The Magnetic reconnection model for blazar emission

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TeVPA

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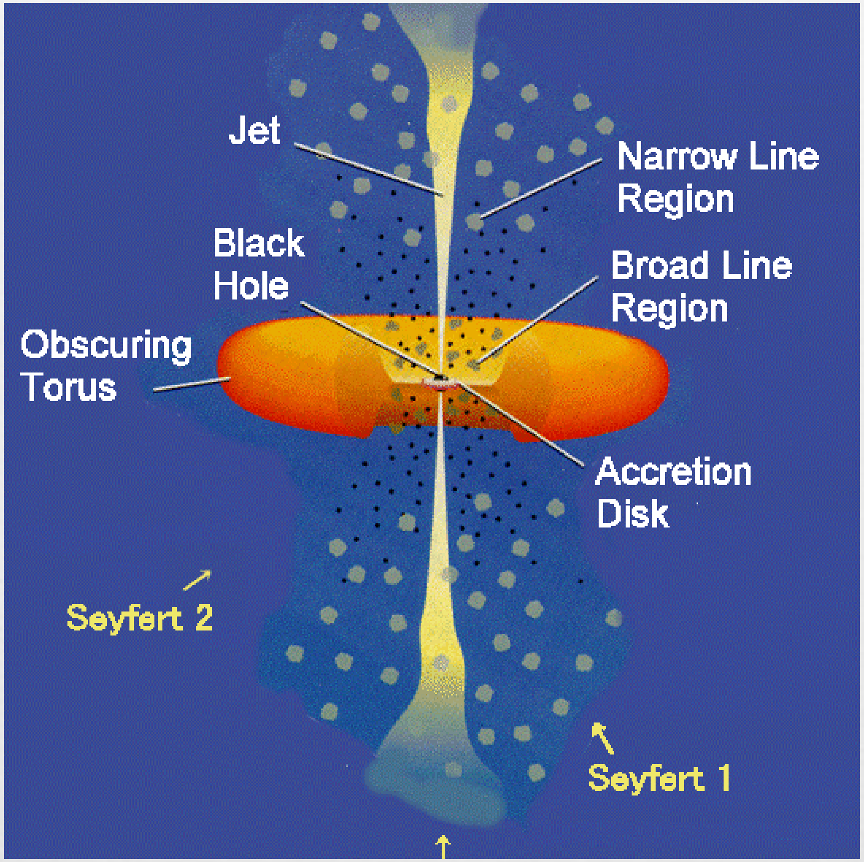
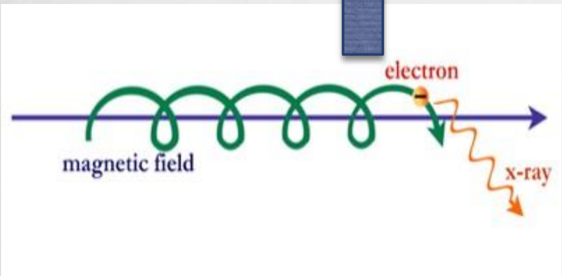
Blazars:
Jets in AGN moving towards us

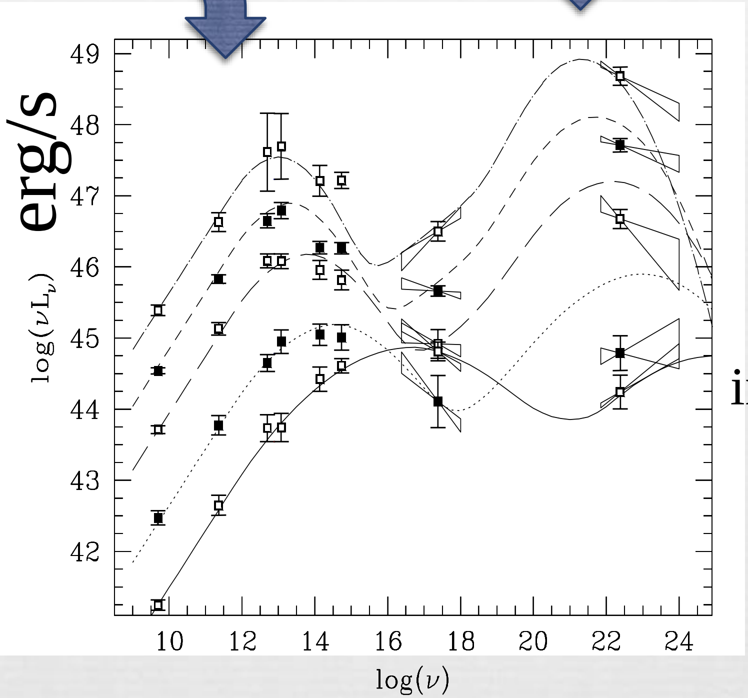


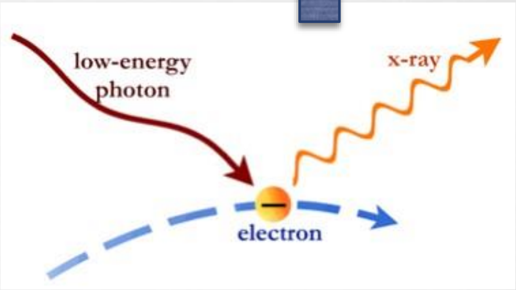
Blazar

Blazars: bright at all frequencies



synchrotron



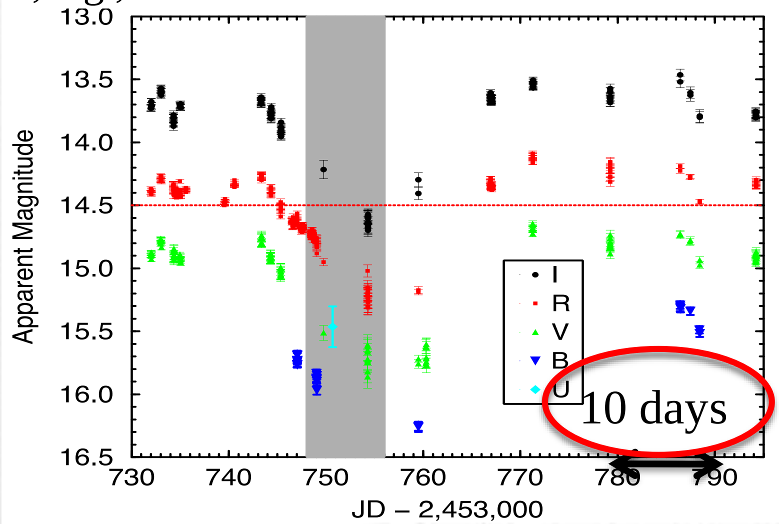


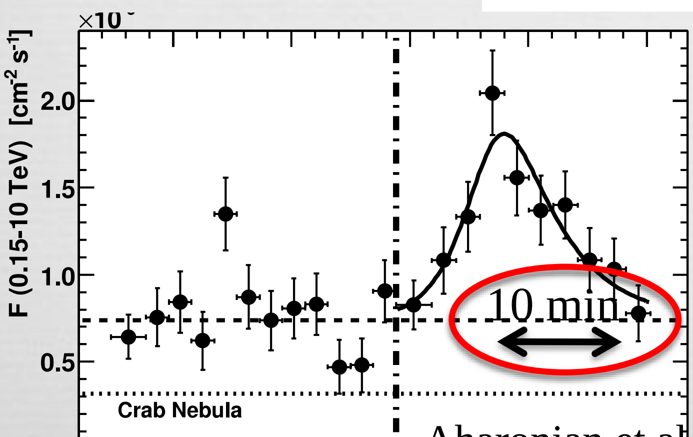
inverse Compton scattering

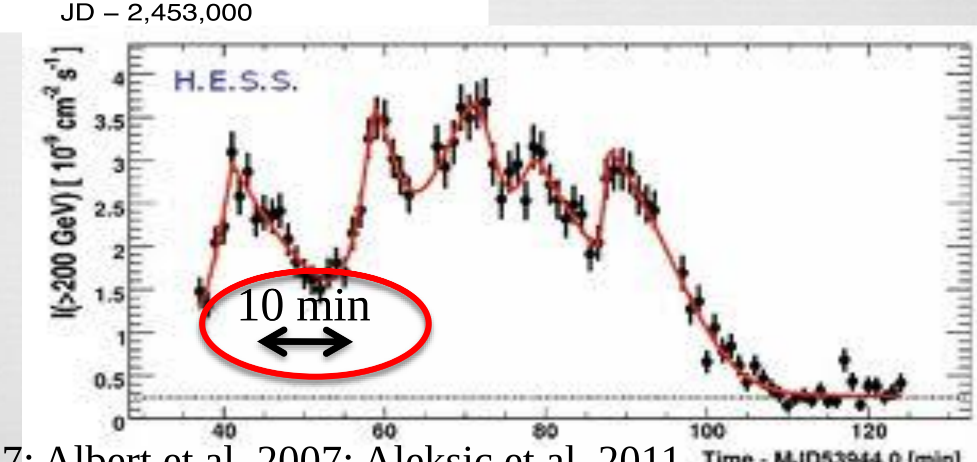
e.g., Fossati et al. 1998

Blazars flaring from weeks down to ~5 minutes!

