



Proposal for LIGO-Virgo Triggered Follow-Up with High Energy Photon Survey Missions

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Motivation for High Energy Sky Search

- In S6/VSR2 run, LIGO-Virgo is entering an era of “plausible detection”
- A coincident EM signal will offer independent support to any GW claim of detection
 - GW triggered surveys may find prompts or afterglows
 - Triggers allow EM searches below nominal thresholds
- A number of NASA missions are now surveying the high energy sky
 - RXTE
 - SWIFT
 - FERMI



Proposed Approach

- L-V provides trigger
 - Time, Sky position
 - Frequency of ~ once per week of loudest trigger
- Using above information, missions will search for excess power below transient threshold
 - Search in time interval of +/- 2 minute (**prompt emission**)
 - Search in time interval of 3 hour (**afterglow**)
 - Search at L-V sky position of 25 sq deg
 - Search at L-V sky position of 5 deg annulus
 - All will help to reject EM background
- Data is analyzed **off-line** - no spacecraft commands (ie, no repointing, no threshold change, etc)



Real motivation for this external collaboration

- Although detection of a gravitational wave from a GRB or SGR in S6/VSR2 is possible, it is not likely, so that probably the best motivation for this proposal is to gain experience in interacting with the high energy astrophysics community, which will be useful in the era of advanced LIGO-Virgo. We have taken measures to make this clear to the EM survey missions.
- We intend to be very conservative in analysis
- Still significant enthusiasm from the missions!

