Recent observations of peculiar Gamma-ray bursts using 3.6-m Devasthal Optical Telescope (DOT)

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ARIES, Nainital

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aries

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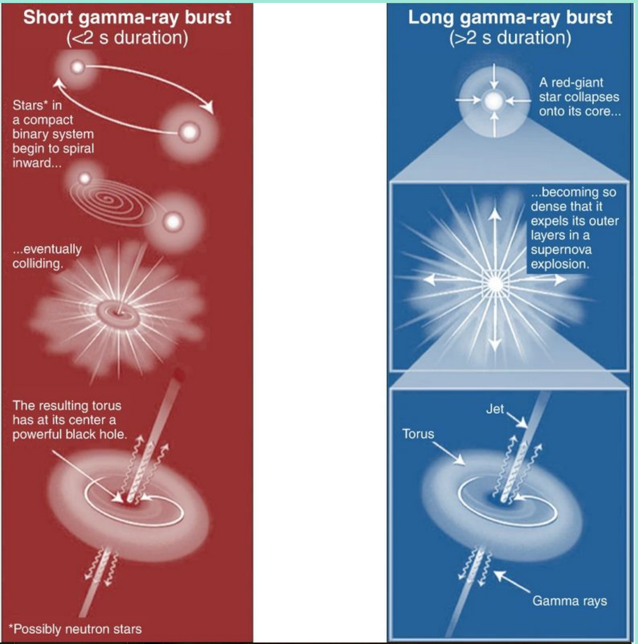
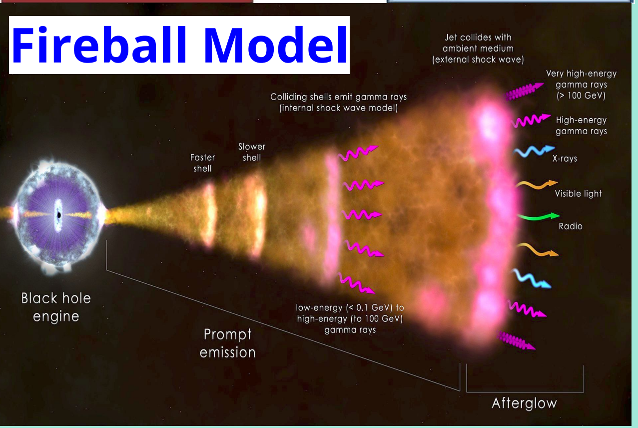




What are Gamma-ray bursts ?

★ Gamma ray bursts (GRBs) are brief, sudden, intense flashes of gamma-ray radiation.

★ They are brightest EM transients ($E_{iso} \sim 10^{50}$ to 10^{55} erg) in the Universe.

★ Lasts from ms to thousands of seconds.

★ Redshift $z = 0.0085$ to 9.4 (Cosmological origin).

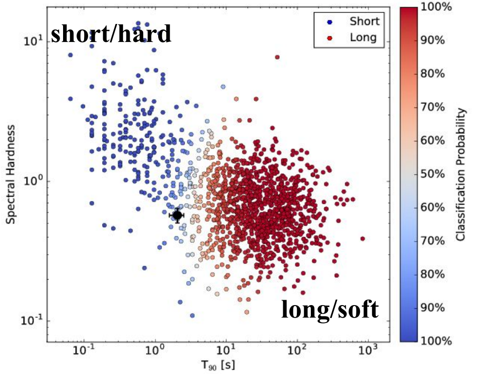
Kumar & Zhang 2015

Phases of GRBs: GRBs emission can be divided into two phases:

1. Prompt emission : MeV
2. Afterglow : VHE to radio bands

Classification of GRBs:

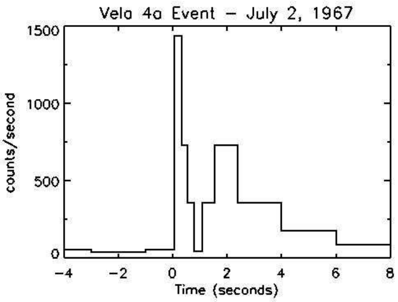
1. Short-duration GRBs: $T_{90} \leq 2$ sec
2. Long-duration GRBs: $T_{90} > 2$ sec



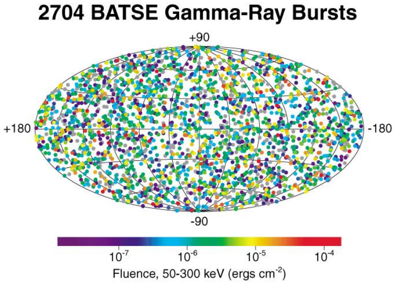
GRBs key discoveries: from Discovery to Multi-Messenger Era

GRBs: The brightest electromagnetic cosmic stellar transients.

