
Magnetoluminescence

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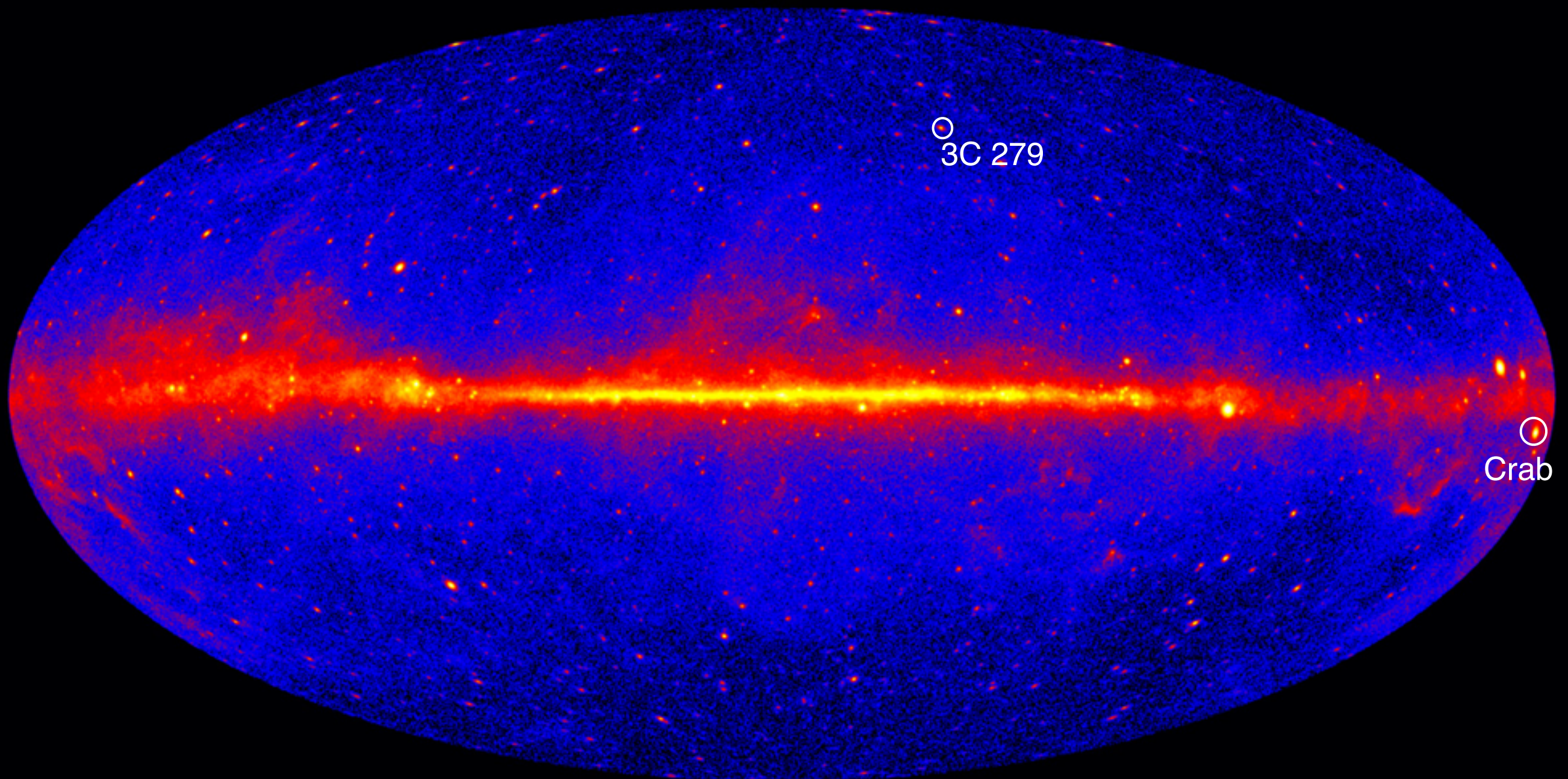
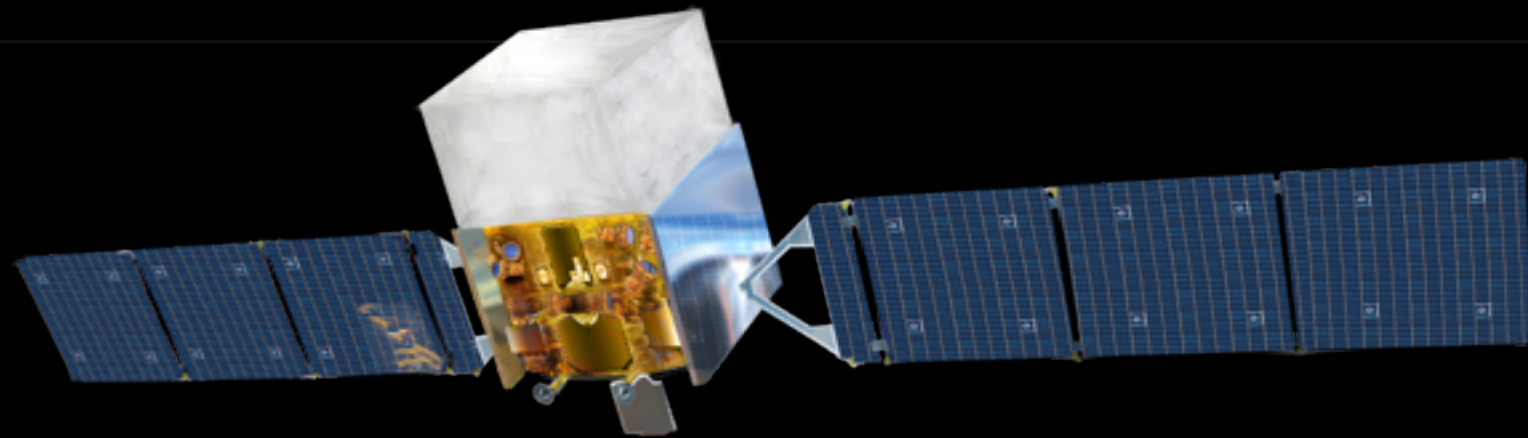
Collaborators: Roger Blandford, William East,
Krzysztof Nalewajko, Jonathan Zrake



Outline

- Observational puzzles
 - “magnetoluminescence” and a possible scenario
 - First principle simulation of plasma dynamics and radiation
 - Conclusions and prospects
-

Observational puzzles

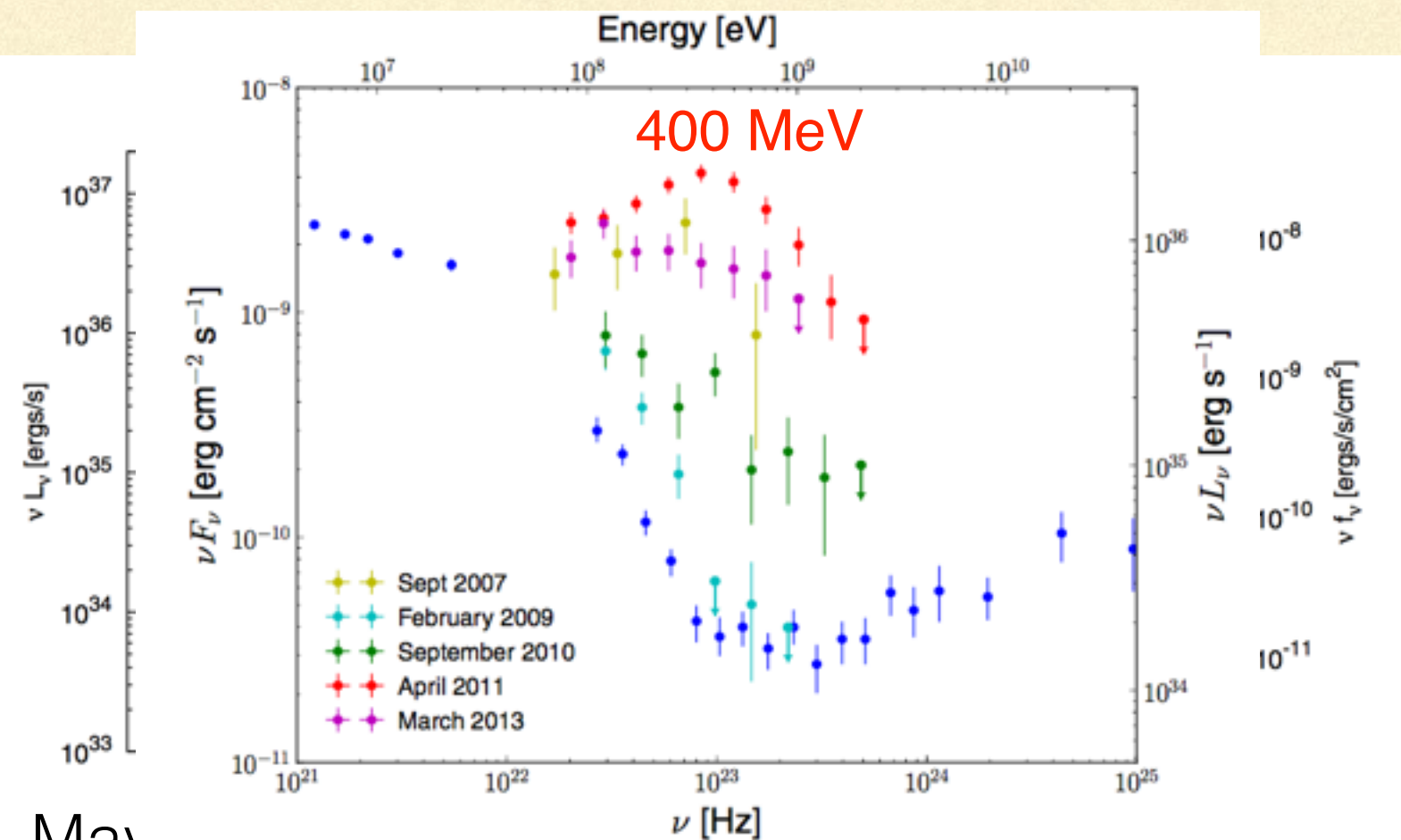
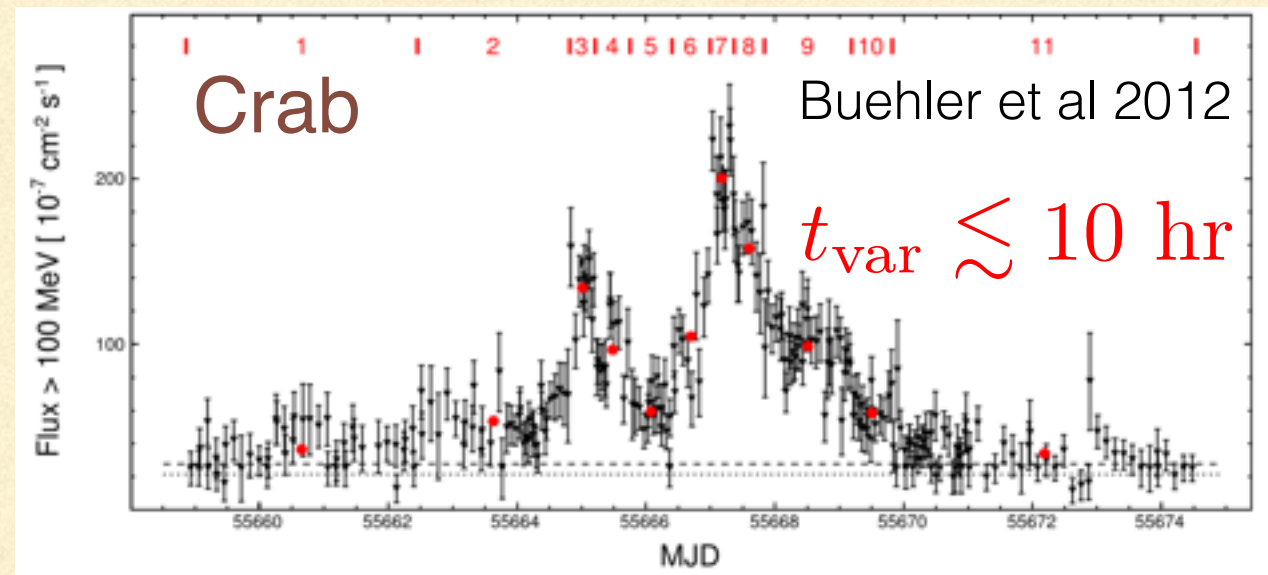