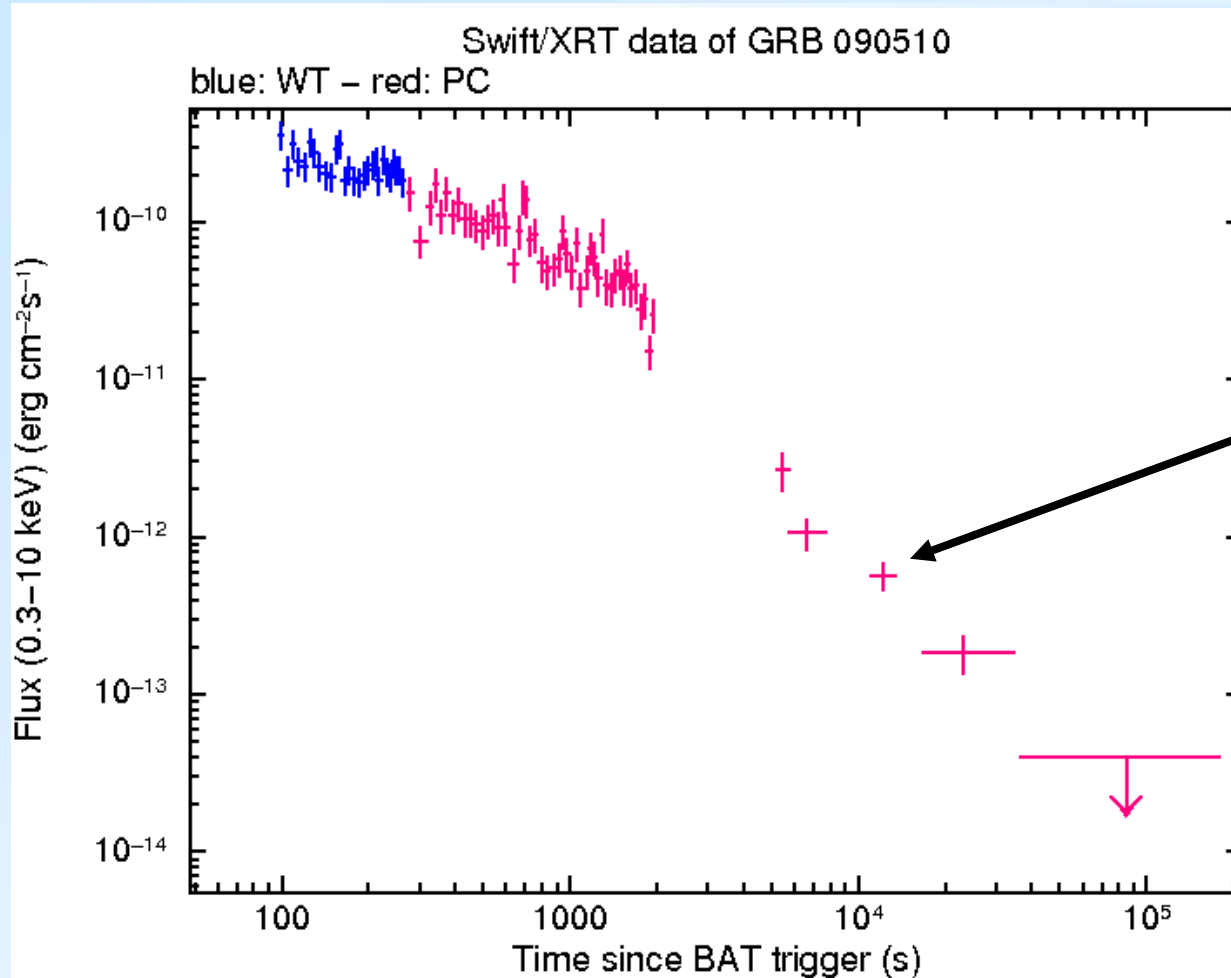


High Energy Photon Survey Satellites

Mission	Instrument	Energy	FOV	$\Delta\theta$	$\Delta T_{\text{transit}}$
RXTE	All Sky Monitor	1 - 10 keV	3 %	$< 1^\circ$	1.5 hour
SWIFT	Burst Alert Telescope	20 - 150 keV	15 %	$< 1^\circ$	NA
FERMI	Gamma Burst Monitor	20 keV - 40 MeV	65 %	5°	3 hour
FERMI	Large Area Telescope	20 MeV - 300 GeV	20 %	$< 1^\circ$	3 hour



SWIFT Light Curve of Recent GRB



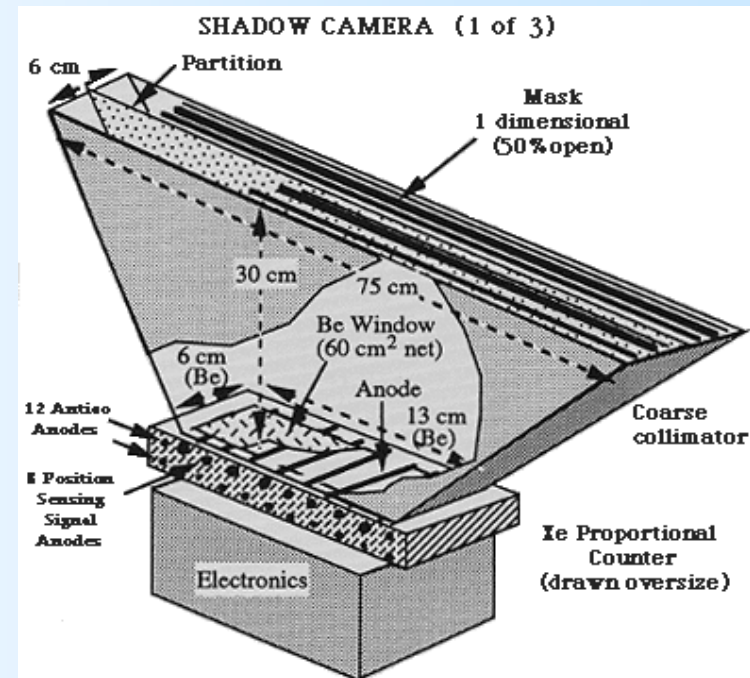
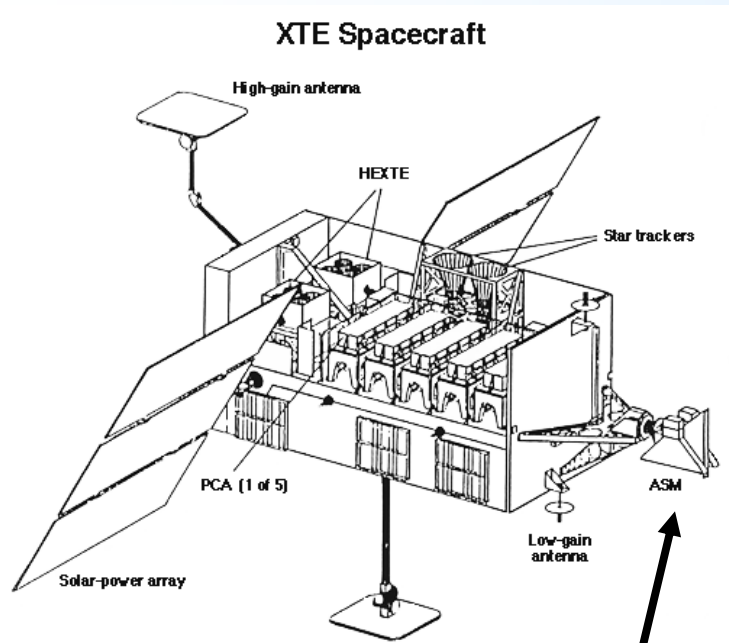
Unusually bright GRB, short, $z = 1$, also seen by FERMI

