Particle Acceleration, and Gamma-ray (& neutrino emission) Around Black Holes and Relativistic Jets

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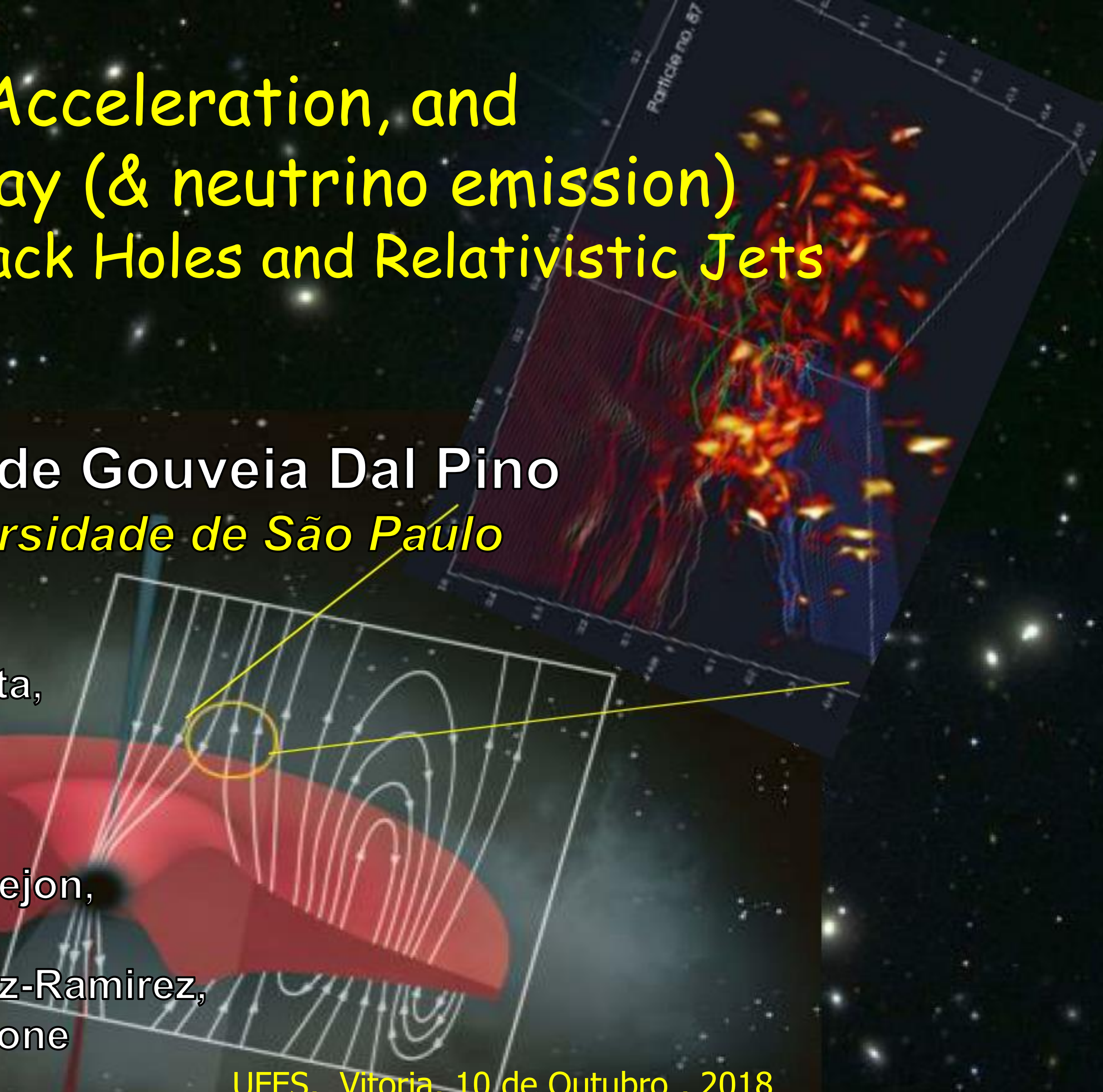
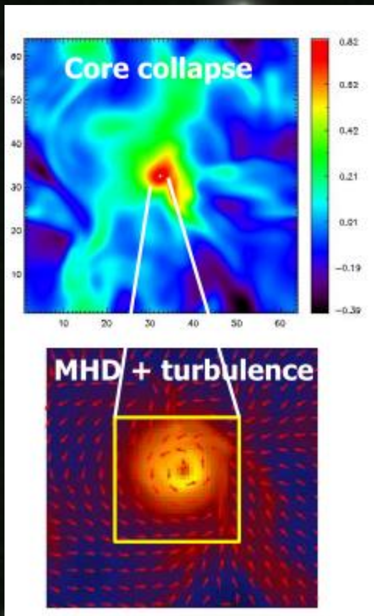
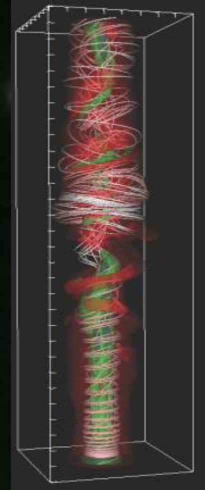
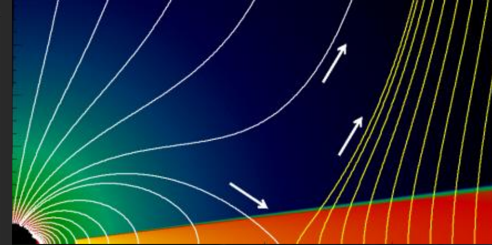
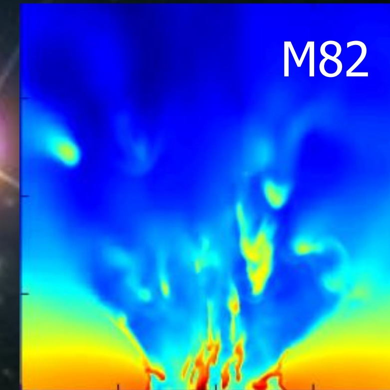


UFES, Vitoria, 10 de Outubro , 2018









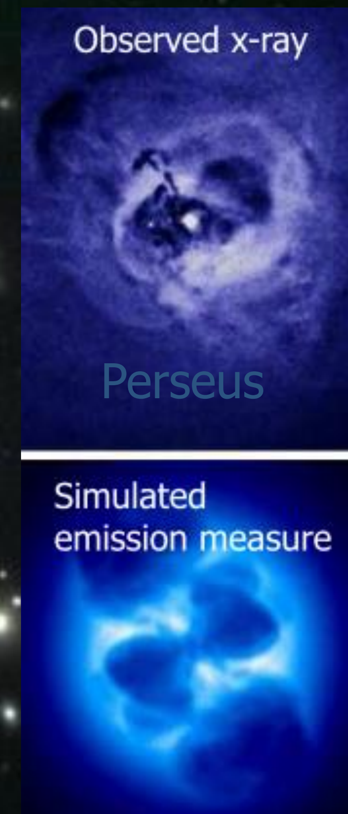
Jets & accretion disks

SN driven galactic winds

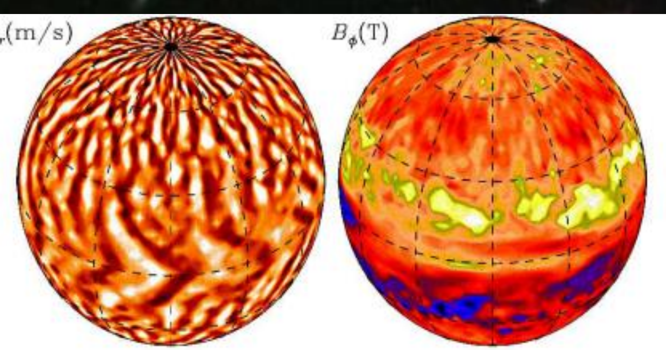
Star Formation-Clouds-SNR-turbulence connection

High Energy & Plasma Astrophysics

AGN/Star formation feedback in clusters



Sun & Stars



- ✓ Particle Acceleration
- ✓ Magnetic reconnection
- ✓ Magnetic flux transport
- ✓ Turbulence
- ✓ Dynamos (solar &, MIS, IGM)
- ✓ Relativistic MHD
- ✓ Radiative Cooling

Major puzzle for particle acceleration and radiation around Black Hole sources & Jets

Particle accelerators and Very High Energy (VHE) emitters

In regions that are magnetically dominated
-> shocks weaker

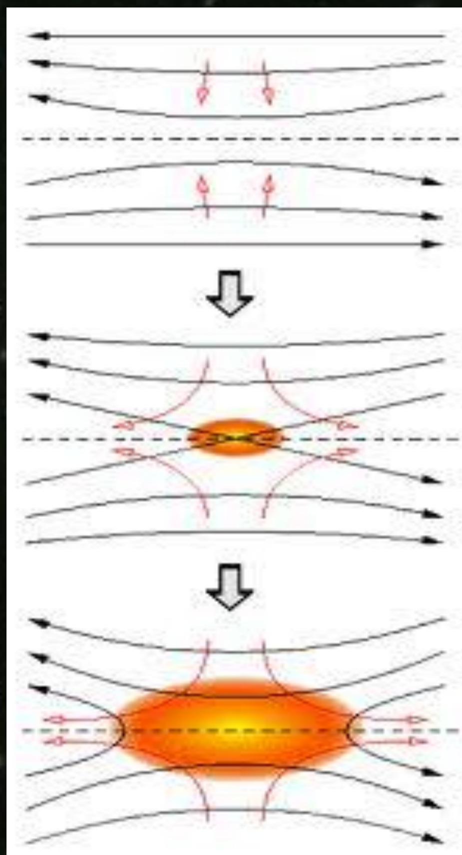
Standard particle **Fermi acceleration in shocks**:

-> may fail to explain relativistic particles origin and associated very high energy emission (up to TeV) occurring in very compact regions

Alternative mechanism -> Magnetic reconnection

WHAT IS MAGNETIC RECONNECTION ?

Approach of magnetic flux tubes of opposite polarity with finite resistivity (η ~1/conduction): **RECONNECT**



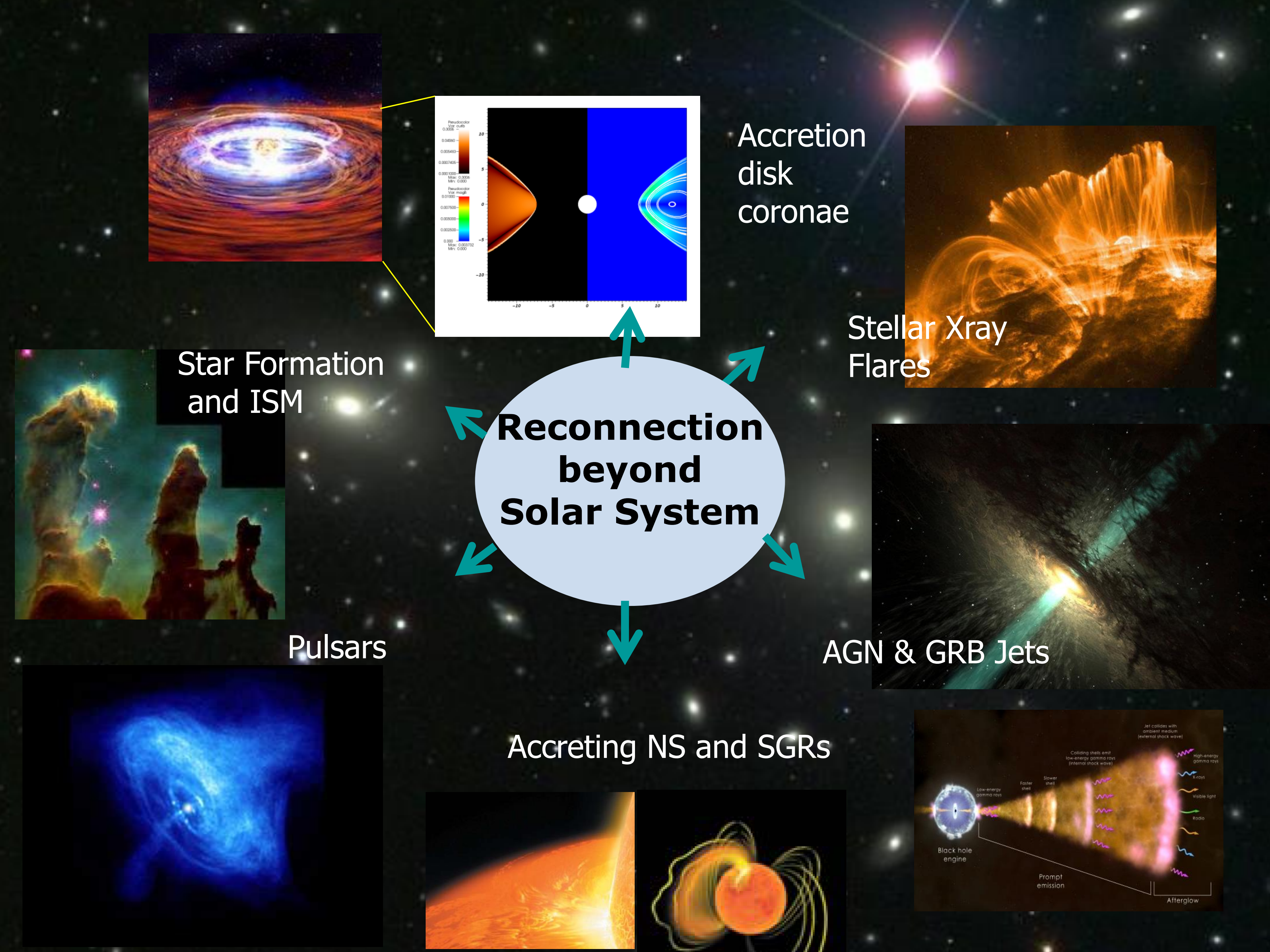
$$J \sim \frac{2Bc}{\Delta}$$

Earth magnetotail

Solar corona

Reconnection is *FAST* in these environments

-> $\mathbf{v_{rec} \sim V_A = B/(4\pi\rho)^{1/2}}$



Reconnection beyond Solar System
Accretion disk coronae
Stellar Xray Flares
Star Formation and ISM
AGN & GRB Jets
Pulsars
Accreting NS and SGRs
Black hole engine
Prompt emission
Afterglow

This talk

MAGNETIC RECONNECTION an alternative:

- Powerful relativistic particle acceleration

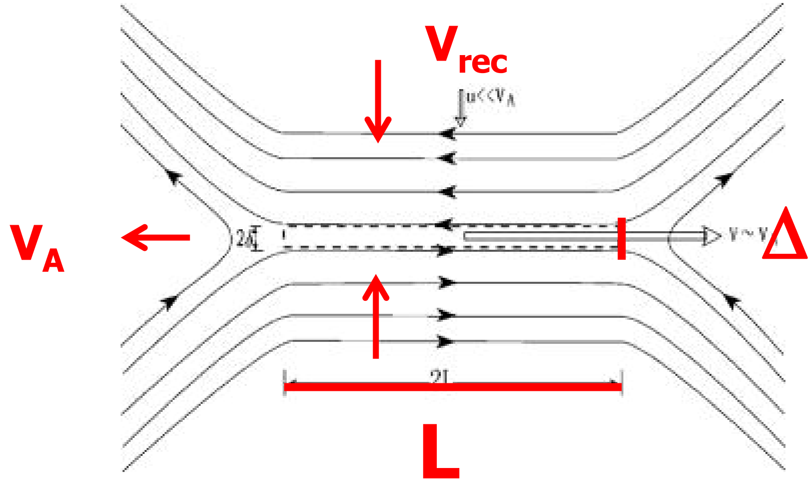
- Efficient conversion of magnetic energy -> into kinetic energy

- May explain very-high energy & neutrino emission in BH sources and relativistic jets, at magnetically dominated regions, solving current puzzles

Magnetic Reconnection
and
Particle Acceleration Connection

Magnetic Reconnection Models

- **Sweet-Parker (1957) reconnection:**



From mass flux conservation:

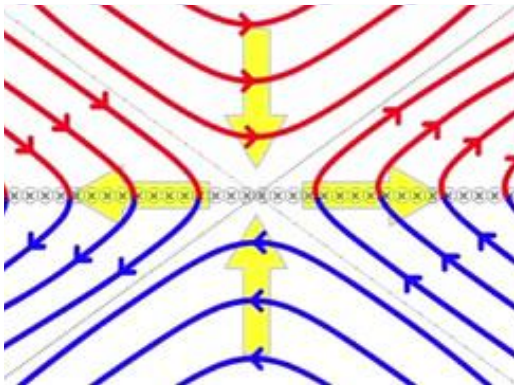
$$\boxed{V_{rec} \sim v_A\,(\Delta/L)}$$

But $\Delta/L << 1$

$V_{rec} << v_A$ → **SLOW reconnection**

Magnetic Reconnection Models

Petschek (1964): X-point configuration ->



Δ $\rightarrow$ $\Delta \sim L$

L

Then reconnection rate is FAST:

$$\boxed{V_{rec} \sim \pi\, v_A / 4 \ln S}$$

Where $S = L\, v_A/\eta \gg 1$

BUT*: unstable and evolves to Sweet-Parker** (Biskamp'96) ***unless:

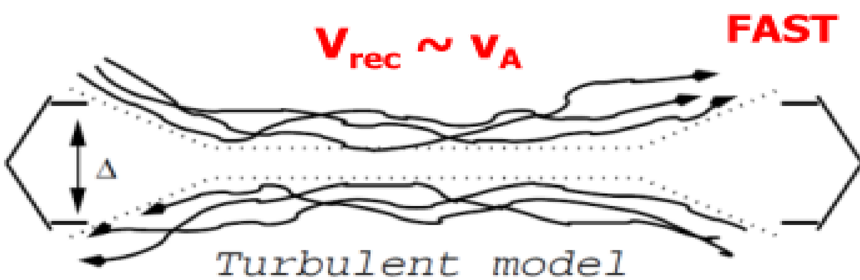
***pair* plasma at kinetic scales** with localized resistivity η

Fast Reconnection in MHD flows

Turbulence drives FAST RECONNECTION

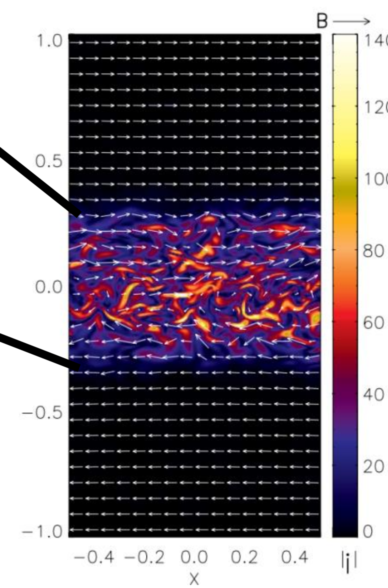
(Lazarian & Vishniac 1999; Eyink et al. 2011)

Magnetic lines wandering: many simultaneous reconnection events



$$V_{\rm rec} = V_{\rm A}\left(\frac{l}{L}\right)^{1/2}\left(\frac{v_l}{V_{\rm A}}\right)^2$$

Tested in 3D MHD numerical simulations (Kowal et al. 2009, 2012; 2015; Takamoto et al. 2015)



(Alternative~descriptions: Shibata & Tanuma01; Loureiro+07; Bhattacharjee+09)

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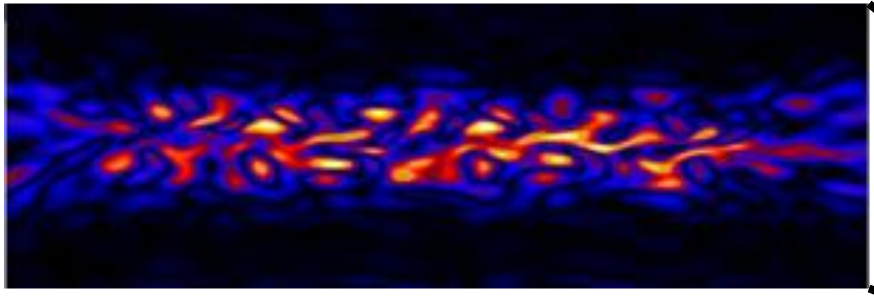

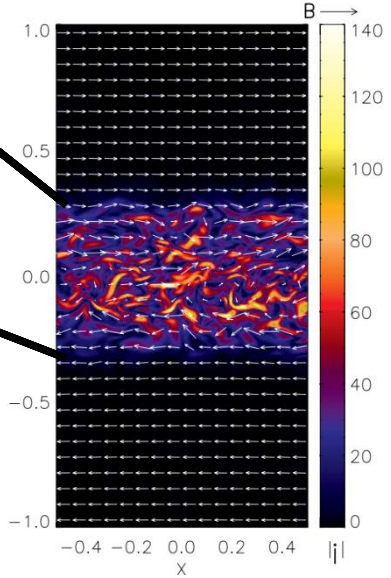

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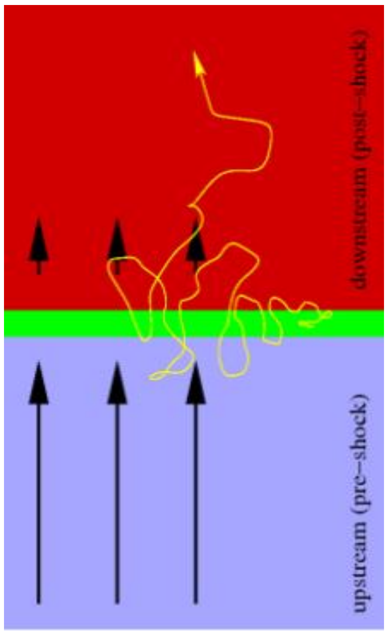
(Alternative~descriptions: Shibata & Tanuma01; Loureiro+07; Bhattacharjee+09)

Particle Acceleration by Reconnection

- **Released magnetic energy by reconnectio**n -> into heating and particle motion (kinetic energy)
- **30%–40%** of magnetic energy converted into particle kinetic energy (PIC simulations, e.g. Werner et al. 2017)
- **Laboratory plasmas: ~50%** goes into kinetic particle acceleration (Yamada+ 2015)

Particles are accelerated in reconnection sites in 1st-order Fermi

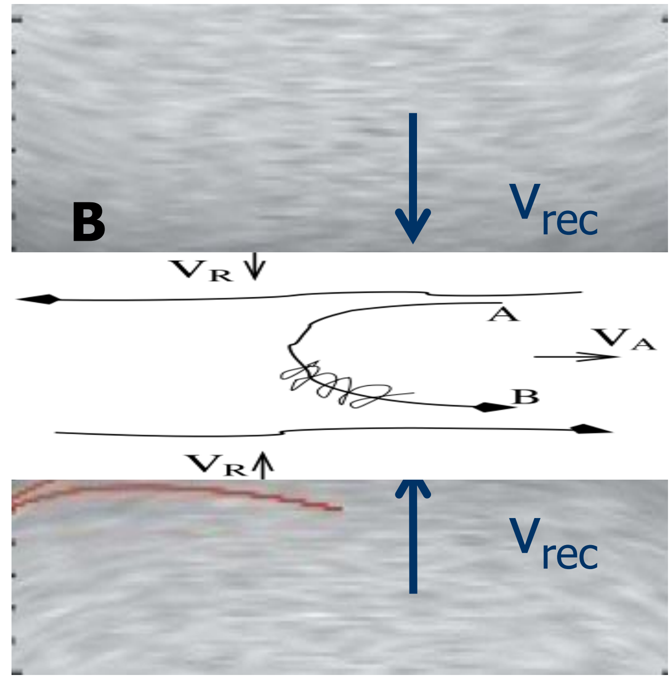
Shock Acceleration



1st-order Fermi (Bell 1978; Begelman & Eichler 1997)

