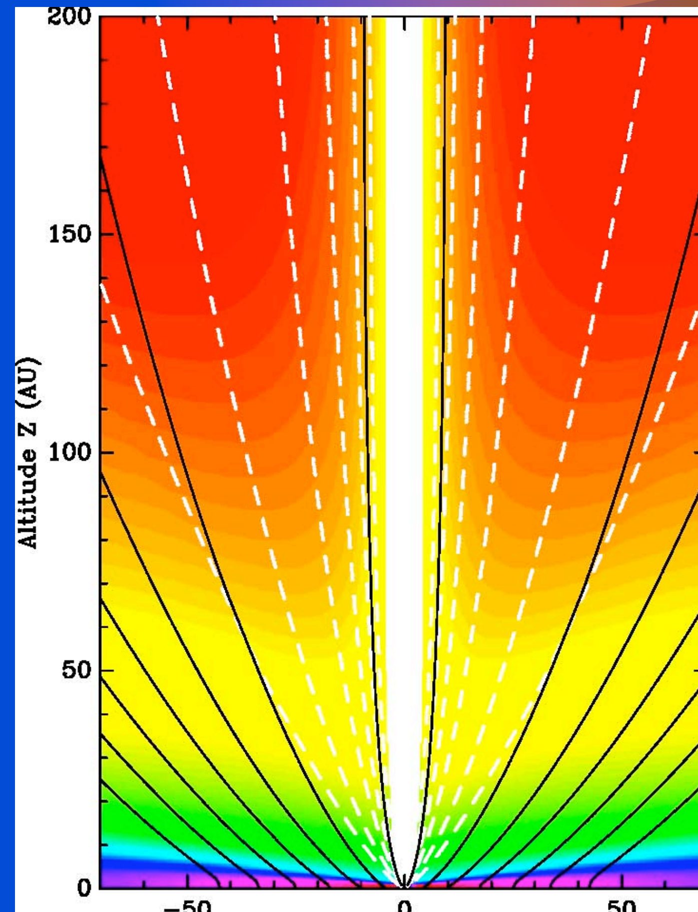


Ideal MHD

- Resistive MHD

Self-similar Accretion Discs driving Jets (Ferreira,Pelletier...)





- B ≈ equipartition
- Ejection efficiency $\dot{M}_{acc}$ r

0.01

Influence of ejection parameter

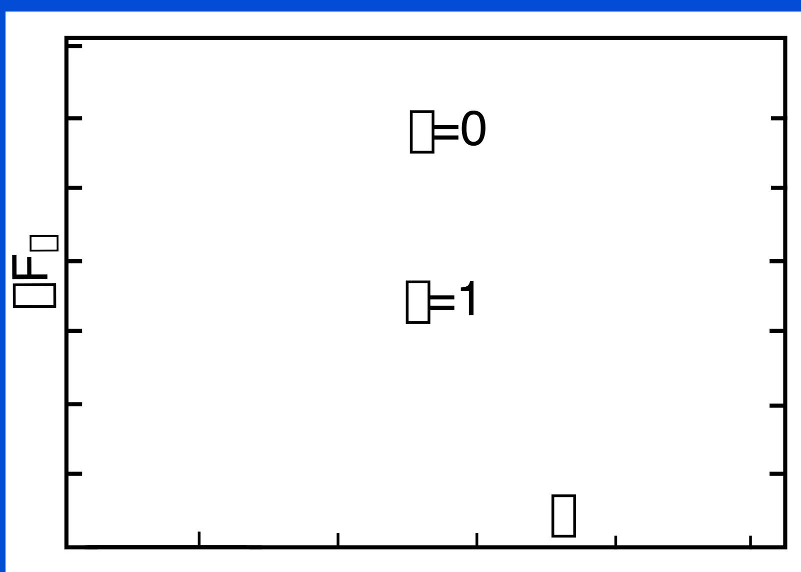
- Disc SED modified by ejection

$$T_{\mathrm{eff}} \quad r^{\square q} \qquad q = \frac{3 \square \square}{4}$$

- Jet terminal velocity

$$V_{\mathrm{jet}} = \square_0 r_0 \sqrt{2 \square \square 3}$$

$$\square = 1 + \frac{1}{2\square}$$



Low ejection efficiency □
--> powerful jets and disks

High ejection efficiency □
--> weak jets and disks

« Two flows » model

But Relativistic jets difficult to produce and collimate
with equipartition Vjet ≈ V Kepler