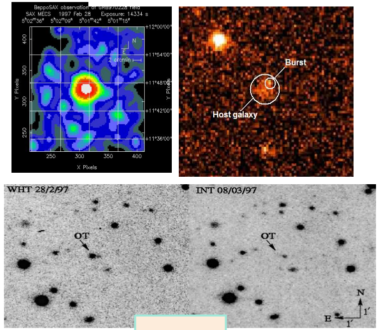
Vela



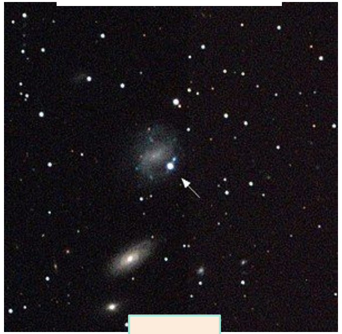
CGRO



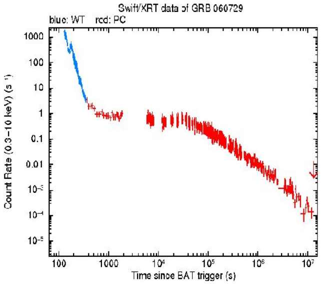
Afterglows



LGRBs+SNe

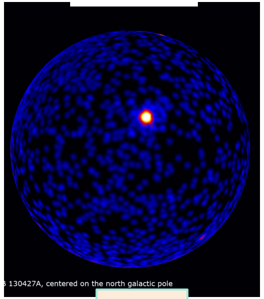


Swift

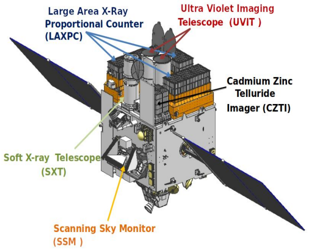


1967 — 1991 — 1997 — 1998 — 2004

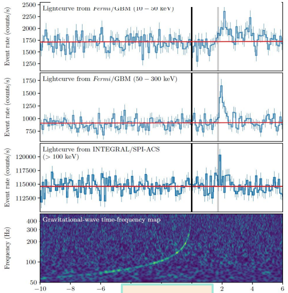
Fermi



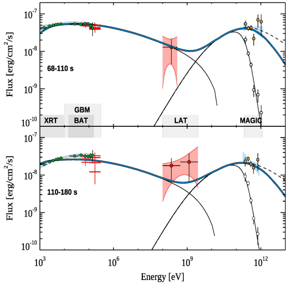
Astrosat/CZTI



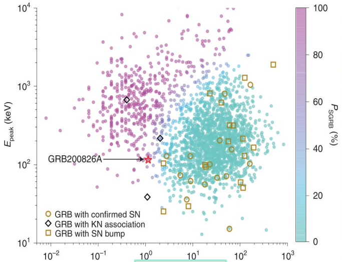
GW+SGRBs



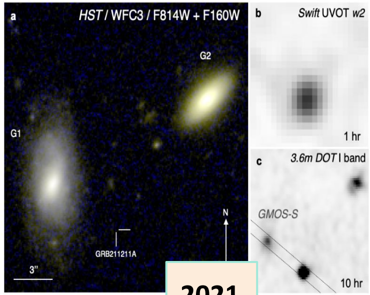
VHE



SGRBs+SNe



LGRBs+Kilonova



2008 — 2015 — 2017 — 2019 — 2020 — 2021

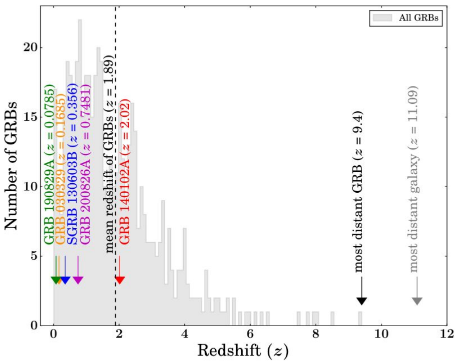
Importance of GRBs study

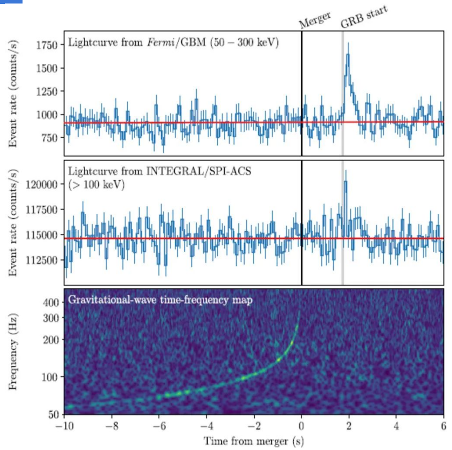
Physics in extreme conditions

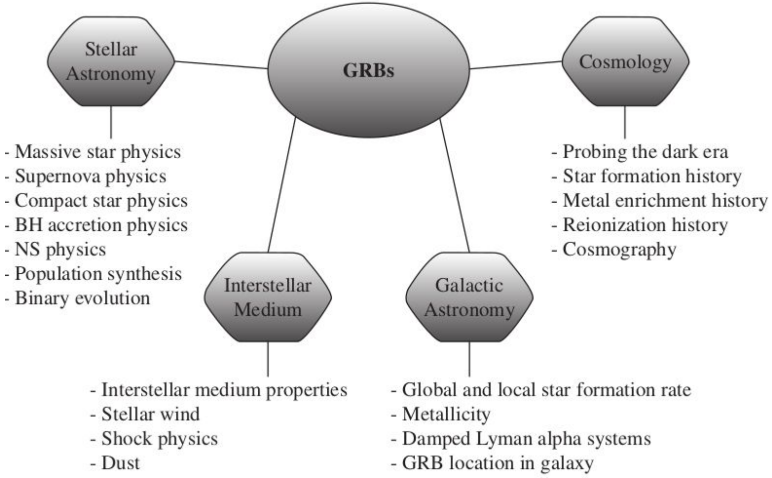
Cosmology

Multi-messenger Astronomy

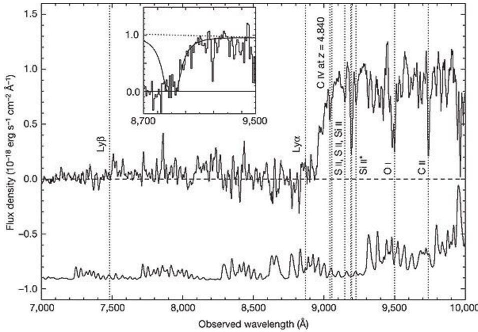
Cosmic mines of Gold/heavy elements







GRB 050904, *z*=6.29 FIRST AT *z*>6

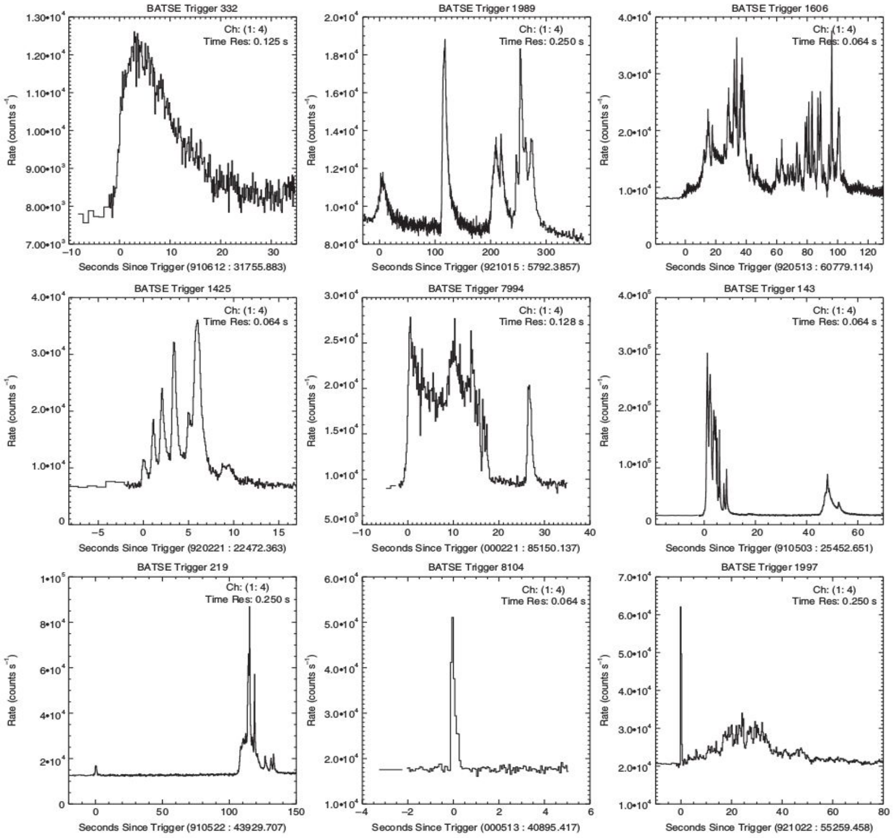


Detected in short exposures by 25 cm robotic telescope

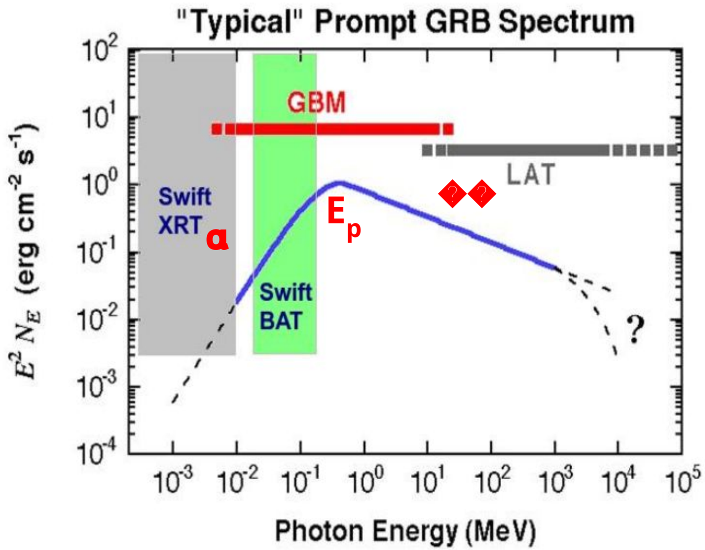
Light Curve

Prompt Emission

Spectrum



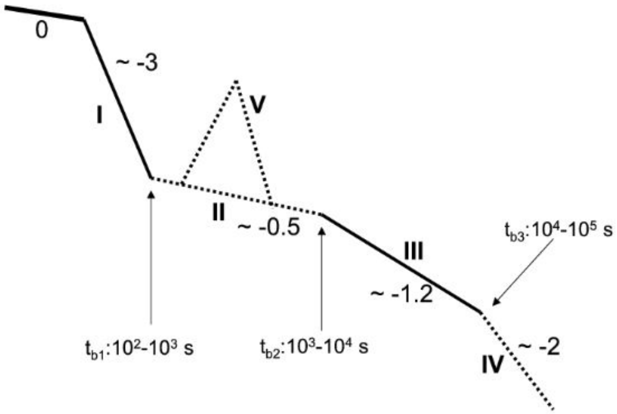
Erratic GRB central engine activities

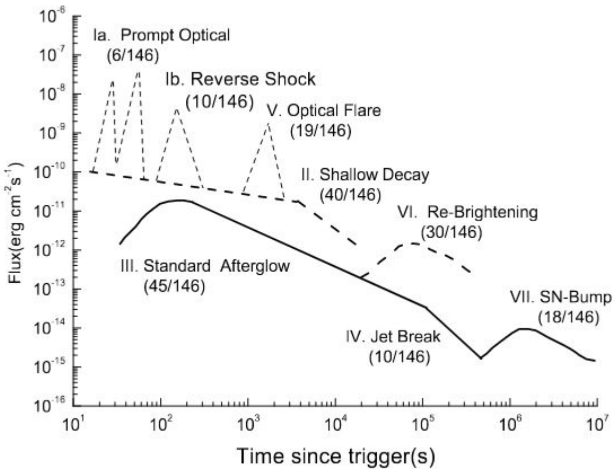


- **-Non-thermal spectrum**
- **-Band function (Band et al., 1993)**
- **-No physical meaning**

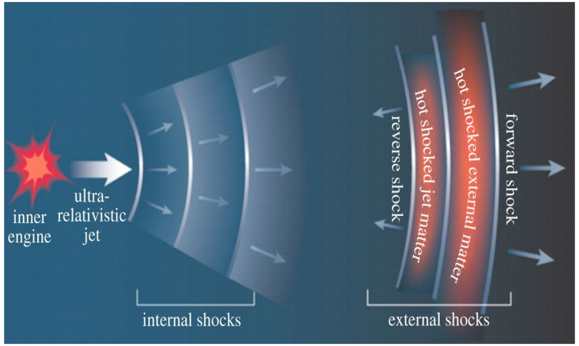
$$N(E) = \begin{cases} A\left(\frac{E}{100\ \mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right), & E < (\alpha-\beta)E_0, \\ A\left[\frac{(\alpha-\beta)E_0}{100\ \mathrm{keV}}\right]^{\alpha-\beta} \exp(\beta-\alpha)\left(\frac{E}{100\ \mathrm{keV}}\right)^{\beta}, & E \geq (\alpha-\beta)E_0, \end{cases}$$

Light Curve



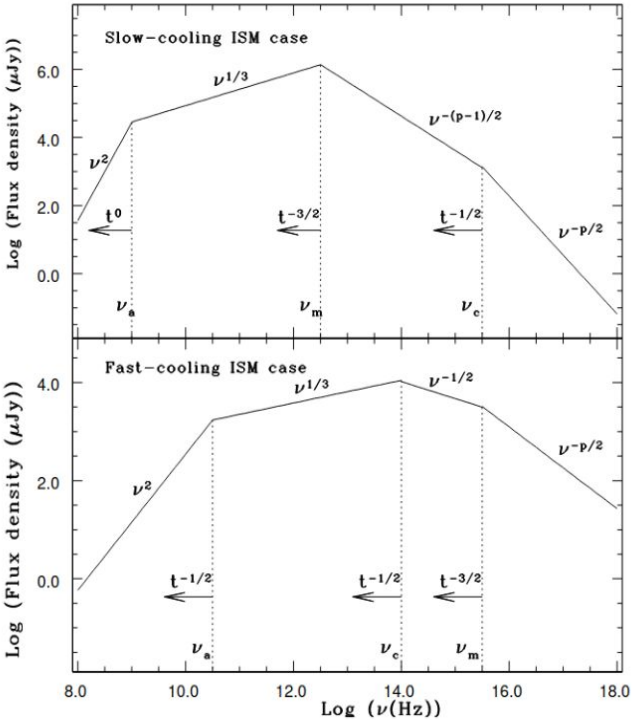


Afterglow Emission



The external shocks can be divided into two forms: a long-lived forward shock that propagates into the circumburst medium and produces a broadband afterglow, and a short-lived RS that propagates into the ejecta and produces a short-lived optical flash.