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

Reconnection Acceleration



As in shocks: 1st-order Fermi
(de Gouveia Dal Pino & Lazarian, A&A 2005):

particles bounce back and forth between 2 converging magnetic flows

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

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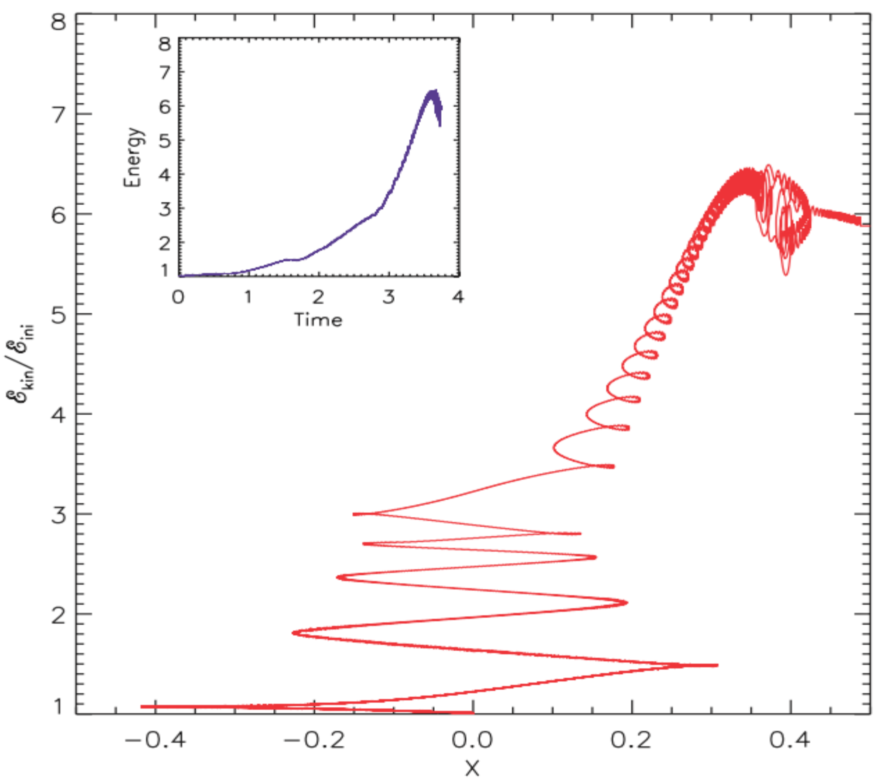
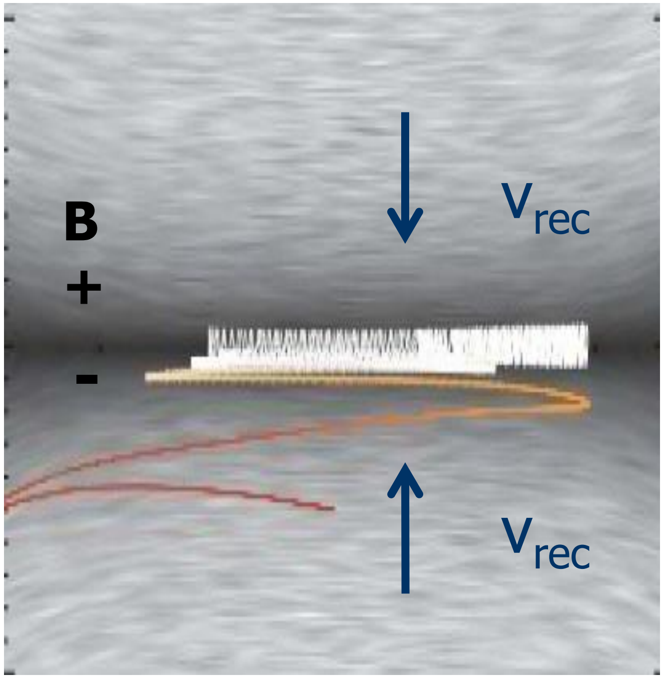


(Kowal, de Gouveia Dal Pino & Lazarian, ApJ 2011)

Reconnection Acceleration



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

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

Particle Acceleration by Reconnection probed with numerical simulations

- Most simulations of particle acceleration by magnetic reconnection: **2D kinetic plasmas (PIC)** (e.g. Drake+ 06; Zenitani & Hoshino 01; 07; 08; Cerutti, Uzdensky+ 13; Li+ 15) **and 3D** (Sironi & Spitkovsky 2014; Guo+2015; 16; 18; Werner+ 17; Sironi+18)

  @ scales: **few plasma inertial length ~ 100-1000 c/ω_p**

- **Larger-scale astrophysical systems (BHBs, AGNs, GRBs):**

  → **MHD description → collisional reconnection**
  (Kowal, de Gouveia Dal Pino & Lazarian 2011, 2012; de Gouveia Dal Pino+ 2014, 2015; 2016; del Valle et al. 2016; Beresnyak & Li 2016; de Gouveia Dal Pino+2017, 2018)

Particle Acceleration by Reconnection using MHD Simulations with test particles

- **Isothermal MHD equations to build reconnection domain:** second-order Godunov scheme and HLLD Riemann solver (Kowal et al. 2009)

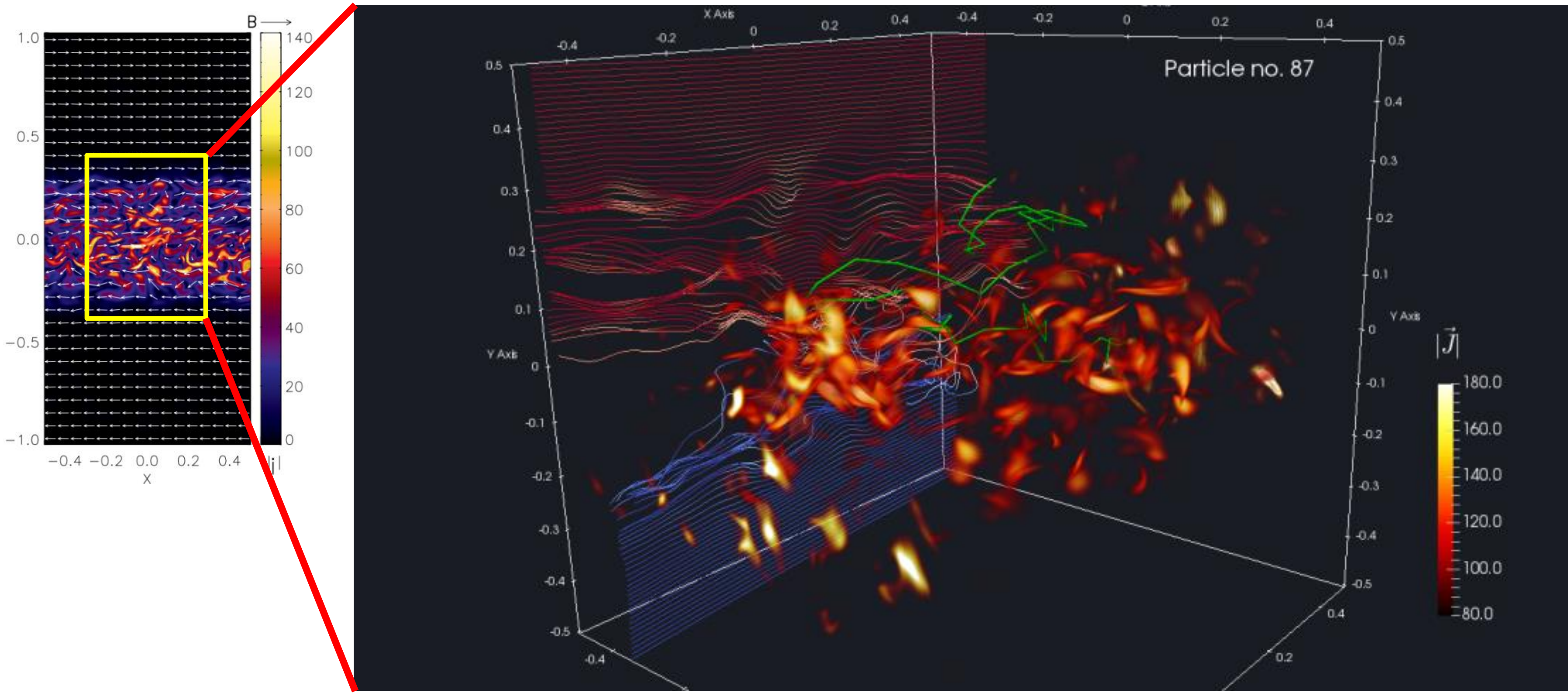
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0, \quad (5)$$

$$\frac{\partial \rho \boldsymbol{v}}{\partial t} + \nabla \cdot \left[\rho \boldsymbol{v}\boldsymbol{v} + \left(a^2 \rho + \frac{B^2}{8\pi} \right) I - \frac{1}{4\pi} \boldsymbol{B}\boldsymbol{B} \right] = \boldsymbol{f}, \quad (6)$$

$$\frac{\partial \boldsymbol{A}}{\partial t} + \boldsymbol{E} = 0, \quad (7)$$

Kowal, de Gouveia Dal Pino, Lazarian ApJ 2011; PRL 2012

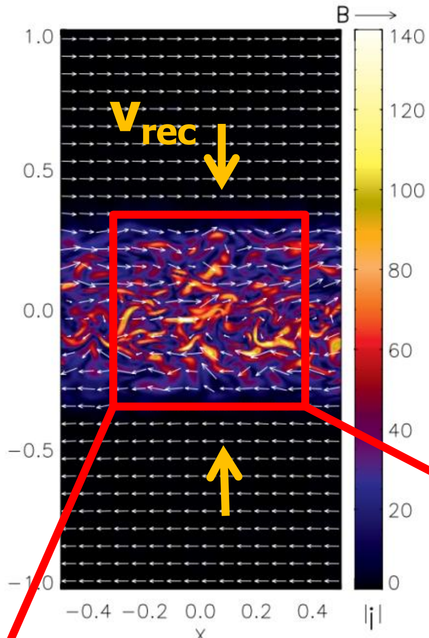
Particle Acceleration by Reconnection using MHD Simulations with test particles



$$\frac{d}{dt}(\gamma\, m\, \mathbf{u}) = q(\mathbf{E} + \mathbf{u} \times \mathbf{B}) \rightarrow \boxed{\frac{d}{dt}(\gamma m \boldsymbol{u}) = q\,[(\boldsymbol{u} - \boldsymbol{v}) \times \boldsymbol{B}]}$$

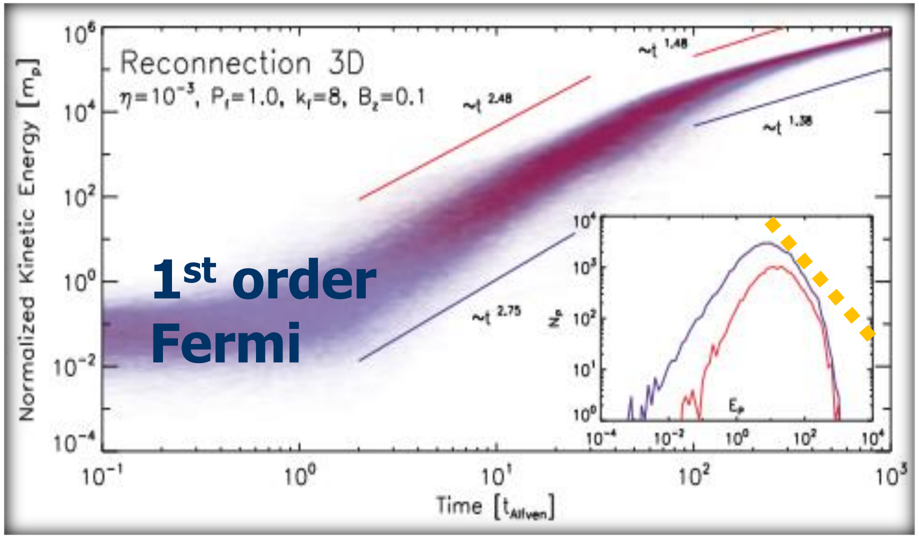
Kowal, de Gouveia Dal Pino, Lazarian ApJ 2011; PRL 2012

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

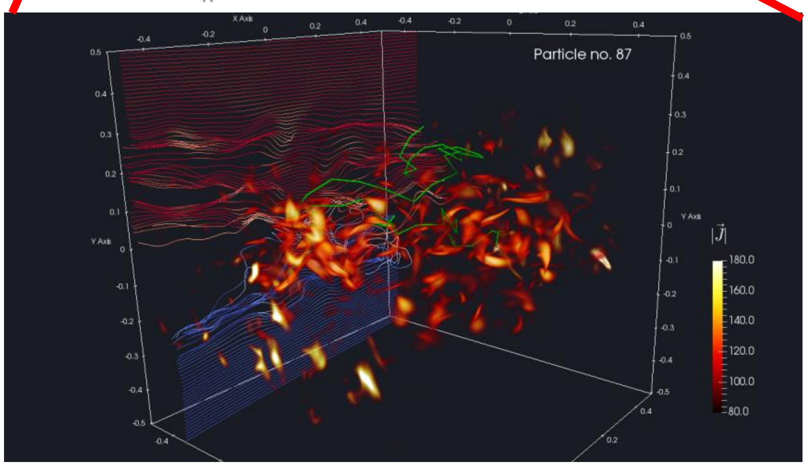


10,000 test particles

Injected in turbulent current sheet



Kowal, de Gouveia Dal Pino, Lazarian, PRL 2012



del Valle, de Gouveia Dal Pino, Kowal MNRAS 2016

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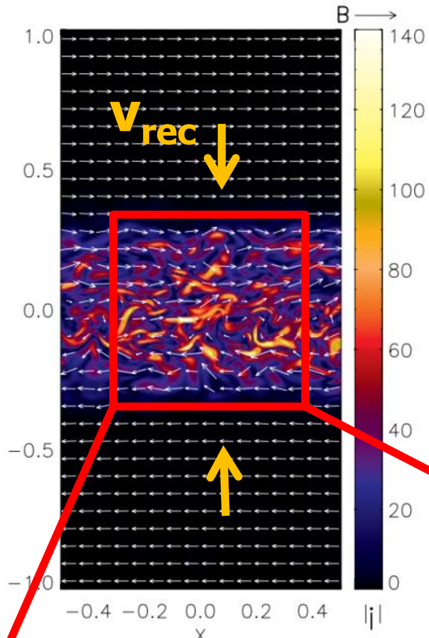

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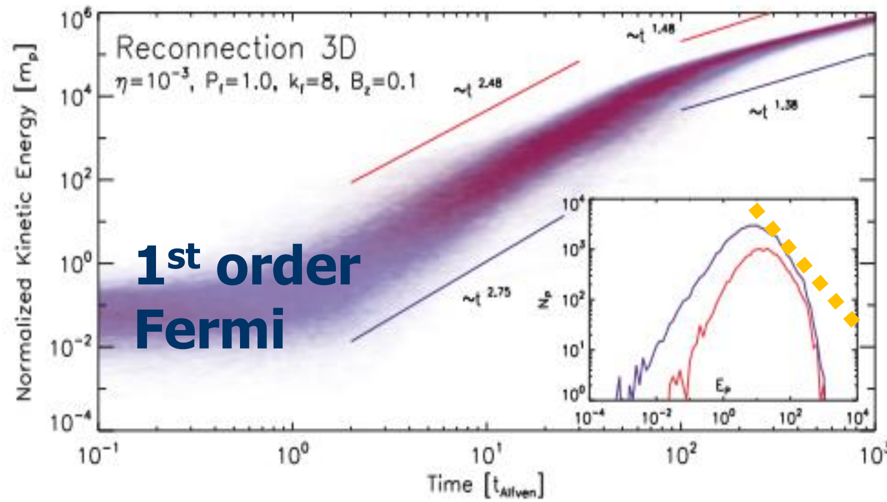
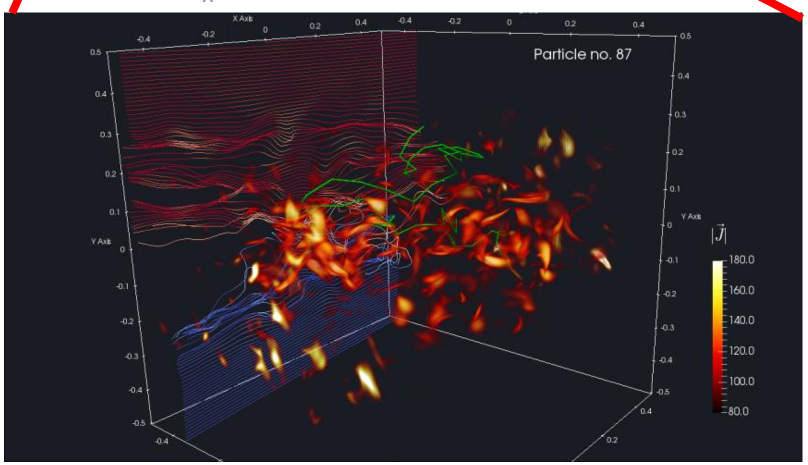
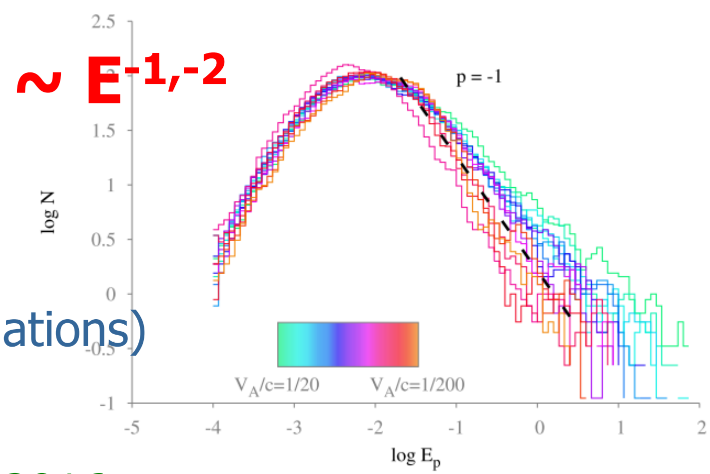


Kowal, de Gouveia Dal Pino, Lazarian, PRL 2012



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

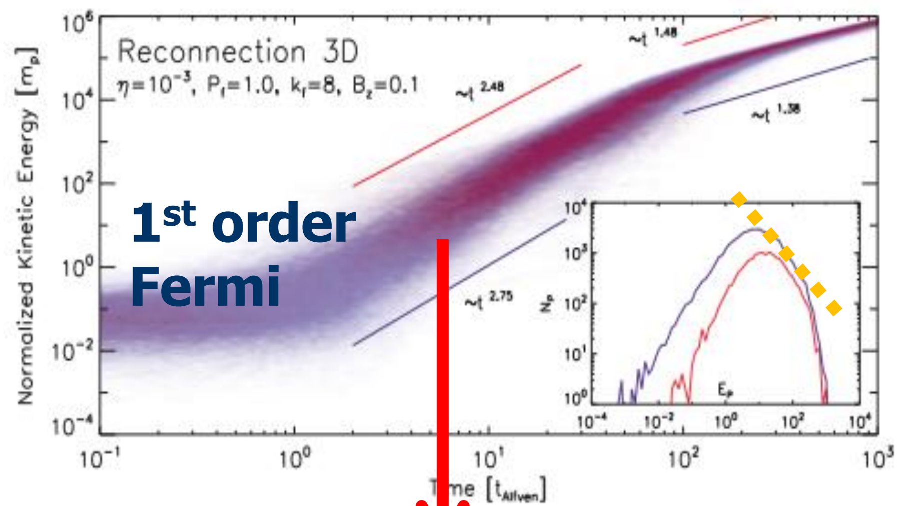
(~PIC simulations)



del Valle, de Gouveia Dal Pino, Kowal MNRAS 2016

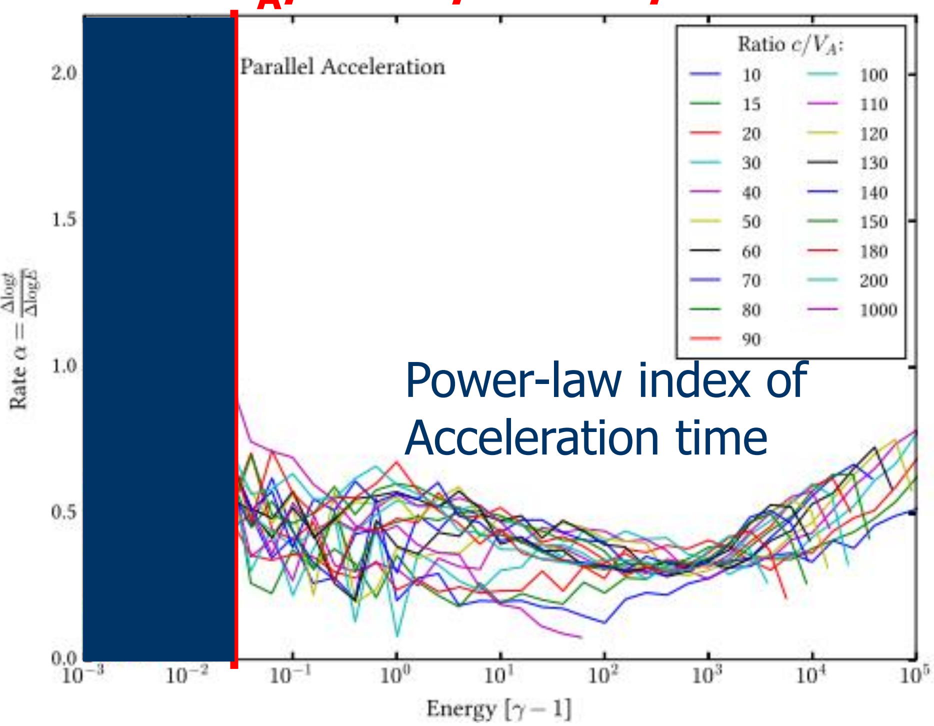
3D MHD Reconnection Acceleration tested for different values of reconnection velocity

