Assessing the Capabilities of THESEUS to observe Giant Flares from Extragalactic Magnetars

Maeve Doyle[1], Lorraine Hanlon[1], Antonio Martin-Carrillo[1], Sandro Mereghetti[2] and Michele Lissoni[2]

[1]School of Physics and Centre for Space Research, University College Dublin, Ireland
[2]INAF, Istituto di Astrofisica Spaziale e Fisica Cosmica, Milano, Italy

Magnetar Giant Flares (GFs)

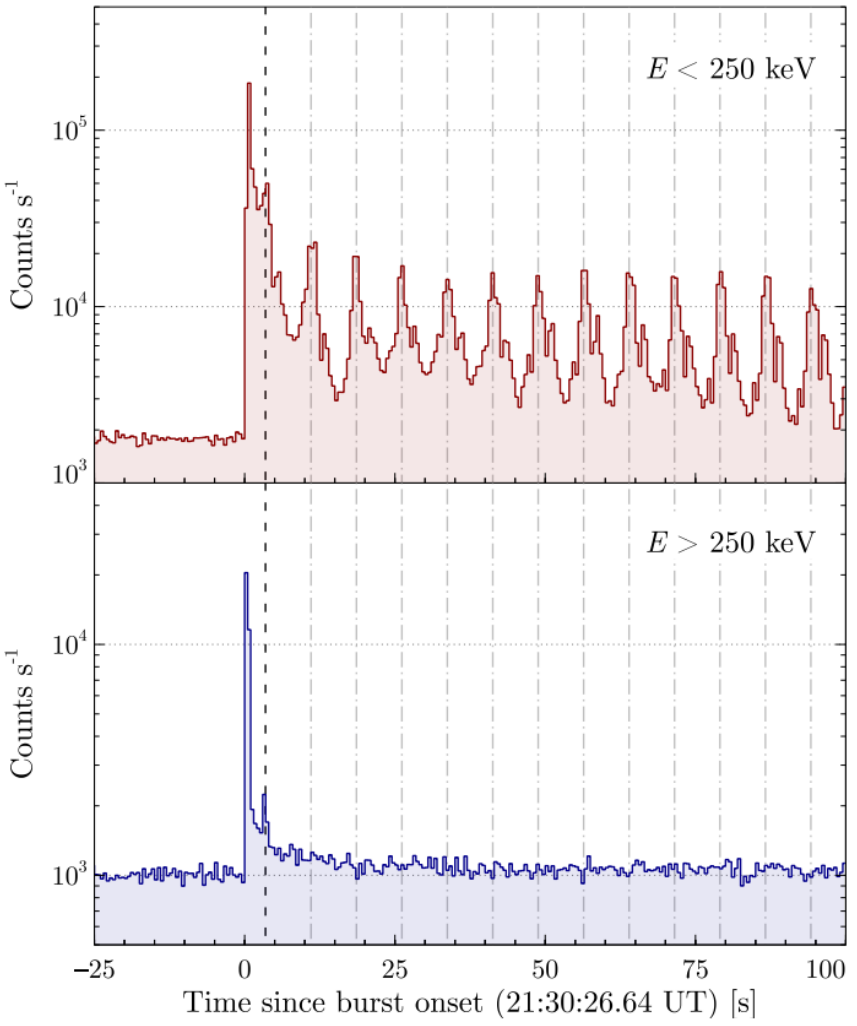
- Characterized by an outburst of X-/γ-ray radiation that is:
  - Extremely energetic ($\geq 10^{44}$erg)
  - Short-lived (lasting tens to hundreds of milliseconds)
  - Spectrally hard ($E_{peak} \sim$MeV)

- Initial spike followed by longer-lived, lower-energy tail

- Peak luminosities (up to 10^{48} erg/s) allow for detections from extragalactic distances
  - Initial spike resembles SGRB emission

- Rare, one-off (?) events
  - 3 known GFs, 4 candidates

GF from the magnetar SGR 1806-20 on 27th December 2004



(Elenbaas et al. 2017)

GF Population

- 3 GFs observed from known magnetars
  - GRB 790305B → SGR 0525−66 (LMC)
  - GRB 980827 → SGR 1900+14 (MW)
  - GRB 041227 → SGR 1806-20 (MW)

- 4 extragalactic GF candidates identified through population-level searches of SGRBs
  - Current results suggest 1-8% of SGRBs are actually GFs
  - Observed to 4.5 Mpc

