Fermi Gamma-Ray Bursts: Statistical Analysis and Coverage Estimation with GIT

PH303 - Supervised Learning Project

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01

Introduction

Gamma Ray Bursts and the Fermi Space Telescope

GROWTH-India Telescope

- **Telescope**
  - Planewave Instruments CDK700
  - 70cm aperture, f/6.5
  - Altitude-Azimuthal mount
  - FOV: 0.7 sq degrees

- **Camera**
  - Andor iKon-XL
  - 4108x4096 pixels, resolution of 0.676"/pixel
  - SDSS ugriz filters

- **Location**
  - IAO, Hanle, Ladakh - 4500m above sea level

(Source: https://sites.google.com/view/growthindia/gallery)

Gamma-Ray Bursts
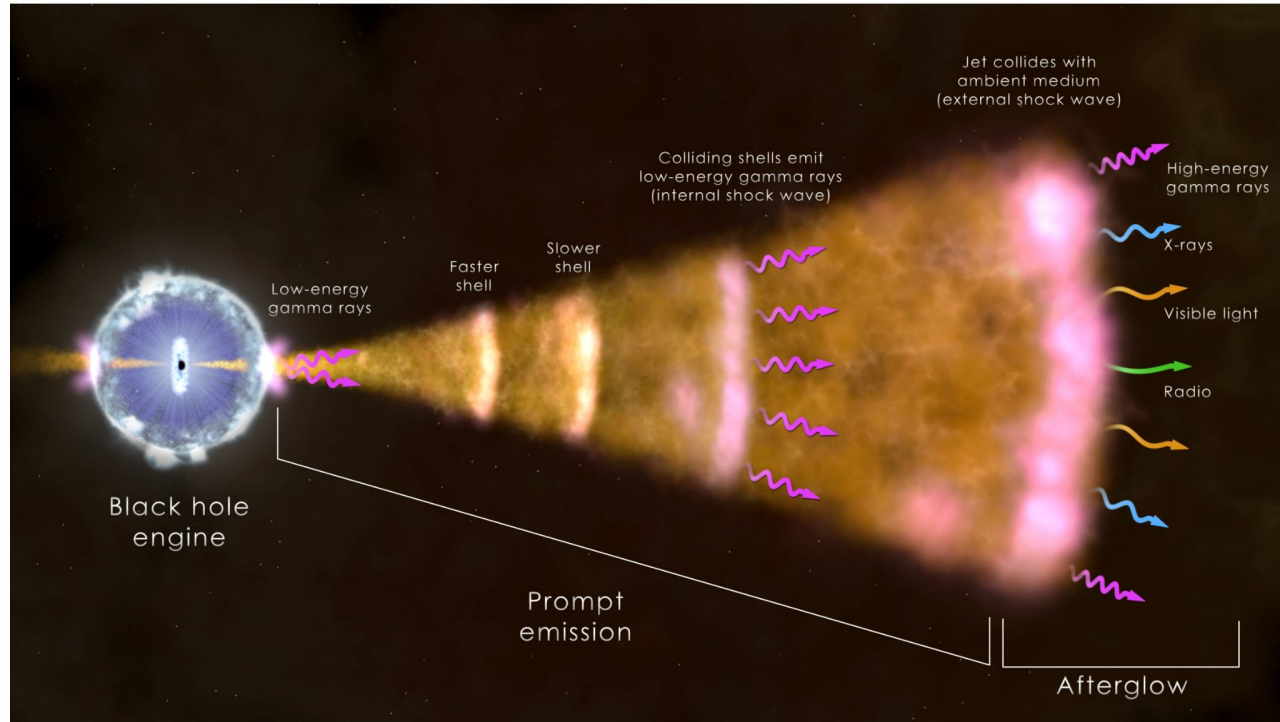
(Source: NASA)

02

Preliminaries

Fermi Gamma-Ray Space Telescope and NASA's GCN

Fermi Gamma-Ray Space Telescope

- Launched - June 11th 2008
- **Large Area Telescope** (LAT)
  - Covers 1/5th the sky at any given moment
  - 20 MeV - 300 GeV
  - 1° localisation (statistical, 90%)
- **Gamma-ray Burst Monitor** (GBM)
  - Complements the LAT
  - 8 keV - 30 MeV
  - 1-10° localisation (statistical, systematic)
- Detected over 3000 GRBs since operation

(Source: https://fermi.gsfc.nasa.gov/)

General Coordinates Network (GCN)

- Public collaboration platform run by NASA
- Rapid communications about transient phenomenon
- Notices:
  - Automated, machine-to-machine, generally real-time
  - Notifications of detections and localizations of transients
- Circulars:
  - Human-readable, citable, rapid but generally not real-time
  - Near-term predictions, requests for follow-up, or future observing plans
- Fermi sends both Notices and Circulars
- Rapid initial notice + Final localisation and light curve circular

