Photospheres in gamma-ray bursts: the Fermi view

1. Photosphere is not Planck but broader: Instrument dependence
2. Significant fraction (1/4) consistent non-dissipative photosphere

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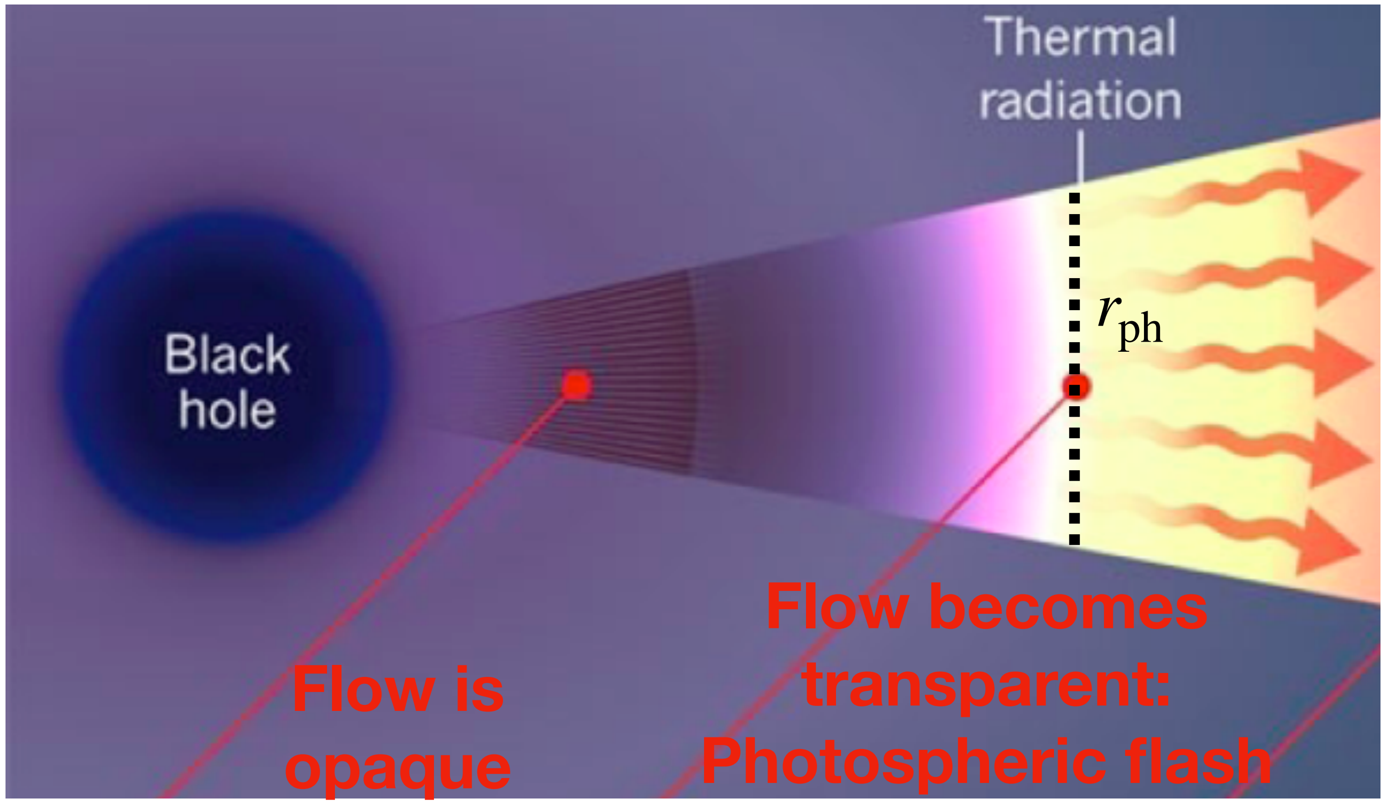
Photospheric emission in GRBs

Natural ingredient in the fireball model



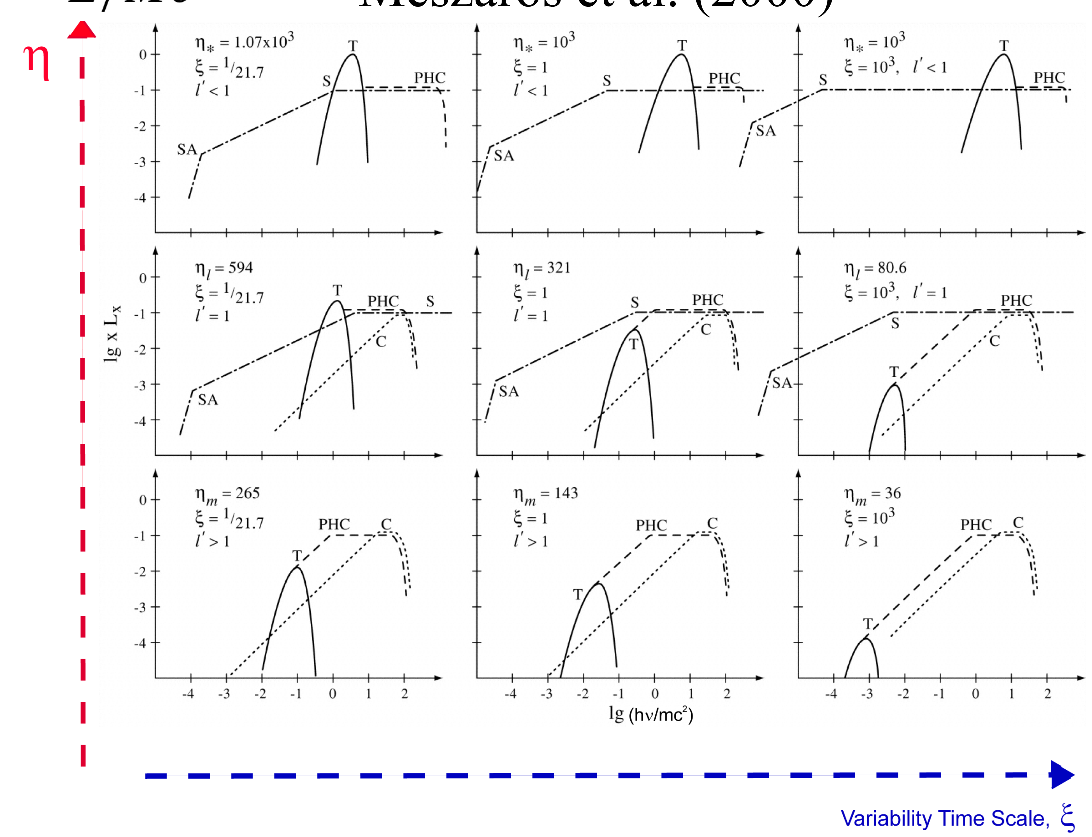
Non-thermal emission

Synchrotron

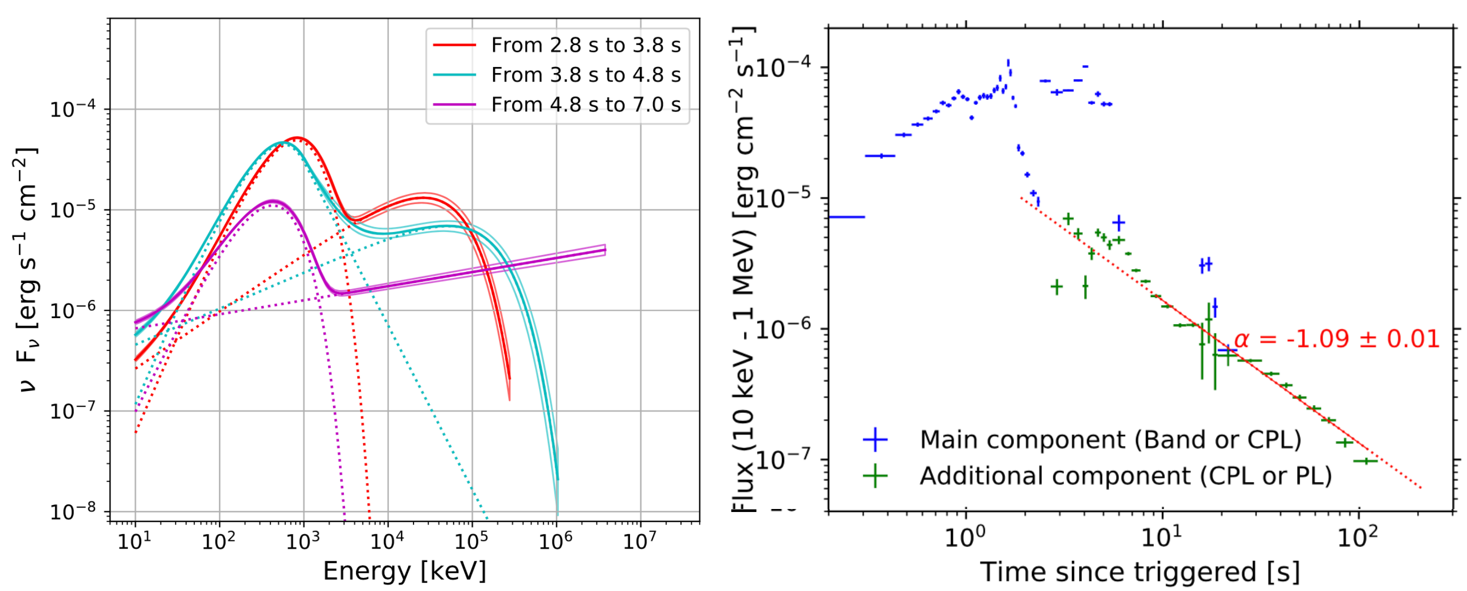
Internal/external shocks

$\eta = L/\dot{M}c^2$

Mészáros et al. (2000)



GRB190114C (Ajello et al. 2020)