Kowal, de Gouveia Dal Pino,Lazarian, PRL 2012



1^{st} order Fermi

v_A/c = 1/10 – 1/1000



Power-law index of Acceleration time

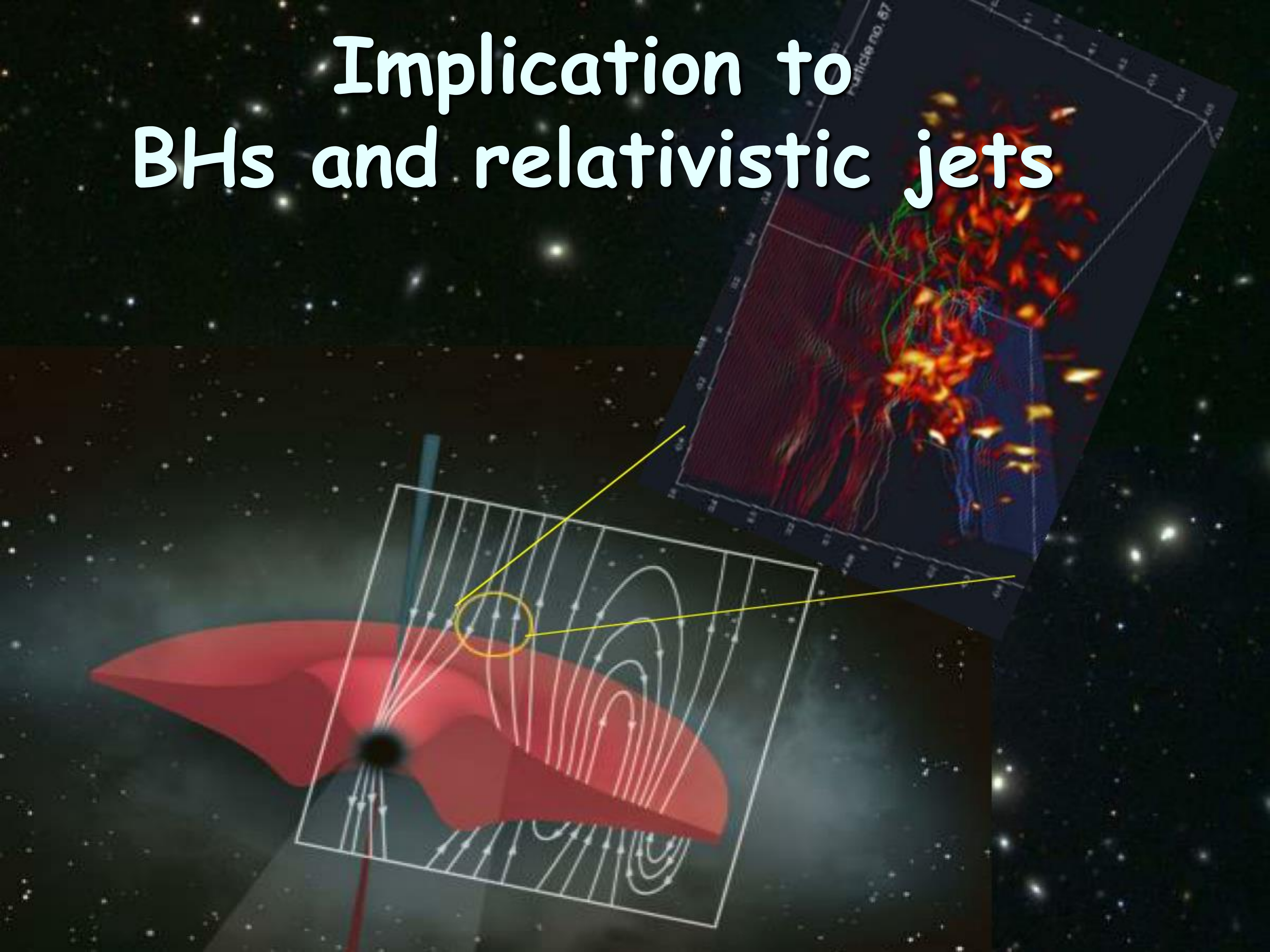
Reconnection acceleration time
(nearly independent of turbulent parameters that drive fast reconnection):

$$\tau_{acc} \sim E^{0.45+-0.15}$$

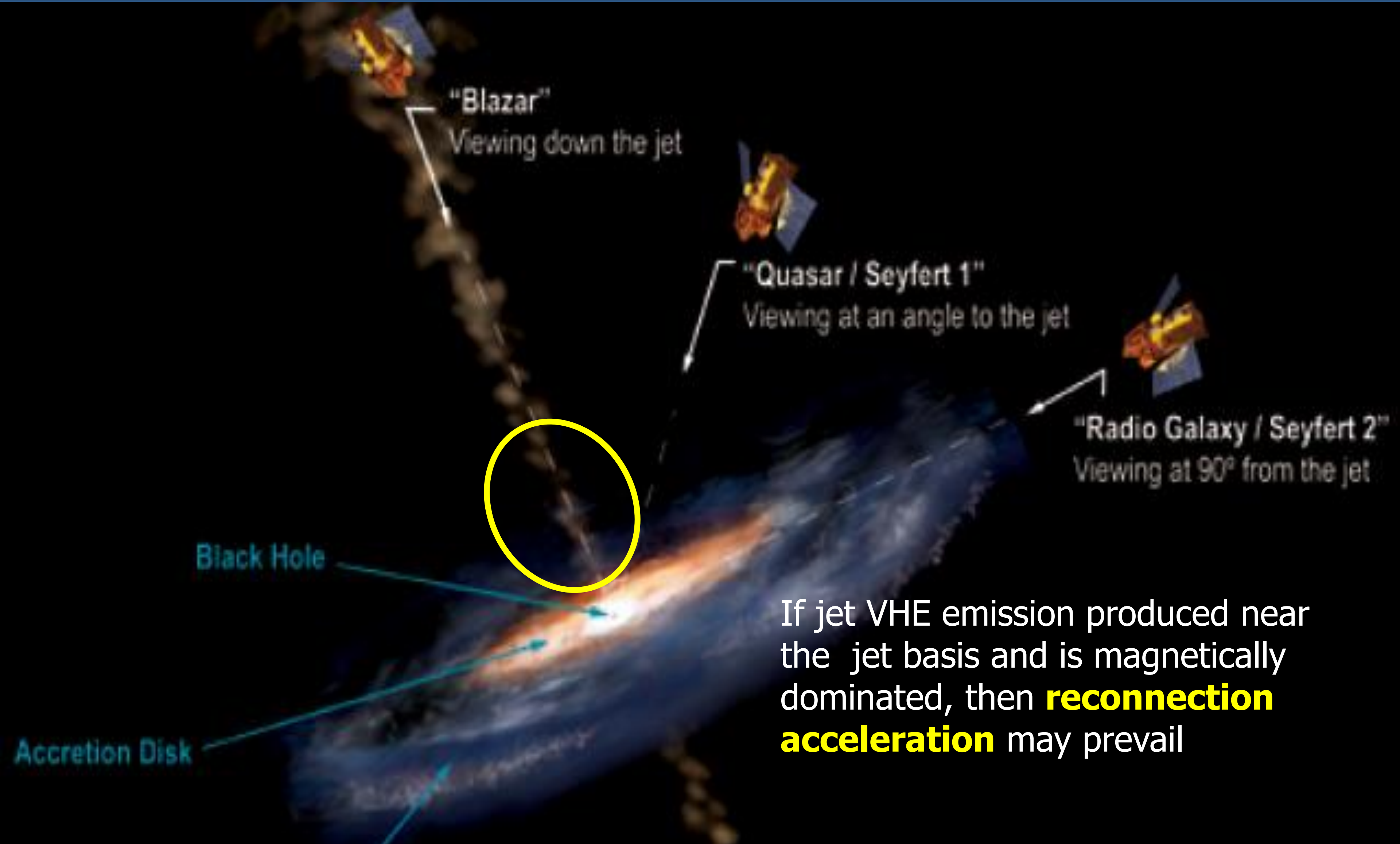
$$(\tau_{min} \sim E_{max}/e\, v_{rec}\, B)$$

del Valle, de Gouveia Dal Pino, Kowal, 2016 MNRAS

Implication to BHs and relativistic jets



Reconnection Acceleration *along* Relativistic Jets

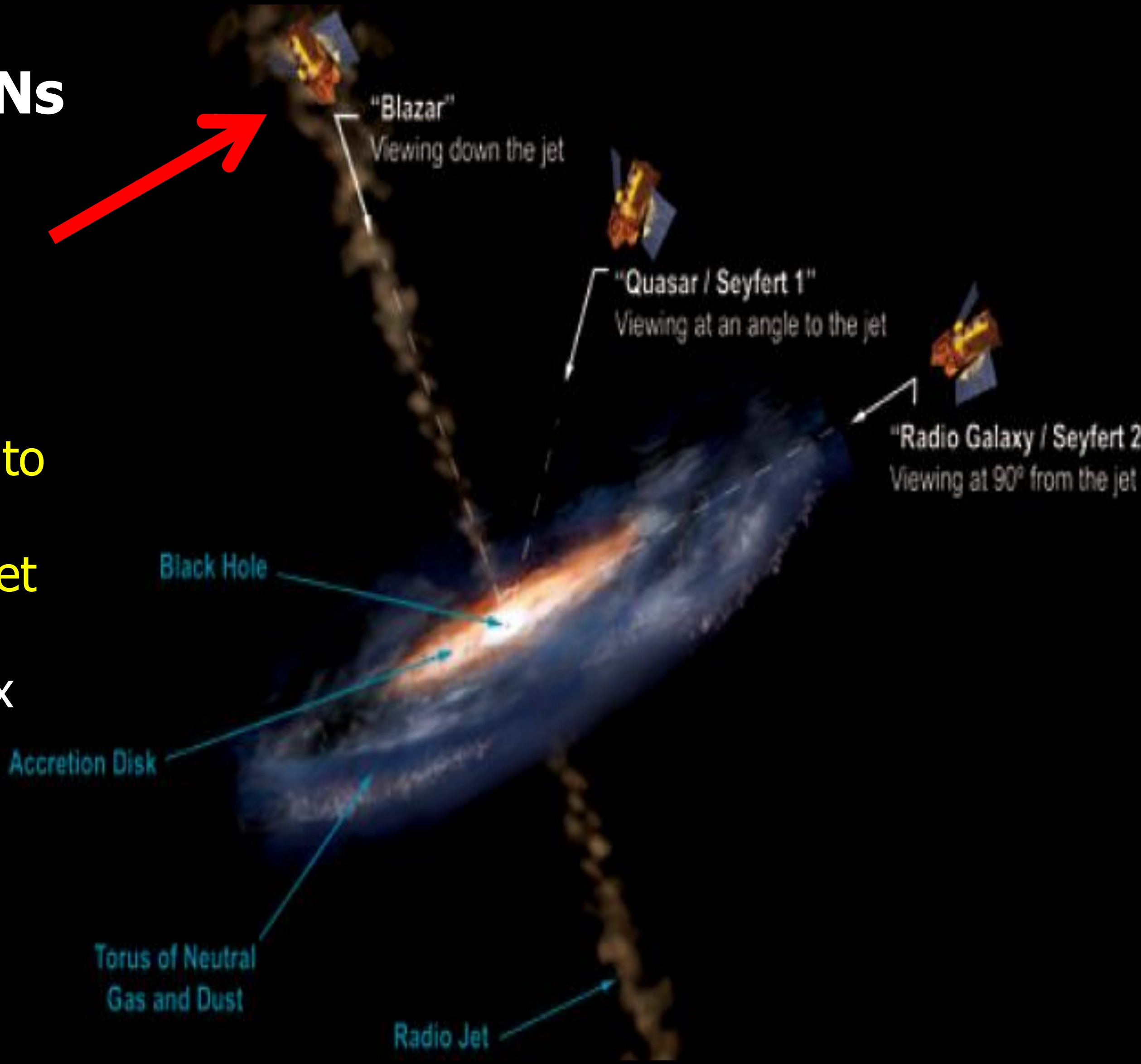


If jet VHE emission produced near the jet basis and is magnetically dominated, then **reconnection acceleration** may prevail

VHE emission much more common in *Blazars*

High Luminous AGNs

- ✓ Jet ~ along our line of sight
- ✓ VHE Emission (poor resolution): 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



Very-rapid TeV Flares in *Blazar Jets* hard to explain with standard acceleration

- **Variation timescale:**

  $t_v \sim 200$ s $< r_s/c \sim 3M_9$ hour

- For TeV emission to avoid pair creation $\Gamma_{em} > 50$ (Begelman, Fabian & Rees 2008)

- But bulk jet $\Gamma \sim$ 5-10

- **Emitter: compact** and/or extremely fast

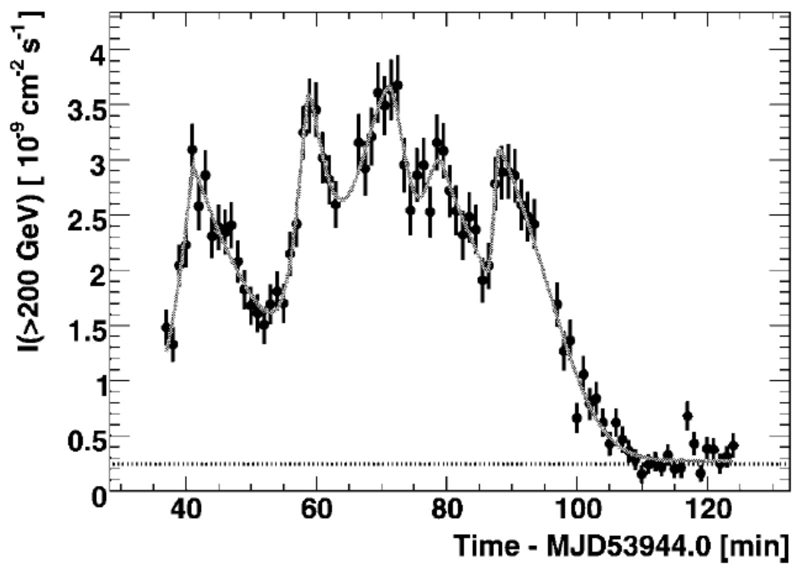
- Only acceleration model able to explain:

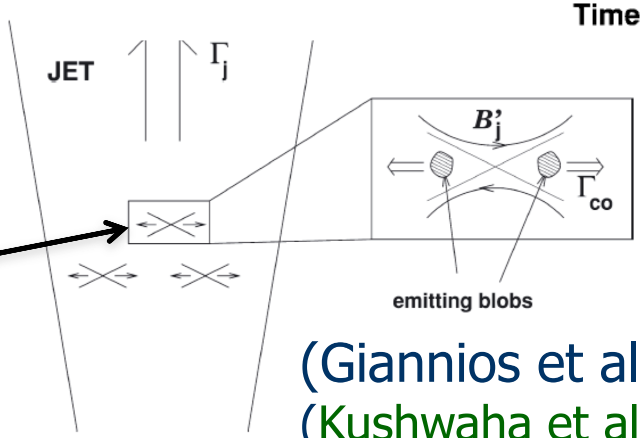
  Reconnection

  inside the jet

PKS2155-304 (Aharonian et al. 2007)

See also Mrk501, PKS1222+21, PKS1830-211



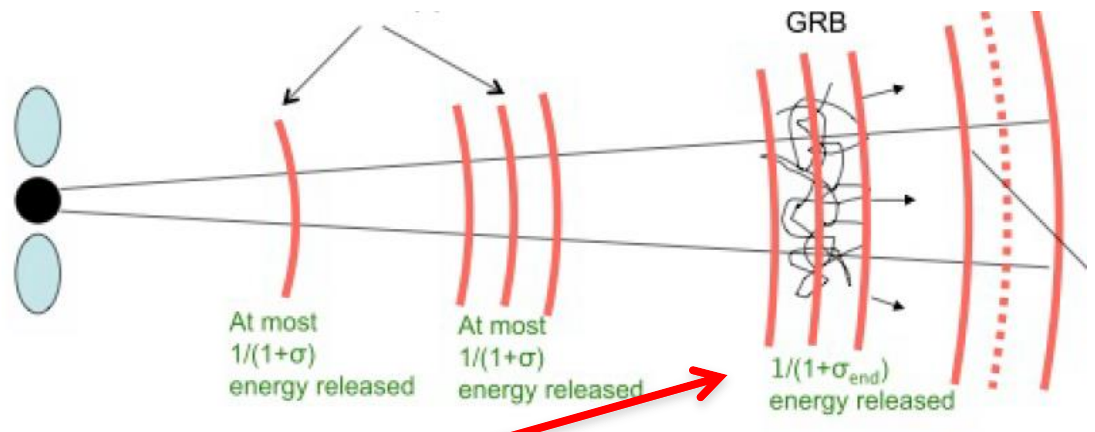


(Giannios et al. 2009)

(Kushwaha et al., MNRAS 2017)

GRB jet prompt gamma-ray emission may require reconnection acceleration too

Internal collision-induced magnetic reconnection turbulent model (ICMART) **(Zhang & Yan 2011):**



- GRB prompt emission: turbulence, magnetic reconnection, and particle acceleration via internal collisions of multiple launched parcels

(See also Giannios 2008; McKinney & Uzdensky 2012)

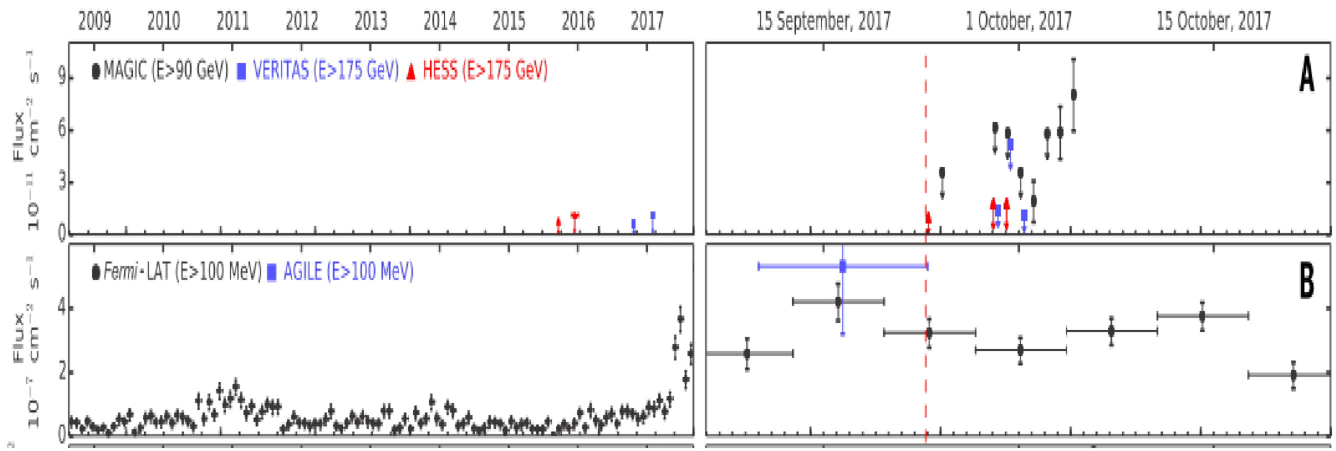
Gamma-ray flare and neutrinos in blazar TXS 0506+056

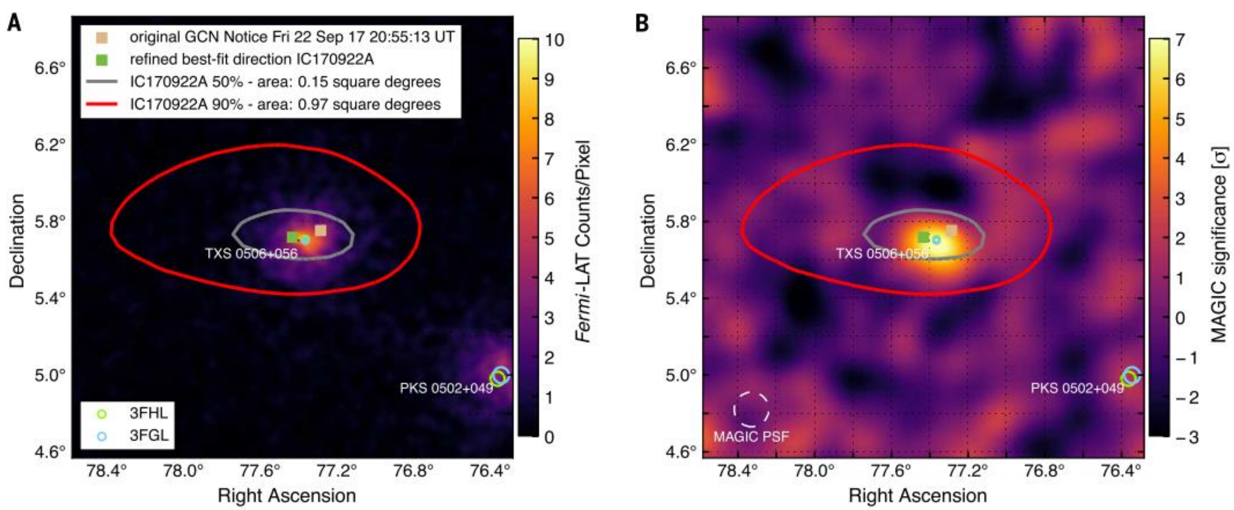
✓ **Neutrinos and gamma-rays are produced by high energy CRs :**

p + photons → π + p

$\pi^o \rightarrow \gamma\gamma$

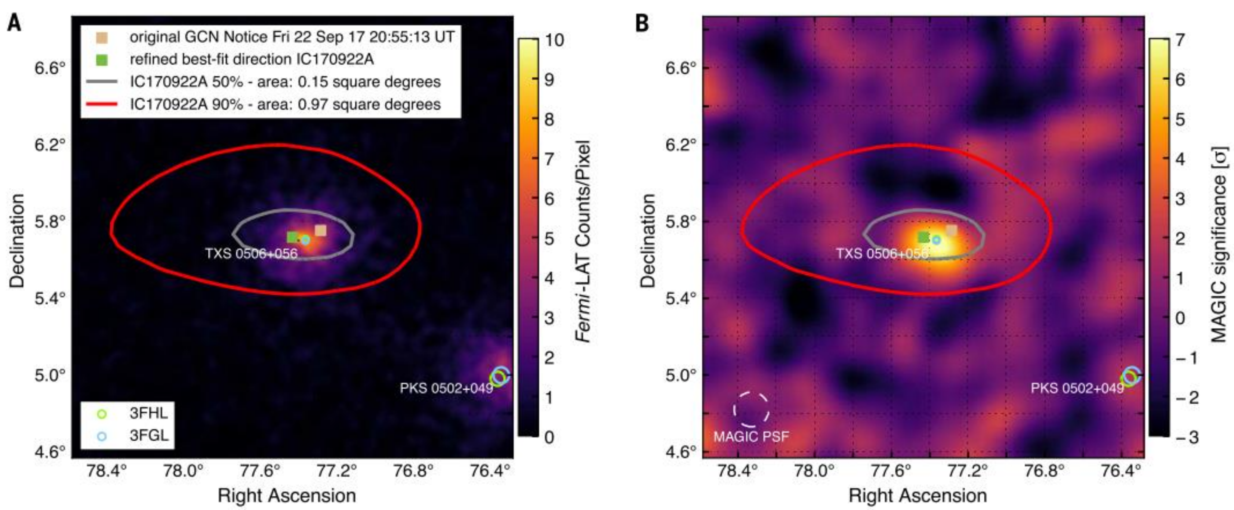
$\pi^{\pm} \rightarrow \mu^{\pm}\,\nu$





✓ Observed by IceCube, Fermi - LAT, MAGIC, HAWC, H.E.S.S, VLA, etc **(Science, 11 july, 2018)**

Are these **Gamma-ray flare and neutrinos** in blazars produced by accelerated CRs in magnetically dominant regions by **reconnection?**



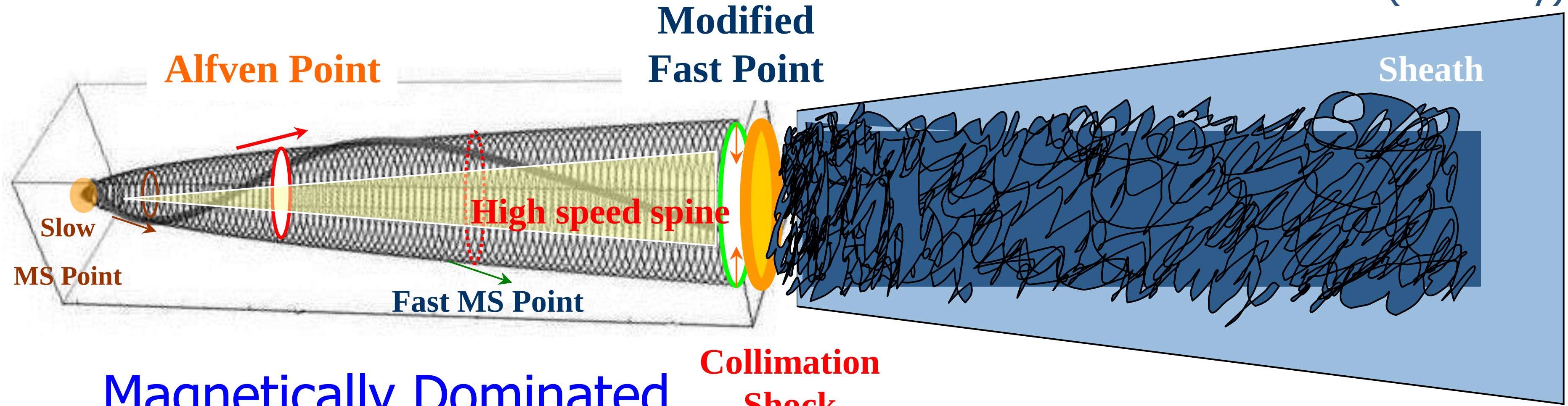
- ✓ Observed by IceCube, Fermi - LAT, MAGIC, HAWC, H.E.S.S, VLA, etc **(Science, 11 july, 2018)**

