Searching for Gravitational Wave Bursts Using External Triggers From Gamma-ray Bursts (GRBs)

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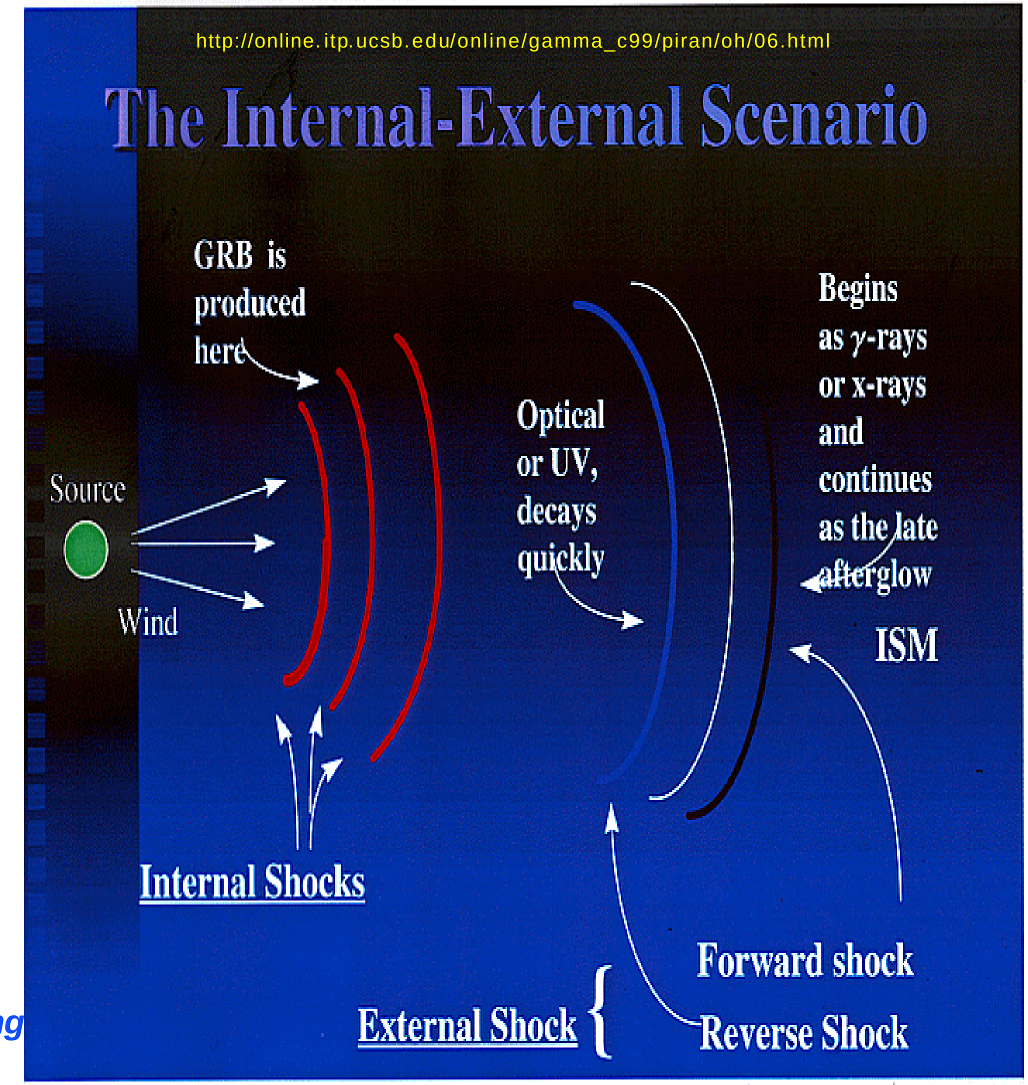
Introduction to Gamma-ray Bursts

- High-energy, short-duration electromagnetic radiation from extra-galactic sources
- Favored models point to exploding fireball
  - Involve large amounts of matter,
  - ejected at relativistic speeds,
  - producing a series of high-energy E/M shockwaves ---
    - initially gamma-rays (some redshift to lower-energy gamma-rays or X-rays, others are absorbed),
    - then X-rays (red-shifted to optical wavelengths),
    - visible light may burst before, during, or after
    - finally radio wavelengths