Fermi 5 year sky map. Credit: NASA/DOE/Fermi LAT Collaboration

Crab Nebula and its γ -ray flares



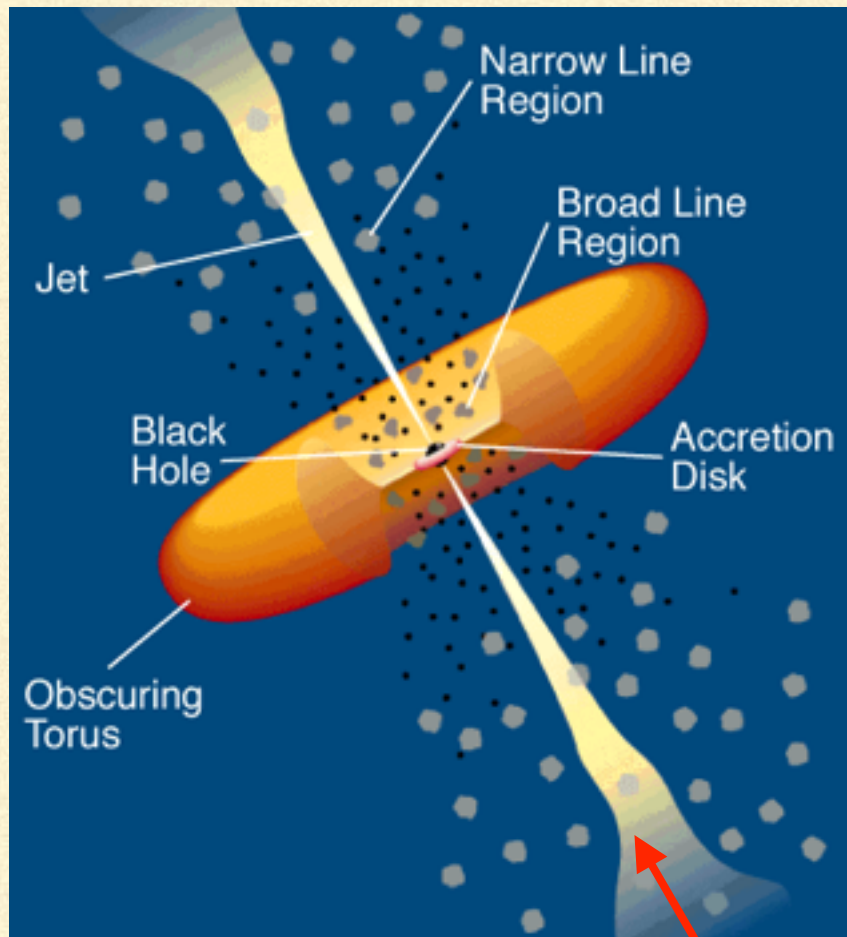
Hubble and Chandra



May

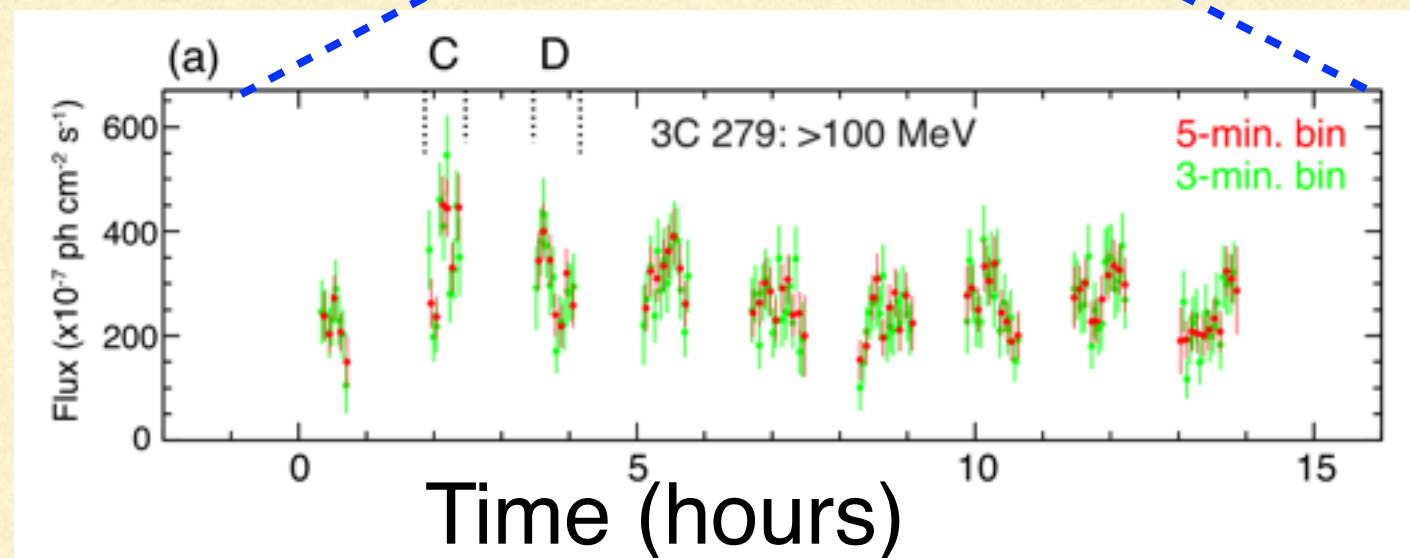
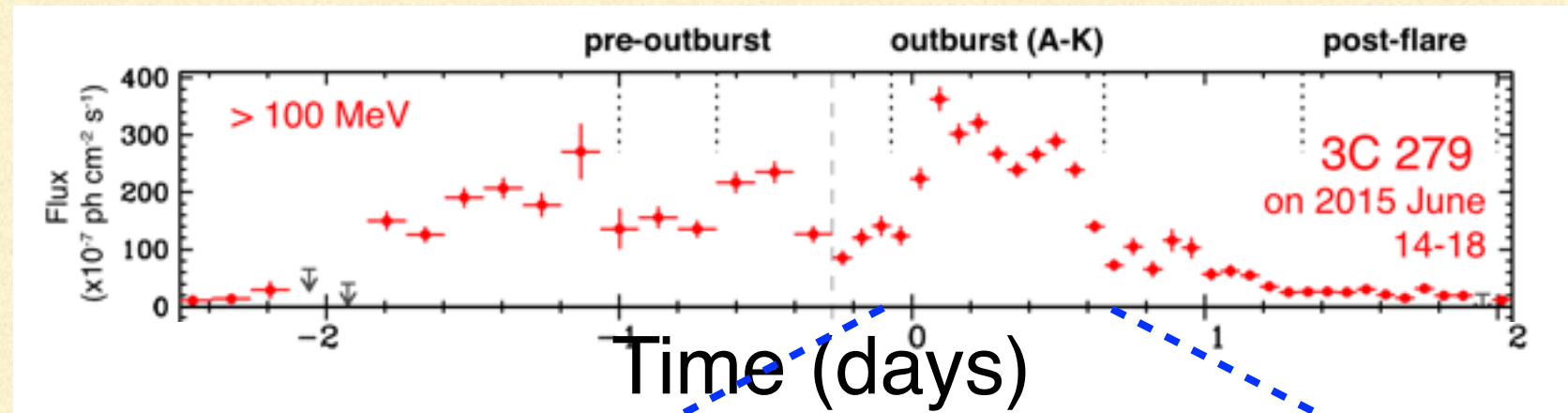
Buehler & Blandford 2014