Type	Contents	Latency
FERMI_GBM_ALERT	Trigger info	5 seconds
FERMI_GBM_FLT_POS	Flight localization, classification	10 seconds
FERMI_GBM_GND_POS	Updated ground localization using finer lookup tables	20–300 seconds
FERMI_GBM_FIN_POS	Final trigger localization	15 minutes
FERMI_GBM_SUBTHRESH	Ground pipeline detected signals	0.5–6 hours
FERMI_LAT_POS_INI	Onboard LAT detection, initial position	2–4 seconds
FERMI_LAT_POS_UPD	Updated onboard localization with more data	2–32 seconds
FERMI_LAT_GND	Ground localization of onboard trigger	8–12 hours
FERMI_LAT_OFFLINE	Ground-detected GRB localization	8–12 hours
FERMI_LAT_TRANS	Unknown source transient	1 day
FERMI_LAT_MONITOR	Known source flare	1 day

(Source: https://gcn.nasa.gov/missions/fermi)
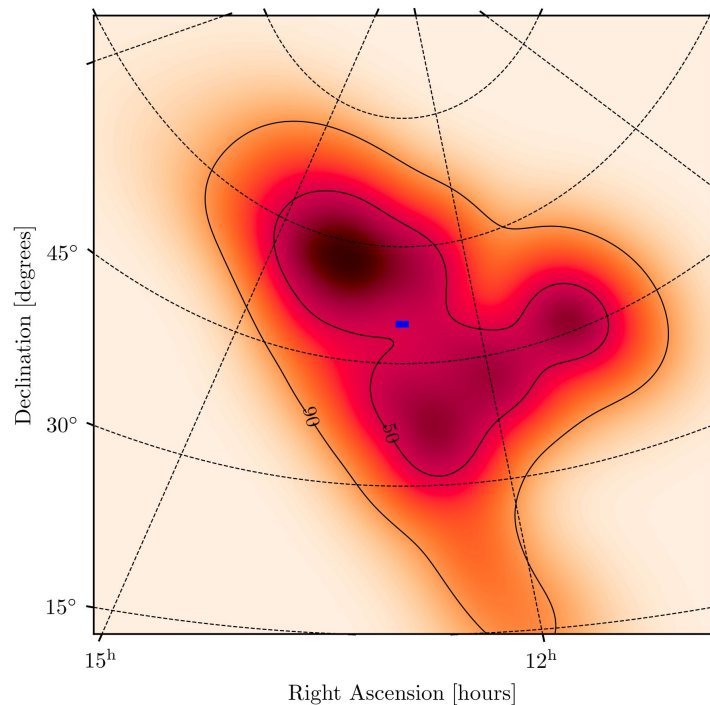
Objective

Need for follow-ups

Problem Overview

- 250+ GRBs detected by LAT and GBM yearly
- Most have 1-sigma localisation > 1°
- Difficult for optical follow-up
- "To what degree can a meter-class telescope, like GIT, be used to follow up Fermi GRB localizations?"
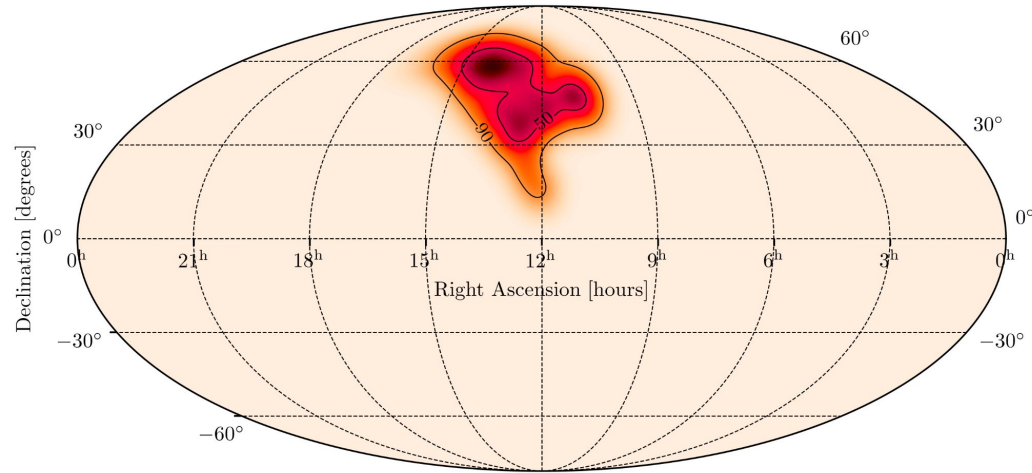
Methodology

