THE REST-FRAME GOLENETSKII CORRELATION VIA A HIERARCHICAL BAYESIAN ANALYSIS

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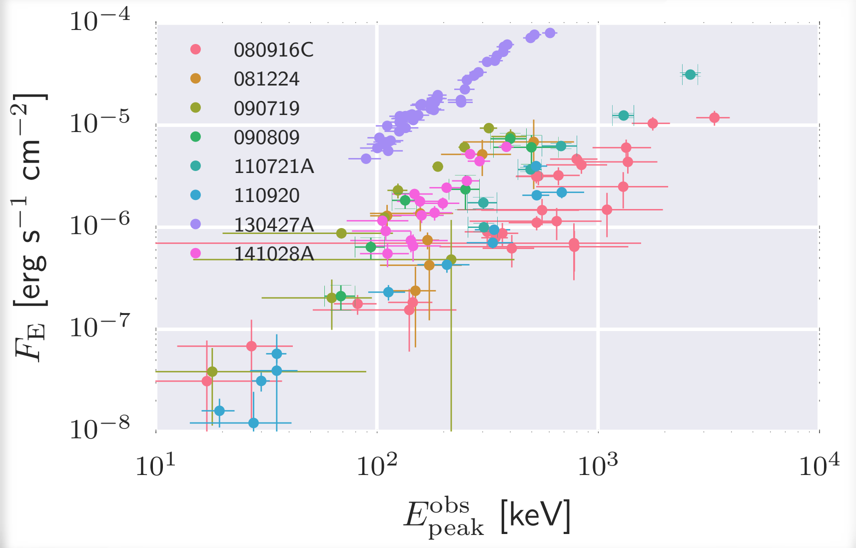
MPE

Problem

The correlation between the time-resolved vF$_v$ peak energy (E$_p$) and flux in many GRB pulses has interesting implications for GRB emission physics. A power law relation between the two quantities is often observed. This was first observed by Golenetskii (1986)



It has been noted that when the redshift of some GRBs are known, then the correlation appears common in the rest frame. Assuming a common emission mechanism between GRBs, the fitted rest frame correlation could be used to estimate GRB redshifts.

Fit for these

$$L = N\left(\frac{E_p^{rest}}{100\,\mathrm{keV}}\right)^{\gamma} \mathrm{erg\ s^{-1}}$$

Plug back in

$$F_E = \frac{N}{4\pi d_L^2}\left(\frac{E_p^{obs}(1+z)}{100\,\mathrm{keV}}\right)^{\gamma} \mathrm{erg\ s^{-1}\ cm^{-2}}.$$

Now fit for redshift

GRB	z	z_{est}	γ_{est}
080916C	4.24	2.51 ± 0.50	1.39 ± 0.09
081224	$\cdots$	3.64 ± 583.90	3.05 ± 1.38
090719	$\cdots$	0.88 ± 0.22	1.80 ± 0.17
090809	$\cdots$	1.29 ± 0.53	1.80 ± 0.25
110721A	3.20	1.70 ± 0.33	1.44 ± 0.09
110920	$\cdots$	2.40 ± 0.34	1.50 ± 0.07
130427A	0.34	0.31 ± 0.02	1.52 ± 0.05
141028A	2.33	1.49 ± 0.68	1.91 ± 0.24

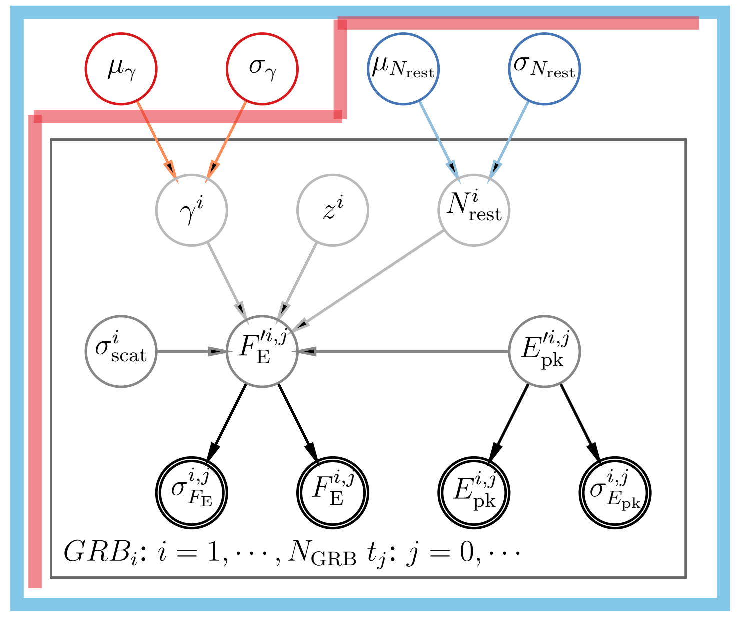
This unfortunately cannot reproduce known redshifts.

