Multi-Zone collision model for GRBs

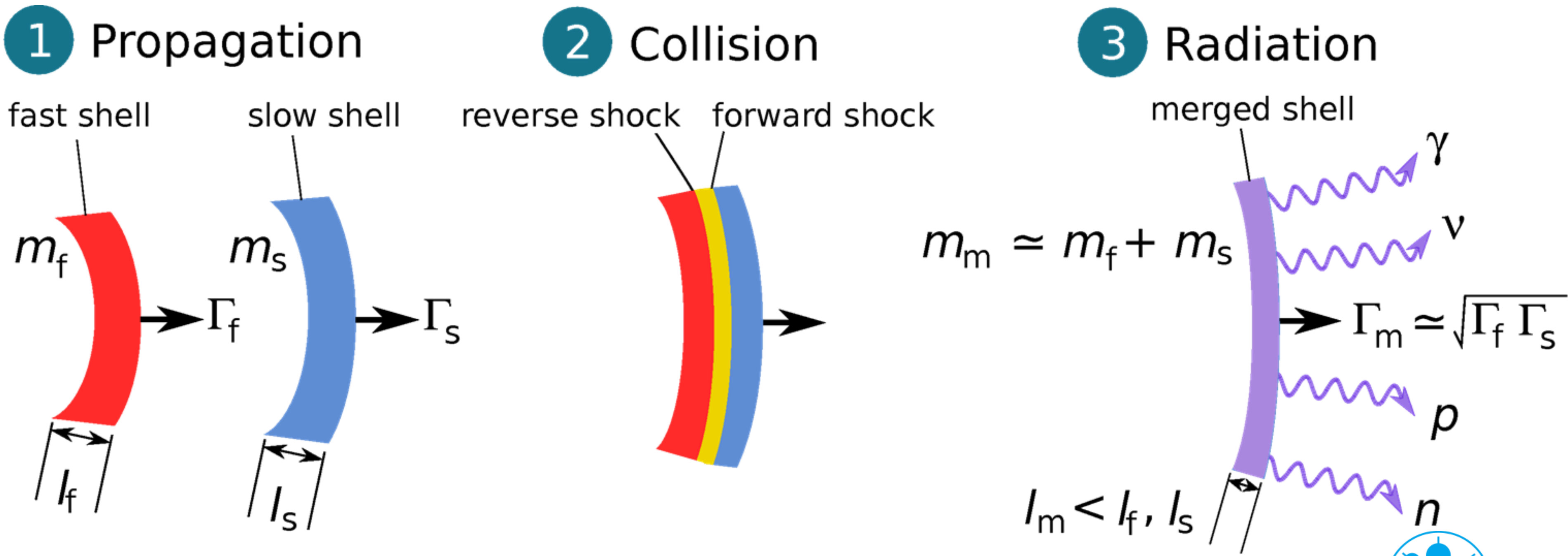
NEUCOS-Workshop

Jonas Heinze
DESY, Zeuthen
29.5.2017

Internal Shock Model - One Zone

- Average collision scaled to whole burst
  - Lorentz factor and variability → radius and width
  - Variability → number of collisions
- Does **not** predict lightcurves

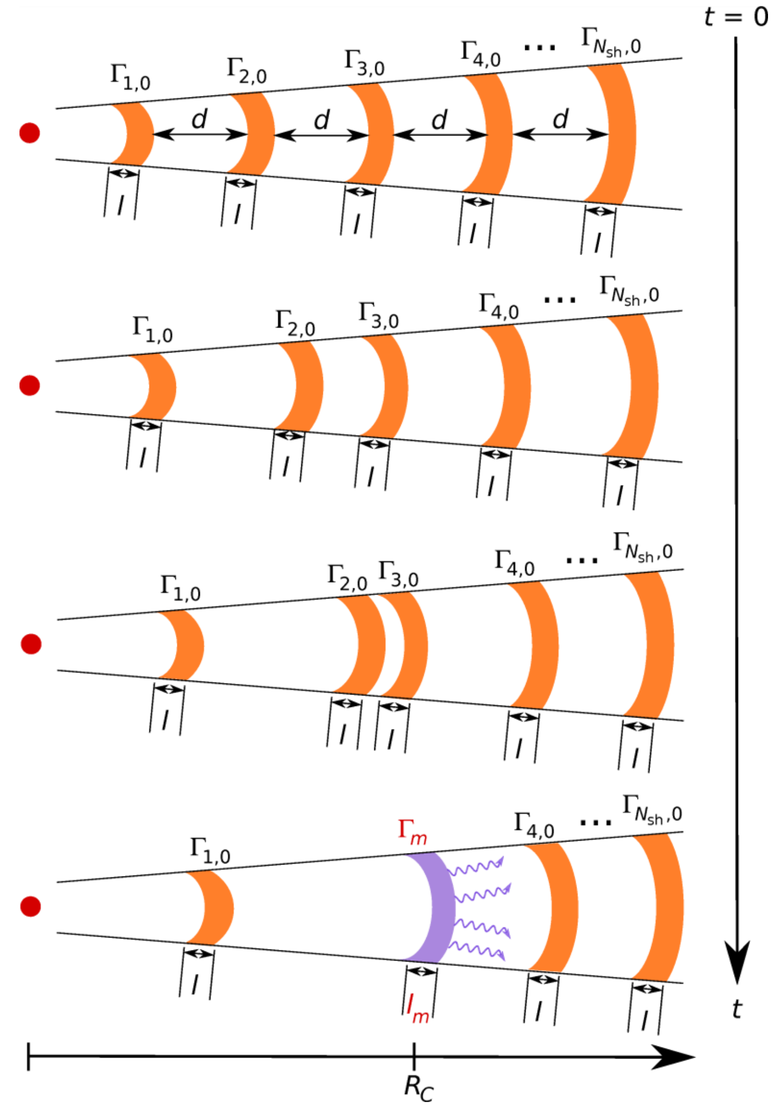
How representative is the average collision?



Internal Shock Model – Multi Collisions

- Evolving Fireball Model (1D)
  - Shells propagate and merge when colliding
  - Internal energy is radiated away
  - $E_{int} = \Gamma_s m_s + \Gamma_r m_r - \Gamma_m (m_s + m_r)$

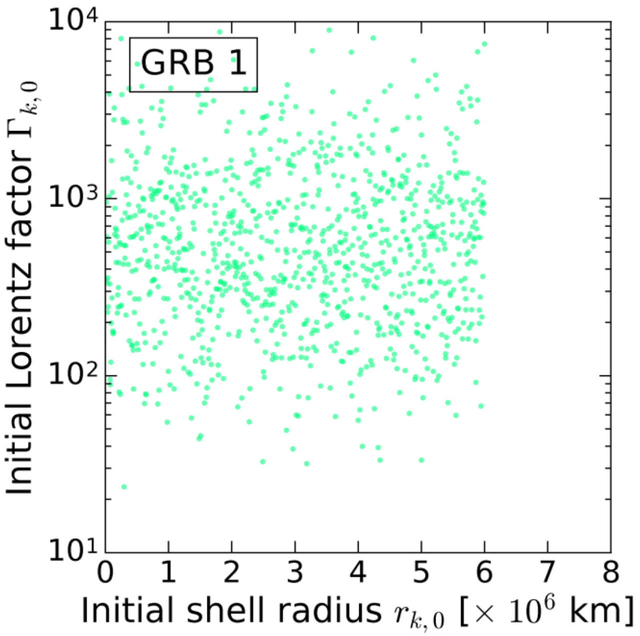
- Simple analytic assumptions for hydrodynamics of the the collisions
  [S. KOBAYASHI, T. PIRAN, R. SARI, ApJ 490, 92 (1997)]
  [F. DAIGNE, R. MOCHKOVITCH, MNRAS 296, 275 (1998)]
  - → Annikas talk for details



> Track all coll. through evolution
> → Python code
>
> Particle Production per collision
> → NeuCosmA (protons only)

Model Parameters

- Initial Shell setup
  - Lorentz factor distribution
  - Mass / energy / density per shell (equal ?)
  - Width and separation ($t_\nu \times c$)
  - Inner/outer radius of burst (10^3 km, 10^{12} km)
- Spectral properties per collisions
  - Energy partition $\epsilon_e, \epsilon_p, \epsilon_B$ (1, 10, 1)
  - Gamma-ray spectrum (power-law, spectral break at 1 keV)



- Total gamma-ray output normalized to observations:

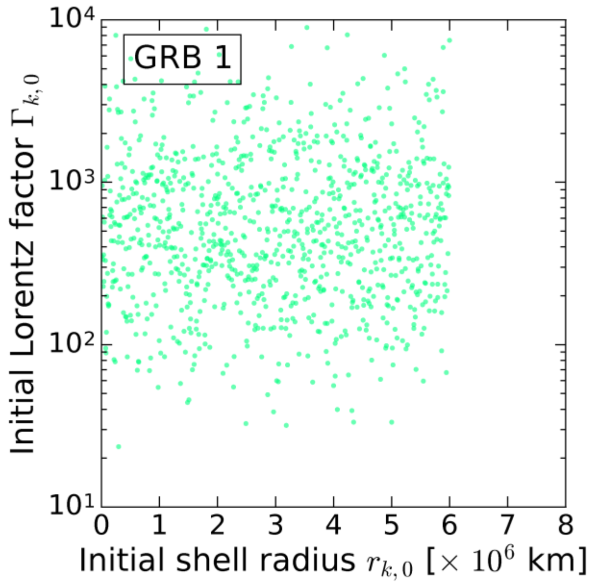
$$E_\gamma = \sum_i^{N_{\mathrm{coll}}} E_{\gamma,i} \approx 10^{53}\mathrm{erg}$$

