CIPS

Anisotropy of Particle Acceleration and Associated Radiation in Relativistic Pair Reconnection

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<u>OUTLINE</u>

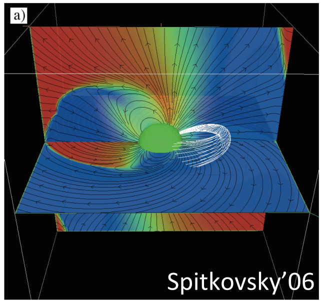
- **Astrophysical motivation**: pulsars, AGN jets, GRBs

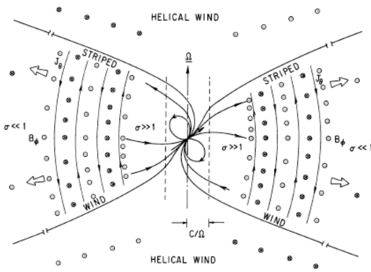
- **New themes** in relativistic pair reconnection:
  - ***anisotropy*** of particle acceleration
  - ***radiative signatures*** of reconnection:
    - anisotropy,
    - spectrum,
    - variability.

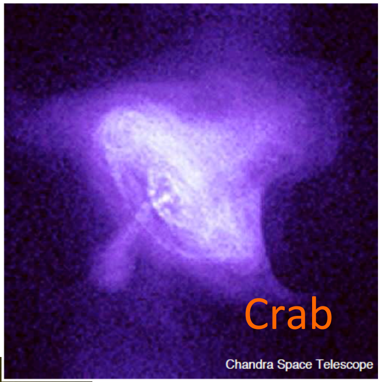
- Summary

Pair Reconnection: Astrophysical Applications

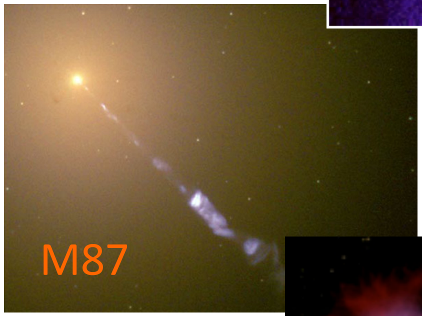
- Pulsars:
  - magnetospheres,
  - (striped) winds,
  - Pulsar Wind Nebulae.





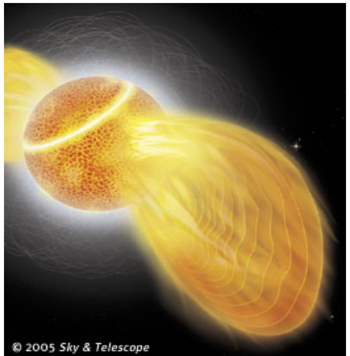


- AGN (e.g., blazar) jets, radio-lobes



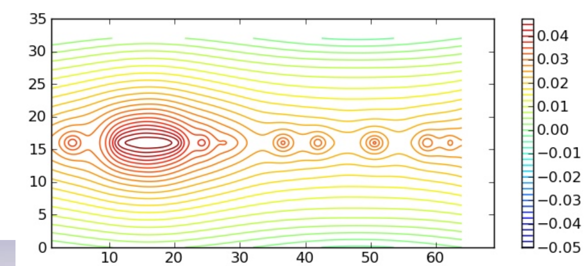
- Gamma-Ray Bursts (GRBs)

- Magnetar flares



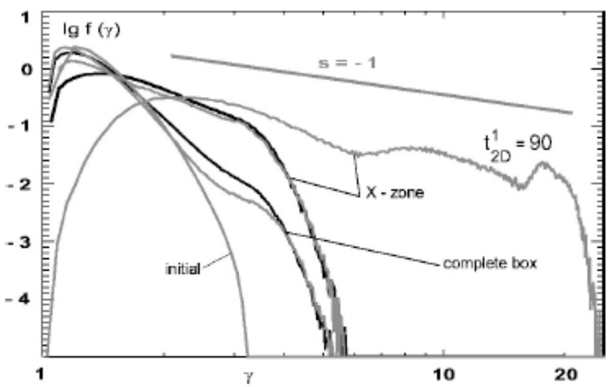
New themes, new questions…

- How do we describe accelerated particle population?
  - (most generally --- distribution in 6D phase space)
  - energy spectrum provides only partial information
  - what is **angular distribution** of accelerated particles?
- How does a reconnection look like, literally?
  - what are (prompt) **radiative signatures** of reconnection, as seen by an outside observer:
    - observable photon spectrum;
    - light curve

