Radiation modeling in (high- and) low-luminosity GRBs

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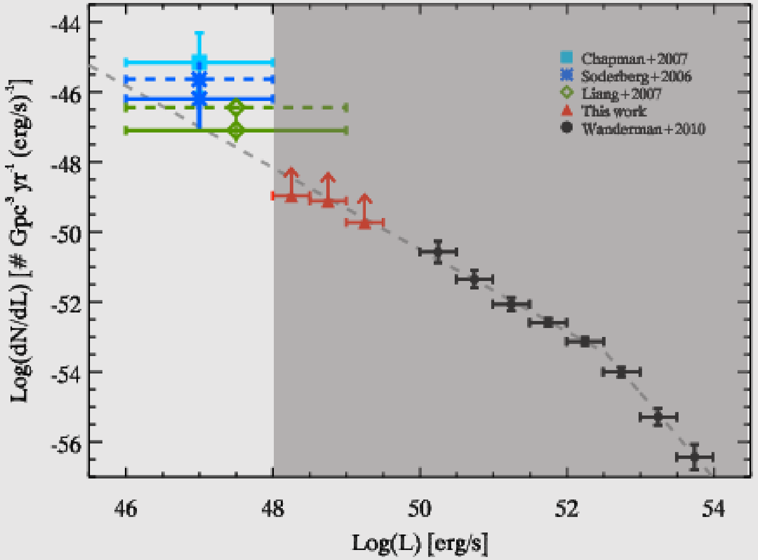
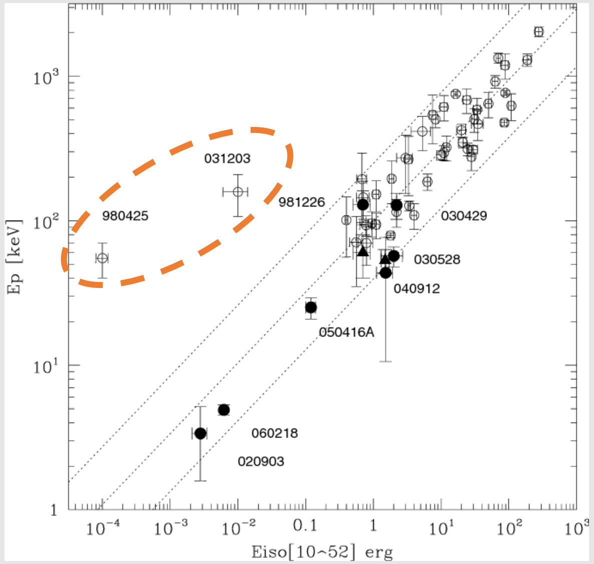
Low-luminosity GRBs



Pescalli et al 2015

Properties and recent discussions

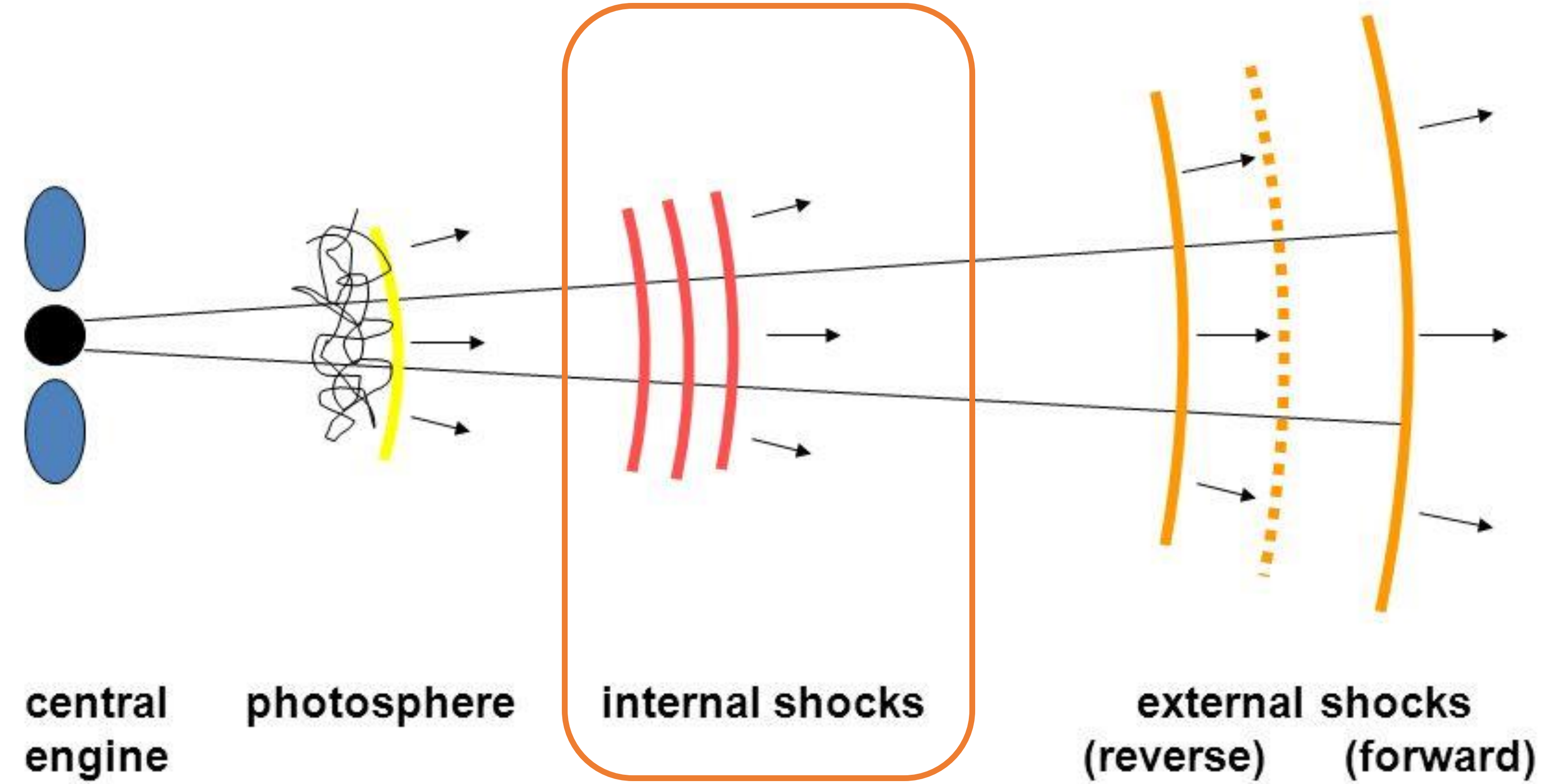
- Subclass of Gamma-Ray Bursts (short duration, energetic events originating from high velocity jet) but with very low isotropic Luminosities **L_{iso} 10^{46} – 10^{48} erg/s**
- Discussed as sources of **UHE cosmic rays** (and HE neutrinos) *(Boncioli et al 2018, Samuelsson et al 2018, Zhang et al 2017)*



Stratta et al 2007

- **High local density** when compared to high-luminosity GRBs, but so far less then 20 LL GRBs observed → could we detect more of them with future instruments like CTA?
- Low-luminosity GRBs seem to be **outliers to known correlations**

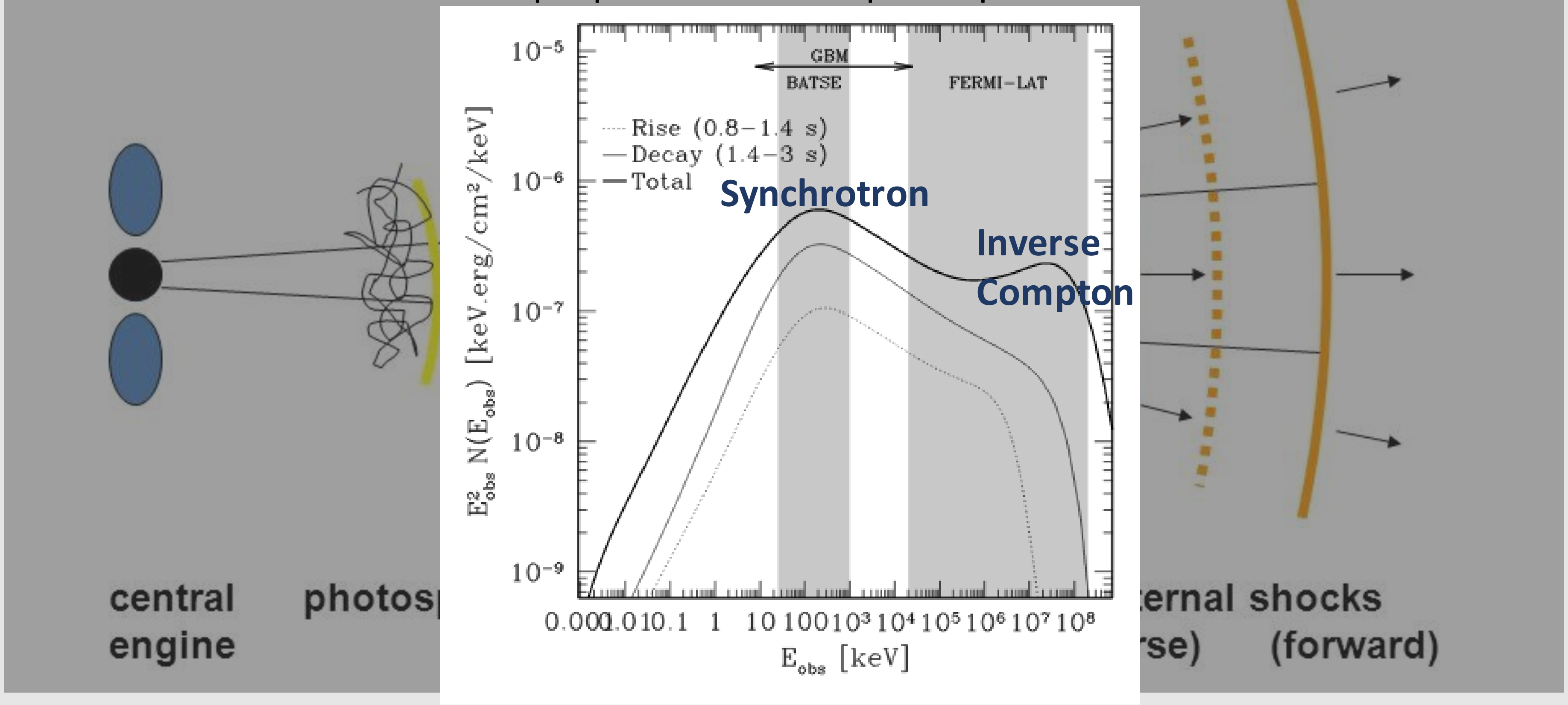
Standard Fireball Shock Model



B. Zhang

Standard Fireball Shock Model

Prompt spectrum from leptonic processes



Bosnjak et al 2009

B. Zhang

Model and methods

1. Fireball modeling

Internal shock model (Daigne & Mochkovitch 1998)
Input parameters: Engine power, injection time, outflow velocity distribution