3C 279 gamma-ray flares



Credit: Urry & Padovani

Blazar



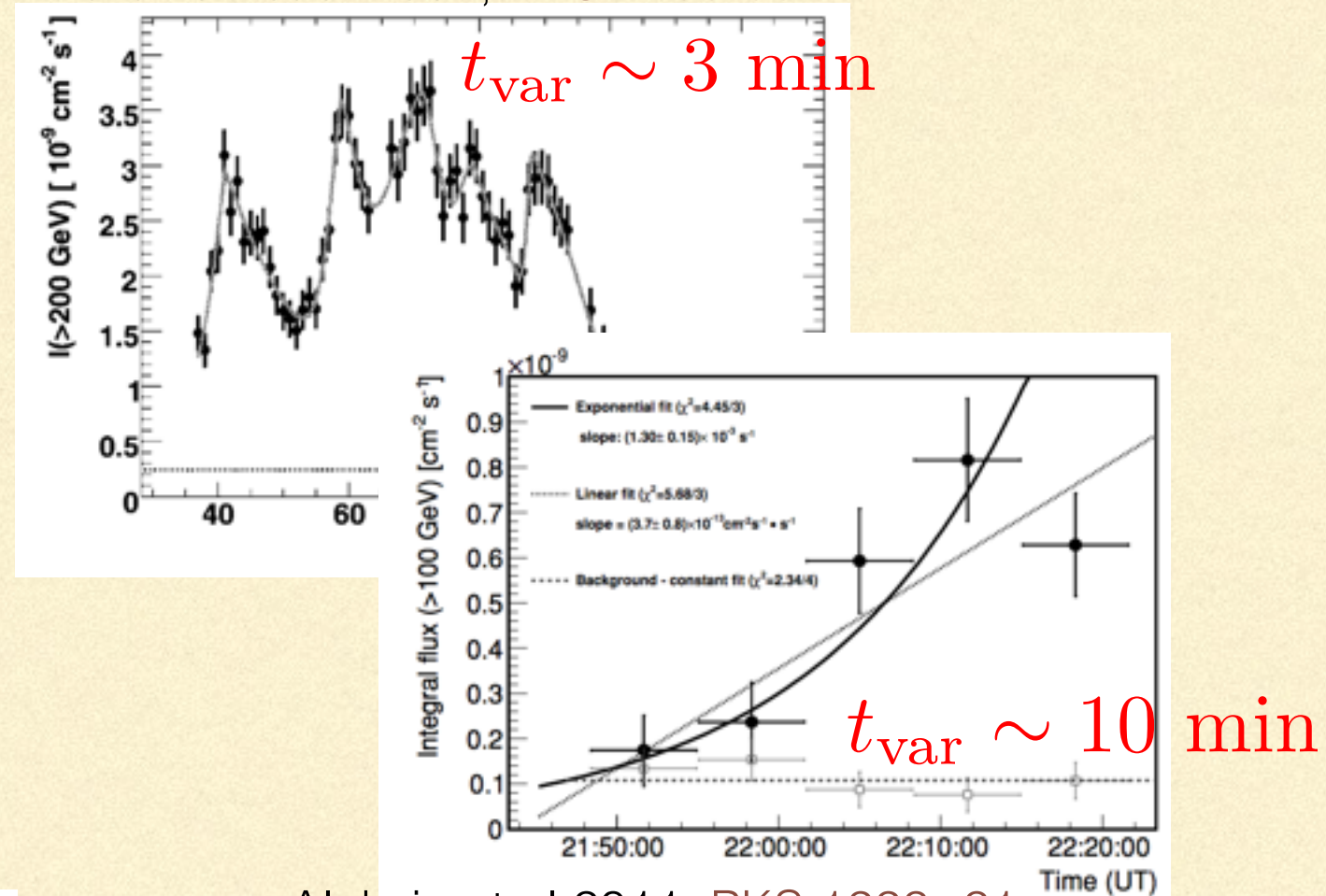
Ackermann et al 2016

- $t_{\text{var}} \sim 5$ min v.s. $r_g/c \sim 1$ hr
- Peak isotropic equivalent luminosity 10^{49} erg/s
- GeV flares might be synchrotron?

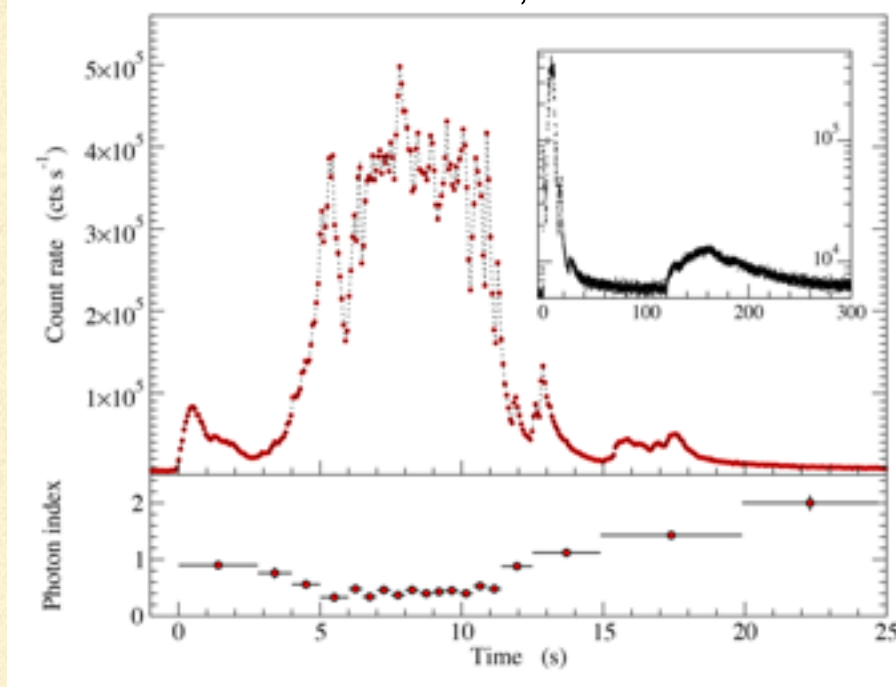
- Similar gamma-ray variability is seen in many other sources:

- Other blazars
- Non-blazar active galaxies
- Gamma-ray bursts
- Galactic superluminal sources/microquasars

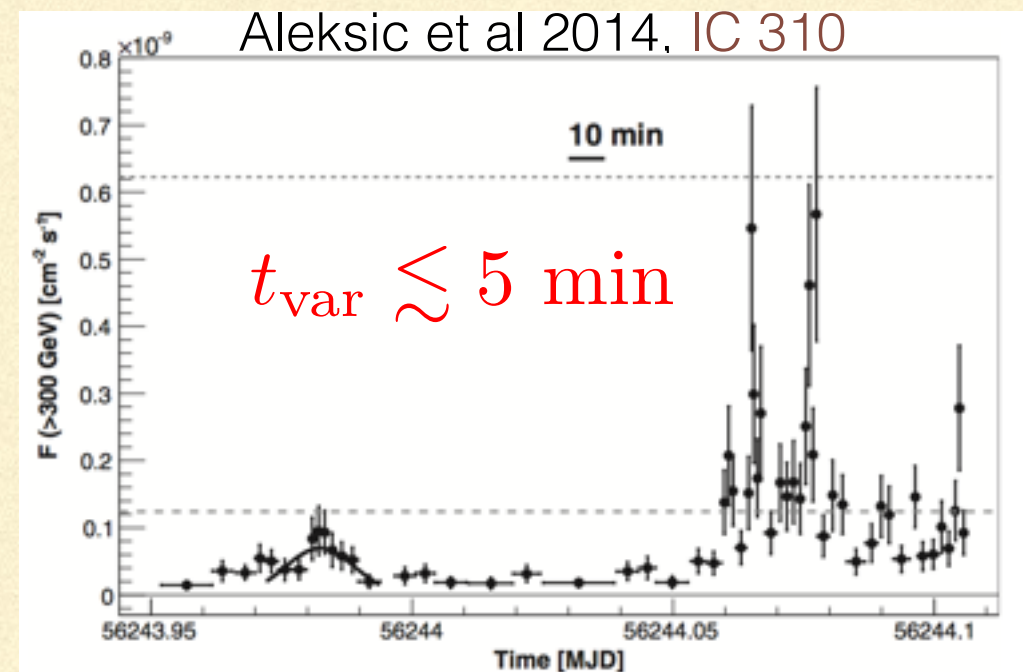
Aharonian et al 2007, PKS 2155-304



Maselli et al 2013, GRB 130427A



Aleksic et al 2011, PKS 1222+21



Aleksic et al 2014, IC 310

Common Challenges

- Fast variability → small emitting region
- Apparently high radiation efficiency!
 - Concentration of magnetic energy into a very small volume and/or relativistic beaming
- Crab (and maybe others): Above radiation reaction limit

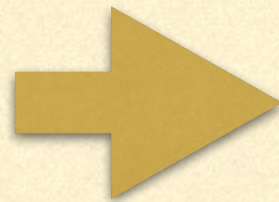
These might be results of efficient particle acceleration and electromagnetic dissipation in a highly magnetized outflow.

