MODELLING OF GRB 221009A THROUGH AN ANALYTICAL DESCRIPTION OF VHE AFTERGLOW LIGHT CURVES

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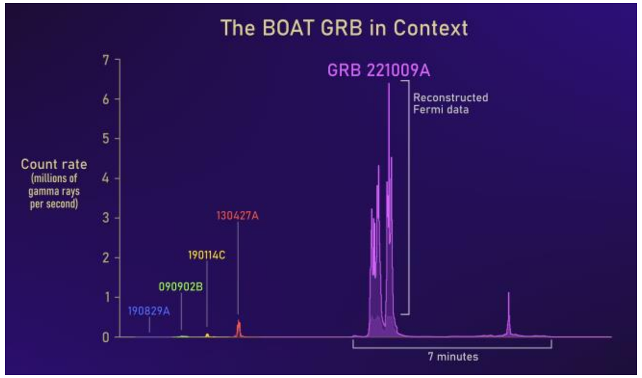
Image by: Anna Fortunati

GRB 221009A: LHAASO OBSERVATIONS OF THE B.O.A.T.



Credit: NASA's Goddard Space Flight Center and Adam Goldstein (USRA)

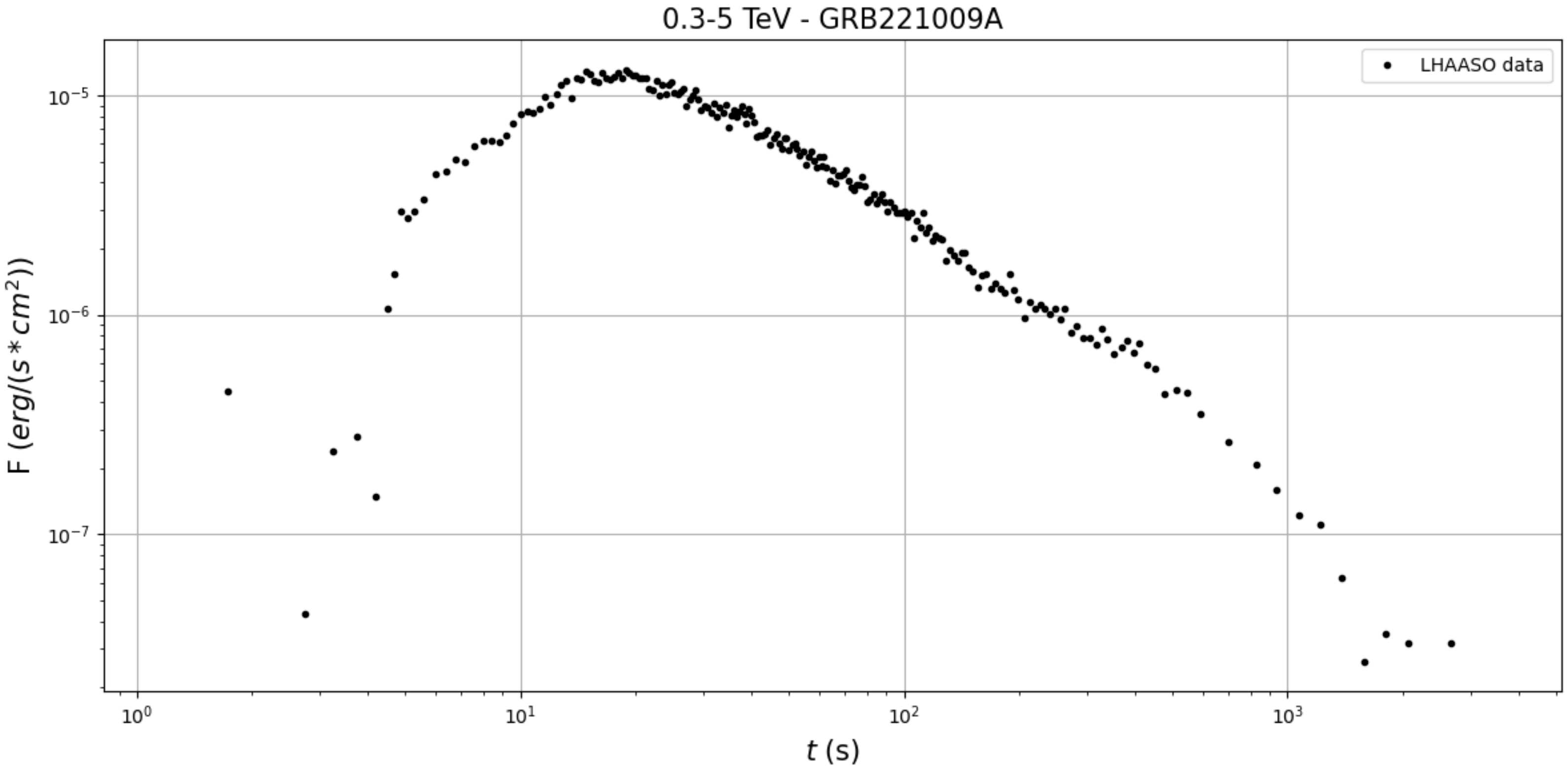
- Redshift: $z = 0.151 \quad (724\ Mpc)$