Data collection, tiling, plots

Methodology

- Collect localisation maps for all Fermi GRBs since 2017 (~6 years)
- Run the tiling algorithm to determine best coverage, if it were followed up.
- 5 minute exposures, starting at trigger time or time of visibility of first 90% confidence tile
- Plots! Plots! Plots!
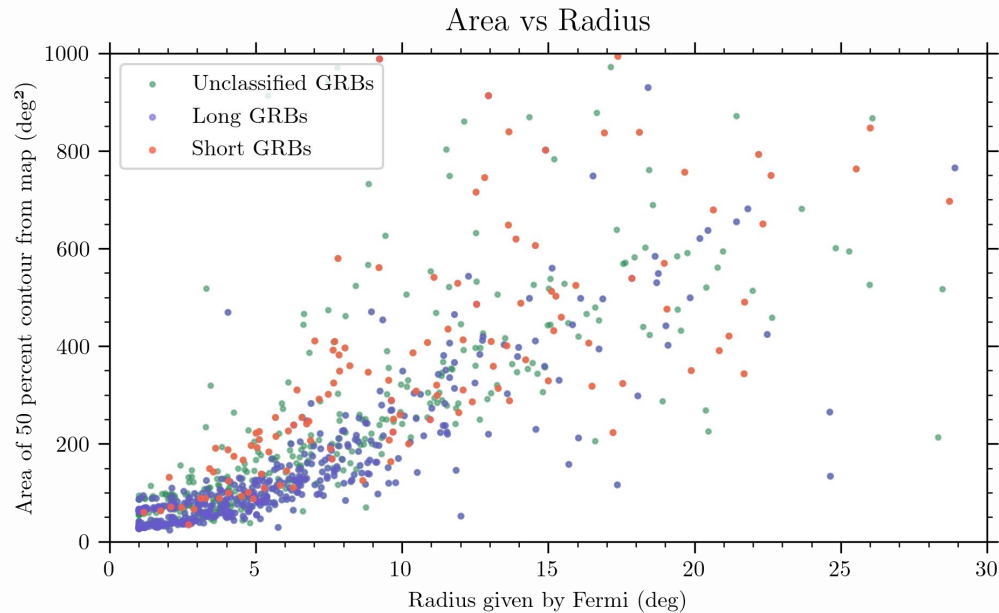

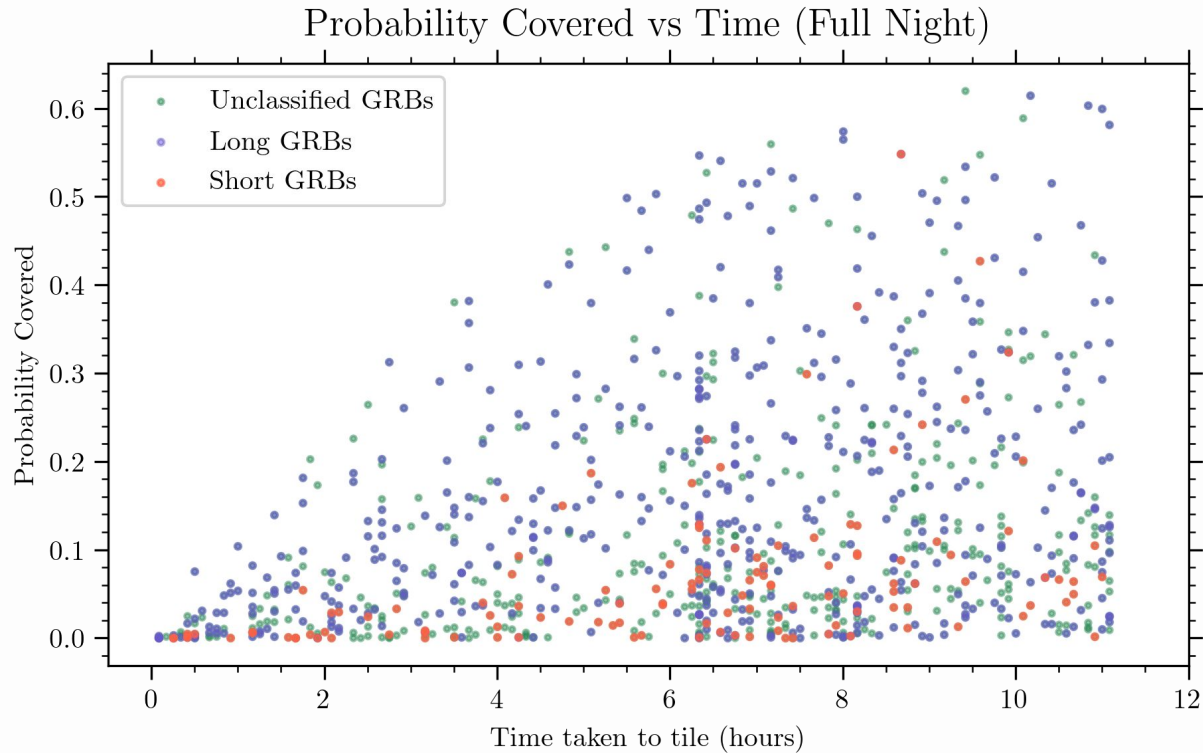
Typical Fermi GRB localisation (GRB 231123C)

Analysis

Trigger-wise coverage analysis

Preliminary Analysis

- 948 "likely" long GRBs and 241 "likely" Short GRBs

Area vs Radius

Full Night Observations

Probability Covered vs Time (Full Night)

Legend:
- Unclassified GRBs
- Long GRBs
- Short GRBs

Y-axis: Probability Covered
X-axis: Time taken to tile (hours)