2. Radiation modeling

Leptonic spectra with time-dependent radiatiative code AM3 (Gao et al 2016)
Processes included: Synchrotron, inverse compton, synchrotron self-absorption, pair annihilation, adiabatic cooling
Additional assumptions: Energy re-distribution between electrons, magnetic field and cosmic rays, injection mechanism of electrons (instantaneous/ contineous injection), fraction of accelerated electrons

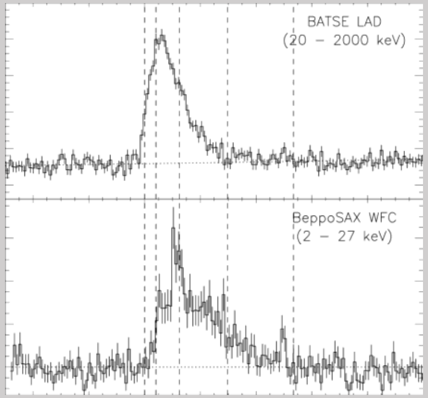
3. Prediction of observed light curves and spectra (plus time resolution)

Taking into account beaming effects and the curvature of the emitting surface (Granot et al 1998)

Benchmark scenarios: Fact sheets

GRB 980425

Observed light curve

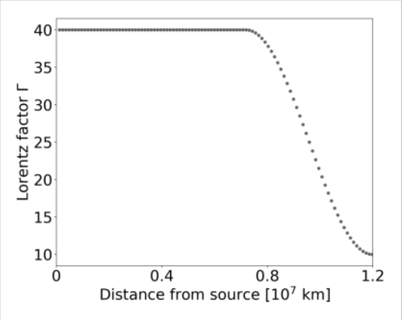


E_{iso} = 1.6 10^{48} erg
$E_{iso\,(1\text{–}10000\ keV)}$ =1.6 10^{48} erg
L_{iso} = 4.6 10^{46} erg/s
T_{90} = 35 s
E_{peak} = 122 keV
z = 0.0085

Lorentz factor varying between 40 and 10
L_{wind} = 2.5 10^{48} erg/s for 40s
Microphysics parameters:

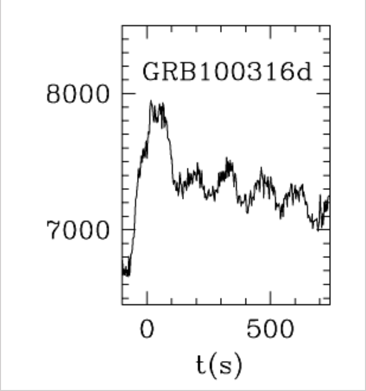
$\varepsilon_B \cong 0.013$
$\varepsilon_e = 0.33$
$\zeta_0 = 4.4\ 10^{-4}$

Jet Γ distribution



GRB 100316D

Observed light curve

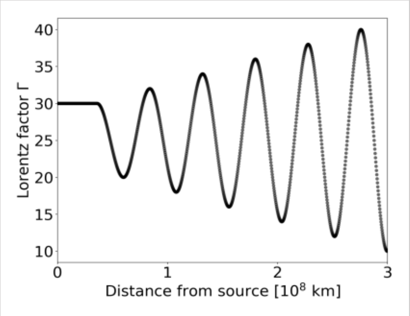


E_{iso} = 3.9 10^{49}
L_{iso} = 1.2 10^{47} erg/s
T_{90} = 1300 s
E_{peak} = 30 keV
z = 0.059

Lorentz factor varying between 40 and 10
L_{wind} = 6 10^{48} erg/s for 1000s
Microphysics parameters:

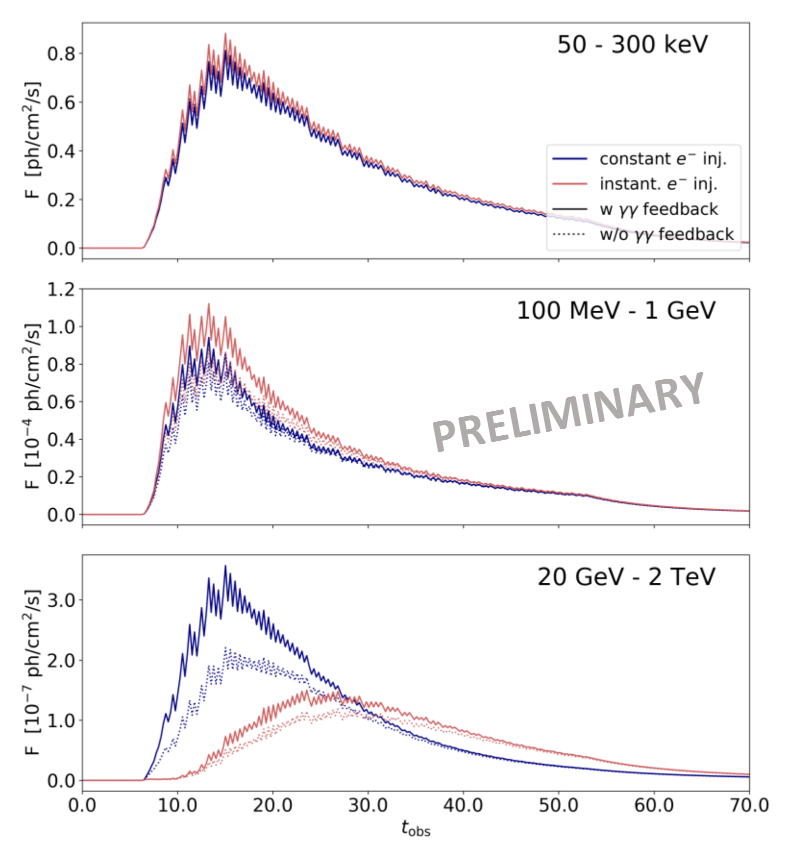
$\varepsilon_B \cong 0.006$
$\varepsilon_e = 0.33$
$\zeta_0 = 1.5\ 10^{-4}$

Jet Γ distribution

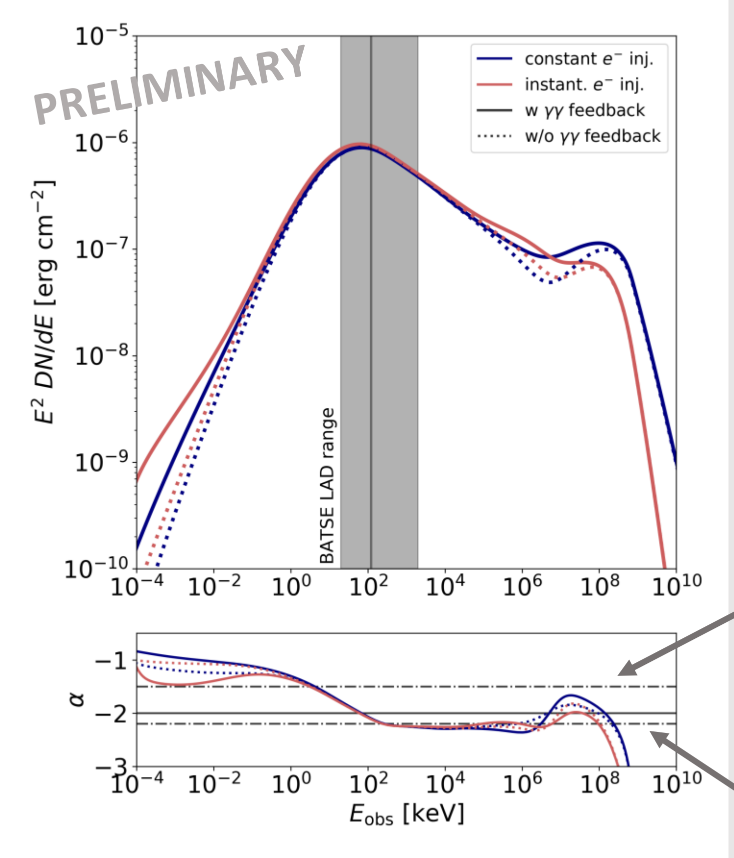


GRB 980425 – results

Light curve in different energy bands



Observed time-integrated spectrum



α = -1.5 synchrotron fast cooling prediction, 'line of death'

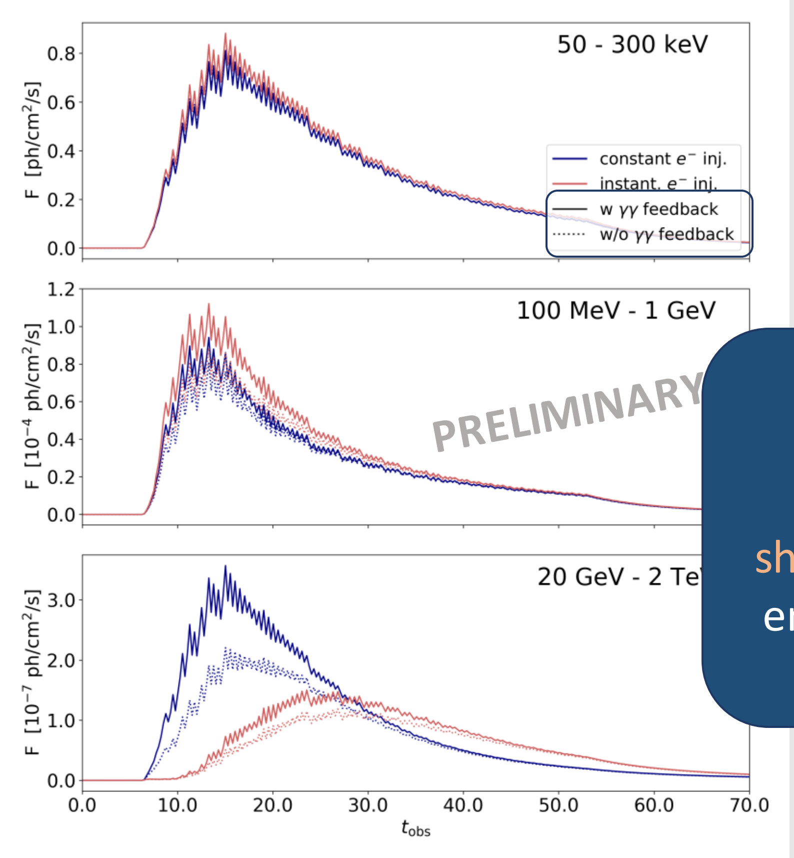
α = -2.2

Different setups

1. Injection of accelerated electrons only at the beginning / continouosly throughout the simulation
2. Feedback from secondary leptons produced via pair annilation included/ not included

