South-Western Institute for Astronomy Research

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Magnetic Reconnection in Jet-Accretion disk Systems

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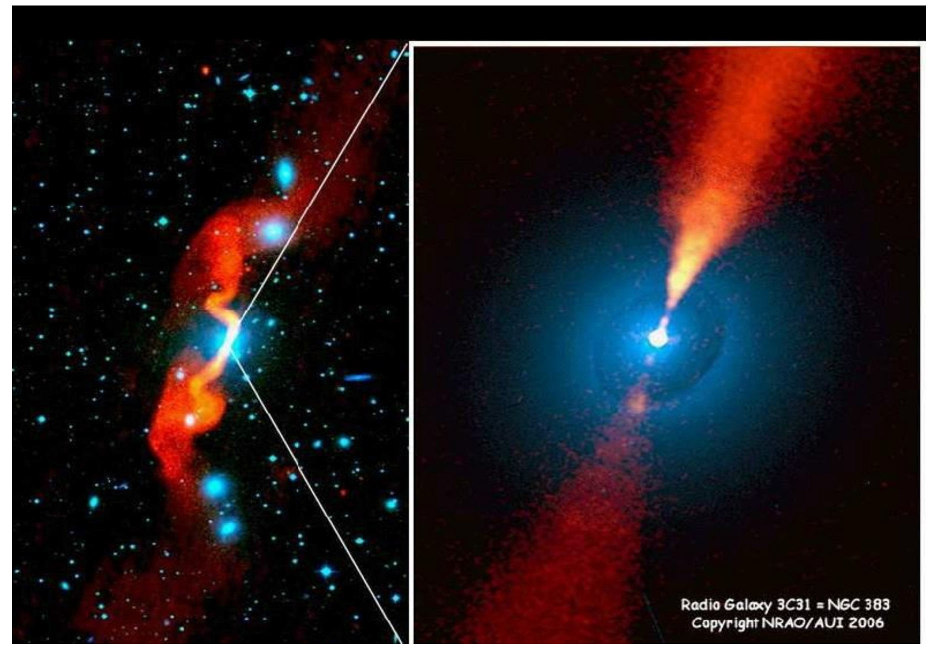
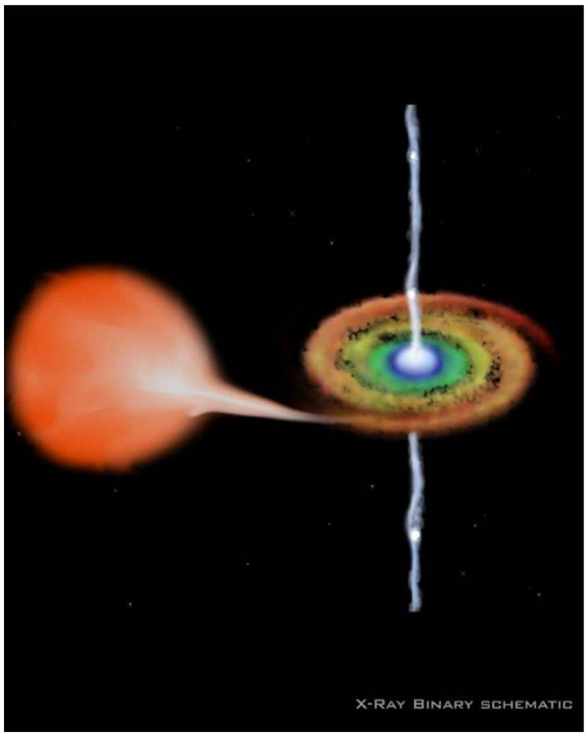
MG16 meeting, July 5, 2021

Black Holes and associated Jets: are cosmic accelerators and VHE emitters

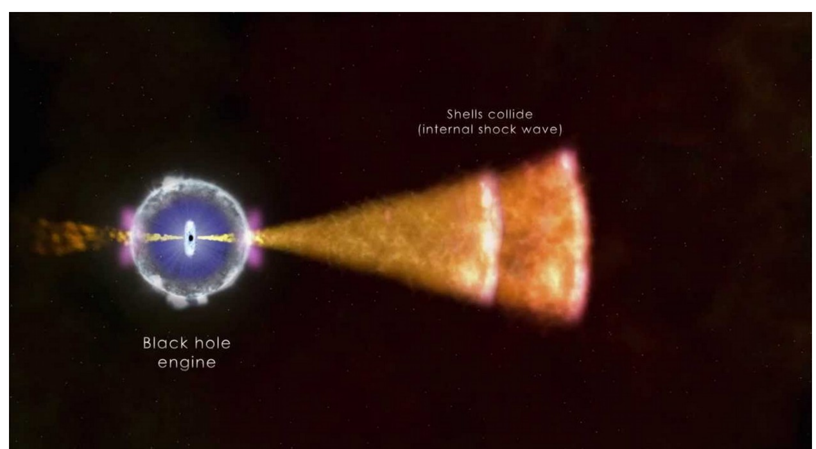
AGNs (blazars, radio-galaxies, seyferts)





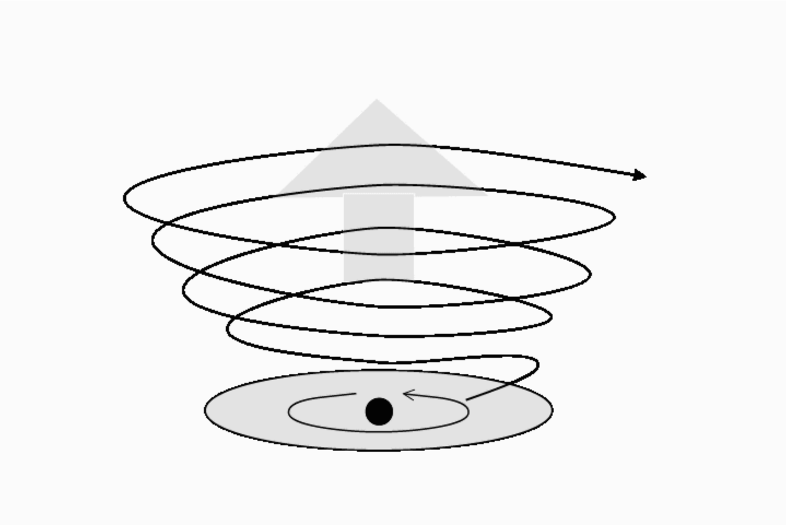
Black Hole Binaries
(Microquasars)

GRBs

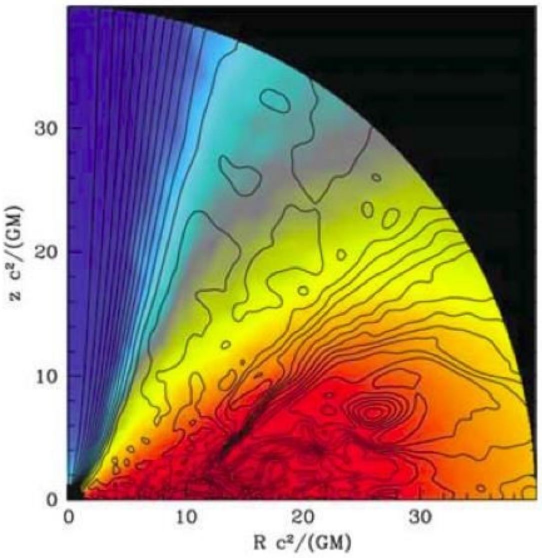


Jet Formation

Collimated jets formed near the central BH accelerate to Lorentz factor >> 1 from the BH scale to Mpc scales



Magneto-centrifugal acceleration by helical field arising from the accretion disk (e.g. Blandford & Payne 1982)



Or powered by BH spin (e.g. Blandford & Znajek 1977)

Major problem-> Need rapid conversion (dissipation) to kinetic energy:
RECONNECTION ?