GRBs and Gravitational Waves

- Gravitational Wave Bursts (GWBs) possibly emitted from same source as GRBs
- Most probably GWBs emitted before GRBs
- Estimates from GRB observations are 10^{54} erg/s luminous energy (assuming isotropic GRB)
- How much GW energy can be expected from these sources? Unknown, but could be very high…

Motivation for a Statistics-based Search

- GRB astronomy is very active
  - Relatively large number of events are detected (~O(1/day))
- Current sensitivity to GW bursts is low due to excess IFO noise
  - Could be confused with noise bursts in interferometer channels
  - However, even at LIGO I design sensitivity most bursts may be too far away
- Expected GW would be broadband in frequency
  - Bursts = short-duration
  - The waveform probably varies from source type to source type
- Uncertainty in time delay between the GW and GRB
  - The delay probably varies from source type to source type

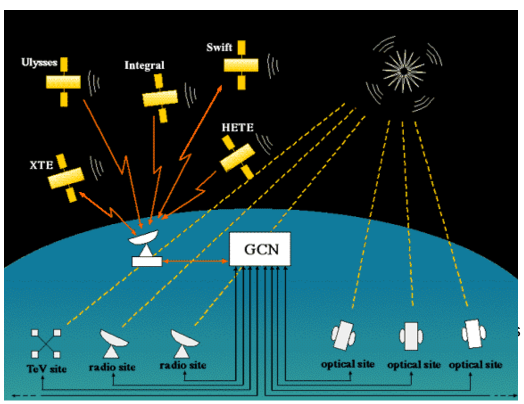
All lead to diminishing confidence for single events…

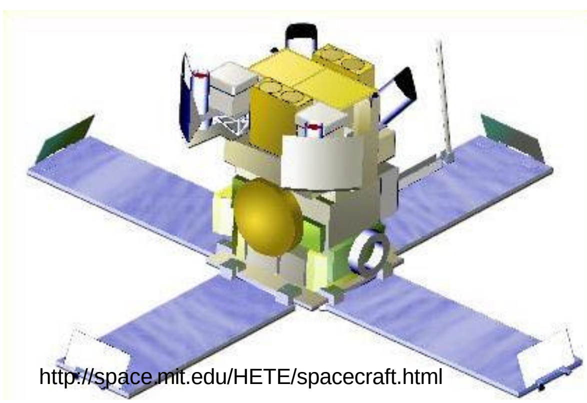
Using a statistical method would increase our confidence!

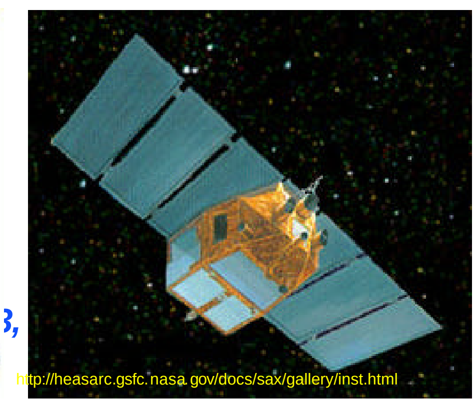
GRB Events Observed During E7

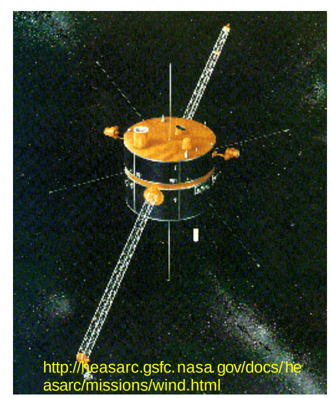
- 13 triggers GRB received
- 5 have directional info
- It seems that most have IFO coverage
  - We have to wait until the vetoes are considered
- We are collecting updated info

