# bulk flows and gamma rays from relativistic magnetic reconnection

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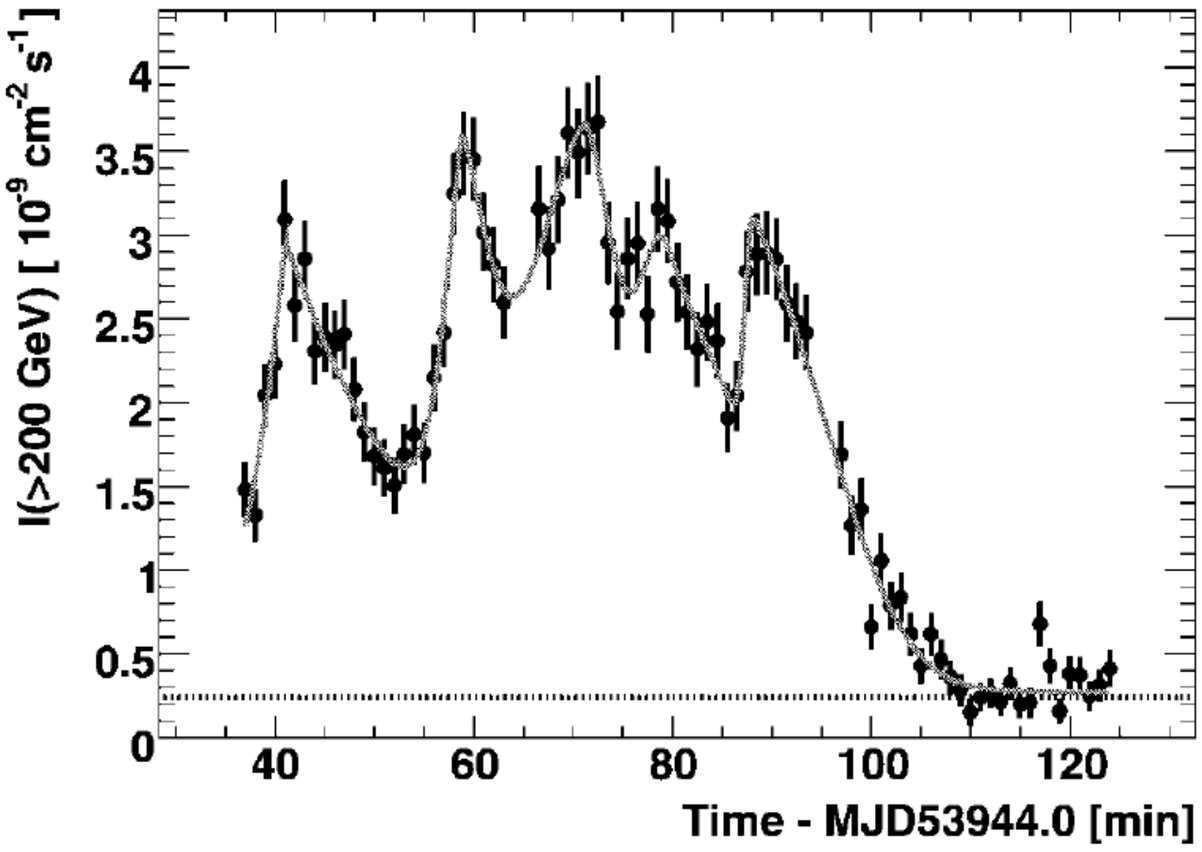
# rapid flares of blazars

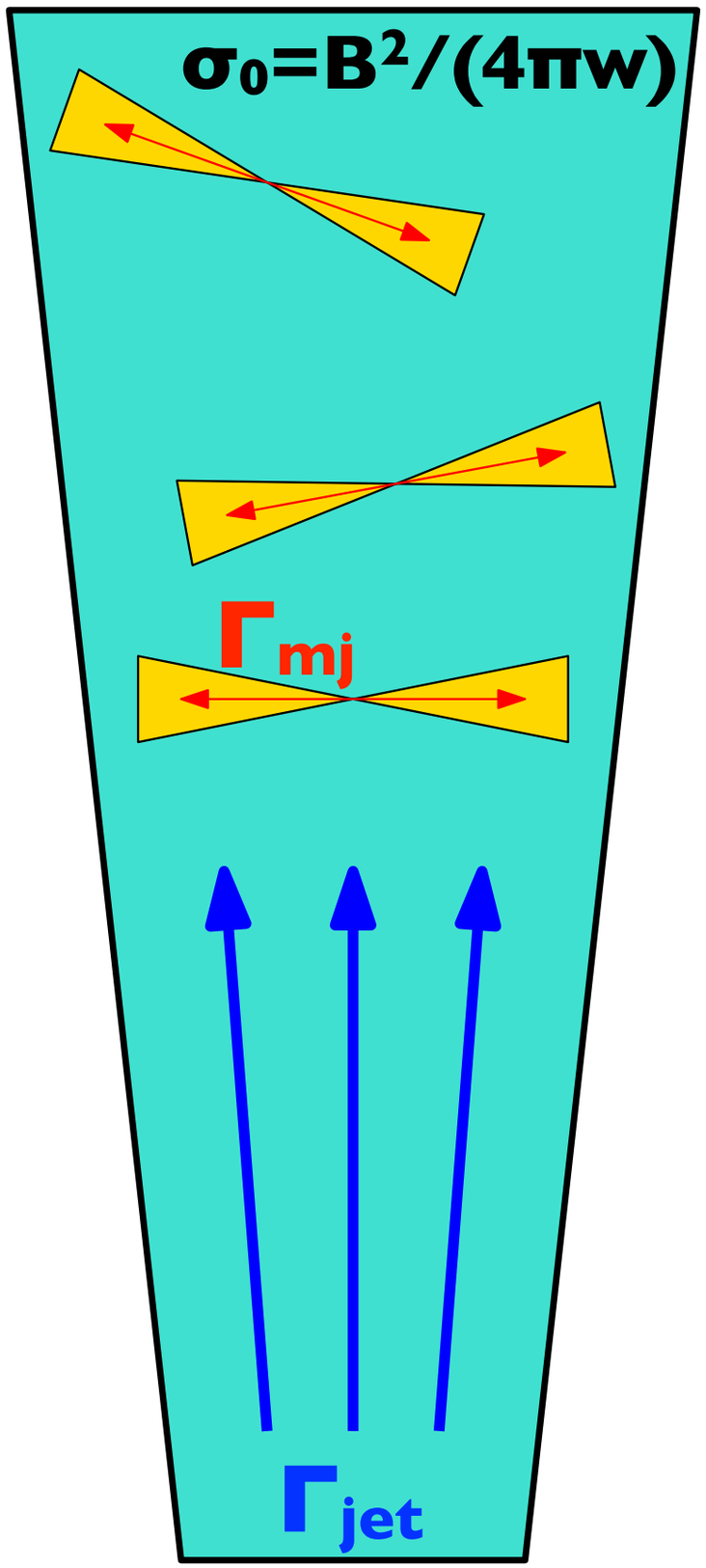
photon energy
**0.2 - 1 TeV**




PKS 2155-304
H.E.S.S. Collaboration
Aharonian et al. 2007

- observed variability time scale
  **$t_{var} \simeq$ 3 min**
- black hole light-crossing time scale **$\simeq$ 1.5 h $\gg t_{var}$**
- extreme compactness (luminosity / volume)
- emitting region of very high Lorentz factor **$\Gamma_{fl} > 50$**, much higher than **$\Gamma_{jet} \sim$10-20** (Begelman et al. 2008)
- relativistic reconnection? (Giannios et al. 2009)

