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GRBS CAN BE COOL SYNCHROTRON SOURCES

SPECTRAL AND POLARIZATION RESULTS FROM POLAR AND FERMI

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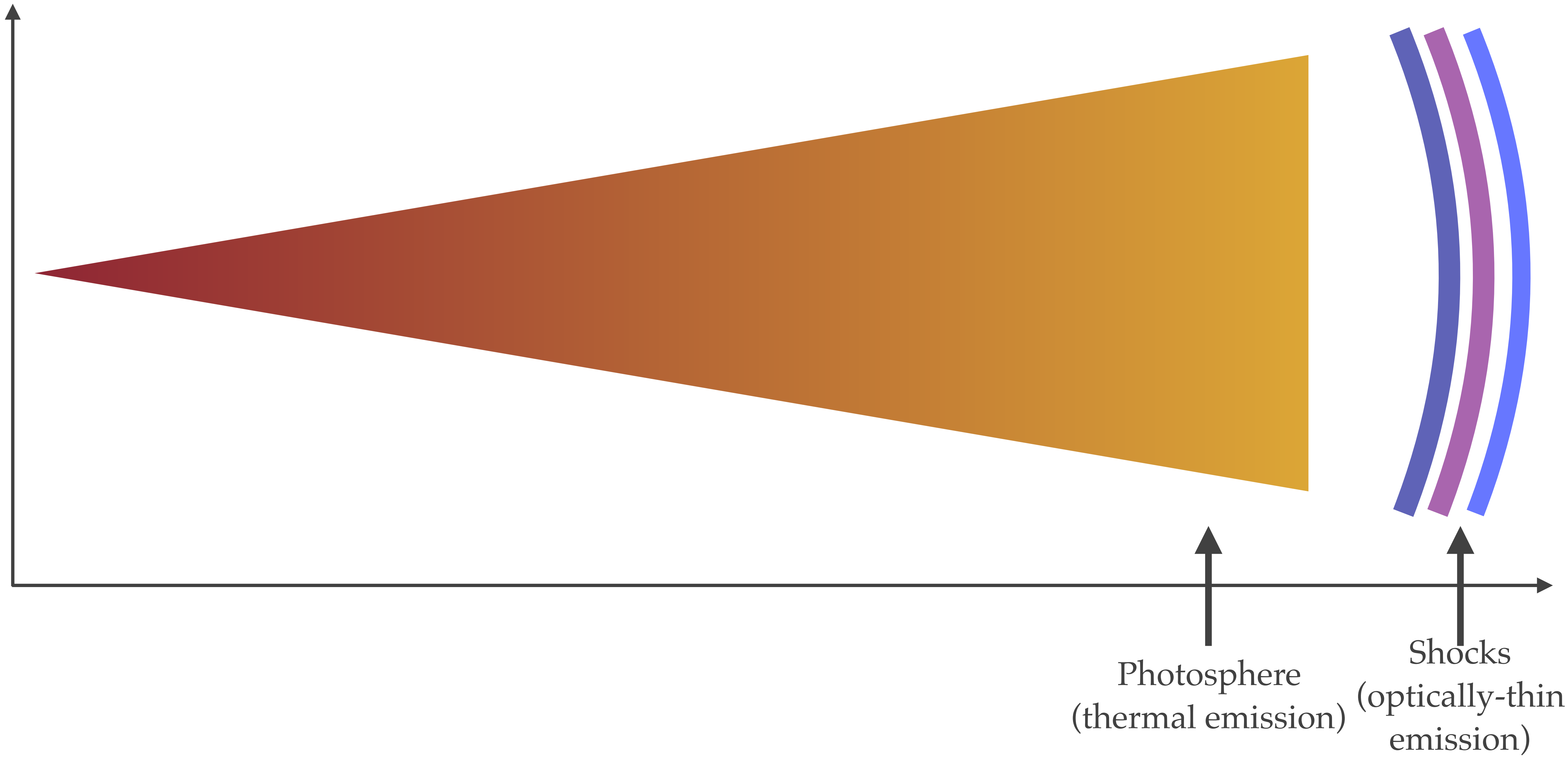
+

MPE

Very quick overview that leaves out most of the details but looks pretty.



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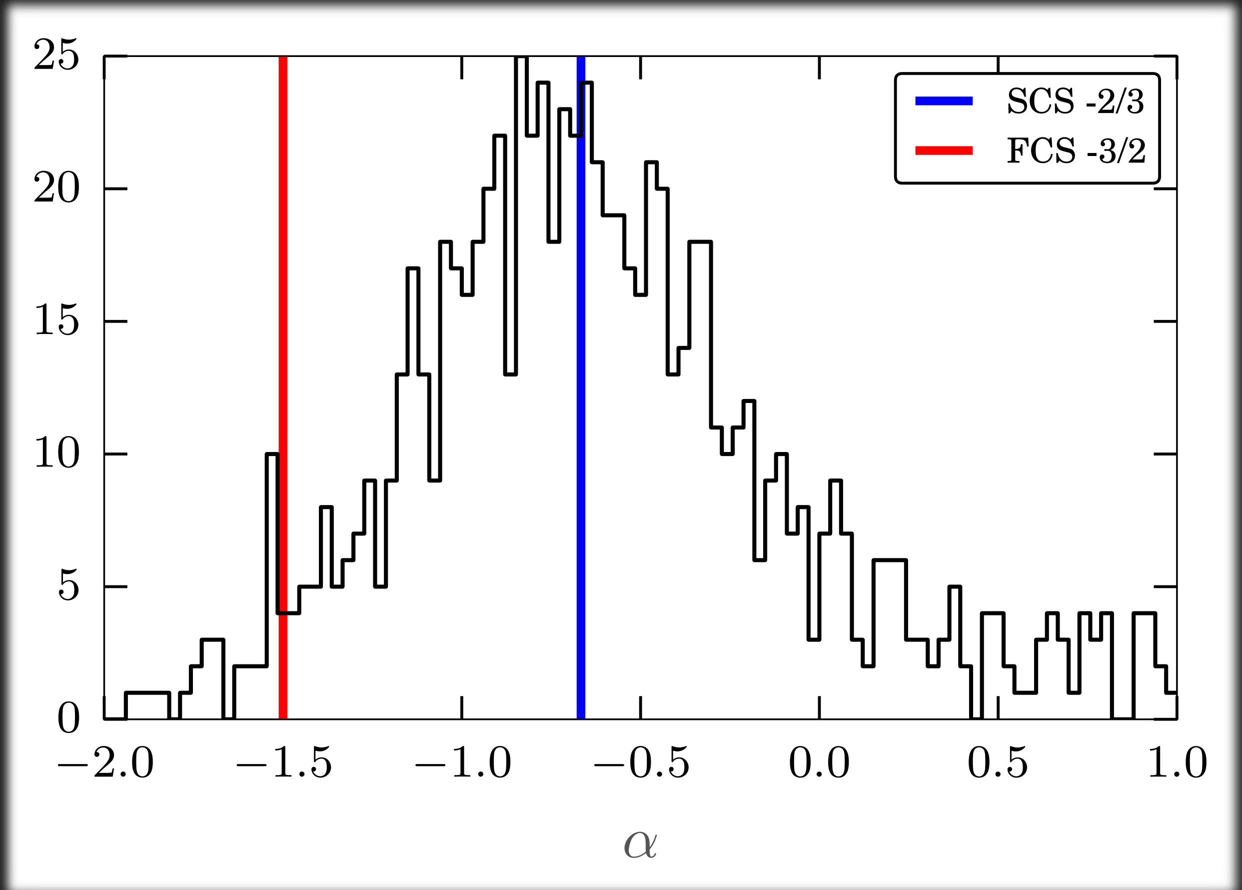
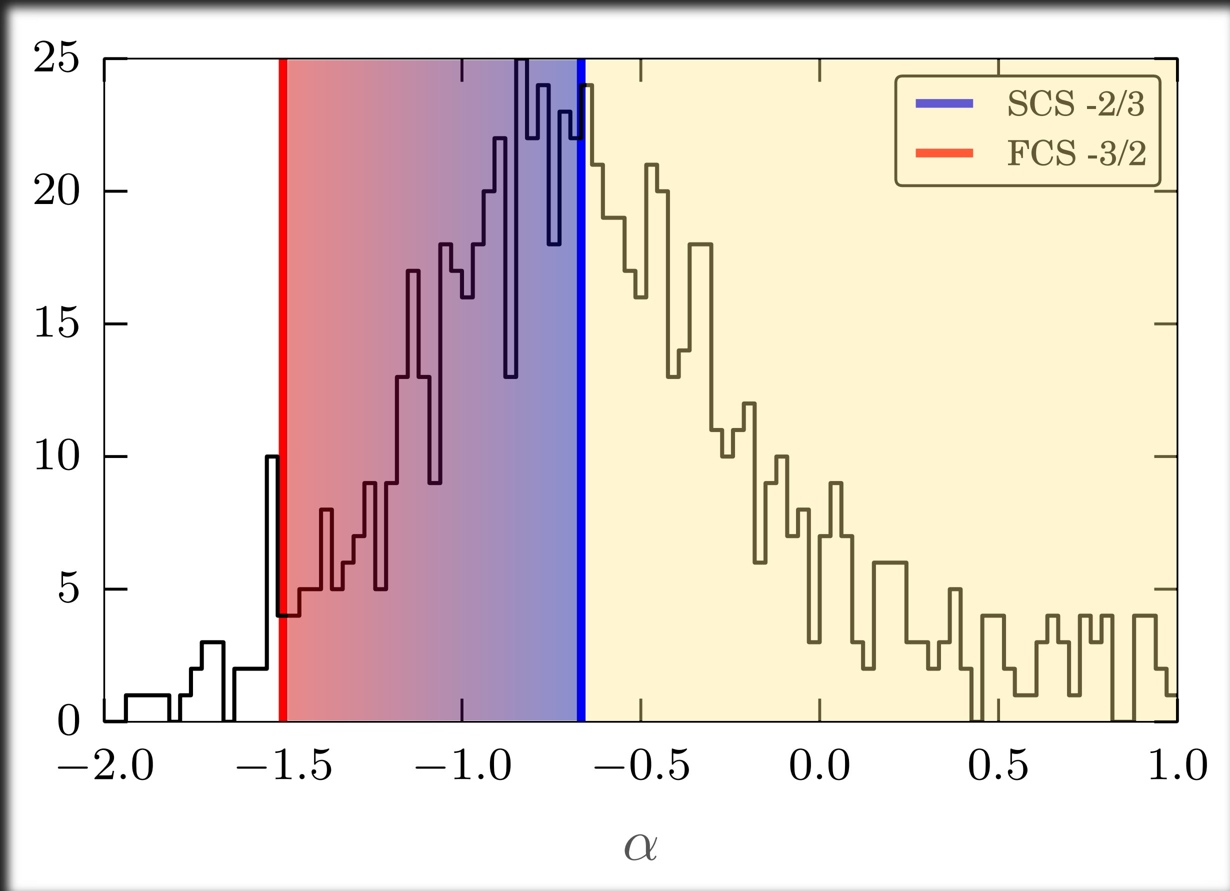


The GBM GRB alpha distribution



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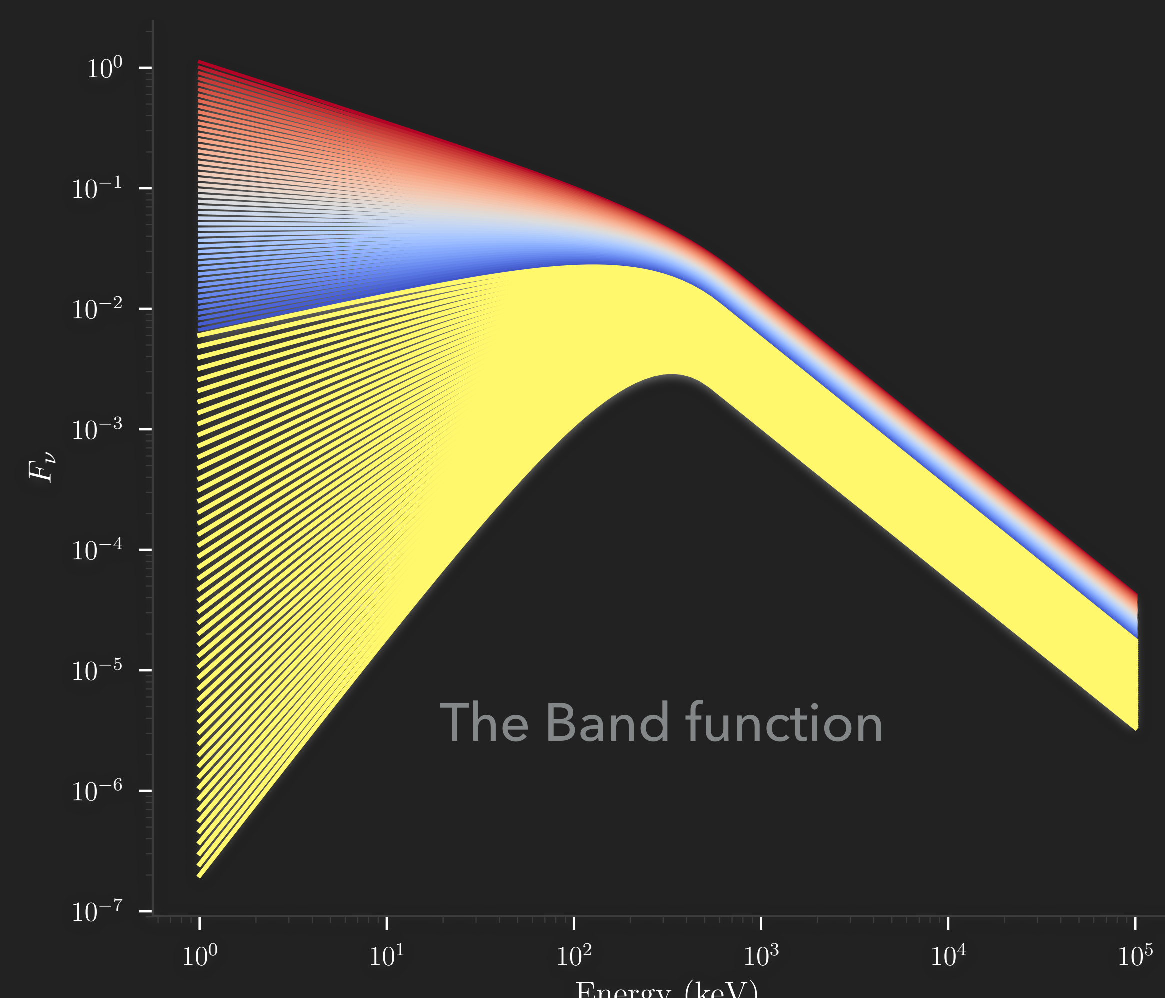


The Band function

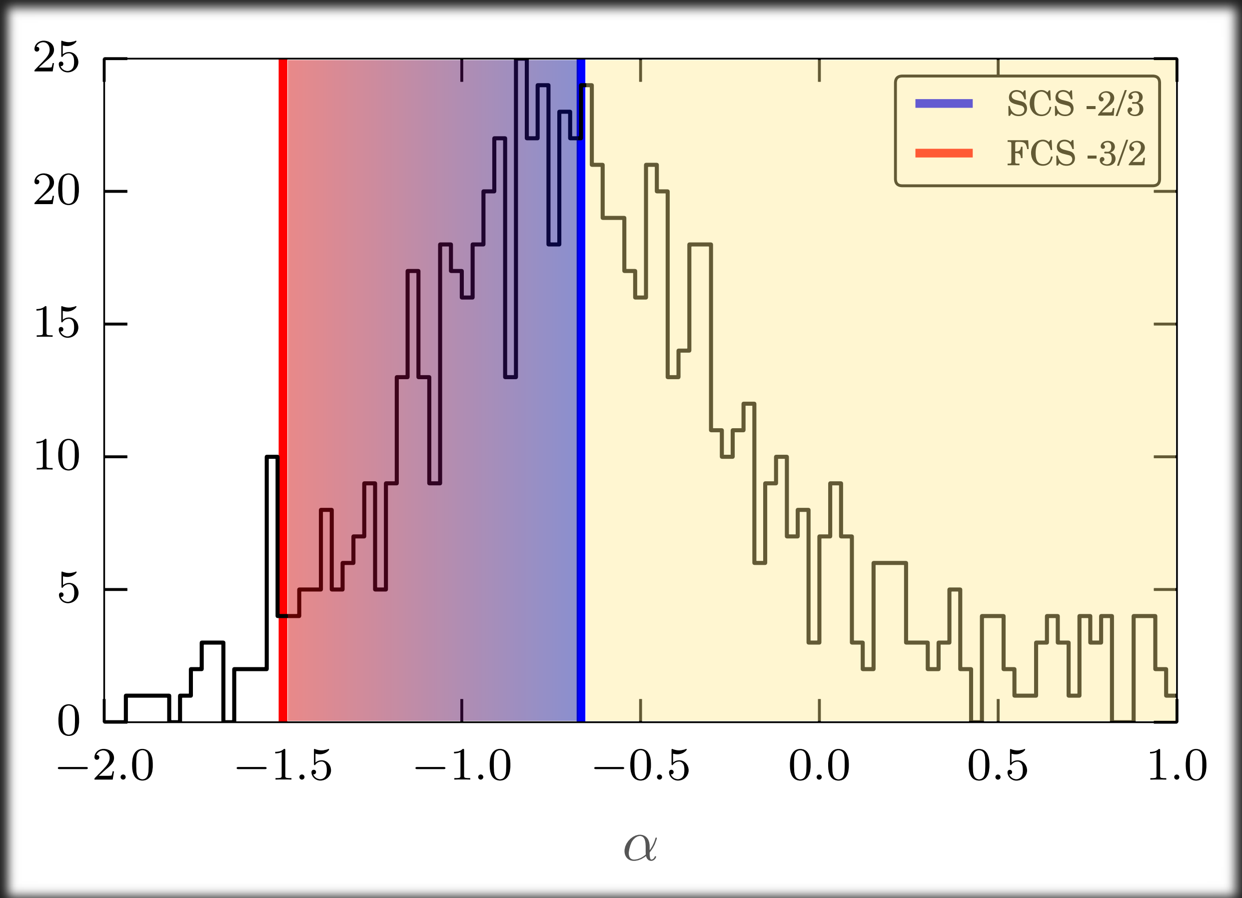
The Band function is function.