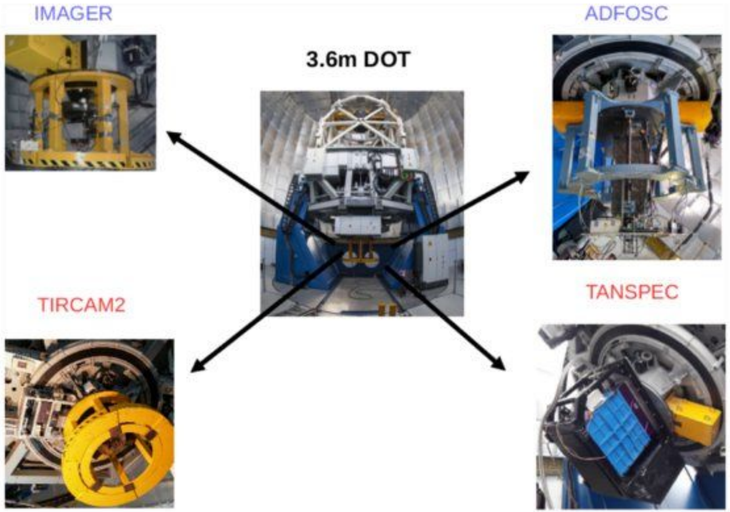
Spectrum

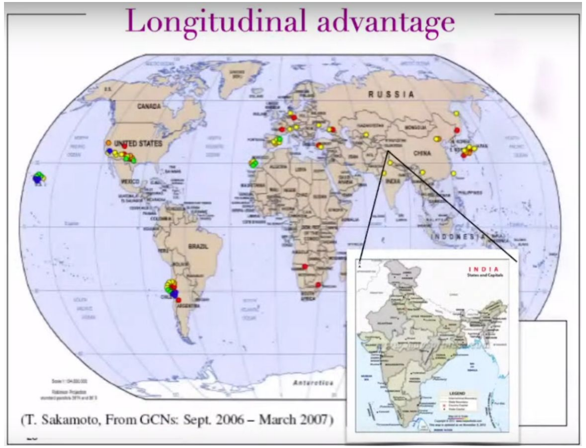


Bright synchrotron emission in the afterglow phase.

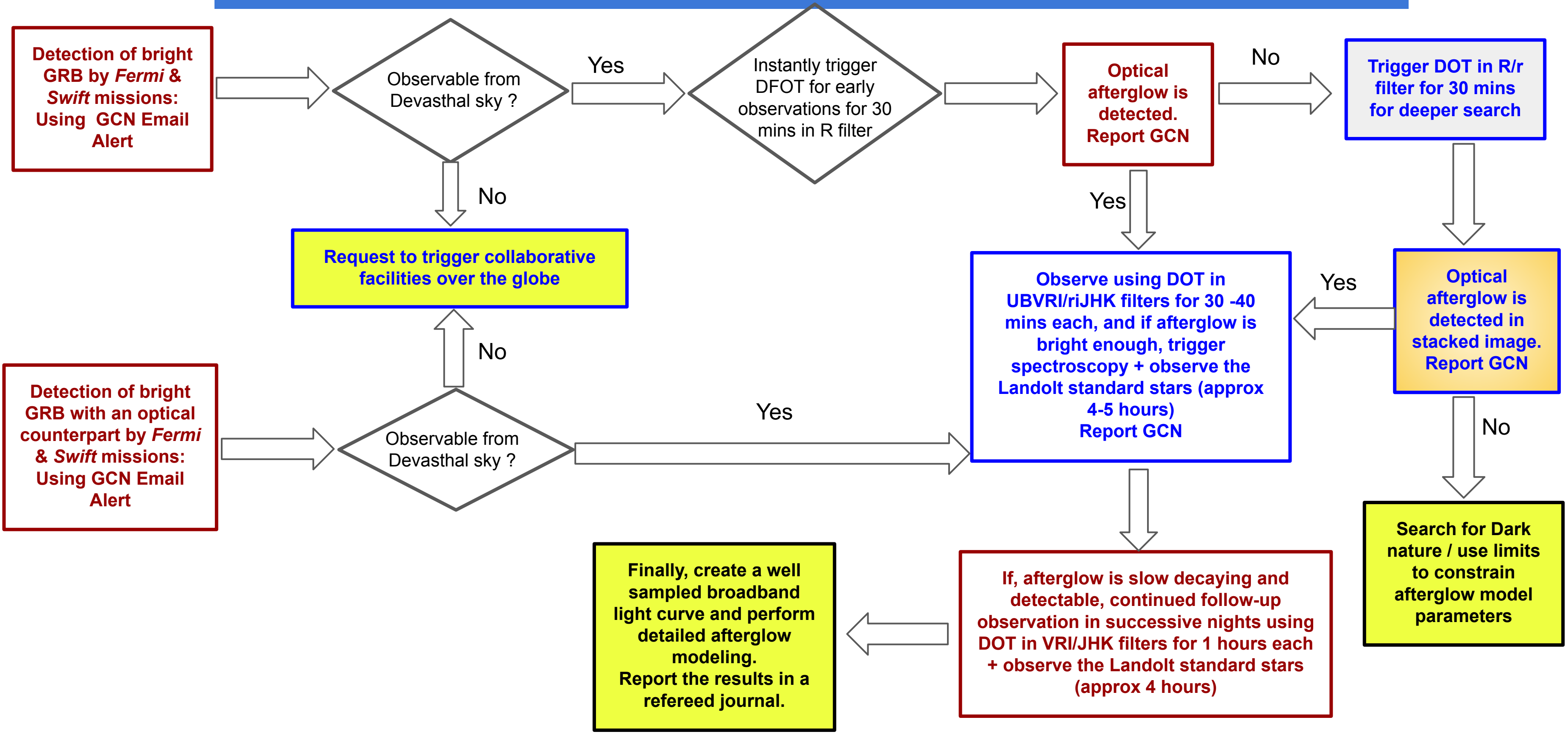
3.6m Devasthal Optical Telescope (DOT)

- India’s largest optical telescope
- Installed at Devasthal observatory
- Altitude of ~2450 m above msl
- India has longitudinal advantage (lies in between the Canary Islands and Eastern Australia) for transients follow-up observations.





Observation Strategy : Optical afterglows



We trigger ARIES telescopes for ~ 60 GRB afterglows follow-up observations (since cycle 2020C2)

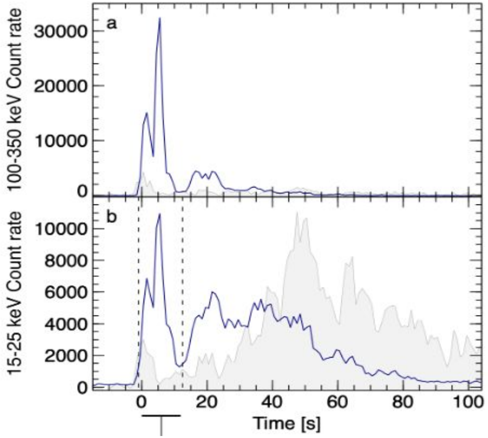
GRB 211211A : A long gamma-ray burst……

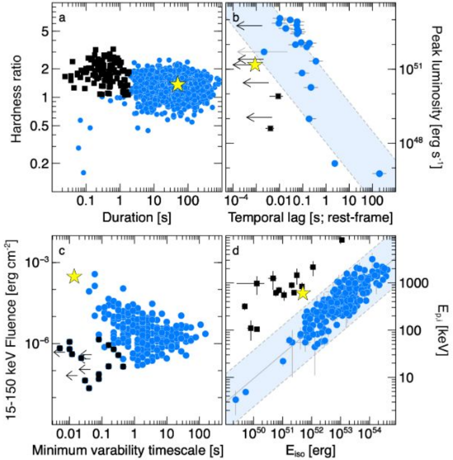
Detected by *Swift* BAT on 11 December 2021 at 13:59:09 UTC.

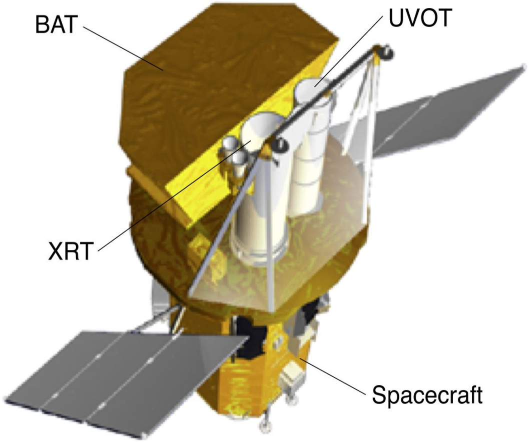
The burst was independently observed by the *Fermi*, *INTEGRAL*, and *CALET* satellites.

Its optical, ultraviolet (UV) and X-ray counterparts were localized within minutes, close to a nearby galaxy, SDSS, at a distance of 346 Mpc.

We obtained multi-band photometry observations using DOT from 0.37 to 4.4 days post detection.







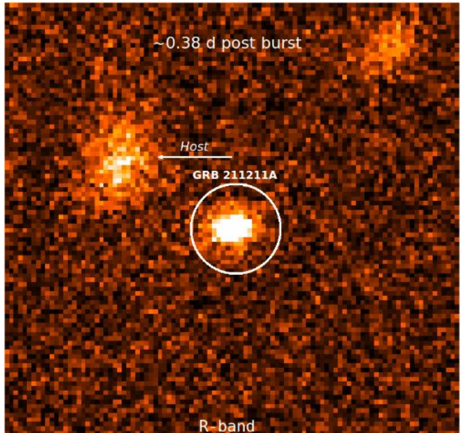
TITLE: GCN CIRCULAR
NUMBER: 31299
SUBJECT: GRB 211211A: observations with the 3.6m Devasthal Optical Telescope
DATE: 21/12/24 16:40:23 GMT
FROM: Rahul Gupta at ARIES, India <rahulbhu.c157@gmail.com>

Rahul Gupta, S. B. Pandey, A. Ror, A. Kumar, A. Aryan, Dimple, A. Ghosh, B. Kumar, and K. Misra (ARIES) as a part of larger international collaboration:

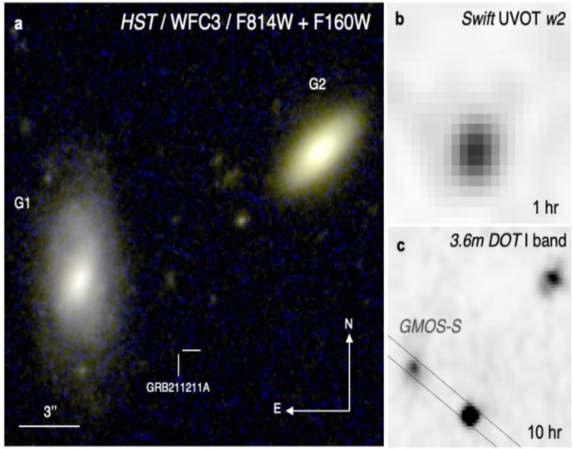
We performed late-time photometric observations of the optical afterglow (Zheng and Filipenko GCN 31203) of Fermi (Fermi GBM team, GCN 31201) and Swift (D'Ai et al., GCN 31202) detected GRB 211211A using the 4Kx4K CCD Imager (Pandey et al. 2017, arXiv:1711.05422v1) mounted at the axial port of the 3.6m Devasthal Optical Telescope of ARIES Nainital at multiple epochs in several filters. We report the preliminary brightness of the afterglow to be R = 21.66 +/- 0.07 mag ~ 1.41 days after the GBM trigger. At successive epochs, we obtained the limiting mag of 23.7 mag ~ 4.42 days post-burst. Our observations are consistent with the rapid decay nature of the afterglow reported by de Ugarte Postigo et al. GCN 31229 and A. Moskvitin et al. GCN 31234.