Inner Regions of AGN & GRB Jets: Magnetically dominated

Most accepted mechanisms for jet formation - **Blandford-Payne and Blandford-Znajeck -> jets are born magnetically dominated**

$\sim 10 - 10^{2.5\pm0.5}\ r_S$

Modified from D. Meier & Y. Mizuno (courtesy)



Collimation Shock

Magnetically Dominated

Kinetic Energy Flux Dominated

Current Driven Kink Instability

(Mizuno et al. 2012)

CD Kink Instability

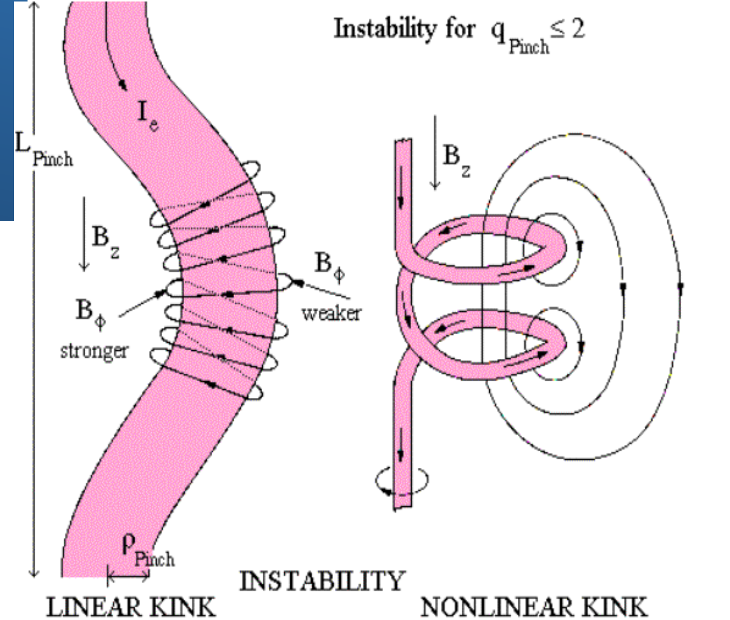
- Well-known instability in laboratory plasma (TOKAMAK) and astrophysical plasmas (Sun, jets, pulsars)

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

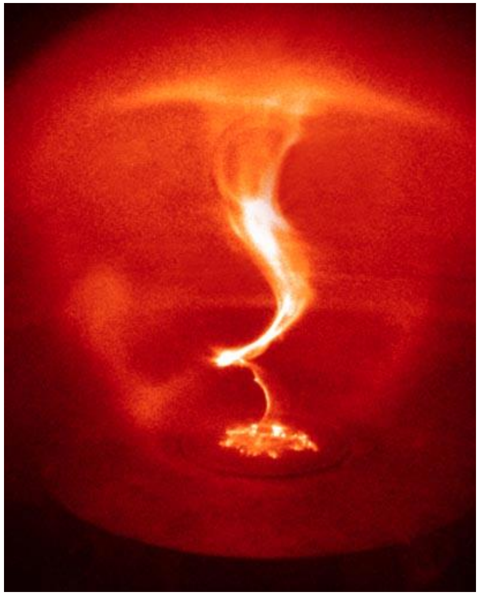
$$t_{\mathrm{kink}} \simeq \frac{2\pi R_{\mathrm{j}}}{c} \frac{B_p}{B_\phi}$$

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

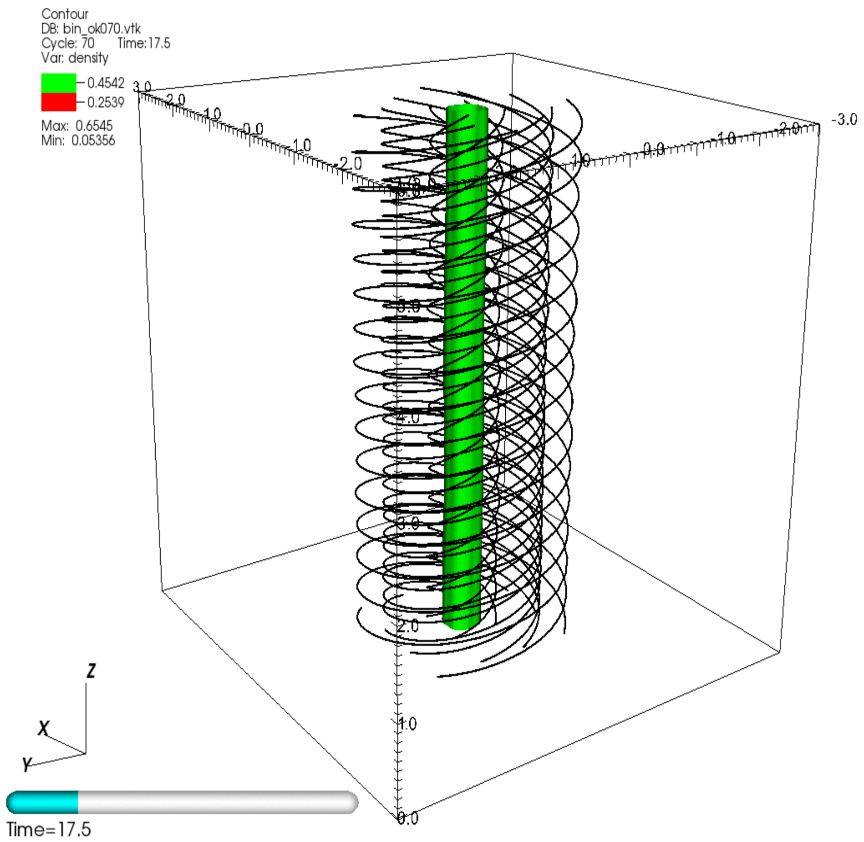
- Distorted magnetic field structure may trigger **magnetic reconnection**

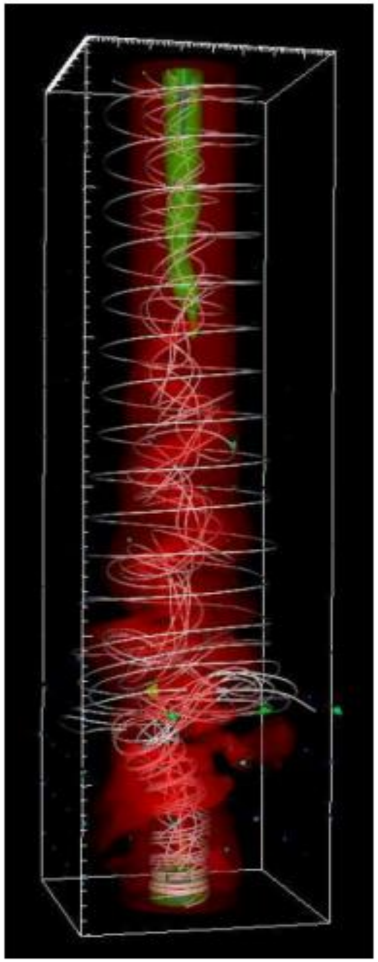


Schematic picture of CD kink instability


Kink instability in lab plasma (Moser & Bellan 2012)

MHD Simulations of Reconnection driven by Kink in Magnetically Dominated Relativistic Jets (AGNs & GRBs)





Singh, Mizuno, de Gouveia Dal Pino, ApJ 2016

(also Torrejon, de Gouveia Dal Pino, Kowal, Mizuno, Kadowaki, Singh, in prep.)

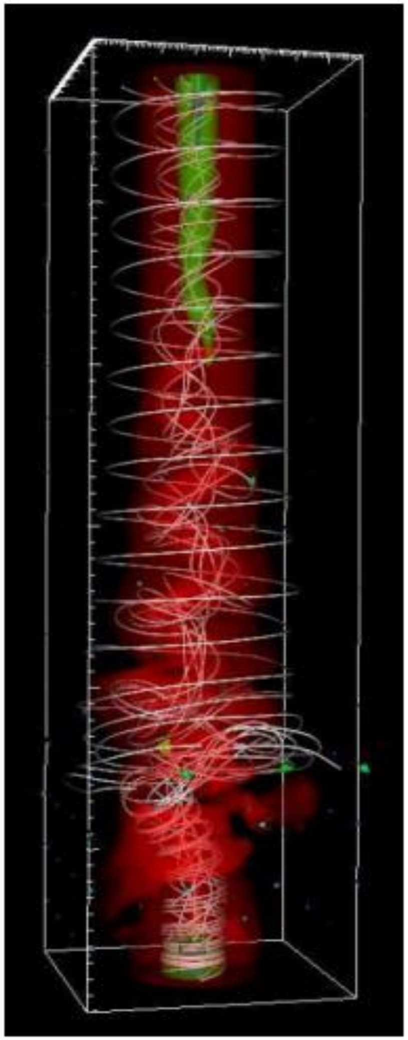
MHD Simulations of Reconnection driven by Kink in Magnetically Dominated Relativistic Jets

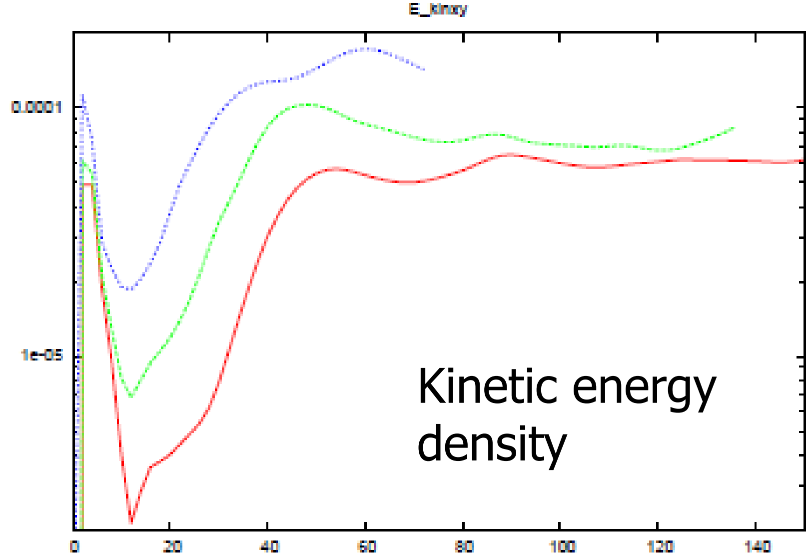
- Precession perturbation allows growth of CD kink instability with helical density distortion.

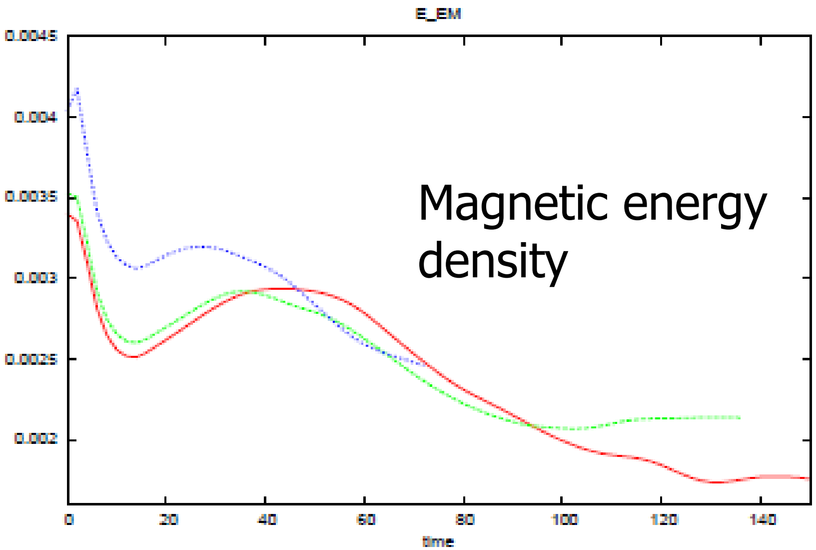
- Helical kink advected with the flow with continuous growth of kink amplitude in non-linear phase.

- Helical structure is disrupted

- ***Magnetic energy converted into kinetic***

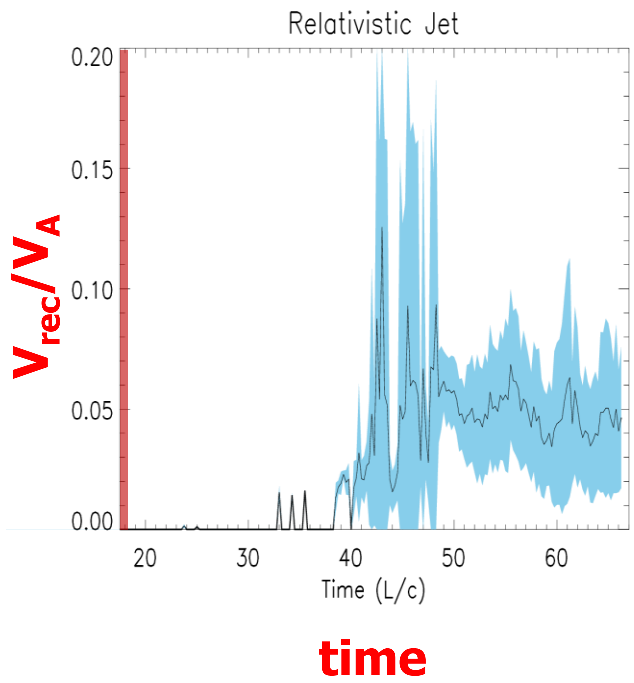


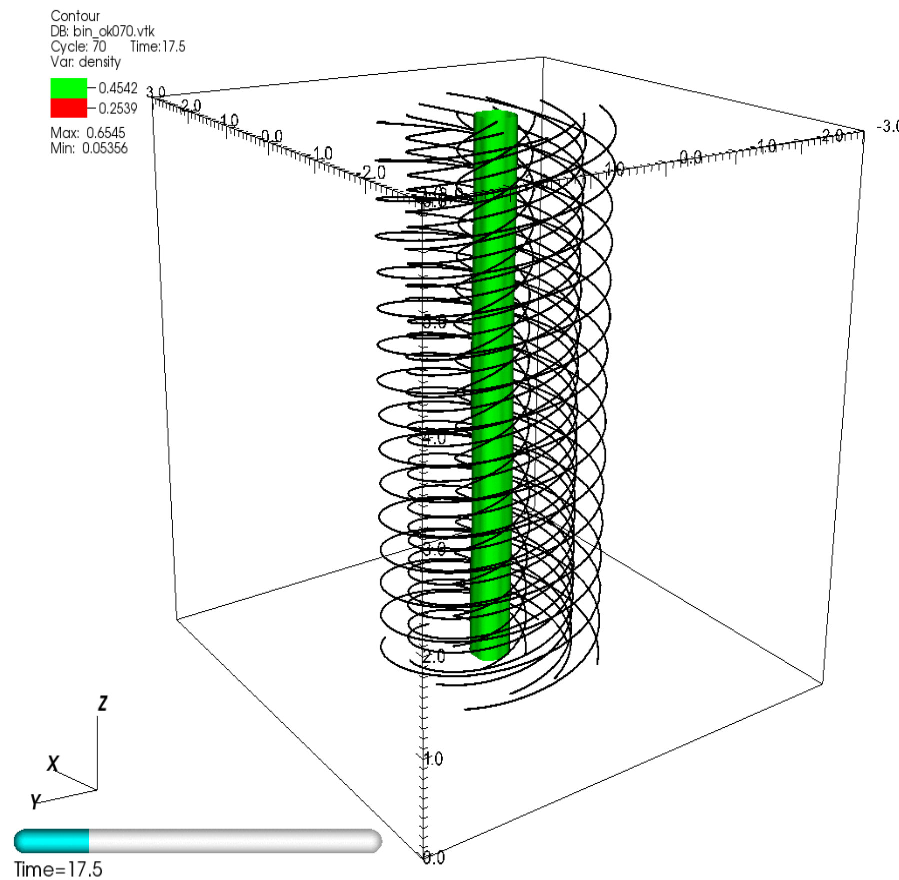




Singh, Mizuno, de Gouveia Dal Pino, ApJ 2016

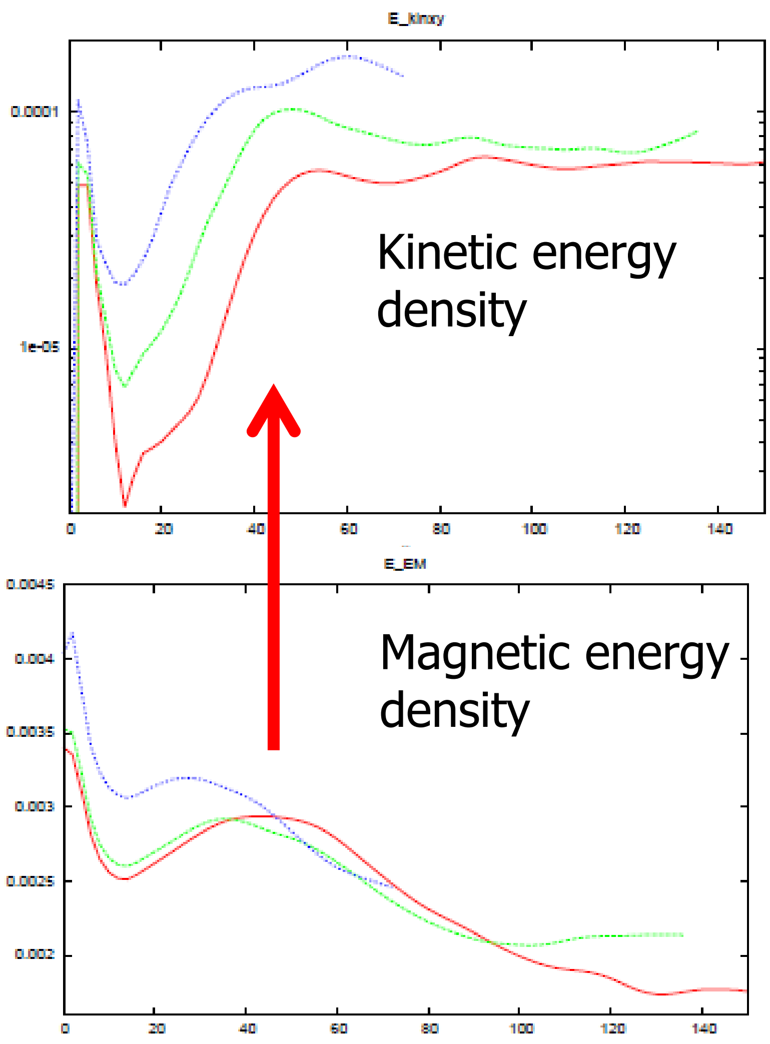
Identification of Fast Reconnection driven by Kink in Relativistic Jets

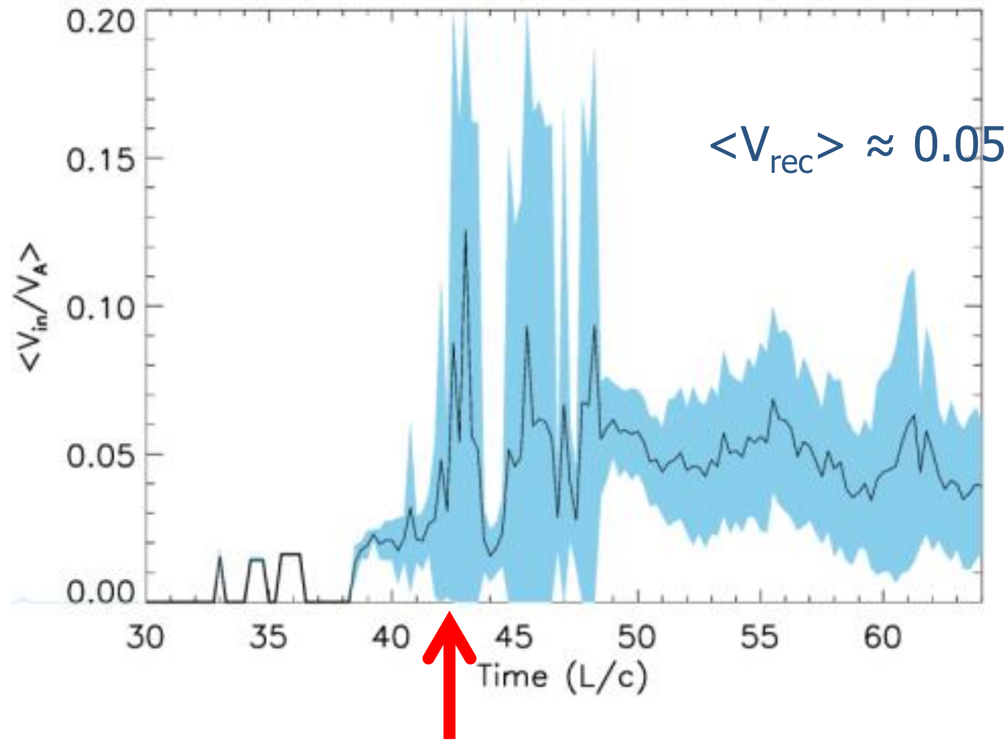




Kadowaki, de Gouveia Dal Pino, Medina-Torrejon, Mizuno, in prep

Identification of Fast Reconnection driven by Kink in Relativistic Jets



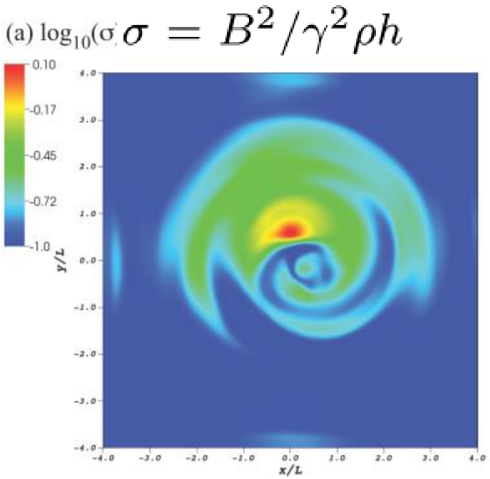


The peak value of v_{rec} ~0.1 occurs when the kink instability attains its maximum

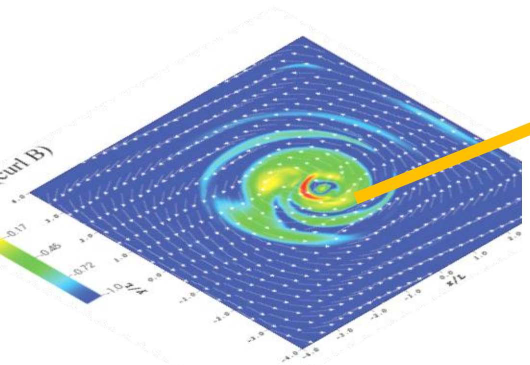
Singh, Mizuno, de Gouveia Dal Pino, ApJ 2016

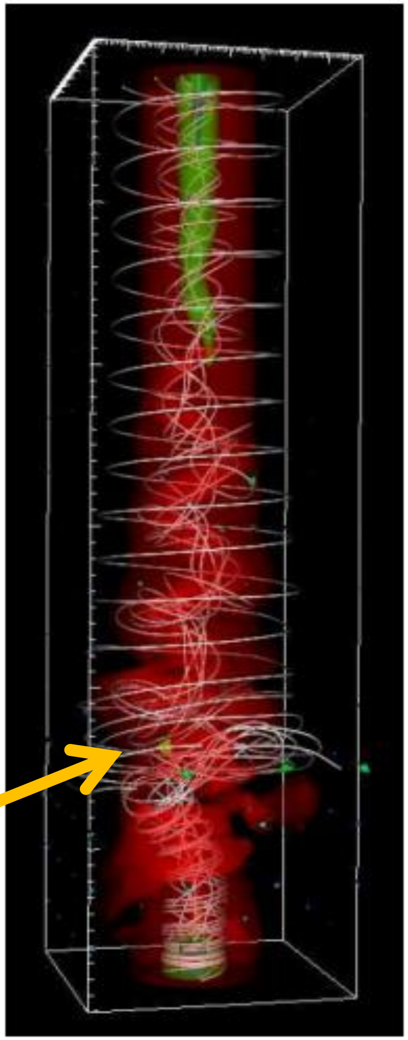
Kadowaki, de Gouveia Dal Pino, Medina-Torrejon, Mizuno, in prep