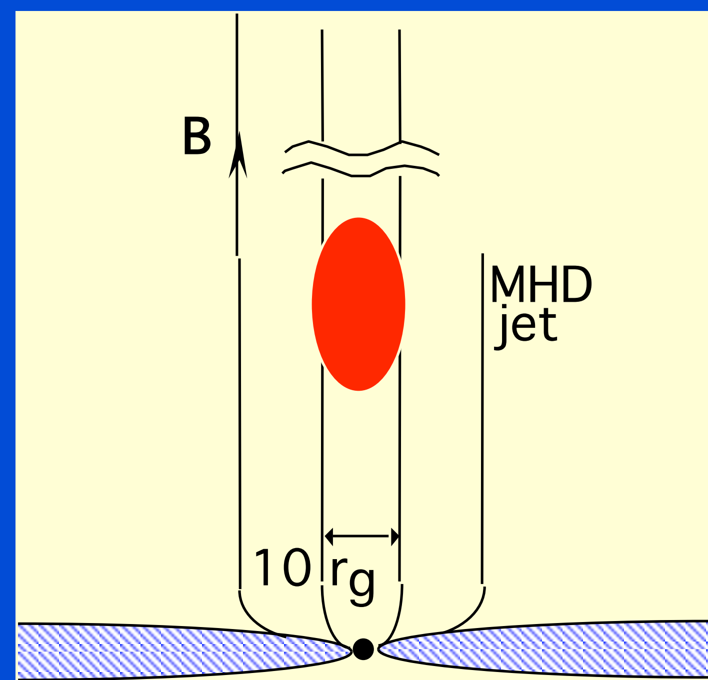
No high Γ_b solution !

Two flows model : 2 distinct flows (Sol, Pelletier, Asséo 1985)

MHD jet $e^- p^+$ mildly relativistic

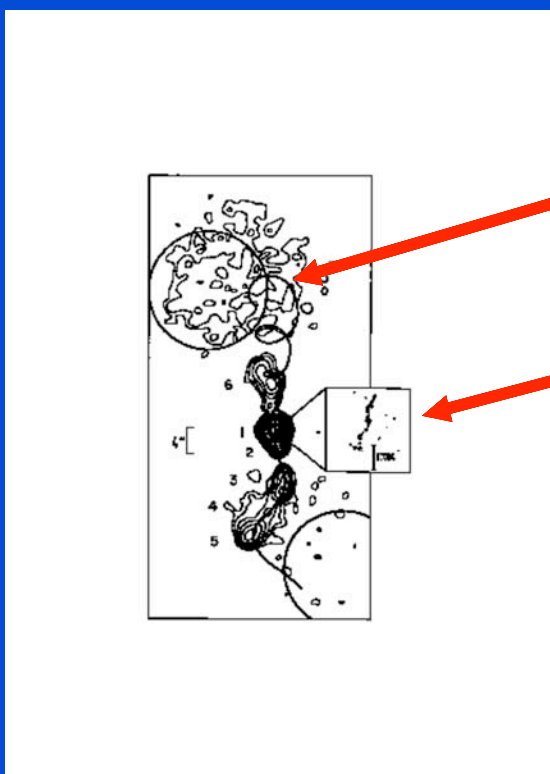
+

Highly relativistic pair plasma



Two-flow model

Account for some contradictions from small scale to large scale jets.