It is only a function.

No physics.

No story.

Stop using it.



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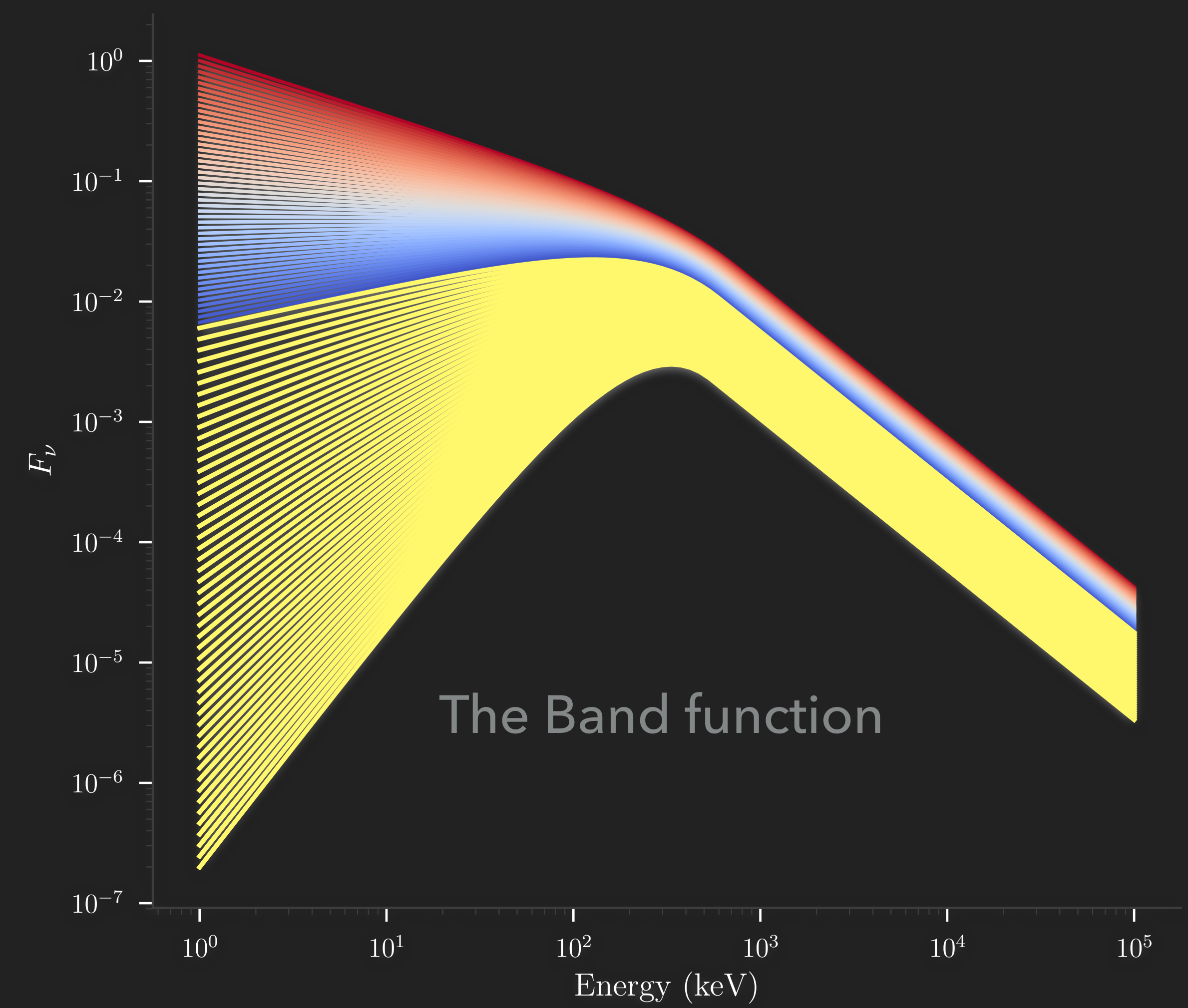


The Band function

SYNCHROTRON REVIEW

Fokker-Planck equation

$$\frac{\partial}{\partial t} n_e(\gamma, t) = \frac{\partial}{\partial \gamma} C(\gamma)\, n_e(\gamma, t) + Q(\gamma)$$

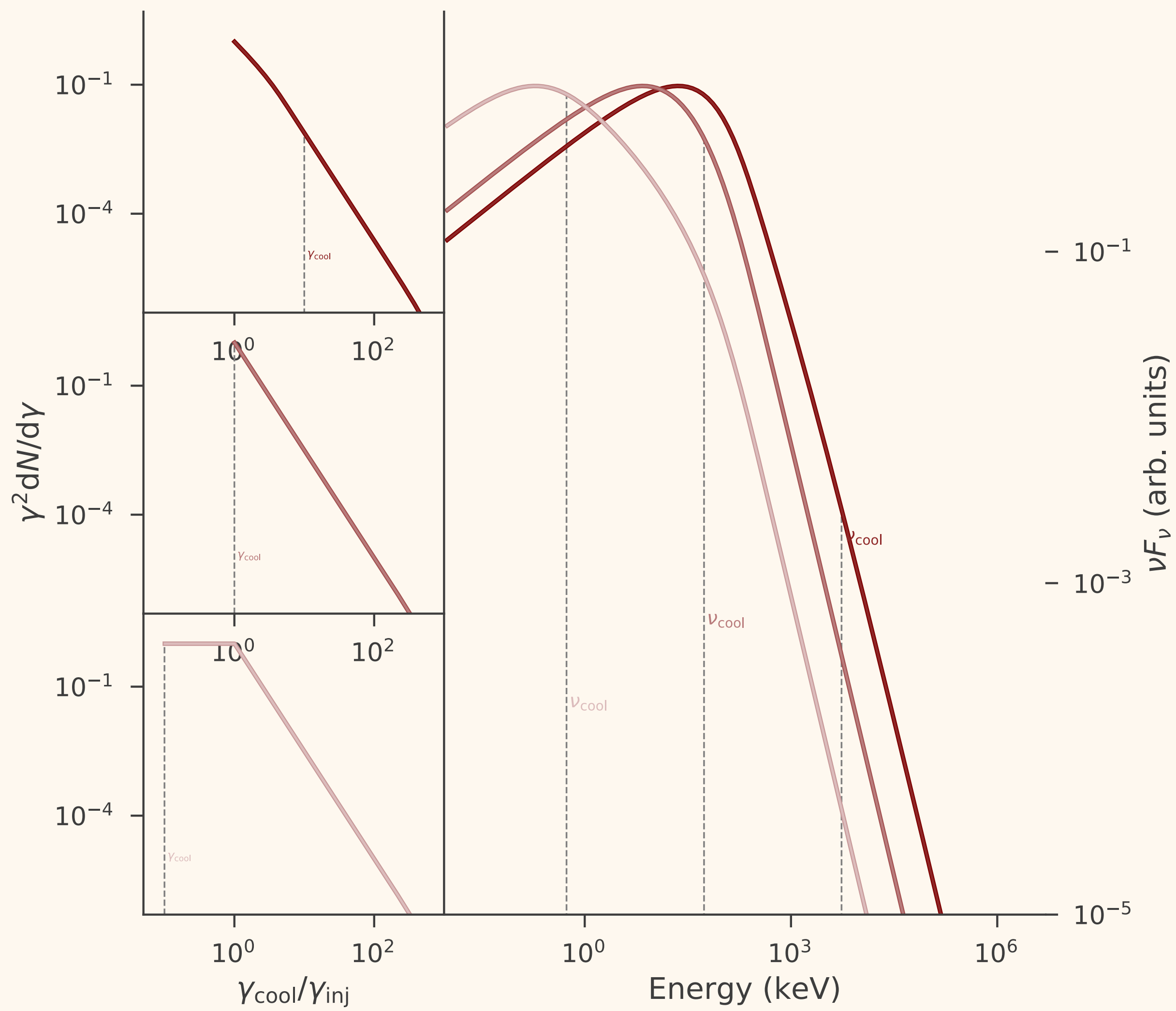
$$Q(\gamma) \propto \gamma^{-p} \quad \forall \gamma \geq \gamma_{\mathrm{inj}} \qquad C(\gamma) = -\frac{\sigma_{\mathrm{T}}}{6\pi m_{\mathrm{e}} c} B^2 \gamma^2$$

power law injection — synchrotron cooling

synchrotron emission

$$n_\nu(\varepsilon; t) = \int_1^{\gamma_{\max}} \mathrm{d}\gamma \; n_e(\gamma, t) \Phi\left(\frac{2\varepsilon b_{\mathrm{crit}}}{3B\gamma^2}\right)$$

$$\Phi(w) = w \int_w^\infty K_{5/3}(x)\, dx$$



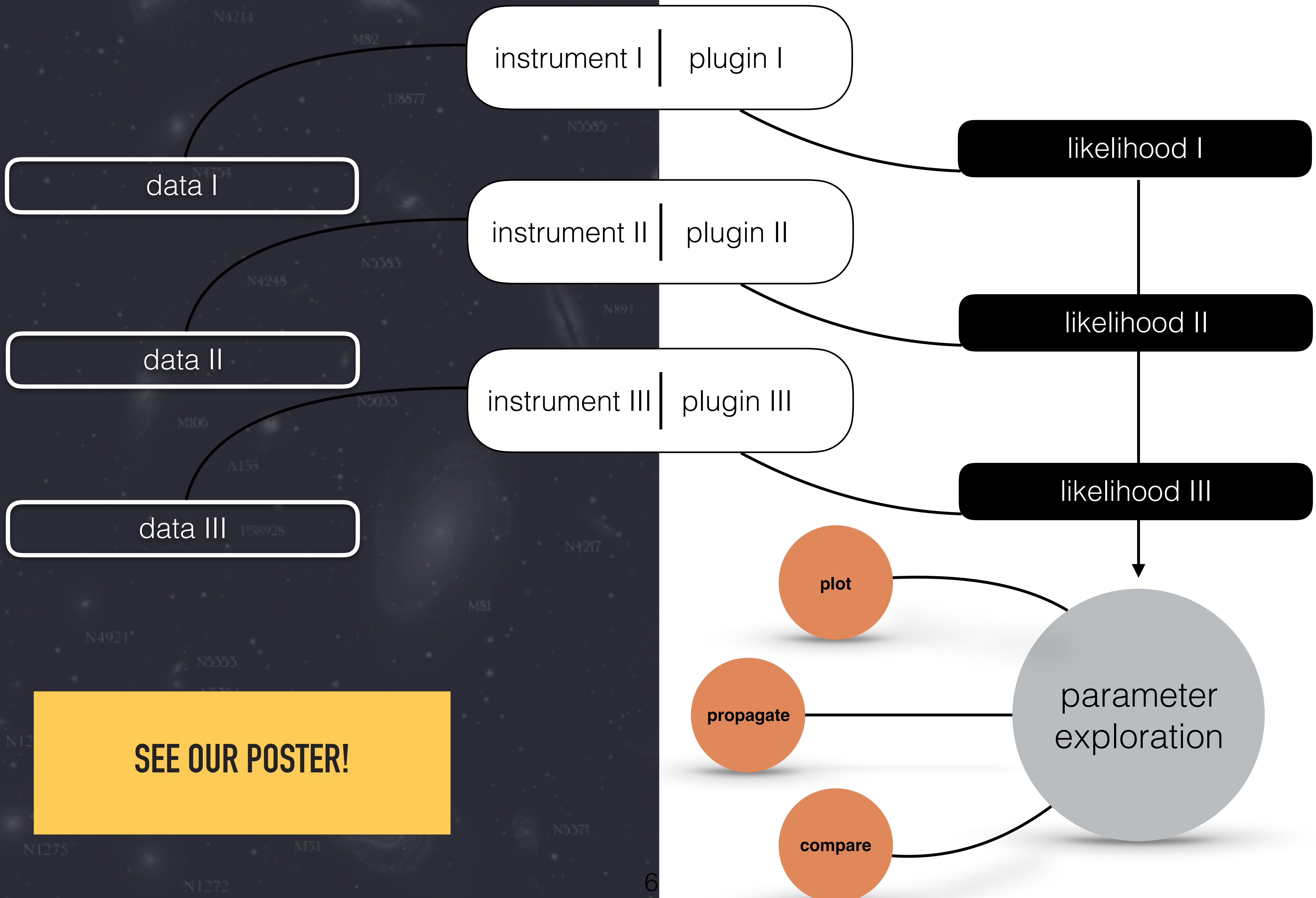
Standard synchrotron emission model. No bells or whistles (or SSC/IC). The model allows us to test all synchrotron cooling regimes as a parameter!

SYNCHROTRON REVIEW

$\gamma_{\rm inj}$	Injection electron energy
$\gamma_{\rm cool}$	Cooling electron energy
p	Injection spectral index
B	Magnetic field strength

The same number of parameters as the Band function

3ML: THE MULTI-MISSION MAXIMUM LIKELIHOOD FRAMEWORK

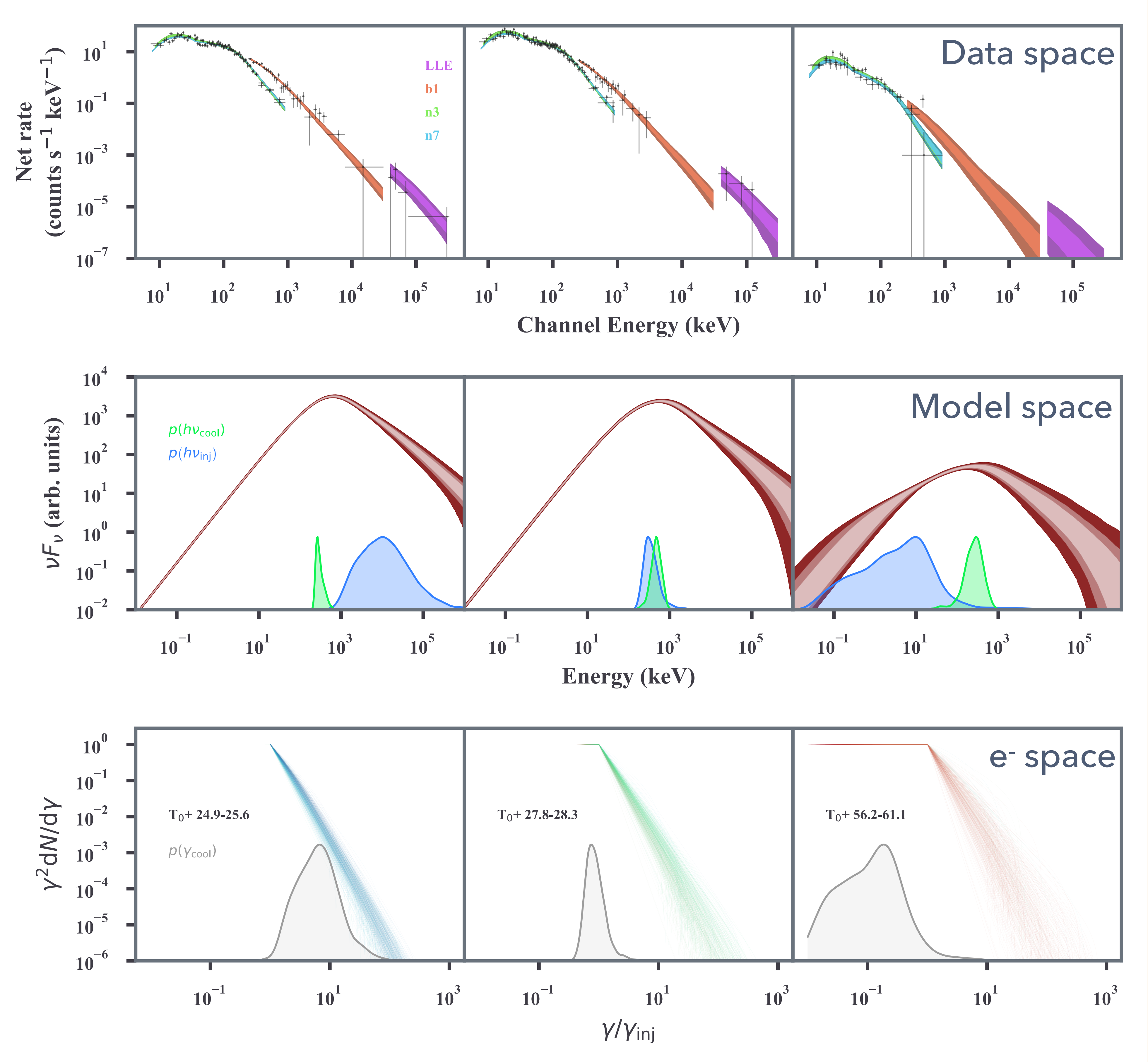


SEE OUR POSTER!