GRB 980425 – results

Light curve in different energy bands



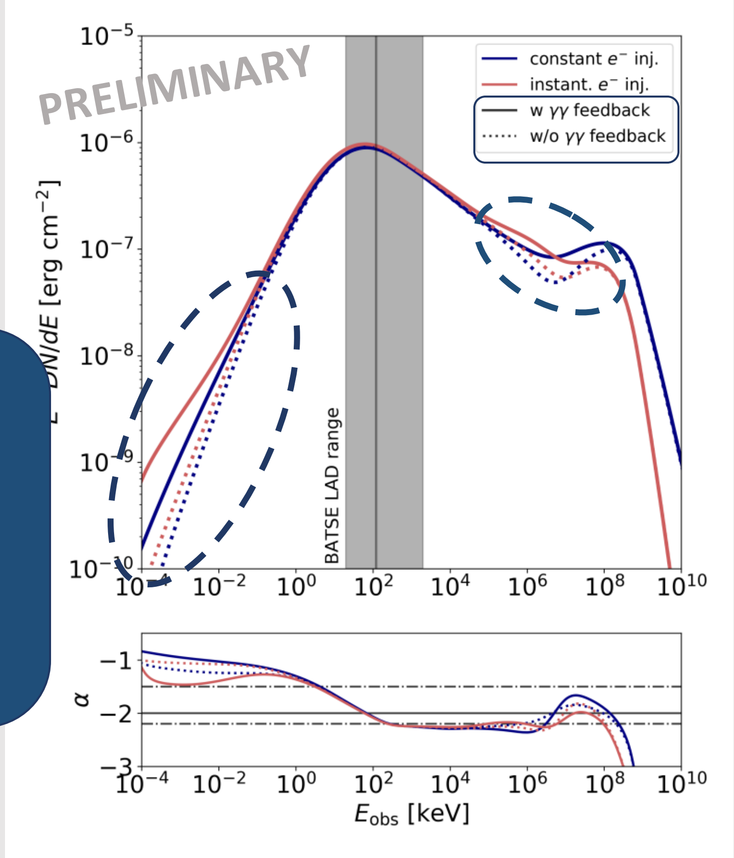
Different setups

1. Injection of accelerated electrons only at the beginning

not included

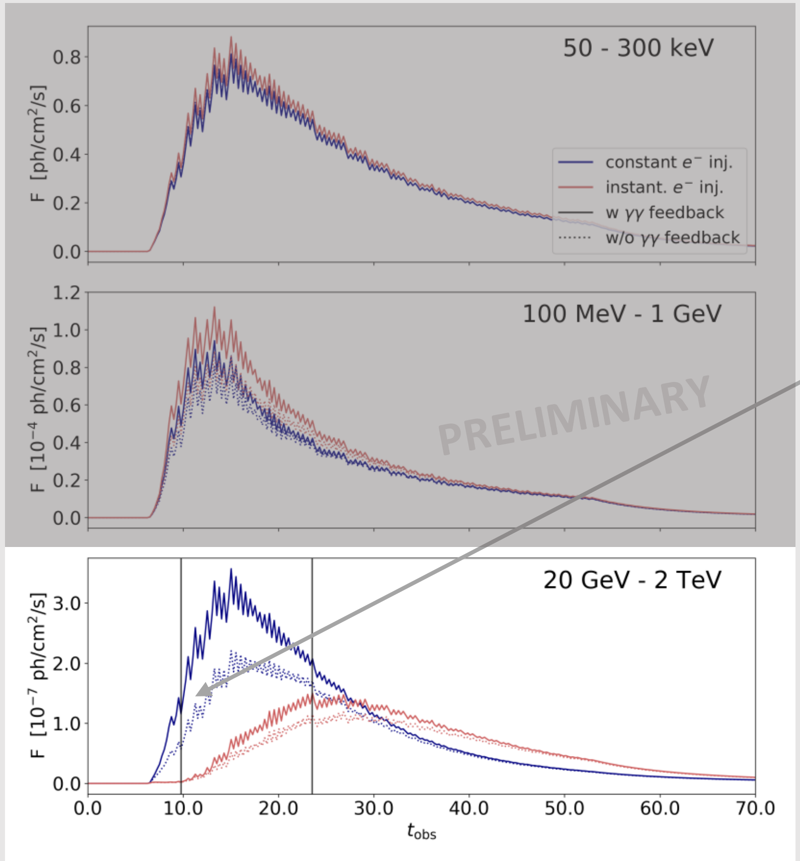
Secondaries from pair annihilation can affect the shape at low and intermediate energies and enhance the flux

Observed time-integrated spectrum

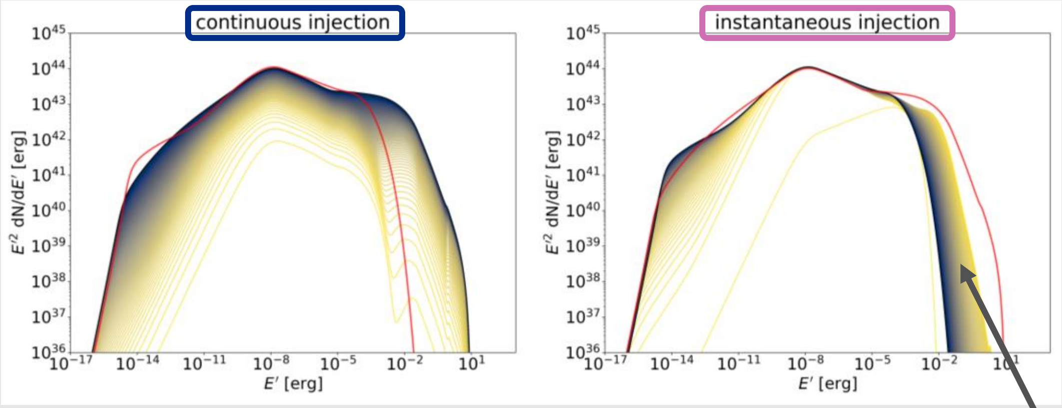


GRB 980425 – high-energy emission

Light curve in different energy bands



The inside of the fireball at different stages

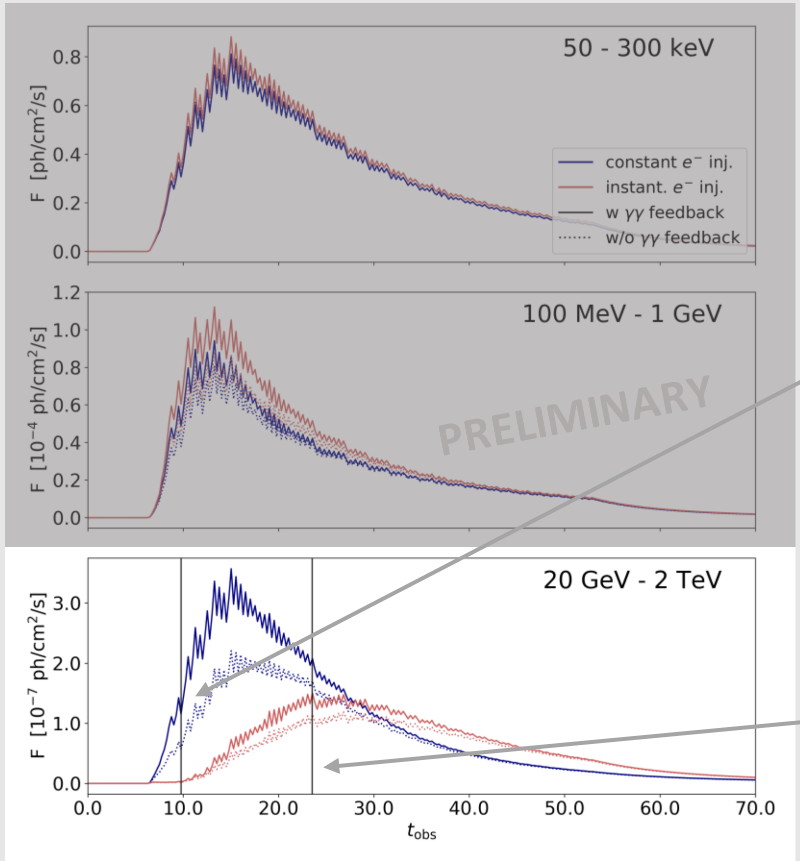


Temporal evolution of the comoving photon field
Yellow: early/ building up
Blue: late/ emitted spectrum

Pair-annihilation of photons lowering the high-energy component

GRB 980425 – high-energy emission

Light curve in different energy bands



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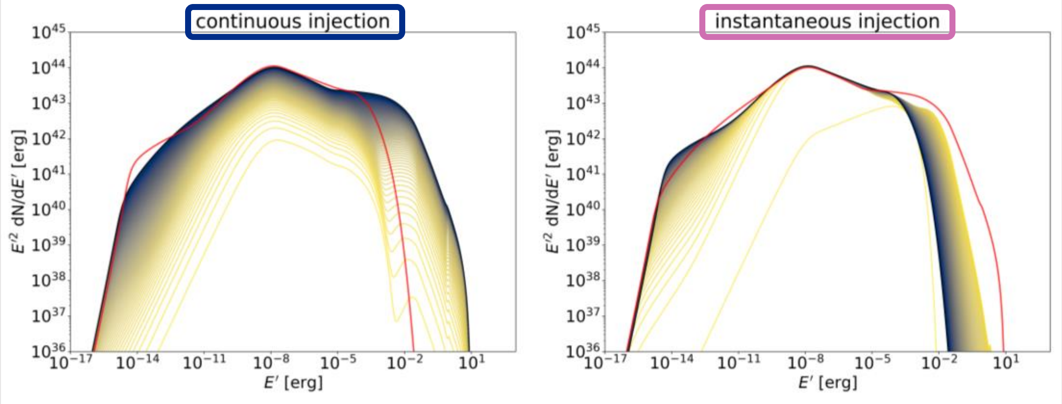
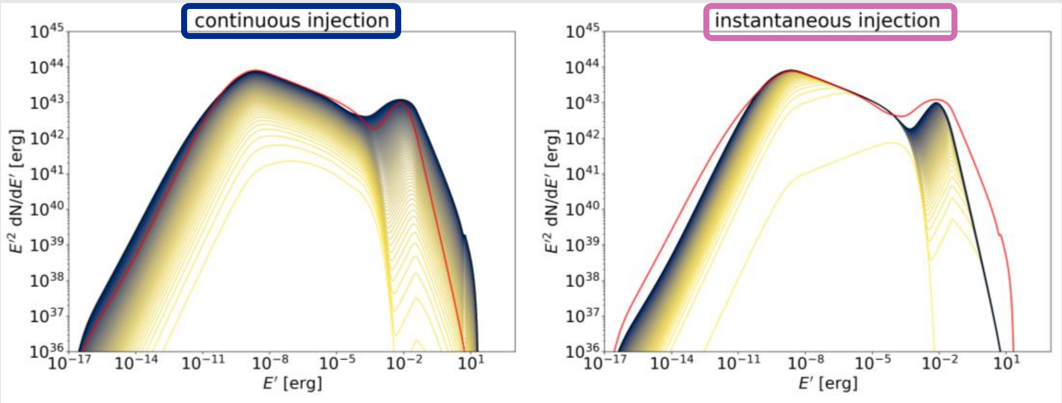
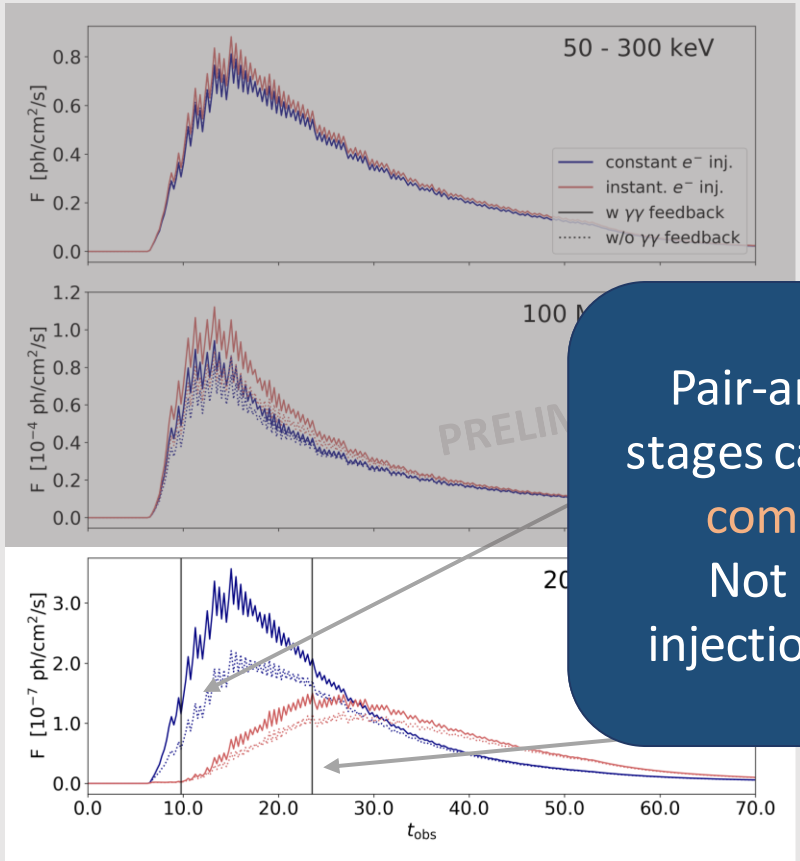