Example = 1928+134

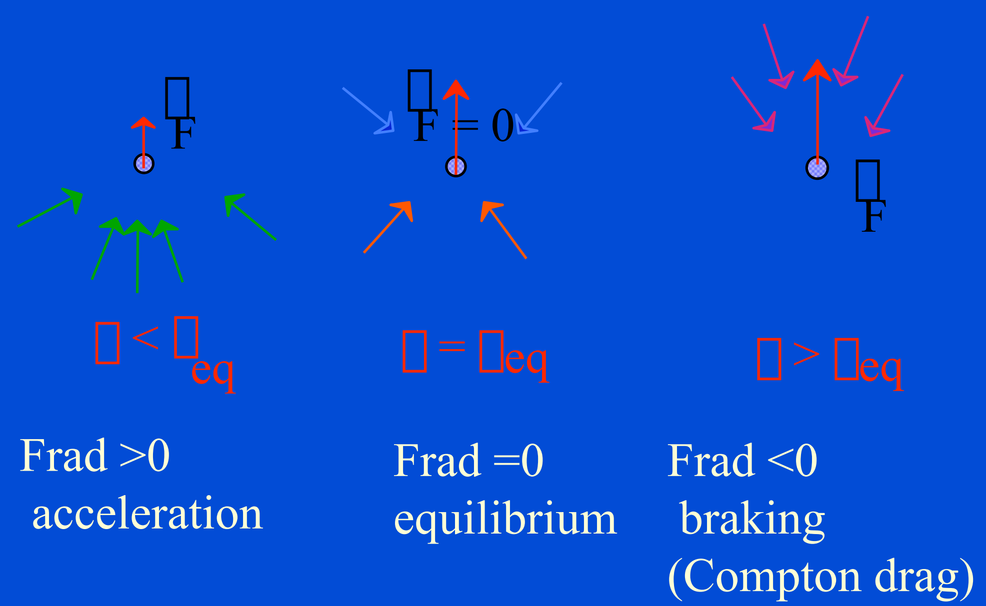
Two-sided jet @ kpc scale

One sided jet @ pc scale
superluminal motion, vapp = 6 c

Either □ is varying by ~ 50°
Or □ is varying from 7 to 1.08…

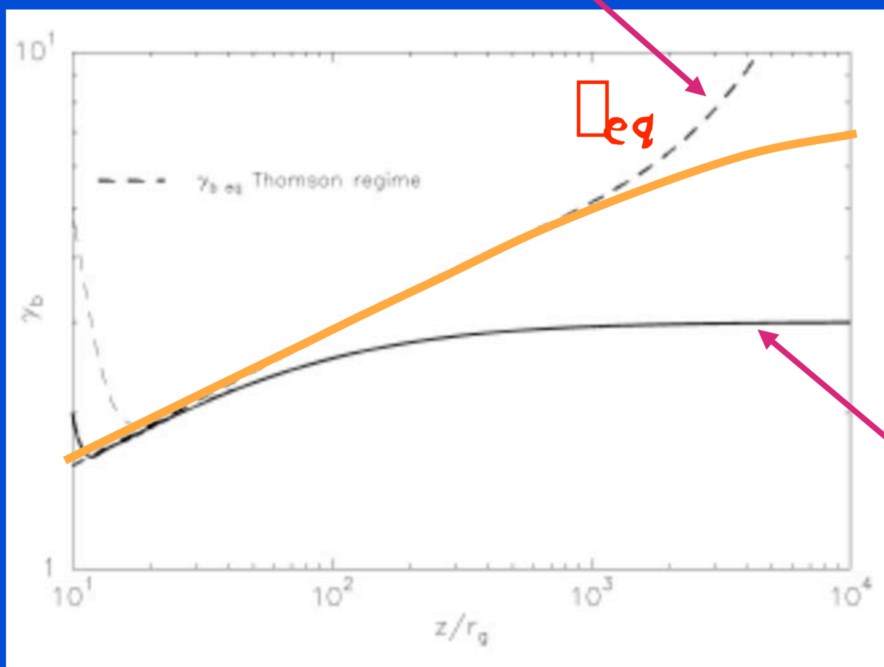
Bulk acceleration of pair plasma

- Compton effect transfers energy and impulsion
- In an anisotropic photon field, directed force (~ radiation pressure)
- Vanishes in some frame due to relativistic aberration.



O'Deill's Compton Rocket effect

- In the vicinity of an accretion disk, γ_{eq} increases with the distance ~ $(z/Rg)^{1/4}$



Hot plasma : same Veq but the force is X by <γ²>
(Compton Rocket effect)
Saturation velocity is reached later and is larger

Cold pair plasma : γ_b increases but reaches a plateau when $T_{acc} > T_{dyn}$

$\gamma_b \propto l_s^{1/7}$ □2□3 where $l_s = \dfrac{\sigma_T L_{soft}}{4\pi m_e c^3 R}$

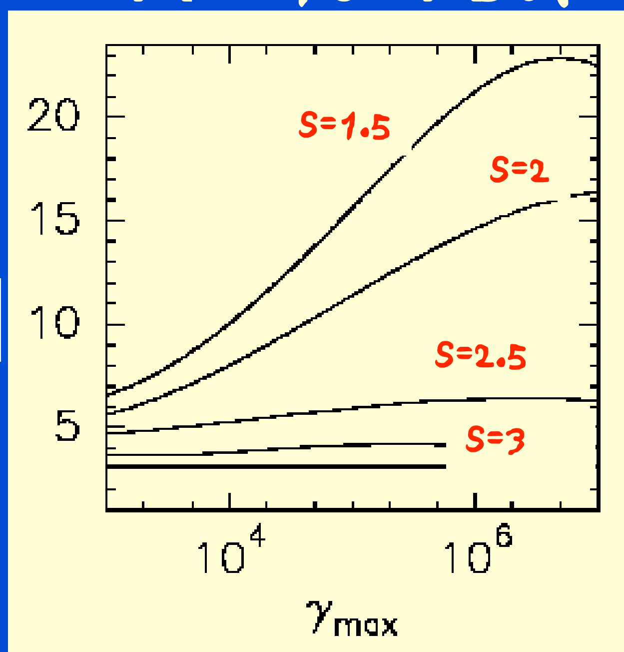
But cooling faster than acceleration (Phinney) !!
Need for continuous reacceleration at large distance