MODEL MEET DATA

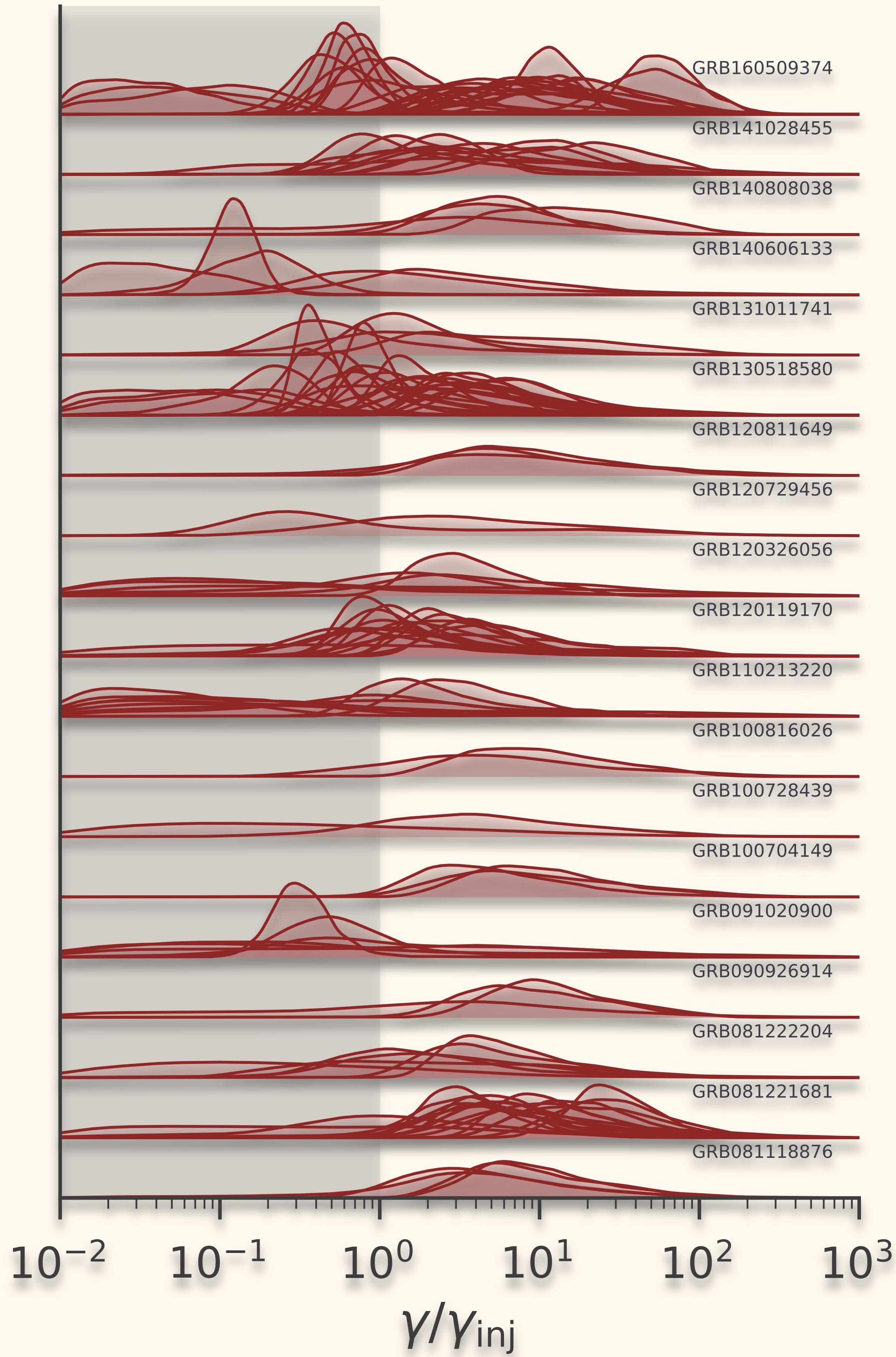
We fit 18 single pulse GRBs with redshift.

168 time-resolved spectra.



MODEL MEET DATA

A diverse population of cooling regimes.



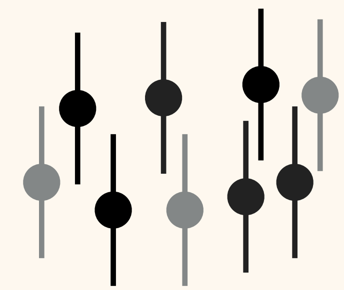
SPI can help us lock down these parameters!

However, most spectra are in the so-called "slow-cooling regime."

POSTERIOR PREDICTIVE CHECKS

$$\pi\left(\tilde{y}\,|\,y\right) = \int \mathrm{d}\theta\, \pi\left(\tilde{y}\,|\,\theta\right) \pi\left(\theta\,|\,y\right)$$

POSTERIOR PREDICTIVE CHECKS



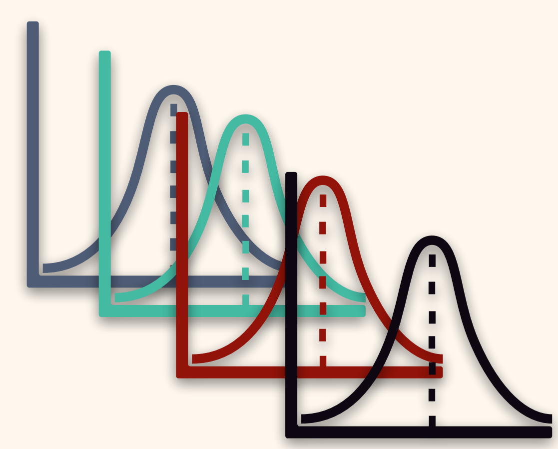
replicated data

likelihood

$$\pi\left(\tilde{y}\,|\,y\right) = \int \mathrm{d}\theta\, \pi\left(\tilde{y}\,|\,\theta\right)\, \pi\left(\theta\,|\,y\right)$$

measured data

posterior



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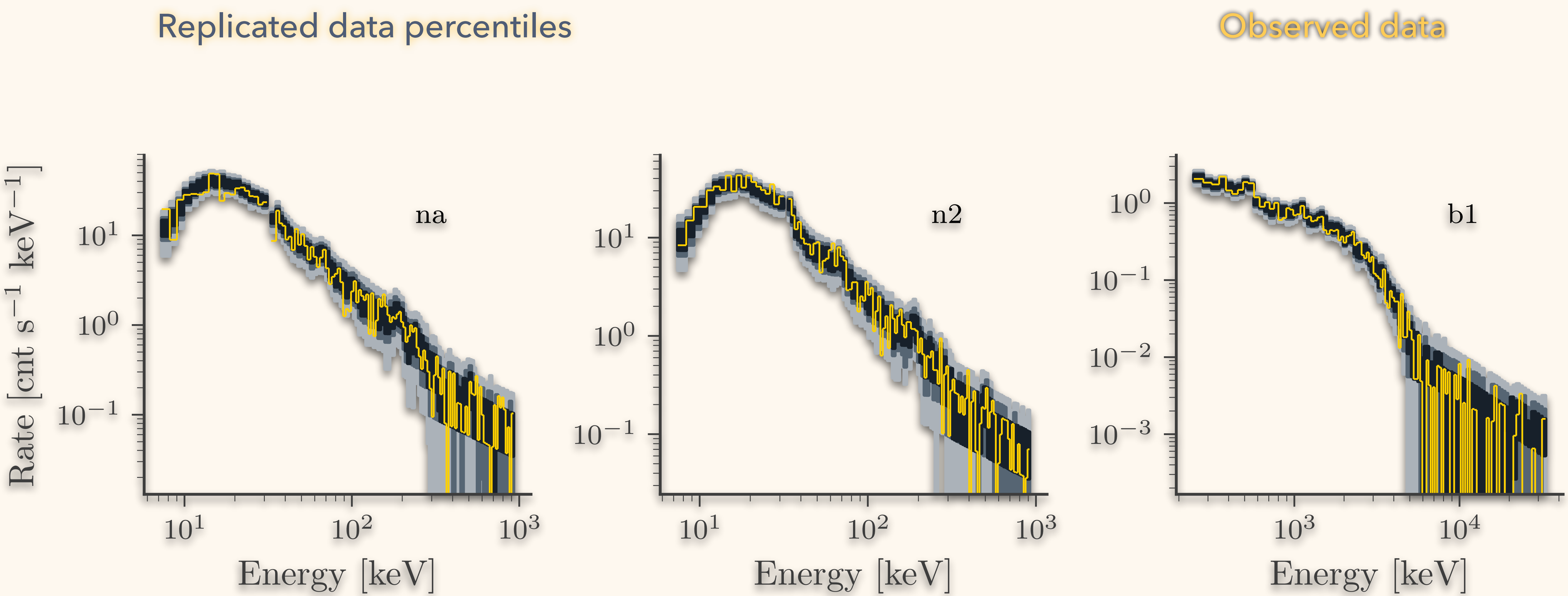
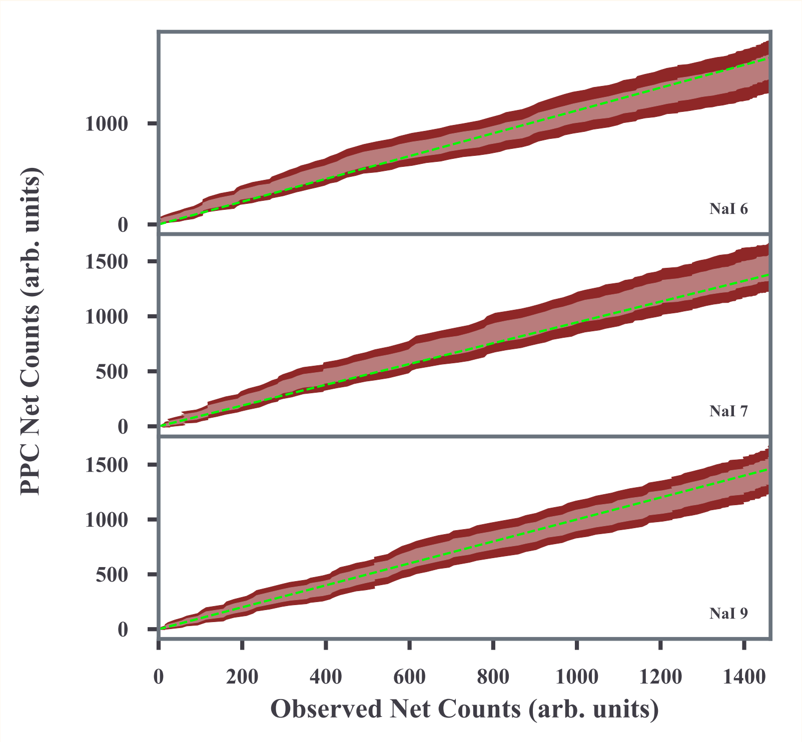


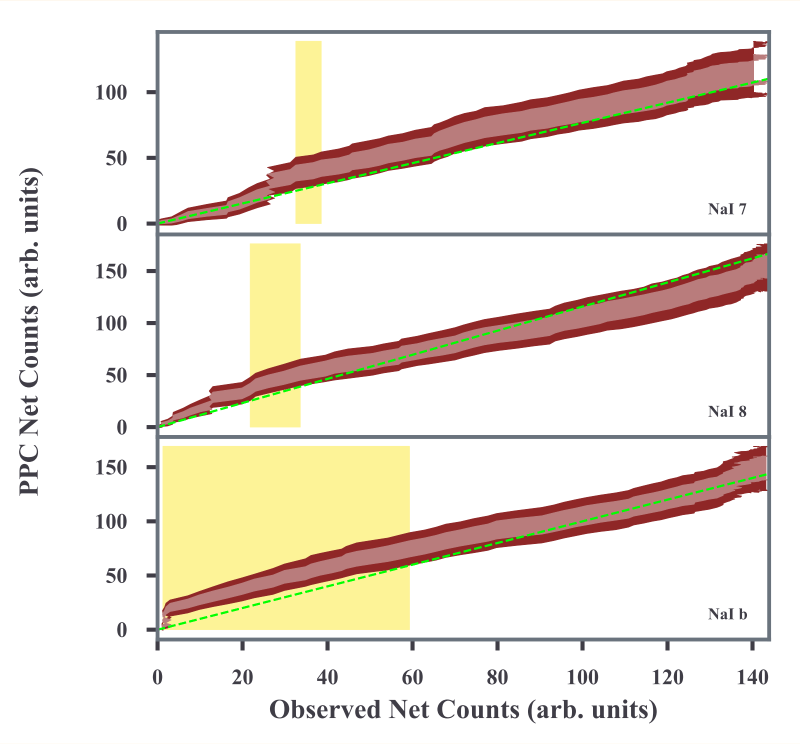
PPCs express the volume in the posterior and the likelihood. Residuals only contain the information about the distance from data to model at one (non-unique) location on a surface.

