Electron Heating and Acceleration in Gamma-Ray Bursts.

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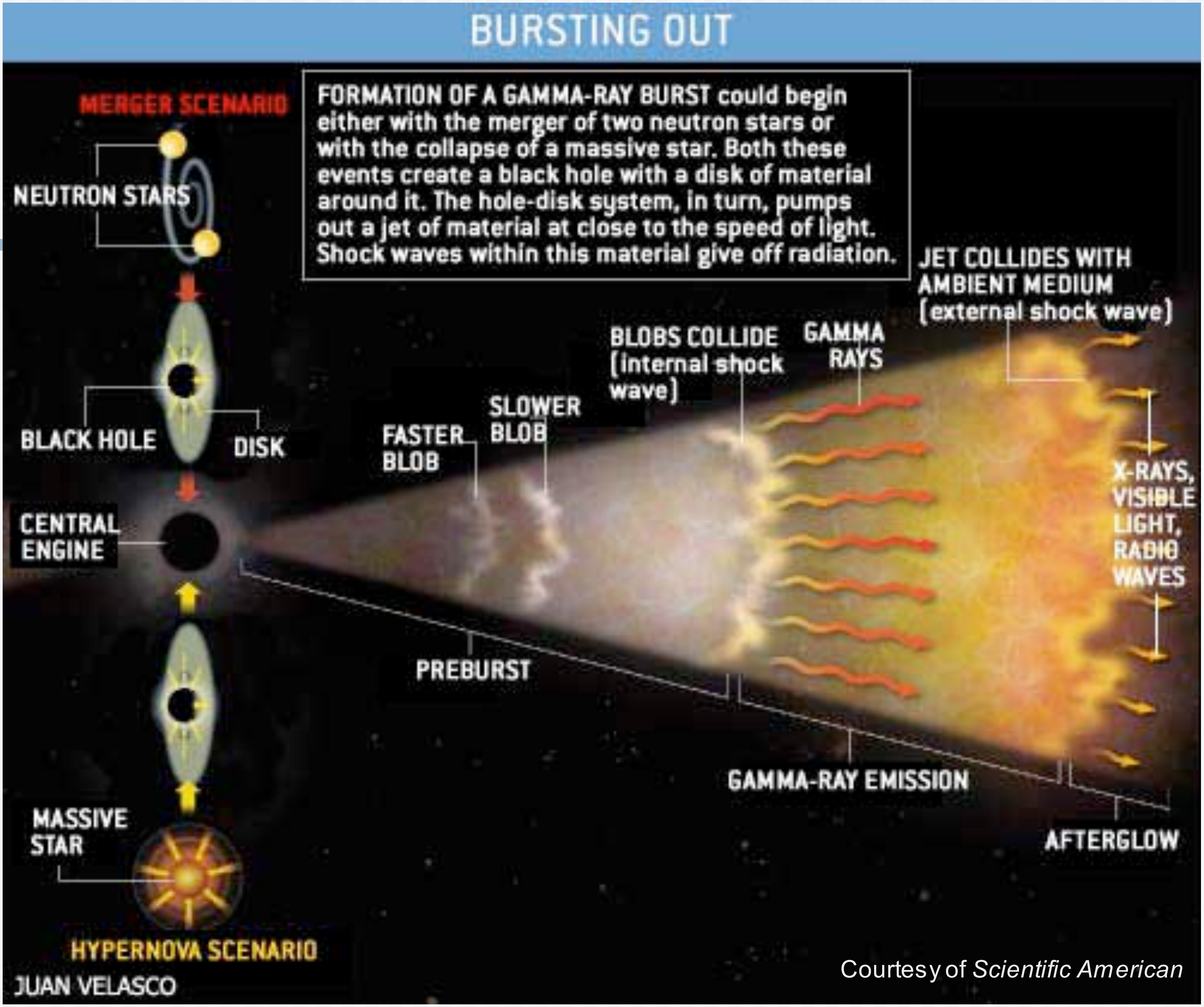


BURSTING OUT

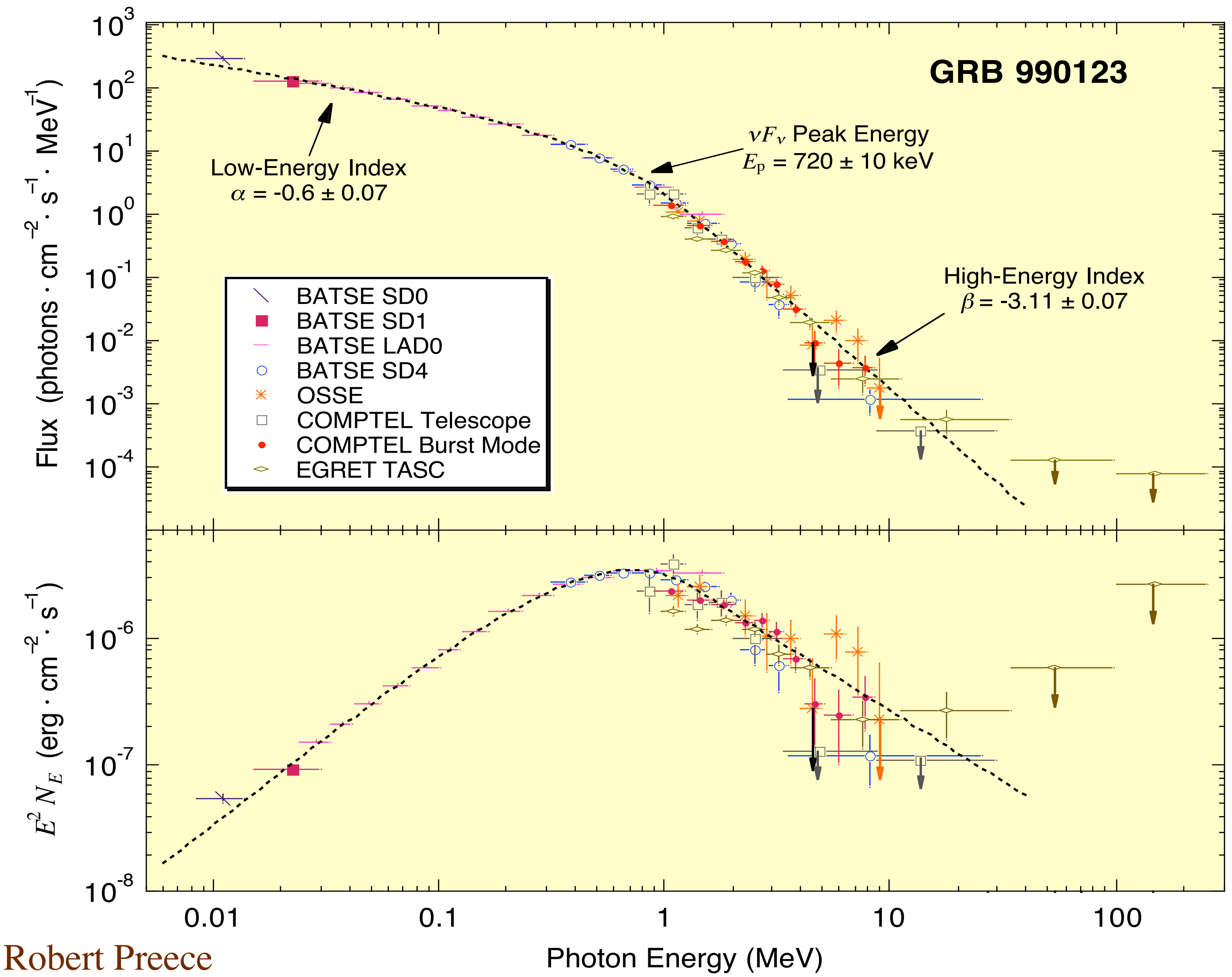
FORMATION OF A GAMMA-RAY BURST could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.

