NC STATE UNIVERSITY

MONTE CARLO SIMULATIONS OF RADIATIVE PROCESSES IN PHOTON-LEPTON PLASMAS

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Introduction and Outline

- Photons and Leptons
- Compton and Inverse Compton scattering
- Pair Production (Preliminary results)
- Parameters:
  - Particle numbers (10k, 100k)
  - Particle Distributions
    - Photons (Wien, Blackbody, Mono-energetic)
    - Leptons (Maxwell Boltzmann / Juttner, Non-thermal)
  - Temperatures
- Explore the Spectral Evolution + Look out for spectral transients

GRBs – A Brief Overview + Prompt Emission

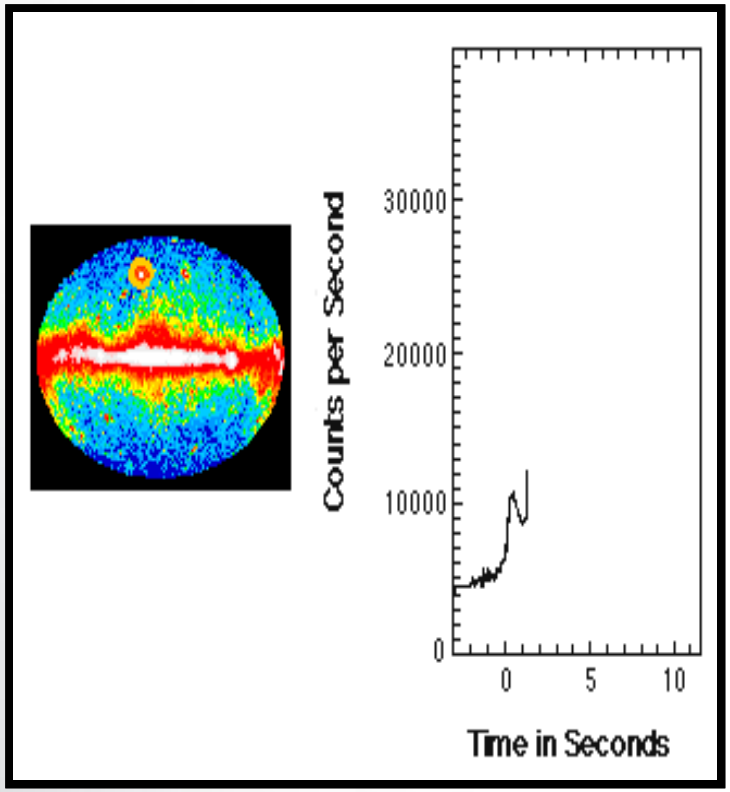

Fig1: A GRB (adapted from http://science.hq.nasa.gov/kids/imagers/ems/grb_animation.gif)

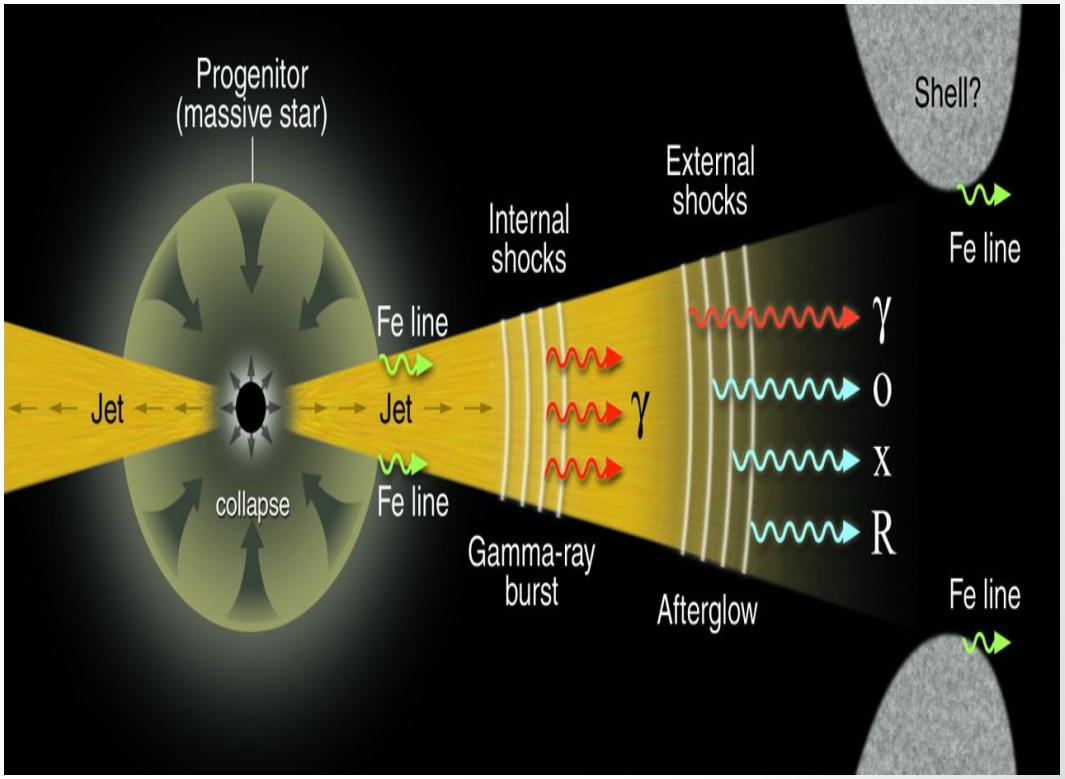

Fig 2: GRB Structure (Credit: P Mészáros Science 2001;291:79-84)