(subphotospheric excluded, no afterglow model)

Reference Case

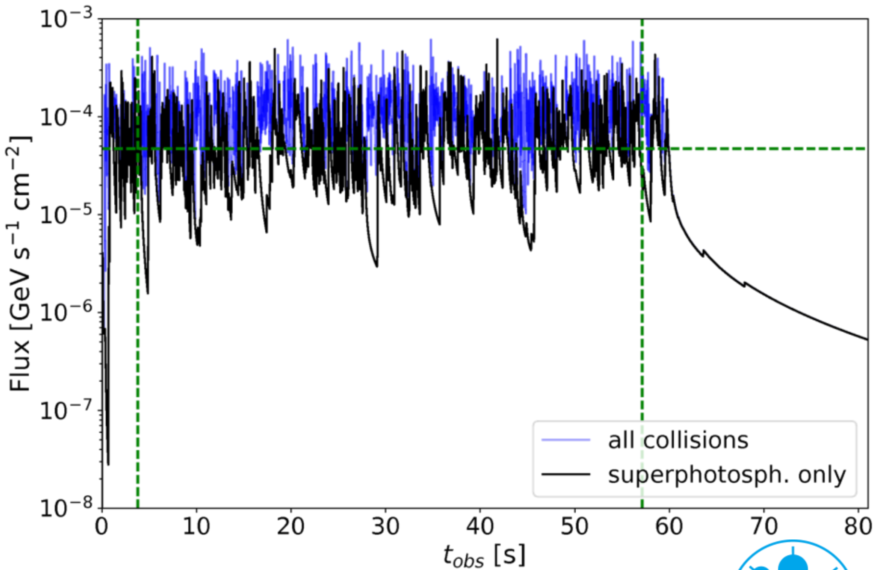
BUSTAMANTE, BAERWALD, MURASE, WINTER
Nature Commun. 2015

- 1000 Shells, equal energy
- Lorentz factor: logarithmic gauß-distr.



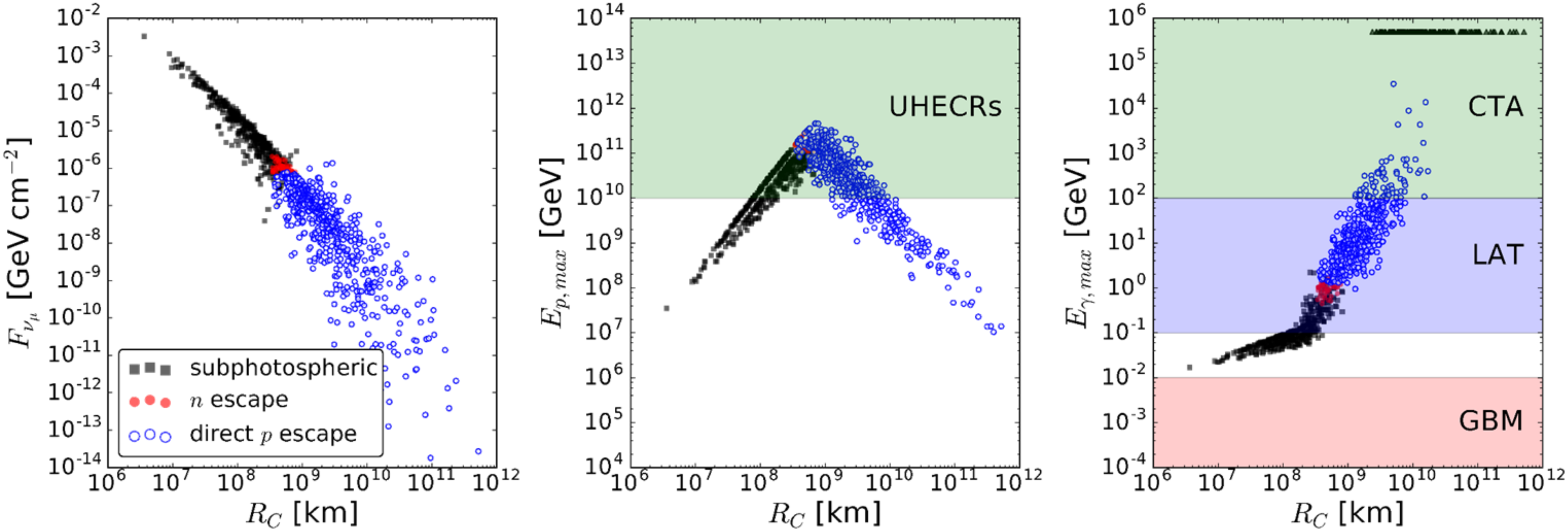
- Collisions time/radius dependend on $\Delta\Gamma$ between neighboring shells

- Synthetic lightcurves
  - A fast-rise-exponential-decay (FRED) gamma-ray pulse for each collision
  - Subphotospheric coll. ignored

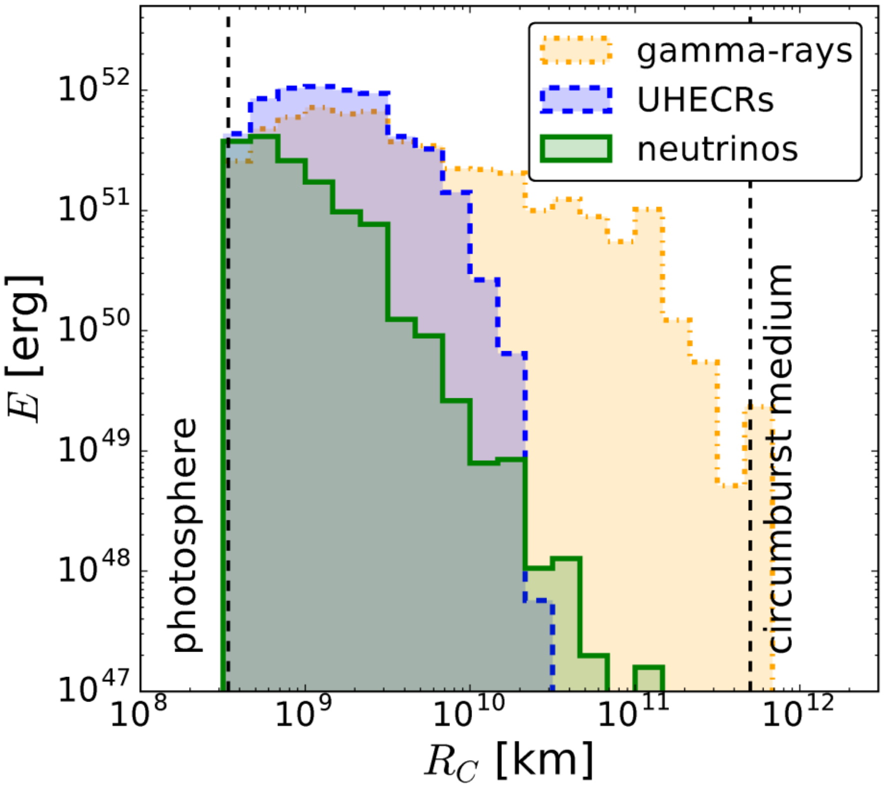


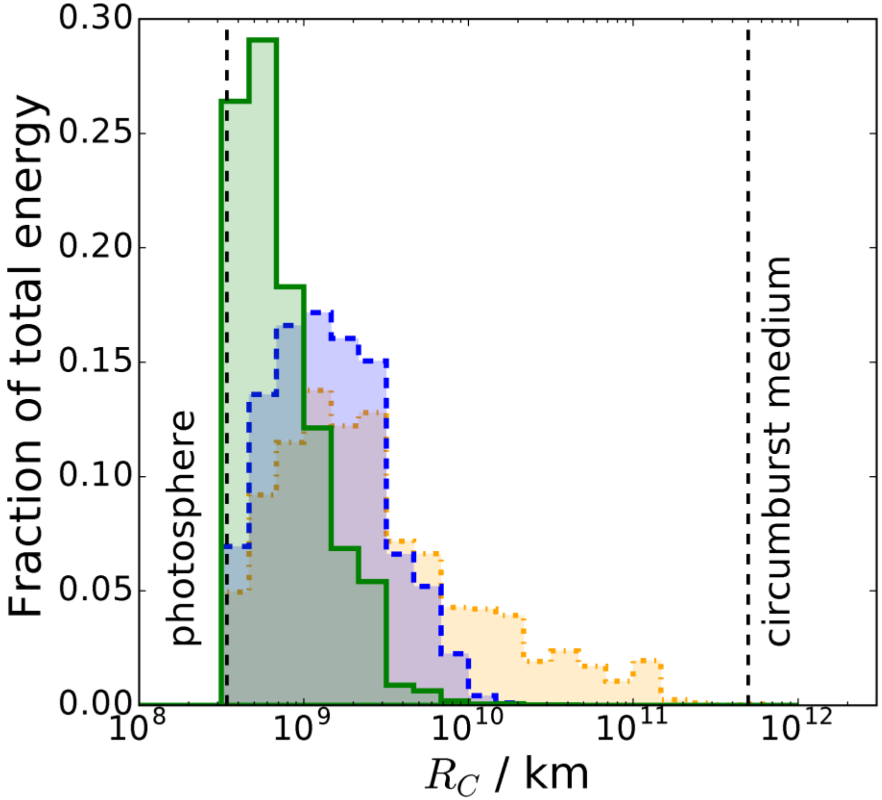
Radiation per collision

- Radiation depends strongly on radius (density $\propto R_c^{-2}$)
  - Gamma ray energy limited by pair production und matter density
  - Cosmic Ray max energy limited by shell size and magn. fields
- Neutrino production dependend on p and γ densities $\rightarrow \propto R_c^{-4}$