Courtesy of *Scientific American*

Compton Gamma-Ray Observatory
1991-2000

Deployment of CGRO from Space Shuttle

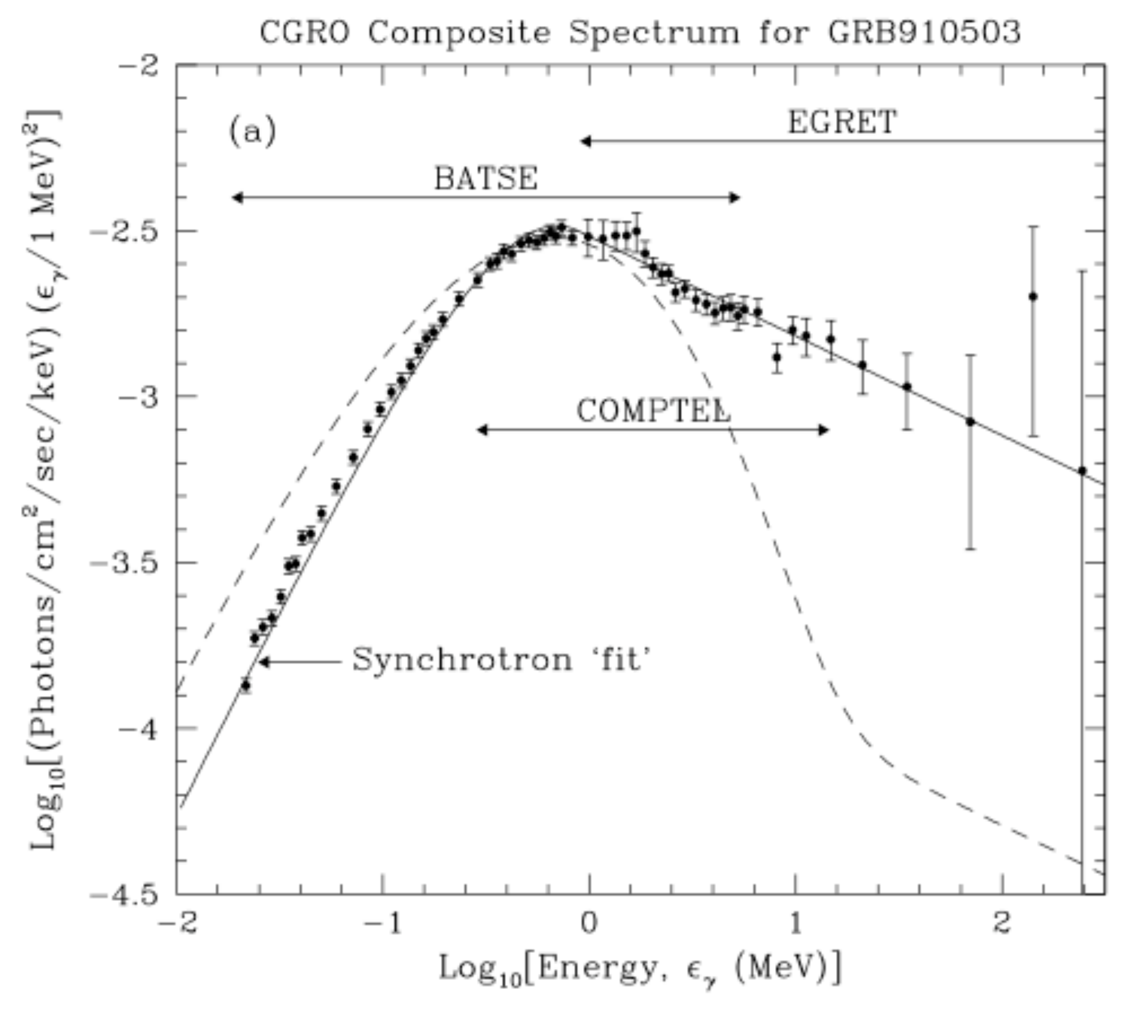
Spectral Character: GRB990123



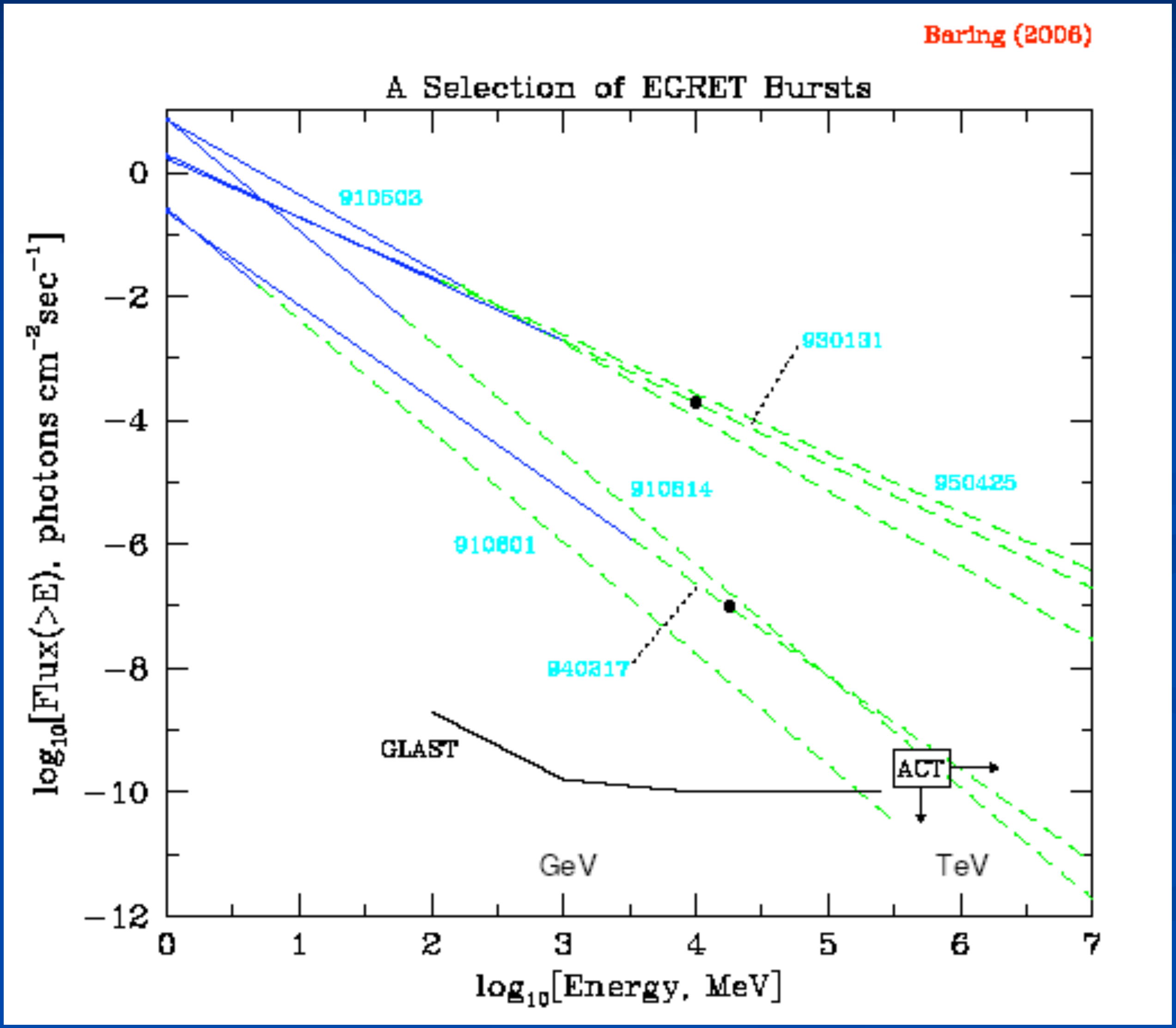
Credit: Robert Preece

GRB Prompt Emission: evidence for relativistic electrons

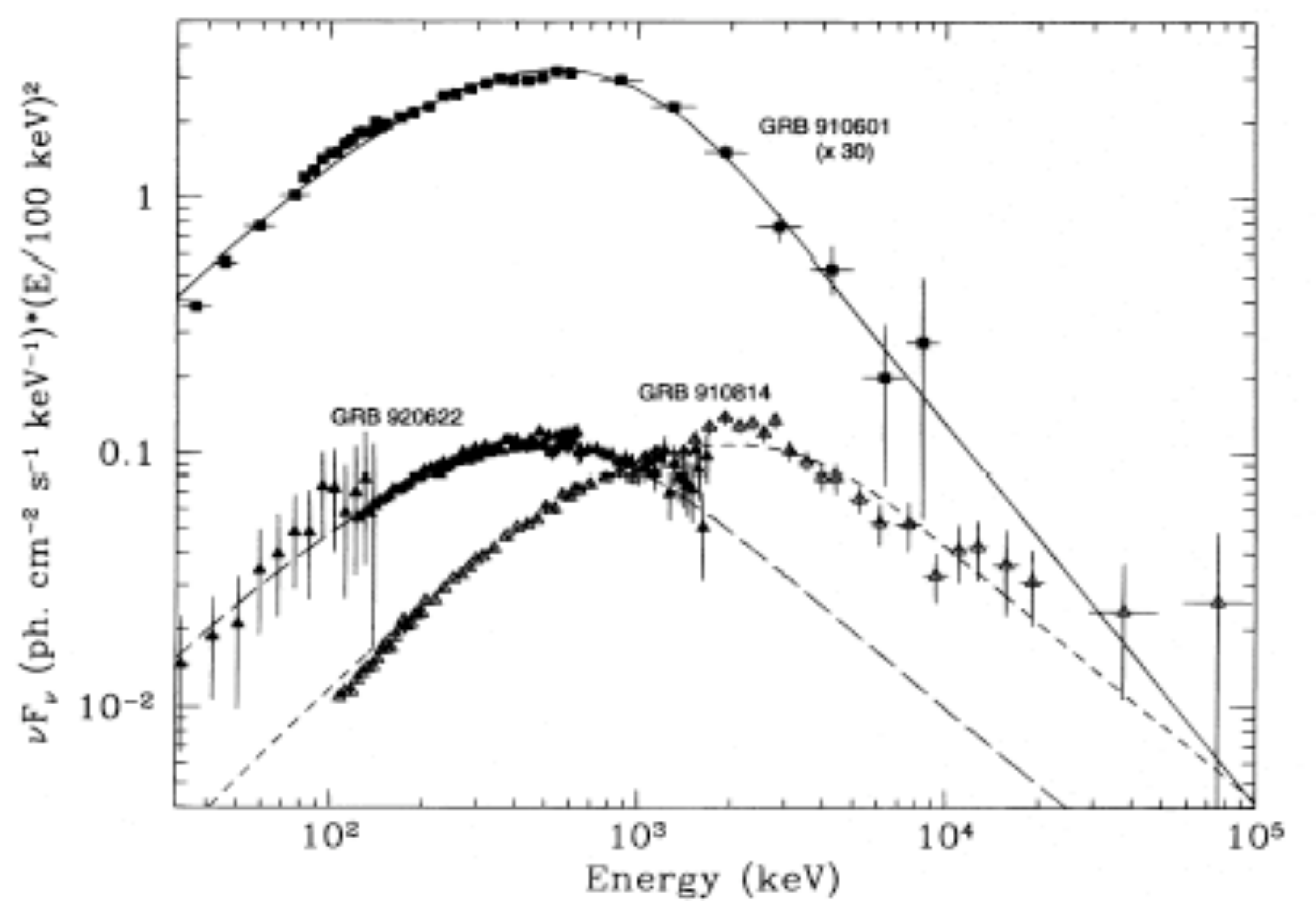
- Gamma-rays => Relativistic e^-;
- Bulk motion is relativistic: pair creation transparency arguments;
- Synchrotron fits work for most bursts.



