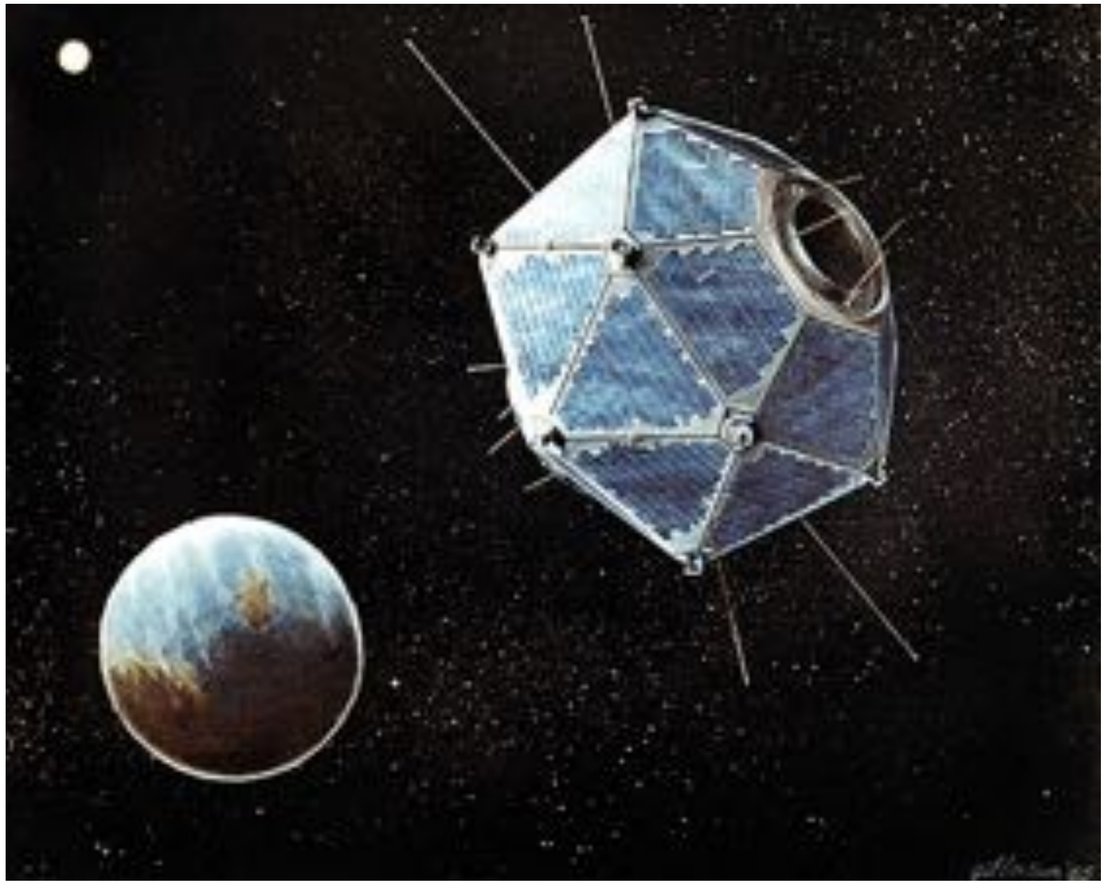
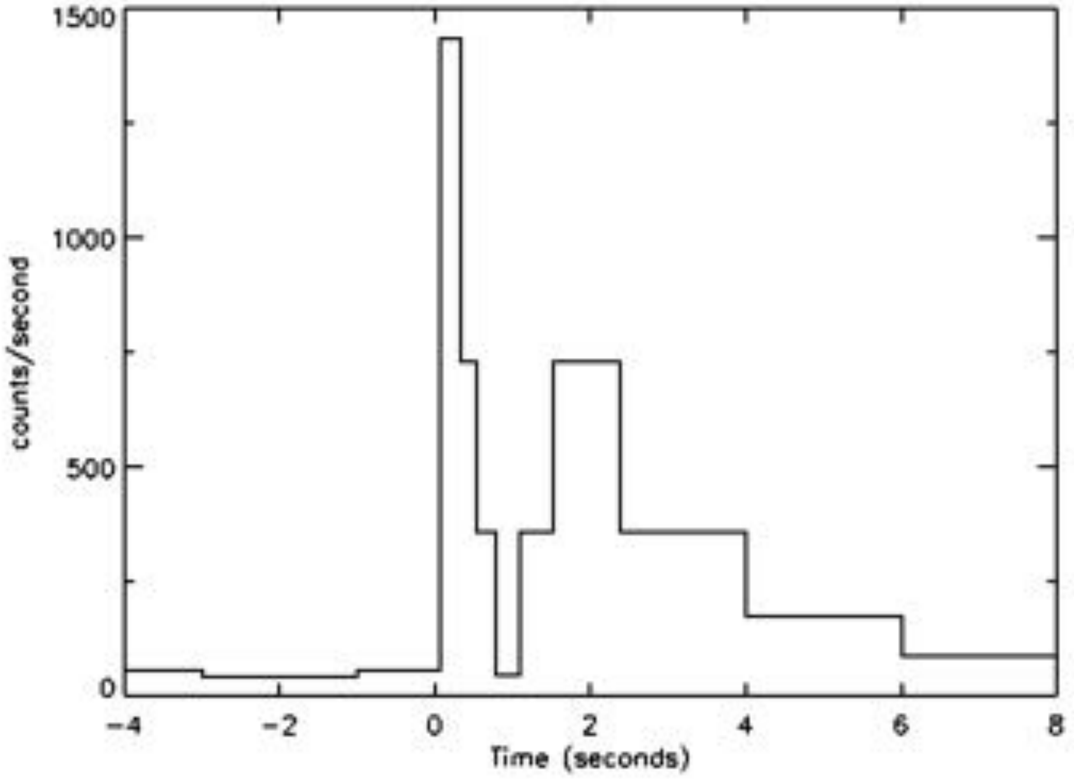
The hunt for gamma-ray counterparts to gravitational-wave sources

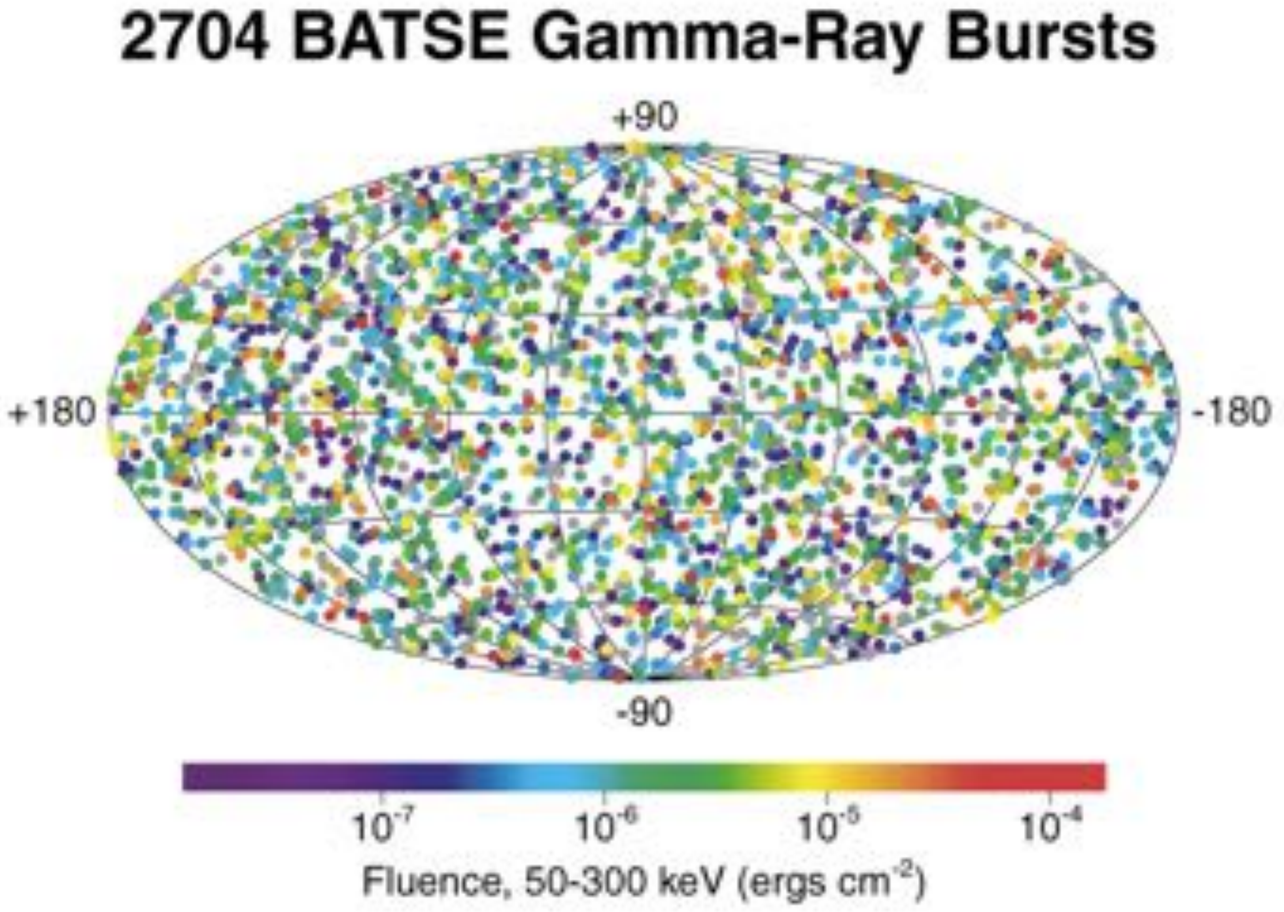
Tyson B. Littenberg (NASA/MSFC)

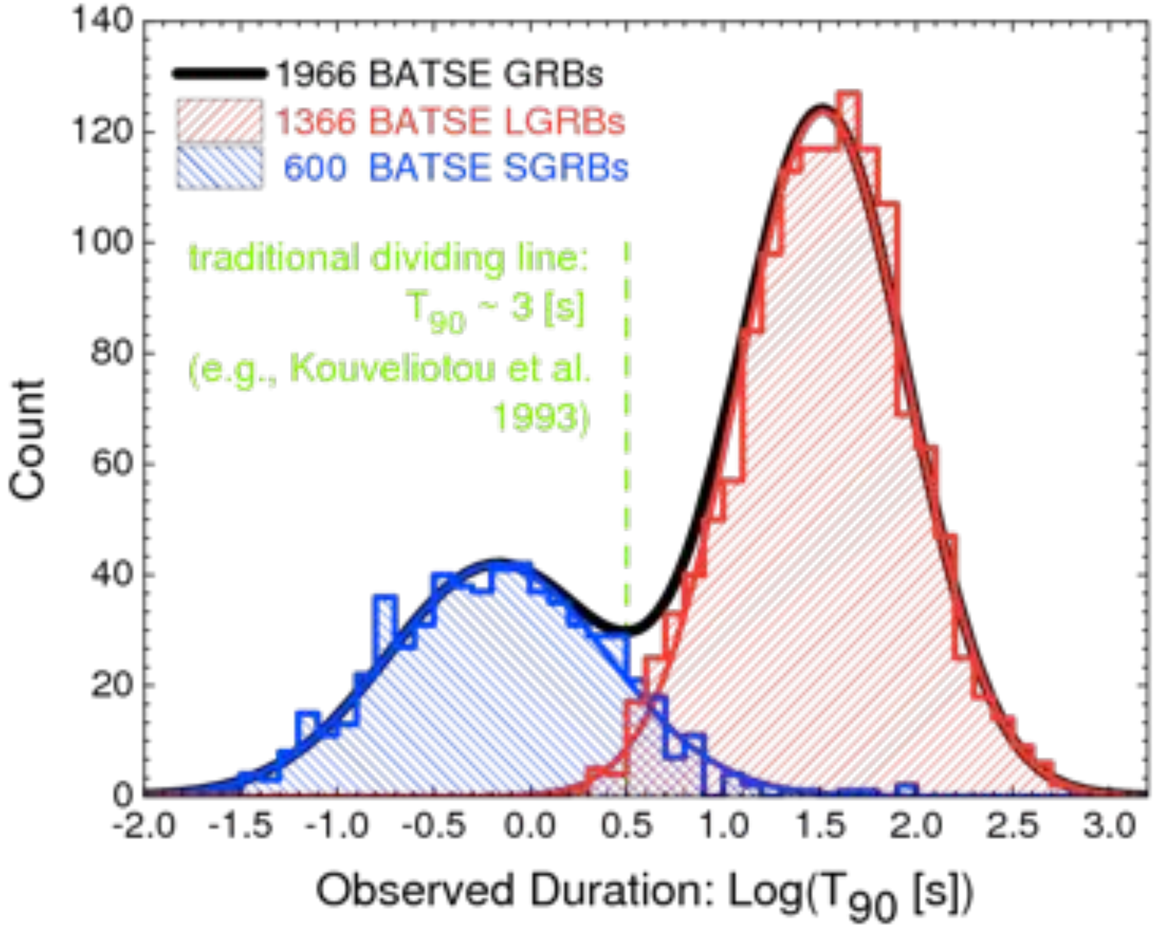
Gamma Ray Bursts

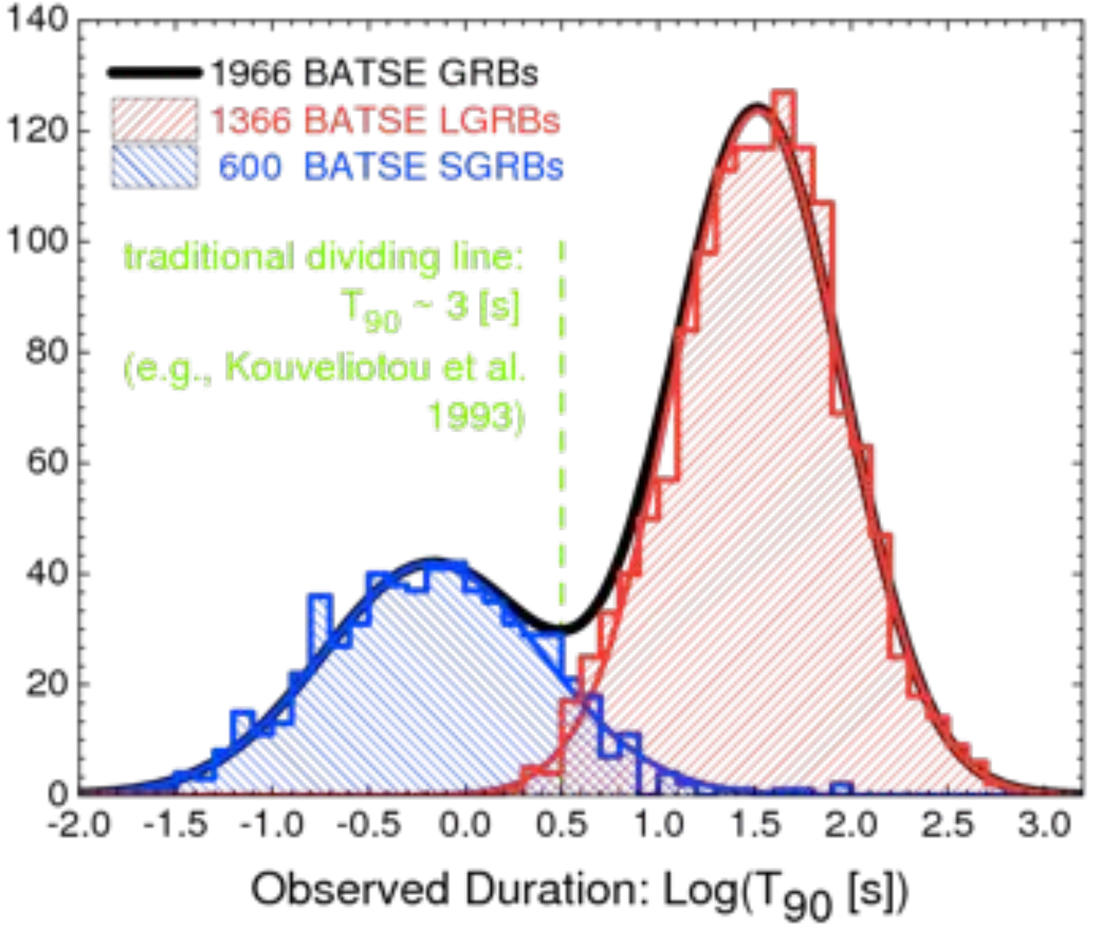


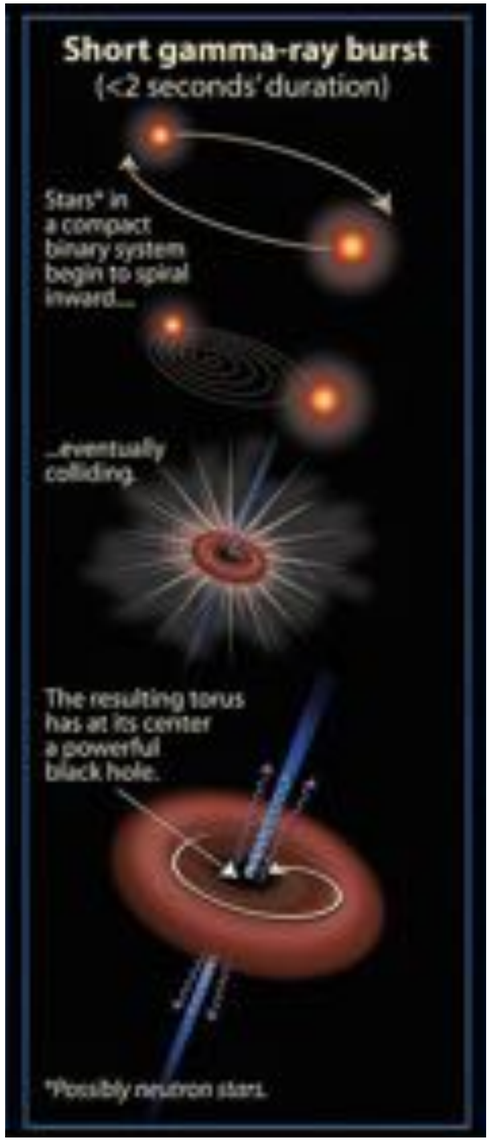


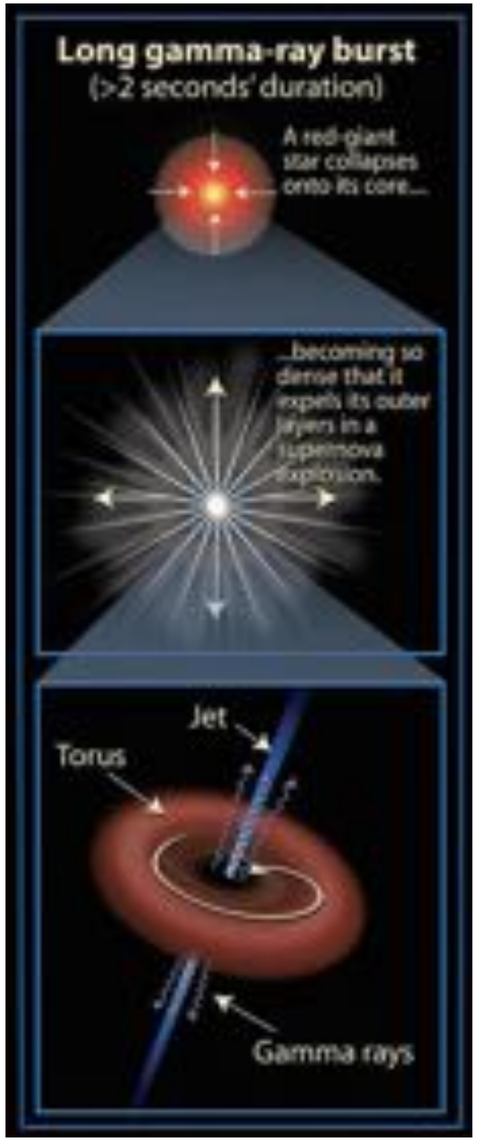
Gamma Ray Bursts


2704 BATSE Gamma-Ray Bursts
+90
+180
-180
-90
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Fluence, 50-300 keV (ergs cm^{-2})


