Time Domain Astrophysics

Multiwavelength, multimessenger, and time domain/transient events are increasingly important in astrophysics. Events to be studied include the neutrino precursors of Local Group Galactic Core Collapse Supernovae (CC-SN), optically bright Gravitational Wave (GW) events, and Gamma Ray Bursts (GRBs)/GRB afterglow. These events span widely different time frames, from a few per century (Local Group supernovae) to one per day for gamma-ray bursts. It would be advantageous if an integrated system could be implemented to detect the rare events as well as the more frequently occurring events.

Introduction and Background

There are several types or categories of high energy targets that would greatly benefit from follow-up optical observations from both professional and amateur astronomers. In addition to the Galactic Supernova, detected with the initial neutrino bursts, other potential high energy targets include Gamma Ray Bursts, GRB afterglow, and kilonovae. Additionally, there are several types of Gravitational Wave events such as neutron star-neutron star (NS-NS) mergers which can result in the formation of kilonovae, neutron star-black hole (NS-BH) mergers, and black hole-black hole (BH-BH) mergers. Each of these high energy events is based upon its own specific physics and detection mechanisms, but all of them require rapid optical follow-up observations. A brief description of the physics and detection mechanism for each type of high energy event follows.

Gamma Ray Bursts and Afterglow: In gamma-ray astronomy, gamma-ray bursts are extremely energetic explosions that have been observed in distant galaxies. They are the brightest electromagnetic events known to occur in the universe. Bursts can last from ten milliseconds to several hours. After an initial flash of gamma rays, a longer-lived "afterglow" is usually emitted at longer wavelengths (X-ray, ultraviolet, optical, infrared, microwave, and radio). The intense radiation of most observed GRBs is thought to be released during a supernova as a high-mass star implodes to form a neutron star or a black hole.

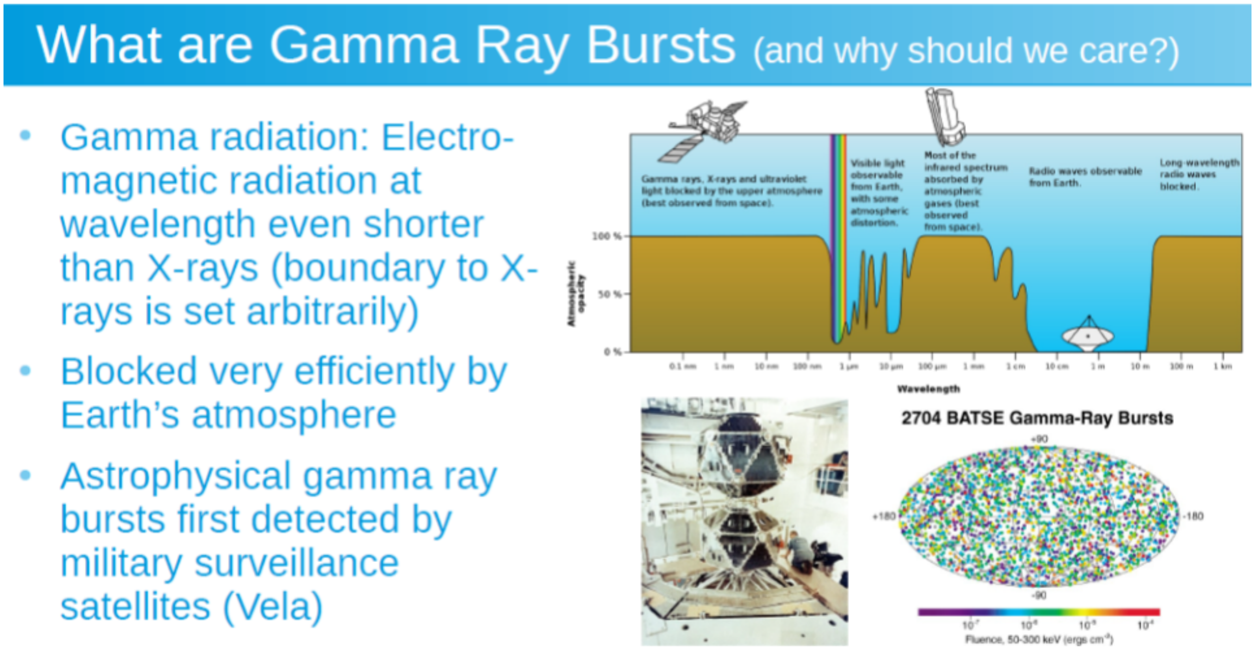
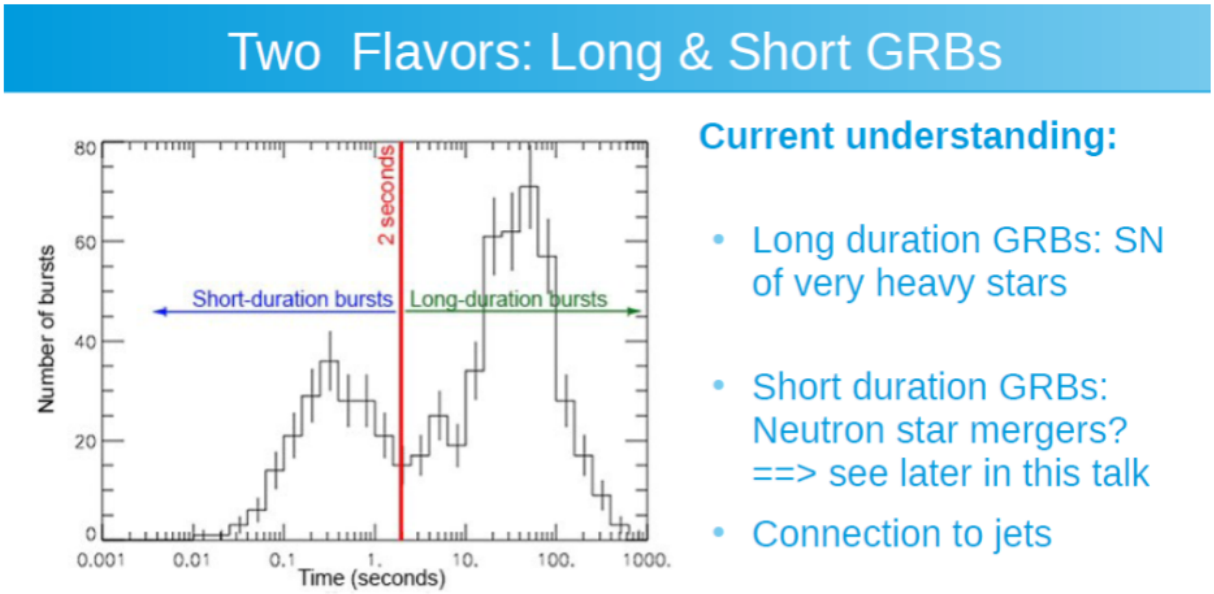


Image Credits: NASA, Los Alamos National Laboratory

The sources of most GRBs are billions of light years away from Earth, implying that the explosions are both extremely energetic (a typical burst releases as much energy in a few seconds as the Sun will in its entire 10-billion-year lifetime) and extremely rare (a few per galaxy per million years). All observed GRBs have originated from outside the Milky Way galaxy, although a related class of phenomena, soft gamma repeater flares, is associated with magnetars within the Milky Way.

There are two kinds of gamma-ray bursts, known as long-soft and short-hard, referring to their duration and the nature of their gamma-ray emission. Long-soft bursts last for a few dozens of seconds, and emit less energetic ("soft") gamma rays; short-hard bursts last for a second or less and emit very energetic ("hard") gamma rays.



Graph of burst duration versus the number of bursts. Graph of the time versus number of bursts for the gamma-ray bursts observed by the BATSE instrument on the Compton Gamma-ray Telescope.

Image Credit: NASA

The long-soft GRBs are the ones which have been detected most often at other wavelengths, and they are believed to be associated with the collapse of supermassive stars, in an event known as a hypernova. When a massive star runs out of the nuclear fuel that makes it shine, the core of the star collapses. If the core collapses into a black hole, the remainder of the star will begin to fall onto it. Black holes sometimes produce jets of material that fly away from the black hole at close to the speed of light, and in a hypernova, the infalling stellar material acts as a source for these jets. These events probably happen dozens of times a day across the entire universe, but we only detect them as a gamma-ray burst if, by chance, the jet from the black hole happens to be pointed in our direction. GRBs produce the most intense radiation along the direction of the jet, and so we only detect them when they're pointed right at us.

Although they haven't been studied as well, the short-hard GRBs are also believed to originate from the formation of a black hole. In this case it is thought that they come from the merger of two black holes or two neutron stars in orbit around one another. Both black holes and neutron stars are very massive and extremely small in size, and when they orbit one another closely, they move very rapidly. If they spiral together and merge with one another, their collision may result in a huge explosion that occurs very quickly, producing a rapid burst of gamma-rays at high energies.

Most of the energy emitted by a gamma-ray burst comes out as gamma-rays, but the jets that create them and the resulting hypernova emits light at other wavelengths too, and by studying the afterglow, more can be learned about the object that created the GRB than can be from just studying the gamma-ray emission. The light emitted in X-rays, optical light, and radio waves can often persist for hours or days after the gamma-ray burst, and because of the nature of radiation at these wavelengths, it is easier to pinpoint where the GRB is from the afterglow than it is from the gamma-ray burst itself. It can be determined what kind of star it was that exploded, how the explosion progressed, or what the environment was like around that star by studying the afterglow.

GRB afterglows are hard to find, but there is now a network of space-based and ground-based observatories dedicated to their detection and localization. Satellites like Swift are designed to quickly detect and localize GRBs to much higher precision than was previously possible. Satellites can now provide gamma-ray localizations to less than 0.5 degrees (sometimes much less), making it easier for ground-based observers to concentrate their search on a particular spot in the sky. The satellite radios the coordinates back to Earth, and these coordinates are then relayed to observatories around the world via the Gamma Ray Burst Coordinates Network or GCN. Reference: Gamma Ray Burst.

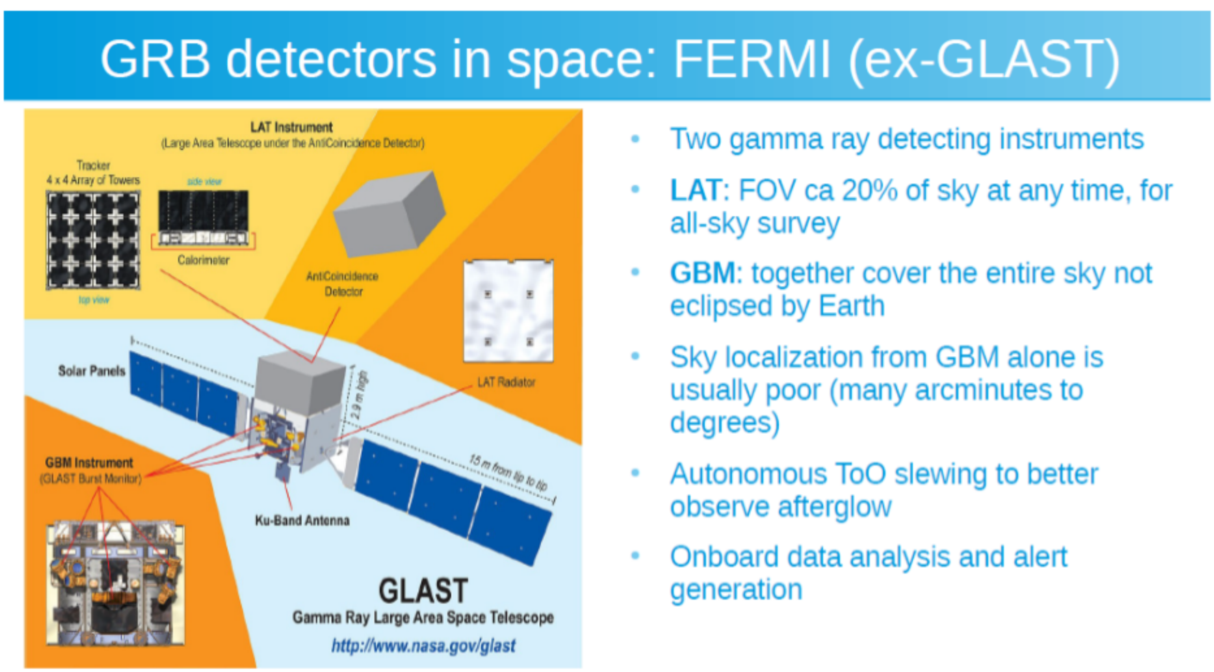
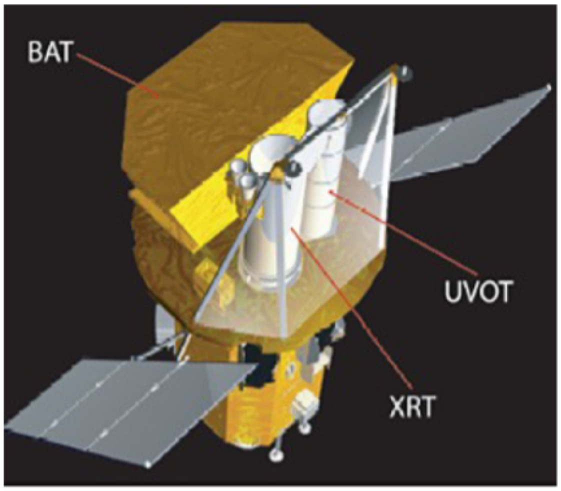