High Energy Emission in EGRET Bursts

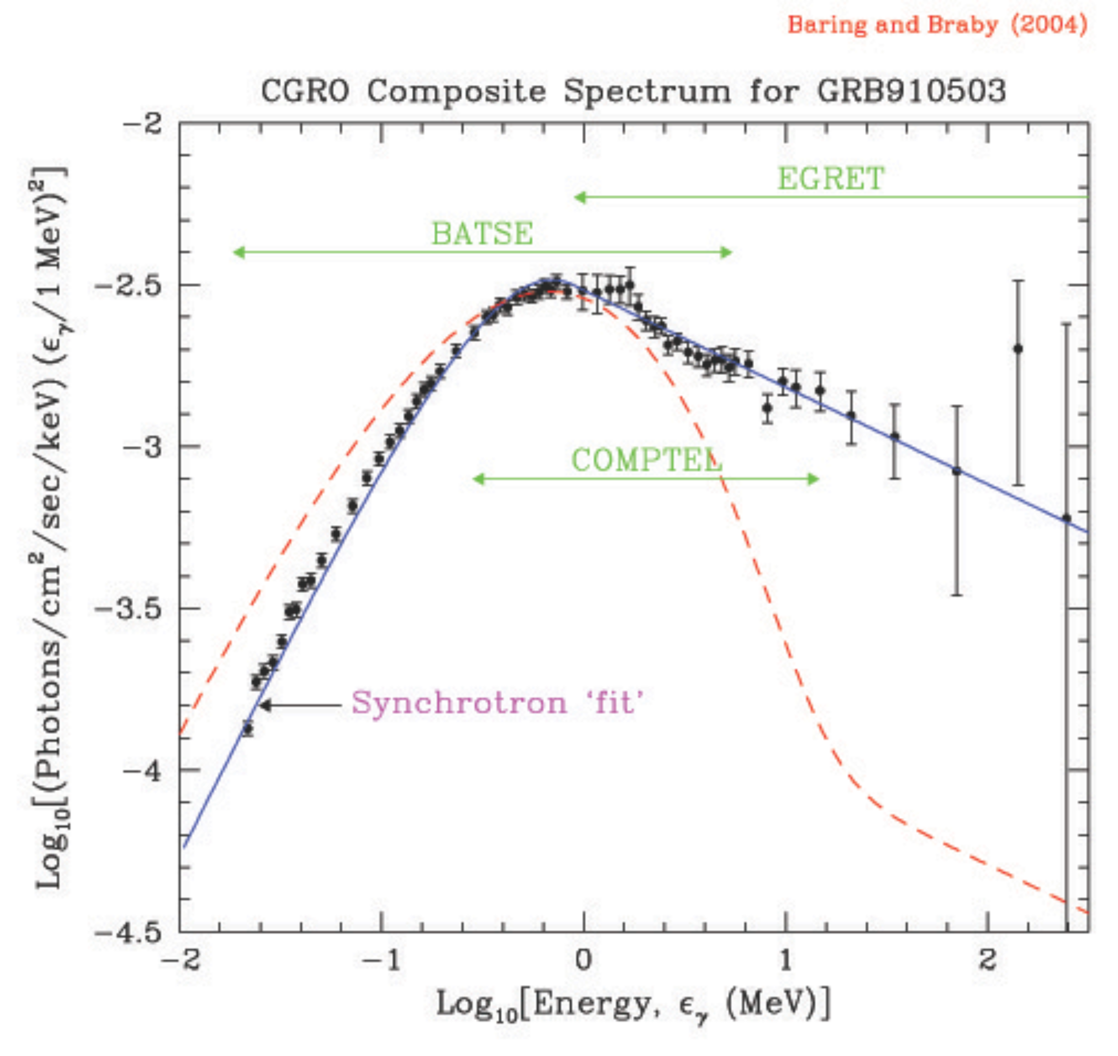


Synchrotron model: Tavani '96

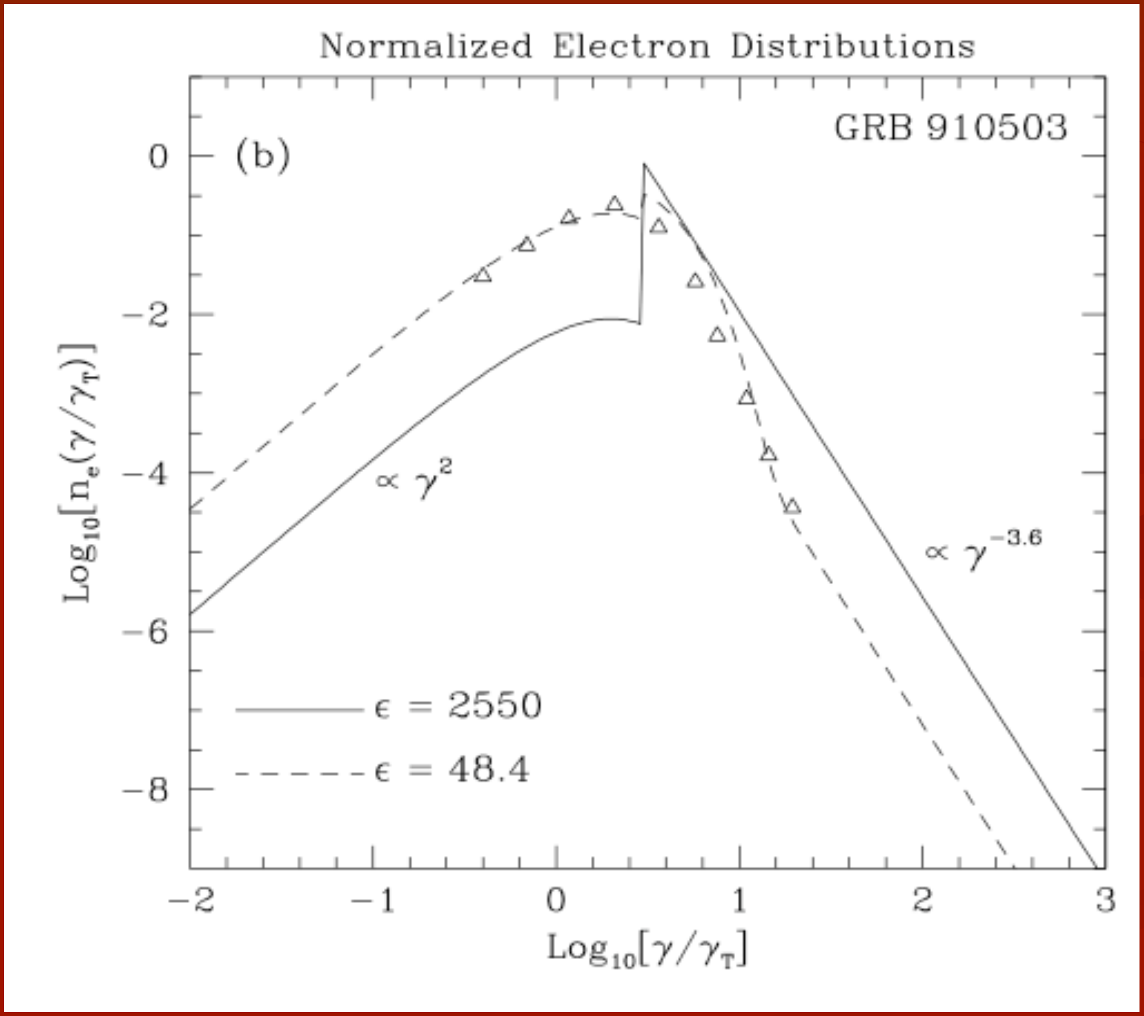


GRB Prompt Emission Continuum fitting

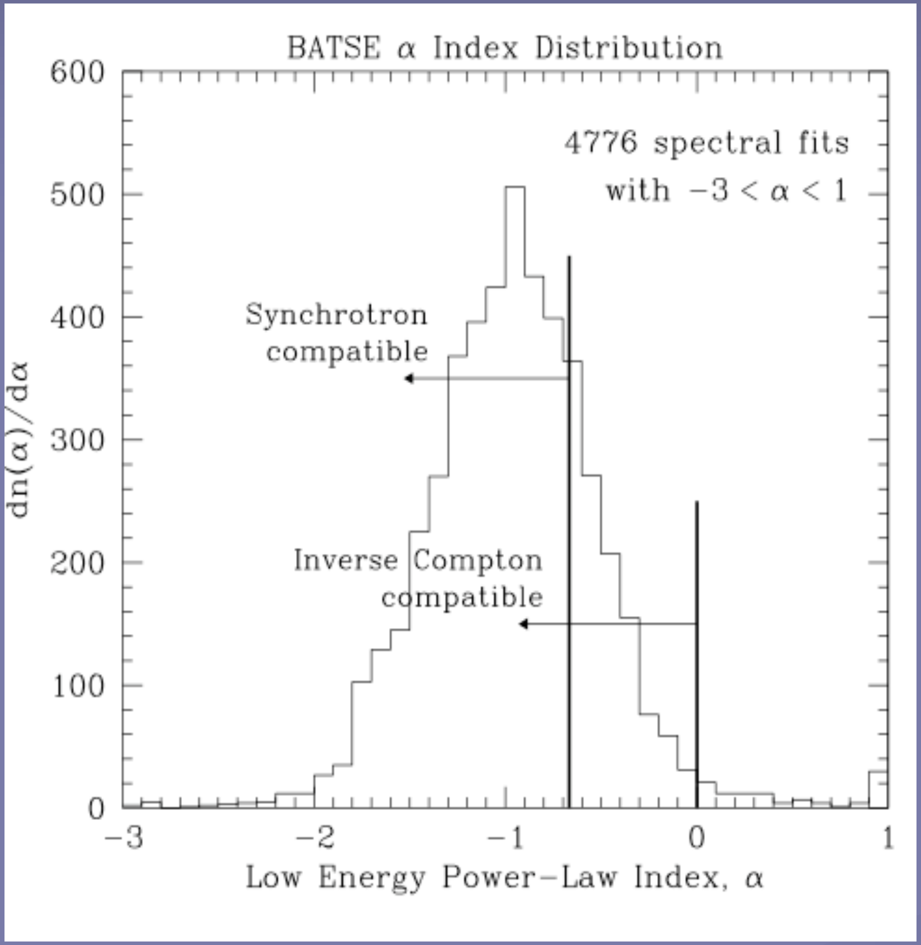
- Baring and Braby (2004)
- Synchrotron fits work for most bursts;
- Underlying electron distribution is unlike shock acceleration predictions.



Parent electron distribution



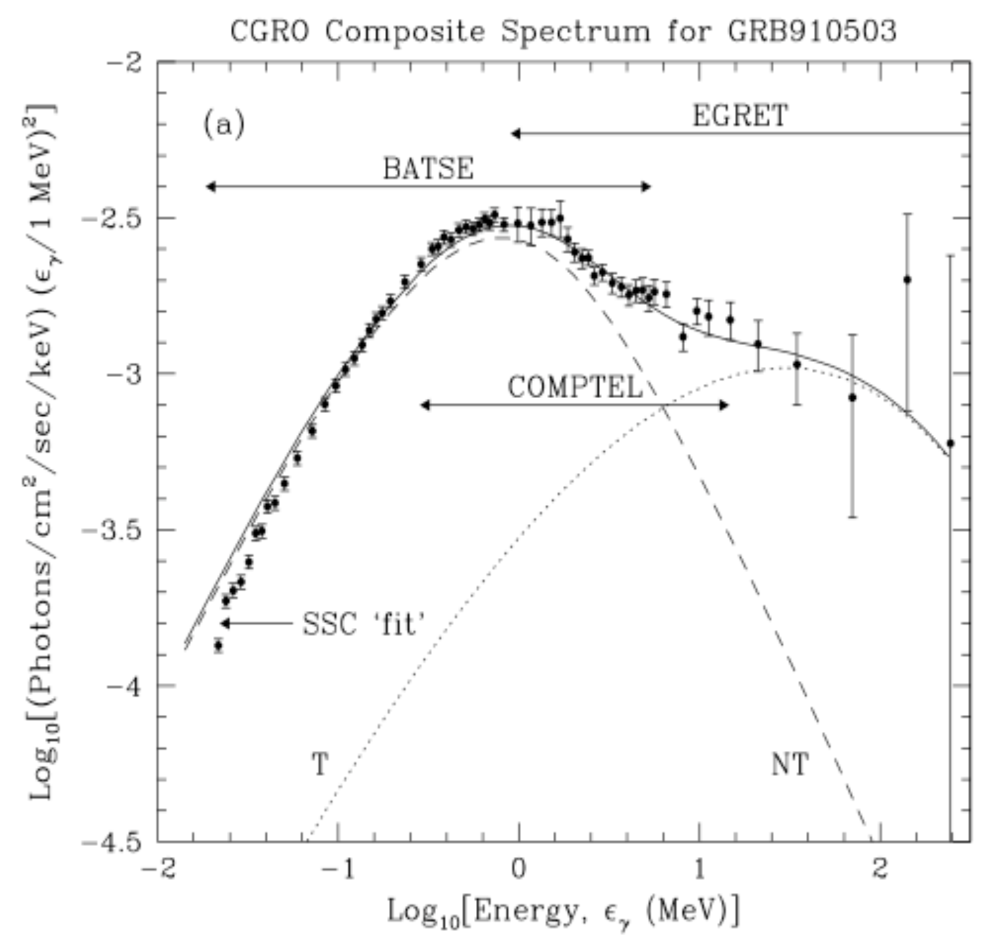
Low Energy BATSE Indices



- About 1/3 of BATSE bursts are incompatible with synchrotron;
  - "Line of Death" issue (Preece et al, 1998);
- Inverse Compton, small angle synchrotron and jitter radiation may be viable for all bursts;
- Synchrotron self-absorption can in principal accommodate most bursts (but…).