POSTERIOR PREDICTIVE CHECKS

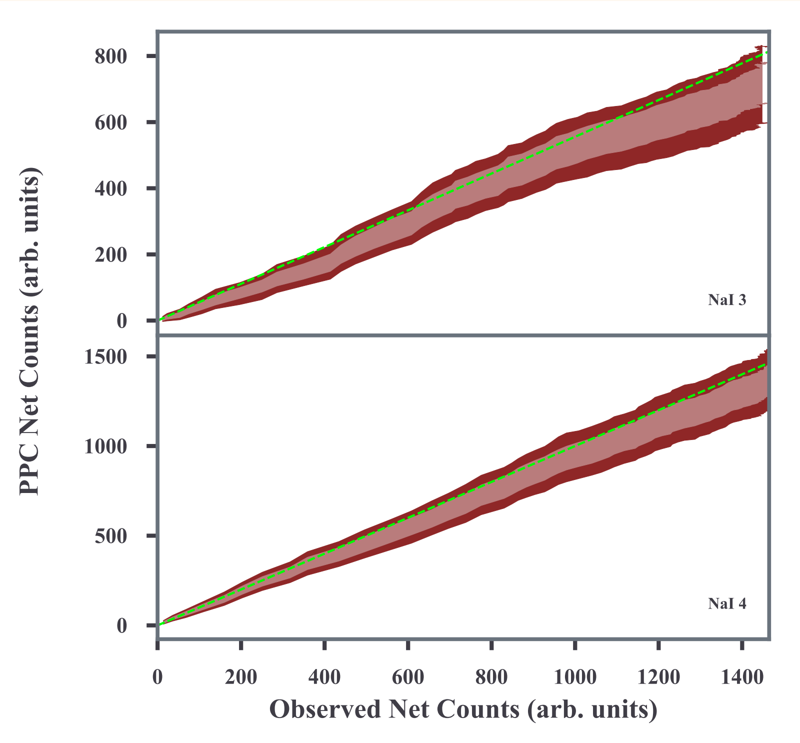
A "good" fit



A "bad" fit



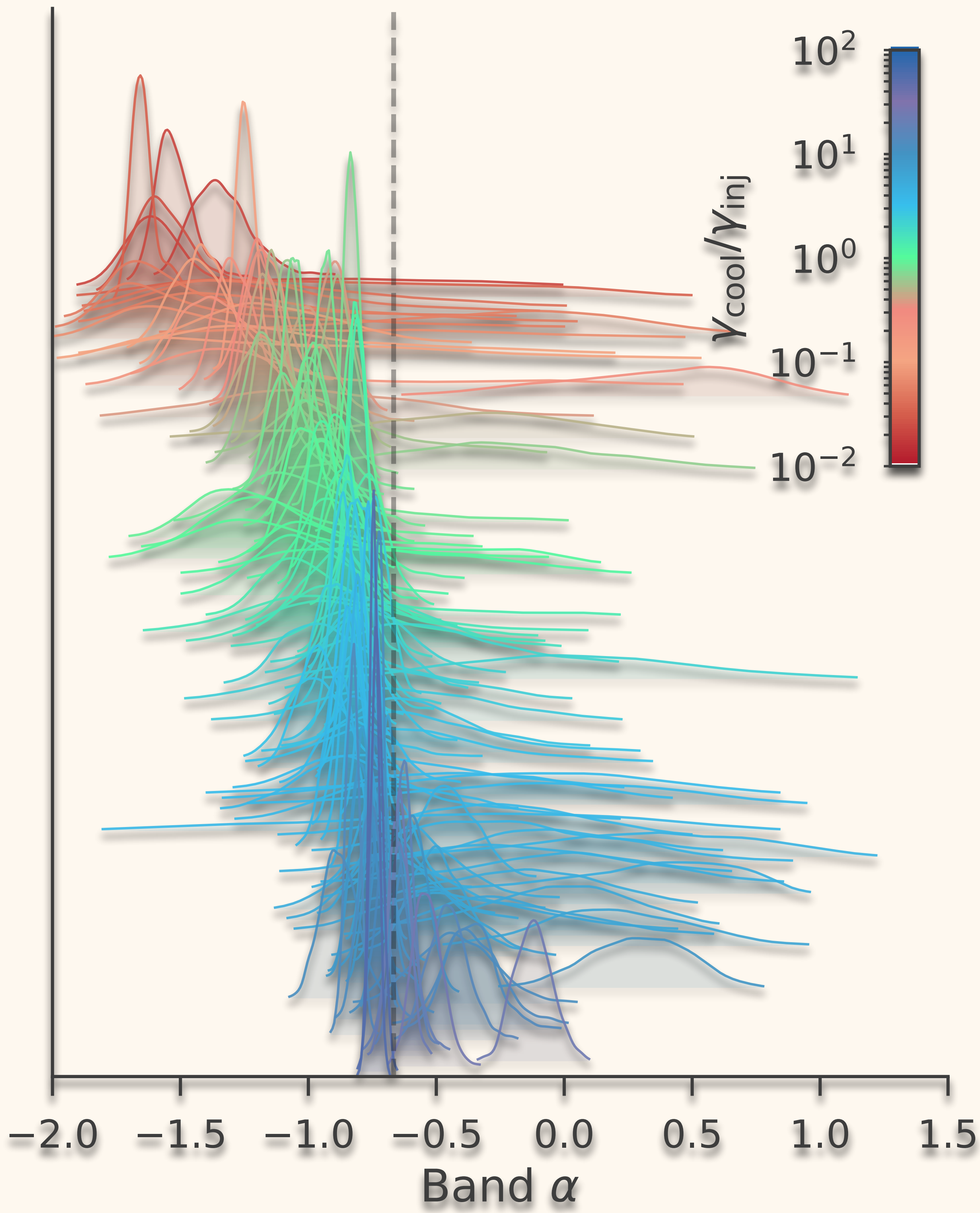
Simulated data



We can compress the PPCs via QQ plots. However, this looses information.

Importantly, we can see that even when we simulate and fit the true model, fluctuations manifest.

THERE IS NO LINE OF DEATH



The band function is not a useful probe of physics!

The marginal distributions of alpha violate the line of death whilst the data are fully consistent with the data!

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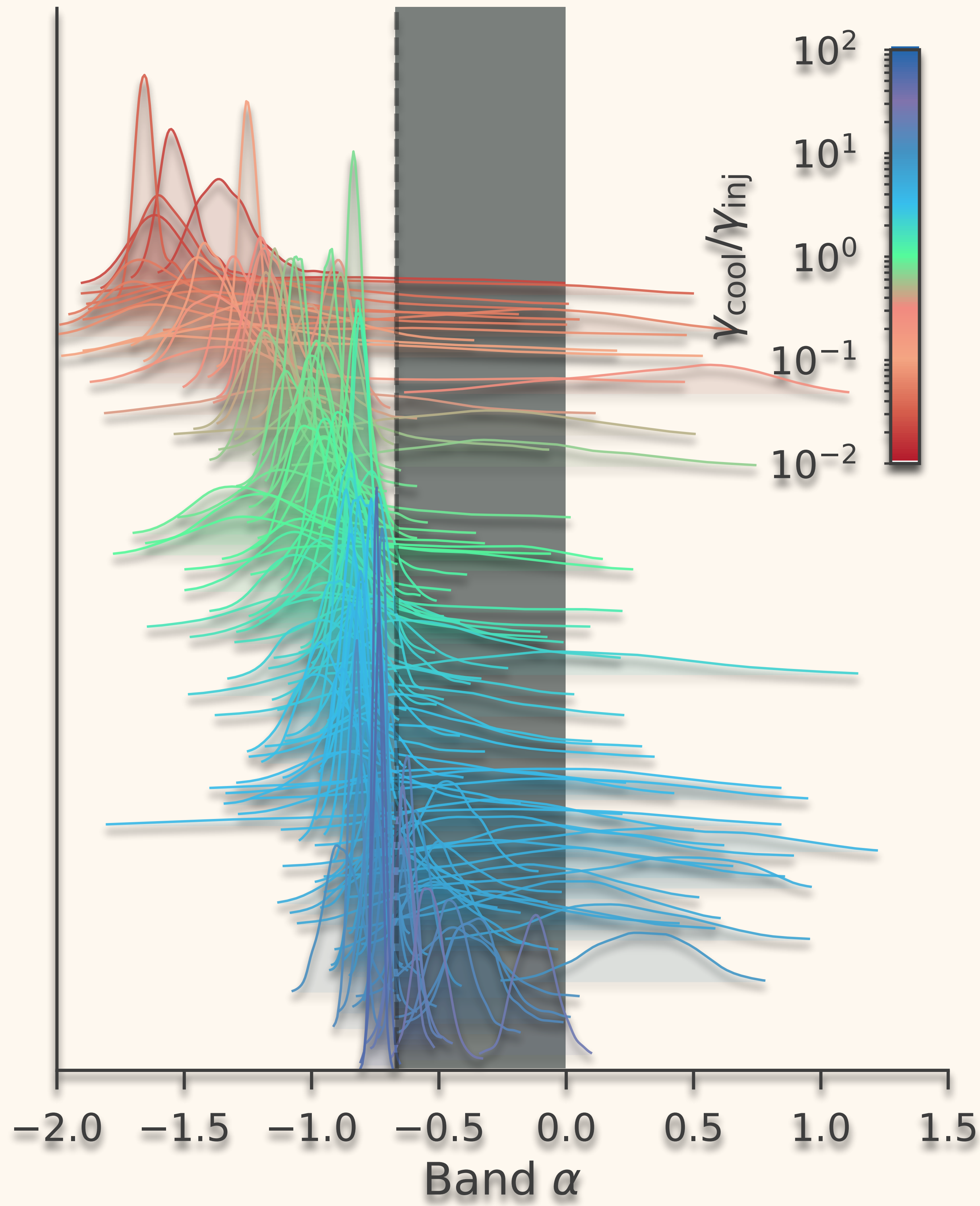

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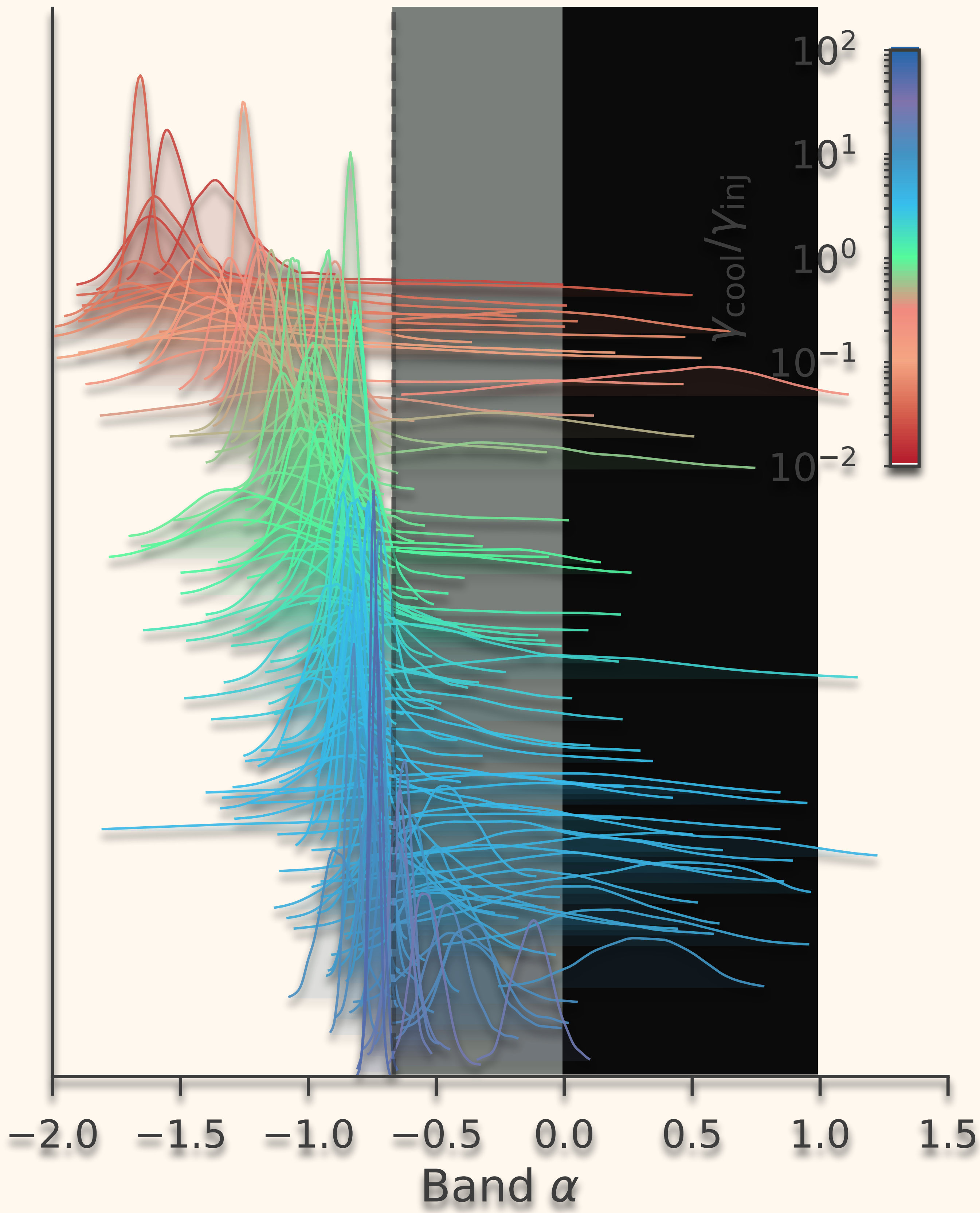

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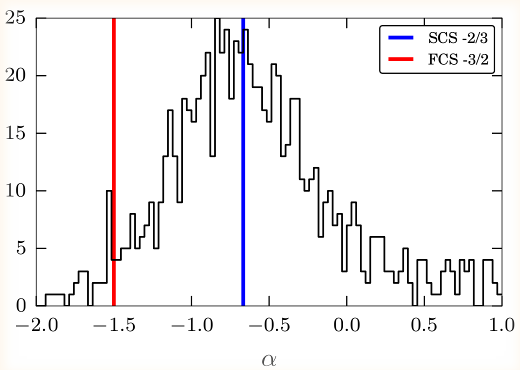

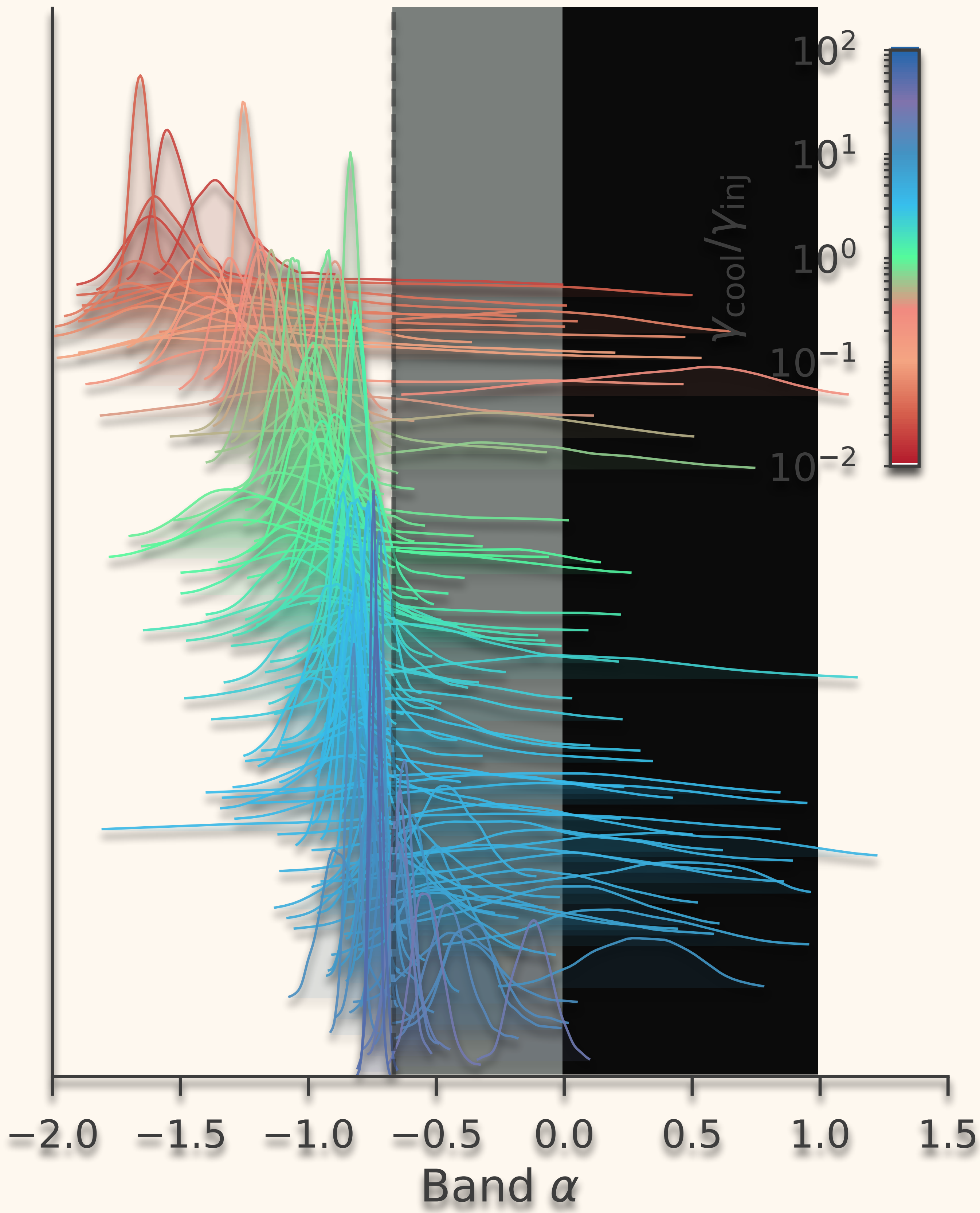

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LIMITS FROM THE FIREBALL MODEL

We want to use our fits to compute physics about the outflows.

$$\Gamma_{\mathrm{obs}} \geq \Gamma_{\gamma\gamma} = \left(\frac{f_{\mathrm{p}} L_{\mathrm{obs}} \sigma_{\mathrm{T}}}{r_0^2 m_{\mathrm{e}} c^2} \right)^{\frac{1}{4+2\beta}}$$