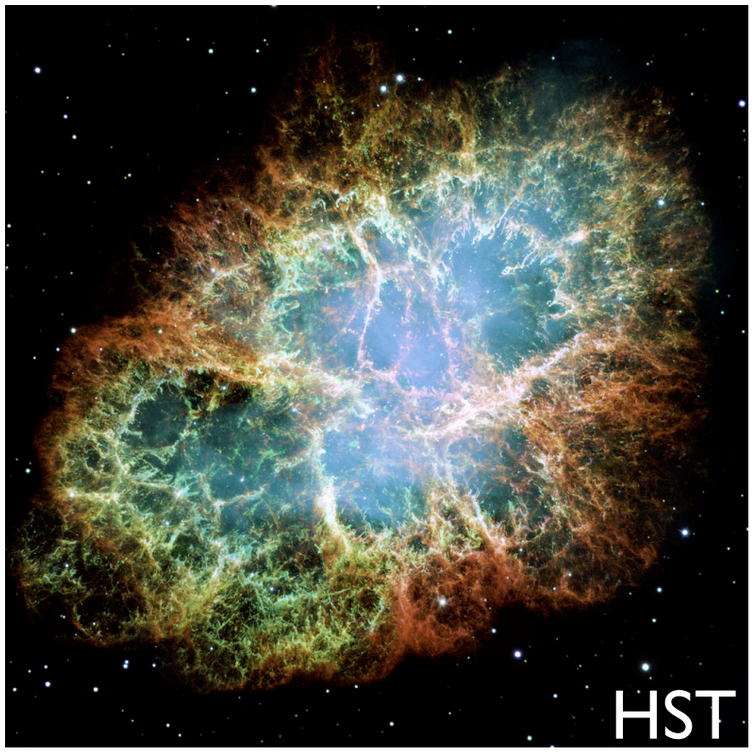
# minijets model

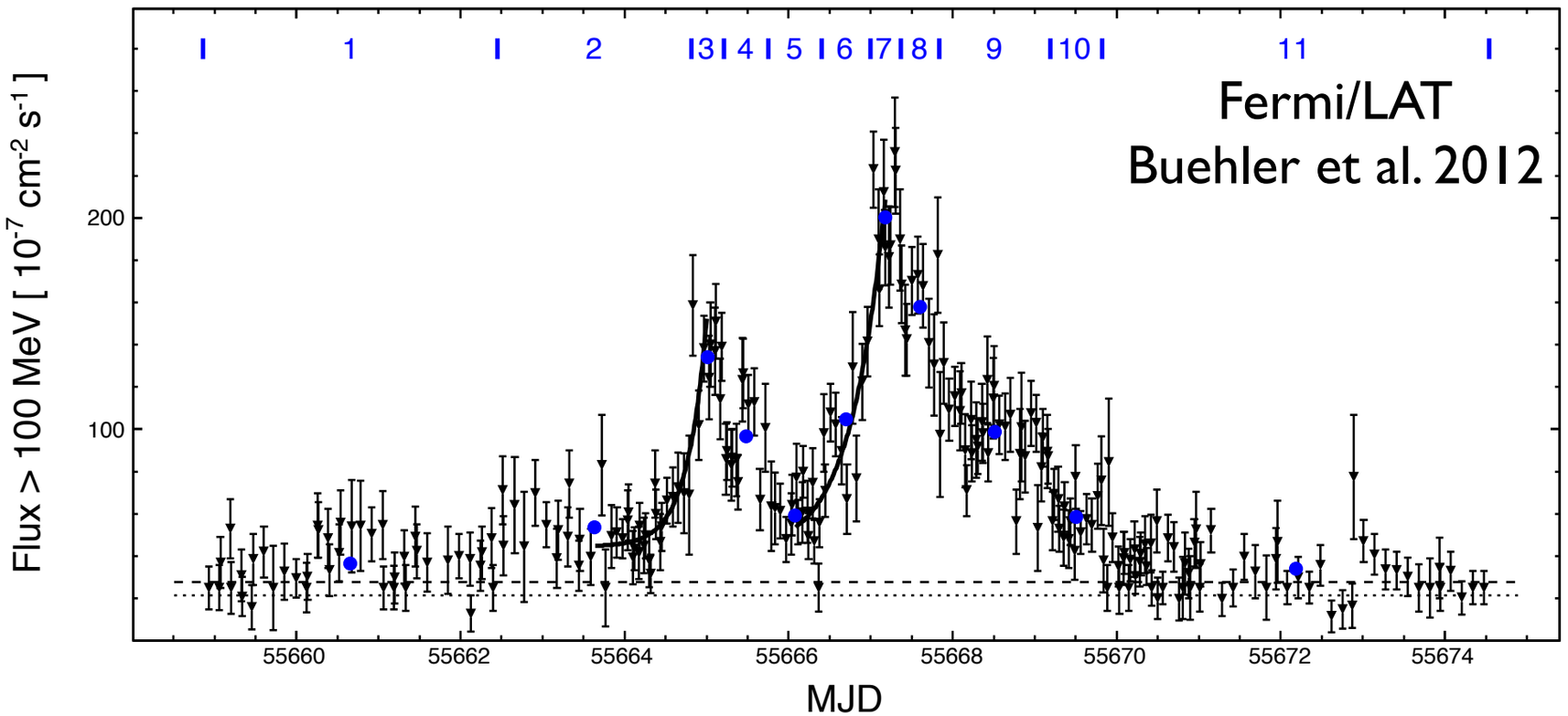



- reconnection produces localized relativistic outflows (minijets) with $\Gamma_{mj}$ within a larger relativistic jet
- explains additional relativistic Lorentz boost ($\Gamma_{fl} \sim \Gamma_{jet}\Gamma_{mj}$) and local dissipation
- based on relativistic Petschek reconnection model (Lyubarsky 2005)
- depends on the scaling of minijet Lorentz factor with jet magnetization $\Gamma_{mj} \propto \sigma_0^{1/2}$ in relativistic regime
- **is this scaling correct?**

Giannios et al. (2009)