The GRB Prompt Emission Spectra:

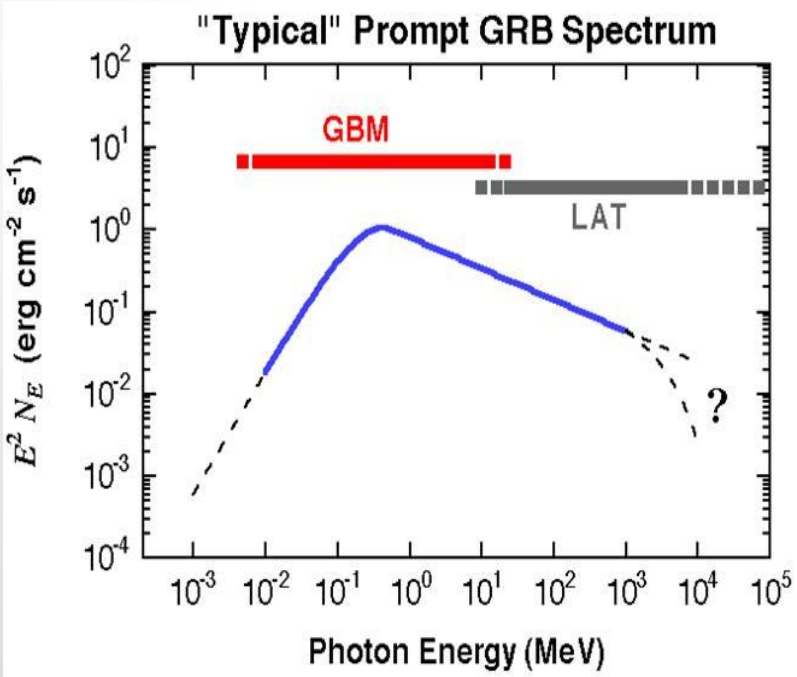

Fig 3: Typical GRB Spectra from Fermi (http://fermi.gsfc.nasa.gov/)

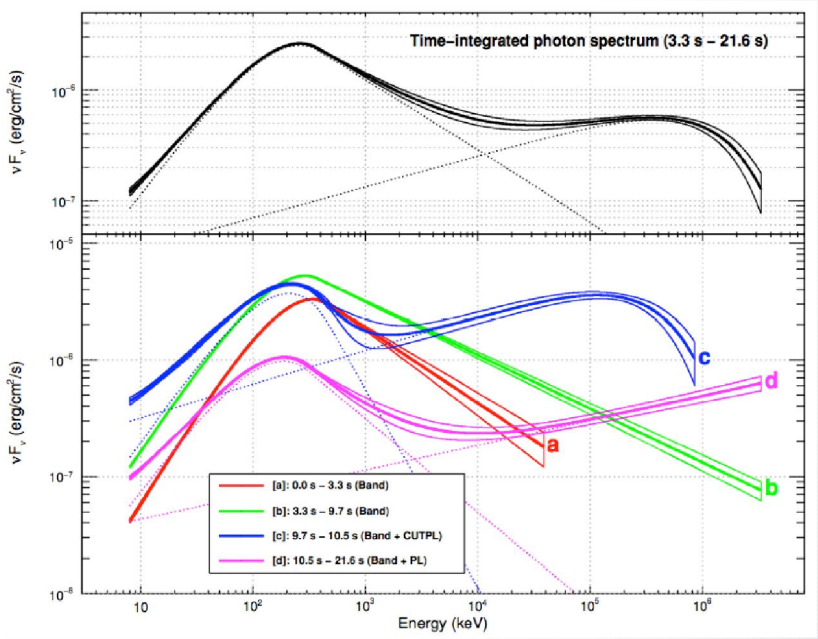

Fig 4: GRB090926A - A two component spectra (M. Ackermann, et al., ApJ. 729, 114 (2011))

Compton / Inverse Compton Scattering – Energy transfer

$$\varepsilon_1 = \frac{\varepsilon}{1 + \frac{\varepsilon}{m_e c^2}\left(1 - \cos\theta\right)}$$

