Magnetic Reconnection in Jet-Accretion disk Systems

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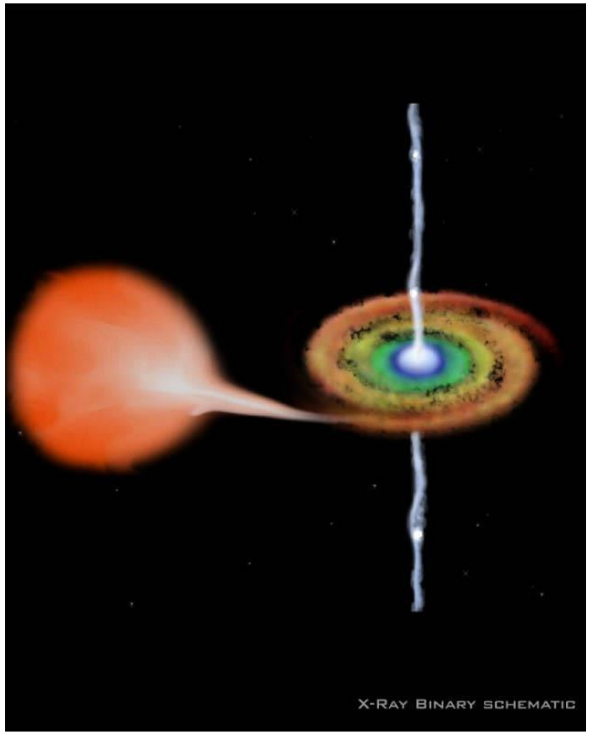
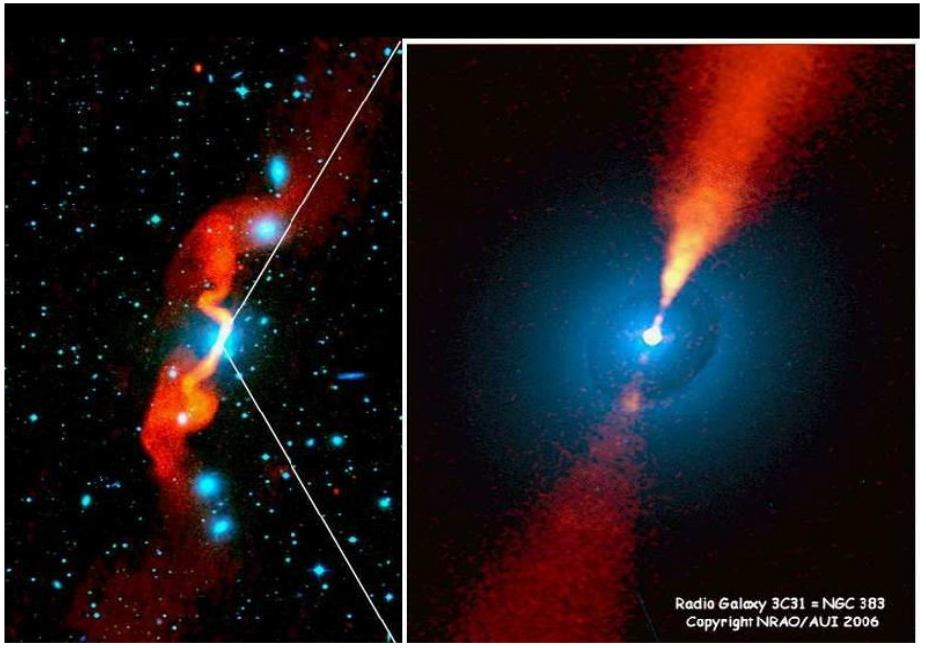
Shining from the heart of darkness : Black Hole Accretion and Jets, Kathmandu, October 21, 2016

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

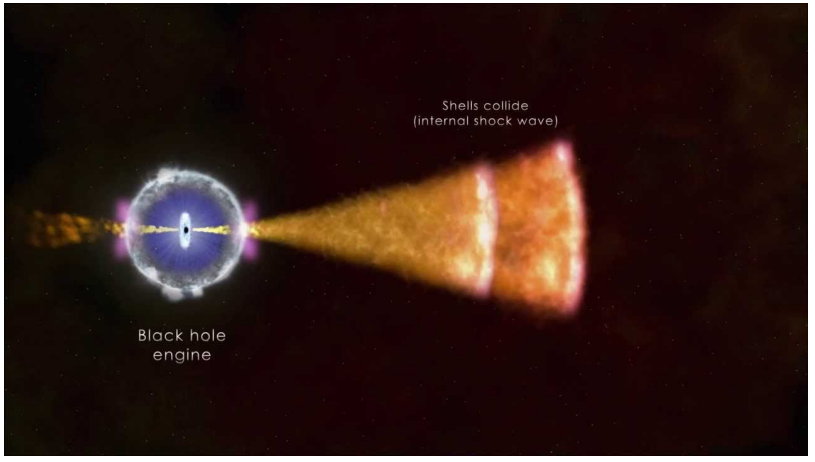
AGNs (blazars, radio-galaxies, seyferts)





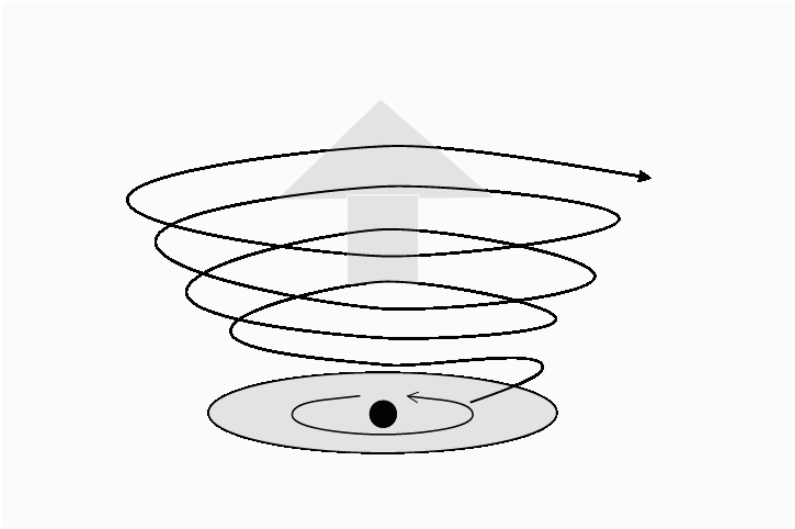
Black Hole Binaries
(Microquasars)