3C279; e.g., Collmar et al. 2007



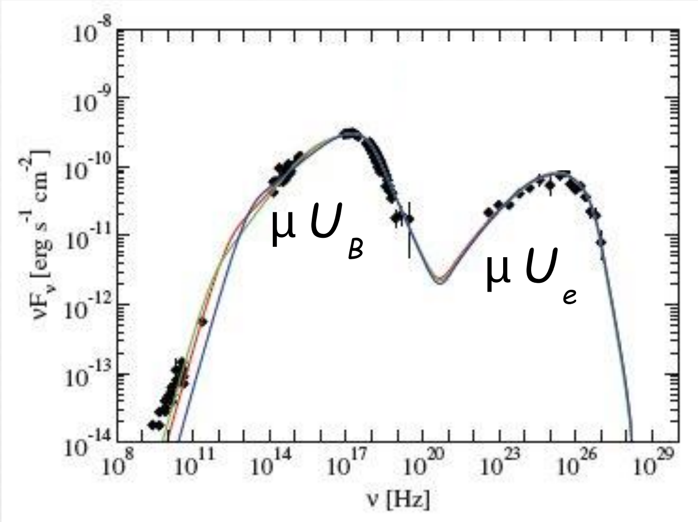




Aharonian et al. 2007; Albert et al. 2007; Aleksic et al. 2011

Basic **Observed**/inferred properties of blazars

SSC model fit of the spectral energy distribution of Mrk 421



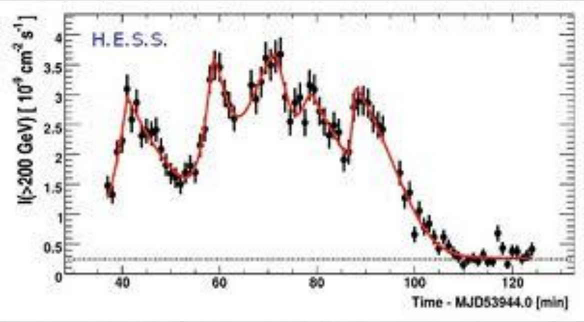
Effective particle accelerators up to multi TeV energies, *at least*

Efficient radiators ~10% radiative efficiency or more!

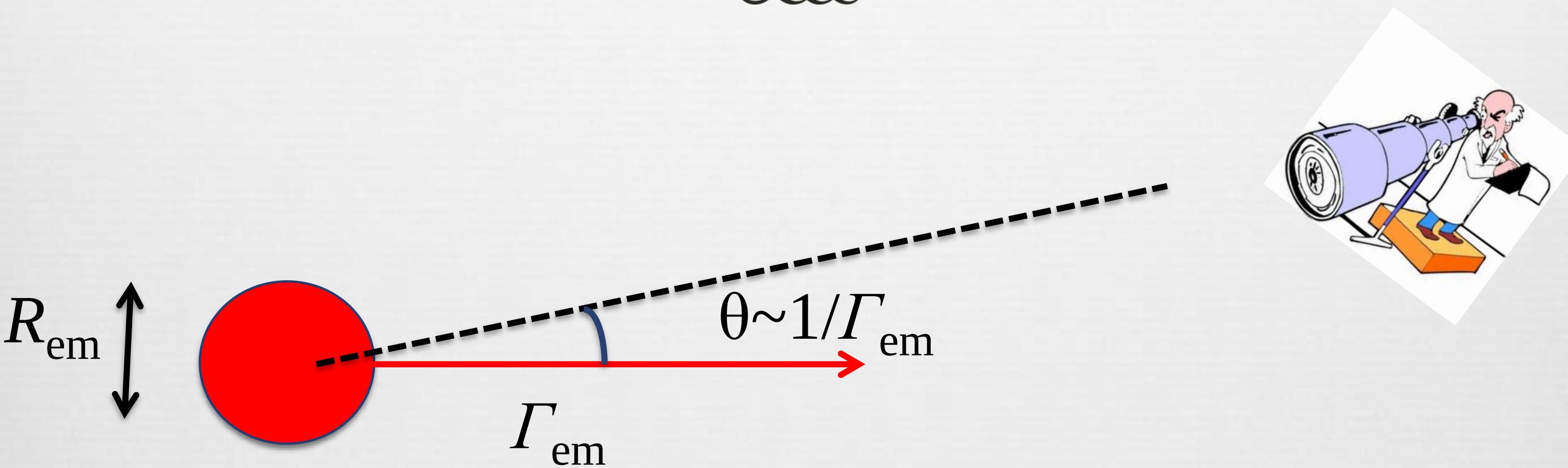
Radiating particles and magnetic field in, very rough, equipartition:

$$U_e \sim U_B$$

Extreme variability variable $t_{var} << R_g/c$ in some cases!



Source of blazar flares: “Blobs” of energetic e^- and B fields



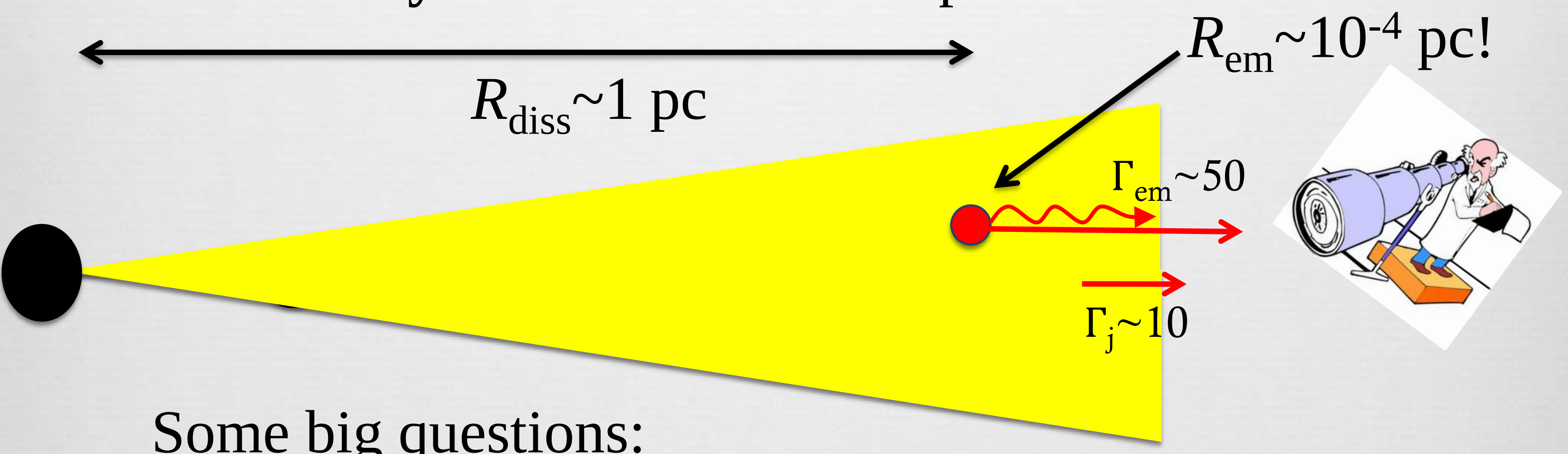
$$R_{em} \leq \delta c t_{flare} \sim 5 \times 10^{14} \delta_{50} t_{300} \mathrm{cm}$$

Doppler factor $\delta = [\Gamma_{em}(1 - \beta_{em} \cos\theta)]^{-1} \sim \Gamma_{em}$

Notation: $\delta = 50 \delta_{50}, \quad t = 300 t_{300} s$

Stringent requirements for emitting region

Emitter must be **very compact** *and* **extremely fast** and form at ~1 pc distance!