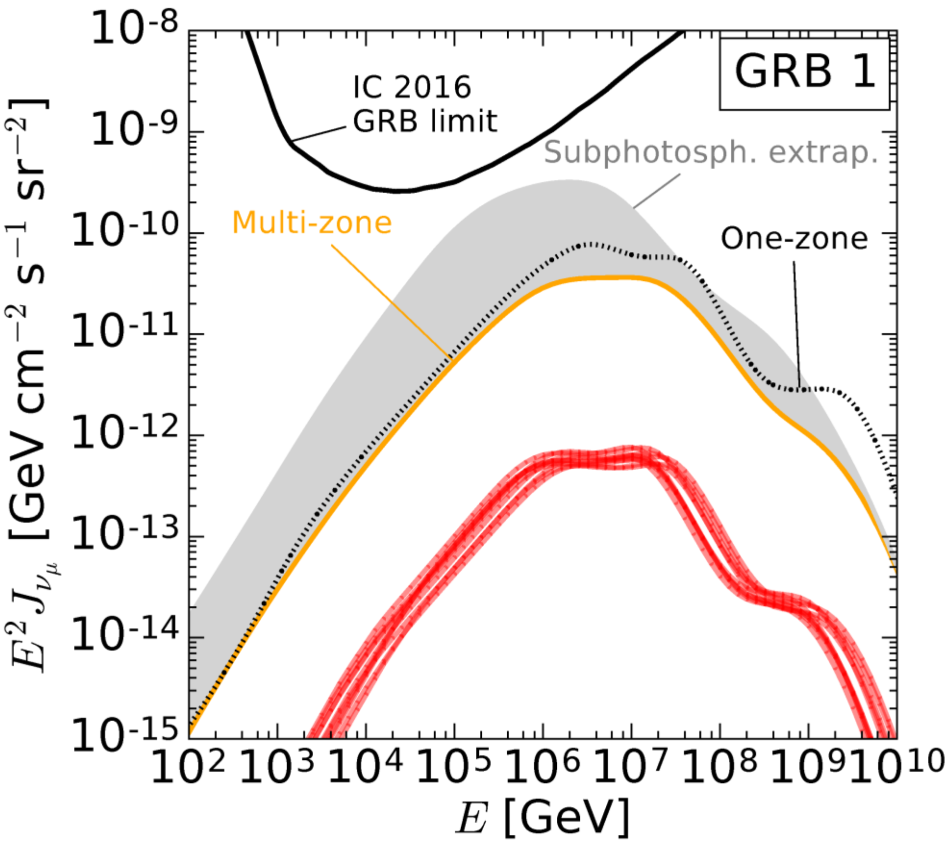
The particles come from different regions!





Neutrino Flux

- Scaled to 667 identical GRBs per year

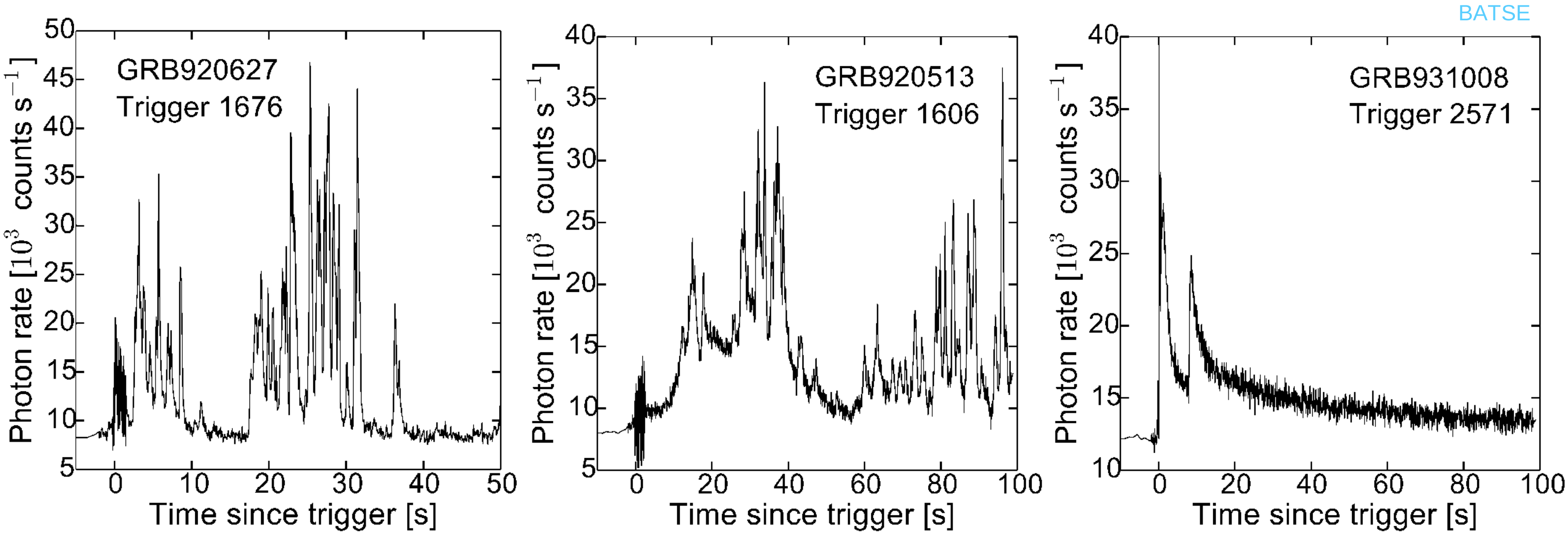


- Slightly lower than One-Zone estimates for avg. parameters
- Subphotospheric extrapolation highly uncertain

GRB - lightcurves

- Some GRBs show more complicated features in their lightcurves

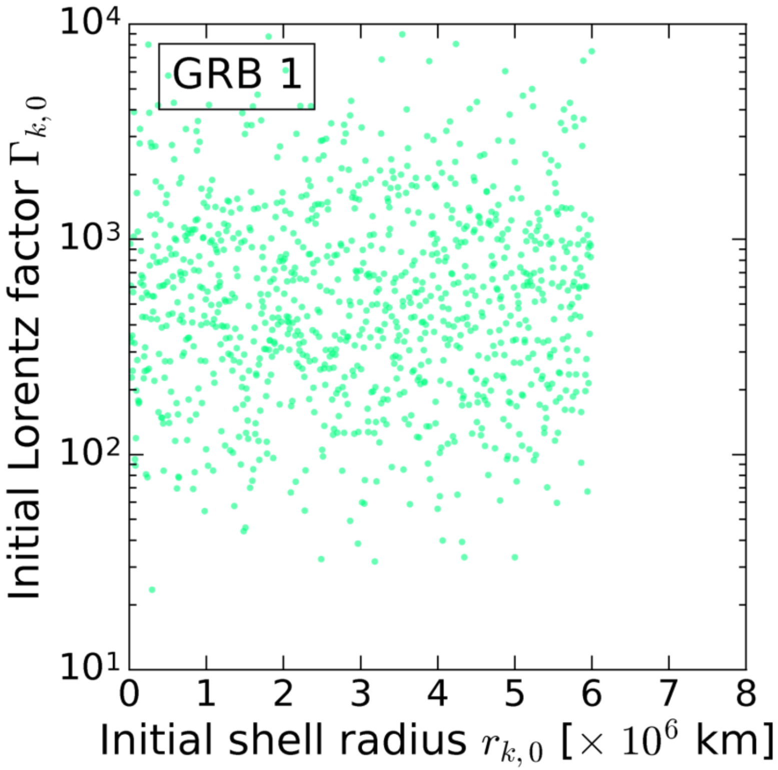
- What information is in the lightcurves?
- How is the particle radiation affected?