GRMHD simulations (e.g., McKinney 06)

Particle acceleration & emission: challenges

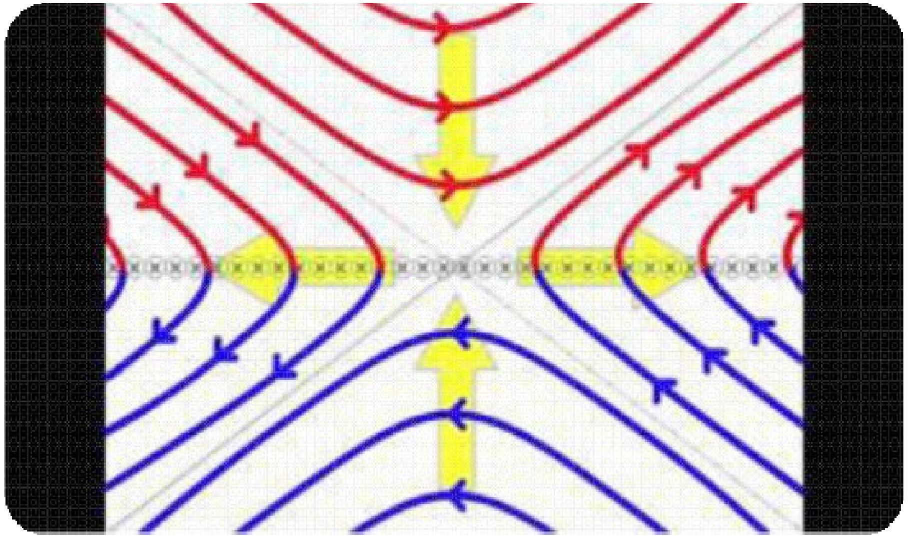
Standard processes – e.g. 1st order Fermi in shocks: difficulties to explain particle acceleration and very high energy emission (up to TeV) in very compact regions in:

- pulsars
- AGN cores
- BHBs (microquasars)
- GRB and AGN relativistic jets

specially in magnetically dominated regions -> where shocks are weak

Magnetic Reconnection

Approach of magnetic flux tubes of opposite polarity:

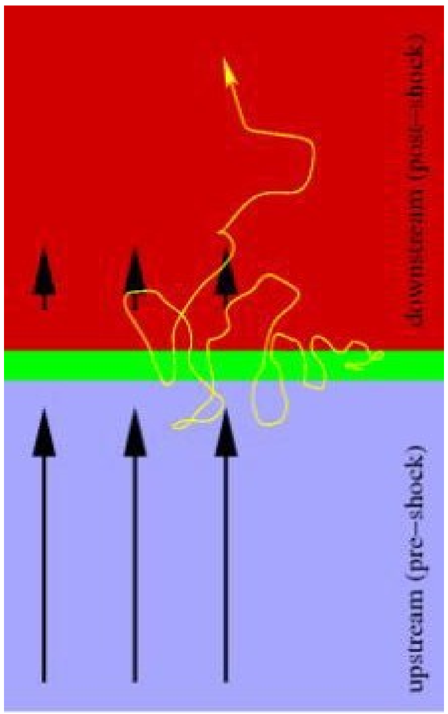


Reconnection is FAST !

$V_{rec} \sim 0.1\ V_A$

First-order Fermi Acceleration

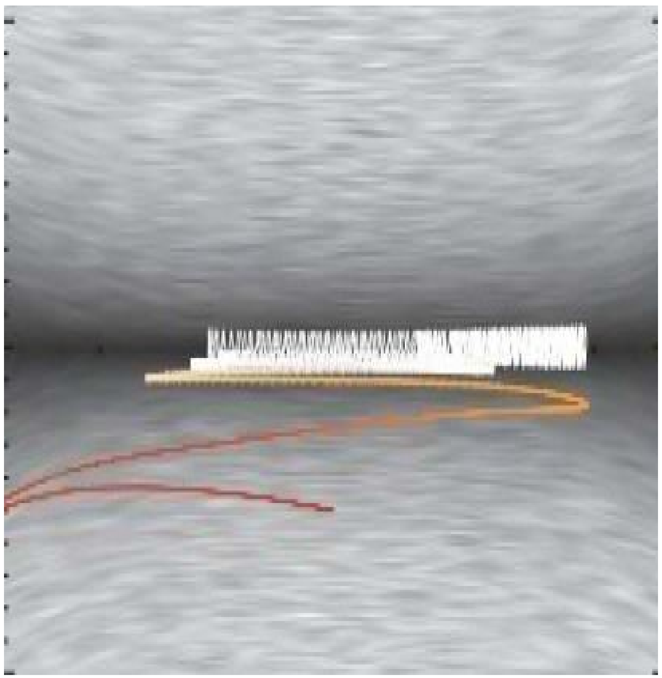
Shock Acceleration



1st-order Fermi (Bell+1978):

$<\Delta E/E> \sim v_{sh}/c$

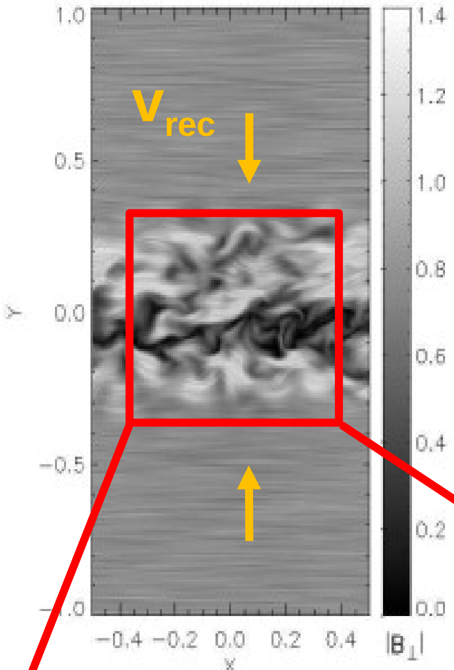
Reconnection Acceleration



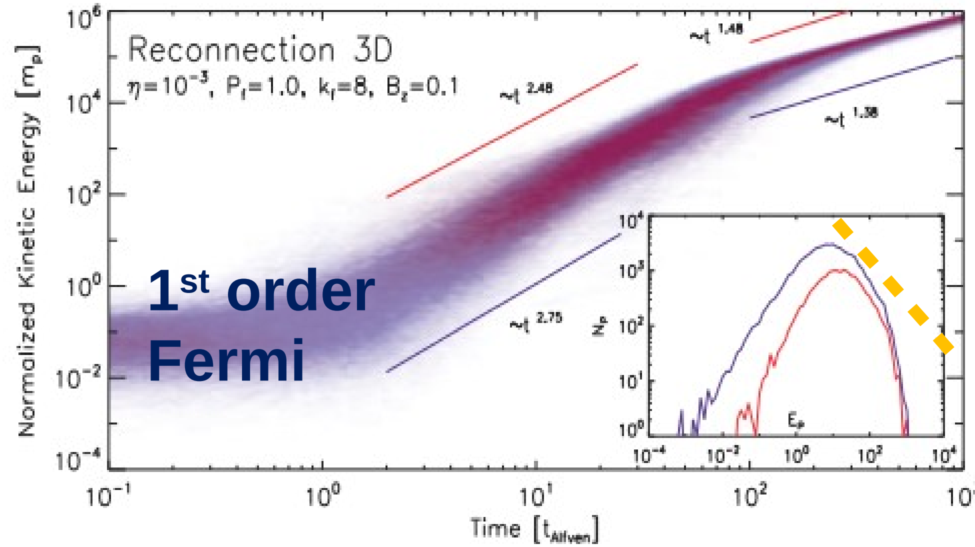
1st-order Fermi (de Gouveia Dal Pino & Lazarian 2005):
particles bounce back and forth between 2 converging magnetic flows