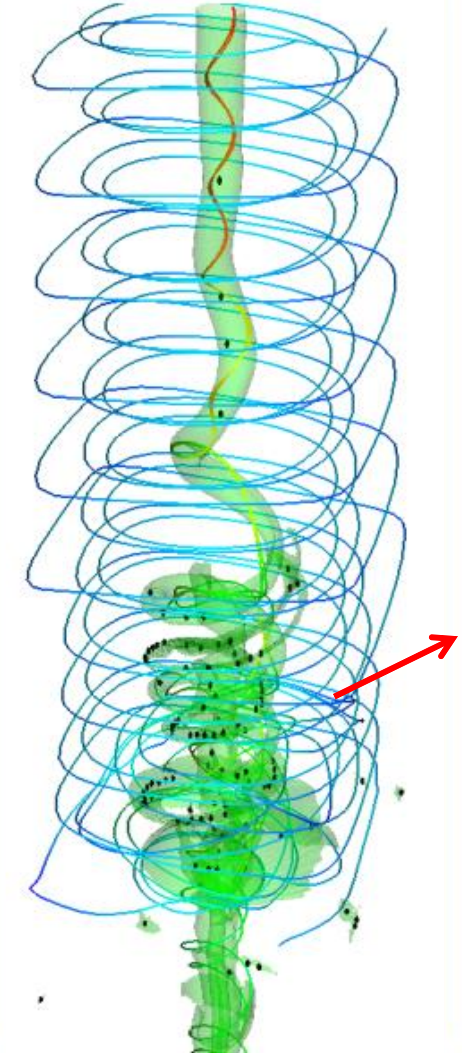
Reconnection driven by Kink in Magnetically Dominated Relativistic Jets (AGNs & GRBs)



$v_{rec} \sim 0.05\ v_A$







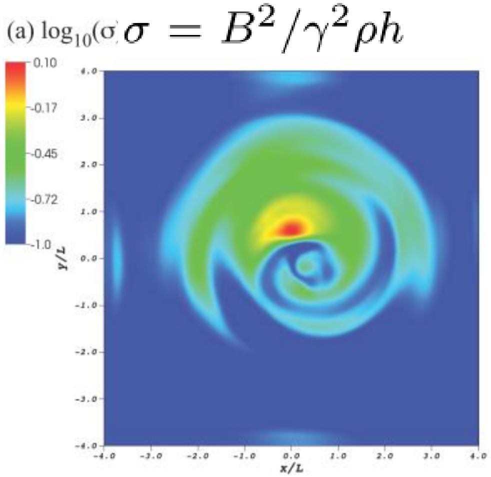
curl B = max

Sites for fast magnetic reconnection

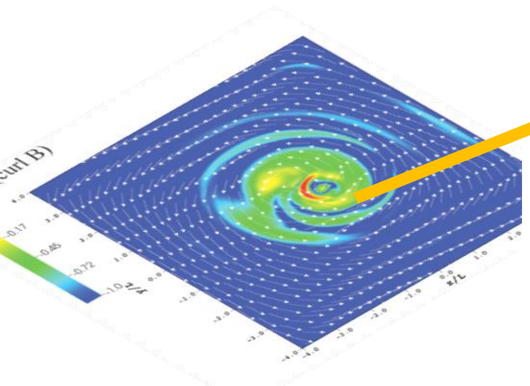
Singh, Mizuno, de Gouveia Dal Pino, ApJ 2016

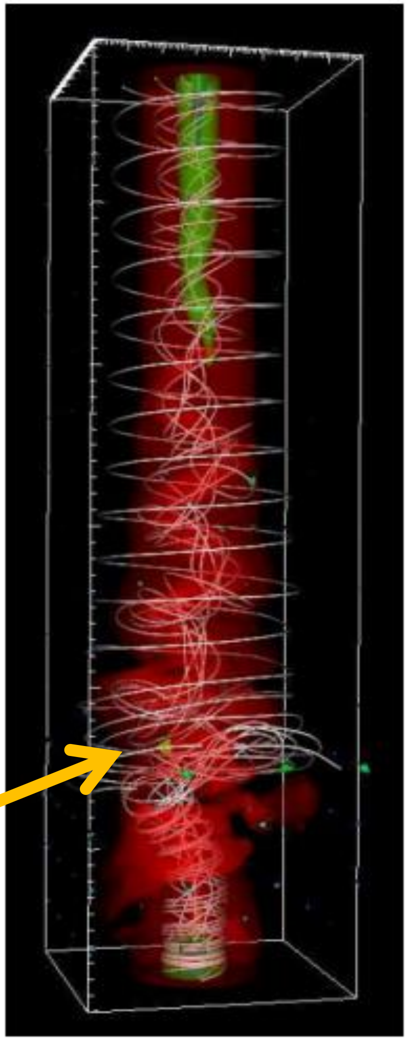
Kadowaki, de Gouveia Dal Pino, Medina-Torrejon, in prep

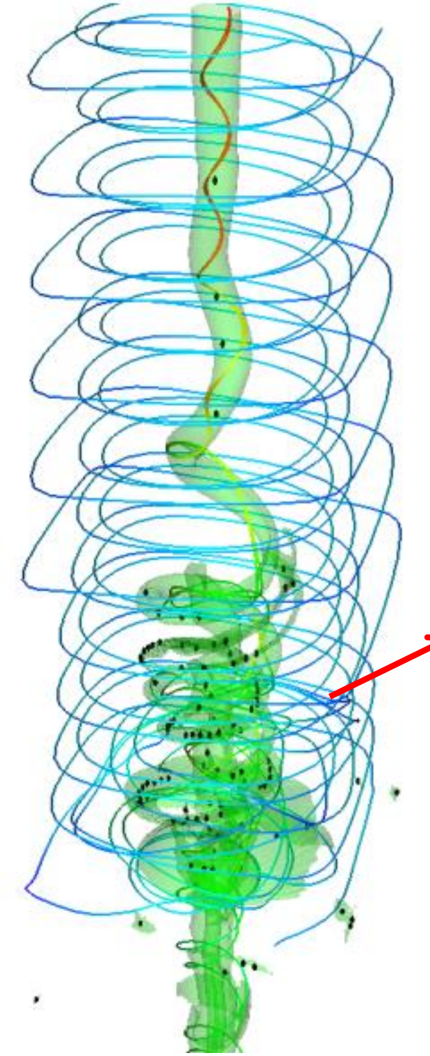
Reconnection driven by Kink in Magnetically Dominated Relativistic Jets (AGNs & GRBs)



$v_{rec} \sim 0.05\ v_A$







curl B = max

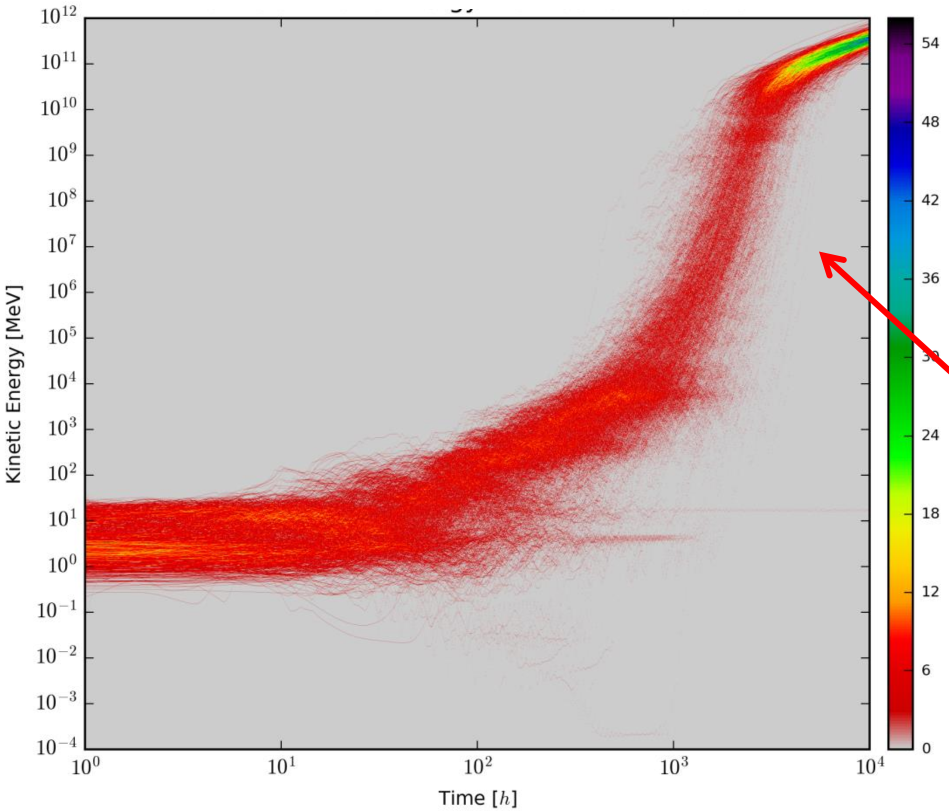
Sites for **magnetic reconnection**, dissipation, **particle acceleration** (and gamma-rays and neutrinos)!

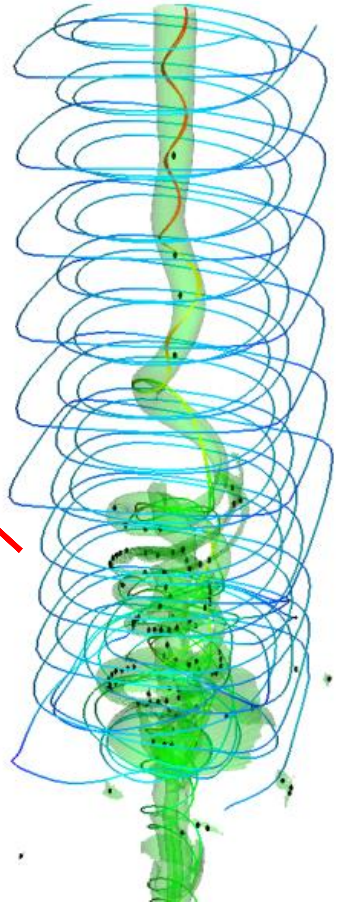
Singh, Mizuno, de Gouveia Dal Pino, ApJ 2016

Medina-Torrejon, de Gouveia Dal Pino, Kowal, Mizuno, Kadowaki, Singh, in prep

Test Particle Acceleration by Magnetic Reconnection in Relativistic Jets

CR energy distribution evolution





Injected 1000 test particles accelerated in reconnection sheets:

10^4 MeV -> 10^{17} - 10^{19} eV
very fast at sub-pc distances (B=0.13 -13 G)

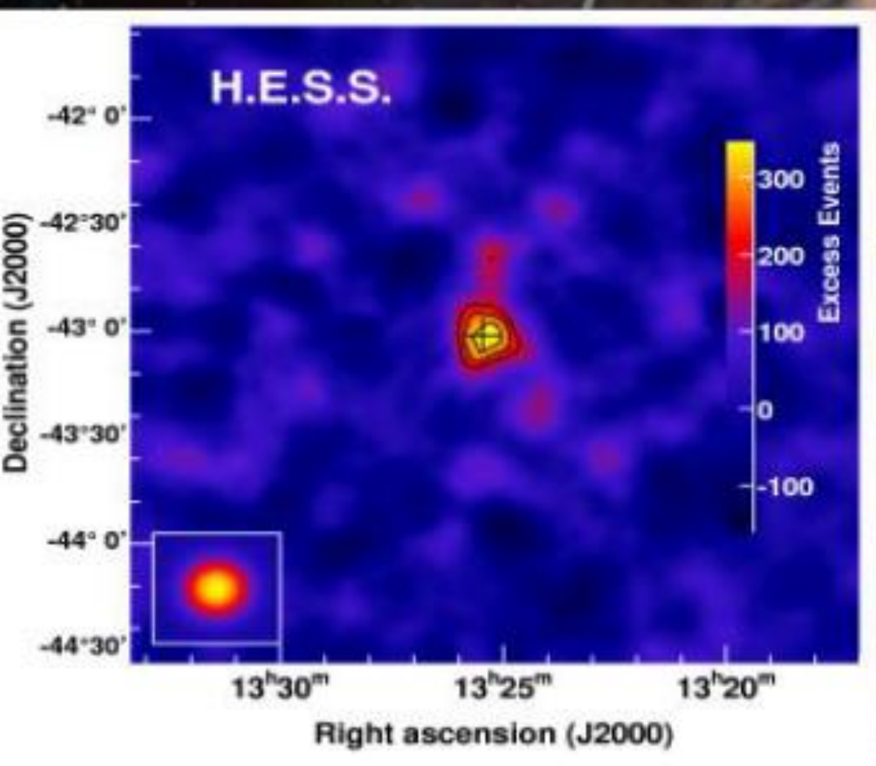
These CRs -> have energy enough to produce Gamma-Rays and Neutrinos !!

(Medina-Torrejon, de Gouveia Dal Pino, Kowal, Mizuno, Kadowaki, Singh, in prep.)

Reconnection Acceleration *in the core region a standing problem ?*

Few Low Luminous AGNs: gamma-ray emitters

Ex. CenA, PerA, IC310, M87, PKS0625-35, 3C 264 (TeVs)
(e.g. Torresi 2018)



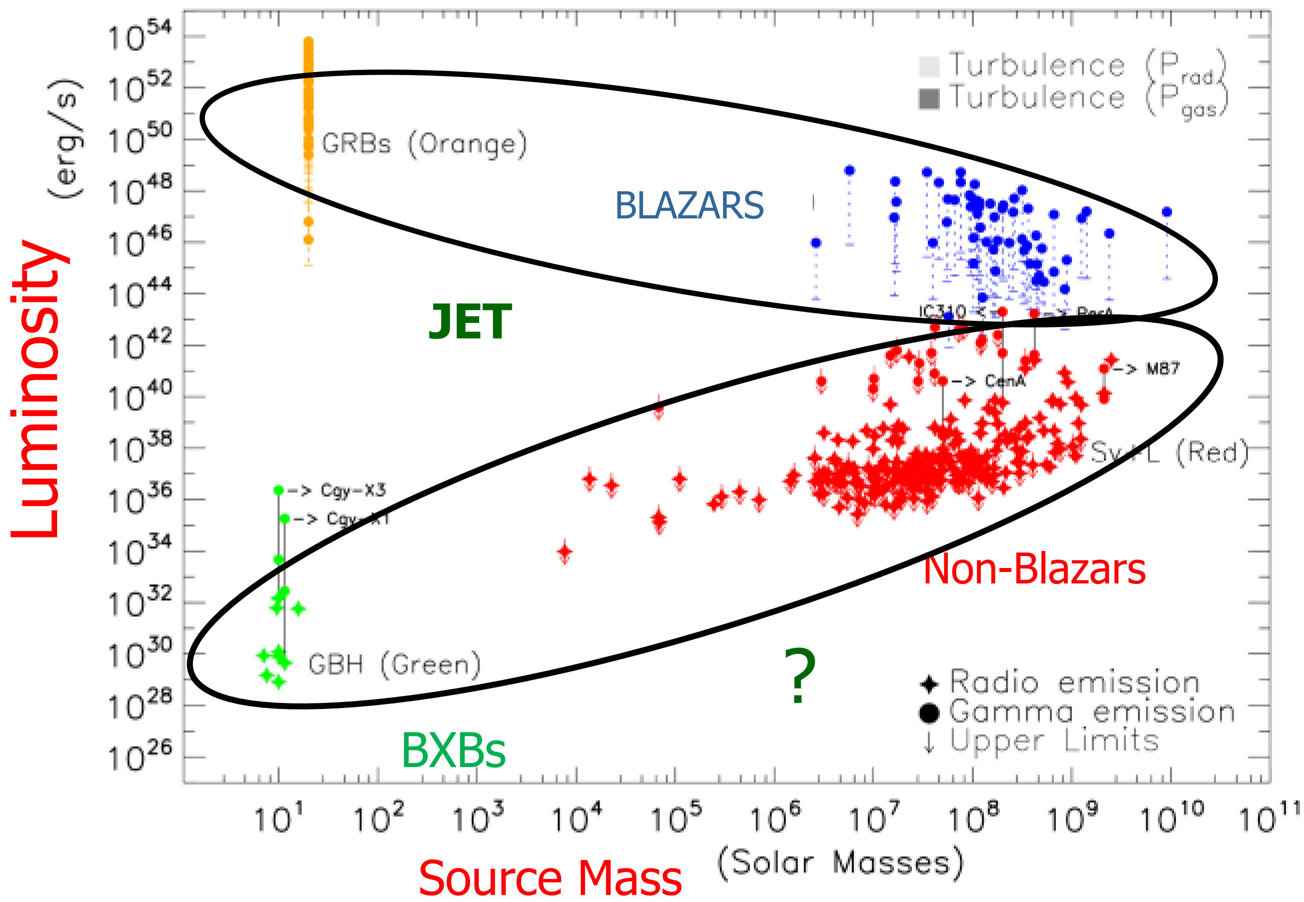
- ✓ *Is emission from core or jet ?*
- ✓ **Rapid variability emission:**
  size ~ c t_{var}~100 r_s

-> compact *emission: core?*

- ✓ ***If core:*** *magnetized*

-> Reconnection acceleration?

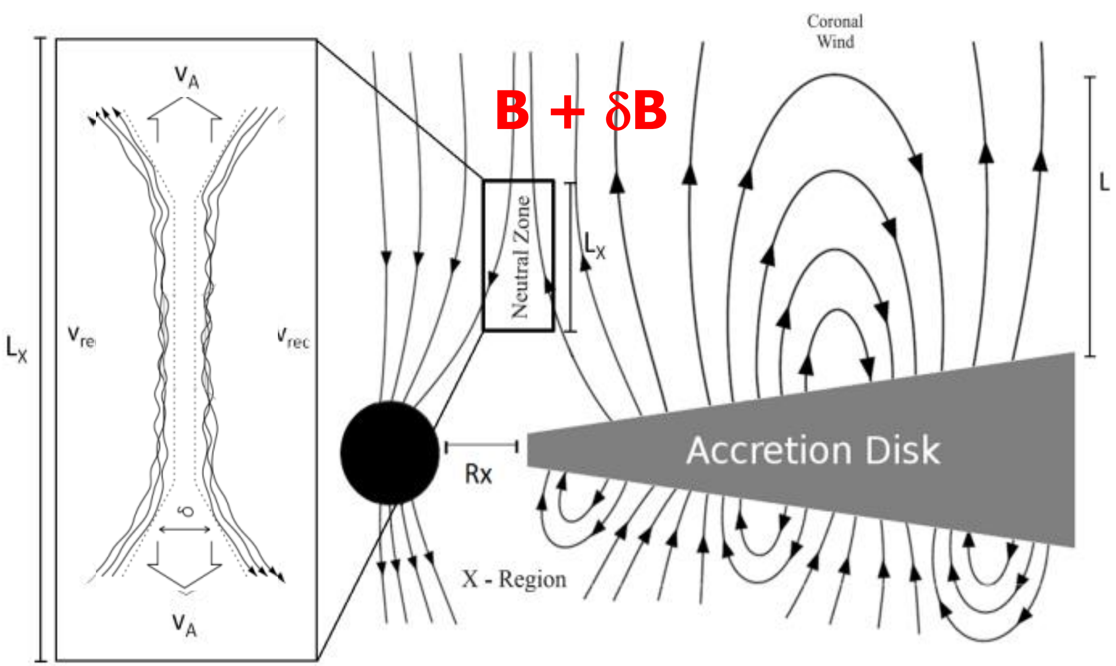
Radio and Gamma-Ray Power versus Mass

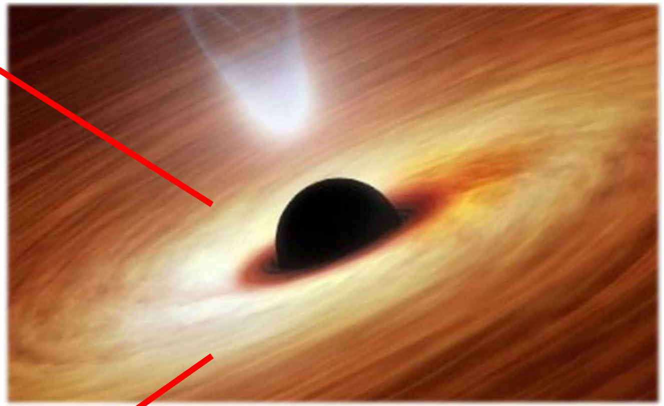


Kadowaki, de Gouveia Dal Pino, Singh, ApJ 2015

Proposed Magnetic Reconnection acceleration model in the surrounds of BHs to explain VHE

Accretion disk/jet systems (AGNs & galactic BHs)



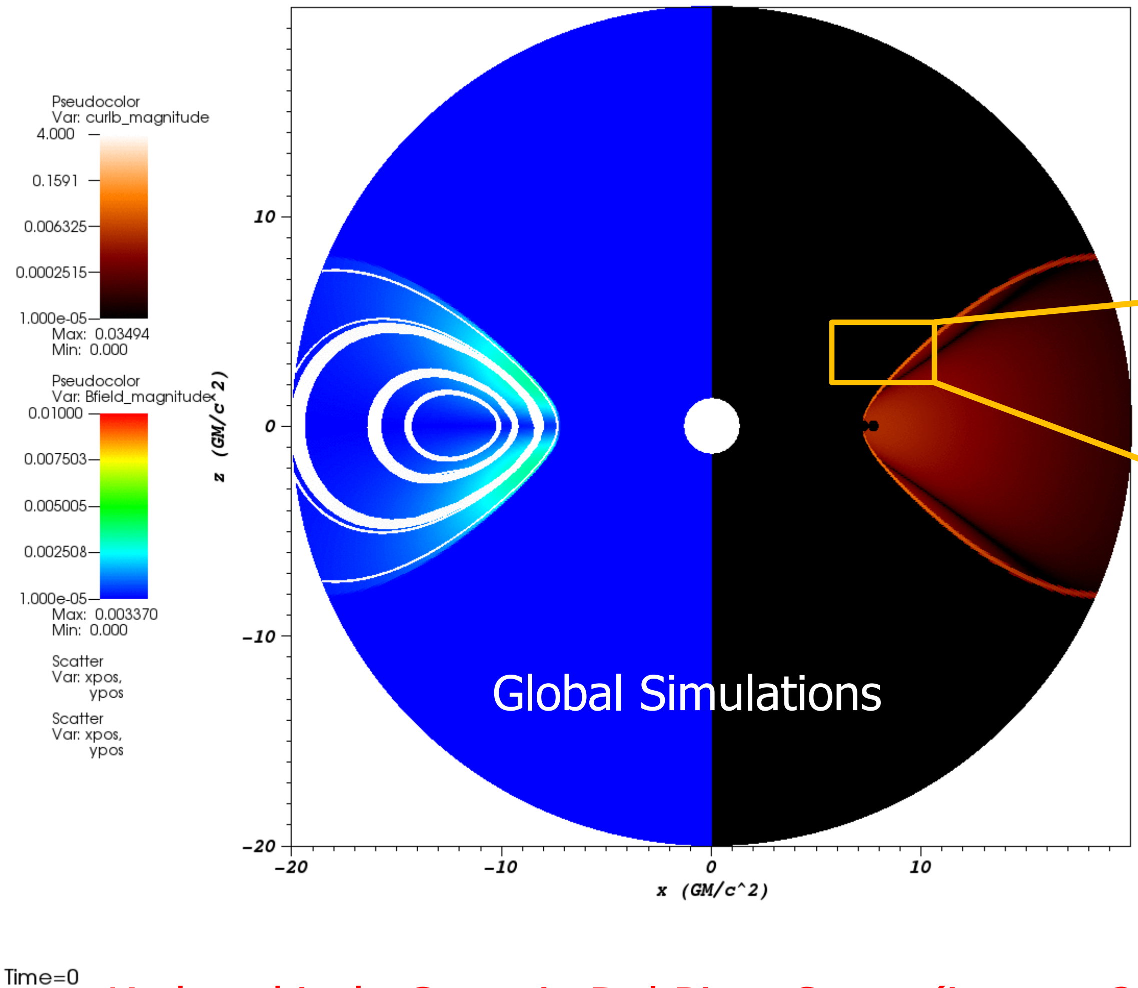


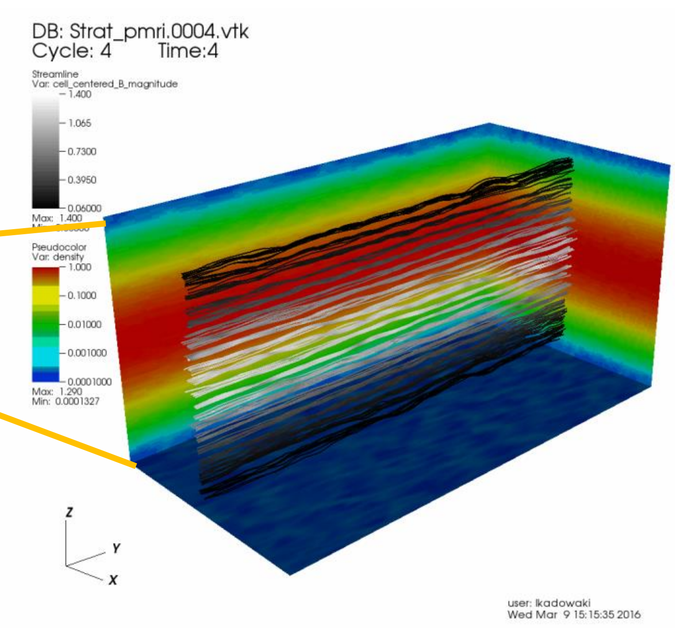
AGNs and BHBs

de Gouveia Dal Pino & Lazarian 2005; de Gouveia Dal Pino+2010
Kadowaki, de Gouveia Dal Pino, Singh, ApJ 2015
Singh, de Gouveia Dal Pino, Singh, ApJ Lett. 2015