Photospheric emission in GRBs

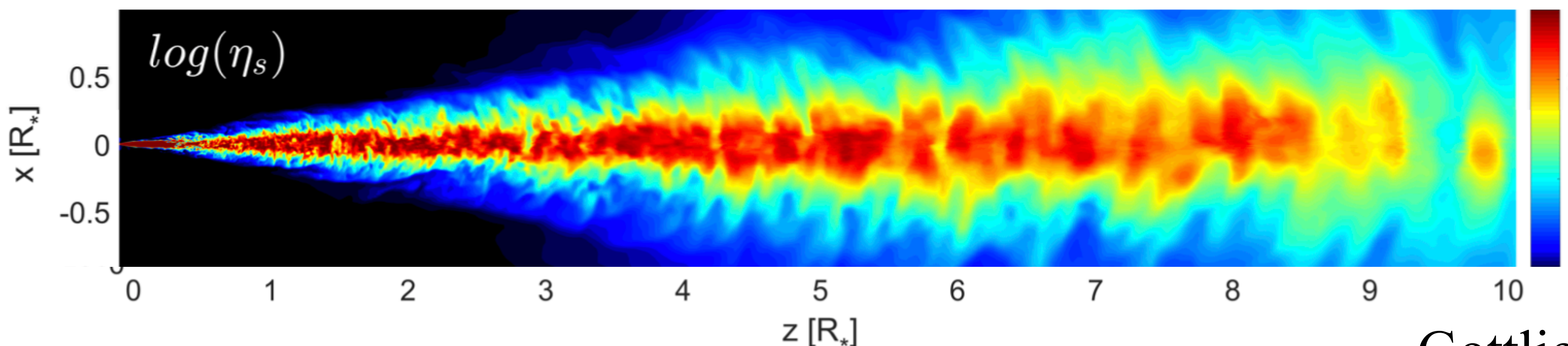
Natural ingredient in the fireball model

Key parameters:

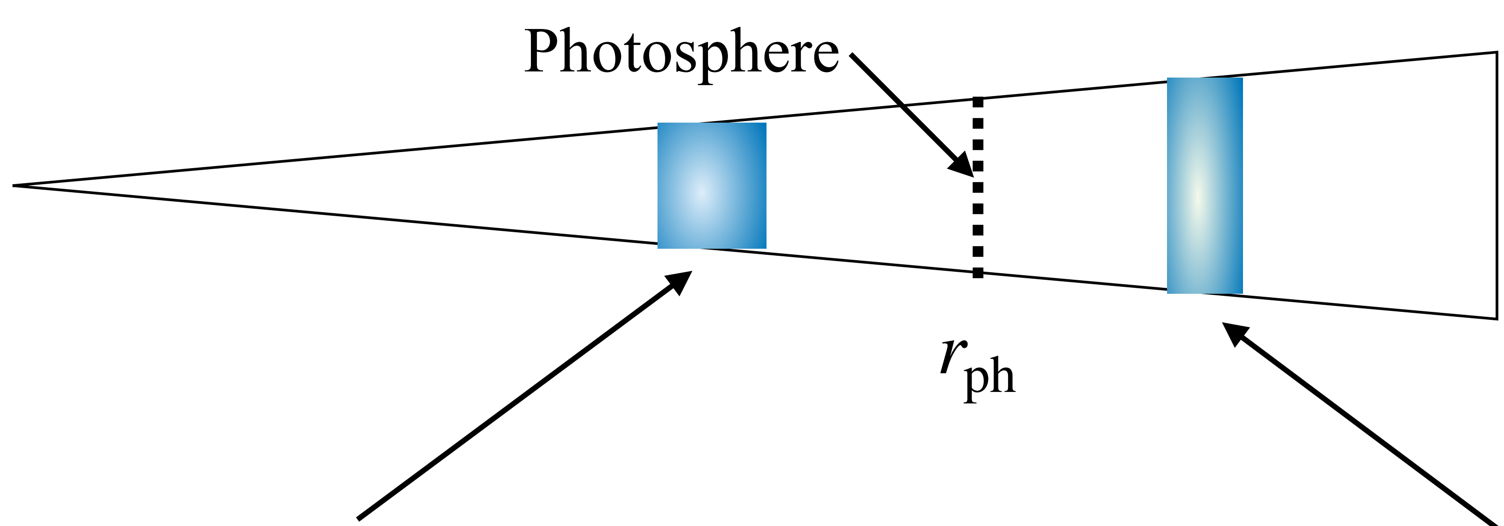
Bulk Lorentz factor Γ

$$r_{\mathrm{ph}} \sim \frac{L\sigma_{\mathrm{T}}}{4\pi m_{\mathrm{p}} c^3 \Gamma^3}$$

Dissipation $\epsilon_{\mathrm{d}}(r)$



Gottlieb+19

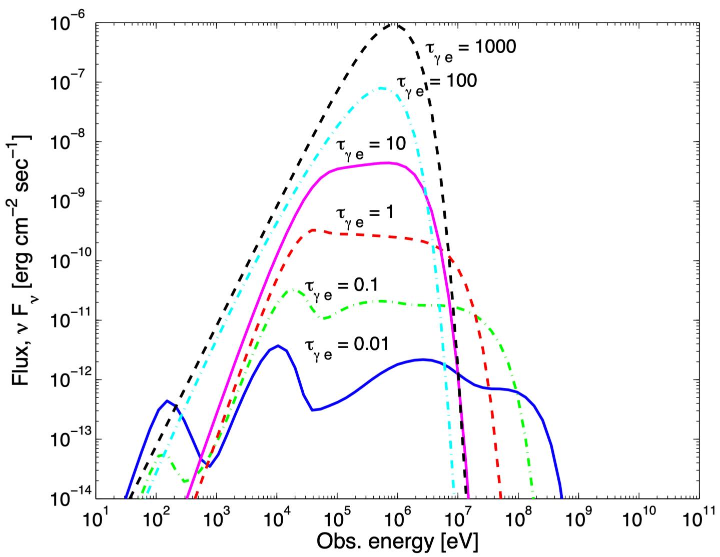


Subphotospheric dissipation
Radiation mediated shocks

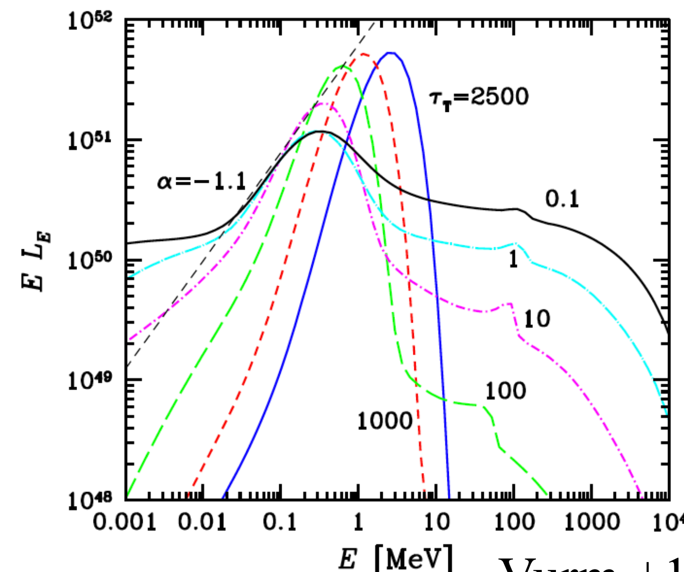
Optically thin dissipation
Collisionless shocks