GRBs



Jet Formation

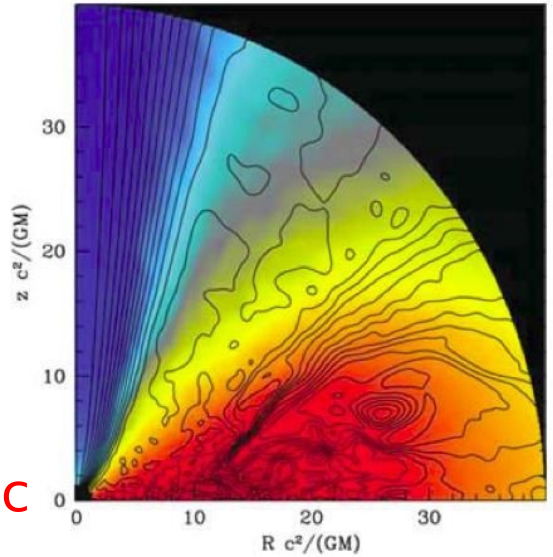
Collimated jets formed near the central BH accelerate $\gamma >> 1$ from the BH scale to Mpc scales



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

Or powered by BH spin (Blandford-Znajek)

Major Problem:
Most energy in Poynting Flux (magnetic field)
-> Need rapid conversion (dissipation) to kinetic energy:
RECONNECTION ?

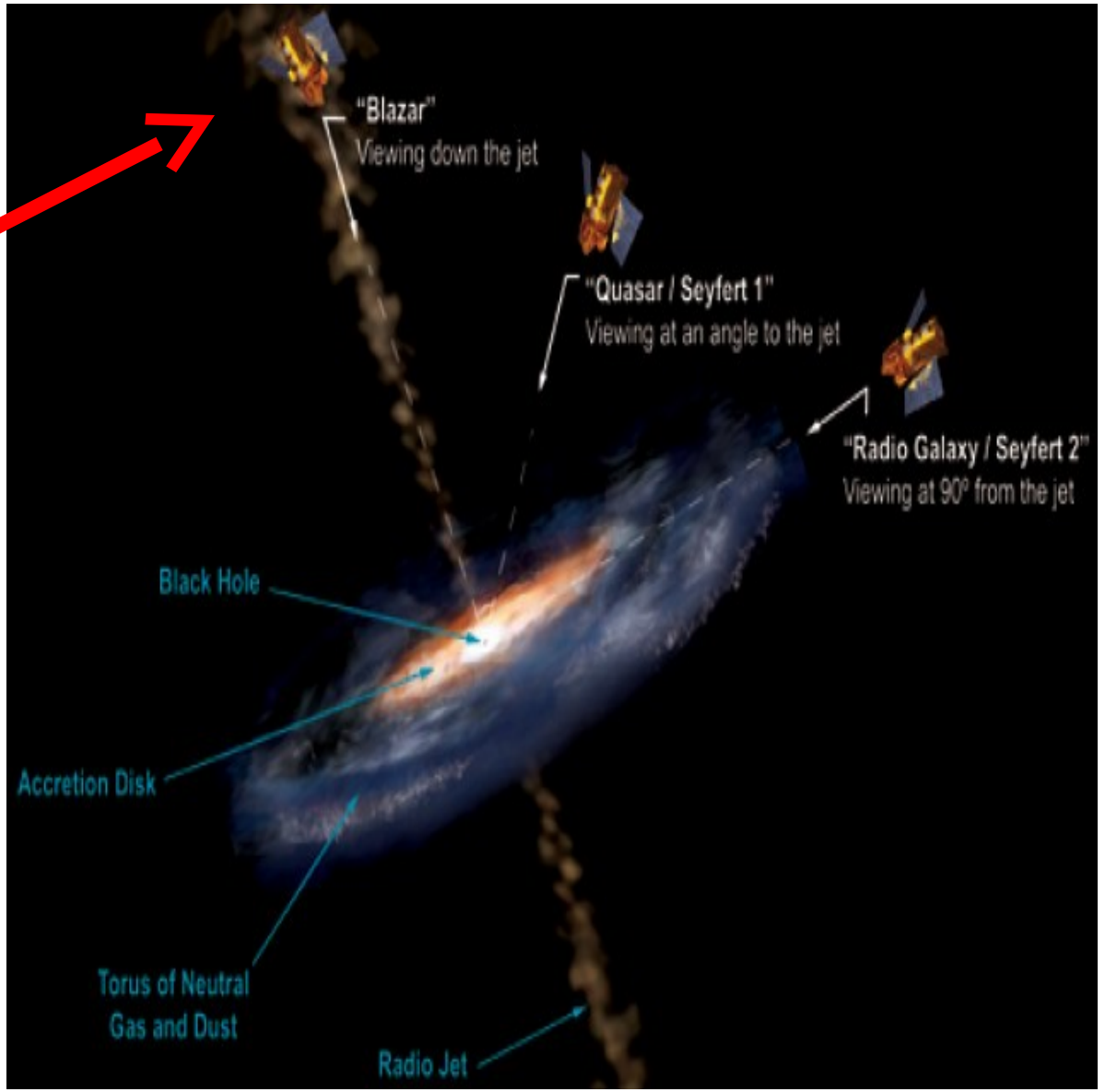


GRMHD simulations (e.g., McKinney 06)

VHE emission more common in **Blazars**

High Luminous AGNs

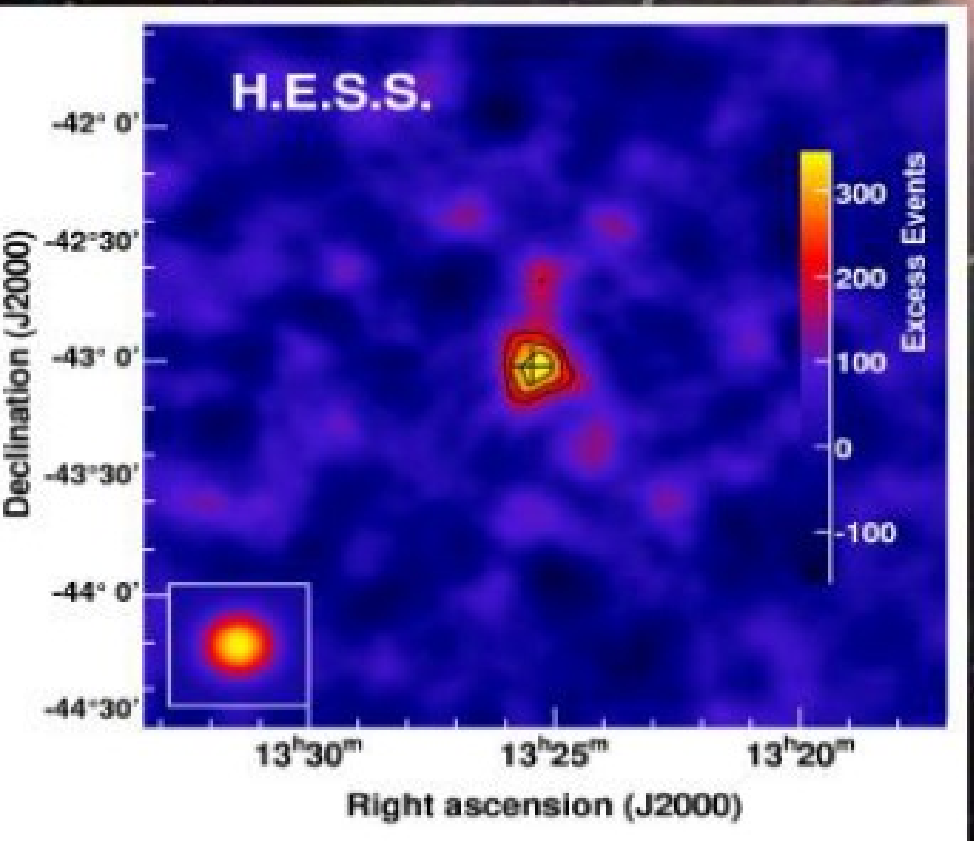
- ✓Jet ~ along our line of sight
- ✓VHE Emission: attributed to particle acceleration ***along*** the relativistic jet
- ✓with apparent high flux due to strong Doppler boosting (γ~5-10)
- ✓shock acceleration in kinetic-dominated flux



