SCIENCE COMMUNICATION LAB/DESY

GRB 160625B: Evidence for a Gaussian-shaped Jet

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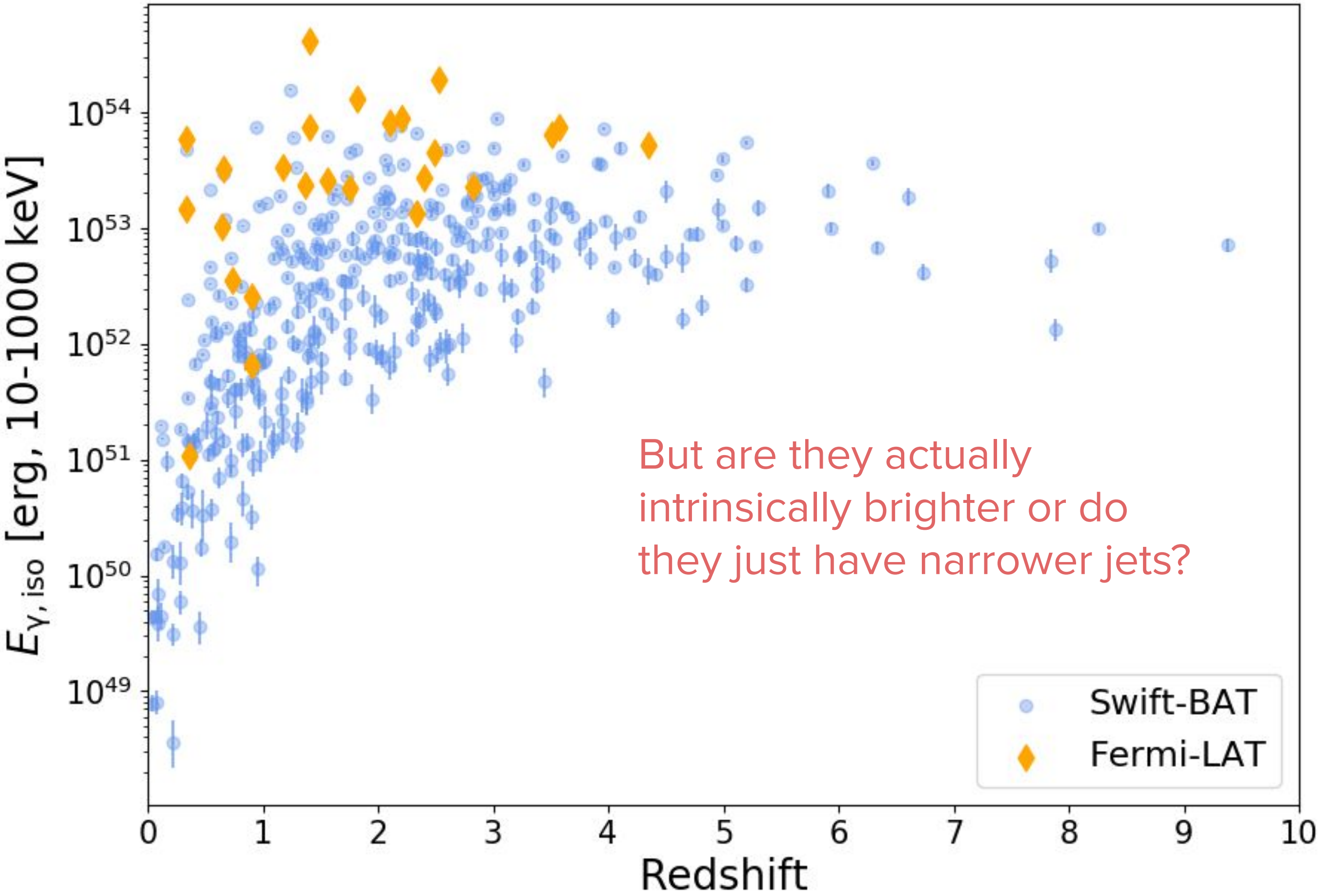
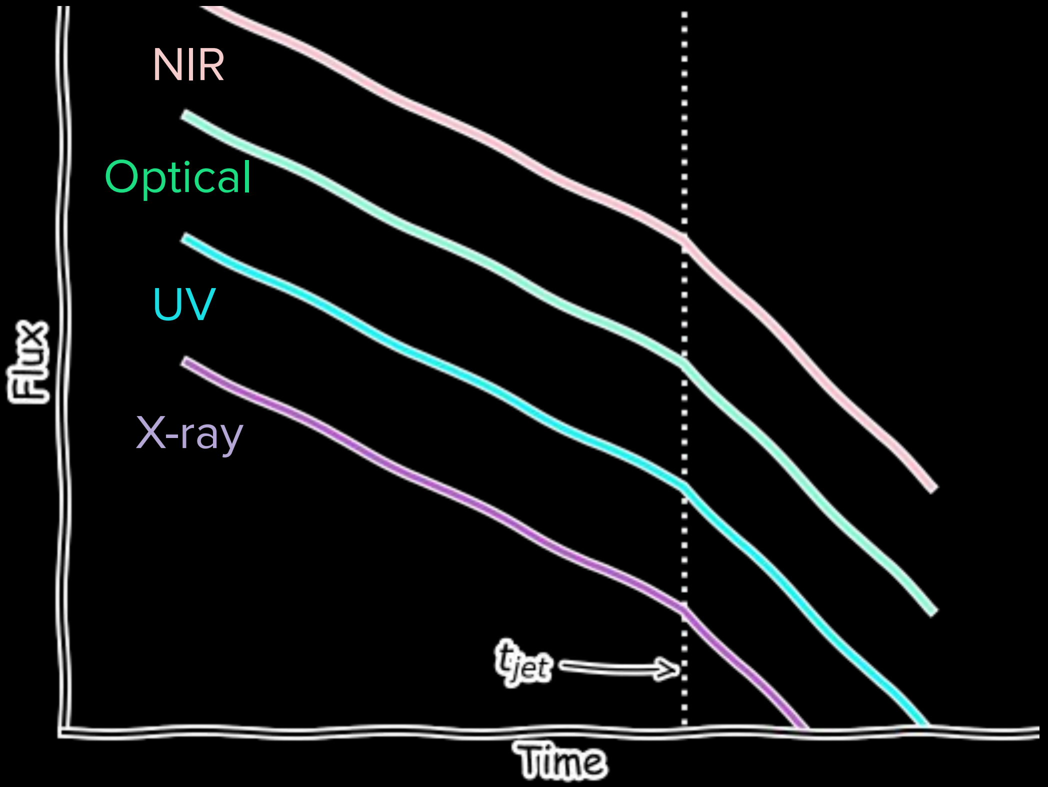
Fermi LAT GRBs are extremely bright.



But are they actually intrinsically brighter or do they just have narrower jets?

Jet breaks reveal information about the burst geometry.



Jet break (t_{jet}) occurs when $\Gamma = 1/\theta_{jet}$.