1-Hour Observations

Probability Covered vs Time (1 hour)

2-Hour Observations

Probability Covered vs Time (2 hours)

3-Hour Observations

Probability Covered vs Time (3 hours)
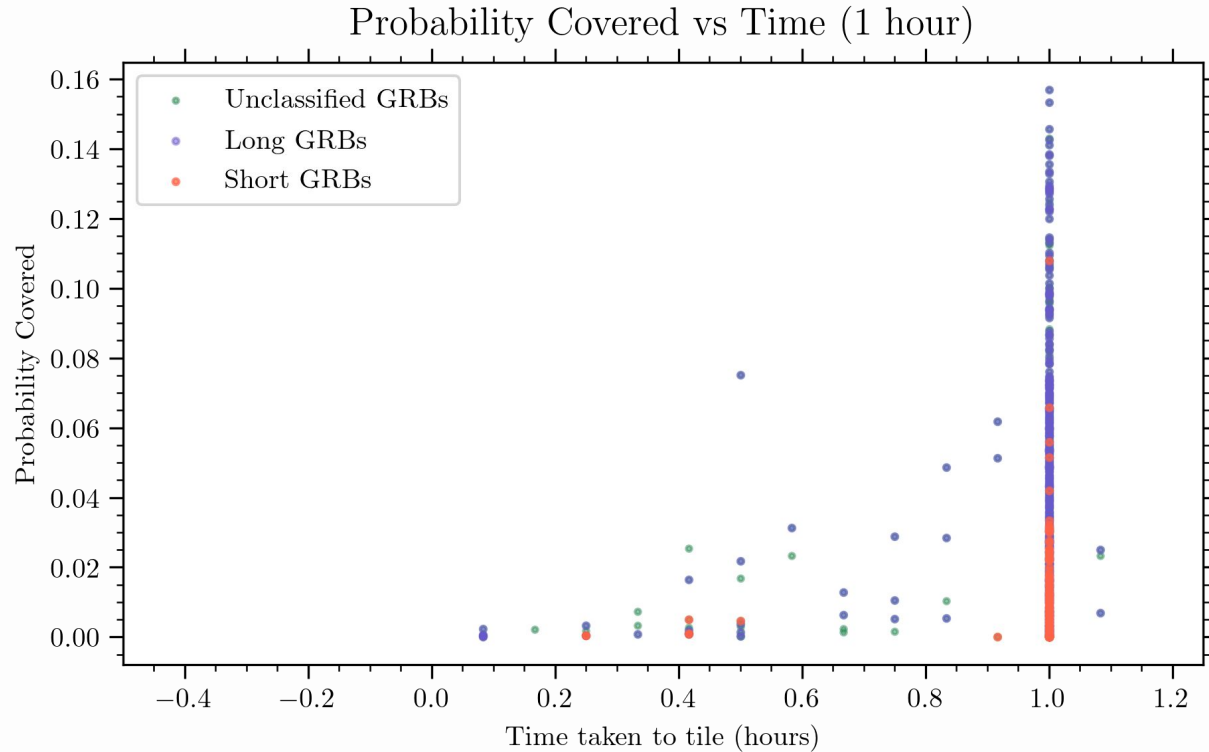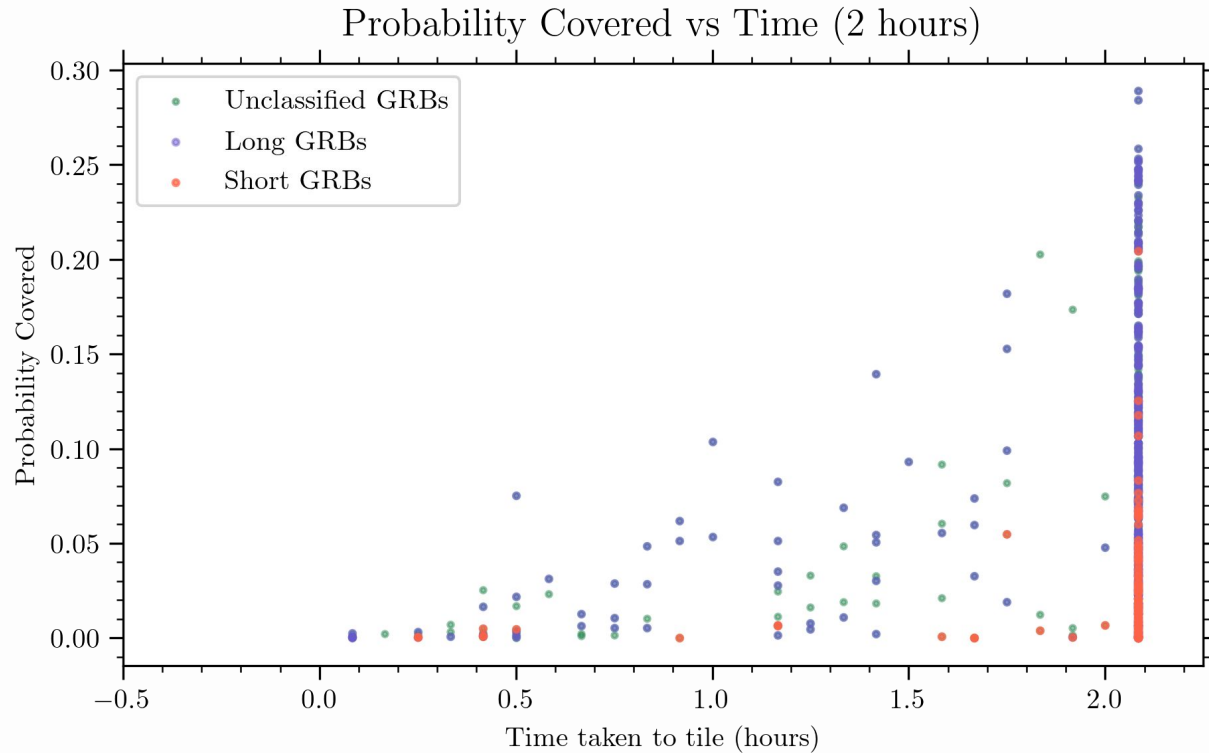
4-Hour Observations
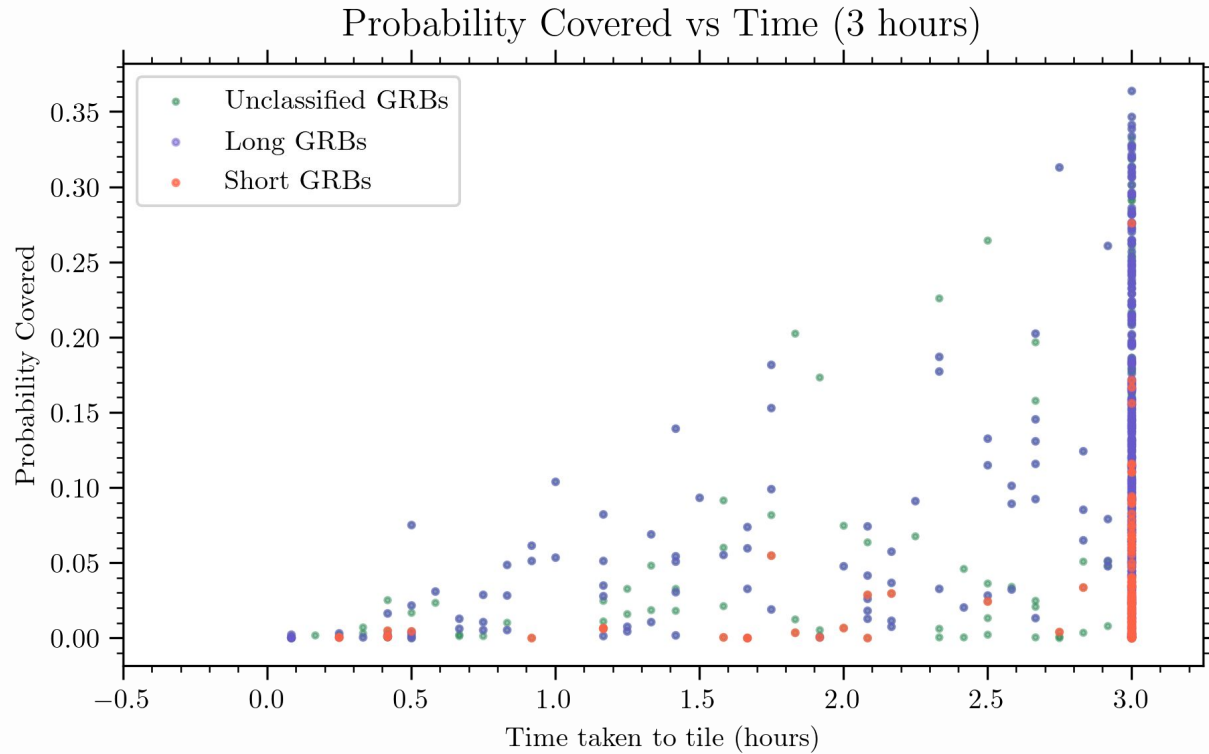
Probability Covered vs Time (4 hours)
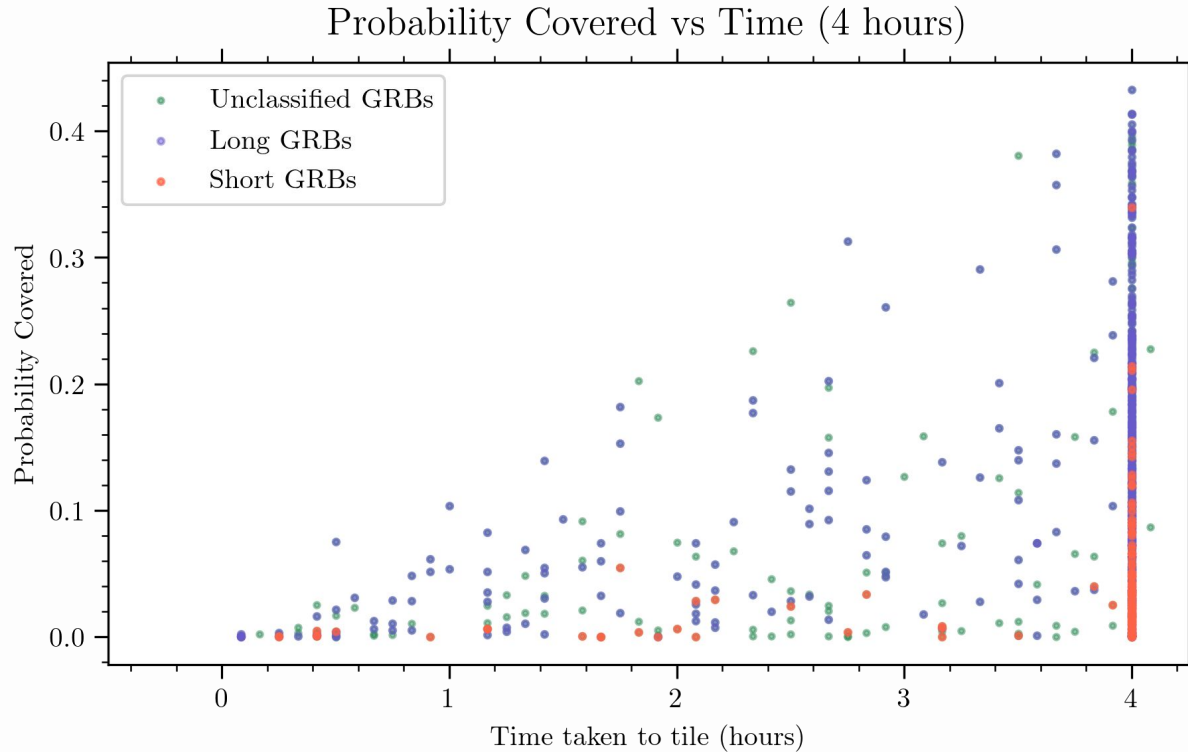
Long GRB Coverage

