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Recent Progress on New Types of Gamma-Ray Bursts

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12/03/2020 Online Colloquium @ DoA Tsinghua

Old-Type GRBs

"Expected"

Typical short & long GRBs

- Prompt Emission: γ -ray , X-ray (sometimes), GeV, EE (seconds ~ hours)
- Afterglow : X-ray, optical, radio, GeV (mintutes ~ hours ~ years)
- SN: optical (~ weeks)
- Kilonova: optical, UV (~ hours)
- Host: optical , radio, other wavelength (~ always)

Old-Type GRBs: What're New?

"Unexpected/Unusal"

Typical short & long GRBs

- Precursors: all-wavelength
- Prompt Emission: optical, radio, (early) X-ray, γ -ray , GeV, EE, TeV
- Afterglow : (early) X-ray, (early) optical, (deep) optical, radio, GeV
- SN
- Kilonova: optical, UV (large sample)
- Host: optical , radio , other wavelength (large sample)
- Neutrinos
- Gravitational Waves

New-Type GRBs

Typical short & long GRBs

- Precursors: all-wavelength
- Prompt Emission: optical, radio, (early) X-ray, γ -ray , GeV, TeV
- Afterglow : (early) X-ray, (early) optical, (deep) optical, radio, GeV
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- Kilonova: optical, UV, (large sample)
- Host: optical , radio , (large sample)
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- Gravitational Waves

"New-Type" GRBs

- Ultral-Long GRBs (~ hours, all wavelength, all time frames)
- Ultral-Soft GRBs (~ low Ep, thermal spectrum, all wavelength, all time frames)
- X-ray only GRBs (a.k.a. X-ray transient, Xue et al. 2019)
- GRB related to other unusual sources (e.g., FRBs ? Dai et al.; GWs ;)
- Sub-TeV GRBs
- Sub-threshold GRBs (more interesting if concidence w/ other messengers/wavelength)
- Temporally or spectrally peculiar GRBs (LL, extra component, etc)
- SGR GF GRB;
- Unknown-Origion GRBs (trouble makers)

New-Type GRBs

Typical short & long GRBs

- Precursors: all-wavelength **<==**
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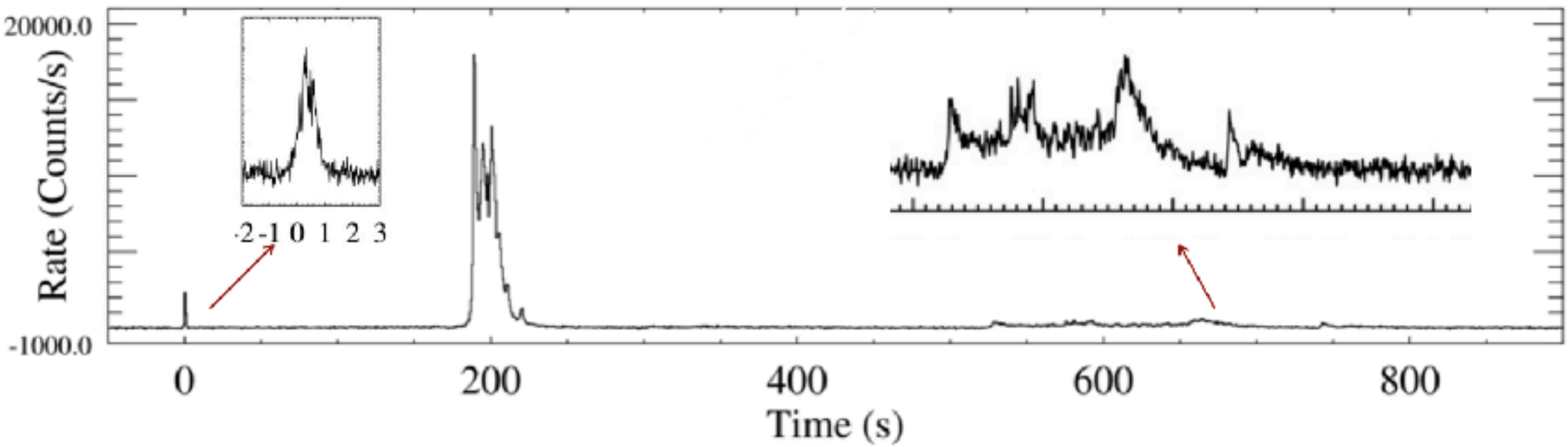
New-Type GRBs

Precursors of GRBs

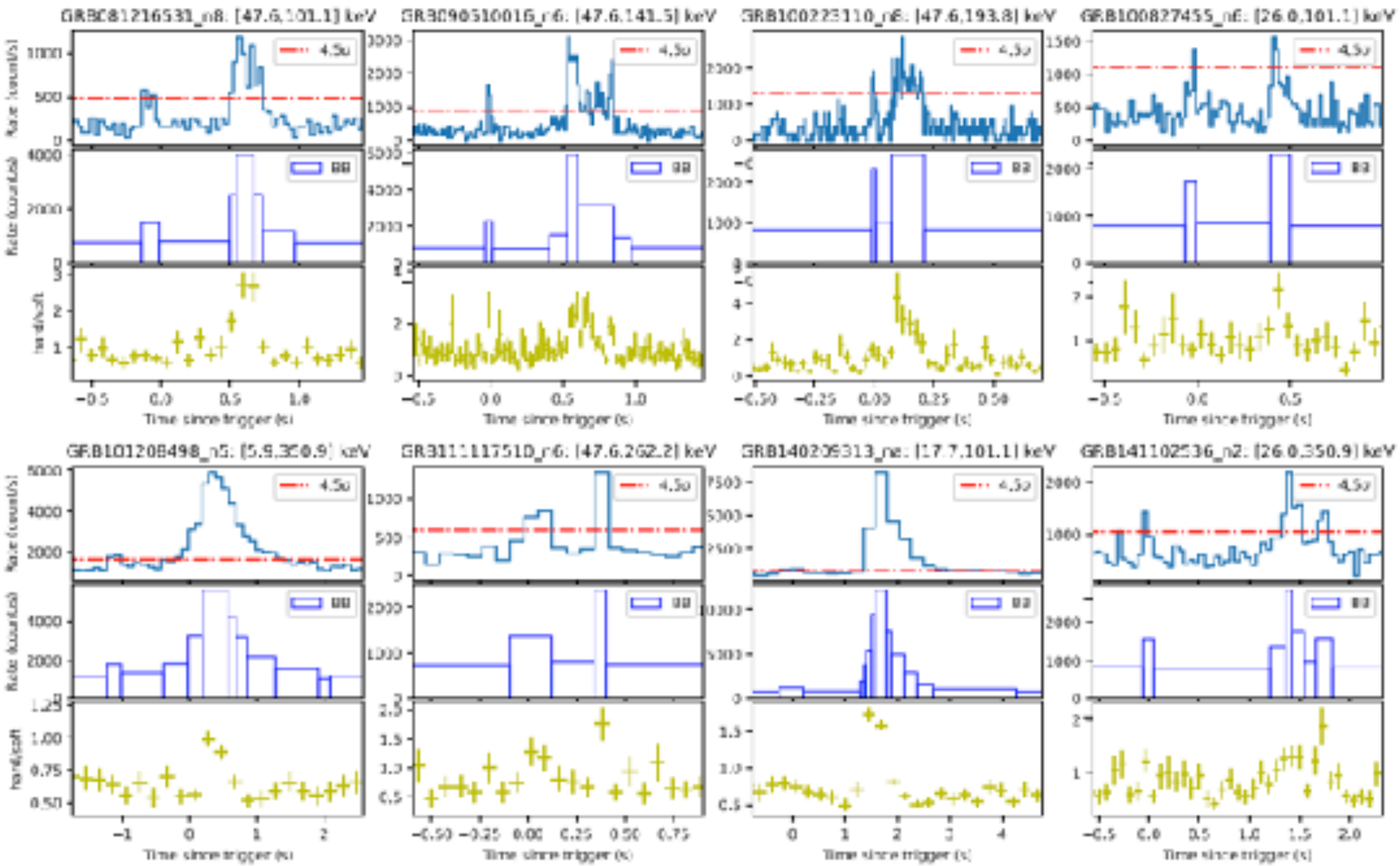
Precursors of GRBs



Zhang B.-B. et al 2018 Nature Astronomy

Precusors can be common: photosphere emission is always there….

Precursors in short GRBs



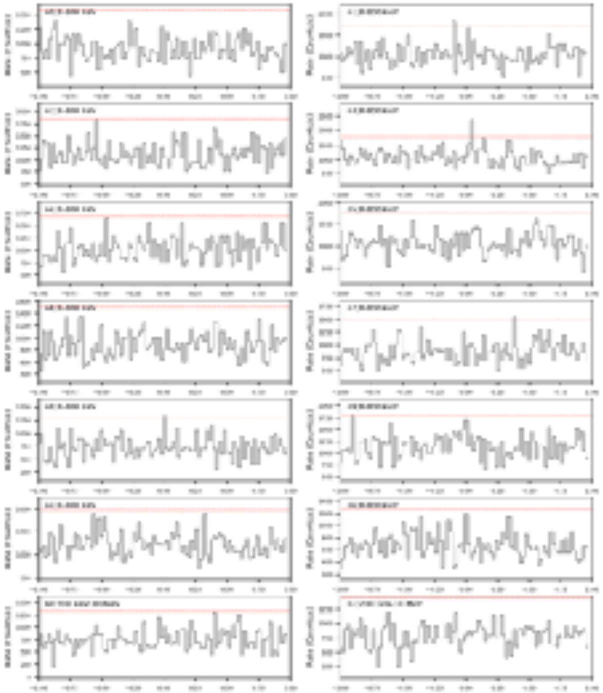
- Found 16 out of 529 sGRB (3%).
- Thermal or Non-Thermal
- Shock breakout, photospheric, magnetospheric
- $\Gamma \sim 30$

Wang, J.-S. et al. 2020, ApJL

New-Type GRBs

Sub-threshold GRBs

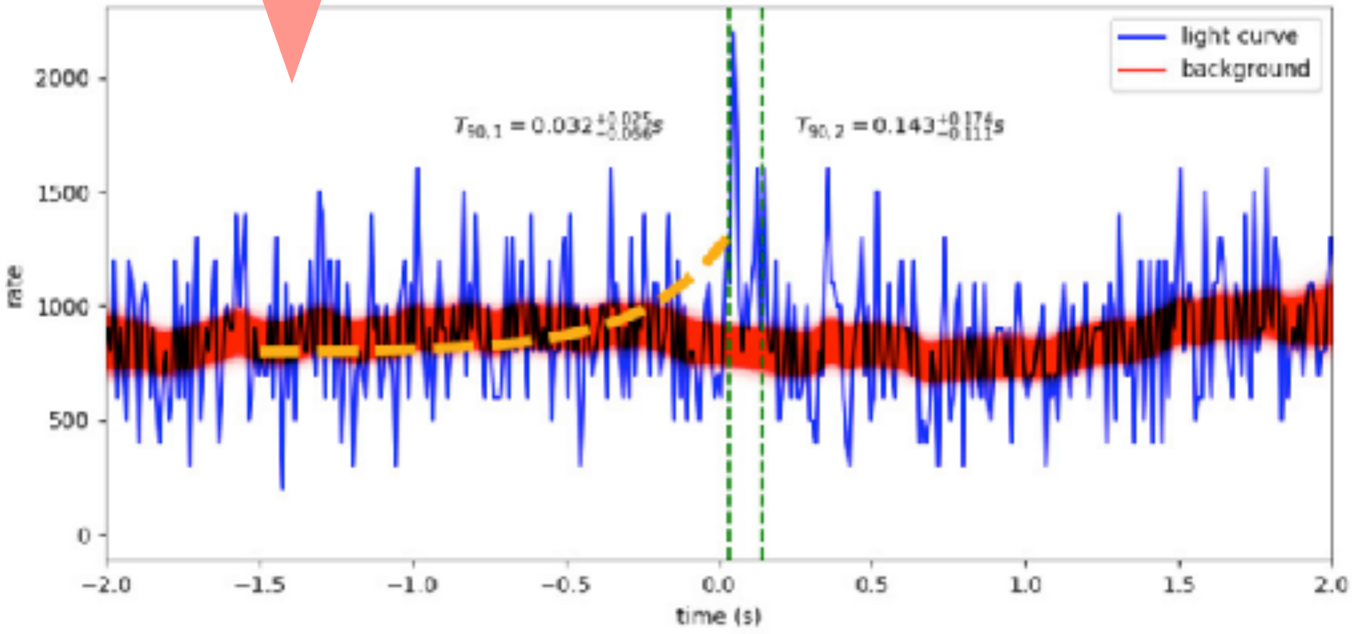
(dig out a needle in a haystack)



Subthreshold GRBs More interesting w/ GW

GW

(NS-BH event, 2nd GW-EM association
subject to LIGO/Fermi official confirmation)



Yang, Y.-S et al 2020, ApJ

Current GW-EM Zoo

Case	Type	EM	Ref.
GW150914-GBM/ GW150914	BH-BH	very unlikely EM	Connaughton+15
GRB170817A/ GW170817/AT 2017gfo	NS-NS	Definitely Beautiful!	Abbott+17
S190510g	NS-NS	13 optical EM candidtes, NONE confirmed	Andreoni+19a
S190814bv	BH-NS	Deep search yeild nothing confirmed in EM	Andreoni+19b Dobie+19, etc
GW190425z	NS-NS	13 optical candiates, nothing confirmed	Coughlin+19a Antier+19
S190426c, S190510g, S190901ap, S190910h	NS-?	deep search, some candiates, nothing confirmed	Coughlin+19b Goldstein+19
"I-OGC 151030"	NS-NS	found by 3rd party, sub-threshold, high FAR, GW NOT confirmed by LIGO	Nitz+19
GBM-190816	BH-?	Both GW and EM are identified as sub-threshod by LVC/Fermi	GCN Circulars

This work →

Words from LVC/Fermi

Fermi GBM-190816: A sub-threshold GRB candidate **potentially** associated with a sub-threshold LIGO/Virgo compact binary merger candidate

LIGO L1 and V1 identified a **possible** compact binary merger candidate at 2019-08-16 21:22:13.027 UTC (GPS Time: 1250025751.027).

The GBM Targeted Search found a sensitive and coherent search for subthreshold GRB-like signals (GBM-190816) at 21:22:14.563 UTC (our T0), 1.57 s after the GW trigger Time.

GBM-190816:

①. Duration: approximately 0.1 s

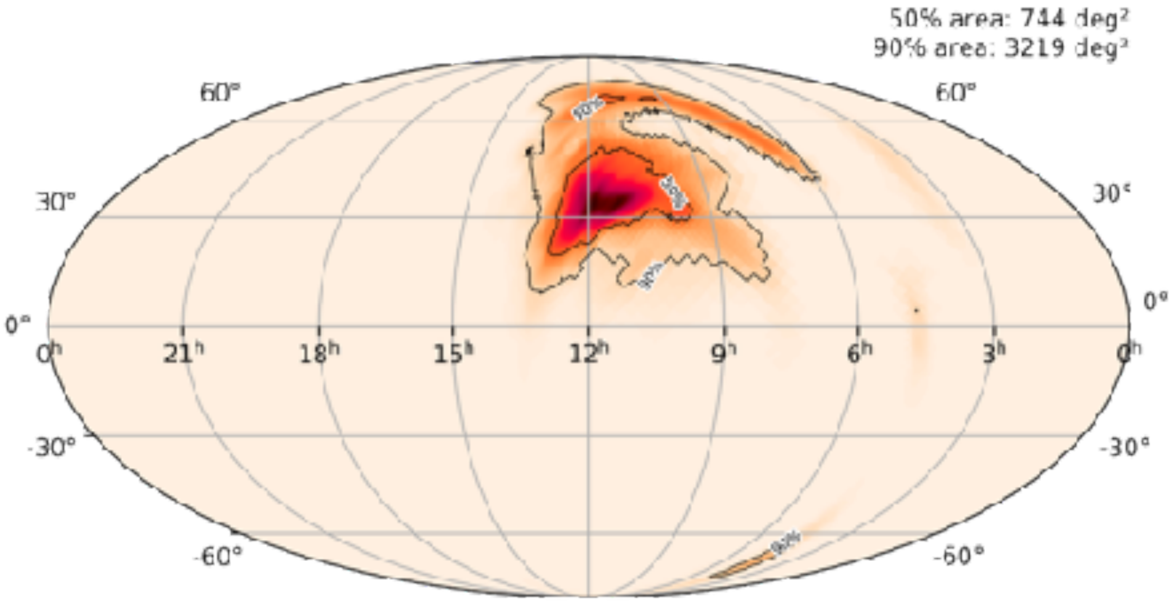
②. Hard spectral template

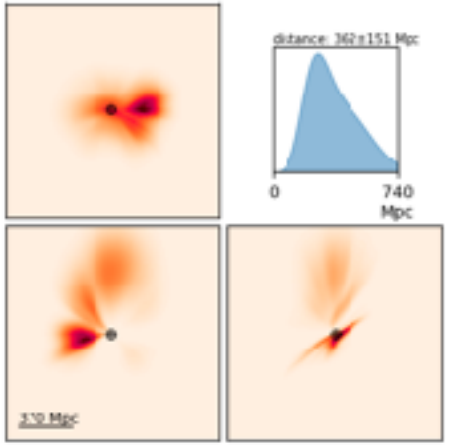
③. **The lighter compact object may have a mass < 3 $M_\odot$.**

④. FAR ~ 1.2×10^{-4}

GCN #25406

Words from LVC/Fermi





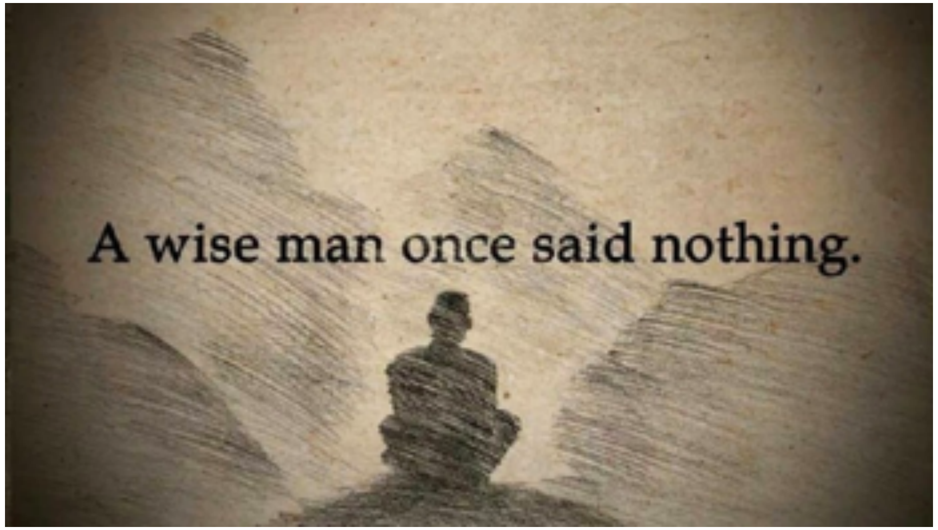
Distance from GW: 352 +/- 151 Mpc

GCN #25406

Excited Community

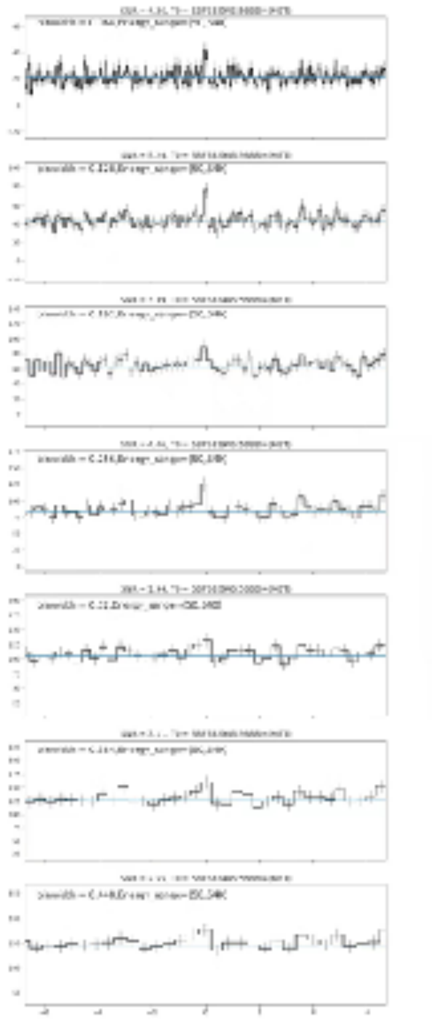
Search by

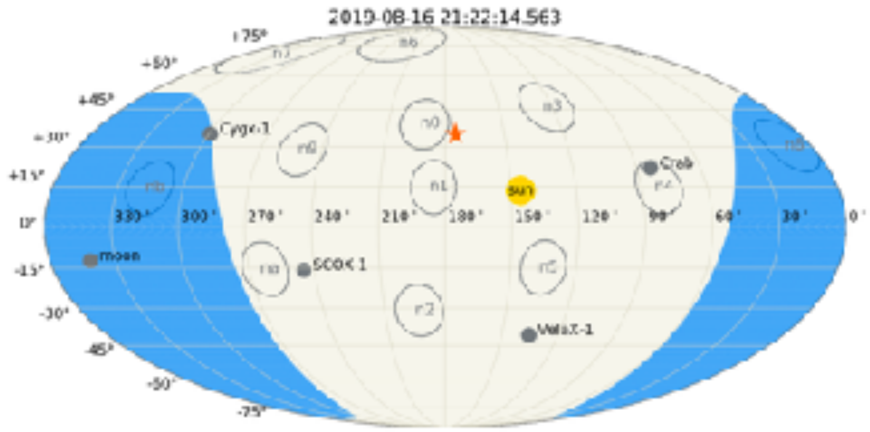
INTEGRAL/SPI-ACS, ANTARES, HAWC, IceCube, Zwicky, AGILE, Fermi-LAT, MAXI/GSC



