Monte Carlo simulations of cosmic ray acceleration in GRB afterglows

Don Warren
North Carolina State University

Don Ellison (NCSU)
Shigehiro Nagataki (RIKEN)

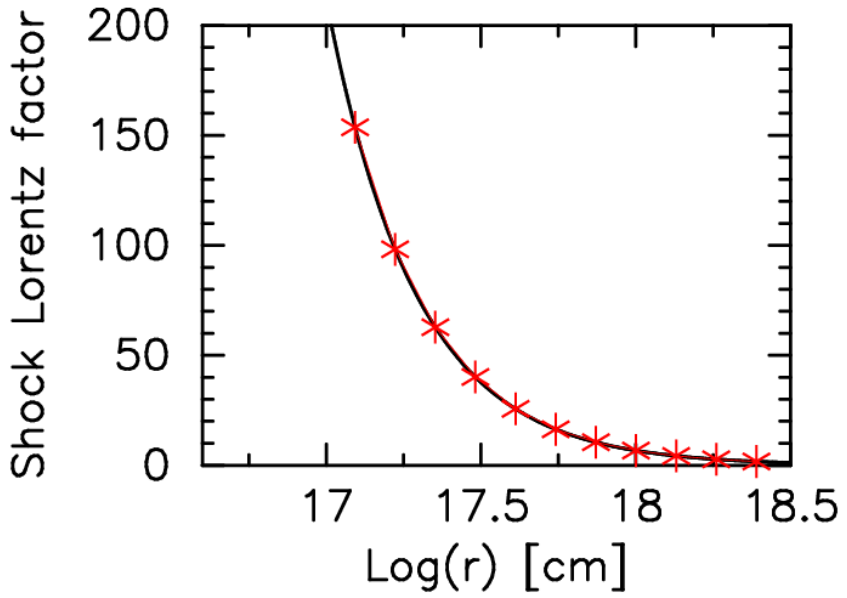
Motivation

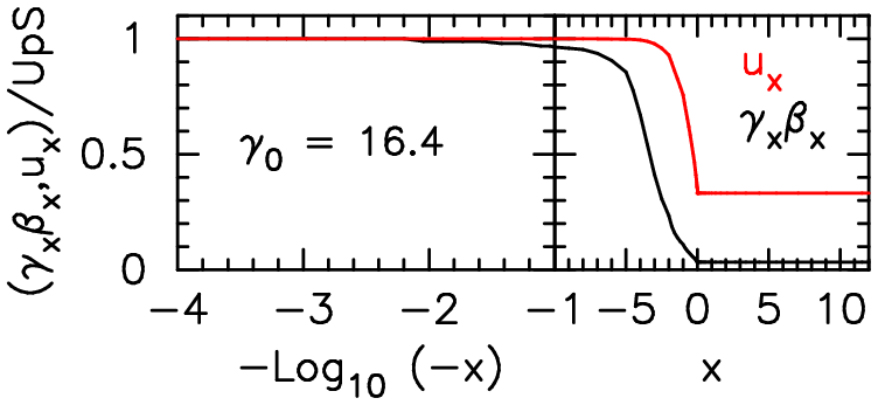
- Hydrodynamics, emission in GRB afterglows, & particle acceleration well-studied, but independently of each other
- Work here couples the topics

- Shocks accelerate particles, which affect shock profile
- GRB shocks slow from ultra-rel. to transrel. during afterglow
- Smoothed rel./transrel. shocks require numerical approach
- PIC simulations are *expensive* computationally
- So use Monte Carlo simulations of GRB shocks to model photon production

Numerical process

- Use numerical solution to get physically motivated input parameters for MC code
- Calculate smoothed shock profile at select times
- Model both electron *and* ion acceleration
- Energy transfer at subshock from ions to electrons (10-20%+ according to PIC simulations)