$<\Delta E/E> \sim v_{rec}/c$

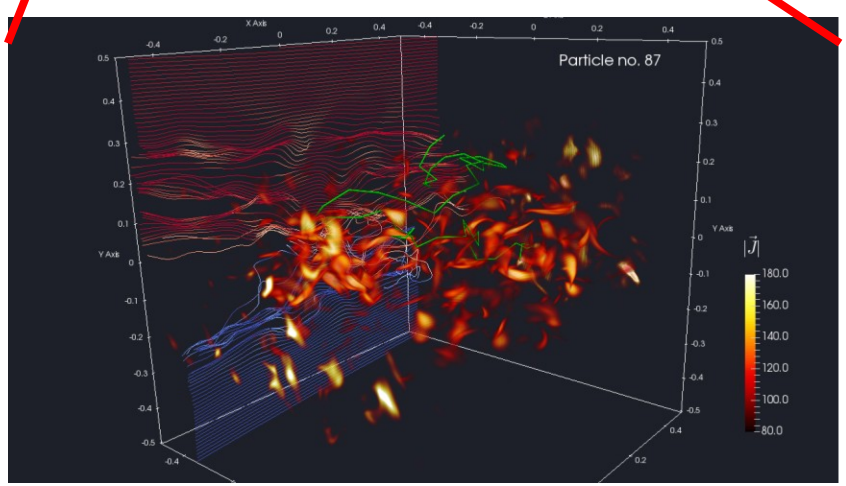
First-order Fermi Reconnection Acceleration:
successful numerical testing in 3D MHD



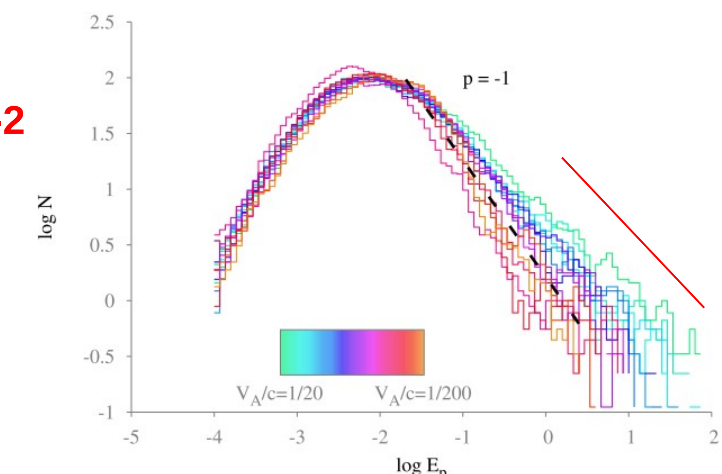
current sheet with turbulence:
fast reconnection
(Lazarian & Vishniac 1999)