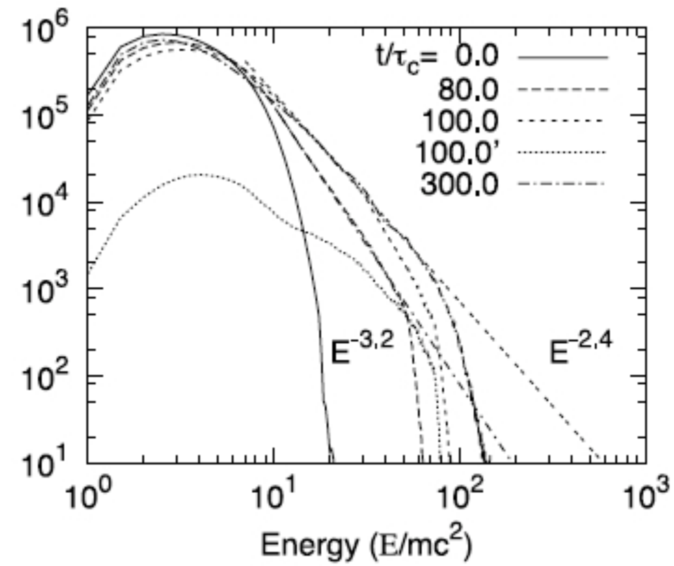


Particle Energy Spectrum

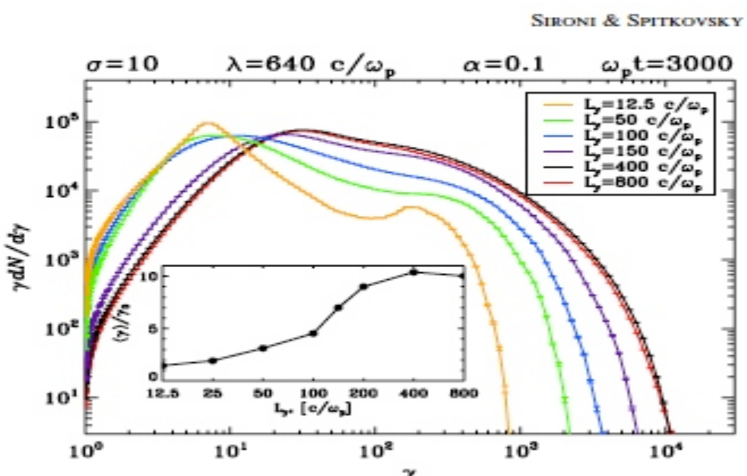
Still an open issue…



Jaroschek et al. 2004



Zenitani & Hoshino 2007



Sironi & Spitkovsy 2011

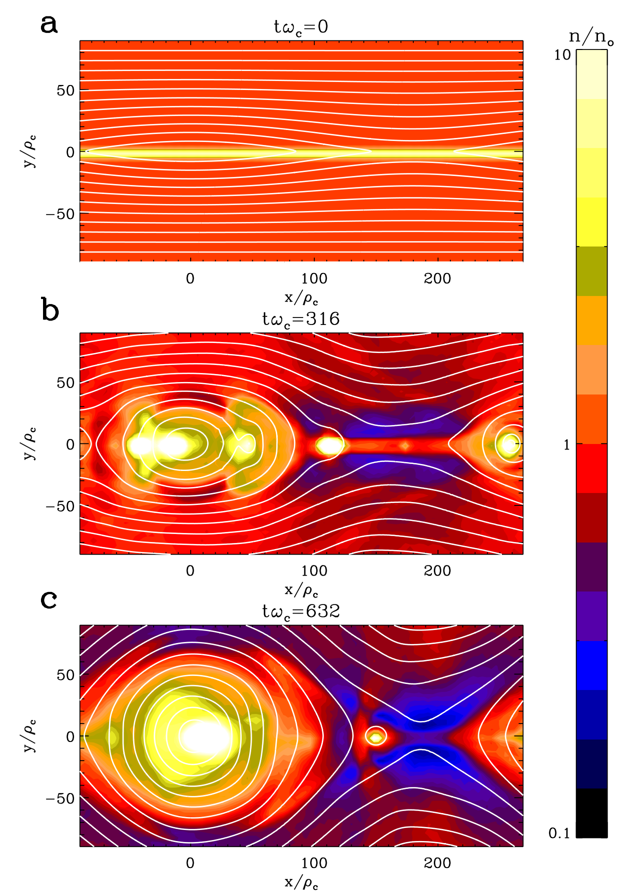
New Themes in Relativistic Pair Reconnection:

I. Particle Anisotropy

- All previous numerical studies focused on particle *energy* distribution f(γ) … but ignored ***angular distribution***.
- Ultra-relativistic particles emit in their direction of motion ➔ ***Particle anisotropy*** translates directly into anisotropy of radiation.
- Hence, ***particle anisotropy*** is important for understanding prompt radiative signatures of reconnection.
- This is especially at **highest energies**, since
  - $\tau_{rad,cool} = \gamma\ m_e c^2 / P_{rad} \sim \gamma^{-1}$
  - $\tau_{iso} \sim \Omega_c^{-1} \sim \gamma$

Particle anisotropy in PIC simulations of relativistic pair reconnection *(Cerutti et al. 2012)*

- Preliminary simulations:
  - sims by G. Werner; data analysis by B. Cerutti;
  - relativistic PIC code VORPAL;
  - 2D, no guide field;
  - double periodic boundary conditions;
  - $n_b/n_d = 0.1$; $T_b = 0.15\ m_ec^2$; $T_d = 1\ m_ec^2$.
  - $360\ \rho_c \times 360\ \rho_c$, $\rho_c = m_ec^2 / eB_0$;
  - 2.7×10^8 particles; 2048^2 grid cells;
  - (bigger simulations are in progress!)

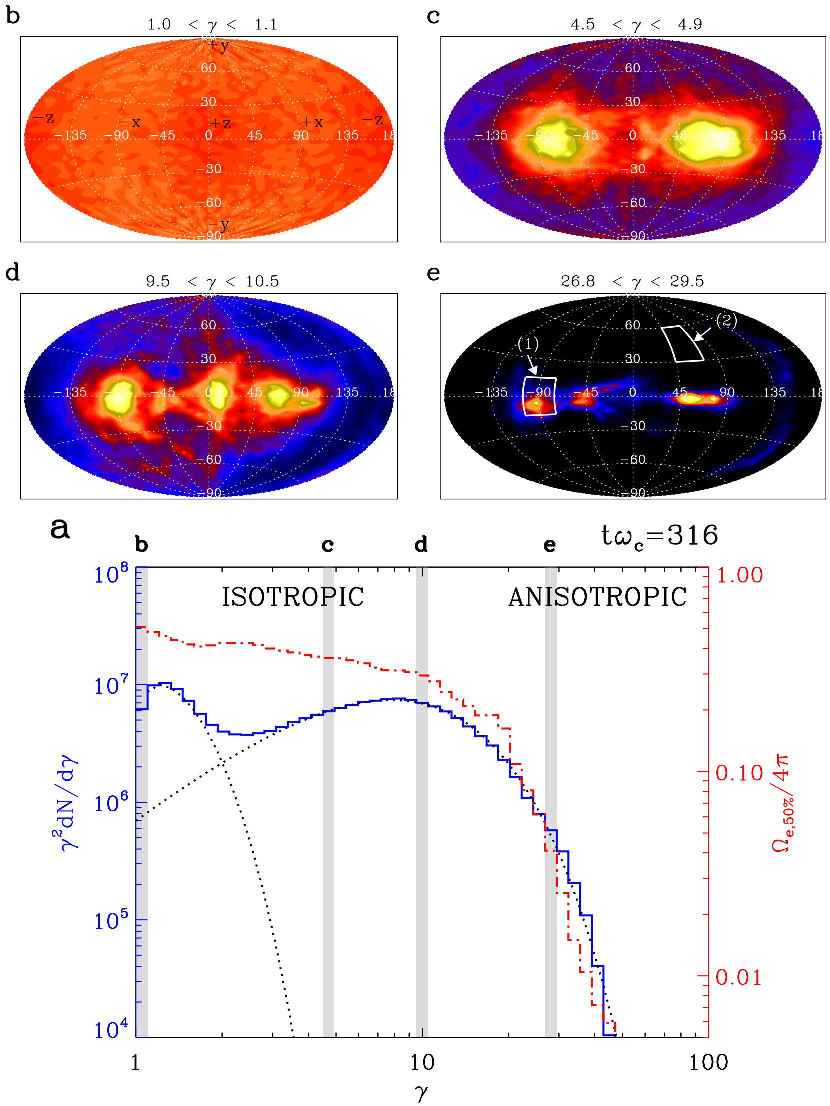


Particle anisotropy in PIC simulations
of relativistic pair reconnection *(Cerutti et al. 2012)*

- **Main result:**

energetic particle population is highly anisotropic!