Model

We can instead try a Bayesian hierarchical model where we fit GRBs with known unknown redshift simultaneously. In this way the redshifts are automatically calibrated and errors are propagated in a statistically sound manner.

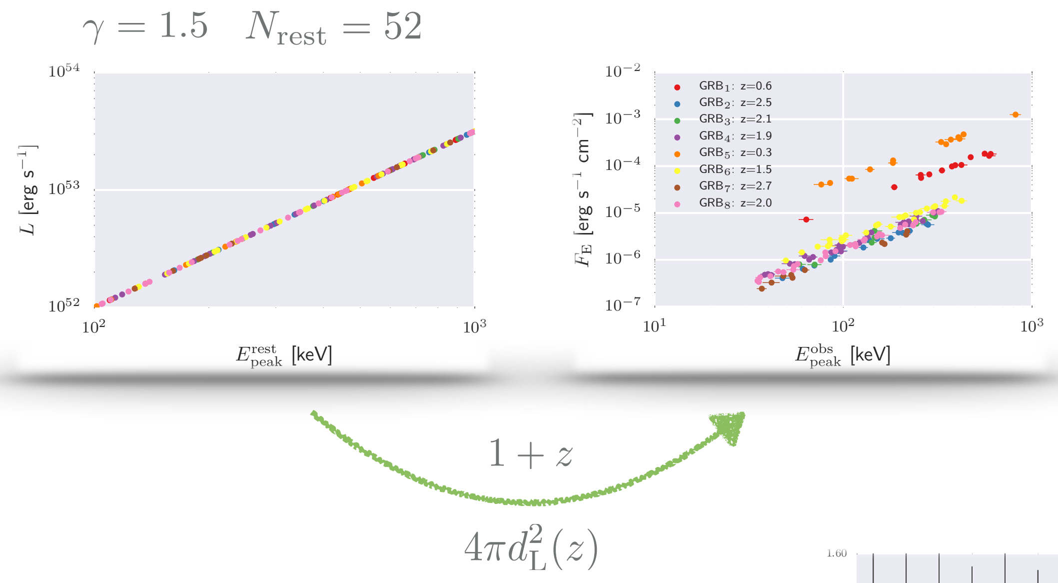
MODEL A
MODEL B
MODEL C

$$\begin{aligned}
\mu_\gamma &\sim \mathcal{N}(0, \mathrm{std}(F_E)/\mathrm{std}(E_{peak}^{obs}))\\
\sigma_\gamma &\sim \mathrm{Cauchy}_{(0,\infty)}(0, 2.5)\\
\gamma^i &\sim \mathcal{N}(\mu_\gamma, \sigma_\gamma)\\
\mu_{N_{rest}} &\sim \mathcal{U}(45, 60)\\
\sigma_{N_{rest}} &\sim \mathrm{Cauchy}_{(0,\infty)}(0, 2.5)\\
N_{rest}^i &\sim \mathcal{N}(\mu_{N_{rest}}, \sigma_{N_{rest}})\\
z^i &\sim \mathcal{U}(0, 20)\\
E_{peak}^{obs\,i,j} &\sim \mathcal{N}(E_{peak}^{obs\,i,j}, \sigma_{E_{peak}}^{i,j})\\
\sigma_{scat}^i &\sim \mathrm{Inv.\ Gamma}(1E-3, 1E-3)\\
F_E^{i,j} &\sim \mathcal{N}(\star, \sigma_{scat}^i)\\
F_E^{i,j} &\sim \mathcal{N}(F_E^{i,j}, \sigma_{F_E}^{i,j})
\end{aligned}$$

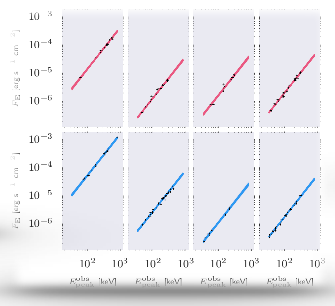


The various models describe different linkages between the data. We can now simulate GRBs from this model and assume we know some redshifts and try to estimate those we do not know