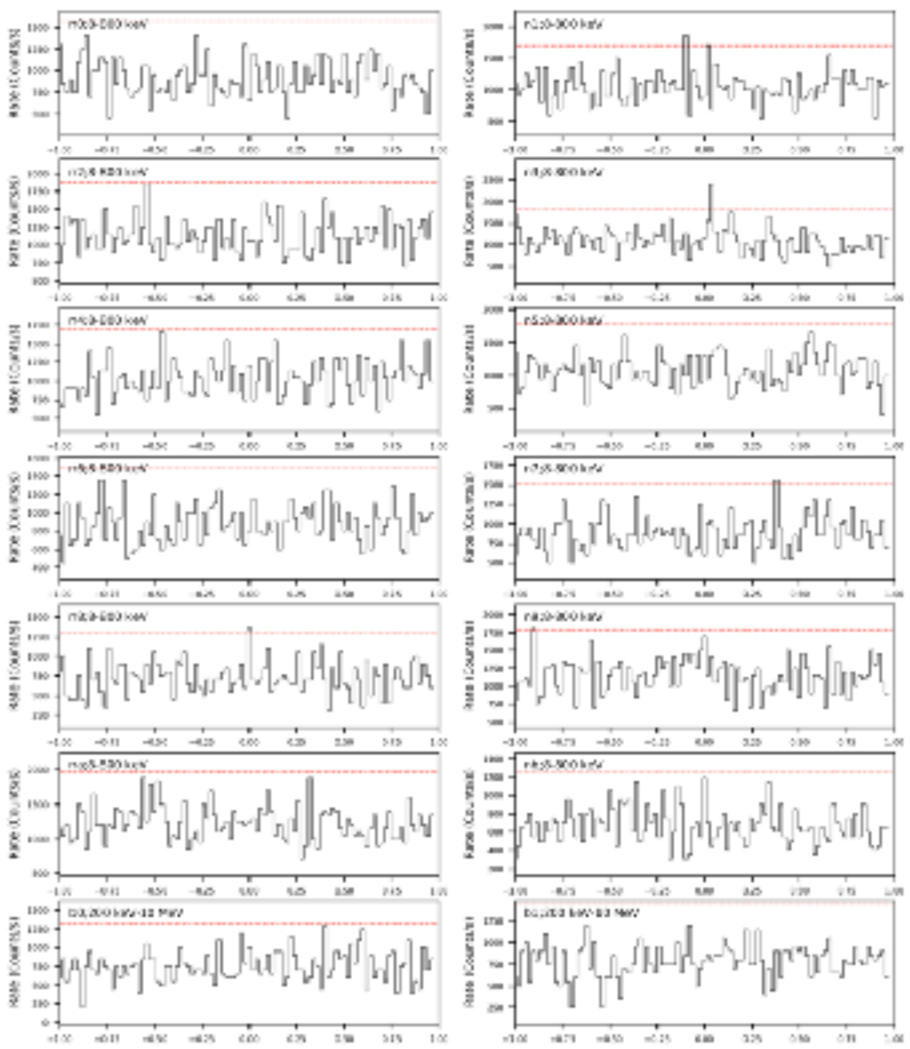
(Nothing in optcal, High-E, neutrinos, X-ray)

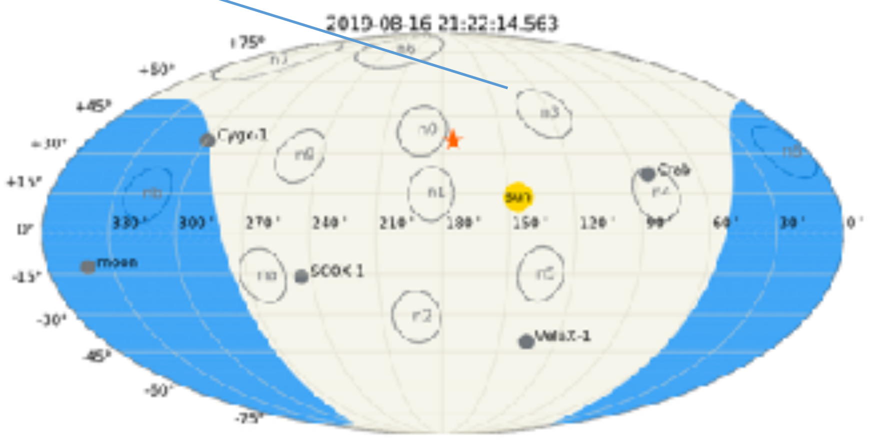
Gamma-ray Caught by 2 of 3 of our blind-search pipelines



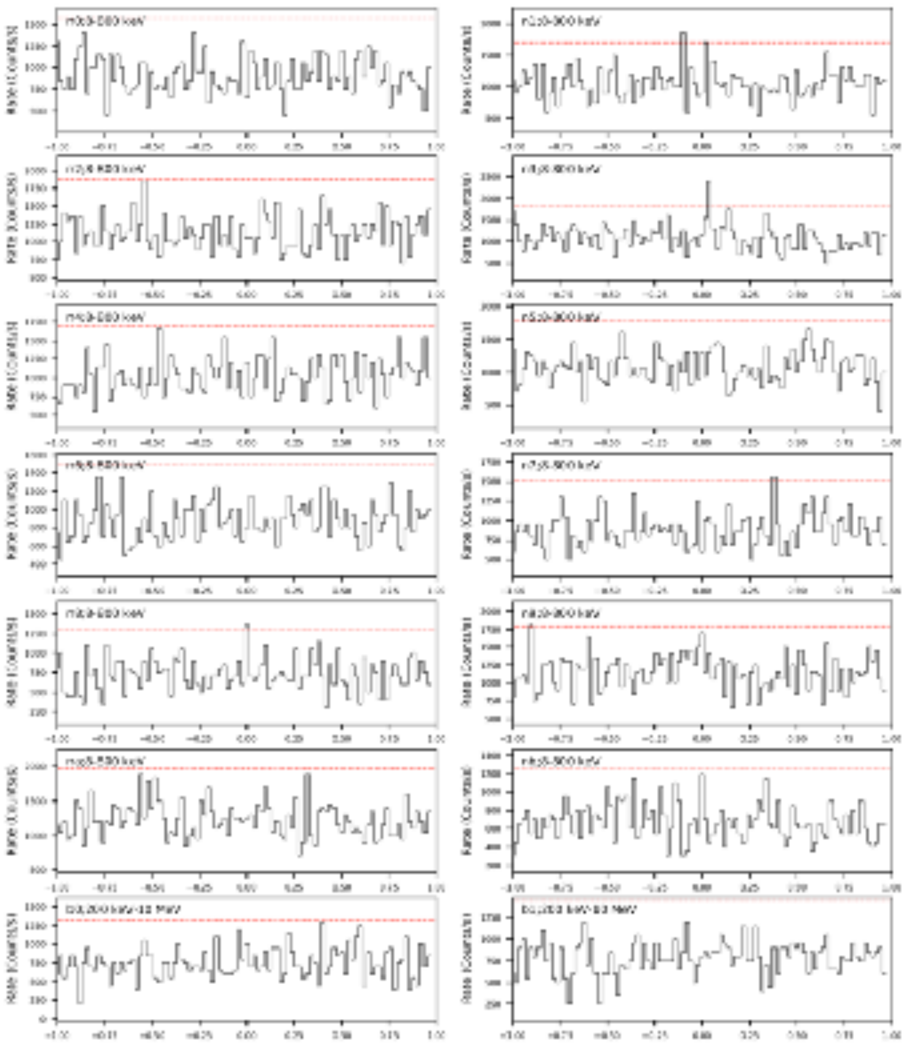


Independently identified by Rongji Cang (Tsinghua)

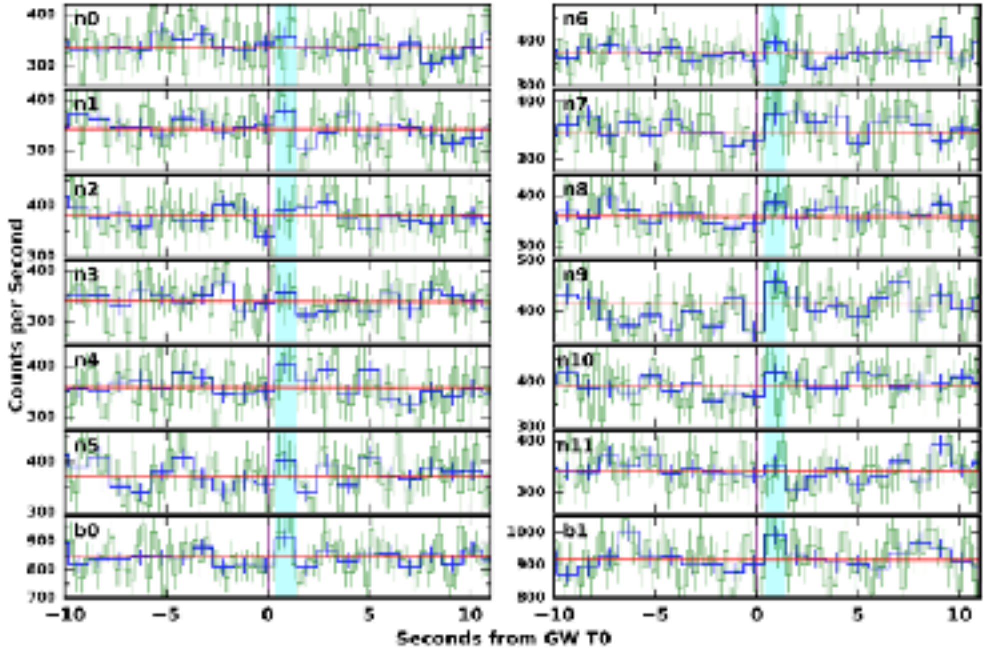



2019-08-16 21:22:14.563
Cyg X-1
Crab
sun
moon
SCO X-1
Vela X-1

Much stronger EM emission than GW150914



NS/BH-BH



BH-BH

Goal:

- Confirm it is a GRB
- What kind of merger can produce such a GRB?
- What kind of merger can produce such
a marginaly-detected GW signal at 352 Mpc?
- What can cause the 1.57 s delay?

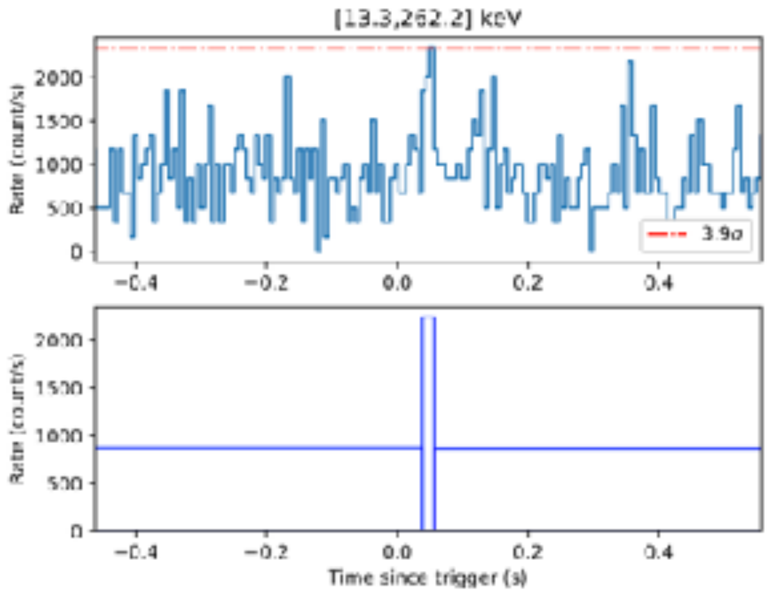
Burst Confirmation

Burst Confirmation

Bayesian Block (BB) (Scargle et al. 2013):

Signal appears in various conditions.

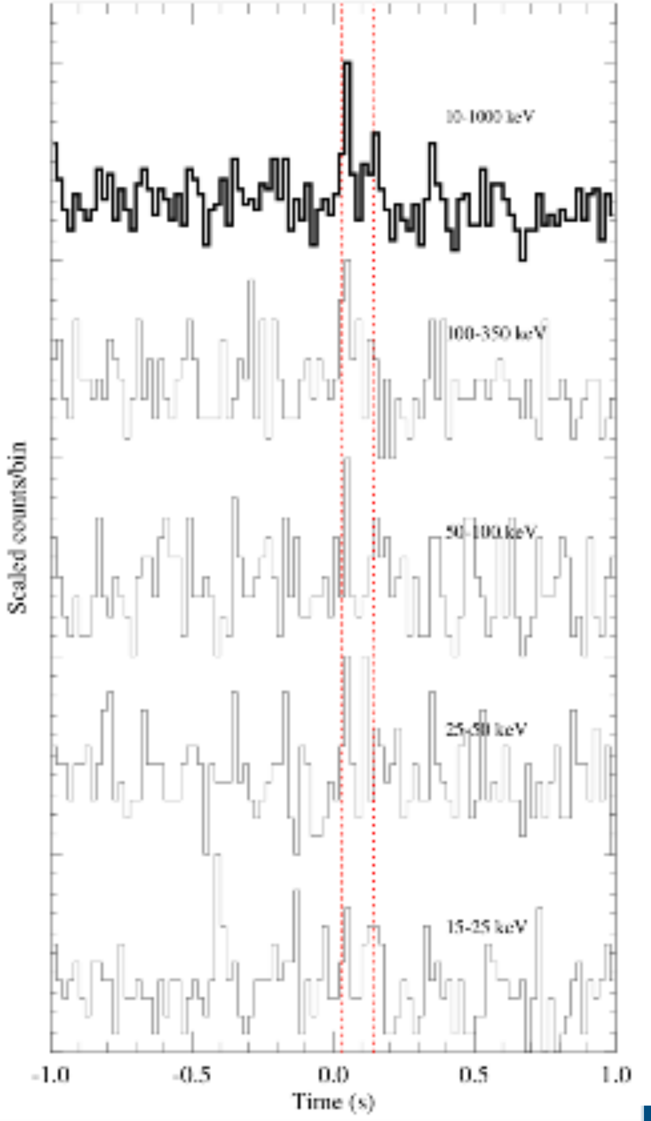
The significance level of the burst S/N reached 3.95.



Burst Confirmation

Multi-wavelegth light curves

Pulse evolution and struture



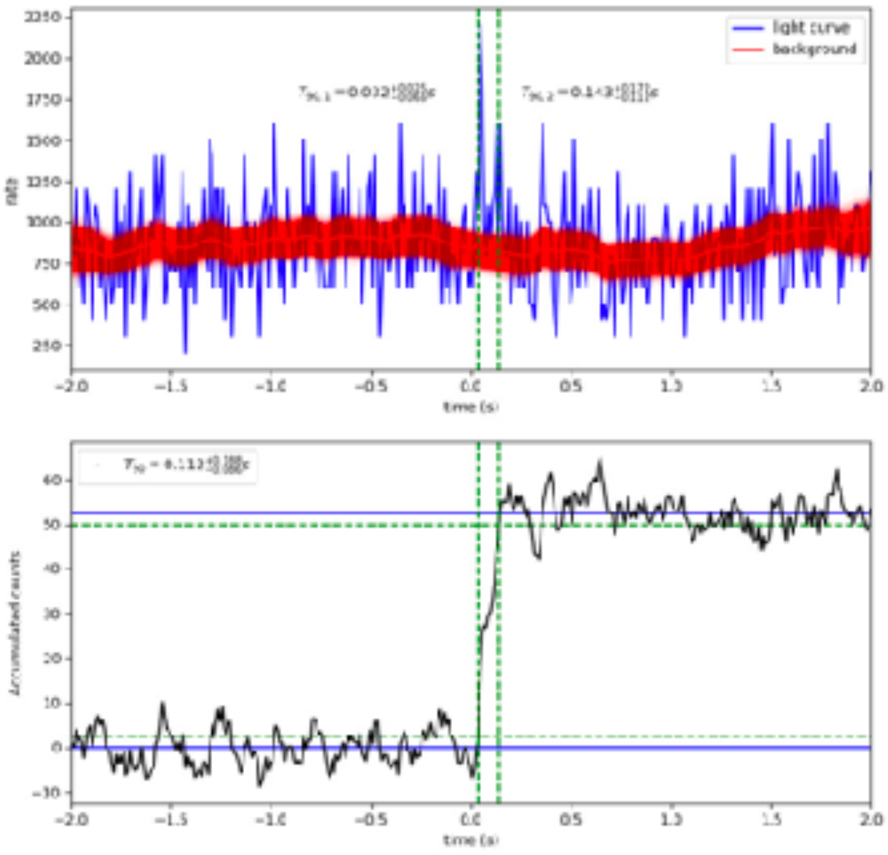
Burst Confirmation

Precise Duration

$$T_{90} = 0.112^{+0.185}_{-0.085}\,s$$

starts at $T_{90,1}$ = $0.032^{+0.025}_{-0.065}\,s$

ends at $T_{90,2}$ = $0.143^{+0.17}_{-0.11}\,s$



Burst Confirmation

f parameter

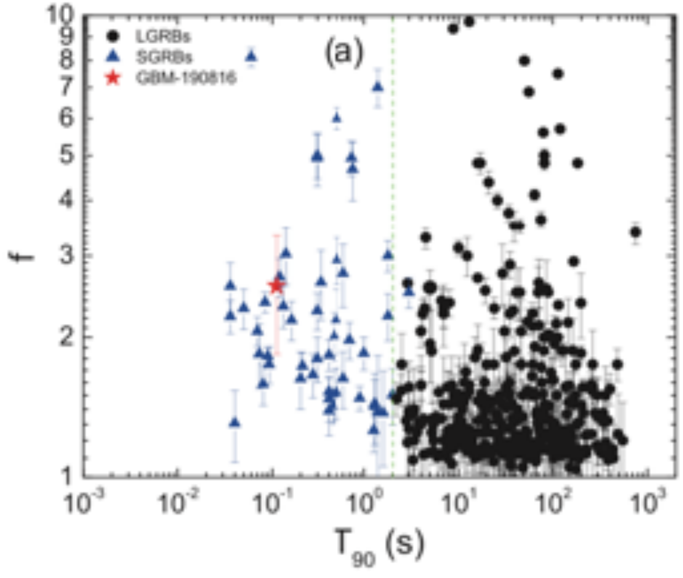
(a.k.a : tip-of-iceberg effect, Lü, H.-J. et al. 2012)

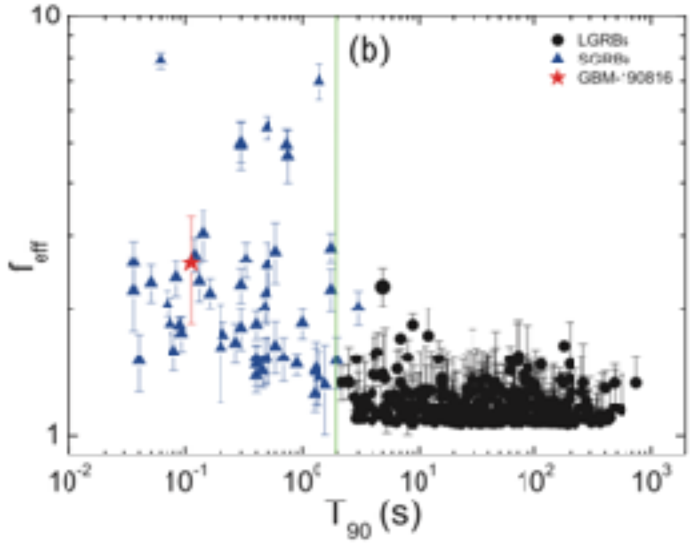
f = 2.58 ± 0.37, typical as a short GRB

f: the ratio between the peak flux and the average background flux

f_{eff}: the ratio between the peak flux of a pseudo-burst and the average background flux.

However, there is a non-negligible probability (p ~ 0.03.) of being the "tip of iceberg" of a longer short burst.