Dissipative photospheres

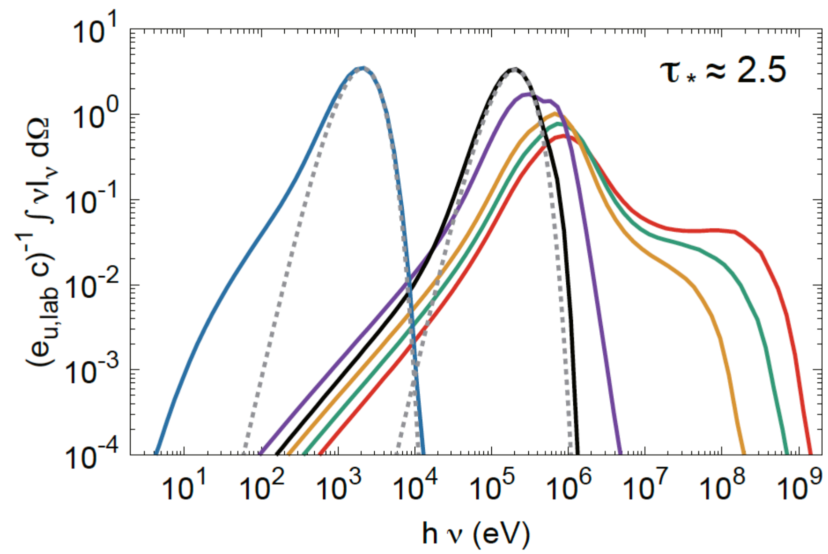
Dissipation below the photosphere



Pe'er, Meszaros Rees +06; Rees+05



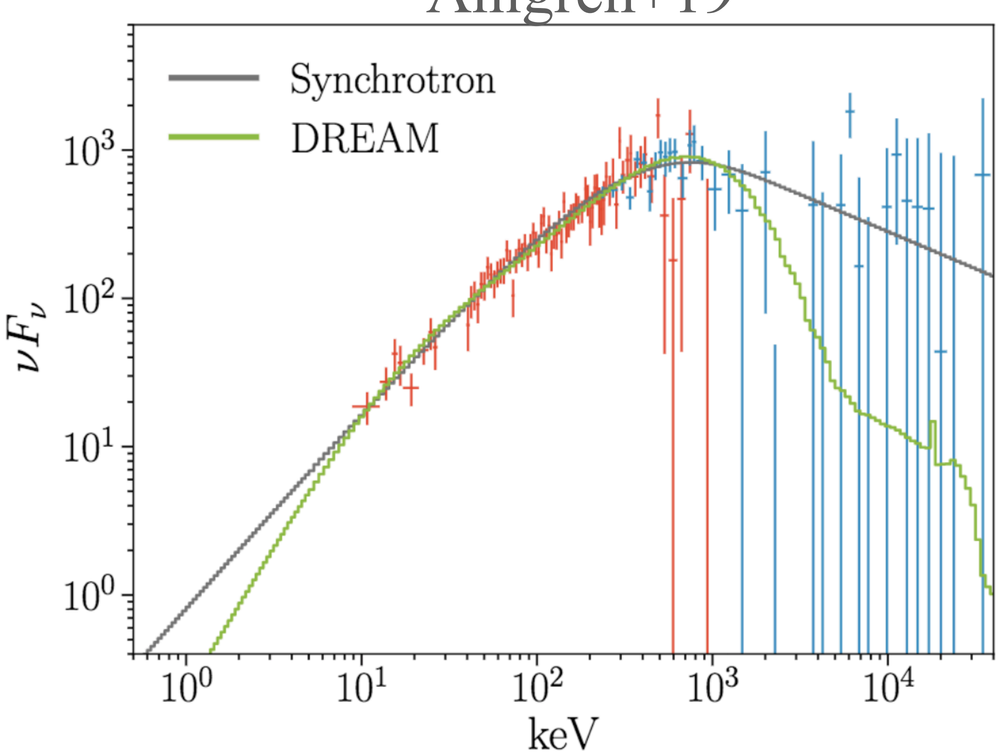
Vurm +14



Ito+19

See also
Thompson+ 14, Ahlgren+15, Ahlgren+19

Ahlgren+19



Synchrotron slow-cooled

A good fit is not conclusive

Subphotospheric dissipation

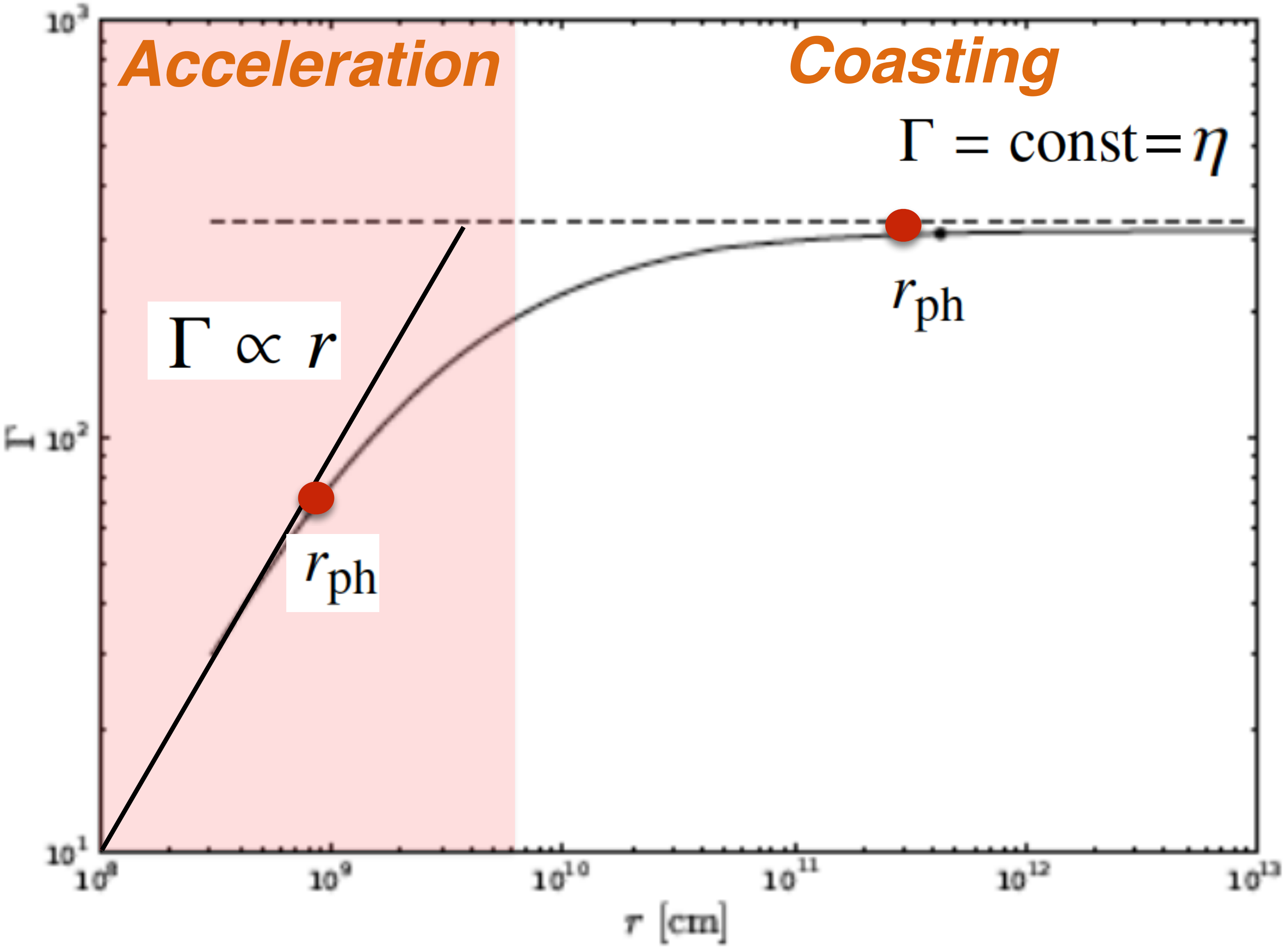
Synthetic GBM

Non-dissipative photospheres (NDP)