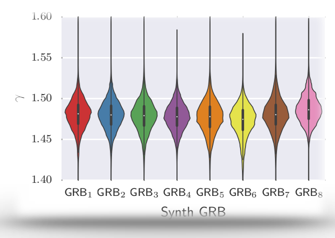
Simulations

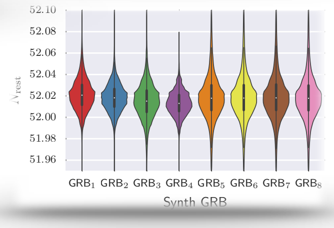


FITS RECONSTRUCT OBSERVER-FRAME

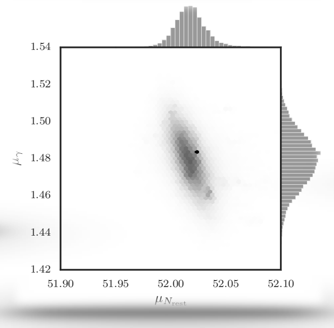


ALL PARAMETERS RECOVERED SUCCESSFULLY EVEN WHEN "Z" IS UNKNOWN

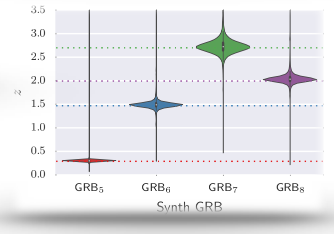




HYPER-PARAMETERS RECOVER GROUP PROPERTIES



REDSHIFT SUCCESSFULLY ESTIMATED

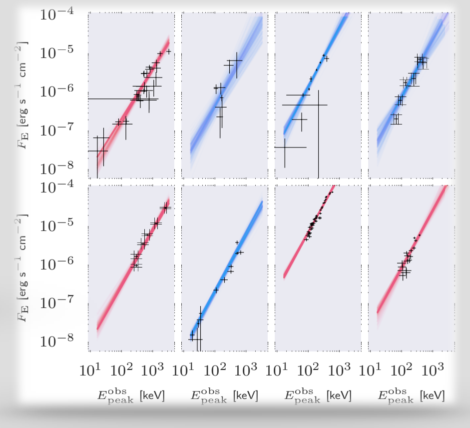


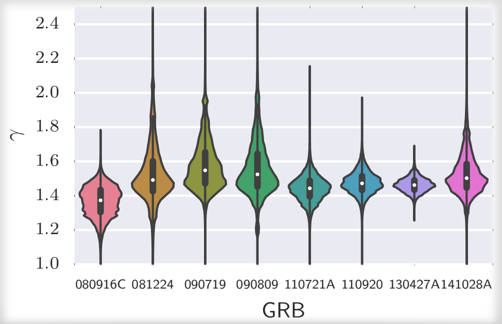
The simulated model fitting shows we should be able to recover redshift! (If the true model is similar.)

Application to data

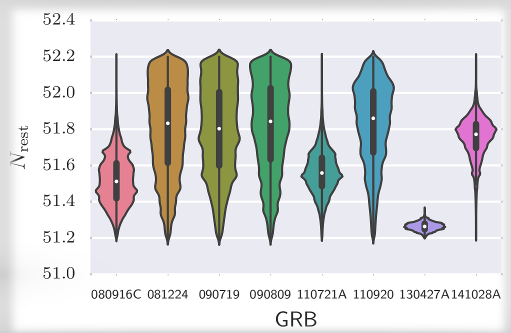
Unfortunately, when applied to real data, the redshifts are unconstrained and hence, under its current construction, the Golenetskii correlation CANNOT be used to estimate GRB redshifts.