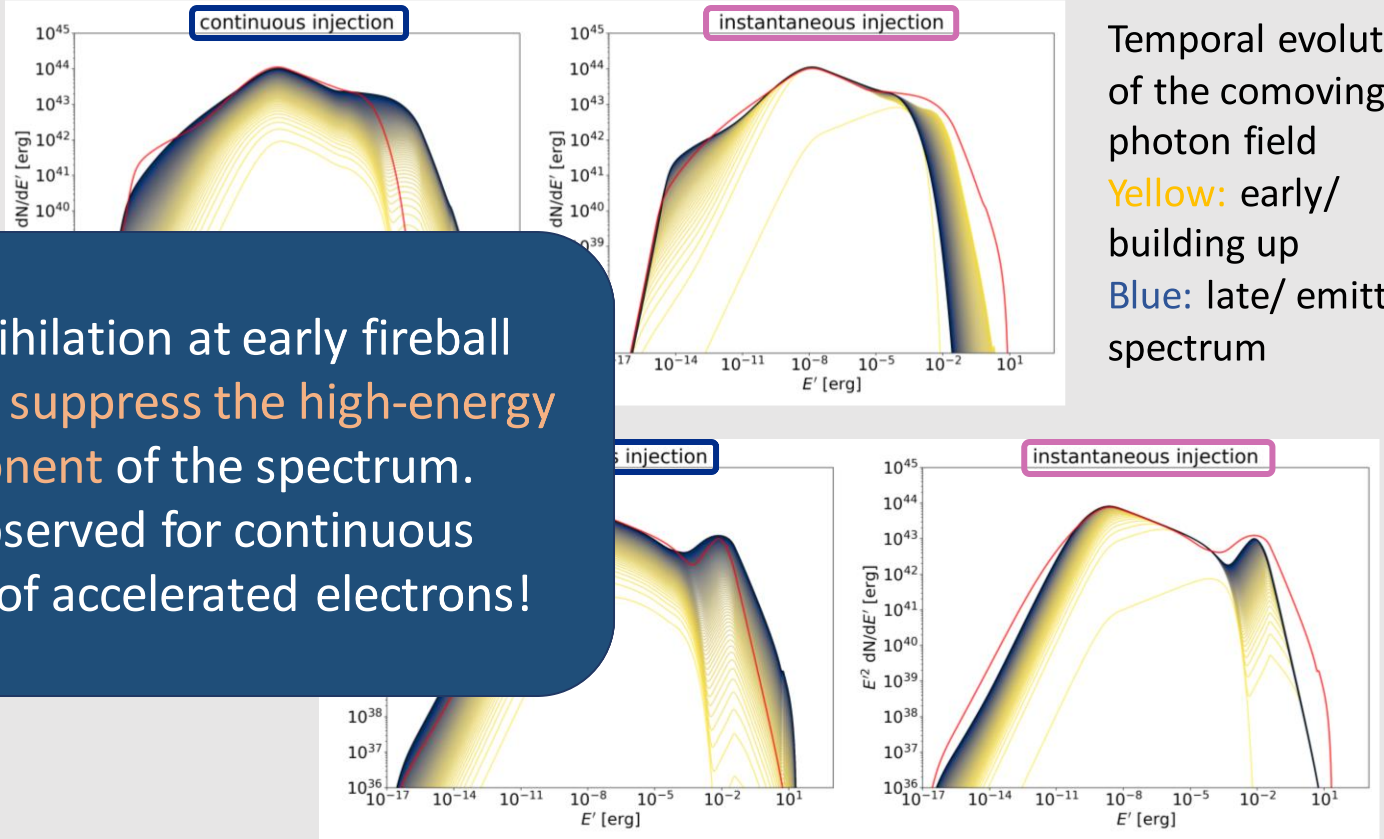
Temporal evolution of the comoving photon field
Yellow: early/ building up
Blue: late/ emitted spectrum

GRB 980425 – high-energy emission

Light curve in different energy bands



The inside of the fireball at different stages



Temporal evolution of the comoving photon field

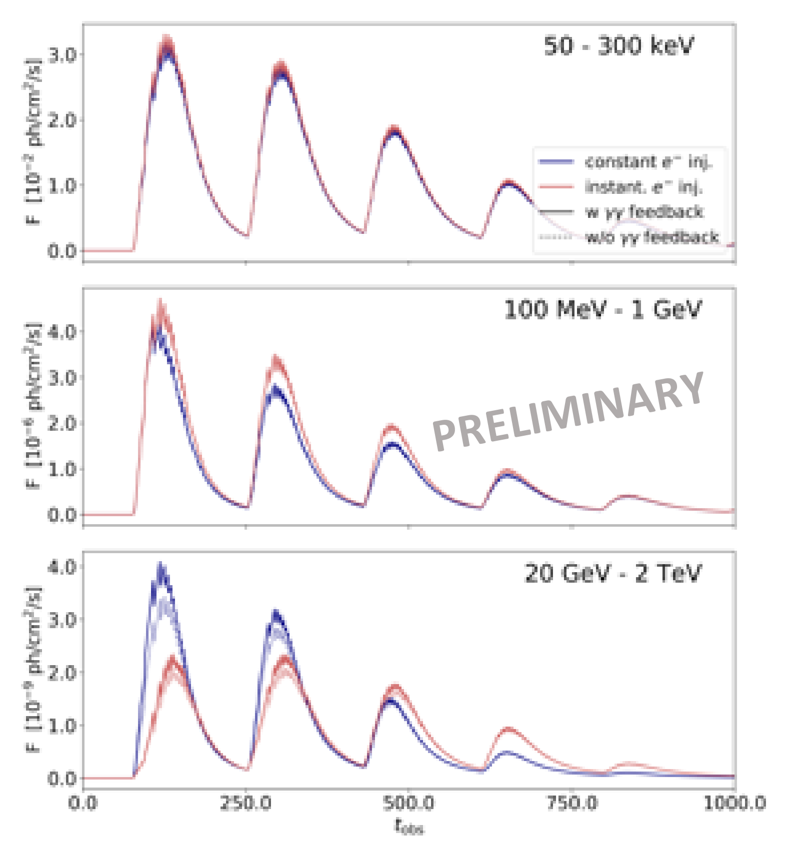
Yellow: early/ building up

Blue: late/ emitted spectrum

Pair-annihilation at early fireball stages can suppress the high-energy component of the spectrum.
Not observed for continuous injection of accelerated electrons!

GRB 100316D – results

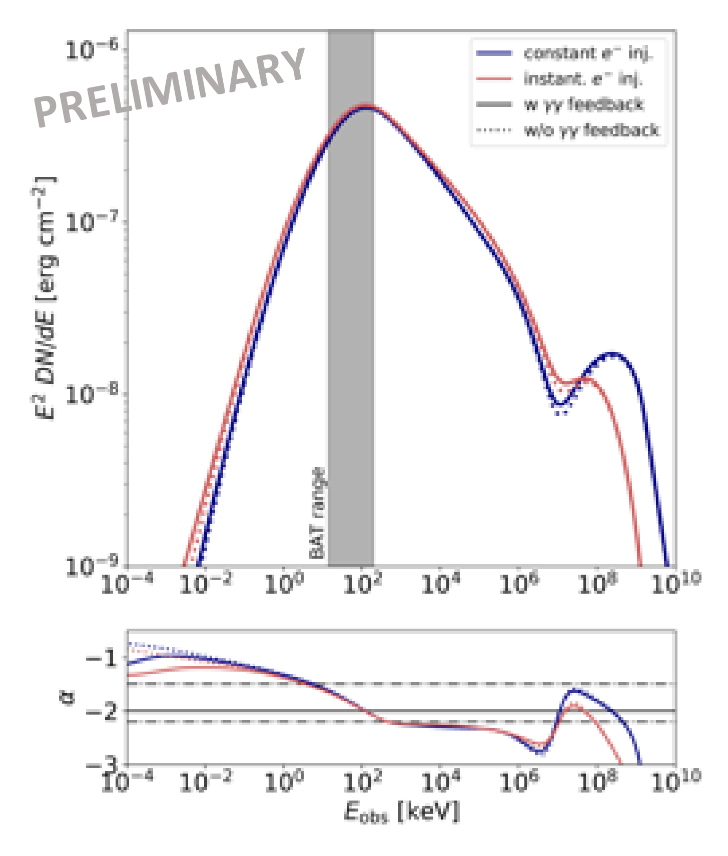
Light curve in different energy bands



Different setups

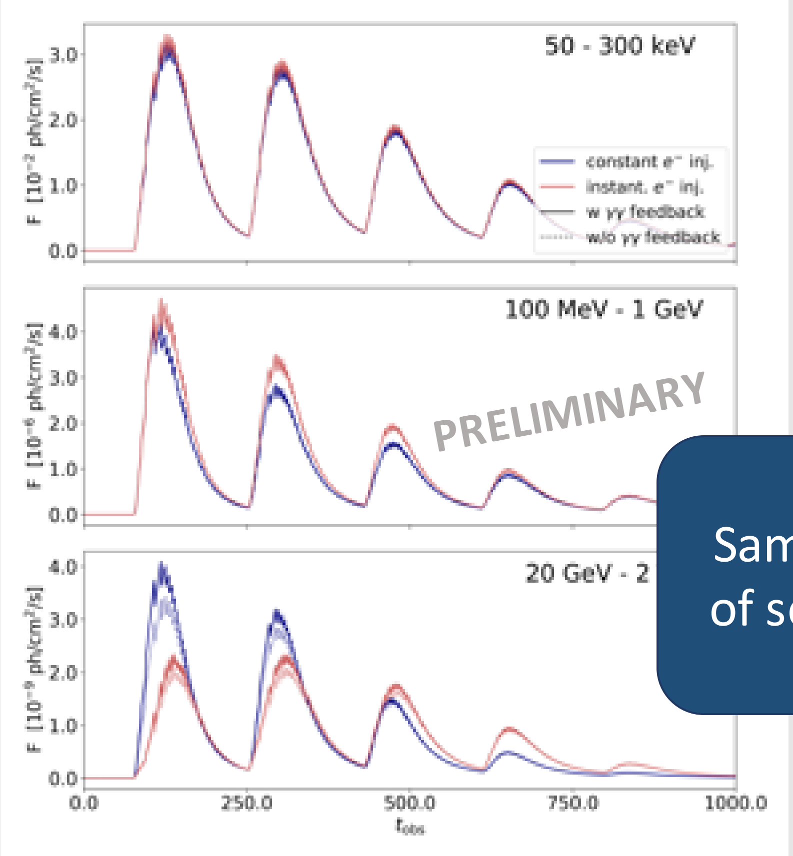
1. Injection of accelerated electrons only at the beginning / continouosly throughout the simulation
2. Feedback from secondary leptons produced via pair annilation included/ not included