...*But*
a few **Non-Blazars** Low Luminous AGNs

- ✓ **Also Gamma Ray emitters**
- ✓ Jet does not point to the line of sight
- ✓ no significant Doppler boosting !

CenA



- ✓ ***Does it come from core or jet ?***
- ✓ **Rapid variability emission: ~100 r_s**
  -> compact *emission (core)?*

- Where are particles accelerated?
- Is acceleration magnetically dominated?

Reconnection Acceleration?

Particle acceleration & emission: challenges

Standard processes – e.g. **1st 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

This talk

Magnetic reconnection in accretion/jets systems:

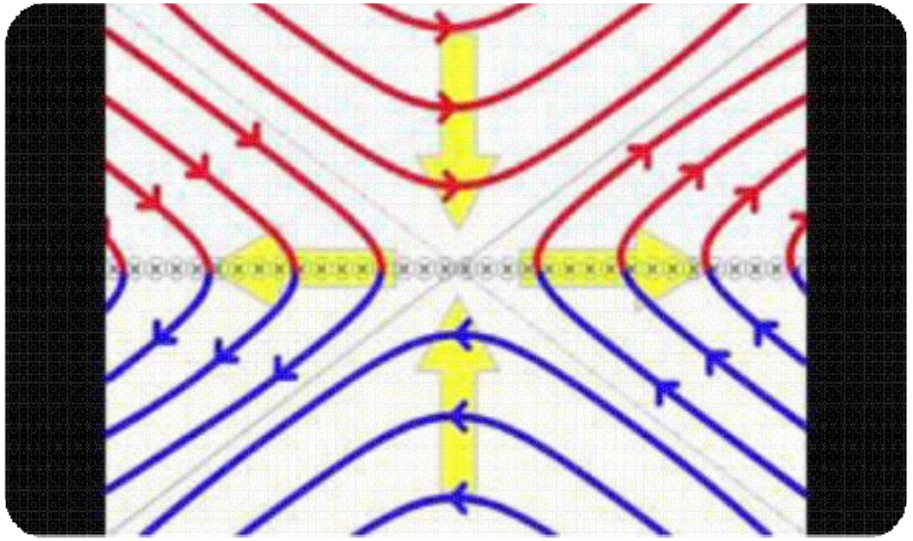
Powerful relativistic particle acceleration

May explain gamma-ray emission

Dissipation of magnetic energy -> conversion into kinetic energy specially in magnetically dominated regions of compact sources

MAGNETIC RECONNECTION

Approach of magnetic flux tubes of opposite polarity:

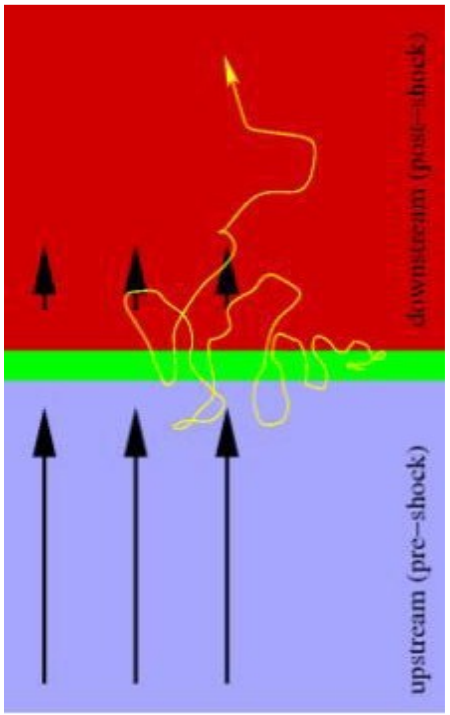


Reconnection is FAST !

$$V_{rec} \sim V_A = B/(4\pi\rho)^{1/2}$$

1st-order FERMI ACCELERATION

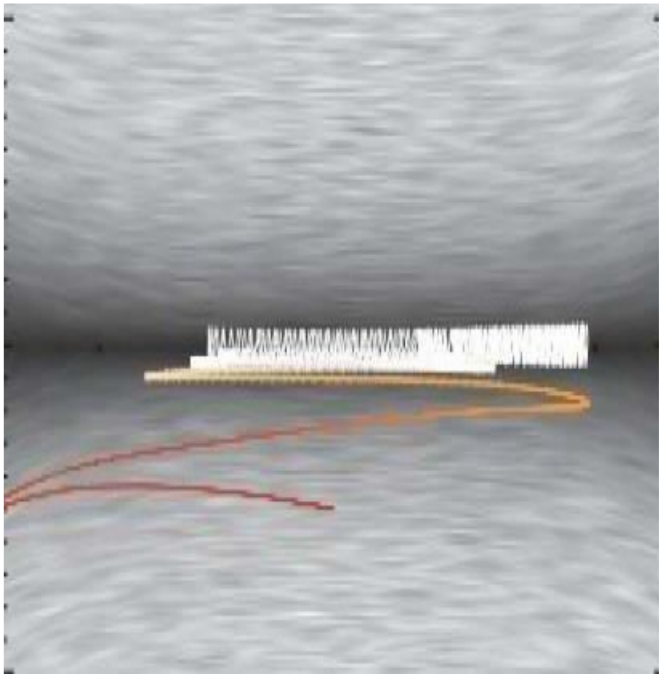
Shock Acceleration



1st-order Fermi (Bell+1978):

