

# The Role of Fast Magnetic Reconnection in Microquasars and AGNs

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October 5, 2015 - HEPRO V

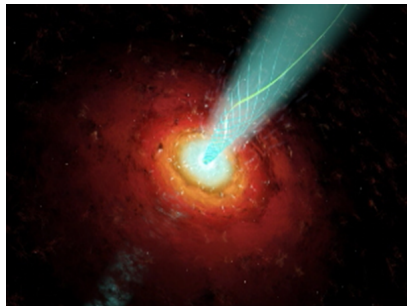


- Fast magnetic reconnection mechanism.
- Their role in the origin of radio and gamma-ray emission and particle acceleration.
- Comparison between the energy extracted by magnetic reconnection with the observed emission of several sources.
- Application to build the SEDs of LLAGNs and microquasars.



# Gamma-Rays produced by Relativistic Particles

- Proton-proton, proton-photon interactions, IC, SSC  $\rightarrow$  Gamma photons
- Gamma-Ray emission is common in Blazars:

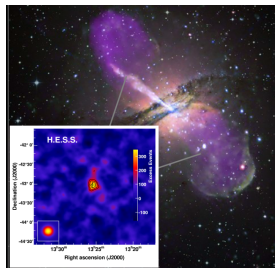


- BLAZARS: luminous AGNs.
- Jet  $\sim$  along the line of sight:
  - Emission dominated by relativistic jet (particle shock acceleration).
  - Radiation is enhanced by relativistic effects (Doppler boosted).



# Gamma-Rays produced by Relativistic Particles

- Recent discovery of Gamma-Ray emission in Low Luminosity AGNs (LLAGNs) and microquasars.
  - LLAGNs: Radio Galaxies M87, Cen A, Per A, IC 310.
  - Microquasars: Cyg X3 and Cyg X1.
- Rapid Variability in gamma emission:
  - It indicates compact emission region:  $c\Delta t \sim 100R_S$ ,
  - where the particle shock acceleration is less efficient.
- Where are particles accelerated?
- What are the acceleration mechanisms?



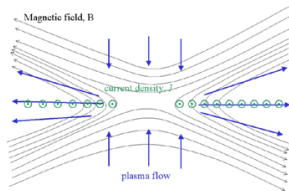
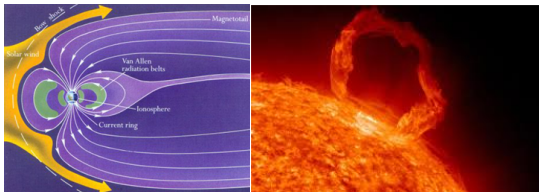
# Possible answers to these questions

- Relativistic particle acceleration by magnetic reconnection around BHs:
  - Powerful acceleration mechanism.
  - Provides gamma-ray emission in the core region of microquasars and LLAGNs.



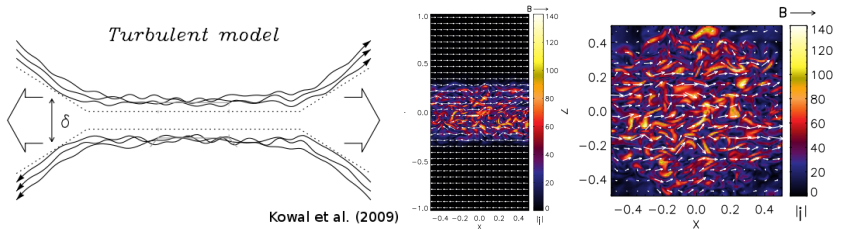
# Magnetic Reconnection Mechanism

- Magnetic reconnection:
  - Occurs when two magnetic fluxes of opposite polarity encounter each other (under finite Ohmic resistivity).
  - Magnetic energy is released in the current sheet.
- Examples:
  - Earth's Magneto-tail.
  - Solar Flares.