Detector	Tr#	Date	Time(UTC)	GPS
Tr #1-10 are courtesy of Kevin Hurley (khurley@ssl.berkeley.edu)				
BEPPOSAX GRBM	1	12/28/01	23:19:15	693616768
KONUS WIND	2	12/29/01	10:23:20	693656613
BEPPOSAX GRBM	3	12/30/01	8:48:23	693737316
BEPPOSAX GRBM	4	12/31/01	3:34:40	693804893
BEPPOSAX GRBM	5	12/30/01	15:03:29	693759822
BEPPOSAX GRBM	7	1/12/02	18:52:02	694896735
KONUS	9	1/13/02	13:37:13	694964246
HETE	10	1/14/02	2:51:02	695011875
GCN/HETE	1885	1/5/02	12:46:01	694269973.9
GCN/HETE	1887	1/8/02	8:20:37	694513250.5
GCN/HETE	1888	1/8/02	8:27:26	694513659.4
GCN/HETE	1890	1/10/02	10:20:43	694693256.1
GCN/HETE	1891	1/13/02	2:04:12	694922665.3

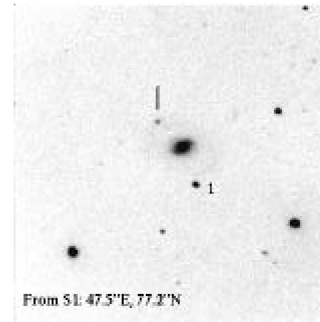



http://space.mit.edu/HETE/spacecraft.html

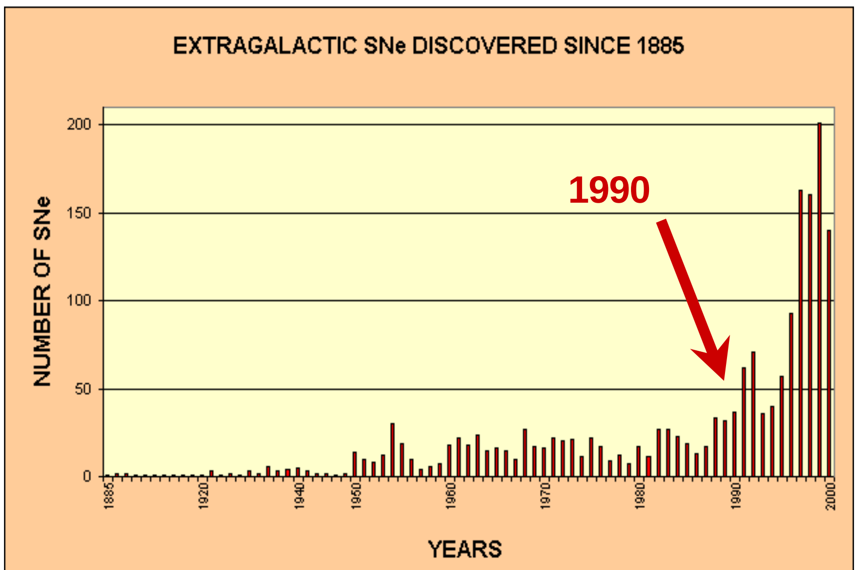

http://heasarc.gsfc.nasa.gov/docs/sax/gallery/inst.html


http://heasarc.gsfc.nasa.gov/docs/heasarc/missions/wind.html

Optical Supernovae and Detected Events During the Period of E7



- 31 records are noted
- Details will be collected
- Positions are WELL KNOWN
- Time info is questionable…