$\langle \Delta E/E \rangle \sim v_{sh}/c$

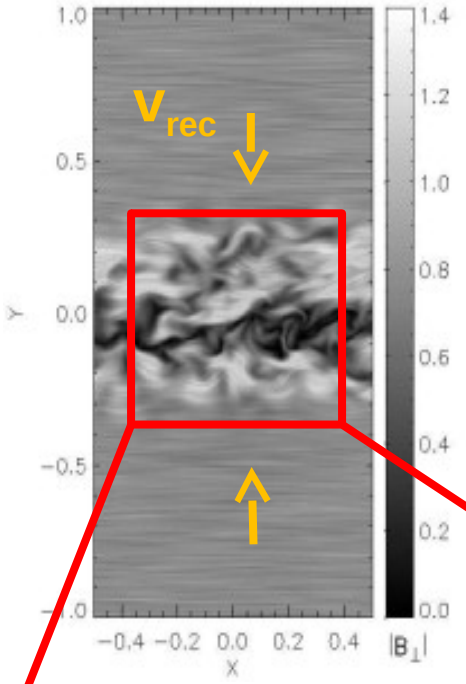
Reconnection Acceleration



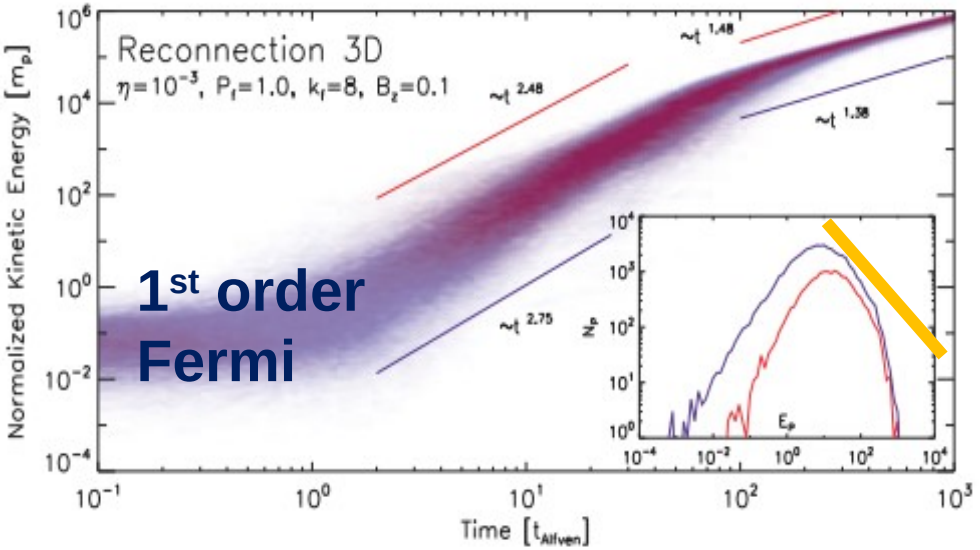
1st-order Fermi (de Gouveia Dal Pino & Lazarian 2005):
particles bounce back and forth between 2 converging magnetic flows

$\langle \Delta E/E \rangle \sim v_{rec}/c$

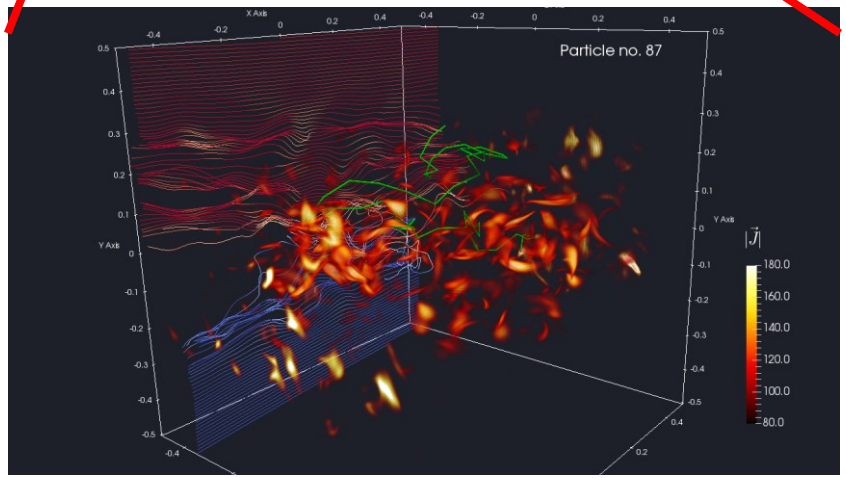
1st order Fermi Reconnection Acceleration: successful numerical testing in 3D MHD



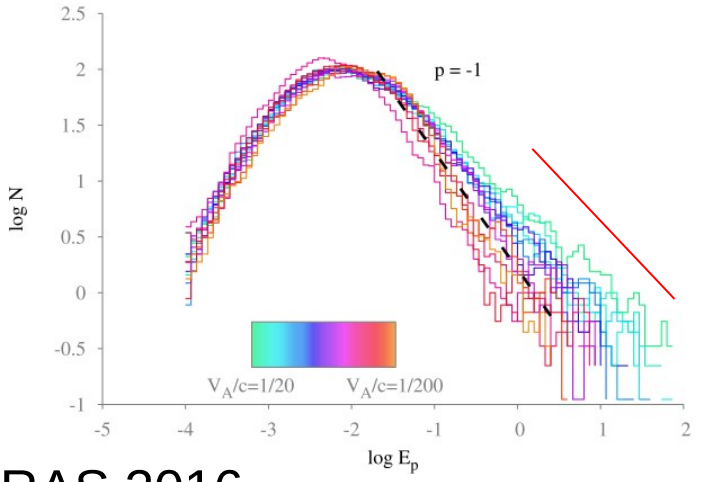
current sheet with turbulence: fast reconnection (LV99)