X-ray afterglow strong enough to be seen by RXTE 1.5 hr after burst **if** this GRB at 30 Mpc

Surprises are likely so it's good to look!



Rossi X-ray Timing Explorer (RXTE)



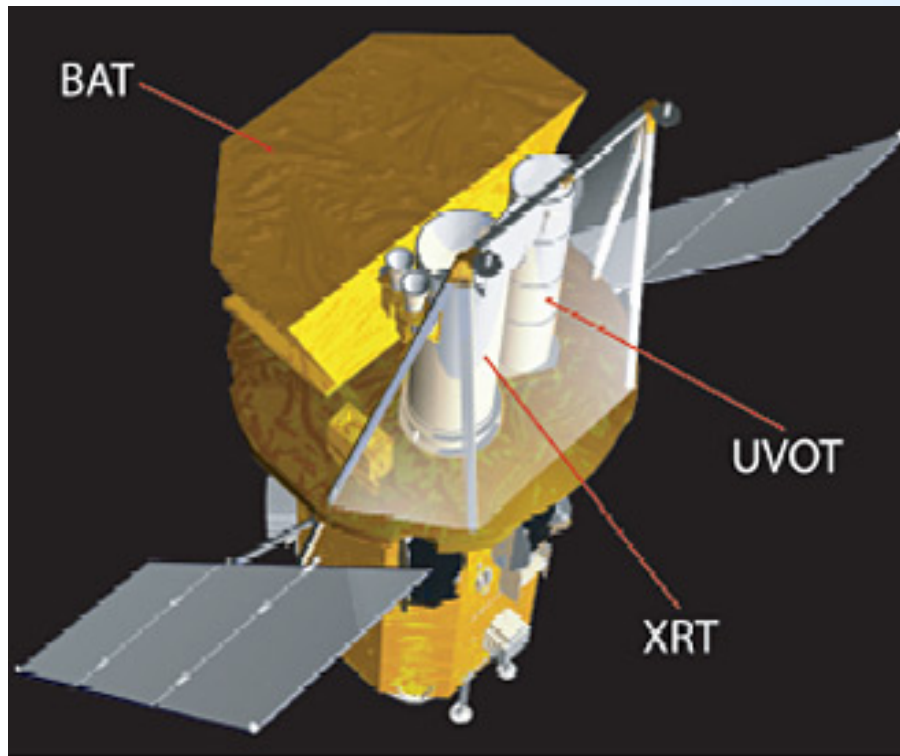
ASM rotates through sky every 1.5 hours

ASM Energy range 1-10 keV

Look below nominal ASM threshold using L-V trigger



SWIFT



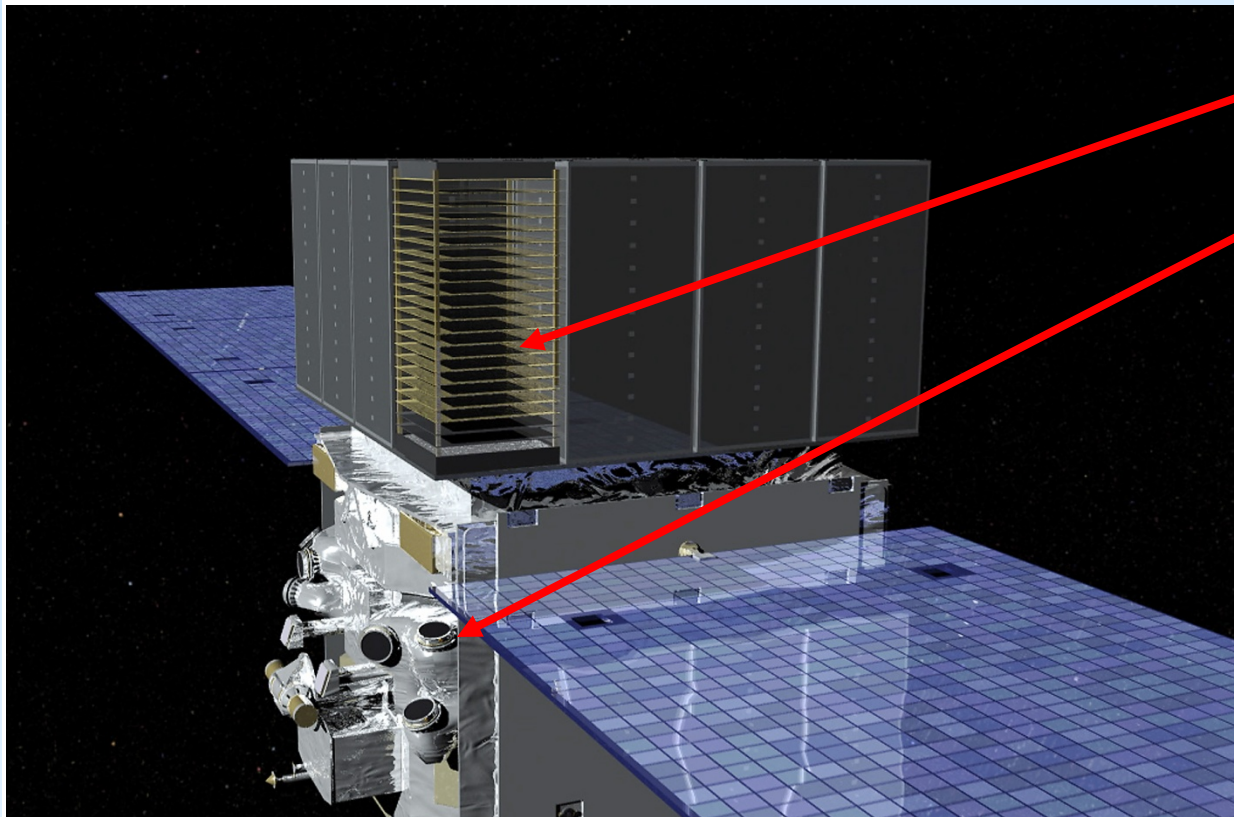
BAT trigger requires both high photon rate and $\text{SNR}_{\text{image}} > 6.5$
Rate $\sim 1/3$ day

L-V triggers (time, sky position) will allow us to look at sub-threshold images for which SWIFT does not slew

Looking at SWIFT events with sub-threshold images



FERMI



LAT and **GBM** have
trigger thresholds
 $\sim 10 \times$ noise

LAT tracking chamber

GBM multiple
oriented scintillators
give FOV $\sim 65\%$

FERMI scans sky
every 3 hours

Looking below LAT, GBM thresholds



EM Instrument trigger rates

Mission	Instrument	Threshold	Rate (/day)