Things we still don't know:

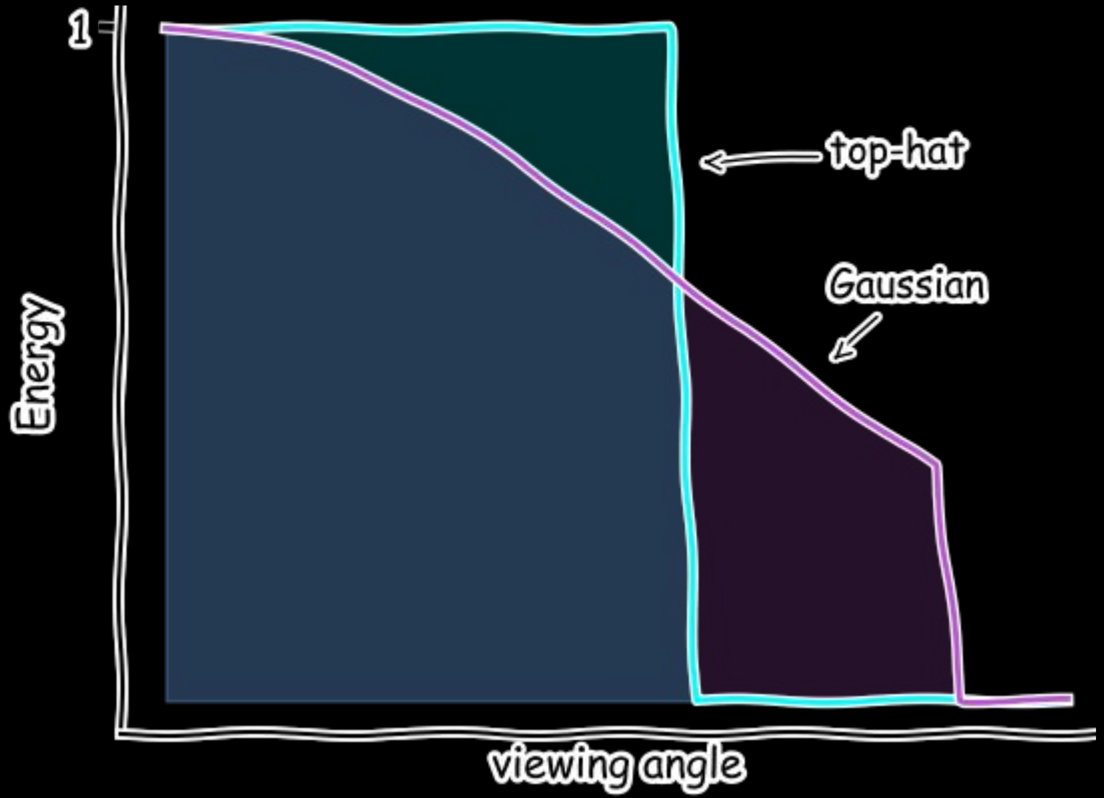
How much energy is released by the explosion?

What's powering their central engines?

What are their local environments like?

How is their jet emission shaped?

And much more...

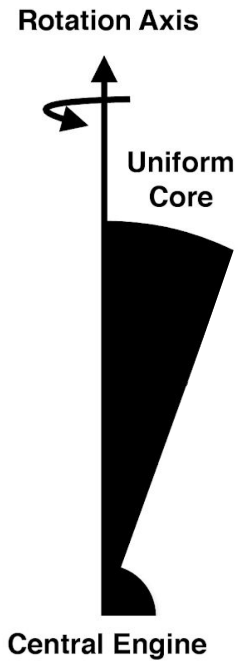


3 Models:

1: Simple conical top-hat model

2: Gaussian jet structure

3: Gaussian with variable participation fraction of electrons



*Adapted from the LIGO discovery paper

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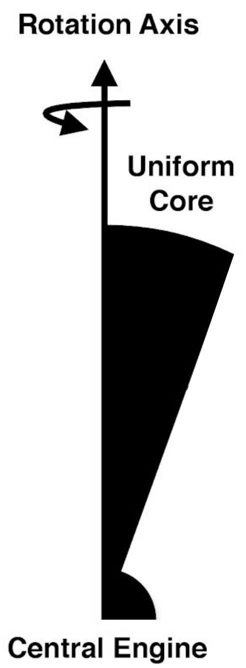

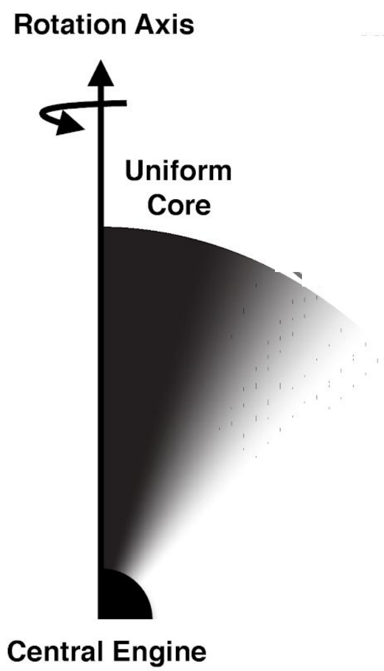

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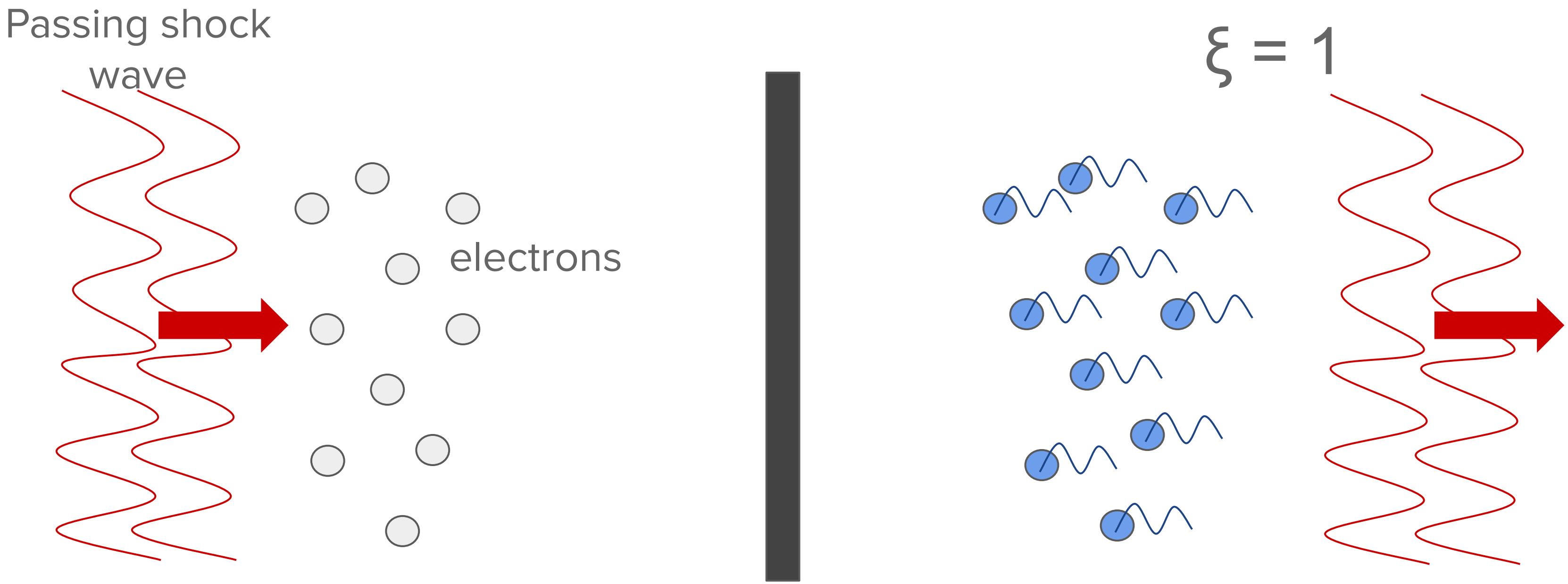