Observation Time Limit	Probability Cutoff	Total Triggers	Total Probability Covered	Total Observation Time (hours)	Effective Time per Detection (hours)
1 hour	0.05	148 (26.15)	12.1 (2.13)	147.3 (1.33%)	12.2
	0.10	35 (6.18)	4.4 (0.77)	35.0 (0.32%)	8.0
	0.15	2 (0.35)	0.3 (0.05)	2.0 (0.02%)	6.4
	0.20	0 (0.00)	0.0 (0.00)	0.0 (0.00%)	nan
2 hours	0.05	276 (48.76)	33.2 (5.86)	561.4 (5.07%)	16.9
	0.10	143 (25.27)	23.4 (4.13)	295.5 (2.67%)	12.6
	0.15	75 (13.25)	15.1 (2.67)	155.6 (1.40%)	10.3
	0.20	36 (6.36)	8.4 (1.48)	75.0 (0.68%)	9.0
3 hours	0.05	324 (57.24)	47.1 (8.33)	933.6 (8.42%)	19.8
	0.10	206 (36.40)	38.6 (6.81)	607.3 (5.48%)	15.7
	0.15	125 (22.08)	28.4 (5.03)	370.5 (3.34%)	13.0
	0.20	74 (13.07)	19.7 (3.48)	221.3 (2.00%)	11.2
4 hours	0.05	339 (59.89)	57.5 (10.16)	1269.1 (11.45%)	22.1
	0.10	241 (42.58)	50.3 (8.88)	930.2 (8.39%)	18.5
	0.15	169 (29.86)	41.5 (7.33)	660.8 (5.96%)	15.9
	0.20	109 (19.26)	31.0 (5.48)	429.8 (3.88%)	13.9
Full Night	0.05	360 (63.60)	79.7 (14.09)	2461.7 (22.21%)	30.9
	0.10	279 (49.29)	73.6 (13.01)	1993.1 (17.99%)	27.1
	0.15	212 (37.46)	65.3 (11.54)	1565.0 (14.12%)	24.0
	0.20	174 (30.74)	58.8 (10.39)	1320.2 (11.91%)	22.4