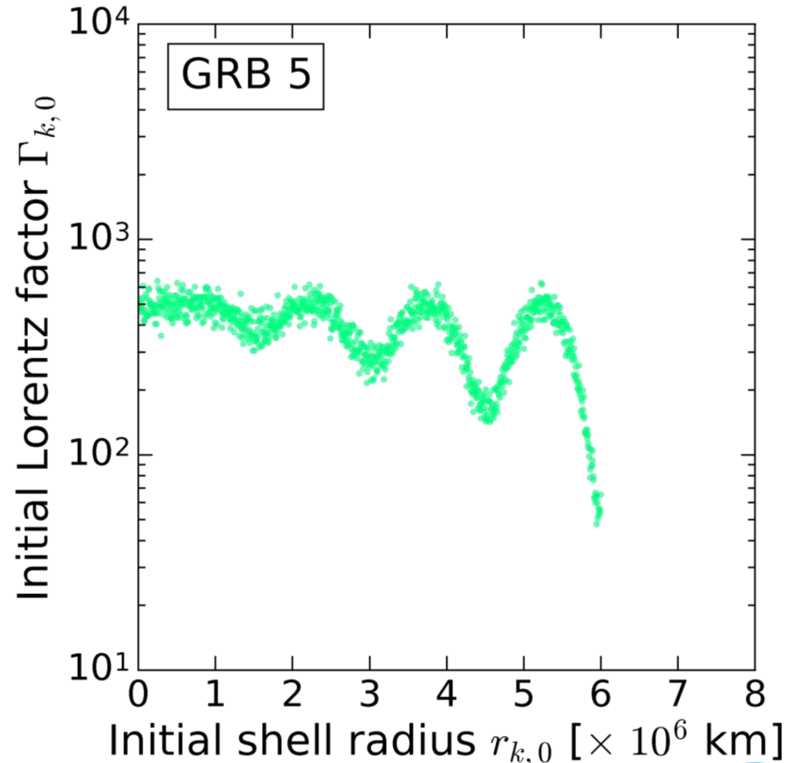
Two cases

> Undisciplined GRB engine
- Broad Gamma distribution
- E.g. reference case,
  log normal distribution

> Disciplined GRB engine
- Narrow Gamma distribution
- Larger structure in outflow



BUSTAMANTE, JH, MURASE, WINTER, ApJ 2017



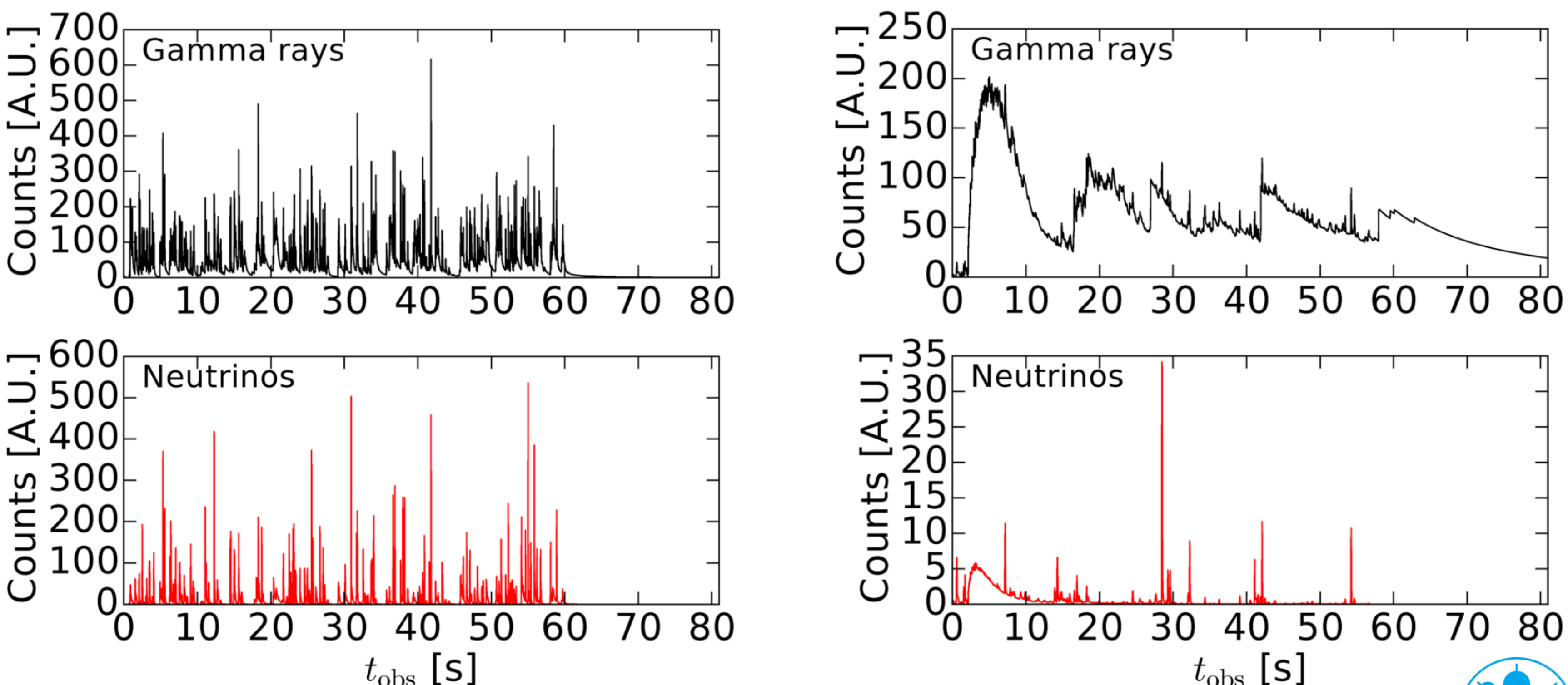
Two cases

> Undisciplined GRB engine

- Dominated by fast variability
- No broad pulses

> Disciplined GRB engine

- Broad pulse structure
- Fast variability on top

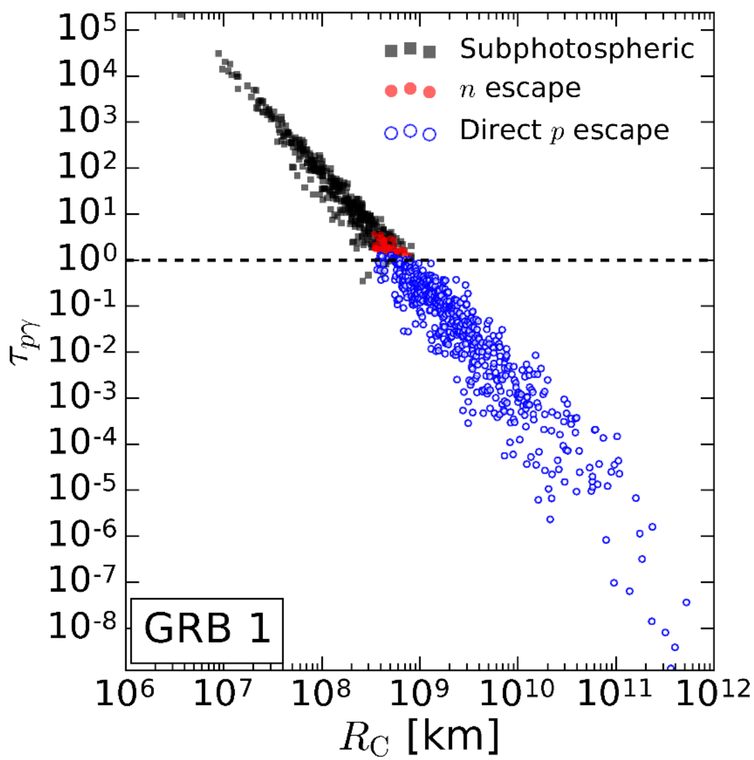


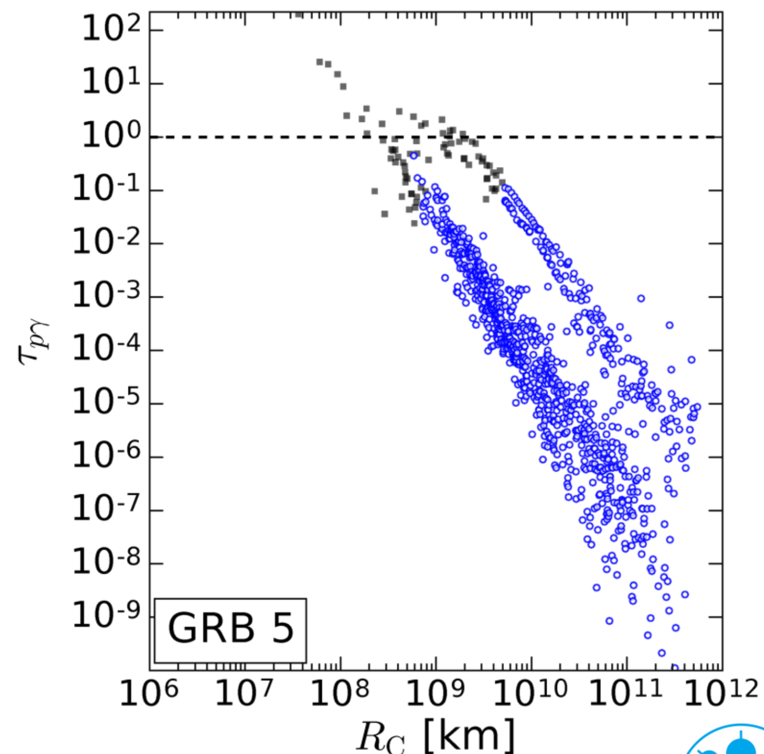
BUSTAMANTE, JH, MURASE, WINTER, ApJ 2017

Two cases

> **Undisciplined GRB engine**
> - Shells collide early, at lower radii
> - Higher p and γ densities
> - Optically thick collisions

> **Disciplined GRB engine**
> - Shells collide later, at larger radii
> - Lower p and γ densities
> - No optically thick collisions