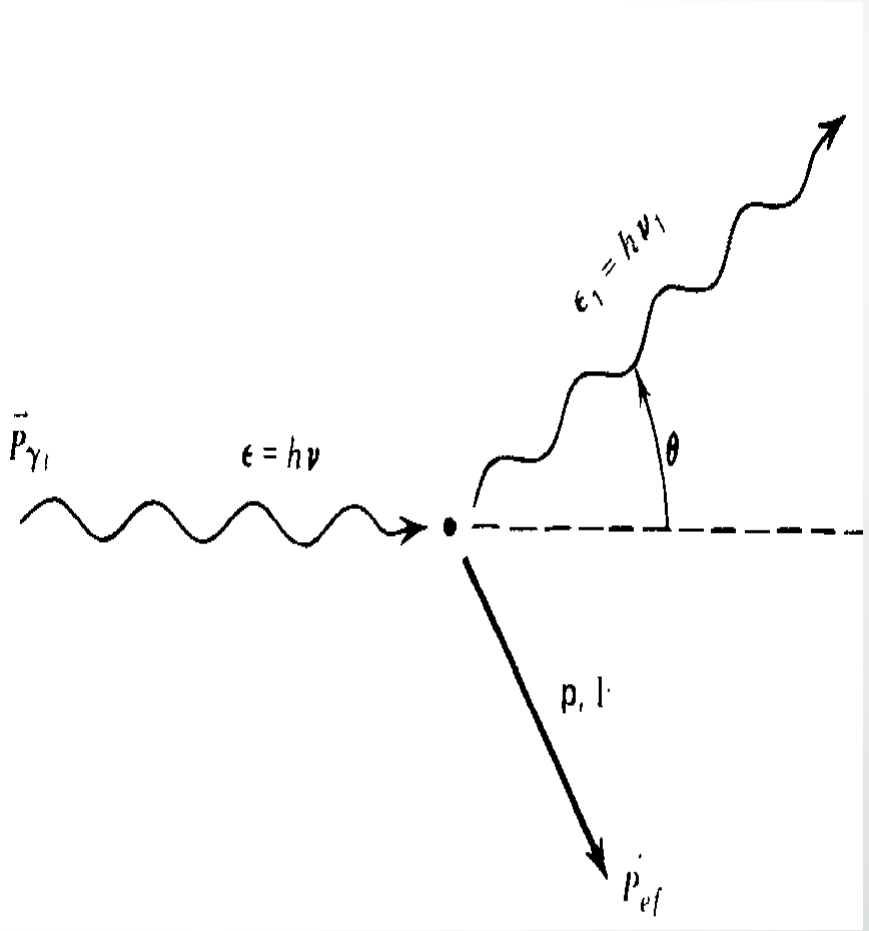

Figure 5: Compton scattering geometry in electron rest frame (from Rybicki and Lightman, 1975)