- Similar properties observed for both populations

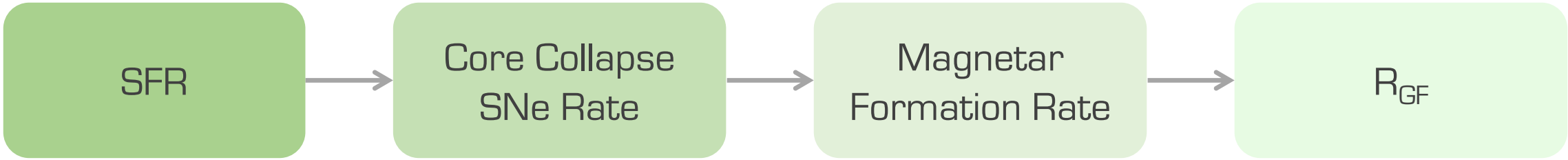
E_{iso}: High isotropic energies ranging from 0.43 to 53 $\times 10^{45}$ erg

Durations: Initial spike rise times of ~ms and spike durations of 10 to <250 ms

Spectra: Well-fit by a cut-off power-law, $N(E) = AE^{-\alpha}\exp[\frac{-(2-\alpha)E}{E_{peak}}]$, with $E_{peak} \sim 1$MeV and $\alpha \sim 0$

GF Rate

- The rate of GFs (R_{GF}) can be related to Star Formation Rate (SFR) as:



- Using the number of extragalactic GFs detected within ~5 Mpc and the evolution of SFR with volume, Burns et al. (2021) estimate

$$R_{GF} \sim 3.8\,^{+4.0}_{-3.1} \times 10^5\ /\mathrm{Gpc}^3/\mathrm{year}$$

How many GFs will THESEUS detect? / Simulations

To what distance must the GF population be simulated?

Prototype GFs					
GF [GRB designation]	Distance [Mpc]	Duration [s]	E_{iso} [erg]	Spectral Properties	
				E_{peak} [keV]	α
200415A	3.50	0.1	1.3×10^{46}	1080	0
070222	4.50	0.038	6.2×10^{45}	1290	1
051103	3.70	0.138	5.3×10^{46}	2150	0.2
070201	0.78	0.01	1.6×10^{45}	280	0.6

Flux limits associated with 7σ detections for SXI, XGIS-X and XGIS-S

GF luminosities in the energy bands of THESEUS's instruments

Maximum detectable distance: ~36 Mpc
(XGIS-S / GRB 051103)

How many GFs will THESEUS detect?/Simulations

How many GFs should be simulated within this distance?