The magnitude value reported is calibrated against UNSO B1 nearby stars.

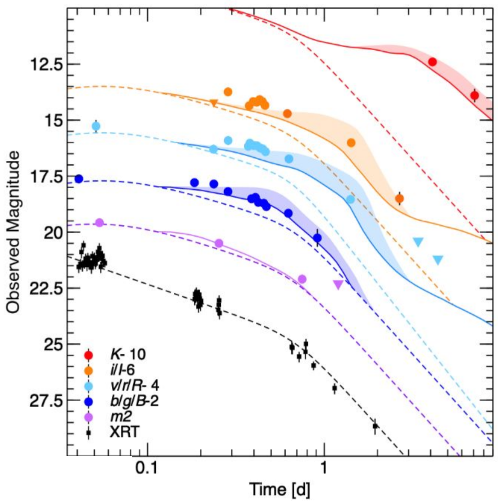
This circular may be cited. 3.6m Devasthal Optical Telescope (DOT) is the recently commissioned facility in the Northern Himalayan region of India (long:79 41 04E, lat:29 21 40N, alt:2540m) owned and operated by the Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital (https://www.aries.res.in). Authors of this GCN circular thankfully acknowledge consistent support from the staff members to run and maintain the 3.6m DOT.

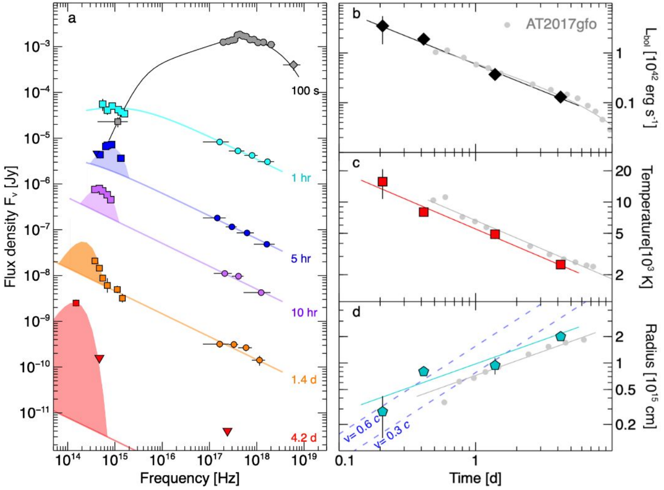


A long gamma-ray burst from a merger of compact objects



GRB 211211A





Azadi Ka Amrit Mahotsav

First data taken by the 3.6-meter telescope detects unexpected kilonova emission from 'a long-duration gamma-ray burst'

Posted On: 07 DEC 2022 9:30PM by PIB Delhi

While tracing a burst of high-energy light detected on December 11, 2021, from the outskirts of the Milky Way located approximately 1 billion light-years away, astronomers have spotted the first astronomical event in which a long GRB has been accompanied by the unexpected discovery of a kilonova emission. Generally, kilonova are visible and infrared light associated with short-period gamma-ray bursts (GRBs) thought to be heat produced by the radioactive decay of heavier elements.

Photometric observations taken with the 3.6 m Devasthal Optical Telescope have provided vital information on the earliest phase of a kilonova ever detected, radically changing the understanding of scientists about the origin of GRBs.

Dec 7, 2022

NASA Missions Probe Game-Changing Cosmic Explosion

On Dec. 11, 2021, NASA's Neil Gehrels Swift Observatory and Fermi Gamma-ray Space Telescope detected a blast of high-energy light from the outskirts of a galaxy around 1 billion light-years away. The event has rattled scientists' understanding of gamma-ray bursts (GRBs), the most powerful events in the universe.

For the last few decades, astronomers have generally divided GRBs into two categories. Long bursts emit gamma rays for two seconds or more and originate from the formation of dense objects like black holes in the centers of massive collapsing stars. Short bursts emit gamma rays for less than two seconds and are caused by mergers of dense objects like neutron stars. Scientists sometimes observe short bursts with a following flare of visible and infrared light called a kilonova.

Troja et al. (RG, AK, AA, KM, SBP), 2022, Nature

एक अरब प्रकाश वर्ष दूर जीआरबी विस्फोट की अप्रत्याशित खोज

उपलब्धि

रमेश चंद्रा • नैनीताल

एरीज व रोम के विज्ञानियों ने एक अरब प्रकाश वर्ष दूर न्यूट्रान सितारों के बीच टकराव के उच्च ऊर्जा प्रकाश वाले गामा किरण विस्फोट (जीआरबी) की अप्रत्याशित खोज की है। आकाशगंगा के दूर के हिस्से में पहली बार यह खोज हुई है। इससे सोना व प्लेटिनम जैसे भारी धातुओं के समझने में मदद मिलेगी। गामा रे विस्फोट की उत्पत्ति को भी आसानी से जाना जा सकेगा।

इस खोज में आर्यभट्ट प्रेक्षण

ये विज्ञानी रहे शामिल

इस अप्रत्याशित खोज में एरीज के शोध छात्र राहुल गुप्ता, अमर आर्यन, अमित कुमार व डा. कुंतल मिश्रा शामिल रहे। टीम का नेतृत्व रोम विश्वविद्यालय के डा. एलोनोरा ट्रोजा ने किया। उन्होंने एरीज की डाट दूरबीन से प्राप्त डेटा की सराहना की।

नैनीताल में एरीज की 3.6 मीटर व्यास की दूरबीन • सौ. एरीज

जीआरबी विस्फोट की वर्तमान समझ को चुनौती

डा. पांडेय के अनुसार इस घटना से नई संभावनाओं को बल मिलेगा। जीआरबी जैसी घटनाएं हमारी समझ के लिए भी चुनौती है। यह घटना अपेक्षाकृत हमारे नजदीक की थी, जिस कारण एक किलोवाट के प्रकाश को देख सके। इससे भी दूर इस तरह की घटनाएं होती होंगी। जिन्हें हम देख नहीं सकते।

डाट दूरबीन ब्रह्मांड के बड़े रहस्यों को खोजने में सक्षम

एरीज के निदेशक प्रो. दीपांकर बनर्जी ने कहा कि यह खोज एरीज समेत देश को गौरवान्वित करने वाली है। यह डाट दूरबीन के जरिए ही संभव हो सकी है। यह दूरबीन ब्रह्मांड के अनंत के गूढ रहस्यों को उजागर करने में सक्षम है।

विज्ञानियों की टीम का नेतृत्व करने वाले डा. शशिभूषण पांडेय ने बुधवार को बताया कि यह ब्रह्मांड की आश्चर्यचकित कर देने वाली घटना है। विज्ञानियों ने

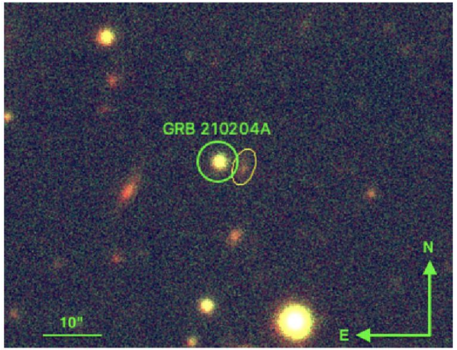
है। इसे देखने में एरीज की 3.6 मीटर (डाट) आप्टिकल दूरबीन की बड़ी भूमिका रही है। डा. पांडेय के अनुसार ब्रह्मांड में भयानक विस्फोटक घटनाएं होती हैं जिनके बारे में आज भी अधिक

जानकारी नहीं मिल पाई है। ऐसी ही एक घटना गामा रे विस्फोट है। इसमें विशाल तारों का आपस में विलय हो जाता है। इनके आपस में टकराने से जबरदस्त विस्फोट होता है। इस दौरान चंद सेकंड

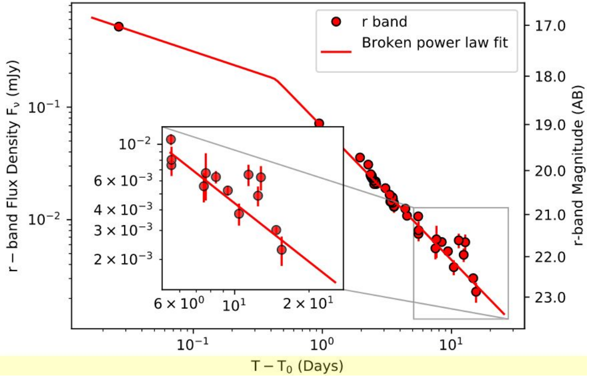
में निकलने वाली ऊर्जा हमारे जीवनभर की ऊर्जा से भी अधिक है। इस खोज में उच्च ऊर्जा करीब एक मिनट तक चला। पर दो सेकंड के ही विस्फोट हो

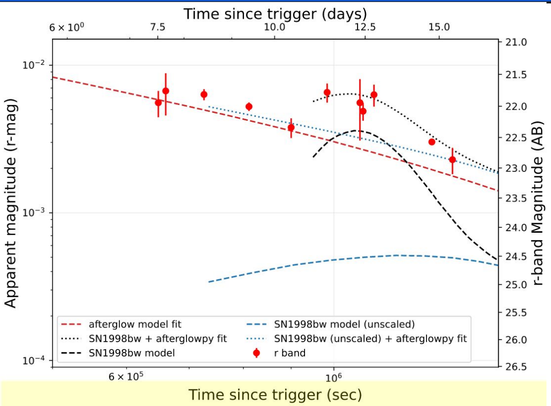
The long-active afterglow of GRB 210204A: Detection of the most delayed flares in a Gamma-ray burst

Discovered by the *Fermi* with an error circle of 4 degrees.