Some big questions:

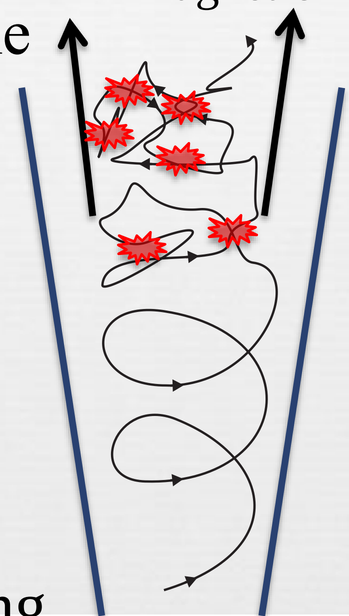
Which process accelerates the particles that radiate?

What determines the distance & size/shape of the emitting region?

A theory view of jets

“blazar” zone

magnetic reconnection region

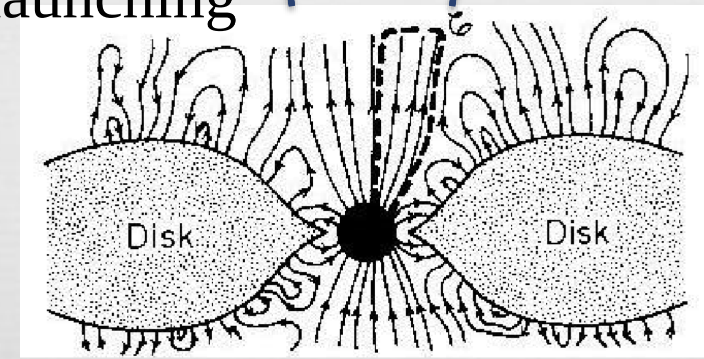


$$\sigma_{diss} \geq 1$$

acceleration

launching

$$\sigma_{initial} = \frac{B^2}{4\pi\rho c^2} >> 1$$

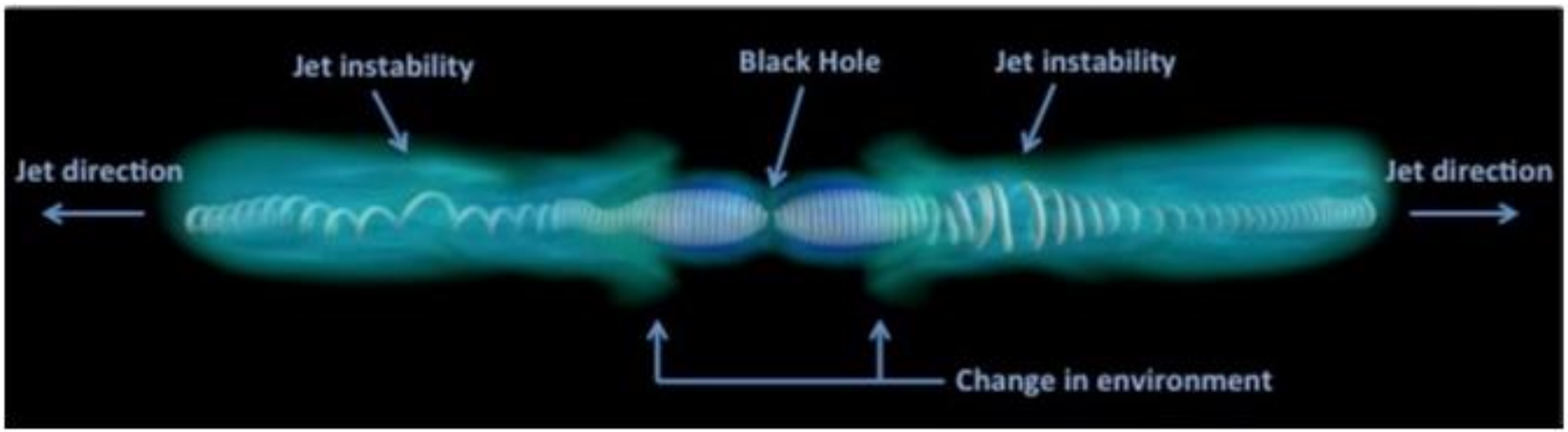


Blandford & Znajek 1977
Begelman & Li 1992
Meier et al. 2001
Koide et al. 2001
Komissarov, Lyubarky,
McKinney, Tchekhovskoy…

Magnetic reconnection due to MHD instabilities in jets

Magnetized jets may be prone to the kink instability

Eichler 1993; Begelman 1998; Nakamura & Meier 2004; Giannios & Spruit 2006; Moll 2009; McKinney & Blandford 2009; Mignone et al. 2010; Porth & Komissarov 2015



Barniol-Duran, Tchekhovskoy & Giannic

kink instability

A very promising dissipative mechanism: Magnetic Reconnection

- An efficient convertor of magnetic energy into bulk motion, heat, energetic particles
  - cold, magnetized plasma enters the reconnection region
  - plasma leaves the reconnection region at the Alfvén speed

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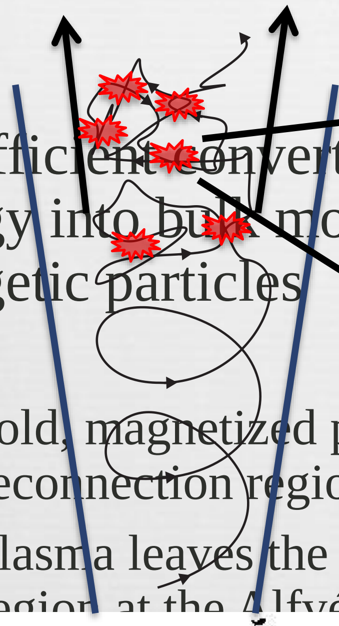
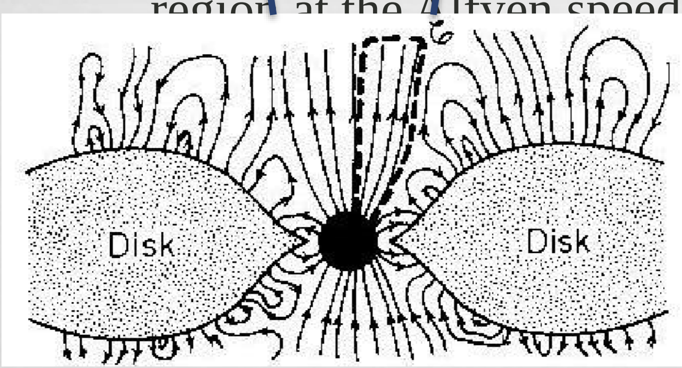
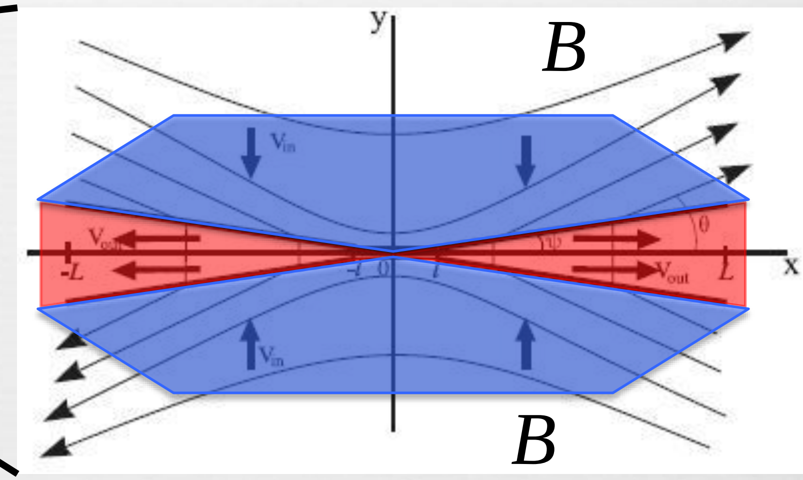
rticles