Eichler & Waxman 2005
Warren, D.C. + 2017, 2018

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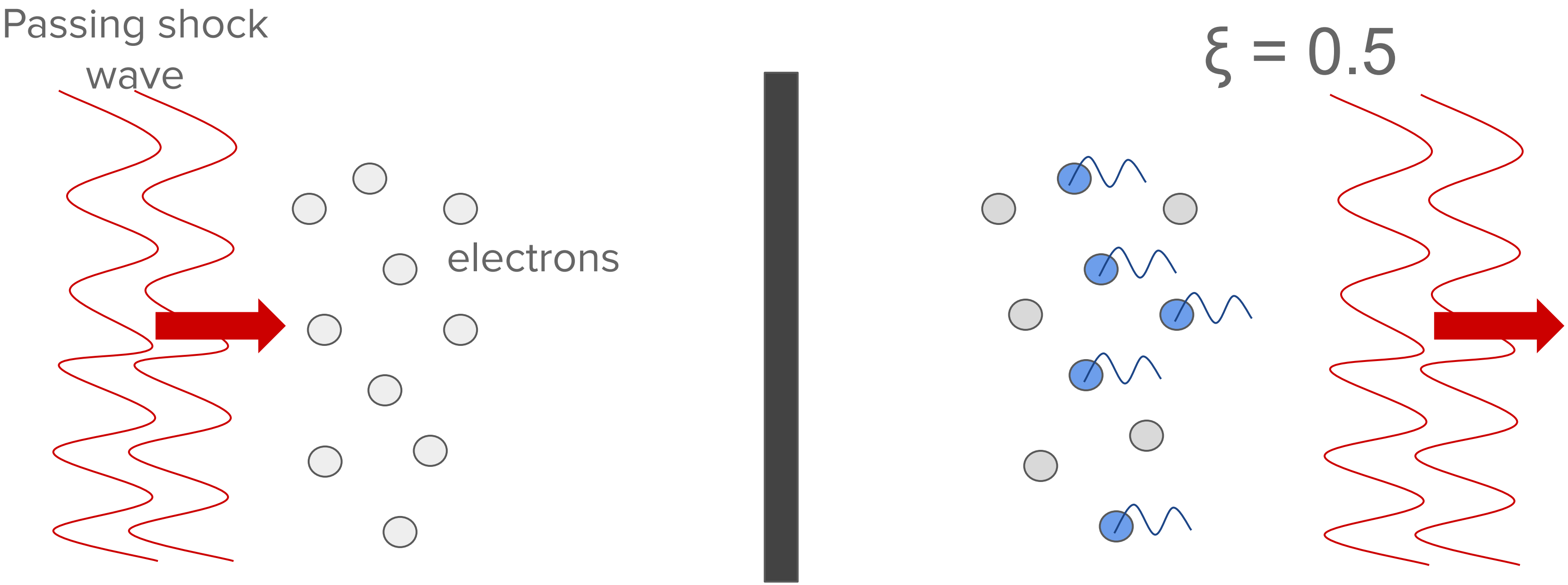

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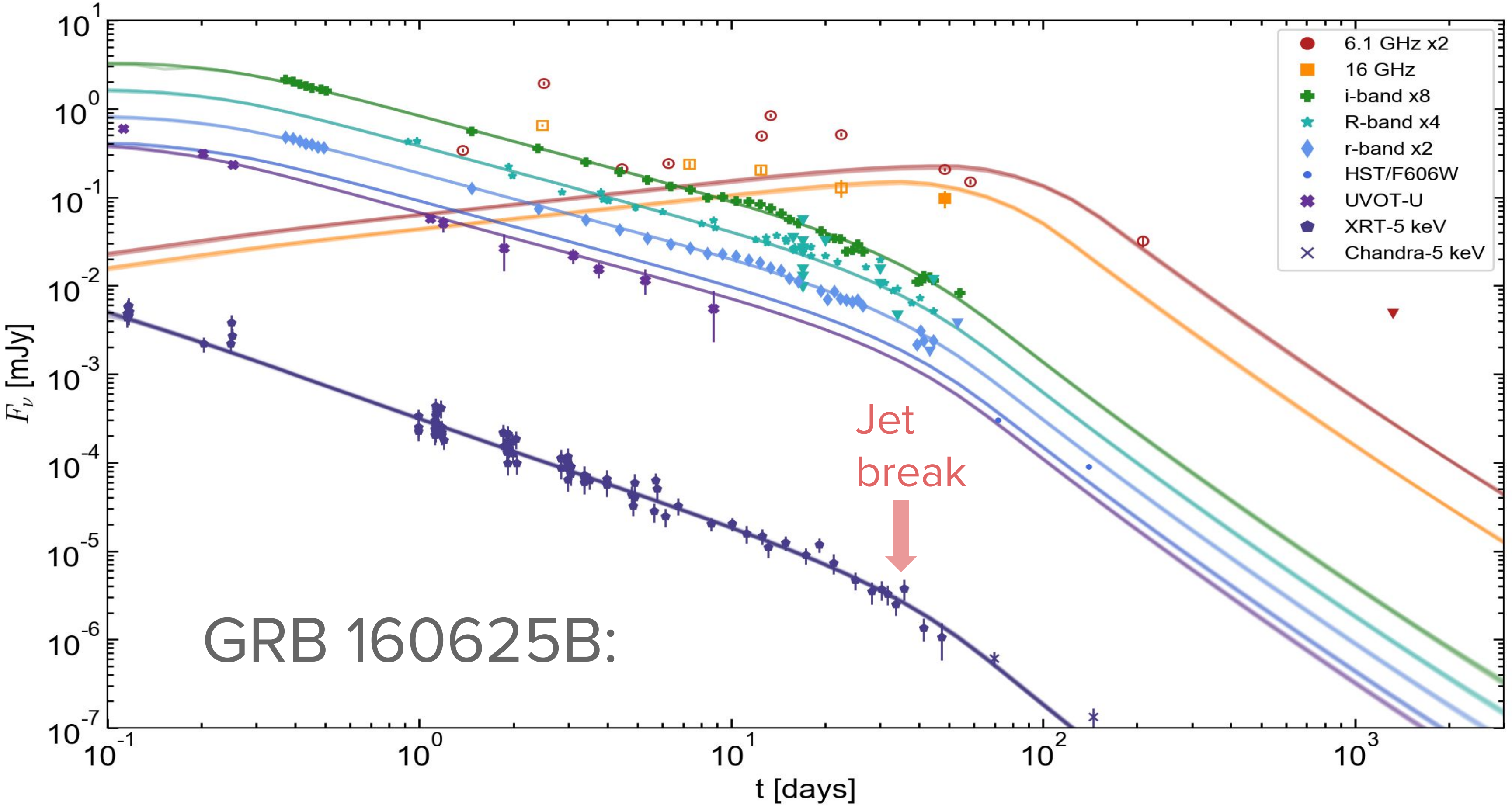