Non Thermal Leptons (p = 2.2) vs Wien Photons @ 10^7 K: Particle Ratio = 10

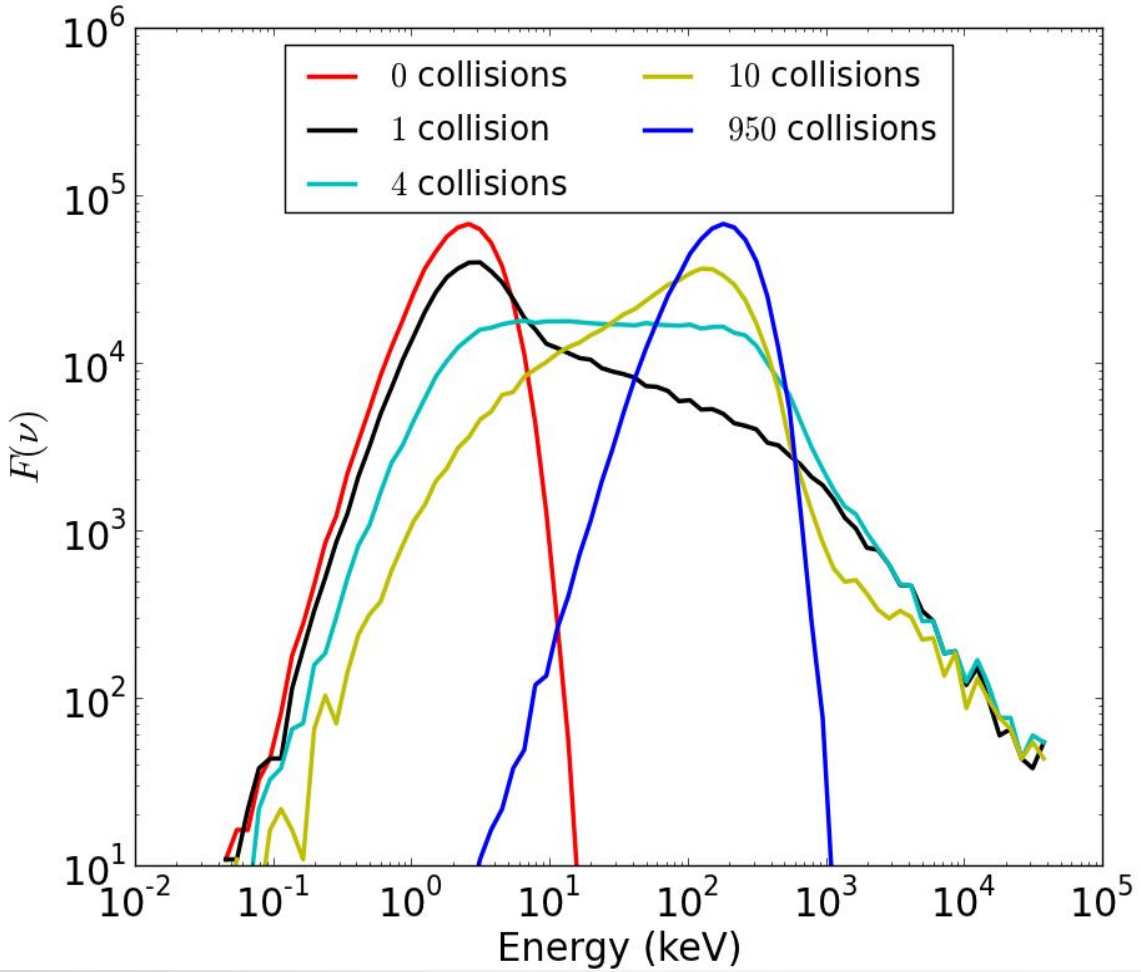

Figure 6: Photon Spectrum Evolution for a non-thermal lepton distribution having power law index p = 2.2, an initial Wien photon distribution at 10^7 K and photon to lepton ratio of 10. Note the dark blue curve, it is the Wien distribution attained at equilibrium. Collisions in the legend denote the number of collisions per photon.

Non Thermal Leptons (p = 2.2) vs Wien Photons @ 10^7 K: Particle Ratio = 10

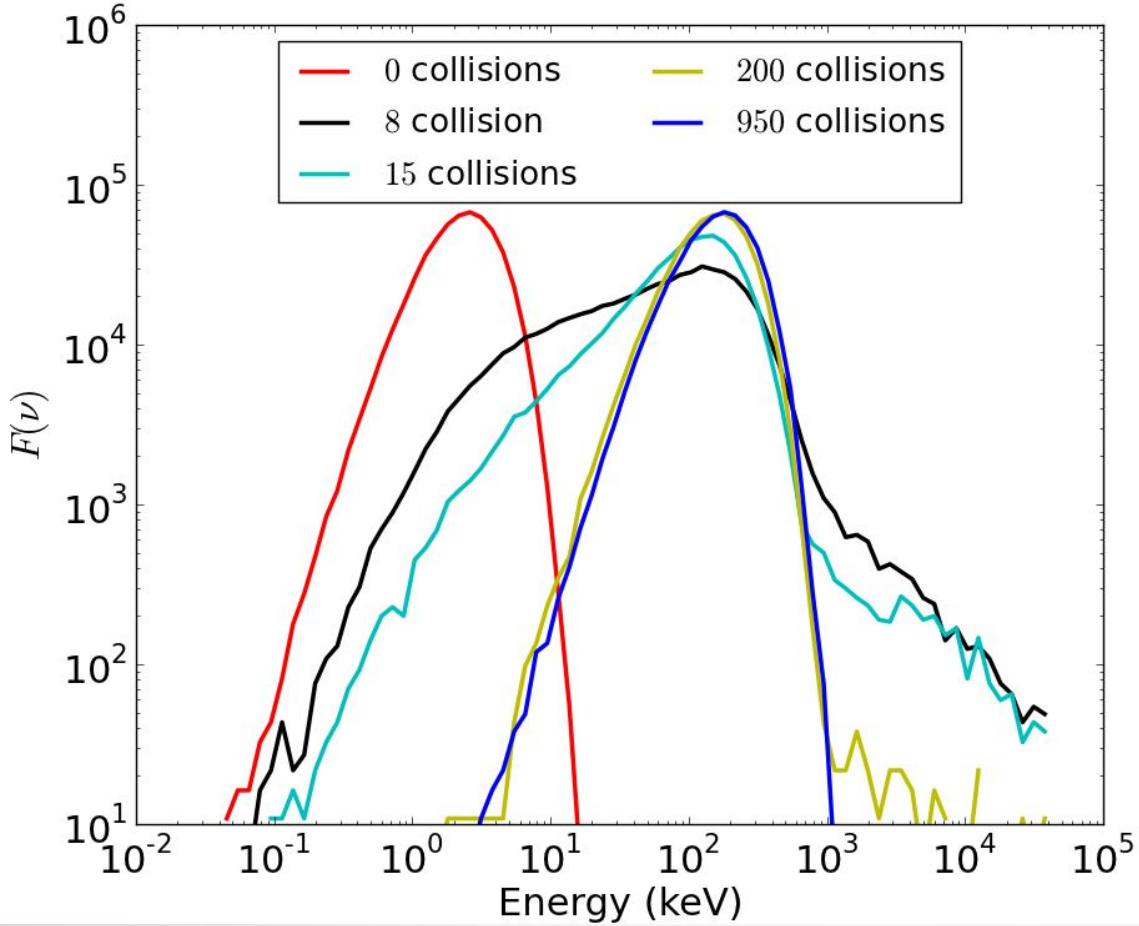

Figure 7: Photon Spectrum for a non-thermal lepton distribution having power law index p = 2.2, an initial Wien photon distribution at 10^7 K and photon to lepton ratio of 10. Note the evolution of the high energy tail. Collisions in the legend denote the number of collisions per photon.