SFR within 36 Mpc^3 interpolated

Scaling the observed rate, we find
$R_{GF} \sim 5.7$ /36 Mpc^3/year

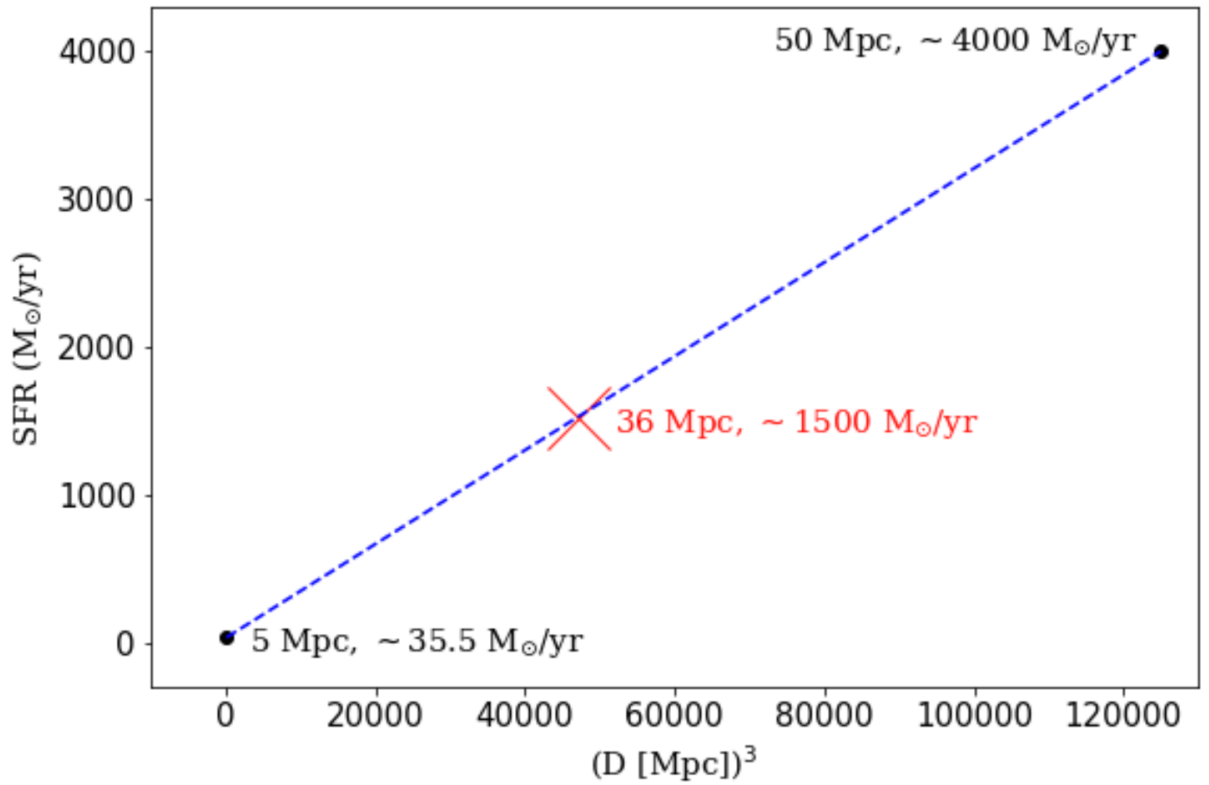
×3.5 years

$R_{GF} \sim 20$ /36 Mpc^3/mission

Account for uncertainties

$R_{GF} \sim 4\text{-}40$ /36 Mpc^3/mission

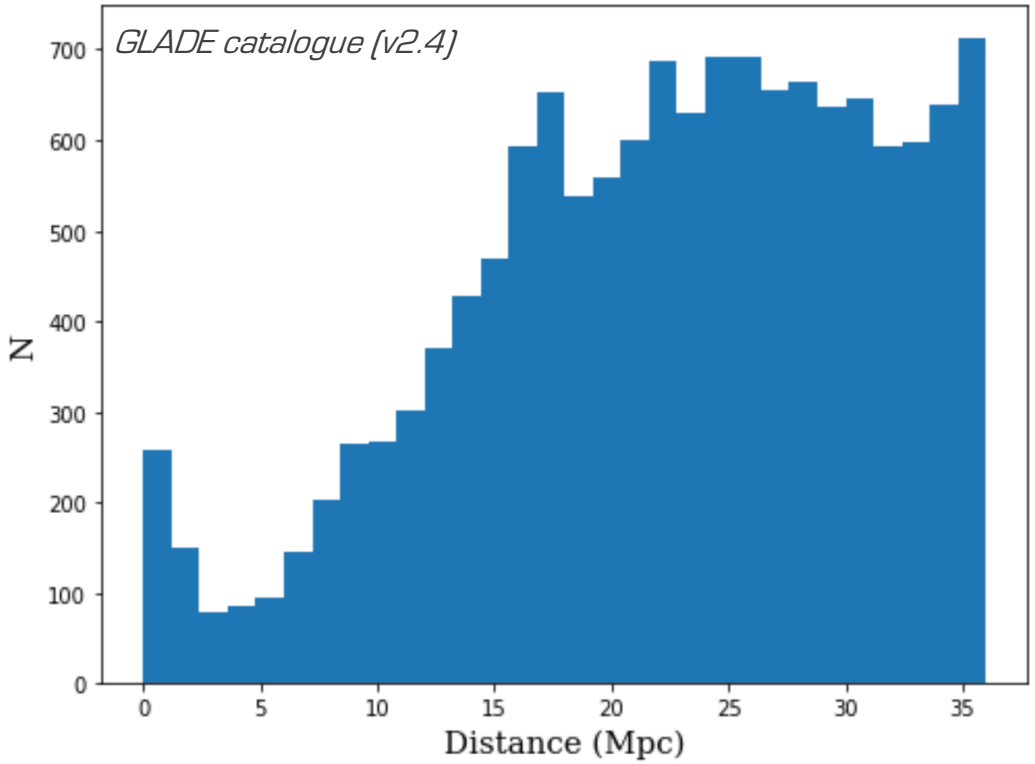
SFR at 5 and 50 Mpc taken from Burns et al. (2021)



How many GFs will THESEUS detect?/Simulations

How should these GFs be distributed?