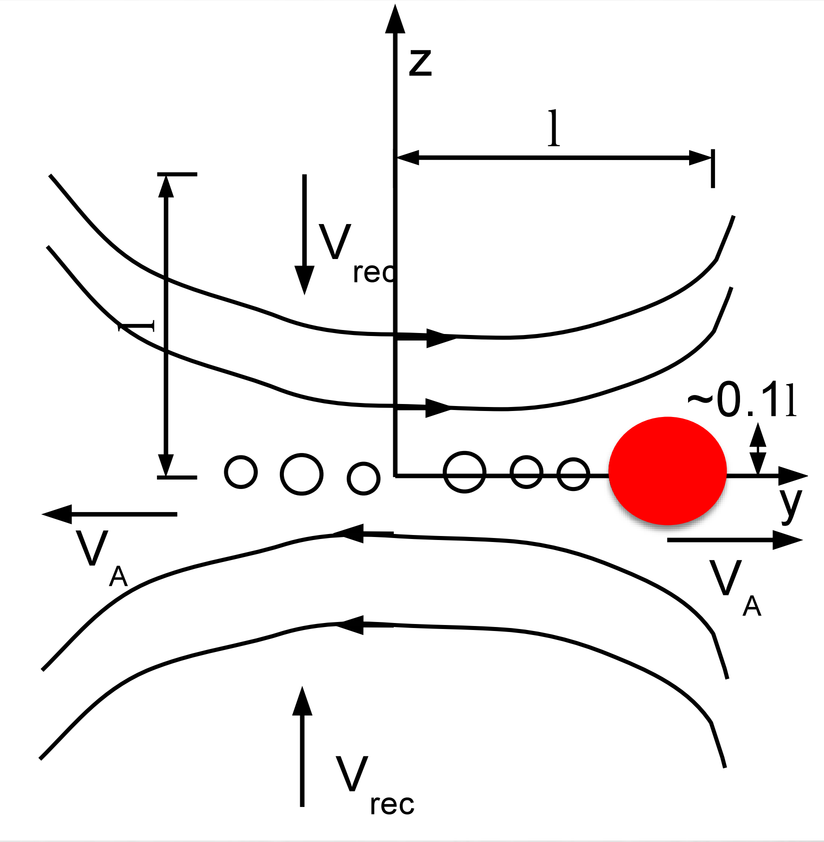


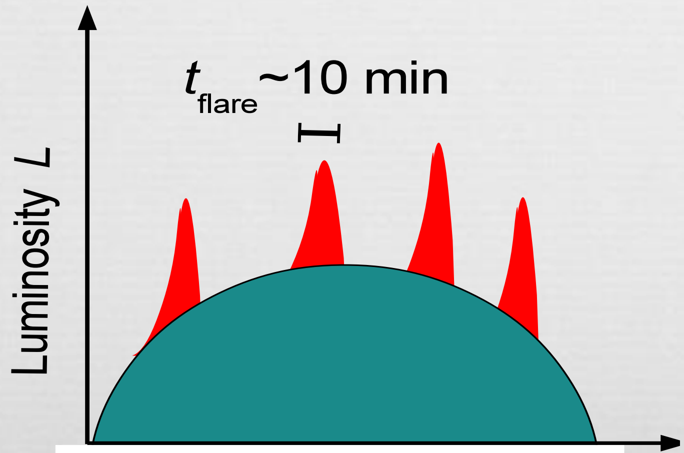


Reconnection Plasmoids = Blazar Blobs?

Giannios et al. 2009; 2010; Giannios 2013

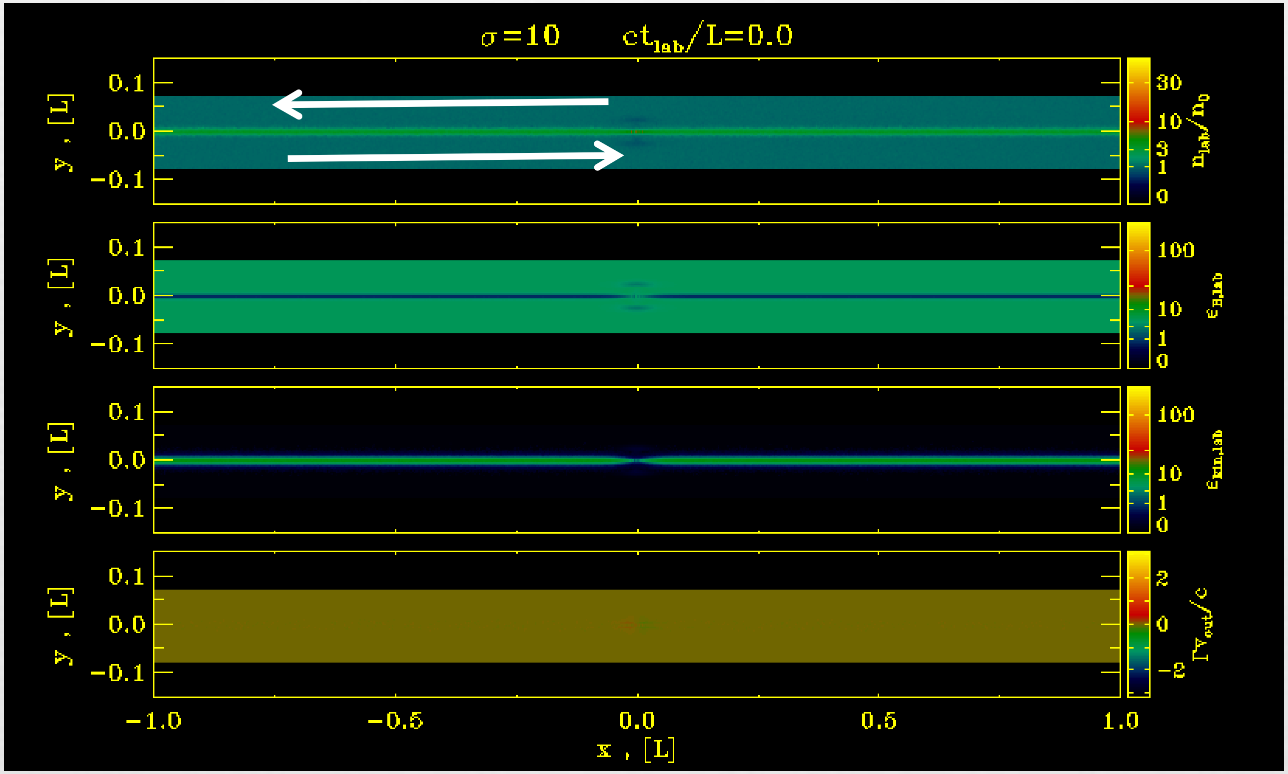
- Current sheet fragments to plasmoids Loureiro et al. 2007; Uzdensky et al. 2010; Loureiro et al. 2012+++
- Plasmoids merge/grow fast leaving the layer at $V_A \sim c$
- Large plasmoids can power blazar flares Giannios 2013





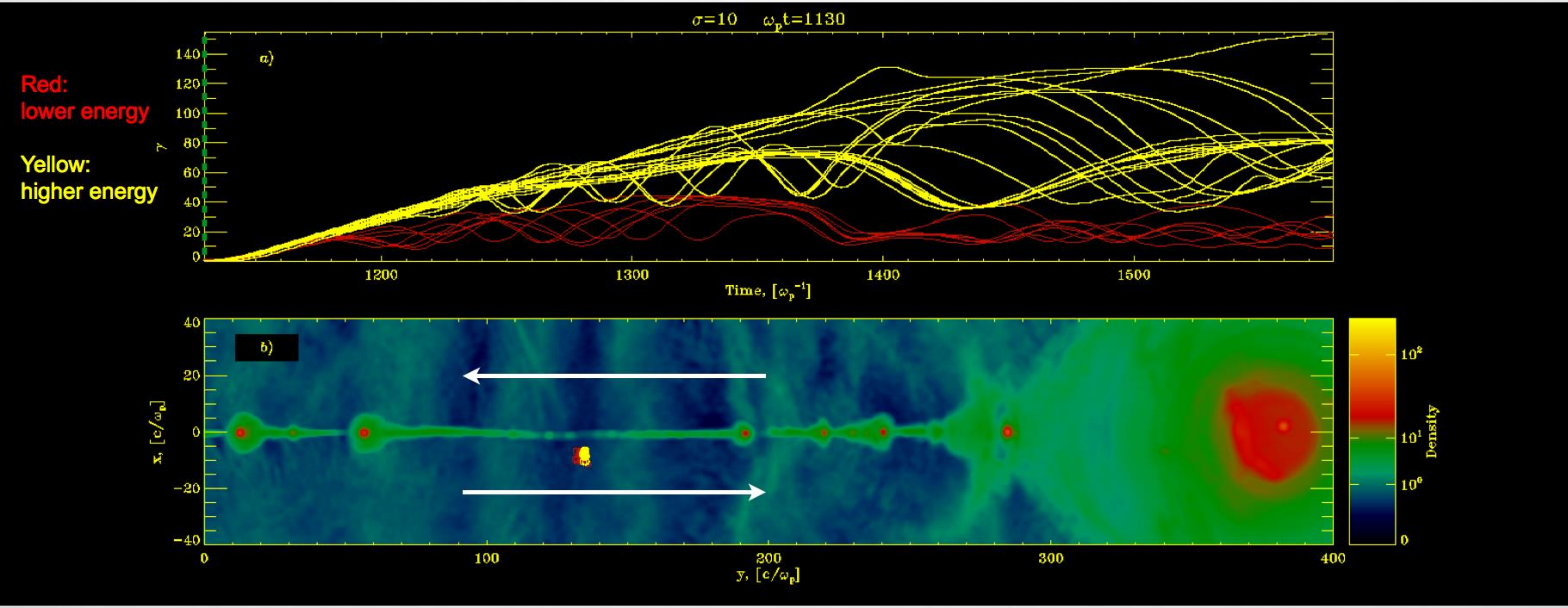
Magnetic reconnection from first-principle simulations