Rocket effect with continuous heating

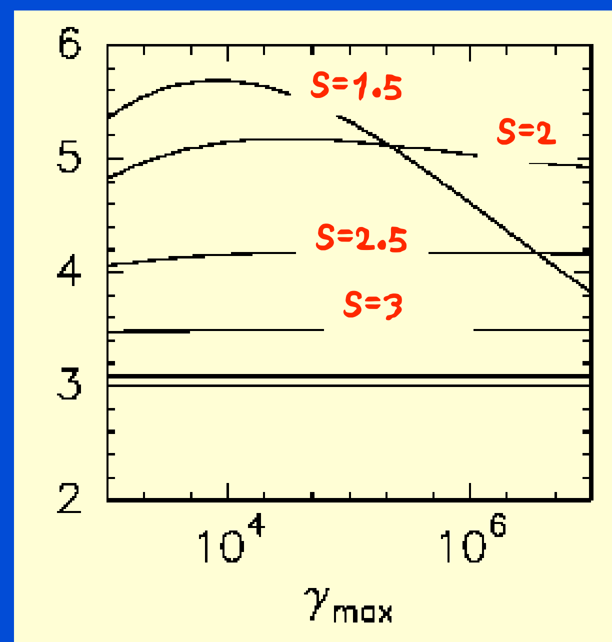
- standard disk, L = Ledd
- power law distribution

$n(\gamma)=n_0\gamma^{-s}$, $1<\gamma<\gamma_{max}$ (Renaud Henri 1998)

M = 10^8 Msol



M = 10 Msol



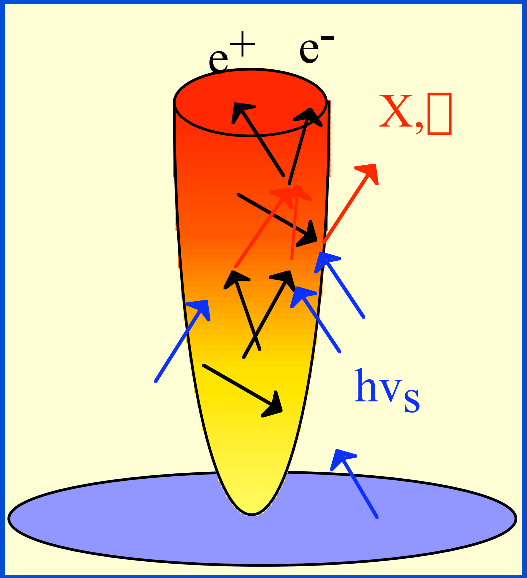
Generation of pair plasma

In situ generation of pair plasma

Feed-back on gamma-ray emission

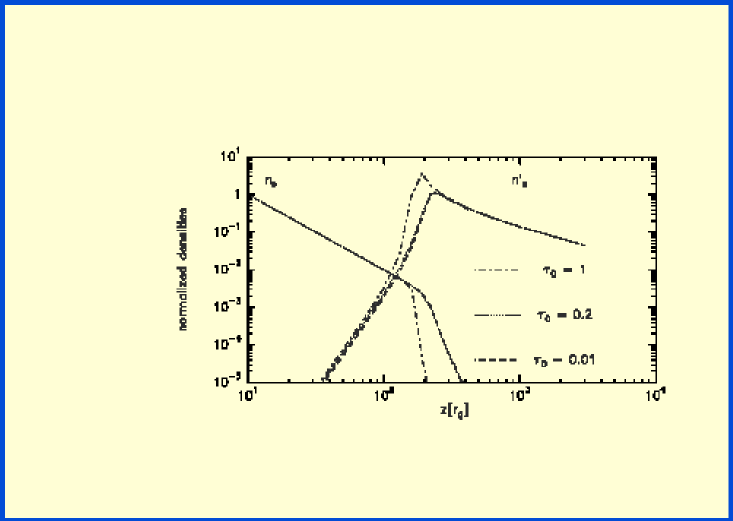
- Some relativistic particles
- X-ray and gamma-ray emission by IC and/or SSC
- □□□ annihilation forms new pairs
- Continuous reacceleration by MHD turbulence

- Processus must stop ! Add a prescription on maximal random Lorentz factor, balancing an acceleration rate □$_0$ with synchrotron and Compton losses