Image Credit: NASA

GRB detectors in space: Neil Gehrels Swift



- **B**urst **A**lert **T**elescope: Wide FOV (2 steradians), gamma ray low resolution "imager"
- Within 20 seconds of a GRB: 3 arcmin position estimate computed and sent to ground
- Then: Automatic slew of satellite to bring target into view of **X**-**R**ay-**T**elescope and **UV**/**O**ptical **T**elescope to observe Afterglow
- Afterglow can then yield arcsec position and sometimes redshift

Image Credit: NASA

GRB detectors in space: Integral

INTErnational Gamma-Ray Astrophysics Laboratory (ESA)

- Main instrument (SPI) alone is not well suited for GRB detection
- SPI has a "stray gamma ray" detector (SPI-ACS) that can be used to detect GRBs

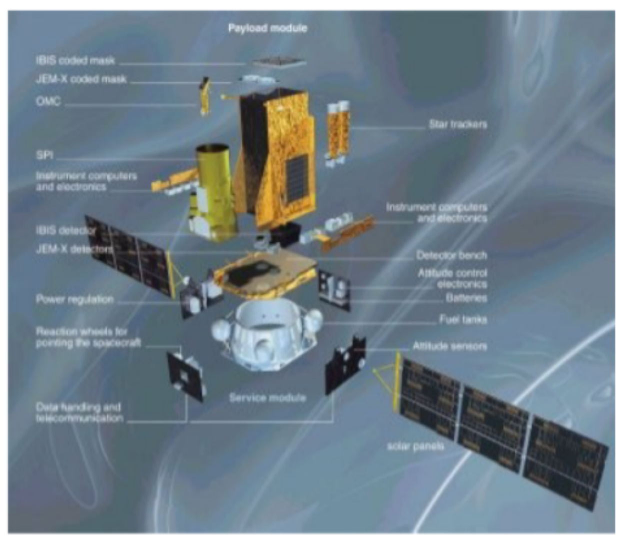
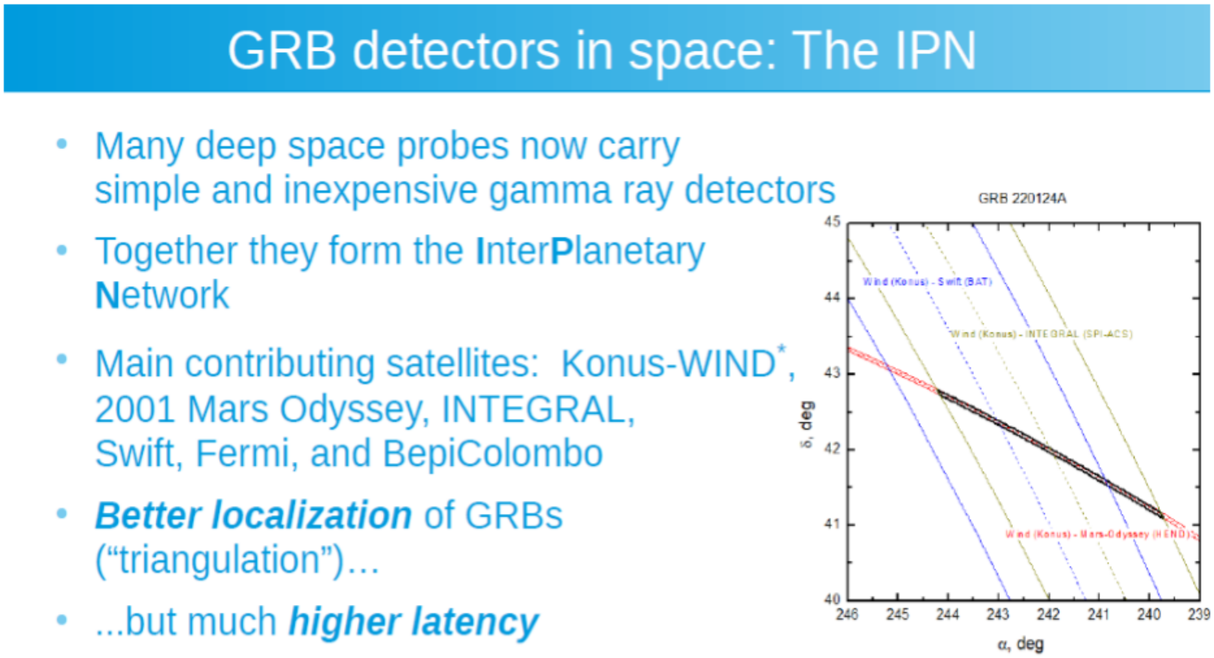
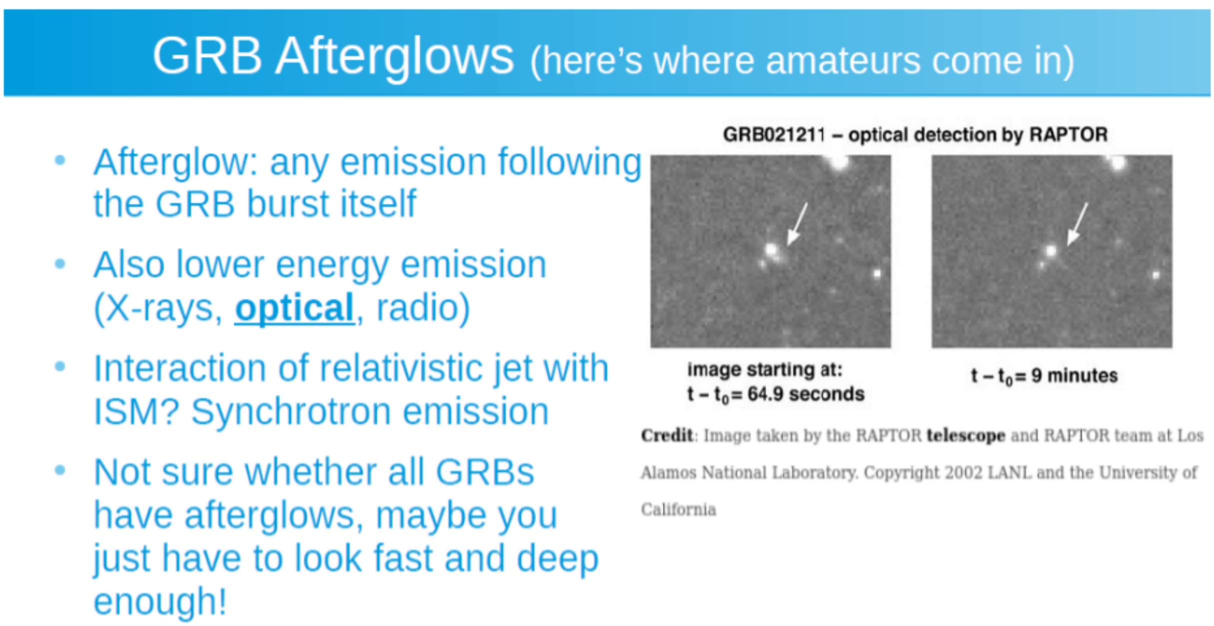
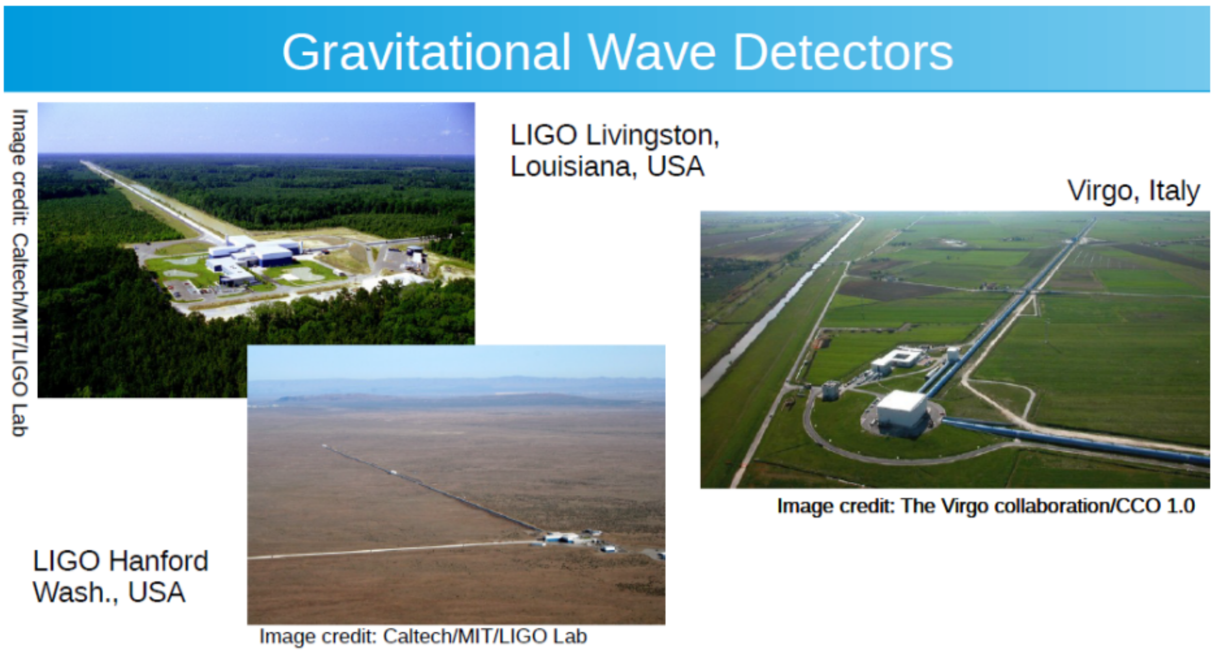