Band Fitting

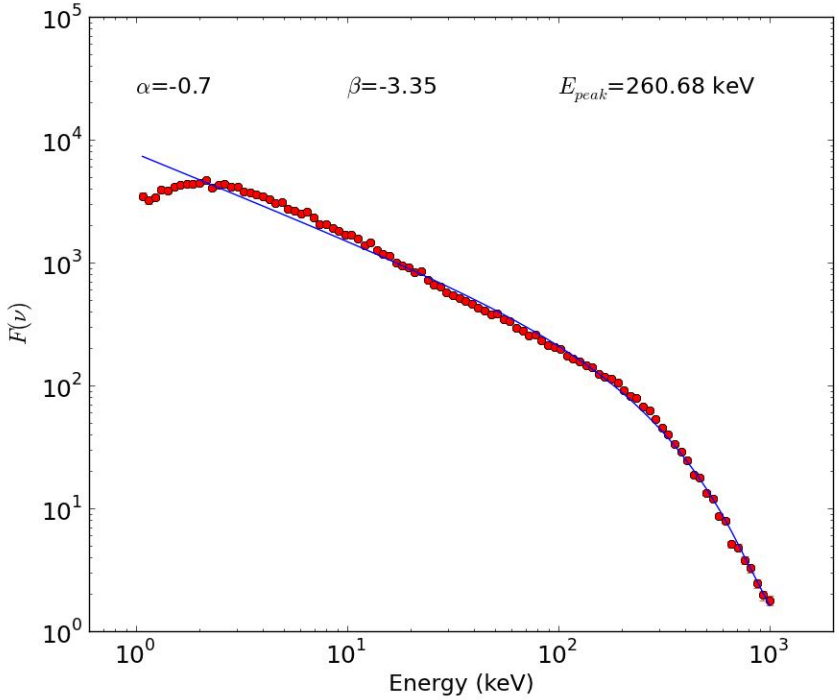

Figure 8: Fitting the band function

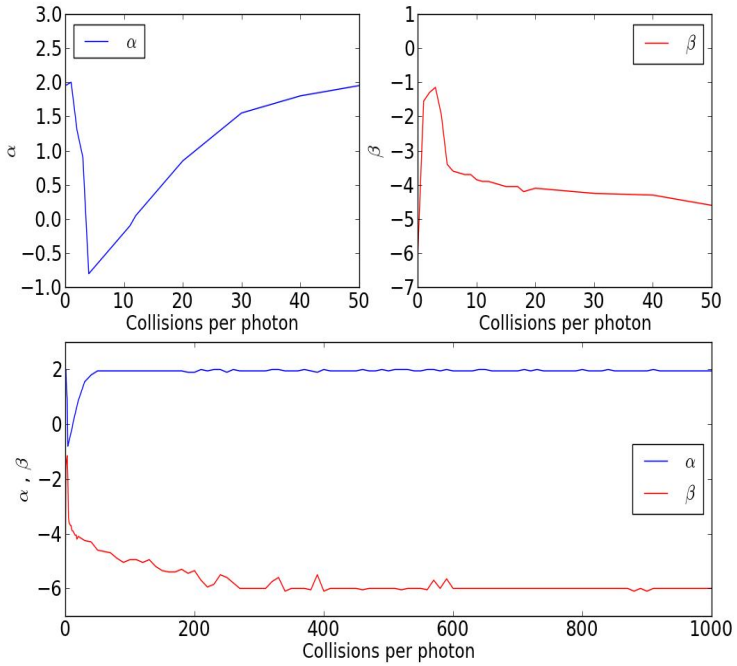

Figure 9: Band parameters for the simulation

MJ Leptons @ 10^{11} K vs Blackbody Photons @ 10^{6} K : Particle Ratio = 0.1

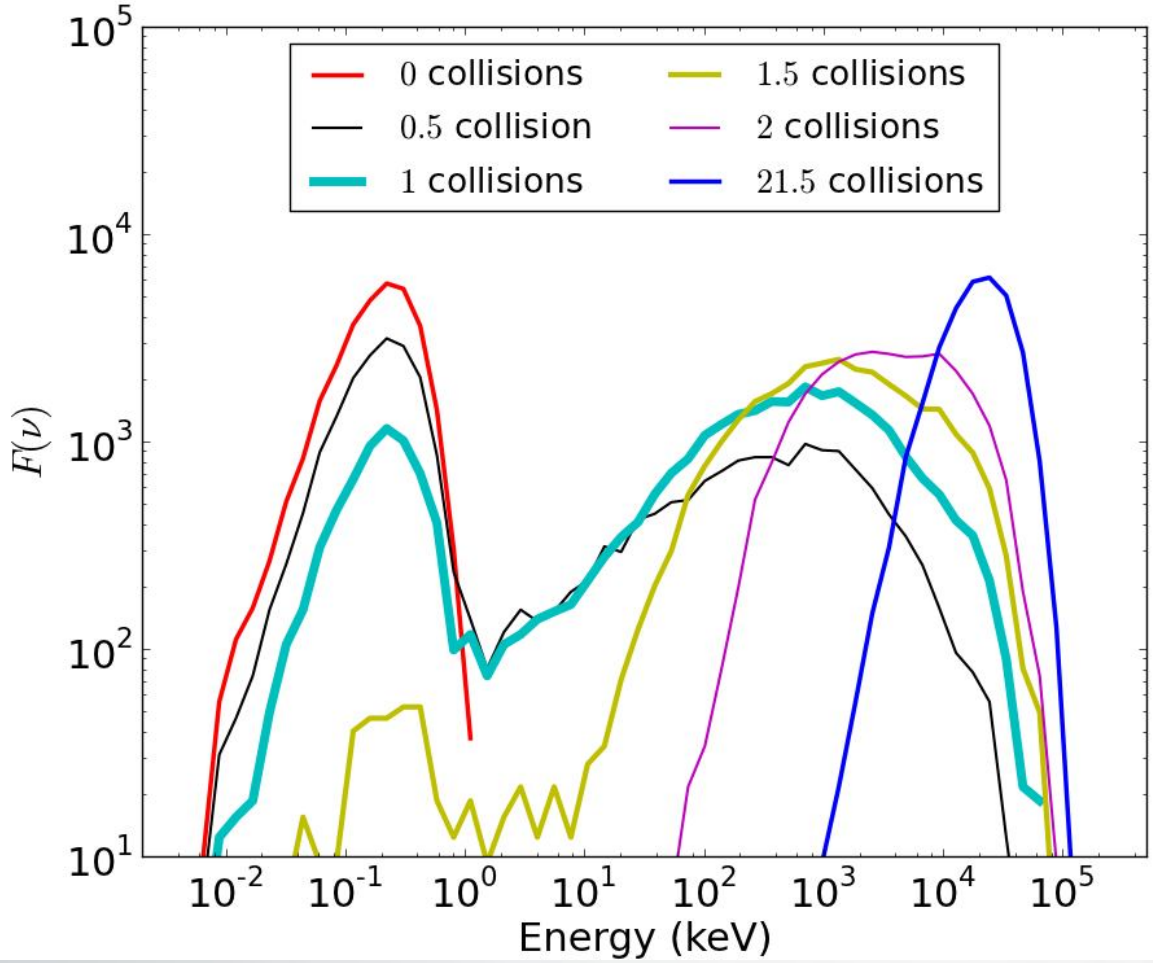

Figure 10: Photon Spectrum for a thermal lepton distribution at 10^{11} K and an initial Blackbody photon distribution at 10^6 K and photon to lepton ratio of 0.1. Notice the light blue curve, indicating both a thermal and a non-thermal component. The dark blue curve is the equilibrium Wien distribution. Collisions in the legend denote the number of collisions per photon.