Kowal, de Gouveia Dal Pino, Lazarian 2012

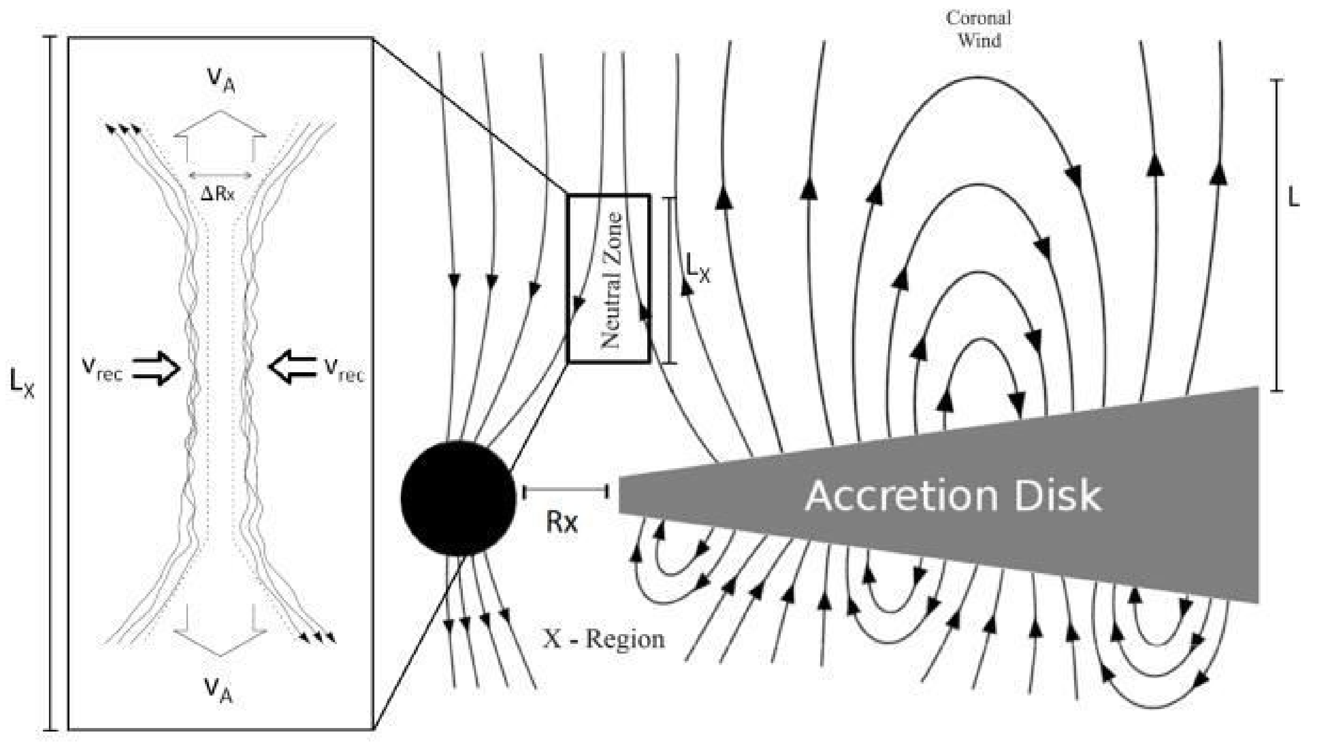


$N(E) \sim E^{-1-2}$



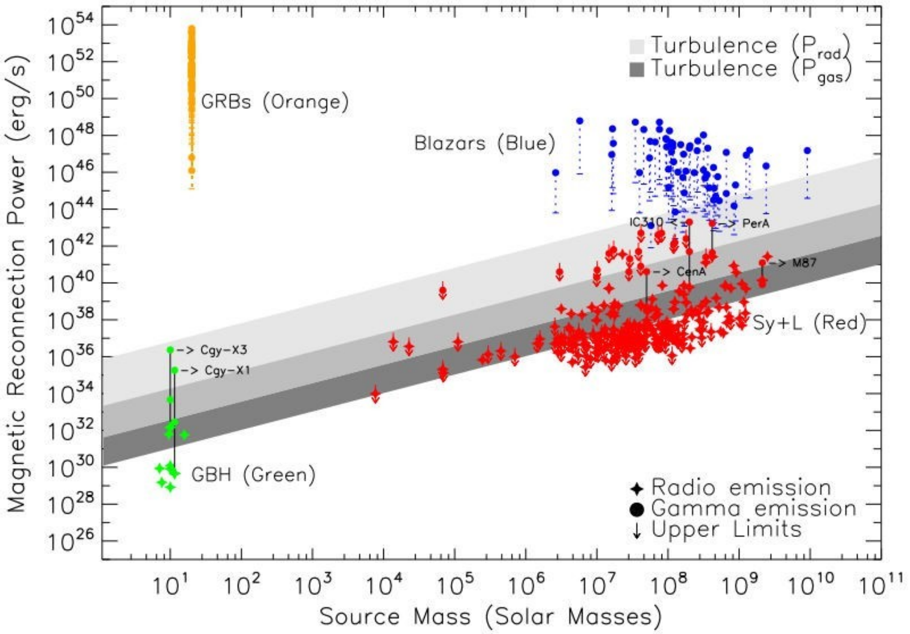
del Valle, de Gouveia Dal Pino, Kowal 2016

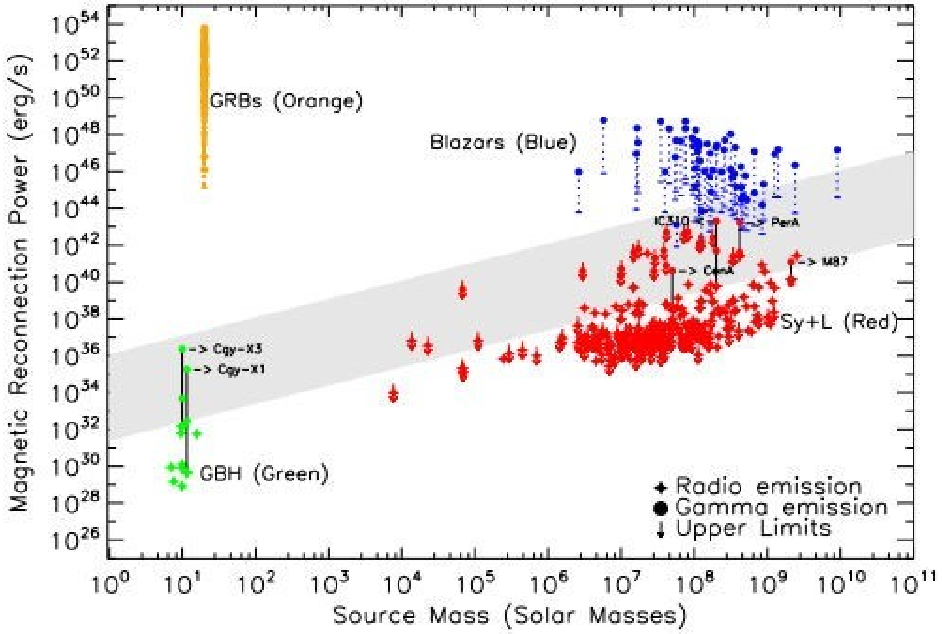
Accretion disk/jet systems



de Gouveia Dal Pino & Lazarian 2005; de Gouveia Dal Pino+2010

Accretion flow and Reconnection





Thin accretion disk+corona

Kadowaki, de Gouveia Dal Pino, **CBS,** ApJ, 2015

Thick accretion disk

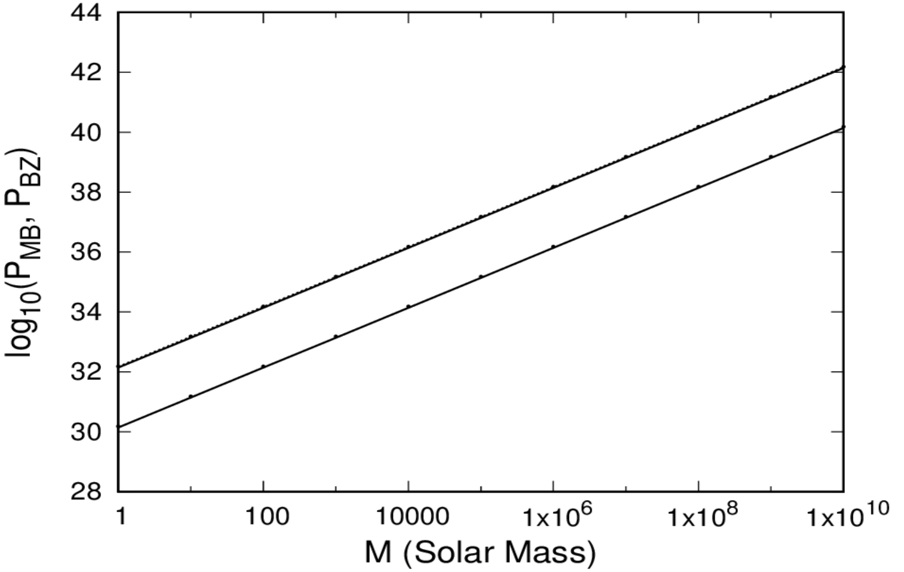
CBS, de Gouveia Dal Pino, Kadowaki, ApJL, 2015

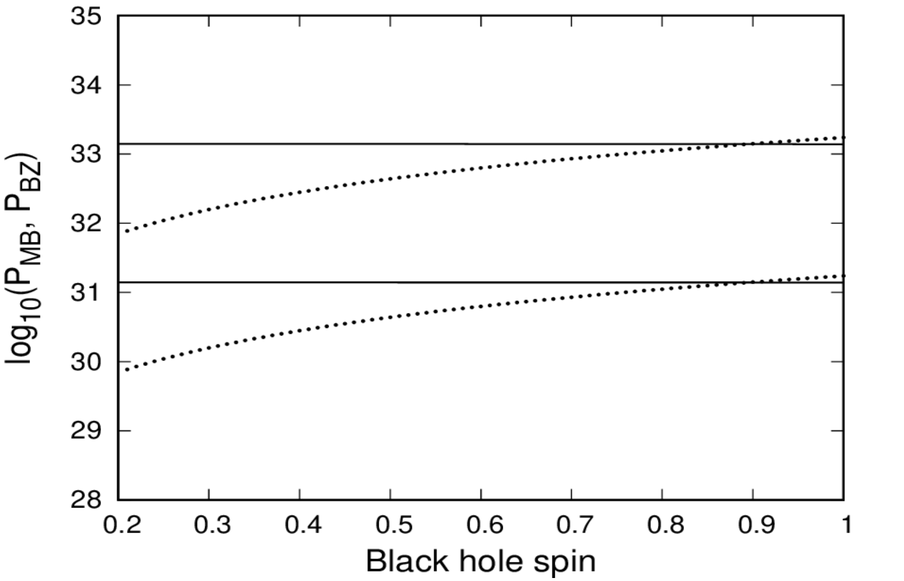
Blandford-Znajek mechanism and magnetic reconnection

Powers from Blandford-Znajek (BZ) process (P_{BZ}) and fast magnetic reconnection(P_{MB}) are comparable.