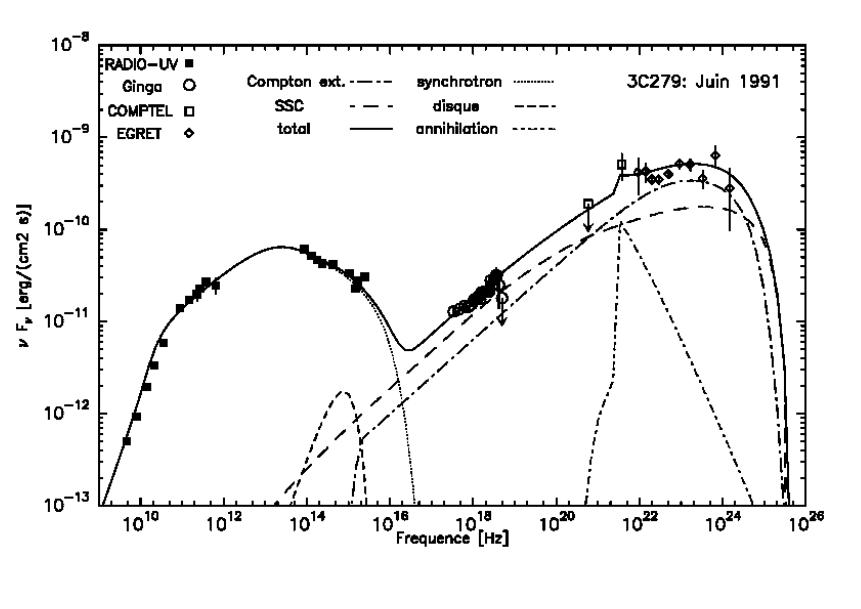


Some results

- Spectral fits



Particle and disk photon density along the jet

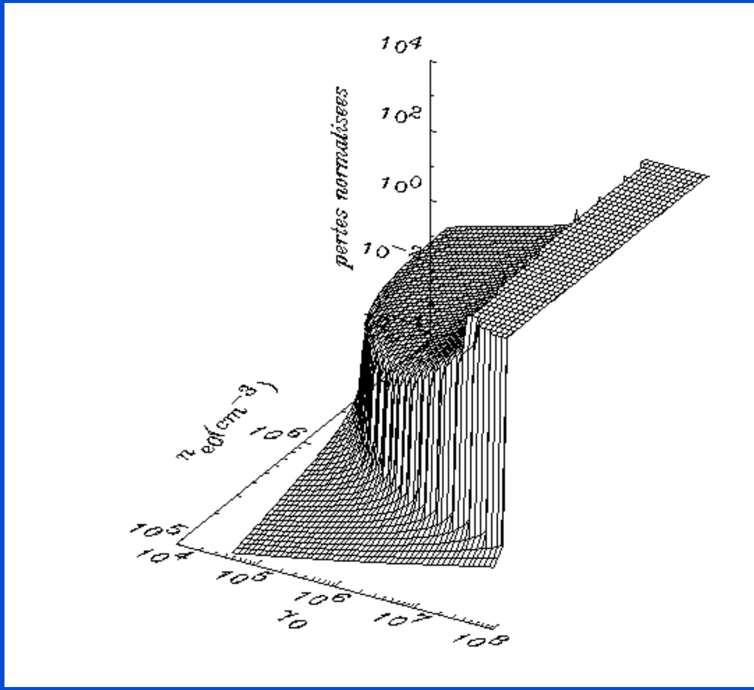


Multiwavelength spectrum

Pair production threshold

- For a given geometry and B field, the solutions depend on initial particle density and the acceleration rate