Cunningham, Cenko, Ryan + 2020, APJ

Beaming angle changes by factor of 2-3

Model		Top-Hat	Gaussian (fixed ξ)	Gaussian (free ξ)
θ_v	[deg]	$0.42^{+0.14}_{-0.09}$	$0.13^{+0.34}_{-0.06}$	$3.78^{+0.57}_{-0.52}$
$E_{\mathrm{K,iso}}$	[erg]	$2.3^{+0.5}_{-0.7} \times 10^{54}$	$3.1^{+0.4}_{-0.8} \times 10^{54}$	$4.2^{+24.0}_{-3.5} \times 10^{55}$
θ_c	[deg]	$1.83^{+0.52}_{-0.23}$	$1.26^{+0.34}_{-0.06}$	$3.90^{+0.57}_{-0.57}$
θ_w	[deg]	-	$1.60^{+0.40}_{-0.11}$	$4.76^{+0.80}_{-0.63}$
n	[cm^{-3}]	$9.6^{+39.0}_{-5.9} \times 10^{-7}$	$3.1^{+11.0}_{-1.1} \times 10^{-6}$	$0.35^{+1.71}_{-0.31}$
p		[illegible]	[illegible]	$2.10^{+0.01}_{-0.01}$
ϵ_e		$0.12^{+0.05}_{-[illegible]}$	$0.19^{+0.07}_{-0.02}$	$0.017^{+0.085}_{-0.014}$
ϵ_B		$0.16^{+[illegible]}_{-0.10}$	$0.17^{+0.05}_{-0.09}$	$3.9^{+21.9}_{-3.3} \times 10^{-5}$
ξ		1.0	1.0	$0.016^{+0.080}_{-0.013}$
η [a]		$0.56^{+0.08}_{-0.05}$	$0.49^{+0.08}_{-0.03}$	$0.067^{+0.253}_{-0.057}$
E_{rel} [b]	[erg]	$2.7^{+1.3}_{-0.5} \times 10^{51}$	$1.6^{+0.6}_{-0.1} \times 10^{51}$	$1.2^{+6.5}_{-0.9} \times 10^{53}$
χ^2/dof		1.24	0.99	0.86

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Circumburst Density

Extremely low

ISM-like

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Isotropic Energy

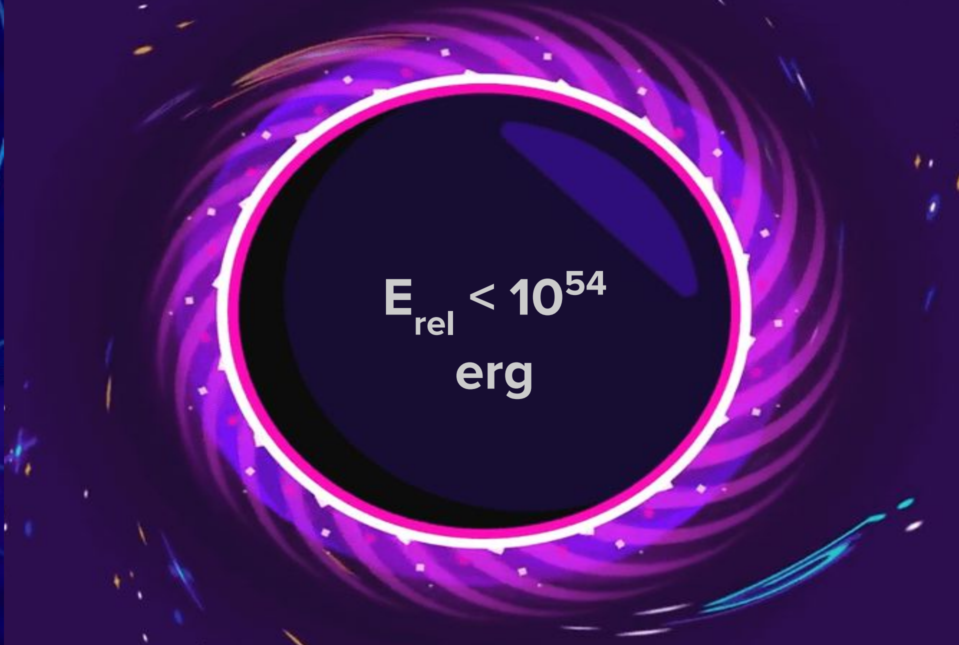
Total Energy

2 orders of magnitude!

Central Engine:

Magnetar? or Collapsar?

Beniamini+ 2017
Metzger+ 2018



Woosley 1993
MacFadyen & Woosley 1999

Kurzgesagt

GRB 160625B:

$E_{rel} = 1.2 \times 10^{53}$ erg

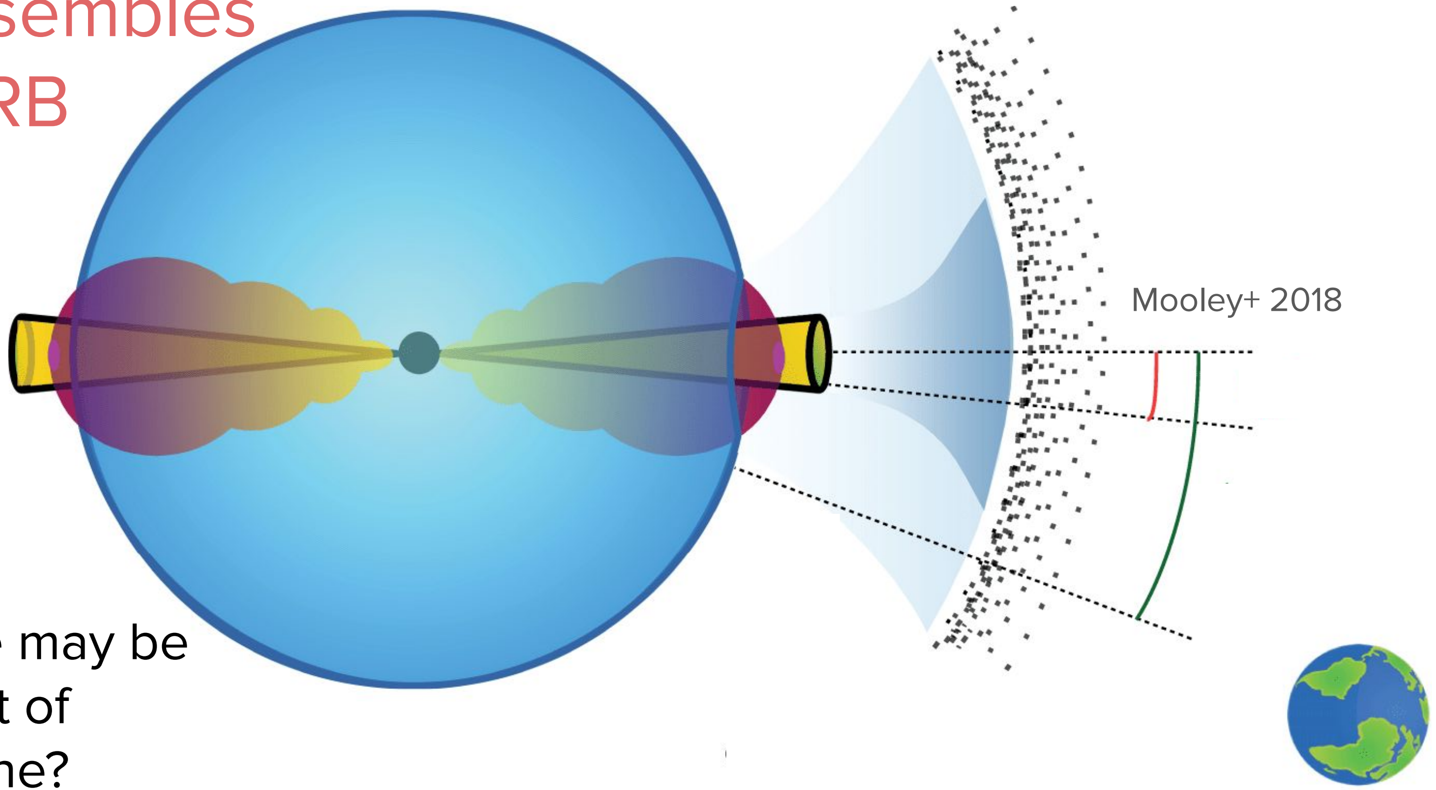
Collapsar ✓

$E_{rel} < 10^{54}$ erg

Woosley 1993
MacFadyen & Woosley 1999

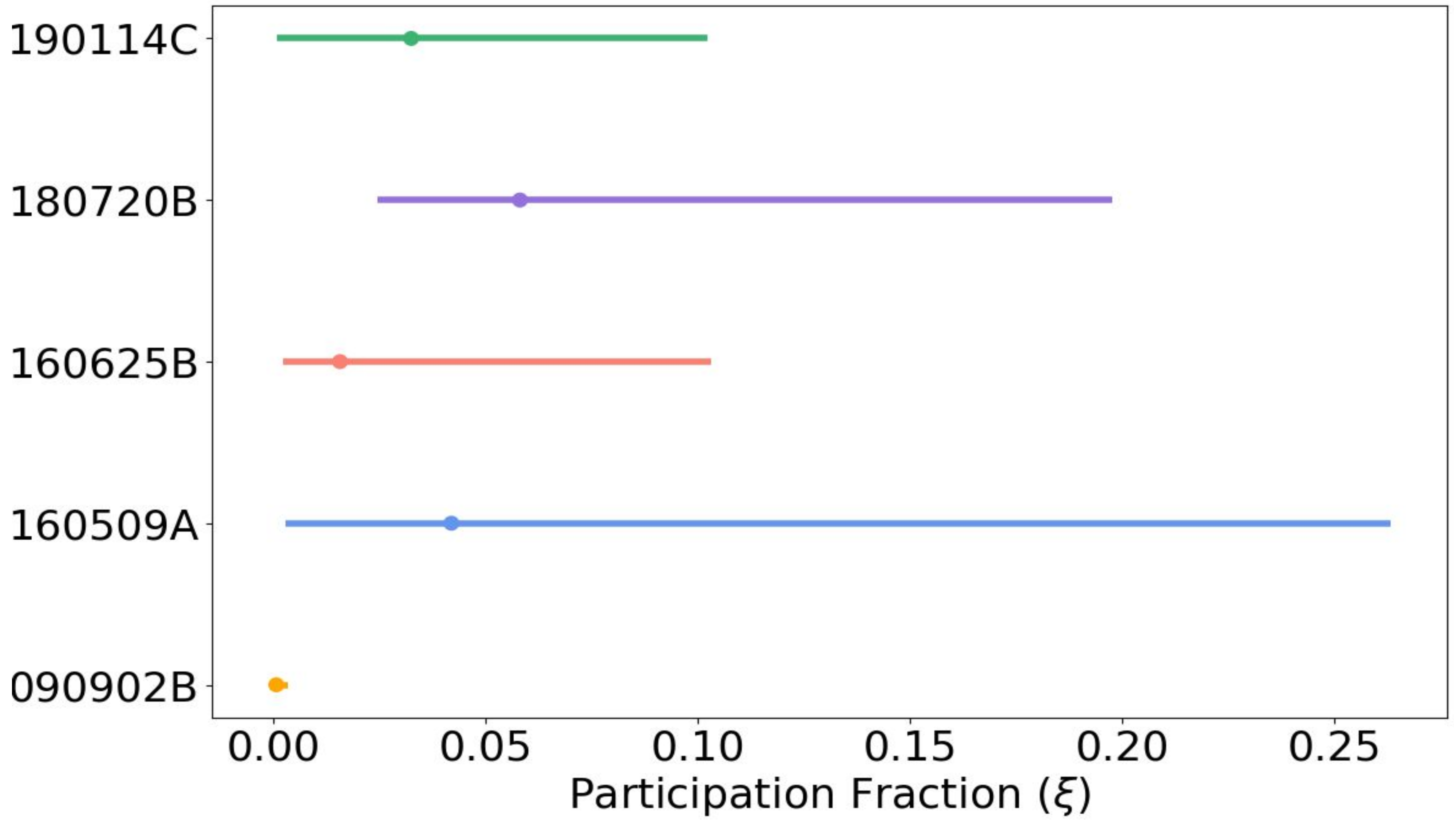
Kurzgesagt

Gaussian jet shape resembles that of GRB 170817A.



Jet structure may be independent of central engine?

Preliminary Results: All GRBs prefer lower participation fractions



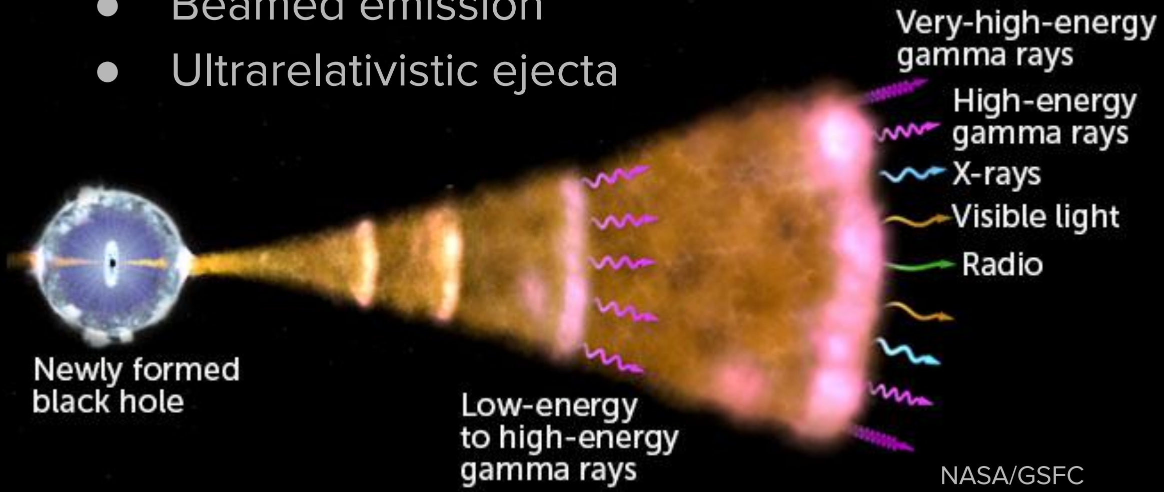
Fermi GRB Summary:

- We tested three jet structure models on the multiwavelength afterglow of GRB 160625B
- Derived parameters between top-hat and Gaussian (fixed ξ) jet models remain consistent, although Gaussian shape is preferred
  - Θ_c: ~1 to 4°
  - E_{rel}: ~2 x 10^{51} erg
  - n: ~10^{-6} cm^{-3}
- Smaller values of ξ are preferred yet also dramatically affect the afterglow light curve
  - E_{rel}: ~1 x 10^{53} erg
  - n: ~10^{-1} cm^{-3}
- 160625B likely prefers a collapsar origin
- Further analysis on a larger sample of bright LAT-detected GRBs hint at similar trends