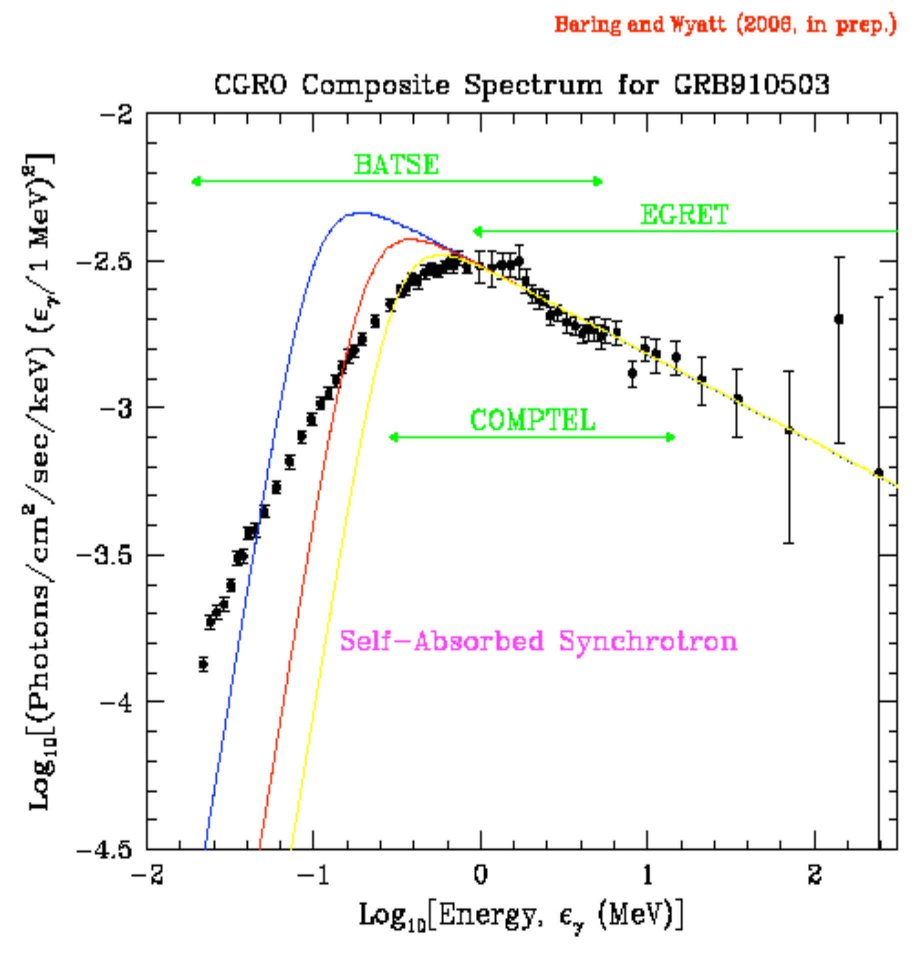
SSC Spectral `Fit’

- Synchrotron self-Compton too broad to explain typical BATSE spectra;
- (Baring & Braby 2004);
- Self-absorption can help to flatten hard X-ray band.



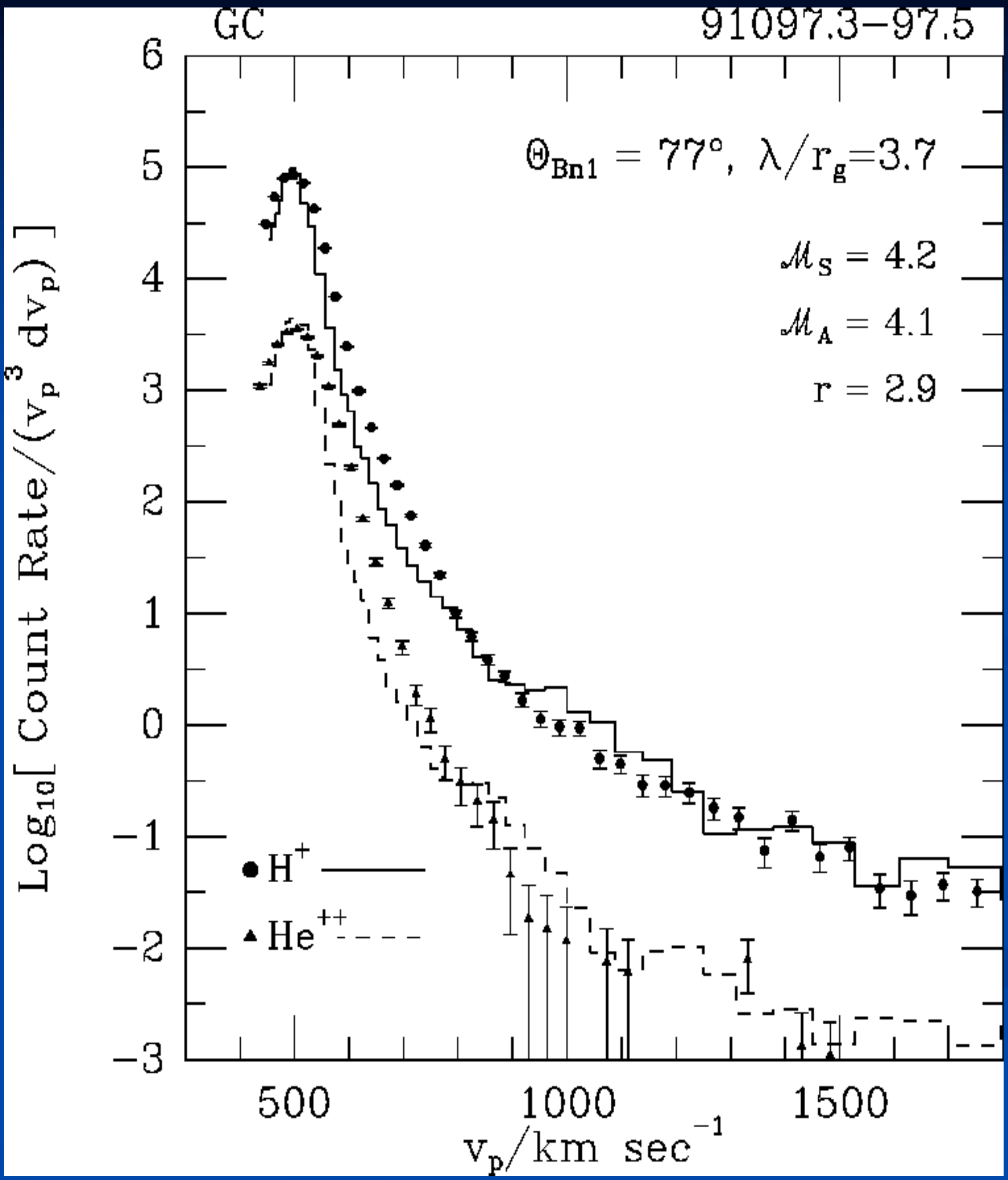
Synchrotron Self-Absorption: Too Steep below Peak.

- Self-absorbed synchrotron fails for bursts; needs high n_e and B;
- Acting in concert with upscattering may work (Panaitescu & Meszaros 2000; Liang, Boettcher & Kocevski 2003; discussed in Baring & Braby 2004);
- Other attractive mechanisms:
    1. small angle synchrotron (Epstein 1973),
    2. jitter radiation (Medvedev 2000, 2006);
- Fitting BATSE database is a priority (current RMFIT work with Wyatt and Preece).

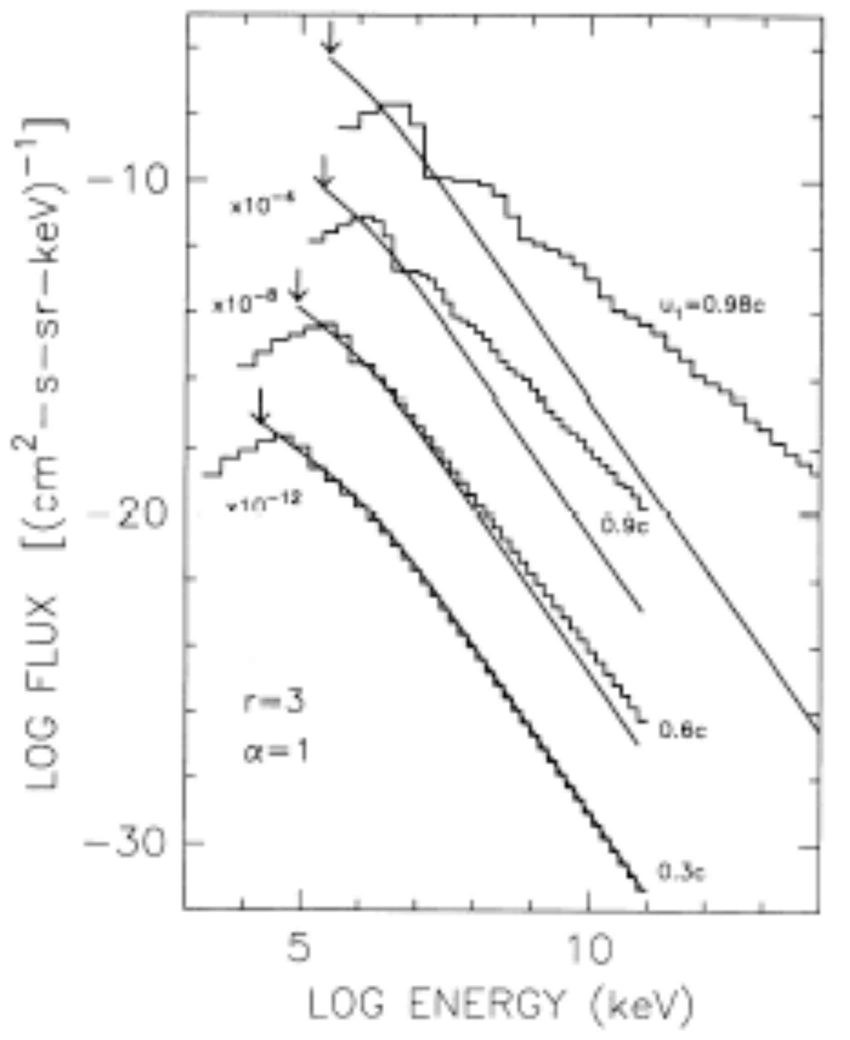


Baring, Ogilvie, Ellison & Forsyth 1997

- Non-relativistic, low Mach number interplanetary shocks;
- SWICS data fit to shock of (April 7, '91) at 2.7AU;
- Shock-heated thermal ions dominate;
- Strong cross-field diffusion again needed: same for H and alphas.