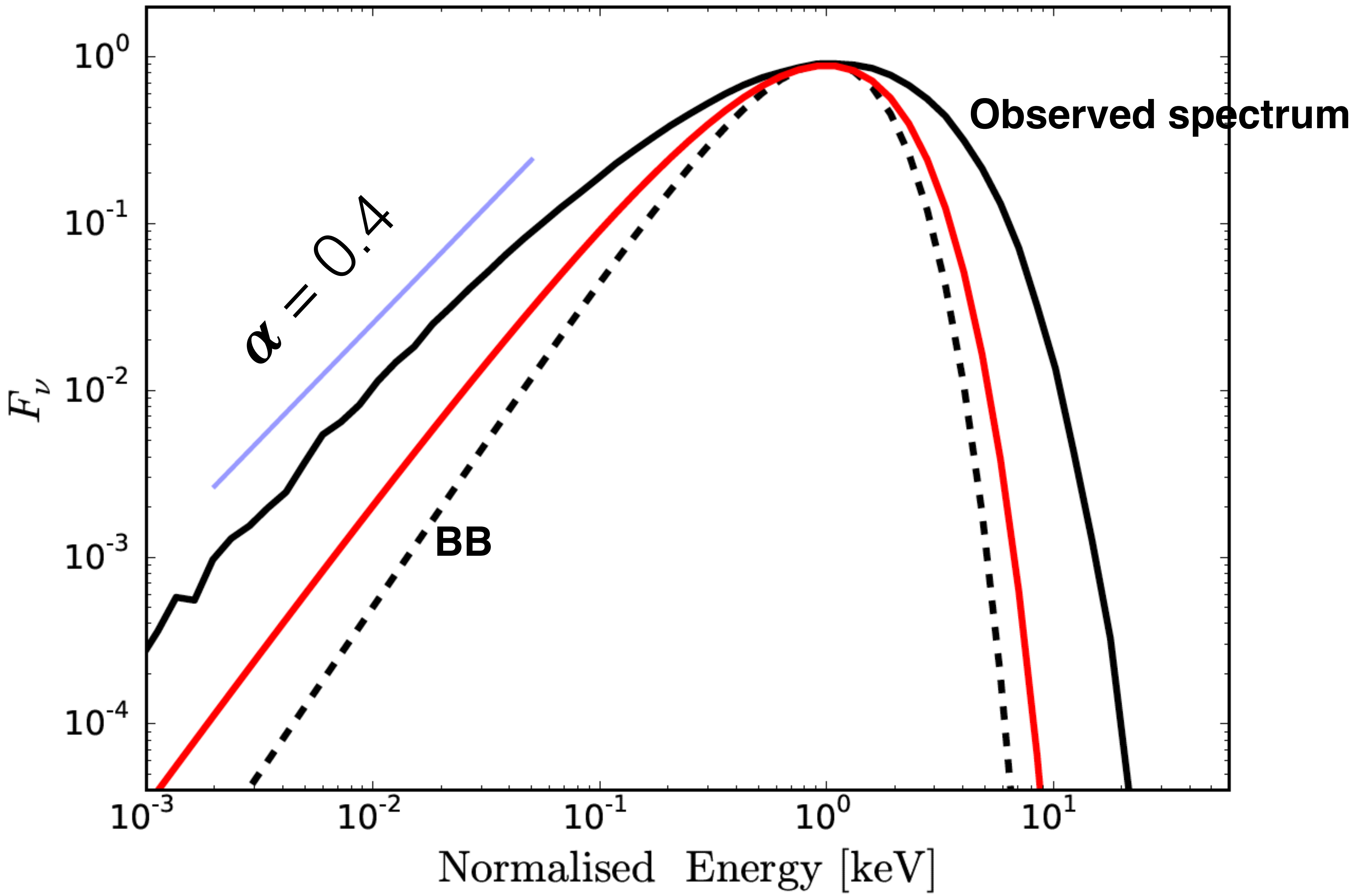
Fireball model:
Lorentz factor

$$\eta = L/\dot{M}c^2$$

Magnetic dominated flow will have a different dynamics



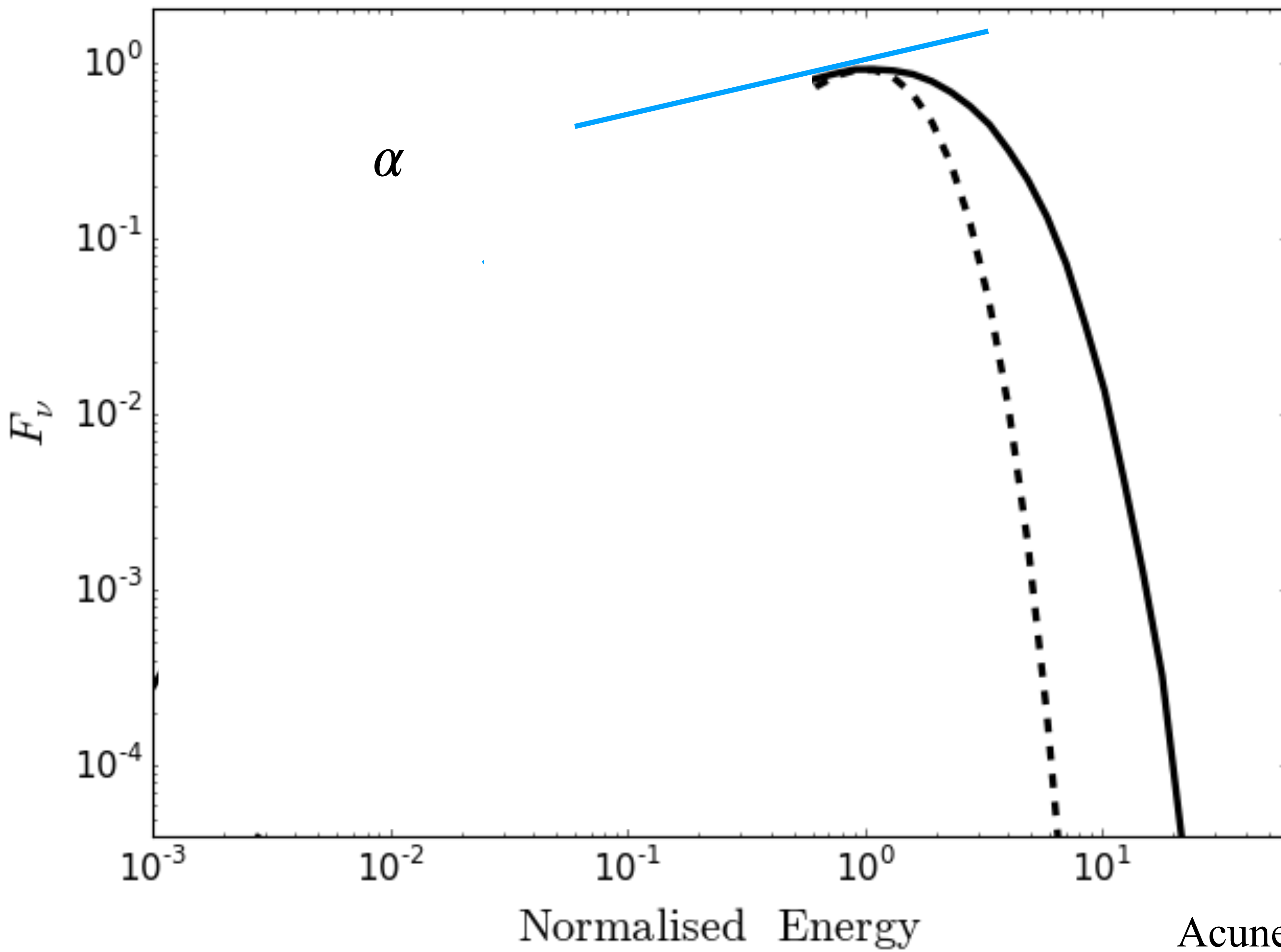
Coasting phase spectrum from a non dissipative jet



Beloborodov 11
Lundman, Pe'er, Ryde 13
Ryde+17

Expected photospheric flux in GBM observations

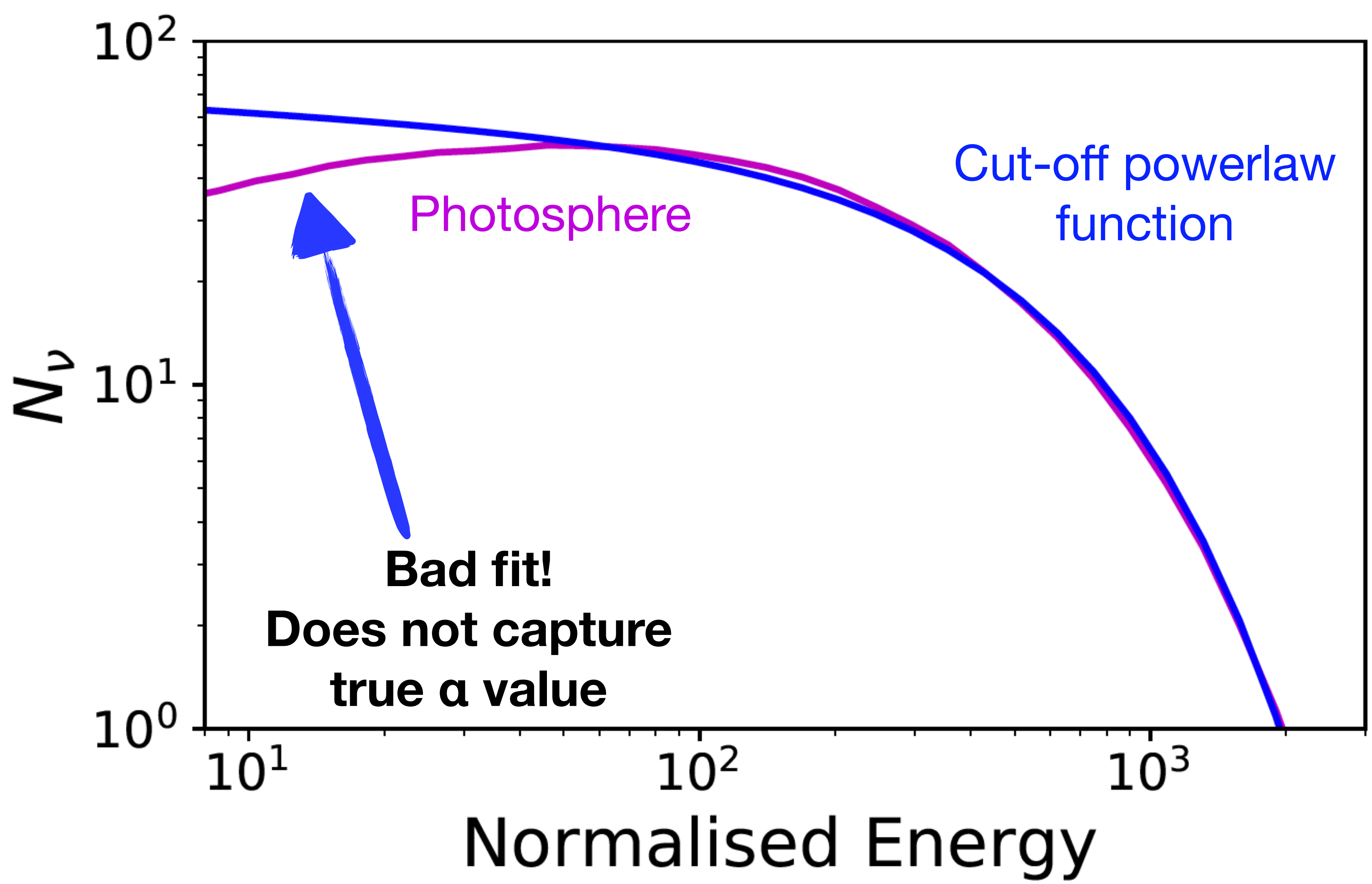
1. Limited band width of the GBM



Acuner, Ryde &Yu 19

Expected photospheric flux in GBM observations

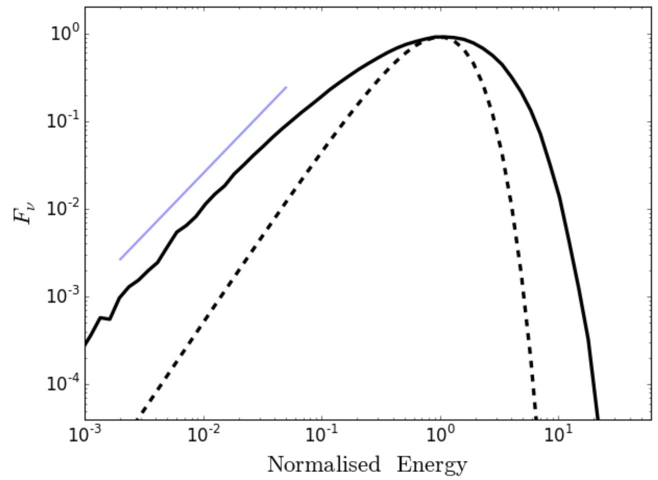
2. Limitations of empirical models



Acuner, Ryde &Yu 19

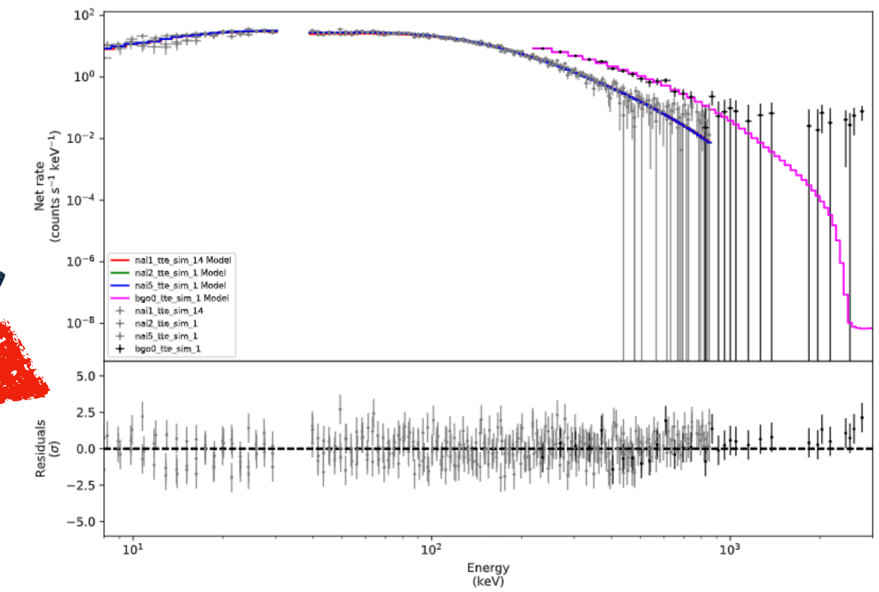
Appearance of the photospheric spectra in the GBM data