1966 BATSE GRBs
1366 BATSE LGRBs
600 BATSE SGRBs
traditional dividing line:
T_{90} ~ 3 [s]
(e.g., Kouveliotou et al. 1993)
Count
Observed Duration: Log(T_{90} [s])

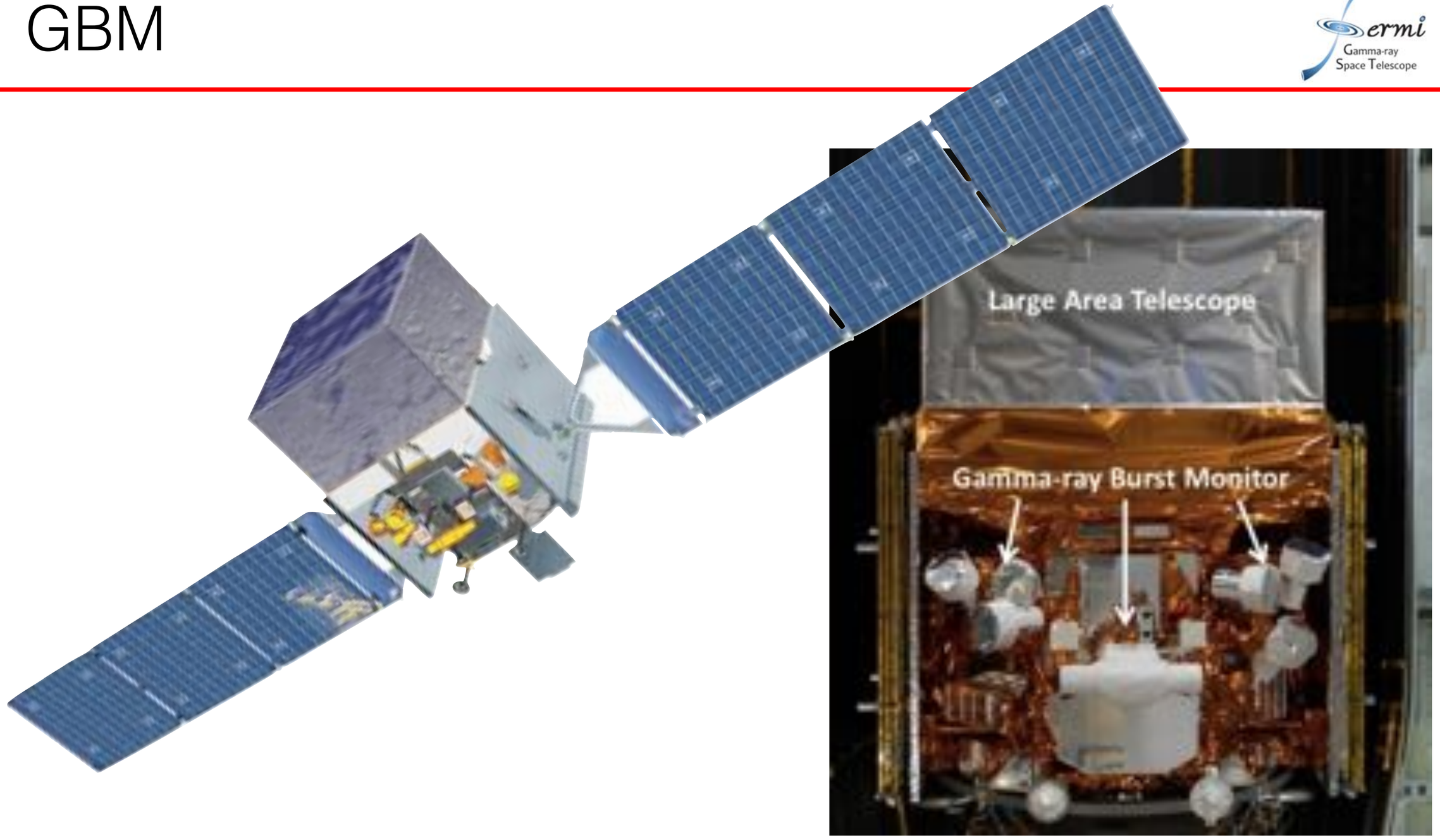

140
120
100
80
60
40
20
0
1966 BATSE GRBs
1366 BATSE LGRBs
600 BATSE SGRBs
traditional dividing line:
T_{90} ~ 3 [s]
(e.g., Kouveliotou et al. 1993)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Observed Duration: Log(T_{90} [s])


Short gamma-ray burst
(<2 seconds' duration)
Stars* in a compact binary system begin to spiral inward....
...eventually colliding.
The resulting torus has at its center a powerful black hole.
*Possibly neutron stars.

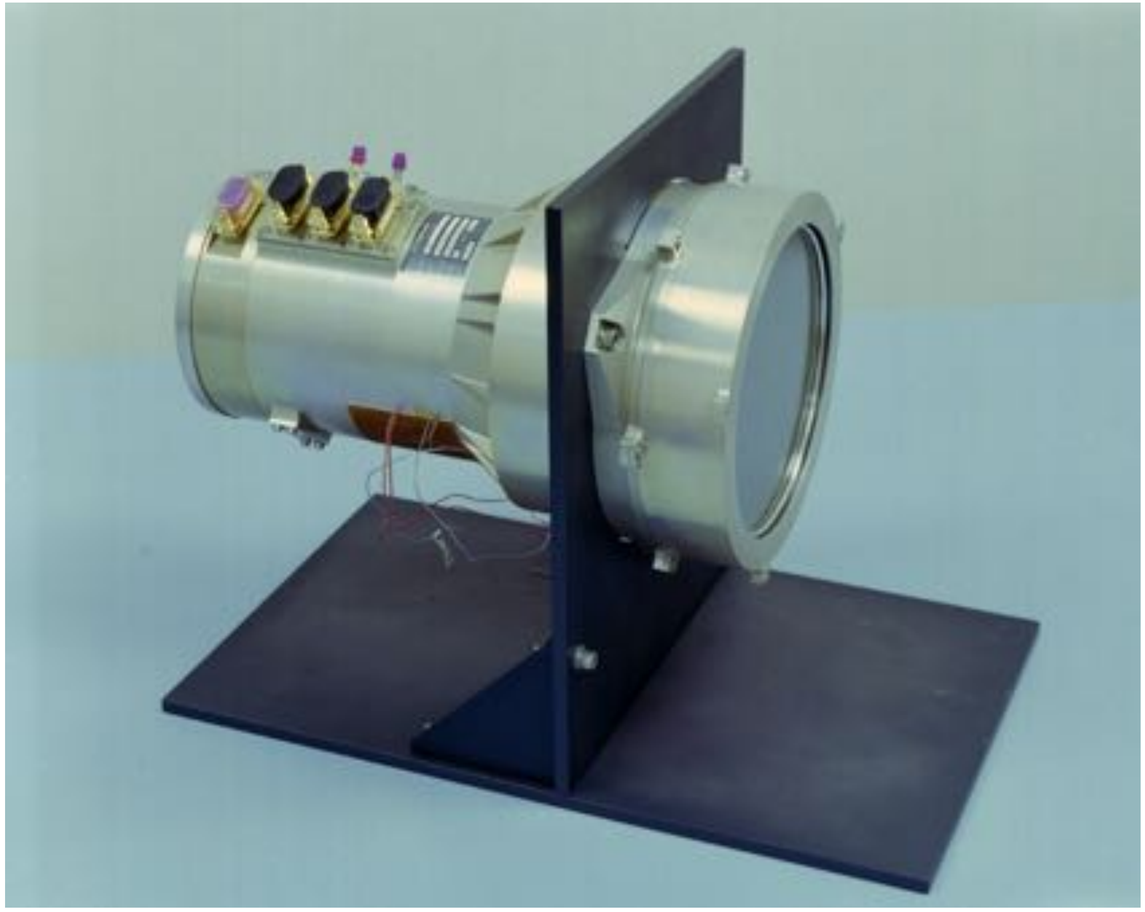

Long gamma-ray burst
(>2 seconds' duration)
A red giant star collapses onto its core....
...becoming so dense that it expels its outer layers in a supernova explosion.
Jet
Torus
Gamma rays

GBM

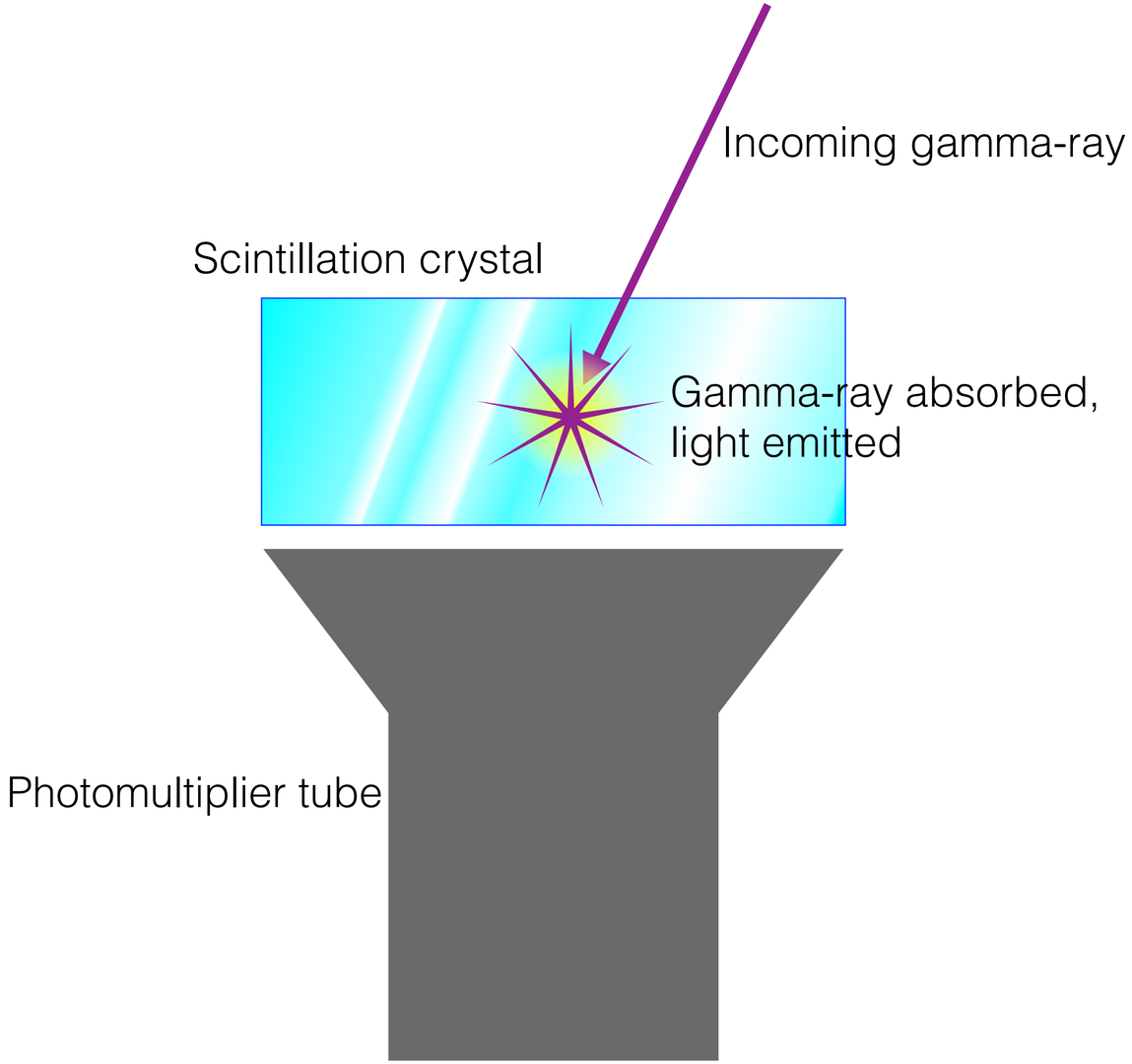
GBM



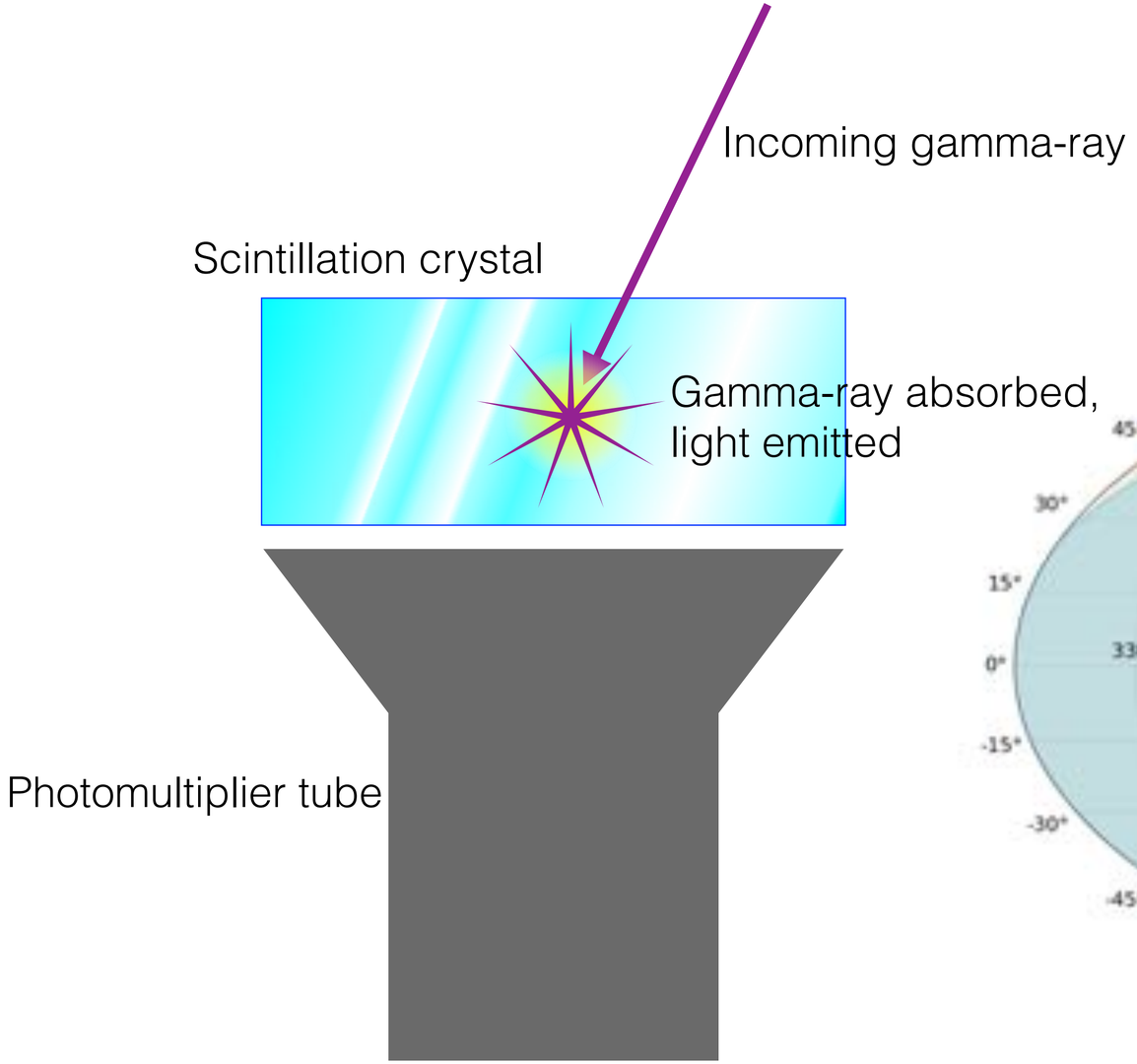
GBM



GBM


Incoming gamma-ray
Scintillation crystal
Gamma-ray absorbed,
light emitted
Photomultiplier tube