BZ mechanism dependent on the black hole spin while fast magnetic reconnection independent of the black hole spin.

BZ process can be quenched in the presence of fast magnetic reconnection and trigger state transitions.





CBS, Garofalo & de Gouveia Dal Pino, MNRAS, 2018

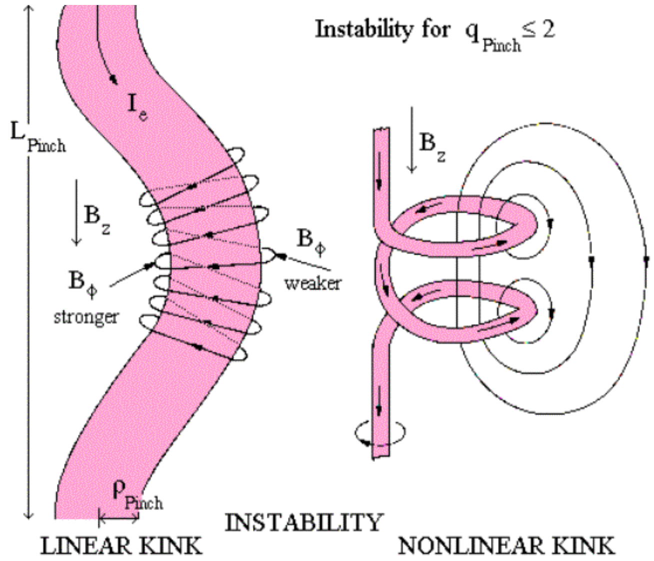
Current Driven Kink Instability

Well-known instability in laboratory plasma (TOKAMAK) and astrophysical plasmas (Sun, jets, pulsars)

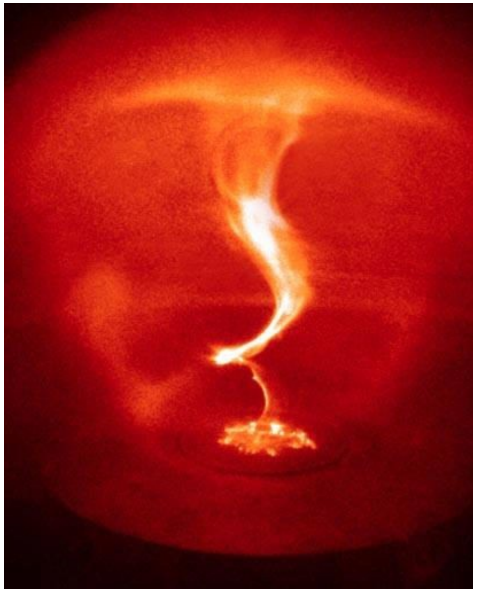
• In configurations with strong toroidal magnetic fields, current-driven (CD) kink mode (m=1) is unstable

• This instability excites large-scale helical motions that can strongly distort or even disrupt the system

• Distorted magnetic field structure may trigger magnetic reconnection



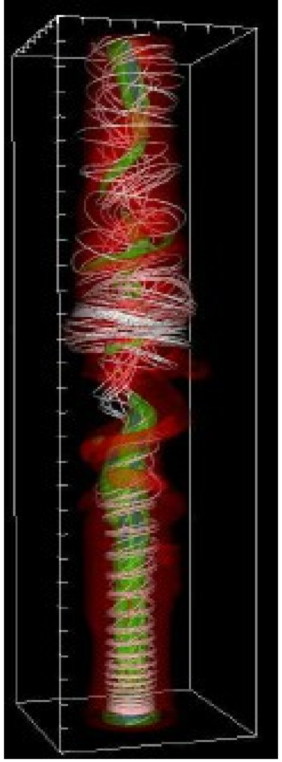
Schematic picture of CD kink instability



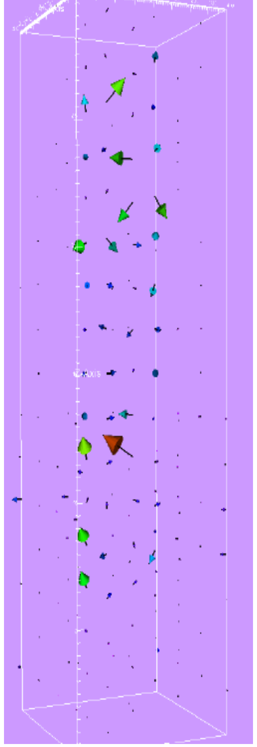
Kink instability in lab plasma (Moser & Bellan 2012)

Kink Instability and Reconnection

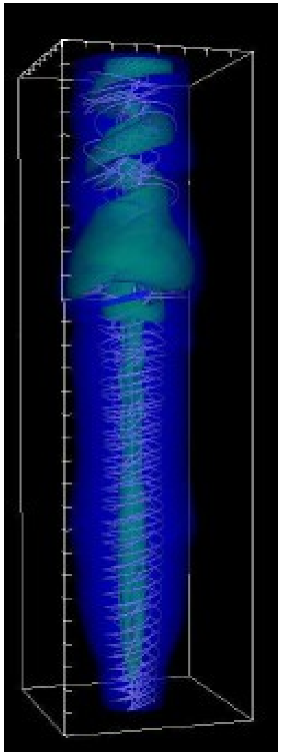
Heavy jet : $\Omega_0 = 2$
Density + field lines (left panel)



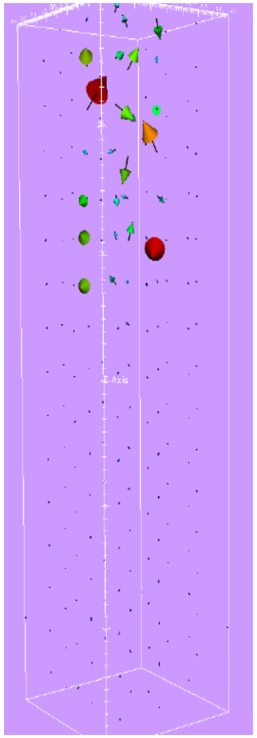
Curl B



Light jet : $\Omega_0 = 2$
Density + field lines (left panel)