Short GRB Coverage

Observation Time Limit	Probability Cutoff	Total Triggers	Total Probability Covered	Total Observation Time (hours)	Effective Time per Detection (hours)
1 hour	0.05	4 (0.71)	0.3 (0.05)	4.0 (0.04%)	14.2
	0.10	1 (0.18)	0.1 (0.02)	1.0 (0.01%)	9.3
	0.15	0 (0.00)	0.0 (0.00)	0.0 (0.00%)	nan
	0.20	0 (0.00)	0.0 (0.00)	0.0 (0.00%)	nan
2 hours	0.05	16 (2.83)	1.4 (0.24)	33.0 (0.30%)	24.4
	0.10	4 (0.71)	0.6 (0.10)	8.3 (0.08%)	15.0
	0.15	1 (0.18)	0.2 (0.04)	2.1 (0.02%)	10.2
	0.20	1 (0.18)	0.2 (0.04)	2.1 (0.02%)	10.2
3 hours	0.05	28 (4.95)	2.6 (0.47)	82.8 (0.75%)	31.3
	0.10	8 (1.41)	1.2 (0.22)	24.0 (0.22%)	19.6
	0.15	4 (0.71)	0.8 (0.14)	12.0 (0.11%)	15.6
	0.20	1 (0.18)	0.3 (0.05)	3.0 (0.03%)	10.9
4 hours	0.05	33 (5.83)	3.6 (0.64)	129.8 (1.17%)	35.7
	0.10	14 (2.47)	2.3 (0.40)	56.0 (0.51%)	24.8
	0.15	6 (1.06)	1.3 (0.22)	24.0 (0.22%)	19.0
	0.20	3 (0.53)	0.8 (0.14)	12.0 (0.11%)	15.7
Full Night	0.05	58 (10.25)	7.5 (1.33)	437.2 (3.95%)	58.0
	0.10	26 (4.59)	5.3 (0.93)	201.0 (1.81%)	38.1
	0.15	15 (2.65)	4.0 (0.71)	114.1 (1.03%)	28.6
	0.20	10 (1.77)	3.1 (0.55)	87.3 (0.79%)	27.9

Conclusion

Follow-up threshold. Some actual follow-ups

Conclusion, Results and Future Work

- Follow-up criteria
  - Long GRBs: More than 20% probability within 2 hours of observations
  - Short GRBs: More than 20% probability during the entire night of observations
- **GRB 231018A**
  - 2023-10-18 12:30:10 UT — Fermi GBM localisation — Predicted coverage 22.2%
  - 2023-10-18 17:28:08.91 UT — GIT started observing the field — Coverage 21.7%
  - Median limiting magnitude — ~19 mags (r')
  - Published the coverage results as a GCN — Circ. 34839

GCN Circular 34839

Subject   GRB 231018A: GROWTH-India Follow-Up of a Fermi Long GRB
Date   2023-10-19T07:33:47Z (a month ago)
From   Varun Bhalerao at IIT Bombay <varunb@iitb.ac.in>
Via   Web form

R. Kumar, Y. Wagh, R. Sharma, A. Salgundi, V. Swain, D. Raman, T. Roychowdhury, V. Bhalerao (IIT Bombay), S. Barway, G. C. Anupama (IIA), K. Angail (IAO)

We observed the field of GRB 231018A detected by Fermi (Fermi GBM Team, GCN Circ. 34826; GCN Circ. 34831) with 0.7m GROWTH–India Telescope (GIT). GIT started observing the field at 2023–10–18 17:28:08.912 UT, i.e., 4.96 hours after the Fermi trigger. We obtained a series of 25 r' band images each of 300s exposure, covering 9.44 square degrees. This corresponds to 21.7% of the probability enclosed in the Fermi GBM Final Real–time Localisation (Fermi GBM Team, GCN Circ. 34826) and 20.17% of the probability enclosed in the BALROG localization (Preis et al., GCN Circ. 34827). Where available, PanSTARRS images (Chambers et al., 2016) were used as references for image subtraction. In other fields, we looked for new point sources absent in the GSC2.3 catalog. We did not find any suitable afterglow candidate, reaching a median limiting magnitude of 18.95 in the r' band. The detailed observing log is:
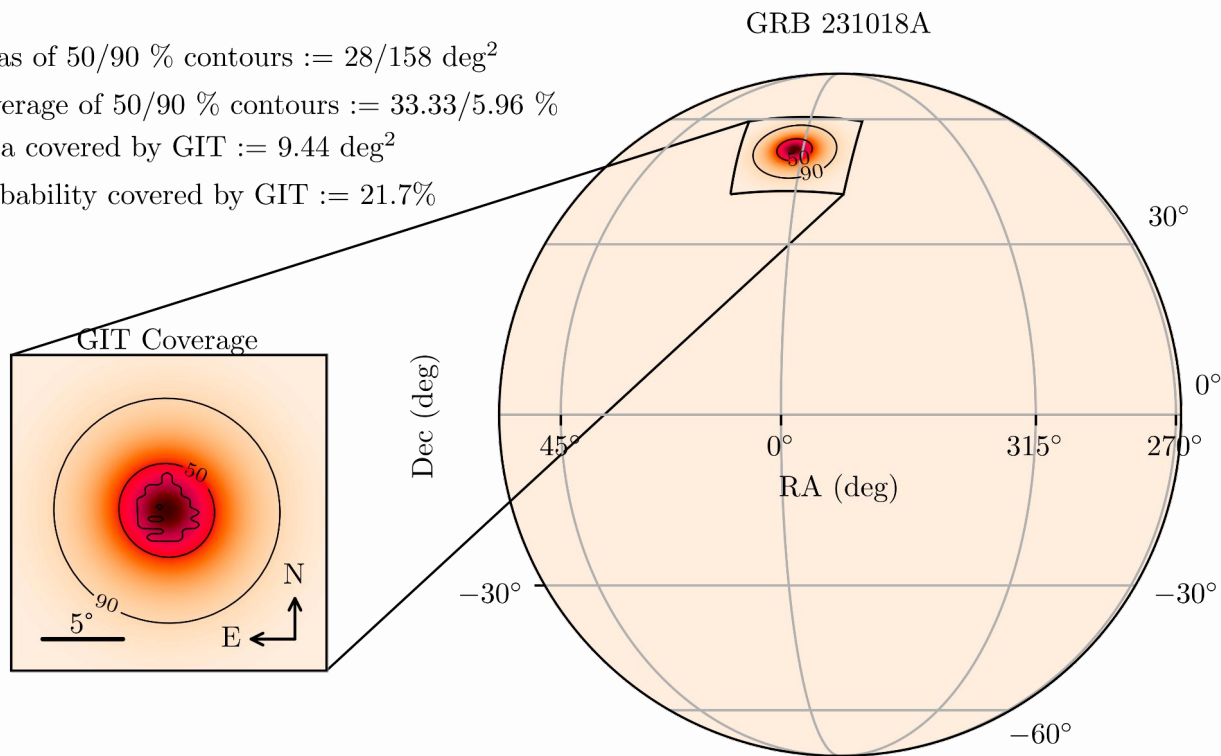
GRB 231018A