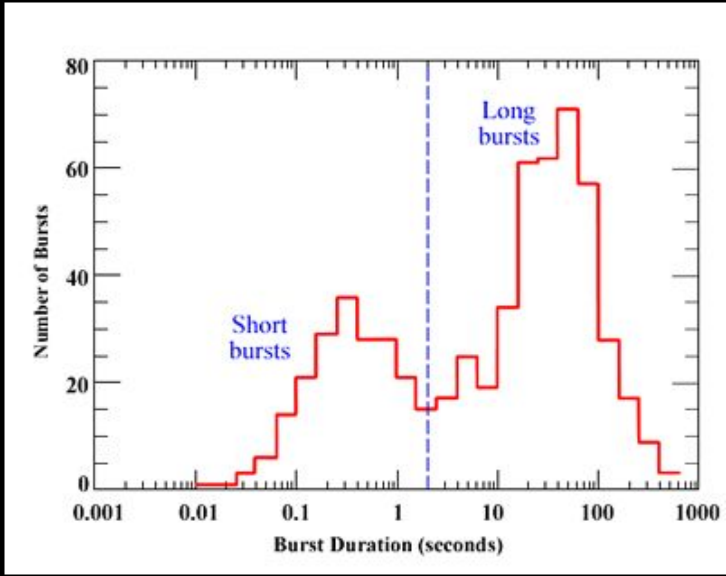
Backup Slides

Gamma-ray Bursts (GRBs)

- Two kinds: short and long
- Bright prompt + long-lasting afterglow
- Visible across EM spectrum
- Beamed emission
- Ultrarelativistic ejecta

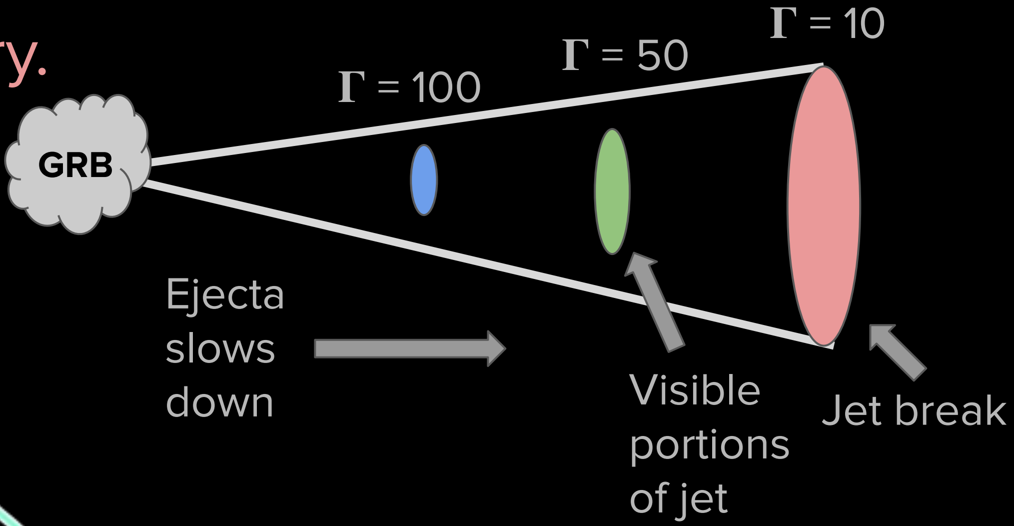


NASA/GSFC



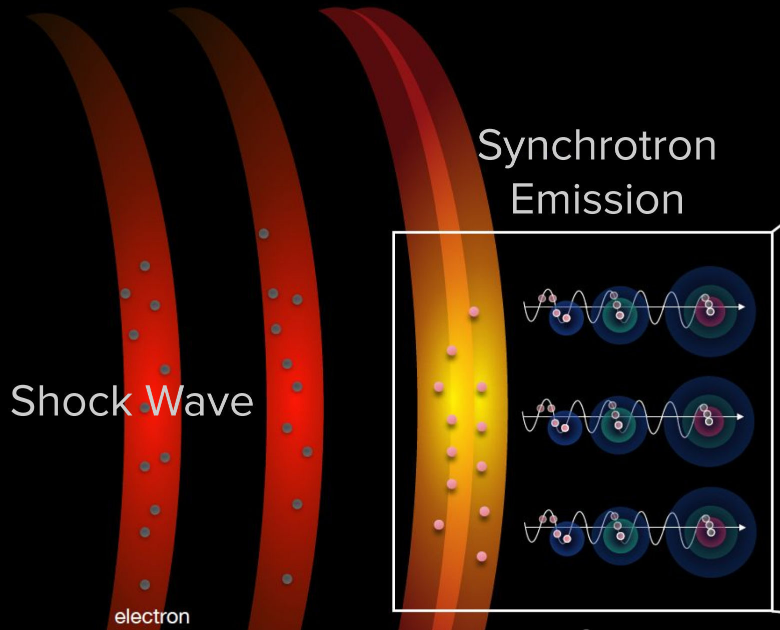
Swinburne University of Technology

Jet breaks reveal information about the burst geometry.



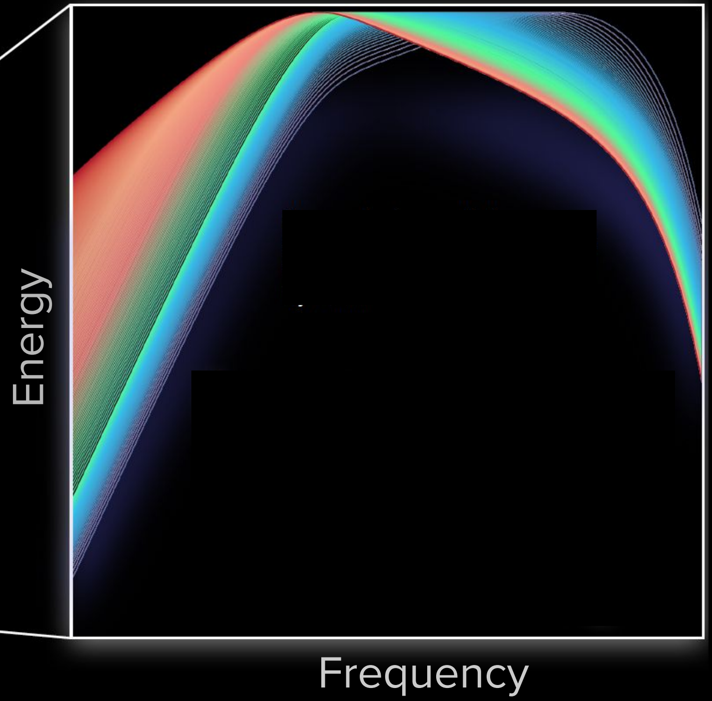
Jet break (t_{jet}) occurs when $\Gamma = 1/\theta_{jet}$.