  $E_{k,iso} \approx 10^{55} erg$
- Available dataset - LHAASO-WCDA

  $[T_0\,, T_0 + 3000\ s]$

  0.3 – 5 TeV

  $\sigma > 250$



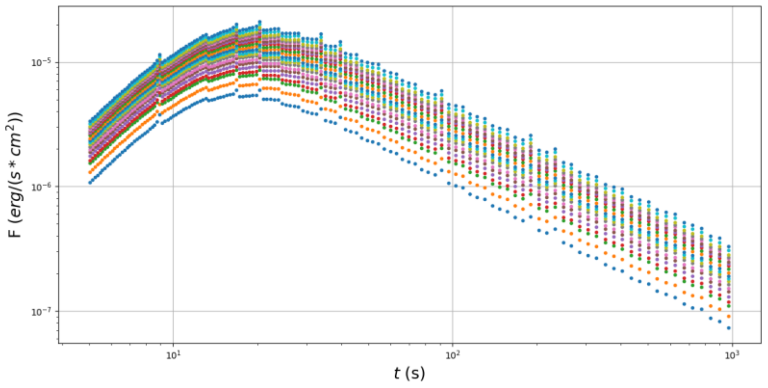
Data from: https://www.nhepsdc.cn/files/20230518/Figure3A_4.txt

LHAASO Collab. (Science 2023)

NUMERICAL MODEL AND ANALYTICAL DESCRIPTION

- Numerical model: *Miceli, Nava – Galaxies 2022, 10, 66*
- LCs produced varying a set of *physical* parameters:

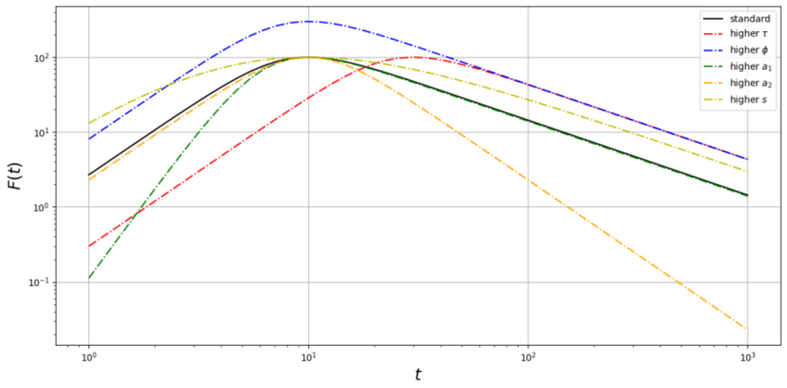
εe = electron energy fraction
εb = magnetic energy fraction
Γ0 = bulk Lorentz factor
n0 = ISM density [cm^{-3}]
p = injected electrons index



- Analytical description: we can define a smooth BPL:

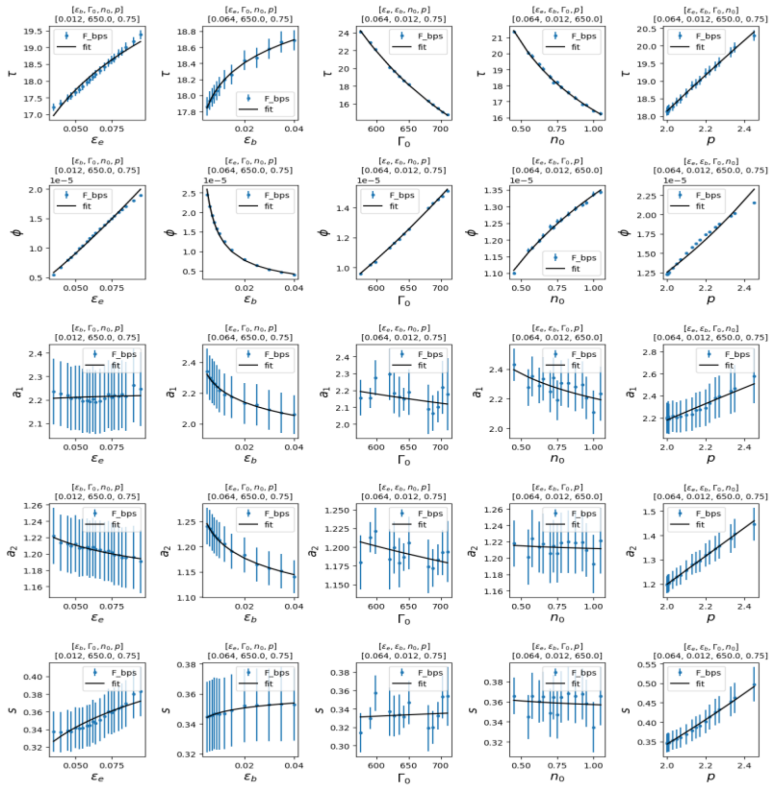
$$F(t) = \Phi \left(\frac{t}{\tau}\right)^{a_1} \left[\frac{a_1\left(\frac{t}{\tau}\right)^{1/s} + a_2}{a_1 + a_2}\right]^{-(a_1+a_2)s}$$

Depending on some *fit* parameters:
τ = peak time
Φ = peak flux
a_1 = low time PL index
a_2 = high time PL index
s = smoothing parameter



- Link each fit par to each phys par through:

$$y = A \ x^b$$



- To have, ultimately:

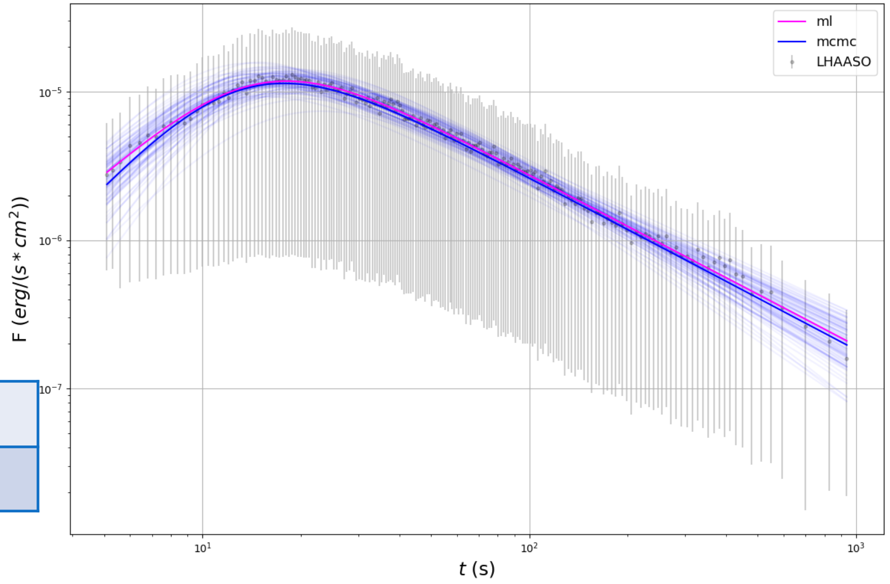
$$(fit\ par) = A \left(\frac{\epsilon_e}{\bar{\epsilon}_e}\right)^{b_e} \left(\frac{\epsilon_b}{\bar{\epsilon}_b}\right)^{b_b} \left(\frac{\Gamma_0}{\bar{\Gamma}_0}\right)^{b_\Gamma} \left(\frac{n_0}{\bar{n}_0}\right)^{b_n} \left(\frac{p}{\bar{p}}\right)^{b_p}$$

GRB 221009A: MODELLING

- Flux now expressed as function of the *physical* parameters!
- Log-likelihood:

$$\ln P\left(y \mid t, \sigma, \epsilon_e, \epsilon_b, \Gamma_0, n_0, p\right) = -\frac{1}{2}\sum_n \left[\frac{(y_n - F(phys))^2}{\sigma^2} + \ln(\sigma^2)\right]$$

- Through a Maximum Likelihood Estimation, we get a first approx for the parameters



$\overline{\epsilon_e} = 6.5 \times 10^{-2}$	$\overline{\epsilon_b} = 1.0 \times 10^{-2}$	$\overline{\Gamma_o} = 650$	$\overline{n_o} = 0.75\ (cm^{-3})$	$\overline{p} = 2.01$
$\boldsymbol{\epsilon_e^{ML} = 1.0 \times 10^{-1}}$	$\boldsymbol{\epsilon_b^{ML} = 2.5 \times 10^{-2}}$	$\boldsymbol{\Gamma_0^{ML} = 580}$	$\boldsymbol{n_0^{ML} = 2.1\ (cm^{-3})}$	$\boldsymbol{p^{ML} = 2.0}$