Pair Production – Preliminary Results

- Compton Scattering + Pair Production

- Lepton Annihilation -> Photon production

- Photon Annihilation -> Lepton production

Maxwellian Leptons @ 10^{10} K – 10k

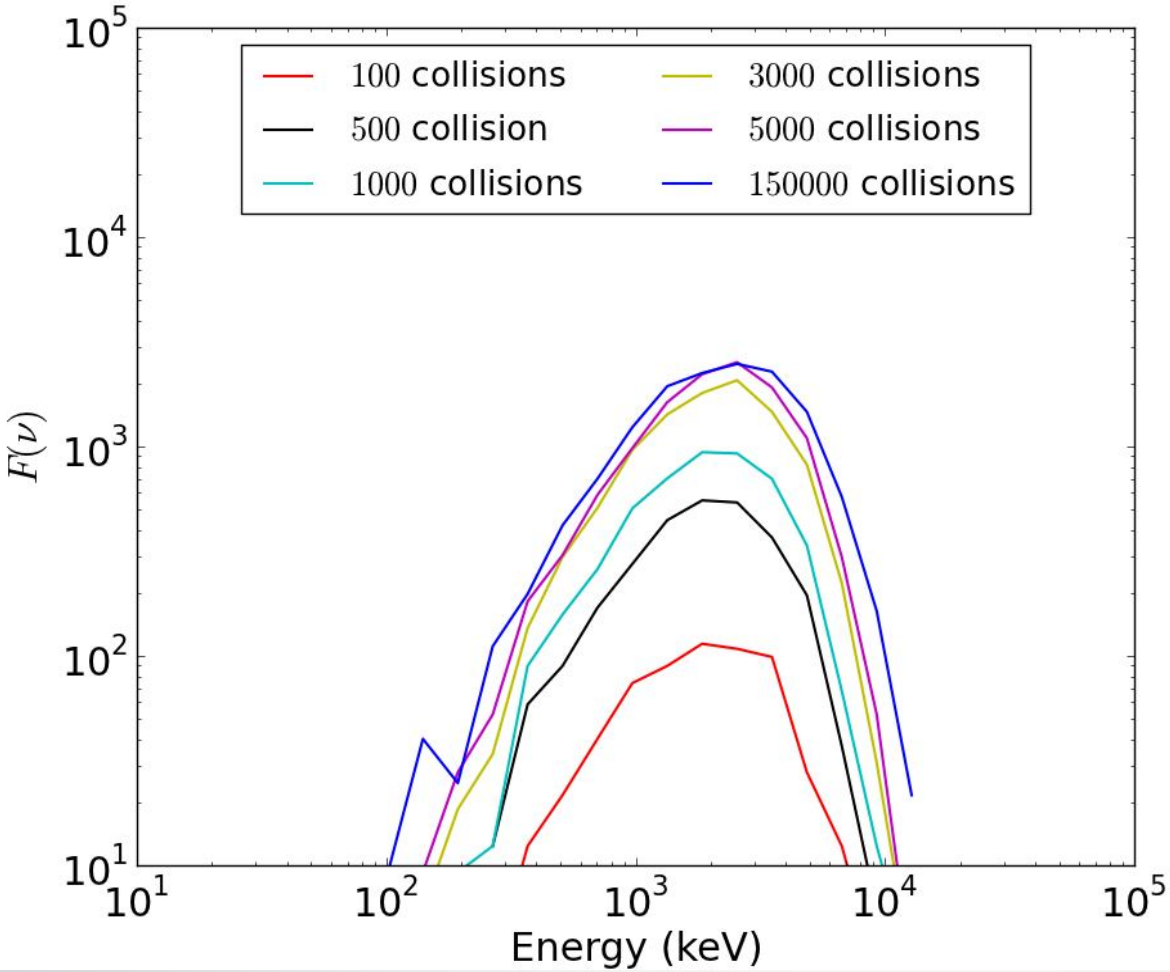

Figure 11: Photon spectrum evolution for an initial state consisting of an equal number thermal lepton-anti-lepton at 10^{10} K. Collisions in the legend denote the total number of collisions. Note that the equilibrium distribution (blue curve) is the blackbody curve.