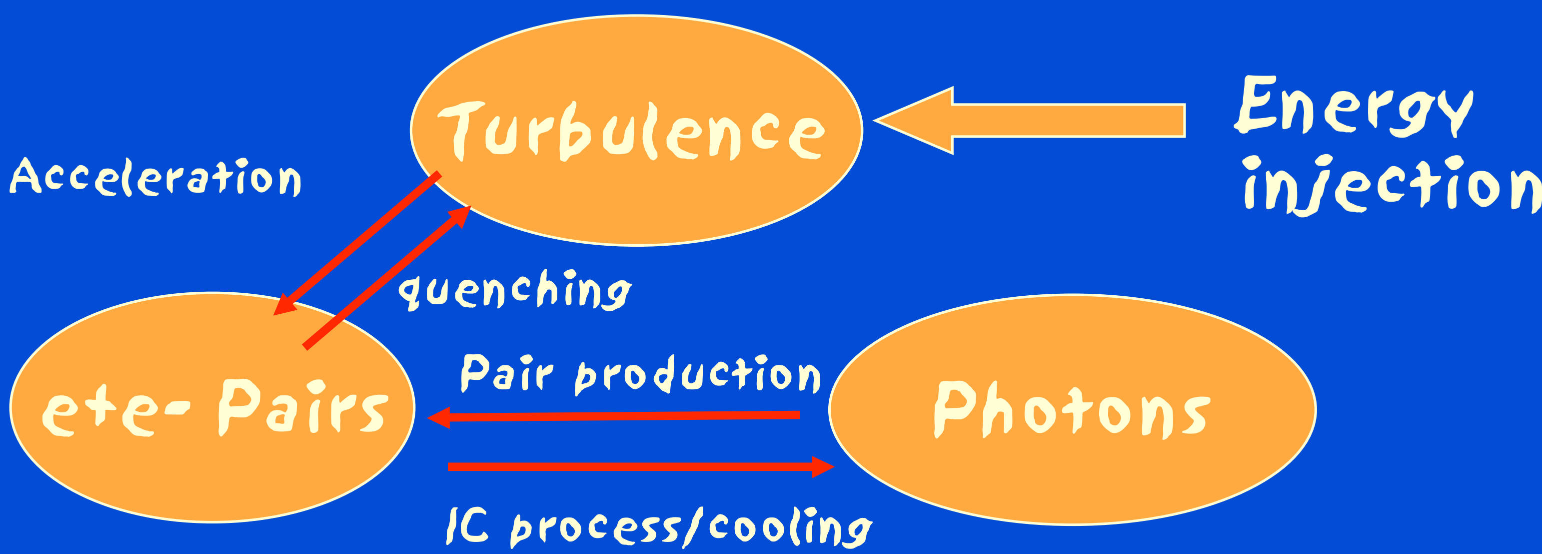
Very sharp transition of jet power when pair production starts : highly non linear



Steady-state solutions probably unphysical, variability expected

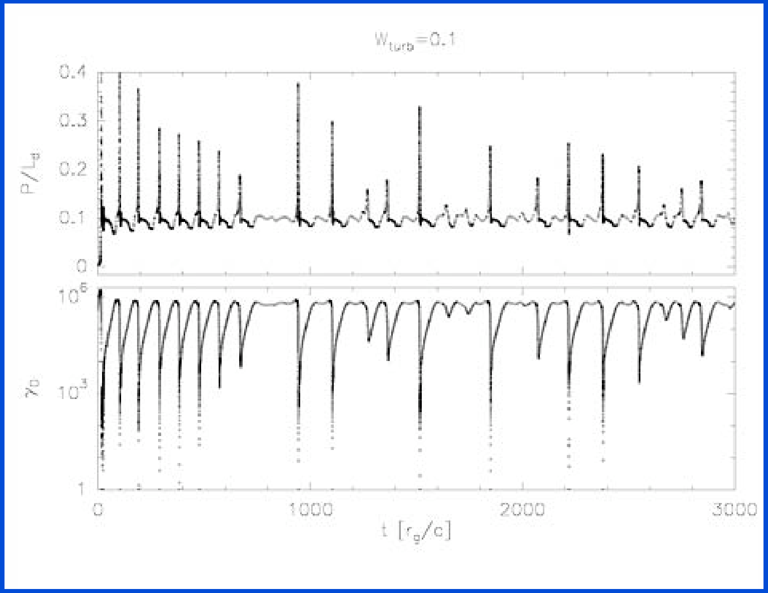
A time-dependant model

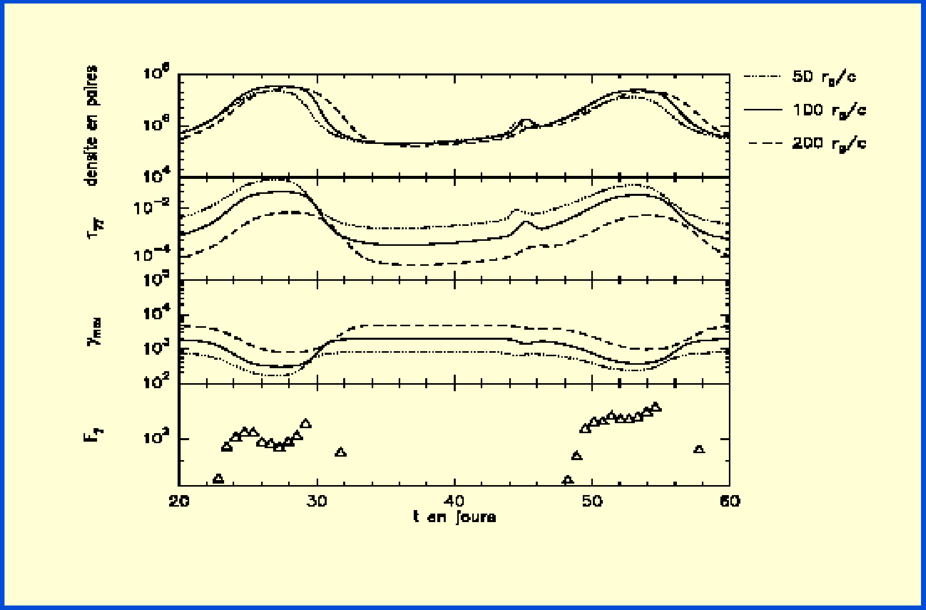
- Assume a time-dependant acceleration rate
- Parametrized by $\square_b(t)$
- assume $\frac{d}{dt}\square b = Q_{inj} \square P_{jet}$