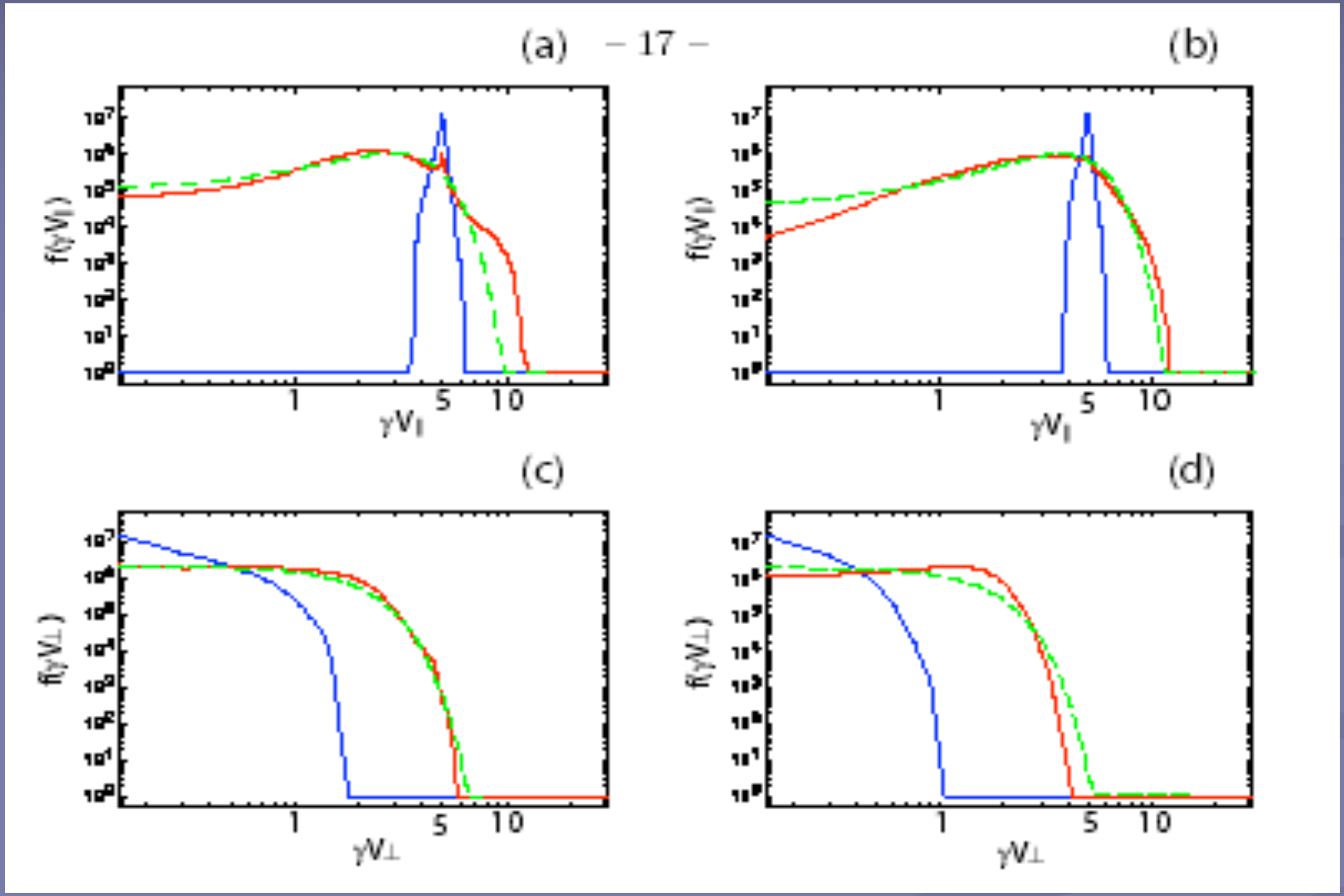


Ellison, Jones & Reynolds (1990): Large Angle Scattering



- Monte Carlo results for parallel shocks;
- Spectrum flattens and becomes more structured as u_1->c.

3D PIC (Particle-in-cell) Plasma Shock Simulation



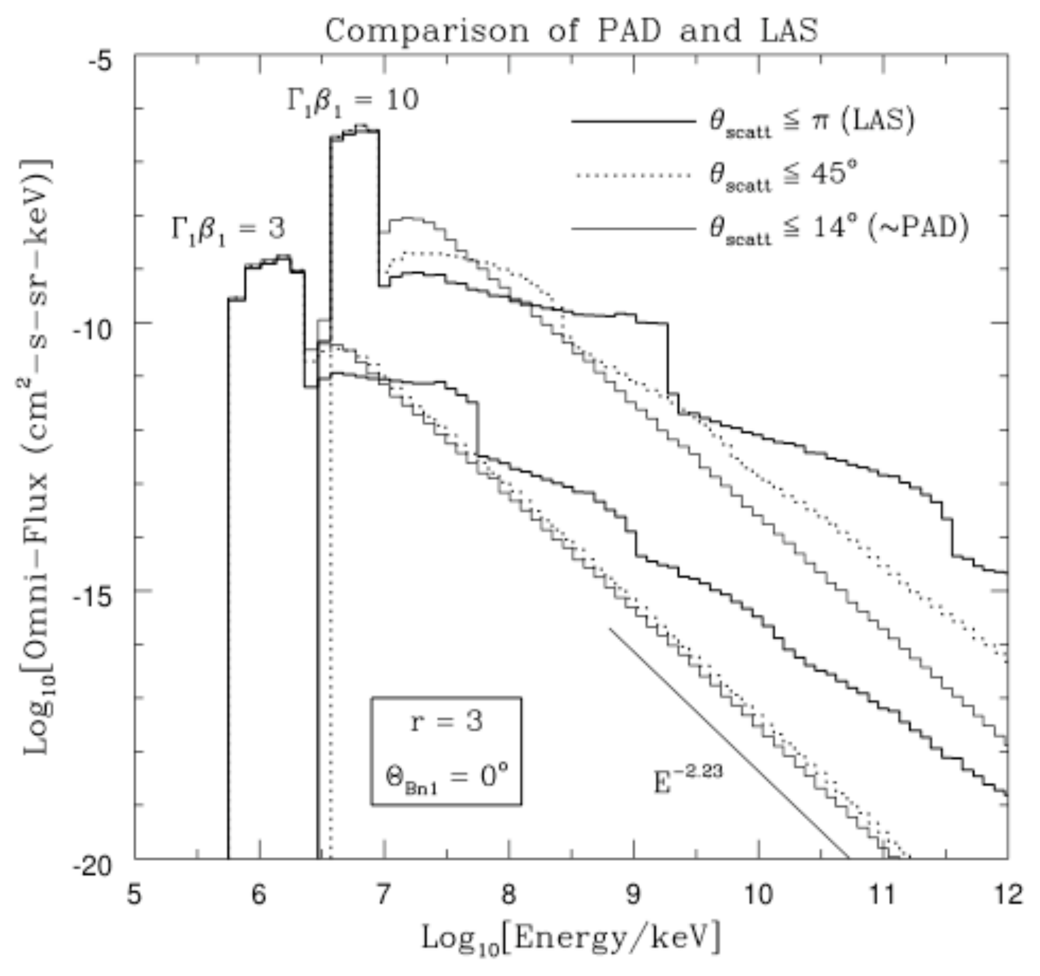
- Nishikawa et al. (ApJ 2006): e-p (left panels) and pair shocks have great difficulty accelerating particles from thermal pool (green is Lorentz-boosted relativistic Maxwellian), dominated by electromagnetic thermal dissipation.

Implications of CGRO GRB Spectroscopy

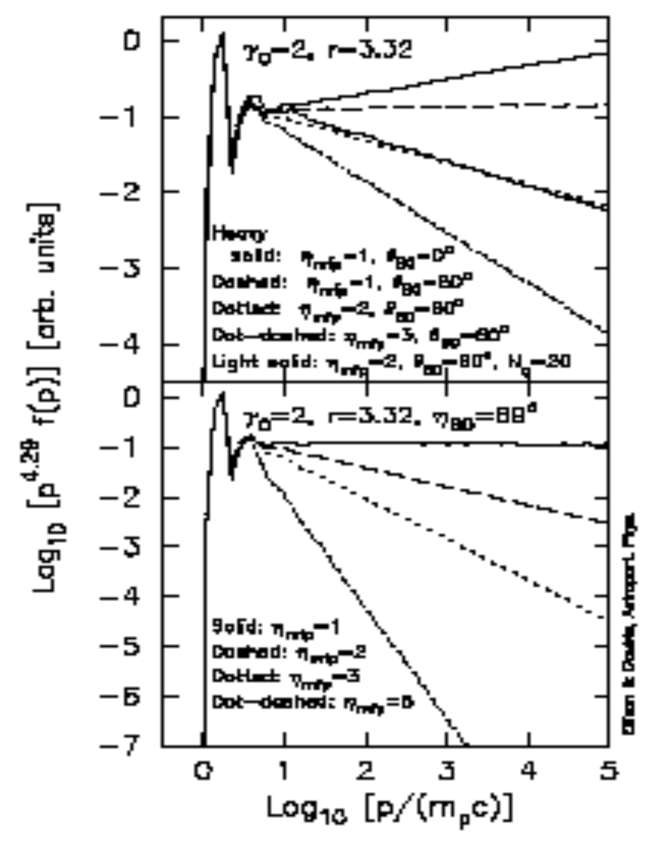
- GRB source models are strongly constrained by photon emission spectra:
- suprathermal energy regime not immediately compatible with shock acceleration scenario;
- Strong self-absorption in GRBs may provide reconciliation with predictions of acceleration theory, *if* it is further processed, e.g. by upscattering.