SN	Galaxy	Date	Mag.	Circular	R.A.	Decl.	Type	Discoverer(s)
2002C	IC3376	1/14/2002	16.7	IAUC-7793	12 27 52.66	27 0 6.1	II	LOTOSS
2002al	N/A	1/11/2002	23.6	IAUC-7804	10 50 21.71	-4 15 5.9	?	Deep Lens Survey
2002ak	N/A	1/11/2002	22.6	IAUC-7804	10 49 4.32	-5 55 33.7	?	Deep Lens Survey
2002aj	N/A	1/11/2002	23.1	IAUC-7804	10 48 56.56	-5 32 14.1	?	Deep Lens Survey
2002ai	N/A	1/9/2002	23.4	IAUC-7802	10 54 21.27	57 27 58.2	?	High-Z SupernovSearchTeam
2002ah	N/A	1/9/2002	24.4	IAUC-7802	10 53 19.5	57 0 36.6	?	High-Z SupernovSearchTeam
2002ag	N/A	1/9/2002	24.2	IAUC-7802	10 53 12.71	57 0 25.9	?	High-Z SupernovSearchTeam
2002af	N/A	1/9/2002	24.1	IAUC-7802	10 52 29.89	57 39 44	?	High-Z SupernovSearchTeam
2002ae	N/A	1/9/2002	23.6	IAUC-7802	10 50 51.02	57 9 4.6	?	High-Z SupernovSearchTeam
2002ad	N/A	1/9/2002	23.2	IAUC-7802	10 50 12.19	57 31 11.6	?	High-Z SupernovSearchTeam
2002ac	N/A	1/9/2002	23.8	IAUC-7802	7 49 39.61	10 19 8.2	?	High-Z SupernovSearchTeam
2002ab	N/A	1/9/2002	22.5	IAUC-7802	7 48 55.7	10 6 6.3	Ia	High-Z SupernovSearchTeam
2002aa	N/A	1/9/2002	24.3	IAUC-7802	7 48 45.28	10 18 0.8	?	High-Z SupernovSearchTeam
2002Z	N/A	1/9/2002	24.2	IAUC-7802	8 49 32.97	44 3 27.6	?	High-Z SupernovSearchTeam
2002Y	N/A	1/9/2002	24.2	IAUC-7802	8 48 50.21	44 13 3	?	High-Z SupernovSearchTeam
2002X	N/A	1/9/2002	23.7	IAUC-7801	8 48 30.54	44 15 35.3	?	High-Z SupernovSearchTeam
2002W	N/A	1/9/2002	24	IAUC-7801	8 47 54.42	44 13 42.9	?	High-Z SupernovSearchTeam
2002V	N/A	1/9/2002	23.7	IAUC-7801	4 39 53.55	-1 13 33.5	?	High-Z SupernovSearchTeam
2002U	N/A	1/9/2002	22.8	IAUC-7801	4 39 42.9	-1 46 4.2	?	High-Z SupernovSearchTeam
2002T	N/A	1/9/2002	23.8	IAUC-7801	4 38 53.87	-1 34 26.6	?	High-Z SupernovSearchTeam
2002S	N/A	1/9/2002	23.1	IAUC-7801	4 37 37.05	-1 32 36.9	?	High-Z SupernovSearchTeam
2002R	N/A	1/9/2002	24.1	IAUC-7801	2 29 27.19	0 51 38.9	?	High-Z SupernovSearchTeam
2002Q	N/A	1/9/2002	24.2	IAUC-7801	2 29 22.19	0 20 25.8	?	High-Z SupernovSearchTeam
2002P	N/A	1/9/2002	23.8	IAUC-7801	2 29 5.17	0 47 20.1	?	High-Z SupernovSearchTeam
2002O	N/A	1/9/2002	23.7	IAUC-7801	2 28 22.17	0 49 46.5	?	High-Z SupernovSearchTeam
2002N	N/A	1/9/2002	23.2	IAUC-7801	2 27 51.91	0 28 53.6	?	High-Z SupernovSearchTeam
2002M	N/A	1/9/2002	23.4	IAUC-7801	2 27 13.14	0 44 41.2	?	High-Z SupernovSearchTeam
2002L	N/A	1/9/2002	23.8	IAUC-7801	2 26 55.69	0 21 37.8	?	High-Z SupernovSearchTeam
2002K	N/A	1/9/2002	24	IAUC-7801	2 26 50.48	0 43 30.1	?	High-Z SupernovSearchTeam
2002B	N/A	1/7/2002	20.5	IAUC-7791	5 40 46.06	-71 51 15.1	Ia	SuperMacMicrolenSurvey
2002A	UGC3804	1/1/2002	17.4	IAUC-7786	7 22 36.14	71 35 41.5	IIn	Beijing SupernovSurvey

Data courtesy of http://cfa-www.harvard.edu/iau/lists/Supernovae.html and http://cfa-www.harvard.edu/iau/cbat.html .