Burst Confirmation

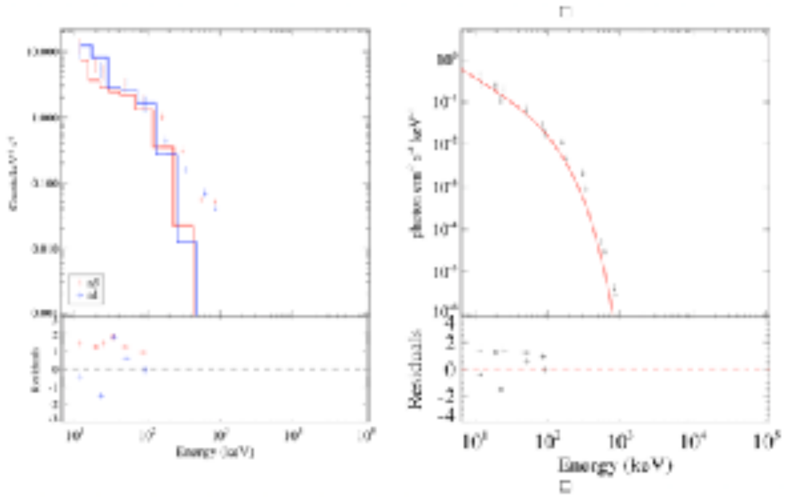
Burst Confirmation

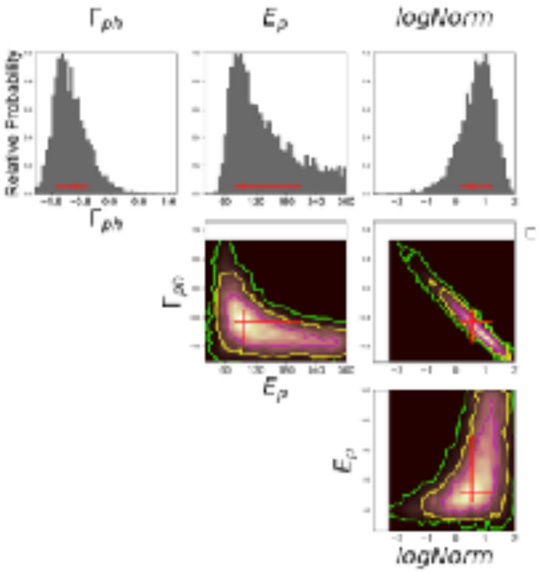
Spectral Analysis

Time Interval		CPL			
t_1	t_2	Γ_{ph}	E_p	$logNorm$	PGSTAT/dof
0.032	0.143	$-0.92^{-0.32}_{-0.58}$	$94.84^{+114.61}_{-17.94}$	$0.53^{+0.72}_{-0.41}$	130.1/227

Advanced mission-independendt data analysis tools:

Input: Time & Location
Output: All you need
Things Considered: Geometry, Detector Rsp, S/N
Counts Statistics, BKG Modeling, Noise Uncertainties …

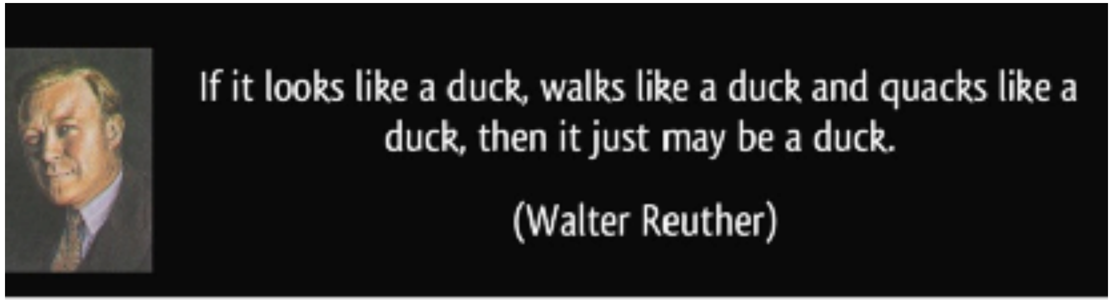


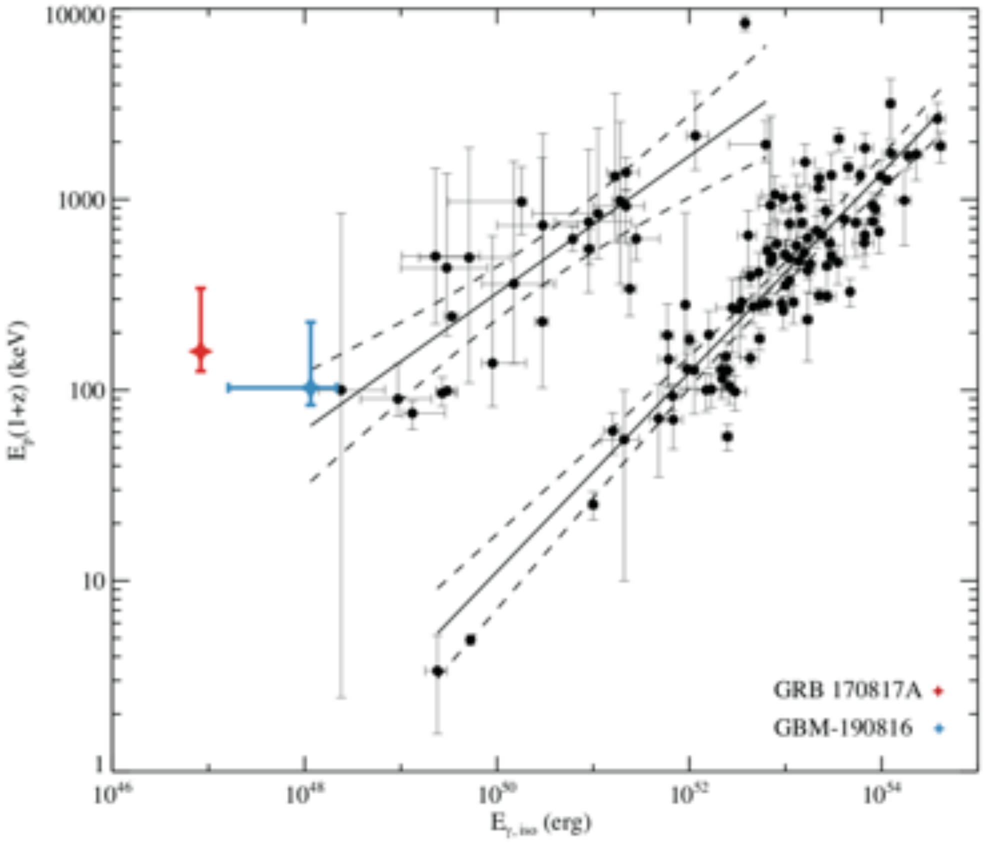


Burst Confirmation

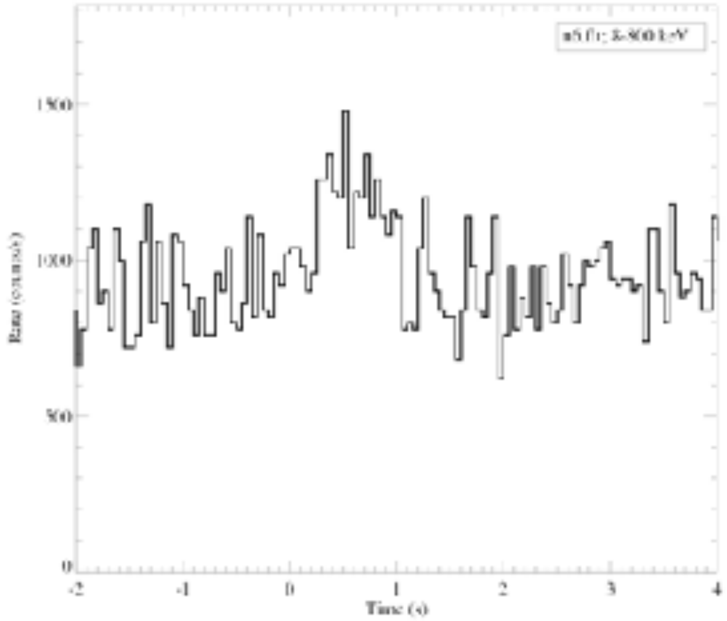
GBM-190816 as a short GRB

Observed Properties	
T_{90} (s)	$0.112^{+0.185}_{-0.085}$
Peak energy E_p (keV)	$94.84^{+114.64}_{-17.94}$
Total fluence(erg cm^{-2})	$7.38^{+6.35}_{-2.51} \times 10^{-8}$
Distance (Mpc)	$362 +/- 151$
Isotropic energy $E_{\gamma,\mathrm{iso}}$ (erg)	$1.14^{+3.18}_{-0.89} \times 10^{48}$
Luminosity $L_{\gamma,\mathrm{iso}}$ (erg s^{-1})	$1.02^{+2.84}_{-0.80} \times 10^{49}$
f parameter	$2.58 + / - 0.37$





Burst confirmed.
Concidence established.



How to make the burst (EM part)?

Case 1: NS-BH (NS is not swallowed)
Case 2: NS-BH (NS is swallowed)
Case 3: BH-BH

Obs:

Burst Energy

NS-BH Merger with Tidal Disruption: Constraints on Model Parameters

Total mass of the matter left outside M_{out}:

$$M_{\rm out} = M_{\rm NS}^{\rm b}\left[\max\left(\alpha\frac{1-2\rho}{\eta^{1/3}} - \beta\tilde{R}_{\rm ISCO}\frac{\rho}{\eta} + \gamma, 0\right)\right]^{\delta}$$

The dimensionless ISCO radius follows

$$\tilde{R}_{\rm ISCO} = R_{\rm ISCO}c^2/GM_{\rm BH} = 3 + Z_2 - {\rm sgn}\left(\chi_{\rm BH}\right)\sqrt{\left(3-Z_1\right)\left(3+Z_1+2Z_2\right)}$$

Dynamical ejecta mass M_{dyn}

$$M_{\rm dyn} = M_{\rm NS}^{\rm b}\left\{\max\left[a_1 q^{n_1}\left(1-2C_{\rm NS}\right)/C_{\rm NS} - a_2 q^{n_2}\tilde{R}_{\rm ISCO}\left(\chi_{\rm eff}\right) + a_3\left(1 - M_{\rm NS}/M_{\rm NS}^{\rm b}\right) + a_4, 0\right]\right\}$$

The disc mass M_{disc}

$$M_{\rm disc} = M_{\rm out} - M_{\rm dyn}$$

The kinetic energy of the jet can be calculated by

$$E_{\rm K,jet} = \epsilon\left(1-\xi_{\rm w}\right)M_{\rm disc}c^2\Omega_{\rm H}^2 f\left(\Omega_{\rm H}\right)$$

The dimensionless spin of the final BH remnant

$$\chi_{\rm BH,f} = \frac{\chi_{\rm BH}M_{\rm BH}^2 + l_z\left(\bar{r}_{\rm ISCO}, \chi_{\rm BH,f}\right)M_{\rm BH}M_{\rm NS}}{M^2}$$

The orbital angular momentum per unit mass of a test particle orbiting the BH remnant at the ISCO

$$l_z\left(\bar{r}_{\rm ISCO}, \chi_{\rm BH,f}\right) = {\rm sgn}\left(\chi_{\rm BH,f}\right)\frac{\bar{r}_{\rm ISCO}^2 - 2\,{\rm sgn}\left(\chi_{\rm BH,f}\right)\chi_{\rm BH,f}\sqrt{\bar{r}_{\rm ISCO}} + \chi_{\rm BH,f}^2}{\sqrt{\bar{r}_{\rm ISCO}}\left(\bar{r}_{\rm ISCO}^2 - 3\bar{r}_{\rm ISCO} + 2\,{\rm sgn}\left(\chi_{\rm BH,f}\right)\chi_{\rm BH,f}\sqrt{\bar{r}_{\rm ISCO}}\right)^{1/2}}$$

we assume a Gaussian-shape structured jet with an angular distribution of the kinetic energy and Lorentz factor Γ following

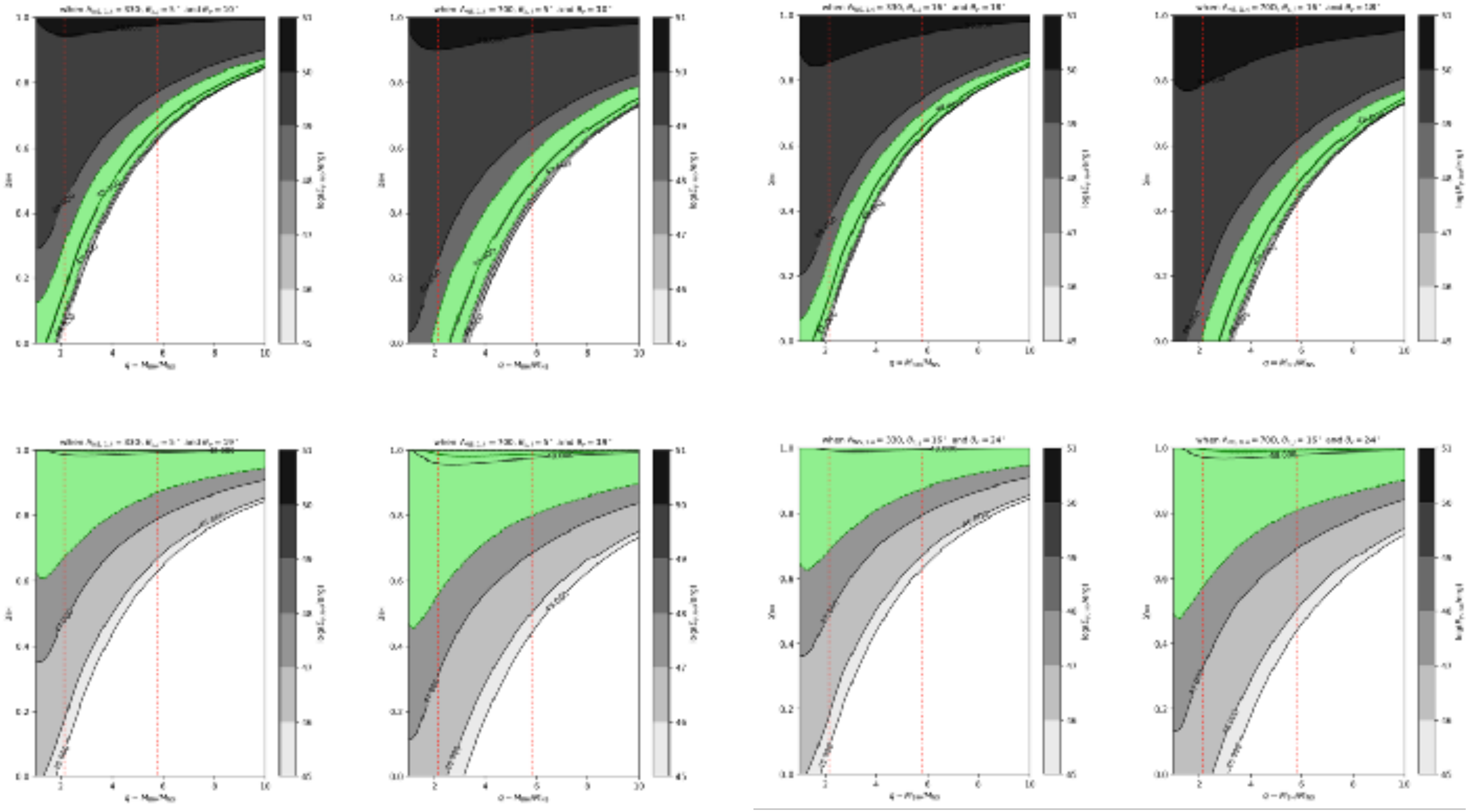
$$\frac{dE}{d\Omega}(\theta) = E_{\rm c}e^{-\left(\theta/\theta_{\rm c,j}\right)^2}, \quad \Gamma(\theta) = \left(\Gamma_{\rm c} - 1\right)e^{-\left(\theta/\theta_{\rm c,j}\right)^2} + 1$$

At the viewing angle θ_v, the isotropic gamma-ray radiation energy can be estimated as

$$E_{\gamma,iso}\left(\theta_v\right) \simeq \eta_\gamma\int\frac{D_{\rm p}^3}{\Gamma}\frac{dE}{d\Omega}d\Omega$$

$E_{iso} = E_{iso}(M_{NS}, q, \varepsilon, \xi_w, \eta_\gamma, \Gamma_c, \theta_{jet}, \theta_{obs}, \Lambda_N \ldots)$

NS-BH Merger with Tidal Disruption: Constraints on Model Parameters



How to make the marginally detected GW Event?

POSSIBLE SUB-THRESHOLD GRAVITATIONAL WAVE SIGNAL

Information:

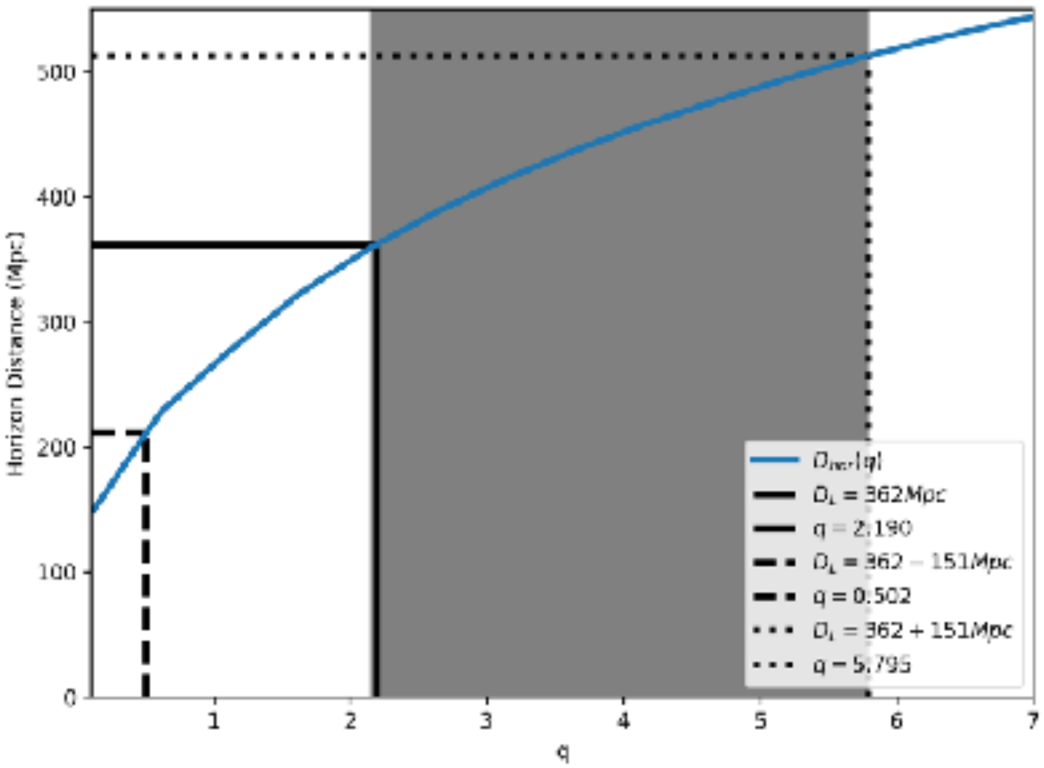
1. L1 and V1 data are available at that time.
2. LVC identified a possible CBC candidate at 2019-08-16 21:22:13.027 UTC.
3. The network S/N of this sub-threshold event is below the threshold of GW analysis pipelines, which is 12.
4. The luminosity distance of the event is constrained to 362±151 Mpc
5. The lighter compact object of this CBC event may have a mass < 3 $M_\odot$

Assumptions:

1. One compact object of this CBC event is an NS with a mass of **1.4 $M_\odot$**
2. The sensitivity of the L1 detector in O3 is twice of that in O1.
3. The **S/N of the event is 8** and mostly contributed by L1.

Constraints:

Follow the FINDCHIRP pipeline (Allen et al. 2012). The mass ratio lies in **q ~ [2.142, 5.795]**



$q \sim$ [2.142, 5.795]:

allows non-tidal-disruption process (large q)

Charged CBC is needed produce the observed GRB

(for cases 2 & 3)

cCBC with Constant Charge (Plunging NS-BH Merger)

Electric dipole radiation luminosity

$$L_{\rm e,dip} = \frac{1}{6}\frac{c^5}{G}\left(\hat{q}_1^2+\hat{q}_2^2\right)\left(\frac{r_s(m_1)}{a}\right)^2\left(\frac{r_s(m_2)}{a}\right)^2$$

Magnetic dipole radiation luminosity

$$L_{\rm B,dip} = \frac{196}{1875}\frac{c^5}{G}\left(\frac{\hat{q}_1 m_1+\hat{q}_2 m_2}{M}\right)^2 \times \left(\frac{r_s(\mu)}{a}\right)^4\left(\frac{r_s(M)}{a}\right)^{11}$$

Zhang, B. 2016, 2019

Isotropic EM luminosity, assuming $\eta_\gamma \sim 1$

$$L_{\gamma,\rm iso} = \eta_\gamma\left(L_{\rm e,dip}+L_{\rm B,cip}\right)$$

For an NS-BH merger system: Under the following simplest assumptions: (1) only the NS carries a constant charge; (2) the NS mass is 1.4 $M_\odot$; (3) $a = a_{min} = r_s(m_{BH})+ 2.4r_s\ (m_{NS}\ )$ ($r_{NS} = 2.4\ r_s$ for neutron star) at the merger time; (4) mass-ratio q lies in [2.142, 5.795]. **$\hat{q}_{NS}$ lies in [1.25, 1.50] $\times 10^{-4}$.**

$$\boxed{\hat{q}_{\rm NS} \simeq \frac{3\Omega B_p R^3}{2c\sqrt{GM}}\cos\alpha = (4.4\times10^{-4})B_{15}P_{-3}^{-1}R_6^3M_{1.4}^{-1}\cos\alpha}$$

B_{15}/P_{-3} should fall in the range of ~ [0.28, 0.34] . Implying that the neutron star has to be a millisecond magnetar. Disfavored.