GBM


Incoming gamma-ray
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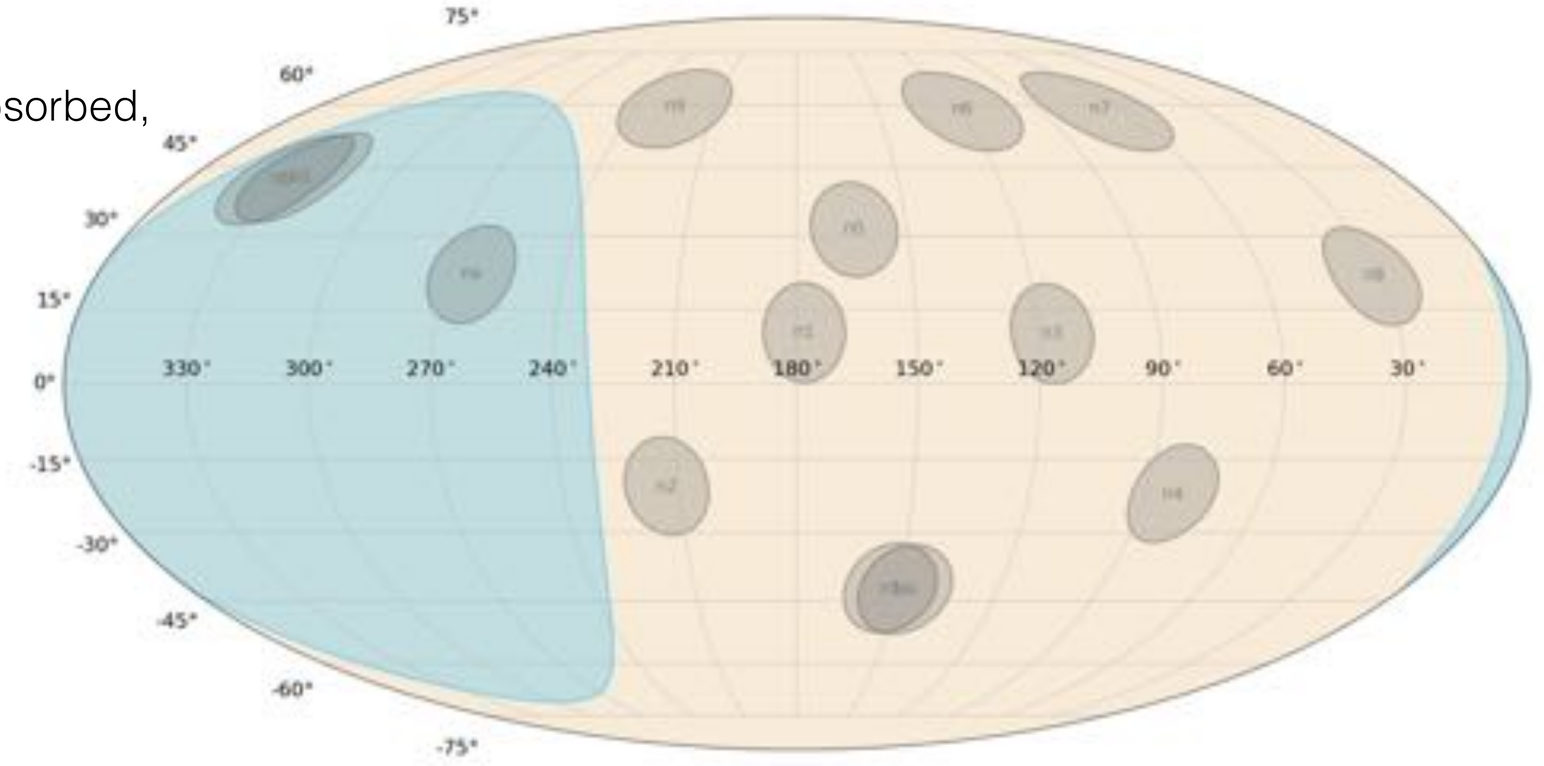
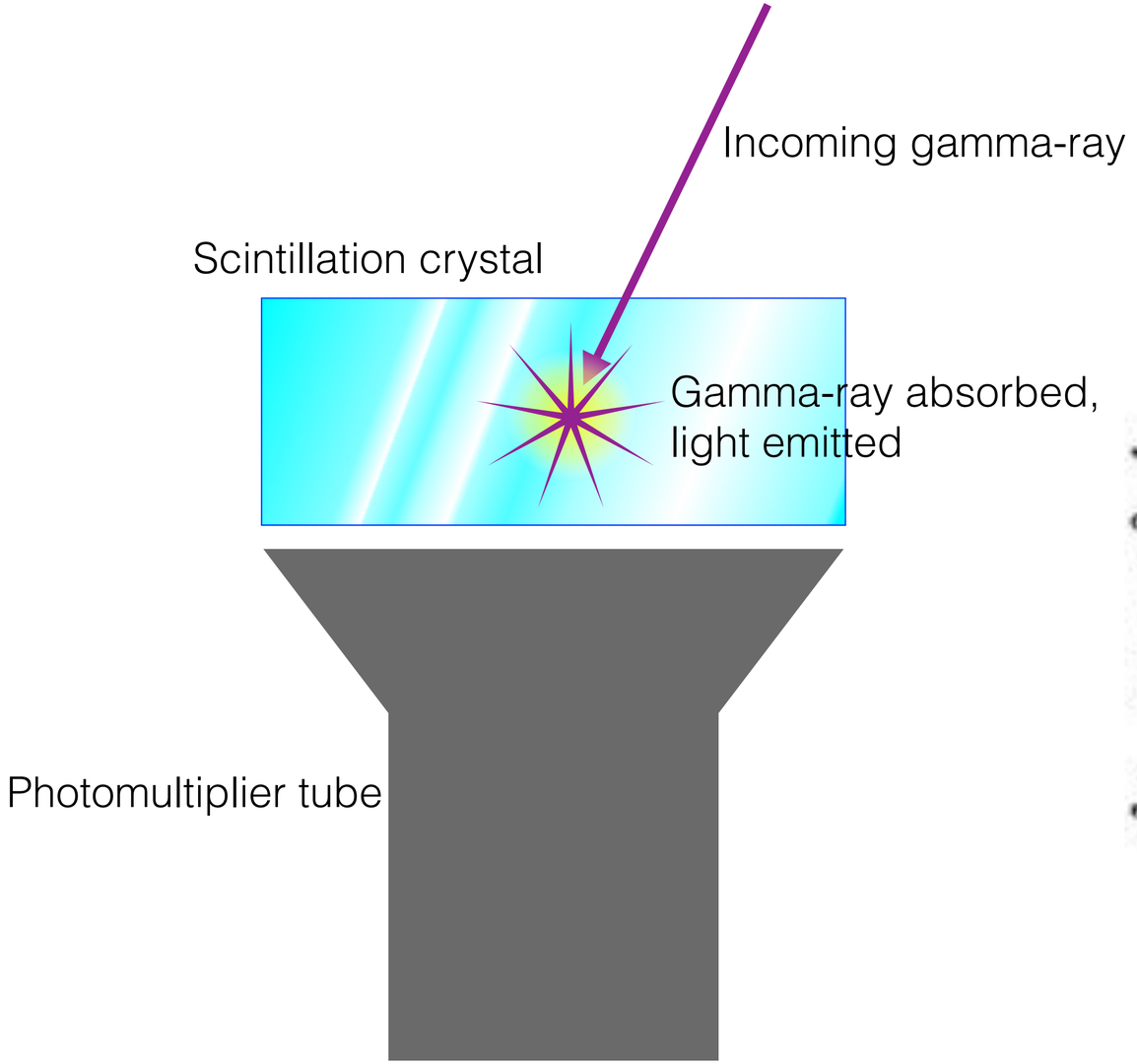
Photomultiplier tube


75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
330°
300°
270°
240°
210°
180°
150°
120°
90°
60°
30°

GBM


Incoming gamma-ray
Scintillation crystal
Gamma-ray absorbed,
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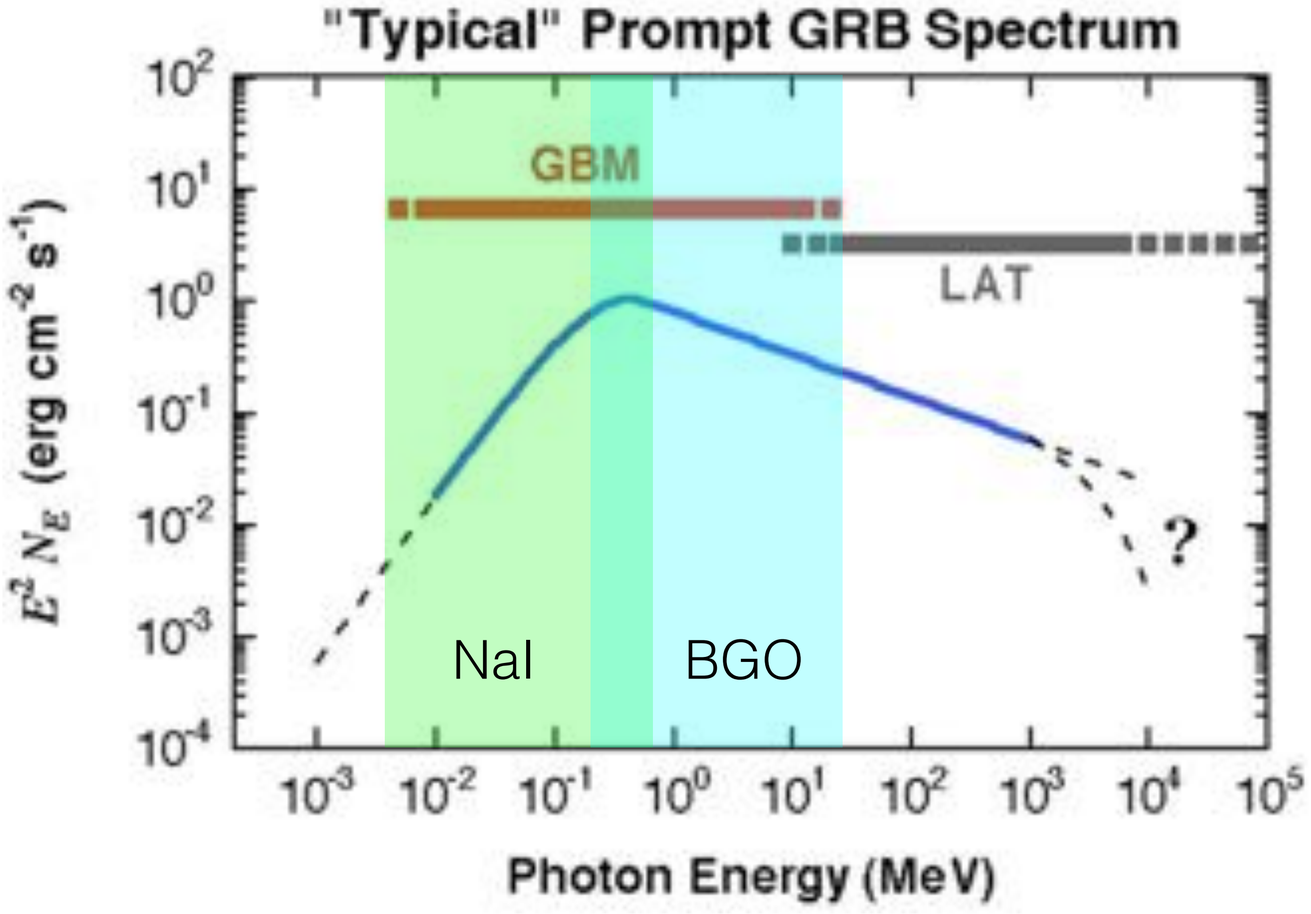
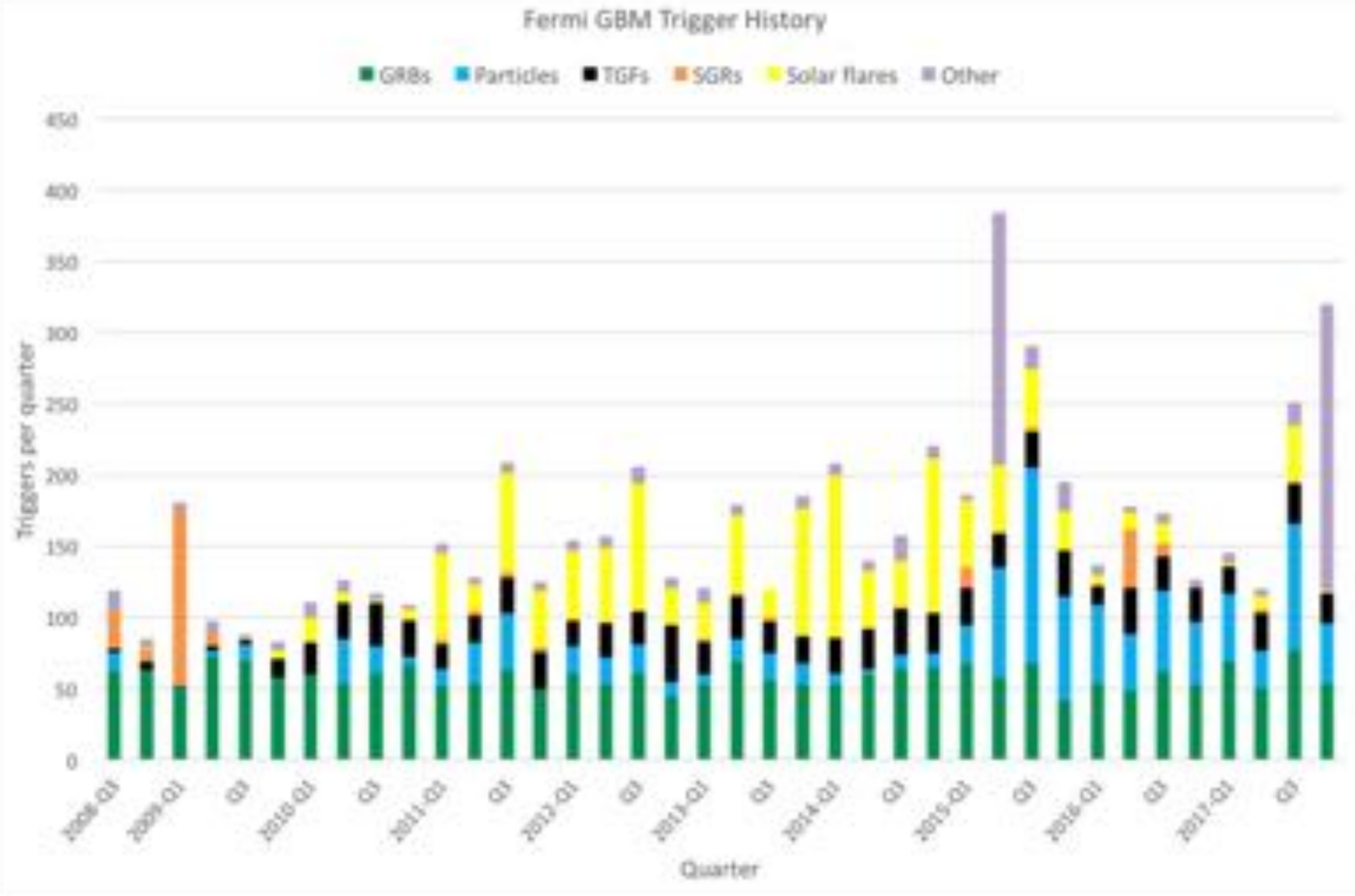
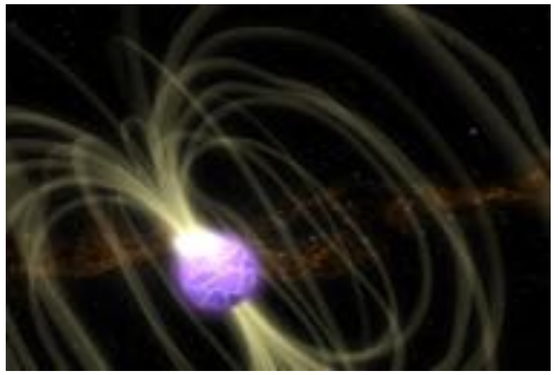

"Typical" Prompt GRB Spectrum
GBM
LAT
NaI
BGO
?
$E^2 N_E$ (erg cm^{-2} s^{-1})
Photon Energy (MeV)