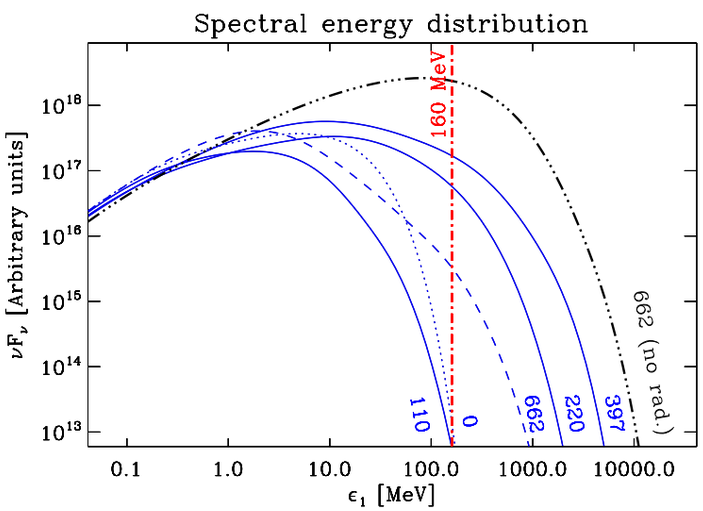
# crab nebula flares



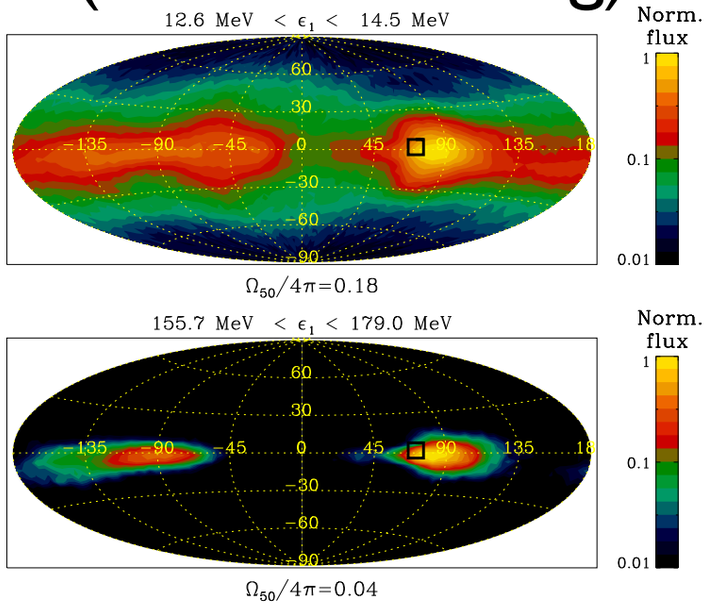




# relativistic reconnection (Cerutti et al. 2013)

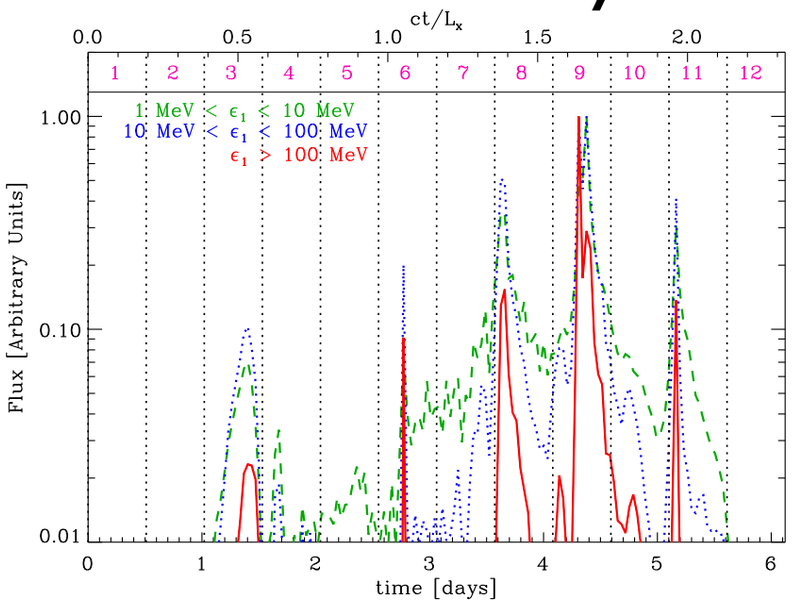
## exceed synchrotron energy limit




## energy-dependent anisotropy (kinetic beaming)

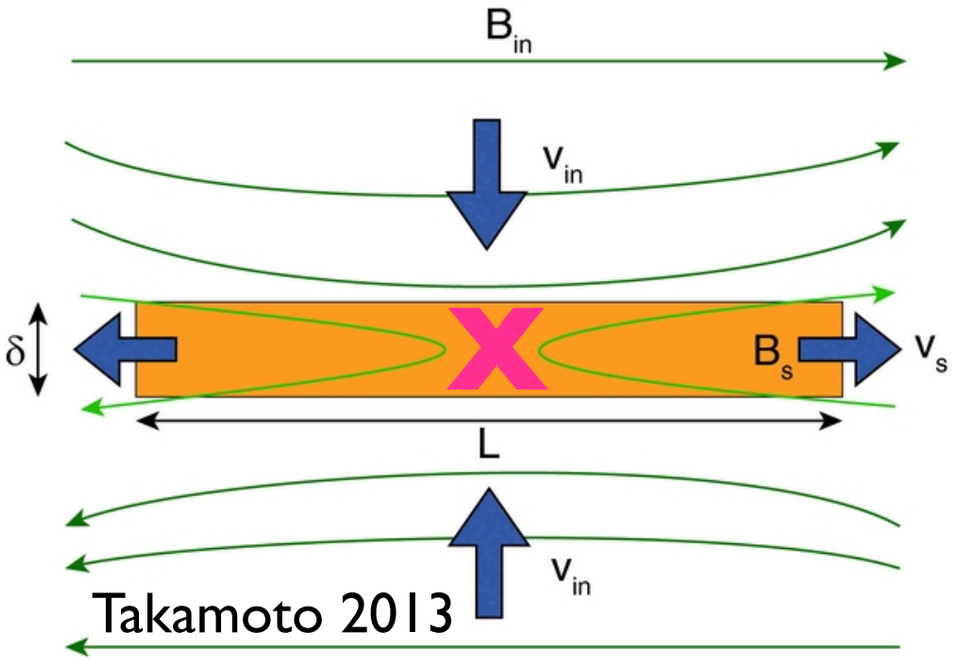



## superluminal variability



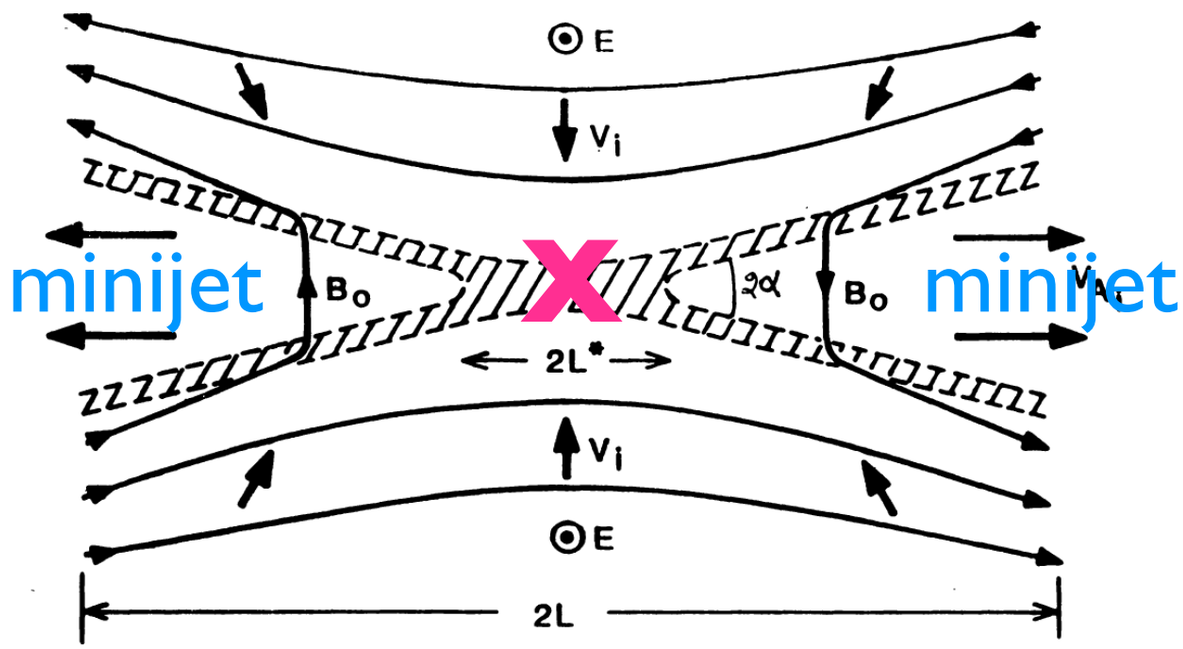
# reconnection models

## Sweet-Parker

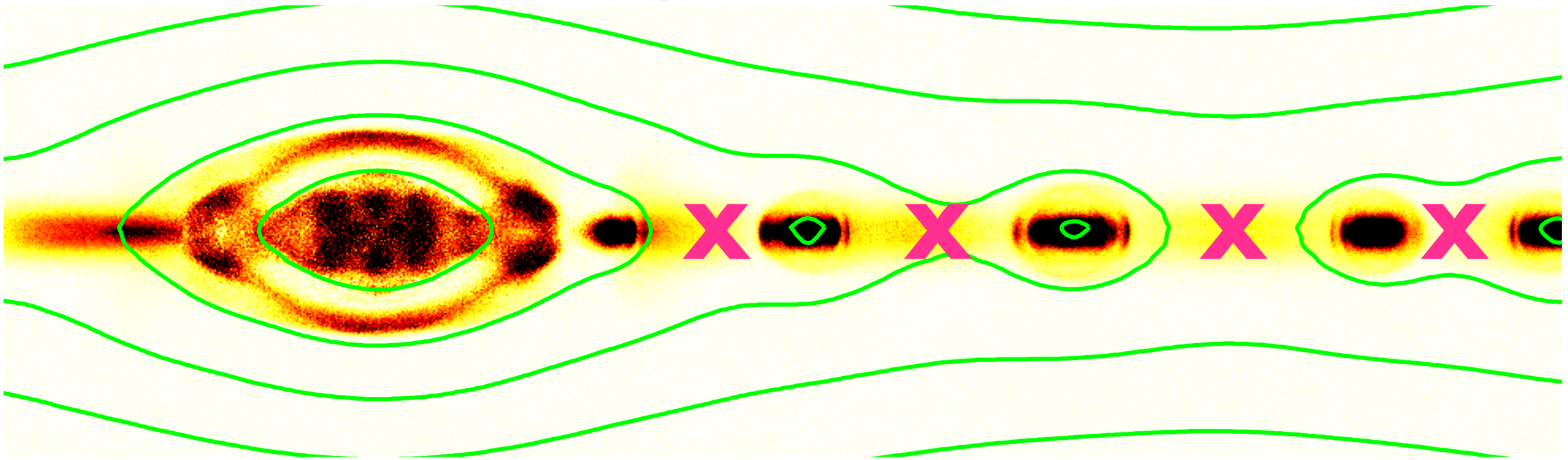



Takamoto 2013

## Petschek




## plasmoid



K. Nalewajko, 25th Texas Symposium

# PIC simulations

we study numerically the kinematics of relativistic reconnection outflows and calculate synthetic lightcurves for different observers