# Turbulent Magnetic Reconnection in Collisional Flows

- Lazarian & Vishniac (1999) model:
  - Reconnection triggered by turbulence.
  - Several reconnection points due to the wandering magnetic field lines.
  - Fast reconnection.
  - $V_{rec} \approx V_A$



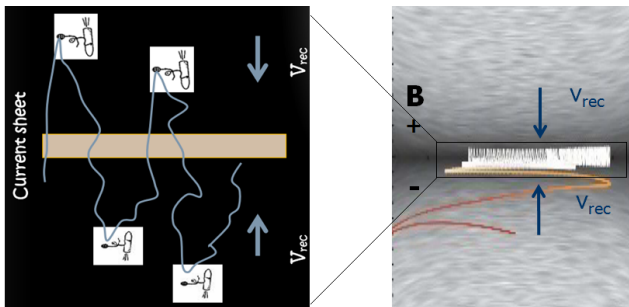
Successfully tested in numerical simulations (Kowal et al. 2009, 2012)



# 1st-order Fermi Acceleration at Reconnection Site

- Magnetic reconnection will heat the coronal/disk gas,
- and accelerate particles to relativistic velocities through a 1st-order Fermi process.

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



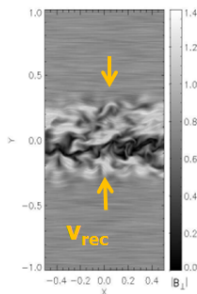
de Gouveia Dal Pino and Lazarian (2005)



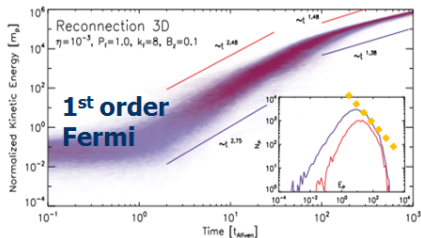


# Magnetic Reconnection Acceleration

- Successfully tested in 3D MHD simulations.
  - Acceleration rate:  $\tau_{acc}^{-1} \approx E^{-0.4}$ .



current sheet with  
turbulence:  
fast reconnection  
(LV99)

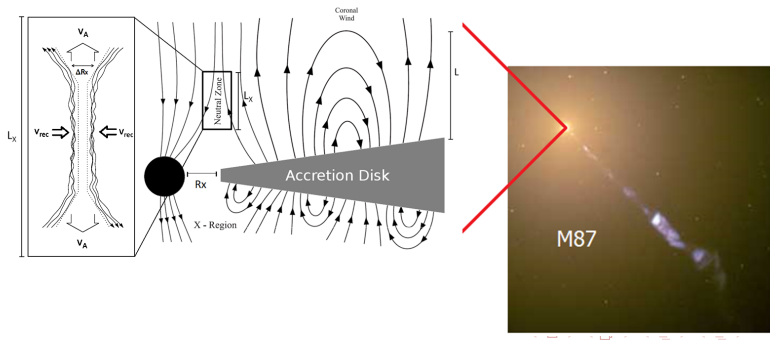


Extracted directly from simulations of Kowal et al. (2012)



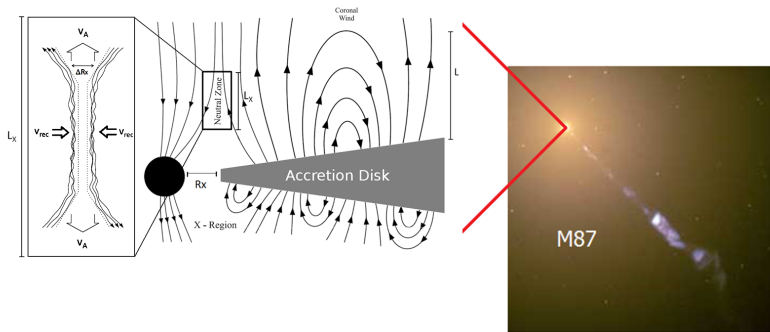
# Reconnection acceleration in the surrounds of BHs

- de Gouveia Dal Pino & Lazarian model (2005):
  - Fast reconnection between the magnetic field lines from the accretion disk and the magnetosphere of BH.
  - Explains the origin of Synchrotron flare radio emission from microquasars.
- de Gouveia Dal Pino, Piovezan & Kadowaki (2010):
  - Extended to AGNs.



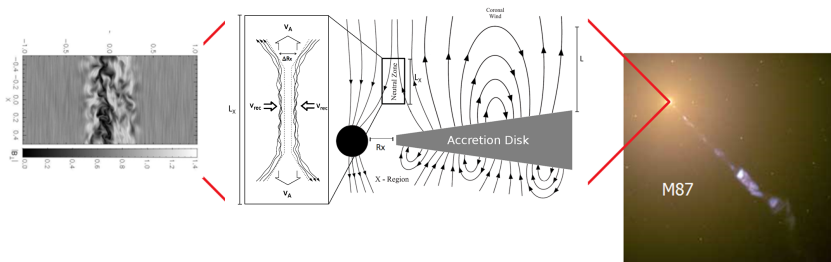
# Reconnection acceleration in the surrounds of BHs

- Most fast magnetic reconnection events are expected to occur when:
  - accretion rate is enhanced via removal of angular momentum by the magnetic lines that arise from the accretion disk.