Spontaneously variable solutions

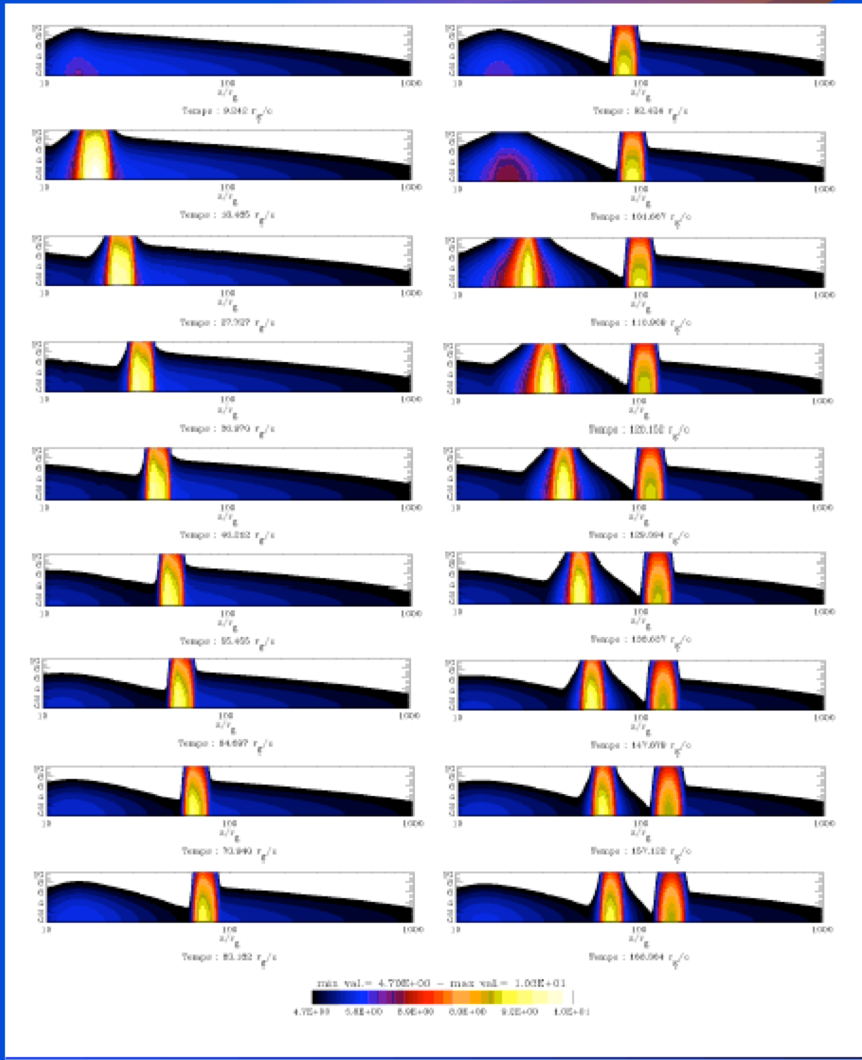
For some values of Qinj (corresponding to the «wall») time - dependent solutions exhibit spontaneous flaring behavior





At least qualitative agreement with observations

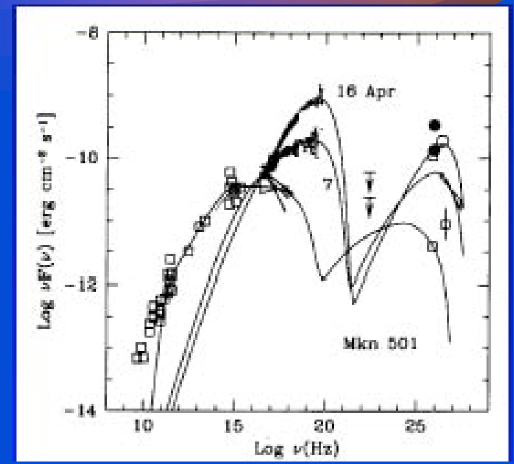
Flares associated with the ejection of discrete components