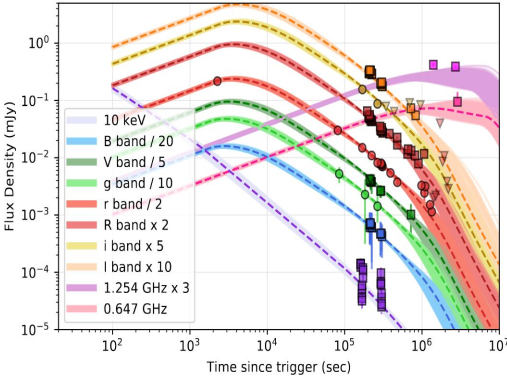


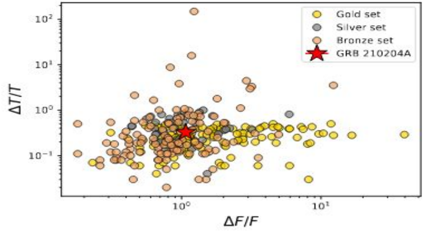
(a) DOT image of GRB



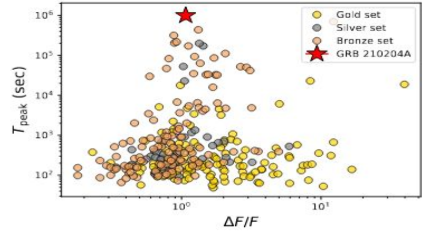


Multiwavelength light curve
Forward shock !!





(a)



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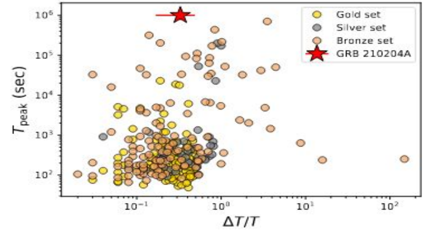
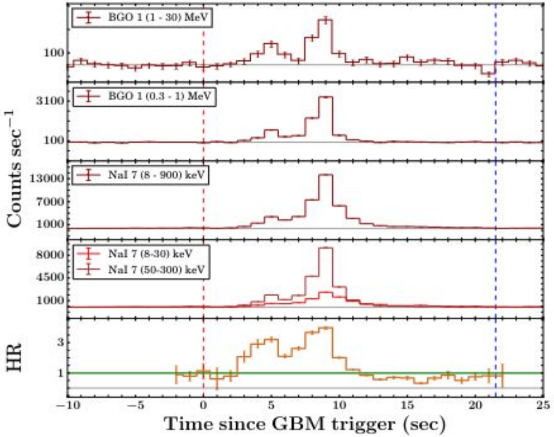
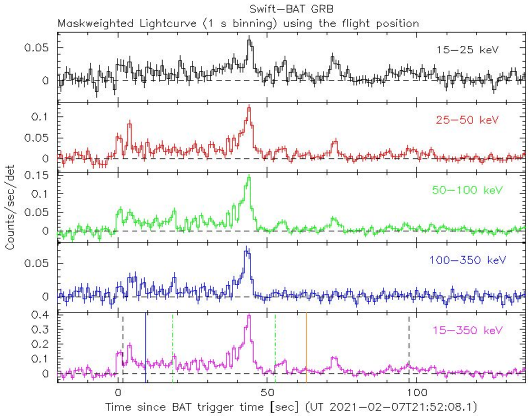


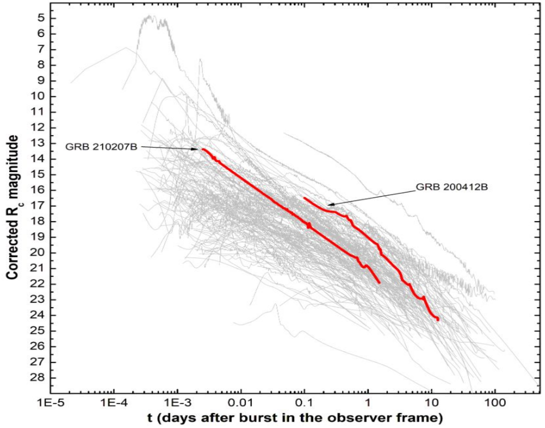
Kumar & Gupta et al. 2022, MNRAS

3.6m DOT observations of the bright long duration afterglows of GRB 200412B and GRB 210207B

Pandey et al. 2023, in prep.







TITLE: GCN CIRCULAR
NUMBER: 27653
SUBJECT: Gagarin-day GRB 200412B: observations with the 3.6m Devasthal Optical Telescope
DATE: 20/04/26 11:12:48 GMT
FROM: Shashi Bhushan Pandey at ARIES, INDIA <shashi@aries.res.in>

Amit Kumar, S. B. Pandey, Amar Aryan, Brijesh Kumar and Kuntal Misra (ARIES Nainital), on behalf of a larger GRB collaboration.

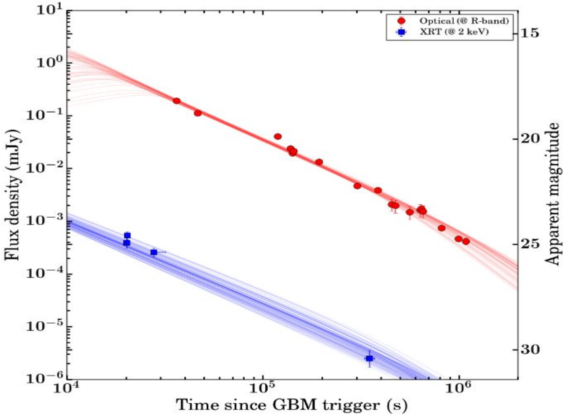
Fermi-GBM triggered GRB 200412B (GCNCs 27547, 27548i, 27558) prompt emissions and high energy observations were also carried out by Fermi-LAT (GCNC 27557) and other space-based facilities like Konus-Wind (GCNC 27581), ASTROSAT (GCNC 27563), CALET (GCNC 27572) and HXMT (GCNC 27567). Categorised as a long-duration GRB, Swift-XRT triggered and found a X-ray afterglow counterpart (GCNC 27561, 27600) decaying typical to those seen in case of other long duration bursts at the epoch of observations.

Our joint spectral analysis of the combined Fermi GBM-LAT data yields E_peak ~ 250 +/- 18 keV and spectral slope \beta ~ -2.8 +/- 0.4 above 100 MeV, similar to those reported in GCNC 27558 and GCNC 27581. Once used with the empirical Amati relation, the estimated value of the E_peak and the observed fluence values (GCNC 27558, GCNC 27581) place a constrain of the redshift to be 0.3 < z < 1.5 for GRB 200412B.

TITLE: GCN CIRCULAR
NUMBER: 29421
SUBJECT: GRB 210207B: optical detection with 3.6m Devasthal Optical Telescope
DATE: 21/02/07 23:39:21 GMT
FROM: Amit Kumar at ARIES, India <amitkundu515@gmail.com>

Amit Kumar (ARIES), Shashi B. Pandey (ARIES), Rahul Gupta (ARIES), Ankur Ghosh (ARIES), Dimple (ARIES), Amar Aryan (ARIES), Brajesh Kumar (ARIES), and Kuntal Misra (ARIES) report:

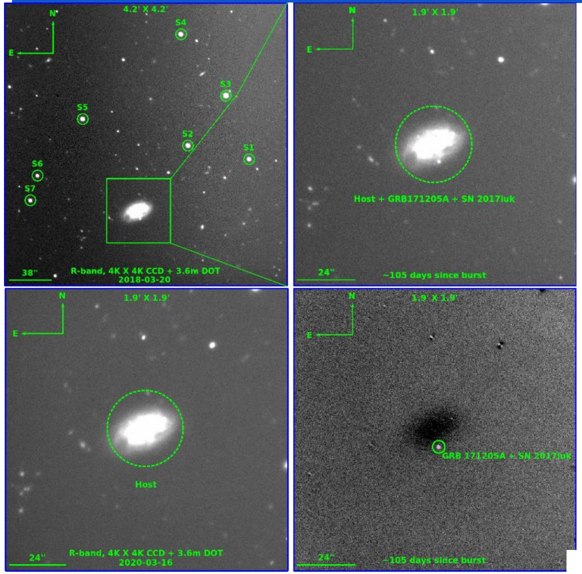
We observed the Swift detected GRB 210207B (Lien et al., GCN 29420) using the 4Kx4K CCD Imager (Pandey et al. 2018, 2018BSRSL..87...42P) mounted at the axial port of the 3.6m Devasthal Optical Telescope (DOT) of ARIES Nainital. The observations were carried out on 2021-02-07 in Bessel UBVRI-bands starting from UT 22:32:31.875 (corresponding to 40.38 minutes after the burst). We clearly detect the optical transient reported by Lien et al., GCN 29420. In the first I band image the afterglow has a I band magnitude of 15.61+/-0.01 mag. Further processing of the data is in progress.

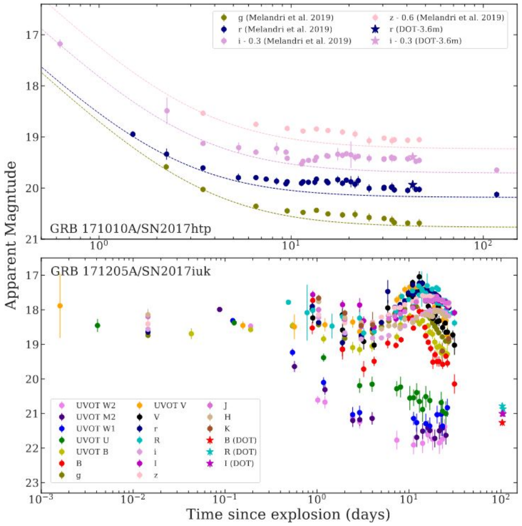


Central engines of GRBs

Hyper-accreting stellar-mass Black hole or
Rapidly spinning, highly magnetised NS, Magnetar

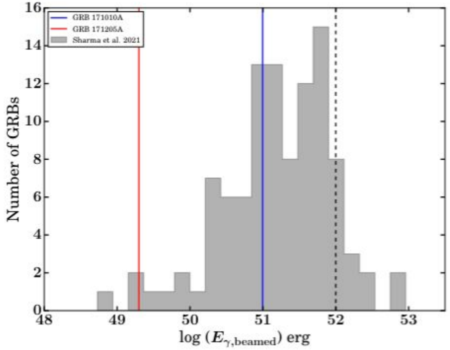
Tale of GRB 171010A/SN 2017htp and GRB 171205A/SN 2017iuk: Magnetar origin?