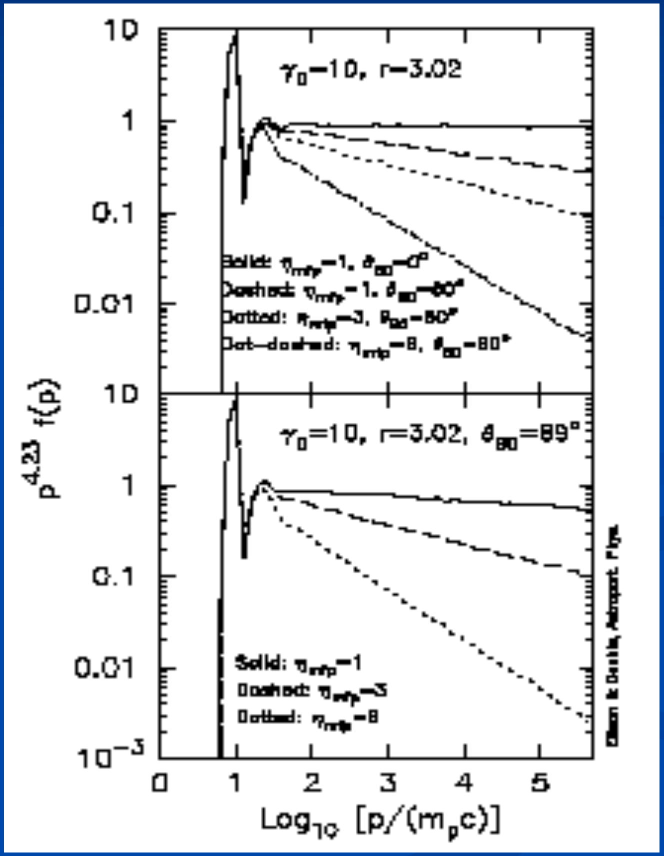
Relativistic Shocks: Spectral Dependence on Scattering

- Deviations from ``canonical'' index of 2.23 (Bednarz & Ostrowski 1998; Kirk et al. 2000; Baring 1999) occur for scattering angles outside Lorentz cone;
- Large angle scattering yields kinematically structured distributions;
- (e.g., Baring 2005)



Relativistic Shocks: Spectral Dependence on Field Obliquity and Diffusion

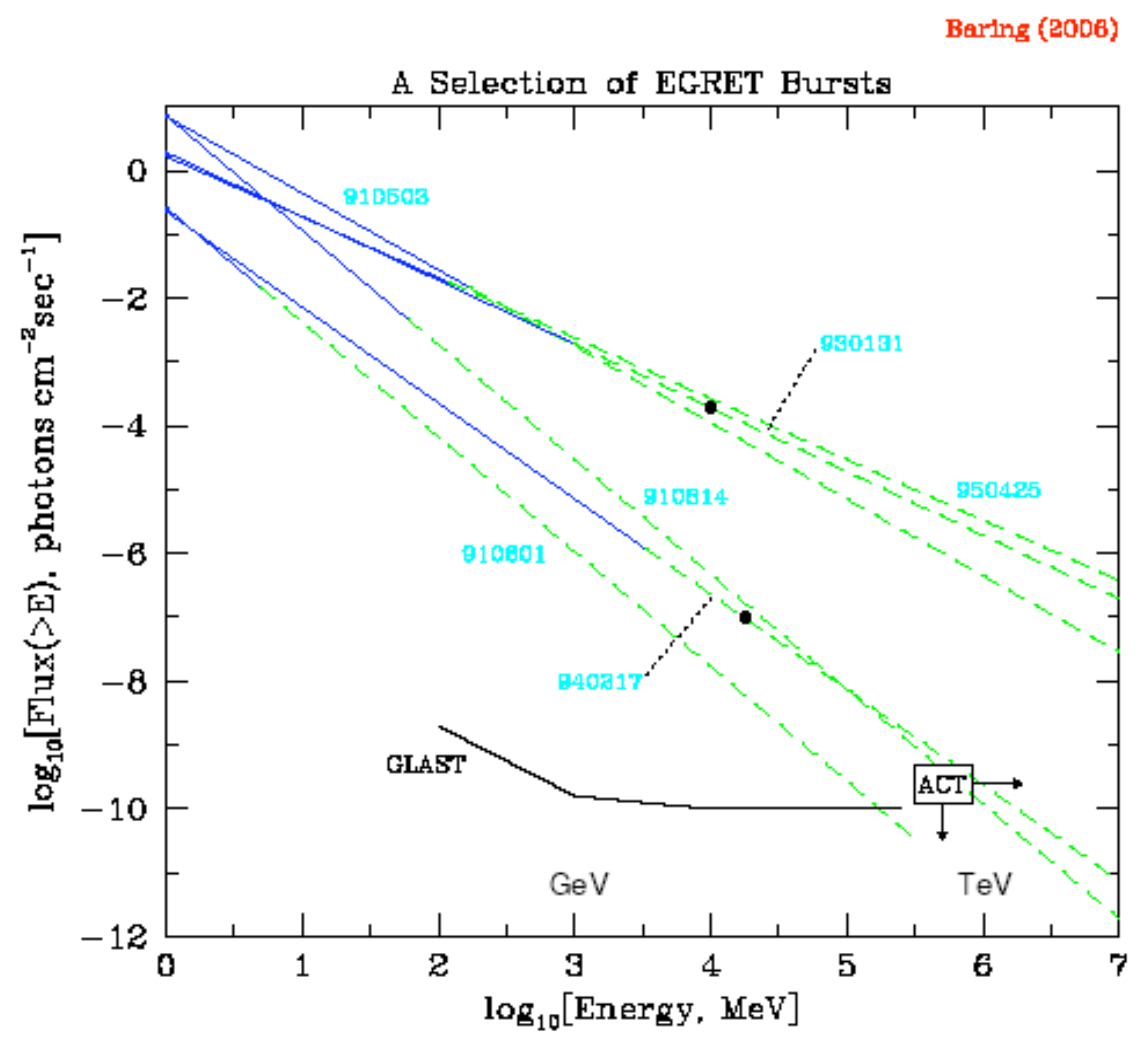




Ellison & Double (2004)

- Increasing upstream B-field obliquity and/or ratio of mean free path to gyroradius steepens the continuum (e.g. Bednarz & Ostrowski 1998; Ellison & Double 2004; see also Kirk & Heavens 1989).