Observed time-integrated spectrum



GRB 100316D – results

Light curve in different energy bands



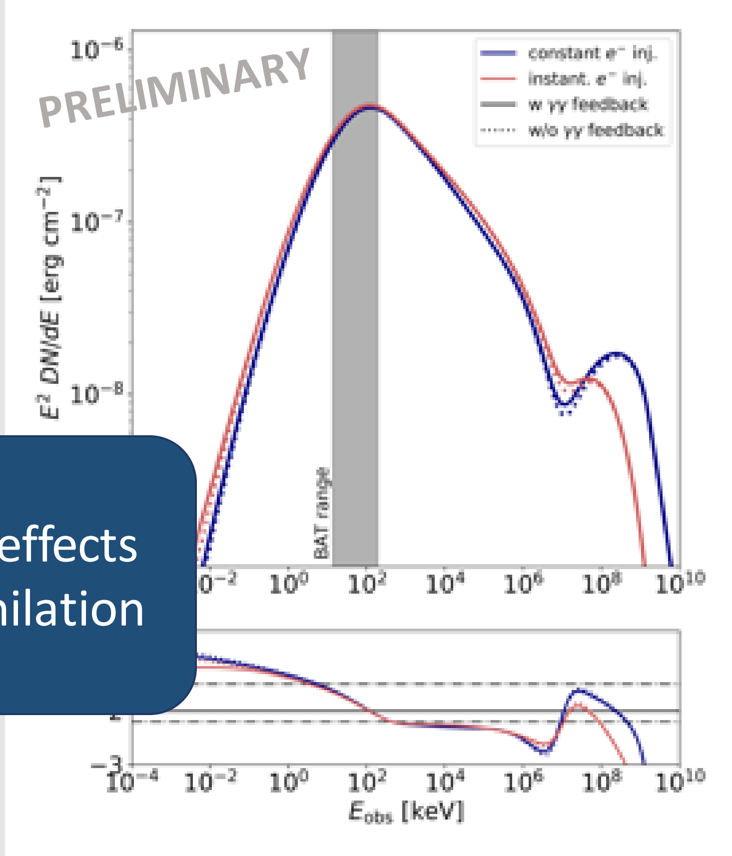
Different setups

1. Injection of accelerated electrons only at the beginning / continouosly throughout the

not included

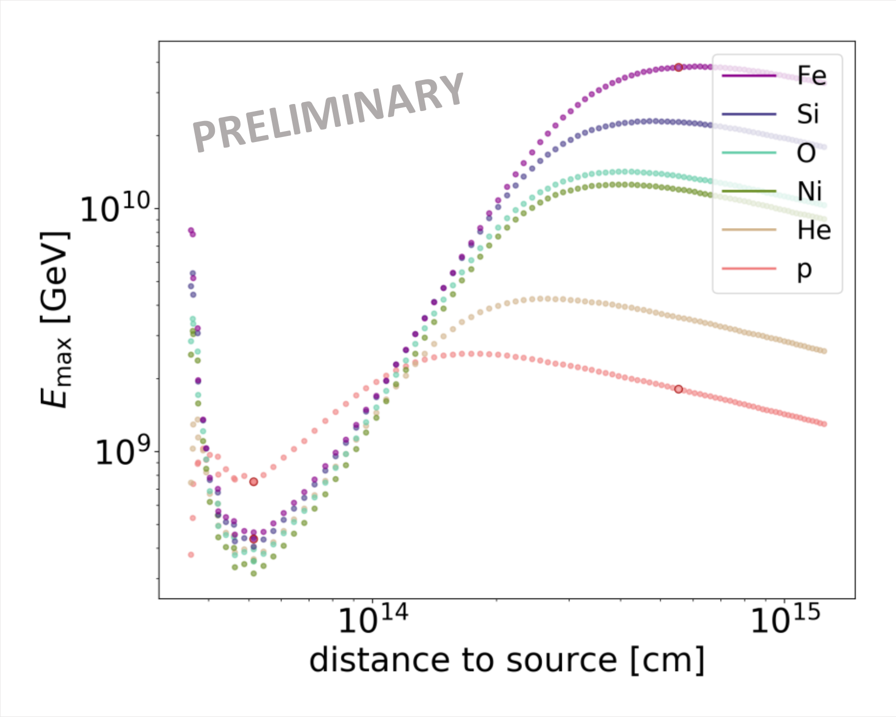
Same qualitative picture, less effects of secondaries from pair annihilation

Observed time-integrated spectrum



Can we reach UHECR energies?

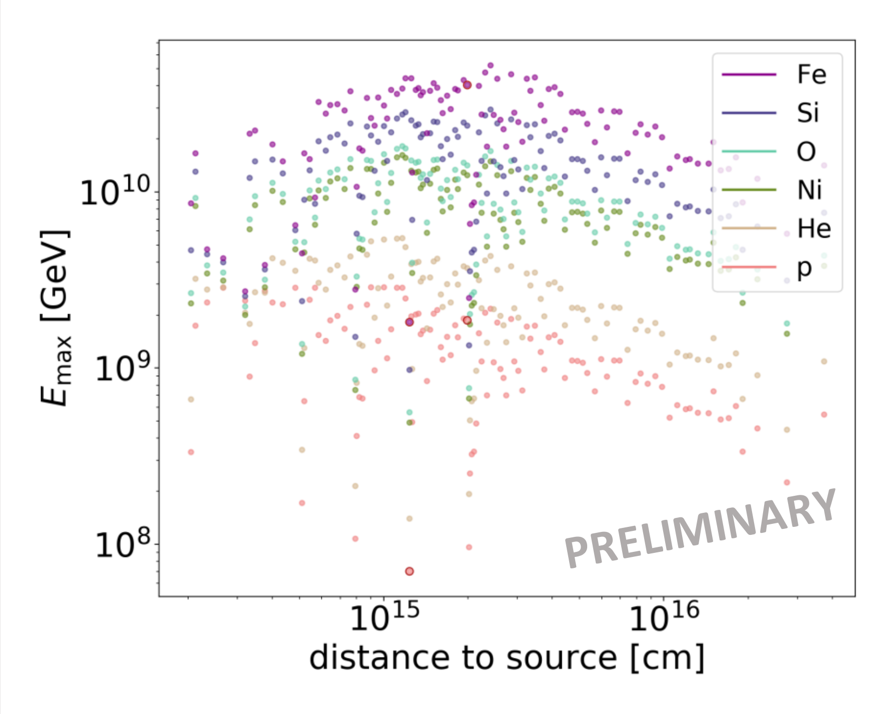
GRB 980425



Self-consistent calculation of maximal energies considering: Bethe-Heitler, Photo-meson interactions, nuclear disintegration, synchrotron and adiabatic cooling

Maximum energies in the source (black-hole) frame

GRB 100316D



Boncioli et al (2018):

Best Fit Parameters:
L_{iso} ~ 5 10^{46} erg/s
$E_{max,\ Si}$ ~ $10^{9.7}$ GeV (shock rest frame)
R ~ 10^{14} cm

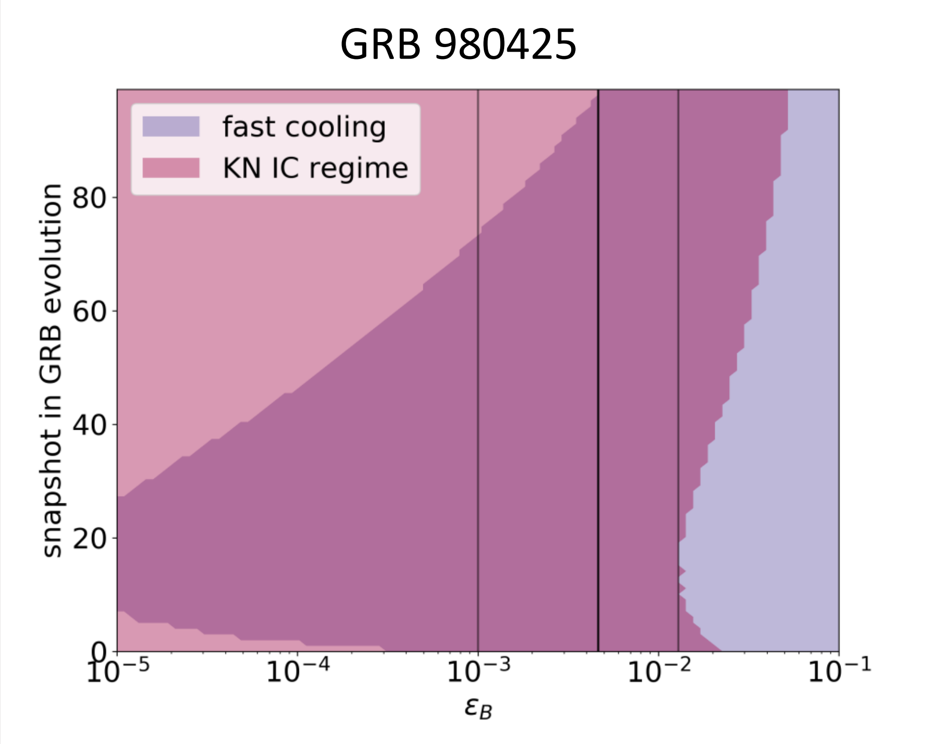
We reach high enough energies and results are (roughly) compatible!