Curl B

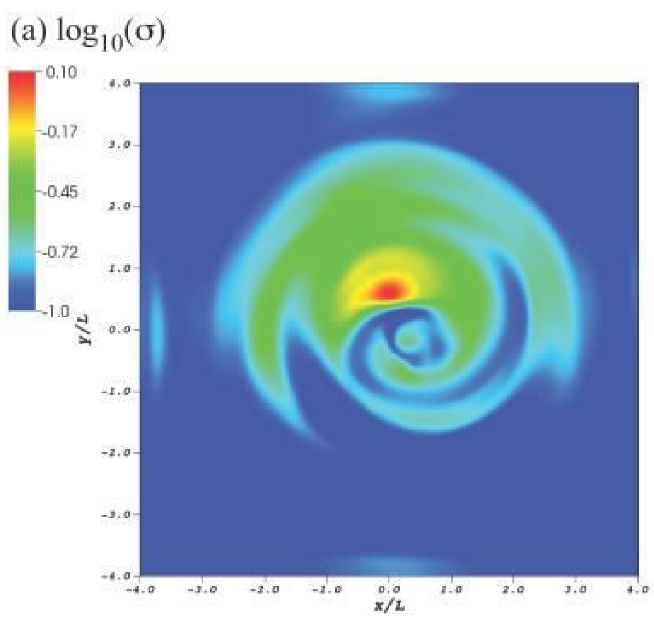


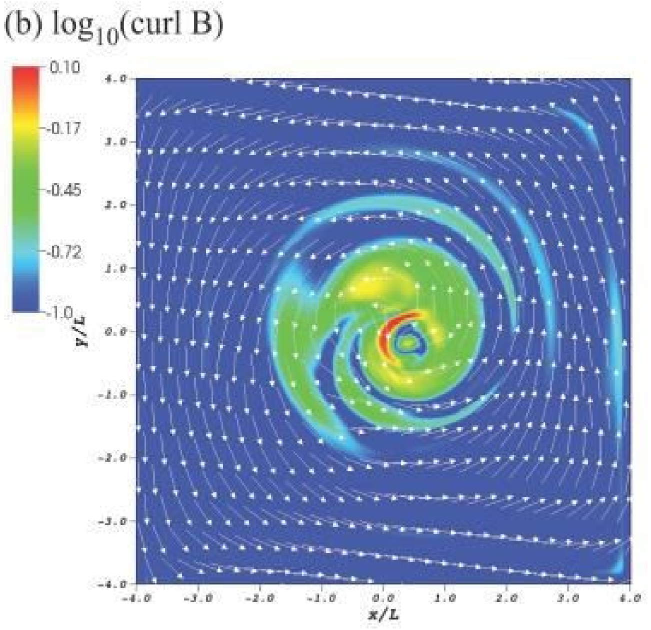
- Localized large values of curlB: sites of reconnection driven by kink instability.

CBS, Mizuno & de Gouveia Dal Pino, ApJ, 2016

Magnetization and Current Density

$$\sigma = B^2/\gamma^2 \rho h$$

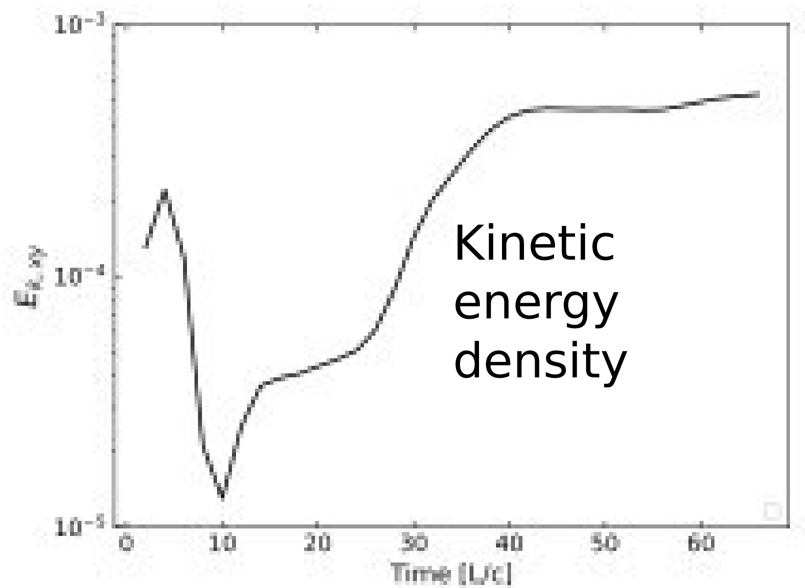


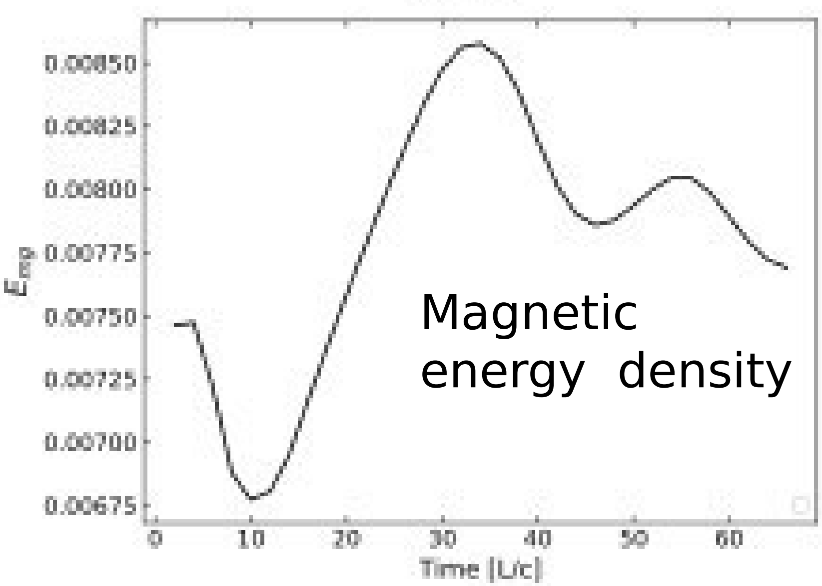


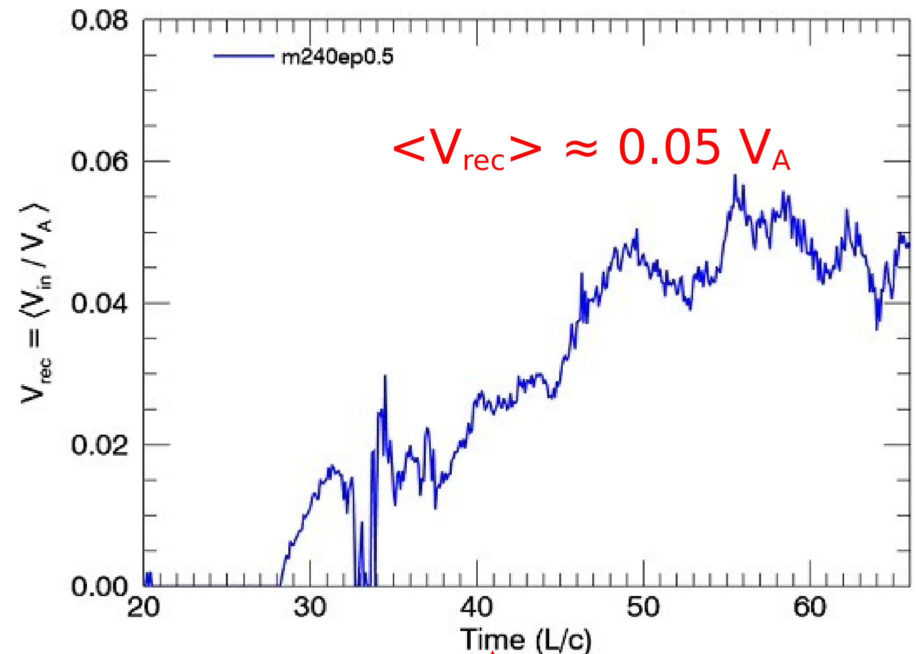
CBS, Mizuno, de Gouveia Dal Pino, ApJ, 2016

(Bromberg, **CBS**, Davelaar, Philippov, ApJ, 2019; Davelaar, Philippov, Bromberg, **CBS,** ApJL, 2020**)**