Image Credit: ESA



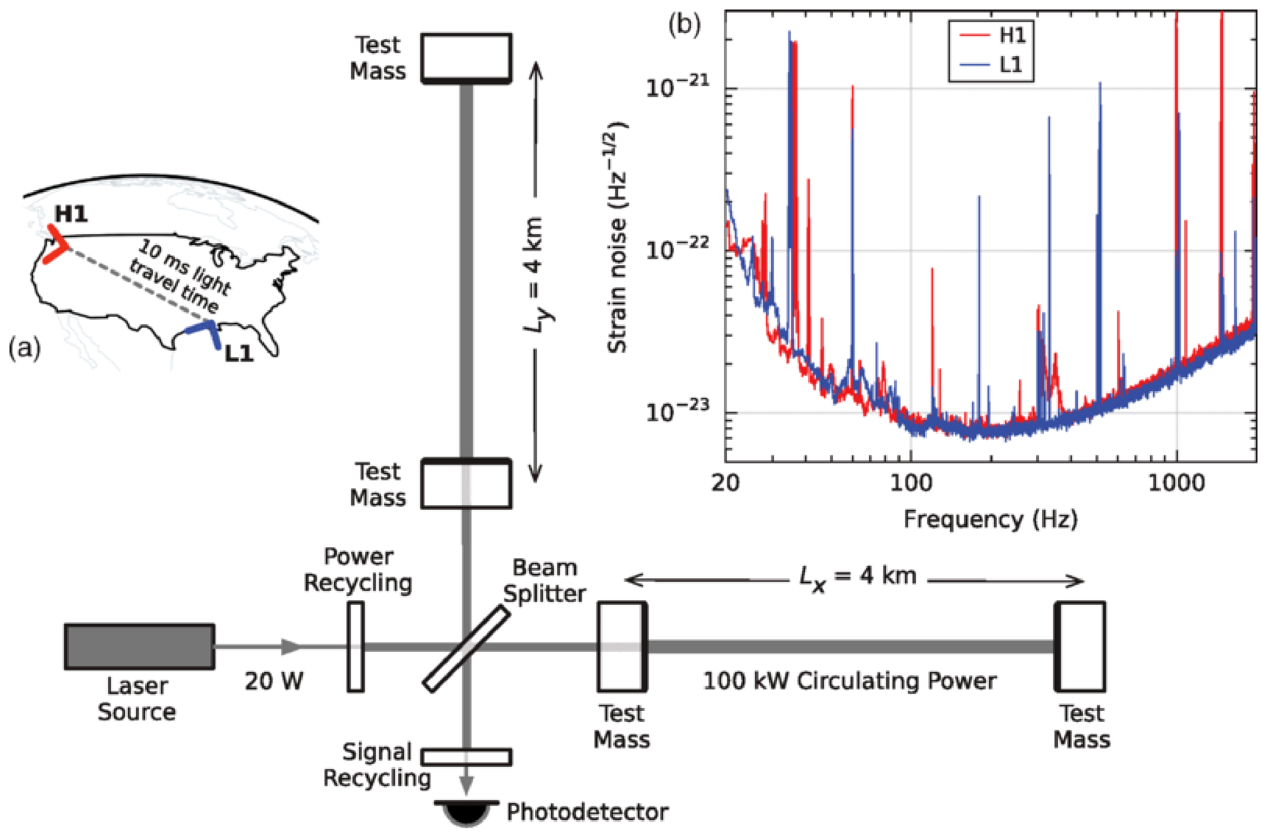


Gravitational Wave Events: Gravitational Wave events consist of three fundamental types of phenomena. These include Neutron Star-Neutron Star (NS-NS) mergers (also known as Binary Neutron Star or BNS mergers), Neutron Star-Black Hole (NS-BH) mergers, and Black Hole-Black Hole (BH-BH) mergers (also known as Binary Black Hole or BBH mergers). Additionally, kilonovae are associated with NS-NS GW events. A kilonova is a transient phenomenon that is relatively fast (days to weeks timescale) and has a faint visible and infrared optical signature (this might also create a GRB). The radiation is fairly isotropic ejecta emitted at fractions of the speed of light (approximately 30%). The kilonova emissions are powered by the radioactive decay of heavy nuclei within the ejecta from intense bombardment of nuclei lighter than iron by energetic neutrons. Called the r-process, physics requires an energetic and extremely neutron-rich environment to be effective. The violent matter ejections resulting from the coalescence of two neutron stars can produce such an environment and have been proposed as being the main candidates of kilonovae and the production sites of the heaviest elements in the universe. Reference: Gravitational Waves.



LIGO/Virgo Gravitational Wave Detectors

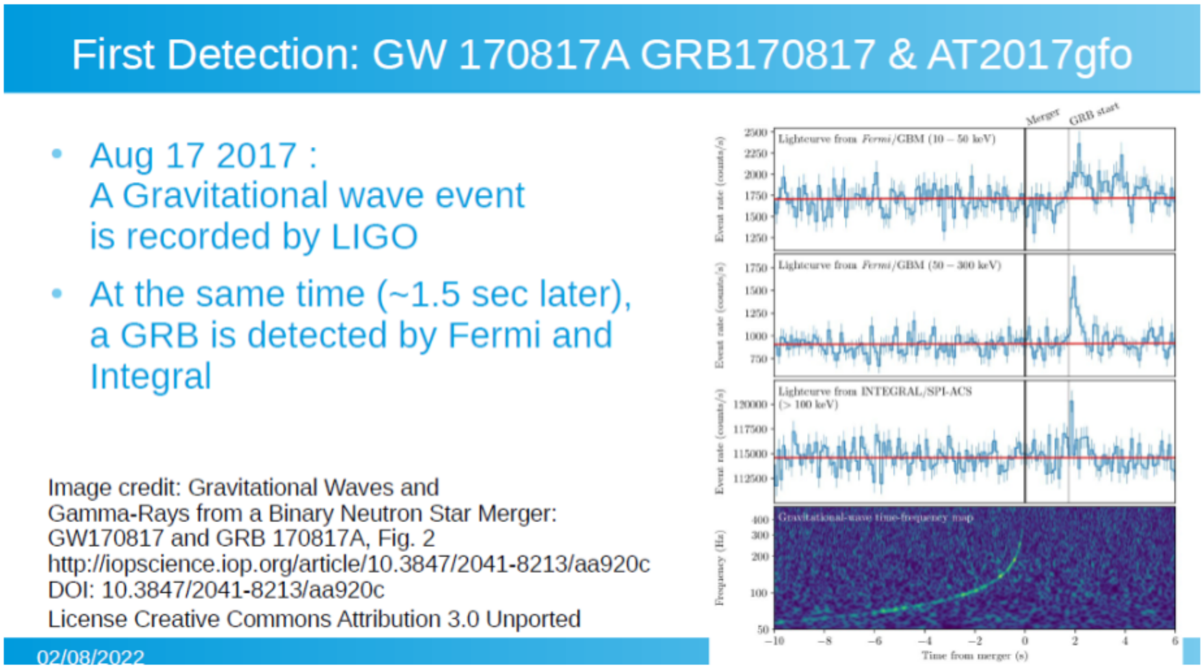
The Laser Interferometer Gravitational-Wave Observatory (LIGO) is a large-scale physics experiment and observatory to detect cosmic gravitational waves and to develop gravitational wave observations as an astronomical tool. Two large observatories were built in the United States (Hanford, Washington and Livingston, Louisiana) with the aim of detecting gravitational waves by laser interferometry. These observatories use mirrors spaced four kilometers apart which are capable of detecting a change of less than one ten-thousandth the charge diameter of a proton. LIGO detectors use laser interferometry to measure the distortions in space-time occurring between stationary, hanging masses (mirrors) caused by passing gravitational waves. The distortions in space-time were predicted by Einstein's General Theory of Relativity. This is shown below. Reference: **LIGO**.

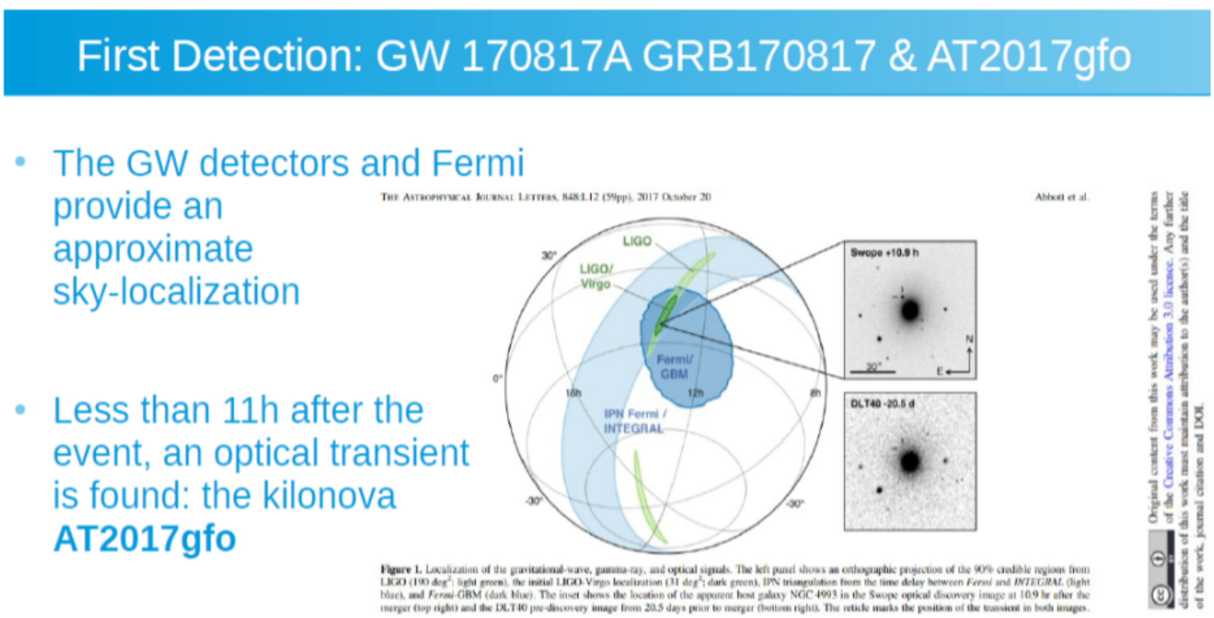


LIGO Gravitational Wave Detector (Abbot, B.P., et.al, LIGO Scientific Collaboration and Virgo Collaboration)

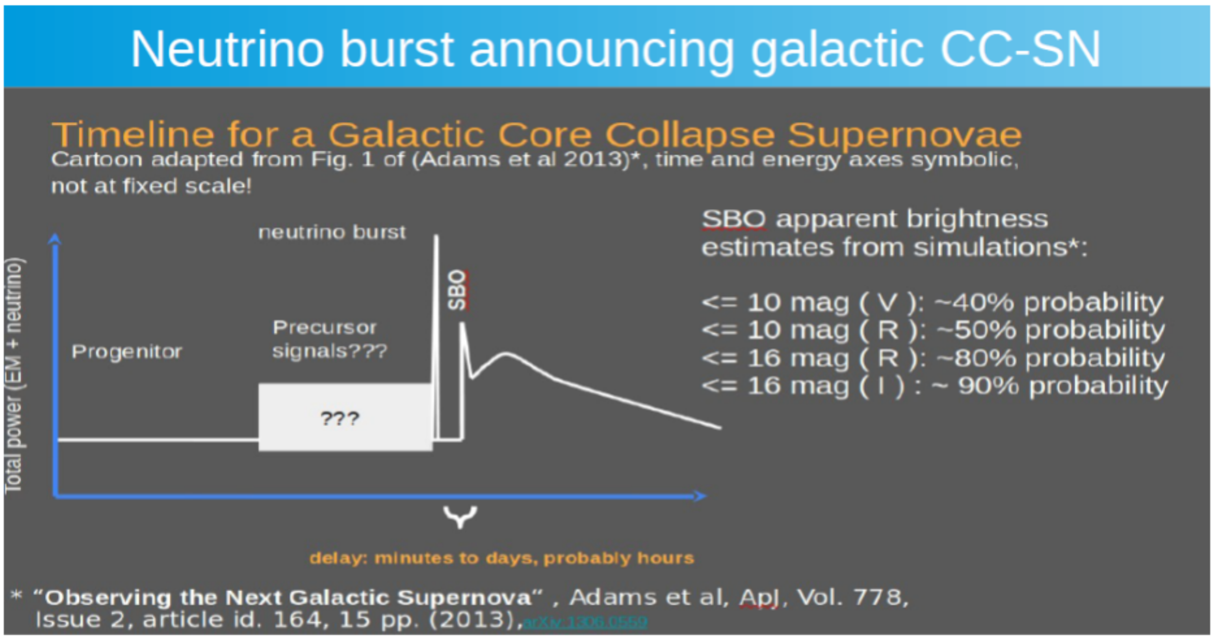
Advanced Virgo is an interferometric detector of gravitational waves hosted by the European Gravitational Observatory (EGO) near Pisa, Italy. It can measure gravitational waves in a wide frequency range; from 10 Hz to 10000 Hz. Advanced Virgo is a laser interferometer with perpendicular, 3 km long arms and suspended mirrors. This is the configuration presently adopted in Advanced Virgo, during the third observation run (named O3, lasting 1 year from April 2019 to April 2020) performed jointly with the two Advanced LIGO detectors in the US. The Virgo system is similar to that of LIGO. Reference: **VIRGO**.

Gravitational Wave detection events are transmitted via GCN as discussed below for gamma ray bursts/afterglows. The first gravitational wave event detection and localization included a gravitational wave (GW 170817A), a GRB (GRB 170817), and a subsequent kilonova (AT2017gfo).