Absolute charge Q_{NS} lies in [1.75, 2.11] $\times 10^{26}$ e.s.u

cCBC with Constant Charge (BH-BH Merger)

Electric dipole radiation luminosity

$$L_{e,\mathrm{dip}} = \frac{1}{6}\frac{c^5}{G}\left(\hat{q}_1^2 + \hat{q}_2^2\right)\left(\frac{r_s(m_1)}{a}\right)^2\left(\frac{r_s(m_2)}{a}\right)^2$$

Magnetic dipole radiation luminosity

Zhang, B. 2016, 2019

$$L_{B,\mathrm{dip}} = \frac{196}{1875}\frac{c^5}{G}\left(\frac{\hat{q}_1 m_1 + \hat{q}_2 m_2}{M}\right)^2 \times \left(\frac{r_s(\mu)}{a}\right)^4\left(\frac{r_s(M)}{a}\right)^{11}$$

Isotropic EM luminosity, assuming $\eta_\gamma \sim 1$

$$L_{\gamma,\mathrm{iso}} = \eta_\gamma\left(L_{e,\mathrm{dip}} + L_{B,\mathrm{dip}}\right)$$

For a charged BH-BH system : Under the following simplest assumptions: (1) the lighter BH has a mass of 2.8 $M_\odot$, (2) only the lighter BH carries a constant dimensionless charge.
We constrains: **$\hat{q}_{BH}$ lies in [5.97, 10.32] $\times 10^{-5}$** . The demanded dimensionless charge is comparable to the one required to explain the putative γ-ray event GW150914-GBM.

Absolute charge Q_{NS} lies in [1.67, 2.89] $\times 10^{26}$. e.s.u

$q \sim [2.142, 5.795]$:
allows non-tidal-disruption process (large q)

Charged CBC must at work to produce the observed GRB

Case 1: Constant Charge —
Contrived conditions needed for a BH to carry very large charge.

$q \sim [2.142, 5.795]$:
allows non-tidal-disruption process (large q)

Charged CBC must at work to produce the observed GRB

Case 1: Constant Charge —
Contrived conditions needed for a BH to carry very large charge.

Case 2: Increasing Charge —
(Dai 2019)

cCBC with Increasing Charge (NS/BH-BH Merger)

A BH is immersed in the magnetic field of the NS and gains charge via the Wald mechanism (Wald 1974).

BH may reach the maximal Wald charge when it could transit from the electro-vacuum state to the force-free state.

At this point, four possible pre-merger mechanisms generate γ-ray emission:

①first and second magnetic dipole radiation

②second magnetic dipole radiation,

③electric dipole radiation,

④magnetic reconnection close to BH's equatorial plane.

And two possible post-merger mechanisms:

①magnetic reconnection at polar regions

②BZ mechanism.

Dai 2019, Zhong, S.-Q. et al 2019

cCBC with Increasing Charge (Plunging NS-BH Merger)

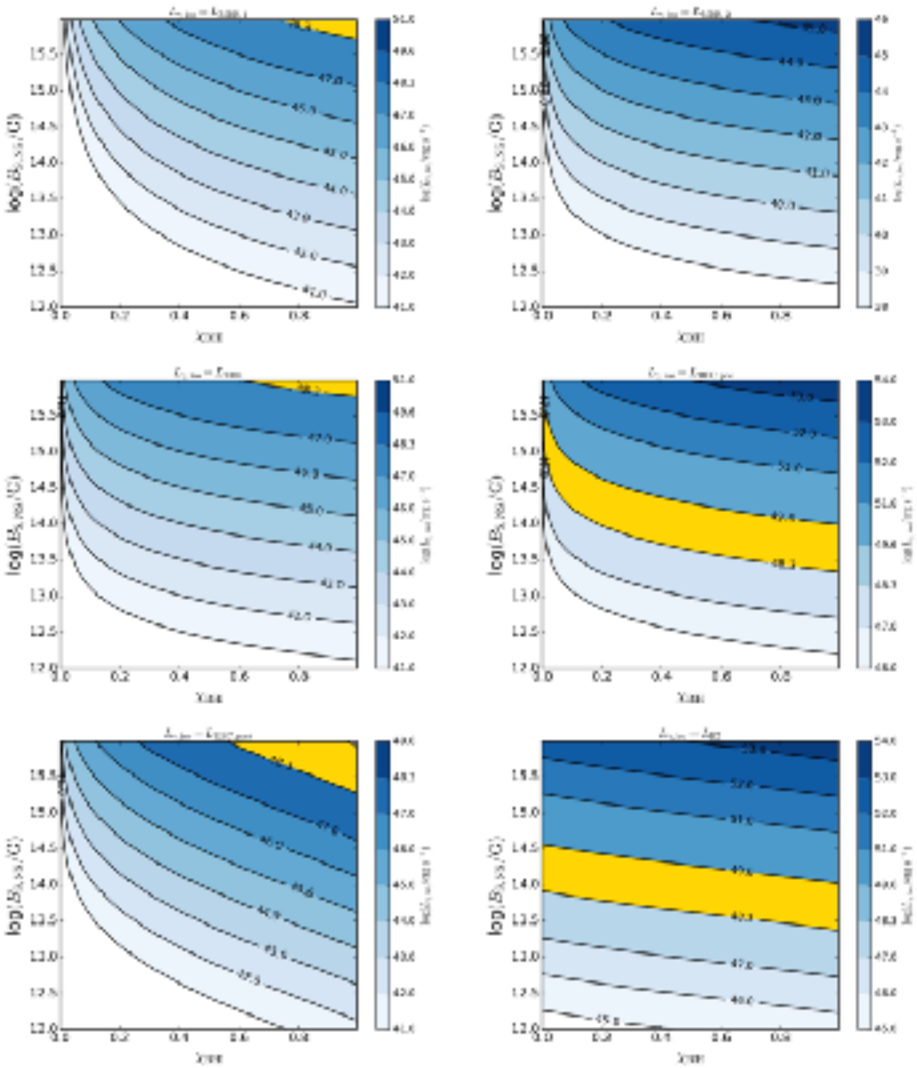
Following Dai (2019) and Zhong et al. (2019), we calculate that the sub-threshold GRB could be produced by the pre-merger magnetic reconnection or the post-merger BZ mechanism if the NS' surface magnetic field $\log(B_{S,NS}/G) > 13.4$ and $\log(B_{S,NS}/G) \sim 13.5 - 14.5$, respectively.

Given the following conditions:

①. The radiative efficiency $\eta_\gamma = 1$,

②. The mass ratio $q = 5.5$,

③. The minimal separation between the BH and the NS $a_{min} = 2GM_{BH}/c^2 + r_{NS}$, and the NS mass $M_{NS} = 1.4\ M_\odot$ and its radius $r_{NS} = 12$ km.



Seems more reasonable

$q \sim [2.142, 5.795]$:
allows non-tidal-disruption process (large q)

Charged CBC must at work to produce the observed GRB for cases 2 & 3

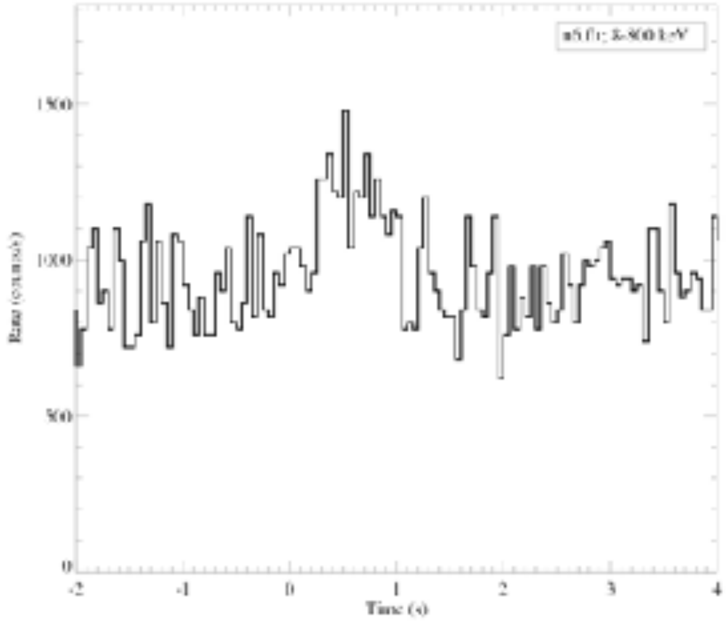
Case 1: Constant Charge —
Contrived conditions needed for a BH to carry very large charge.

Case 2: Increasing Charge —
Seems possible.

The GW-GRB Time Delay

GW

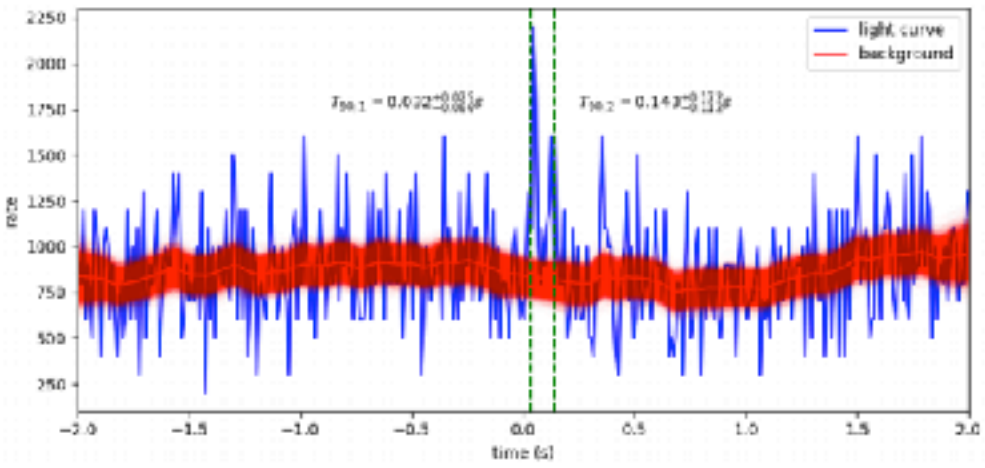
GRB 170817A
Duration: 2 s
Delay: 1.7s



GW

GBM-190816

Duration: 0.1 s
Delay: 1.57s



What can cause the delay?

(1) **Δt_{jet},**

delay time to launch a clean relativistic jet. Includes three parts :

①.The waiting time Δt_{wait} for a central object (BH) to form,

②. The accretion time scale Δt_{acc},

③. time Δt_{clean} for the jet to become clean.

In the case GBM-180916, at least one BH exists in the pre-merger system so Δt_{wait} is 0.
$\Delta t_{clean} \sim 0$ (BH)
Δt_{acc} is typically $\sim$ 10 ms.
So Δt_{jet} is at most 0.01 s.

(2) **Δt_{bo}**

delay time for the jet to break out from the surrounding medium.
For an NS-BH central engine, **Δt_{bo}** is typically **10 ms to 100 ms.**

(3) **Δt_{GRB},**

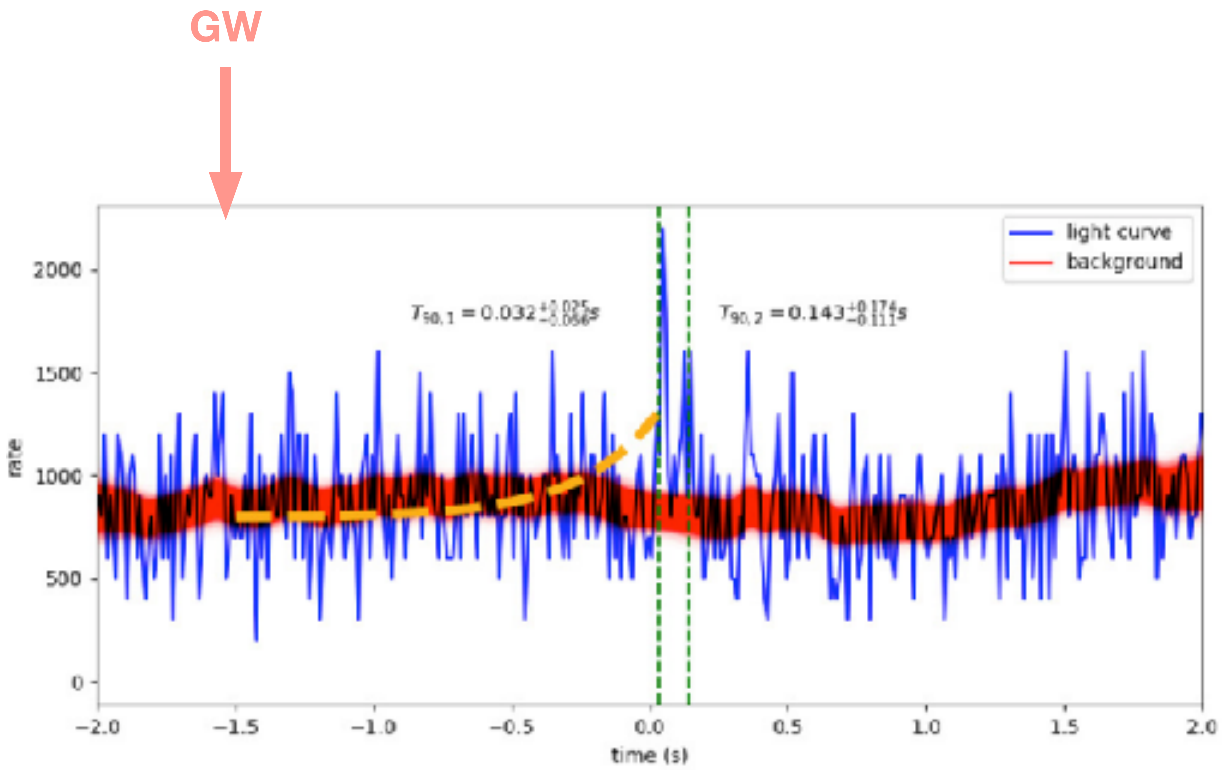
delay time for the jet to reach the energy dissipation and GRB emission site.
$\Delta t_{GRB} = R/2c\Gamma^2$. <— should mostly account for the delay

The GW-GRB Time Delay

Implications:

- GBM-190816's 1.57 s-delay is similar to the 1.7 s-delay in GW170817/GRB 170817A, suggesting Δt_{jet} of ~1.6-1.7 s can be common and due to fact that GRBs happen at large radius (Zhang, B.-B et al 2018, Zhang, B. 2019).

- 0.1 s peak of GBM-190816 seems to be a tip of iceberg



Summary

Table 2. Observational Properties and Derived Constraints of GBM-190816.

Observed Properties	
T_{90} (s)	$0.112^{+0.185}_{-0.085}$
Peak energy E_p (keV)	$94.84^{+111.64}_{-17.94}$
Total fluence(erg cm^{-2})	$7.38^{+6.35}_{-2.51} \times 10^{-8}$
Distance (Mpc)	362 +/− 151
Isotropic energy $E_{\gamma,\rm iso}$ (erg)	$1.14^{+3.18}_{-0.89} \times 10^{48}$
Luminosity $L_{\gamma,\rm iso}$ (erg s^{-1})	$1.02^{+2.84}_{-0.80} \times 10^{49}$
f parameter	$2.58 +/- 0.37$
Assumed Parameters	
Jet core angle $\theta_{c,j}$	assumed 5° (16°)
Viewing angle θ_v	10° − 19° (18° − 24°)
Γ_e	assumed 100
m_2 ($M_\odot$)	assumed 1.4
Derived Constrains	
q from GRB	varies
q from GW	[2.142, 5.795]
m_1 ($M_\odot$)	varies
Intrinsic duration(s)	1.57
Charge of BH (e.s.u.)	[1.75, 2.11] $\times 10^{26}$ (for NS-BH system)
	[1.67, 2.89] $\times 10^{26}$ (for BH-BH system)

1. A confirmed short GRB, potentially with GW.
   (Sub-threshold is just because of it is far)
2. CBC of BH-NS model parameters can be constrained.
3. cCBC is also possible but likely with increasing charge
4. Constant CBC may work better for FRBs.
5. large emission radius can cause the delay

May be the only EM counterpart in O3 so far!

AAS NOVA

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An Explosive Merger ... Maybe

By Susanna Kohler on 5 October 2020 FEATURES

Share:

Artist's illustration of the merger of a black hole with a neutron star. [Carl Knox, OzGrav ARC Centre of Excellence]

GBM-190816

5

May be the only EM counterpart in O3 so far!

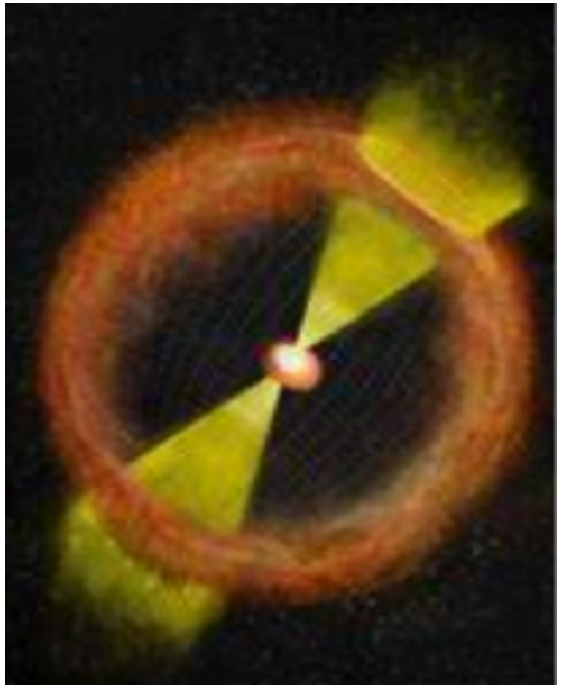
New-Type GRBs

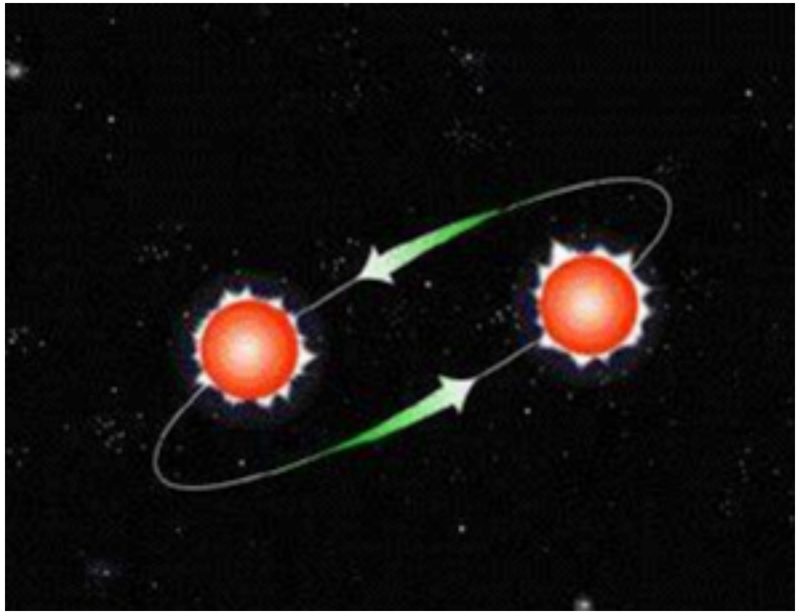
SGR-GF GRBs

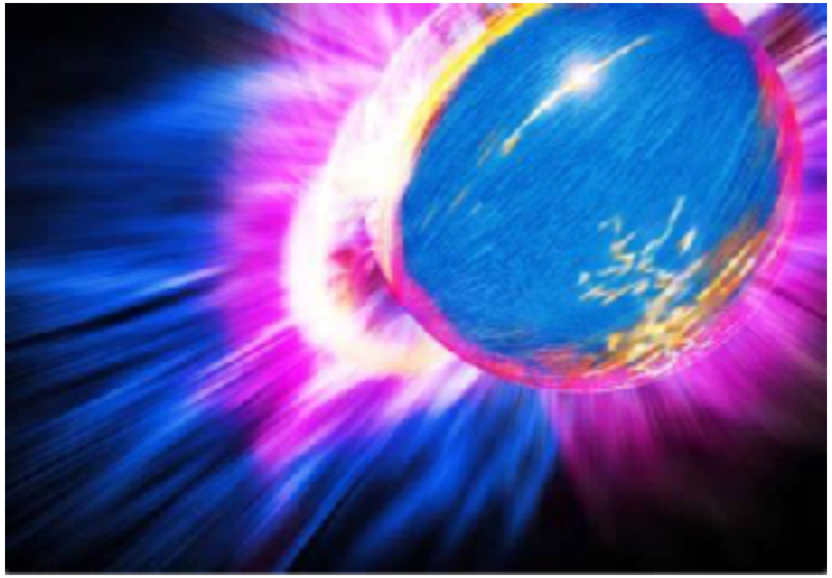
SGR GF GRB 200415A

1st confirmed short GRB that comes from magnetar giant flare

(Not a sGRB from NS-NS, NS-BH merger)