Model spectrum



DRM

Simulated count spectrum



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Appearance of the photospheric spectra in the GBM data

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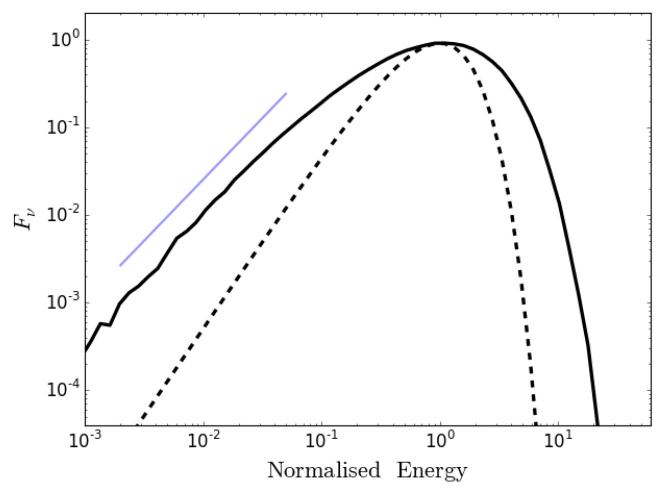
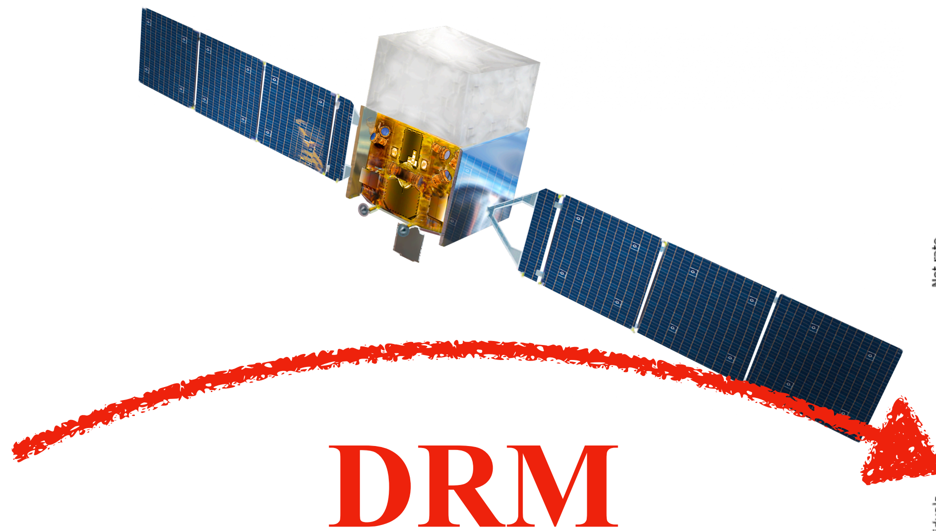
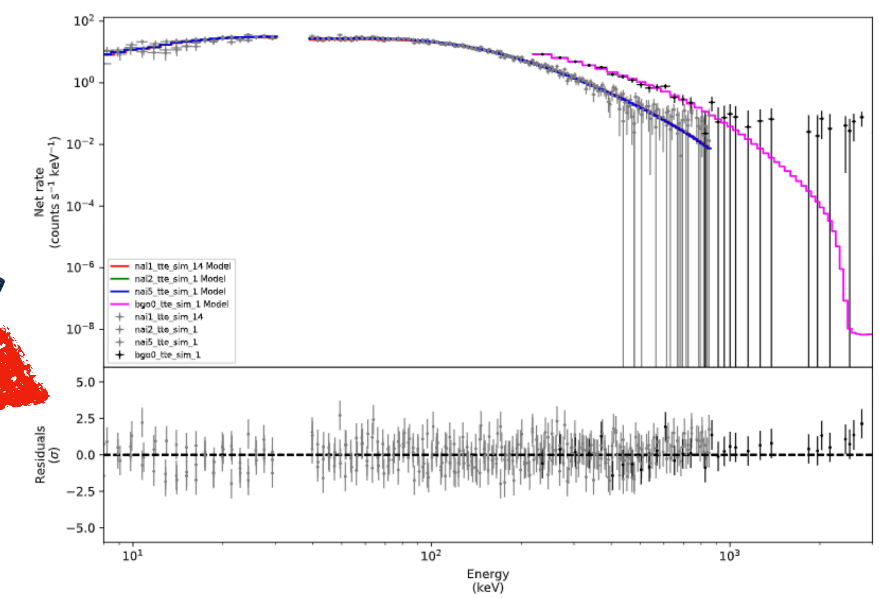
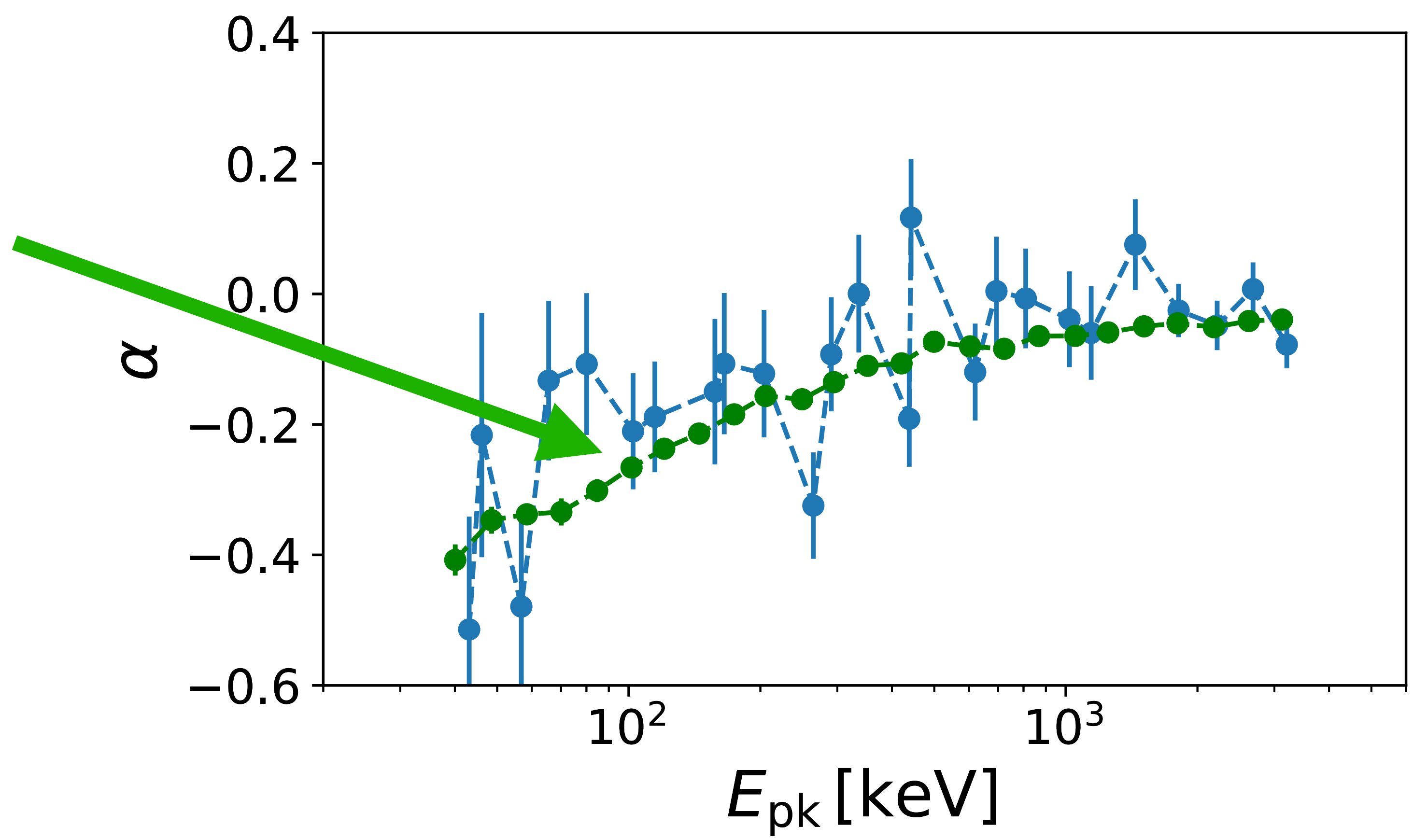