# Reconnection acceleration in the surrounds of BHs

- Revisited the model to evaluate reconnection power and acceleration (applied 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.

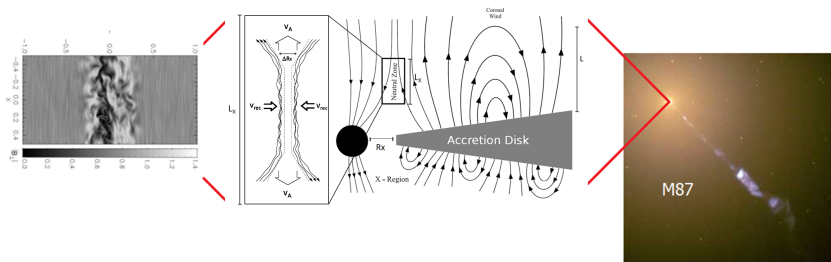


# Rate of magnetic energy released by reconnection

- Magnetic energy power released during fast reconnection:  
(Kadowaki, de Gouveia Dal Pino & Singh, ApJ, 2015, 802, 113)

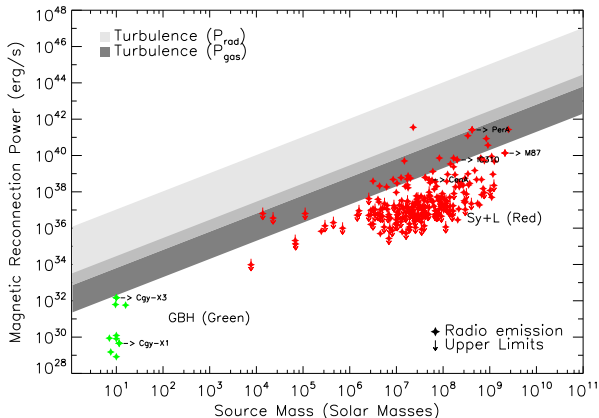
Turbulence (Thin disk + Coronal model)

$$\dot{W}_B \simeq 1.66 \times 10^{35} \Gamma^{-\frac{1}{2}} r_X^{-\frac{5}{8}} l^{-\frac{1}{4}} l_X q^{-2} \dot{m}^{\frac{3}{4}} m \text{ erg/s}$$



# Reconnection acceleration in the surrounds of BHs

## Radio Emission (microquasars and LLAGNs)



$$0.0005 \leq \dot{m} \leq 1$$

$$1 \leq l \leq 18$$

$$l_x \leq l$$

$$r_x = 6$$

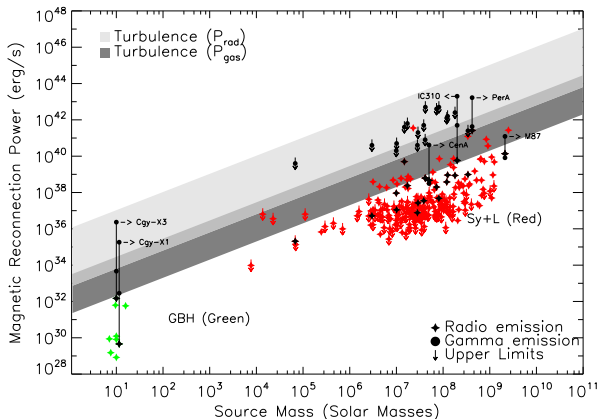
$$\Gamma \sim 1$$

(Kadowaki, de Gouveia Dal Pino & Singh, ApJ, 2015, 802, 113)