Multiwavelength Modeling with Afterglowpy:



Adapted from J. Michael Burgess

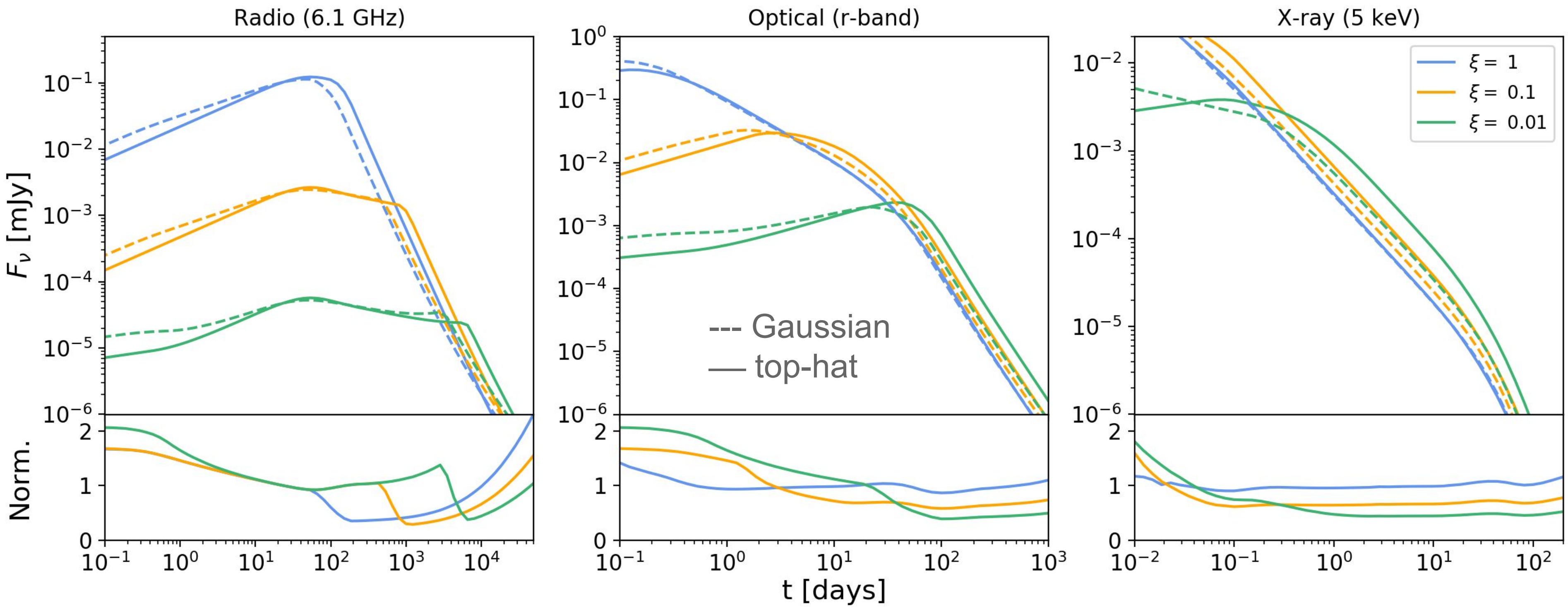
- Semi-Analytical
- MCMC
- Function of viewing angle and jet structure



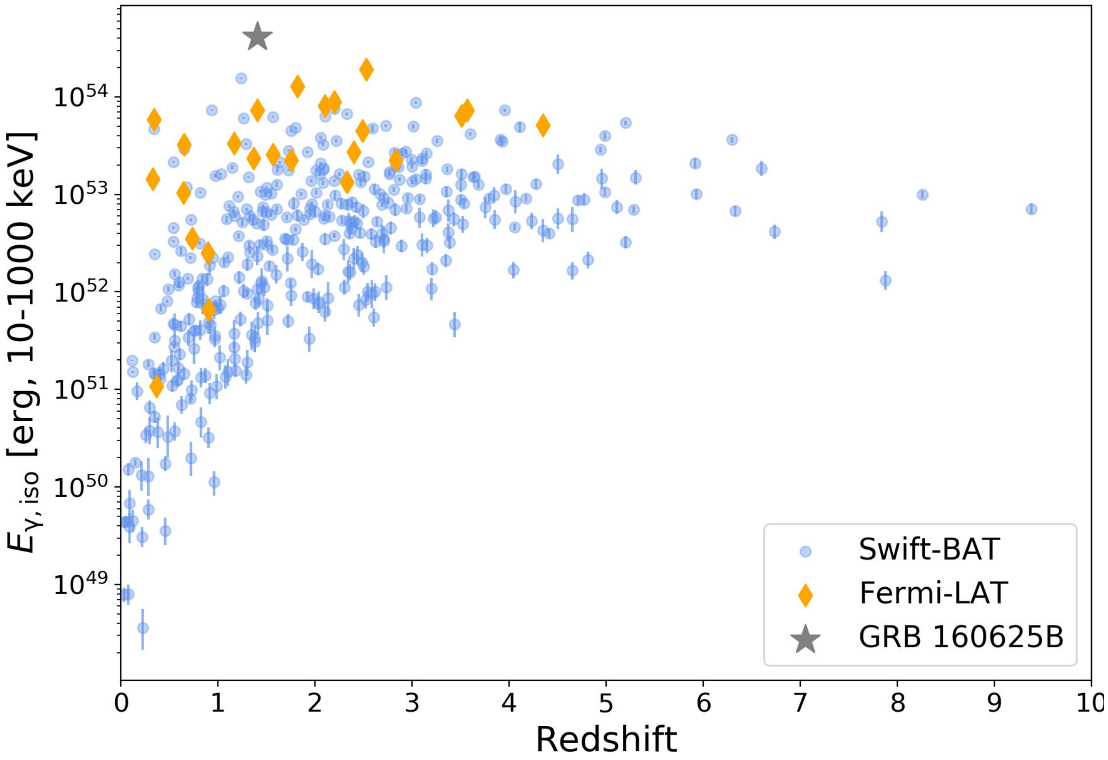
Ryan, van Eerten, Piro & Troja 2020, ApJ, 896, 166

https://pypi.org/project/afterglowpy/

Participation Fraction (ξ): fraction of electrons contributing to the observed flux



First test case:
GRB 160625B



Extremely Bright

$E_{\gamma,iso} = 6 \times 10^{54}$ erg

LAT, Swift XRT, Chandra, LCO, Magellan, RATIR, Swift UVOT, VLA, ATCA, +

Alexander, Laskar, Berger + 2017

Troja, Lipunov, Mundell + 2017

Kangas, Fruchter, Cenko + 2020

Model Comparison:

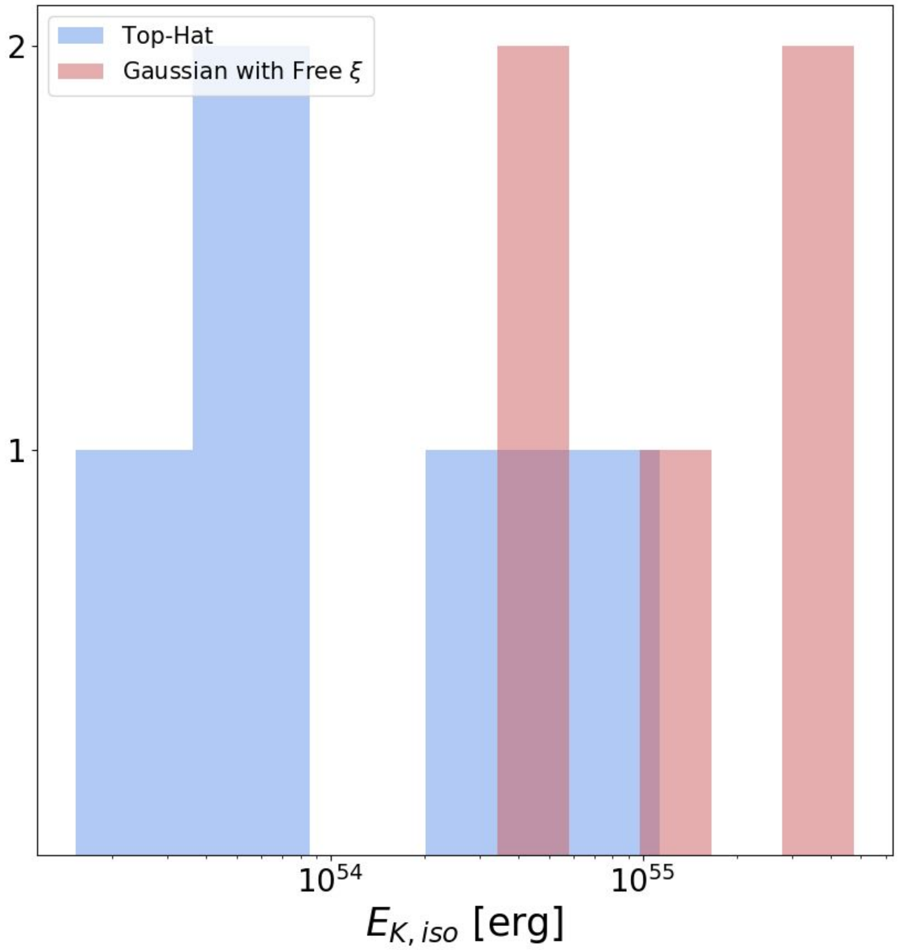
	Model 3:	Model 2:	Model 1:
	Gaussian (free ξ)	Gaussian (fixed ξ)	Top Hat
WAIC	1782.7 ± 79.1	1744.3 ± 78.5	-3561.8 ± 167.2
ΔWAIC/N	-	0.10 ± 0.09	-14.5 ± 2.7
Confidence Level	-	$(0.58\text{-}1.16)\sigma$	$(2.7\text{-}5.3)\sigma$

WAIC: Widely Applicable Information Criterion (Gelman 2013)

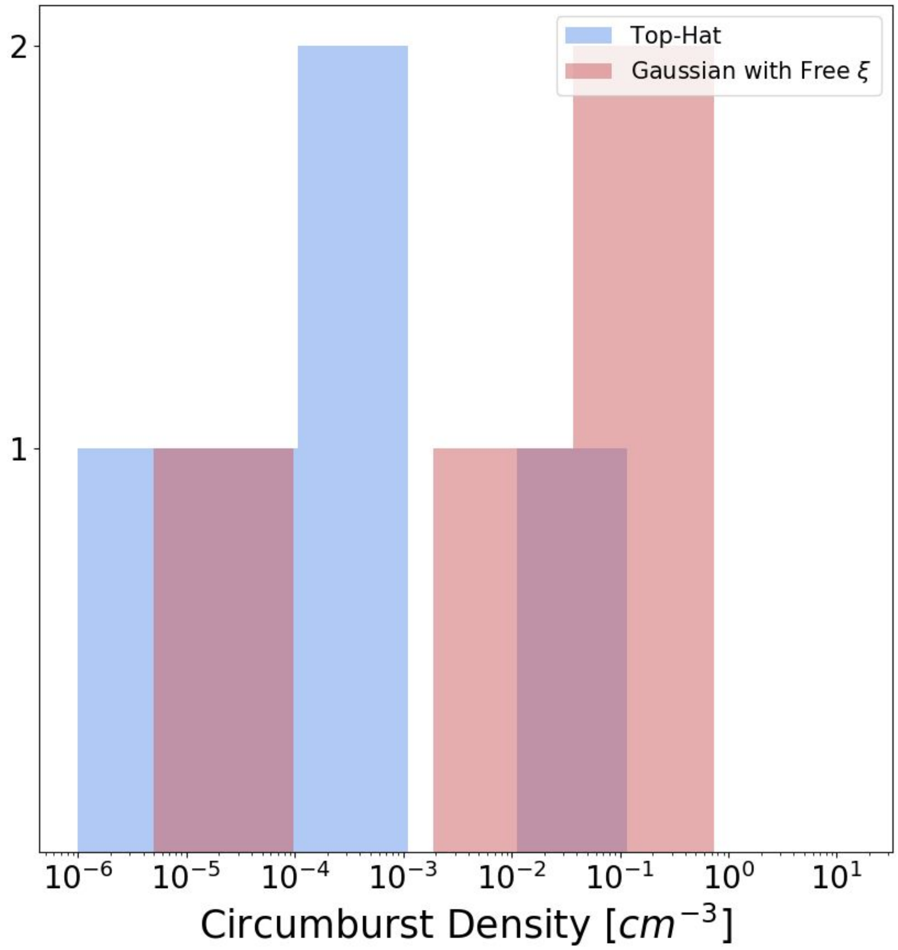
➔ Measure of future predictability

Preliminary Results:

Isotropic Energy increases by 1-2 orders of magnitude when participation fraction is allowed to vary



Preliminary Results:
Circumburst density increases by several orders of magnitude when participation fraction is allowed to vary

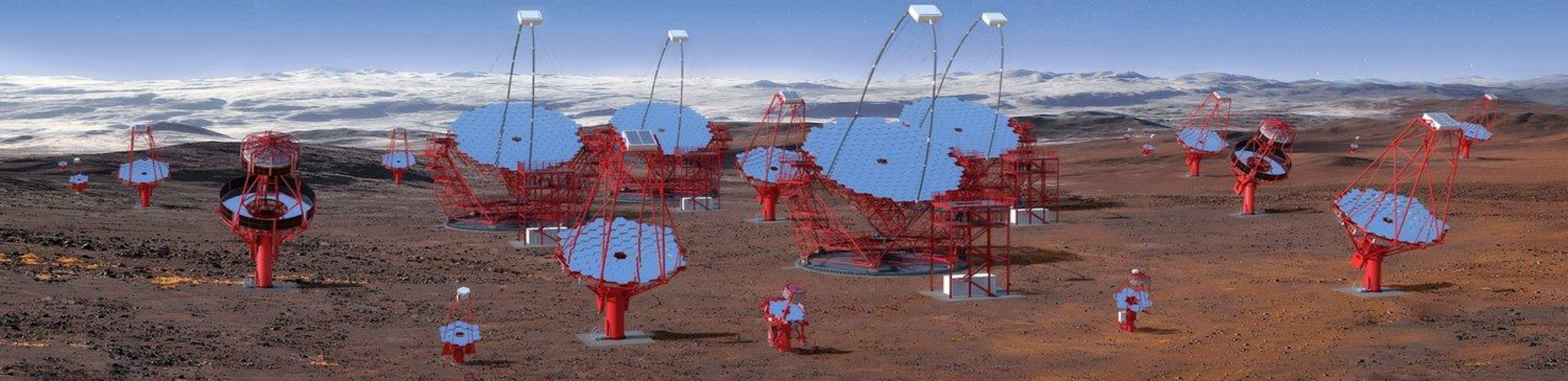


Future work:

VHE follow-up of *Fermi* GRBs

- 3 GRBs have been detected with MAGIC, HESS
  - ~1 TeV

- CTA first light scheduled for 2022
- 10 x more sensitive than VERITAS
  - 100 telescopes



CTA/M-A. Besel/IAC (G.P. Diaz)/ESO