Kowal, de Gouveia Dal Pino, Lazarian, PRL 2012

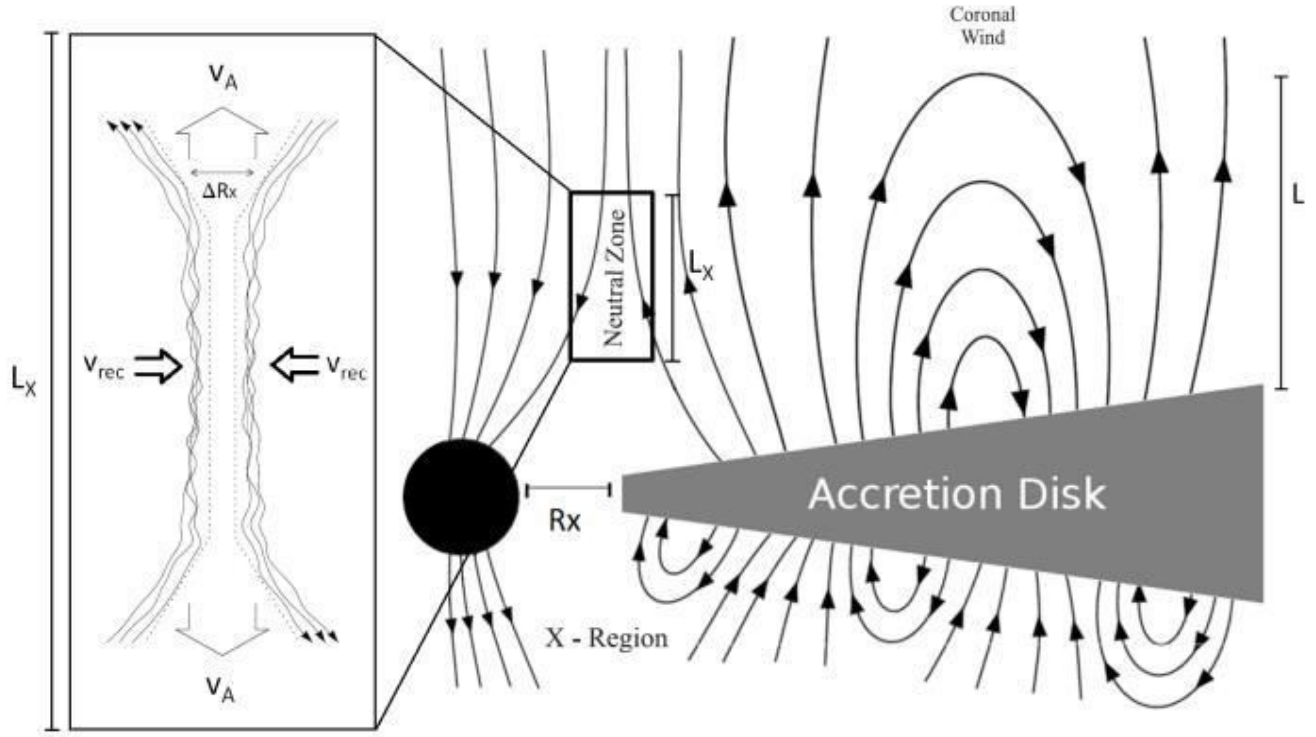


N(E) ~ E^{-1-2}



del Valle, de Gouveia Dal Pino, Kowal MNRAS 2016

Accretion disk/jet systems (AGNs & galactic BHBs)

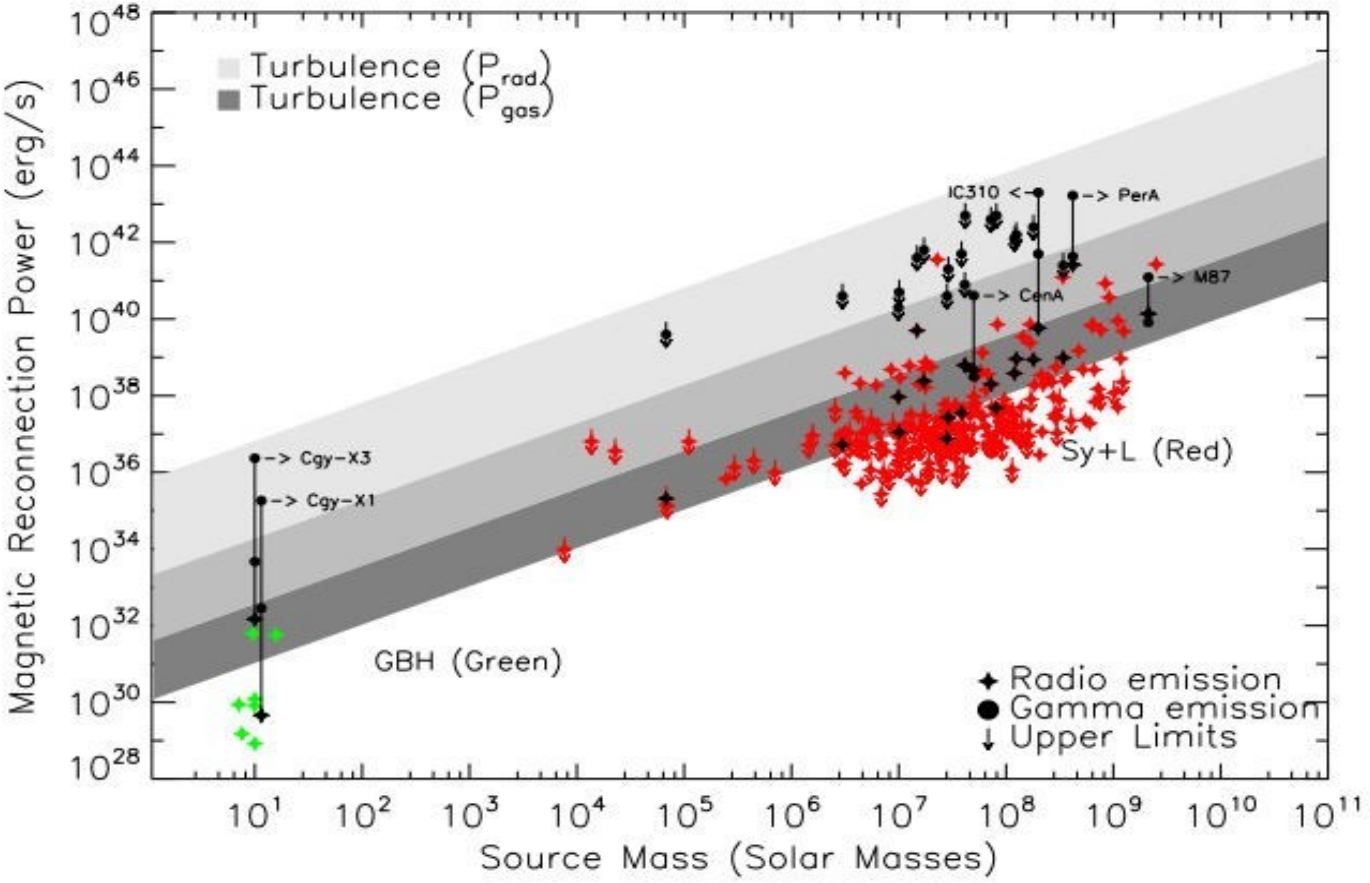


de Gouveia Dal Pino & Lazarian 2005; de Gouveia Dal Pino+2010

Revisited the model to evaluate reconnection power and acceleration -> apply to more than 200 sources:

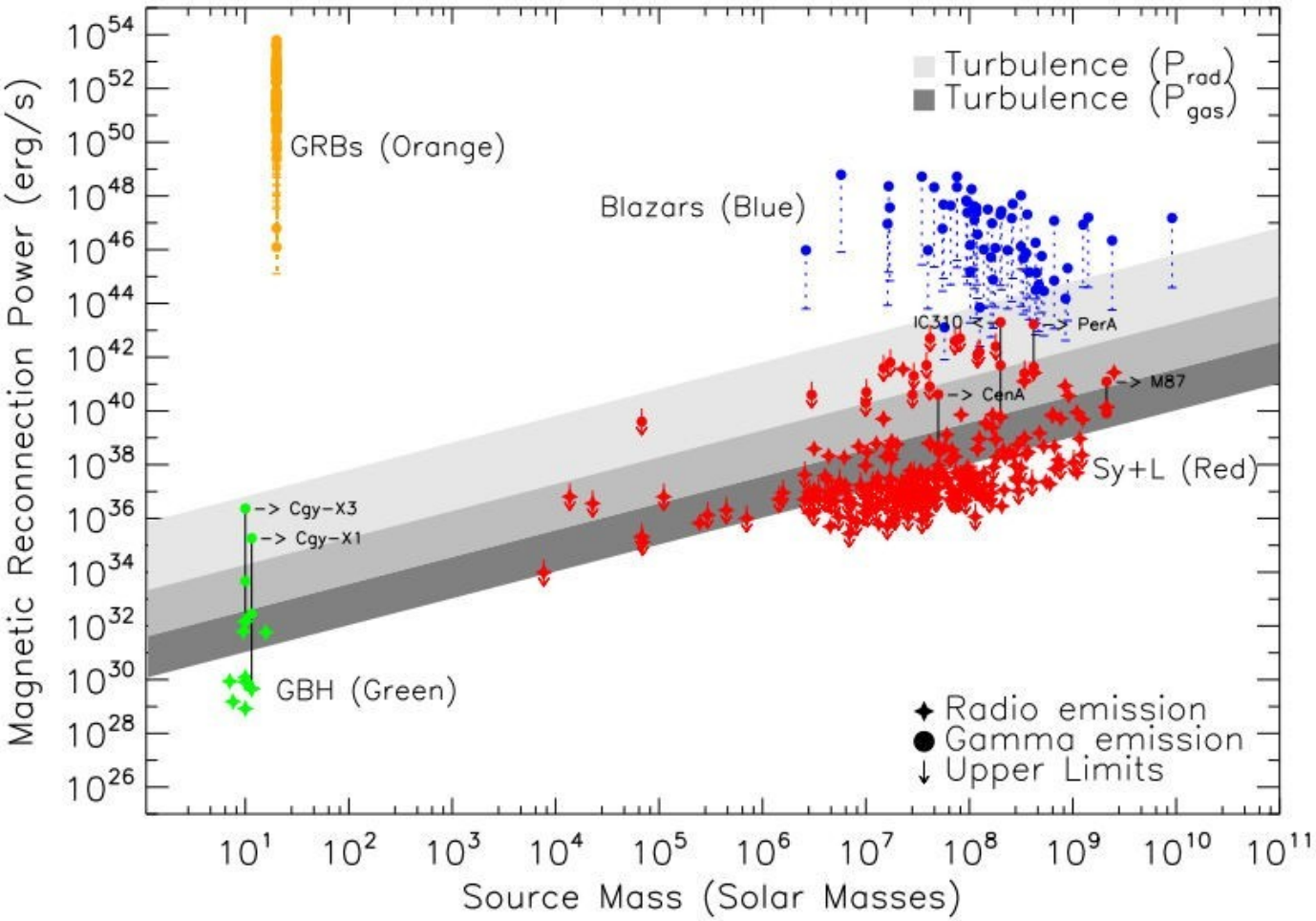
- Different accretion disk models (Shakura-Sunyaev; MDAF)
- Coronal model by Liu et al. (2002, 2003).
- Fast reconnection in the surrounds of the BH driven by turbulence

Kadowaki, de Gouveia Dal Pino, Singh, ApJ 2015
Singh, de Gouveia Dal Pino, Kadowaki, ApJ Lett. 2015

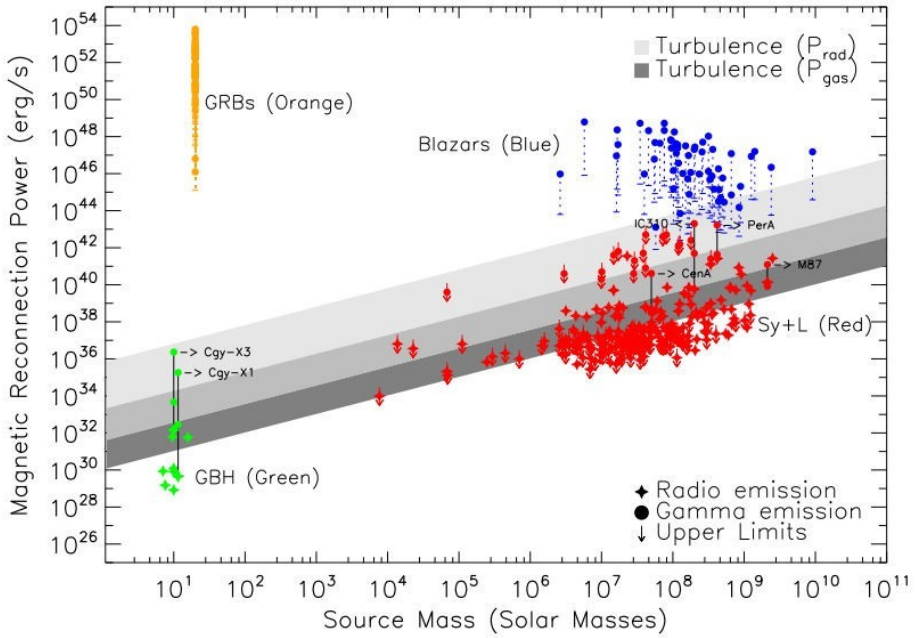


$$0.0005 \leq \dot{m} \leq 1$$
$$1 \leq l \leq 18$$
$$l_x \leq l$$
$$r_x = 6$$
$$\Gamma \sim 1$$