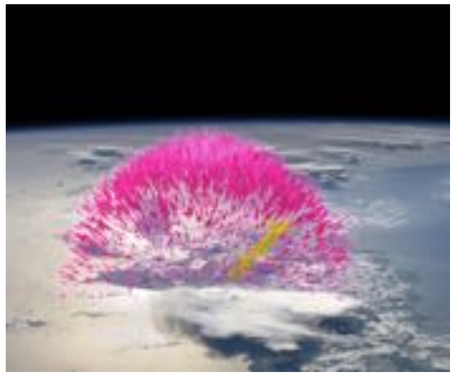
GBM



>2K GRBs

>1K Solar Flares

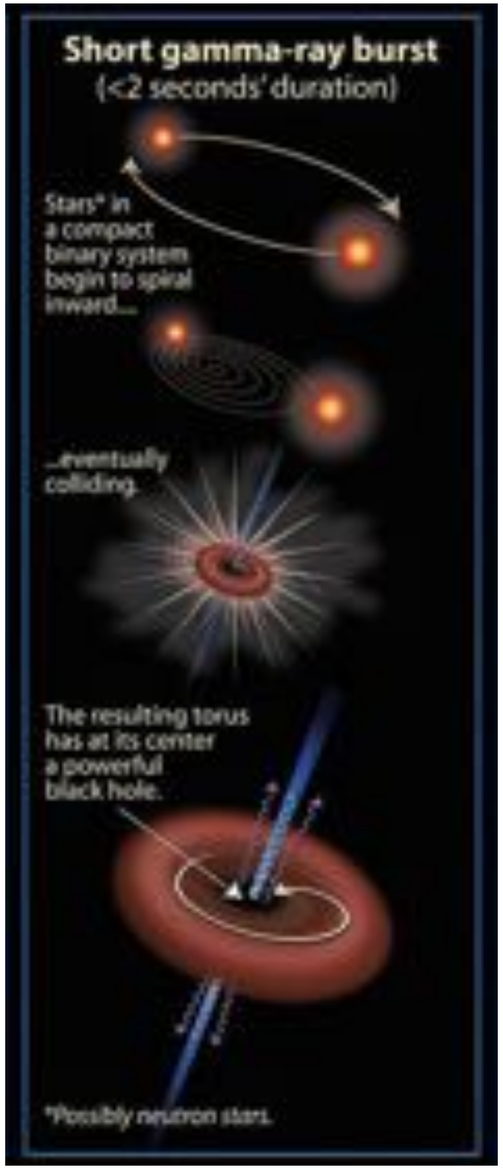




>200 Magnetar Flares

~1K TGFs

GBM


Short gamma-ray burst
(<2 seconds' duration)
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...eventually colliding.
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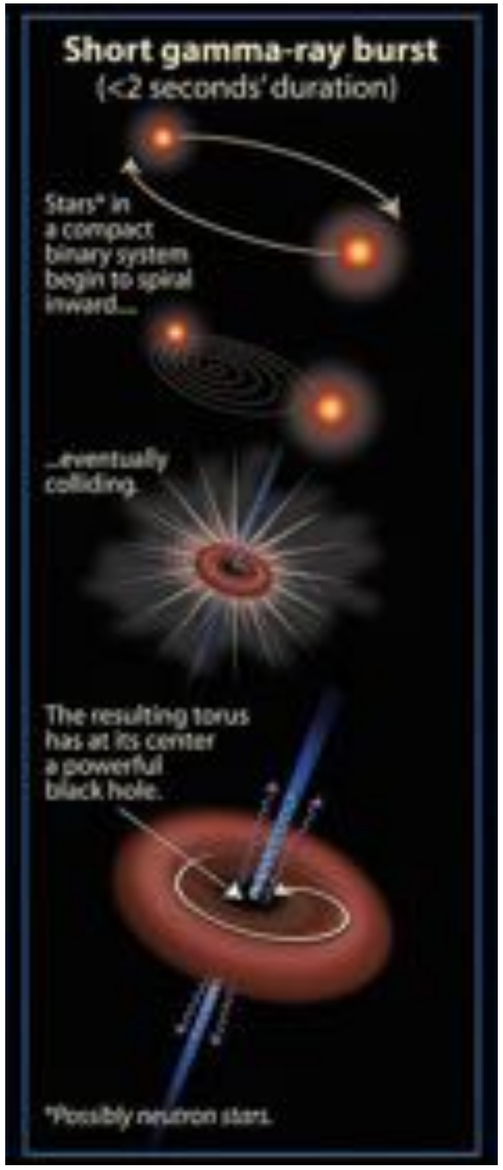
GBM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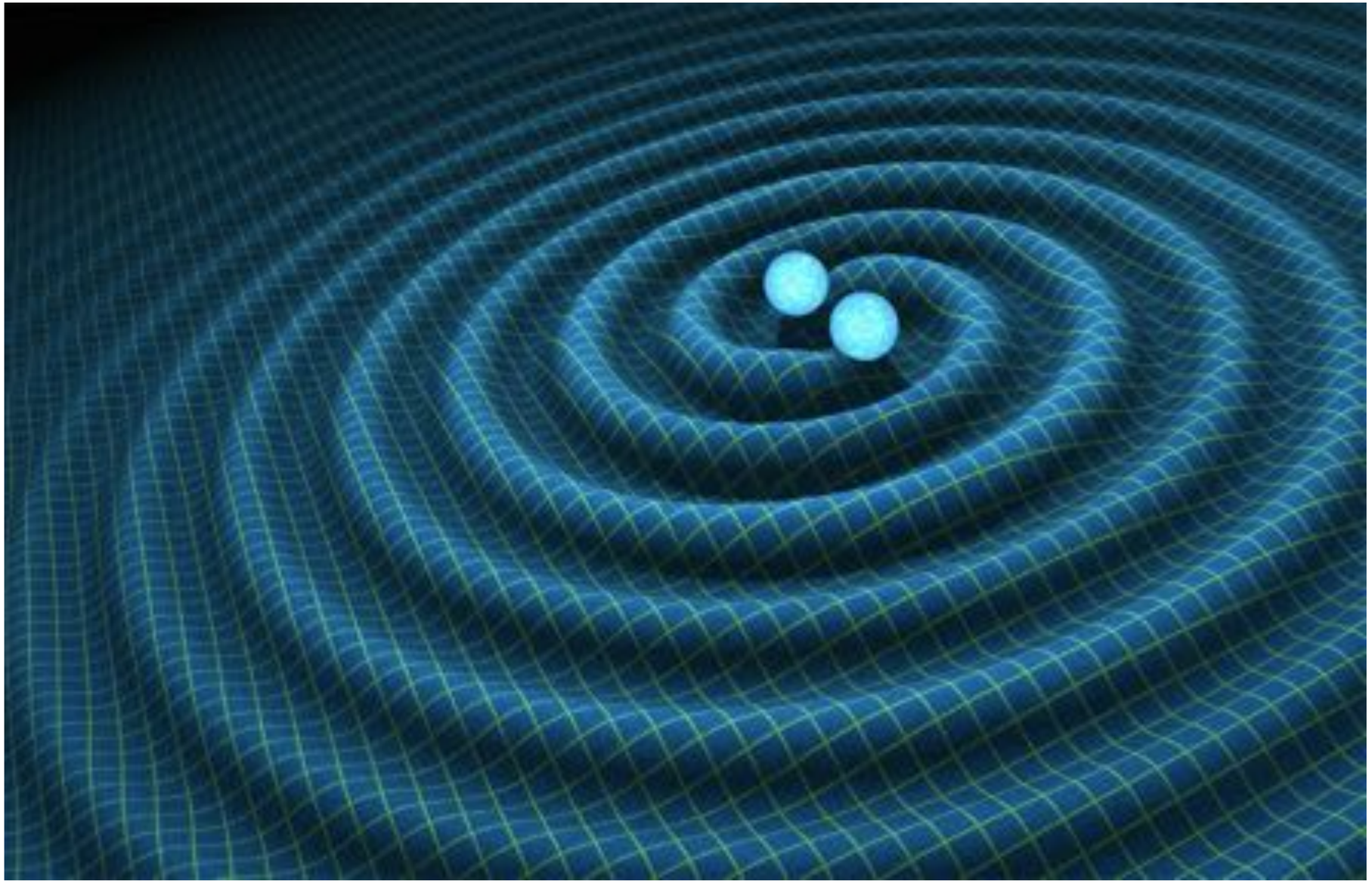
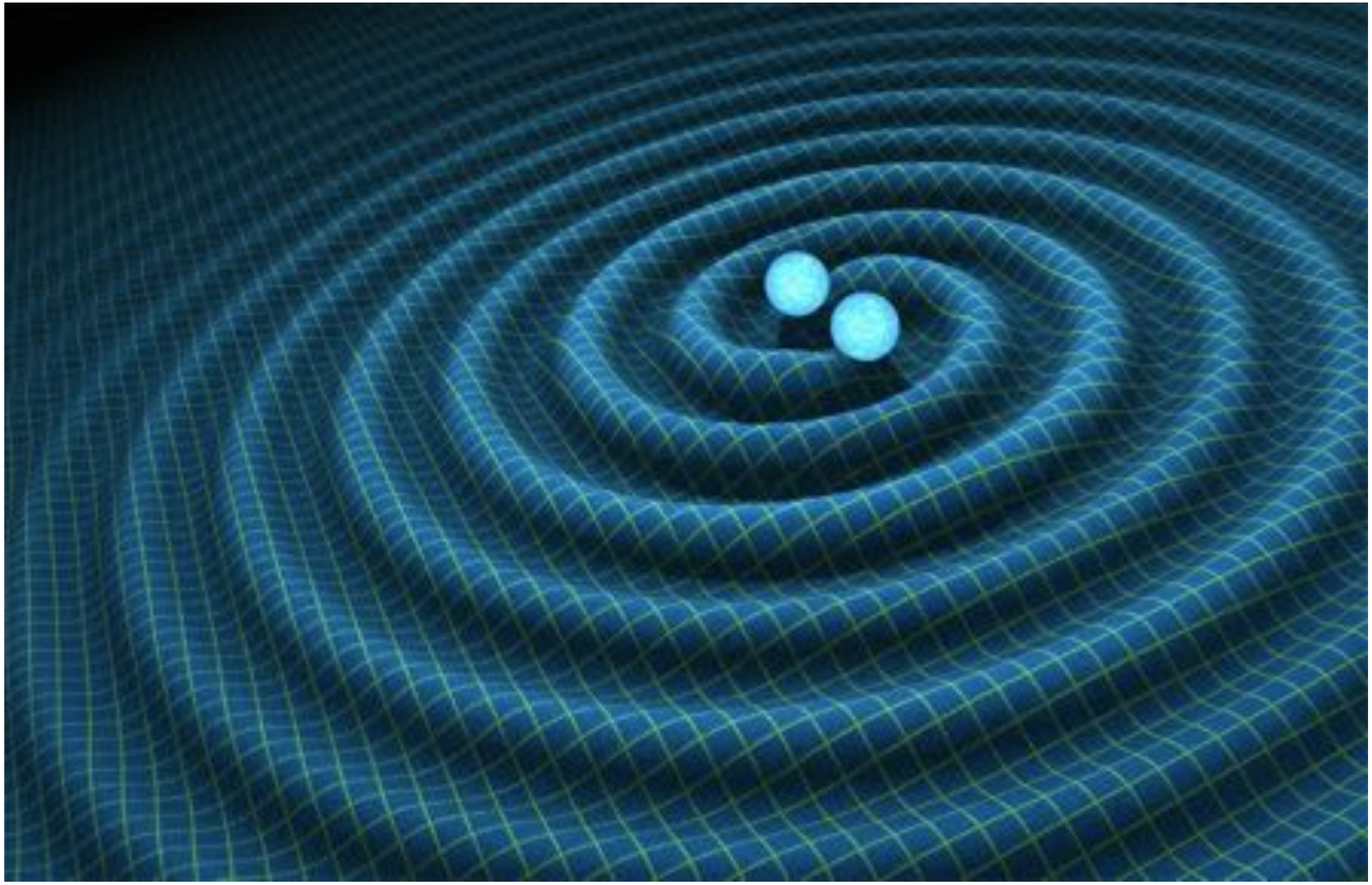
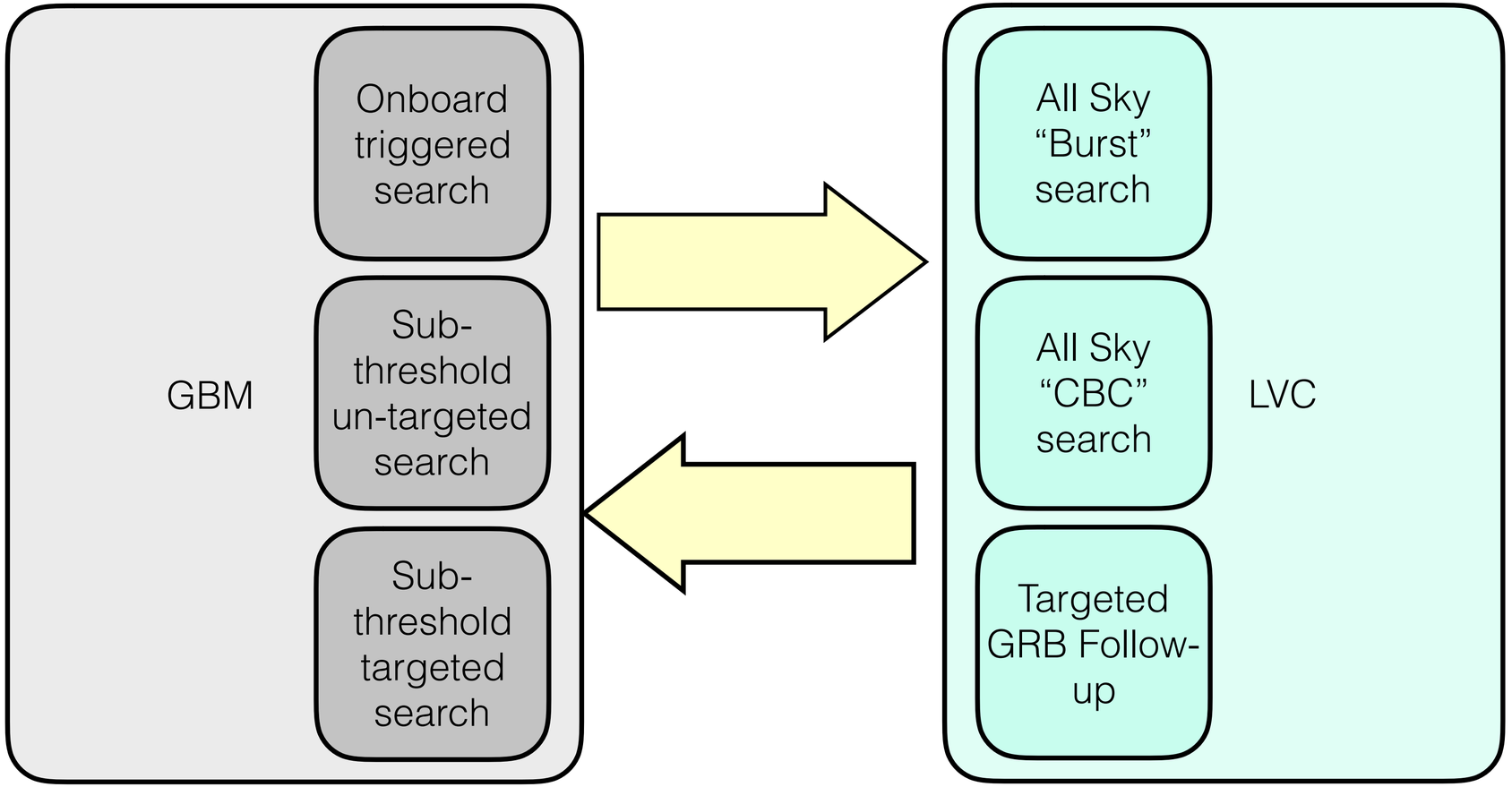
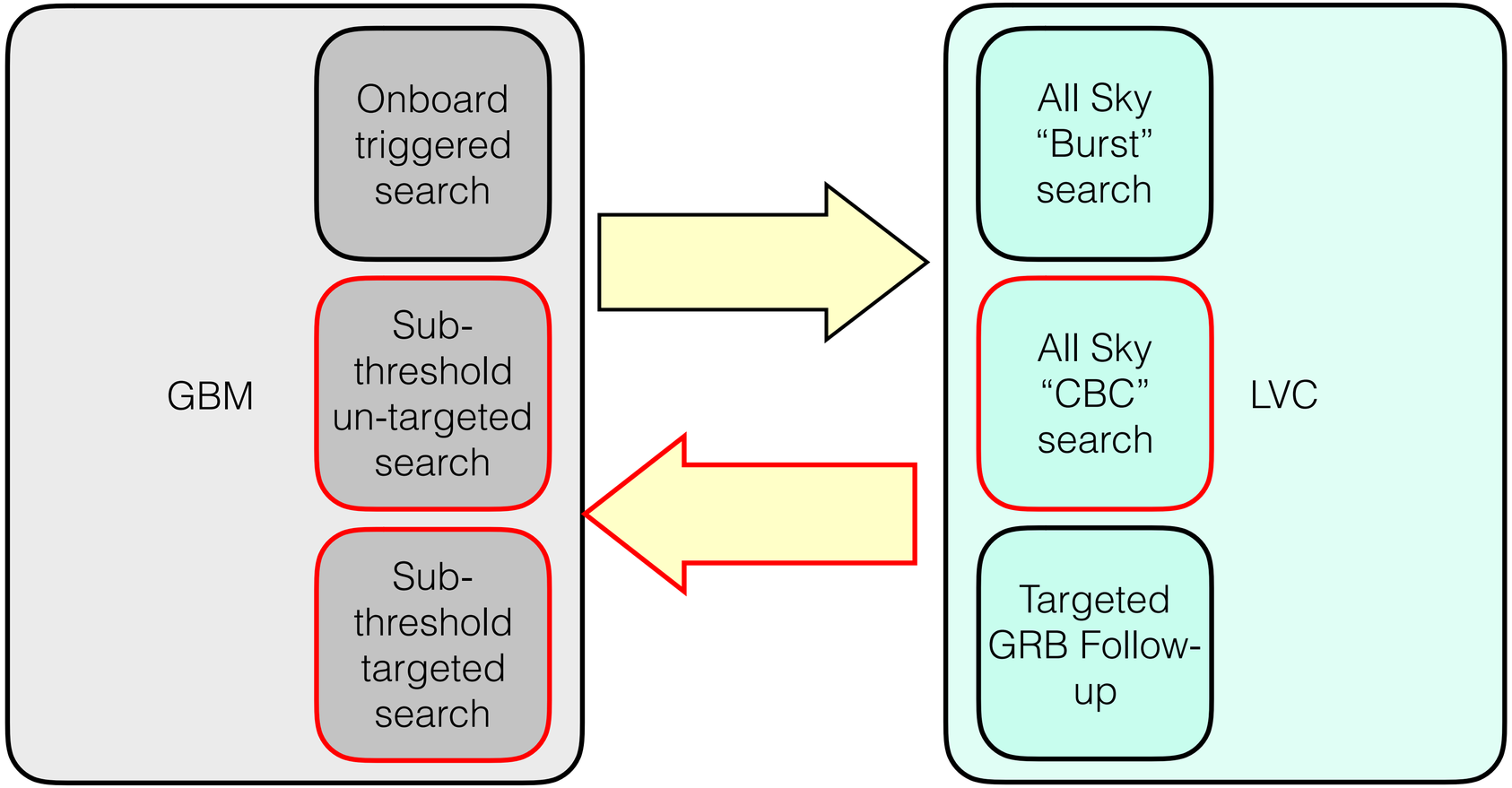