Magnetoluminescence

A possible scenario

Follow the energy

Rotational energy of
the compact object

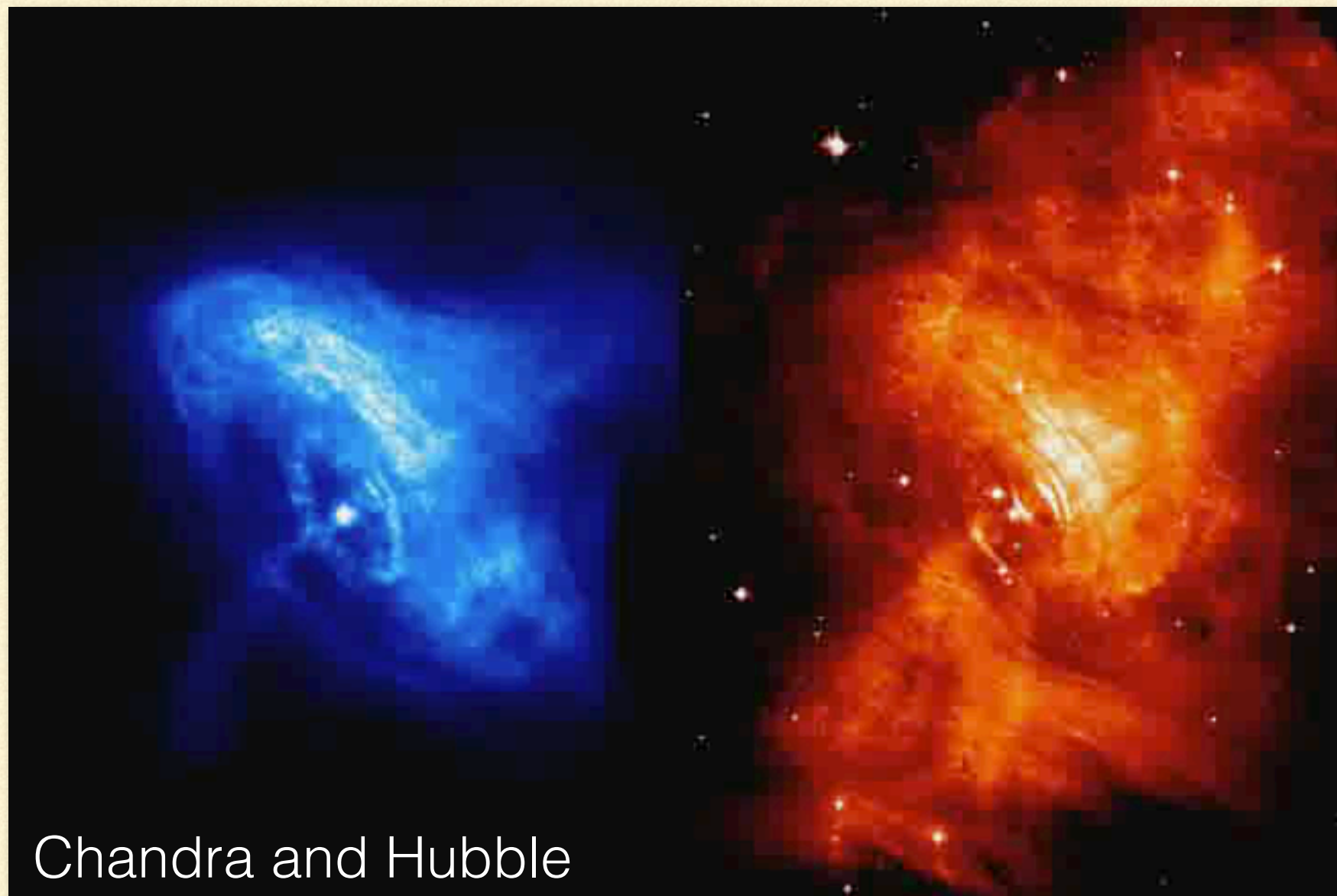


Magnetized plasma
outflow

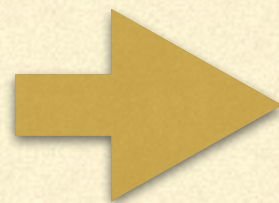
- Global circuit: $V \sim \Omega \Phi$, $I \sim V/Z$, $P = VI$, $Z = \mu_0 c \sim 377 \Omega$
 - Crab: $V \sim 50$ PV, $I \sim 200$ TA
 - 3C279: 300 EV, $I \sim 1$ EA

How to tap the potential difference,
and how to do this quickly?

Follow the energy

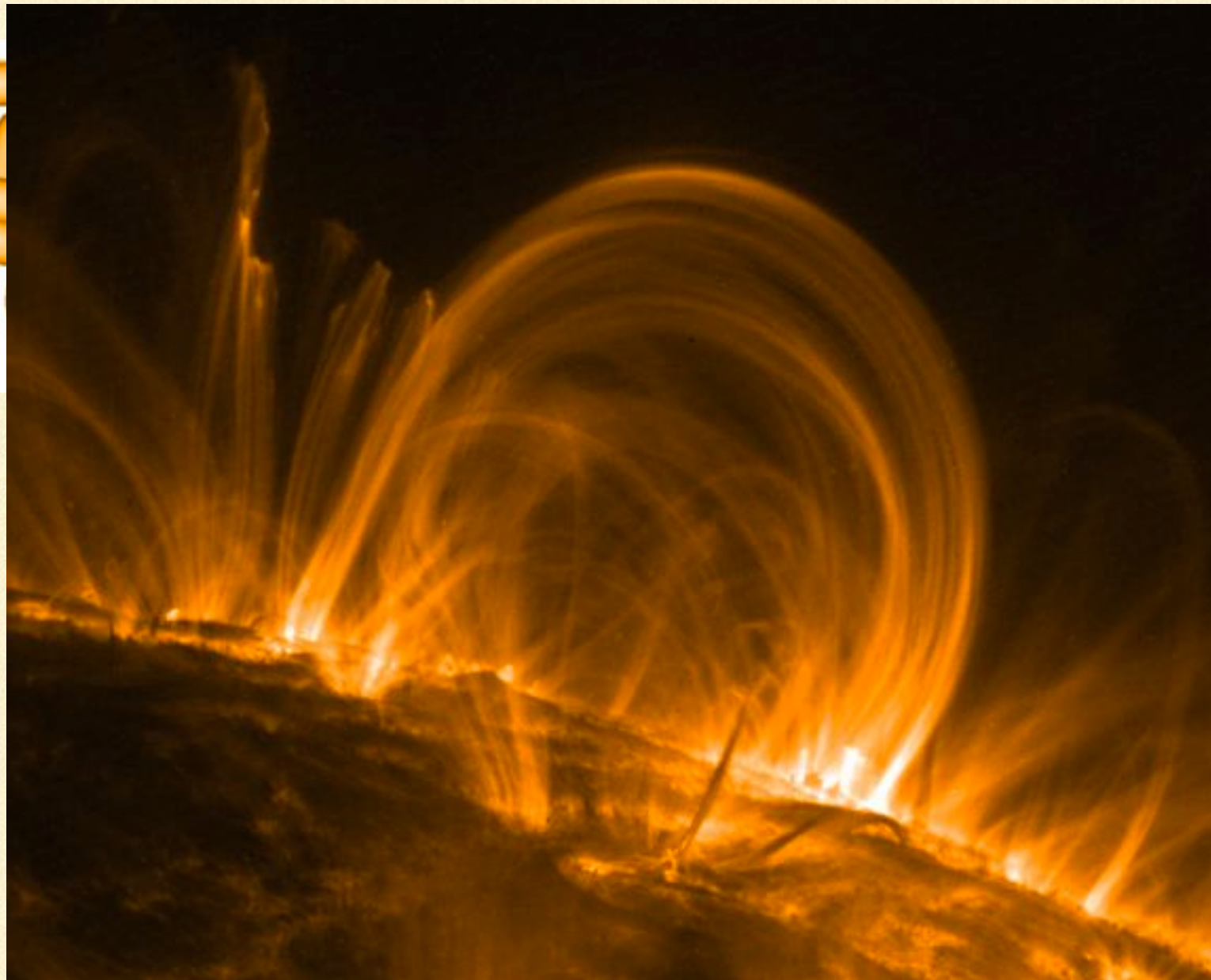


Rotational energy of
the compact object

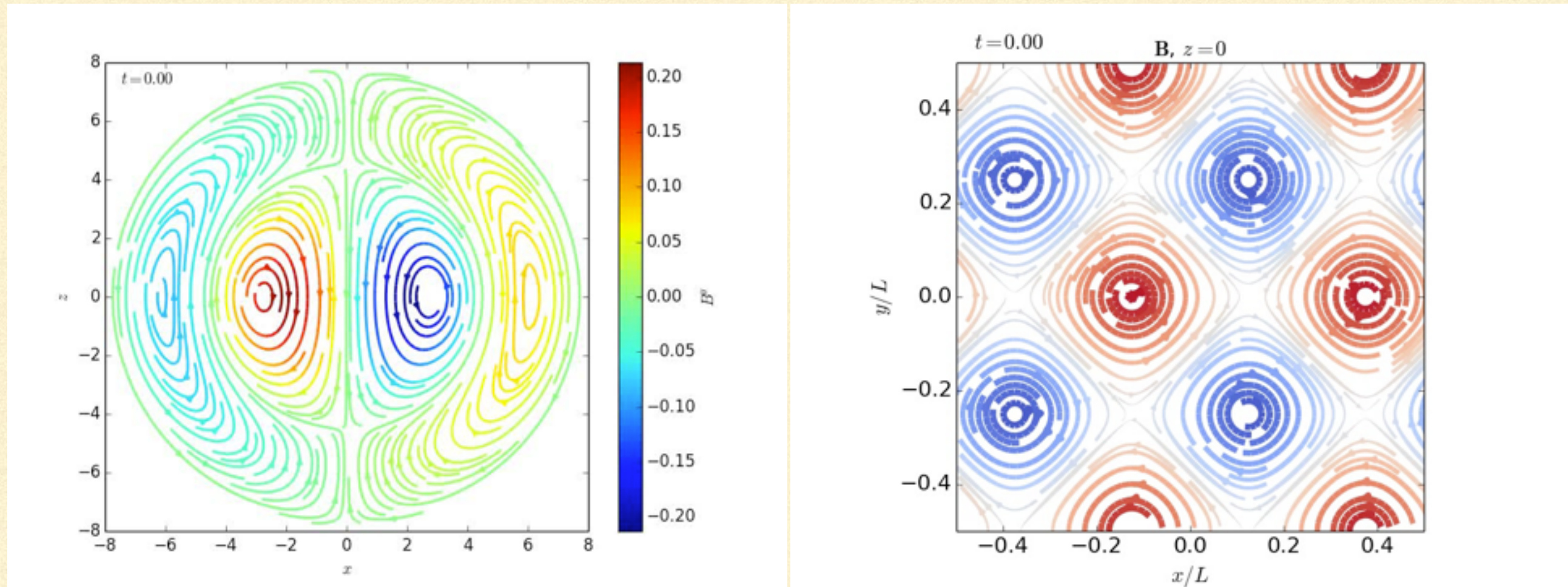


Magnetized plasma
outflow

Conjecture: Locally tangled magnetic flux ropes may untangle and release energy over dynamic time scales.