- **Zeltron** - relativistic PIC code with radiation reaction force (Cerutti et al. 2013)
- 2-dimensional
- pair plasma
- Harris sheet with long-wavelength perturbation
- no guide field
- radiation reaction off
- magnetization $\sigma_{bg} = B^2/(4\pi n_e m_e c^2) \gg 1$
- temperature $\theta_e = kT/(m_e c^2) = 1$
- drift velocity $\beta_d = 0.6$
- 256 particles per cell

t = 0

$j_z$ $B$

y

x

$u_x$ $u_z$

x

$n_e$ $\langle g' \rangle$

x

$L_{syn,x-}$ $L_{ec,x-}$

x

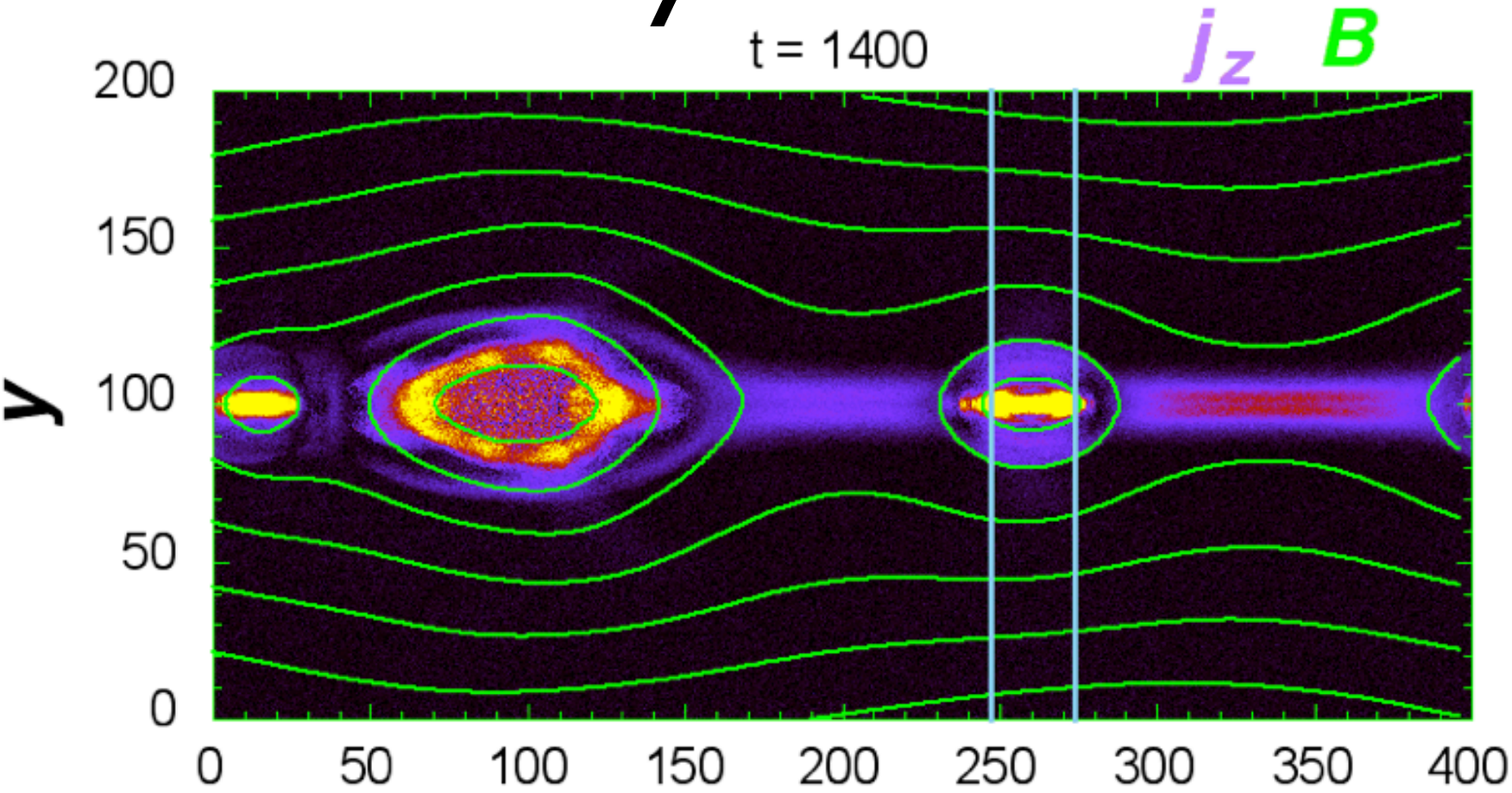
$L_{syn,x+}$ $L_{ec,x+}$

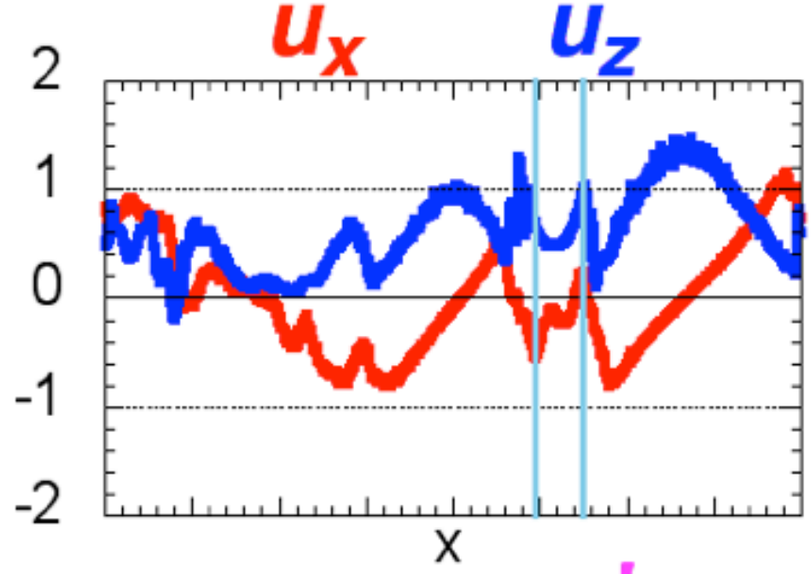
x

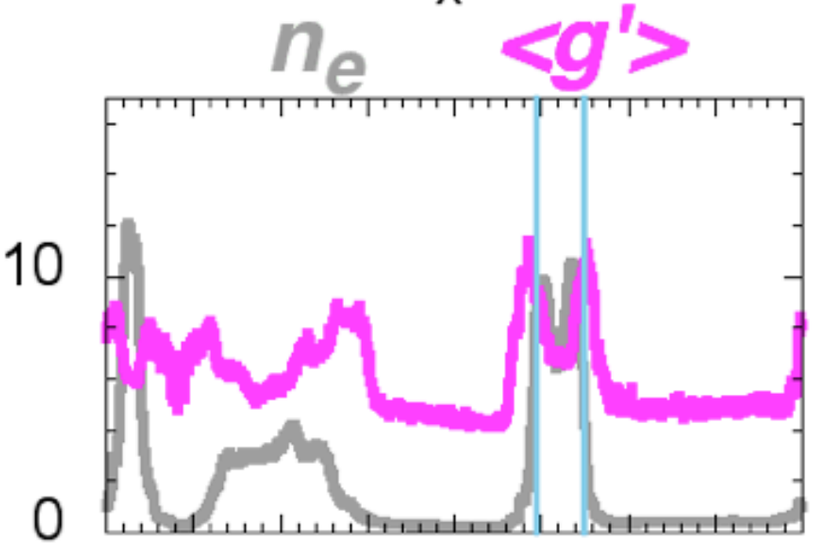
$D_{x+}$ $L'_{syn}$ $L'_{ec}$

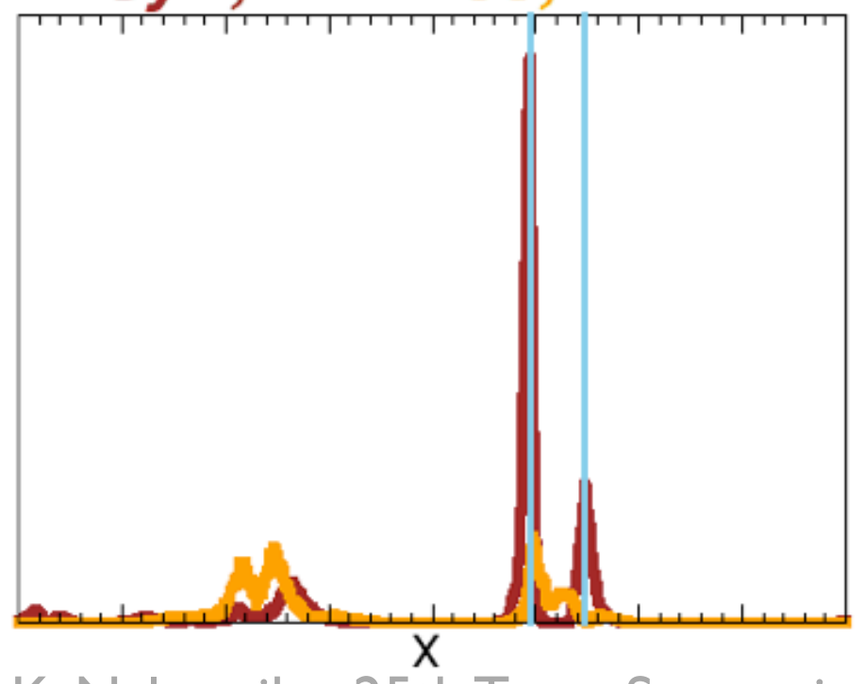
x

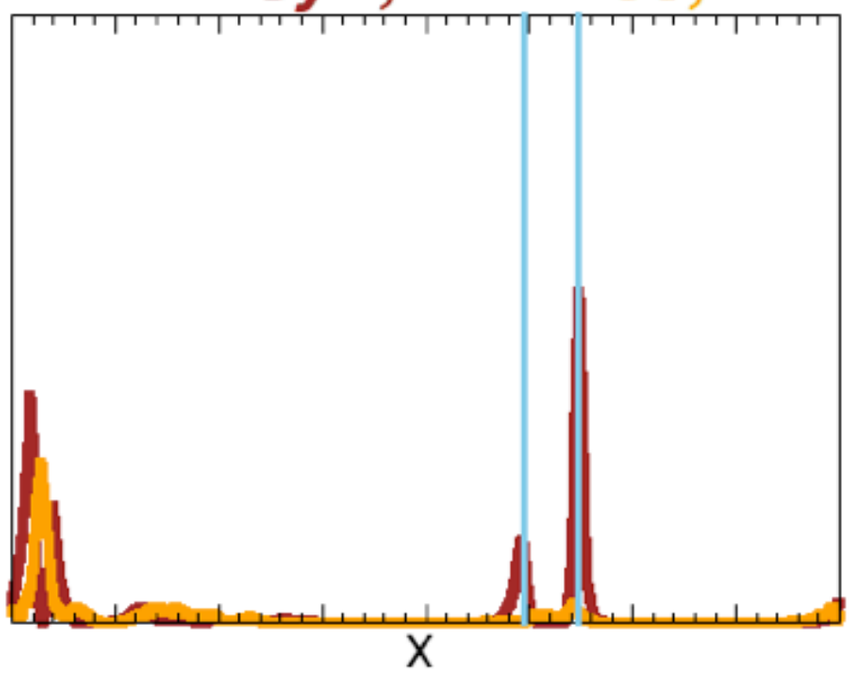
# synchrotron flares

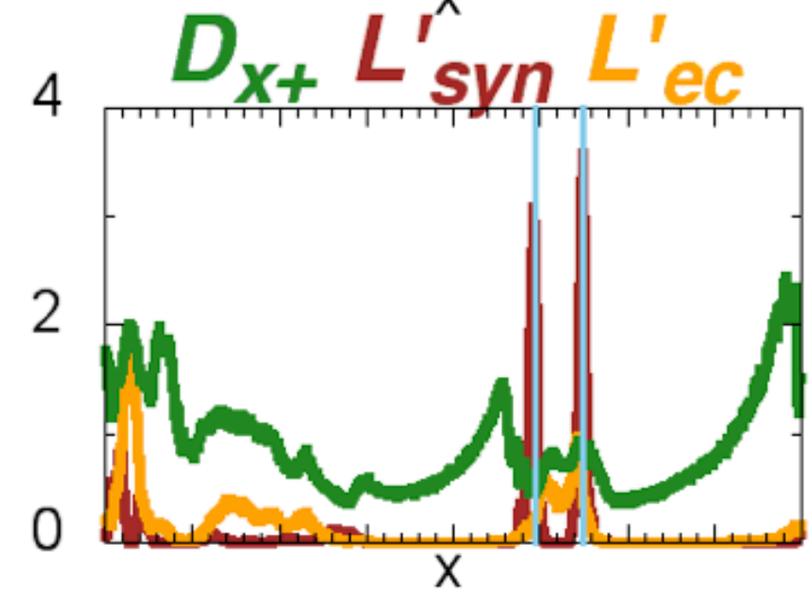