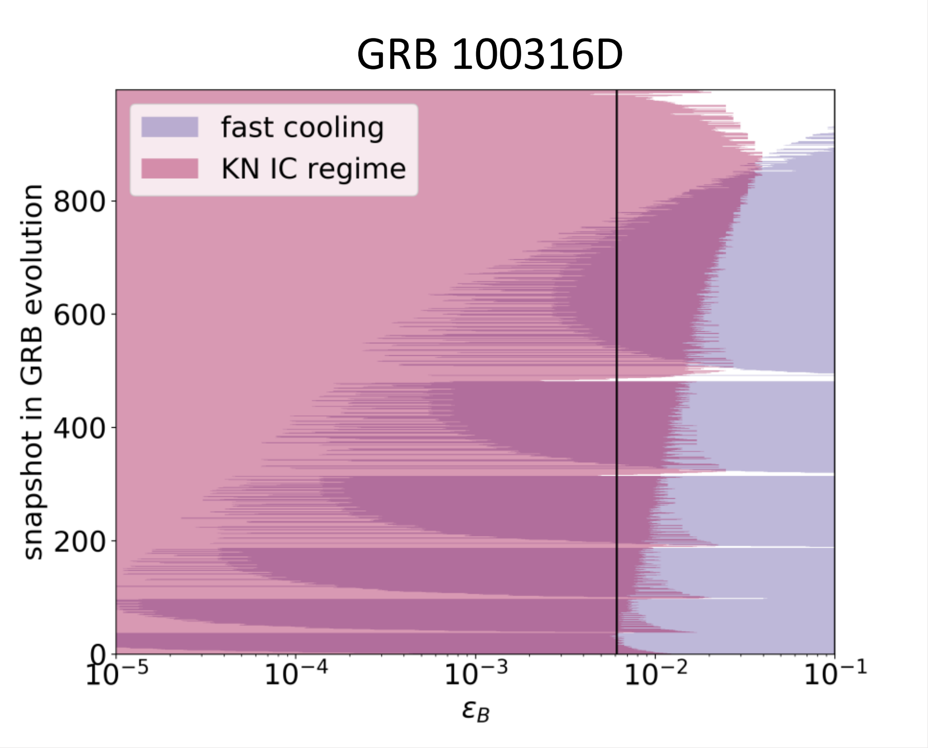
Summary and Conclusions

- Successful modeling of two benchmark LL-GRB scenarios in the internal shock model
- LL GRBs can have an Inverse-Compton induced high-energy component that could potentially be observed by CTA (further studies examining this coming up).
- The intensity of the HE component can be suppressed by pair annihilation, resulting in a delayed onset of the HE emission. This is not observed in the case of continuous injection of accelerated electrons.
- Secondary pairs from photo-pair production can re-shape the spectrum at low and intermediate energies
- In a self-consistent calculation of the maximum energies of different nuclei, ultra-high energies are be reached.

Backup

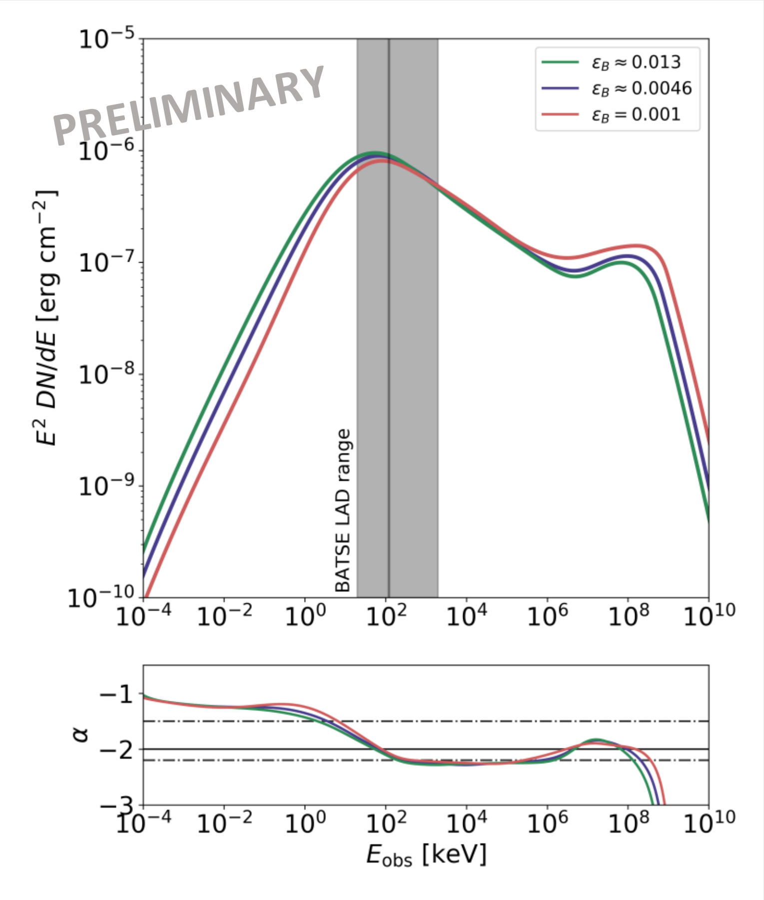
Choice of microphysics parameters

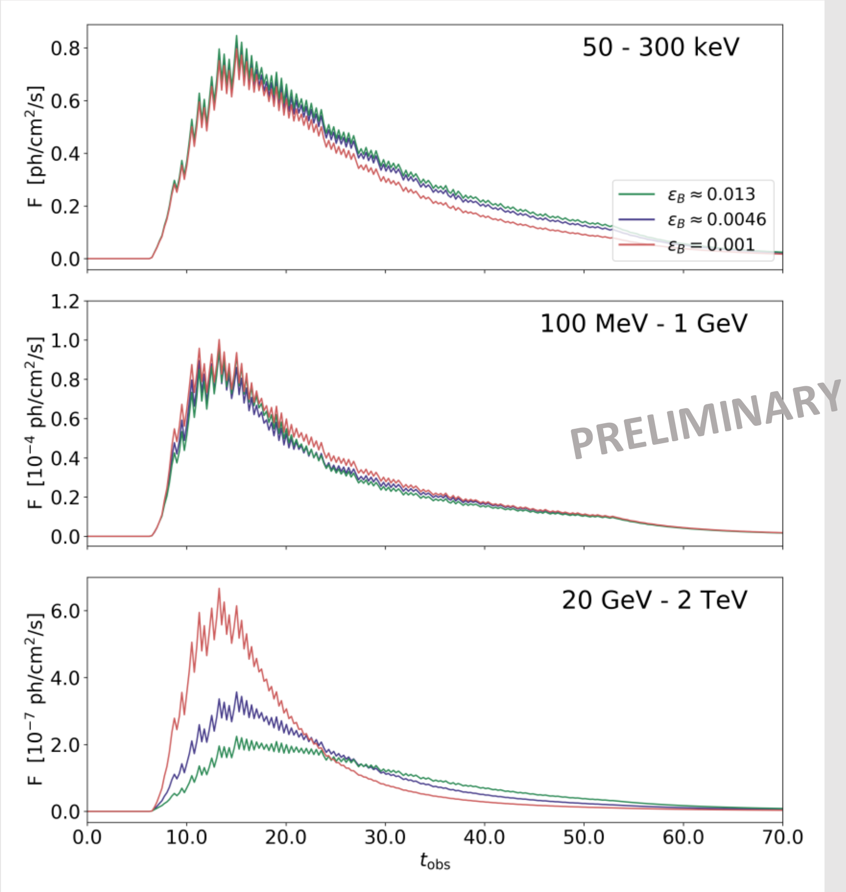




Method Varying the fraction of energy in the magnetic field while keeping the fireball evolution and peak energy cst.
Fast cooling regime if all electrons cool on the adiabatic timescale (usually via synchrotron cooling)
KN IC regime Inverse Compton scatterings in Klein-Nishina in correct regime to achieve lower-energy slopes compatible with observations (see Daigne et al 2011)

GRB980425: Different choices of ε_B



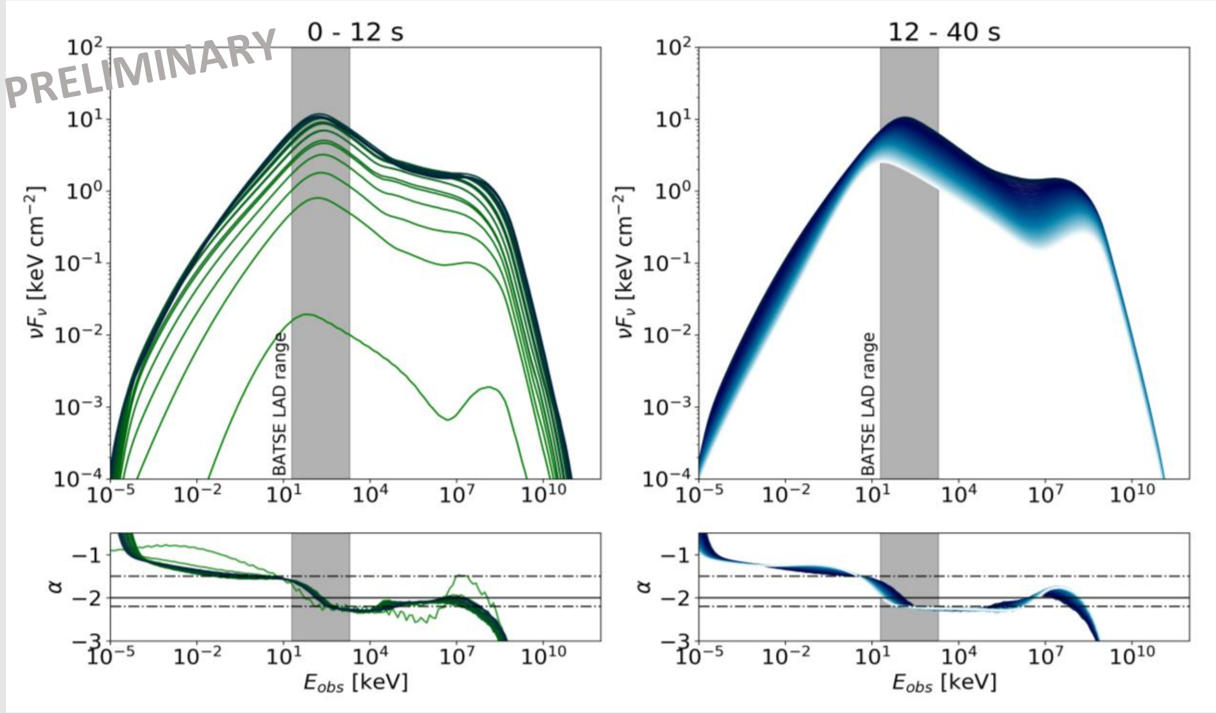


Setup: Continuous electron injection and full consideration of pairs from photon-annihilation