Wien Photons @ 10^{10} K – 10k

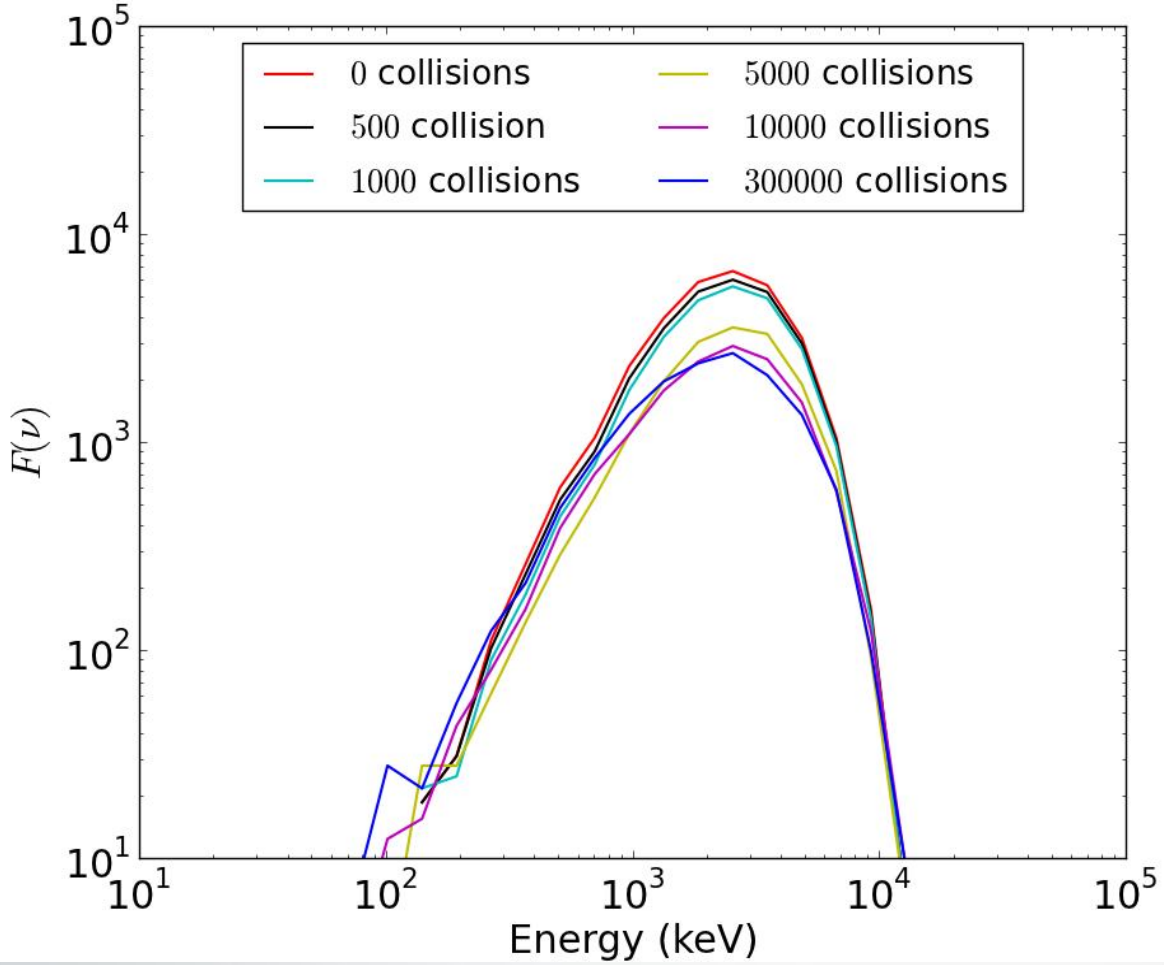

Figure 12: Photon spectrum evolution for an initial state consisting of a Wien distribution of photons at 10^{10} K . Collisions in the legend denote the total number of collisions. Note that the equilibrium distribution (blue curve) is the blackbody curve.

Maxwell Boltzmann Leptons @ 10^6 K vs Wien Photons @ 10^{10} K: Ratio = 1

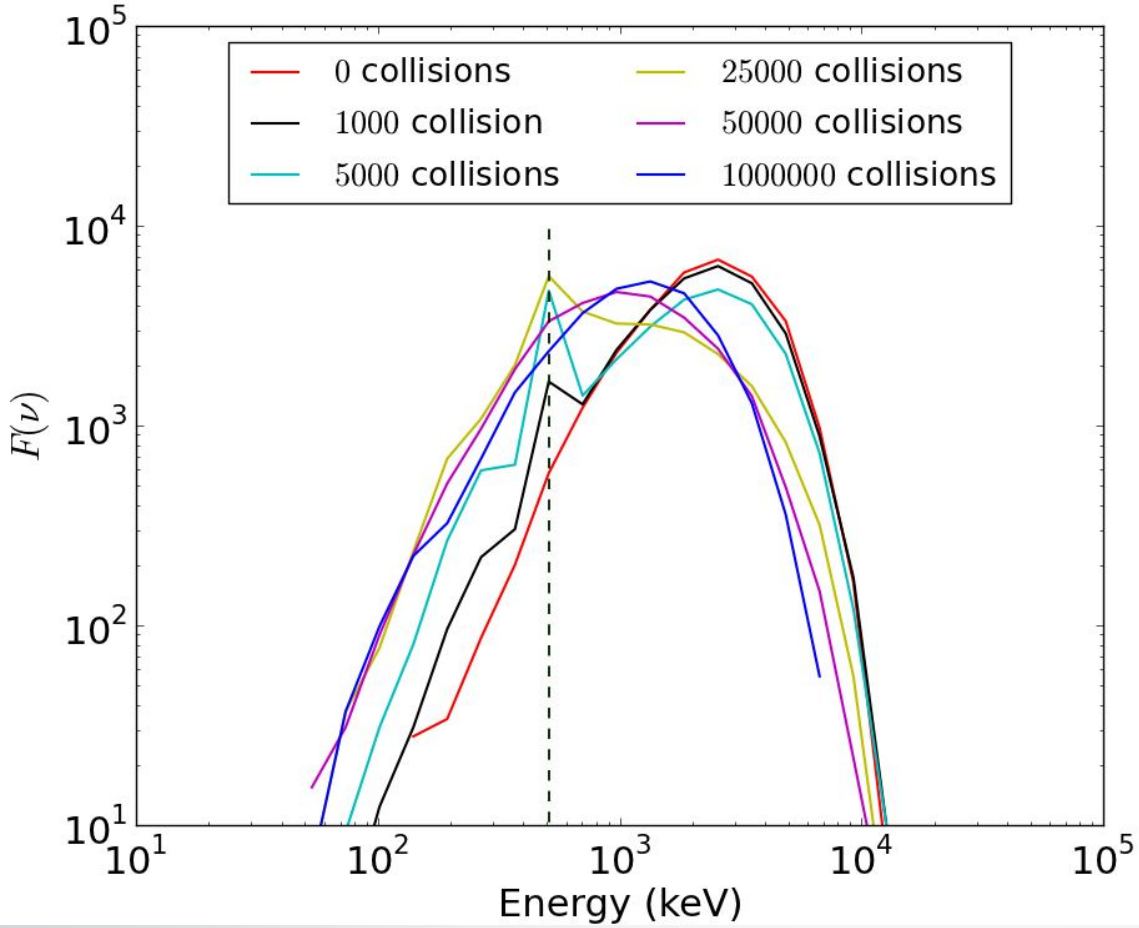

Figure 13: Photon Spectrum for a thermal lepton distribution at 10^6 K, Wien photon distribution at 10^{10} K and photon to lepton ratio of 1. The hotter photons lose energy to the leptons. The dashed green line denotes the 511 keV annihilation line. Collisions in the legend denote the total number of collisions.

Conclusions

- Incomplete Comptonization leads to transient spectra
  - Non Thermal
  - Spans several orders of magnitude
  - Fits the Band function parameters
  - Multi-component spectra
- Equilibrium distributions – Wien / Blackbody

Towards the future

- Analyses of Pair production spectra

To Include-
- Bremsstrahlung
- Synchrotron Radiation

THANK YOU!