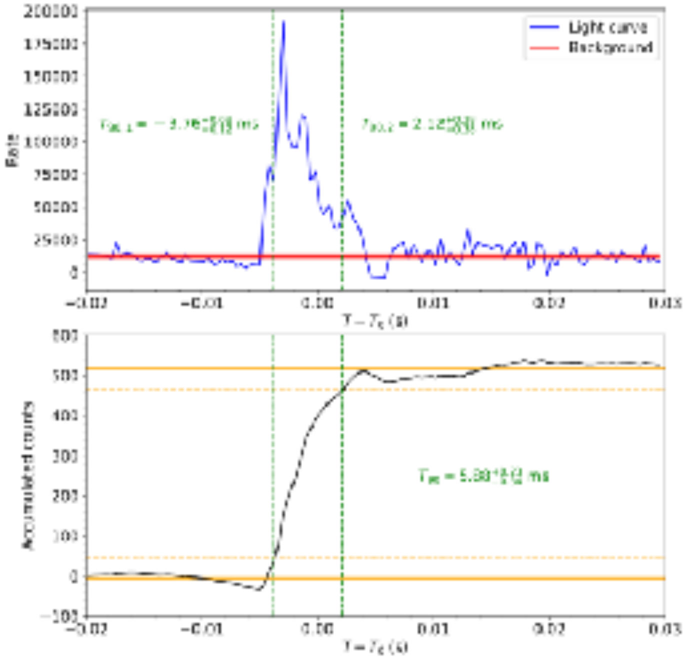






Yang, Jun et al 2020, ApJ

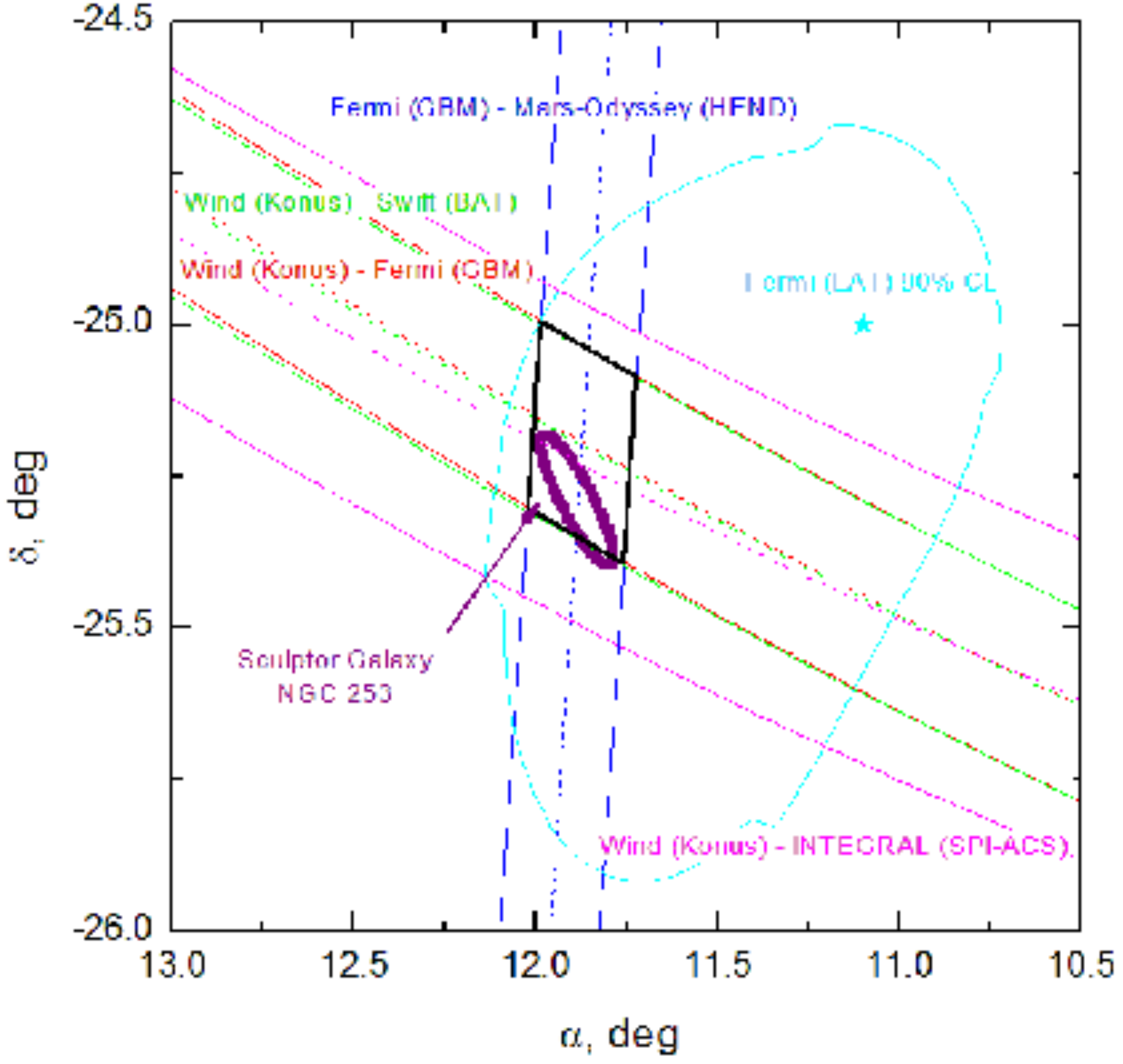
Direct Hint



✓Spatially associated with a nearby galaxy @ 3.5 Mpc

✓Short, Bright, High E_{peak} , LAT detection

Localization



IPN location to the Sculptor galaxy : 5.7 arcmin

Chance probability: 1.3×10^{-5} **(Bloom et al 2002)**

Distance of Sculptor galaxy (NGC 253): 3.5 Mpc

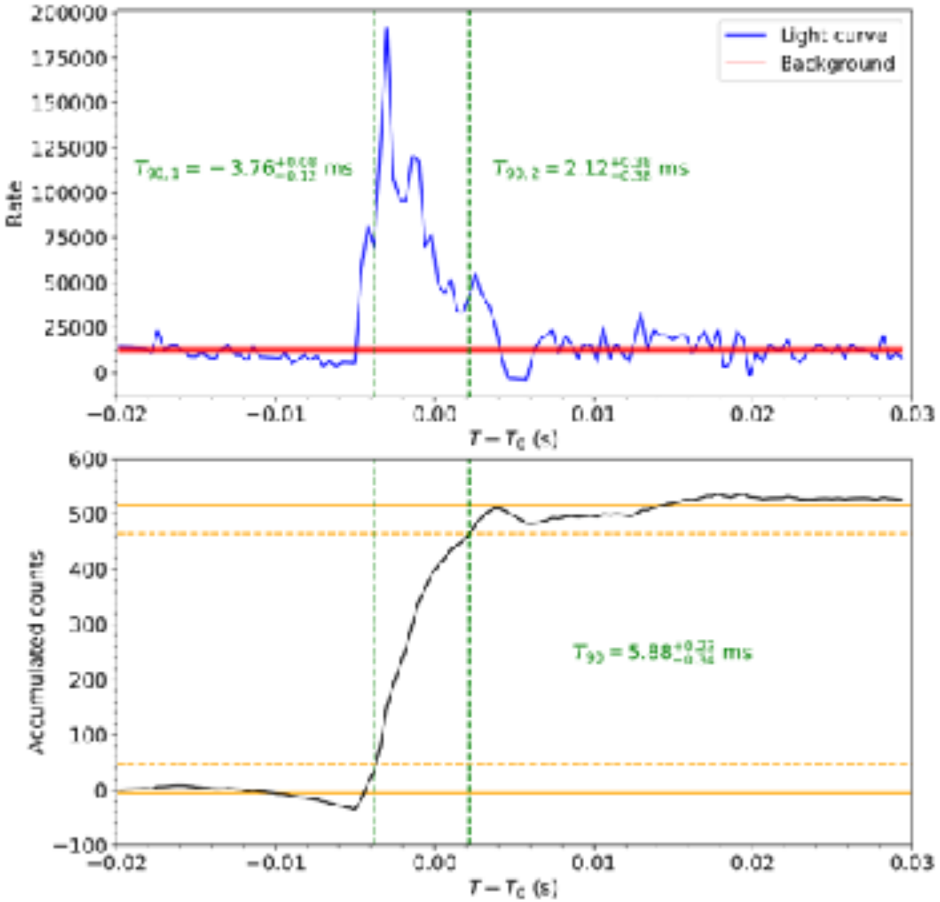
If a typical merger type GRB really happens at 3.5Mpc …

typical sGRB flux 1e-7 cgs at Gpc (z=1)

---- >

at 3 Mpc , flux =   1e-2 cgs ! (brightest ever)

Is GRB 200415A a typical short burst at 3.5 Mpc?



Bright; but not as bright as expected

Plus:

It is very short , energetic and not following the sGRB track!

Observed Properties	GRB 200415A	
Abrupt rise time	~2 ms	
Steep decay time	~8 ms	
T_{90} (sharp peak only)	$5.88^{+0.23}_{-0.34}$ ms	Sharp Spike
Total duration	~200 ms	
Γ_{ph} at peak	$-0.00^{+0.26}_{-0.16}$	
E_p at peak	$1688.27^{+304.76}_{-224.37}$ keV	High Peak Energy
Time-integrated Γ_{ph}	$-0.14^{+0.06}_{-0.06}$	
Time-integrated E_p	$926.68^{+51.78}_{-52.33}$ keV	
Total fluence	$9.29^{+0.92}_{-0.90} \times 10^{-6}$ erg cm^{-2}	
Peak flux	$1.11^{+0.15}_{-0.11} \times 10^{-3}$ erg cm^{-2} s^{-1}	Large Flux at peak
Possible host galaxy	Sculptor galaxy (NGC 253)	
Distance	3.5 Mpc	
Isotropic energy $E_{\gamma,iso}$	$1.36^{+0.14}_{-0.13} \times 10^{46}$ erg	Very Small Energy
Peak luminosity $L_{\gamma,p,iso}$	$1.62^{+0.21}_{-0.16} \times 10^{48}$ erg s^{-1}	

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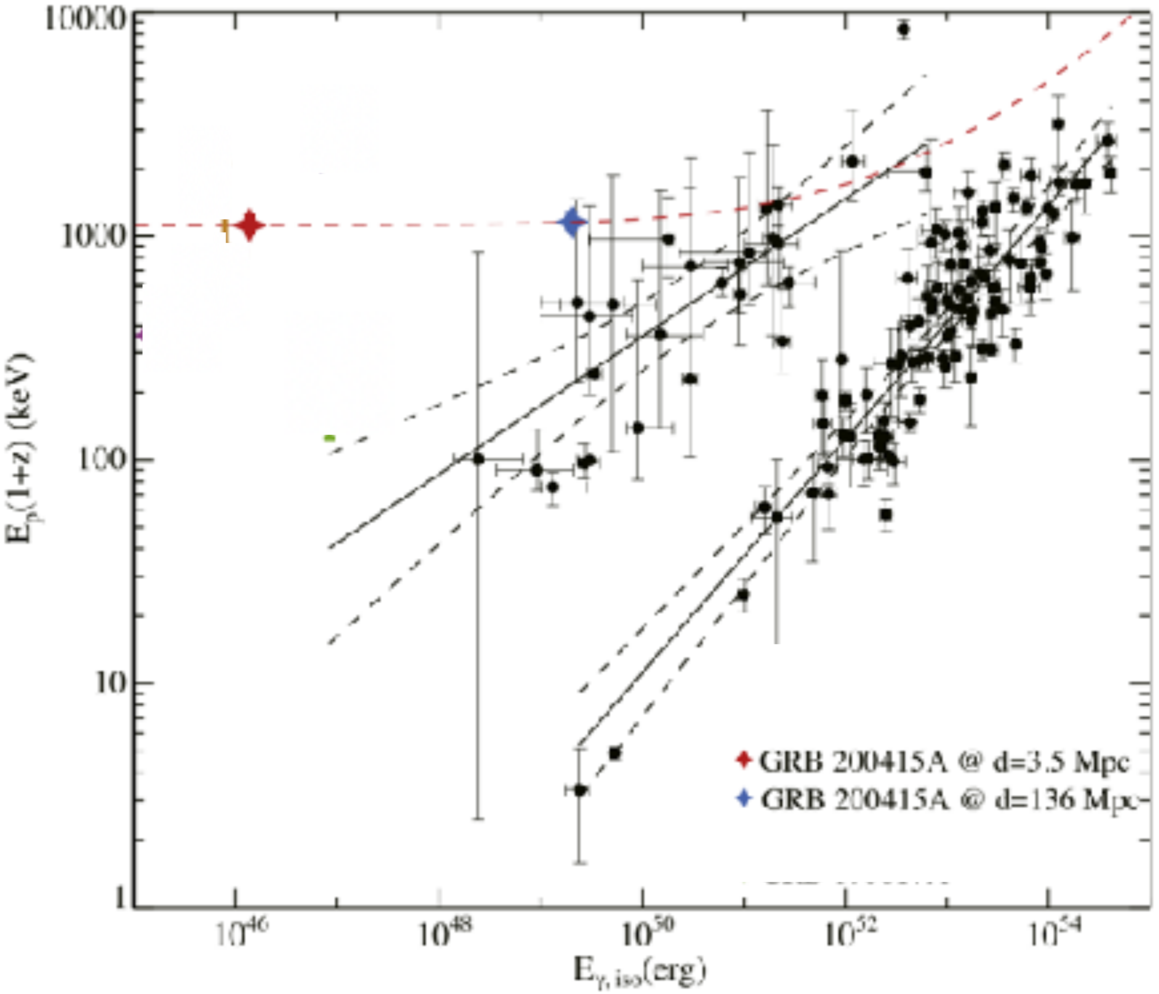
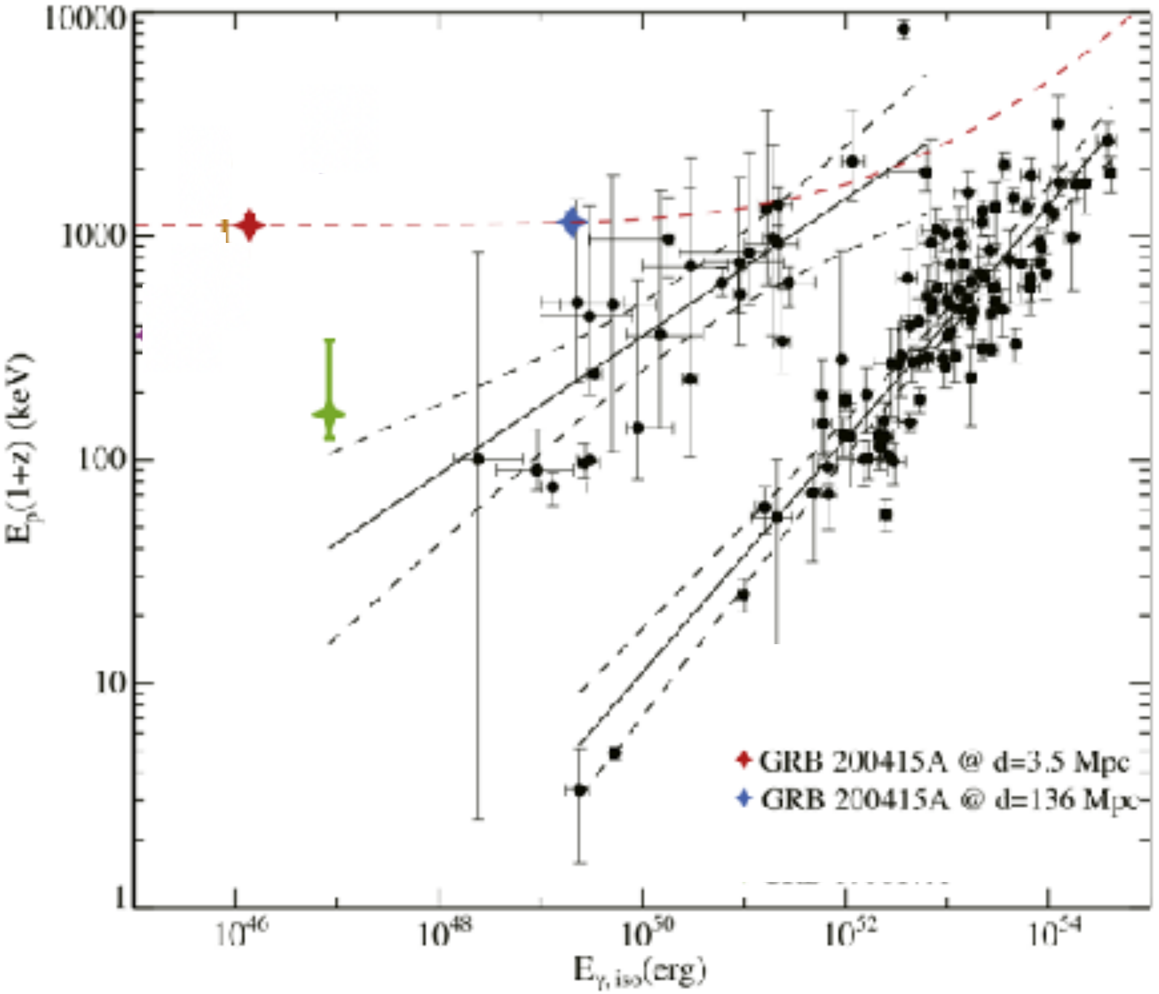
GRB 200415A : Compared with other GRBs



Not typical at all unless you put it 40 times farther

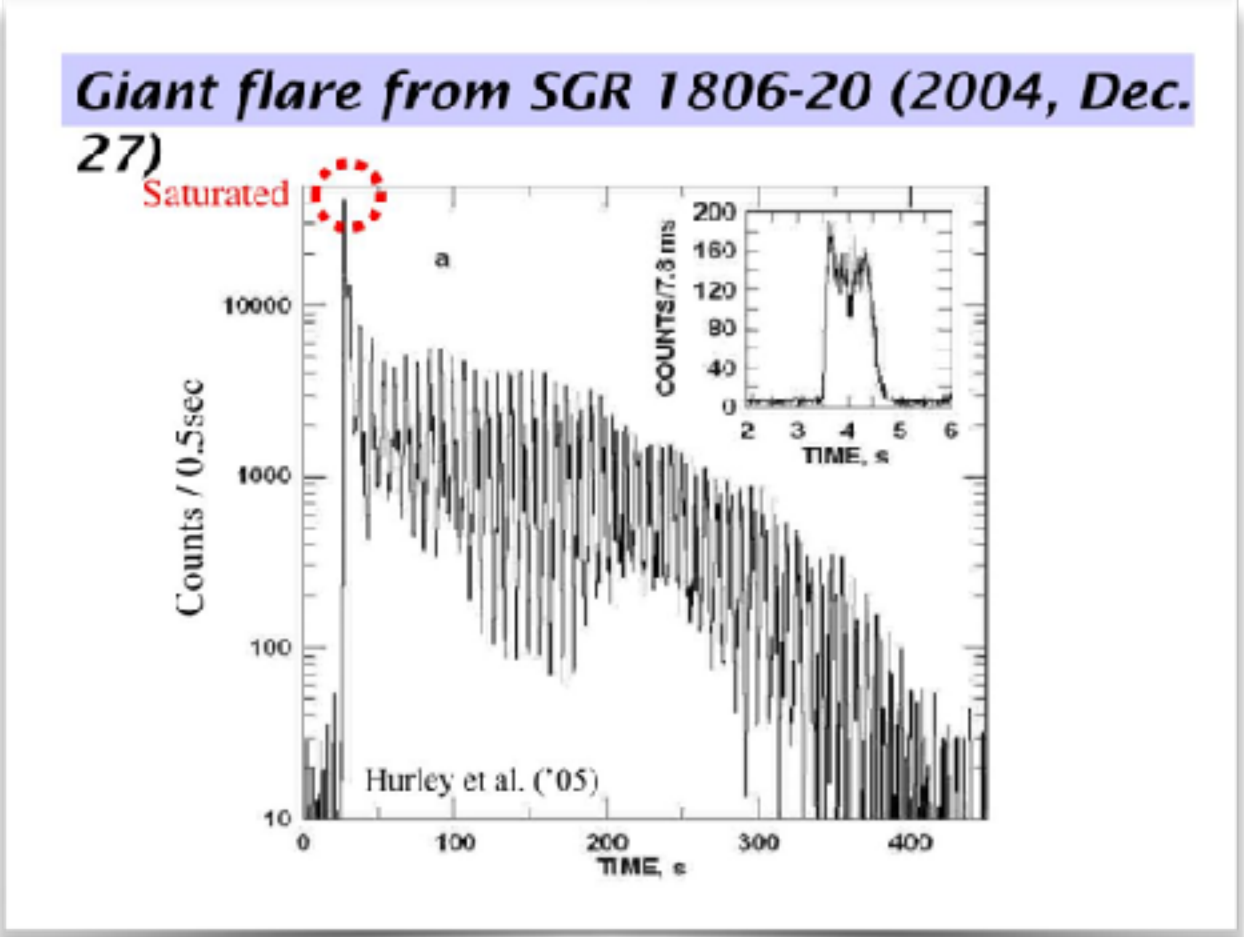
GRB 200415A : Compared with other GRBs



Can it be an off-axis GRB (like GRB 170817A)?