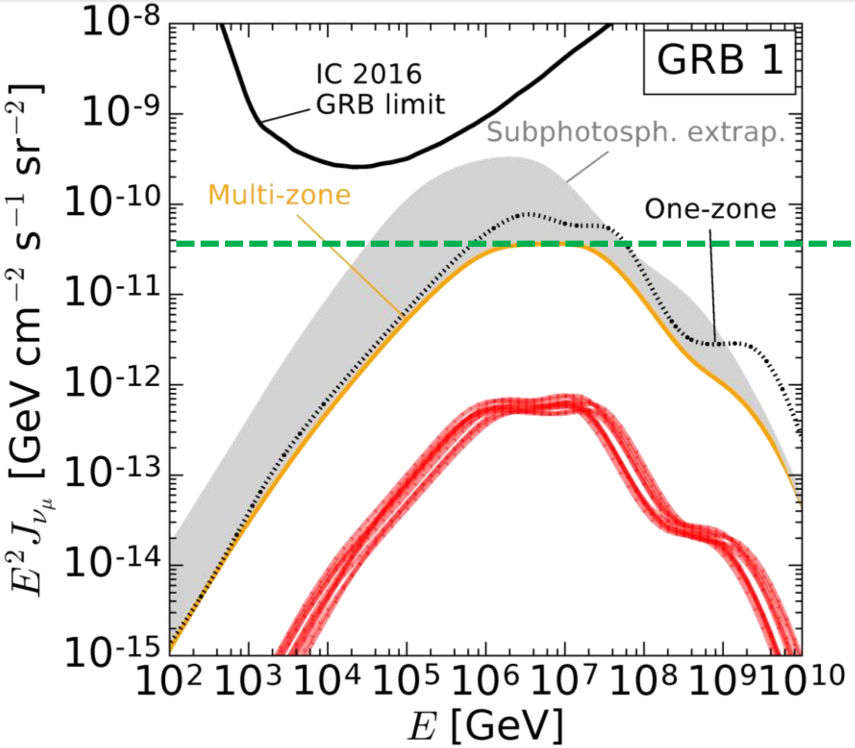


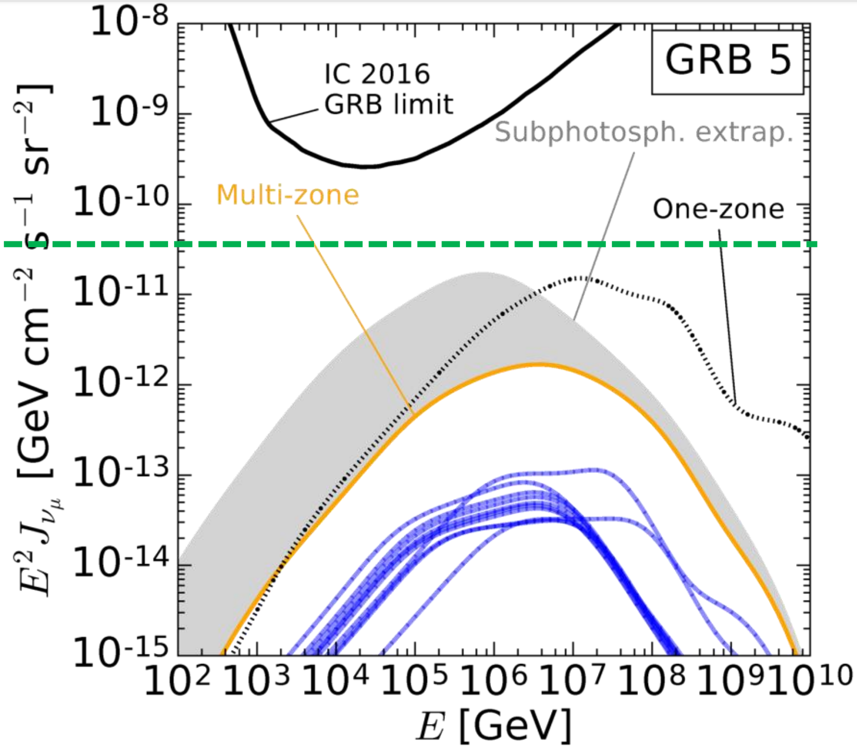
BUSTAMANTE, JH, MURASE, WINTER, ApJ 2017

Two cases

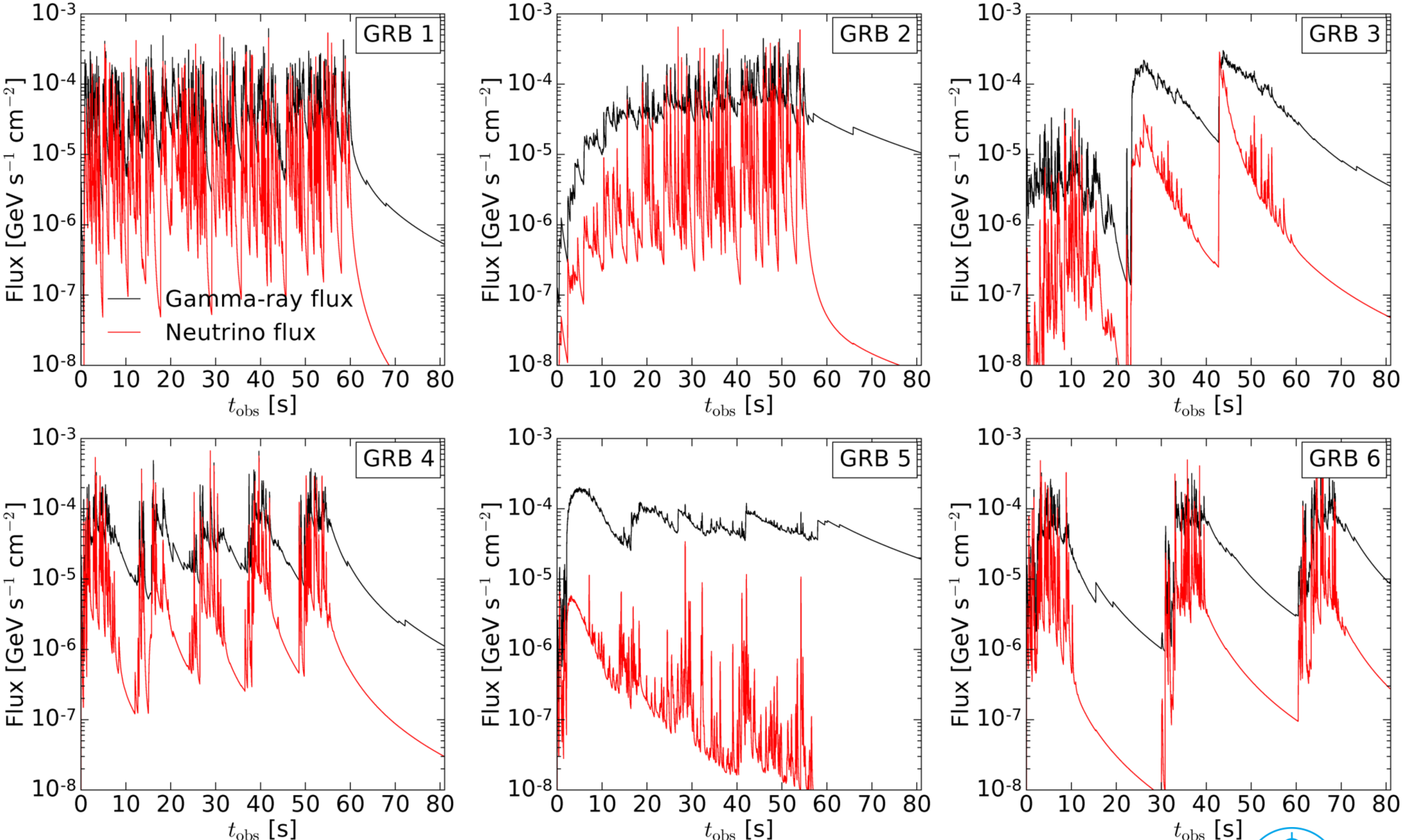
> Undisciplined GRB engine
- Optically thick collisons dominating
- $\sim 10^{-11}\,\mathrm{GeV\,cm^{-1}\,s^{-1}sr^{-1}}$

> Disciplined GRB engine
- Only optically thin collisions
- $\sim 10^{-12}\,\mathrm{GeV\,cm^{-1}\,s^{-1}sr^{-1}}$