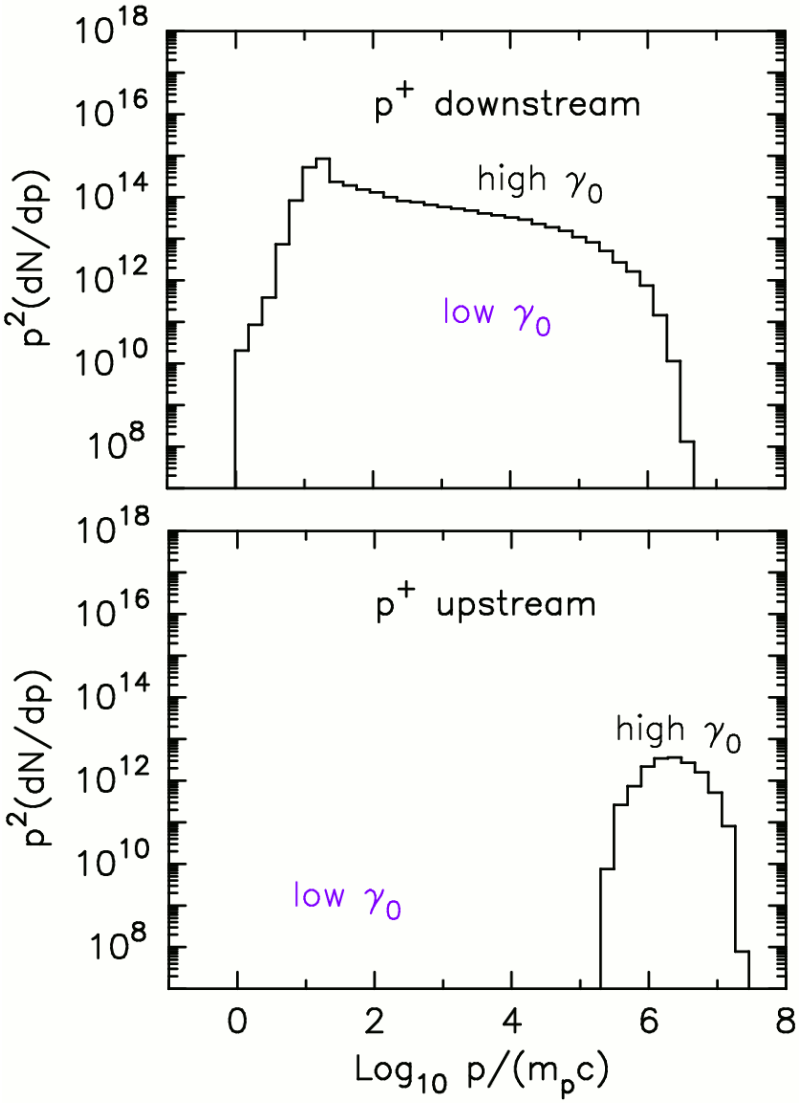


Numerical process

- Model photon emission using accelerated particle spectra
  - Synchrotron (background $\vec{B}$ parameterized)
  - Pion decay
  - Inverse Compton (*can* do SSC, but not done here)
- Process photon emission from shock & explosion frames to observer's
  - Redshift
  - Lorentz beaming
  - Doppler shift
  - Emitted/received power
  - Surface of equal arrival time (not shown here)