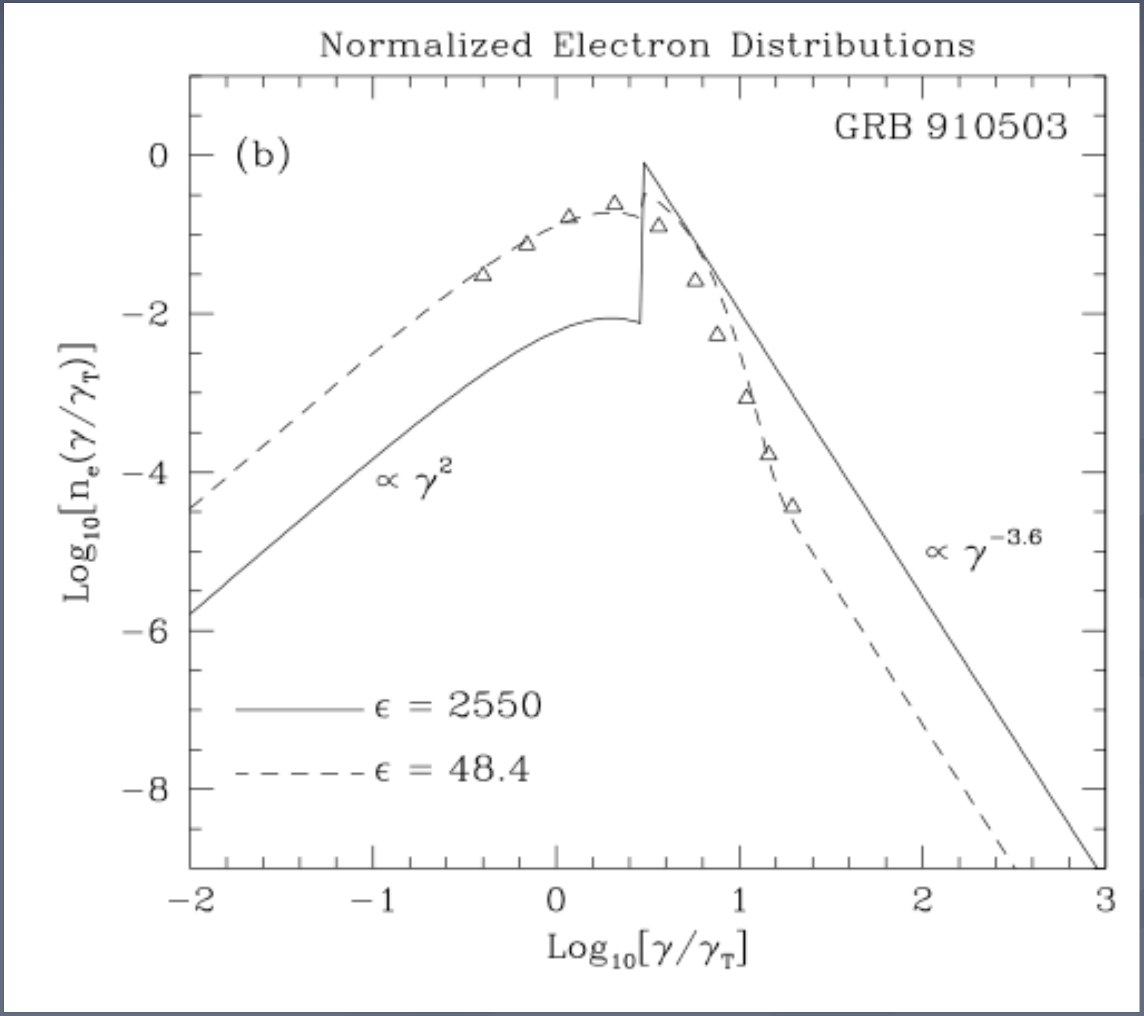
High Energy Emission in EGRET Bursts

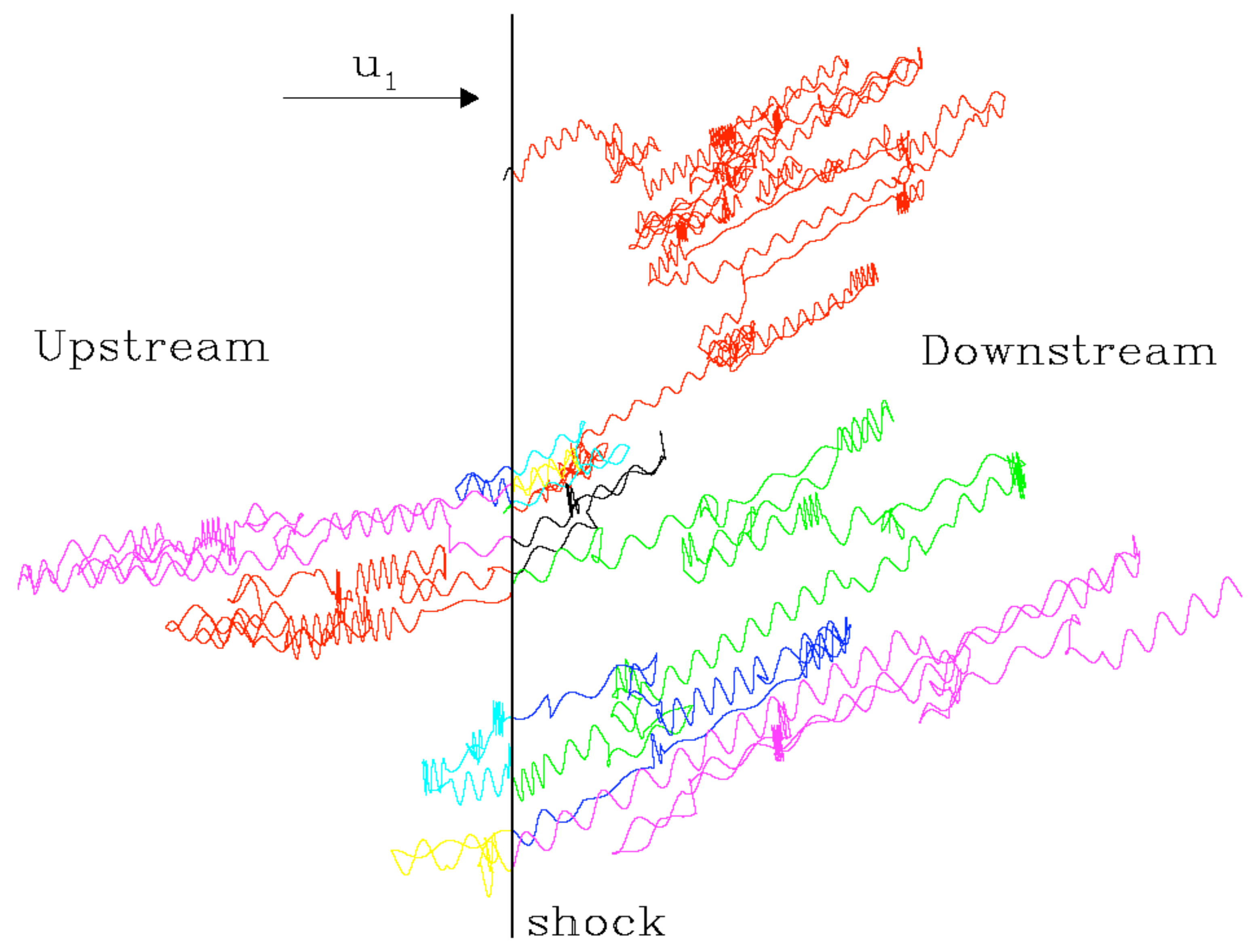

Baring (2006)

Implications for Gamma-Ray Bursts

- Relativistic shocks can generate a multitude of spectral forms: power-law indices depend on shock parameters and scattering properties;
- => **Non-canonical spectral index**
- Distinct contrast to non-relativistic case [depends on *r* only];
- Spectrum is only flat for quasi-parallel shocks *and* strong turbulence;
- GRB prompt and afterglow emission, and also UHECR generation must be explained by *mildly-relativistic shocks* that are *not quasi-perpendicular* (for diffusive acceleration scenarios).

Addressing a dominance of non-thermal electrons…

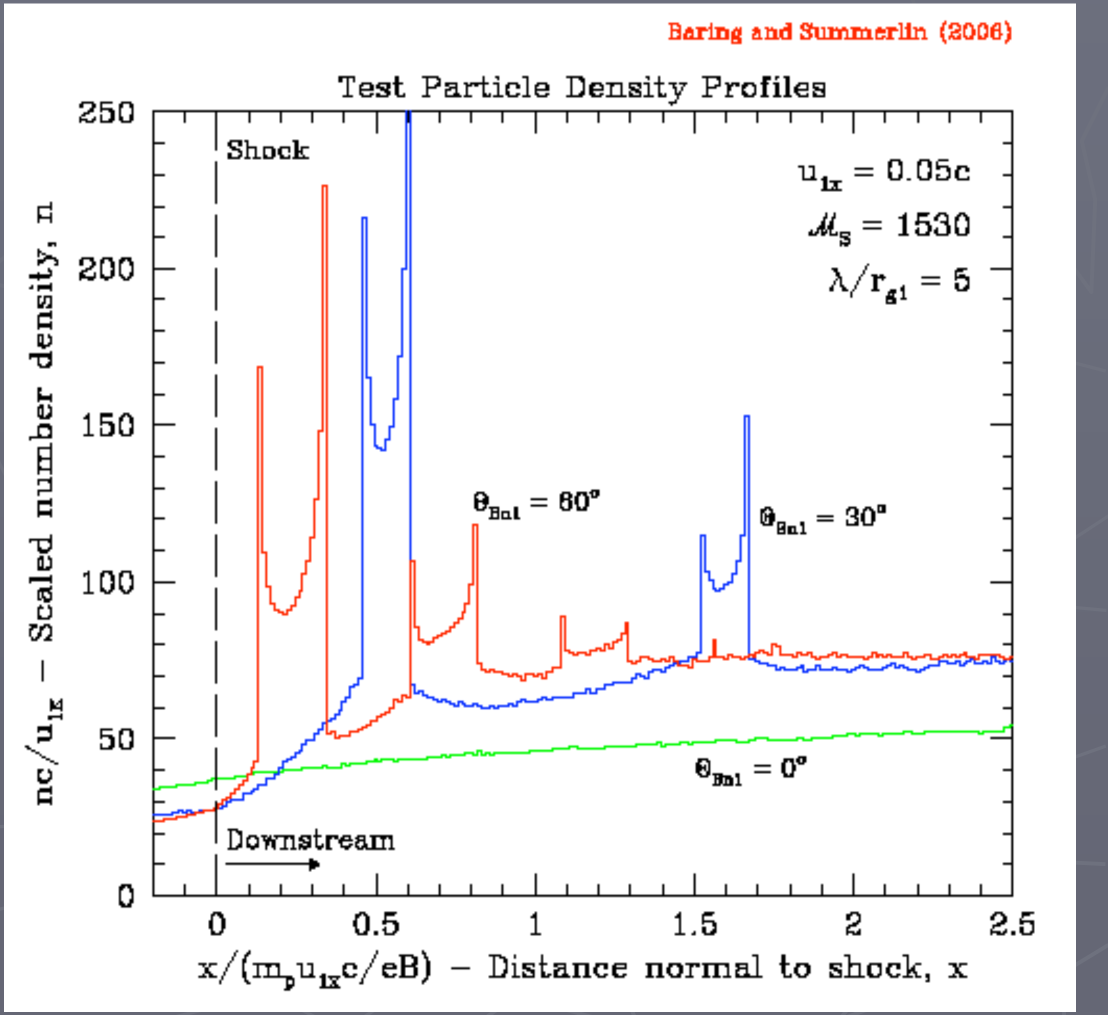



u_1
Upstream
Downstream
shock

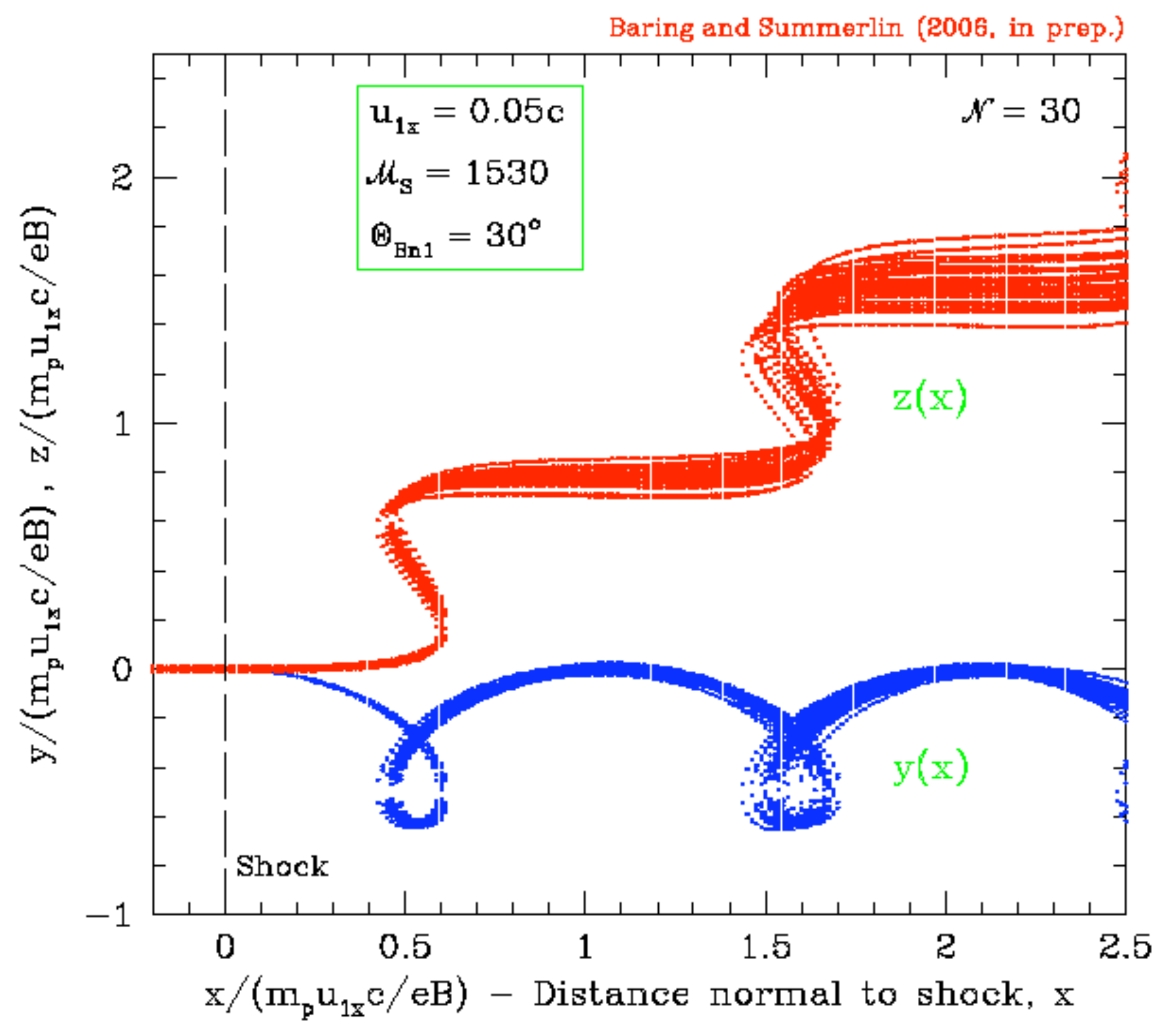
Shock Layer Density Profiles - high M_S

- Cold beam density profiles trace particle gyration;
- Density prop. to $1/\langle v_x \rangle$;
- Downstream gyrational cusp structure degraded on diffusive lengthscale;
- Charge separation implied by disparate electron-ion inertial scales.