GLADE

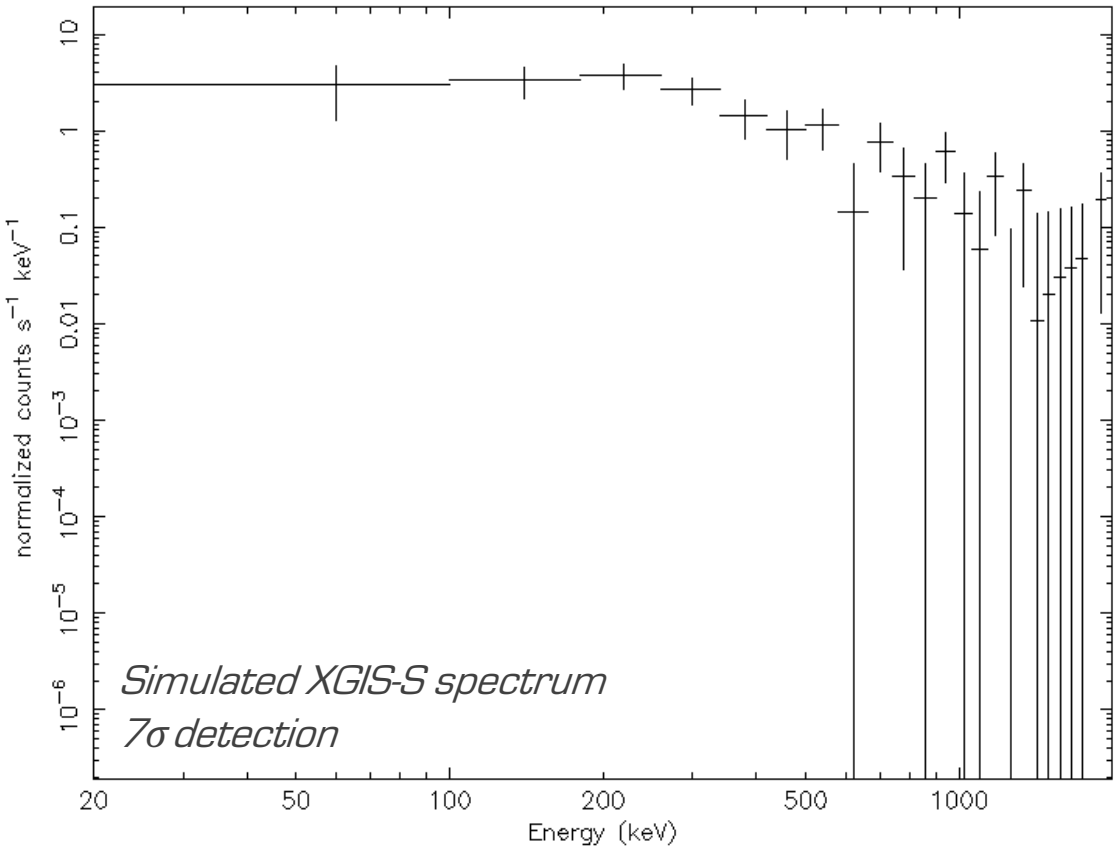


Results (1/3): Detectable GFs

- Highest number of GFs detectable by XGIS-S
- Only a fraction of XGIS-S detected GFs also detectable by XGIS-X
- ~0 GFs detectable by SXI

Number (N) of simulated GFs detectable by XGIS-S

GF Prototype	$N\sigma > \sigma_{thresh}$ (where $\sigma_{thresh} = 7$)
200415A	1 - 23
070222	2 - 21
051103	4 - 40
070201	2 - 20



Results (2/3): Impact of energy range

- Current instrumentation should detect GFs to ~tens of Mpc (Burns et al. 2021)
- Spectral shape of GFs leads to fewer photons in the typical energy range used for triggering (50 – 300 keV)
- How does this impact THESEUS's detection capabilities?

GF ProtoType	$N\sigma > \sigma_{thresh}$ (where σ_{thresh} = 7 and using max. value in N range)		% Undetected
	20 keV - 2 MeV (full XGIS-S range)	50 keV - 300 keV (triggering range)	
200415A	23	14	39 %
070222	21	14	33 %
051103	40	24	40 %
070201	20	14	30 %

30-40% of events undetected with 7σ threshold

Results (3/3): Effect of FoV

- 'Effective' FoV of XGIS considering sensitivity of the detector across the full FoV (2.2 sr) is approximated as ~1 sr
  - $1/4\pi \sim 8\,\%$ sky coverage