A lower limit from pair-opacity

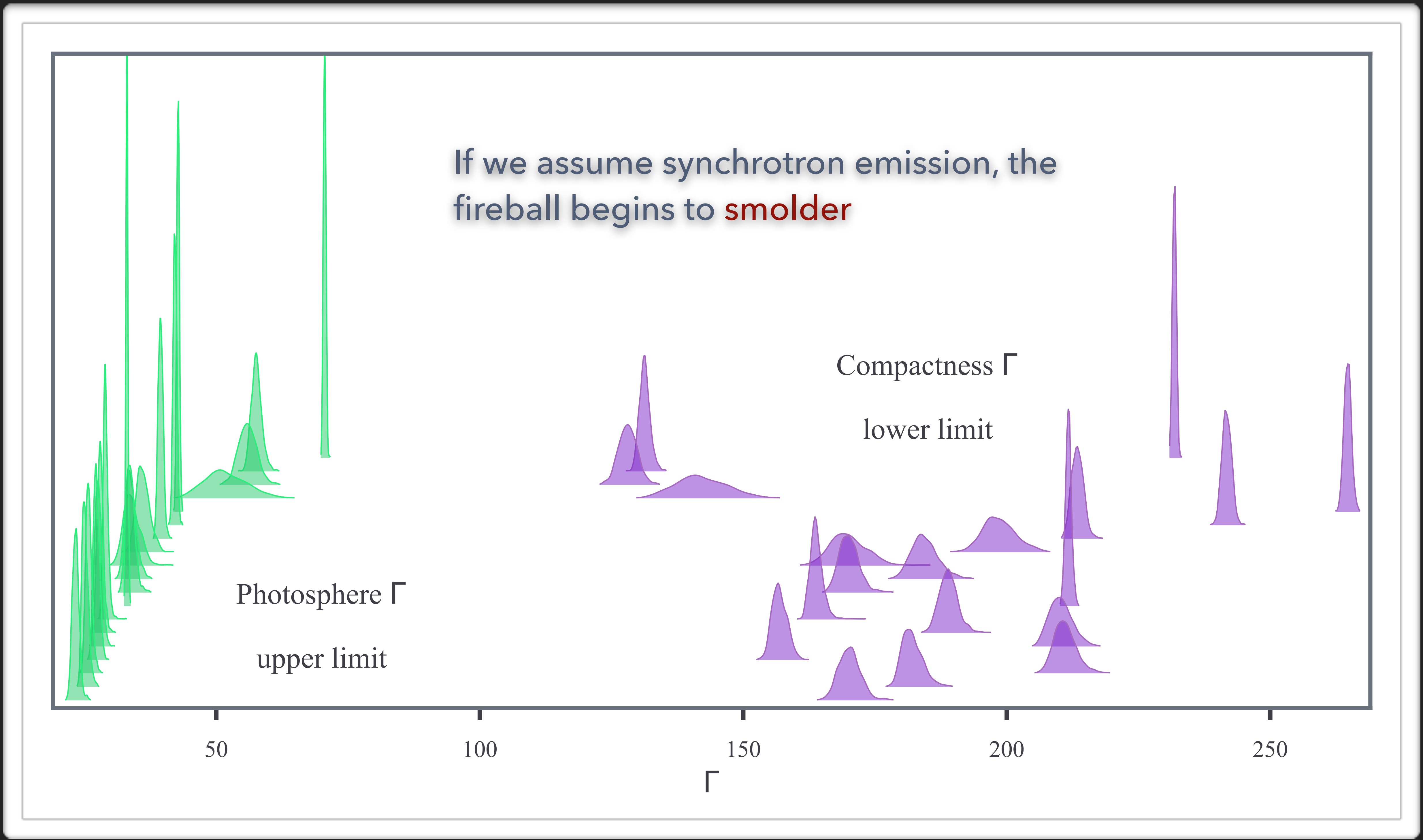
$$\Gamma_{\mathrm{obs}} \leq \Gamma_{\mathrm{photosphere}} = \frac{\sqrt{2}}{4} \frac{\varepsilon^{1/8} L_{\mathrm{obs}}^{1/4} \sigma_{\mathrm{T}}^{1/4}}{\pi^{1/4} r_0^{1/4} (1+z)^{3/2} c^{3/4} m_{\mathrm{p}}^{1/4}}$$

An upper limit from lack of a photosphere.

The peak of the emission is non-thermal in our model and we do not require an additional thermal component to model the data.

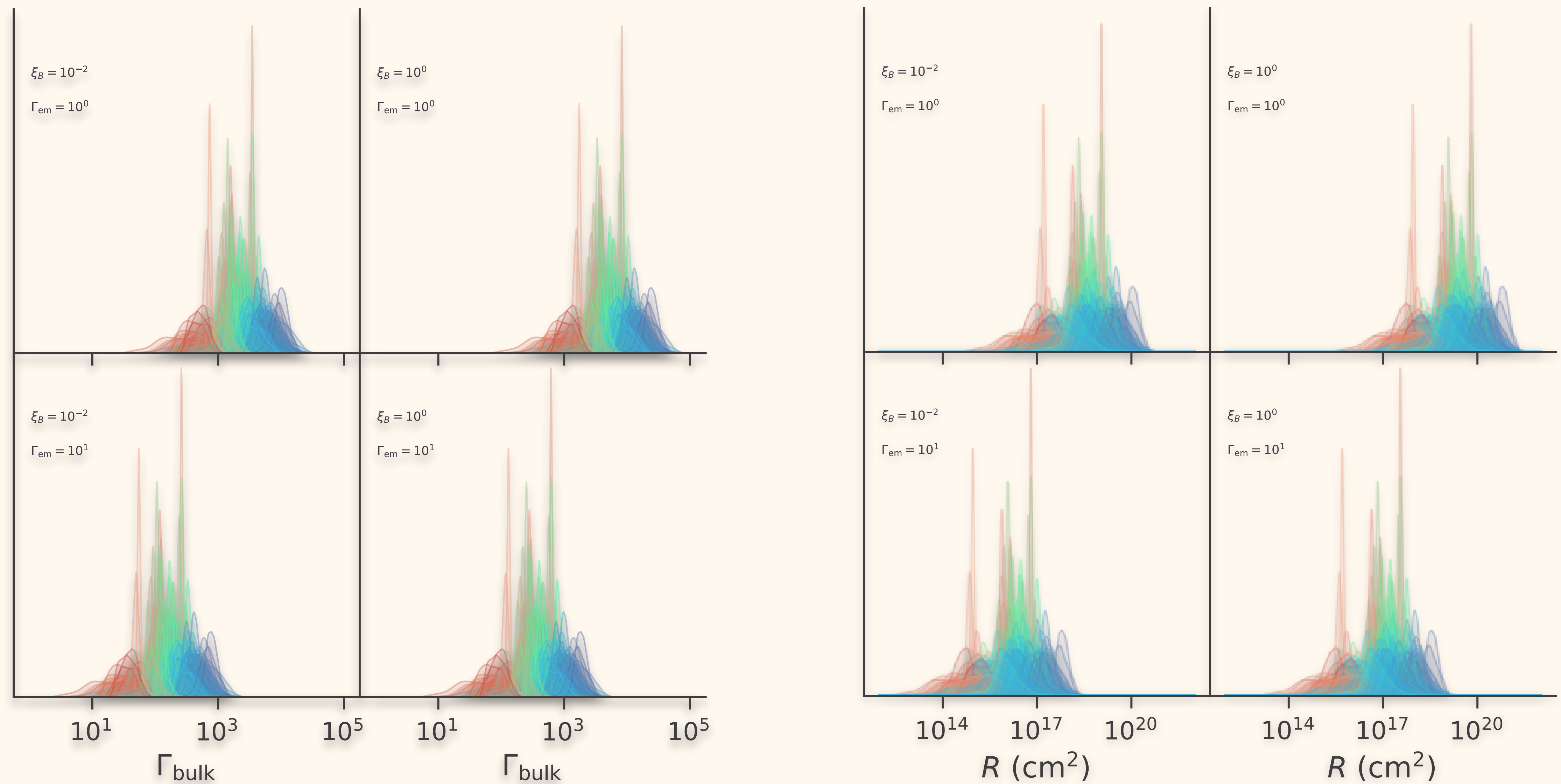
We **conservatively** assume that there could be a subdominant thermal component with **50% of the energy flux** from the observed emission.

WHERE THERE IS SMOKE, THERE WAS ONCE A FIREBALL MODEL



This falls apart IF the νF_{ν} peak is photospheric.
See Vianello, Gill, Granot + (2018)

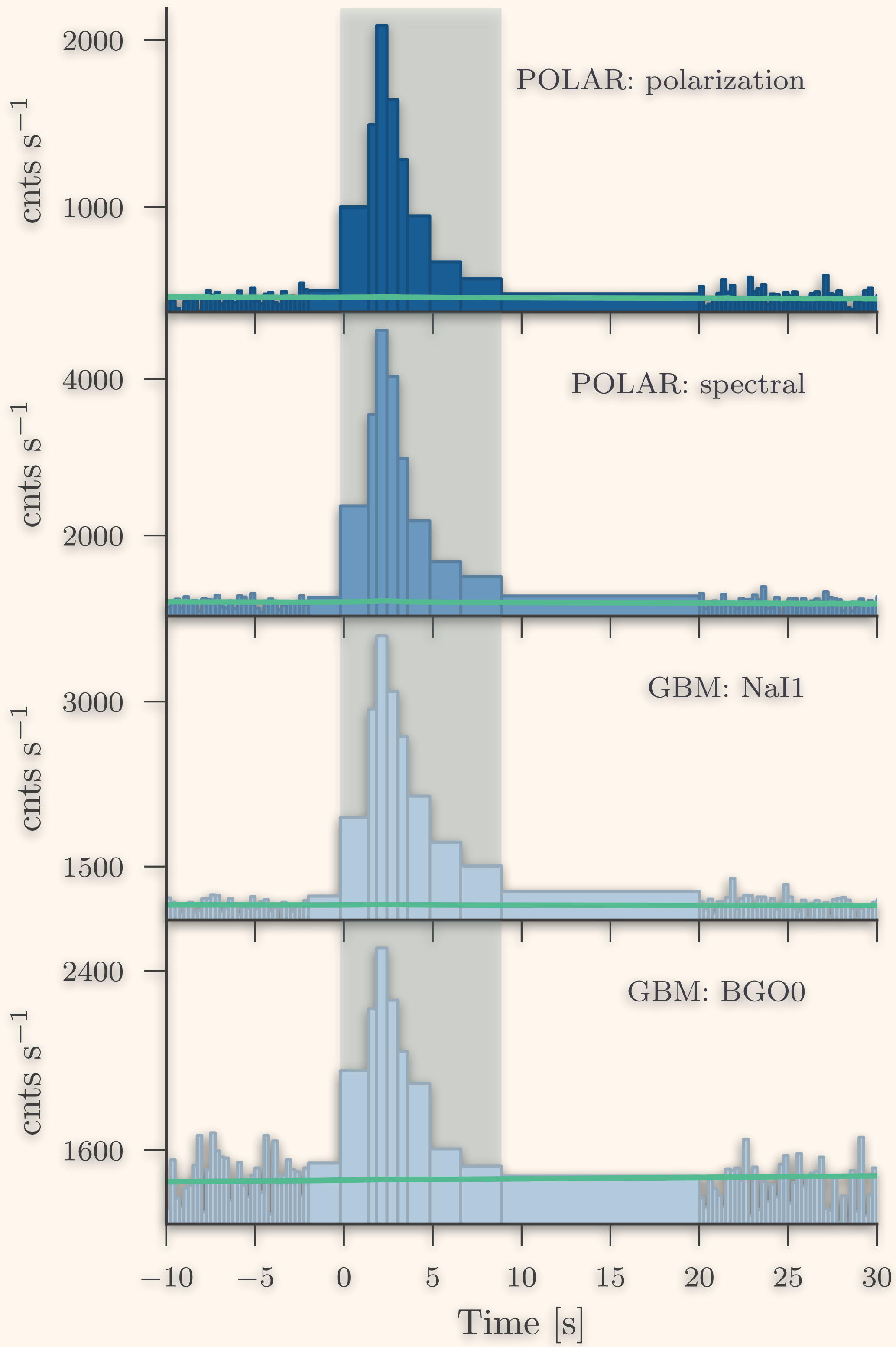
MANY BURST IMPLY MINI-JETS



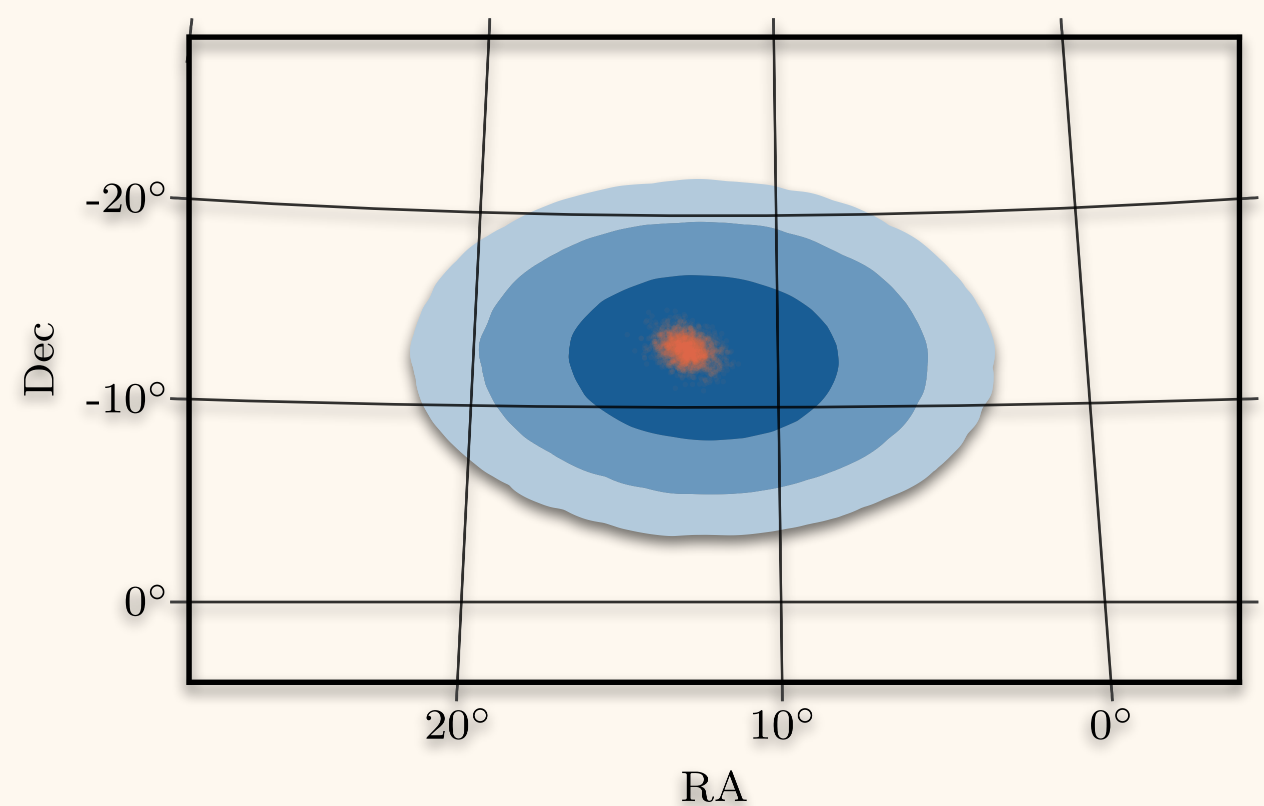
No fireball implies magnetization, but this pushes the emission site far beyond classical deceleration radius. Thus, we invoke comoving emission sites (some would say mini-jets) which allow for sane emission radii.

