GRB Searches with X-PIPELINE

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August 3, 2007

Outline

- Coherent detection statistics and veto
- X-Pipeline and triggered searches
- Test analysis of 9 GRBs

Detectors space

N detectors, N dimensional space

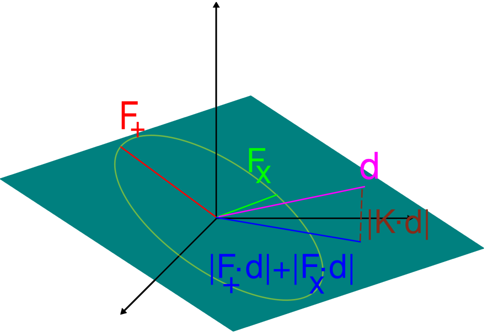
$$\begin{bmatrix} d_1 \\ \vdots \\ d_N \end{bmatrix} = \begin{bmatrix} F_1^+/\sigma_1 \\ \vdots \\ F_N^+/\sigma_N \end{bmatrix} h_+ + \begin{bmatrix} F_1^\times/\sigma_1 \\ \vdots \\ F_N^\times/\sigma_N \end{bmatrix} h_\times + \begin{bmatrix} n_1 \\ \vdots \\ n_N \end{bmatrix}$$

- given time–frequency pixel
- time shifted according to GRB sky postion
- GW affect only 2 out of N dimensions

$$\mathbf{d} = \mathbf{F}_+^w h_+ + \mathbf{F}_\times^w h_\times + \mathbf{n}$$

d – vector of whitened data at a given time/frequency, time shifted according to GRB sky postion

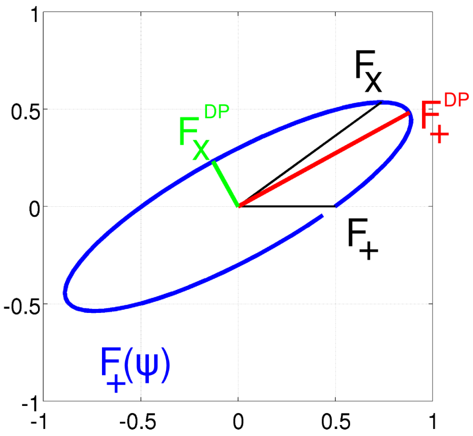
Dominant Polarization frame
a convenient network basis



$$\mathbf{d} = \mathbf{F}_{+}^{w} h_{+} + \mathbf{F}_{\times}^{w} h_{\times} + \mathbf{n}$$

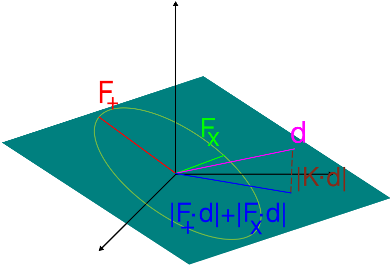
- $\mathbf{F}_{+}(\psi)$ – sensitivity to linear polarization
- DP frame :
  - $\mathbf{F}_{+}^{DP} \cdot \mathbf{F}_{\times}^{DP} = 0$
  - $|\mathbf{F}_{+}^{DP}| / |\mathbf{F}_{\times}^{DP}|$ is maximal

Two dimensional plane spanned on $\mathbf{F}_{+}$, $\mathbf{F}_{\times}$ (H1L1V1 network)



Likelihoods for gaussian noise

$$L = \frac{P(\mathbf{d}|\text{signal in noise})}{P(\mathbf{d}|\text{noise})} = \cdots \propto \exp(\tfrac{1}{2}\text{SL})$$