Evidence of Fast Reconnection in GR-MHD Simulations of accretion disk/corona around BHs

Kadowaki, de Gouveia Dal Pino, Stone, ApJ (2018a)

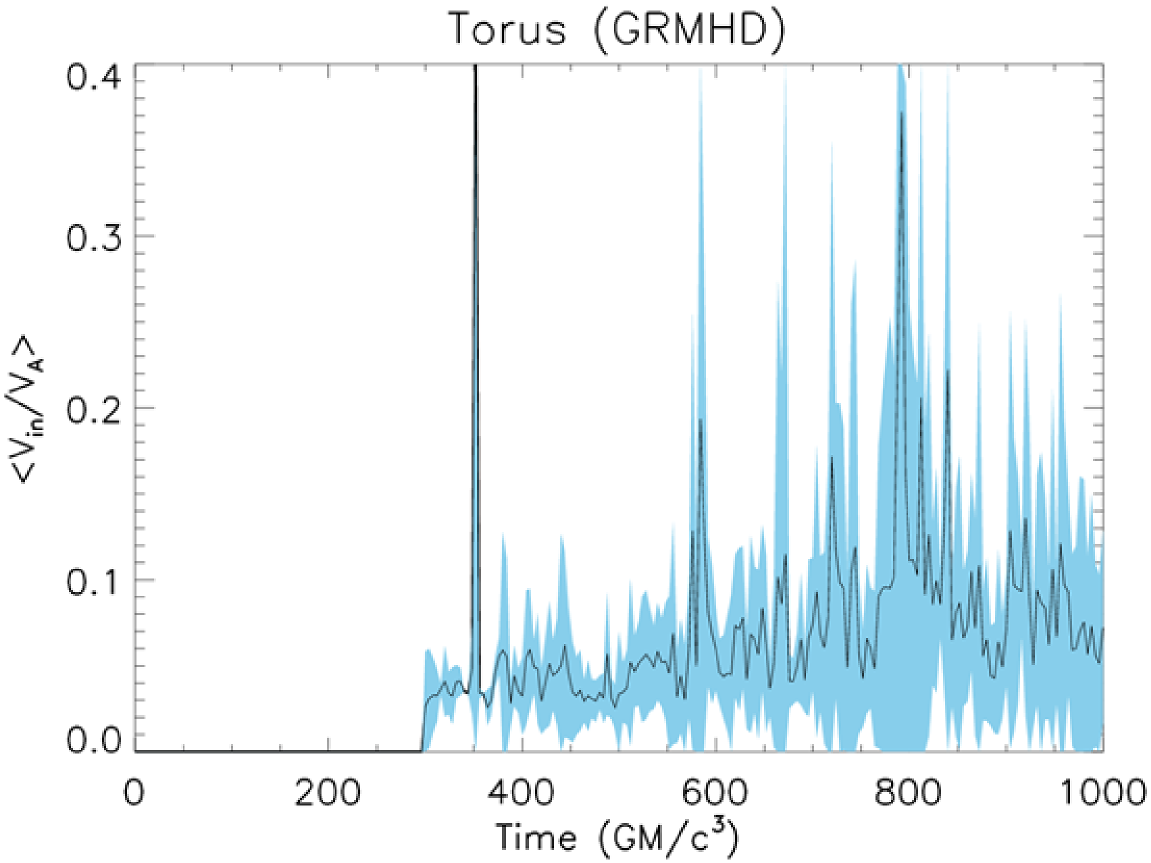




High resolution shearing box 3D MHD simulations (ATHENA)

Kadowaki, de Gouveia Dal Pino, Stone (in prep.2018b)

Reconnection Velocities in the accretion disk around BHs



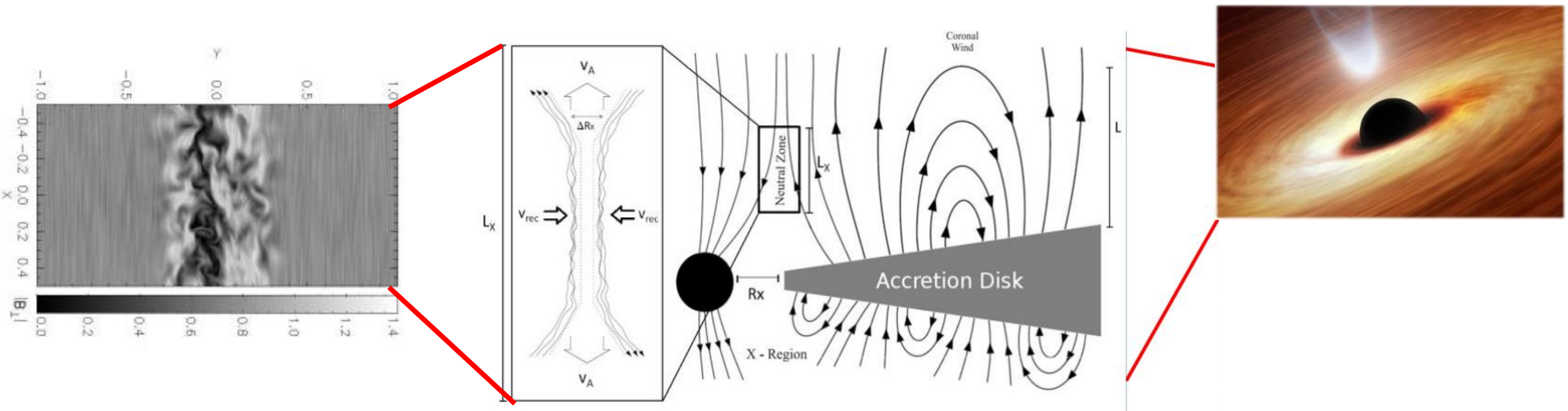
- **Average reconnection velocities $V_{rec} \sim 0.05\ V_A$**

(Kadowaki, de Gouveia Dal Pino, Stone, 2018b, in prep.)

Calculating Reconnection Power in the surrounds of BHs

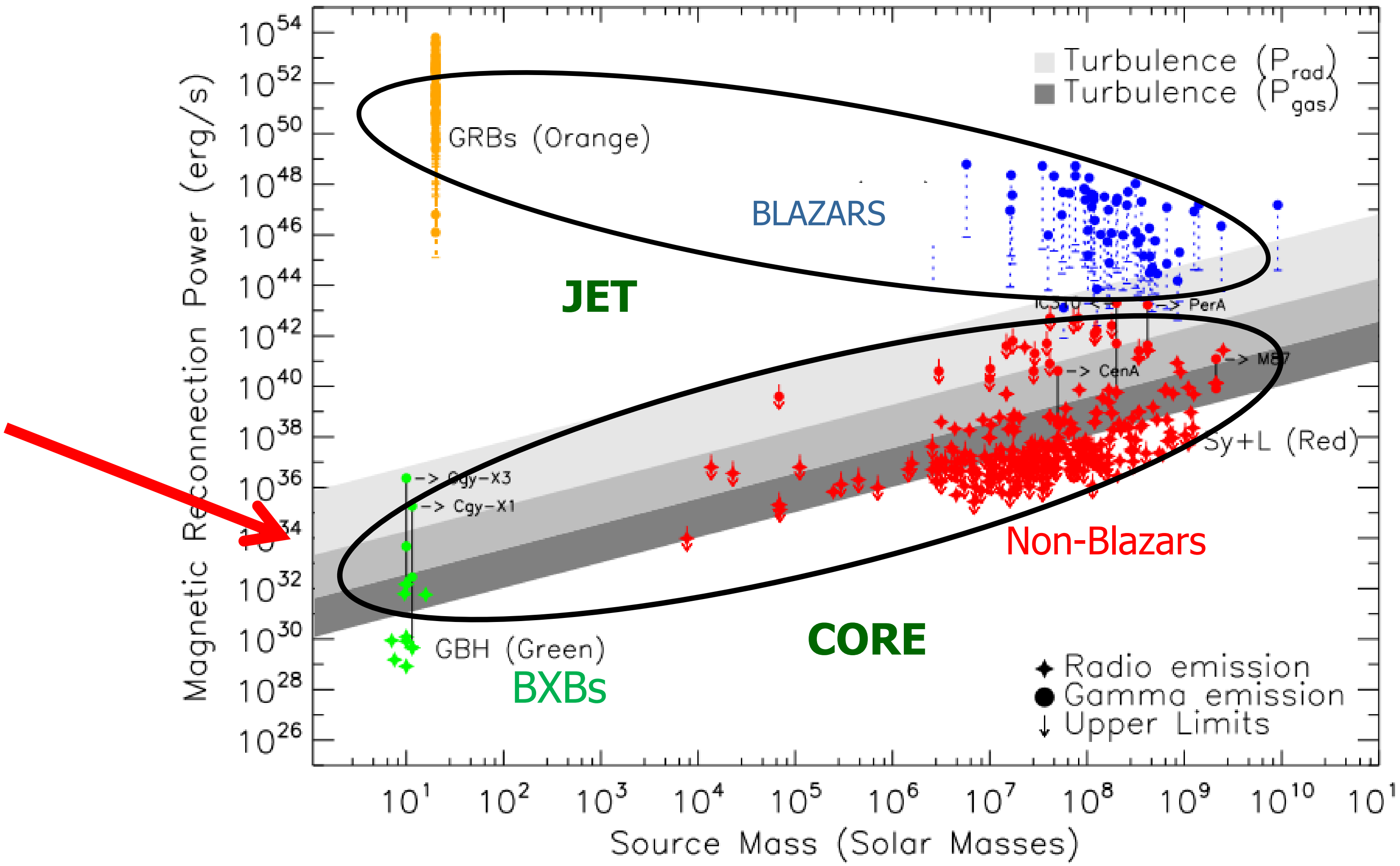
Magnetic Power released by fast reconnection

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



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

Proposed Magnetic Reconnection Model around BHs for Gamma-Ray emission

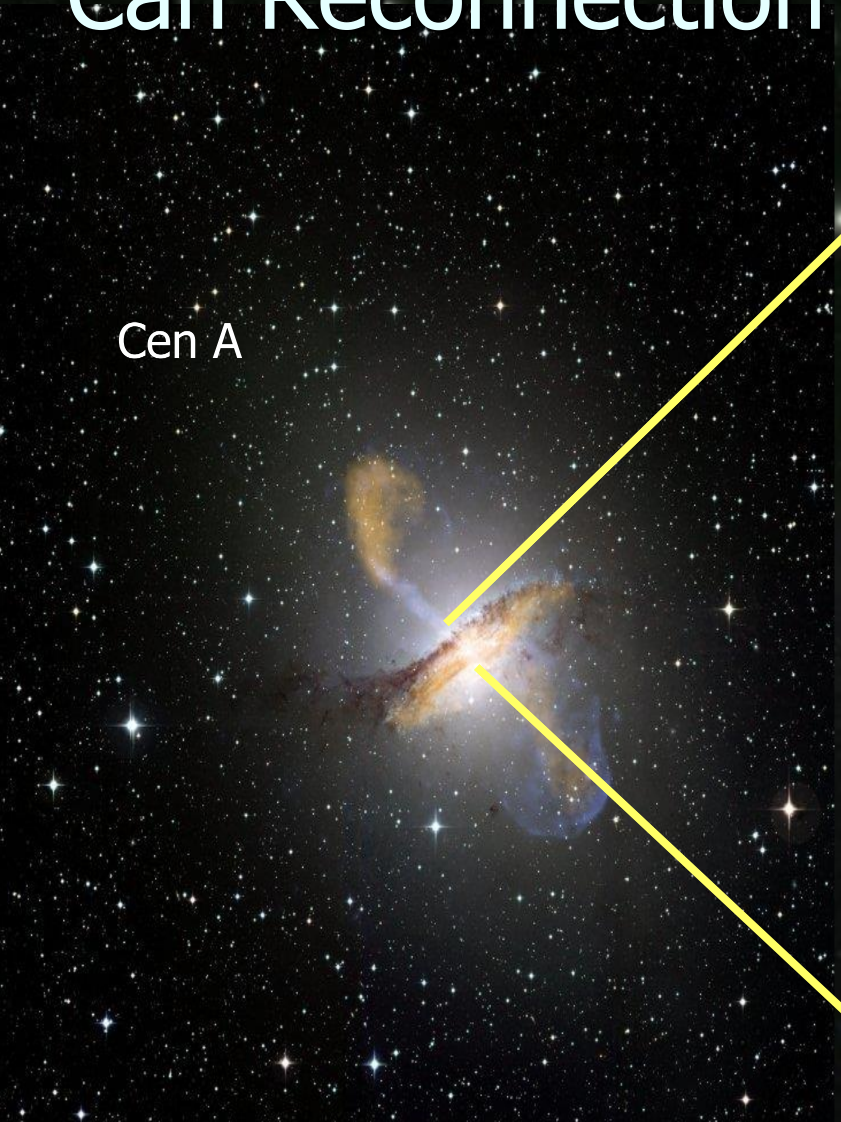


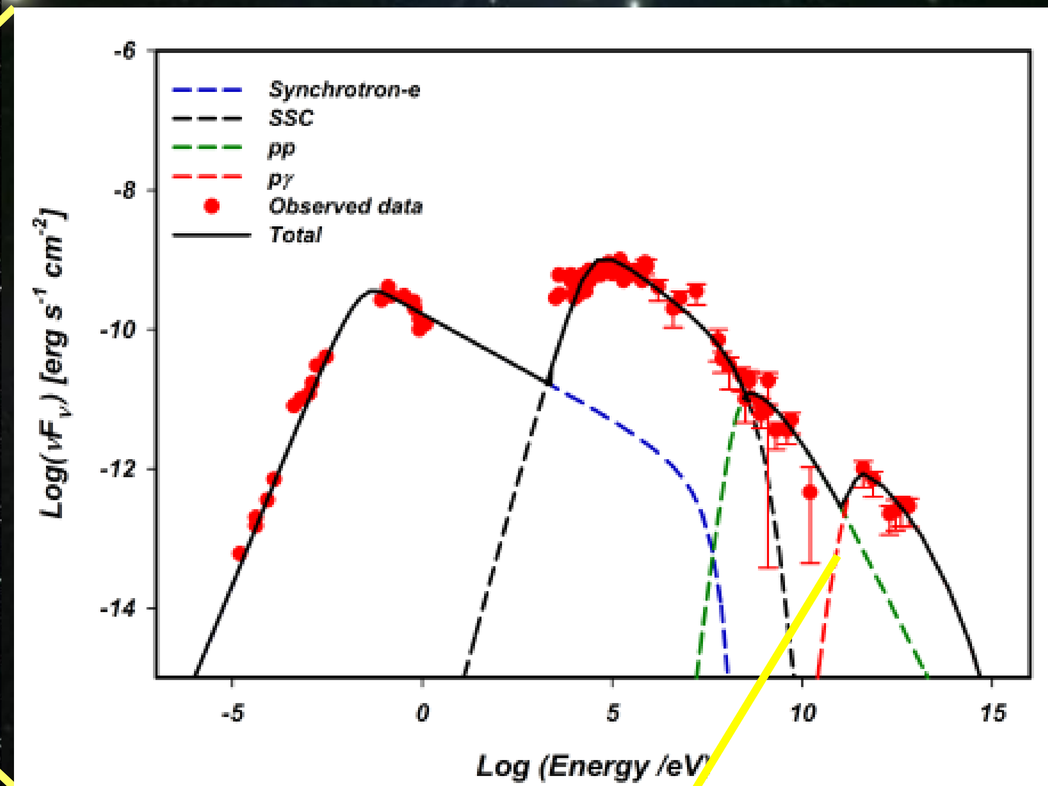
$0.0005 \le \dot{m} \le 1$
$1 \le l \le 18$
$l_x \le l$
$r_x = 6$
$\Gamma \sim 1$

L_X = 0.02 - 44 R_S
R_X = 1.1 - 186 R_S
m = 0.0005 - 0.05

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

Can Reconnection explain observed SEDs?



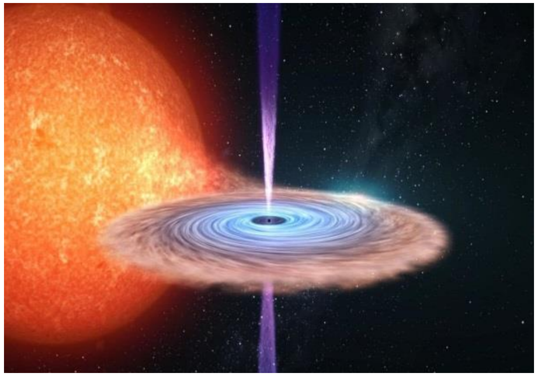


TeV Gamma-rays

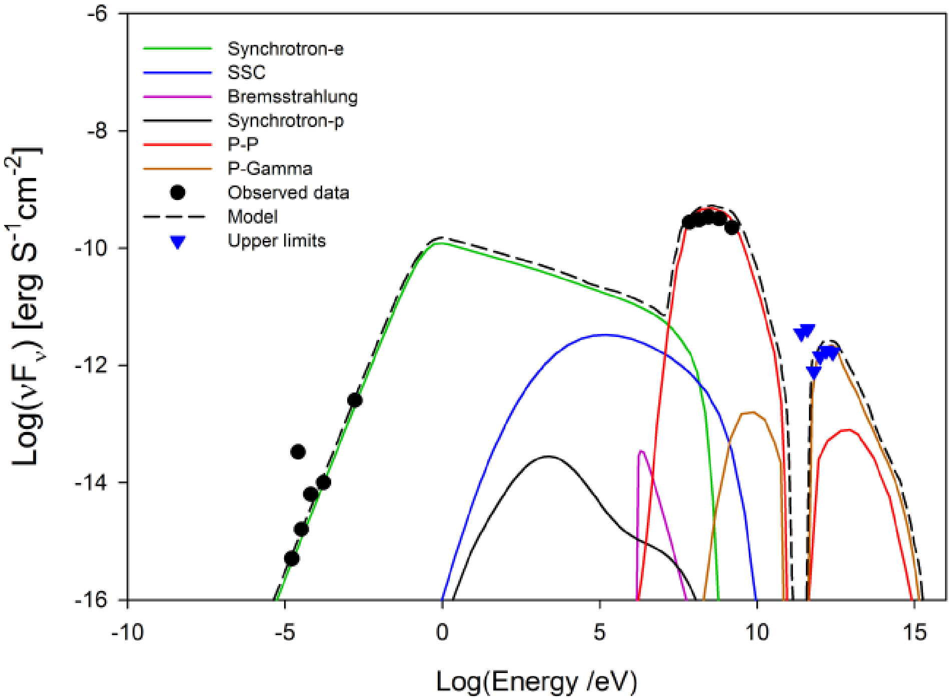
Reconnection Acceleration & Radiative Losses

✓ **Cooling of the accelerated particles -> emission:**

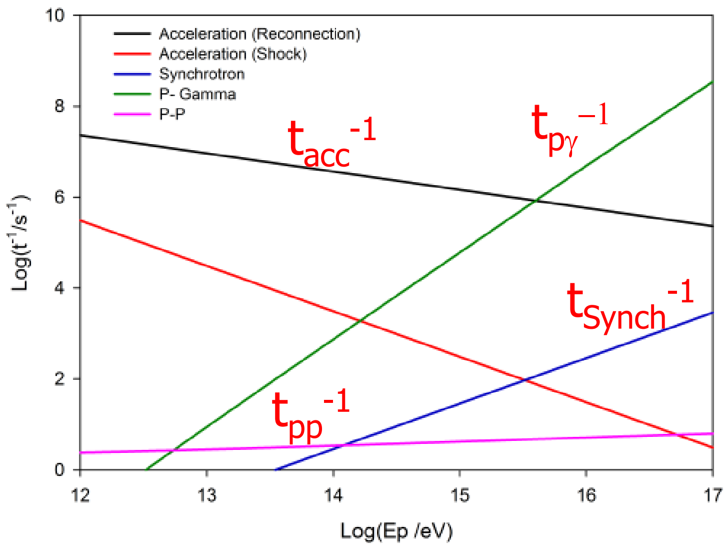
$t_{acc} \sim t_{loss}$**(Synchrotron, SSC, pp, pγ)**



Ex.: Galactic Black Hole Cyg X3



Spectral Energy Distribution (SED)



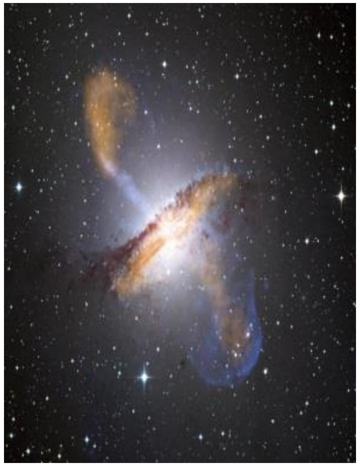
Khiali, de Gouveia Dal Pino, del Valle, MNRAS 2015