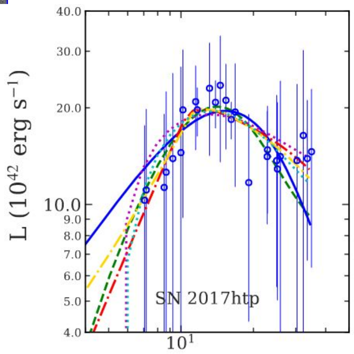


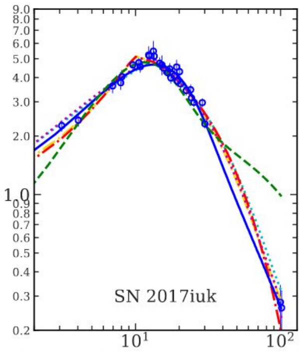


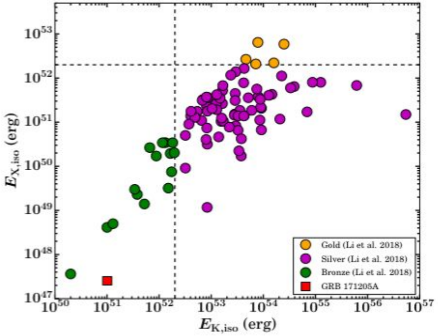
Hyper-accreting stellar-mass Black hole or Rapidly spinning, highly magnetised NS, Magnetar

Maximum extractable energy in case of magnetars ~ 10^{52} erg



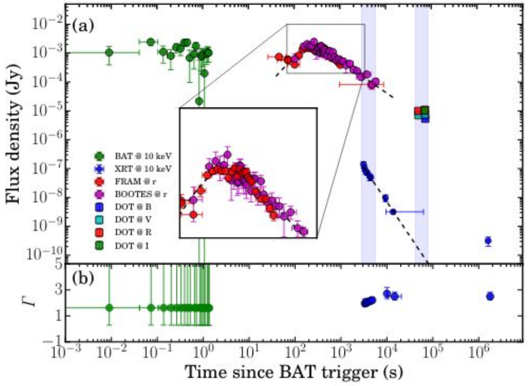




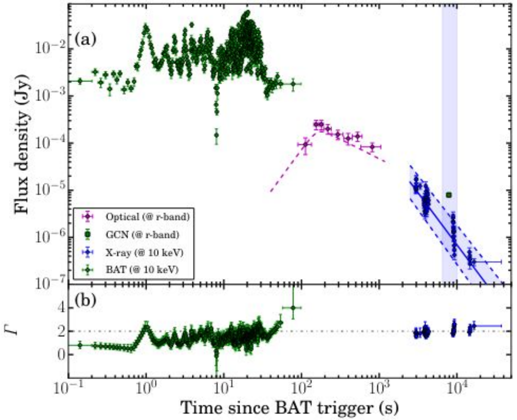


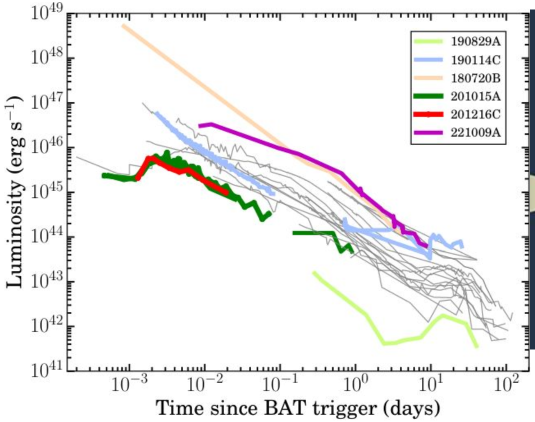
Kumar, Pandey, & Gupta et al. 2022

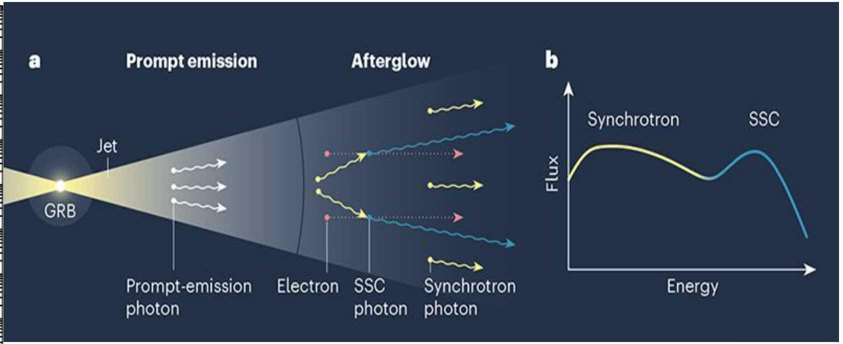
Early optical afterglow of VHE detected GRB 201015A and GRB 201216C: onset of the external forward shock



VHE detected GRBs	M2007			L2010			G2015		
	t_p (s)	Γ_0	R_{dec} (cm)	T_{90} (s)	Γ_0	R_{em} (cm)	t_{mvts} (s)	$\Gamma_{0,min}$	R_c (cm)
160821B	-	-	-	0.5	69 ± 8	1.18×10^{14}	0.068	>88.74	2.78×10^{13}
180720B	< 73	>576	$<2.19\times10^{17}$	49	506 ± 66	4.55×10^{17}	0.024	>457.20	1.82×10^{14}
190114C	<33.2	>341	$<4.10\times10^{16}$	25	407 ± 41	1.74×10^{17}	0.016	>472.86	1.53×10^{14}
190829A	-	-	-	63	76 ± 8	2.02×10^{16}	0.210	>47.74	2.67×10^{13}
201015A	184.64	204	8.16×10^{16}	9.78	143 ± 4	8.41×10^{15}	~ 0.1	>92.07	$\sim 4.81\times10^{13}$
201216C	179.9	310	1.23×10^{17}	29.9	513 ± 68	2.24×10^{17}	0.152	>286.99	3.60×10^{14}
221009A	<179	>440	$<4.50\times10^{17}$	327	>757	$<9.7\times10^{18}$	~ 0.001	>450.01	$\sim 1.1\times10^{13}$







Ror & Gupta et al. 2023, ApJ (see the poster by Amit for more details)

"Dark" GRBs: History

Are all GRBs accompanied by an optical afterglows (OA) ?

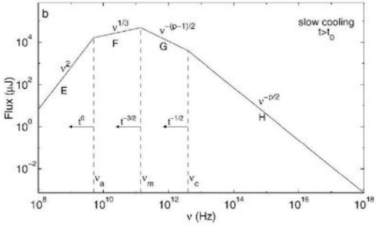
With the beginning of the operation of *Swift* and many ground-based telescopes with fast reaction, ~25-35% GRBs are discovered without an OA.

No. of GRBs	No. of X-ray AGs	No. of Optical AGs	No. of Radio AGs	No. of redshifts
2311	1526	874	150	562

GRB and afterglow (AG) statistics
https://www.mpe.mpg.de/~jcg/grbgen.html (Upto 2021)

If we assume the fireball model, where $F \sim \nu^{\beta}$, than β depends on p and ν_c:

$$\beta = \begin{cases} (p-1)/2, & \nu < \nu_c \\ p/2, & \nu > \nu_c \end{cases}$$



(Sari, Piran, Narayan 1998)

Assuming that both X-ray and optical components are produced by synchrotron radiation: optical spectral index (β_O) should be equal to (β_X) or to β_X – 0.5.

$$\beta_X - 0.5 < \beta_{OX} < \beta_X$$

van der Horst+ 2009

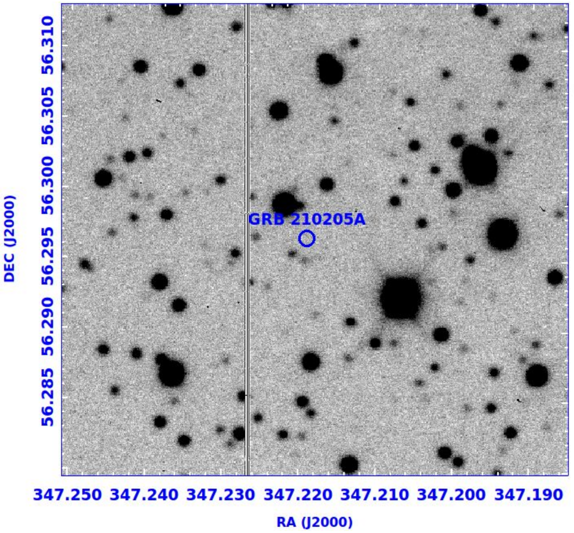
for dark GRBs $\beta_{OX} < \beta_X - 0.5$