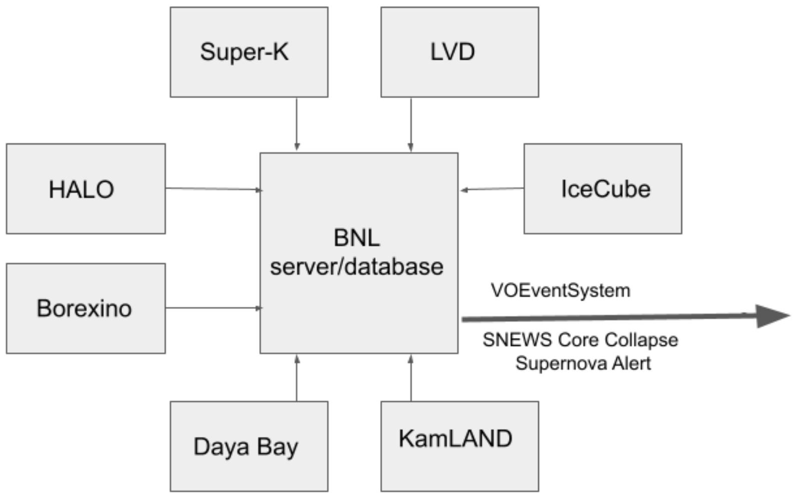
Galactic Core Collapse Supernova: These are extremely rare events, occurring 1-10 times per century. As such, it is important to have the technical capability to detect galactic supernovae and quickly perform as much follow-on optical backup as possible. When a massive star reaches the end of its life, its core collapses. More than 99% of the binding energy of the resulting neutron star or black hole is released in the form of neutrinos and antineutrinos of all flavors, with energies in the tens of MeV (million electron volt) range. The energy leaves via neutrinos/antineutrinos because neutrinos/antineutrinos interact so weakly that they readily leave the star. They bring information from deep inside the stellar core and great insight about core collapse physics. The time scale of neutrino/antineutrino emission is a few tens of seconds immediately after core collapse. The optical photon signal, in contrast, can take hours to days to emerge from the stellar envelope. Therefore, the detection of a burst of neutrinos/antineutrinos will give an early warning of the supernova collapse so that optical followup will be possible. Reference: Scholberg, K.,[0803.0531] The SuperNova Early Warning System.



Observing the Next Galactic Supernova

Core collapse supernova detection does not use spacecraft as in the case of GRBs/afterglows. The basic idea of the core collapse supernova alert system is to have a central computer which accepts neutrino burst candidate messages from neutrino detectors around the world and sends an alarm message to astronomers if it finds a coincidence within a short period of time (10 seconds). The central computer is located at Brookhaven National Lab. The coincidence search is both "blind" (decision is made when messages are received without polling the other experiments) and automated (alerts go out without human intervention for maximum speed). The neutrino experiments currently involved are Super-K, LVD, IceCube, Borexino, KamLAND, Daya Bay, and HALO. This is depicted below along with the interface to GCN for followup electromagnetic/optical observations. Reference: SNEWS and https://snews2.org/.

SNEWS System Architecture

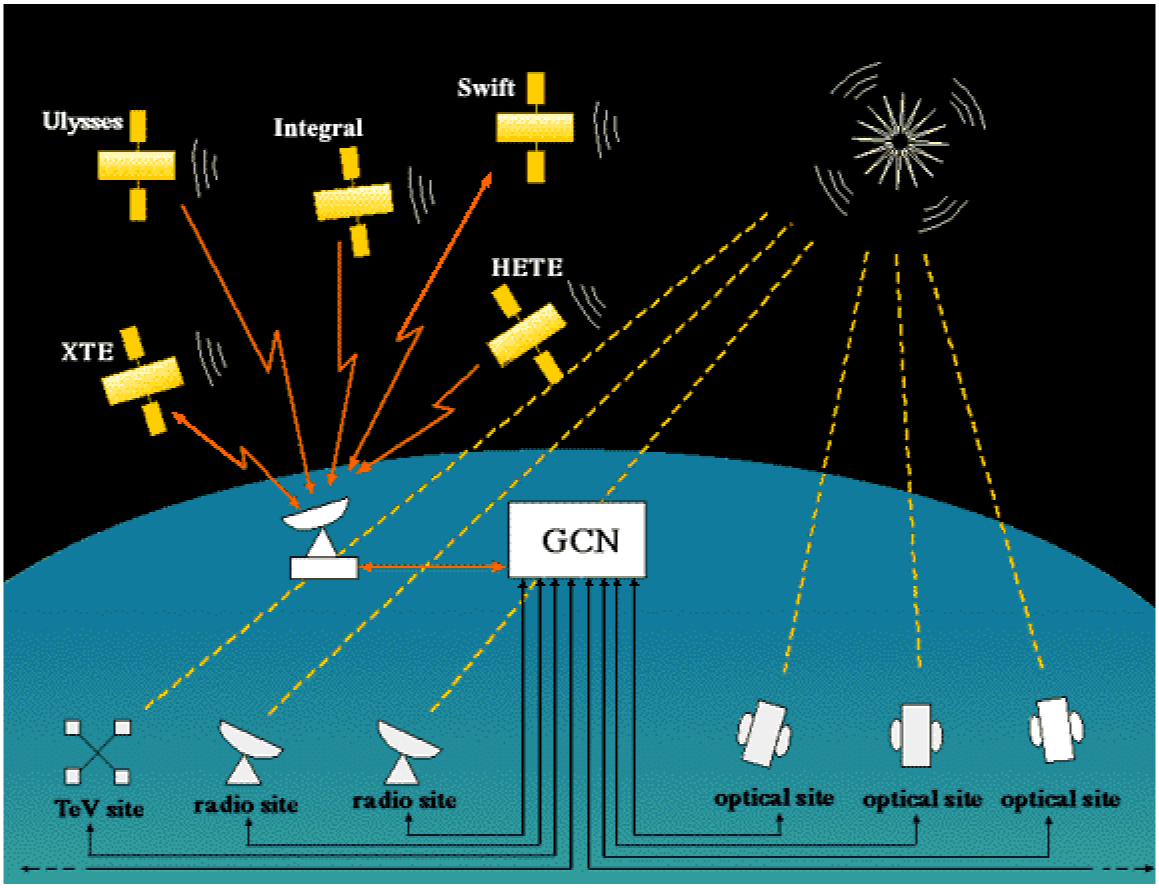


High Energy Event Detection Triggers and Alerts

GRBs/afterglow, Gravitational Wave events, and Core Collapse Supernovae all utilize the GRB Coordinate Network (GCN) hosted by the NASA Goddard Space Flight Center (GSFC).

GCN architecture

The GRB observational technique begins with the distribution of information from the Gamma-ray Coordinate Network, specifically the GCN Circular Archive. There are two parts to the GRB Coordinates Network: (1) the distribution of GRB/transient locations detected by various spacecraft, and (2) receiving and automatically distributing to the GRB/transient community prose-style e-mail messages about follow-up observations on various GRBs/transients. The overall high level physical GCN architecture is shown below.

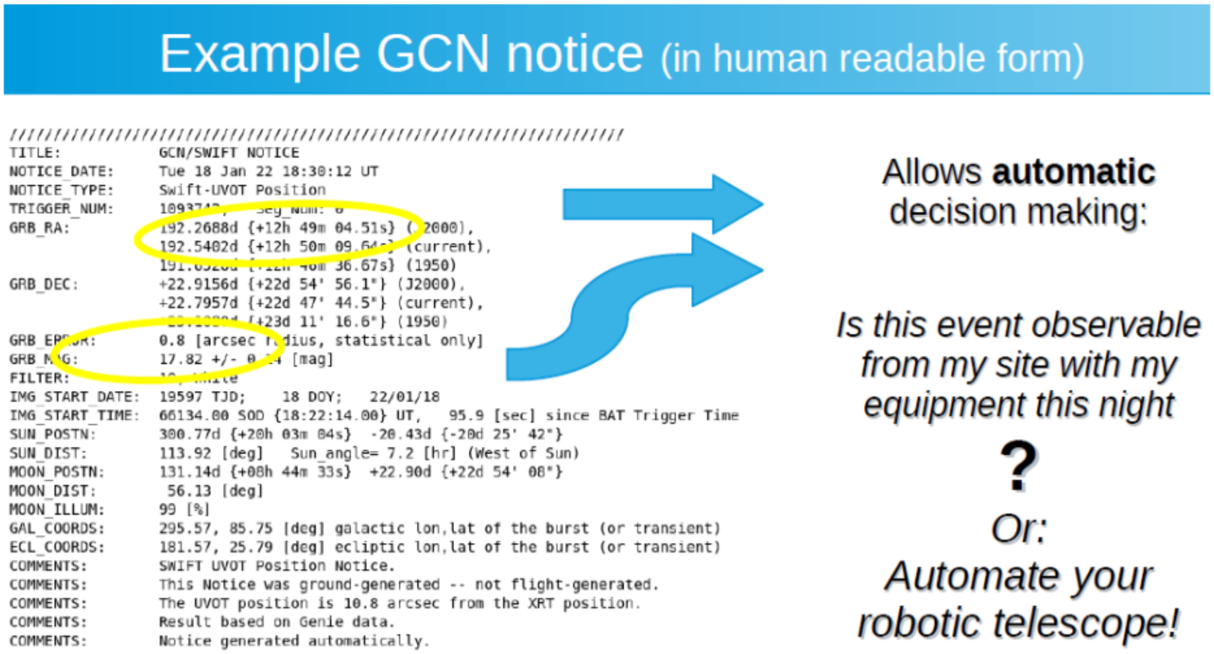


The Physical GCN Network (Courtesy NASA Goddard Space Flight Center)

GCN Circular Archive

Part 1 (the GCN Notices):

This portion of GCN consists of distributing the GRB/transient locations determined by the Fermi, Swift, INTEGRAL, IPN (Interplanetary Network), MOA (micro-lensing events), and other spacecraft systems. The collection and distribution of these Notices are done without any humans-in-the-loop, and as such for missions with real-time downlinks, the time delay from when the GRB/transient occurs to when the Notices are being sent out to the customer/observer is in the 2-10 sec range. Many socket-based and email-based formats and protocols are available. This combining of all the sources of GRB/transient location information into a single network means that user sites need only maintain a single interface for all their GRB/transient needs.



Courtesy NASA Goddard Space Flight Center

Part 2 (the GCN Circulars):

This part allows the GRB community to submit messages to a central queue where they are automatically vetted and distributed (via email) to the entire GRB community. These are prose-style messages (as opposed to the "TOKEN: value" style of the GCN e-mail Notices) from follow-up observers reporting on their results (detections or upper limits) or for coordinating with others. Reference: GCN.

Public GCN circulars on the Internet

GCN ciculars can be subscribed to by email, and you can see them here:

https://gcn.gsfc.nasa.gov/gcn3_archive.html

GCN Circulars Archive (in serial number order)

This page changes after each Circular submission, so hit the <reload> button NOW.

The processing of Circulars to this page was stopped (from ~01:30 to ~18:00 UT 01 Dec 2020).
The Circulars page has been fixed as of ~18:00 UT 01 Dec 2020.
(The Circulars WERE ALWAYS BEING DISTRIBUTED -- it is only this archive web page (and sub-pages) that had problems.)

1. The Latest Circulars
2. Older Circulars
3. Tarfile of all Circulars
4. Circulars grouped by each Event
5. All Circulars on the GRB source type
6. All Circulars on the GW source type
7. All Circulars on the SGR source type
8. All Circulars on the misc source type (ie not in any of the above 3 pages).

This is the archive of all the GCN Observation Report Circulars (listed in reverse serial number order, newest first).

To learn more about the GCN Circulars and how to subscribe; and to unsubscribe here.

1) The Latest Circulars (listed in reverse serial number order -- newest first)

- 31541 GRB 220131B: Swift/BAT-GUANO detection outside the coded FOV
- 31540 GRB 220201A: Fermi GBM Final Localization
- 31539 GRB 220128A: AstroSat CZTI detection
- 31538 GRB 220130A: Fermi GBM Observation
- 31537 Konus-Wind detection of GRB 220128A
- 31536 IPN triangulation of GRB 220128A (long)
- 31535 Fermi GRB 220131A: Global MASTER-Net observations report
- 31534 GRB 220131B: GECAM detection

Example GCN circular

```
//////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  31490
SUBJECT: GRB 220118A: Swift detection of a burst with an optical counterpart
DATE:    22/01/18 18:33:38 GMT
FROM:    Kim Page at U.of Leicester  <kimlpage1978@gmail.com>

N. J. Klingler (GSFC/UMBC/CRESSTII), E. Ambrosi (INAF-IASFPA),
A. D'Ai (INAF-IASFPA), V. D'Elia (SSDC & INAF-OAR), S. Dichiara (PSU),
J.D. Gropp (PSU), H. A. Krimm (NSF), F. E. Marshall (NASA/GSFC),
K. L. Page (U Leicester), D. M. Palmer (LANL),
T. M. Parsotan (GSFC/UMBC/CRESSTII), B. Sbarufatti (PSU) and
M. H. Siegel (PSU) report on behalf of the Neil Gehrels Swift
Observatory Team:

At 18:20:38 UT, the Swift Burst Alert Telescope (BAT) triggered and
located GRB 220118A (trigger=1093742).  Swift slewed immediately to the burst.
The BAT on-board calculated location is
RA, Dec 192.274, +22.909 which is
   RA(J2000) = 12h 49m 06s
   Dec(J2000) = +22d 54' 33"
with an uncertainty of 3 arcmin (radius, 90% containment, including
systematic uncertainty).  The BAT light curve showed a single-peaked
structure with a duration of about 20 sec  The peak count rate
was ~1400 counts/sec (15-350 keV), at ~0 sec after the trigger.
```