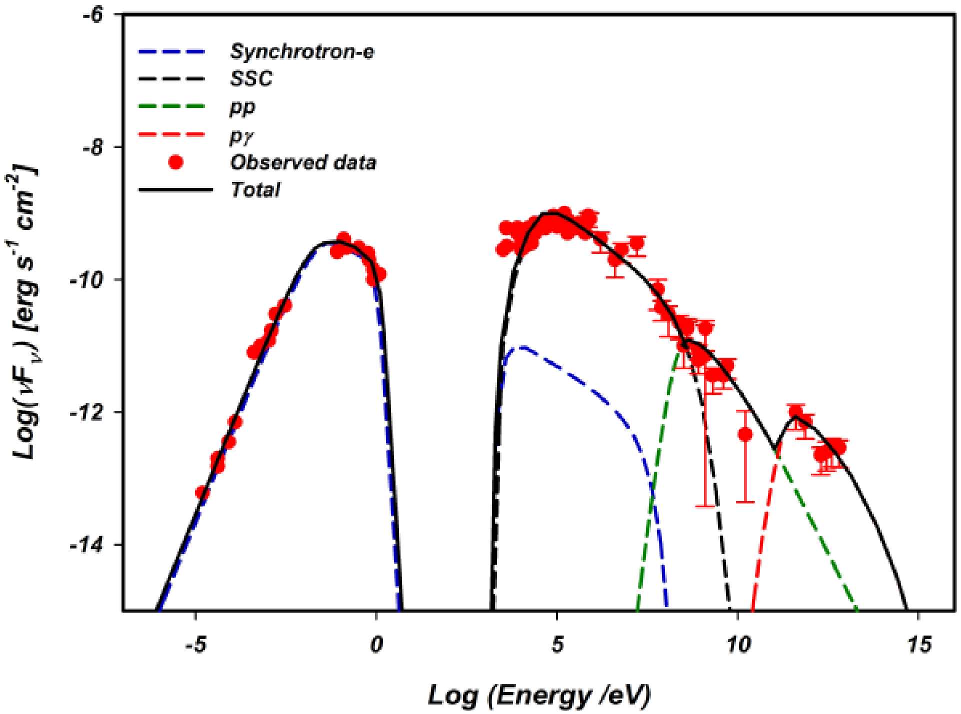
Reconnection Acceleration & Radiative Losses

✓ **Cooling of the accelerated particles -> emission:**

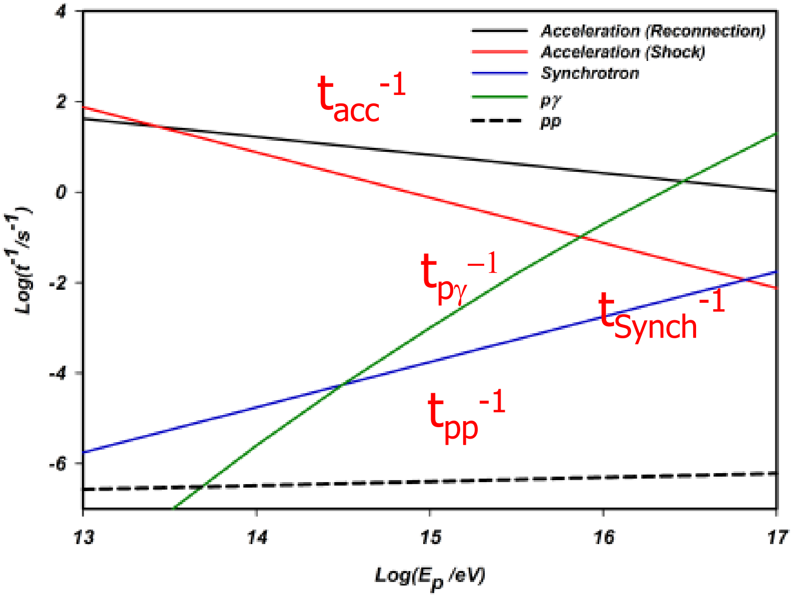
$$t_{acc} \sim t_{loss}(\text{Synchrotron, SSC, pp, p}\gamma)$$

Ex.: Radio-galaxy Cen A





Spectral Energy Distribution



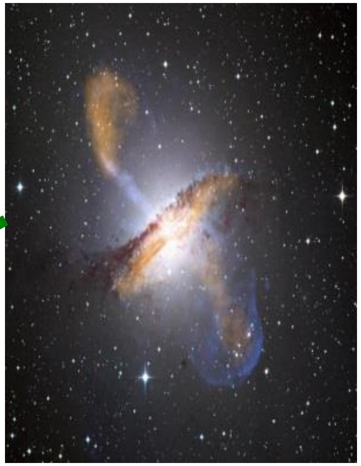
Khiali, de Gouveia Dal Pino, Sol 2016 (arXiv:1504.07592)

Reconnection Acceleration & Radiative Losses

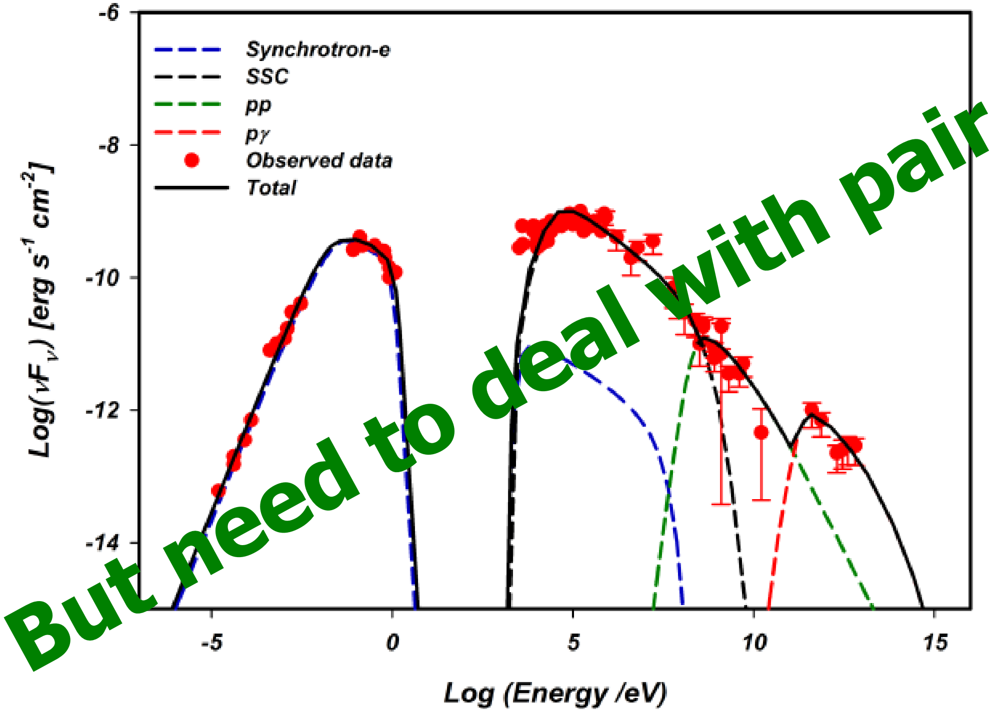
- ✓ **Cooling of the accelerated particles -> emission:**

$t_{acc} \sim t_{loss}$(Synchrotron, SSC, pp, pγ)

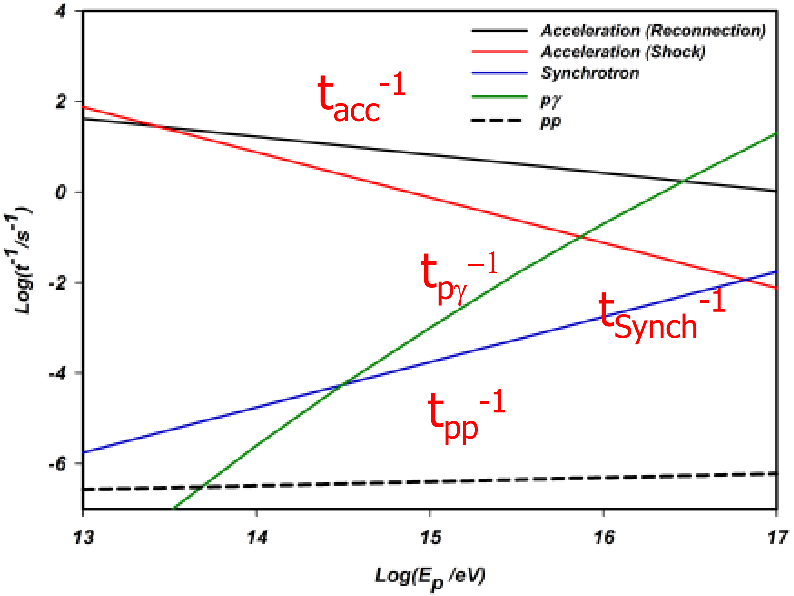
Ex.: Radio-galaxy Cen A



But need to deal with pair absorption!



Spectral Energy Distribution



Khiali, de Gouveia Dal Pino, Sol 2016 (arXiv:1504.07592)

VHE emission due to CR acceleration by reconnection in the surrounds of BHs

We combine 3 techniques (to deal with full emission and also gamma-ray absorption by pair production)

GRMHD:

Axi-symmetric HARM code Gammie et al. (2003)

↓

Gas density and magnetic field

Radiative Transfer:

GRMONTY code Dolence et al. (2009)

↓

Background Photon field: leptonic synchrotron & IC

Propagation of CR Accelerated by Reconnection :

CRPropa3 code Alves Batista et al. (2016)

↓

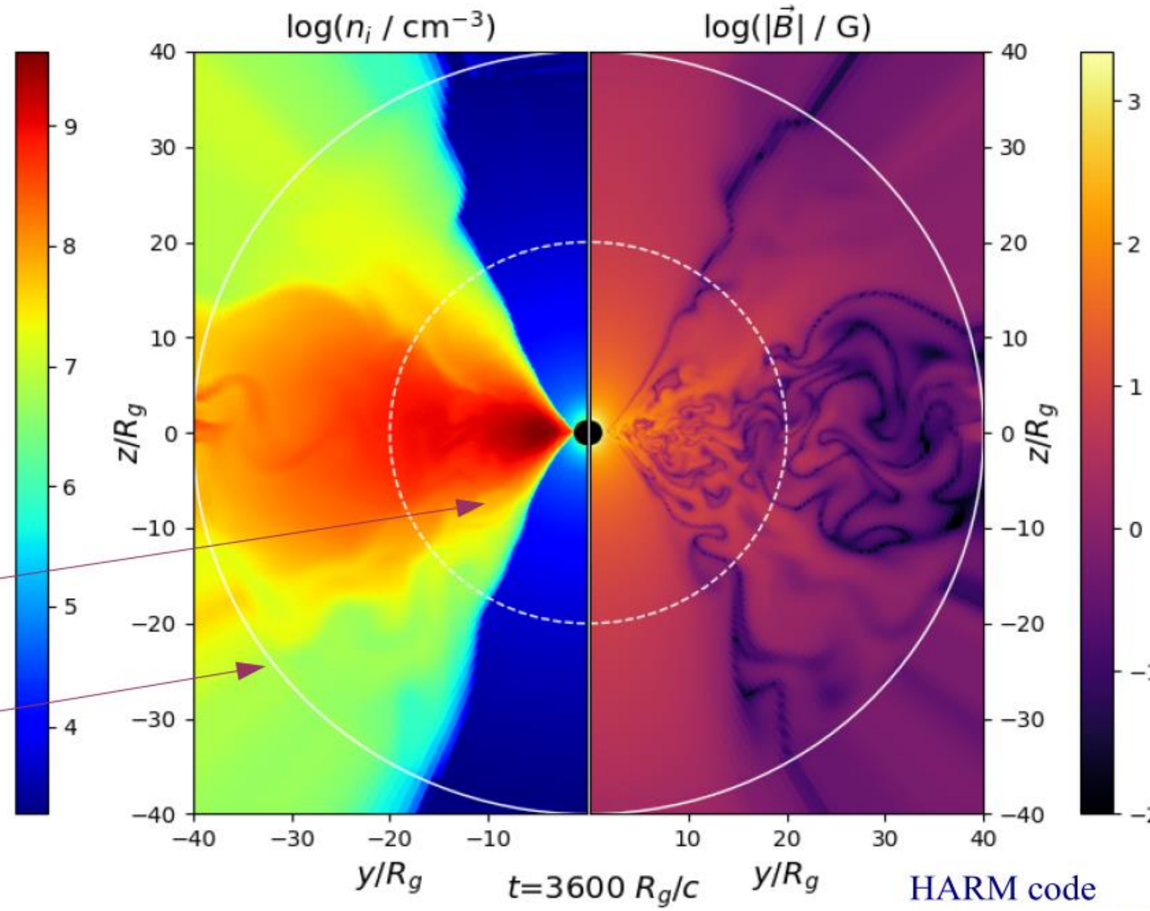
To probe hadronic Emission/absorption (TeVs)

(Rodriguez-Ramirez, de Gouveia Dal Pino, Alves-Batista 2018, in prep.)

VHE emission due to CR acceleration by reconnection in the surrounds of BHs

- BH mass: $3.4 \times 10^8\ M_{\odot}$
- Spin parameter: 0.95
- Tp/Te = 120

Numerical GRMHD ADAF simulations of the core region of LLAGN –
Ex.: **Cen A**



GRMHD simulations -> provide **background matter and magnetic fields distributions** for 3D simulations of CRs interactions with photons, matter and magnetic fields (alsoRodriguez-Ramirez's talk)

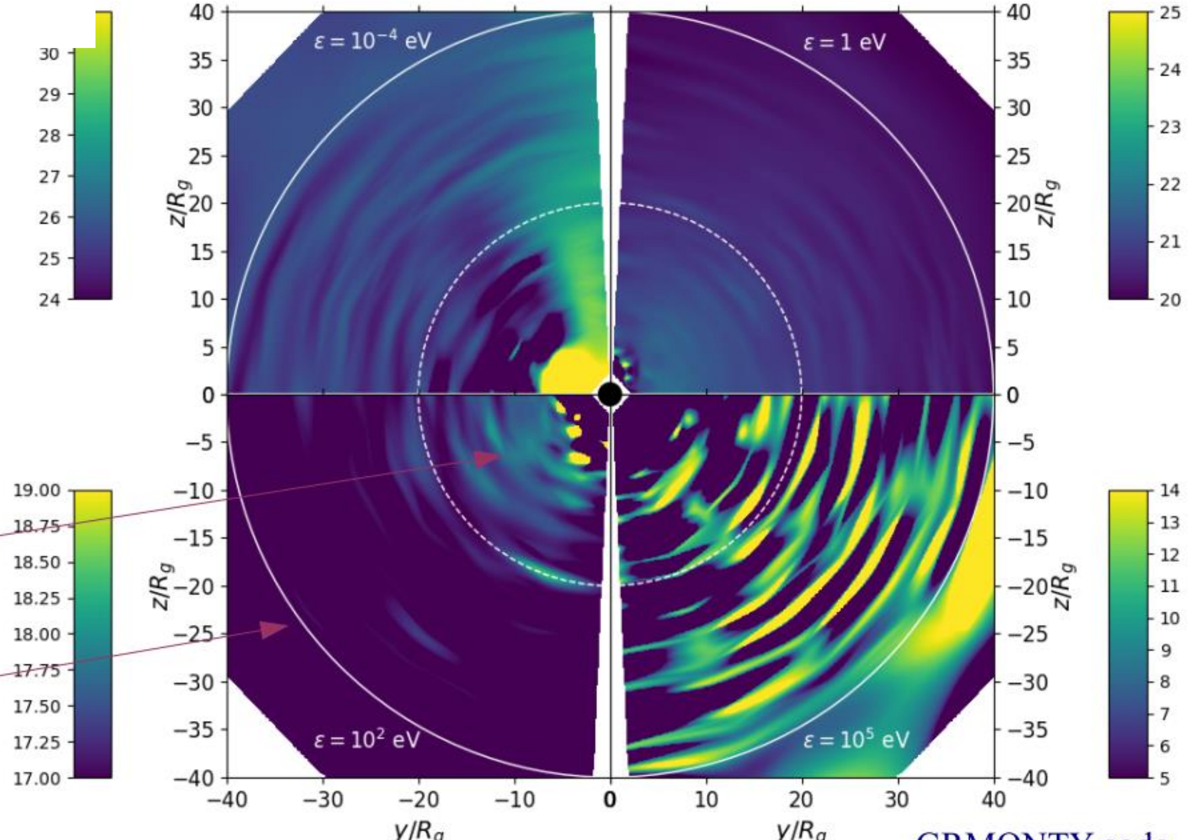
VHE emission due to CR acceleration by reconnection in the surrounds of BHs

- Spin parameter: 0.95
- Tp/Te = 120

Radiative Transfer simulations of the core region of LLAGN –
Ex.: Cen A

CRs injection

Detection boundary

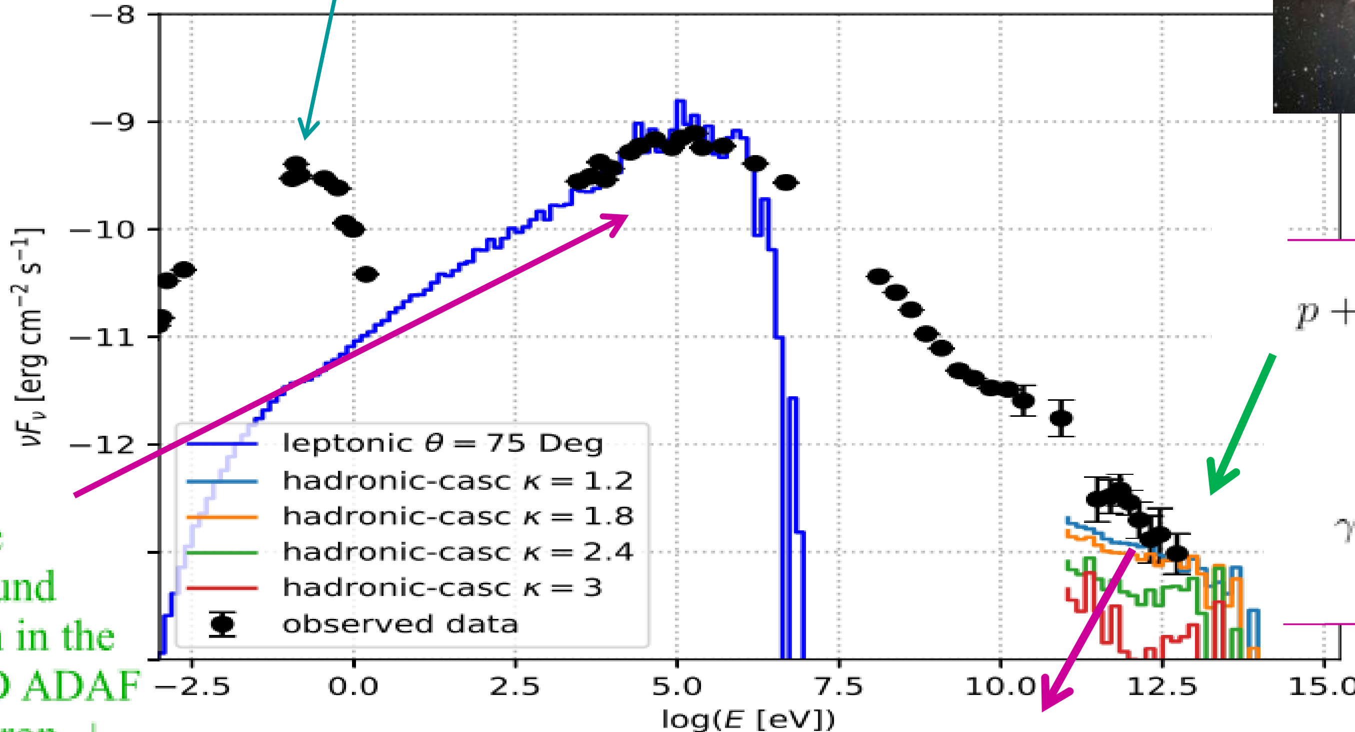


GRMONTY code
Dolence et al. (2003)

Radiative Transfer simulations -> provide **background photon field distribution (Synch+IC)** for simulations of CRs interactions with photons, matter and magnetic fields (Rodriguez-Ramirez, de Gouveia Dal Pino, Alves-Batista 2018, in prep.)

Reconnection acceleration and Hadronic-Leptonic Emission of CenA core

This comes from the jet not treated here



Hadronic

$$p + p_b \to \begin{cases} \pi^0 \to 2\gamma, \\ \eta \to 2\gamma. \end{cases}$$

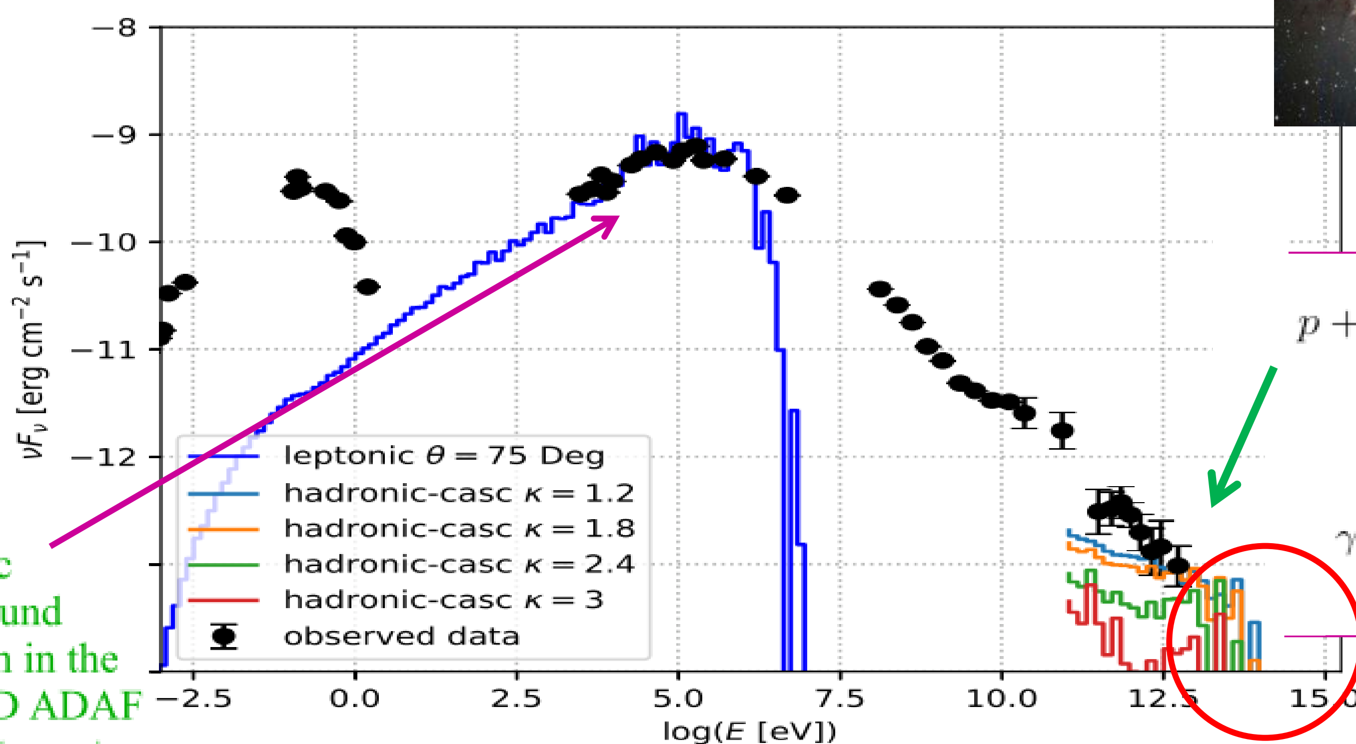
$$\gamma + \gamma_b \to \begin{cases} \mathrm{e}\pm \\ \mathrm{e}\pm + \mathrm{e}\pm \end{cases}$$

Leptonic background radiation in the GRMHD ADAF (synchrotron + IC) from core

TeVs from the core !

(Rodriguez-Ramirez, de Gouveia Dal Pino, Alves-Batista 2018, in prep.)