# Reconnection acceleration in the surrounds of BHs

## Radio and Gamma Emission



$$0.0005 \leq \dot{m} \leq 1$$

$$1 \leq l \leq 18$$

$$l_x \leq l$$

$$r_x = 6$$

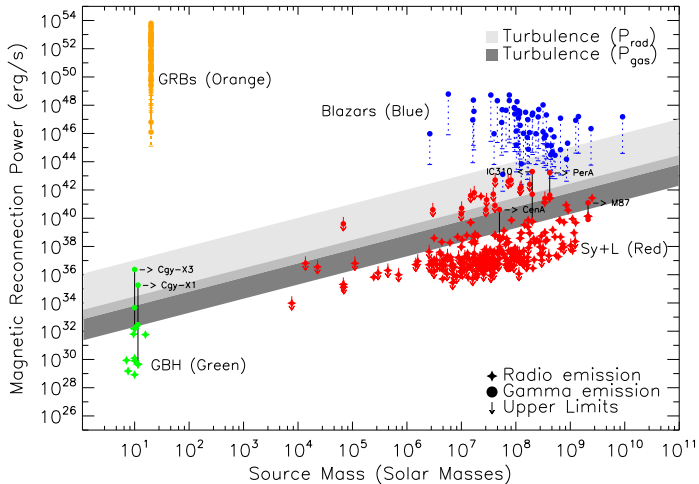
$$\Gamma \sim 1$$

(Kadowaki, de Gouveia Dal Pino & Singh, ApJ, 2015, 802, 113)



# Reconnection acceleration in the surrounds of BHs

## BHBs, LLAGNs, Blazars and GRBs



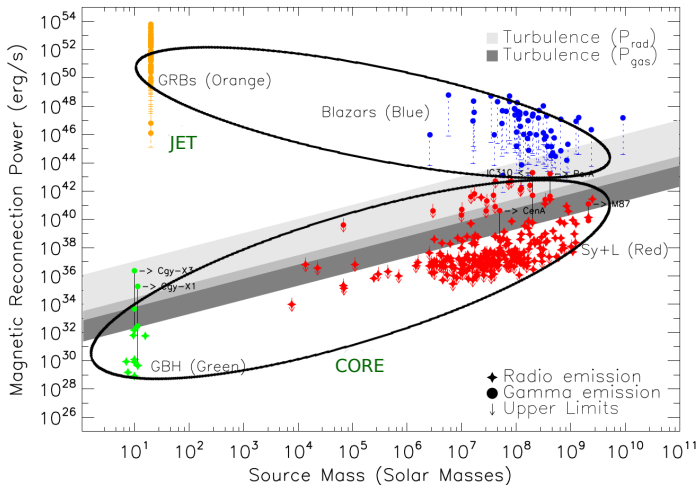
(Kadowaki, de Gouveia Dal Pino & Singh, ApJ, 2015, 802, 113)





# Reconnection acceleration in the surrounds of BHs

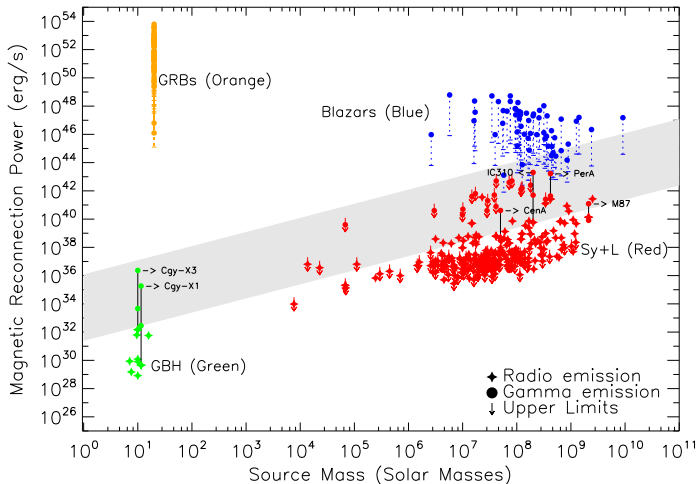
## Jet and Core emission



(Kadowaki, de Gouveia Dal Pino & Singh, ApJ, 2015, 802, 113)



# Reconnection acceleration in the surrounds of BHs



## MDAF accretion disk model

(Singh, de Gouveia Dal Pino & Kadowaki, 2015, ApJL, 799, L20)

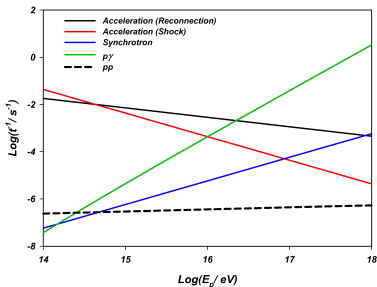
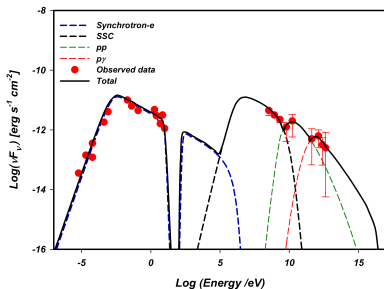