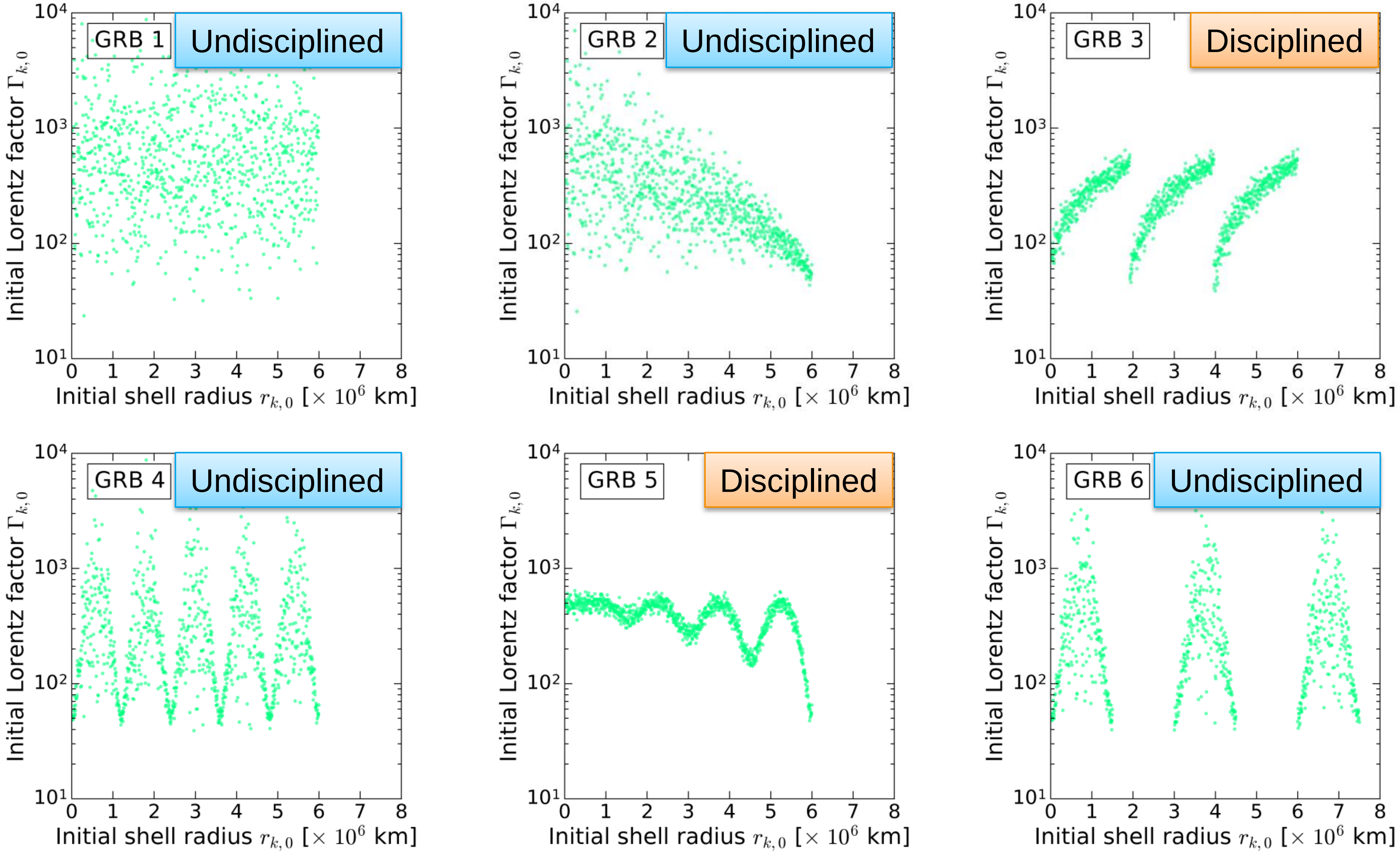




More test cases - lightcurves

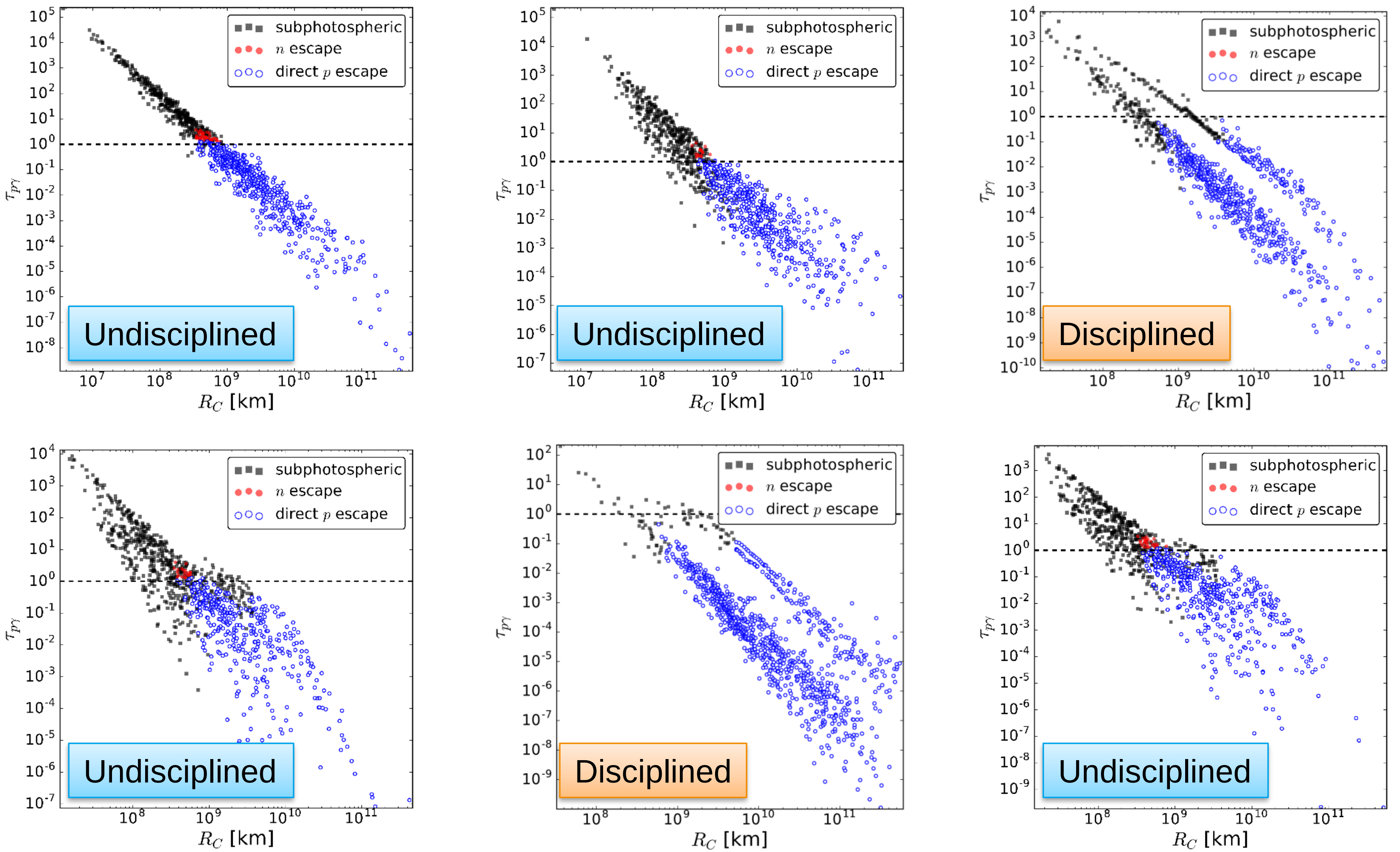


More test cases – shell distribution

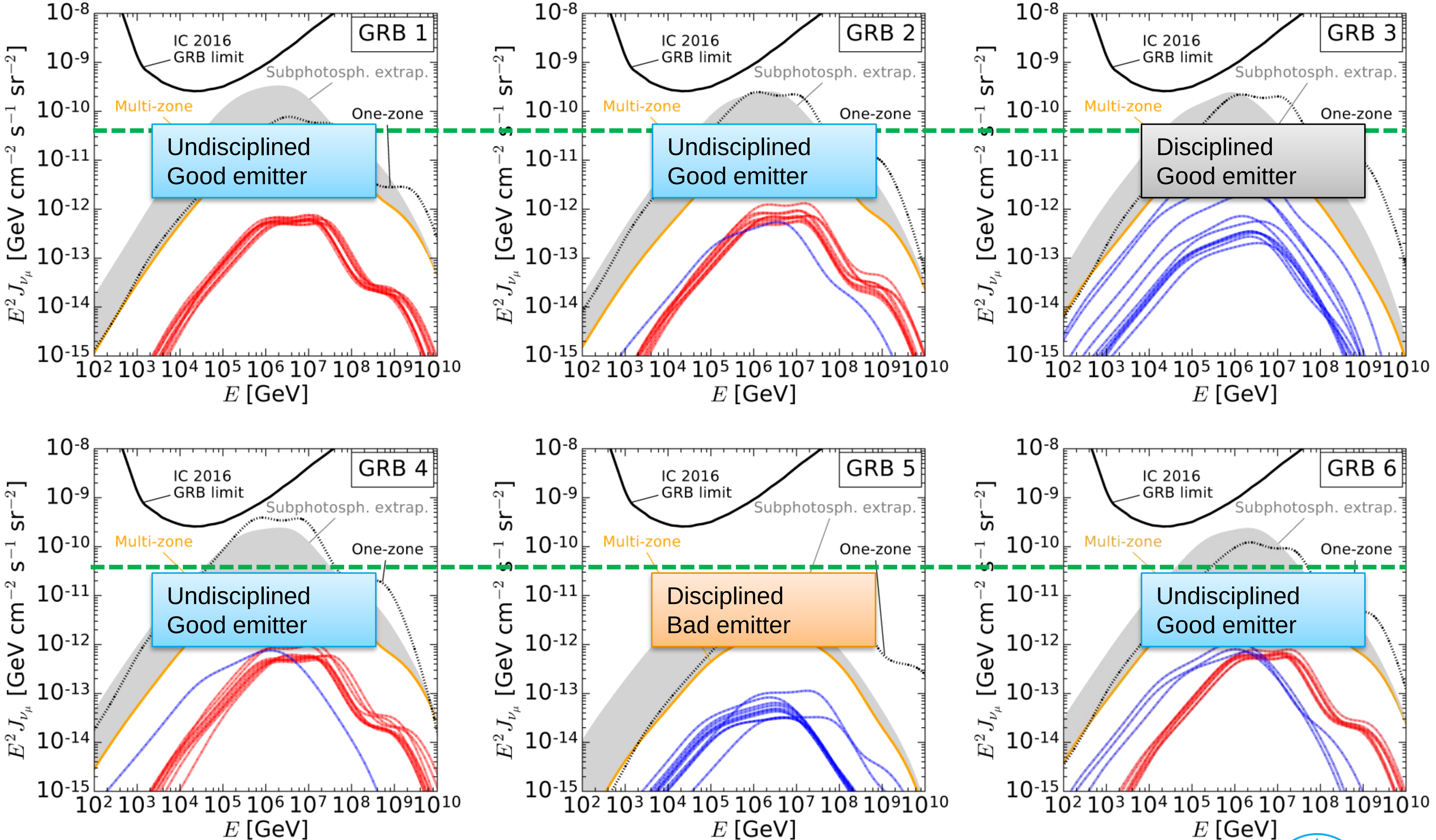


DESY

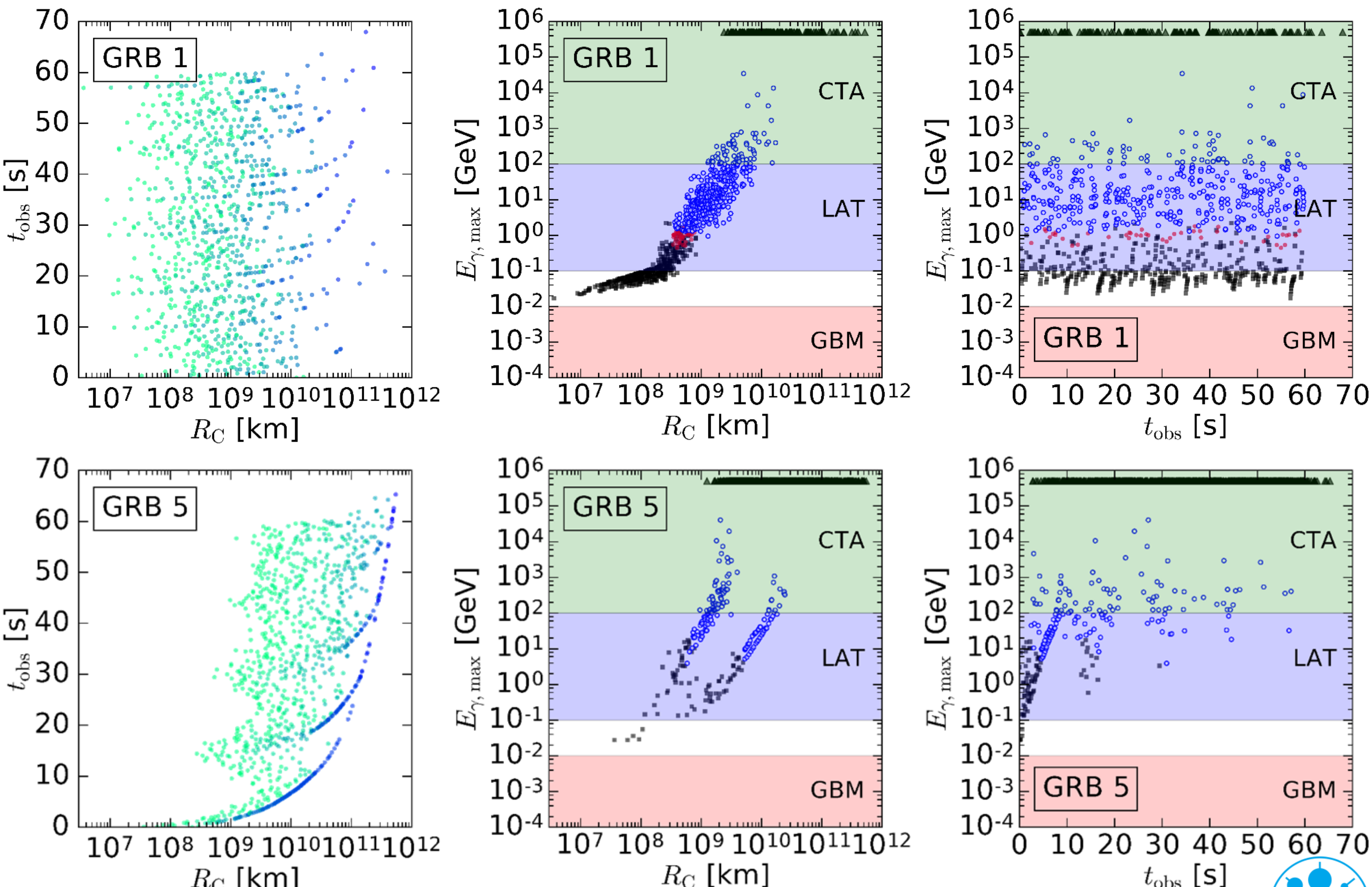
More test cases – collisions



More test cases – neutrino fluxes

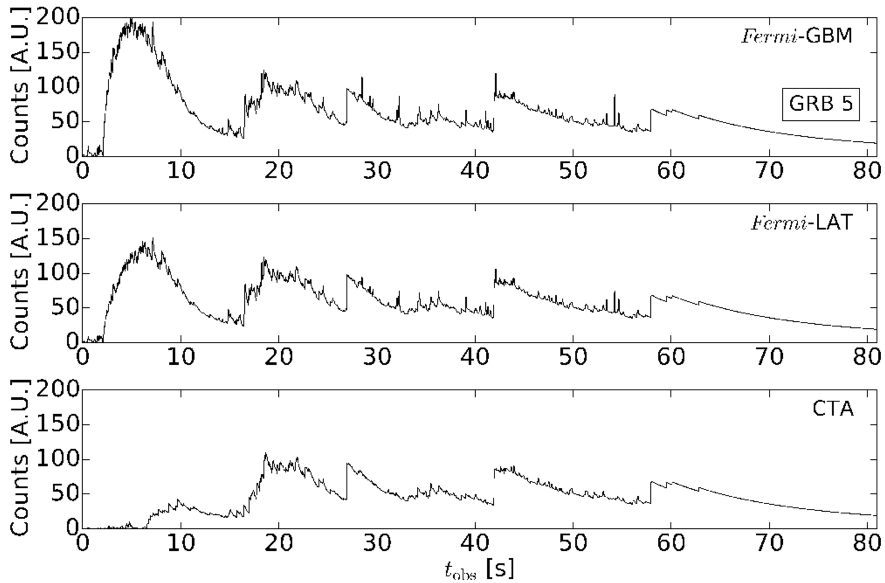


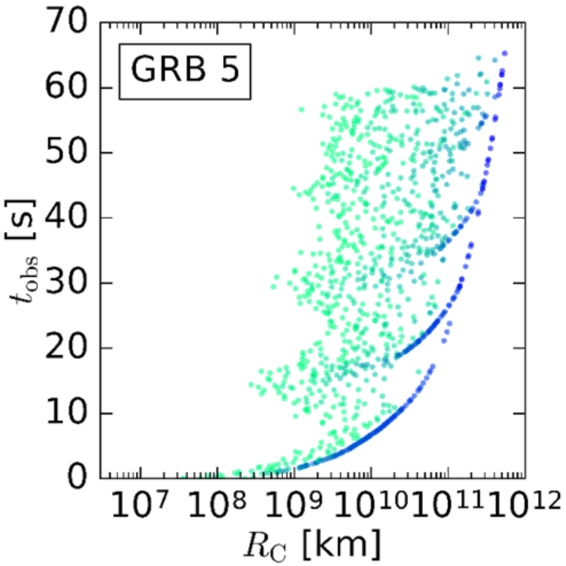
