GRB follow-up with MeerLICHT as preparation for O4

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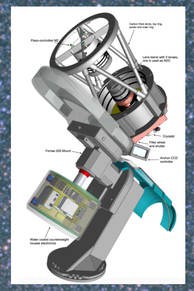
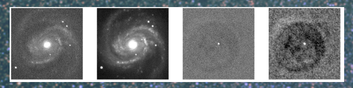
About MeerLICHT

- 60cm, fully-robotic optical telescope located at the South African Astronomical Observatory site in Sutherland, South Africa
- Built as precursor to the BlackGEM array with aim to co-observe with MeerKAT
- Wide FOV: 98.6' x 98.6' sampled at 0.56"/pixel
- 5 SDSS *ugriz* filters and a wide *q*-band (roughly *g+r*)
- Reference images of the entire southern sky in all filters enable difference-imaging to find transients
- New transients rapidly identified through software pipeline: fully reduced images, catalogues, and transient products available ~10



From Bloemen et al., 2016: "MeerLICHT and BlackGEM: custom-built telescopes to detect



A new supernova in M100 as detected by MeerLICHT. From L to R: new science image, reference image, difference image, and corrected significance image. All cutouts are 5'x5'.

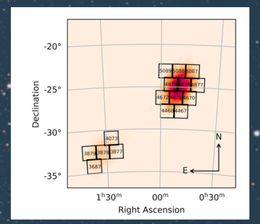
Results: 20 GRBs followed-up with 10 optical afterglow detections

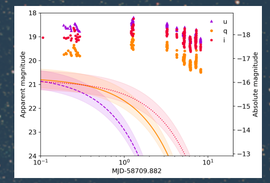
- We follow-up Swift and Fermi/GBM GRBs observable within 5 hours of a trigger. GBM GRBs must cover 70% with <80 tiles.
- Fully-automated triggering, quqgqrqiqz filter sequence for Swift, q-band only for GBM
- Fast, consistent reporting of results to GCN

GRB	UT time	Triggering mission[a]	T_{90} (s)[b]	Response time (hrs)	ML afterglow detection (Y/N)[c]	Field ID[d]	ML GCN
210610A	15:03:43	*Swift*/manual	13.62	1.75	Y	10601	(de Wet et al., 2021a)
210610B	19:51:27	*Swift*/manual	69.38	1.15	Y	10626	(de Wet et al., 2021b)
210702A	19:07:13	*Swift*	138.2	0.25	Y	3388	(Groot et al., 2021a)
210724A	20:14:09	*Swift*	50.57	0.18	N	7658	(de Wet et al., 2021c)
210725B	12:00:48	*Swift*	48.00	4.83	N	11036	-
210731A	22:21:08	*Swift*	22.51	0.07	Y	3433	(de Wet et al., 2021d)
211106A	04:37:31	*INTEGRAL*/manual	1.75	14.02	N	1822	(de Wet et al., 2021e)
211130A	15:16:27	*Fermi*	218.63	3.25	Possible	Multiple/4772	(de Wet et al., 2021f)
211221A	20:48:40	*Swift*	671.67	3.59	N	8479	(Groot et al., 2021b)
220114A	14:01:47	*Fermi*	0.73	12.62	N	Multiple	-
220418B	17:16:21	*Fermi*	2.43	1.17	N	6080	-
220427A	21:00:34	*Swift*/manual	57.2	2.69	Y	1521	(de Wet et al., 2022a)
220430A	13:53:15	*Swift*	43.10	3.28	N	9861	(Groot et al., 2022a)
220514A	12:24:32	*Fermi*/manual	66.31	6.79	Y	10343	(de Wet et al., 2022b)
220527A	09:17:15	*AGILE*/manual	10.50	17.60	Y	6363	(de Wet et al., 2022c)
220627A	21:21:00	*Fermi*	136.71, 126.98	0.35	Y	Multiple/3975	(Groot et al., 2022b; de Wet et al., 2022d)
220810A	23:15:42	*Fermi*	8.96	0.24	Possible	Multiple/8856/9314	(de Wet et al., 2022e)
220921A	11:05:59	*Fermi*/manual	44.29	14.64	Y	2977	(de Wet et al., 2022f,g)
221009A	13:16:59	*Swift*	325.83	4.55	Y	11312	(de Wet et al., 2022h)
221115B	09:46:15	*Swift*/manual	~ 5	35.52	N	5976	GCN 32943