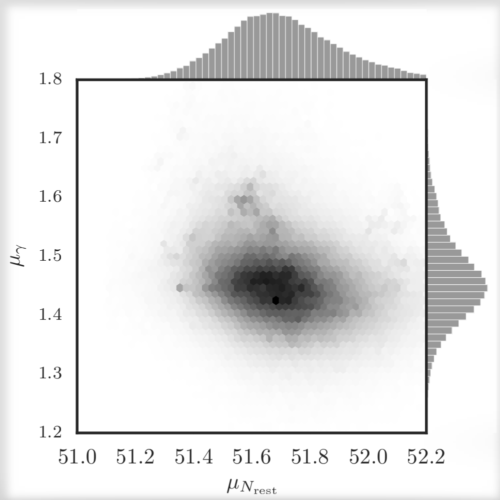
OBSERVER-FRAME SUCCESSFULLY FIT



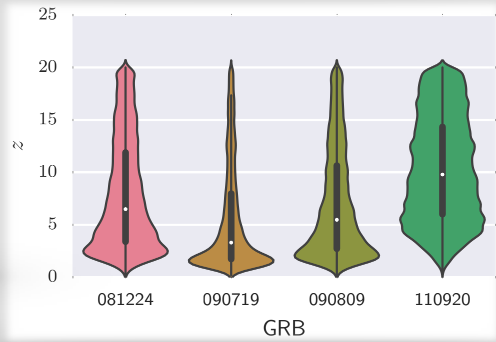


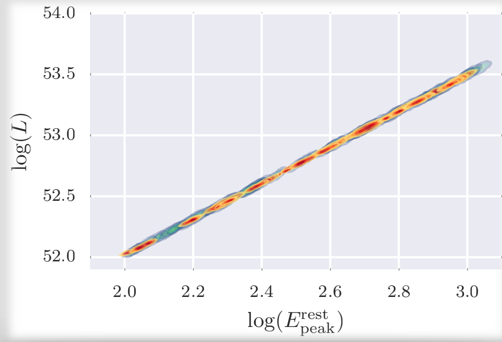
CANNOT CONSTRAIN A COMMON NORMALIZATION

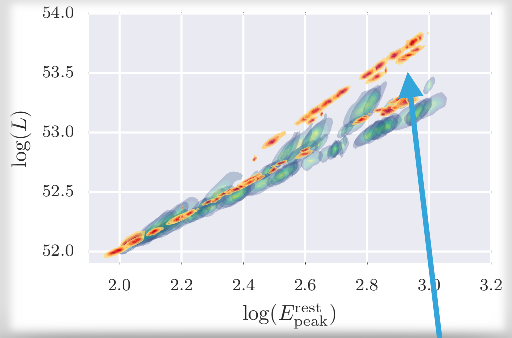


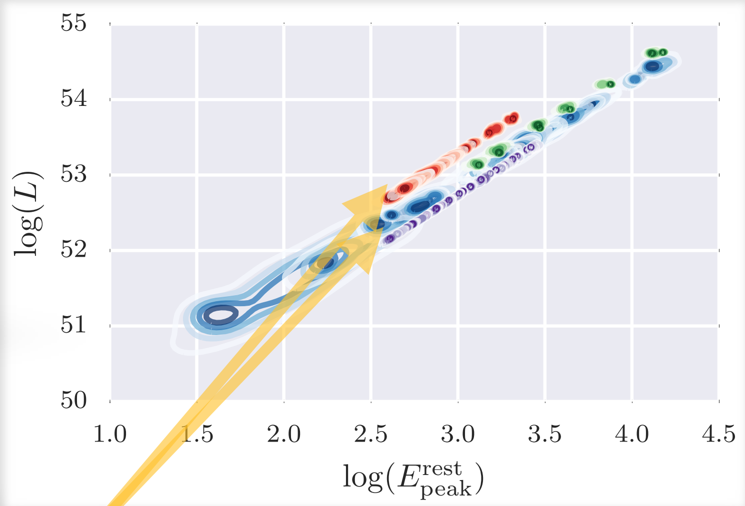


REDSHIFTS UNCONSTRAINED

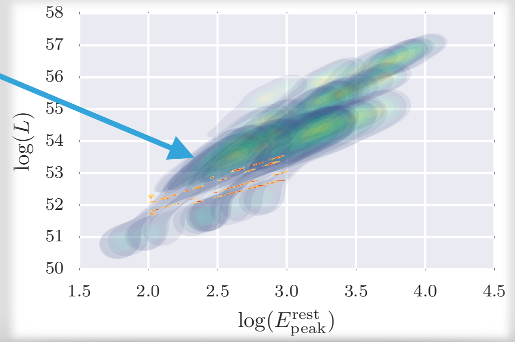








Unknown Z



Known Z

GRBS WITH KNOWN REDSHIFT HAVE DIFFERENT NORMALIZATIONS IN THE REST-FRAME

Conclusion

The posteriors from the fitting can be propagated back into the rest frame and it becomes clear that the quantities for GRBS without known redshift are poorly modeled. However, we can use the fits to GRBs with known redshift to see that this is because GRBs have different rest frame normalizations pointing to different intrinsic emission physics.

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ABSTRACT

Gamma-ray bursts (GRBs) are characterised by a strong correlation between the instantaneous luminosity and the spectral peak energy within a burst. This correlation, which is known as the hardness-intensity correlation or the Golenetskii correlation, not only holds important clues to the physics of GRBs but is thought to have the potential to determine redshifts of bursts. In this paper, I use a hierarchical Bayesian model to study the universality of the rest-frame Golenetskii correlation and in particular, I assess its use as a redshift estimator for GRBs. I find that using a power-law prescription of the correlation, the power-law indices cluster near a common value, but have a broader variance than previously reported ($\sim 1-2$). Furthermore, I find evidence that there is spread in intrinsic rest-frame correlation normalizations for the GRBs in our sample ($\sim 10^{51} - 10^{53}$ erg s^{-1}). This points towards variable physical settings of the emission (magnetic field strength, number of emitting electrons, photospheric radius, viewing angle, etc.). Subsequently, these results eliminate the Golenetskii correlation as a useful tool for redshift determination and hence a cosmological probe.