RXTE	ASM	2 σ	30
		3 σ (nominal)	2
SWIFT	BAT	2.5 σ	100
		6.5 σ (nominal)	0.3
FERMI	LAT	4 σ	1
		5 σ (nominal)	0.1
FERMI	GBM	4 σ	10
		5 σ (nominal)	1



EM-GW False Alarm Rates (/yr)

L1, H1, V1 (H1, V1)

Mission	Instrument	EM-GW False Alarm Rate	
		Prompt	Afterglow
RXTE	ASM	10^{-4} (10^{-2})	10^{-2} (1)
SWIFT	BAT	10^{-5} (10^{-3})	10^{-3} (10^{-1})
FERMI	LAT	10^{-6} (10^{-4})	10^{-4} (10^{-2})
FERMI	GBM	10^{-5} (10^{-3})	10^{-3} (10^{-1})

Assumes $R_{L-V} = 1/\text{yr}$ and 30 times nominal EM trigger rate



NASA proposed involvement

- **RXTE: Jean Swank (Project Scientist), Ron Remillard (ASM PI).**
- **SWIFT: Neil Gehrels (Project Scientist), Hans Krimm (BAT detector scientist)**
- **FERMI LAT: Dave Thompson (Deputy Project Scientist), James Chiang, Vlasios Vasileiou (LAT detector scientists)**
- **FERMI GBM: William Paciesas (PI), Valerie Connaughton, Michael Briggs (GBM detector scientists)**
- **Lots of enthusiasm!**