GBM

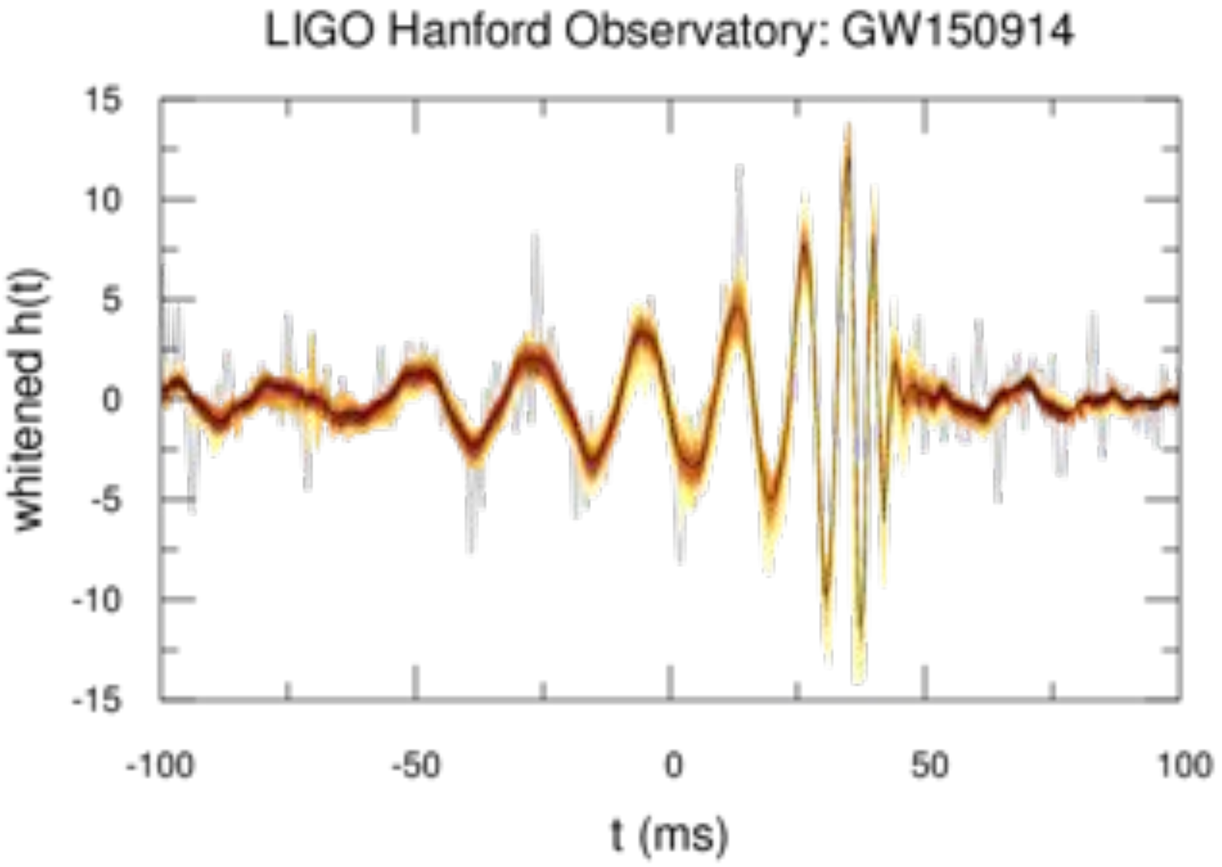



GBM
Onboard triggered search
Sub-threshold un-targeted search
Sub-threshold targeted search
LVC
All Sky "Burst" search
All Sky "CBC" search
Targeted GRB Follow-up

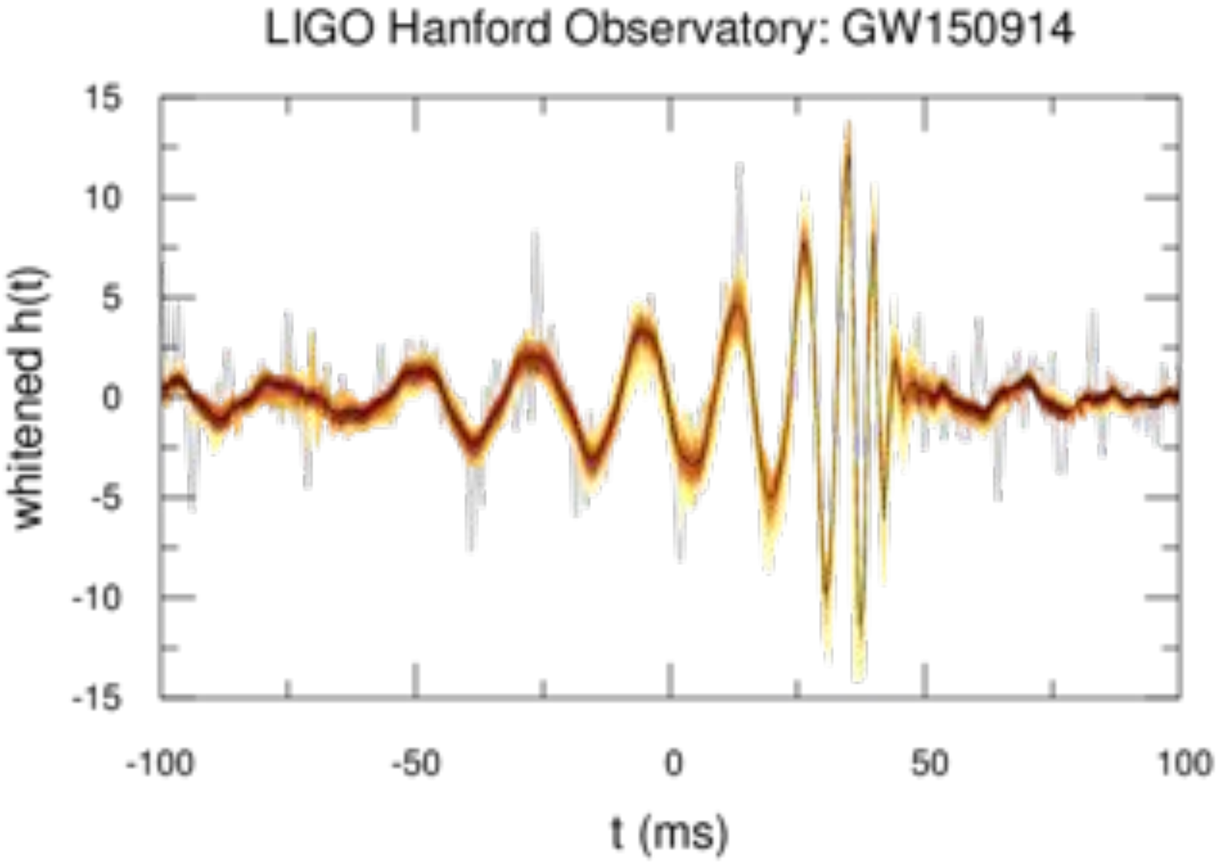

Onboard triggered search
Sub-threshold un-targeted search
Sub-threshold targeted search
GBM
All Sky "Burst" search
All Sky "CBC" search
Targeted GRB Follow-up
LVC

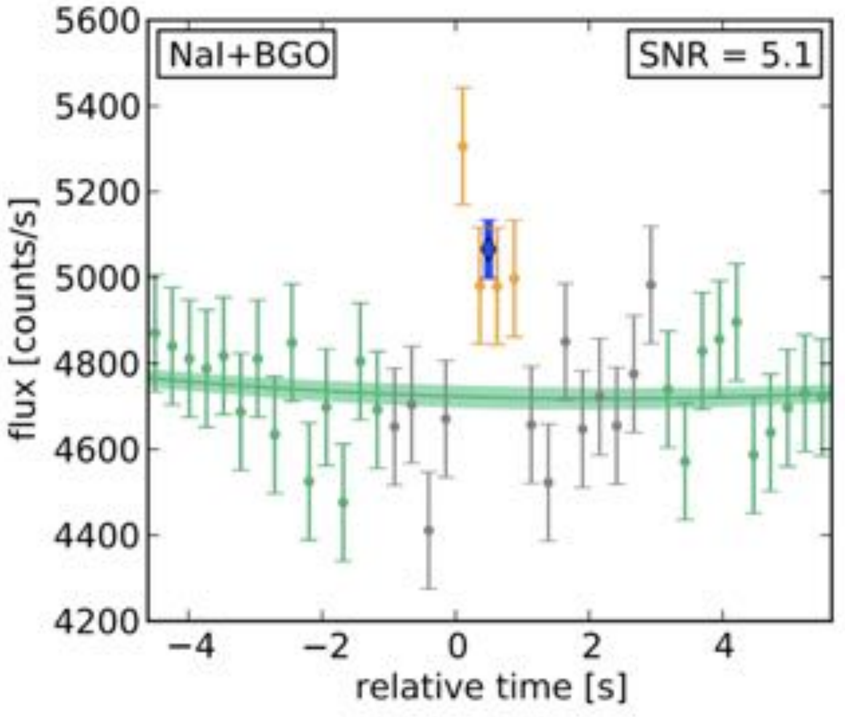
Advanced LIGO Observing Runs

GW150914


LIGO Hanford Observatory: GW150914
whitened h(t)
15
10
5
0
-5
-10
-15
-100
-50
0
50
100
t (ms)

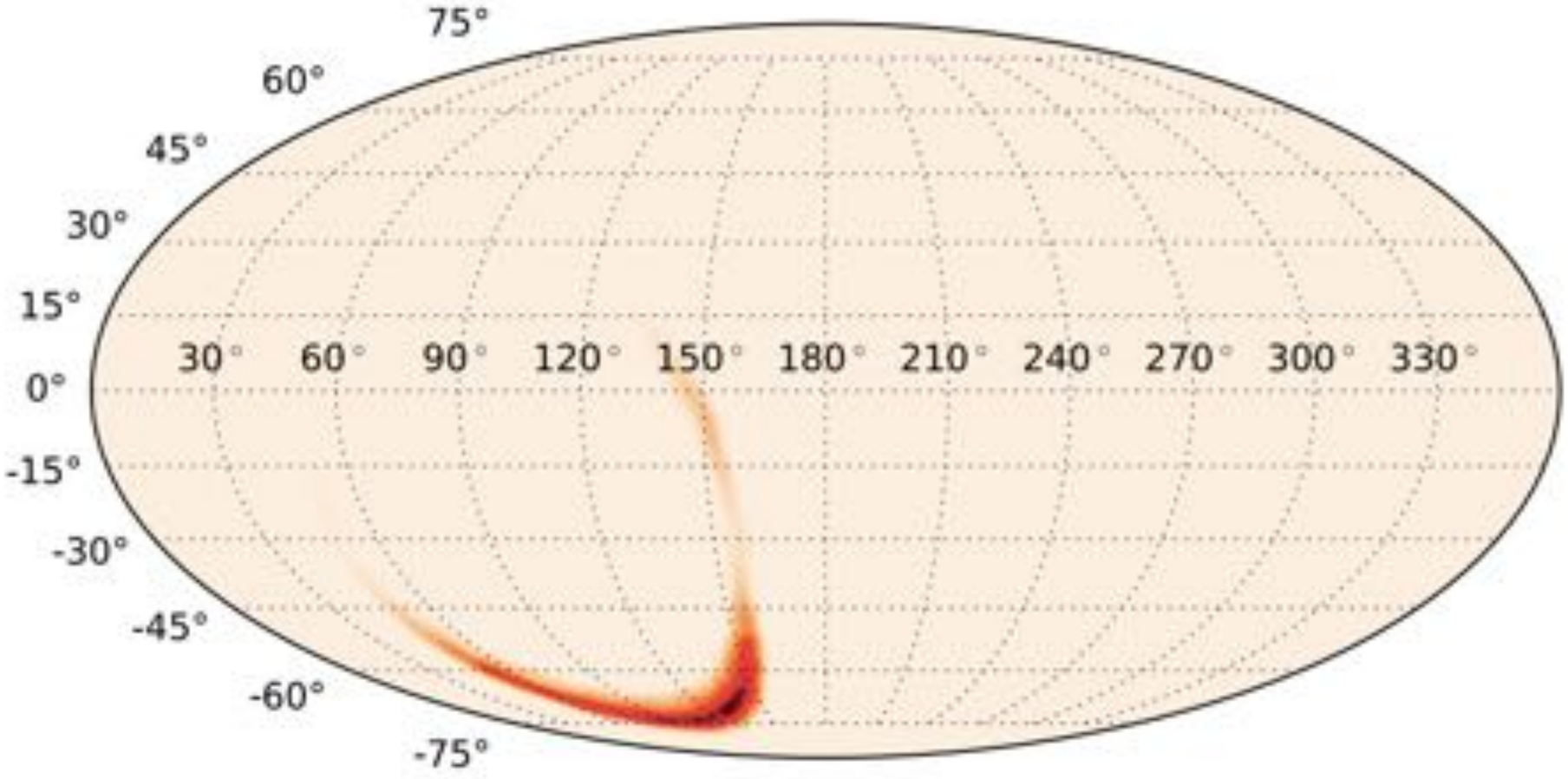
GW150914



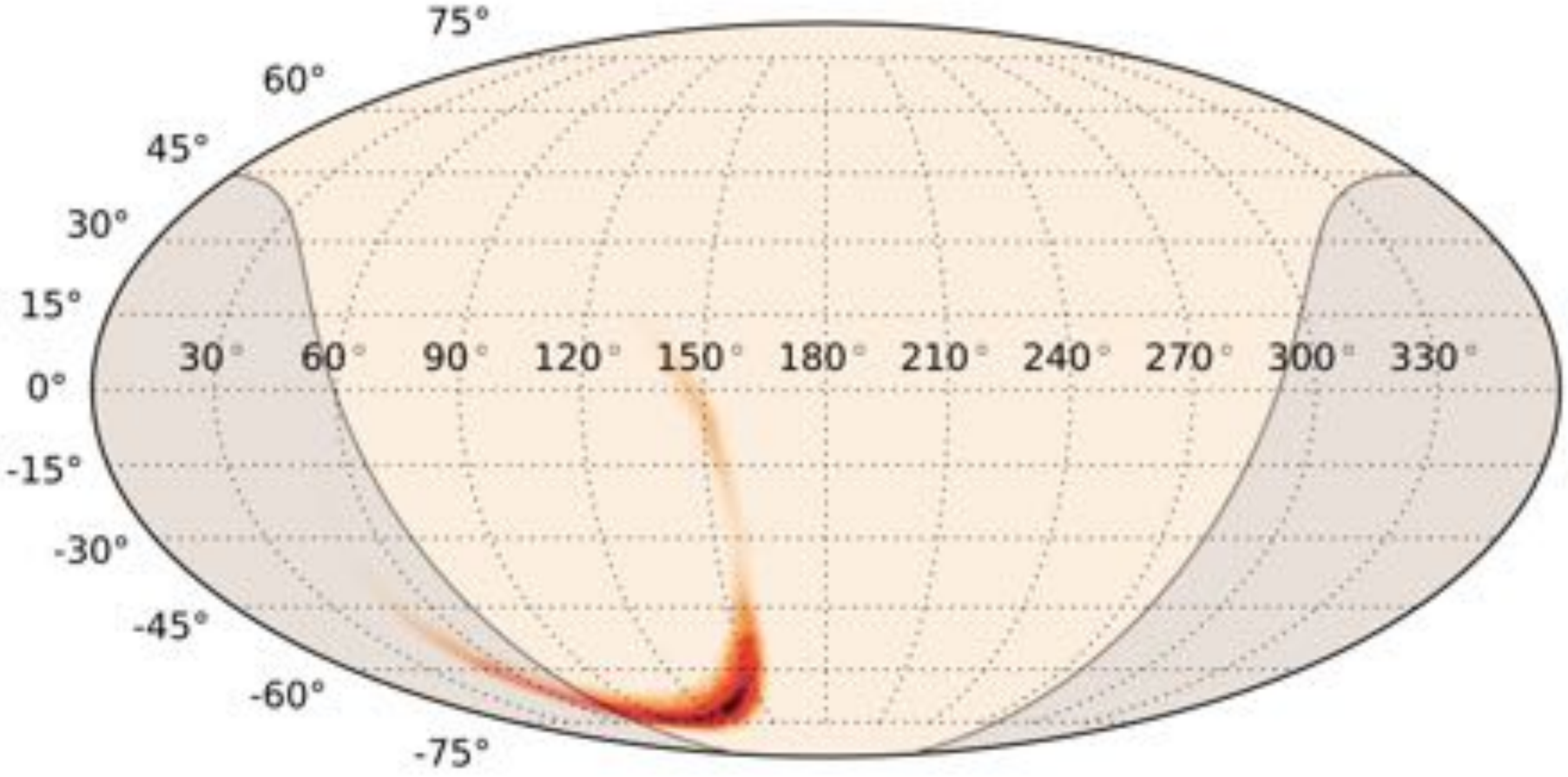


Connaughton et al, ApJL (2016)