NOW A BIT OF POLARIZATION WITH POLAR

GRB 170114A



- Seen by GBM+POLAR
- Bayesian block temporal binning
- BALROG location consistent with IPN



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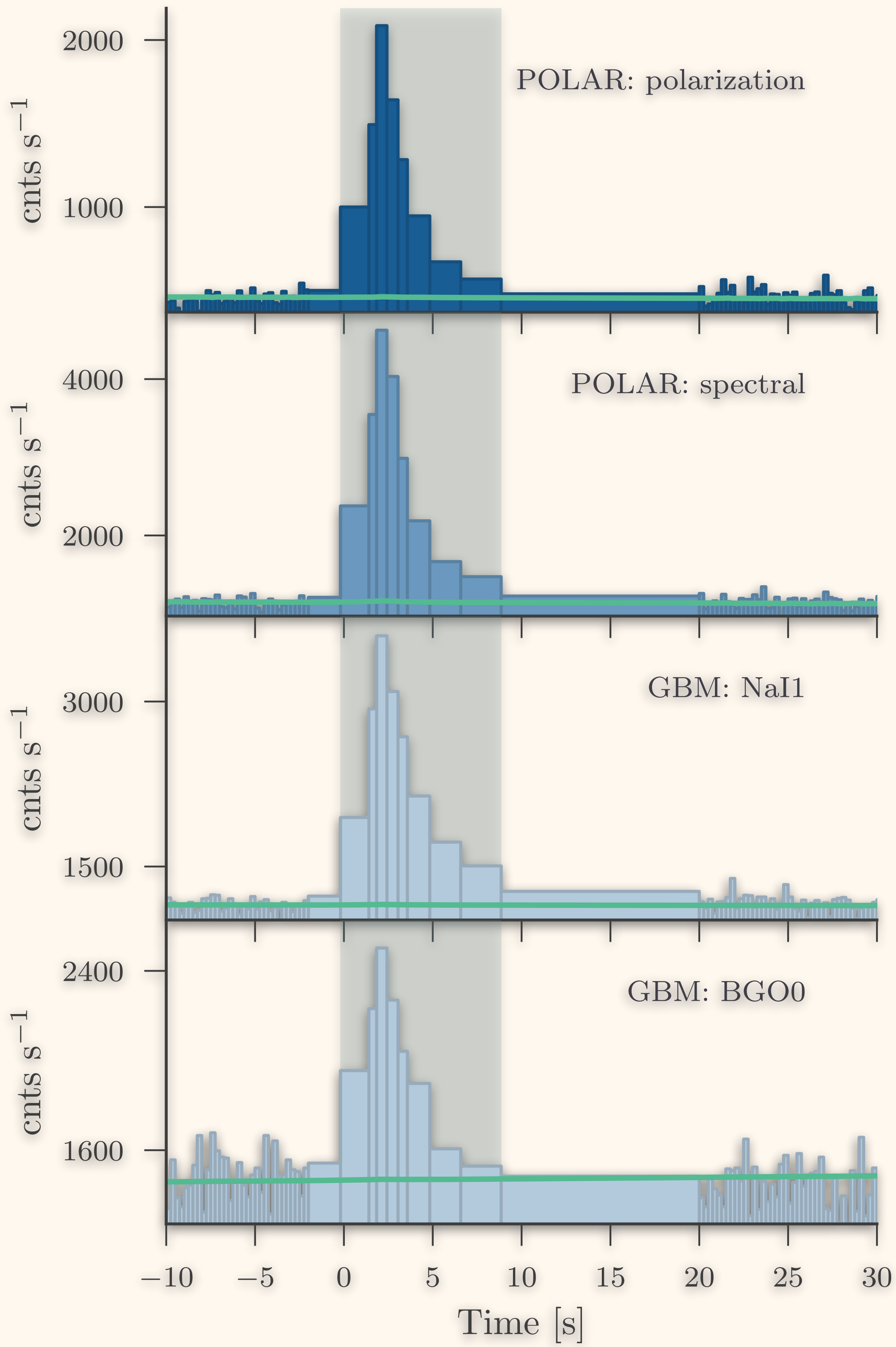

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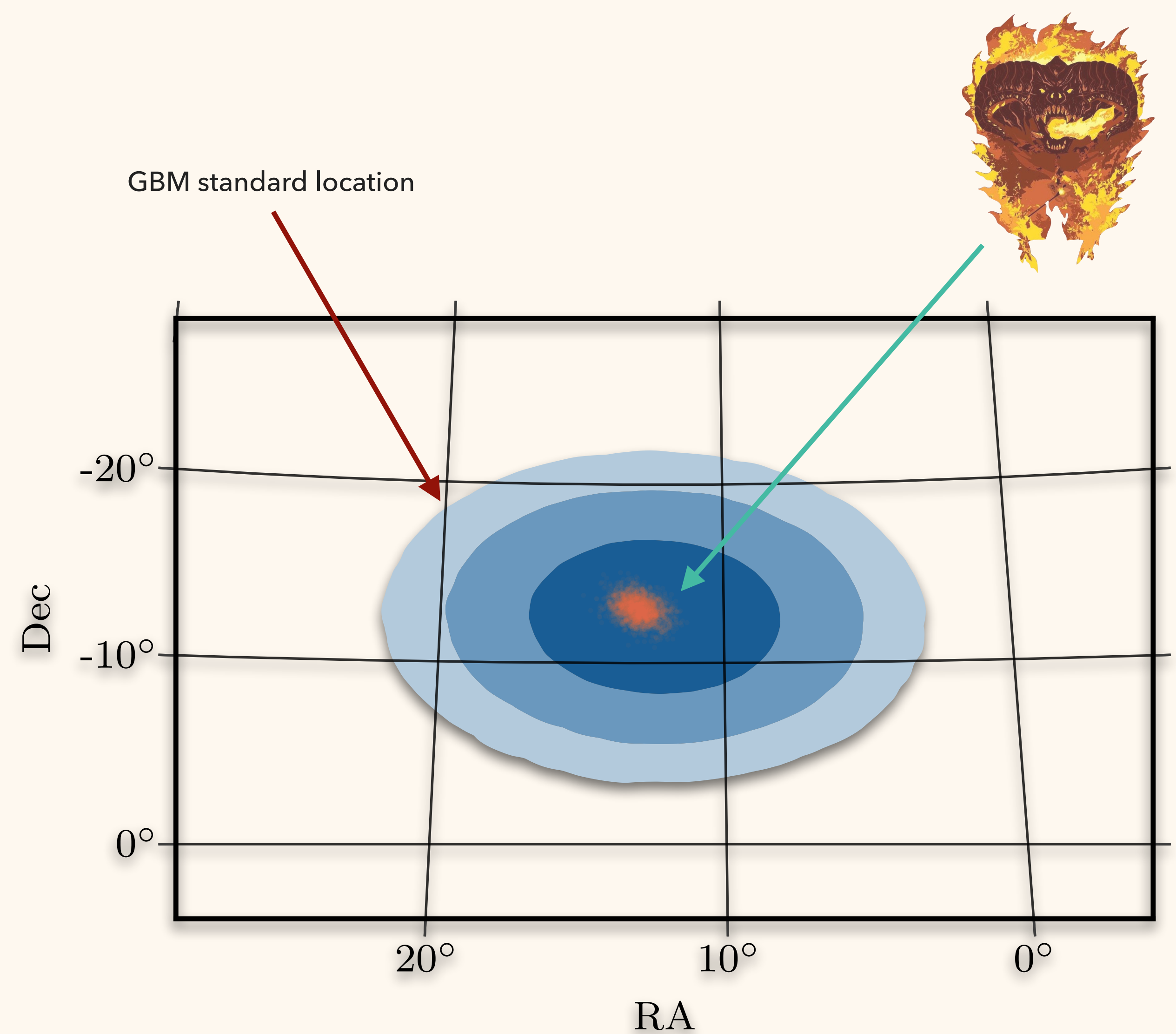


WHAT ARE THE DATA?

Polarization likelihood — Spectral likelihood

$$\pi(\bar{p}, \phi, \psi \,|\, N) \propto \pi(\bar{p})\pi(\phi)\pi(\psi) \boxed{\prod_k \pi(\lambda_k(\bar{p}, \phi; \psi) \,|\, n_k)\pi(\lambda_k^b \,|\, b_k)} \boxed{\prod_j \pi(\gamma_j(\psi) \,|\, m_j)\pi(\gamma_j^b \,|\, b_j)}$$

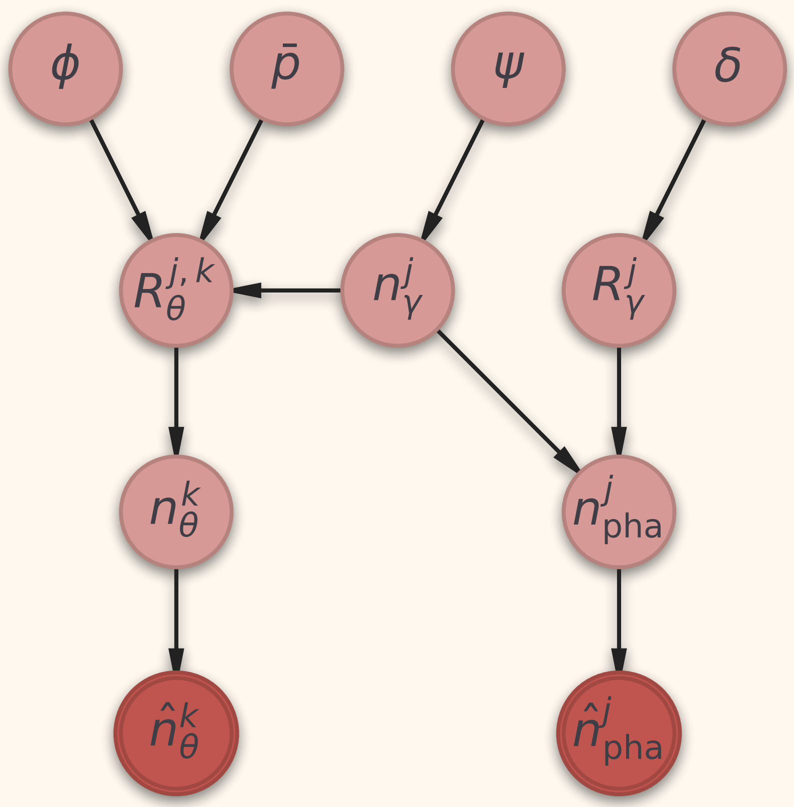
Latent data:

$$\lambda_k(\bar{p}, \phi; \psi) = \int \mathrm{d}\varepsilon \; n_\gamma(\varepsilon; \psi) R^k(\varepsilon, \phi, \bar{p}) \qquad \gamma_j(\psi) = \int_{\varepsilon_{1,j}}^{\varepsilon_{2,j}} \mathrm{d}\varepsilon \; n_\gamma(\varepsilon; \psi) R^j(\varepsilon)$$

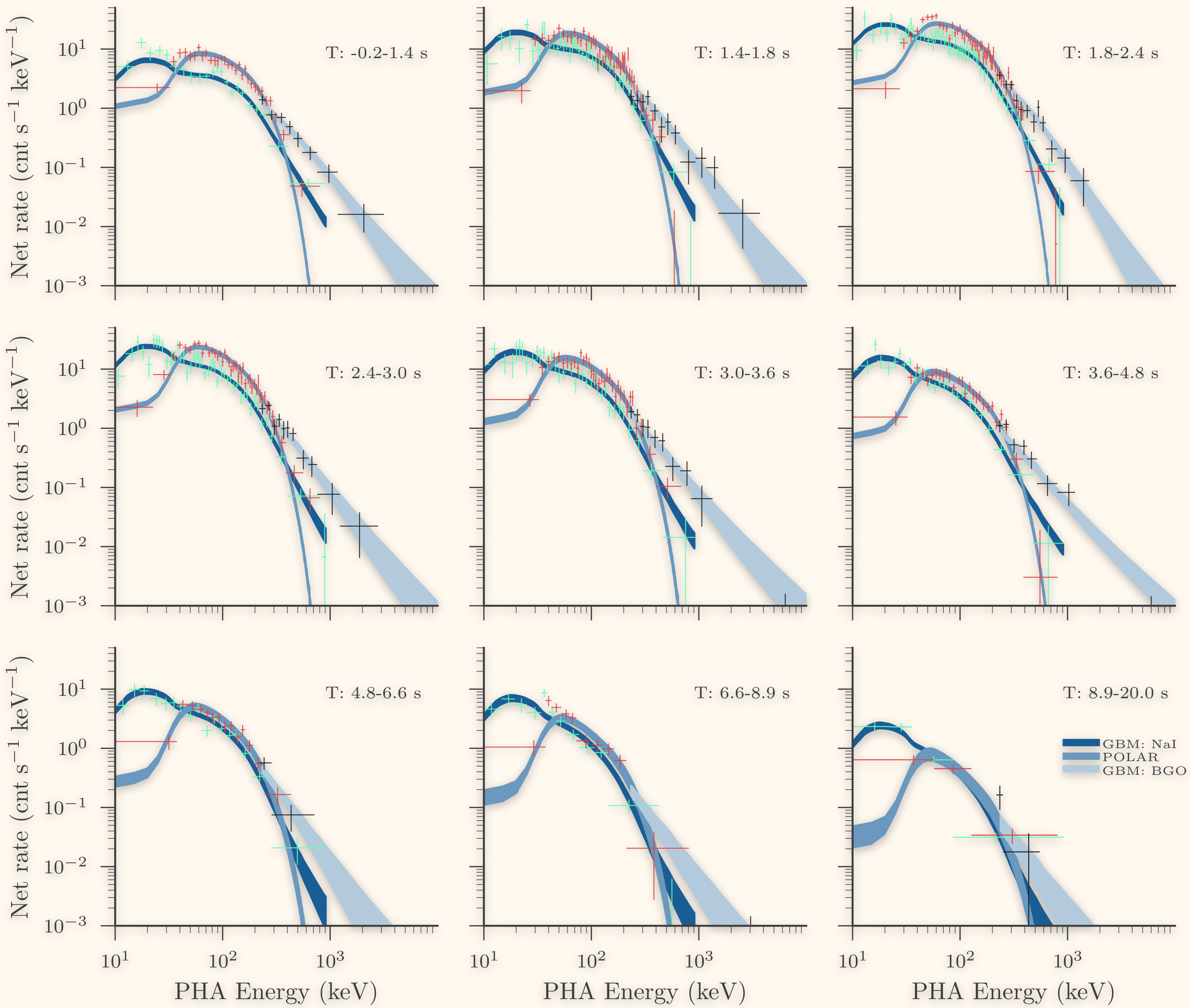
Our full posterior relies on the **polarization** data and the **spectral** data.

The posterior **cannot be analytically** determined as proposed in the past.

This is why we have numeric integration routines!



SPECTRAL ANALYSIS



- POLAR+GBM data calibrated well
- Emission described with **synchrotron**
- No Band function!

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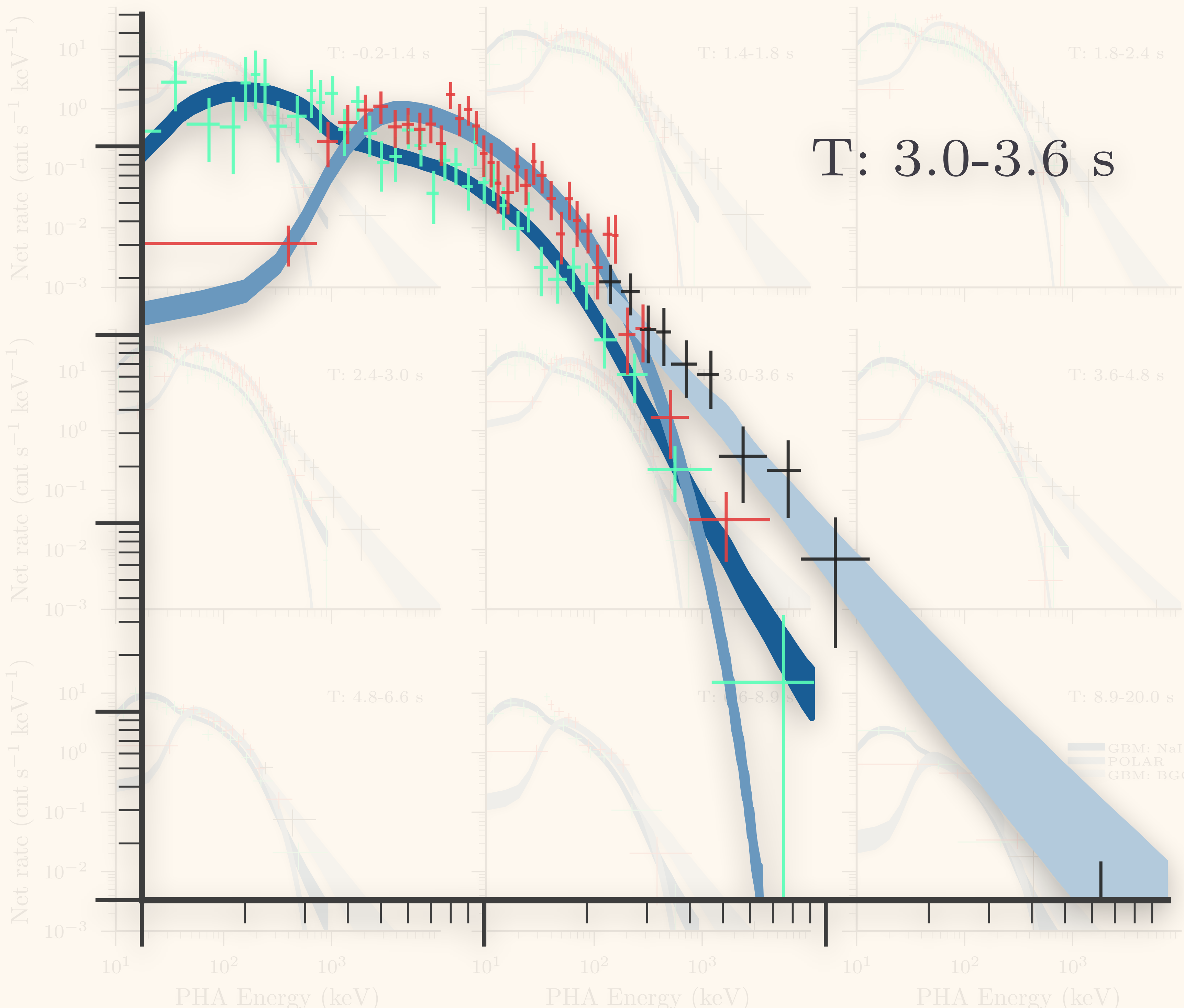