The particle distribution function

Spectra usually fitted with power laws
$N(\gamma) \propto \gamma^{-s}$
but sometimes in very narrow ranges

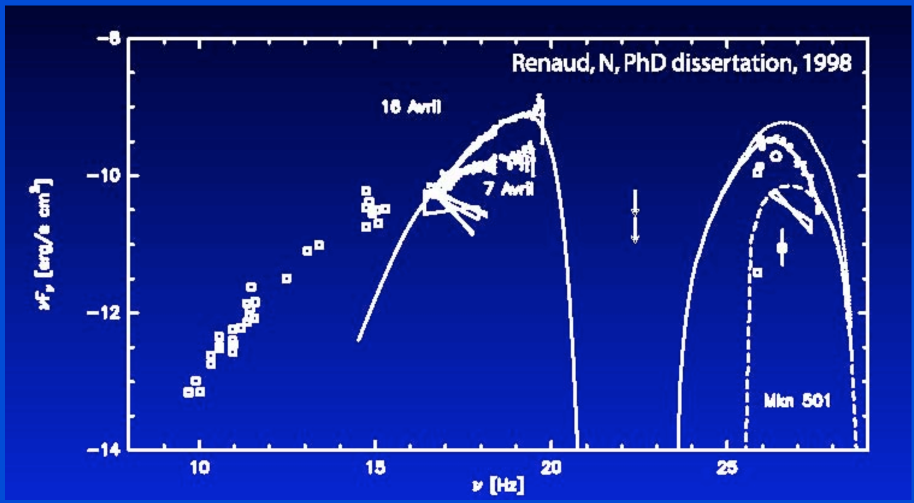
Pian et al '98
S=1
$\gamma_{min} = 4\ 10^5$
$\gamma_{max} = 3\ 10^6$



Extreme blazars can be fitted equally well with pile-up (quasi-maxwellian) distributions

$N(\gamma) \propto \gamma^2 \exp(-\gamma/\gamma_{max})$

More naturraly predicted by bulk turbulence acceleration

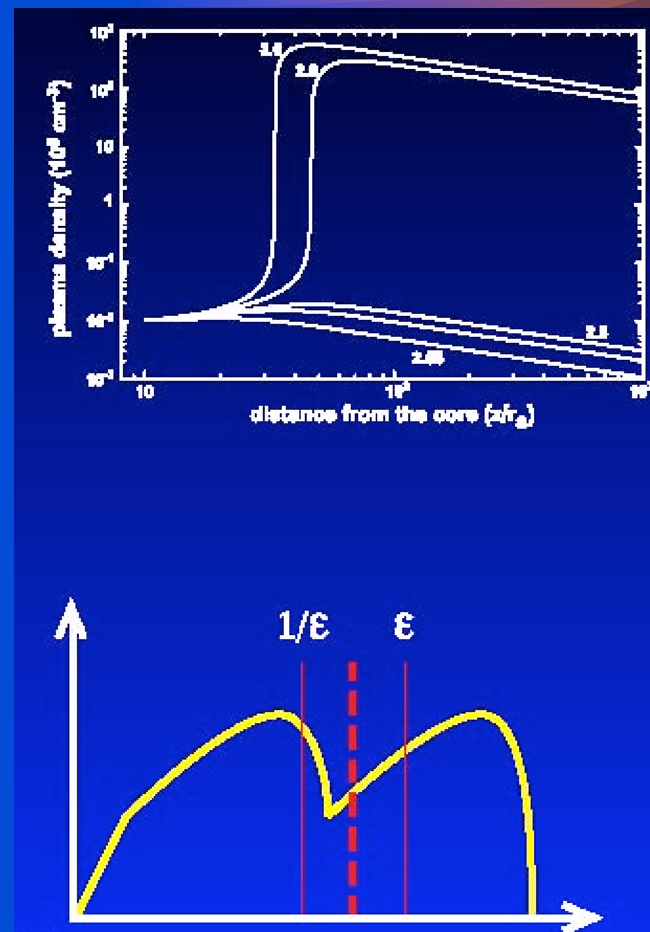


First results with pile-up distribution

Extremely sharp pair transition

Pair creation directly on synchrotron X-ray photons

Violent variability expected



Some conclusions

Pair model can reproduce the qualitative features and the quantitative SED of AGNs

Need for simultaneous multi wavelength and time-resolved spectra to better test the models : leptonic/hadronic, homogeneous/ inhomogeneous, pairs or not, particle distribution function...

High sensitivity and energy coverage of GLAST extremely valuable for temporal and spectral resolution, encourage multi-□ campaigns