13 minutes delay

Courtesy NASA Goddard Space Flight Center

Example GCN circular cont'd

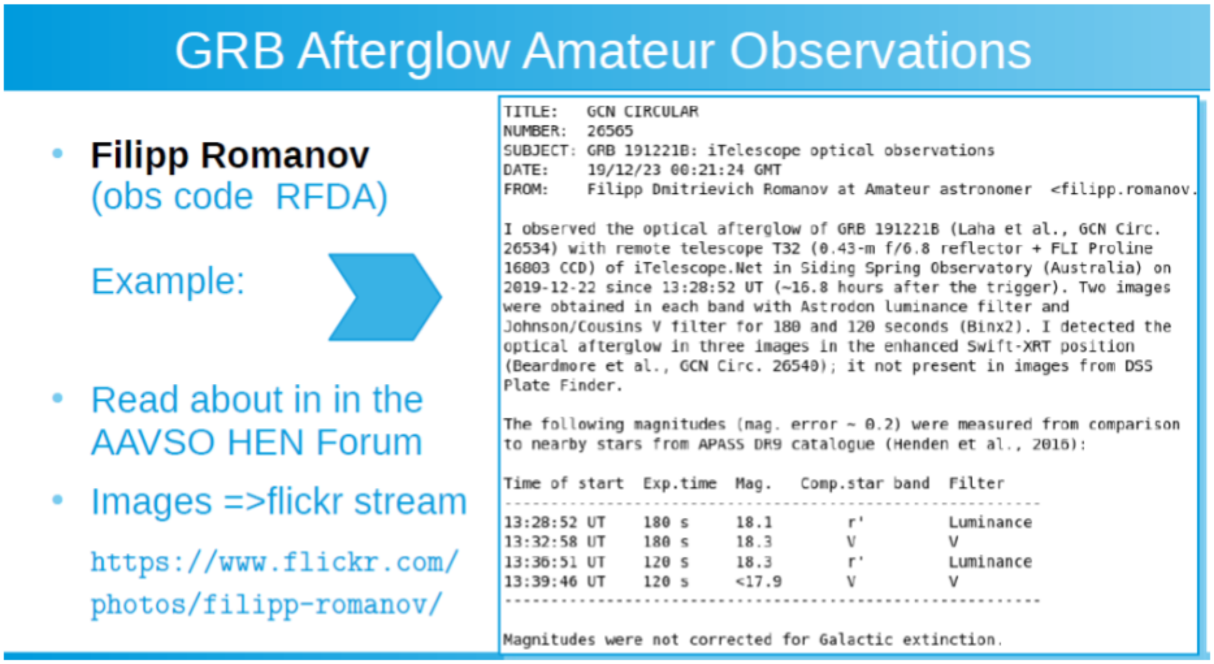
```
The XRT began observing the field at 18:22:08.3 UT, 90.3 seconds after
the BAT trigger. Using promptly downlinked data we find a bright,
fading, uncatalogued X-ray source located at RA, Dec 192.26936,
22.91600 which is equivalent to:
   RA(J2000)   = 12h 49m 04.65s
   Dec(J2000) = +22d 54' 57.6"
with an uncertainty of 3.5 arcseconds (radius, 90% containment). This
location is 29 arcseconds from the BAT onboard position, within the BAT
error circle. This position may be improved as more data are received;
the latest position is available at https://www.swift.ac.uk/sper.

A power-law fit to a spectrum formed from promptly downlinked event
data gives a column density in excess of the Galactic value (2.25 x
10^20 cm^-2, Willingale et al. 2013), with an excess column of 3.4
(+2.60/-2.24) x 10^21 cm^-2 (90% confidence).

The initial flux in the 2.5 s image was 4.57e-10 erg cm^-2 s^-1 (0.2-10
keV).
```

Courtesy NASA Goddard Space Flight Center

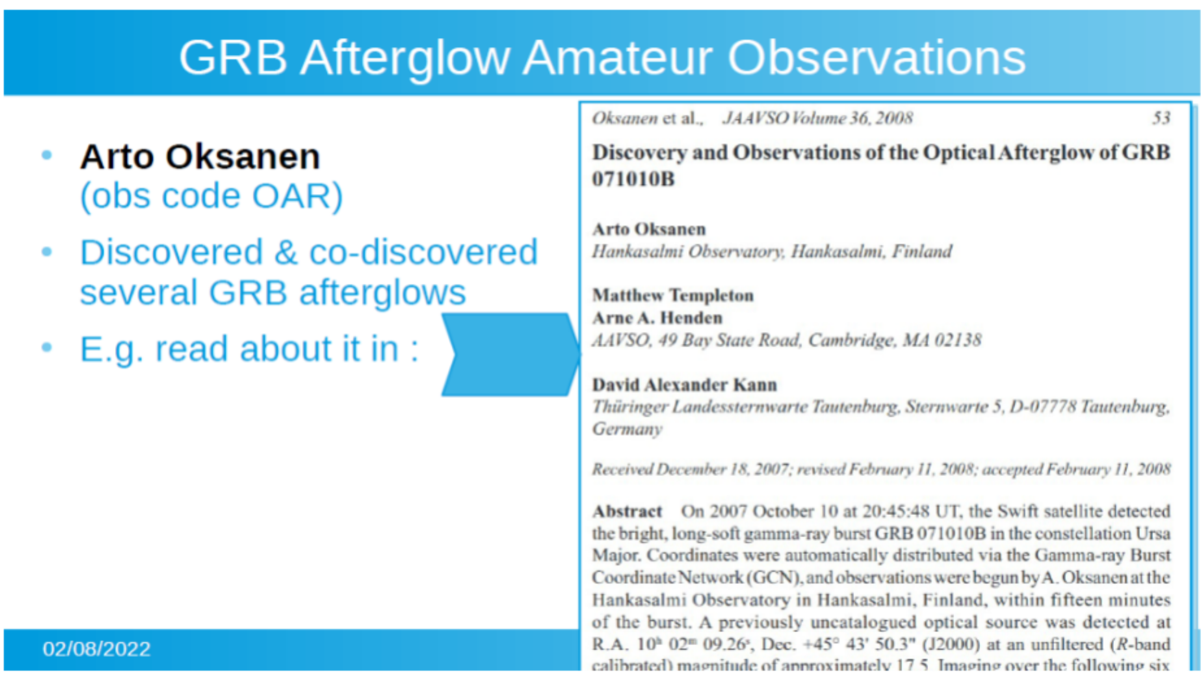
Example GCN circular cont'd

```
UVOT took a finding chart exposure of 150 seconds with the White filter
starting 99 seconds after the BAT trigger. There is a candidate afterglow in
the rapidly available 2.7'x2.7' sub-image at
  RA(J2000)  =  12:49:04.53 = 192.26888
  DEC(J2000) = +22:54:56.2  =  22.91562
with a 90%-confidence error radius of about 0.75 arc sec. This position is 1.8
arc sec. from the center of the XRT error circle. The estimated magnitude is
17.83 with a 1-sigma error of about  0.15. No correction has been made for the
expected extinction corresponding to E(B-V) of 0.025.

Burst Advocate for this burst is N. J. Klingler (noelklin AT umbc.edu).
Please contact the BA by email if you require additional information
regarding Swift followup of this burst. In extremely urgent cases, after
trying the Burst Advocate, you can contact the Swift PI by phone (see
Swift TOO web site for information: http://www.swift.psu.edu/)
```

Courtesy NASA Goddard Space Flight Center



Courtesy Filipp Romanov



Courtesy Arto Oksanen

Time Domain Astrophysics Techniques

GCN is utilized for all three types of time domain events. In order to interface with the GCN, the observer simply needs anything that will run Python code and has a 24/7 internet connection. Because the messages are machine readable and the API is Python, the observer can react to events in a very customizable way, e.g., you can filter out “interesting” events based on observability at your site or the size of the uncertainty of the sky localization. All it takes to receive these messages are a few lines of Python code, thanks to the PyGCN package that you can find here: https://pypi.org/project/pygcn/. There are two servers available (identical servers for redundancy); 45.58.43.186 port=8099 and 68.169.57.253 port=8099. These addresses are already preconfigured in the Python library as defaults https://github.com/lpsinger/pygcn.

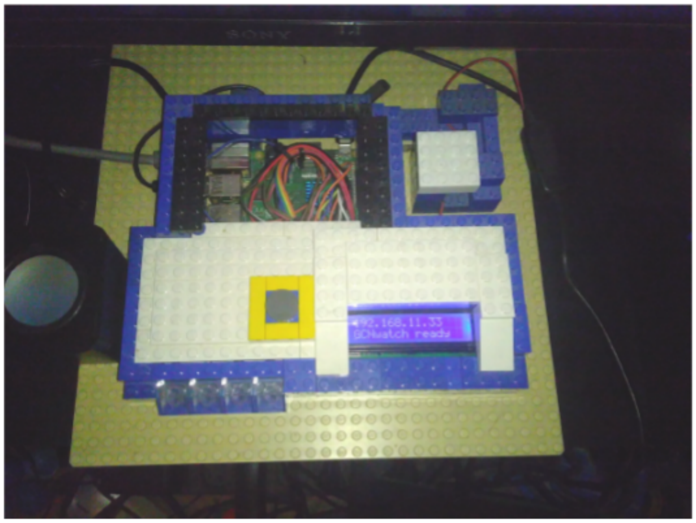
PyGCN example: listening for FERMI:

```python
#!/usr/bin/env python
import gcn

# Define your custom handler here.
@gcn.include_notice_types(
    gcn.notice_types.FERMI_GBM_FLT_POS,  # Fermi GBM localization (flight)
    gcn.notice_types.FERMI_GBM_GND_POS,  # Fermi GBM localization (ground)
    gcn.notice_types.FERMI_GBM_FIN_POS)  # Fermi GBM localization (final)
def handler(payload, root):
    # Look up right ascension, declination, and error radius fields.
    pos2d = root.find('.//{*}Position2D')
    ra = float(pos2d.find('.//{*}C1').text)
    dec = float(pos2d.find('.//{*}C2').text)
    radius = float(pos2d.find('.//{*}Error2Radius').text)

    # Print.
    print('ra = {:g}, dec={:g}, radius={:g}'.format(ra, dec, radius))

# Listen for VOEvents until killed with Control-C.
gcn.listen(handler=handler)
```

PyGCN example: listening for SNEWS:

```
#!/usr/bin/env python
import gcn

# Define your custom handler here.
@gcn.include_notice_types(
    gcn.notice_types.SNEWS)
def handler(payload, root):
    print('SNEWS Alert!')
    # .... if at night: switch bedroom lights on
    # .... play a loud sound
    # .... send emails to yourself and friends
    # P.S. there are test alerts every Tuesday , you might want
    # to filter out those once you are confident everything
    # works ... :-)
# Listen for VOEvents until killed with Control-C.
gcn.listen(handler=handler
```

Raspberry Pi: Raspberry Pi is an inexpensive, single board microcomputer that can be programmed for a wide variety of applications. One such application is an alert system that receives, processes, and displays GCN alerts from LIGO/VIRGO, Goddard Space Flight Center, and any detector/trigger that requires a rapid follow-up response (e.g., an optical observation of a Gamma Ray Burst or Gravitational Wave Event). Raspberry Pi can be utilized by amateur observers and/or robotic telescope systems to configure their equipment to perform observations. PyGCN, as described above, can be run on Raspberry Pi.



Courtesy Heinz-Bernd Eggenstein

Mobile/Cell Phone Apps (iPhone/Android): One potentially important high energy event alert is mobile apps for cell phones, both iPhone and Android. These apps receive a GCN or similar high energy event trigger and generate an SMS/text message to a user's mobile device. This would likely be one of the quickest ways to alert observers that an event has occurred, since cell phone use is ubiquitous. There are two unofficial apps for mobile devices that can be used to view GW alerts on smartphones or tablets. These can be found here Mobile Device GW Alerts.

GRB Observational Techniques

1. Receipt of GCN message: GCN sends a message, as described above, from the Swift gamma-ray location function. Coordinates are automatically distributed in the message. The detected GRB/afterglow should be observed as soon as possible after receiving the GCN alert. It is also useful to learn to know if/when a GRB has potential prior to any alert.