Sironi & Spitkovsky 2014; Sironi, Petropoulou & Giannios 2015;
Sironi, Giannios & Petropoulou 2016; Petropoulou, Giannios & Sironi 2016



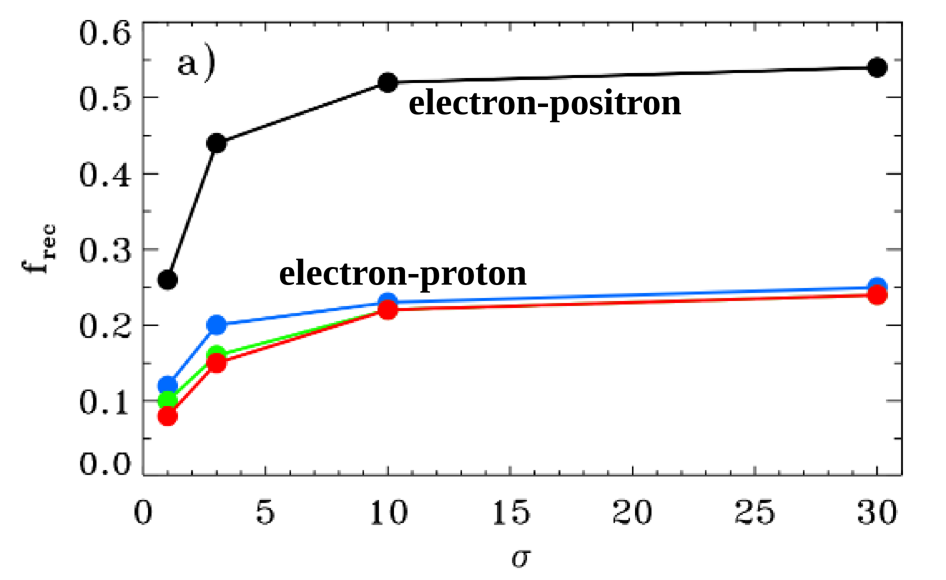
Particle acceleration from first principle simulations

Sironi, Petropoulou & Giannios 2015



(1) Relativistic reconnection is efficient

$$f_{\rm rec} \equiv \frac{\sum_i \int_{V_i} U_{\rm e} {\rm d}V_i}{\sum_i \int_{V_i} (e + \rho c^2 + U_{\rm B})\, {\rm d}V_i}$$



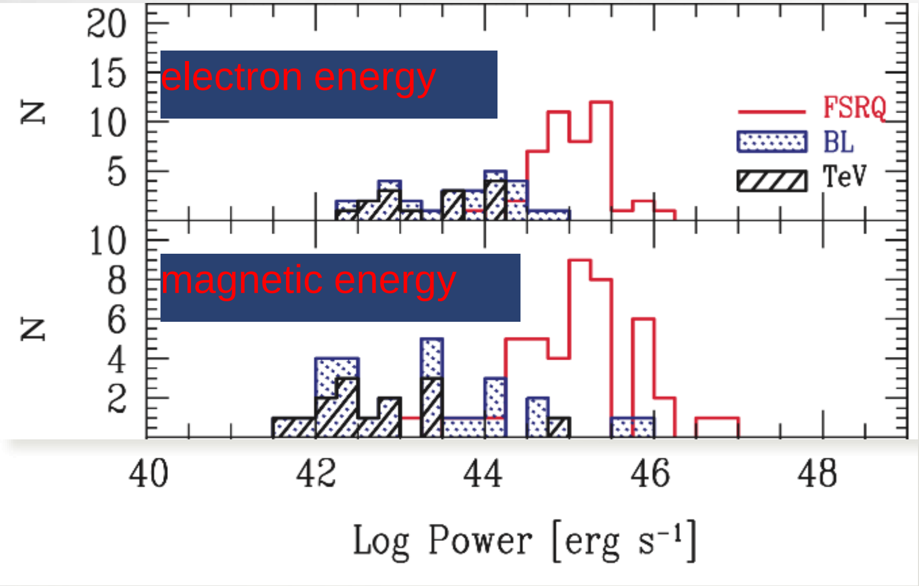
(Sironi, Petropoulou, Giannios 15)

Relativistic reconnection:

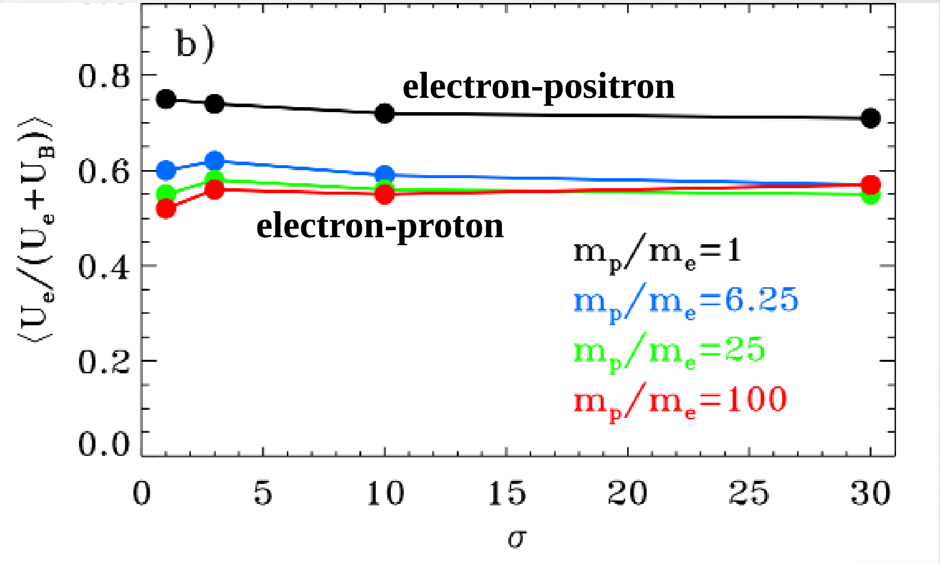
✓ it transfers ~ 50% of the flow energy (electron-positron plasmas) or ~ 25% (electron-proton) to the emitting particles

(2) Equipartition of particles and fields

$$\left\langle \frac{U_e}{U_e + U_B} \right\rangle \equiv \frac{\sum_i \int_{V_i} U_e \frac{U_e}{U_e+U_B} dV_i}{\sum_i \int_{V_i} U_e dV_i}$$



(Celotti+ 08)



(Sironi, Petropoulou & Giannios 2015)

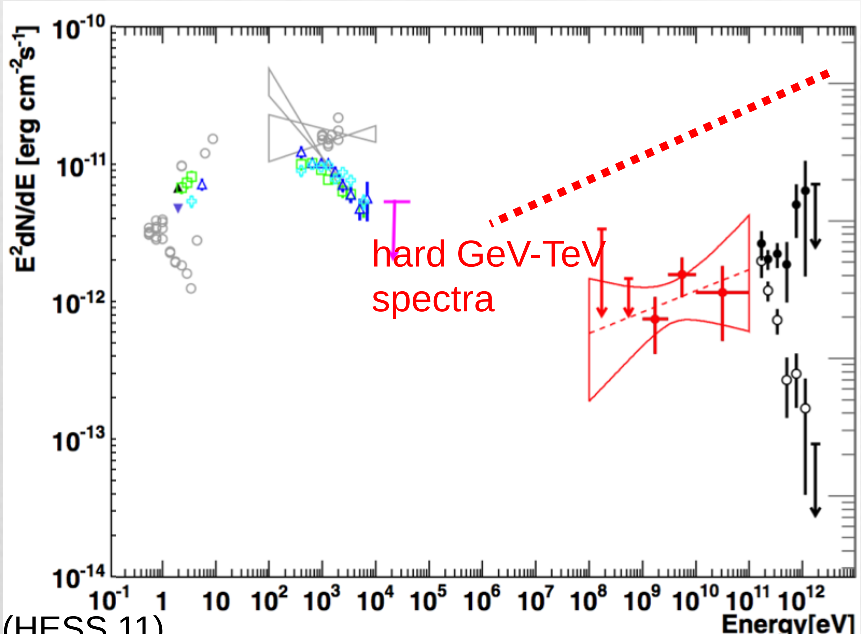
Blazar phenomenology:

- rough energy equipartition between emitting particles and magnetic field

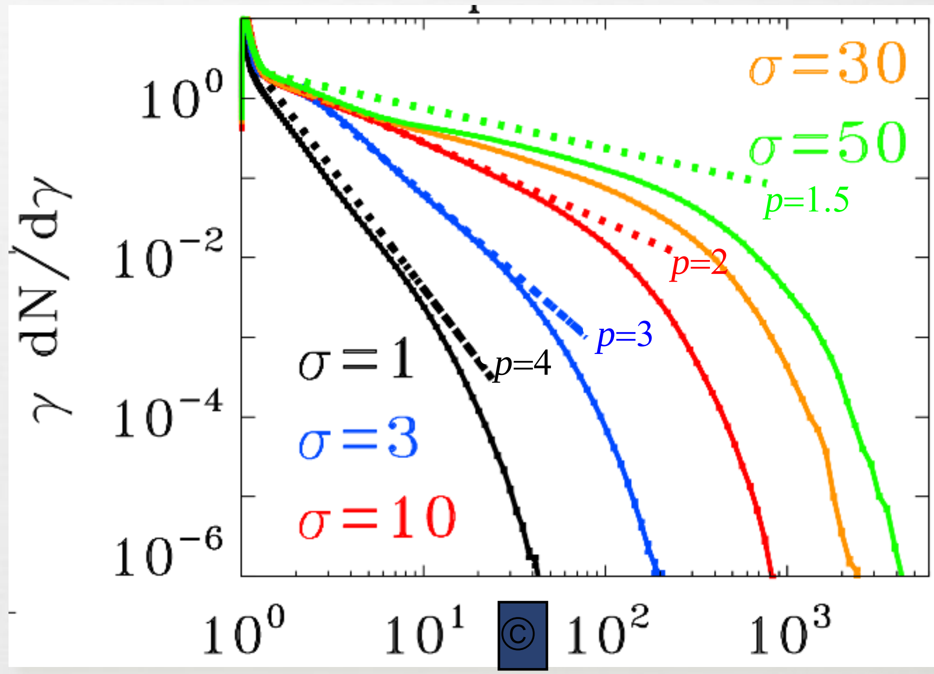
Relativistic reconnection:

✓ in the magnetic islands, it naturally results in rough energy equipartition between particles and magnetic field

(3) Extended non-thermal distributions



(HESS 11)



(Sironi & Spitkovsky 14, Guo et al. 14, Werner et al. 14)

Blazar phenomenology:

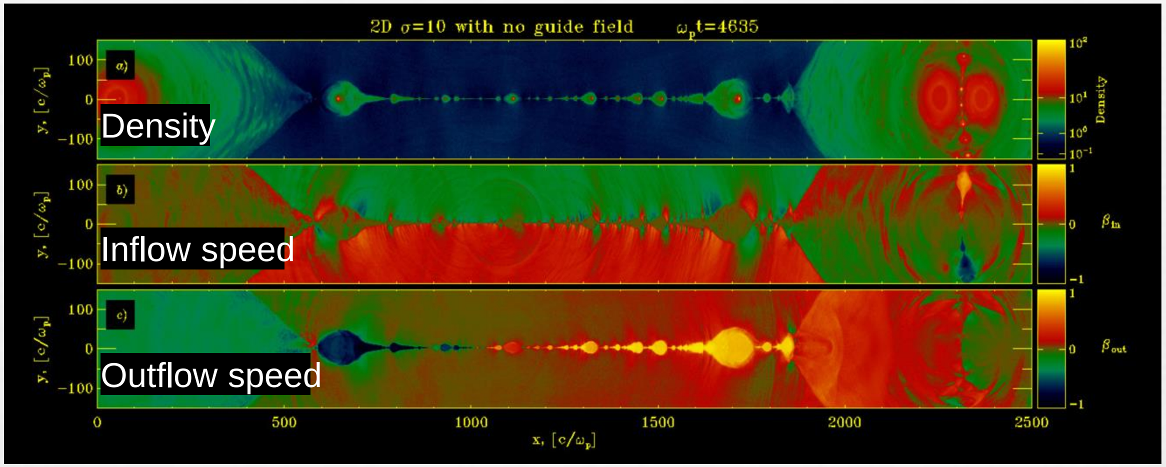
- extended power-law distributions of the emitting particles, with hard slope

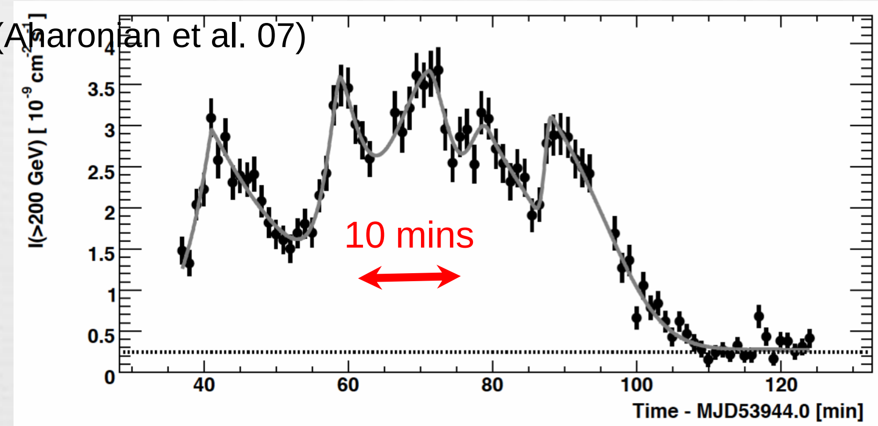
$$\frac{dN}{d\gamma} \propto \gamma^{-p}, \quad p \le 2$$

Relativistic reconnection:

✓ it produces extended non-thermal tails of accelerated particles, power-law slope can be harder than *p*=2

(4) Extreme temporal variability?