Very difficult because
(1) Very high Ep ~ 1.5 MeV
(2) Very sharp spike of 5 ms

Giant Flare : A Natural Solution



Sharp Spike
Appropriate energy (10^{46} erg)
Similar spectral domain

Giant Flare Sample

Giant Flares	SGR 0526-66	SGR 1900+14	SGR 1806-20	GRB 200415A
Date	1979 March 5	1998 August 27	2004 December 27	
Location	N49	Cluster	Cluster	NGC 253
Distance	53.6 kpc	12.5 kpc	8.7 kpc	3.5 Mpc
Initial pulse				
Duration, s	~ 0.25	~ 0.35	~ 0.2	~ 0.2
Peak luminosity, erg s^{-1}	3.6×10^{44}	3.8×10^{44}	1.19×10^{47}	
Energy, erg	1.6×10^{44}	1.5×10^{44}	7.88×10^{45}	
Tail				
Duration, s	~ 200	~ 400	~ 380 s	
Period, s	8.1	5.15	7.56	
QPO, Hz	43	54, 84, 155	18, 30, 92.5	

Giant Flare GRBs : Previous Attempts

Vol 438 15 December 2005 doi:10.1038/nature04310 **nature**

LETTERS

An origin in the local Universe for some short γ-ray bursts

N. R. Tanvir[1], R. Chapman[1], A. J. Levan[1] & R. S. Priddey[1]

GRB 070201: A POSSIBLE SOFT GAMMA-RAY REPEATER IN M31[1]

E. O. Ofek,[2] M. Muno,[2] R. Quimby,[2] S. R. Kulkarni,[2] H. Stiele,[3] W. Pietsch,[3] E. Nakar,[2] A. Gal-Yam,[4] A. Rau,[2] P. B. Cameron,[2] S. B. Cenko,[2] M. M. Kasliwal,[2] D. B. Fox,[5] P. Chandra,[6,7] A. K. H. Kong,[8,9] and R. Barnard[10]

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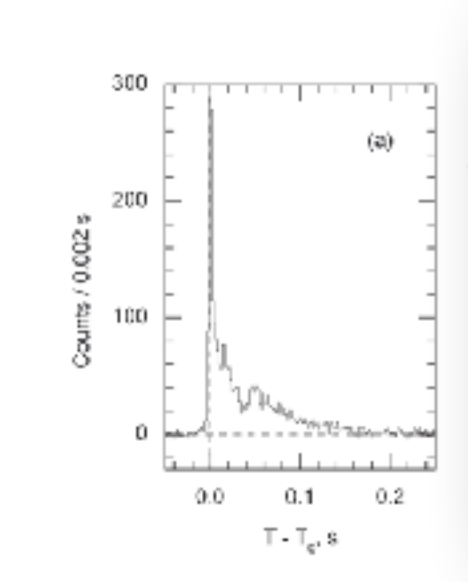
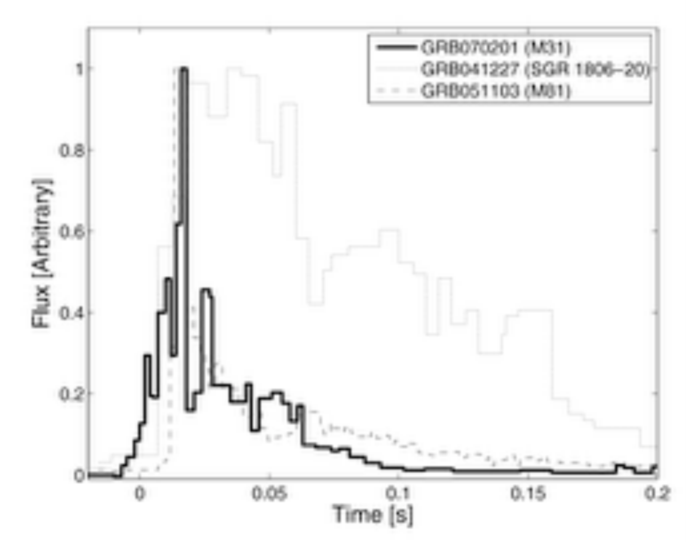
Published: January 2007

On the possibility of identifying the short hard burst GRB 051103 with a giant flare from a soft gamma repeater in the M81 group of galaxies

D. D. Frederiks, V. D. Palshin, R. L. Aptekar, S. V. Golenetskii, T. L. Cline & E. P. Mazets

Astronomy Letters **33**, 19–24(2007) | Cite this article





NO Smoking Gun!

GRB 200415A: unprecedented data and smoking guns!

The Astrophysical Journal, 899:106 (11pp), 2020 August 20
https://doi.org/10.3847/1538-4357/aba745

CrossMark

GRB 200415A: A Short Gamma-Ray Burst from a Magnetar Giant Flare?

Jun Yang[1,2], Vikas Chand[1,2], Bin-Bin Zhang[1,2,3], Yu-Han Yang[1,2], Jin-Hang Zou[4], Yi-Si Yang[1,2], Xiao-Hong Zhao[5,6,7], Lang Shao[4], Shao-Lin Xiong[8], Qi Luo[8,9], Xiao-Bo Li[8], Shuo Xiao[8], Cheng-Kui Li[8], Cong-Zhan Liu[8], Jagdish C. Joshi[1,2], Vidushi Sharma[10], Manoneeta Chakraborty[11], Ye Li[12,13], and Bing Zhang[3]

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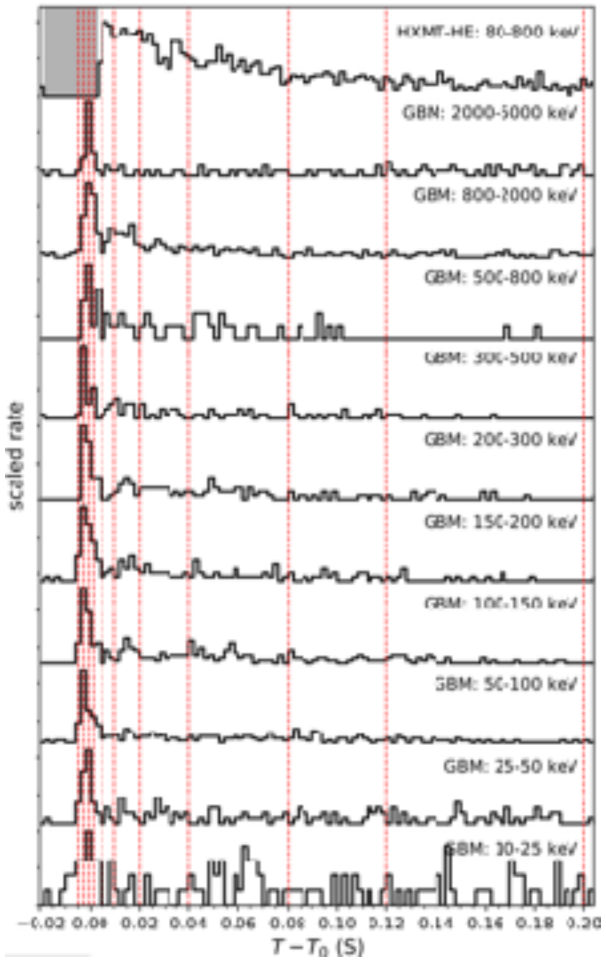
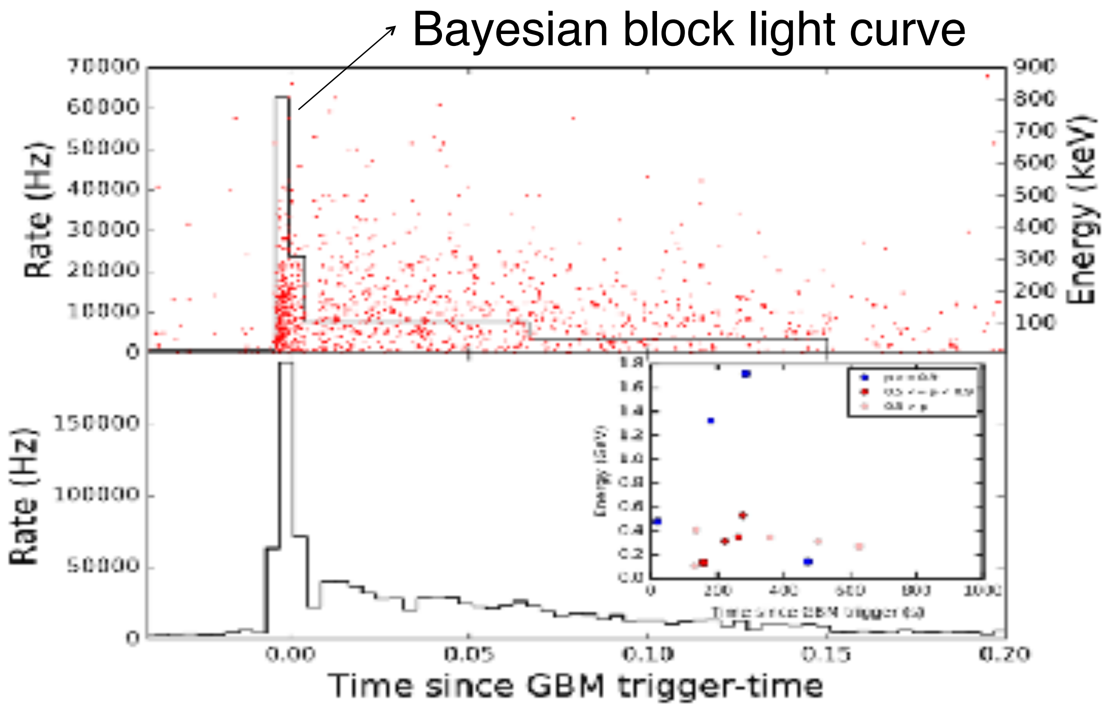
GRB 200415A: Light Curve





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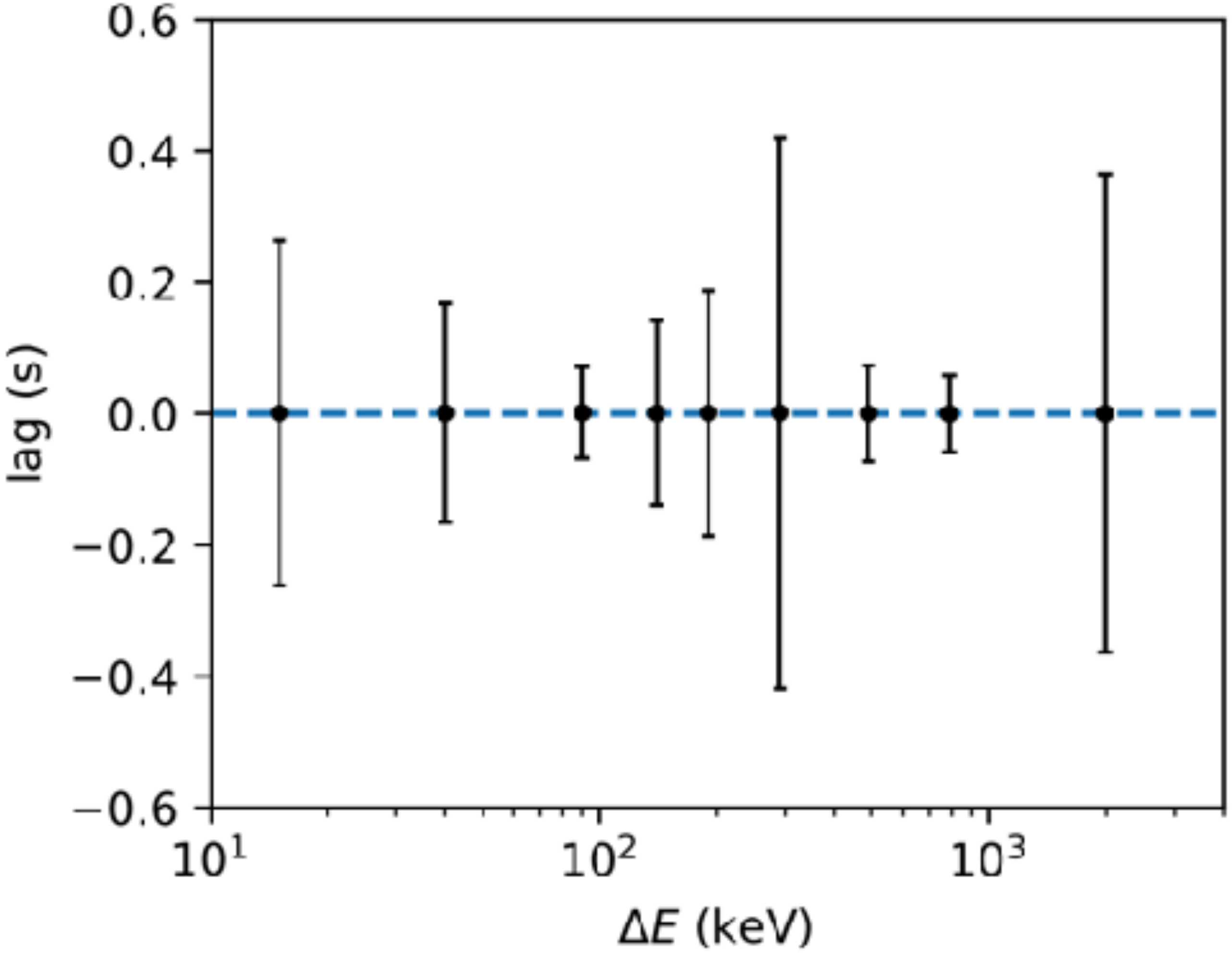
GRB 200415A: Tiny Lags



Emission Region should be one-time fireball-like.

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GRB 200415A: Time-Dependent Spectral Analysis

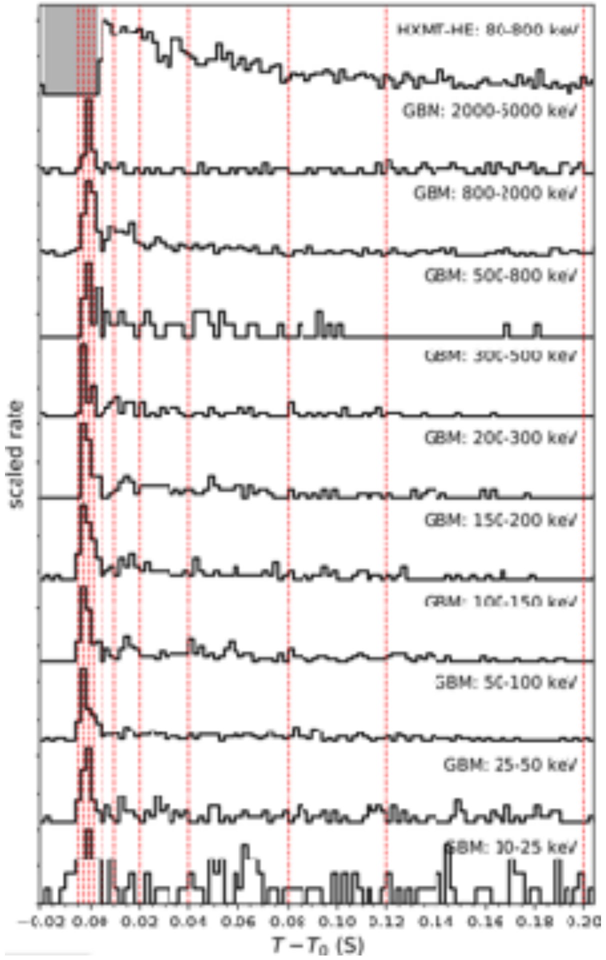

Table 1
Both Time-integrated and Time-dependent Spectral Fittings of GRB 200415A

Time Intervals (t_1, t_2) (s)	Best Model	Flux (erg cm^{-2} s^{-1})	mBB Parameters kT_{min} (keV)	kT_{max} (keV)	m	pgstat/dof	BIC
(−0.005, 0.005)	mBB	4.22×10^{-4}	29.40	800.00	−0.33	270.5/350	302.01
(0.005, 0.200)	CPL	2.39×10^{-5}	27.95	399.83	0.36	277.8/350	301.38
(−0.005, 0.200)	mBB	4.53×10^{-5}	34.24	542.61	−0.00	279.9/350	303.34
(−0.005, −0.003)	CPL	1.99×10^{-6}	43.32	402.21	−1.18	193.1/350	215.55
(−0.003, −0.001)	mBB	4.10×10^{-6}	47.96	539.31	−0.85	206.5/350	231.96
(−0.001, 0.001)	CPL	6.61×10^{-4}	42.29	789.59	0.45	221.1/350	244.28
(0.001, 0.005)	BB	1.79×10^{-5}	94.08	553.12	−0.76	206.2/350	229.64
(0.005, 0.010)	BB	1.27×10^{-4}	68.85	298.35	1.64	177.1/350	200.60
(0.010, 0.020)	CPL	1.16×10^{-4}	77.42	325.41	0.63	218.4/350	241.91
(0.020, 0.040)	BB	5.07×10^{-5}	98.51	273.80	0.81	194.2/350	217.66
(0.040, 0.080)	CPL	3.76×10^{-5}	34.31	269.64	0.81	257.4/350	280.83
(0.080, 0.120)	BB	8.38×10^{-6}	48.89	221.48	−0.85	195.2/350	218.67
(0.120, 0.200)	PL	3.78×10^{-5}		Unconstrained			

Time Intervals (t_1, t_2) (s)	CPL Parameters Γ_{ph}	E_p (keV)	pgstat/dof	BIC	BB Parameters kT (keV)	pgstat/dof	BIC
(−0.005, 0.005)	−0.28	1118.09	300.2/351	317.73	146.45	458.4/352	470.10
(0.005, 0.200)	−0.01	828.43	279.1/351	296.68	143.09	385.3/352	397.05
(−0.005, 0.200)	−0.14	928.68	292.3/351	309.92	142.12	333.5/352	345.23
(−0.005, −0.003)	0.30	393.53	196.6/351	214.18	82.23	205.5/352	217.19
(−0.003, −0.001)	0.01	609.43	217.7/351	235.26	97.81	237.5/352	249.27
(−0.001, 0.001)	−0.00	1698.27	222.6/351	240.22	289.57	241.2/352	252.97
(0.001, 0.005)	0.60	857.28	206.6/351	226.25	182.55	212.4/352	224.10
(0.005, 0.010)	1.07	847.10	176.4/351	194.05	233.18	177.0/352	188.73
(0.010, 0.020)	0.53	907.19	220.4/351	238.05	202.23	227.9/352	239.66
(0.020, 0.040)	0.63	743.53	194.6/351	212.19	168.98	198.8/352	210.55
(0.040, 0.080)	0.31	676.50	257.9/351	275.50	139.09	273.9/352	285.62
(0.080, 0.120)	0.65	374.23	196.4/351	214.00	85.80	199.0/352	210.70
(0.120, 0.200)		Unconstrained				Unconstrained	

Note. The CPL model can be expressed as $N(E) = AE^{\Gamma_{ph}} \exp[-E(2+\Gamma_{ph})/E_p]$. The PL model gives an acceptable fit in the time slice between $T_0 + 0.12$ and $T_0 + 0.20$ s: $\Gamma_{ph} = -1.44^{+0.11}_{-0.30}$, pgstat/dof = 179.2/352, BIC = 190.96. Flux is derived based on the best model within 10–10,000 keV for each slice. Here the errors correspond to the 1σ credible intervals.

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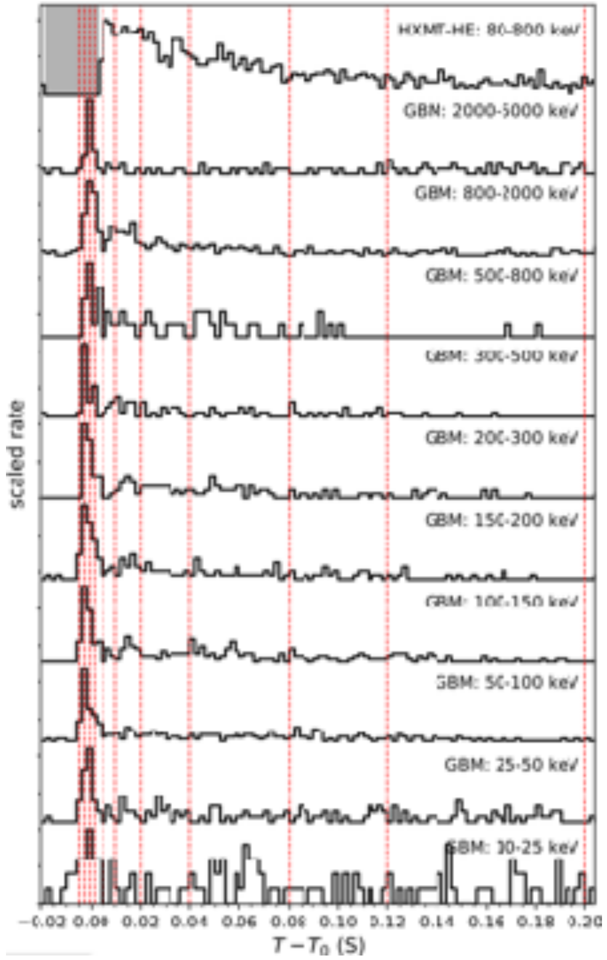
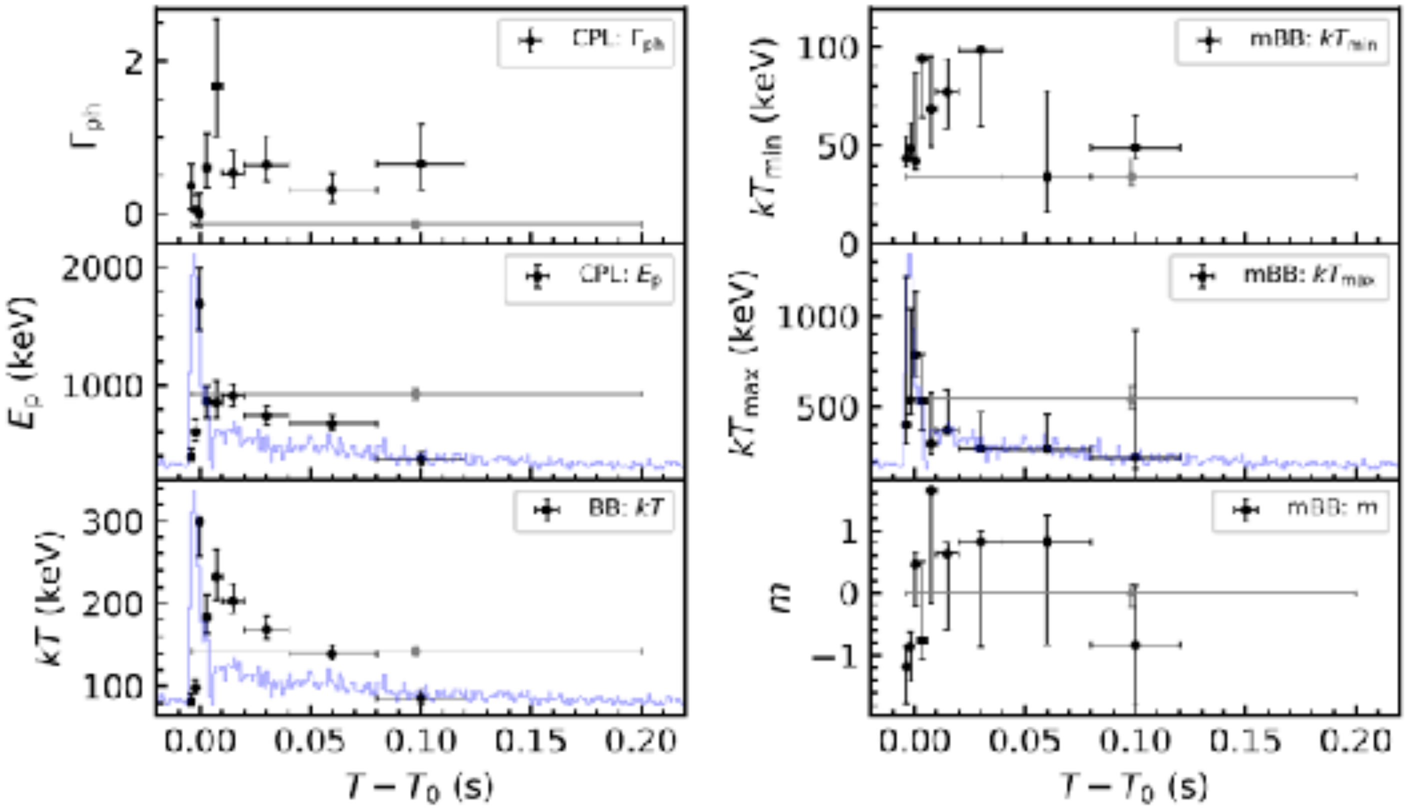
GRB 200415A: Time-Dependent Spectral Evolution