Scientific justification for GRB programme

- MeerLICHT and BlackGEM will follow-up gravitational wave (GW) events during the fourth LIGO/Virgo/KAGRA observing run
- Finding an EM counterpart is challenging due to large error boxes and large numbers of transients
- GRBs are fast transients with rapidly-fading afterglows, requiring immediate follow-up
- Connection between short GRBs and neutron star mergers firmly established through joint detection of GRB 170817A and GW170817
- GRB science returns alone can be high due their high redshift, possibility of a SN or KN, or unusual afterglows
- Fermi/GBM GRBs have large error boxes requiring 10s to 100s of pointings to cover 90% probability, just like GW events - ideal practice for O4 follow-up
- GW follow-up was coordinated through GCN, demonstrating strong ties to GRB community



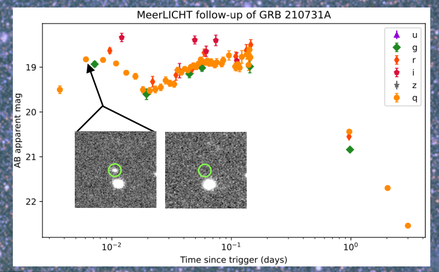


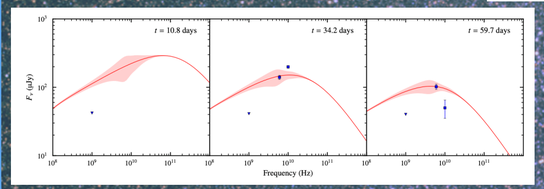
MeerLICHT follow-up of GW190814 during O3. Our limits were not particularly constraining for an AT2017gfo KN at 267 Mpc

Science highlights of programme

1 GRB 210731A: an unusual optical light curve with puzzling MeerKAT upper limits

- MeerLICHT began observing 286 seconds after Swift trigger
- Discovered new optical afterglow in first 60s exposure
- Redshift z=1.25 (X-shooter)
- First 4 hours of MeerLICHT coverage revealed unusual optical light curve with 3 peaks
- Evolution was achromatic
- Energy injection (refreshed shock) is most likely explanation
- First peak is likely onset of afterglow, with $\Gamma_0 \approx 24$



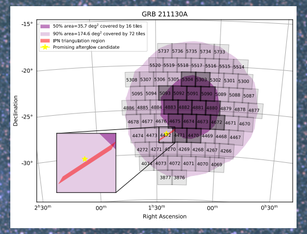


Radio SEDs along with best-fit model

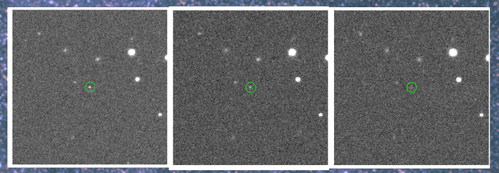
- Obtained radio observations with VLA and MeerKAT
- Theoretical modelling after last optical peak consistent with a wind medium
- 3 epochs of MeerKAT upper limits inconsistent with forward shock model
- Could hint at thermal electron population in forward shock

2 GRB 211130A: first Fermi/GBM burst observed with MeerLICHT with possible afterglow

- GBM burst triggered observations of 72 MeerLICHT fields
- Started observing 3 hours after trigger, most fields observed 3 times
- IPN region announced 3 days post-trigger
- Found promising afterglow candidate (below), but results only reported 10 days post-trigger, so no confirmation of afterglow

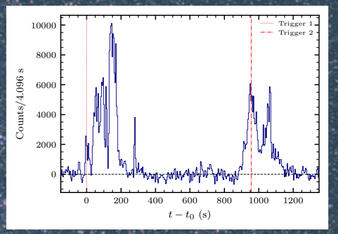


GBM error box with MeerLICHT telescope pointings



Promising afterglow candidate detected at 3 epochs: 3.74, 5.57, 7.05 hours post-trigger

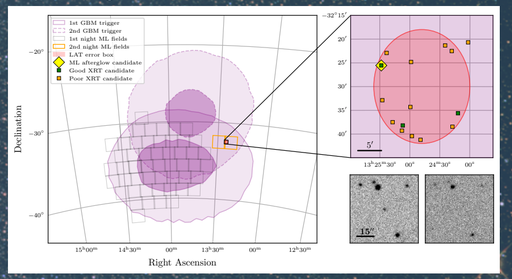
3 GRB 220627A: a possible lensed GRB with a MeerLICHT-discovered afterglow



GBM light curve of GRB 220627A

- MUSE on VLT found redshift z=3.08, with very strong foreground absorber
- Optical photometry revealed presence of jet break at1.23 days
- Radio afterglow also detected
- Lensed scenario ruled out by different spectra in GRB pulses

- GRB triggered Fermi/GBM twice, with almost 1000s between triggers
- Also detected by Fermi/LAT.
- Identified as possibly lensed or ultra-long GRB
- Swift/XRT and MeerLICHT observations identified X-ray and optical afterglow



Localisation of GRB 220627A by MeerLICHT