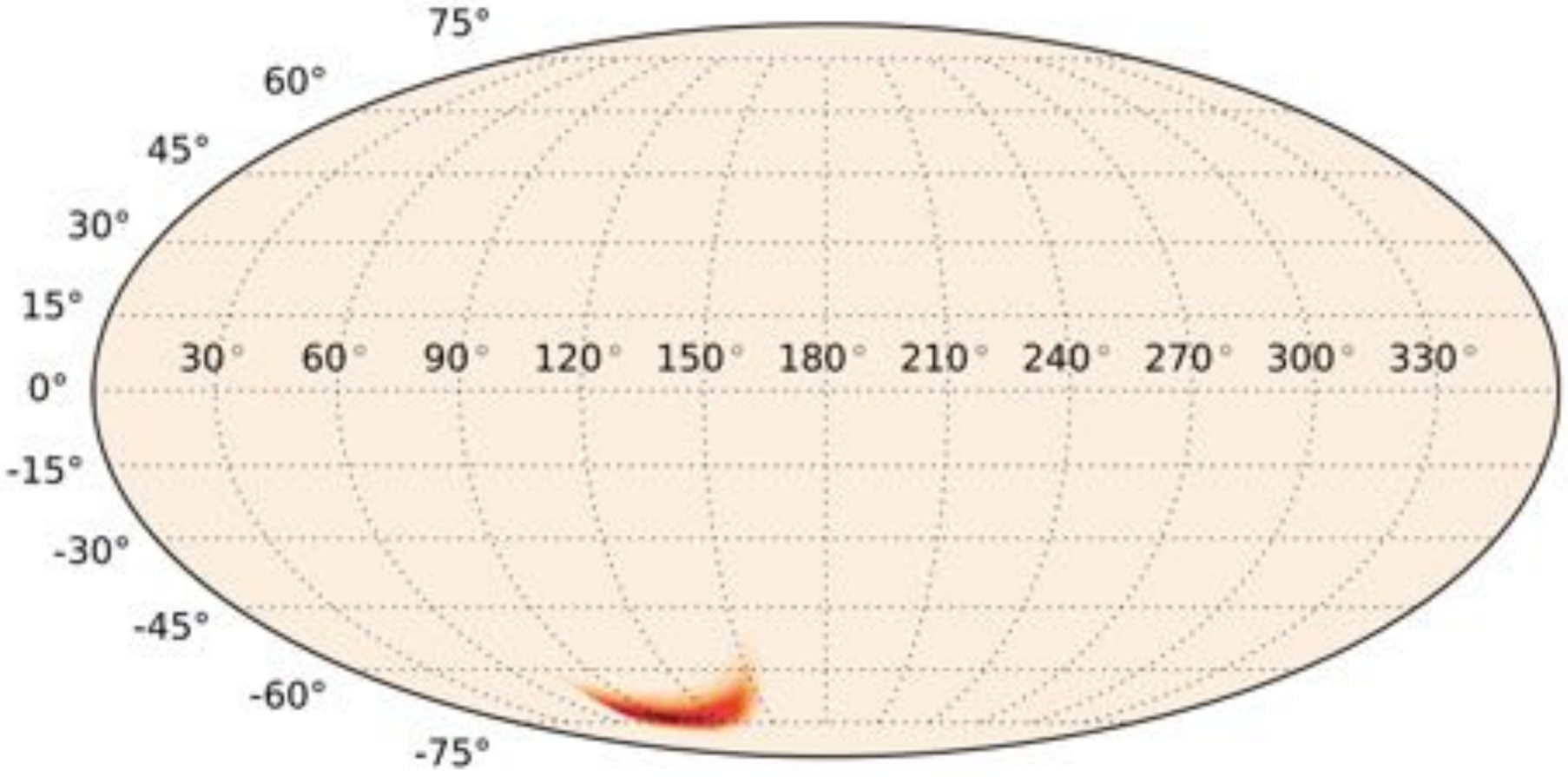
LIGO-only sky map

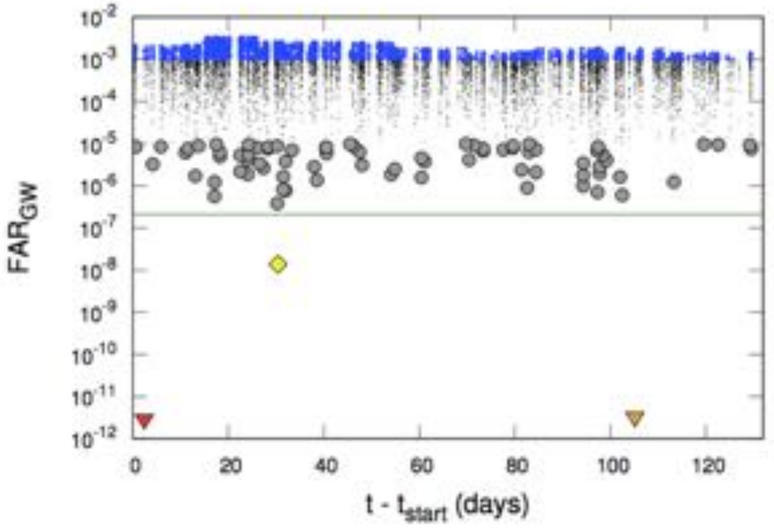


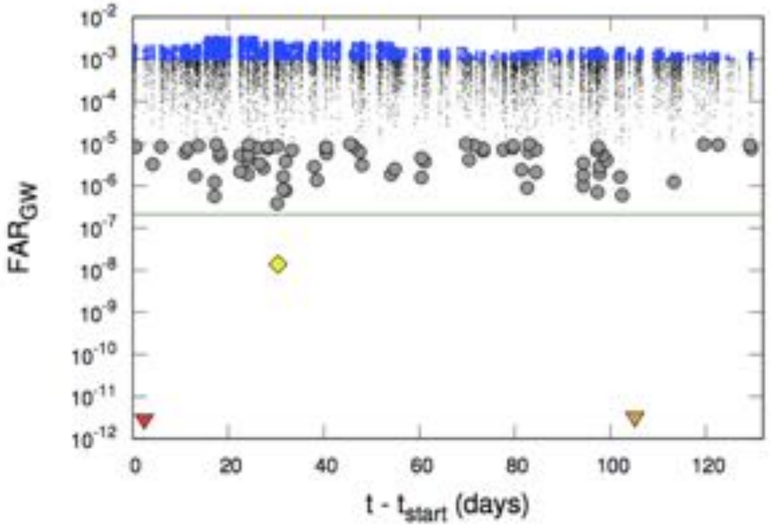
LIGO-only sky map + Earth occultation for GBM

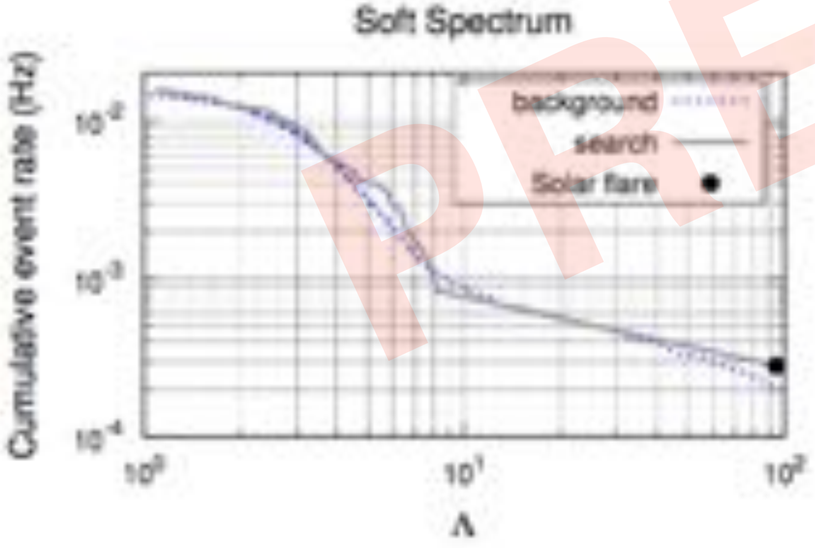


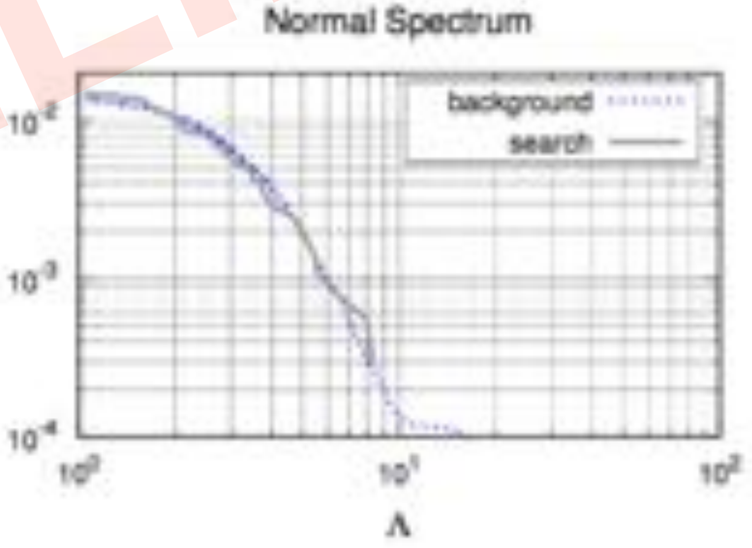
Joint LIGO-GBM sky map

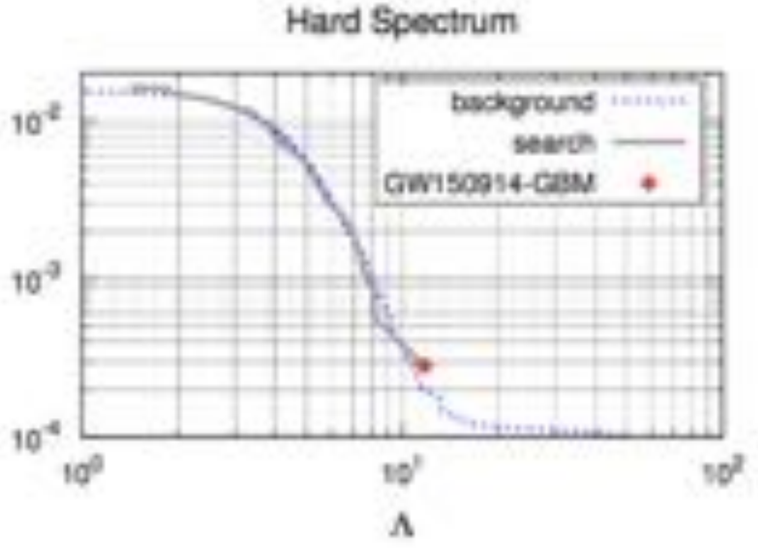








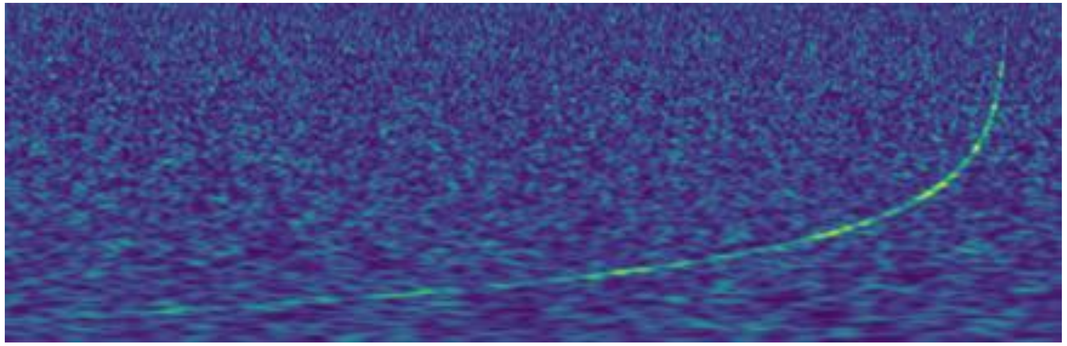


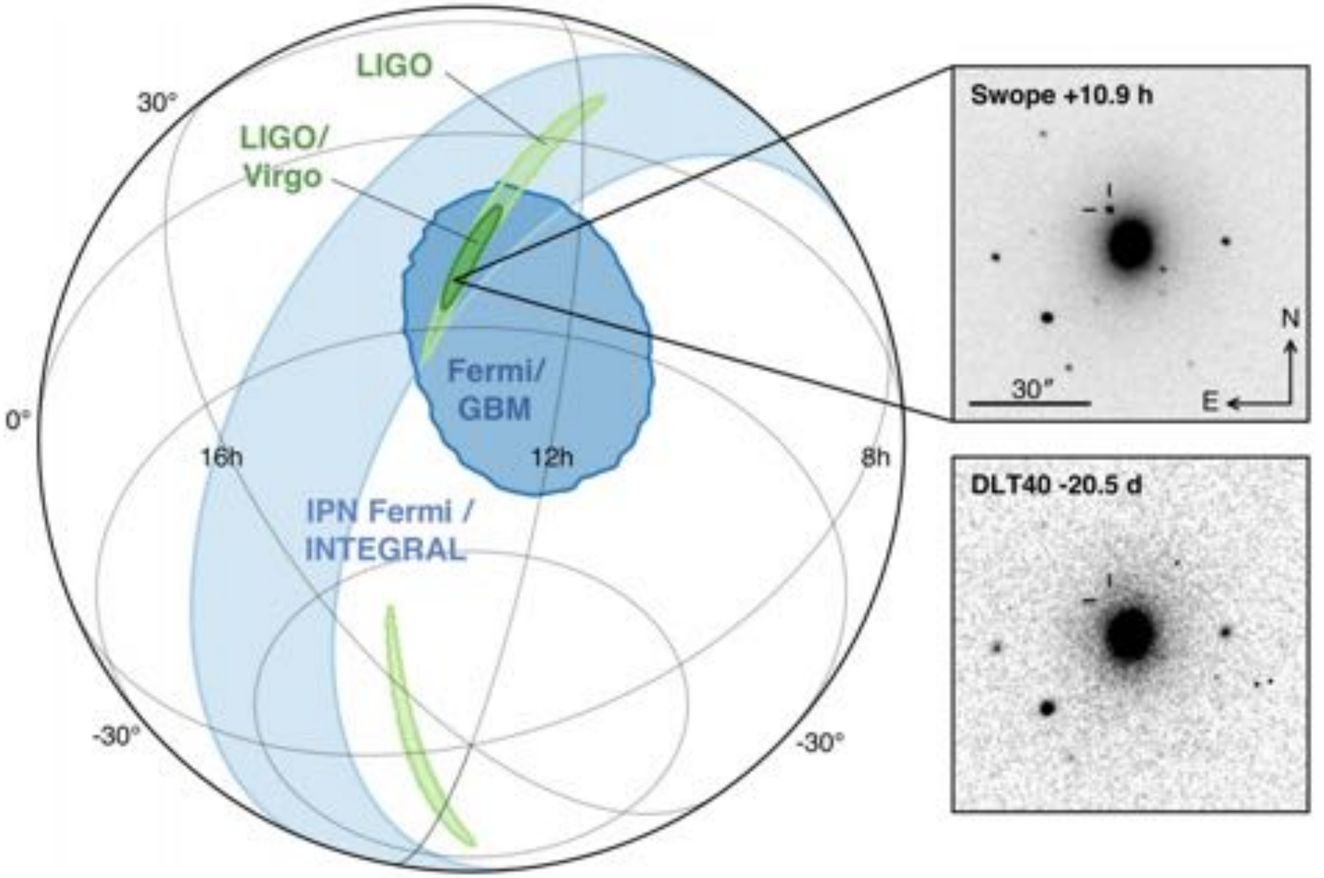


Advanced LIGO Observing Runs

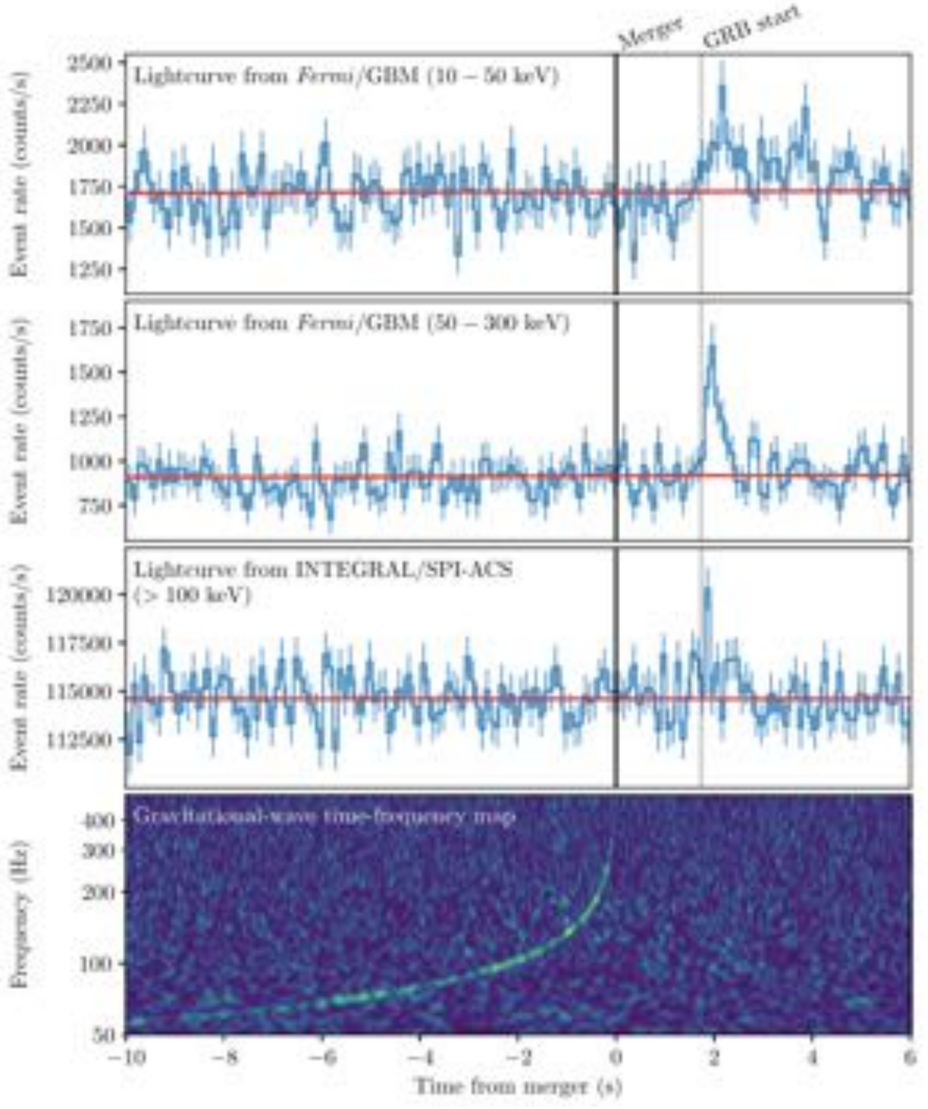
Advanced LIGO Observing Runs

GW170817/GRB170817A





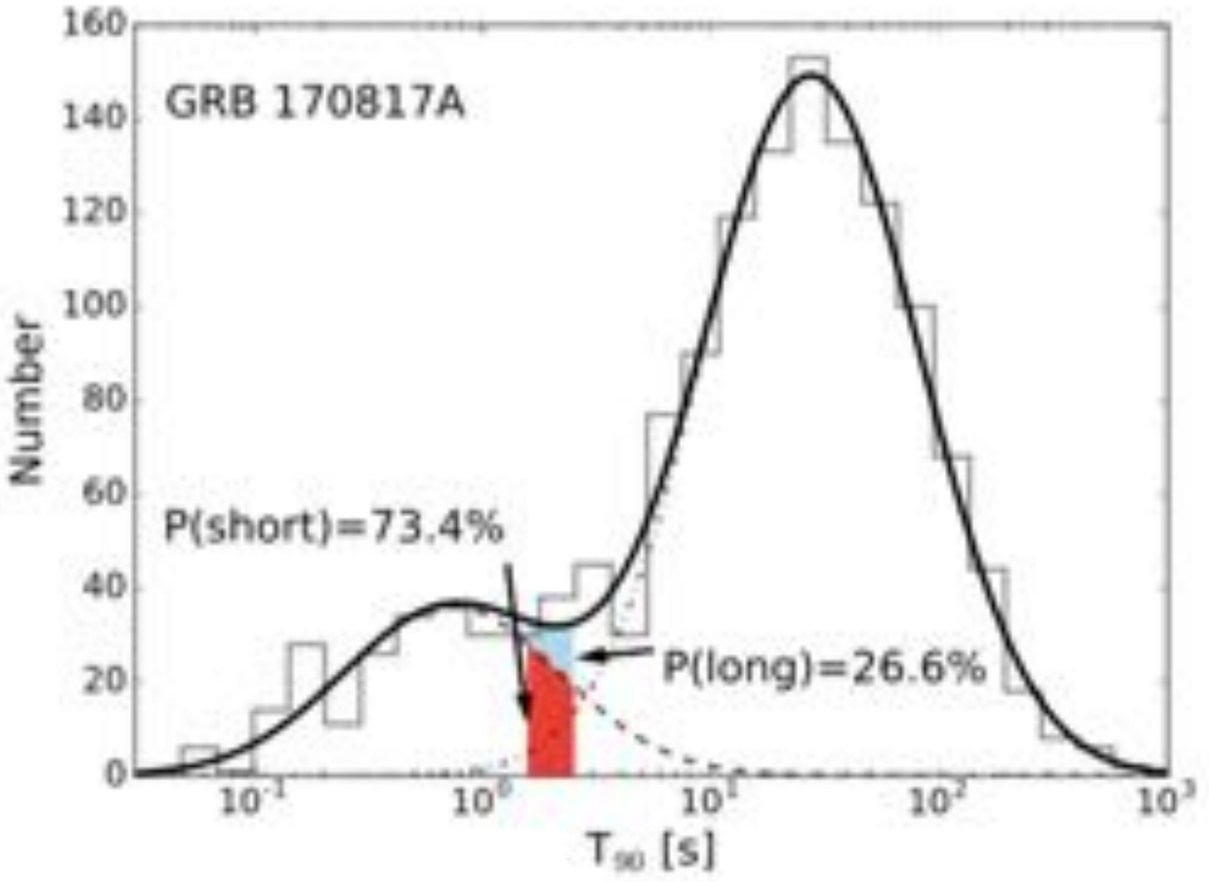
All of Astronomy et al, ApJL (2017)