Reconnection Rate in Relativistic Jets







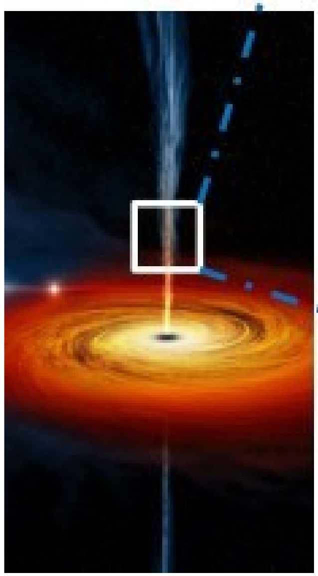
Kink instability attains its maximum

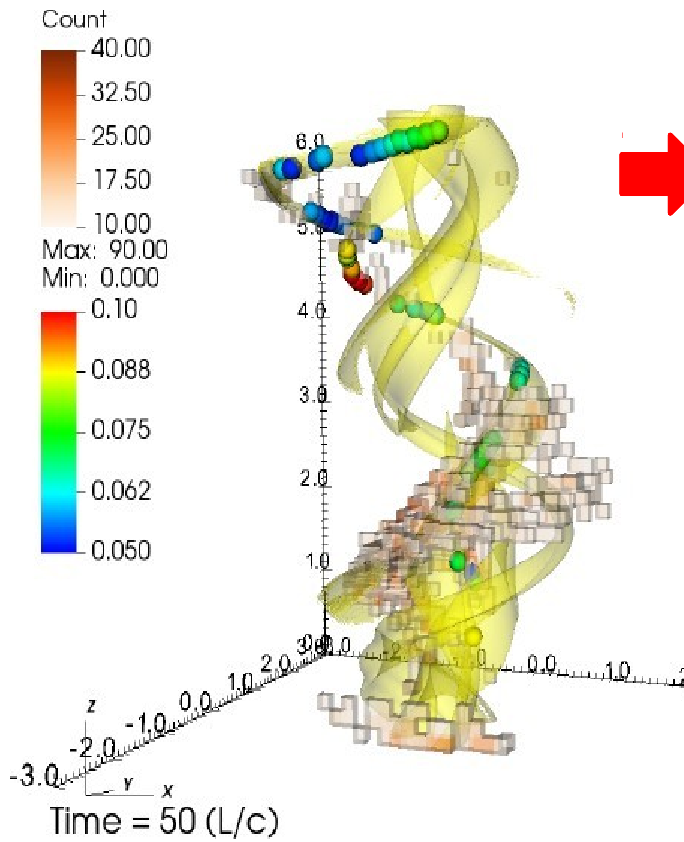
Medina-Torrejon, de Gouveia Dal Pino,..**CBS**.., ApJ, 2021

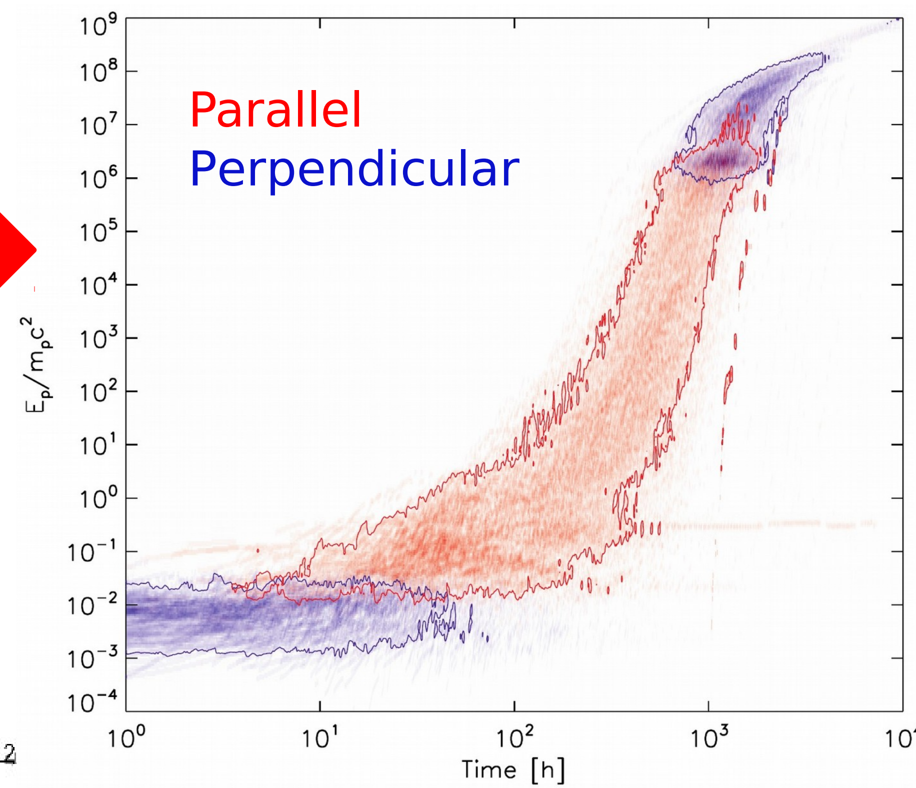
In situ acceleration of test particles by Magnetic Reconnection

Injected 1000 test particles accelerated in reconnection sheets from:
25 MeV=0.03 mc^2
To 10^{17}- 10^{19} eV
at sub-pc scales
(B~ 0.1 -10 G)

