GRBS CAN BE COOL
SYNCHROTRON SOURCES

SPECTRAL AND POLARIZATION RESULTS FROM POLAR AND FERMI

J. MICHAEL BURGESS
DAMIEN BÉGUÉ        MERLIN KOLE
JOCHEN GREINER
FRANCESCO BERLATO
+
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 GBM GRB alpha distribution

The Band function is function.

It is only a function.

No physics.

No story.

Stop using it.
Fokker-Planck equation

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

\[ Q(\gamma) \propto \gamma^{-p} \quad \forall \gamma \geq \gamma_{\text{inj}} \]

\[ C(\gamma) = -\frac{\sigma_T}{6\pi m_e c} B^2 \gamma^2 \]

Power law injection synchrotron cooling

Synchrotron emission

\[ n_\nu(\epsilon; t) = \int_1^{\gamma_{\text{max}}} d\gamma n_e(\gamma, t) \Phi \left( \frac{2\epsilon b_{\text{crit}}}{3B\gamma^2} \right) \]

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

Standard synchrotron emission model. No bells or whistles (or SSC/IC). The model allows us to test all synchrotron cooling regimes as a parameter!
\[ \gamma_{\text{inj}} \] Injection electron energy
\[ \gamma_{\text{cool}} \] 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

- **Data I**: Instrument I, Plugin I, Likelihood I
- **Data II**: Instrument II, Plugin II, Likelihood II
- **Data III**: Instrument III, Plugin III, Likelihood III

- **Parameter Exploration**
  - Plot
  - Propagate
  - Compare

SEE OUR POSTER!
We fit 18 single pulse GRBs with redshift.

168 time-resolved spectra.
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

\[ \pi(\tilde{y} | y) = \int d\theta \pi(\tilde{y} | \theta) \pi(\theta | y) \]
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\[ \pi(\tilde{y} | y) = \int d\theta \pi(\tilde{y} | \theta) \pi(\theta | y) \]

replicated data

likelihood

measured data

posterior
POSTERIOR PREDICTIVE CHECKS

Replicated data percentiles

Observed data

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.
A “good” fit

A “bad” fit

Simulated data

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

Importantly, we can see that even when we simulate and fit the true model, fluctuations manifest.
THERE IS **NO LINE OF DEATH**

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

The band function is not a useful probe of physics!
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The band function is not a useful probe of physics!
We want to use our fits to compute physics about the outflows.

\[
\Gamma_{\text{obs}} \geq \Gamma_\gamma = \left( \frac{f_p L_{\text{obs}} \sigma_T}{r_0^2 m_e c^2} \right)^{\frac{1}{4+2p}}
\]

A lower limit from pair-opacity

\[
\Gamma_{\text{obs}} \leq \Gamma_{\text{photosphere}} = \frac{\sqrt{2}}{4} \frac{\varepsilon^{1/8} L_{\text{obs}}^{1/4} \sigma_T^{1/4}}{\pi^{1/4} r_0^{1/4} (1 + z)^{3/2} c^{3/4} m_p^{1/4}}
\]

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

If we assume synchrotron emission, the fireball begins to smolder.

This falls apart if the $vF_{\nu}$ peak is photospheric.

See Vianello, Gill, Granot + (2018)
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
GRB 170114A

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

![Histograms showing polarization and spectral data](image)

- POLAR: polarization
- POLAR: spectral
- GBM: NaI1
- GBM: BGO0

![Map showing GBM standard location and BALROG location](image)

- RA
- Dec
- Time [s]
WHAT ARE THE DATA?

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

Latent data:
\[
\lambda_k(\bar{p}, \phi; \psi) = \int d\varepsilon \; n_\gamma(\varepsilon; \psi) R^k(\varepsilon, \phi, \bar{p})
\]

\[
\gamma_j(\psi) = \int_{\varepsilon_{1,j}}^{\varepsilon_{2,j}} d\varepsilon \; n_\gamma(\varepsilon; \psi) R_j(\varepsilon)
\]

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!
POLAR+GBM data calibrated well

Emission described with *synchrotron*

No Band function!
SPECTRAL ANALYSIS

- POLAR+GBM data calibrated well
- Emission described with synchrotron
- No Band function!
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 provide 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
MODEL MEET DATA
Merlin Kole has created polarization + energy responses for POLAR which allow for fitting in the true data space via proposed photon and polarization models.
MODEL IN THE DATA SPACE

\[ \text{Net rate [cnts s}^{-1} \text{ bin}^{-1}] \]

- \(T: -0.2-1.4 \text{ s}\)
- \(T: 1.4-1.8 \text{ s}\)
- \(T: 1.8-2.4 \text{ s}\)
- \(T: 2.4-3.0 \text{ s}\)
- \(T: 3.0-3.6 \text{ s}\)
- \(T: 3.6-4.8 \text{ s}\)
- \(T: 4.8-6.6 \text{ s}\)
- \(T: 6.6-8.9 \text{ s}\)
- \(T: 8.9-20.0 \text{ s}\)

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

\[ Q(\gamma, t) \propto t^q \gamma^{-\nu} \quad \forall \gamma \geq \gamma_{\text{inj}} \]

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