2. Telescope observations: In principle, GRBs can be imaged within seconds of detection of gamma-rays so long as the observer is in darkness, can view the field from their location, has a clear sky, and has equipment quickly available (a large telescope with CCD camera helps). The telescope characteristics include the location (latitude/longitude/elevation) of the observing platform as well as the

optical and photometric parameters of the telescope. For example, iTelescope T18, AstroCamp Observatory, Nerpio, Spain (North 38 deg/ West 2 deg, 19 min/ 1650 meters); 0.32 m, f/8.0 reflector + SBIG-STXL-6303E CCD. Some specific telescope systems used to develop these observation procedures are:

iTelescope

iTelescope is a worldwide network of robotically controlled telescopes. It is comprised of four observatories in both the Northern and Southern Hemispheres: Siding Springs Observatory, Australia; Astrocamp, Nerpio, Spain; New Mexico Skies, New Mexico; Sierra Remote Observatory, California, and Chile. These observatories host 23 robotic telescopes with varying capabilities controlled across the internet.

Abbey Ridge Observatory

The observatory is built around a fiberglass 10-foot diameter Home-Dome. Inside is a Celestron C14 Schmidt-Cassegrain Telescope mounted on a Losmandy Titan German equatorial mount controlled by a SiTech controller. Its imaging camera is an SBIG ST8XME CCD camera with dual Optec IFW filter wheels (9 effective filters), Optec NextGen telecompressor, and an Optic TCF electric focuser. Abbey Ridge Observatory also uses an AAG CloudWatcher to monitor the sky conditions. There are more details here.

Burke-Gaffney Observatory

The Burke-Gaffney Observatory and its Dr. Ralph M. Medjuck Telescope are primarily used for undergraduate astronomy education, public outreach, and modest research projects. It is one of only two observatories in the world, along with the nearby Abbey Ridge Observatory, that can be controlled from Twitter, Facebook Messenger, cell phone text messaging, and a dedicated App in a fully-automatic way.

The observatory is named in honor of Reverend M. W. Burke-Gaffney , S. J (1896-1979). The new telescope, installed in December of 2013, is named in honor of Dr. Ralph M. Medjuck. It is located on the roof of the 22-story Loyola Residence tower. It was opened in 1972 with a 16-inch Ealing telescope, but was extensively upgraded and renovated in 2013. The main instrument is a Planewave CDK24, a 0.61-metre diameter reflecting telescope. Technical details for the telescope and its instruments can be found here. The observatory also owns a 40-cm diameter reflecting telescope, ten 20-cm diameter reflecting telescopes (with several white light solar filters), and a dedicated solar telescope with a narrowband hydrogen alpha filter.

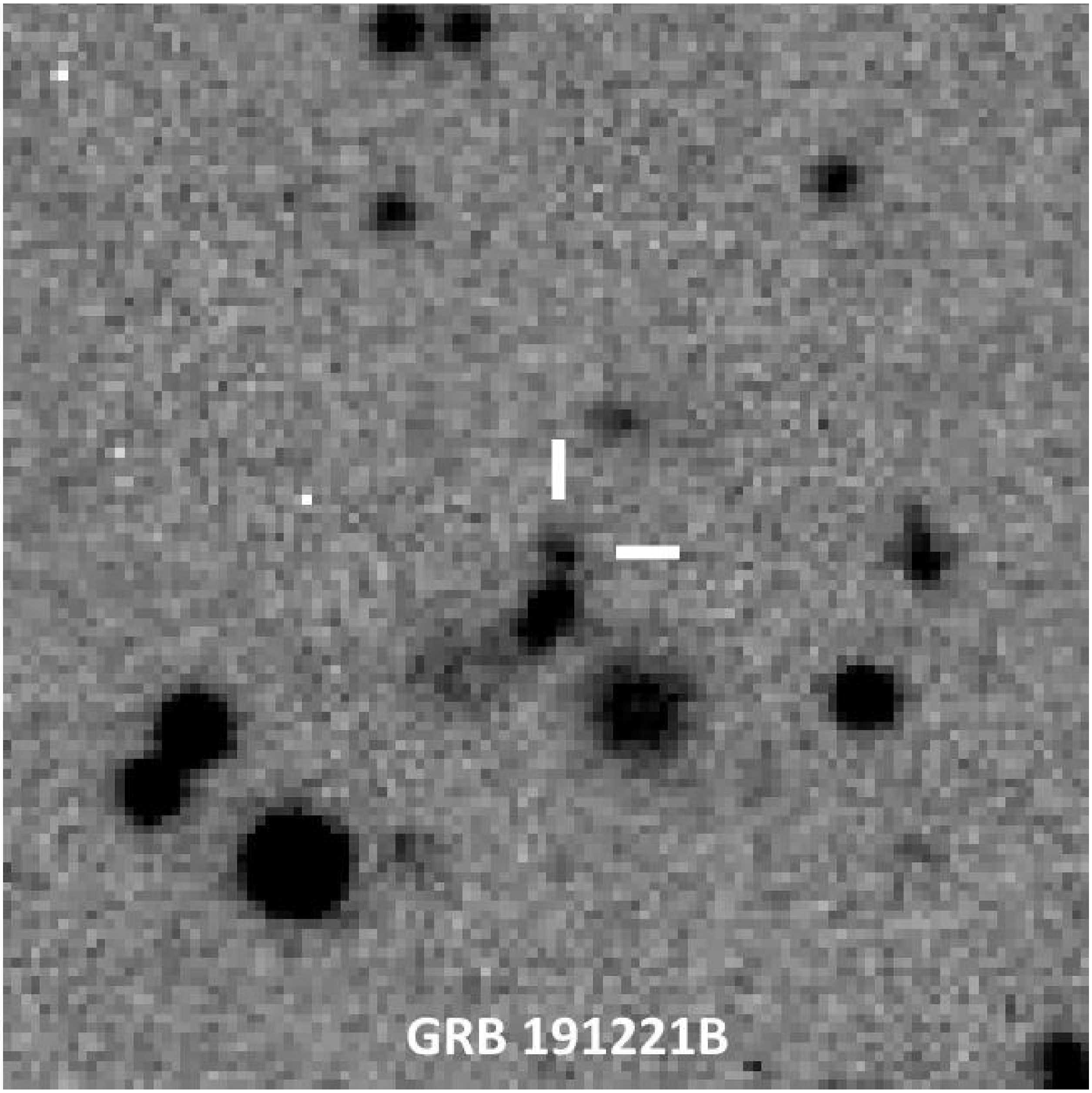
3. Observation and Image Parameters: The observation parameters include UT time of exposure, time after trigger (for example 2020-12-23 from 19:49:22 UT: 1 hour, 50 minutes, 56 seconds after trigger), RA/Dec of observations, e.g., RA

08:51:09.46, Dec +71:10:47:00. Image parameters include number of images, exposure time, bin number, and filter type (e.g., V, luminance, Sloan). For example, 5 images with exposures 300, 120, 180 seconds with an Astrodon luminance filter and 4 images with exposures 300 and 60 seconds with a photometric Johnson V filter. Finally, any image stacking should be indicated, for example, 4x300 + 2x120 + 180 seconds. More specifically, 2x300V + 2x300lum + 2x120lum + 180lum seconds.

4. Results: Indicate all of the pertinent results of the observations and measurements. For example, measured magnitude from comparison to r' magnitudes of nearby stars from the Pan-STARRS DR1 catalog (Chambers et al., 2016). This will typically be as follows:

Time of start 19:49:22 UT; Exposure time 300 seconds; Bin=1; Mag. r'=19.2; Mag error 0.2; Filter = Luminance
Time of start 19:56:25 UT; Exposure time 300 seconds; Bin=1; Mag. r'=19.3; Mag error 0.4; Filter = V
Time of start 20:26:25 UT; Exposure time 300 seconds; Bin=2; Mag. r'=19.9; Mag error 0.4; Filter = V
Time of start 20:33:07 UT; Exposure time 300 seconds; Bin=2; Mag. r'=20.1; Mag error 0.3; Filter = Luminance

Include magnitude, error, comparison star band, limits of parameters if applicable, and SNR. Indicate if a correction was made for galactic extinction (yes/no) and indicate if an optical afterglow was detected (yes/no). Finally, present and publish the finished optical image product and supporting data on the AAVSO International High Energy Network HEN Forum. An example of a finished image product is:



Courtesy Filipp Romanov

Include any appropriate notes, information, data, comments, suggestions for further observations or research, etc.

5. Submit a GCN Circular of the discovery/observation as soon as possible with all the pertinent data. Here are links to sample GCN Circulars (courtesy of Filipp Romanov and Arto Oksanen). If assistance is needed, contact Arto Oksanen at arto.oksanen@jklsirius.fi.

Sample GRB Circulars (Courtesy Filipp Romanov and Arto Oksanen)

GRB 191029A: iTelescope optical upper limits

https://gcn.gsfc.nasa.gov/gcn/gcn3/26091.gcn3

GRB 191123A: iTelescope optical upper limits

https://gcn.gsfc.nasa.gov/gcn/gcn3/26283.gcn3

GRB 191221B: iTelescope optical observations

https://gcn.gsfc.nasa.gov/gcn/gcn3/26565.gcn3

GRB 201223A: iTelescope optical afterglow observations

https://gcn.gsfc.nasa.gov/gcn/gcn3/29165.gcn3

GRB 210104A: iTelescope optical upper limit

https://gcn.gsfc.nasa.gov/gcn/gcn3/29269.gcn3

GRB 210226A: Burke-Gaffney Observatory optical upper limit

https://gcn.gsfc.nasa.gov/gcn/gcn3/29572.gcn3

GRB 210306A: iTelescope optical afterglow observations

https://gcn.gsfc.nasa.gov/gcn/gcn3/29599.gcn3

GRB 210610B: iTelescope optical afterglow observations

https://gcn.gsfc.nasa.gov/gcn/gcn3/30181.gcn3

GRB 210610B: correction to GCN 30181

https://gcn.gsfc.nasa.gov/gcn/gcn3/30184.gcn3

GRB 210610B: optical observations from Burke-Gaffney Observatory and Abbey Ridge Observatory

https://gcn.gsfc.nasa.gov/gcn/gcn3/30228.gcn3

GRB 210619B: iTelescope optical afterglow observation

https://gcn.gsfc.nasa.gov/gcn/gcn3/30292.gcn3

GRB 210619B: Abbey Ridge Observatory optical afterglow observation https://gcn.gsfc.nasa.gov/gcn/gcn3/30305.gcn3

GRB 210702A: iTelescope optical afterglow observations

https://gcn.gsfc.nasa.gov/gcn3/30364.gcn3

GRB 220101A: iTelescope optical observations

https://gcn.gsfc.nasa.gov/gcn3/31387.gcn3

GRB 210822A: Abbey Ridge Observatory optical afterglow observation

https://gcn.gsfc.nasa.gov/gcn3/30701.gcn3

GRB 210702A: iTelescope optical afterglow observations

https://gcn.gsfc.nasa.gov/gcn3/30364.gcn

GRB 071010B possible optical transient

GCN Circular 6873

GRB140206A - Optical afterglow candidate

GCN Circular 15786

GRB 071010B correction to GCN 6892 optical observations

GCN Circular 6903

Gravitational Wave Observational Techniques

The interfaces for the amateur optical follow-up of gravitational wave events are GRANDMA and Kilonova Catcher.

Global Rapid Advanced Network Devoted to the Multi-messenger Addicts (GRANDMA)

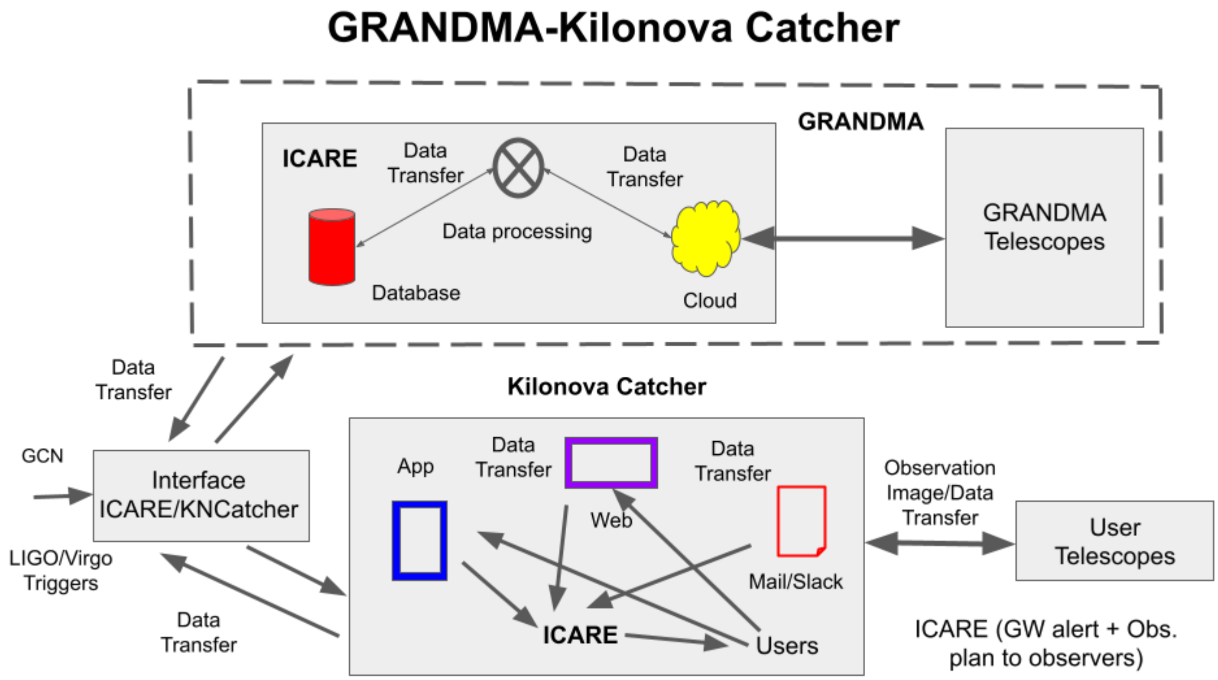
An international scientific collaboration of astrophysicists that work on gravitational wave astronomy, utilizing crowdsourcing and volunteer astronomers to assist in research. GRANDMA utilizes a network of robotically controlled telescopes with both photometry and spectrometry capabilities for time-domain astronomy.