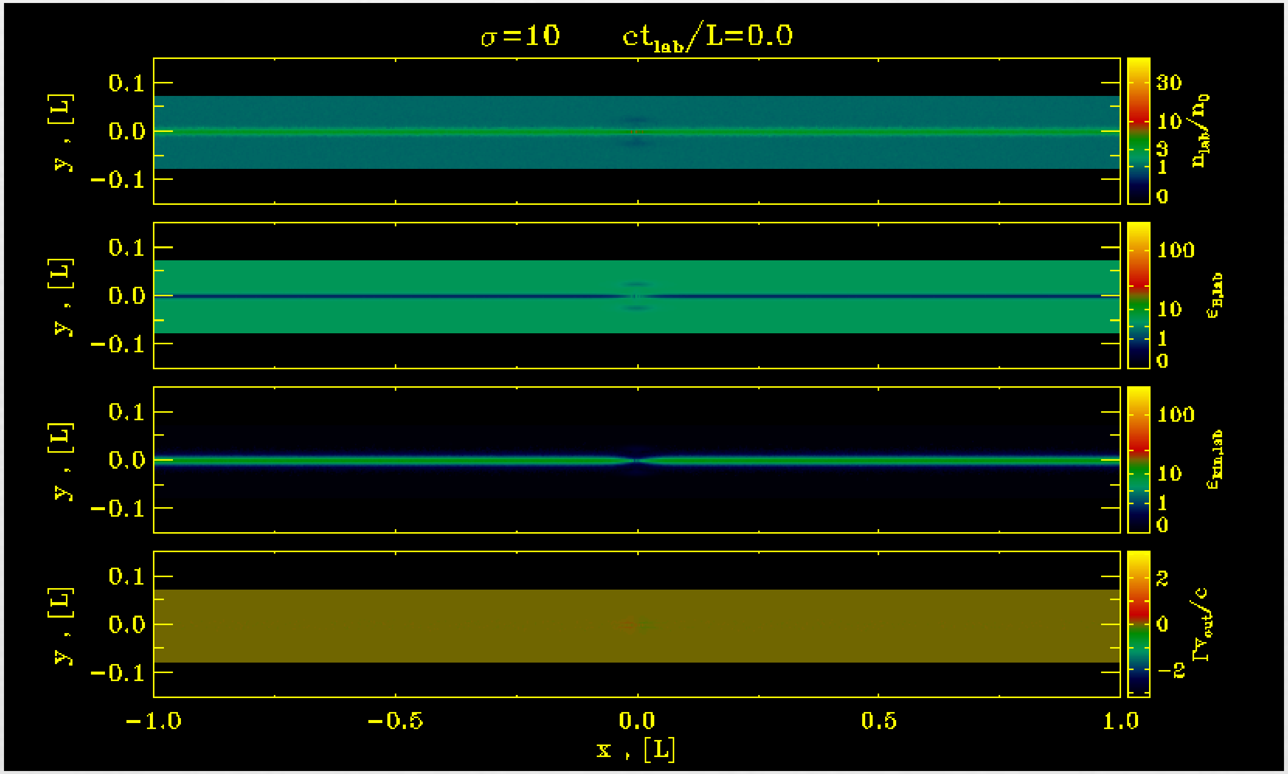


Blazar phenomenology:

- at TeV energies, fast (~10 minutes) flares on a high-state envelope lasting for ~days