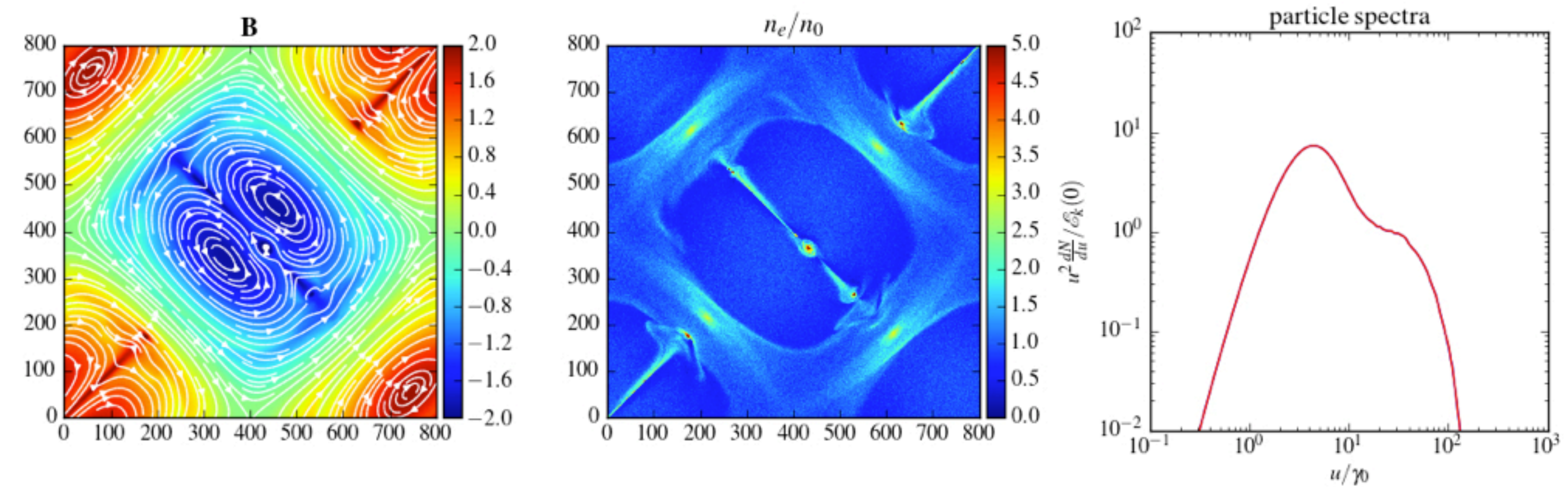


An illustrative model problem: Equilibria of highly magnetized plasma



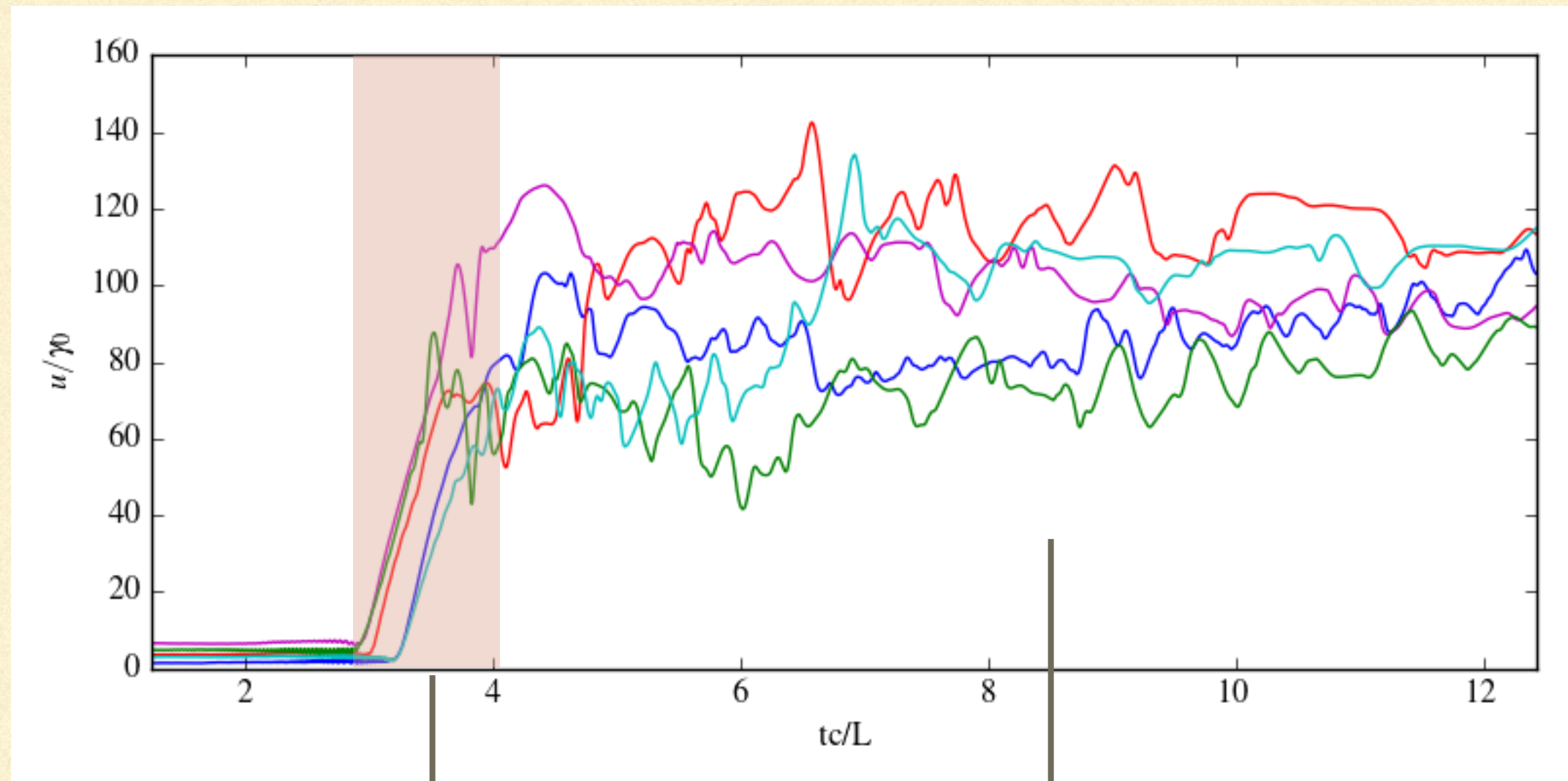
- Equilibria with free magnetic energy are unstable.
- The instability is ideal and grows on Alfvén time scales.
- Efficient dissipation of magnetic energy upon saturation of the instability.

First principle modeling of plasma dynamics and radiation



- Complex, small scale structures develop self-consistently from an initially smooth configuration
- Magnetic reconnection happens at the current layer—high reconnection rate and efficient particle acceleration
- Overall evolution is consistent with MHD results.