- Particle anisotropy is highly energy-dependent, with ***stronger focusing for highest energy particles***.

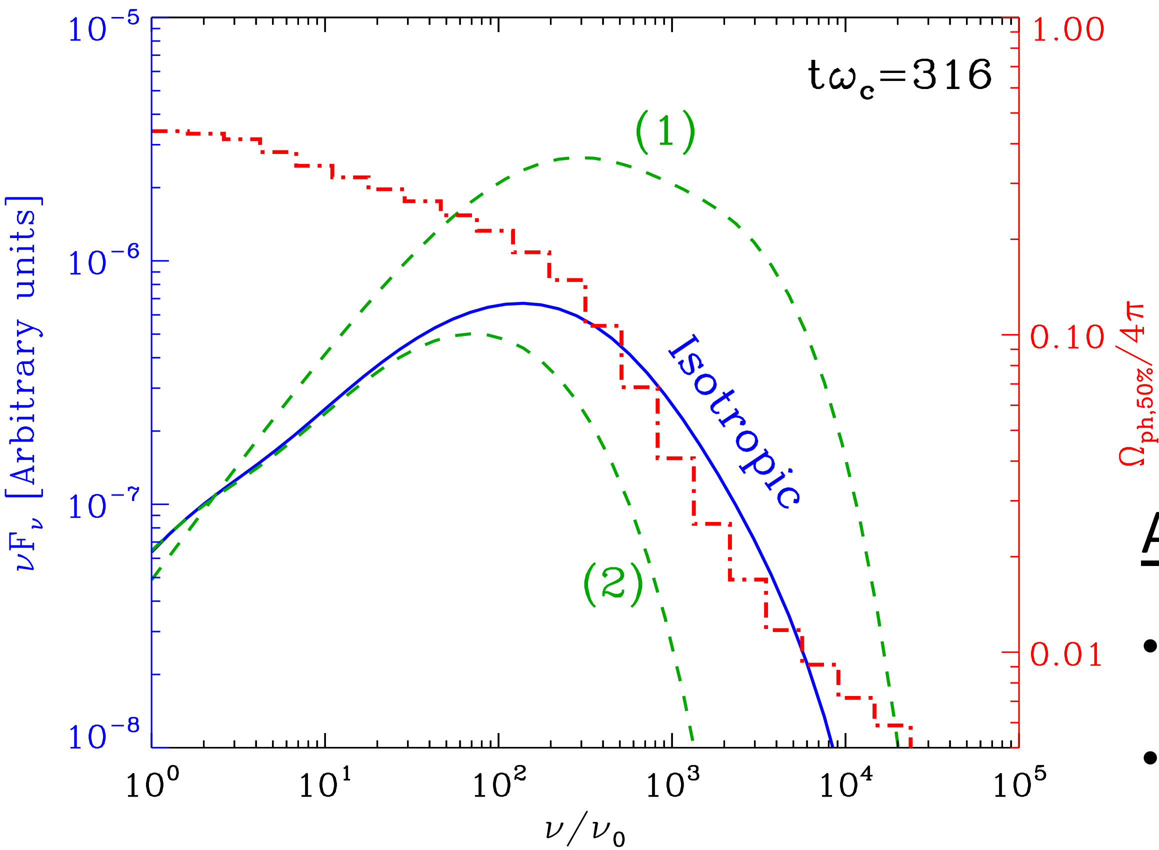


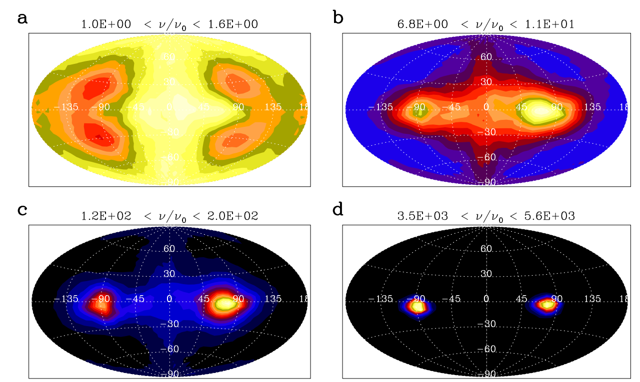
New Themes in Relativistic Pair Reconnection:

II. Radiative Signatures

- Radiation is our only **observational probe** into astrophysical reconnection.
- Fundamental question: How does a reconnection layer **look like**? What are the observable **radiative signatures** (spectrum, light curve) of reconnection?
- Radiation can also affect reconnection process itself:
  - Radiative losses may inhibit particle acceleration, especially for highest-energy particles near radiation-reaction limit (e.g., in Crab Nebula flares).
  - In the pulsar wind and near Light Cylinder, synchrotron cooling is strong even for bulk particles, limiting plasma temperature.

Synchrotron emission anisotropy in relativistic pair reconnection *(Cerutti et al. 2012)*

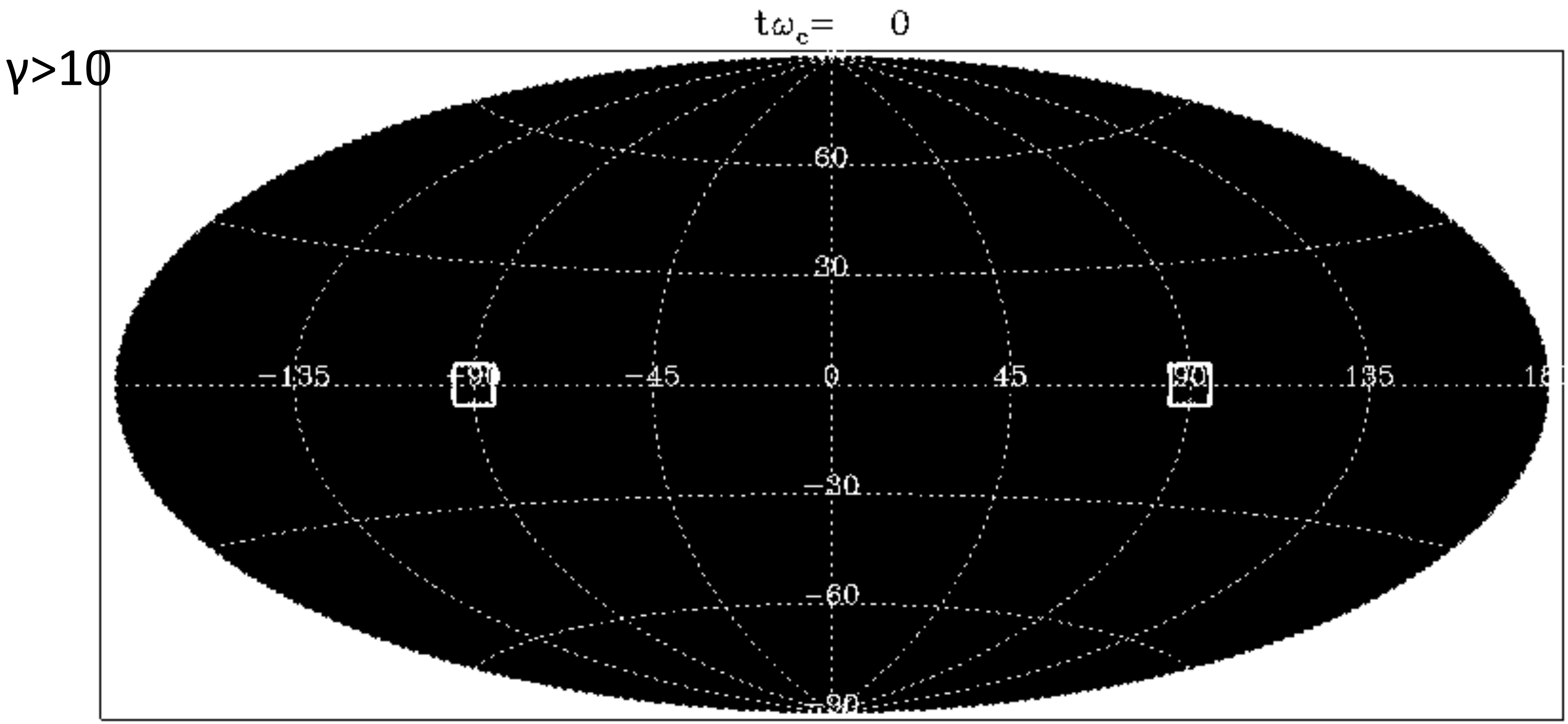




Astrophysical implications:

- flare energetics
- flare statistics
- different from traditional achromatic Doppler boosting

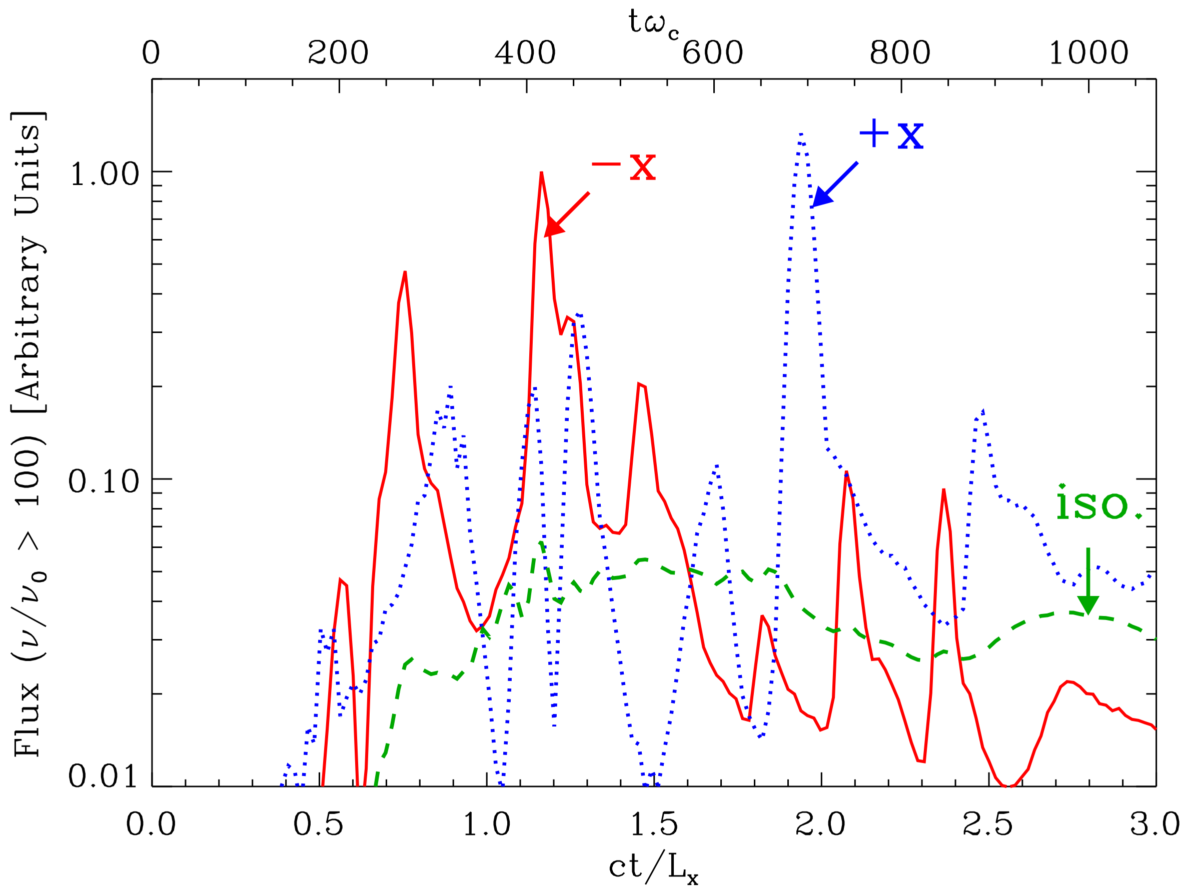
Rapid emission variability in relativistic pair reconnection *(Cerutti et al. 2012)*



Energetic particles form highly focused beams that sway from side to side in the reconnection layer midplane.

Rapid emission variability in relativistic pair reconnection *(Cerutti et al. 2012)*

Swaying beams create rapid variability of radiation seen by external observer.



Simulated high-energy emission light curve

Summary

- How does a reconnection layer **look like**?
- Strong, energy-dependent **anisotropy** of energetic particles produced in relativistic pair reconnection.
- Observational appearance of reconnection layer:
  - strong anisotropy of radiation ("kinetic beaming").
  - implications for flare energetics and statistics;
  - rapid variability of observable emission.
- **Applications** for flares in pulsar winds/nebulae, AGN/blazar jets, Gamma-Ray Bursts….