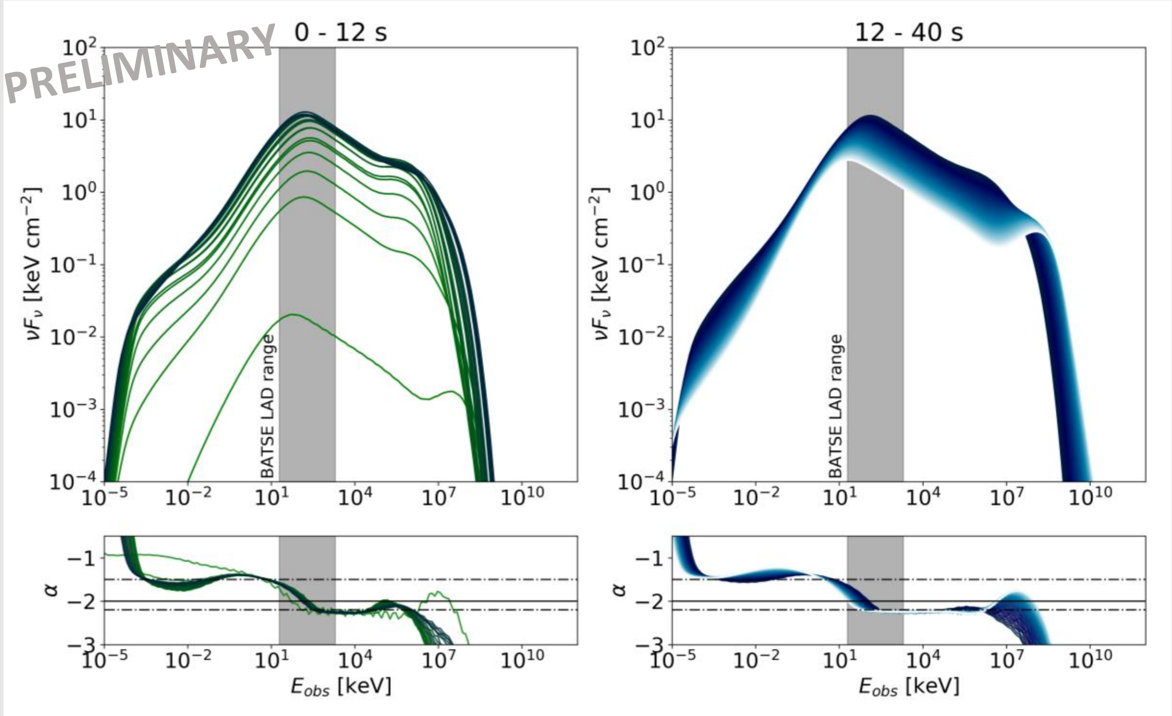
Results:
Lower magnetic fields enhance IC component but reduce flux in synchrotron compoment (peak energy is constant as minimum Lorentz factor has been adjusted accordingly)