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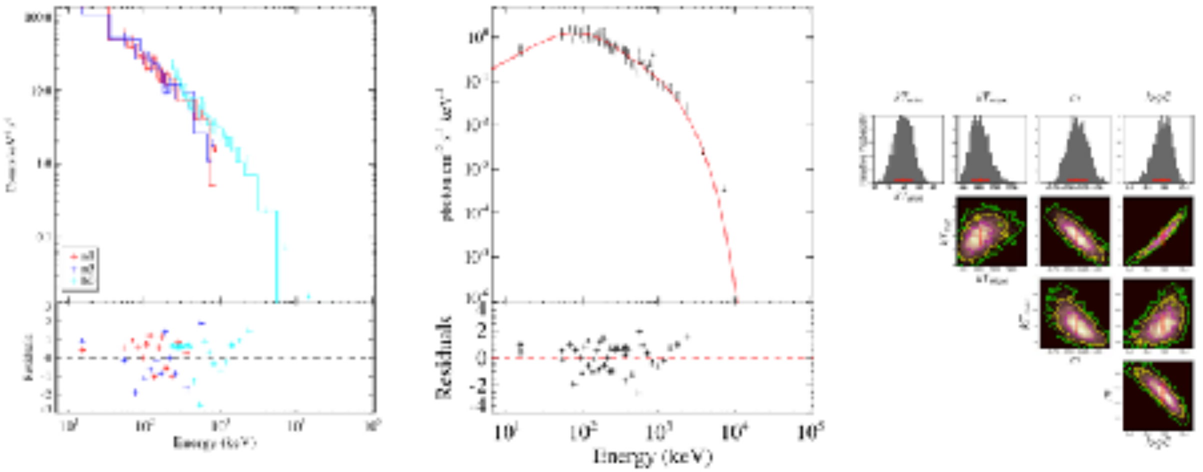
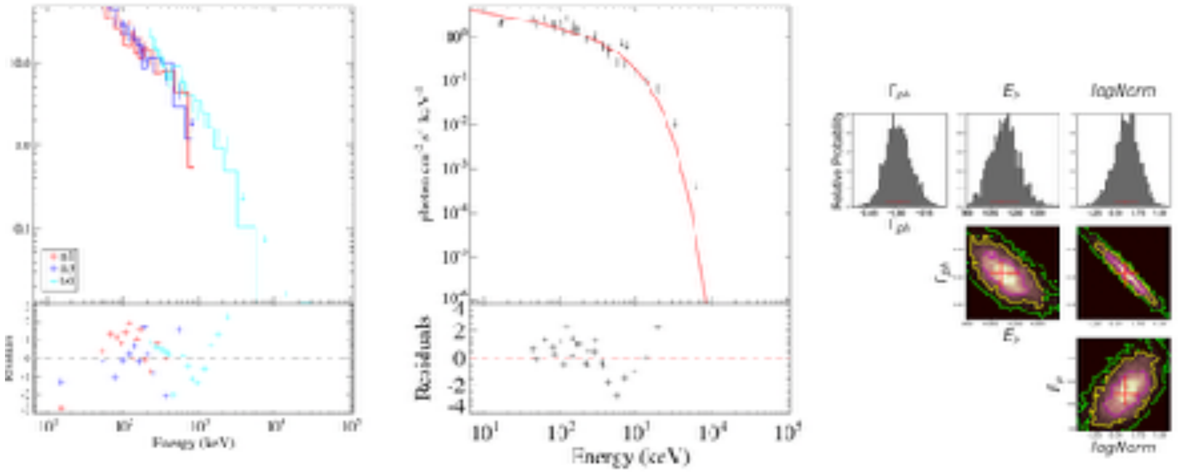
GRB 200415A: Time-Dependent Spectral Constraints



mBB



CPL

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GRB 200415A: Summary of Properties

Observed Properties	GRB 200415A
Abrupt rise time	$\sim$2 ms
Steep decay time	$\sim$8 ms
T_{90} (sharp peak only)	$5.88^{+0.23}_{-0.34}$ ms
Total duration	$\sim$200 ms
$\Gamma_{\rm ph}$ at peak	$-0.00^{+0.26}_{-0.16}$
$E_{\rm p}$ at peak	$1688.27^{+304.76}_{-224.37}$ keV
Time-integrated $\Gamma_{\rm ph}$	$-0.14^{+0.06}_{-0.06}$
Time-integrated $E_{\rm p}$	$926.68^{+51.78}_{-52.33}$ keV
Total fluence	$9.29^{+0.92}_{-0.90} \times 10^{-6}$ erg cm^{-2}
Peak flux	$1.11^{+0.15}_{-0.11} \times 10^{-3}$ erg cm^{-2} s^{-1}
Possible host galaxy	Sculptor galaxy (NGC 253)
Distance	3.5 Mpc
Isotropic energy $E_{\gamma,\rm iso}$	$1.36^{+0.14}_{-0.13} \times 10^{46}$ erg
Peak luminosity $L_{\gamma,\rm p,iso}$	$1.62^{+0.21}_{-0.16} \times 10^{48}$ erg s^{-1}

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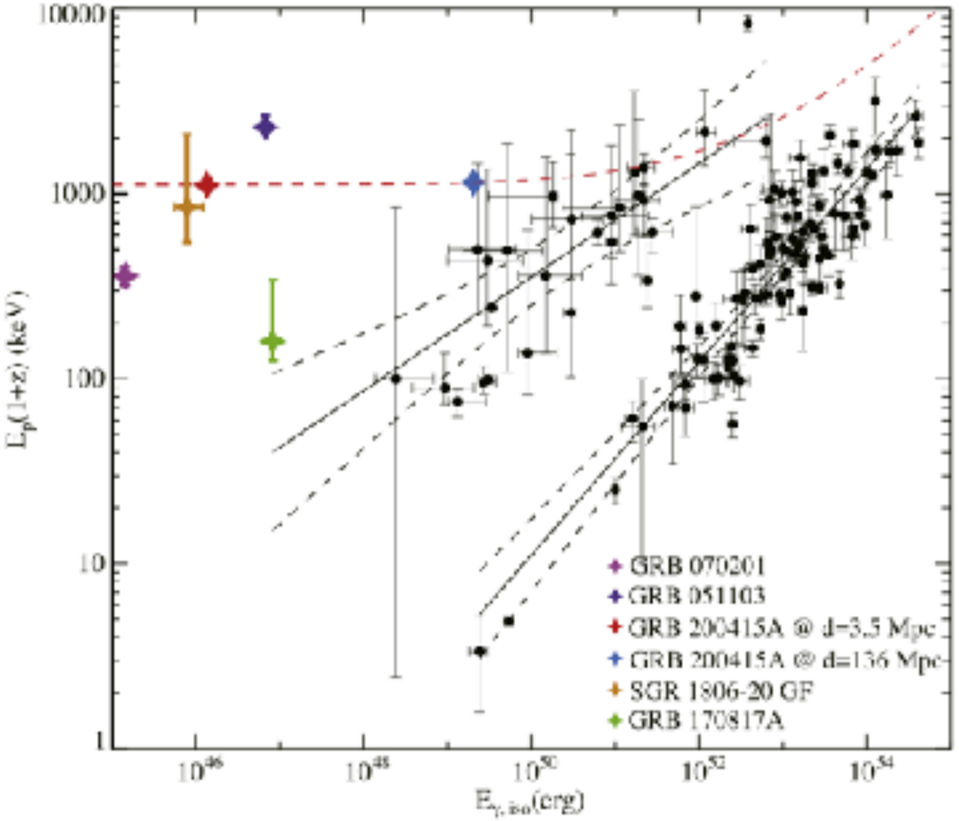
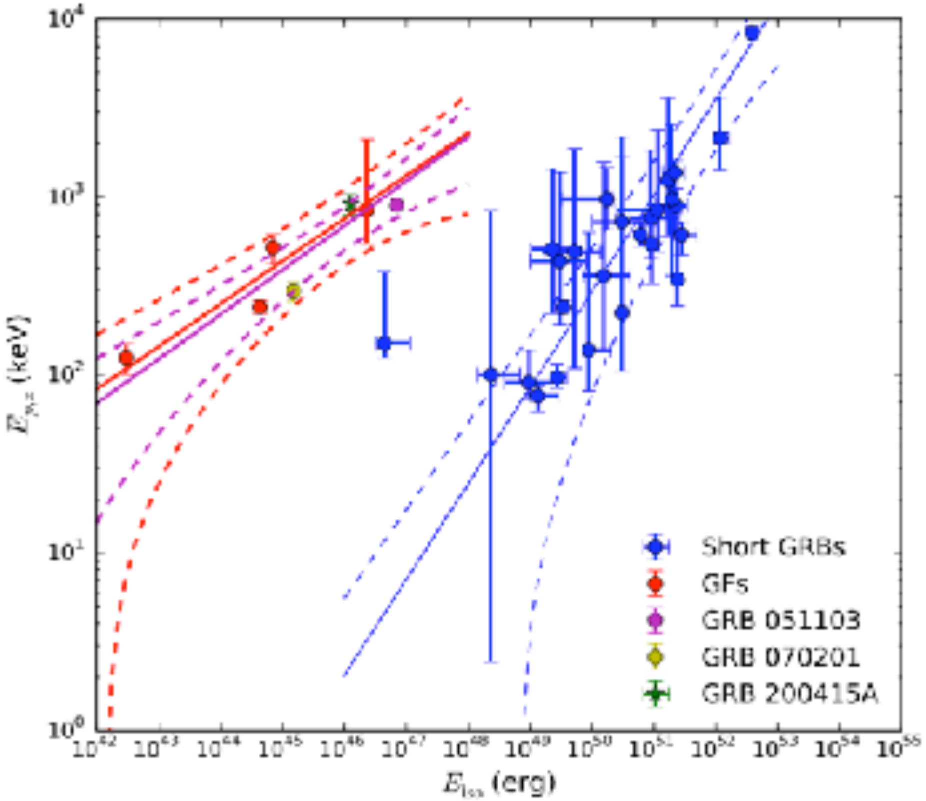
GRB 200415A: Comparison with Other GF GRB Candidates

Properties	GRB 200415A	SGR 1806–20 GF	GRB 051103	GRB 070201
Location	NGC 253	Massive star cluster	M81	M31
Distance	3.5 Mpc	8.7 kpc	3.6 Mpc	0.78 Mpc
Initial Pulse				
Steep rise, ms	$\sim$2	$\sim$1	$\lesssim$6	$\sim$20
Decay, ms	$\sim$8	$\sim$200	$\sim$40	$\sim$160
Rapid spectral evolution	✓	✓	✓	✓
CPL photon index Γ_{ph}	$-0.28^{+0.06}_{-0.08}$	$-0.73^{+0.64}_{-0.47}$	$0.16^{+0.19}_{-0.15}$	$-0.52^{+0.15}_{-0.13}$
CPL peak energy, keV	$1118.09^{+113.39}_{-75.49}$	850^{+1259}_{-303}	2300^{+350}_{-150}	360^{+44}_{-38}
BB temperature, keV	$140.45^{+8.48}_{-6.83}$	175 ± 25, 116	...	...
Peak flux, erg cm^{-2} s^{-1}	$1.11^{+0.15}_{-0.11} \times 10^{-3}$	$\sim$5.0, $13.1^{+8.0}_{-4.4}$	$(2.8 \pm 0.3) \times 10^{-3}$	$1.61^{+0.29}_{-0.50} \times 10^{-3}$
Peak luminosity, erg s^{-1}	$1.62^{+0.21}_{-0.16} \times 10^{48}$	$0.45(1.19) \times 10^{47}$	$(4.34 \pm 0.46) \times 10^{48}$	1.2×10^{47}
Tail				
Tail duration	$\sim$150 ms	$\sim$380 s	$\sim$130 ms	$\sim$100 ms
Period, s	...	7.56	...	...
QPO	...	✓	...	...
BB temperature, keV	$143.09^{+5.27}_{-5.38}$	$\sim$30	...	...
CPL photon index Γ_{ph}	$-0.01^{+0.09}_{-0.08}$	...	$0.43^{+0.34}_{-0.40}$	$\sim(-1)$
CPL peak energy, keV	$826.43^{+59.65}_{-52.00}$	...	530 ± 80	$\sim$125
Fluence, erg cm^{-2}	$5.44^{+0.63}_{-0.52} \times 10^{-6}$	8×10^{-3}	$(2 \pm 0.3) \times 10^{-6}$	$\sim 10^{-6}$
Total fluence, erg cm^{-2}	$9.29^{+0.92}_{-0.90} \times 10^{-6}$	$0.87^{+0.50}_{-0.24}$	$(4.4 \pm 0.5) \times 10^{-5}$	$2^{+0.10}_{-0.26} \times 10^{-5}$
Total energy, erg	$1.35^{+0.14}_{-0.13} \times 10^{46}$	$7.88^{+4.53}_{-2.17} \times 10^{45}$	$(6.82 \pm 0.78) \times 10^{46}$	$1.5^{+0.07}_{-0.19} \times 10^{45}$
References		Hurley et al. (2005) Frederiks et al. (2007a)	Frederiks et al. (2007b) Ofek et al. (2006)	Mazets et al. (2008) Ofek et al. (2008)

GRB 200415A: Amati Relation

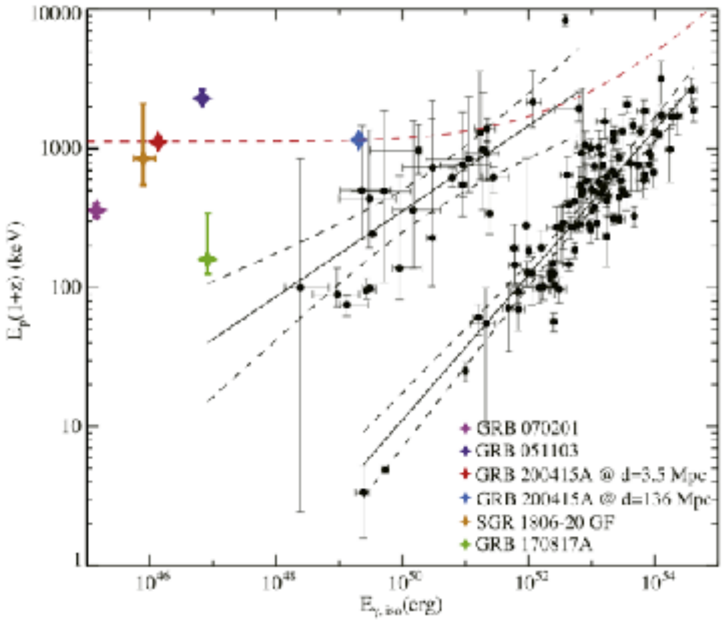


Yang, Jun, Vikas Chanda, BBZ et al. 2020 ApJ, 899, 106

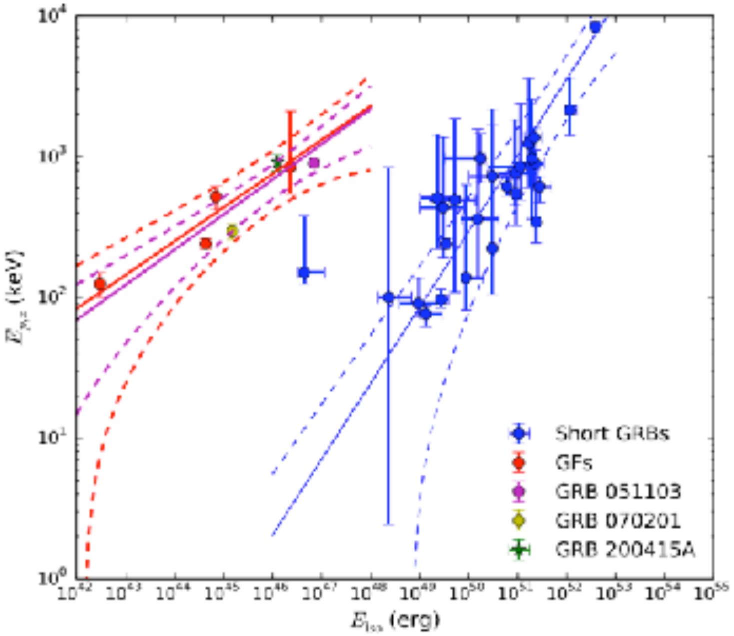


Zhang, H.-M. et al. , ApJL

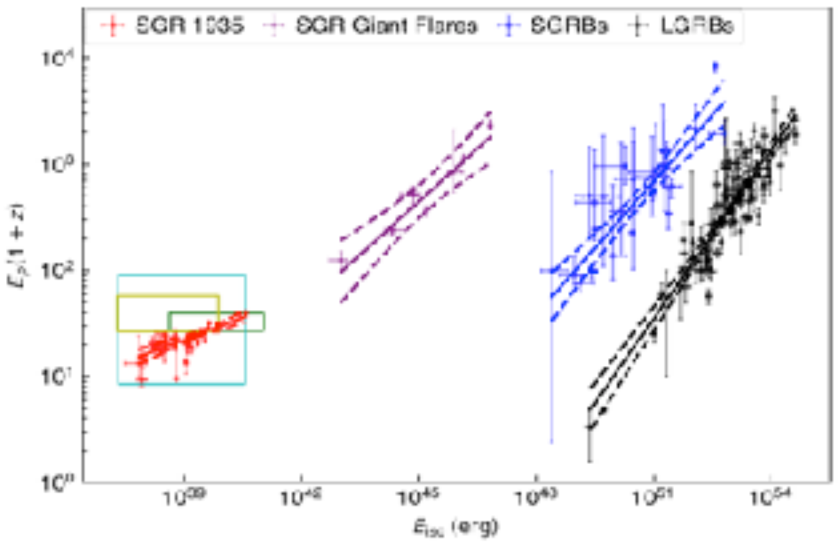
GRB 200415A: Amati Relation



Yang, Jun, et al . 2020 ApJ,

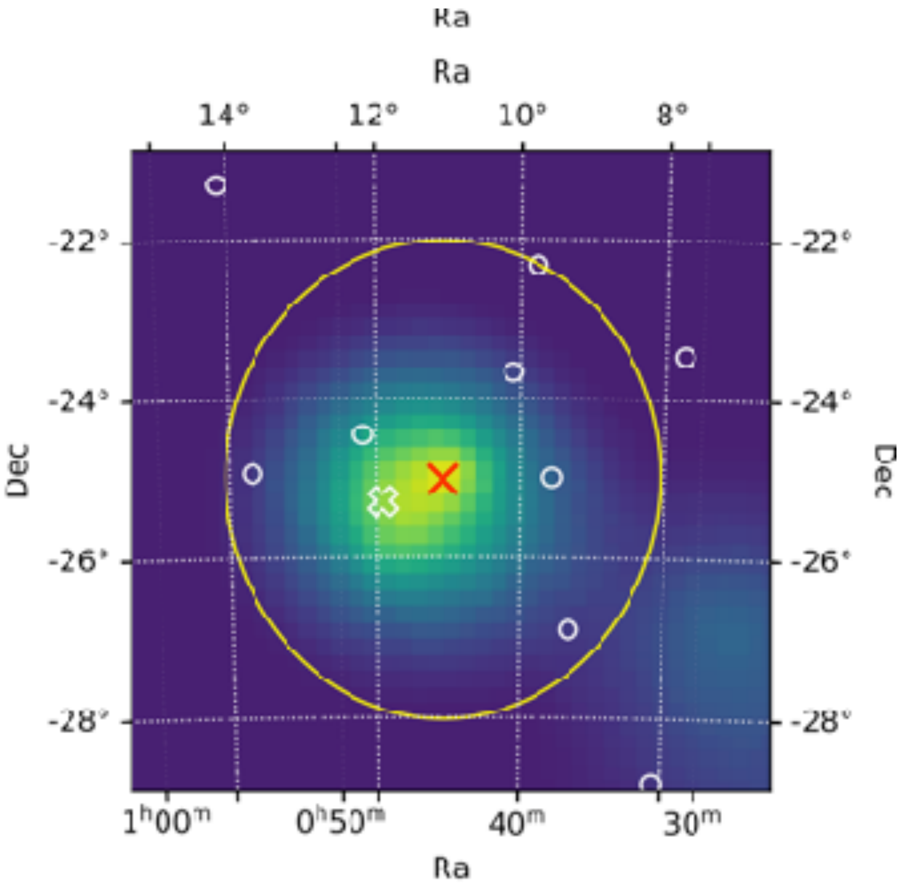


Zhang, H.-M. et al. , ApJL

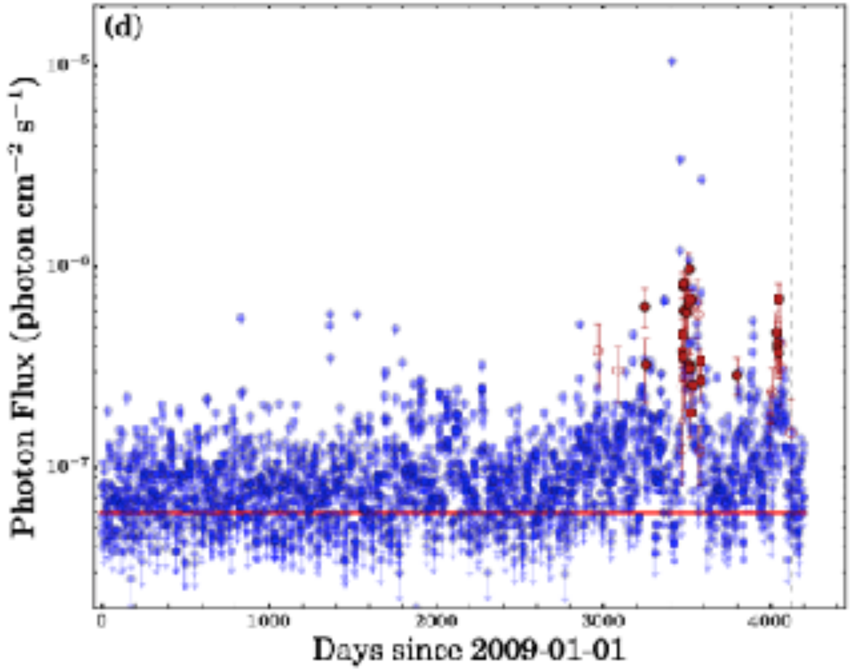


Yang, Y.-H. et al. , ApJL submitted

GRB 200415A: LAT Emissions



GeV afterglow of the GF



Vikas Chand et al., 2020, ApJ Submitted, arxiv 2008.10822

GRB 200415A: Benchmark

Properties	GF	sGRB
Location	√	
Tiny spectral lag	√	
Significant thermal spectra	√	
Spectral evolution parttern	√	
Similar to giant flare and its candidates	√	
Inconsistent with other short GRBs and contrived jet conditions		×
Small duration, energy, radius of emission region	√	
Significant outlier away from the short GRB track		×

GRB 200415A: Connection to GF Theory

Starquake model: the instability of the interior magnetic field ruptures the magnetar crust. The crossing time of Alfvén wave is $T_{spike} \gtrsim R_{NS}/V_A \gtrsim$ 0.1 s (Feroci et al. 2001).