# Reconnection acceleration & SEDs

- Cooling of the accelerated particles
- $\tau_{acc}^{-1} \sim \tau_{loss}^{-1}$  (Synchrotron, SSC, pp, p $\gamma$ )



M87

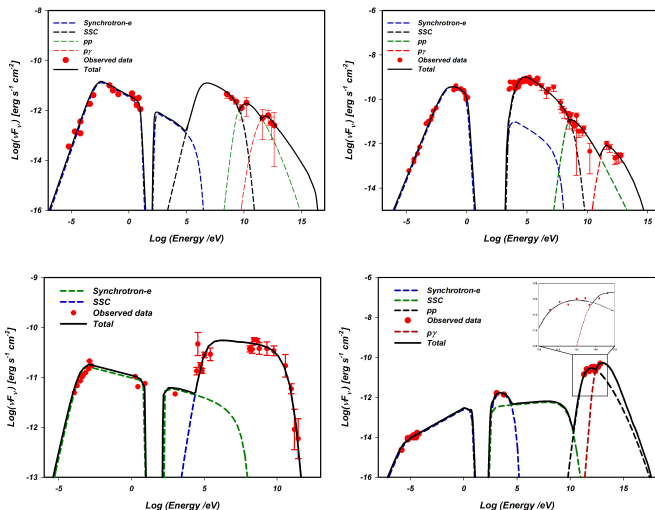


Khiali, de Gouveia Dal Pino & Sol, 2015 (arXiv:1504.07592)



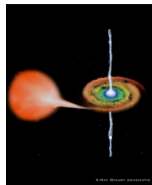
# Reconnection acceleration & SEDs

- Radio galaxies: M87, Cen A, Per A and IC 310

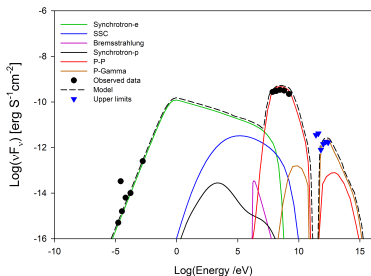
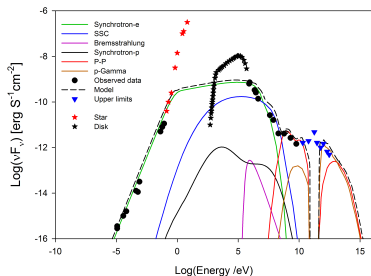


Khiali, de Gouveia Dal Pino & Sol, 2015 (arXiv:1504.07592)





## ● Microquasars: Cgy-X1 and Cgy-X3



Khiali, de Gouveia Dal Pino and del Valle, 2015, MNRAS



# Conclusions

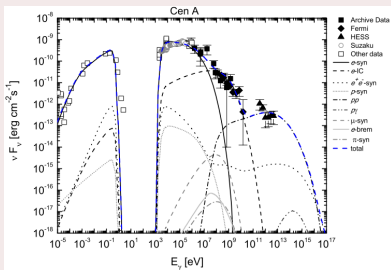
- The radio and gamma-ray emission of microquasars and LLAGNs can be explained by the magnetic power released by fast magnetic reconnection in the core region of these sources.
- Blazars and GRBs clearly do not have their gamma emission correlated with magnetic reconnection in the core.
  - Which is compatible with the notion that the emission of these sources is originated in the jet.
- The results of magnetic reconnection model are not much sensitive either to the details of accretion physics or magnetic field configuration.
  - As tested for standard and MDAF accretion disk model.
- These conclusions have been reinforced with the application of this core model in the reconstruction of SEDs of several Radio galaxies and microquasars.



# Is location of Gamma Emission in LLAGNs really in the core?

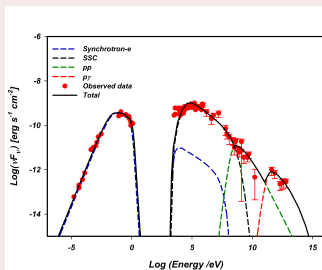
## Cen A

### Shock Acceleration in the jet



e.g. Reynoso, Medina, Romero 2011

### Magnetic Reconnection Acceleration in the core



Khiali, de Gouveia Dal Pino, Sol 2015



Thank You!