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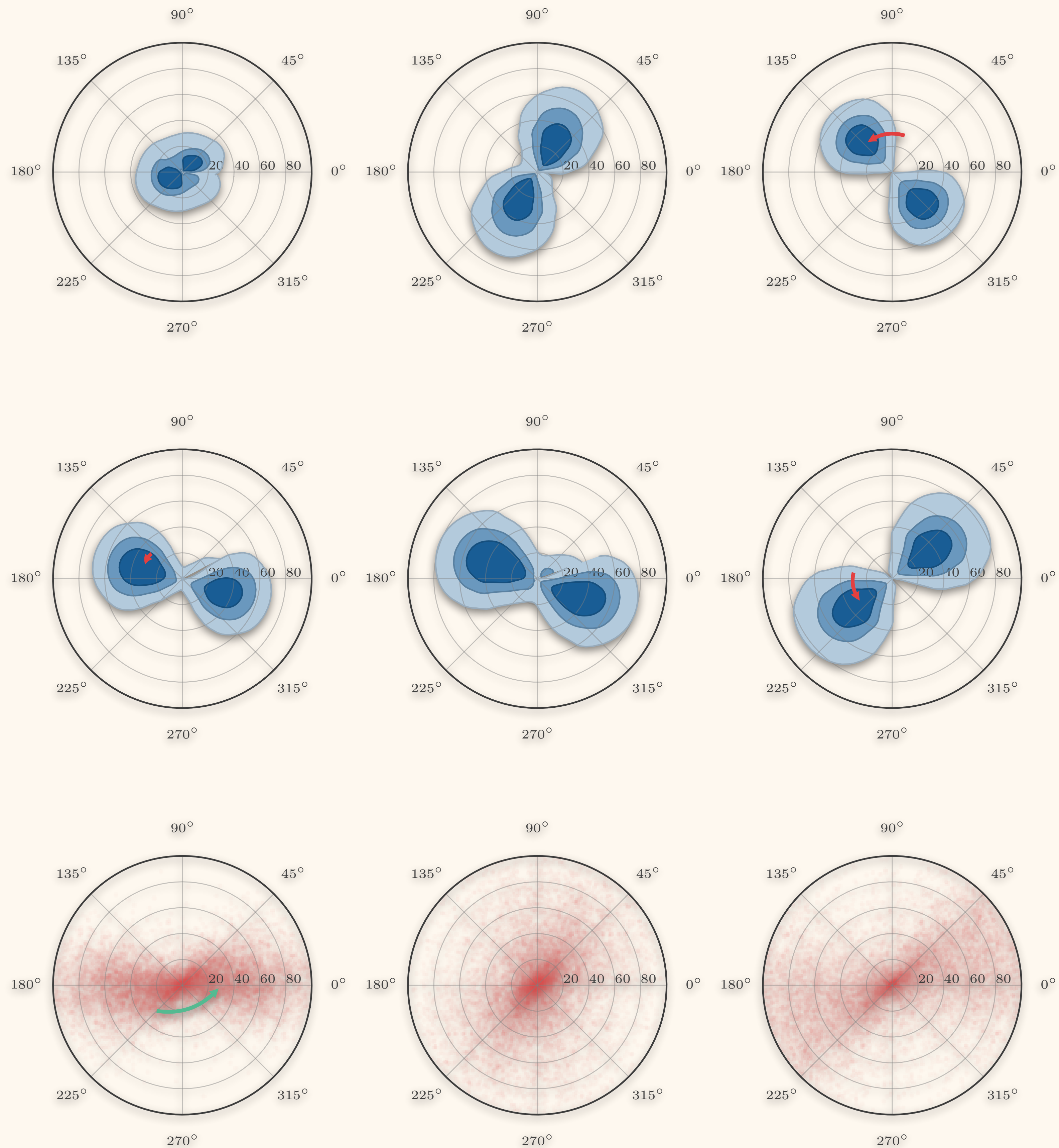
POLARIZATION (POLAR PLOTS)

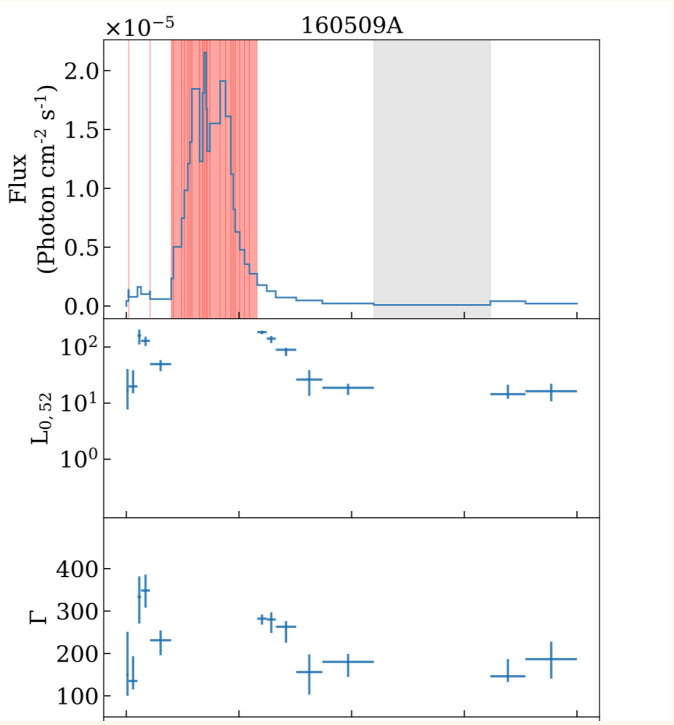


FOR DETAILS ON POLAR SEE NICOLAS' TALK

CONCLUSIONS

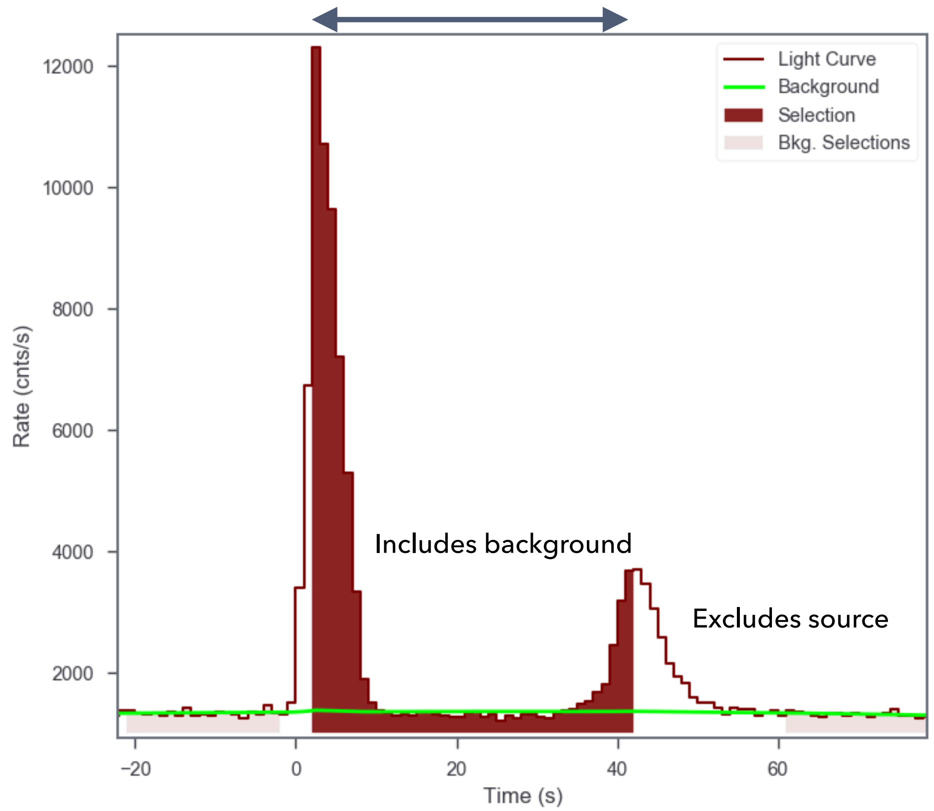
- The line of death is no longer a subject we should concentrate on
- Synchrotron emission fits the data of both instruments well
- Proper statistical modeling of polarization data allows for richer science
- Polarized emission combined with synchrotron spectra can provides a smoking gun for GRB emission theory
- We need better predictive theories and more physical model fits to move forward

New results from Ahlgren + (2019) show that subphotospheric dissipation cannot explain the emission!

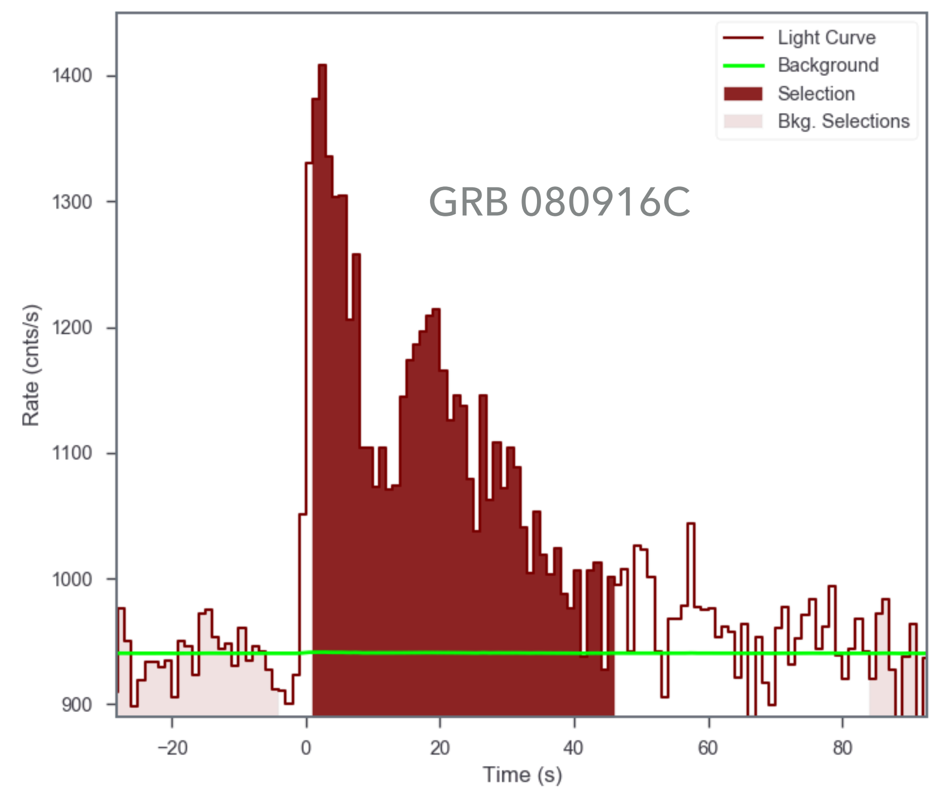


Backup slides

GBM catalog fluence selection
(available online)

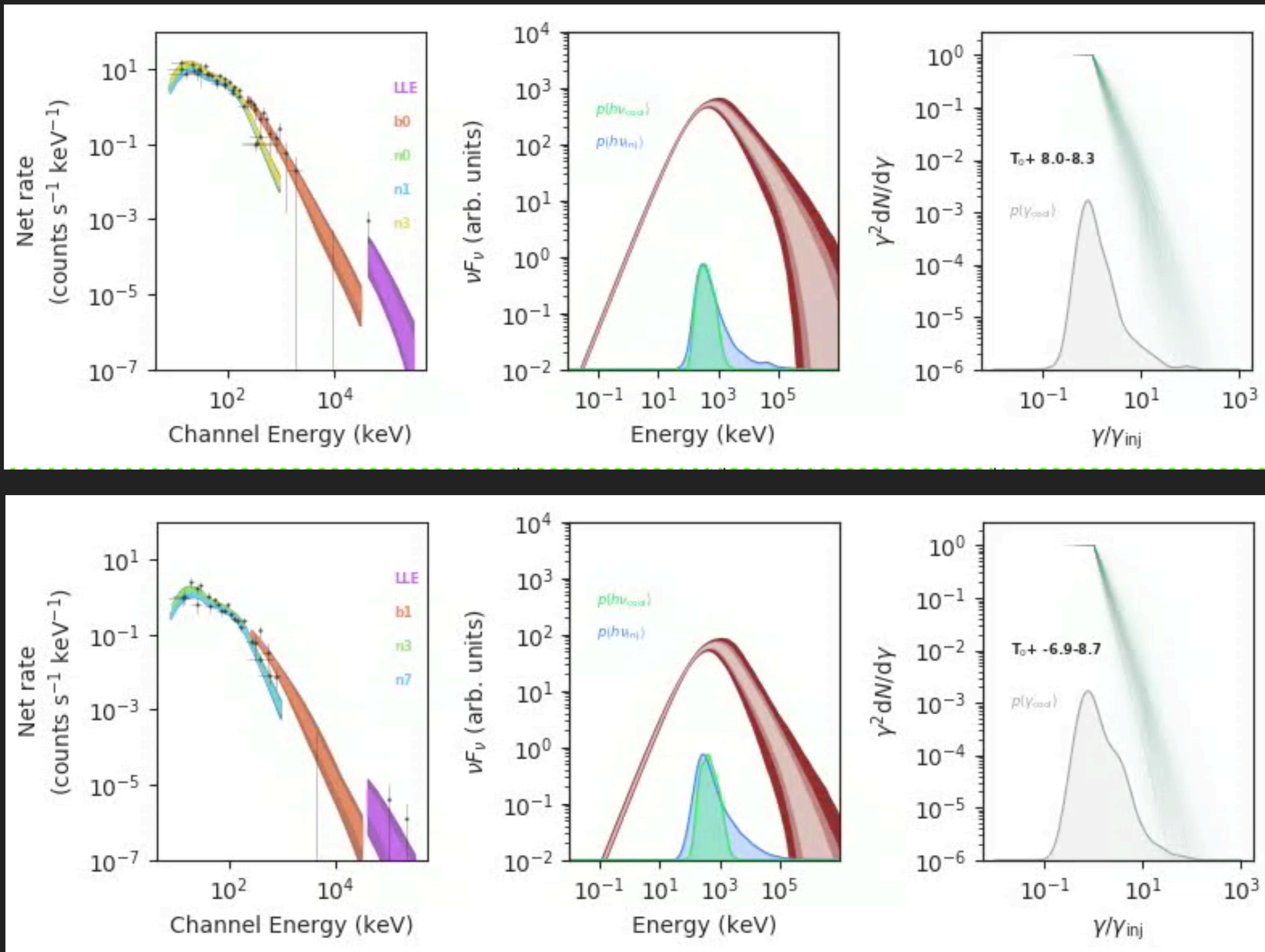


Our alpha values may differ from the catalog. This is likely due to the source selection applied to the catalog. Often, background is included in the spectral fit or the source is not fully selected. This occurs even for landmark GRBs.



When in doubt, always analyze GRBs yourself!