Kadowaki, de Gouveia Dal Pino, Singh, ApJ 2015

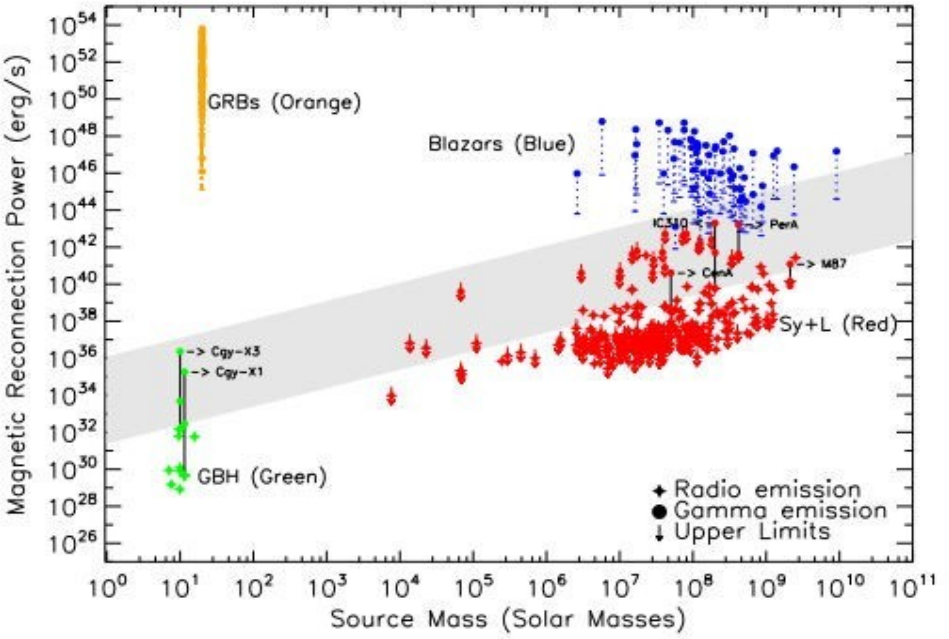


Kadowaki, de Gouveia Dal Pino, Singh , ApJ 2015



Standard accretion disk

Kadowaki, de Gouveia Dal Pino, Singh, ApJ 2015

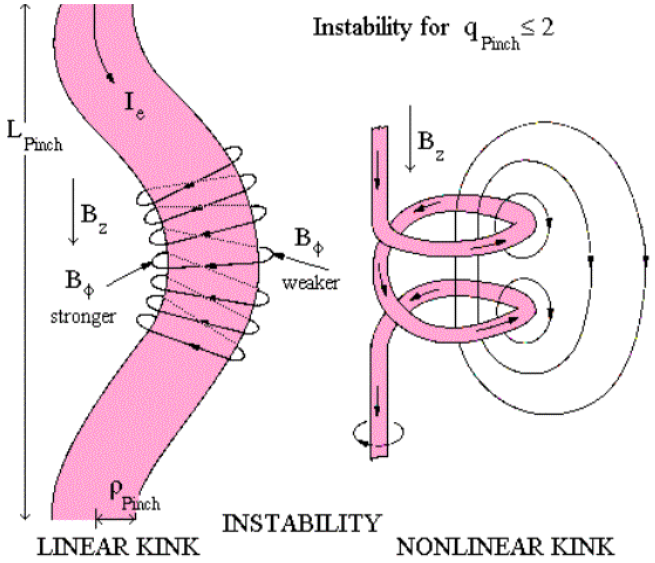


MDAF accretion disk

Singh, de Gouveia Dal Pino, Kadowaki, ApJL 2015

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)

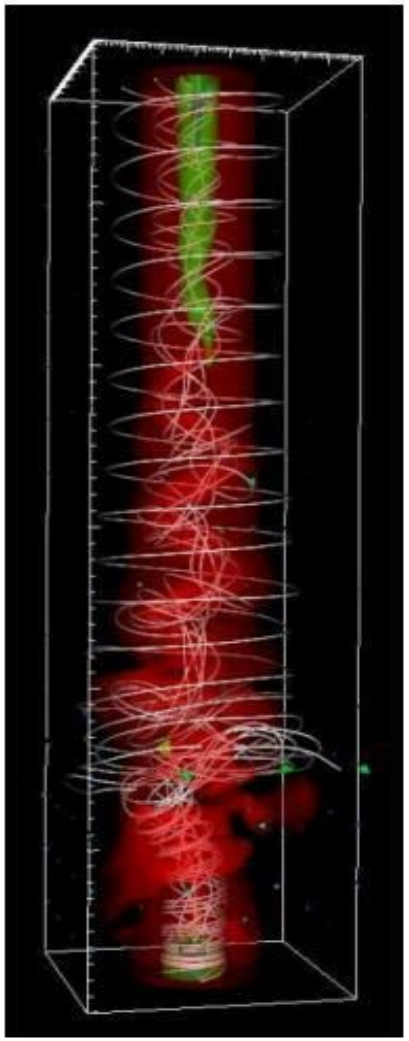
Reconnection driven by Kink in Magnetically Dominated Relativistic Jets

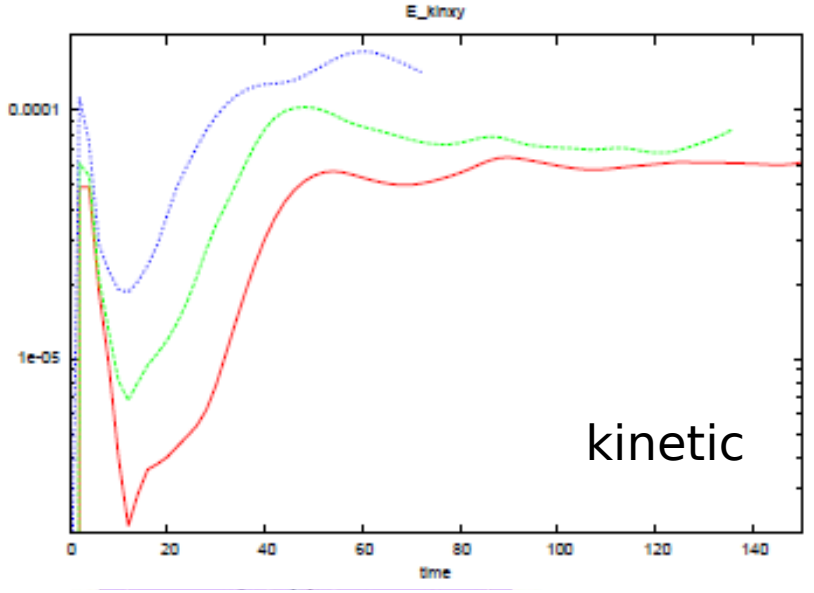
Precession perturbation allows growth of CD kink instability with helical density distortion.