$\sigma = B^2/\gamma^2 \rho h$ ~1

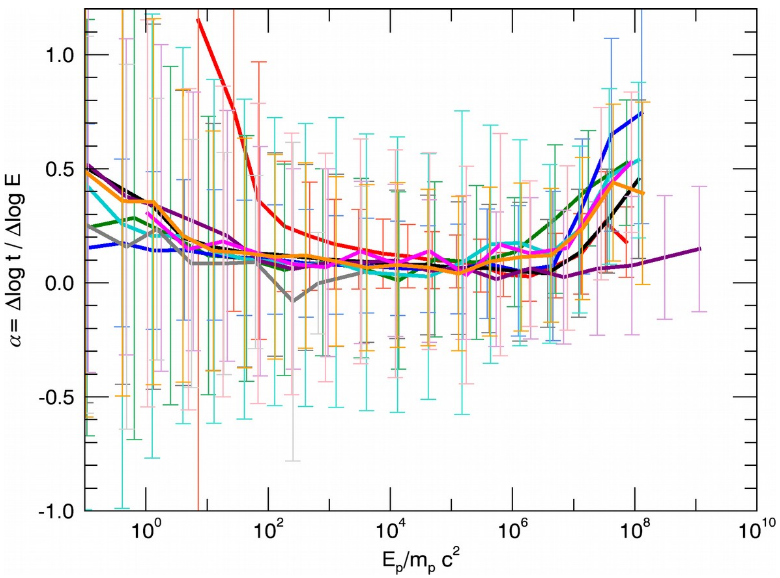


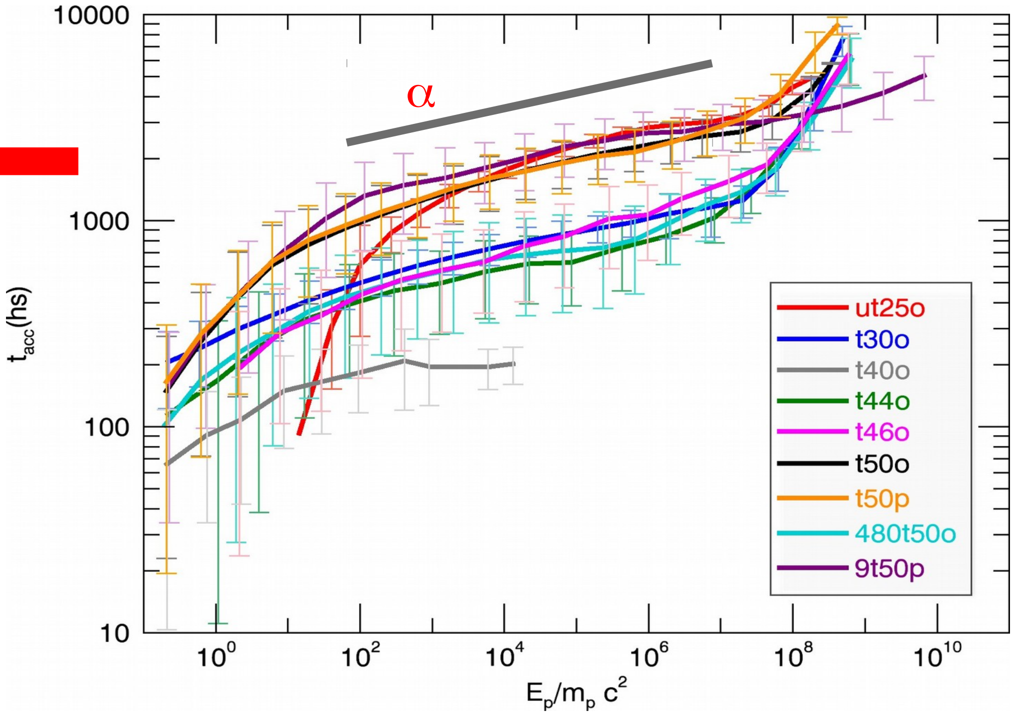




Medina-Torrejon, de Gouveia Dal Pino, ….**CBS**.., ApJ, 2021

Acceleration time of particles by Magnetic Reconnection

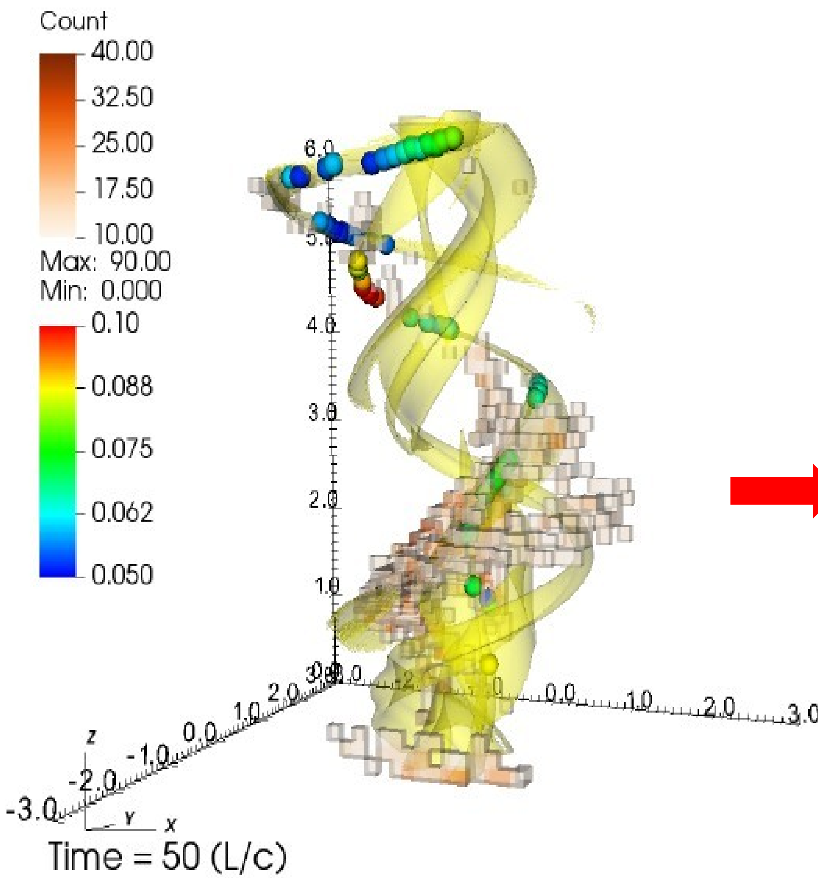


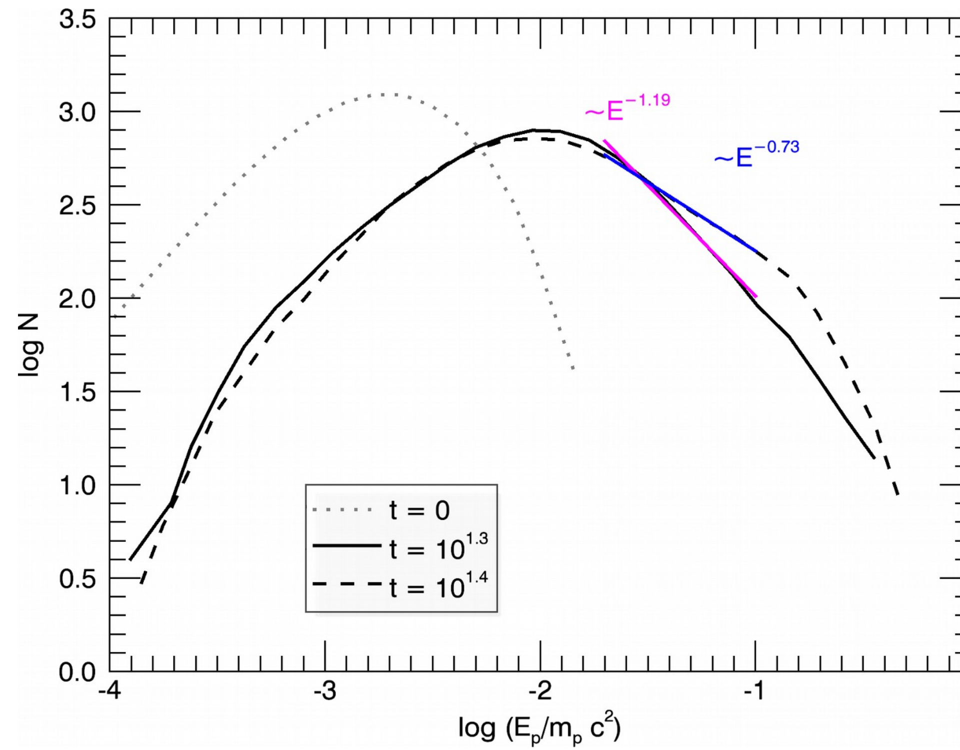


$\alpha \sim 0.1$ ➡ $t_A \propto E^{0.1}$

Medina-Torrejon, de Gouveia Dal Pino, ...**CBS**,.., ApJ, 2021

Accelerated Particles Spectrum





$N \sim E^{-1}$

Similar particle spectrum to PIC simulations and observations

Medina-Torrejon, de Gouveia Dal Pino, .., **CBS**,.., ApJ, 2021

Summary

Reconnection can be important in accretion/jet systems for particle acceleration, dissipation of magnetic energy and conversion MDF -> KDF.

Fermi particle acceleration by magnetic reconnection can explain gamma-ray of microquasars and non-blazar AGNs as coming from the jet base.

Black hole rotation and magnetic reconnection can drive jets of comparable power and even compete with each other.

Reconnection in magnetically dominated relativistic jets can be triggered by CD kink instability, possibly drive Fermi acceleration and lead to gamma-ray emission.