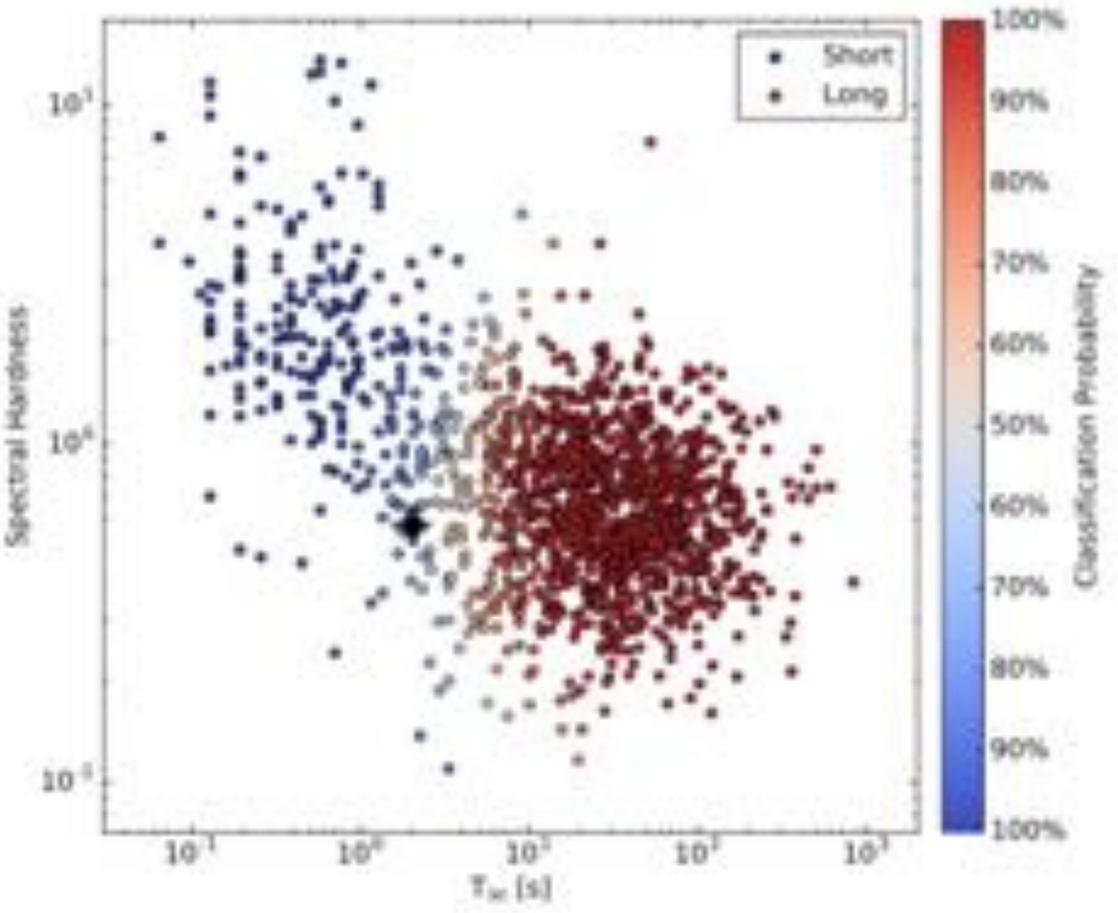


Time (UTC)	Relative	Comment
12:41:06.474598	0	Trigger Time: End of 0.256 s interval containing statistically significant rate increase
12:41:06.477006	+2.4 ms	Triggered: Autonomously detected in-orbit by the *Fermi* GBM flight software
12:41:20	+14 s	*Fermi* GBM Alert Notice sent by the GCN system at NASA/GSFC
12:41:31	+25 s	Automatic location from GBM flight software sent by the GCN: RA=172.0, Dec=-34.8, err=32.6 deg
12:41:44	+38 s	More accurate automatic location by ground software sent by GCN: RA=186.6, Dec=-48.8, err=17.4 deg
13:26:36	+44.9 min	More accurate human-guided localization sent by GCN: RA=176.8, Dec=-39.8, err=11.6 deg
13:47:37	+66.5 min	LVC GCN Circular reporting localization and consistency of signal with a weak short GRB (Connaughton et al. 2017)
20:00:07	+7.3 hr	Public GCN Circular establishing GRB name and standard GBM analysis (von Kienlin et al. 2017)
00:36:12 (next day)	+11.9 hr	LVC GCN Circular reporting updated spectral analysis, energetics, and association significance (Goldstein 2017)

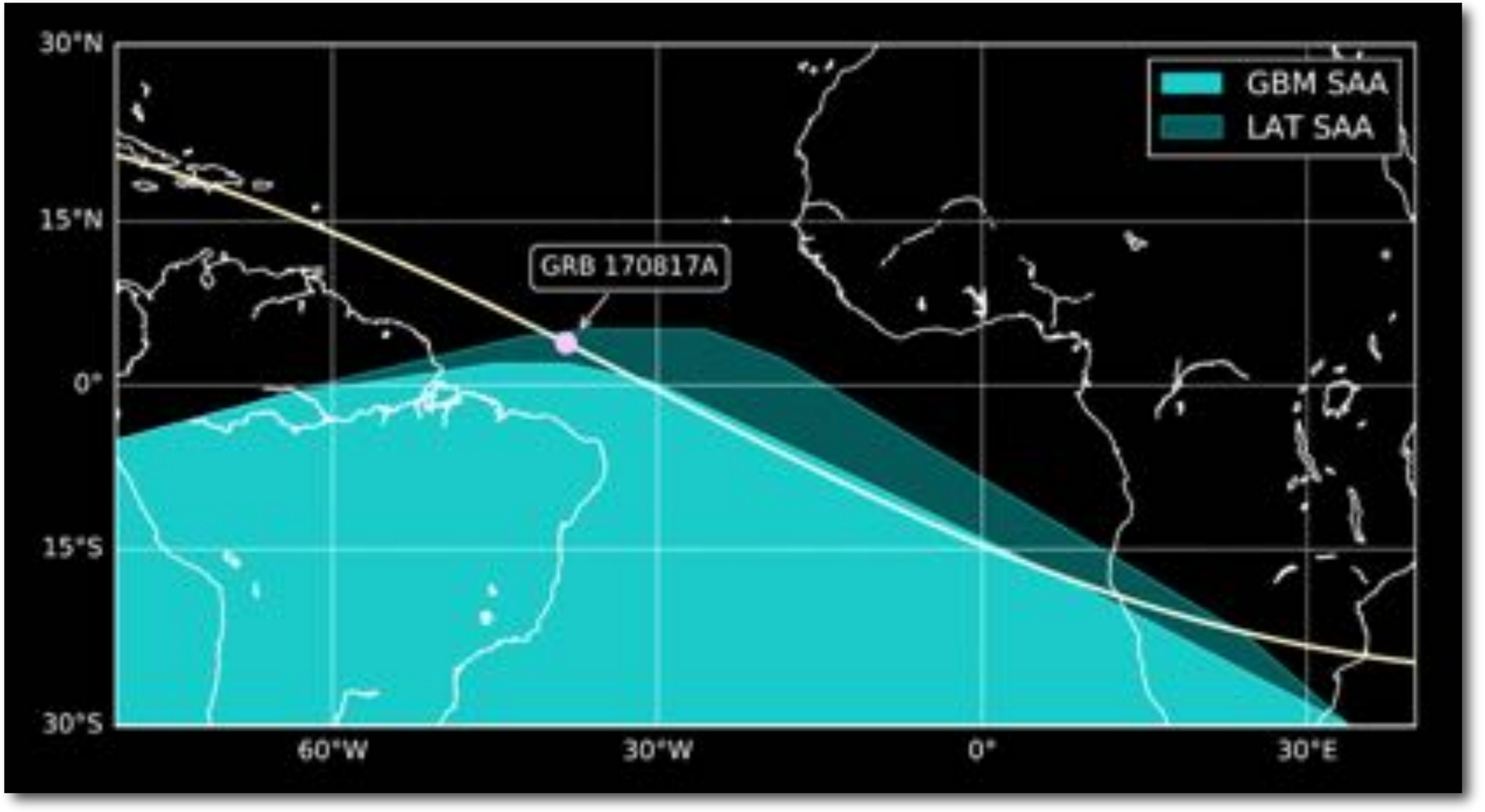
LVC, Fermi and INTEGRAL, ApJL (2017)

Goldstein et al, ApJL (2017)

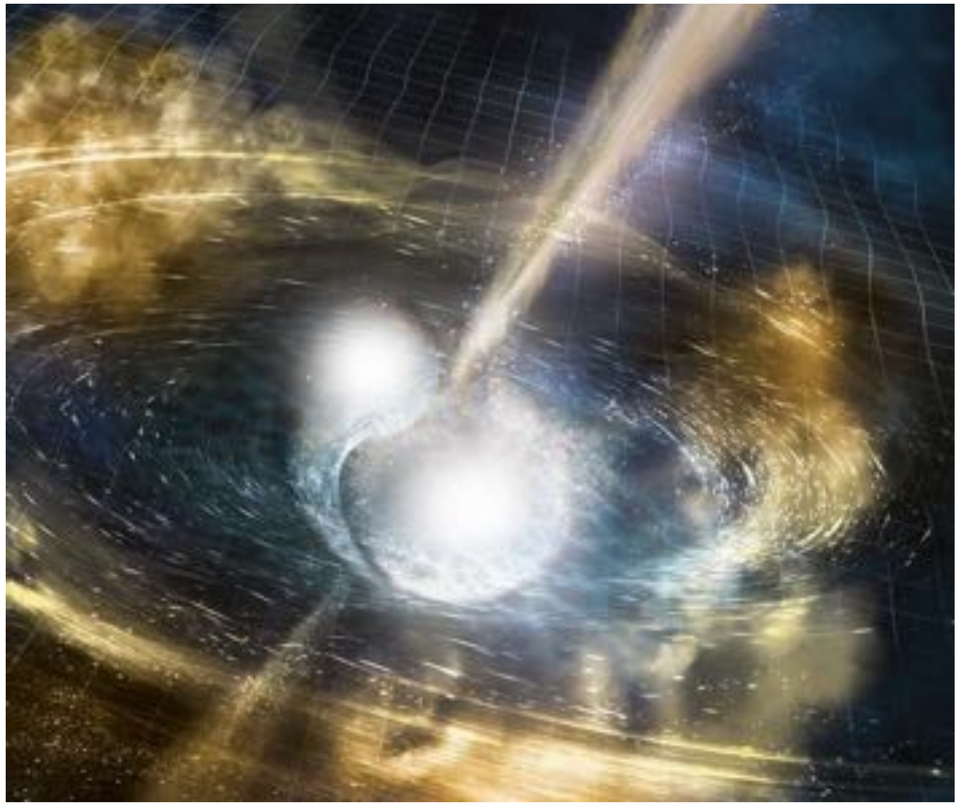




Goldstein et al, ApJL (2017)



Credit: R. Hamburg, adapted from Goldstein et al, ApJL (2017)



Credit: LIGO/Sonoma State University/A. Simonnet

Credit: LIGO/Sonoma State University/A. Simonnet

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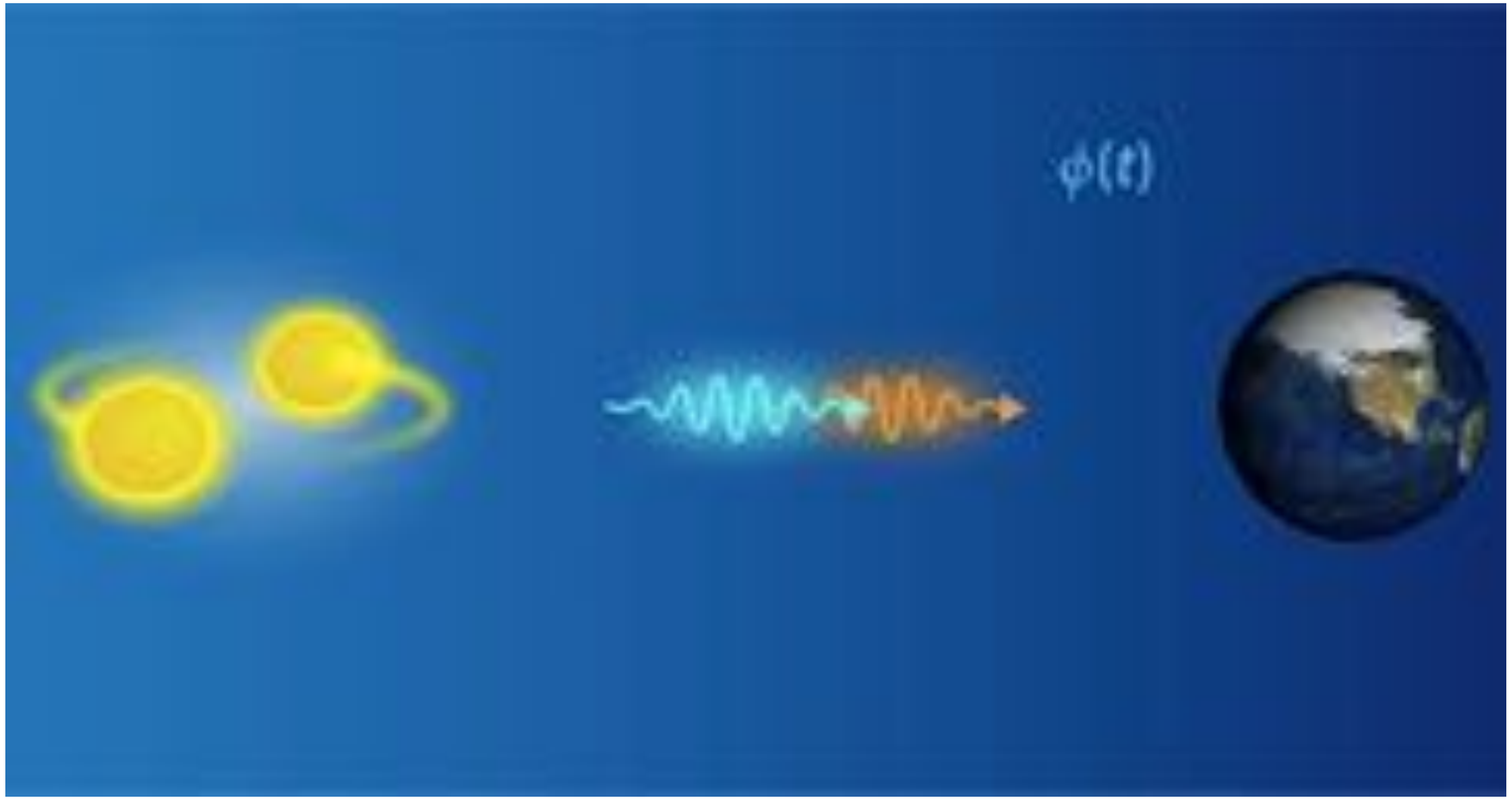