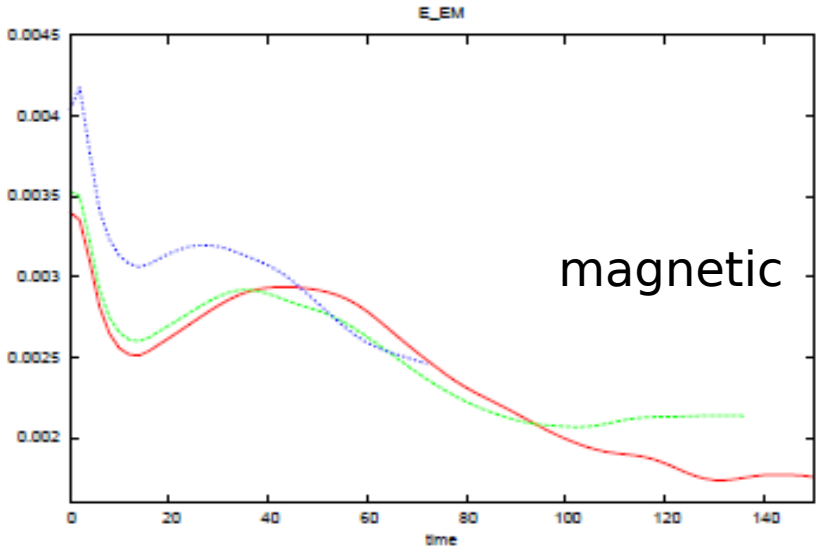
Helical kink advected with the flow with continuous growth of kink amplitude in non- linear phase.

Helical structure is disrupted

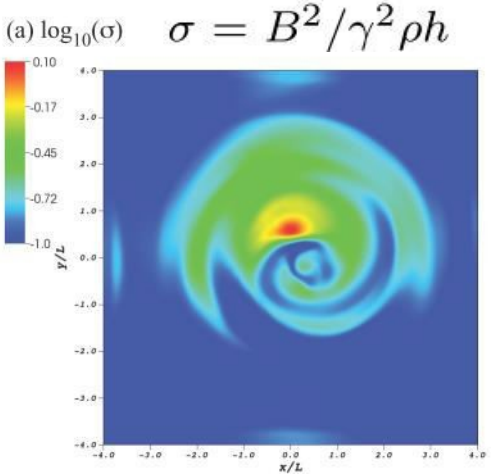
Magnetic energy converted into kinetic energy



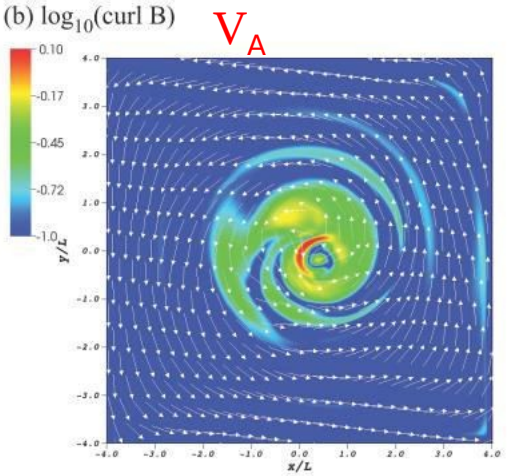


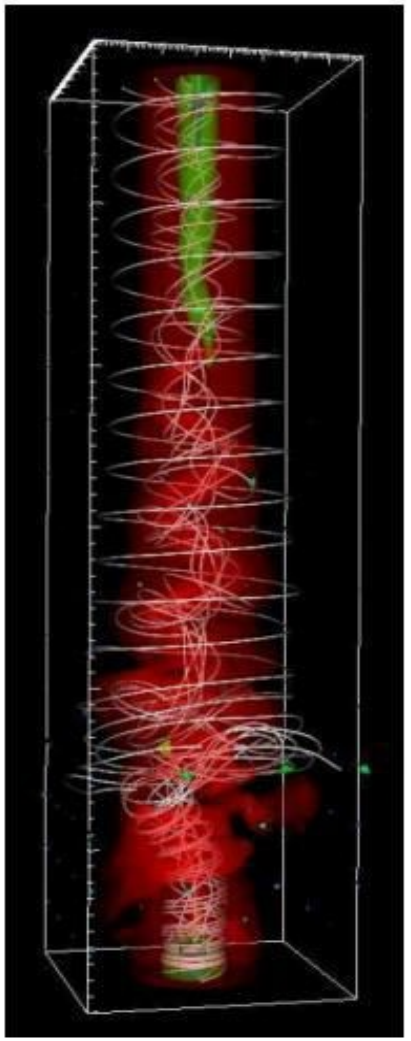


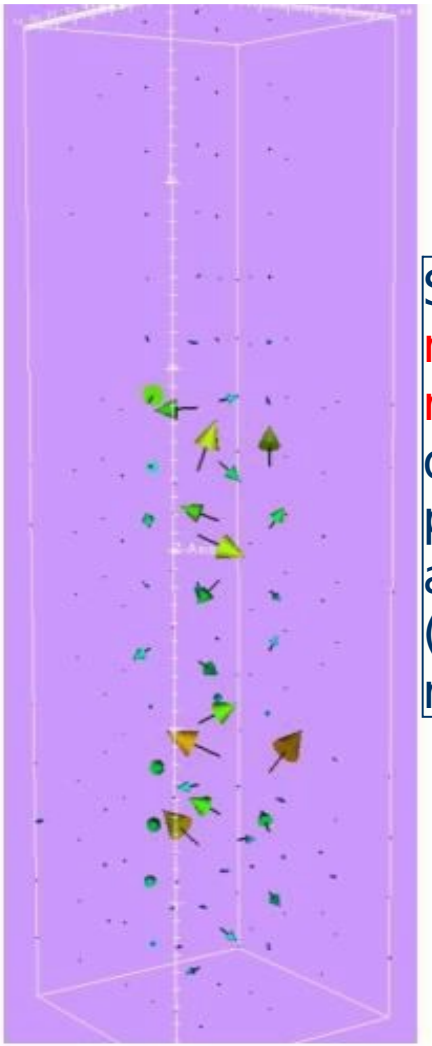
Singh, Mizuno, de Gouveia Dal Pino, ApJ 2016



$V_{rec} \sim 0.05$ V_A







curl B = max

Sites for magnetic reconnection, dissipation, particle acceleration (and gamma-rays)!

Singh, Mizuno, de Gouveia Dal Pino, ApJ 2016

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 (numerically tested): can explain gamma-ray of microquasars and non-blazar AGNs as coming from the core.

The magnetic reconnection power matches well with the observed correlation of radio/gamma-ray luminosity versus BH mass of microquasars and non-blazar AGNs over 10^{10} orders of magnitude in mass.

Reconnection in magnetically dominated relativistic jets can be triggered by CD Kink instability, can explain rapid variability and possibly drive Fermi acceleration and gamma-ray emission too.

THANK YOU FOR YOUR ATTENTION