From first principle simulations to lightcurves

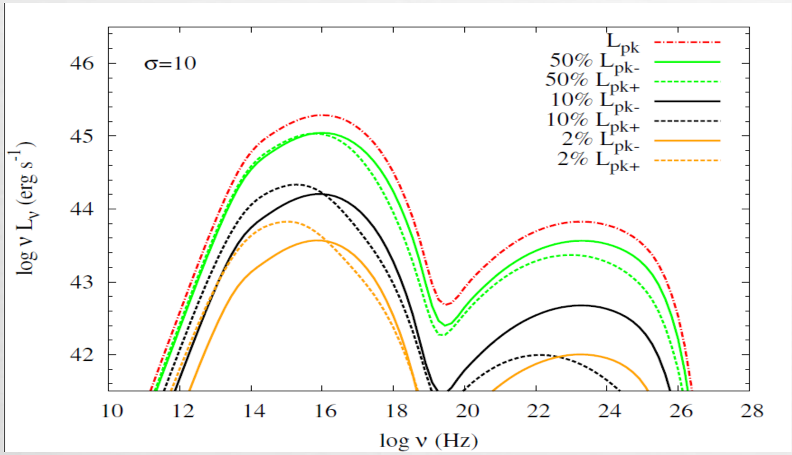
Sironi, Giannios & Petropoulou 2016

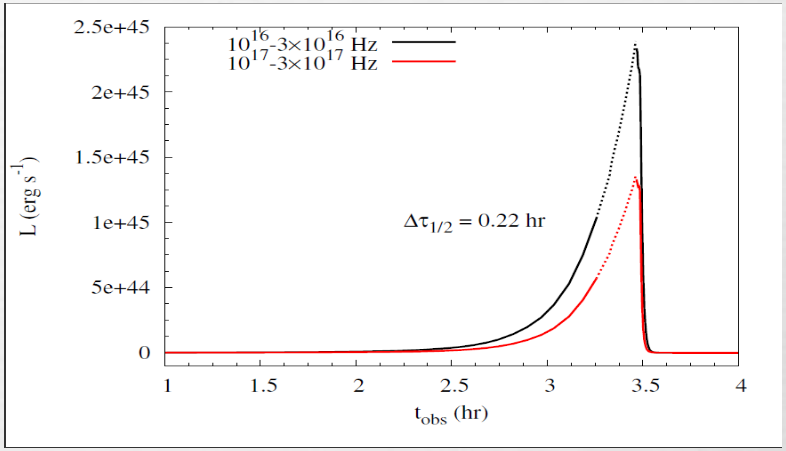


From simulations to lightcurve: Single Plasmoid

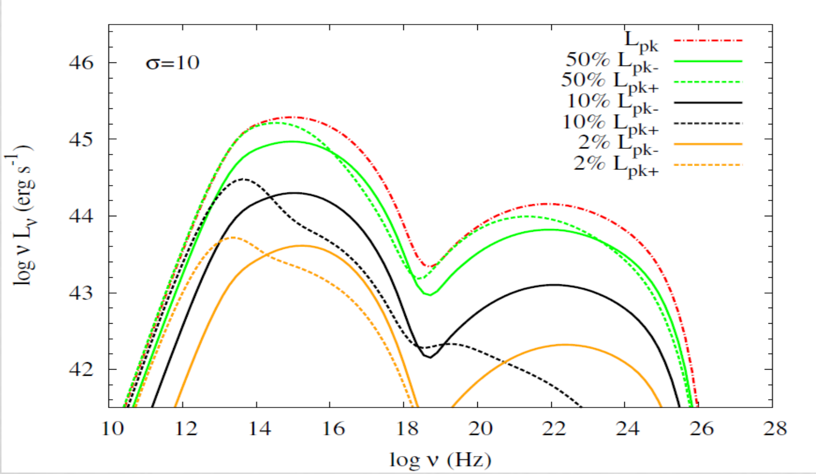
Petropoulou, Giannios & Sironi 2016

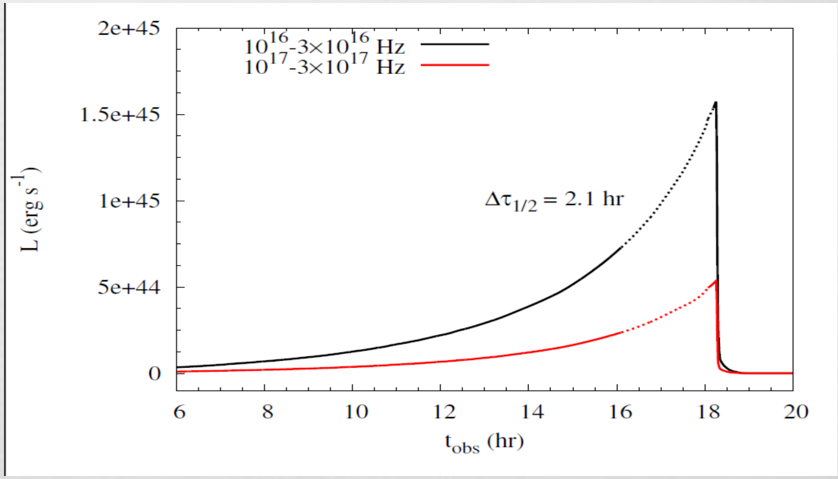
Small & Fast Plasmoid





Large & Slow plasmoid

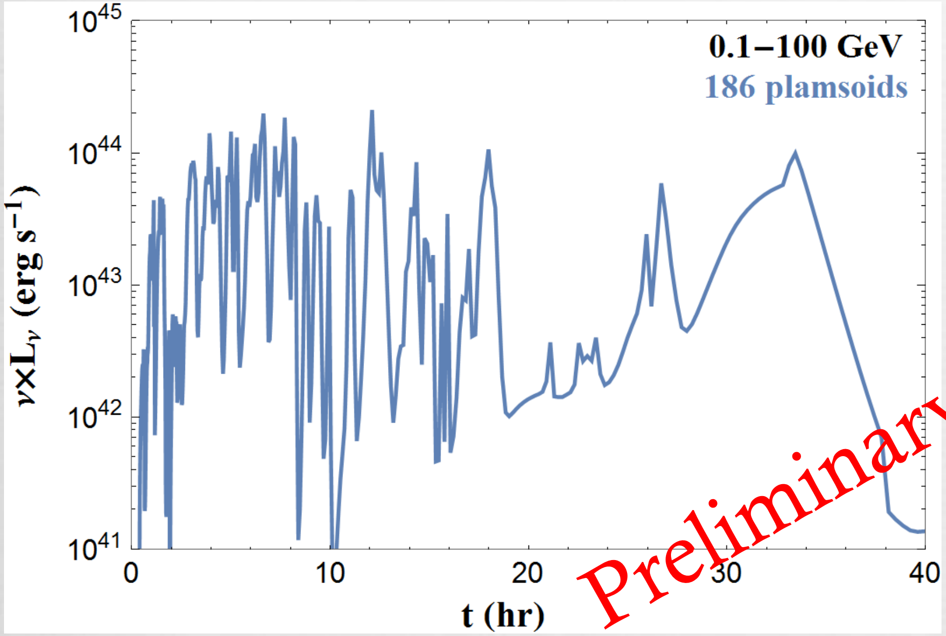




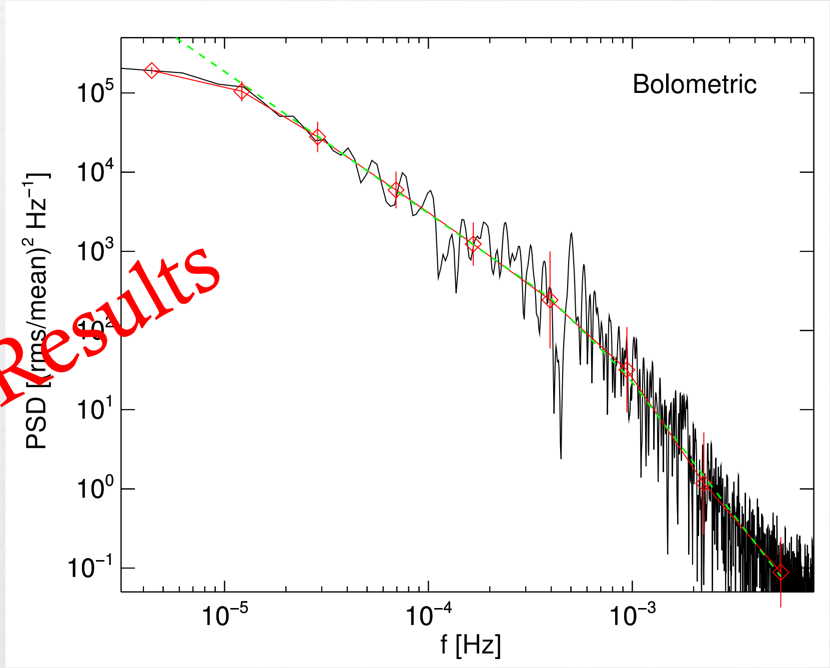
From simulations to lightcurve: the whole reconnection layer

Christie et al., in prep.

Light curve



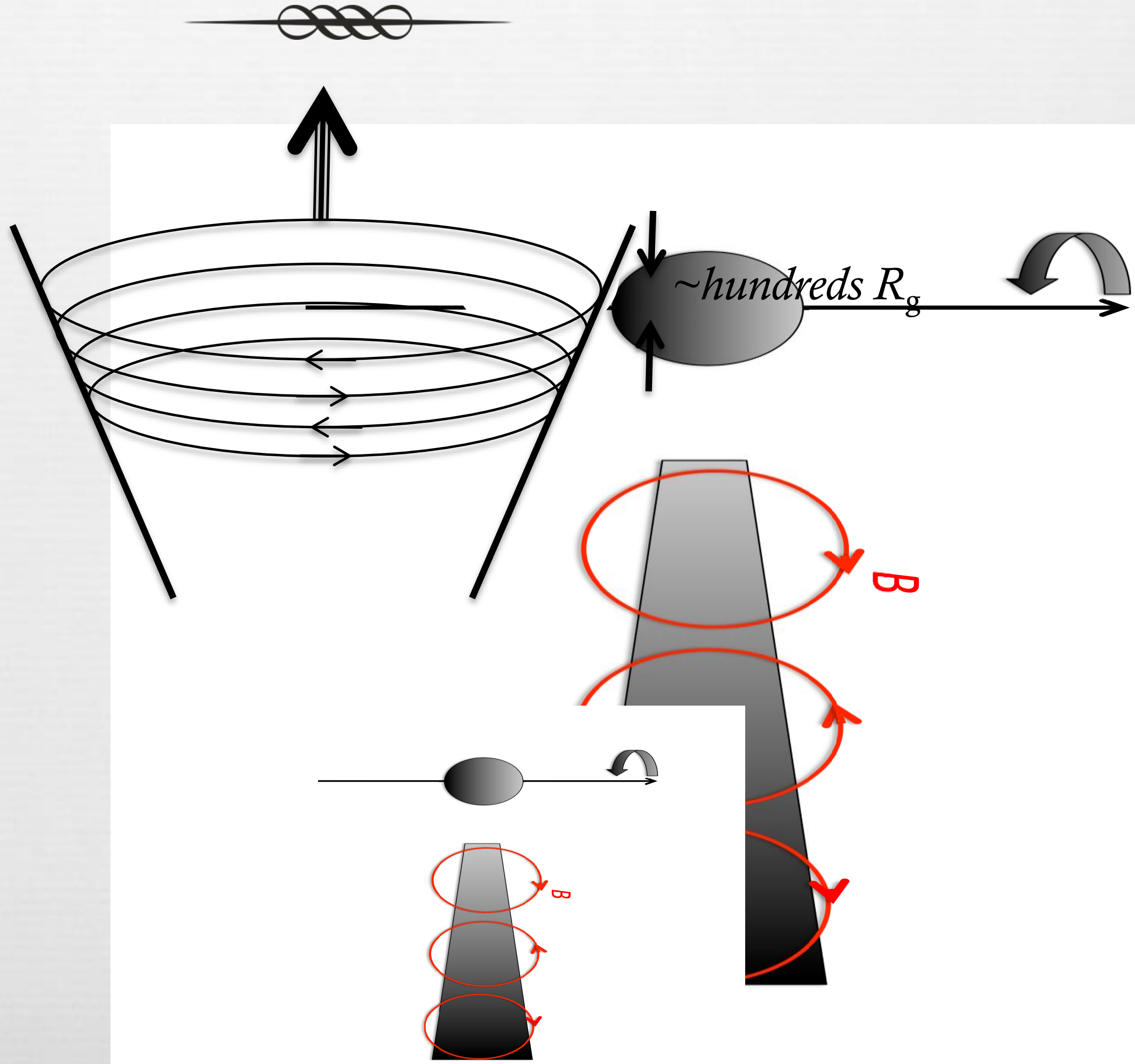
Power Density Spectrum



Concluding

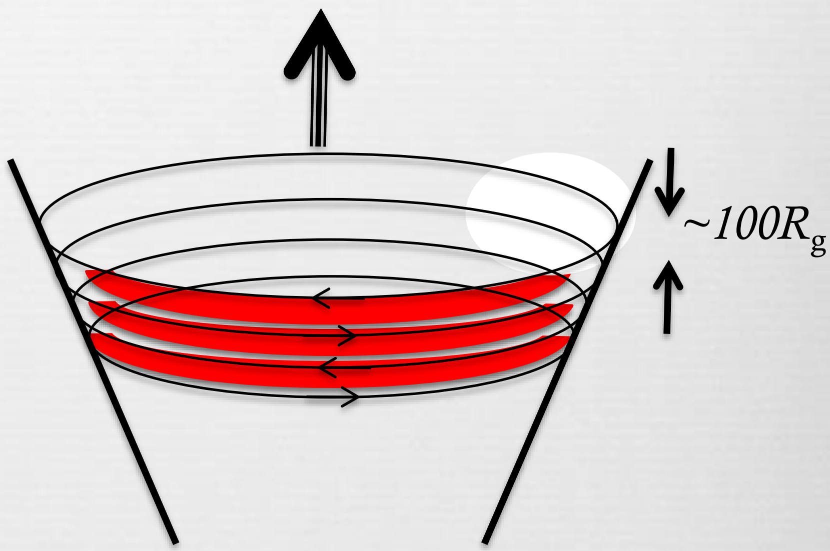
- Jets are observed to be efficient particle accelerators, highly variable
- Magnetic reconnection can produce fast variability, efficient particle acceleration, equipartition conditions
  - Blazar "blobs" = reconnection plasmoids ?
- Lots of work left
  - Connection to the large-scale jet
  - long wavelength emission (larger scales)
  - polarization (radio through gamma-rays)

Large-scale jet and emission



Magnetic reconnection in the jet

- Jet may contain field reversals on small scale $\sim 100\ R_g$
- magnetic-reconnection becomes effective when



$t_{exp} \sim t_{rec}$

where $v_{rec} = \varepsilon c$

$$r_{diss} / G_j c \sim 100 G_j R_g / \varepsilon c$$

$$r_{diss} \sim G_j^2 100 R_g / e \sim 1 M_8 G_{j,10}^2 e_{-1}^{-1}\ \mathrm{pc}$$