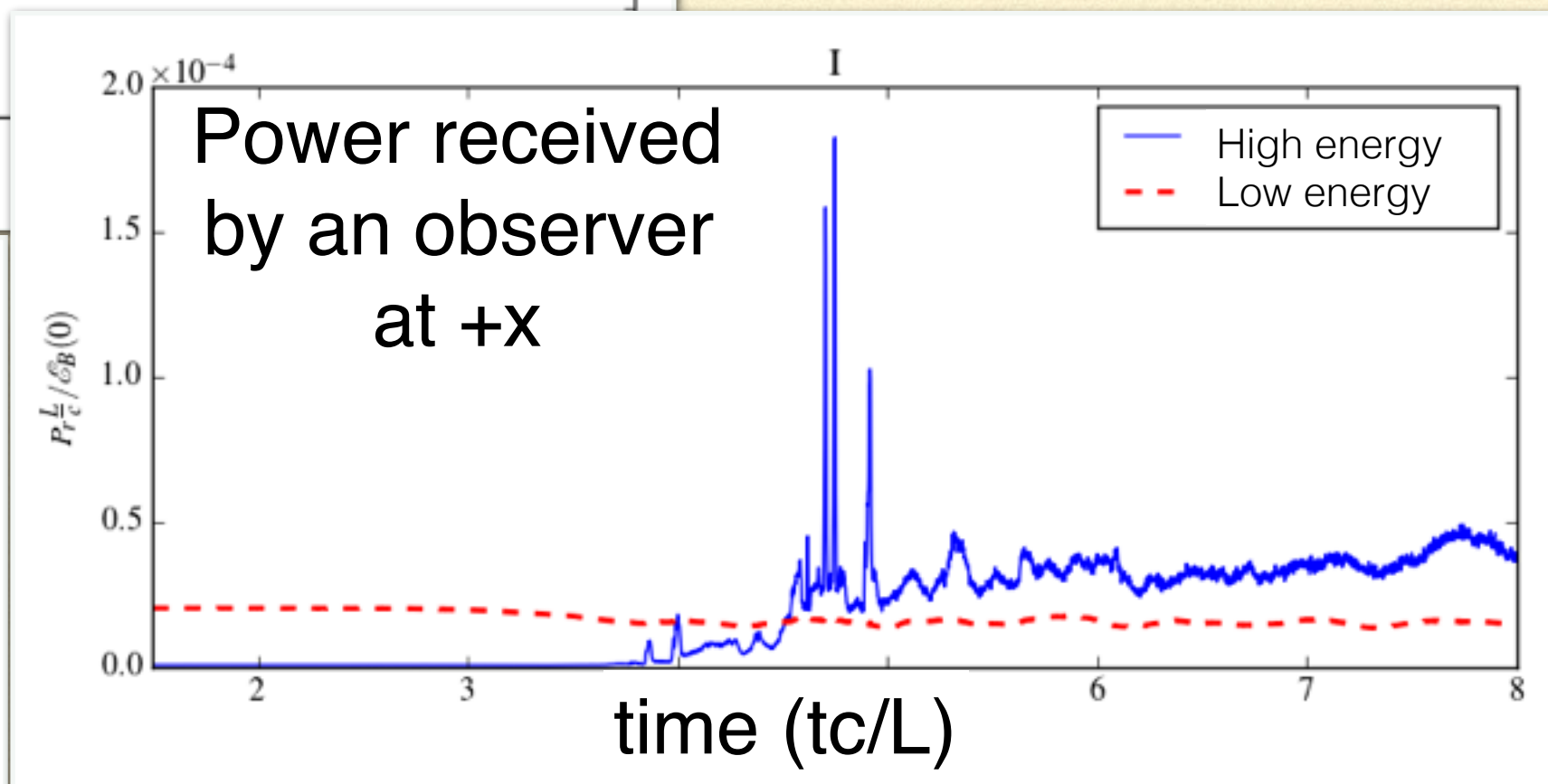
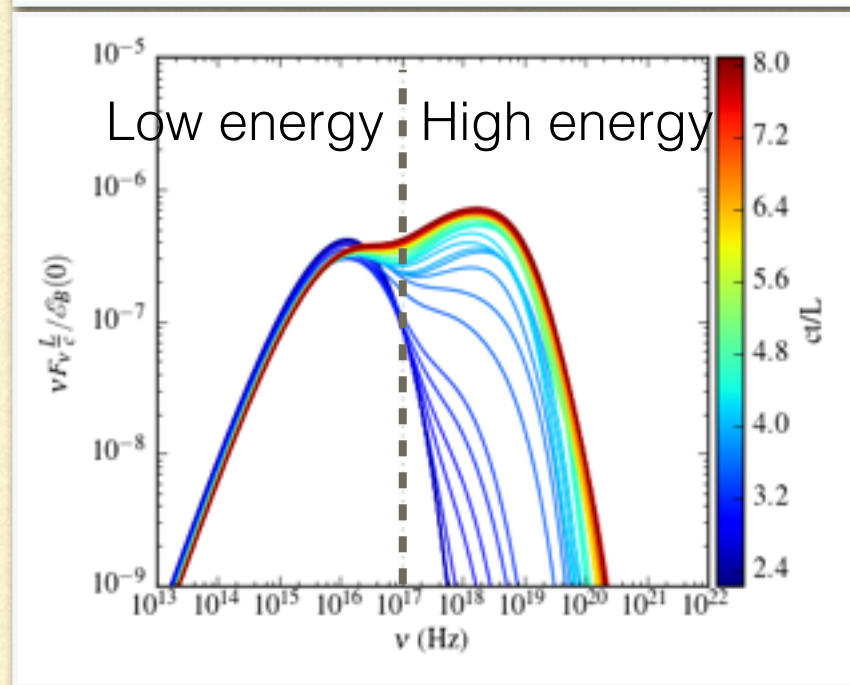
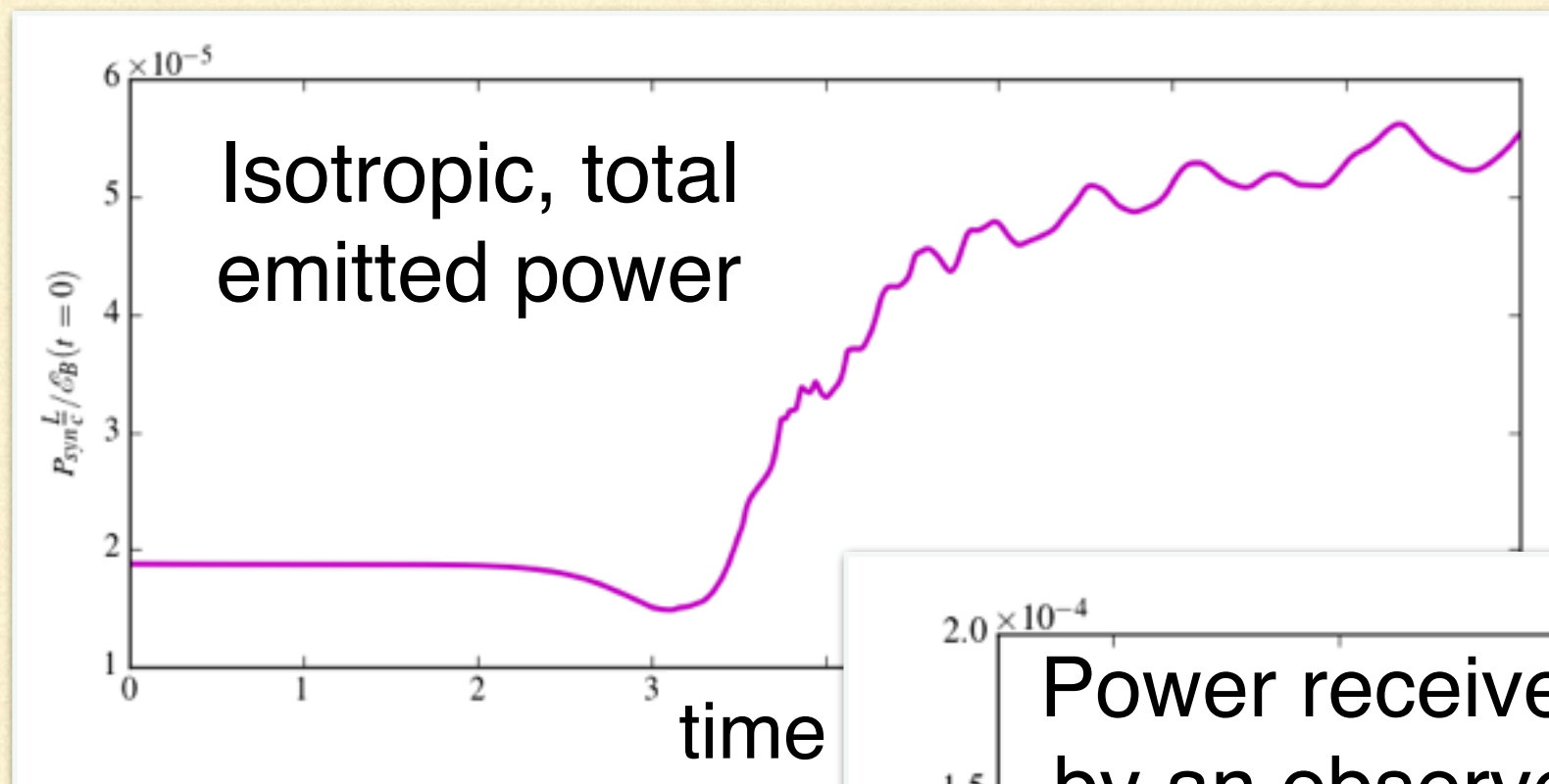
Mechanisms of particle acceleration



Phase I: impulsive
acceleration by $E_{||}$

Phase II: stochastic
acceleration

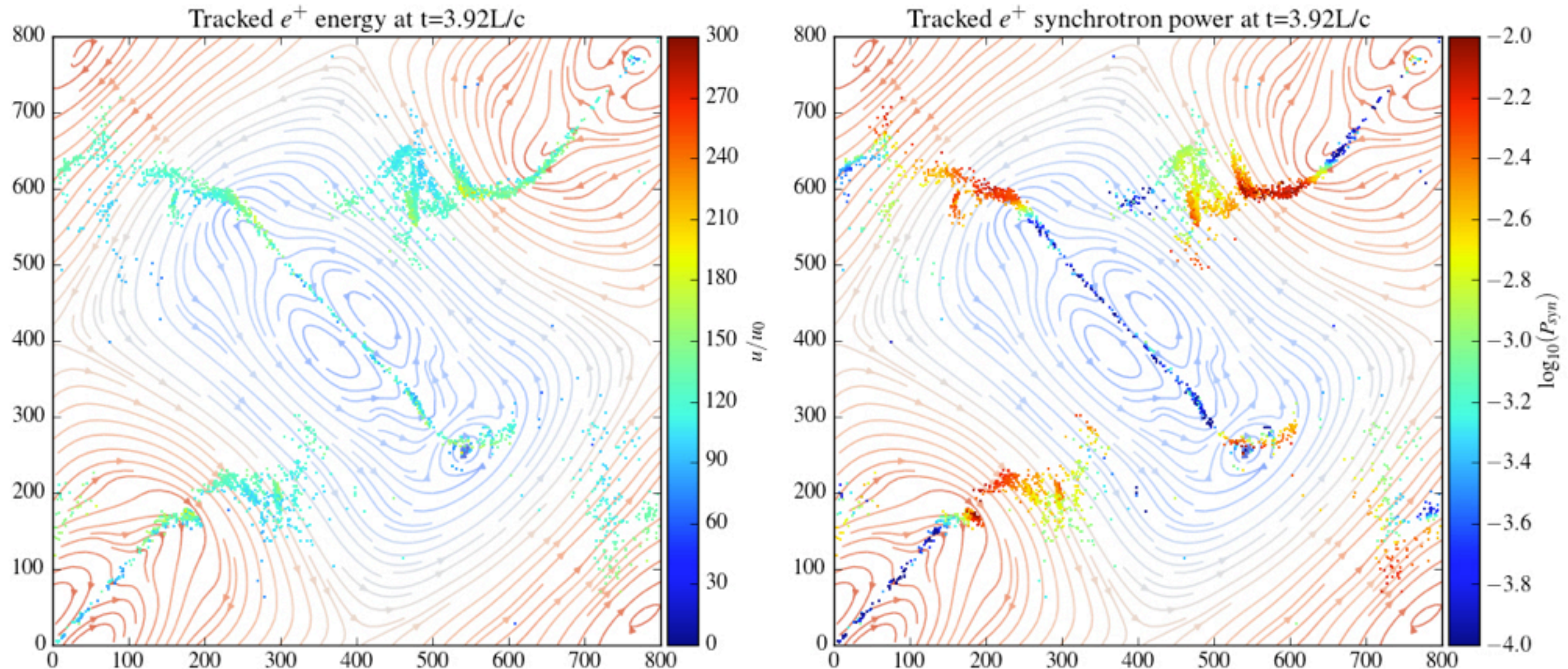
Variability of observed radiation



$$t_{\text{var}} \sim 0.01 L/c$$

Isotropic emitted spectrum

Where does most of the high energy radiation come from?