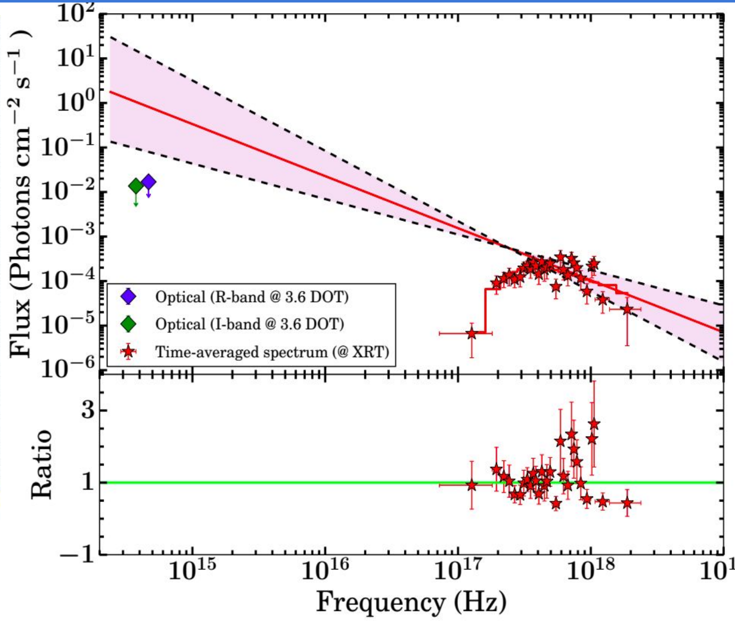
- **Intrinsically low luminosity and faint GRB (e.g., Gehrels et al. 2008)**
- **High redshift (e.g., Tanvir et al. 2009)**
- **Large extinction along the line of sight to GRB (e.g., Perley et al. 2009)**

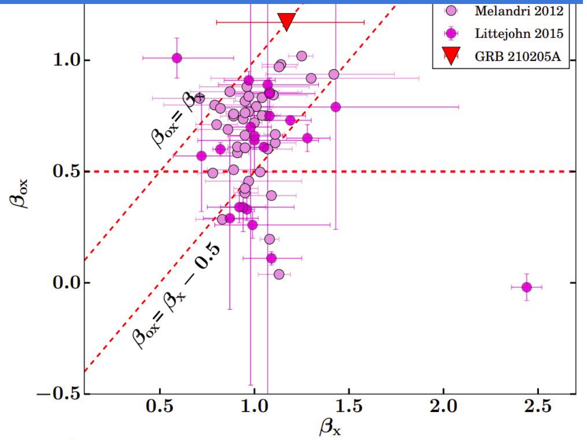
In most cases the GRB is dark due to a significant absorption of the optical radiation in the medium of the host galaxy.

Why they are "Dark"?

Revealing nature of GRB 210205A, and follow-up observations with the 4K×4K CCD Imager+3.6m DOT





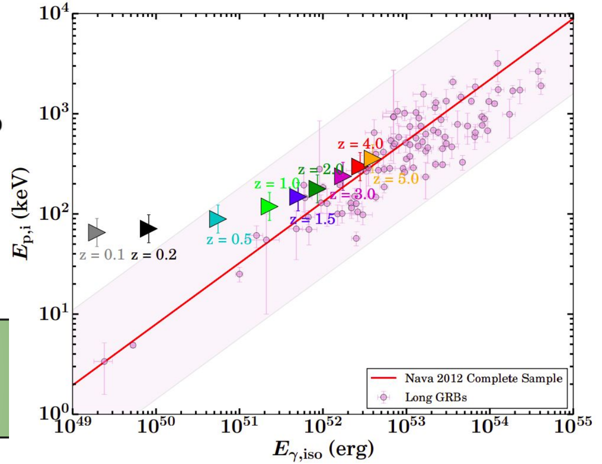


The R-band finding chart of GRB 210205A (no redshift measurements) obtained ~ 1.10 days post burst using the 3.6m DOT.

Gupta et al. 2021b

The host extinction in I filter (A_I) > 0.25 mag

GRB 210205A: A Dark burst

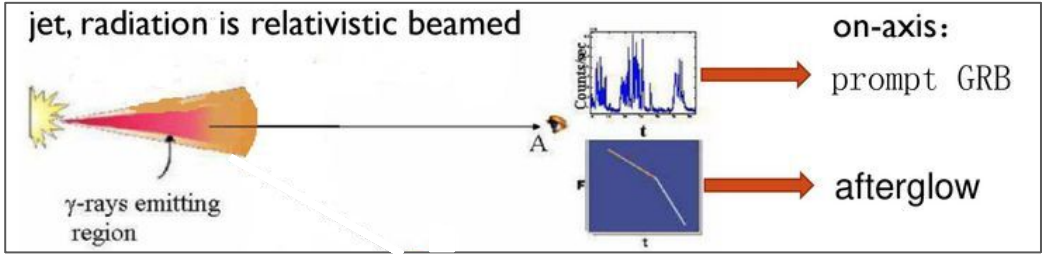


"Orphan" Afterglows

Are all optical afterglows detected with a GRB? No. Afterglows of GRBs without any prompt emission detection are known as "orphan afterglows."

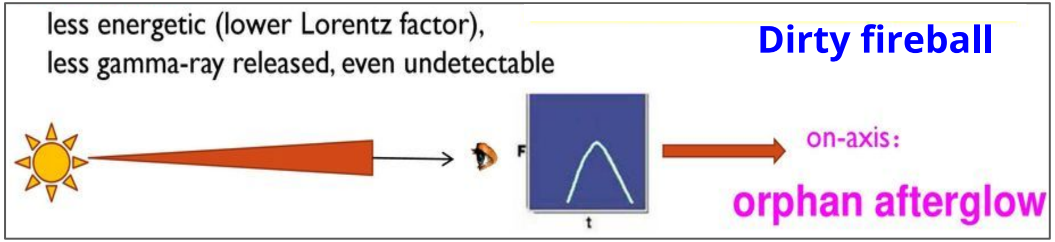
Possible explanations of the orphan afterglow

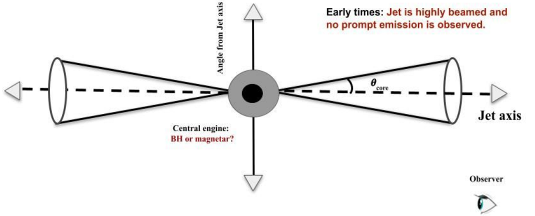
1.



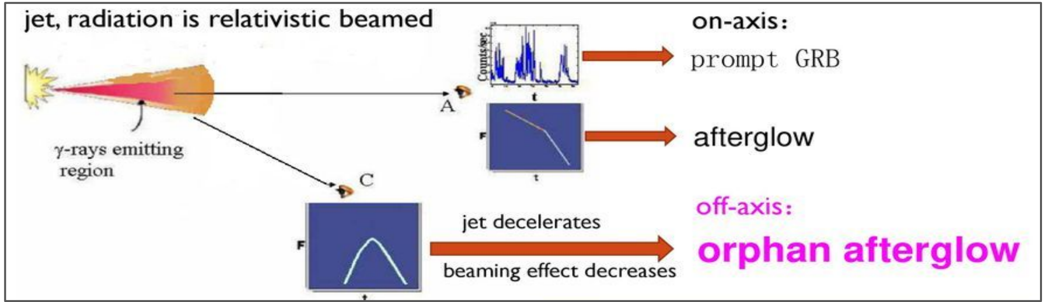
If the source is observed on-axis, however, the prompt emission of GRBs was unambiguously missed by space-based gamma-ray telescopes, either due to their limiting sensitivity or source was not in their field of view.

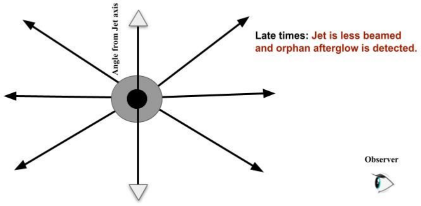
2.





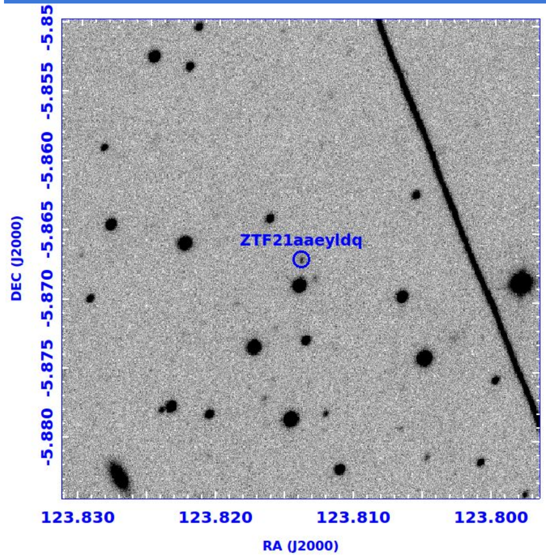
3.



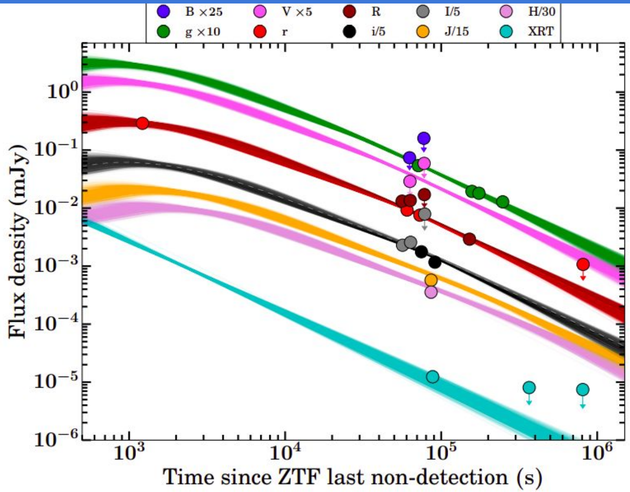


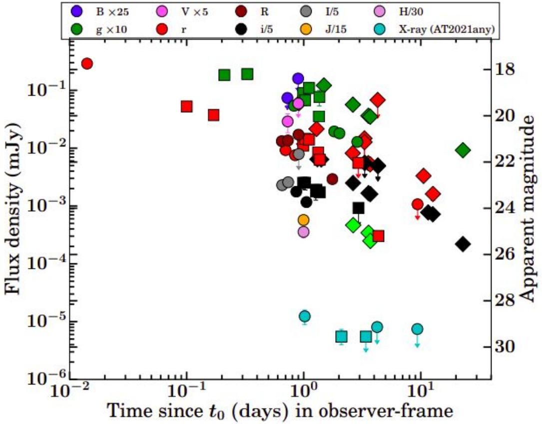
Off-axis

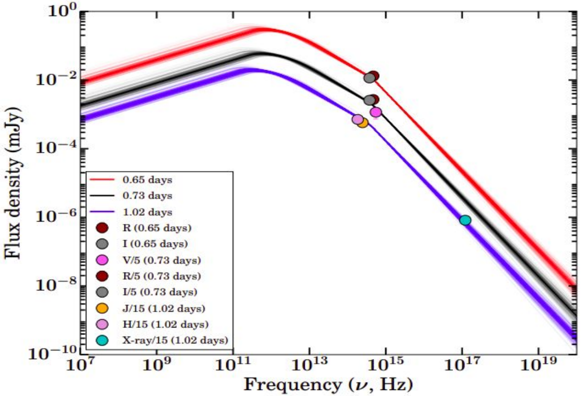
Revealing nature of ZTF21aaeyldq (AT2021any), and follow-up observations with the 4K×4K CCD Imager+3.6m DOT

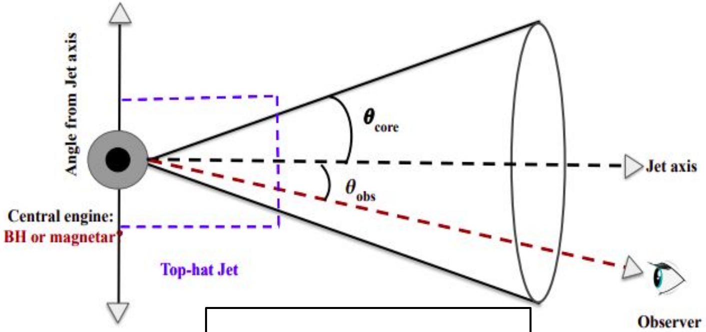


The R-band finding chart of ZTF21aaeyldq obtained using the 3.6m DOT.