A Statistical Approach

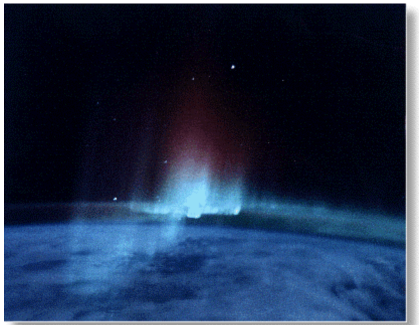
(based on method proposed by Finn, Mohanty, and Romano, gr-qc/9903101)

- Make two types of cross-correlated time series for two interferometers
  - “on-source”: cross-correlated during times containing possible GW
  - “off-source”: cross-correlated during (related) times which likely do not contain GW signals
  - Takes out uncorrelated noise while GW signal remains
- Repeat for many GRBs
  - Increases signal-to-noise
- Compare the two distributions of cross-correlations
  - Check if there is a statistical difference due to the GRB trigger

Implementation: Overview

Search might be computationally intensive during particular event times (though rare) and statistical summary must be prepared (optimally) based on several weeks worth of GRB data

It is very natural to break up the search into LDAS and non-LDAS parts



Implementation: LDAS

(✓ – what's been done so far)

- ✓ ❑ (pre-LDAS) Obtain GRB timestamps t_{GRB} and source directions, when available
- ✓ ❑ Grab data from both interferometers around t_{GRB}
- ✓ ❑ Pick a likely time segment, length t_w, for GWB to occur (e.g. between 1-5sec before GRB) $\Leftarrow$ "on-source"
- ❑ Pick a number of (randomly selected) segments, length t_w, during times when GWB is unlikely to occur (i.e. after GRB) $\Leftarrow$ "off-source" (but still reflects the "local" noise of the IFO signal)

Implementation: LDAS (cont'd.)

(✓ – what's been done so far)

- ❑ For "on-source" segment, make use of expected time delay between interferometers due to direction of GRB source
- ✓ ❑ Compute and store cross-correlations (x_{on} and x_{off}) for each "on-source" and "off-source" segment

Implementation: non-LDAS

(✔ – what's been done so far)

- [Veto cross-correlations of suspect data, due to e.g. non-stationarity or bad data quality]
- Determine the sample means $\langle X \rangle$ and sample variances σ^2 of "on-source" (X_{on}) and "off-source" (X_{off}) distributions
- Use Student's t-test to determine how well $\langle X_{on} \rangle$ and $\langle X_{off} \rangle$ coincide:

$$t = \frac{\langle X_{\rm on} \rangle - \langle X_{\rm off} \rangle}{\Sigma} \sqrt{\frac{N_{on} N_{\rm off}}{N_{\rm on} + N_{\rm off}}}$$

$$\Sigma^2 = \frac{(N_{\rm on} - 1)s_{\rm on}^2 + (N_{\rm off} - 1)s_{\rm off}^2}{N_{\rm on} + N_{\rm off} - 2}$$

Foreseen Challenges

- Dealing w/ error-bars or missing information of source direction
- Choice of t_{GWB} and t_w
- How much non-stationarity is acceptable?
- Sensitivity studies
- Using data from more than two interferometers
- Validation & verification of results

LDAS Factors to Consider

- Getting data out of LDAS which can be used by non-LDAS part
  - Currently writing to file using multi_burst table format
  - Write ~20 entries/day to multi_burst table?
  - Non-LDAS part can use Event Tool to read entries
- Line removal
  - Implemented in datacondAPI yet?
- Testing on coincident data
  - Non-coincident data doesn't reflect possibly correlated noise
  - Will start testing when coincident playground data is available

Summary / Short-term Outlook

- Making good progress!
  - DSO has progressed since inception at E6
  - Work is underway to deal with error-bars, non-stationarity
- Will calibrate sensitivity experimentally by "searching" for bursts at simulated (random) GRB times (maybe late April)
- Will test sensitivity by injecting short, broadband bursts into coincident (playground?) data (maybe May)