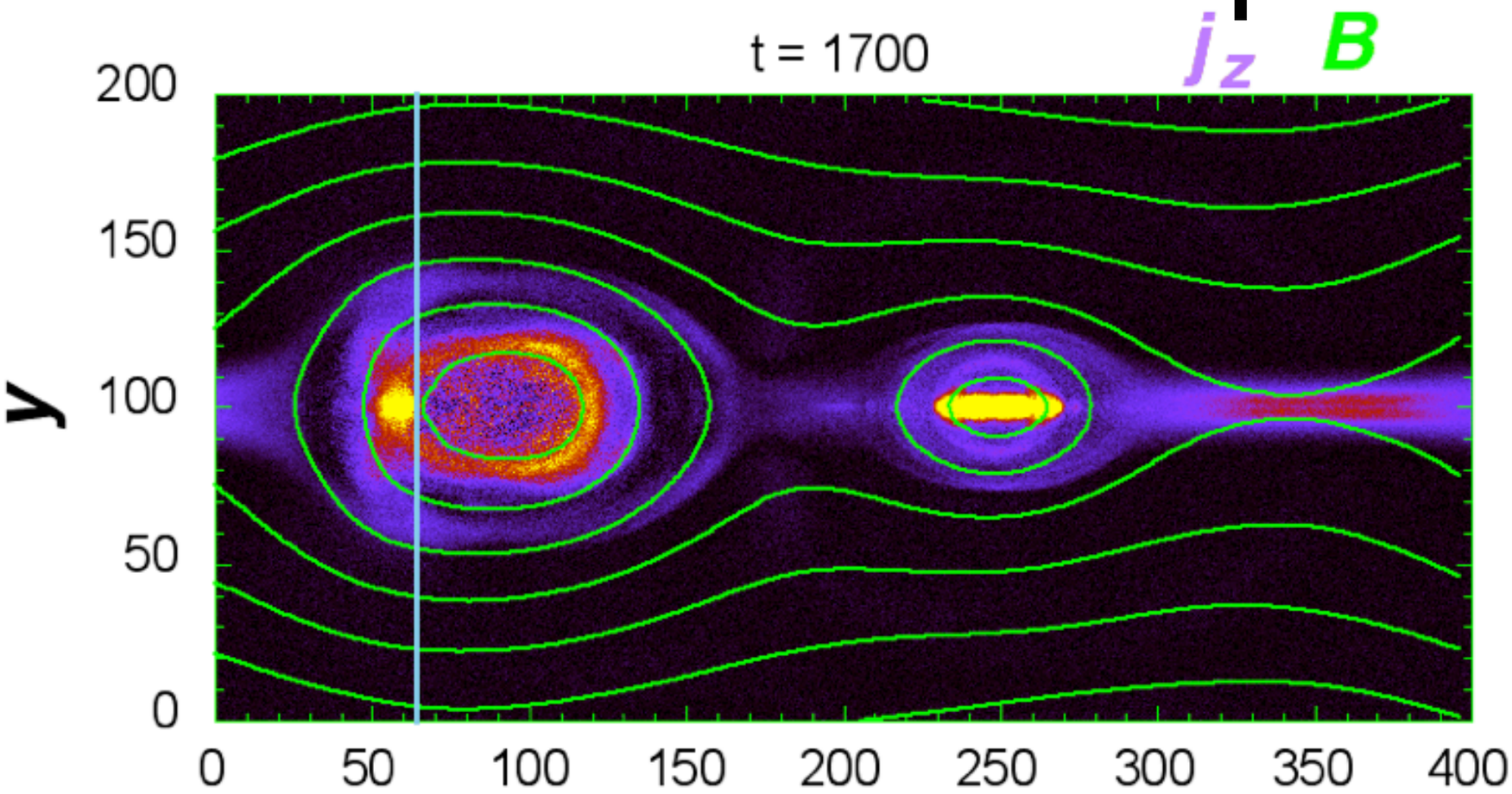



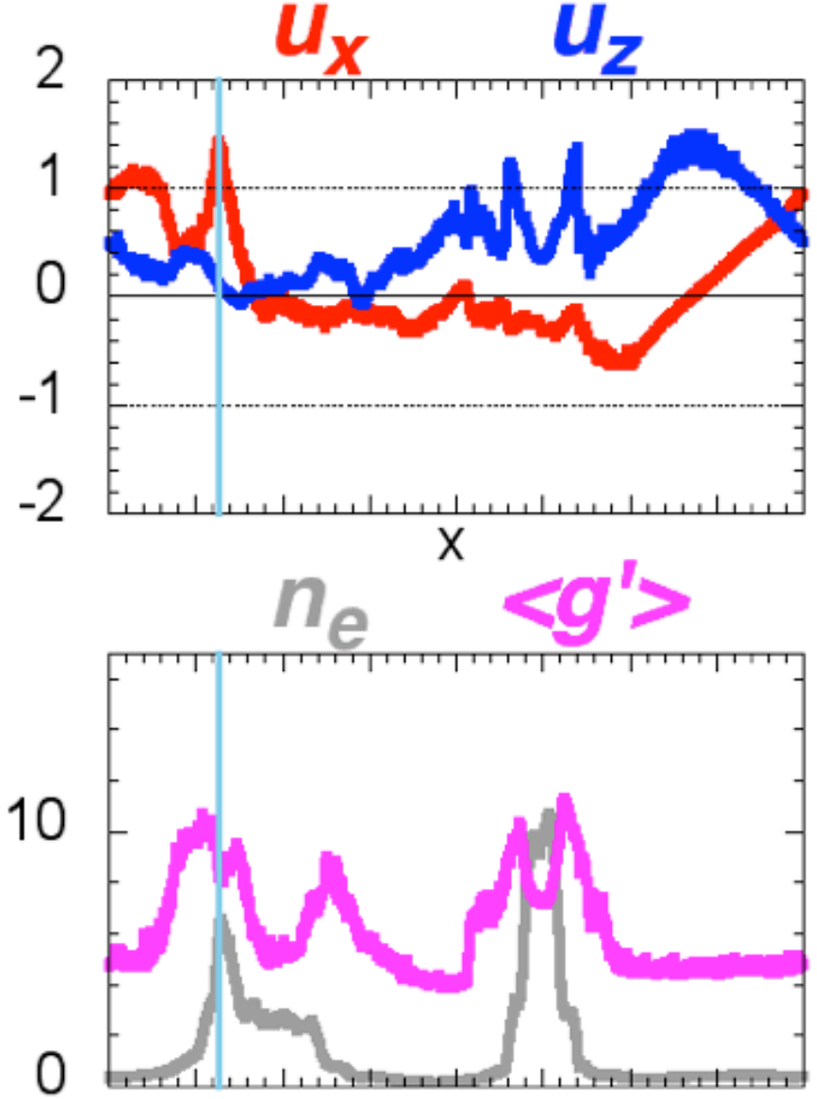



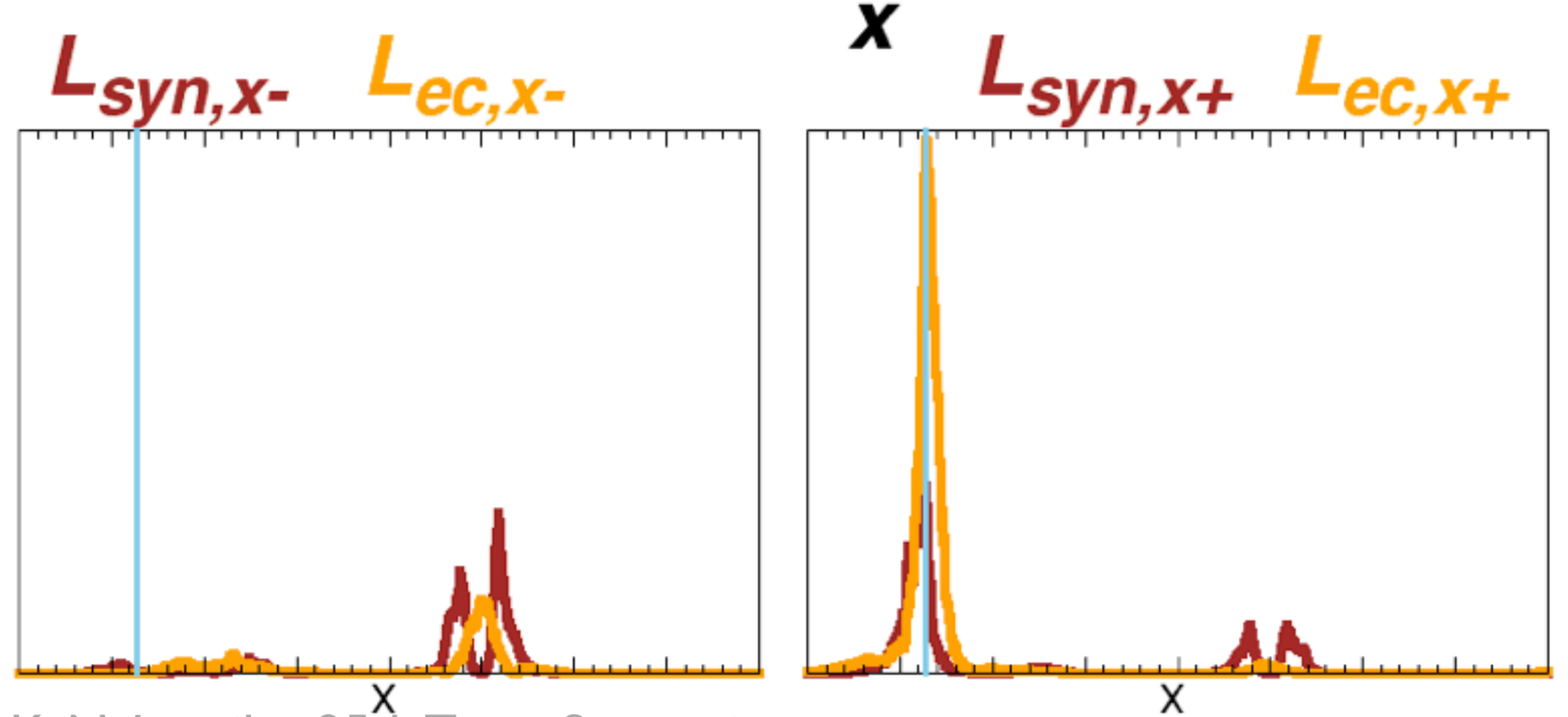



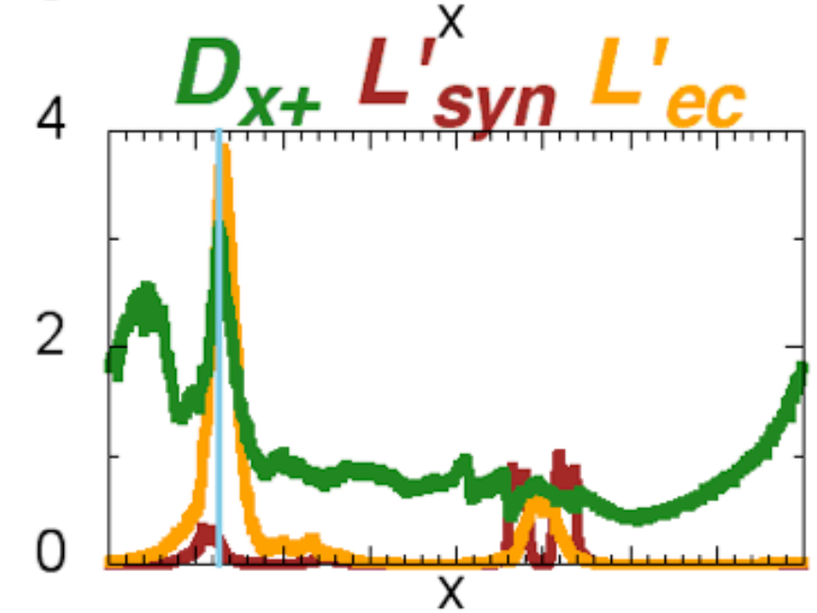



# external Compton flare



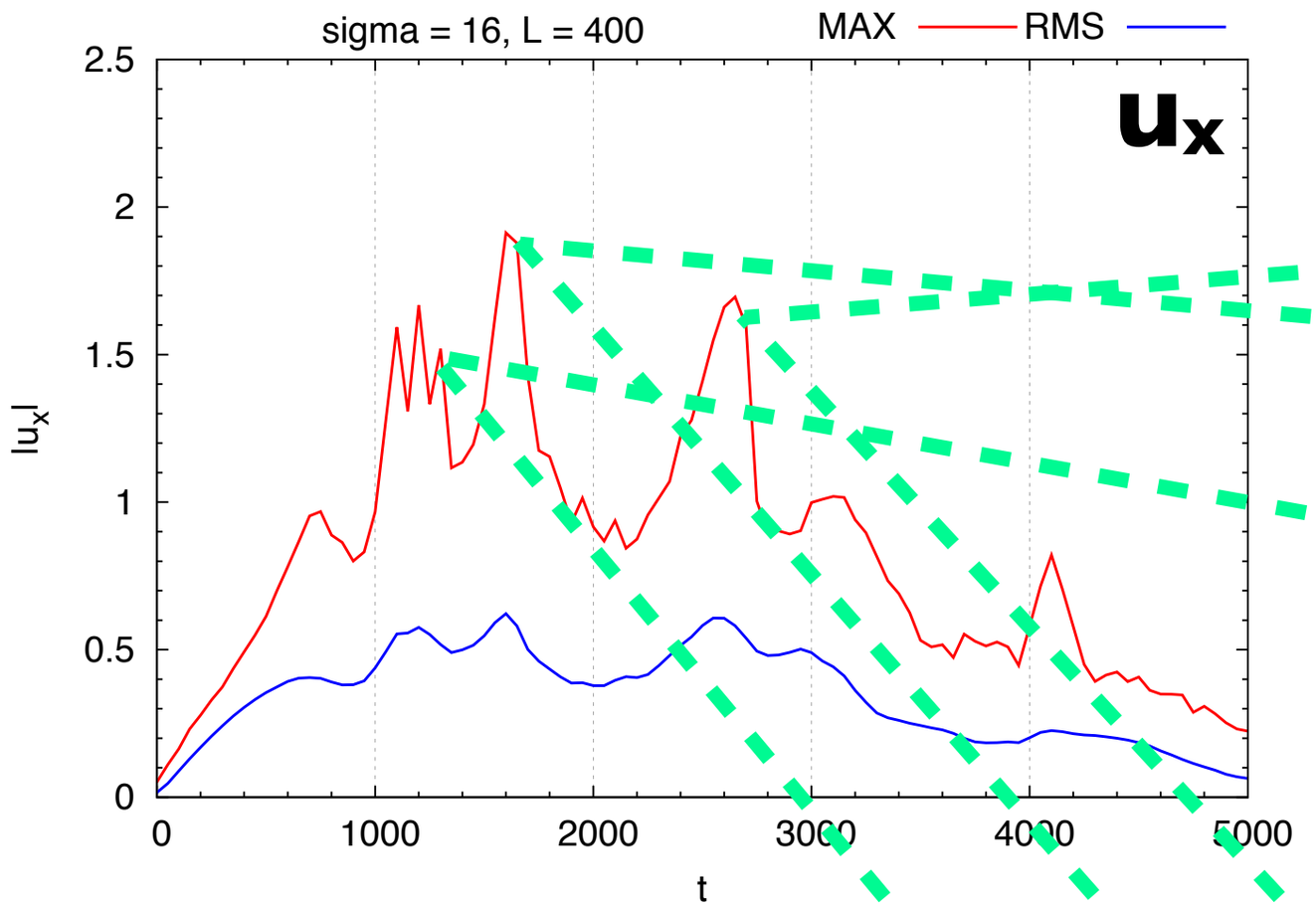



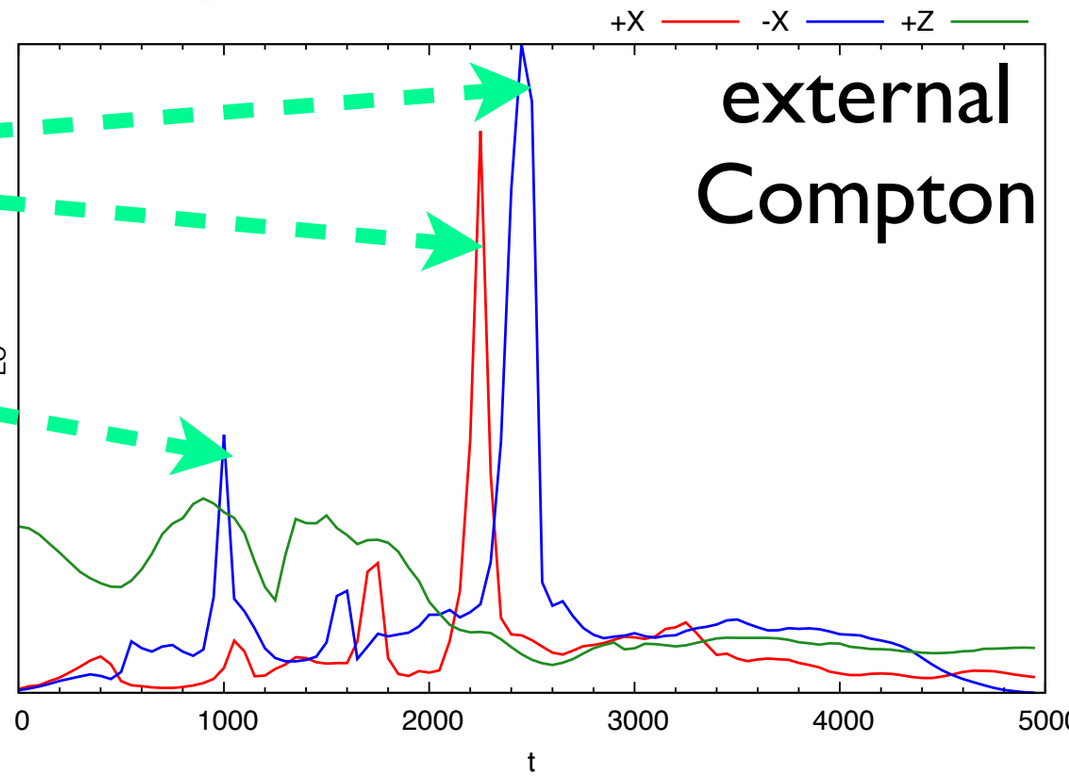



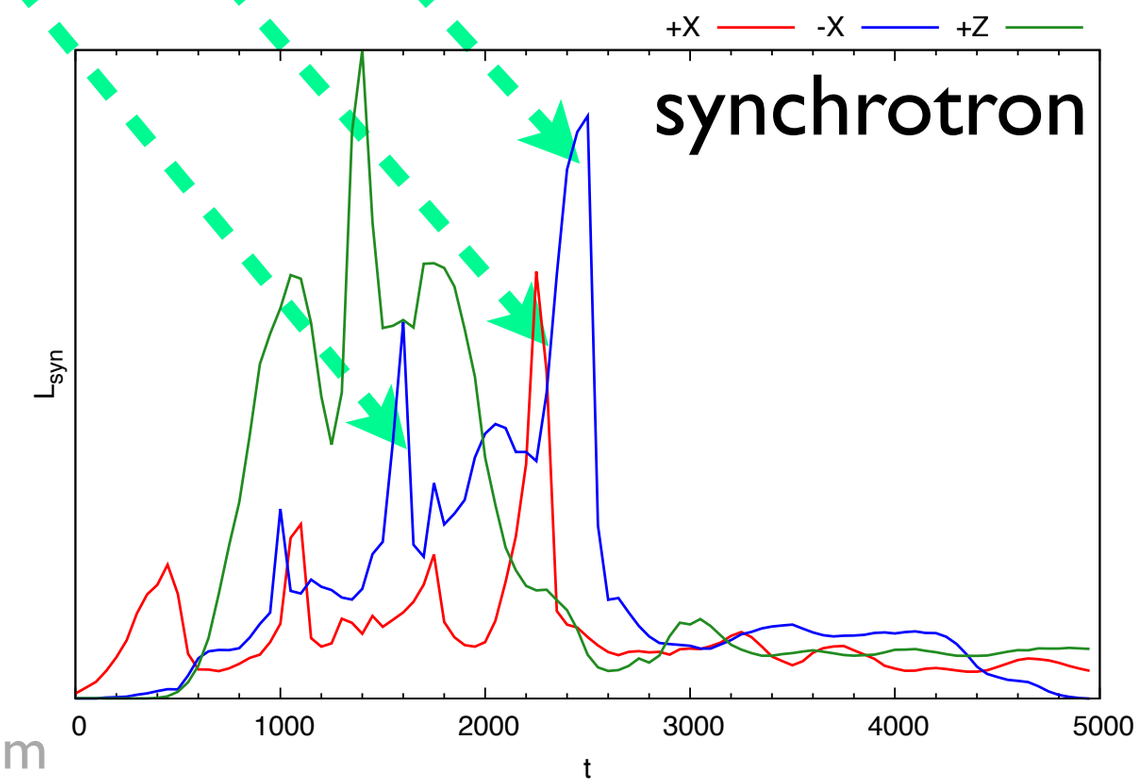



# bulk kinematics

# observed light curves

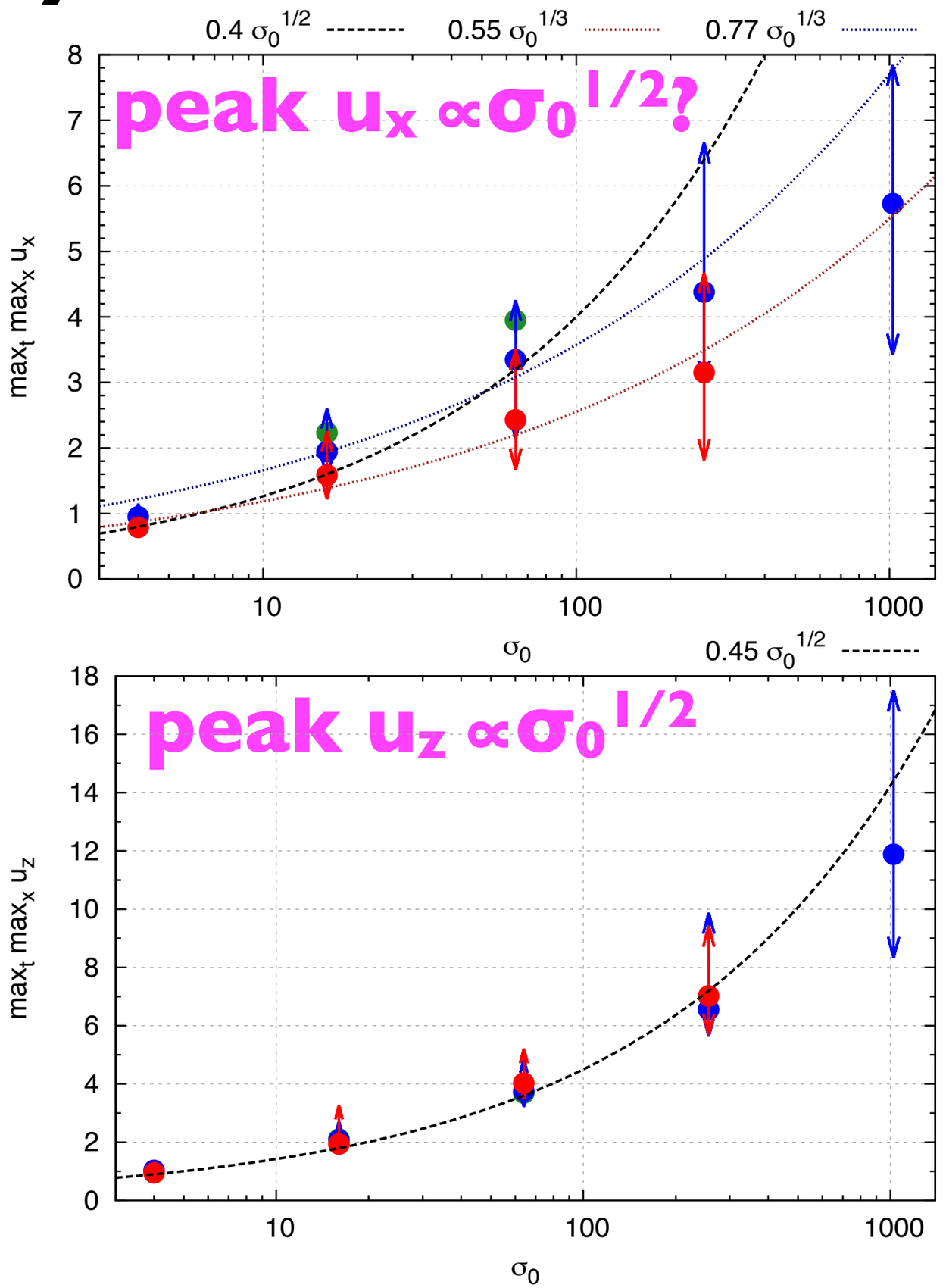


# peak velocity statistics

- **$u_x$, $u_z$** - maximum over **x, t**
- average over many simulations
- 3 grid sizes:
  **L = 200, 400, 800**
- **$u_x$** scaling underresolved
- weak scaling of rms velocities



# summary

- extreme astrophysical gamma-ray flares (blazars, Crab nebula) may be explained by relativistic outflows from magnetic reconnection
- this motivates us to study the relation between kinematics and radiation in relativistic magnetic reconnection
- we perform 2D PIC simulations of pair plasma reconnection with very high upstream magnetization
- we observe sharp, roughly correlated, synchrotron and EC flares related to transient spikes in $\mathbf{u_x}$ velocity component due to plasmoid mergers
- peak velocities scale like $\mathbf{u_x \propto \sigma_0^{1/2?}}$ and $\mathbf{u_z \propto \sigma_0^{1/2}}$