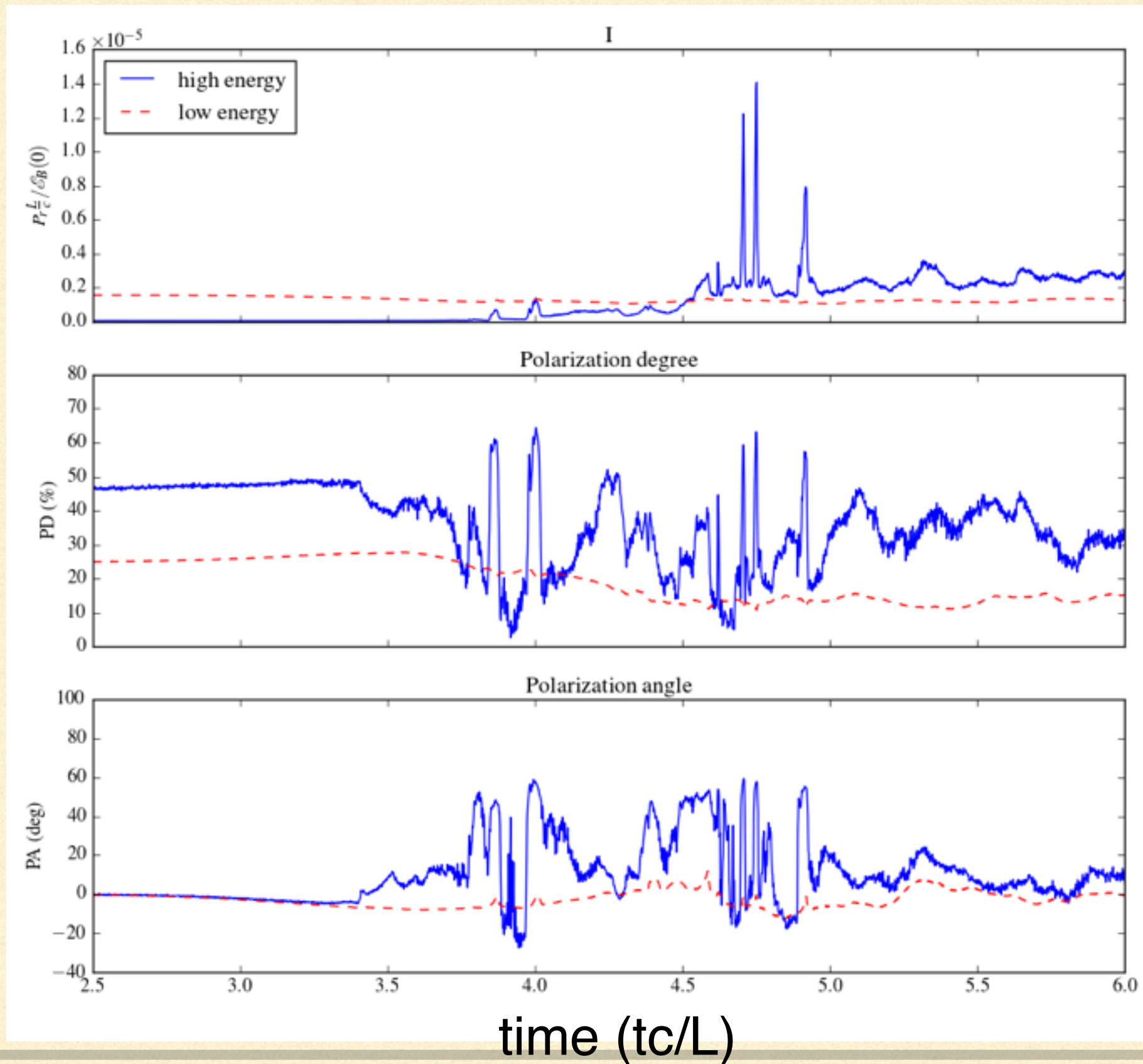
- In current layers: $E_{\parallel}$ acceleration, small radiative loss; high energy particles are bunched by tearing modes
- Exiting current layers: B direction change $\rightarrow$ increased trajectory curvature, strong synchrotron radiation