MODEL MEET DATA



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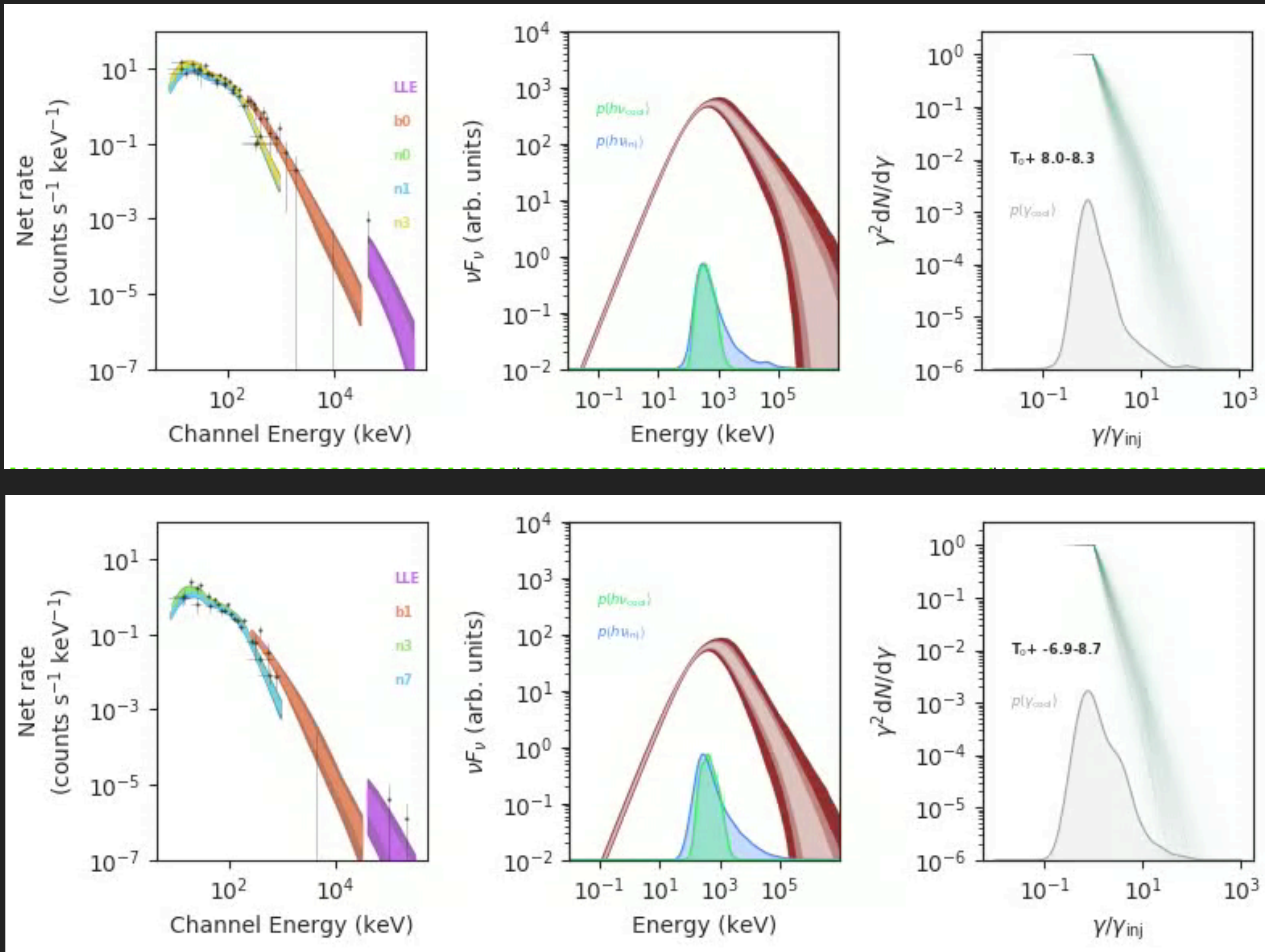
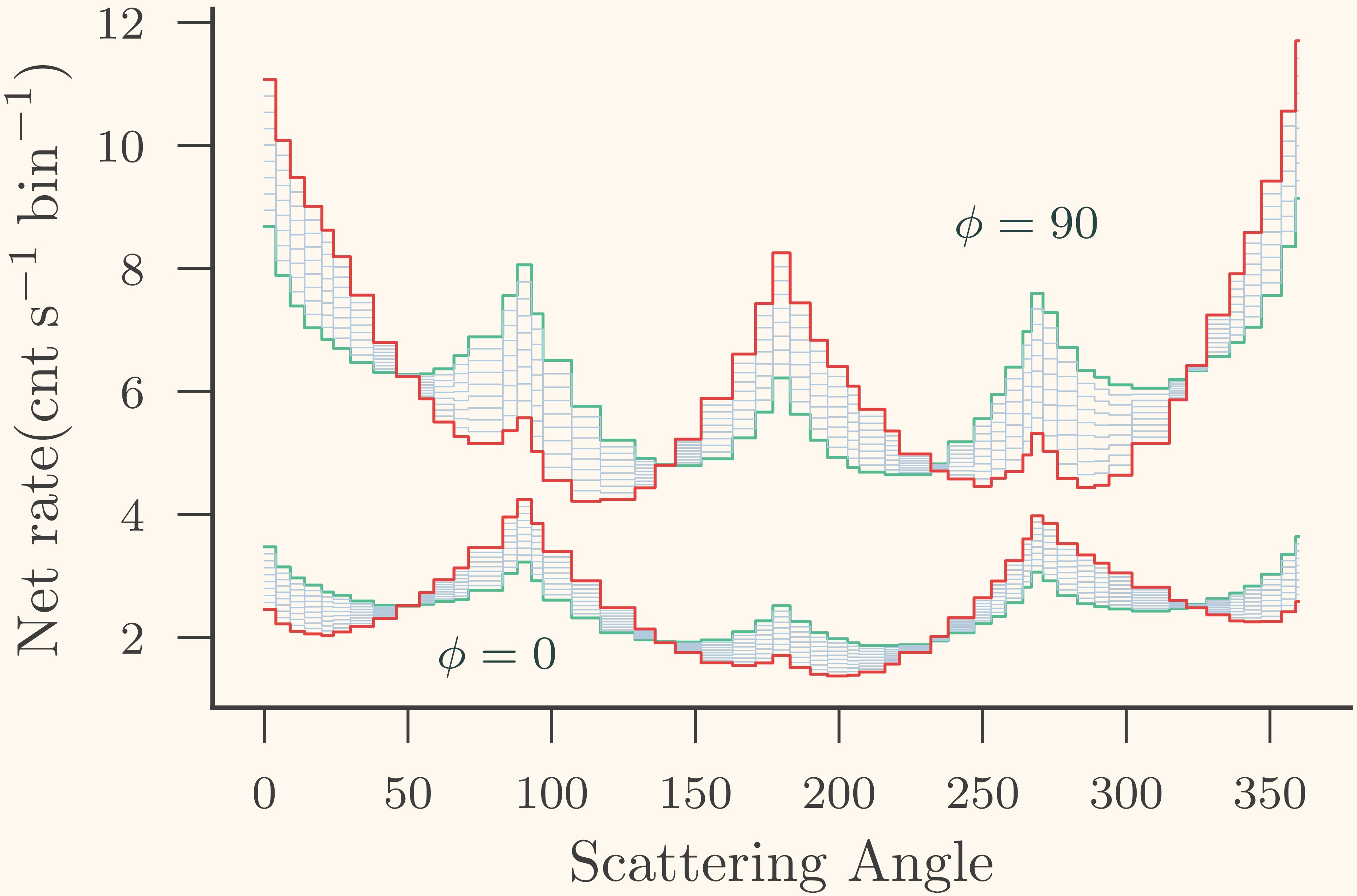
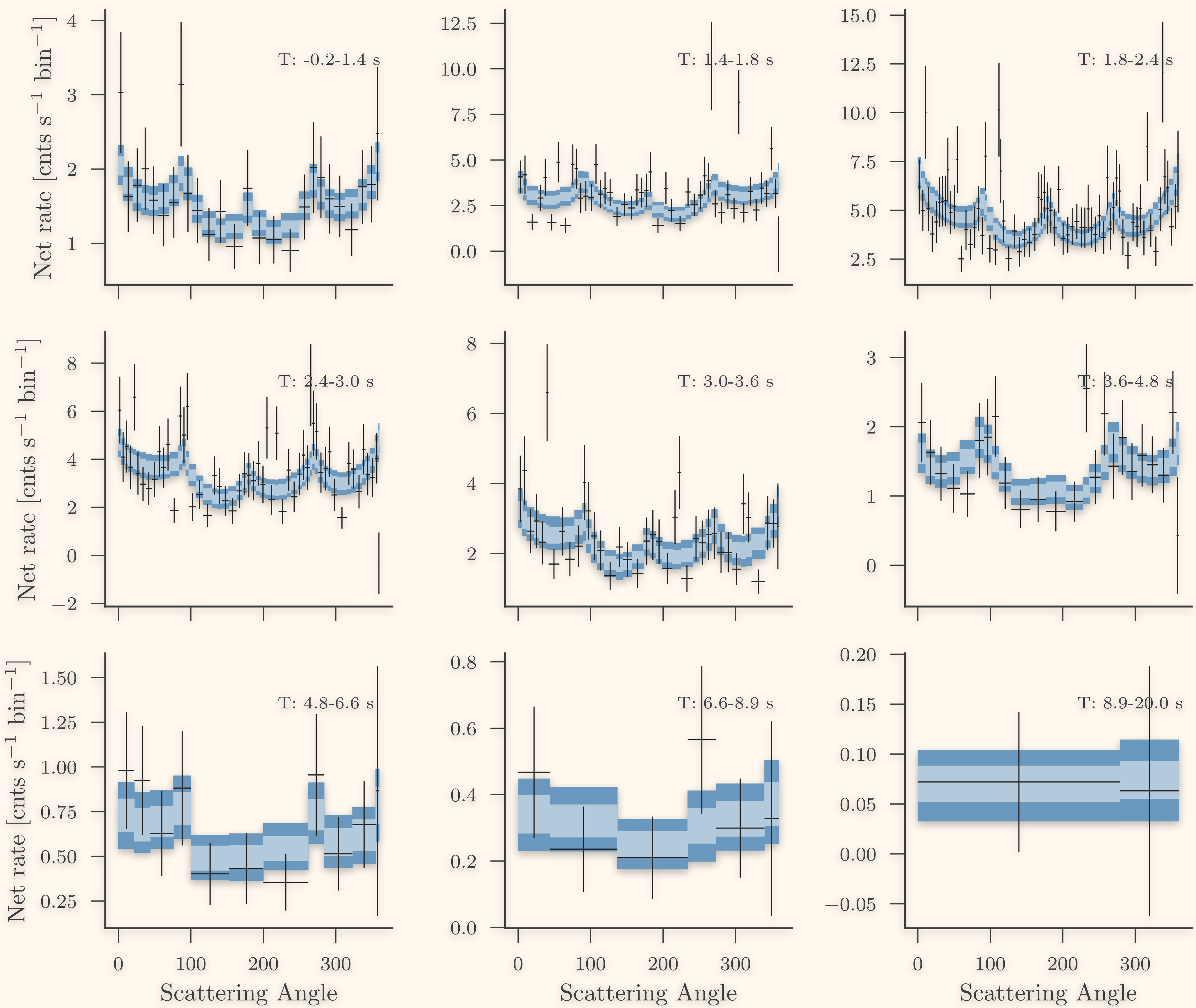


POLAR RESPONSE: FORWARD FOLDING

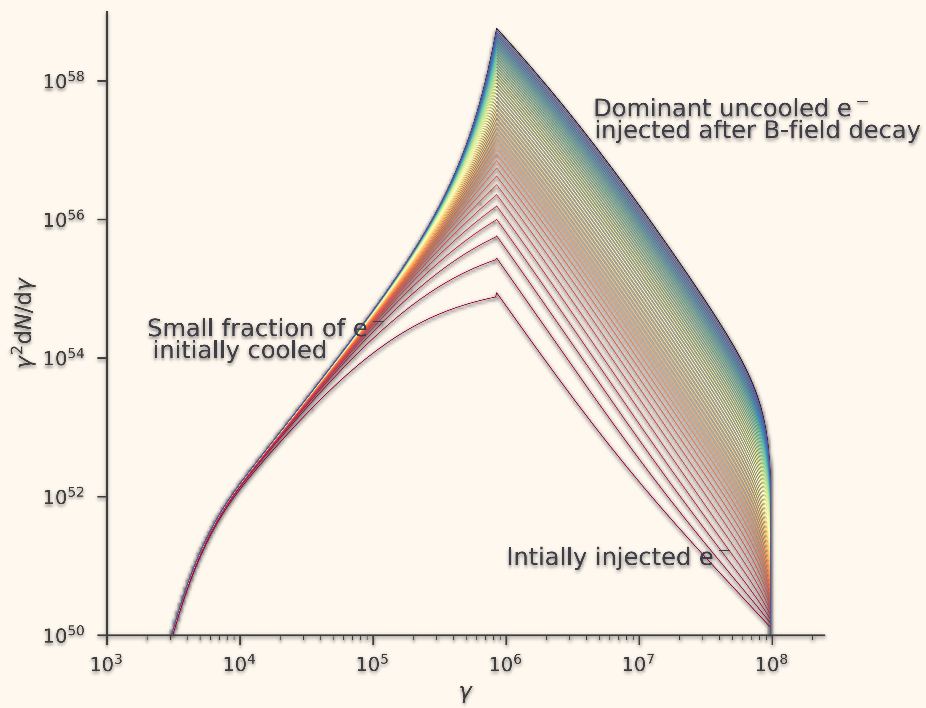


Merlin Kole has created polarization + energy responses for POLAR which allow fo fitting in the true data space via proposed photon and polarization models.

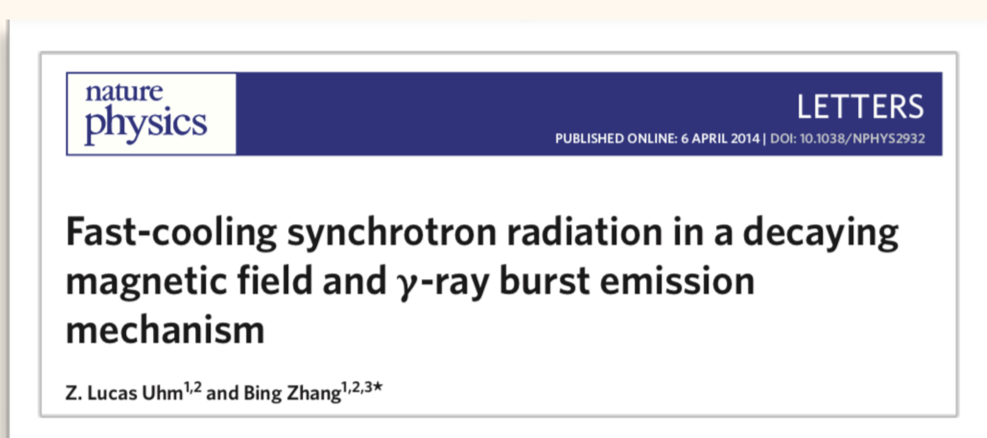
MODEL IN THE DATA SPACE



"FAST" COOLING BUT ACTUALLY A LITTLE SLOW



Uhm & Zhang claim that a decaying temporally/radially decaying magnetic field allows for the fast-cooled synchrotron model to be saved.

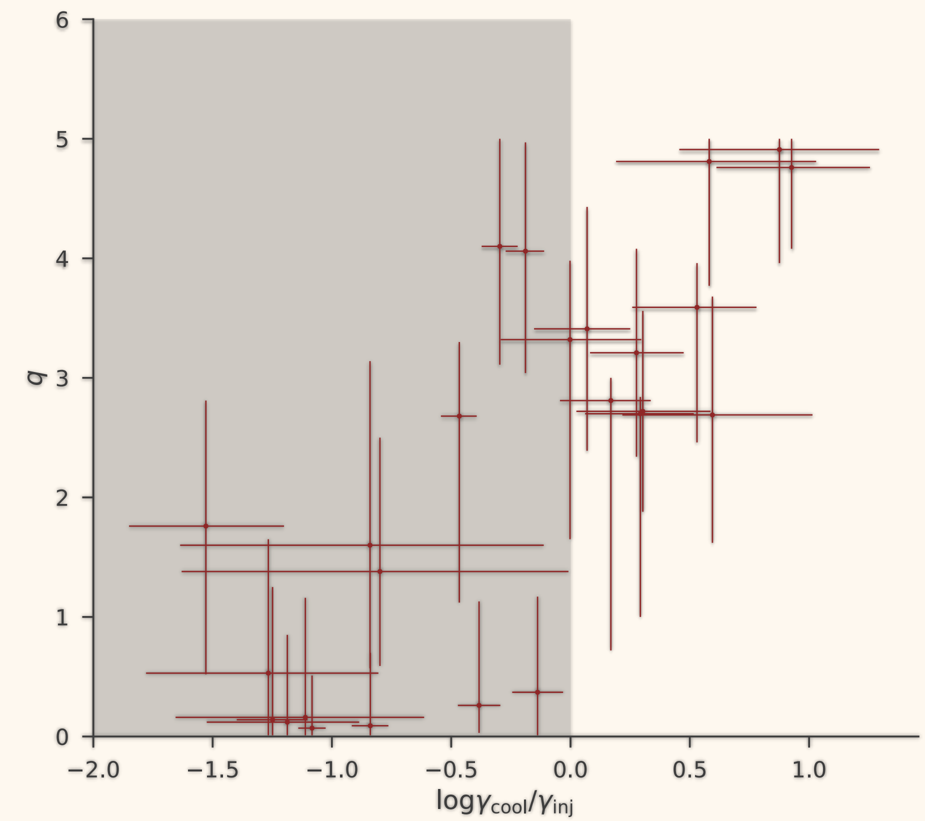

nature physics

LETTERS

PUBLISHED ONLINE: 6 APRIL 2014 | DOI: 10.1038/NPHYS2932

Fast-cooling synchrotron radiation in a decaying magnetic field and γ-ray burst emission mechanism

Z. Lucas Uhm[1,2] and Bing Zhang[1,2,3*]



$$Q(\gamma, t) \propto t^q \, \gamma^{-p} \quad \forall \gamma \geq \gamma_{\rm inj}$$

We see that our cooling is tied to their injection rate which implies that they are simply compensating for no cooling with injection. In other words, it is not a fast cooling model.

OPEN SOURCE SOFTWARE

3ML

The Multi-Mission Maximum Likelihood framework

CONCEPT

- Multi-Mission, Multi-wavelength, Multi-species analysis
- Plugin based system (many provided but build your own)
- Maximum Likelihood and Bayesian analysis
- Time-Energy-Polarization dependent likelihood
- Python based + C interface

PLUGINS

- Generic XY data
- OGIP/FITS/XSPEC-style data
- Photometric Spectra
- Fermi-LAT
- HAWC
- VERITAS
- MAGIC
- POLAR

MODELS

- 1,2,3 -D models
- Basic spectral models
- Extended source models (dark matter, etc.)
- All XSPEC models
- Custom models (on the fly!)

threeml.readthedocs.io

https://github.com/giacomov/3ML