Assessing the detectability of optical afterglows of short gamma-ray bursts by ground-based facilities in the THESEUS era

Lána Salmon
University College Dublin

L. Hanlon, A. Martin-Carrillo, G. Stratta, R. Ciolfi
Short Gamma-Ray Bursts

- Classical GRB Fireball Model
  - collapsar
  - merger
GRB170817A

- Not a classical short GRB
  - off-axis
  - structured jet/cocoon
  - kilonova
GRB170817A

- Not a classical short GRB
  - off-axis
  - structured jet/cocoon
  - kilonova
How many short GRBs will THESEUS detect?

- Unambiguous host galaxy detection

- Results from the MOS, credit A.
  Rocchi, ESA
How many short GRBs will THESEUS detect?

- Large number of galaxies is challenging for host identification

- Results from the MOS, credit A. Rocchi, ESA

>950 extended objects from:
- PanSTARRS
- GLADE
down to $r_{\text{Kron}} = 22$ mag
How many short GRBs will THESEUS detect?

- Galaxy catalogues are incomplete
- Multi-Object Spectrographs like WEAVE (WHT) and surveys like LSST will help
- Ground-based afterglow detection can help

- Results from the MOS, credit A. Rocchi, ESA
Recover redshift on the ground

- Aim: determine fraction of optical afterglows observable by ground-based facilities

- Simulate short GRB optical afterglow light curves
- Compare to telescope magnitude limits
- Determine fraction of afterglows detectable
Simulation set-up

- **Afterglowpy**
  - Python package for calculating GRB afterglows in the forward shock model (Ryan et al. 2019)

**Inputs**

- $E_{\text{iso}}$ Isotropic equivalent energy
- $d_L$ Luminosity distance
- $z$ Redshift
- $p$ Electron energy distribution index
- $\epsilon_e$ Thermal energy fraction in electrons
- $\epsilon_B$ Thermal energy fraction in magnetic field
- $n$ Circumburst density of ISM
- $\theta_{\text{view}}$ Viewing angle from axis
- $\theta / 2$ Jet half-opening angle
1. Energy

- $E_{\text{peak}}$ distribution defined in Ghirlanda et al. (2016)
- $E_{\text{iso}}$ determined through Amati relation
2. Distance

- Redshift distribution defined in Ghirlanda et al. 2016
3. Syncrotron

- Median values from Fong et al. 2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>$2.9 \times 10^{-3}$ cm$^{-3}$</td>
</tr>
<tr>
<td>$\varepsilon_e$</td>
<td>0.1</td>
</tr>
<tr>
<td>$\varepsilon_B$</td>
<td>0.1</td>
</tr>
<tr>
<td>$p$</td>
<td>2.43</td>
</tr>
</tbody>
</table>
4. Geometry

- Top-hat jet
- Skew-normal distribution from 2-10 degrees
- Peaking at 5 degrees (median from Fong et al. 2015)
4. Geometry

- 3 viewing angle scenarios

(A) On Axis

\[ \theta_{\text{view}} = 0 \]
4. Geometry

- 3 viewing angle scenarios

(B) Within jet

\[ \theta_{\text{view}} < \frac{\theta_j}{2} \]
4. Geometry

- 3 viewing angle scenarios

(C) Outside jet

\[
\frac{\theta_j}{2} < \theta_{\text{view}} < 32^\circ
\]
Simulated Light Curves

On-Axis

Within jet

Outside jet
Simulated Light Curves

On-Axis

Within jet

Outside jet
Simulated Light Curves

On-Axis

Within jet

Outside jet
Quantify ground-based successful follow-up

Simulate short GRB optical afterglow light curves

Compare to telescope magnitude limits

Determine fraction of afterglows detectable

Photometric

Spectroscopic

Gran Telescopio de Canarias 10.4m

Vera Rubin Observatory 8.4m

Liverpool Telescope 2m

E-ELT 39m

Gran Telescopio de Canarias 10.4m

Integration Times

30 sec 1 hour 30 sec 1 hour 1 hour

R magnitude limits

Grey time

Airmass = 1

SNR = 5

Δλ/λ=1000
Photometric limits

On-Axis

Within jet

Outside jet

![Graphs showing photometric limits for On-Axis, Within jet, and Outside jet. The graphs compare different observing times and exposure conditions, with data points and error bars illustrating the magnitude variations over time.](image-url)
Spectroscopic limits

On-Axis

Within jet

Outside jet
Fraction of Detectable Afterglows - Photometric

Simulate short GRB optical afterglow light curves

Compare to telescope magnitude limits

Determine fraction of afterglows detectable

On-Axis

Within jet

23
Spectroscopic fractions

Simulate short GRB optical afterglow light curves → Compare to telescope magnitude limits → Determine fraction of afterglows detectable

On-Axis → Within jet

Graphs showing the fraction of light curves above limiting magnitude over time since trigger for GTC/OSIRIS (1hr) and ELT (1hr).
Photometric limits - 30s integration

- Simulate short GRB optical afterglow light curves
- Compare to telescope magnitude limits
- Determine fraction of afterglows detectable
- 30s integration
- On-Axis
- Within jet
- $T_0 + 5\text{hr}$

![Graph showing afterglow detection probabilities for GTC, VRO, and LT](image-url)

- Afterglow detected
- No afterglow detected

![Graph showing afterglow detection probabilities for GTC, VRO, and LT](image-url)
Photometric limits - 1 hour integration

Simulate short GRB optical afterglow light curves → Compare to telescope magnitude limits → Determine fraction of afterglows detectable

1 hour integration

On-Axis

Within jet

T₀+5hr

<table>
<thead>
<tr>
<th></th>
<th>Afterglow detected</th>
<th>No afterglow detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTC</td>
<td></td>
<td></td>
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<tr>
<td>LT</td>
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</tbody>
</table>
Spectroscopic results - 1 hour integration

- Simulate short GRB optical afterglow light curves
- Compare to telescope magnitude limits
- Determine fraction of afterglows detectable

1 hour integration

On-Axis

Within jet

\[ T_0 + 5 \text{ hr} \]

Graphs showing afterglow detection rates for E-ELT and GTC.
• Ground-based follow-up will significantly increase the sample size of THESEUS’ short GRBs with redshift

- Results from the MOS, credit A. Rocchi, ESA