Credit: APS/Alan Stonebraker

Credit: LIGO/Sonoma State University/A. Simonnet

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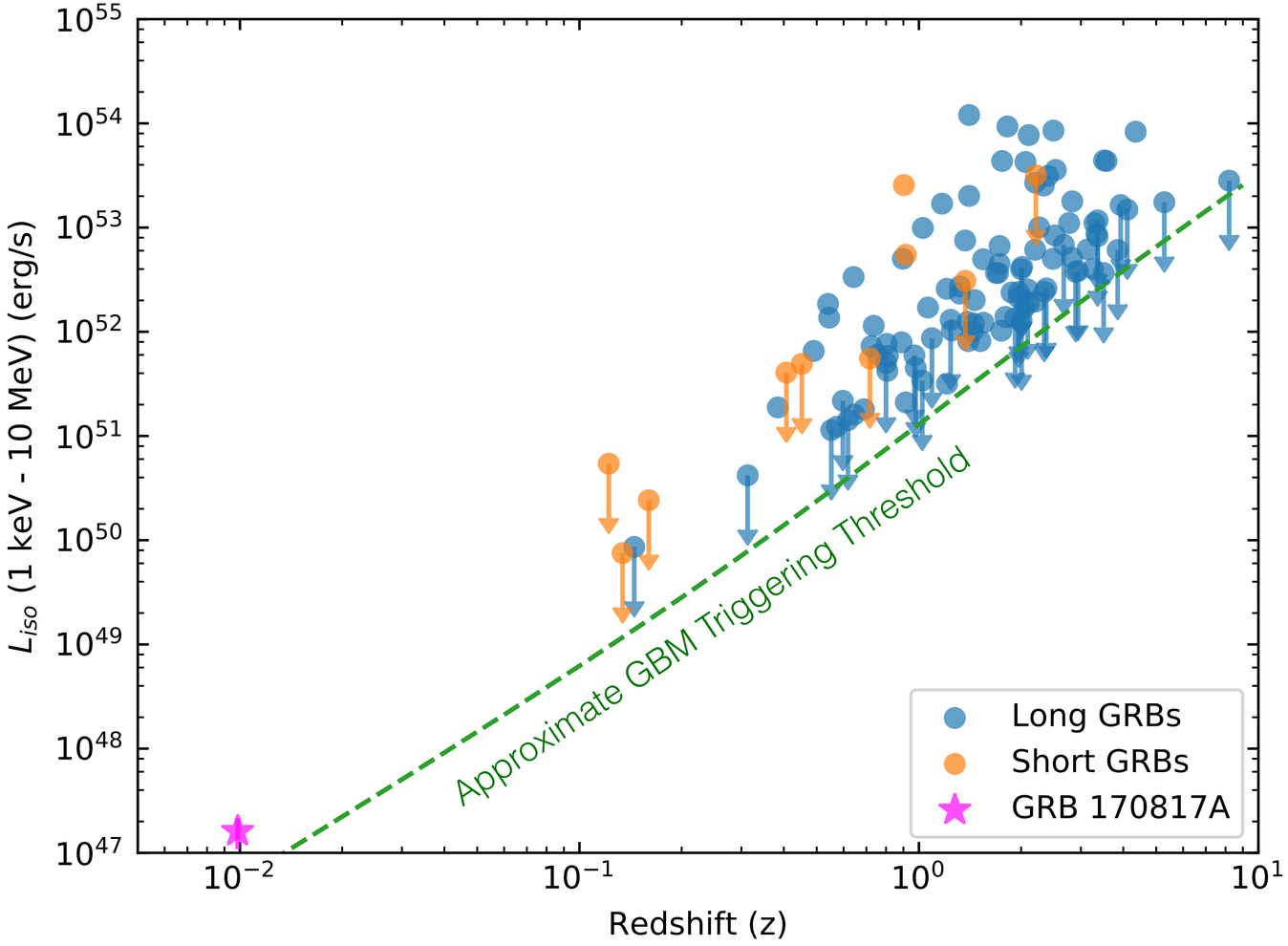
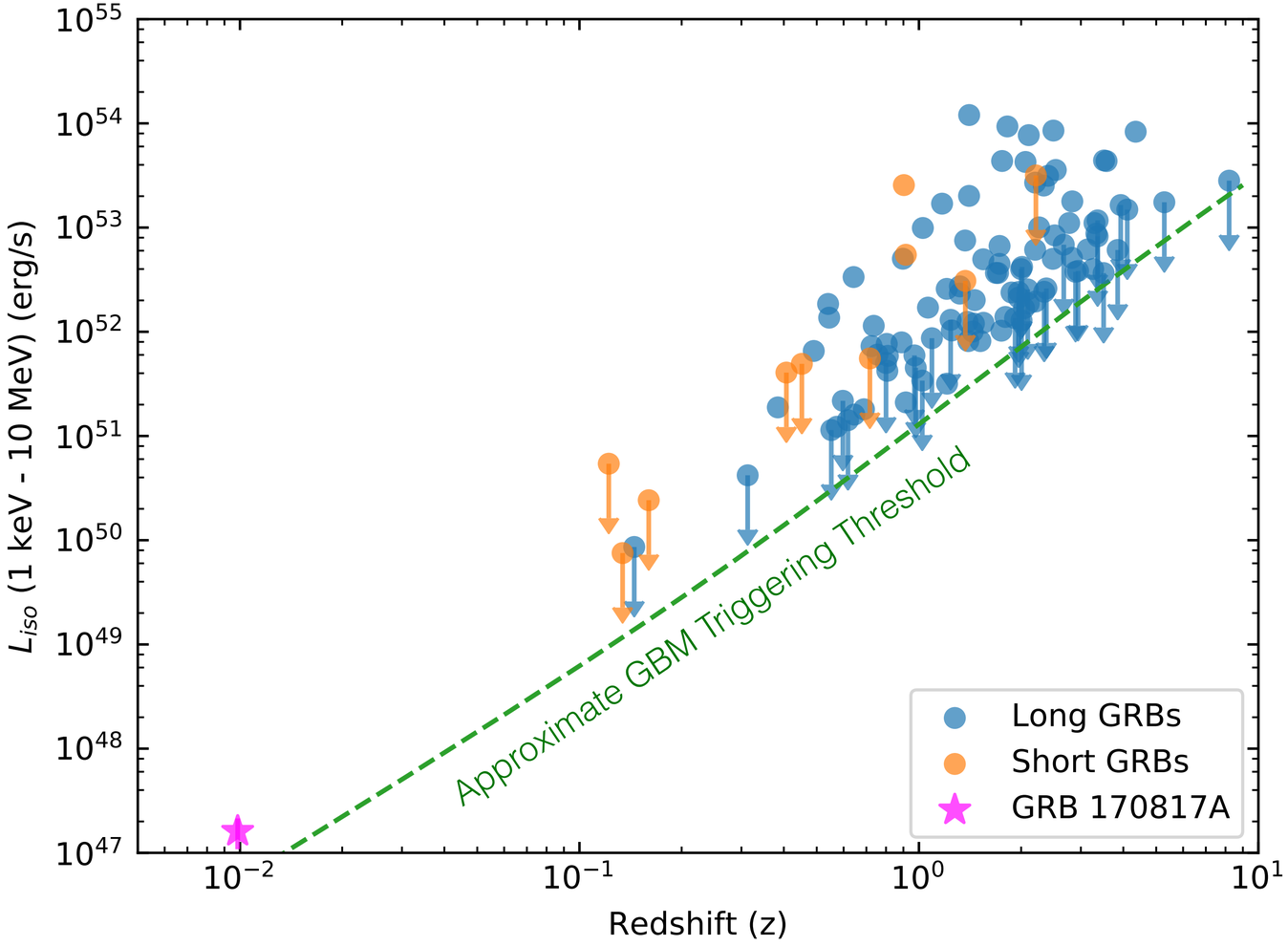


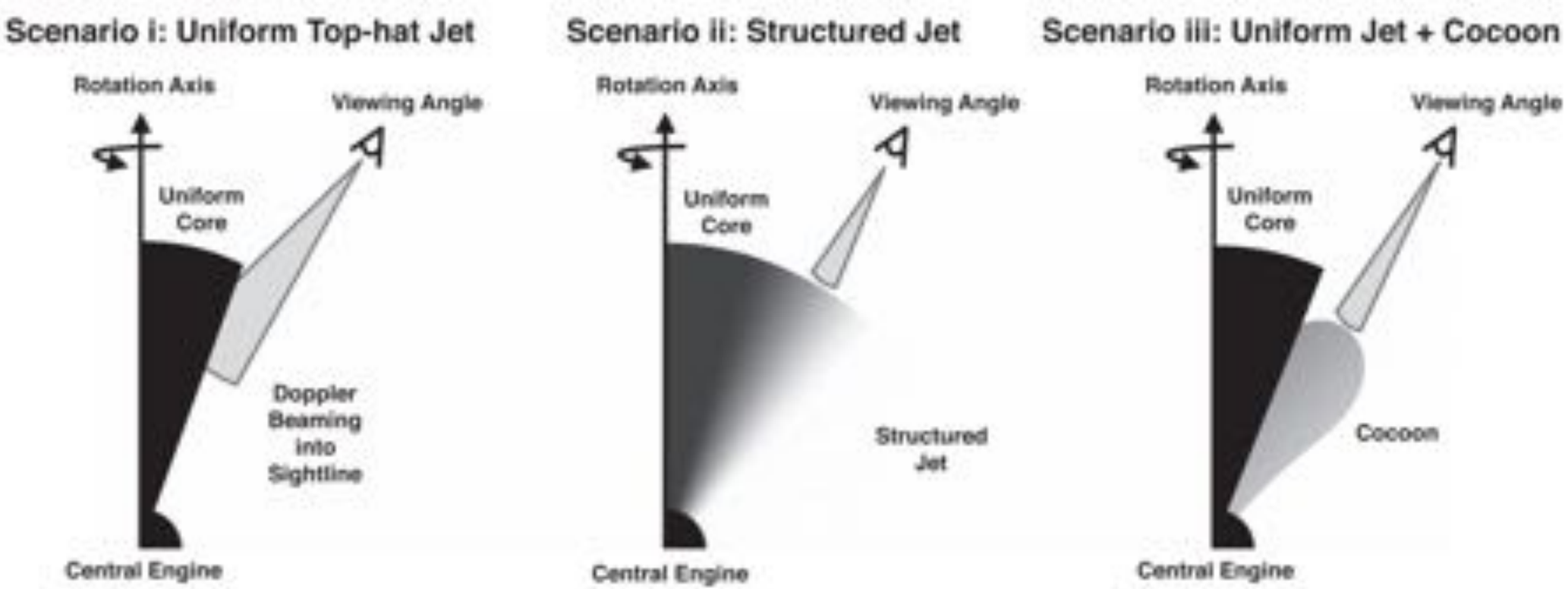
Adapted from LVC, Fermi and INTEGRAL, ApJL (2017)



Adapted from LVC, Fermi and INTEGRAL, ApJL (2017)

If GRB170817A brightness reduced to:

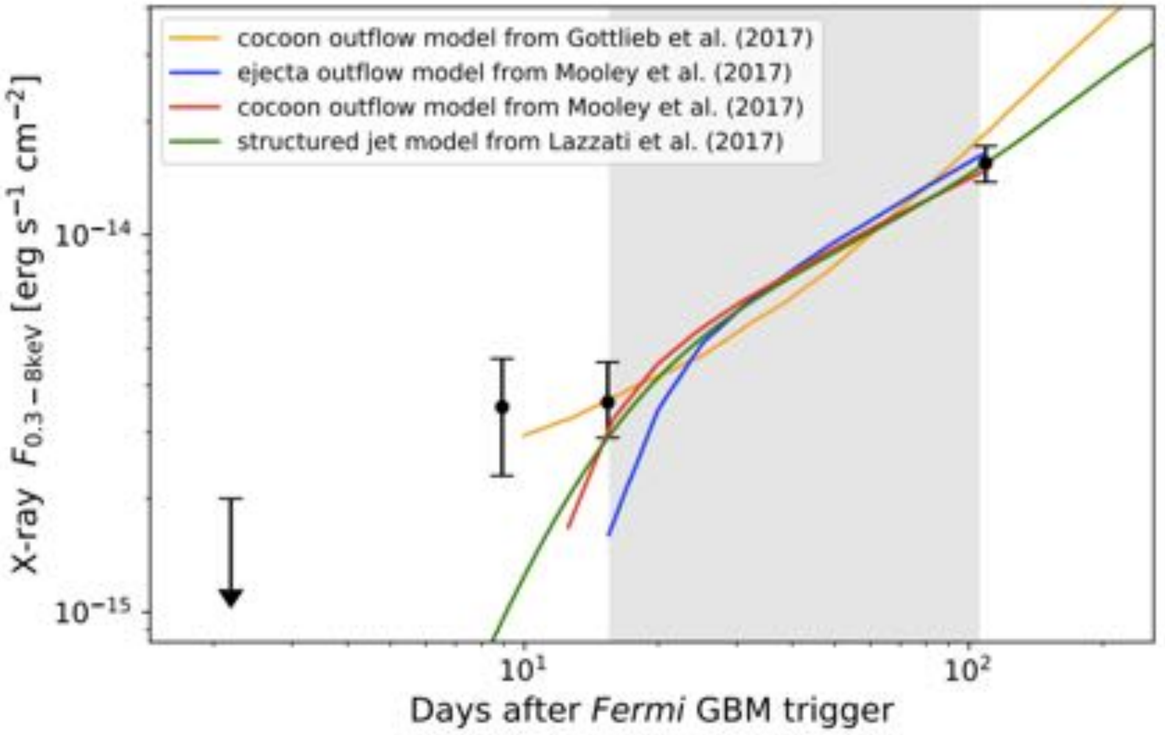
- ~70%…no onboard trigger
- ~50%…at untargeted search threshold
- ~40%…at targeted search threshold



?

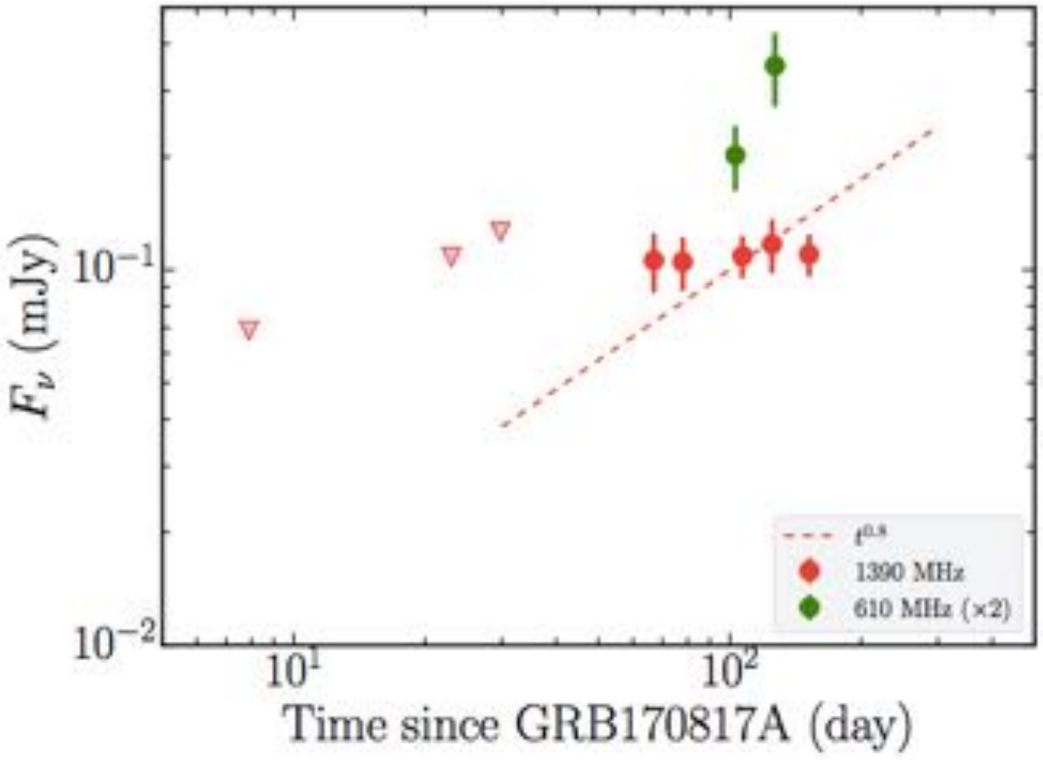
LVC, Fermi and INTEGRAL, ApJL (2017)

Chandra X-Ray Observatory

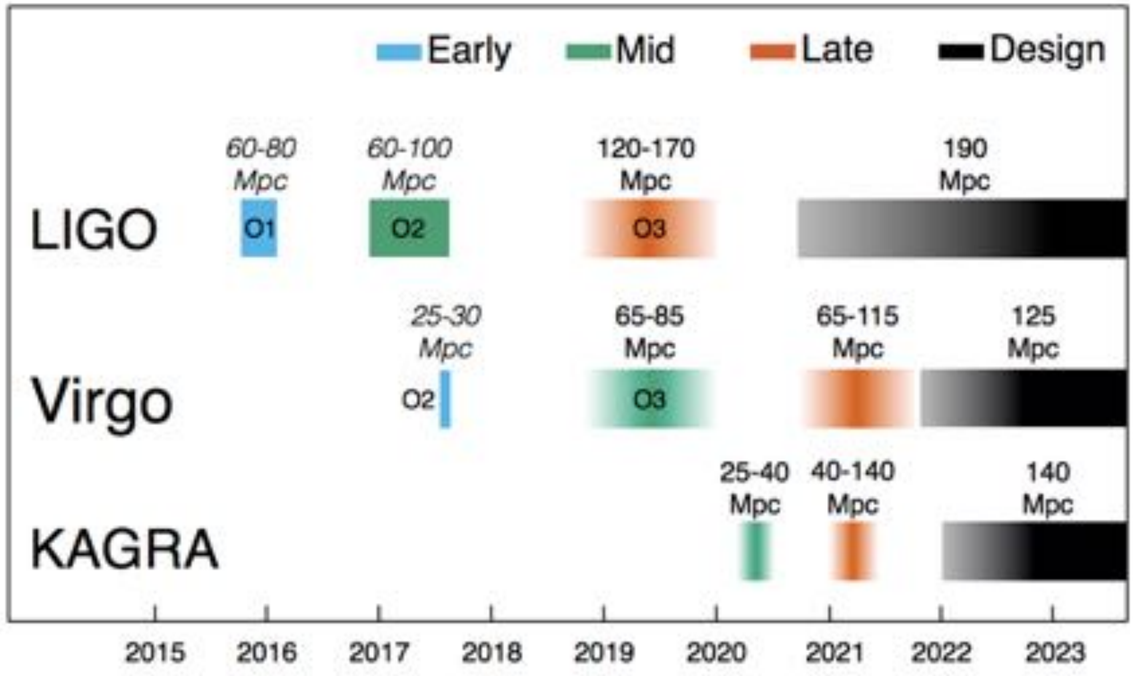


Ruan et al, ApJL (2018)

Giant Meterwave Radio Telescope



Misra et al, arXiv:1803.02768



LIGO-P1200087, VIR-0288A-12

Median (full range) O3 detections

BNS: ~5-10 (0-30)

BBH: ~30 (10-100)

NSBH: < ~1 (if they exist)

C. Pankow, private communication, (2018)

The hunt for gamma-ray counterparts to gravitational-wave sources

Tyson B. Littenberg (NASA/MSFC)