Areas of 50/90 % contours := 28/158 deg^2

Coverage of 50/90 % contours := 33.33/5.96 %

Area covered by GIT := 9.44 deg^2

Probability covered by GIT := 21.7%
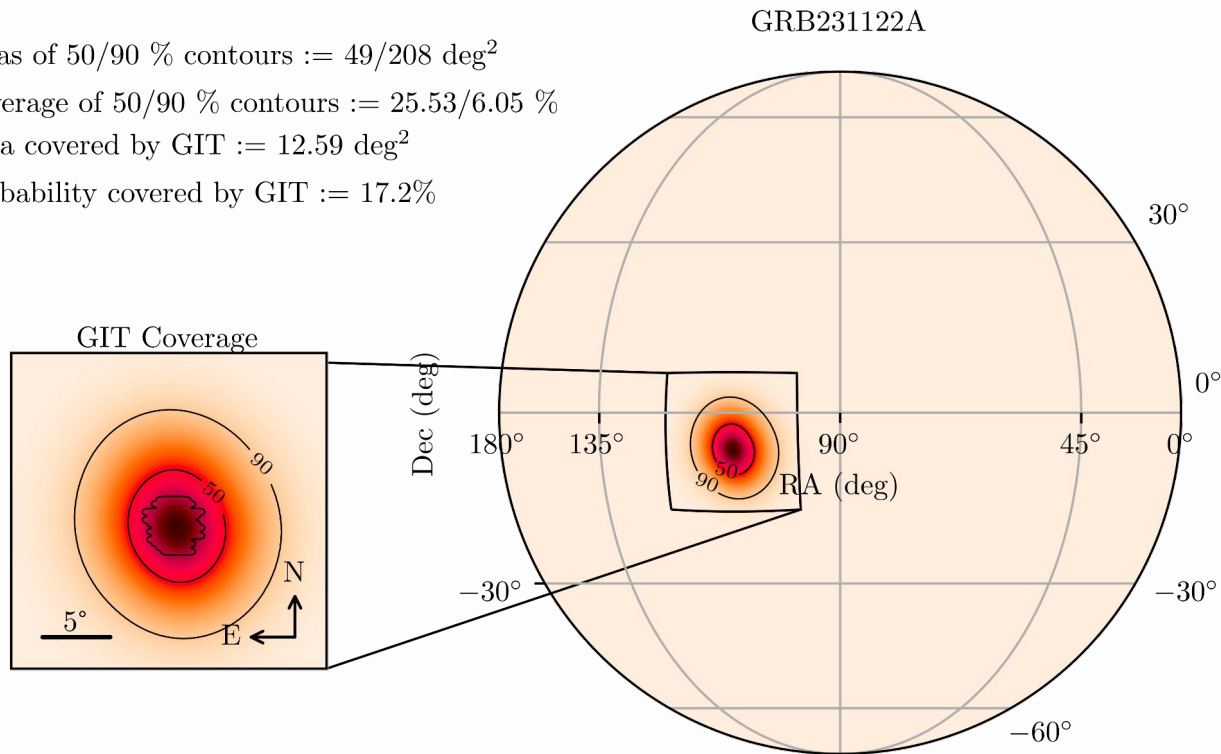
GRB 231018A

GIT Coverage

GRB 231122A

Areas of 50/90 % contours := 49/208 deg^2

Coverage of 50/90 % contours := 25.53/6.05 %

Area covered by GIT := 12.59 deg^2

Probability covered by GIT := 17.2%

GIT Coverage

GRB231122A

Thank You