Simulated count spectrum



Fitted α-values



SNR = 100

SNR = 20

Epk of simulated spectrum

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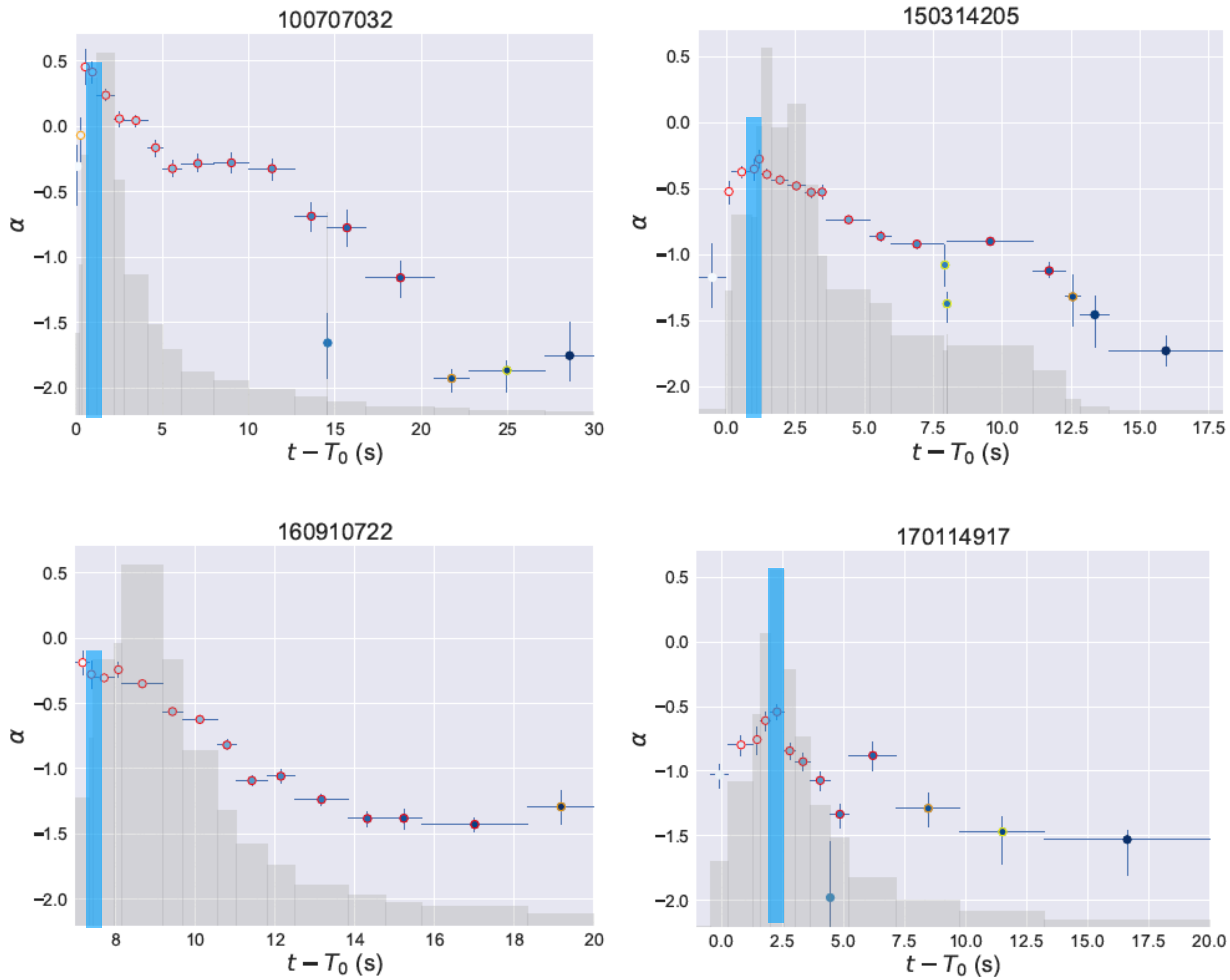
Results