Kilonova Catcher

Kilonova Catcher is focused on the optical followup of any gravitational wave event that is detected by the currently operating gravitational wave observatories, specifically to catch the kilonova emissions emerging from the coalescence of two neutron stars bound in a compact binary system.

Watch the AAVSO Webinar, 2nd part, https://youtu.be/WIDxZDA2ZvY for a detailed discussion of GRANDMA/Kilonova Catcher with Dr. Sarah Antier.

The overall system architecture of GRANDMA/Kilonova Catcher is shown below.



Courtesy Kilonova Catcher

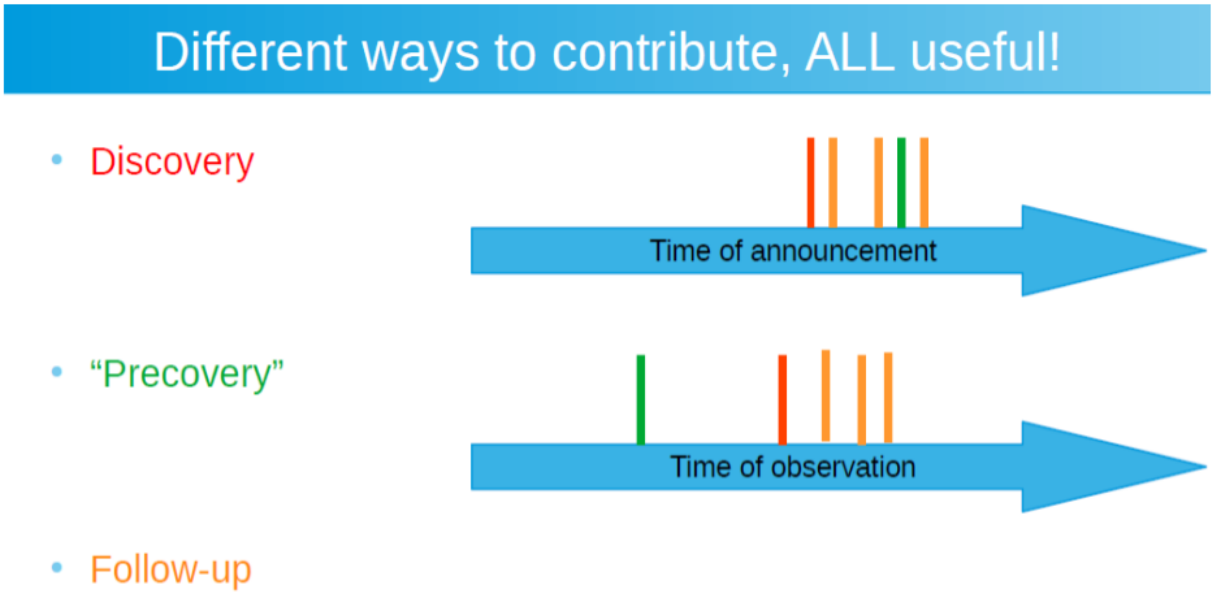
Galactic Supernova Observational Techniques

The SuperNova Early Warning System (SNEWS) is the interface for the amateur optical follow-up of Core Collapse Supernovae. SNEWS sends neutrino detection alerts in real time via email or NASA's GCN system. The initial alert is currently without sky localization.

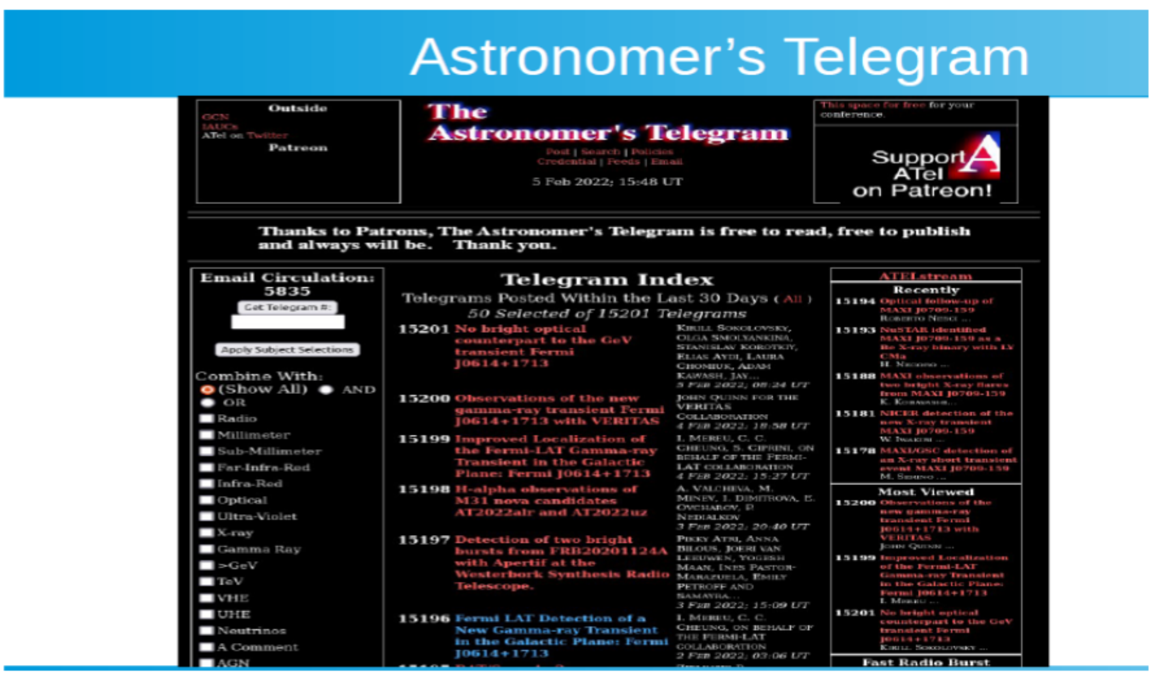
Reference: SNEWS and https://snews2.org/ and https://snews2.org/alert-signup/

Watch the AAVSO Webinar, 3rd part, **https://youtu.be/WIDxZDA2ZvY** for a detailed discussion of Gravitational Waves and Multi-messenger astronomy with Dr. Michael Coughlin.

How amateurs can and should prepare for observing these events



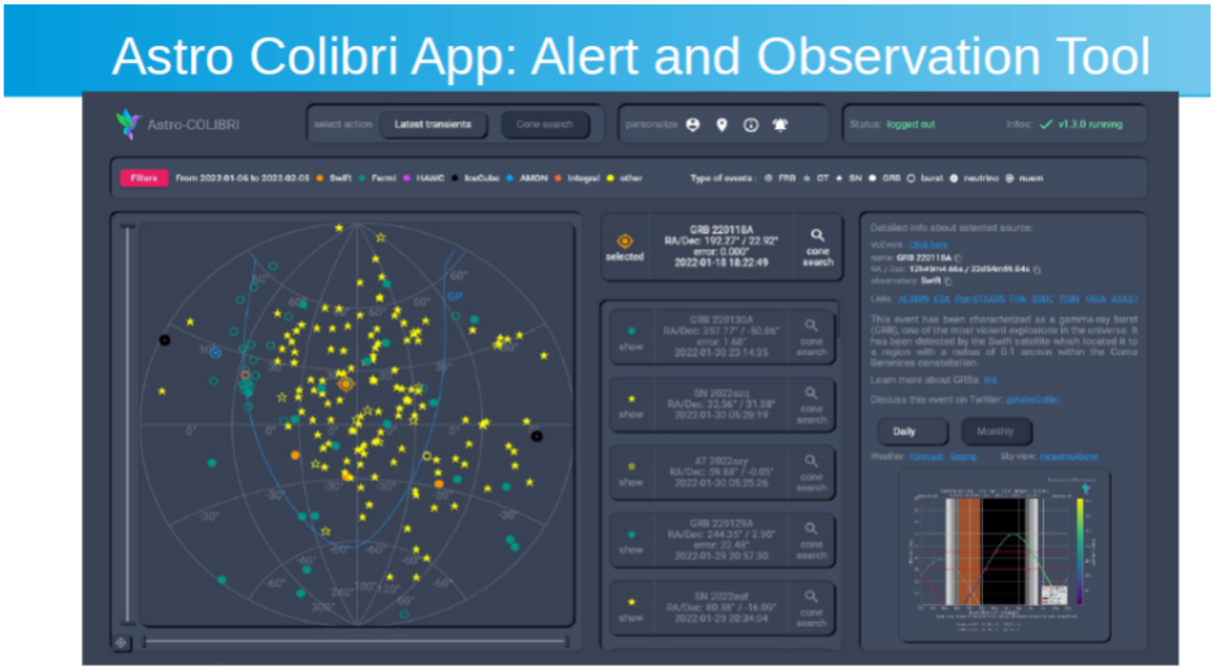
One way to monitor possible time domain events is through the Astronomer's Telegram (https://www.astronomerstelegram.org/).



Additionally, observers can access the Astro Colibri App Alert and Observation Tool.

https://astro-colibri.herokuapp.com/welcome

https://astro-colibri.com/



IOS and Android apps in their respective app stores can send notifications to your phone for new events including GRBs, GW events, as well as supernova and other transients.

Additionally, by monitoring red supergiant stars (Red Supergiants), it may be possible to build the light curve history in order to understand if a star might be a candidate for explosion. The AAVSO will manage the candidate list and make it available as a web page and an API to facilitate the effort.

Example Walk-Thru

GCN

Example Walk-Thru

- **GRB 220124A**

```
TITLE:   GCN CIRCULAR
NUMBER:  31521
SUBJECT: GRB 220124A: AstroSat CZTI detection of a bright long GRB
DATE:    22/01/24 08:11:18 GMT
FROM:    Gaurav Waratkar at IIT,Bombay  <gauravwaratkar@iitb.ac.in>

V. Prasad (IUCAA), G. Waratkar (IITB), A. Suresh (IITB), A. Vibhute
(IUCAA), V. Bhalerao (IITB), D. Bhattacharya (IUCAA), A. R. Rao
(IUCAA/TIFR), and S. Vadawale (PRL) report on behalf of the AstroSat
CZTI collaboration:

Analysis of AstroSat CZTI data with the ML pipeline (Abraham et al.,
2021, MNRAS, 504, 3084) and the CIFT framework (Sharma et al., 2021,
JApA, 42, 73) showed detection of a long GRB 220124A.
```

Example Walk-Thru

- **However....**

We note that the burst has not been localised, and we cannot rule out an association with any SGRs. The ASIMOV tool (http://astrosat-ssc.iucaa.in:8080/ASIMOV/ASIMOV [1]) indicates that other active missions were covering different parts of the sky, hence confirmed non-detections from other missions can help localise the source by inferring earth-occulted regions.