Reconnection acceleration and Hadronic-Leptonic Emission of Cen A



Hadronic

$$p + p_b \to \begin{cases} \pi^0 \to 2\gamma, \\ \eta \to 2\gamma. \end{cases}$$

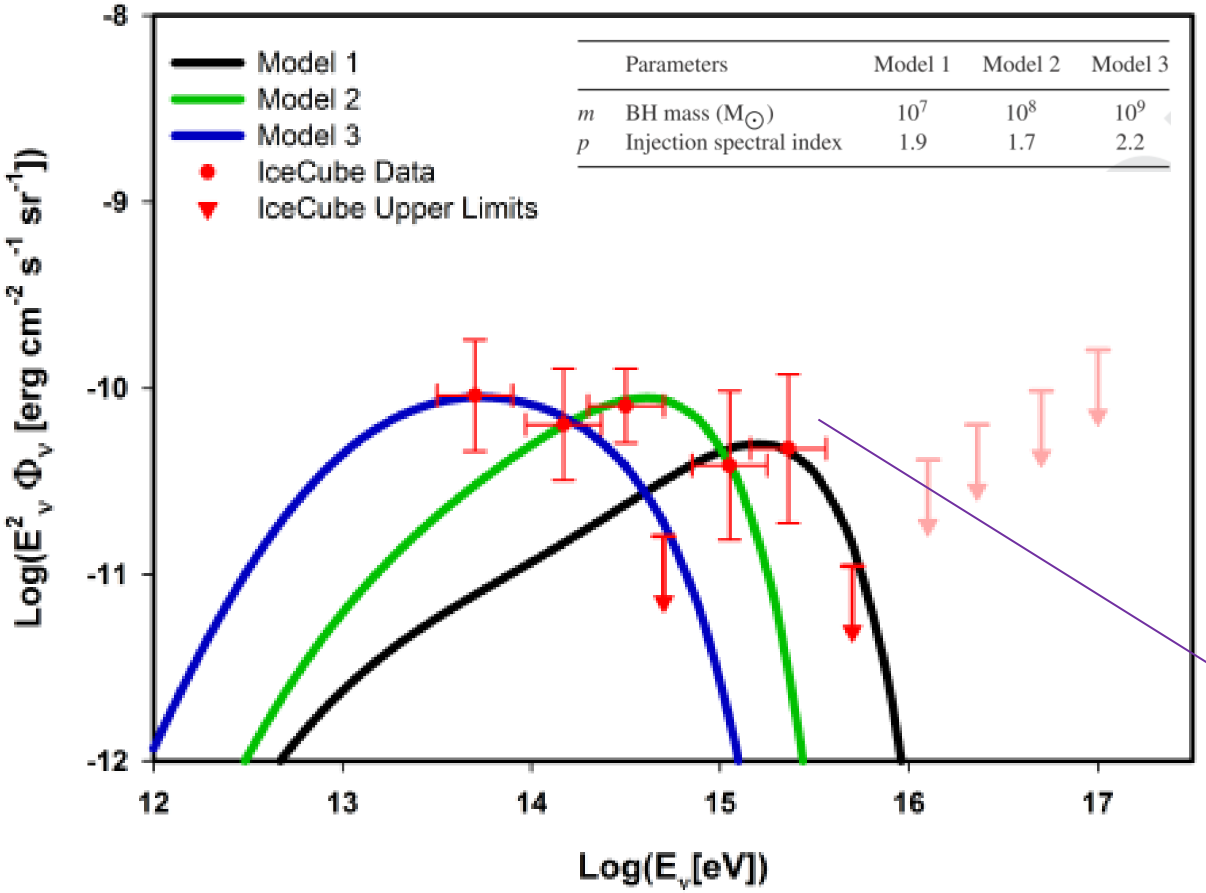
$$\gamma + \gamma_b \to \begin{cases} e\pm \\ e\pm + e\pm \end{cases}$$

Leptonic background radiation in the GRMHD ADAF (synchotron + IC)

CTA ?

(Rodriguez-Ramirez, de Gouveia Dal Pino, Alves-Batista 2018, in prep.)

Production of Ice-cube neutrino emission in *cores* of low luminous AGNs (z ~ 0 - 5.2) due to particles accelerated by reconnection



p + photons → π + p

$\pi^o \rightarrow \gamma\gamma$

$\pi^{\pm} \rightarrow \mu^{\pm}\,\nu$

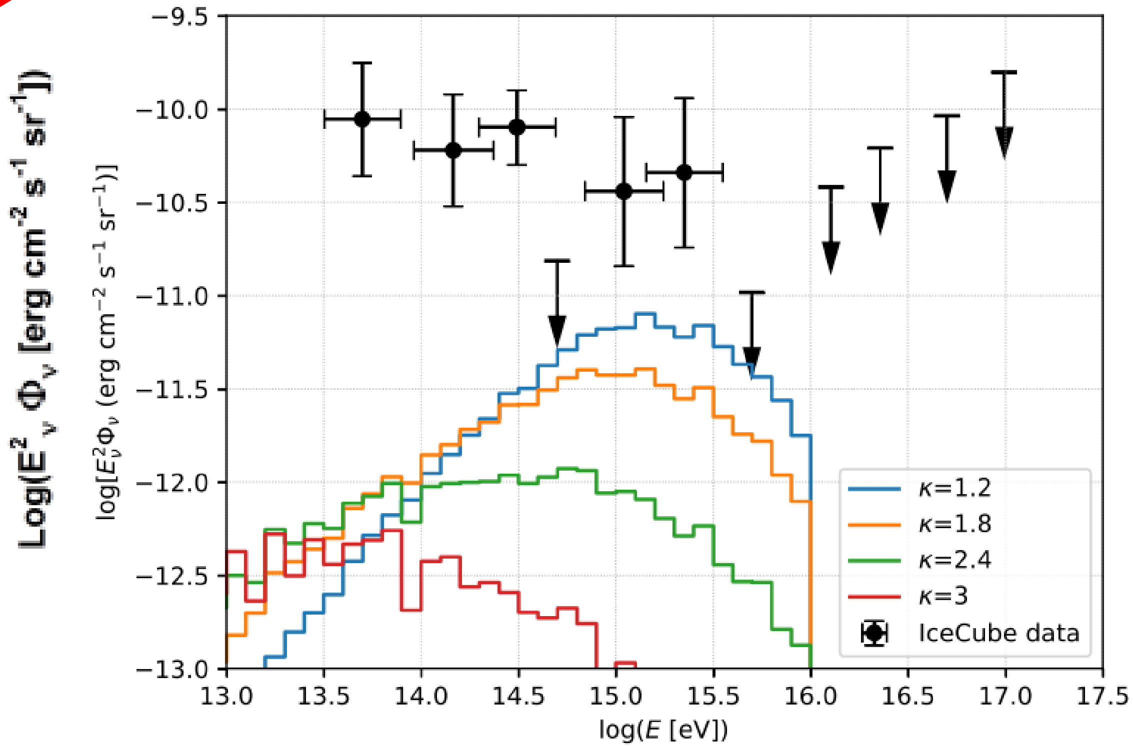
IceCube flux of Neutrinos

(Khiali & de Gouveia Dal Pino, MNRAS 2016)

Production of IceCube neutrino emission in *cores* of low luminous AGNs due to particles accelerated by reconnection - Cen A contribution alone

Preliminary

GRMHD + Radiative Transfer + CR cascading simulations



p + photons → π + p

$\pi^o \rightarrow \gamma\gamma$

$\pi^\pm \rightarrow \mu^\pm \nu$

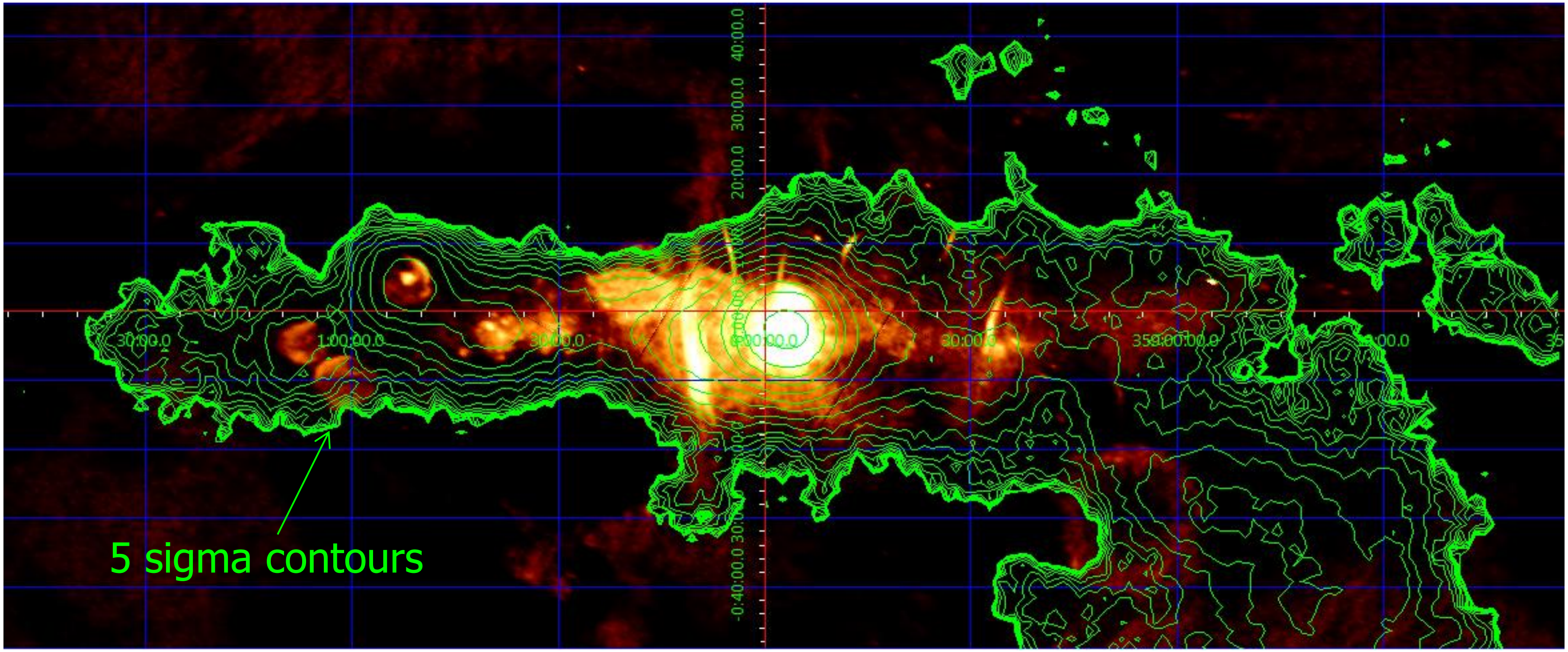
IceCube flux of Neutrinos

Cen A contribution

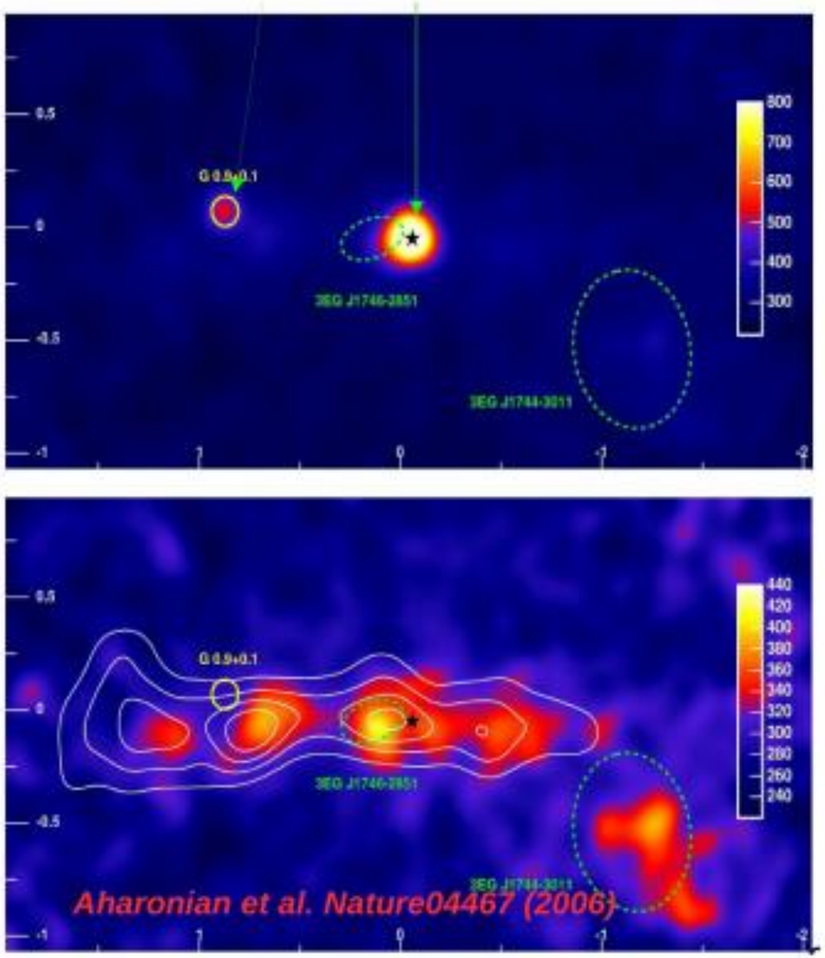
Log(E_ν[eV])

(Rodriguez-Ramirez, de Gouveia Dal Pino, Alves-Batista 2018, in prep.)

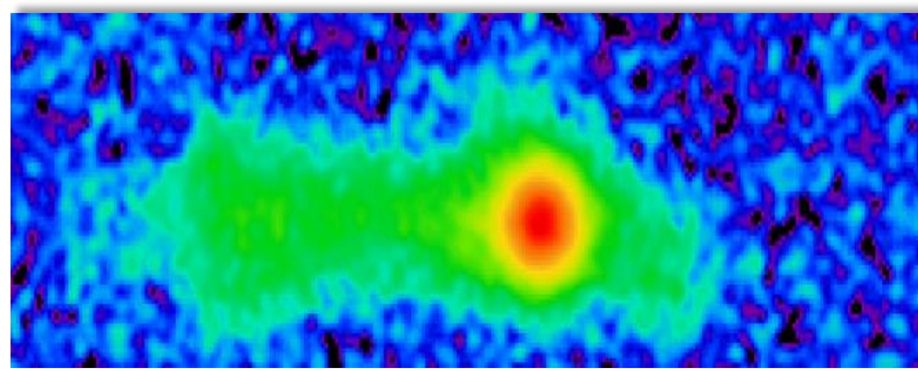
Galactic center region –SgrA* ?



Galactic center - SgrA* -> in gamma ray



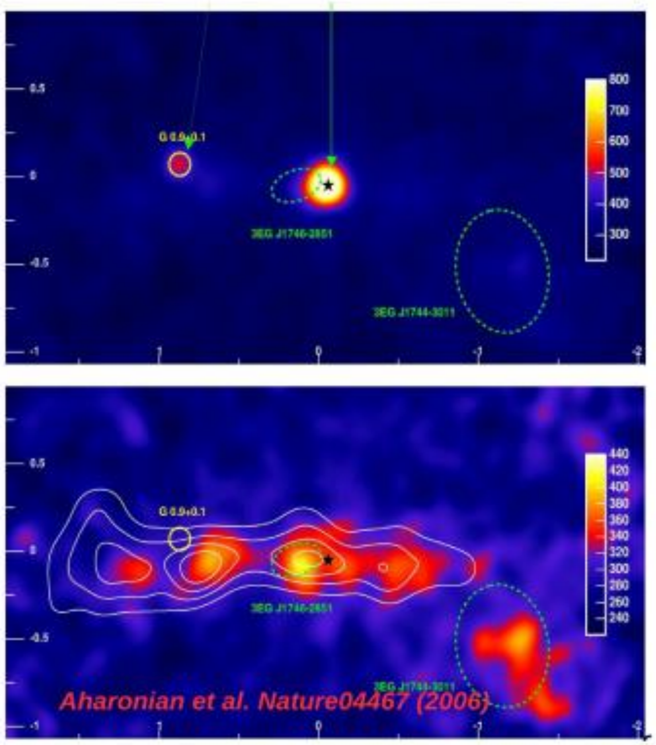
PeVatron source detected !



CTA

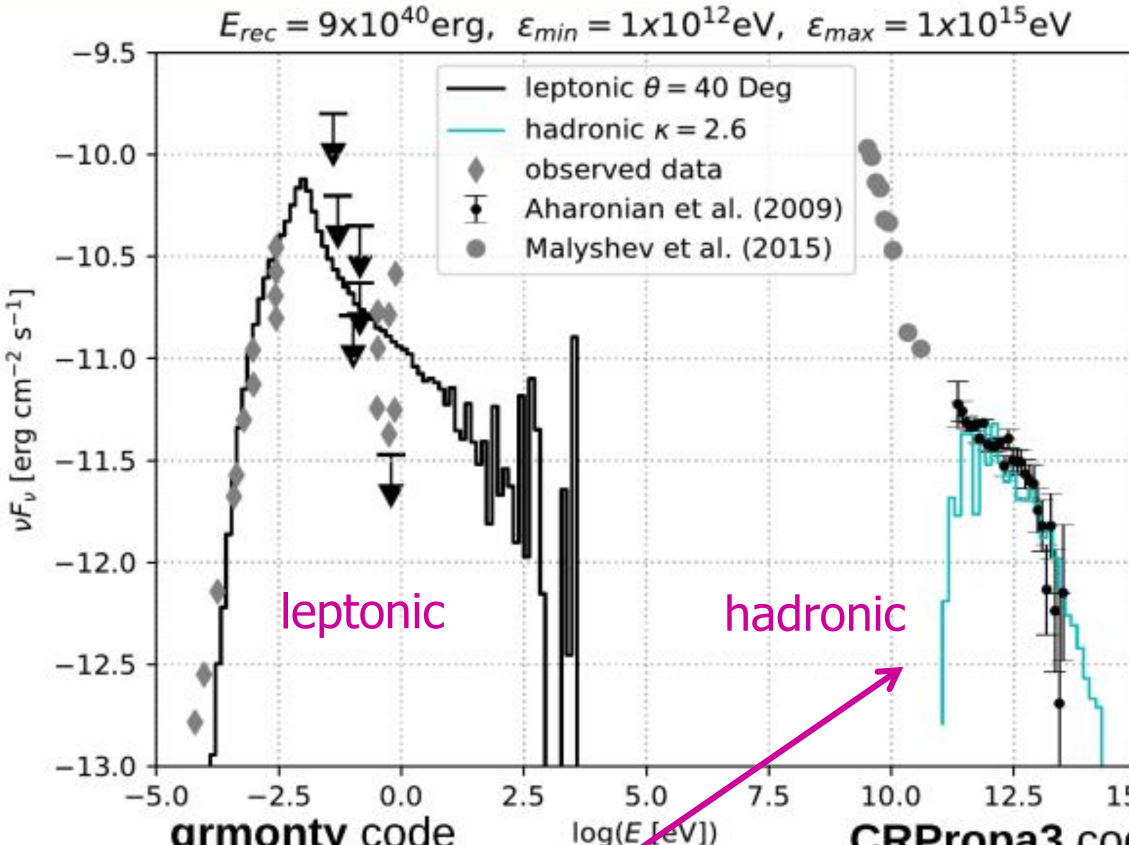
Reconnection acceleration and Hadronic-Leptonic Emission of SgrA*

GRMHD + Radiative Transfer + CR cascading simulations



Sgr A*

D=7.9kpc



grmonty code

CRPropa3 code

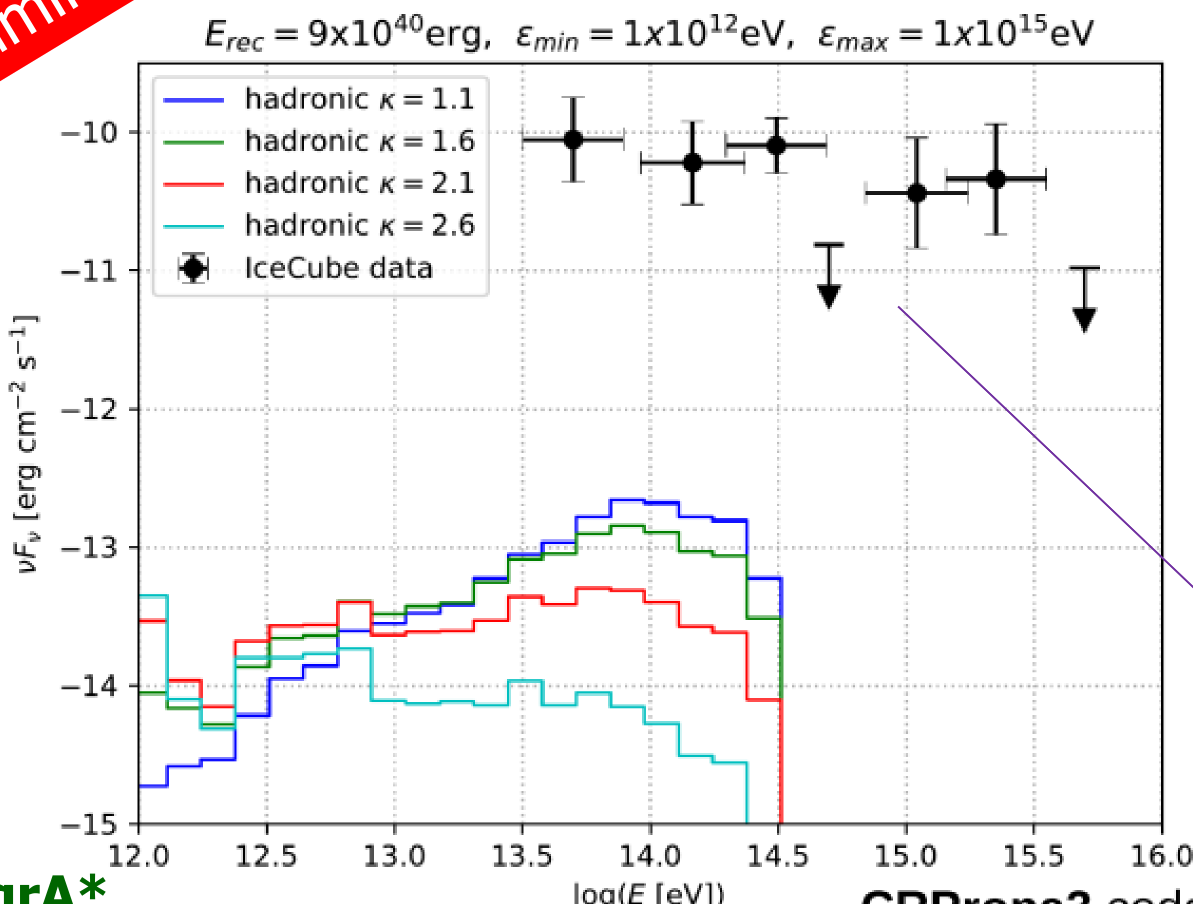
> TeVs explained by pγ interactions!

(Rodriguez-Ramirez, de Gouveia Dal Pino, Alves-Batista 2018, in prep.)

Production of neutrinos in the galactic center SgrA* versus IceCube data

Preliminary

GRMHD + Radiative Transfer + CR cascading simulations



p + photons → π + p

$\pi^o \rightarrow \gamma\gamma$

$\pi^{\pm} \rightarrow \mu^{\pm} \nu$

IceCube flux of Neutrinos

SgrA*

CRPropa3 code

(Rodriguez-Ramirez, de Gouveia Dal Pino, Alves-Batista 2018, in prep.)

Summary

- ✓ In magnetized plasmas particles can be accelerated by fast magnetic reconnection (e.g. driven by turbulence) in a 1st order Fermi: $N(E) \sim E^{-2-1}$
- ✓ Reconnection acceleration important in **Blazar jets** (produces CRs with $\sim 10^{17}$ eV or more) -> thus may explain flare gamma-ray emission and neutrinos (in magnetically dominated regions) (e.g. in TXS 0506+056 ?)
- ✓ Magnetic reconnection power can explain gamma-ray of BH binaries and low luminous AGNs (non-blazars) as coming from near the *core of these sources*
- ✓ Reconnection power matches well with the observed correlation of gamma-ray luminosity versus BH mass of BHX-binaries and low-luminous (non-blazar) AGNs over 10 orders of magnitude in mass
- ✓ Reconneciton accelerated CRs in the surrounds of LLAGNs – BHBs: produce TeV gamma-rays that are not entirely absorbed by pair production (and also neutrinos)
- ✓ **Reconnection: important in accretion/jet systems for particle acceleration, dissipation of magnetic energy and conversion into -> kinetic energy**

The ASTRI Mini-Array: CTA precursor

Mini-array with 9 SST-2M telescopes at the CTA south site (Chile): our 3 telescopes are currently in construction -> in 2019