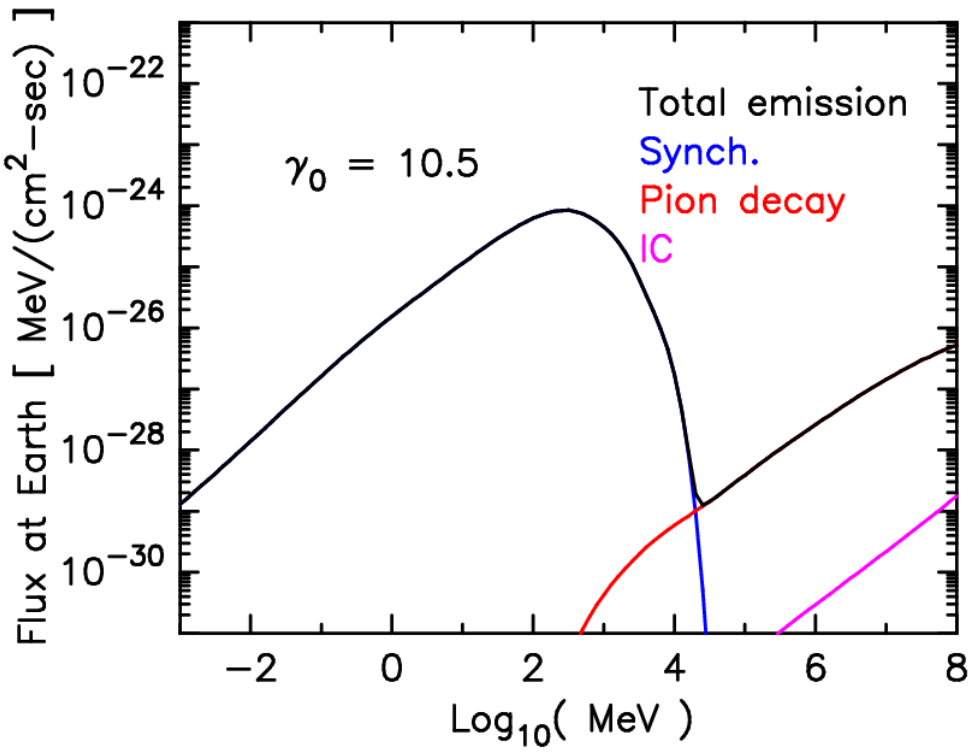
Results: particle spectra

- Transition seen in Ellison, Warren & Bykov (2013) occurs here also
- Transition especially dramatic for upstream regions
- Electron spectra largely similar to ions
- Predictions affecting photons:
  - Turnover energy, sharpness
  - Spectral index of power law



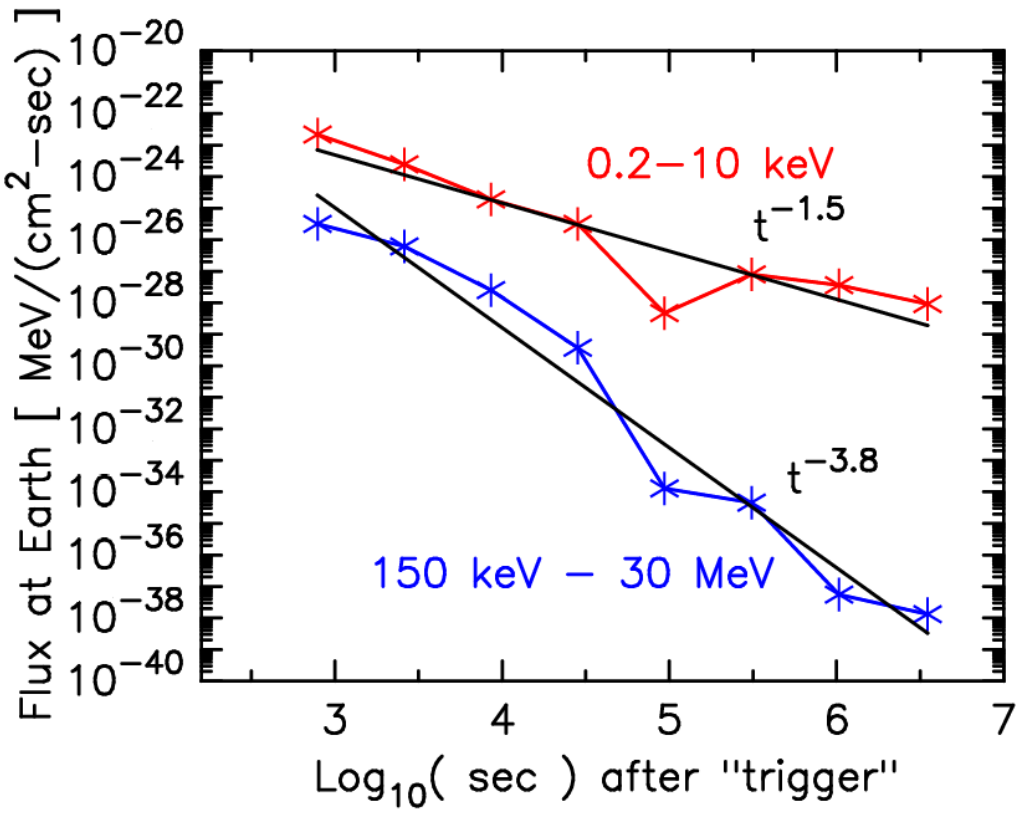
Results: photon spectra I

- Emission in Swift XRT, Fermi GBM energy ranges dominated by synchrotron mechanism
- Photons produced with E > 10 TeV even at late times (t_{obs} ≈ 30ks here)
- Source of TeV photons can be pion decay or IC – our model can distinguish



Results: photon spectra II

- **Simulated SWIFT & Fermi GBM data show rough power law**
- ***Very* preliminary; much still to consider**



Conclusions

- Developing a model to link hydrodynamics of GRB shocks to observed photon emission
- Both electrons and ions accelerated
- Interesting trends seen as shocks slow from ultra- to transrel.

- Extensions / future work
  - Information about escaping CRs
  - Dependence on hydro. parameters
  - Reverse shock?

Results: particle spectra

- Transition seen in Ellison, Warren & Bykov (2013) occurs here also
- Transition especially dramatic for upstream regions
- Electron spectra largely similar to ions
- Predictions affecting photons:
  - Turnover energy, sharpness
  - Spectral index of power law