Time delays in energy bands

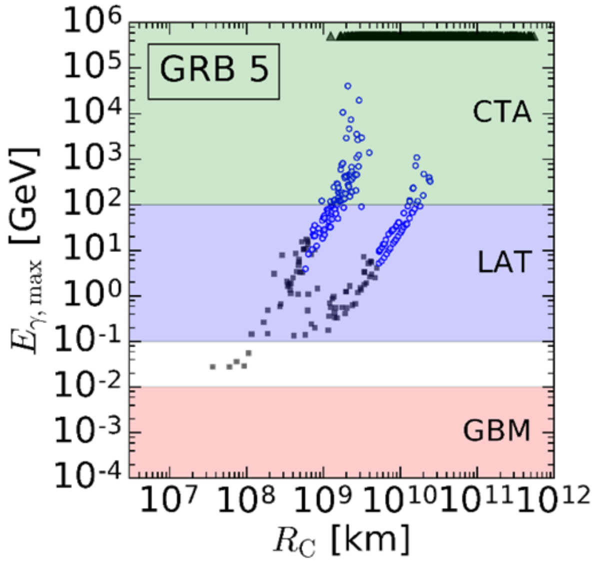


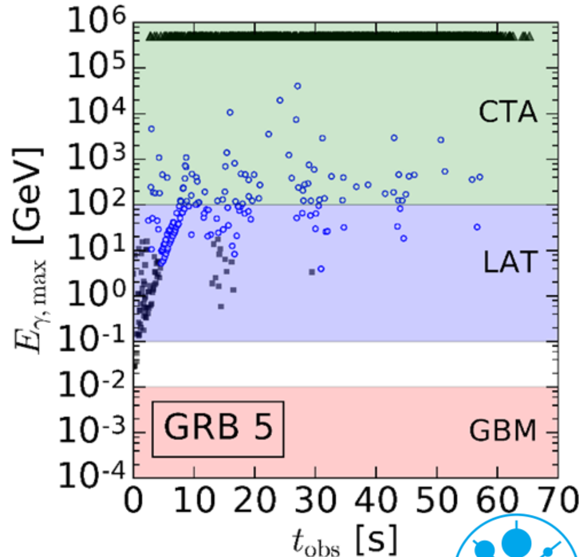
Time delays in energy bands

- High density / low radii limit max. gamma energy
- Radius – observed time correl. → delay in energy bands









DESY

Future Propects

> Improved hydrodynamic assumptions (Annikas talk)

- Coupling to hydrodynamic code?