Example Walk-Thru

- **Later on GCN:**

  GECAM also detected the GRB, and it has a localization

TITLE: GCN CIRCULAR
NUMBER: 31524
SUBJECT: GRB 220124A: GECAM detection
DATE: 22/01/25 14:48:59 GMT
FROM: Y Q Zhang at IHEP <yqzhang@ihep.ac.cn>

J. C. Liu, S. L. Xiong, S. Xiao, Y. Q. Zhang, C. Cai, P. Zhang,
C. Y. Li, S. L. Xie, X. Y. Zhao, Y. Huang, X. Y. Song,
C. Zheng, Y. Zhao, Z. W. Guo, W. C. Xue, C. W. Wang,
Q. B. Yi, B. X. Zhang, W. X. Peng, R. Qiao, D. Y. Guo, X. B. Li,
X. Ma, L. M. Song, P. Wang, J. Wang, Z. Zhang, S. J. Zheng, W. Chen,
J. J. He, G. Y. Zhao, Y. Q. Du, H. Wu, J. Liang, Q. Luo, X. L. Zhang,
H. M. Zhang, Z. H. An, M. Gao, K. Gong, B. Li, C. Li, J. H. Li,
X. Q. Li, Y. G. Li, X. H. Liang, X. J. Liu, Y. Q. Liu, X. L. Sun,
Y. L. Tuo, J. Z. Wang, X. Y. Wen, Y. B. Xu, Y. P. Xu, S. Yang,
C. Y. Zhang, D. L. Zhang, Fan Zhang, Fei Zhang,
X. Zhou, F. J. Lu, S. N. Zhang (IHEP)
report on behalf of GECAM team:

During the commissioning phase, GECAM-B was triggered in-flight by a long burst,
GRB 220124A, at 2022-01-24T03:37:38.200 UTC (denoted as T0),
which was also observed by CALET/GBM(triggerID: 1327030648),
AstroSAT/CZTI(GCN #31521).

GECAM alert data was downlinked to the ground through the short message
service of BeiDou Navigation Satellite System (BDS) within ~60 s after T0.

According to the BDS alert data, this burst mainly consists of multiple pulses
with a duration of about 240 s.

The GECAM light curve could be found here:
http://[illegible]ist/GRB220124ALC_.png.png

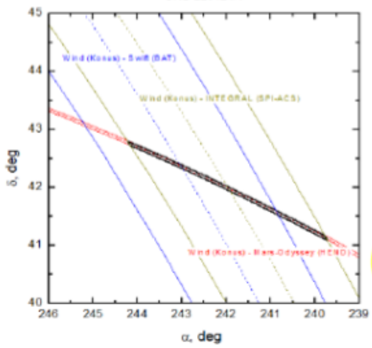
Using the automatic on-ground localization pipeline with the BDS alert data,
GECAM-B localized this burst to the following position (J2000):
Ra: 246.18 deg
Dec: 42.29 deg
Err: 2.96 deg (1-sigma, statistical only)
The current systematic error of location is estimated to be several degrees
which could be minimized by the ongoing calibration.

GCN

Example Walk-Thru

- **Still later on GCN: IPN has a "triangulation out on GCN:**

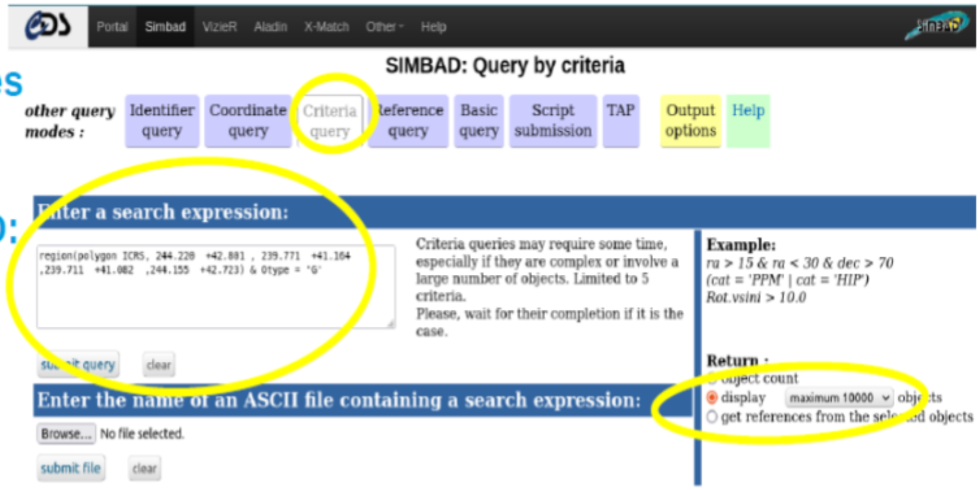
GRB 220124A




```
TITLE:   GCN CIRCULAR
NUMBER:  31525
SUBJECT: IPN triangulation of GRB 220124A
DATE:    22/01/25 15:07:51 GMT
FROM:    Dmitry Svinkin at Ioffe Institute  <svinkin@mail.ioffe.ru>

A.S. Kozyrev, D.V. Golovin, M.L. Litvak, I.G. Mitrofanov, and A.B.
on behalf of the HEND/Mars Odyssey team,

D. Svinkin, D. Frederiks, A. Ridnaia, A. Lysenko,
and T. Cline on behalf of the Konus-Wind team,

A. von Kienlin, X. Zhang, A. Rau, V. Savchenko, E. Bozzo,
and C. Ferrigno, on behalf of the INTEGRAL SPI-ACS GRB team,

S. Barthelmy, J. Cummings, H. Krimm, D. Palmer, and A. Tohuvavohu
on behalf of the Swift-BAT team, and

W. Boynton, C. Fellows, K. Harshman, H. Enos, R. Starr,
and A.S. Gardner on behalf of the GRS-Odyssey GRB team, report:

The long-duration GRB 220124A
(AstroSat-CZTI detection: Prasad et al., GCN Circ. 31521;
GECAM detection: Liu et al., GCN Circ. 31524)
has been detected by AstroSat (CZTI), Konus-Wind, Swift (BAT),
INTEGRAL (SPI-ACS), Mars-Odyssey (HEND), CALET (CGBM),
and GECAM-B (GRD) ,so far, at about 13058 s UT (03:37:38).
The burst was outside the coded field of view of the BAT.

We have tri[illegible] it to a preliminary, [illegible] error box
whos[illegible] coordinates are:
  ------------------------------------------------
   RA(2000), deg                 Dec(2000), deg
  ------------------------------------------------
  Center:
   241.945 (16h 07m 47s) +41.979 (+41d 58' 45")
  Corners:
   244.220 (16h 16m 53s) +42.801 (+42d 48' 02")
   239.771 (15h 59m 05s) +41.164 (+41d 09' 51")
   239.711 (15h 58m 51s) +41.082 (+41d 04' 54")
   244.155 (16h 16m 37s) +42.723 (+42d 43' 23")
  ------------------------------------------------
The error box area is 678 sq. arcmin, and its ma[illegible]
[illegible]mension is 3.8 deg (the minimum one is [illegible]arcmin).
The Su[illegible] was 84 deg.
```

Example Walk-Thru

- **Search for galaxies in this polygon in SIMBAD:**



Example Walk-Thru: Simbad result:

region(polygon ICRS, 244.220 +42.801 , 239.771 +41.164 ,239.711 +41.082 ,244.155 +42.723) & Otype = 'G'

other query modes : Identifier query | Coordinate query | Criteria query | Reference query | Basic query | Script submission | TAP | Output options | Help

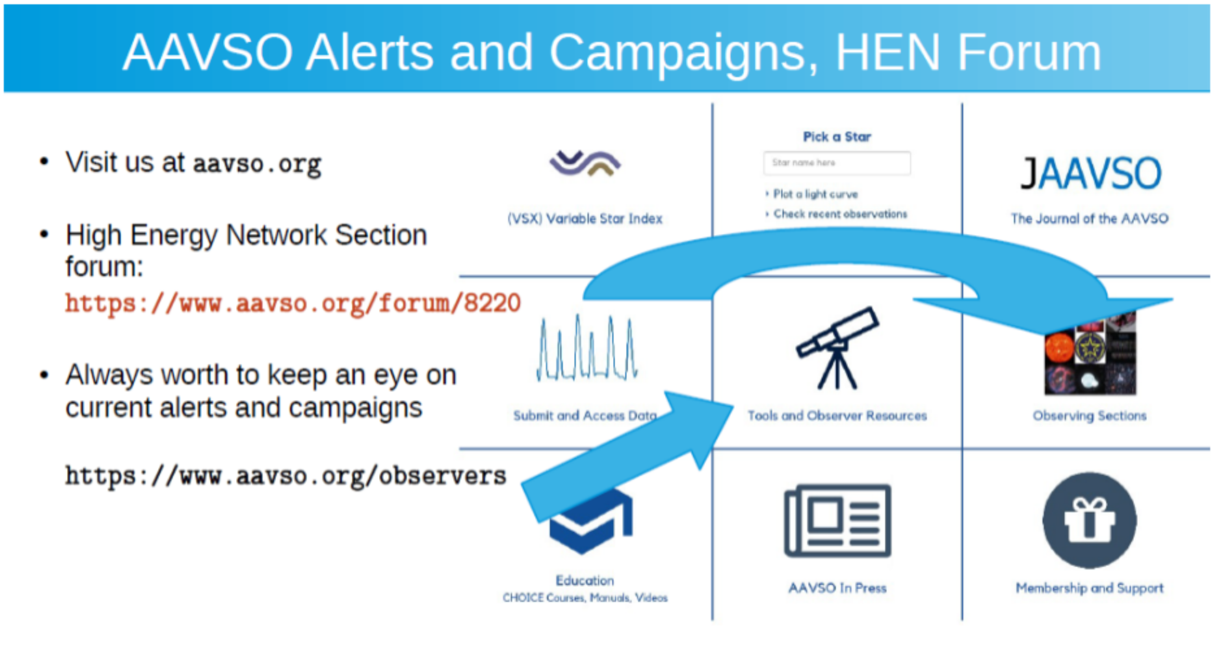
Query : region(polygon ICRS, 244.220 +42.801 , 239.771 +41.164 ,239.711 +41.082 ,244.155 +42.723) & Otype = 'G'

Number of rows : 9

Show 100 entries

Search:

N	Identifier	Otype	ICRS (J2000) RA	ICRS (J2000) DEC	Mag U
1	LEDA 56789	G	16 02 20.405	+41 27 39.75	
2	SDSS J160924.76+420624.8	G	16 09 24.764	+42 06 24.86	
3	LEDA 2205680	G	16 16 40.224	+42 45 51.03	
4	LEDA 2176874	G	15 59 43.2	+41 10 32	
5	2MASX J16091874+4207067	G	16 09 18.7434001848	+42 07 06.901291056	
6	2MASX J16145890+4237371	G	16 14 58.916	+42 37 37.22	
7	2MASX J16094346+4207507	G	16 09 43.495	+42 07 50.68	
8	SDSS J161023.56+421338.6	G	16 10 23.564	+42 13 38.68	
9	SDSS J155915.34+410729.1	G	15 59 15.348	+41 07 29.11	



The AAVSO International High Energy Network Observing Section Webinar *"How to Observe Optical Counterparts of High Energy Astronomical Transients"*, presented by section co-lead Heinz-Bernd Eggenstein, can be found here. [How to Observe Optical Counterparts of High Energy Astronomical Transients].

Acknowledgements

Contributors to this page are Heinz-Bernd Eggenstein, Arto Oksanen, Filipp Romanov, and Dave Hinzel.

The GRB observational techniques presented herein were developed and successfully utilized by AAVSO members Arto Oksanen and Filipp Romanov. Their work is critical to further research in GRB astrophysics.

References (with links)

New Supernova Alert System Promises Early Access to Spectacles in Space (Scientific American; February 22, 2021)

SNEWS (SuperNova Early Warning System); Pietro Antonioli *et al* 2004 *New J. Phys.* 6 114; SNEWS: the SuperNova Early Warning System

LIGO (Laser Interferometer Gravitational-wave Observatory); The LIGO Scientific Collaboration et al 2021 Search for anisotropic gravitational-wave backgrounds using data from Advanced LIGO's and Advanced Virgo's first three observing runs

VIRGO; B.P. Abbott et al (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 116, 061102 2016 Observation of Gravitational Waves from a Binary Black Hole Merger

Personal communications among the contributors to this page; Heinz-Bernd Eggenstein, Arto Oksanen, Filipp Romanov, and Dave Hinzel.

Oksanen, A., et al. 2008, “Discovery and Observations of the Optical Afterglow of GRB 071010B”, JAAVSO Volume 36, 2008.

Oksanen, A., et al. 2002, “Gamma-Ray Burst Optical Afterglow Observations at Nyrola Observatory”, JAAVSO Volume 30, 2002.

AAVSO High Energy Network Observing Section webinar (July 25, 2020): https://www.youtube.com/watch?v=mfr0ZoPh2_o&list=PLnZ_rvnR35rf3rDie-XWhapGZIqYIrJwn&index=5 (Observing GRB Optical Afterglows-Arto Oksanen).