We compare this prediction with Fermi/GBM data of

- time resolved time bins
- with S>15
- Time bins with the maximal value of α

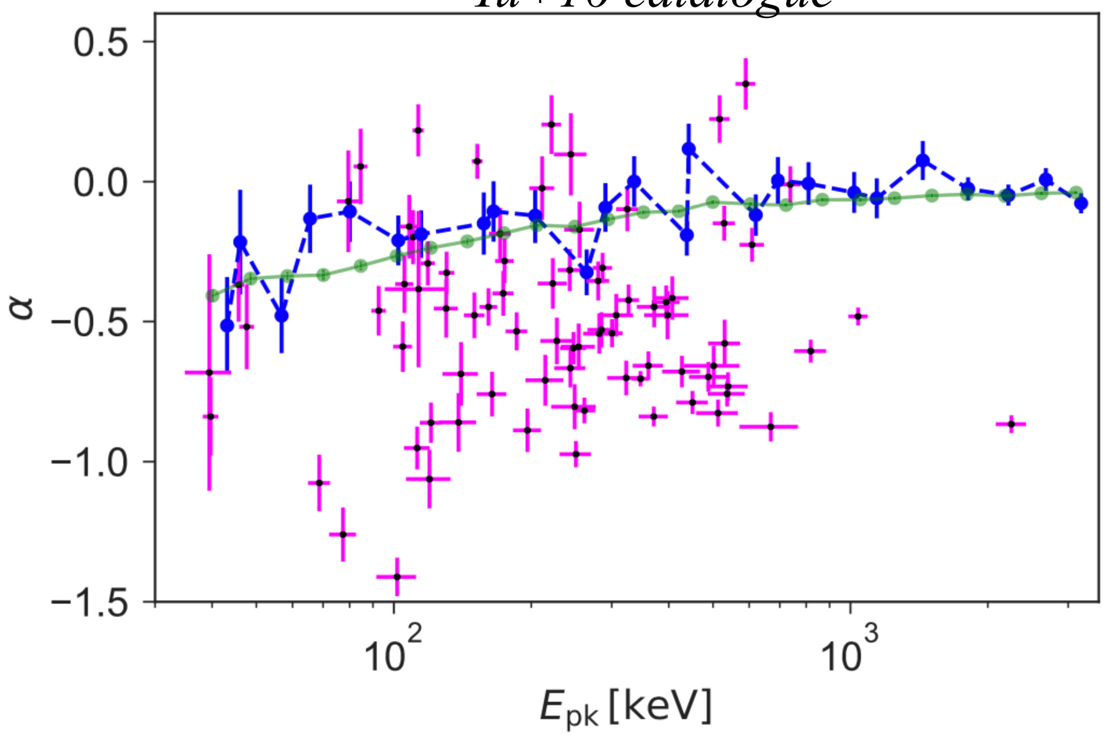
α-evolution of GBM bursts



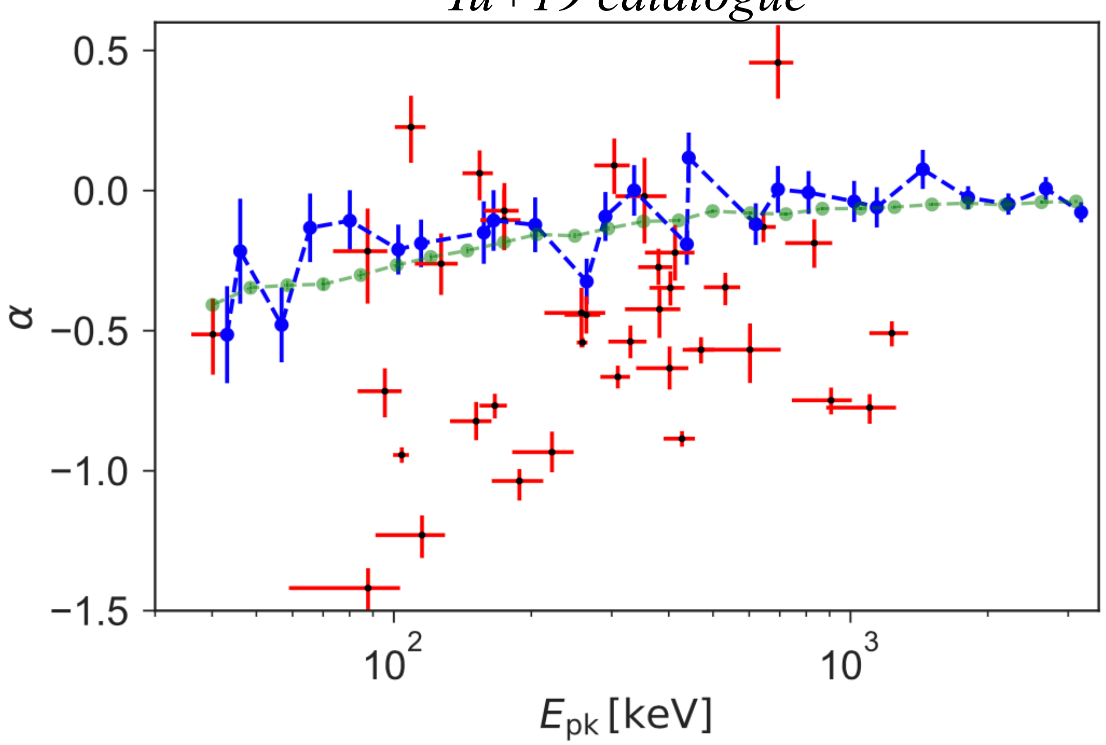
Results

1/4 of long bursts have spectra consistent with NDP

Yu+16 catalogue



Yu+19 catalogue



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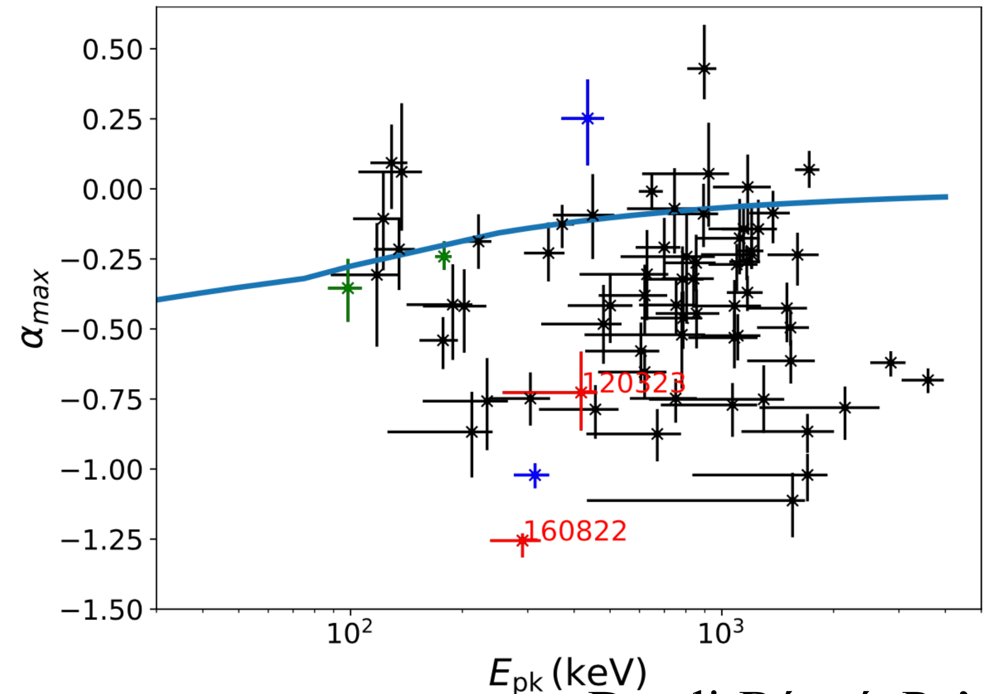
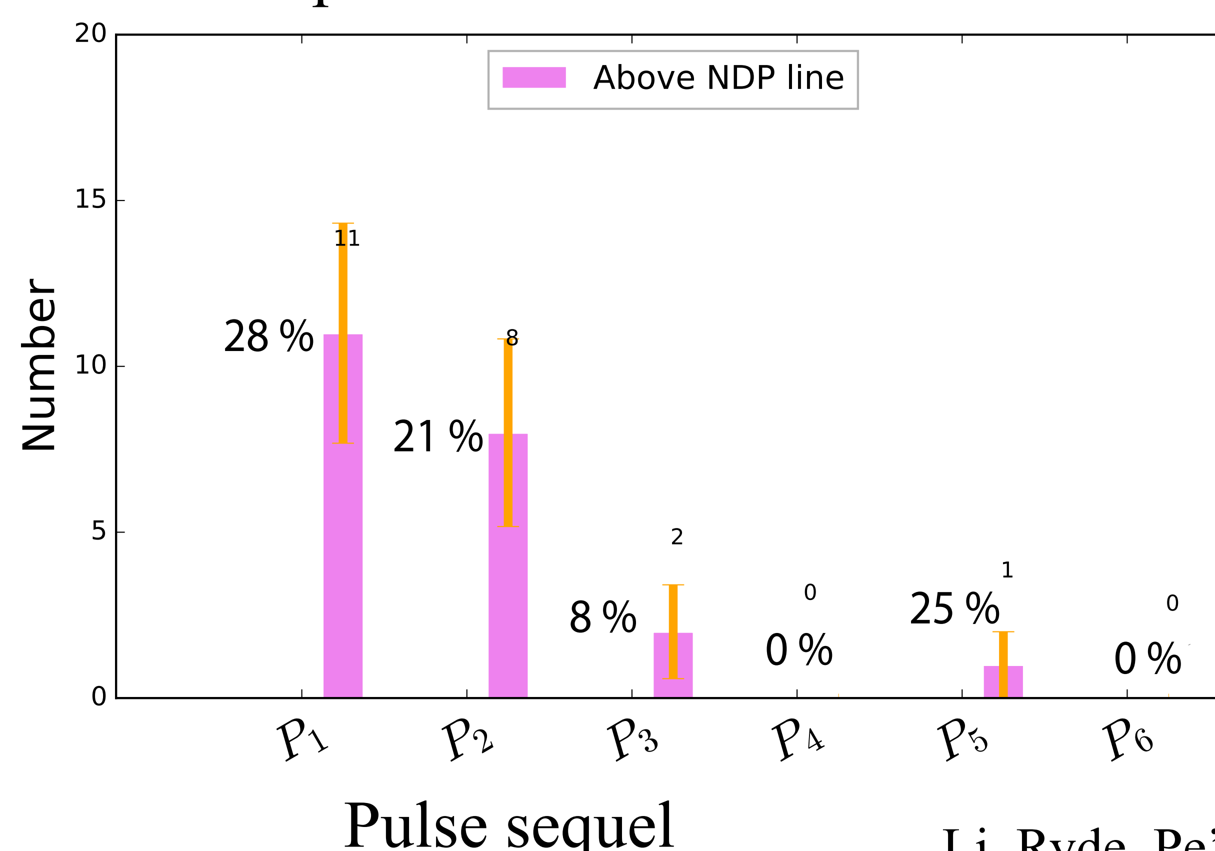
1/3 of long bursts have spectra consistent with NDP



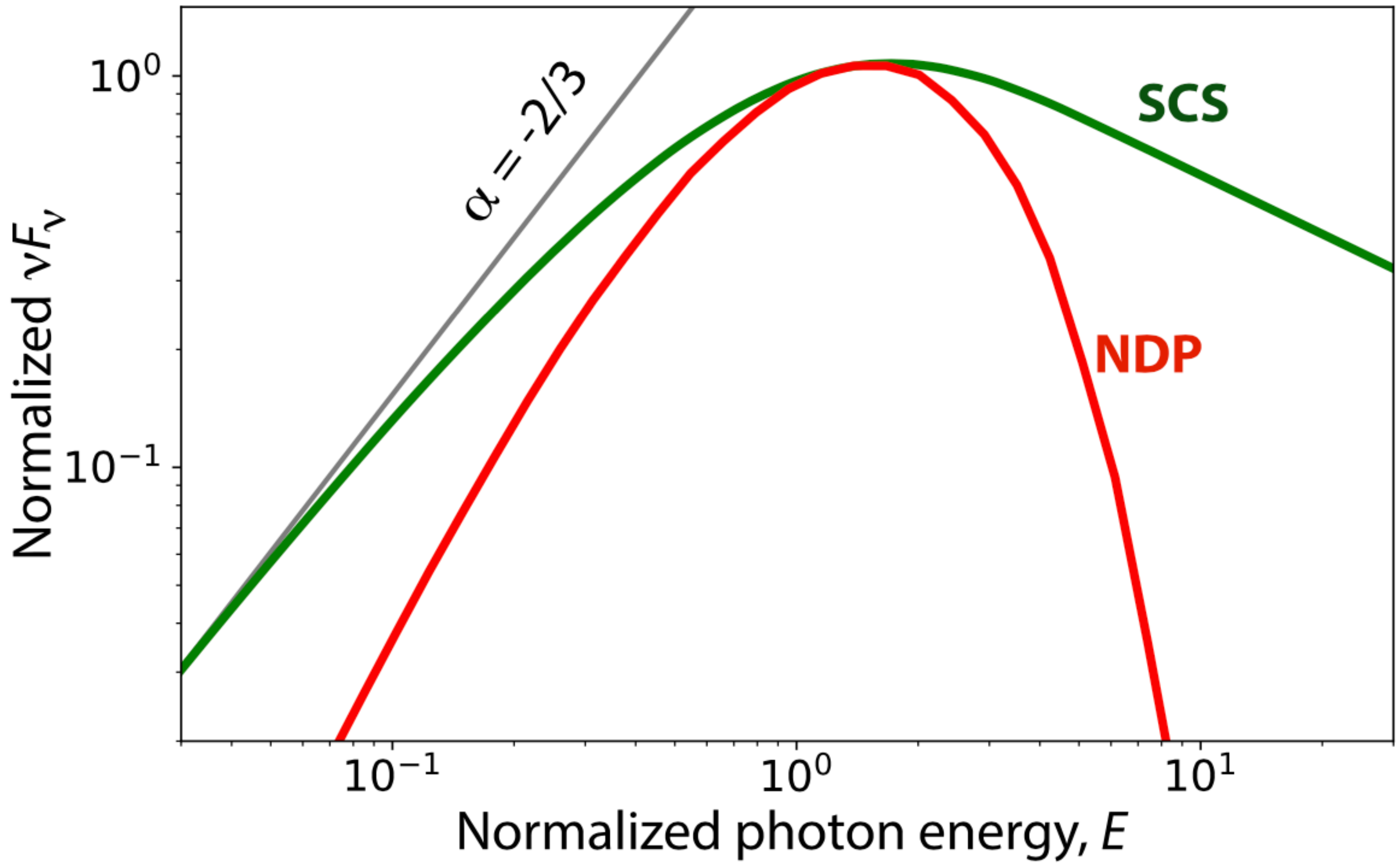
Dereli-Bégué, Pe'er & Ryde 20

For multi-pulsed bursts this fraction decreases



Li, Ryde, Pe'er+21

Alternative analysis:
Synchrotron versus photosphere
Model comparison using Bayesian evidences



Slow cooled synchrotron from mono-energetic electrons

Non-dissipative photosphere during the coasting phase

For each model we calculate the marginal likelihood or Bayesian evidence $Z_n = \int d\theta \; P(D \mid \theta_n, M_n) P(\theta_n \mid M_n)$