GF Prototype	$N\sigma > \sigma_{thresh}$ (where $\sigma_{thresh} = 7$)
	20 keV - 2 MeV (full XGIS-S range)
200415A	1 - 23
070222	2 - 21
051103	4 - 40
070201	2 - 20

GF Prototype	$N\sigma > \sigma_{thresh}$ (where $\sigma_{thresh} = 7$)
	20 keV - 2 MeV (full XGIS-S range)
200415A	0 - 2
070222	0 - 2
051103	0 - 3
070201	0 - 2

Conclusions

- This work shows that THESEUS/XGIS-S has the capability to detect a few extragalactic GFs
  - R_{GF} is uncertain
  - Several approximations made for simulations

- Potential to increase chances of detection, e.g.;
  - Ensure favorable energy ranges and timescales considered by at least some on-board triggering algorithms
  - More targeted approach to monitoring galaxies

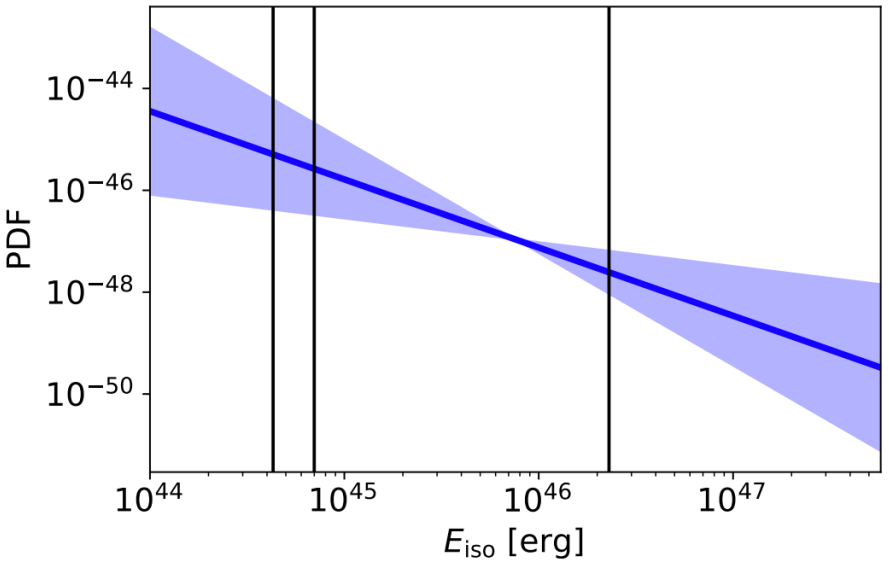
- Importance of THESEUS to GF research:
  - Increase the population of known GFs
  - Allow for better constraints on R_{GF}

Future Work

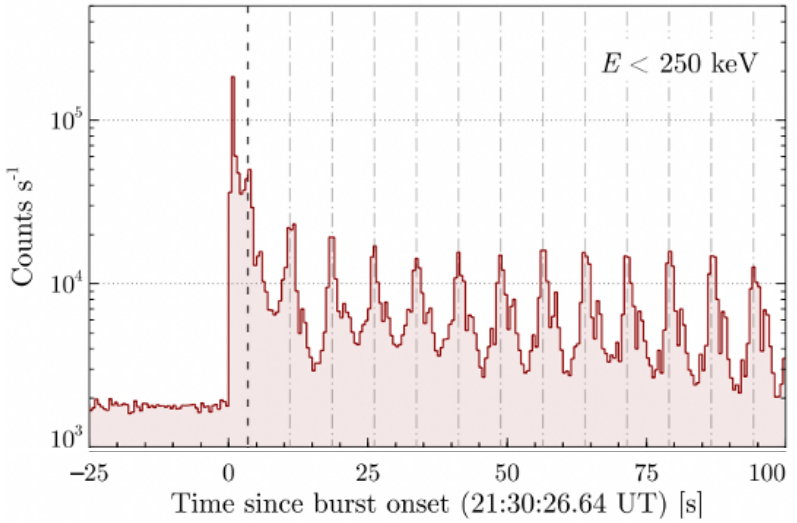
- More representative simulations, e.g.;
  - Different spectral shapes, energetics, durations
  - Host galaxy distribution weighted by SFR

- Assess potential for follow-up observations
  - Host galaxy observations
  - Afterglow tail

Potential GF energetics distribution considered by Burns et al. (2021)



Pulsating X-ray tail (Elenbaas et al. 2017)



Thank you for your attention!
Questions?

Contact: maeve.doyle.1@ucdconnect.ie