Non-relativistic shocks



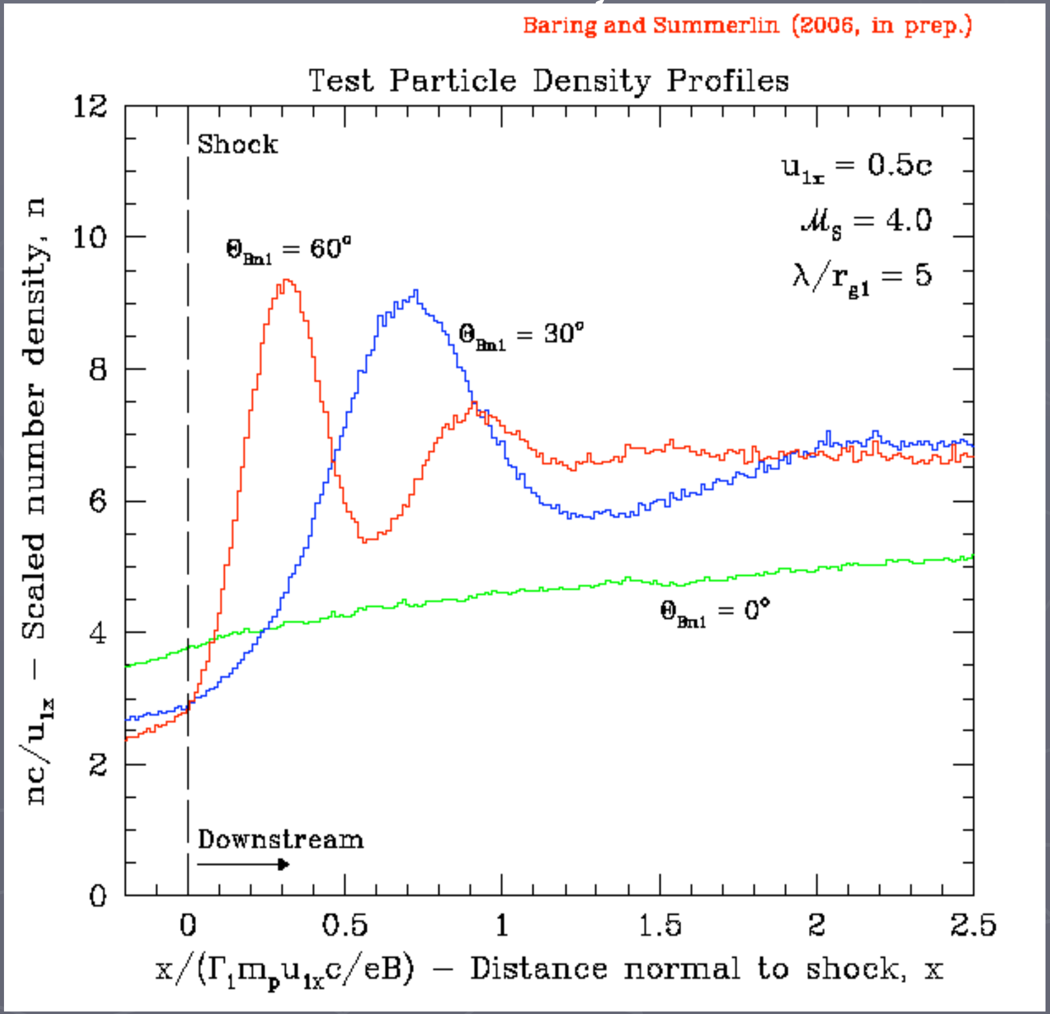
Shock Layer Particle Trajectories - high M_S



Shock Layer Density Profiles - low M_S

- Heating the beam smooths out the gyrational influence on density profiles;
- Density prop. to $1/\langle v_x \rangle$; still correlates to particle gyration;
- Gyrational clumping structure degraded on diffusive lengthscales;
- Profiles similar for relativistic and non-relativistic shocks.

Mildly-relativistic shocks

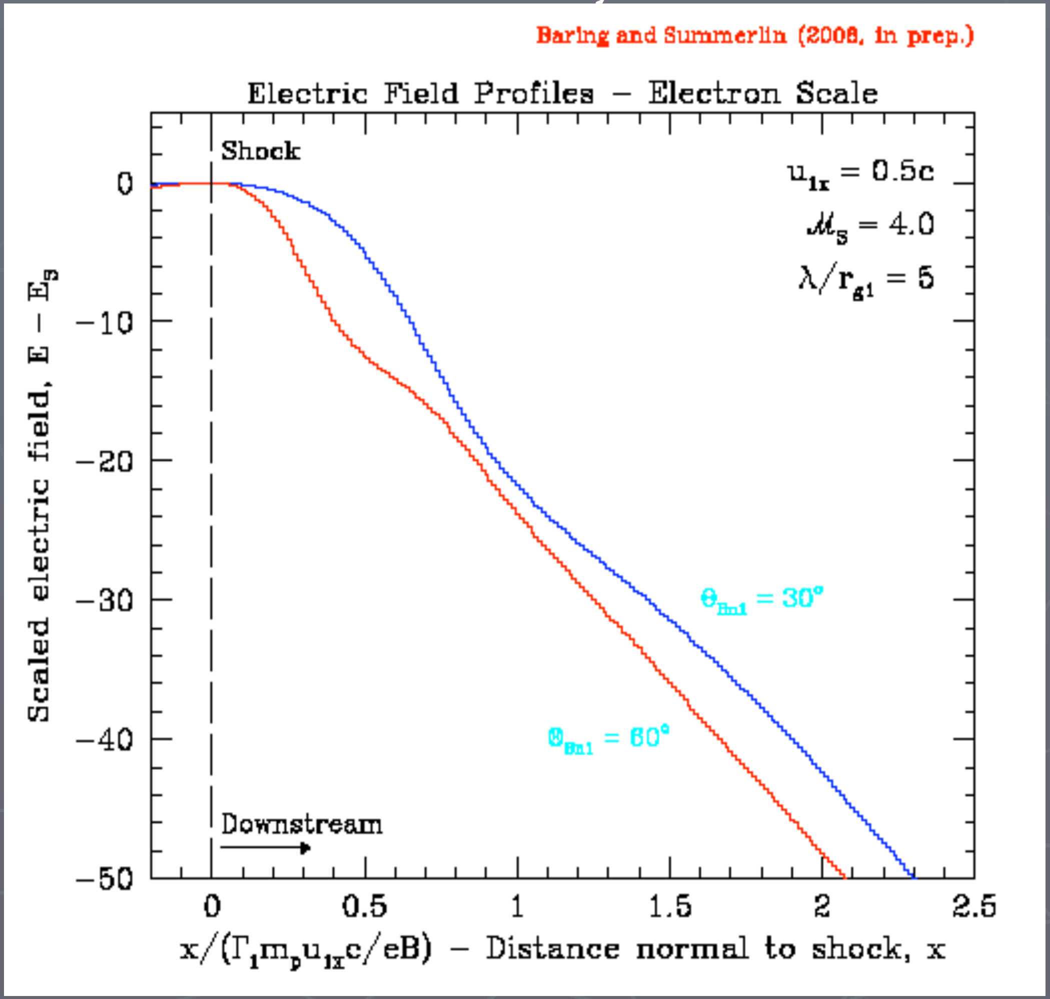


Baring and Summerlin (2006, in prep.)

Electron Scale Electric Field - low M_S

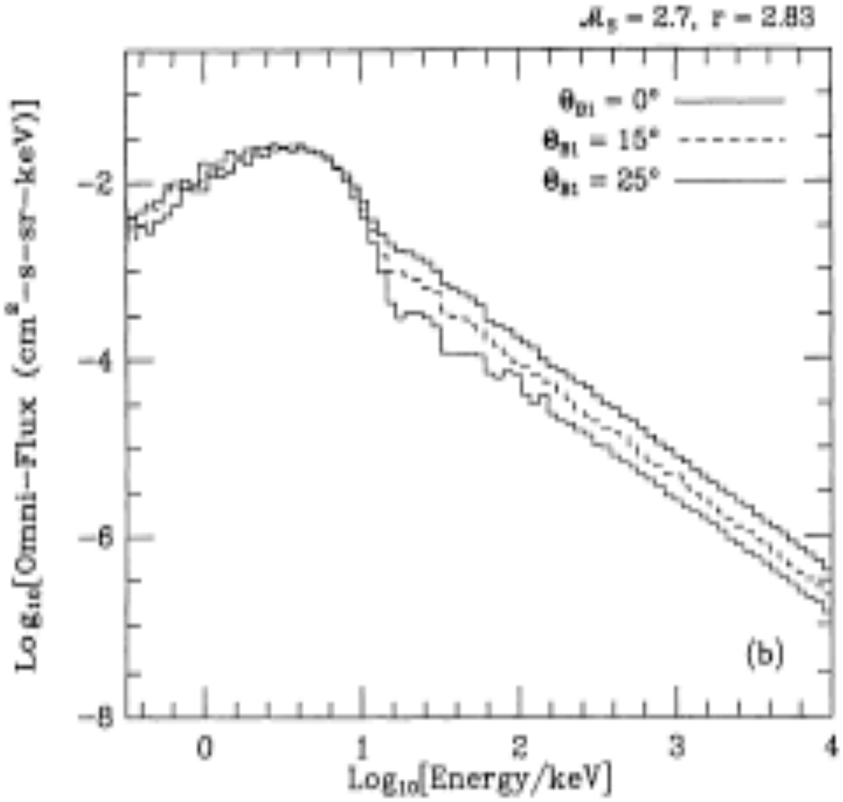
- Solving Poisson's equation smooths out the gyrational influence in density;
- E prop. to integral of charge density over x;
- Field is quenched on lengthscales of u_{1x}/w_p for proton plasma frequency w_p;
- Work currently on field profile in quenching zone.

Mildly-relativistic shocks


Baring and Summerlin (2008, in prep.)

Thermal vs. Non-Thermal

- Without cross-shock potential, power-law blends into dominant thermal population;
- Coherent **E** field energizes electrons, without broadening thermal “width” beyond diffusive value $m_e(u_{1x}-u_{2x})$;
- Electrostatic instability (e.g. Shimada & Hoshino 2000) can heat e^-.
- Turbulent contributions can be treated via transport coefficients;
- **Goal**: to explore distribution shape at minimum e^- momentum for GRBs (also SNR problem).



Baring, Ellison & Jones (1994)
[test particle simulations]

2704 BATSE Gamma-Ray Bursts