Polarization signal

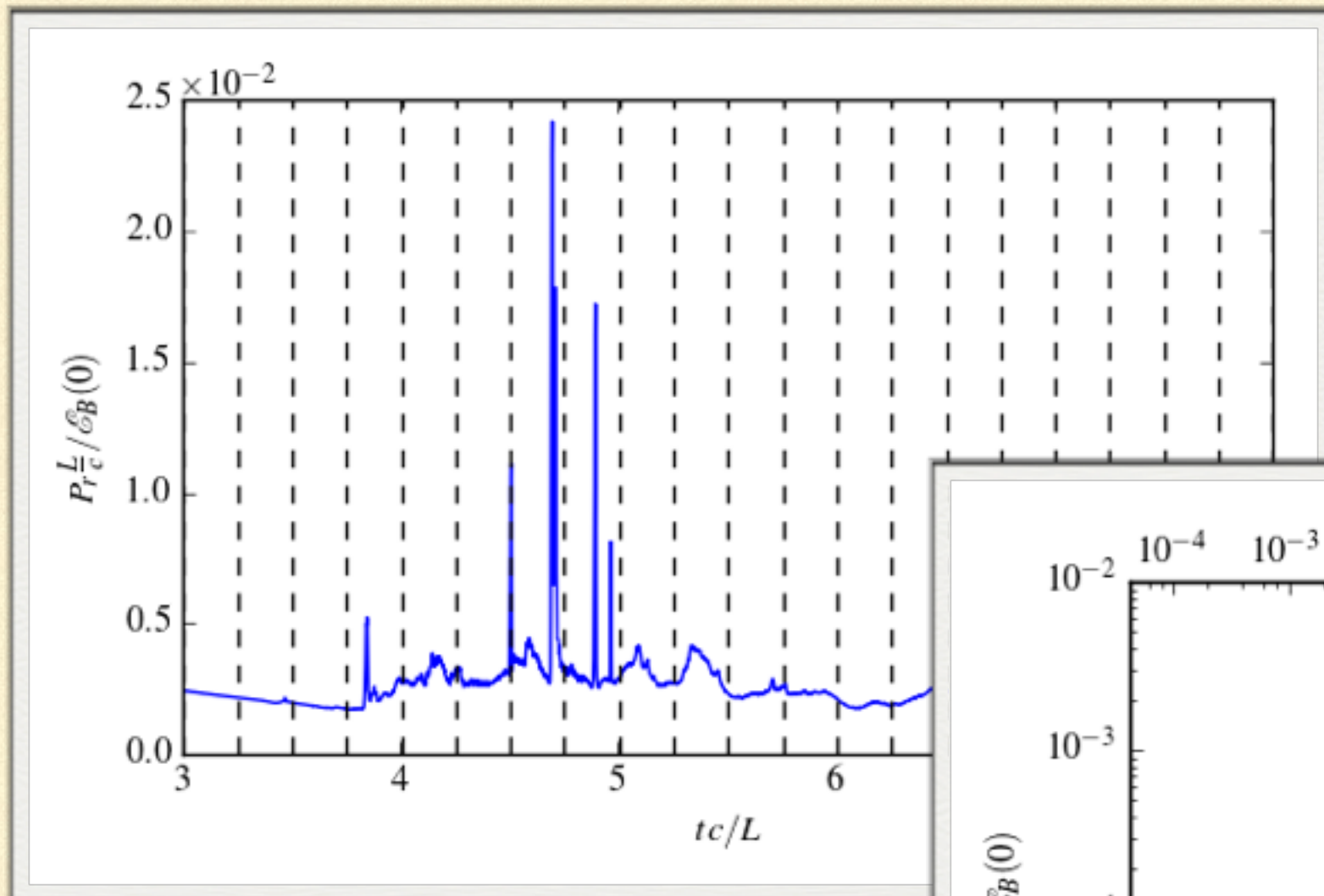
Total
intensity

PD

PA

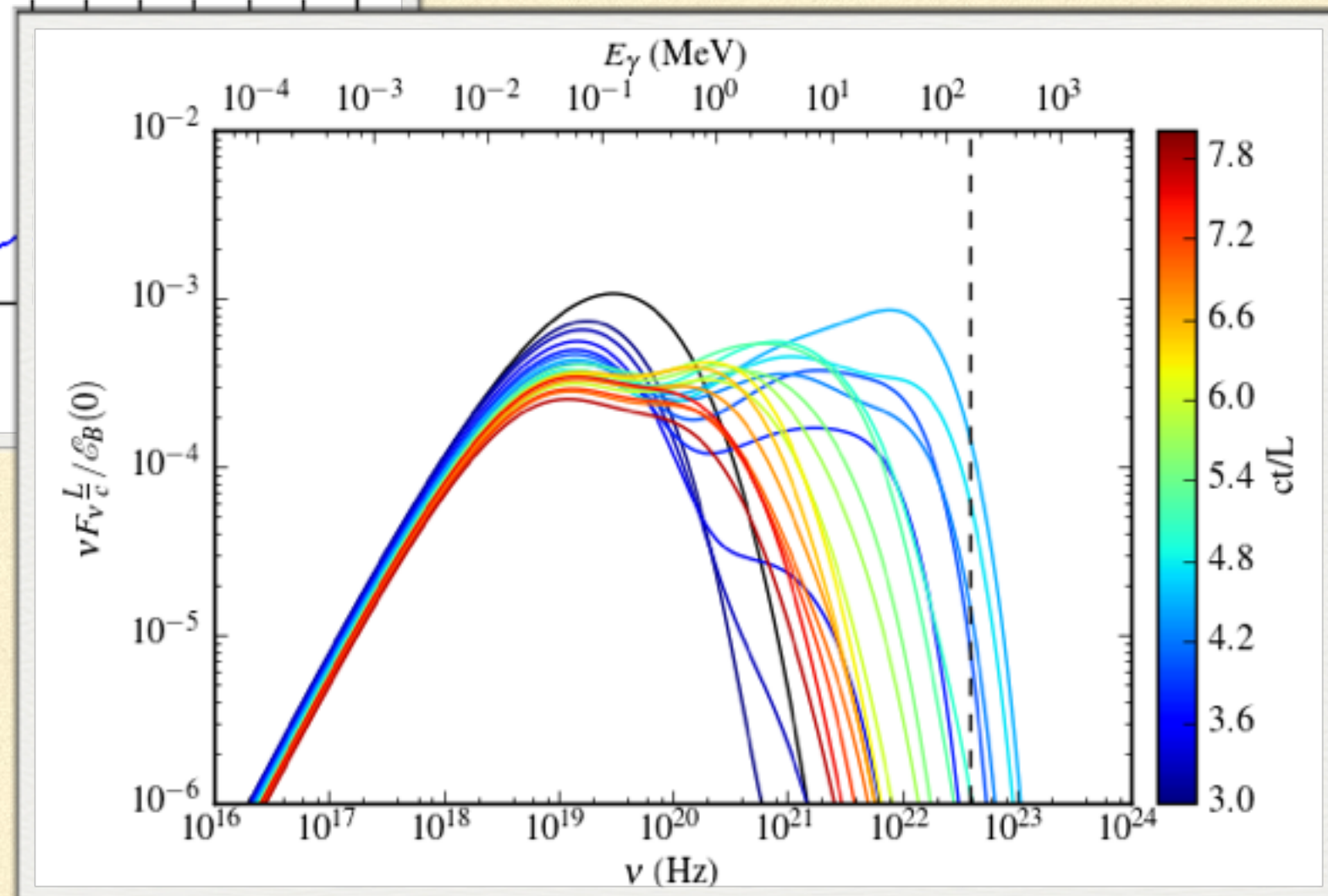


Variability, radiation efficiency, and time dependent spectrum



Example: strong cooling case,
light curve and spectrum
seen at +x

$$t_{\text{var}} \sim 0.01L/c$$



Fast variability results from...

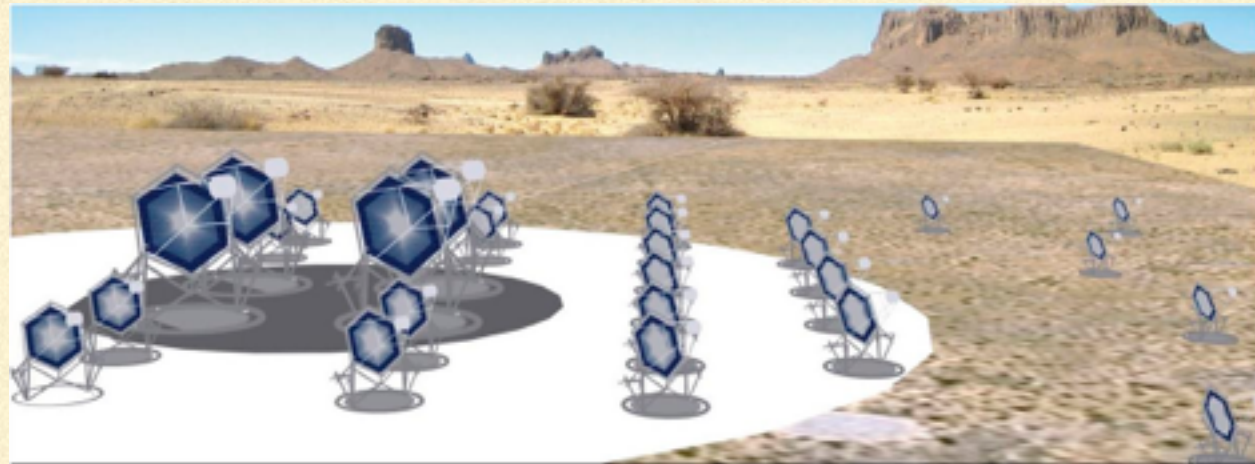
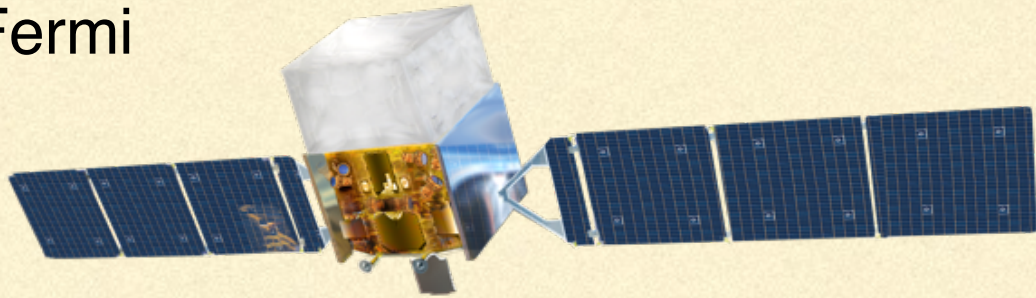
- Anisotropy of accelerated particles (kinetic beaming)
- Spatial bunching of particle beams due to tearing modes

Applications to astrophysical sources

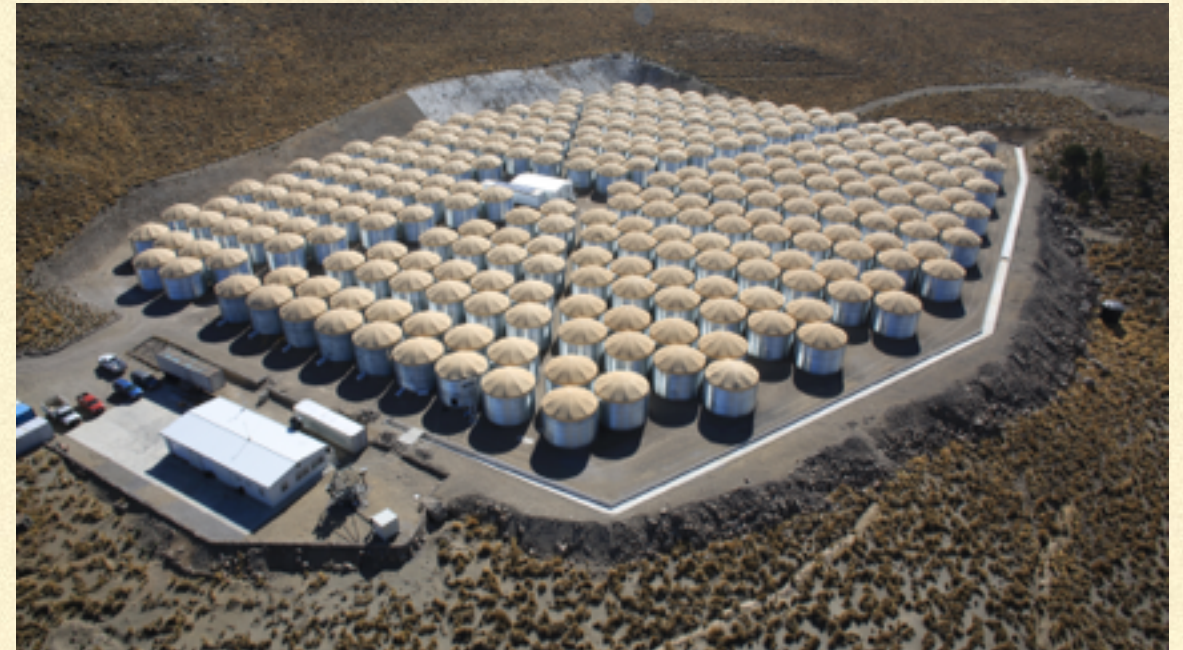
- Fast variability: emitting regions are smaller than the energy reservoir
 - Impulsive acceleration during current layer formation may beat radiation reaction limit
 - Modest radiation efficiency
 - Caveats:
 - Scale separation in simulations vs. real systems
 - 2D vs. 3D
 - Need higher σ
 - TeV flares: Inverse Compton or other radiation mechanism
-

Future prospects

Fermi



CTA



HAWC

LHAASO



Future prospects

- Understanding how the engines work
 - Available potential: Crab~50 PV; 3C279~300 EV
- Leptonic or hadronic?
- Sites of gamma-ray emission in jets?

Summary

- Many extreme γ -ray sources require efficient particle acceleration mechanisms!
 - A possible scenario: relaxation of tangled magnetic flux ropes over dynamic time scales
 - A simple setup: magnetostatic equilibria with free energy
 - PIC simulations:
 - Impulsive acceleration during current sheet formation
 - Fast variability of radiation
 - Modest apparent radiation efficiency
 - The future is bright!
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Thank you!