Magnetospheric instability model: the large-scale magnetic reconnection event will last $10^2 R_{NS}/c \sim 10^{-2}$ s (Parfrey et al. 2013).

The expected expanding fireball emission is consistent with the spectral lag result and spectral evolution pattern.

The radius of the emission source is calculated to be 27.80 km, which is similar to previous studies (e.g., Nakar et al. 2005; Ofek et al. 2006, 2008).

The magnetic field can be constrained to be $\lesssim 2 \times 10^{15}$G via $B(R_{NS} + \Delta R) \lesssim \left(\frac{8\pi E_{\gamma,iso}}{3\Delta R^3} \right)^{1/2}$

(Thompson & Duncan 1995).

Additional Smoking Guns?

GRB 200415A: Additional Smoking Guns?

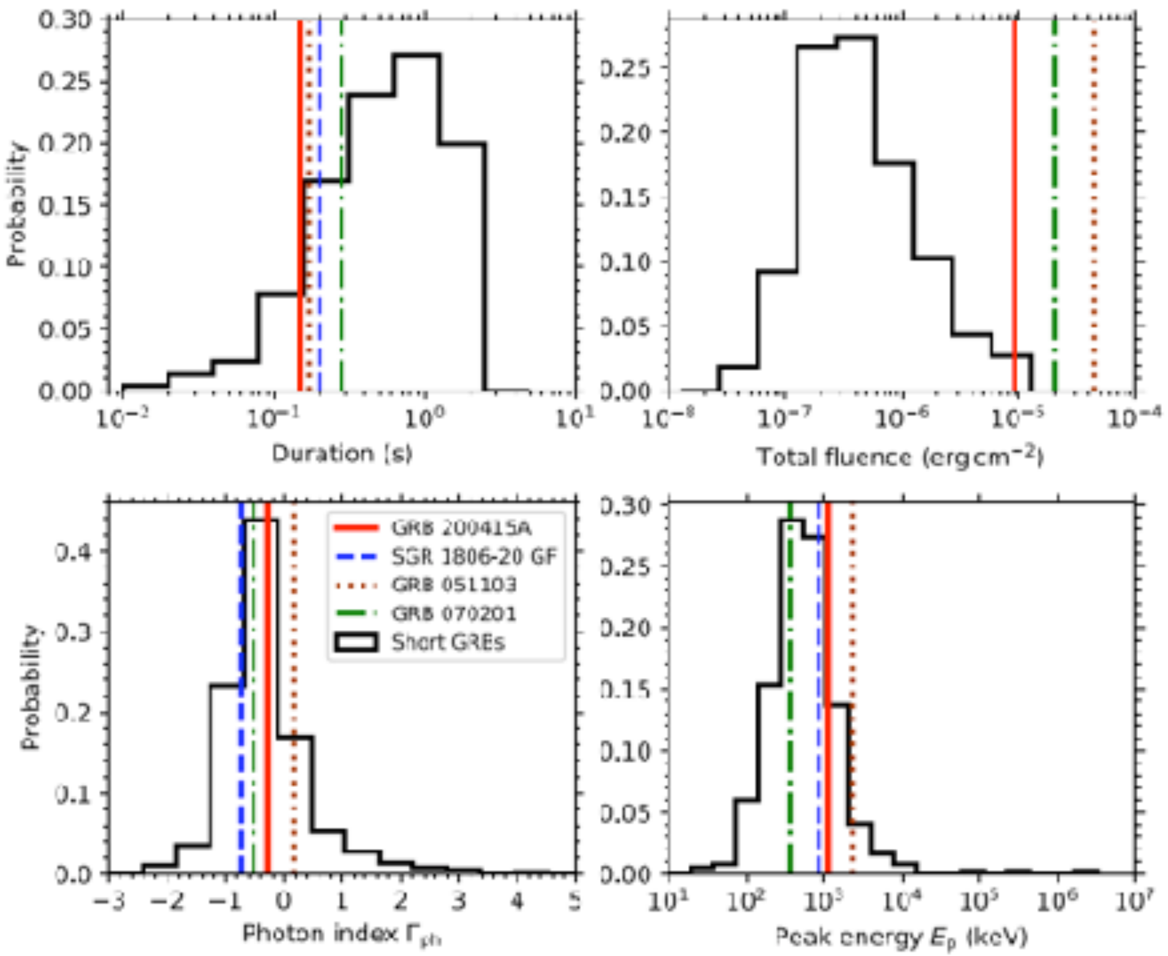
Yes!

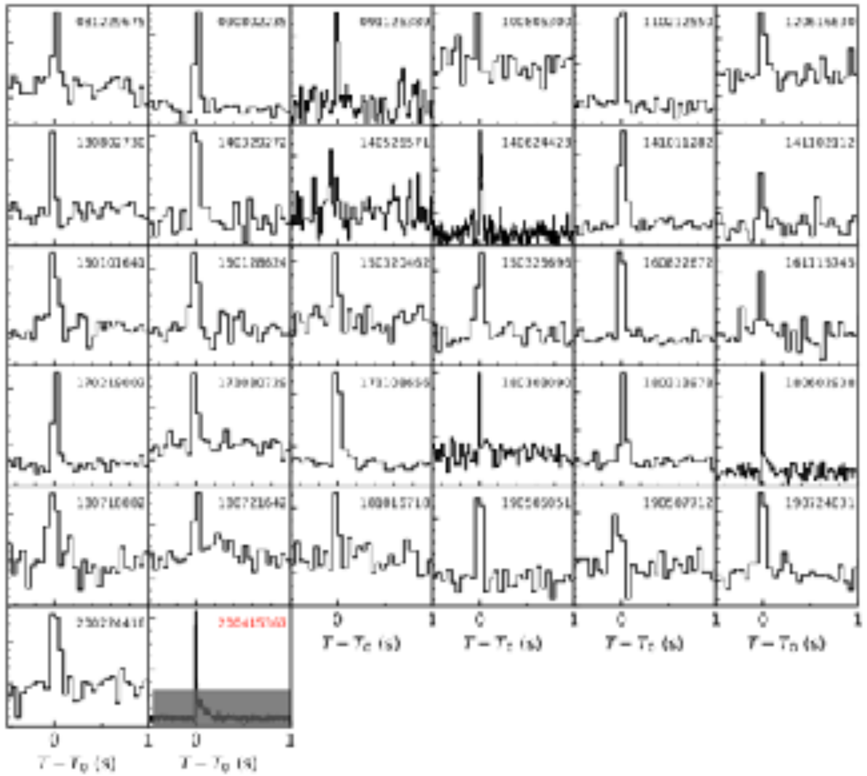
A few Nature papers in press (review).

Additional Cases?

Additional Cases?

Yes!

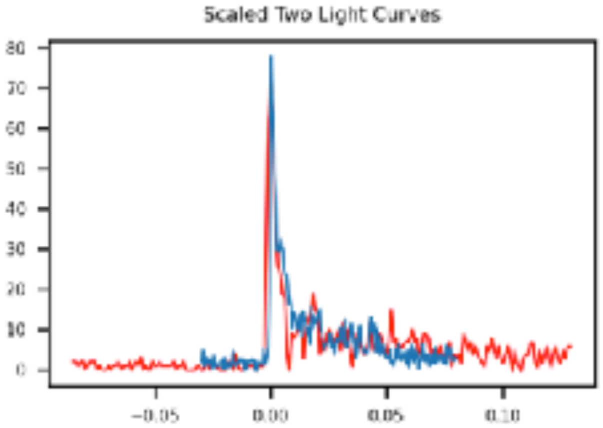


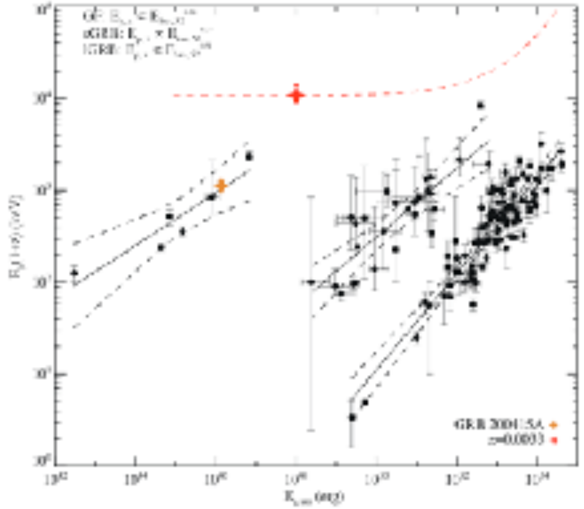


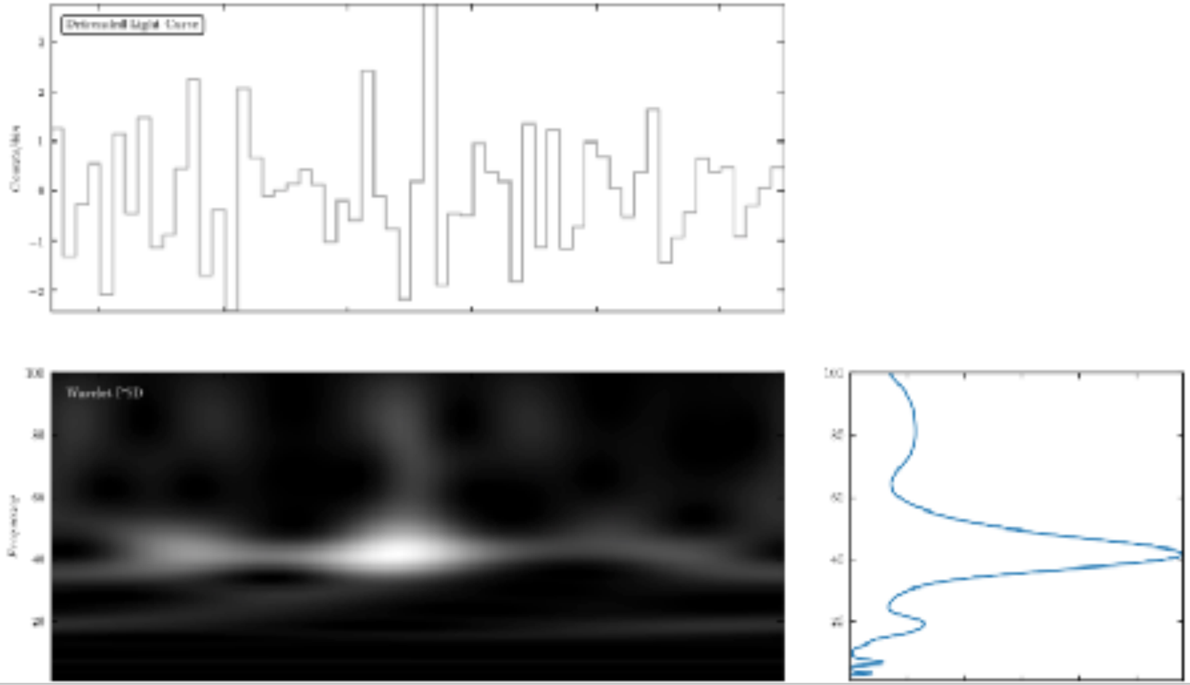
Yang, Y.-S. et al in prep.

Additional Cases?

Yes!







Yang, Y.-S. et al in prep.

New Type **Unusual** GRBs

Trouble Makers:

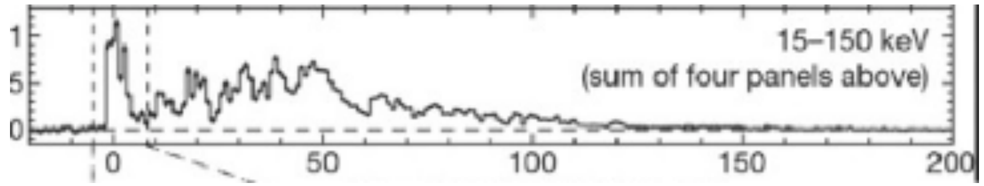
Unknown-Origin GRBs

Unusual GRBs

- Short GRBs can be apparently long (because of extended emission/tails)

(so we can ignore the tail, and make a short GRB from a long one)

THE ASTROPHYSICAL JOURNAL, 655: L25–L28, 2007 January 20



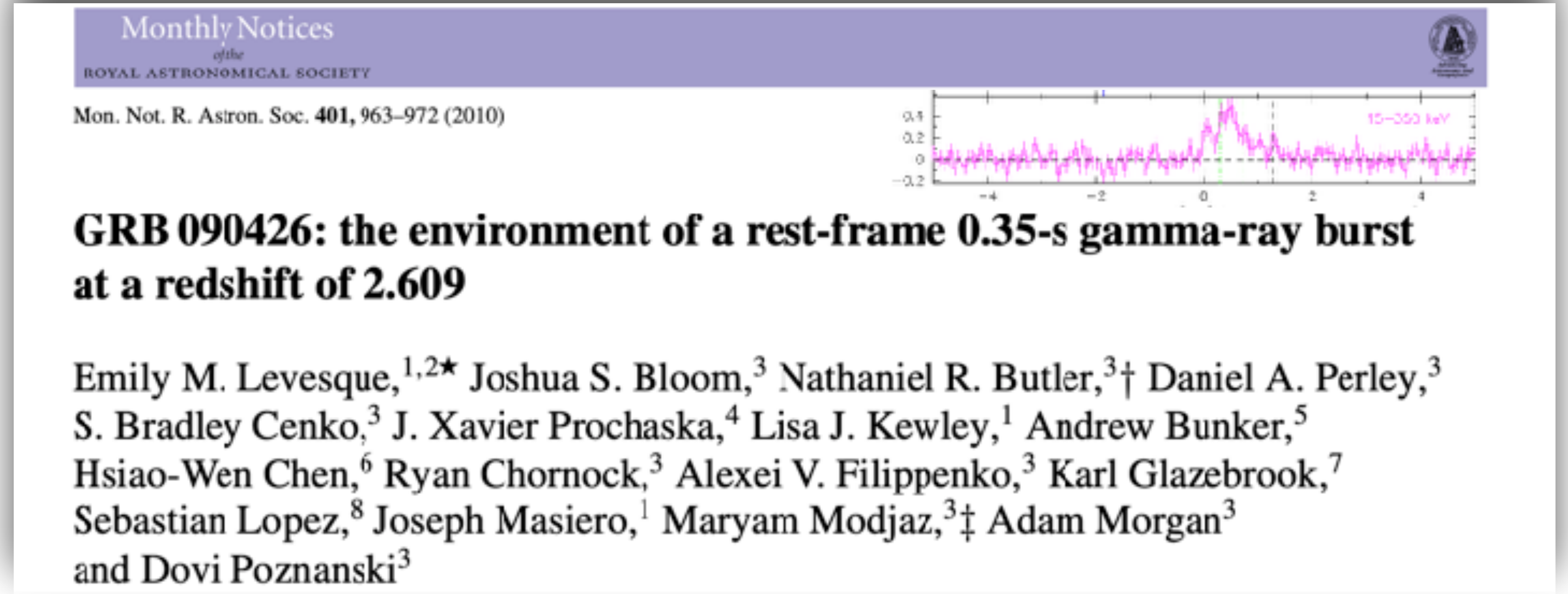
MAKING A SHORT GAMMA-RAY BURST FROM A LONG ONE: IMPLICATIONS FOR THE NATURE OF GRB 060614

BING ZHANG,[1] BIN-BIN ZHANG,[1,2,3] EN-WEI LIANG,[1,4] NEIL GEHRELS,[5] DAVID N. BURROWS,[6] AND PETER MÉSZÁROS[6,7]
Received 2006 October 22; accepted 2006 December 13; published 2007 January 4

ABSTRACT

Unknown-Origin GRBs

- Short GRBs can be apparently long (because of extended emission/tails)
- Long GRBs can be apparently (fat-)short (because of tip of iceberg effect)



Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **401,** 963–972 (2010)

GRB 090426: the environment of a rest-frame 0.35-s gamma-ray burst at a redshift of 2.609

Emily M. Levesque,[1,2★] Joshua S. Bloom,[3] Nathaniel R. Butler,[3†] Daniel A. Perley,[3] S. Bradley Cenko,[3] J. Xavier Prochaska,[4] Lisa J. Kewley,[1] Andrew Bunker,[5] Hsiao-Wen Chen,[6] Ryan Chornock,[3] Alexei V. Filippenko,[3] Karl Glazebrook,[7] Sebastian Lopez,[8] Joseph Masiero,[1] Maryam Modjaz,[3‡] Adam Morgan[3] and Dovi Poznanski[3]

Plus, recent GRB 201015A (short+tails)

Unknown-Origin GRBs

- Short GRBs can be apparently long (because of extended emission/tails)
- Long GRBs can be apparently short (because of tip of iceberg effect)

- But:

Long GRBs can **NOT** be genuinely short
if it is really an accretion powered massive star collapsar

$$t_{\rm ff} \sim (\frac{3\pi}{32 G\bar{\rho}})^{1/2} \sim 210 \ {\rm s} \ (\frac{\bar{\rho}}{100 \ {\rm g \ cm^{-3}}})^{-1/2}$$

Trouble Maker GRB XXXXX

NO Tail and NOT fat

Zhang, B.-B. et al 2020 in prep.

Everything looks like a long GRB, except for its definitely short duration!

Zhang, B.-B. et al 2020 in prep.

Summary

"Old-Type" short & long GRBs

- Precursors: all-wavelength **<==**
- Prompt Emission: optical, radio, (early) X-ray, γ -ray , GeV, TeV
- Afterglow : (early) X-ray, (early) optical, (deep) optical, radio, GeV
- SN
- Kilonova: optical, UV, (large sample)
- Host: optical , radio , (large sample)
- Neutrinos
- Gravitational Waves

"New-Type" GRBs

- Ultra-Long GRBs (~ hours, all wavelength, all time frames)
- Ultra-Soft GRBs (~ low Ep, thermal spectrum, all wavelength, all time frames)
- X-ray only GRBs (a.k.a. X-ray transient, Xue et al. 2019)
- GRB related to other unusual sources (e.g., FRBs ? Dai et al.; GWs ;)
- Sub-threshold GRBs (more interesting if concidence w/ other messengers/wavelength) **<==**
- Temporally or spectrally peculiar GRBs (LL, extra component, etc)
- SGR GF GRB; **<==**
- Unknown-Origion GRBs (trouble makers) **<==**

Prospects

GRID Project
@
Tsinghua & NJU

HXMT
FAST

GECAM (12/10 4am Xichang)
EP
SVOM
ET2.0
….