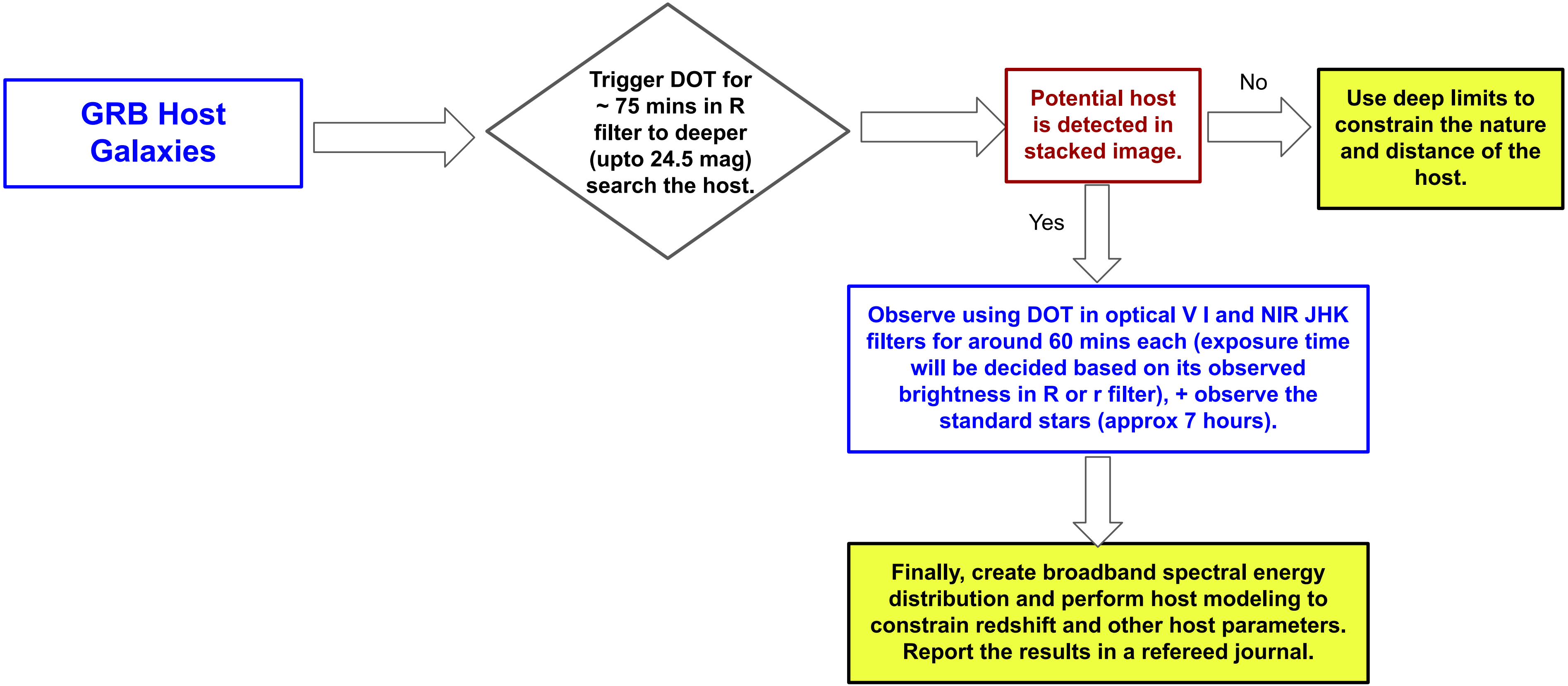




AT2021any/ZTF21aaeyldq: An orphan afterglow

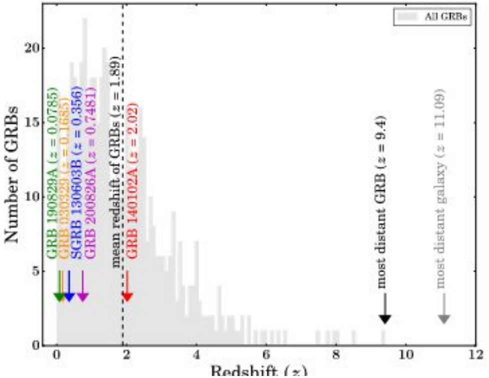
Gupta et al. 2021b

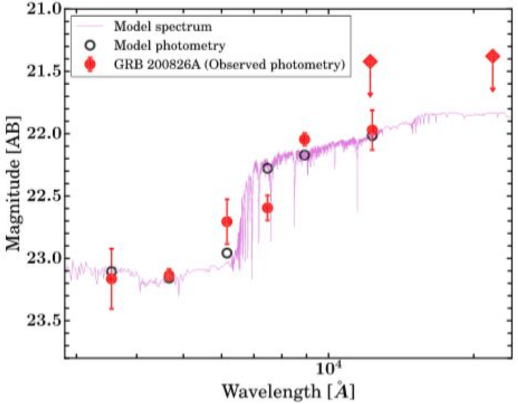
Observation Strategy : Host Galaxies of GRBs



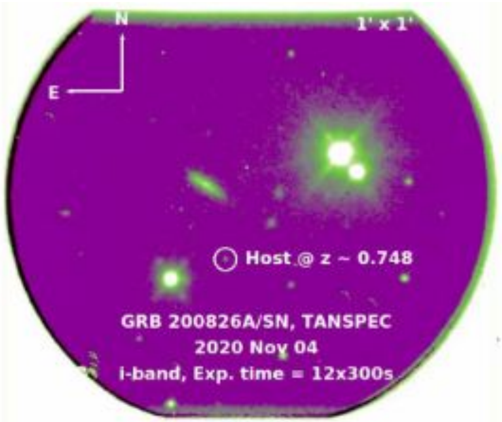
Total observations time for the GRB host and standard stars: ~ 7 hours per GRB host.

Photometric studies on the host galaxies of gamma-ray bursts using 3.6m Devasthal optical telescope



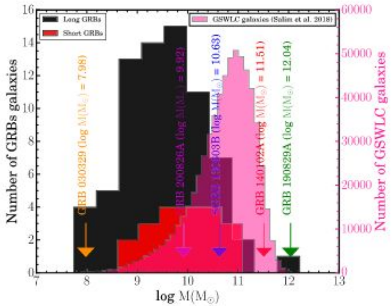


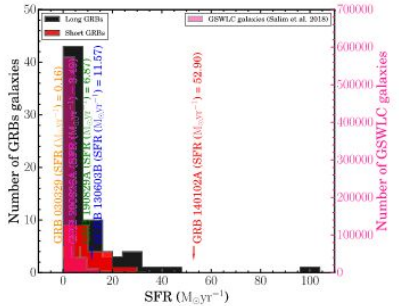
The SED of the host galaxy of GRB 200826A.

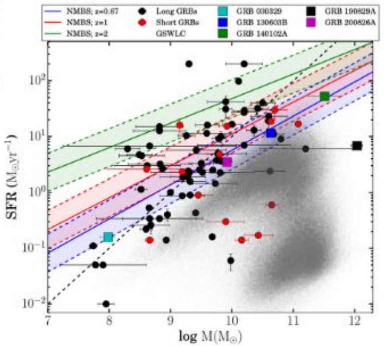


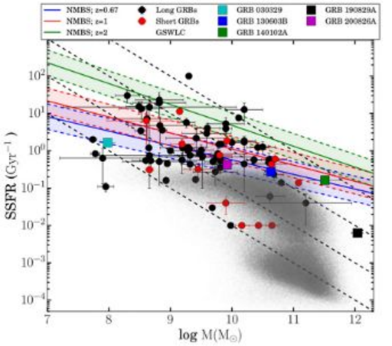
Gupta et al. 2022b

Savaglio et al. 2006, 2009









SFR vs stellar mass for a sample of GRB hosts

SSFR vs stellar mass for a sample of GRB hosts

Summary and Conclusion

The discovery of GRB 211211A accompanied by kilonova emission suggests that some long-duration GRBs may be produced by merging neutron stars.

GRB 210204A has the most delayed flaring activity ever detected in GRBs.

Semi-analytical light-curve modeling of GRB 171010A/SN 2017htp and GRB 171205A/SN 2017iuk demands a spin-down millisecond magnetar as a central engine.

Exploring the evolution of the bulk Lorentz factor can solve the problem of the jet composition of GRBs.

Our observations and analysis suggest that GRB 210205A and AT2021any are dark and orphan GRBs, respectively.

Our results also demonstrate the capabilities of 3.6m DOT and the back-end instruments for the deeper photometric studies of the afterglow/host galaxies of energetic transients such as GRBs, supernovae, and other transients as a part of time-domain astronomy in the long run.

Thank you for your attention!

Rahul Gupta*

*rahulbhu.c157@gmail.com & rahul@aries.res.in