> Nuclei in multi collision model (WIP with Daniel)

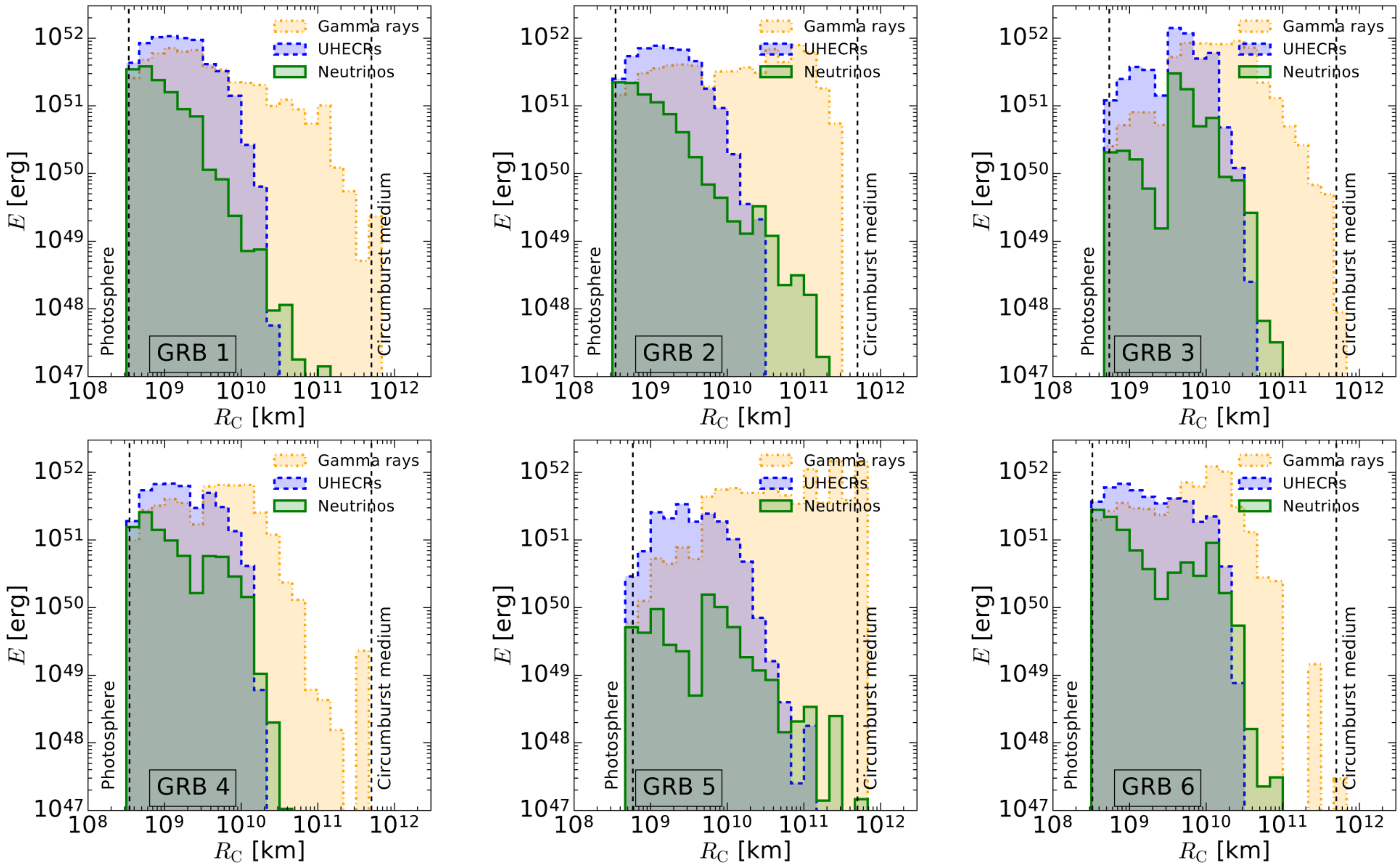
> More realistic γ - ray spectra

- Evolution with radius
- (Eventually) feedback from disintegration / photopion

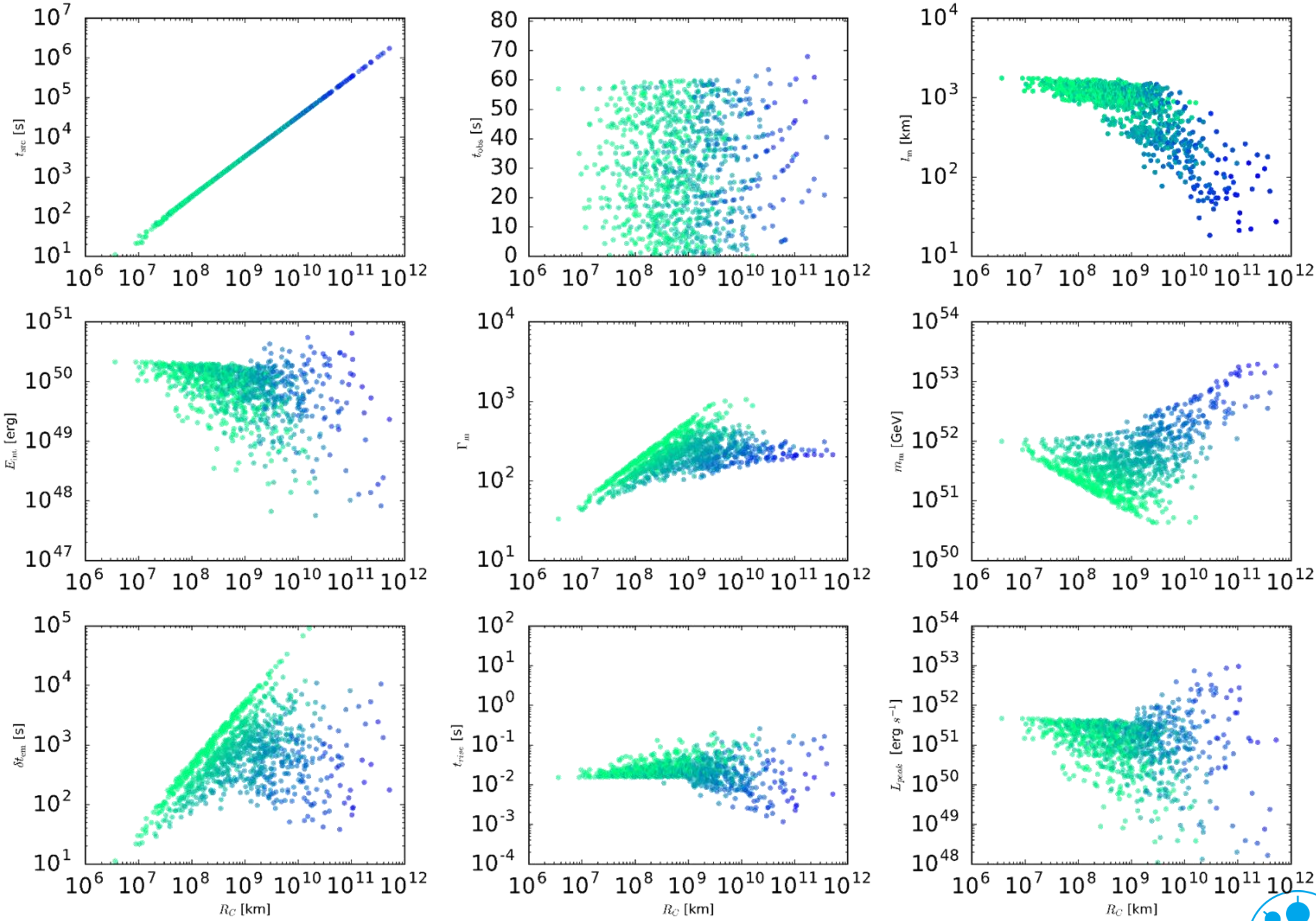
> Extending the model

- Subphotospheric model
- Afterglow model

More test cases - histograms



Collision Parameters GRB1



Collision Parameters GRB1