The ratio of the respective evidences, Z_2/Z_1, summarizes the evidence given by the data in favor of one of the models

$$\ln \frac{Z_2}{Z_1} = \ln Z_2 - \ln Z_1$$

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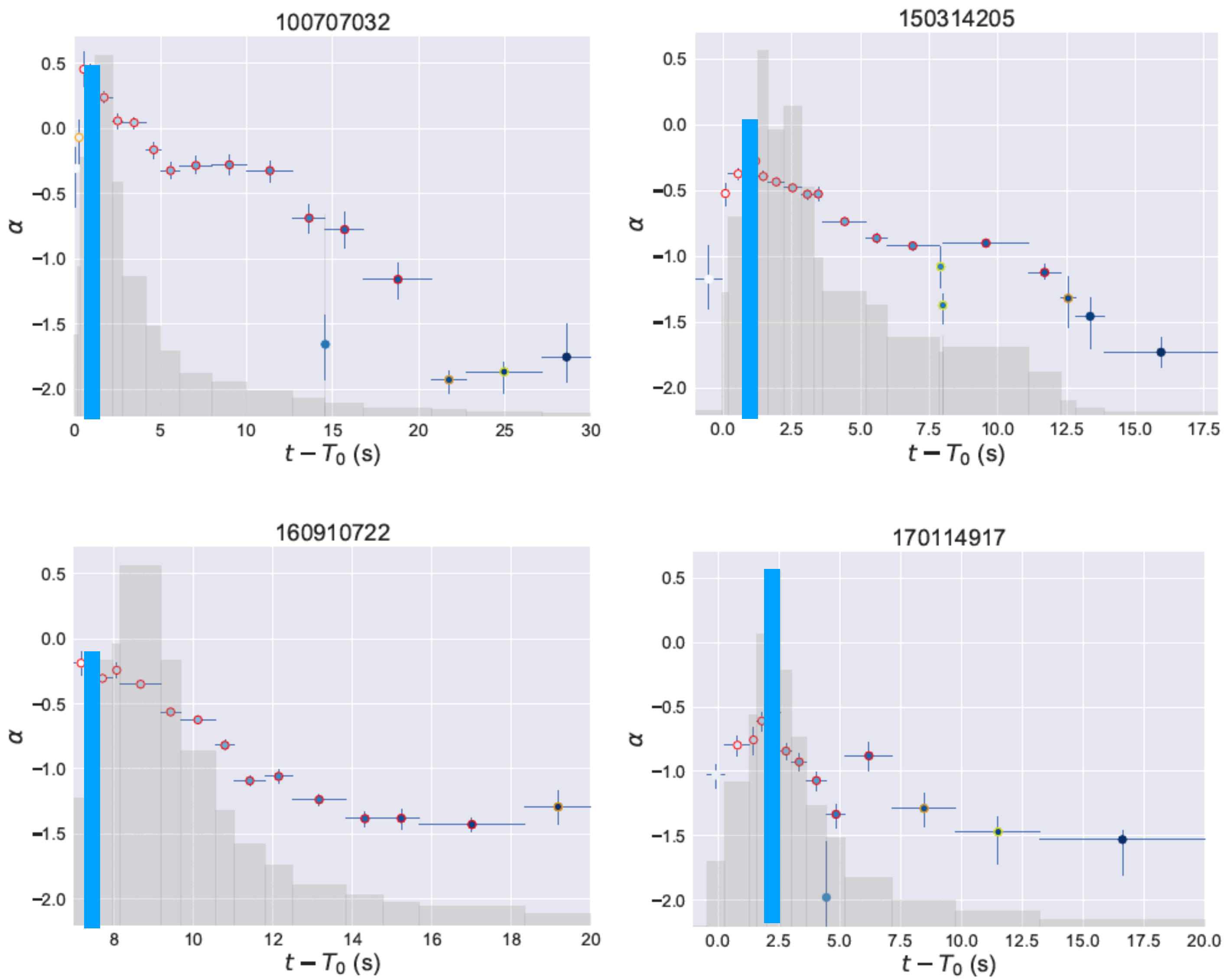
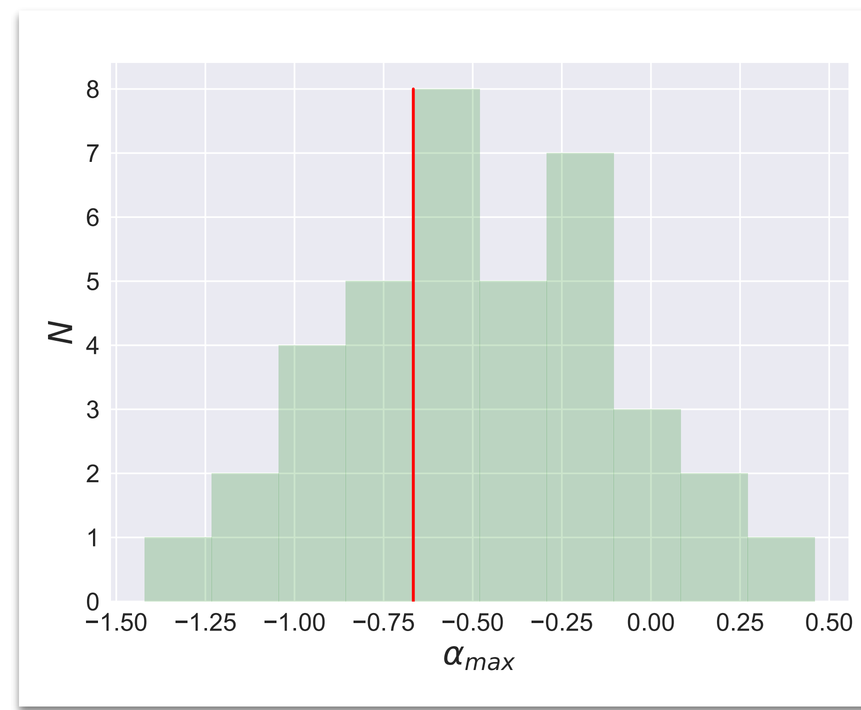
We do this on the complete catalogue of Yu+19 (37 pulses)



Distribution of α_{max}



α from fits to CPL

68% of pulses
have $\alpha_{max} > -0.67$

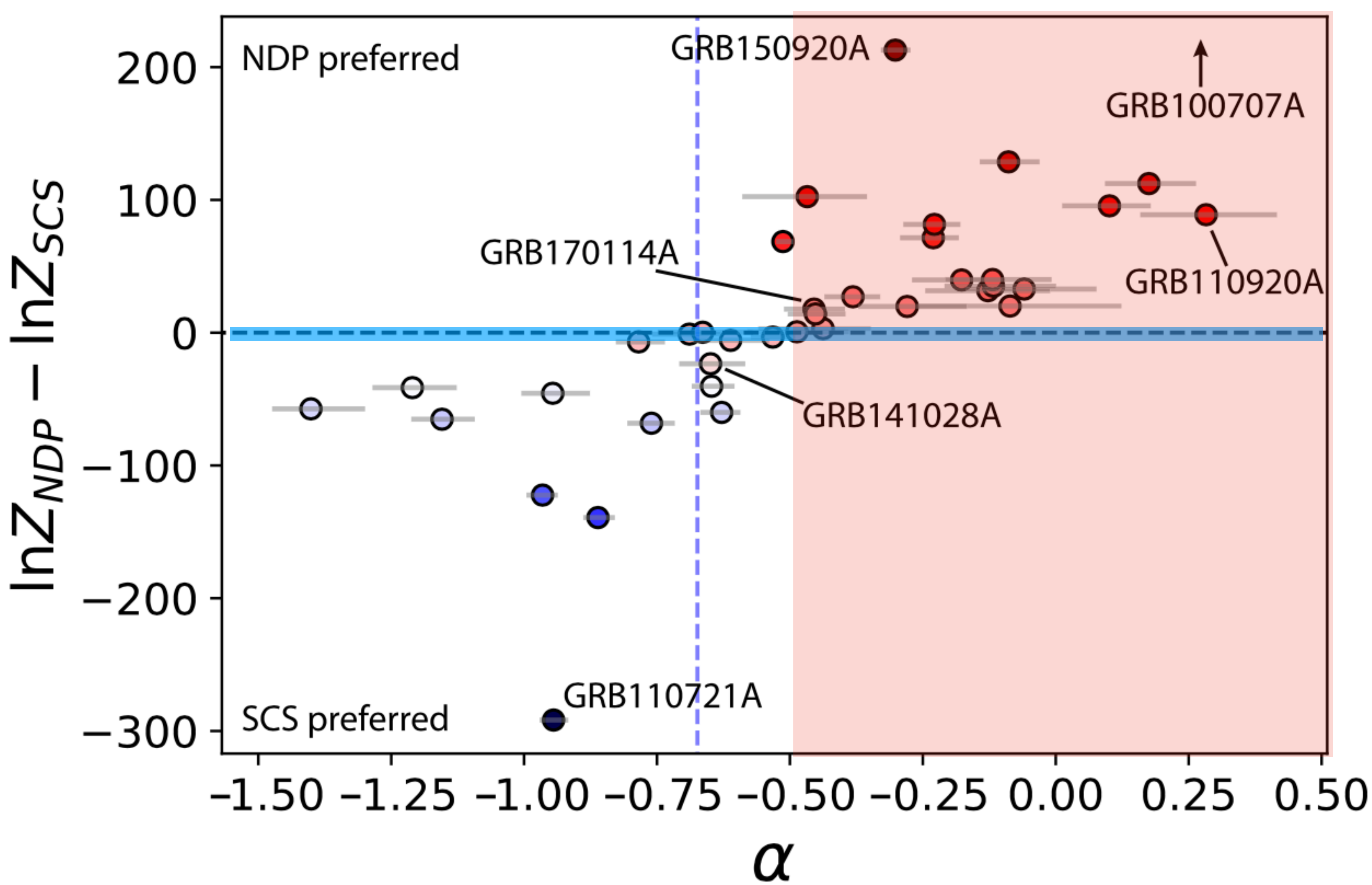
see also Ghirlanda+02

37 spectra are fitted with the synchrotron and the photosphere models

Model comparison using Bayesian evidences: Results

We do this on the 37 pulses in the catalogue of Yu+19

S > 15 , time resolved, $\alpha_{\max}$ bin



The photospheric spectral shape is preferred by 54%±8% of the spectra (20/37),

The synchrotron spectral shape is preferred by 38%±8% of the spectra (14/37)

Three spectra are inconclusive

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- α good estimator for preferred model: $\alpha \gtrsim -0.5$ prefer NDP
- We also find that information criteria (AIC and DIC) are good approximations of the evidences

Conclusions:Photospheres in GRBs

1. Dissipative photospheres:
   - Broad spectra, with diagnostic information
   - Degenerate with non-thermal models

2. Non-dissipative photospheres: Spectra broader than Planck
   - 1/4 of all pulses have at least on bin consistent with emission from a photosphere where the flow is non-dissipative
   - GBM spectra $\alpha \gtrsim -0.5$ prefer NDP over synchrotron
   - Multi-pulse bursts: Fraction decreases

Find photospheric emission:
1. $S \gtrsim 15$, time resolved data
2. Close to the trigger time