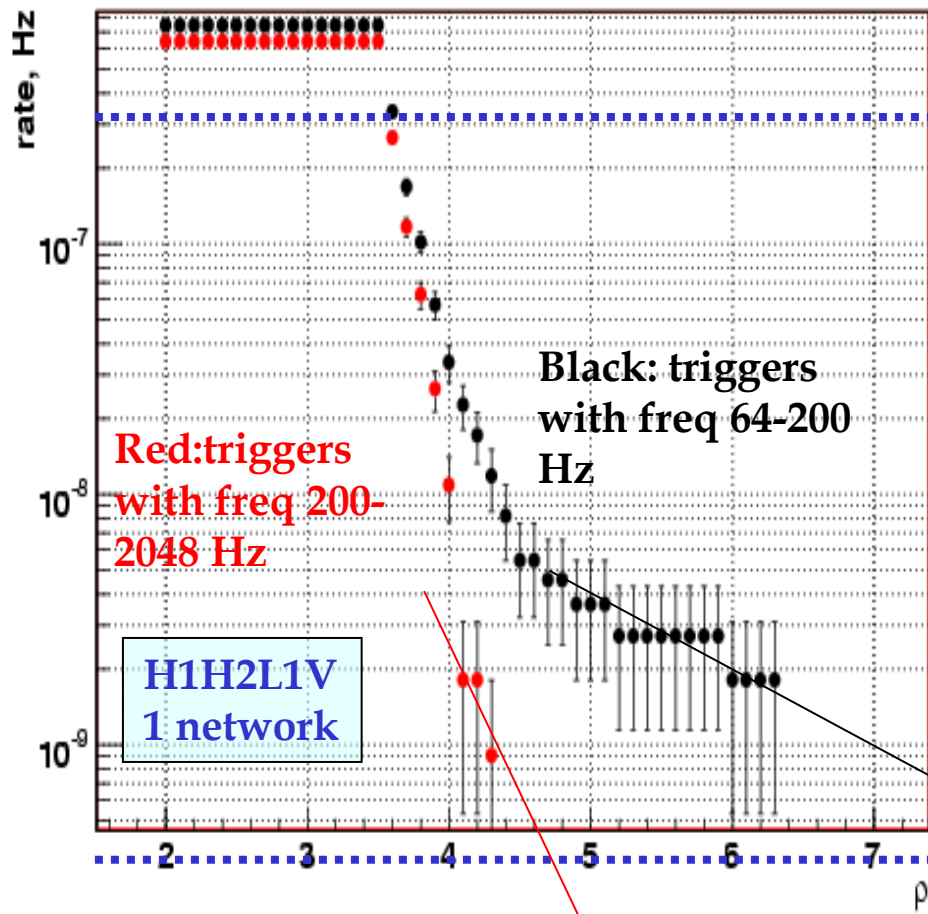
Possible Joint Detection Scenario

- There has been considerable discussion recently on the criteria to announce a GW detection
- I discuss a hypothetical detection scenario for discussion
 - Virgo NS-NS observation with sensitivity 40 Mpc
 - LIGO NS-NS observation with sensitivity 20 Mpc
 - EM coincidence with NASA photon survey mission
- I hope this may stimulate some discussion on the LIGO side about the possibility of the continued allocation of one detector to S6



Effect of EM coincidence on detection threshold (from P. Shawhan)

rate vs threshold



Ten per year

A 1-in-1000 astronomical event coincidence would allow ~25% lower threshold for 200-2048 Hz, ~55% lower for 64-200 Hz

EM coincidence raises *effective* LIGO range from 20 to 40 Mpc

One per century



Possible Detection Scenario

- **With EM counterpart, we can (roughly) have scenario of 2 detectors with effective sensitivities of 40 Mpc**
 - Background rate of 1 / 100 yr
- **Best estimate of CBC rate at this sensitivity is ~ 1 / yr**
- **This assumes EM counterpart is not missed because of beaming**
 - Searching below nominal detector thresholds may help
- **A gravitational wave seen in coincidence by 2 detectors years before “advanced era” could be valuable to growth of international field**





Summary

- **NASA EM survey missions are very interested in joint EM-GW search**
 - **RXTE, SWIFT, FERMI**
- **A joint detection would add significant confidence to any claim by LIGO - Virgo**
- **Hope to begin analyzing data in coming months**