- Markov-Chain Monte Carlo:

  "ML" as initial values

  Walkers: 32 × # par (5 phys pars)

  2 × 10^4 steps

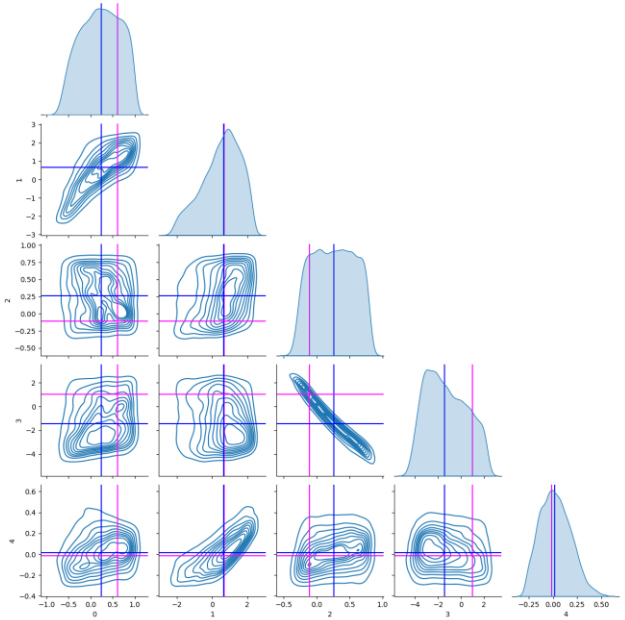
$$\theta_{\epsilon_e} = \frac{\epsilon_e}{\overline{\epsilon_e}} - 1$$

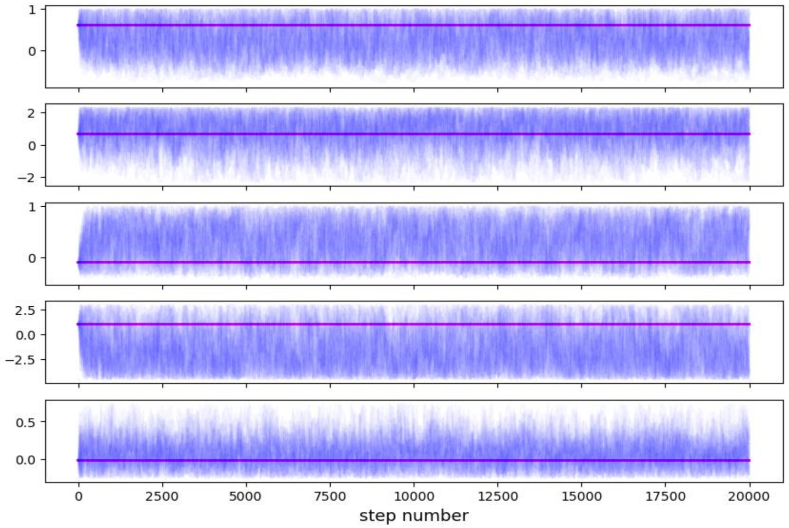
$$\theta_{\epsilon_b} = \ln\left(\frac{\epsilon_b}{\overline{\epsilon_b}}\right)$$

$$\theta_{\Gamma_0} = \frac{G_0}{\overline{G_0}} - 1$$

$$\theta_{n_0} = \ln\left(\frac{n_0}{\overline{n_0}}\right)$$

$$\theta_p = \ln\left(\frac{p}{\overline{p}}\right)$$





MCMC results:

$\epsilon_e = 0.079^{+0.03}_{-0.03}$, $\epsilon_b = 0.023^{+0.038}_{-0.017}$,

$\Gamma_0 = 820^{+240}_{-240}$, $n_0 = 0.18^{+1.55}_{-0.15}$,

$p = 2.04^{+0.39}_{-0.29}$

CONCLUSIONS AND PERSPECTIVE

- In this work, we got two main results:
  - we showed the developed analytical method to describe generic broken power law LCs, explaining the workflow for the modelisation of a GRB, with precise estimates of the parameters driving the emission,
  - performed a preliminar study of GRB 221009A - quite good agreement
- To do:
  - production of new data for other sets of parameters
  - try a different function for the *fit – physical parameters* relation
- Better results soon to come!

Thanks for your attention!