GRB980425: Time-integrated spectra

Continuous injection



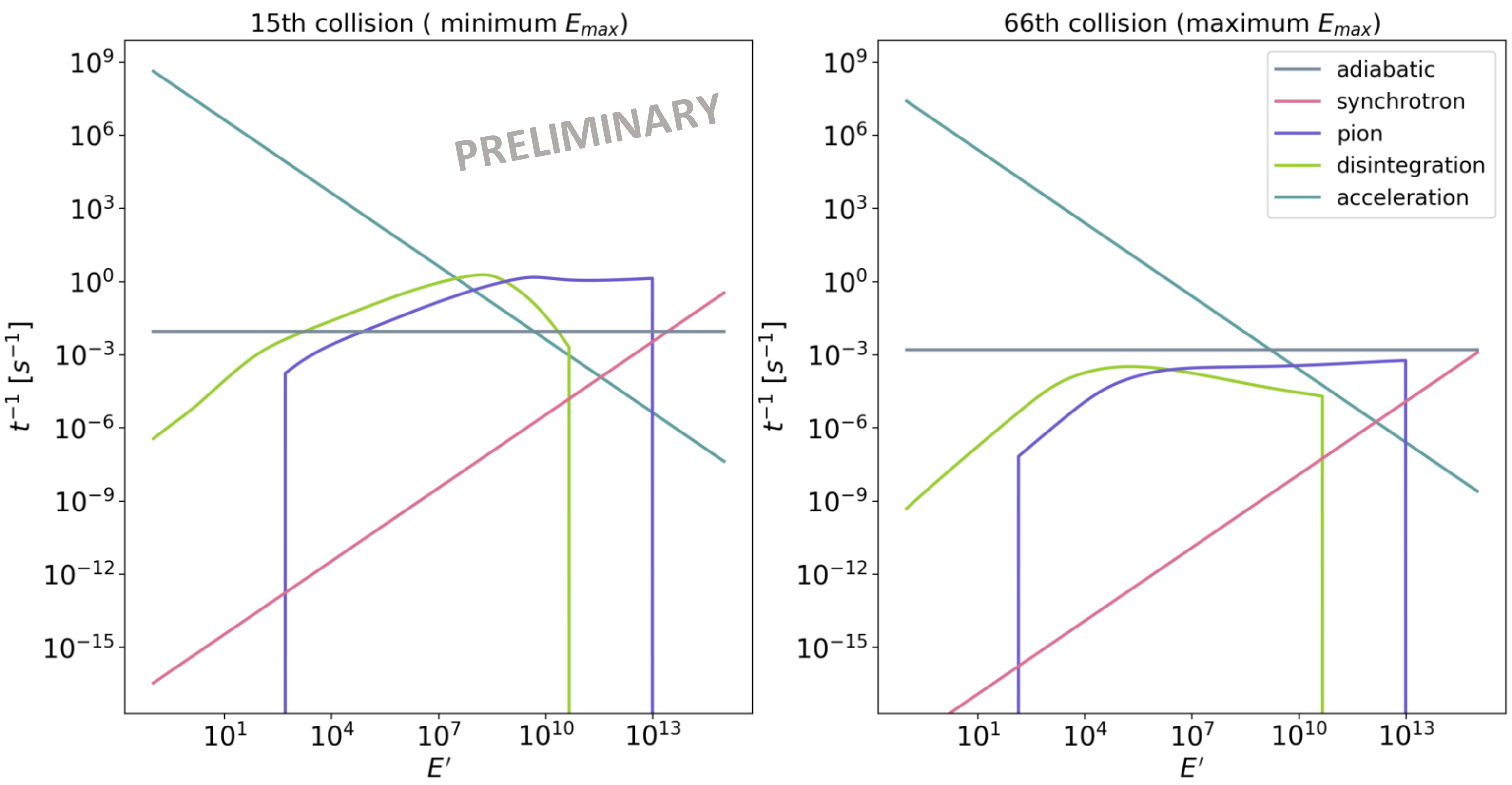
Instantaneous injection



Timescale plots for CR maximum energies

Interaction rates for **iron**

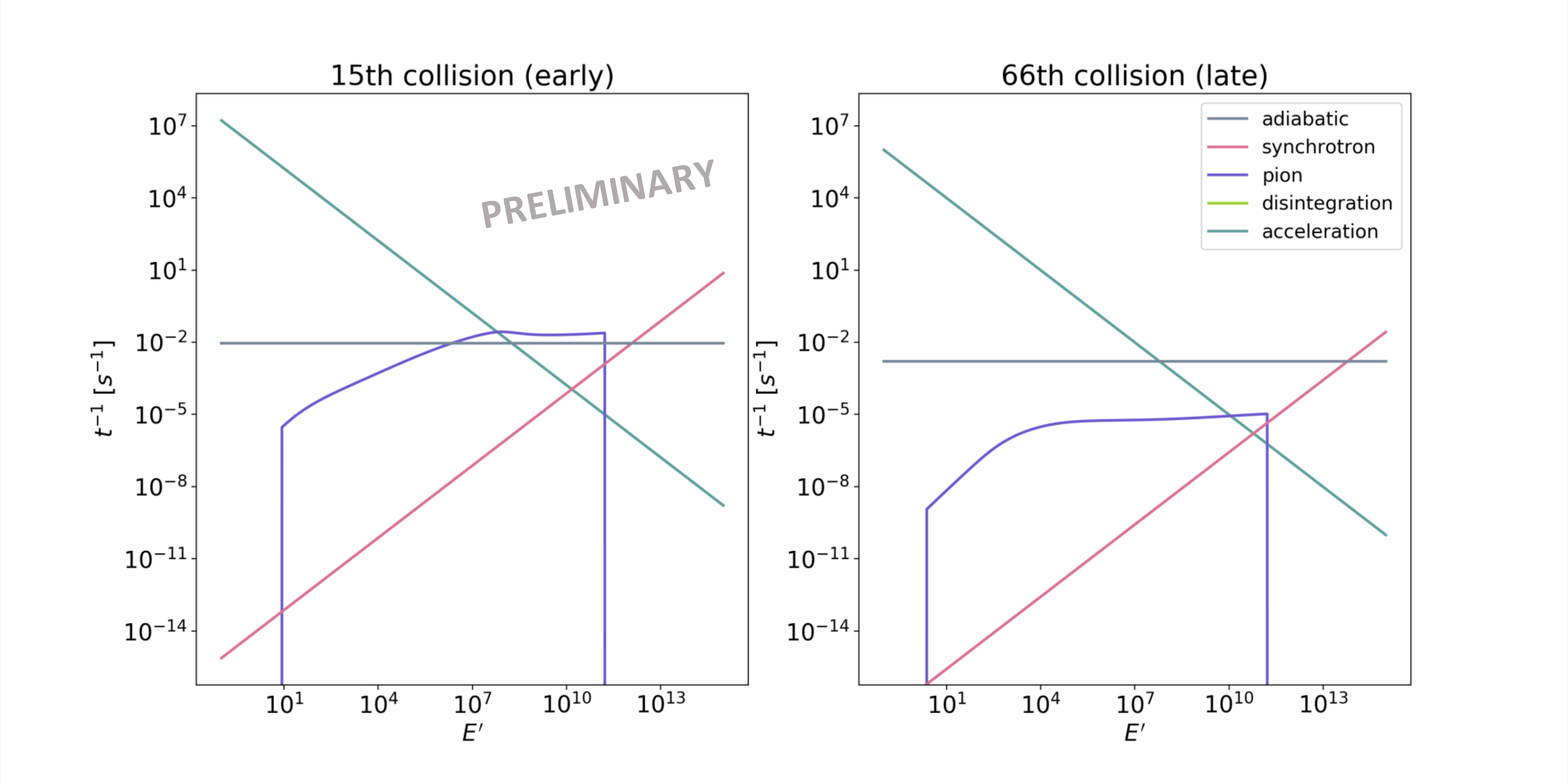
GRB 980425



Timescale plots for CR maximum energies

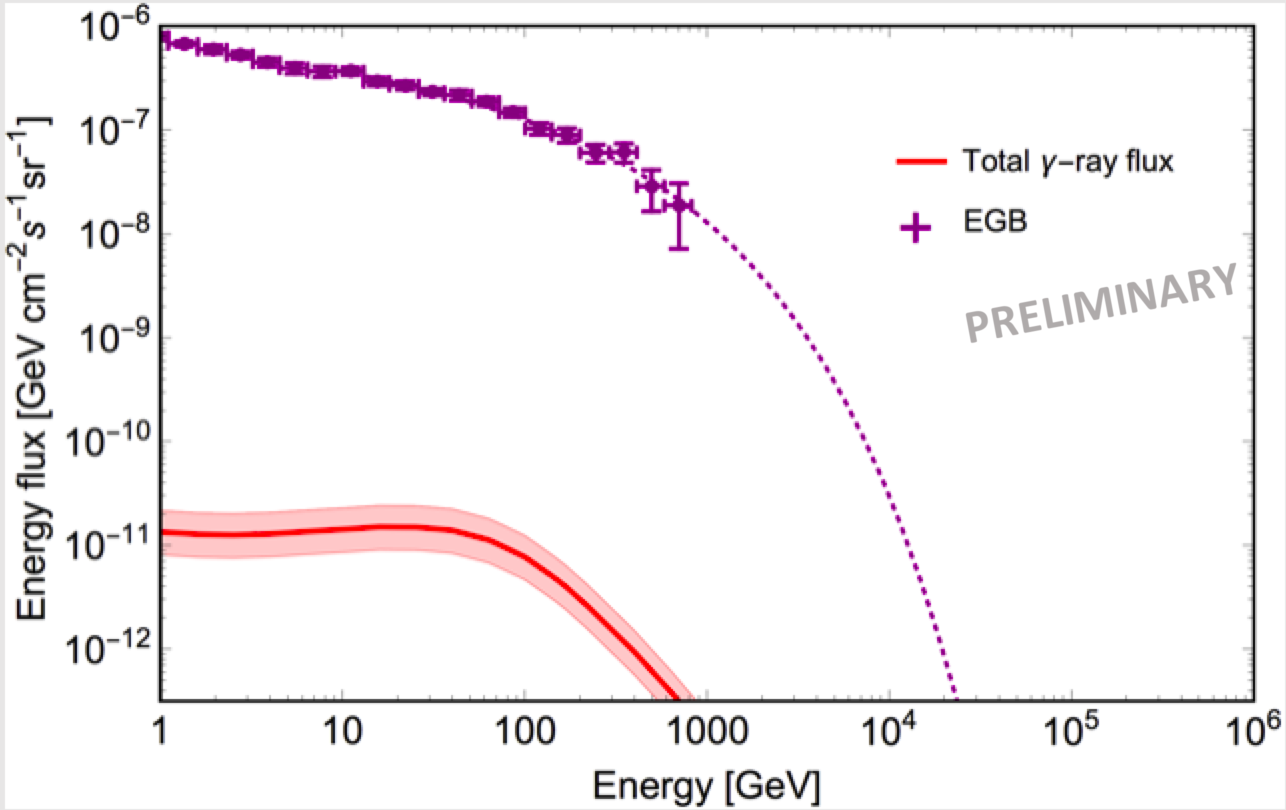
Interaction rates for **protons**

GRB 980425



Diffuse flux

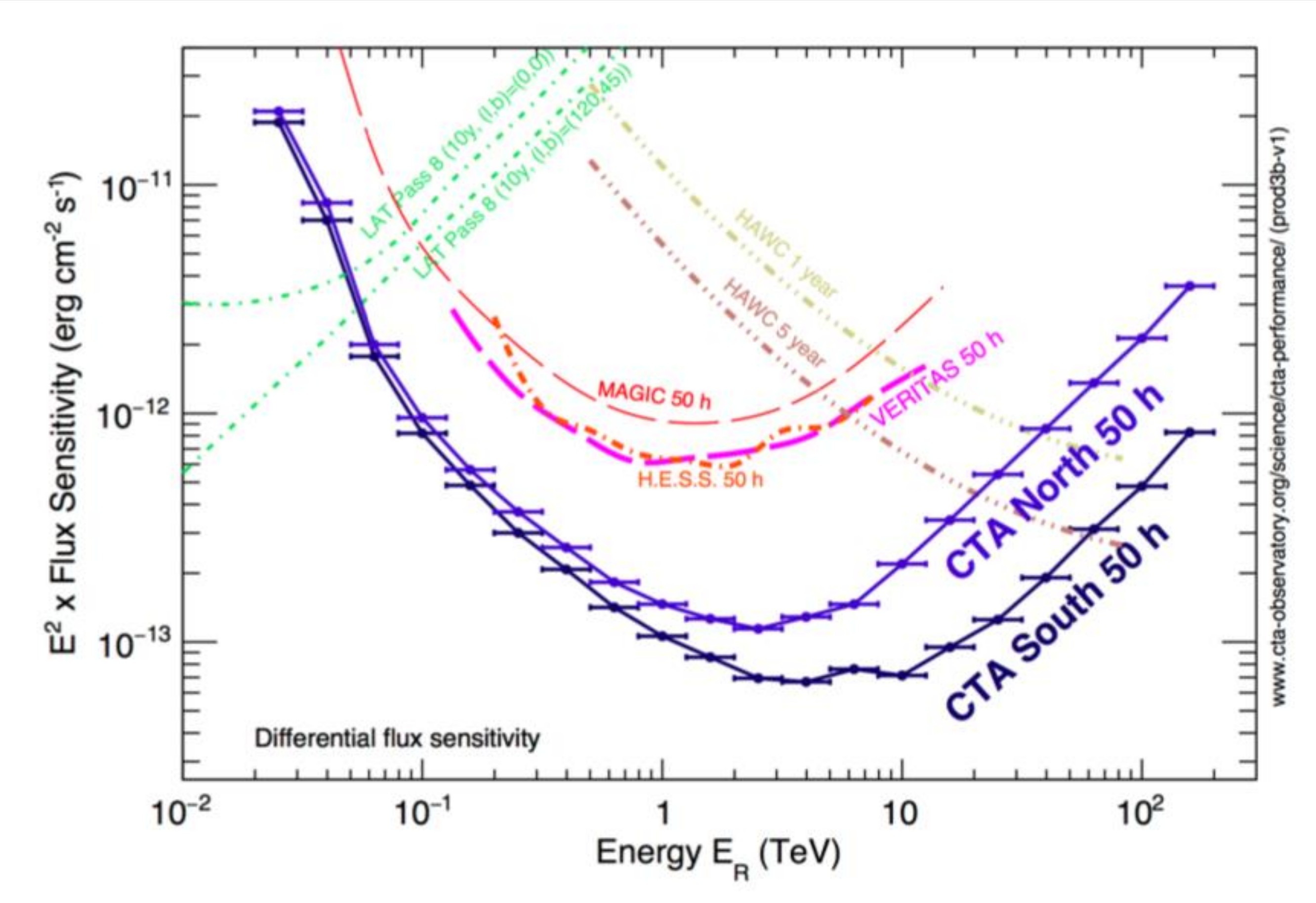
GRB 980425



Assumptions

- *Emitted spectral shape of luminosity the same for all GRBs,* scaling of luminosity and duration
- *Local density* 440(+264-175) [Gpc^{-3} yr^{-1}]
- *source evolution* is Star Formation Rate

CTA sensitivity



Observations

GRB980425

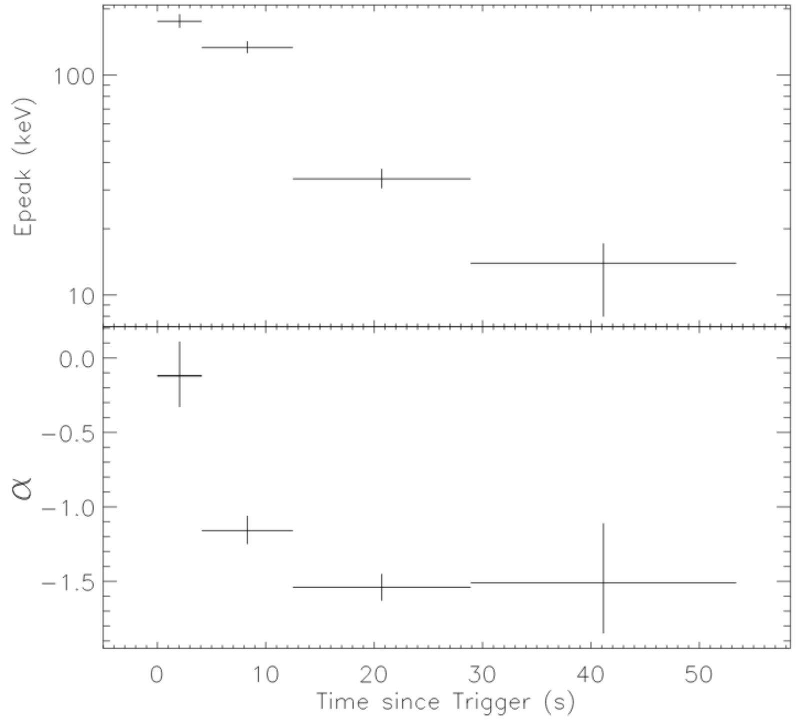
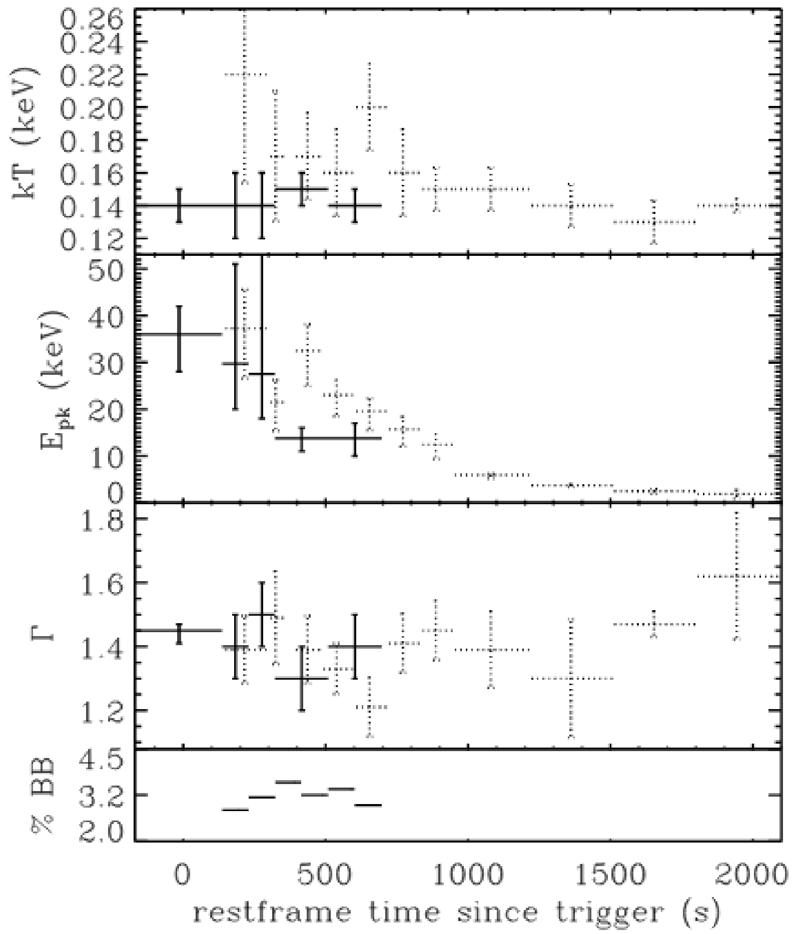


Fig. 2.— Spectral parameter evolution of GRB 980425; the data points correspond to the intervals indicated in Figure 1. The uncertainties are 1σ.

Kaneko et al 2006

GRB100316D



Starling et al 2011

Figure 4. Evolution of power-law photon index Γ, peak energy E_{pk} and blackbody temperature kT in the blackbody plus exponentially cut-off power-law model fitted to the BAT-XRT spectra for GRB 100316D (solid error bars), compared with the same model fitted to BAT-XRT data of GRB 060218 (taken from Kaneko et al. 2007, dotted error bars) in the source rest frames. Errors are 90 per cent confidence. The bottom panel shows the percentage contribution of the blackbody component to the total observed 0.3–10 keV X-ray flux, in time-sliced XRT spectral fits to GRB 100316D.