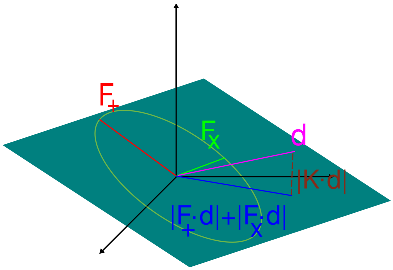
Dominant Polarization frame, $\hat{\mathbf{F}}^w_+ \cdot \hat{\mathbf{F}}^w_\times = 0$:

$$\text{Standard Likelihood} = \text{SL} = \left|\hat{\mathbf{F}}^w_+ \mathbf{d}\right|^2 + \left|\hat{\mathbf{F}}^w_\times \mathbf{d}\right|^2$$

magnitude of projection on $\mathbf{F}_+$, $\mathbf{F}_\times$ plane
ie part of **d** that can be due to a GW

$$\text{Hard Constraint} = \text{HC} = \left|\hat{\mathbf{F}}^w_+ \mathbf{d}\right|^2$$

$\hat{\mathbf{F}}_+$ – Network most sensitive polarization (ellipse major axis)



Total Energy $= E_{tot} = |\mathbf{d}|^2$

total magnitude of **d**

Null Energy $= E_{null} = |\hat{\mathbf{K}} \cdot \mathbf{d}| = E_{tot} - \mathrm{SL}$

part of **d** that cannot be due to a GW, noise only

Incoherent Energy $= E_{inc} = \sum_{\alpha=1}^{N} |K_\alpha d_\alpha|^2$

autocorrelation term of E_{null}

Incoherent vs null energy test :

- GW coherently cancelled in $E_{null} \longrightarrow E_{inc}/E_{null}$ is large
- no cancellation for glitches $\longrightarrow E_{inc}/E_{null} \simeq 1$

$\hookrightarrow$ reject events with $E_{inc}/E_{null} < 1.5$

glitch standard likelihood

Goal : fold detection statistic and glitch veto
gaussian noise + long tail

$$P(\mathbf{d}|\text{noise + glitches}) \propto \prod_\alpha \exp(\tfrac{1}{2}|d_\alpha|^2) + R_\alpha$$

R_α characterize non-gaussianity of detectors

$$L = \frac{P(\mathbf{d}|\text{signal in noise})}{P(\mathbf{d}|\text{noise + glitches})} = \cdots \propto \exp(\tfrac{1}{2}\text{SL})\frac{1}{\prod_\alpha 1 + R_\alpha \exp(\tfrac{1}{2}|d_\alpha|^2)}$$

simplify : $R_\alpha = R \ll 1$

$$\text{gSL} = \log L = \tfrac{1}{2}\text{SL} - \log(1 + R\sum_\alpha \exp(\tfrac{1}{2}|d_\alpha|^2))$$

Interpretation : $\text{gSL} \simeq \text{SL} - \max_\alpha |d_\alpha|^2$
largest strain may be due to a glitch

X-Pipeline

- X-Pipeline base algorithm
  - condition data
  - time shift to GRB position
  - make TF maps of detection statistic
  - cluster TF maps (black pixel probability 1%)
  - cluster across analysis times (FFT integration times)
- running GRB searches with X-Pipeline is easy
  - create directory and find which detectors were on
    `./multiGRB.py -p grb.ini -g grblist.txt`
    grblist.txt — simple ascii file with GRB name, time and sky position
  - estimate injection scales to use, based on detectors' spectra
    `./grbInjScale.sh`
  - submit jobs
    `condor_submit_dag grb_*.dag`
  - create report web pages with results/upper limits for each GRB
    `./grbResults.sh`

CLOSED BOX analysis procedure

- on-source data — ±60s around GRB trigger
- network selection — detectors that where on during the whole on source period (±60s)
- background estimation
  - off-source data: coincident data within ±12 hours of GRB trigger
  - off-source data cut into 2 minutes segments
  - loudest event in each segments
  - median/90 percentile loudest event → estimate loudest on-source event
- upper limits
  - GWB injections into on-source data
  - upper limits against estimated loudest on-source event
- Parameters
  - analysis times :
    1/256, 1/128, 1/64, 1/32, 1/16, 1/8, 1/4, 1/2 seconds
  - frequency band : 64–1792 Hz
  - gSL free parameter R set to 0.5, veto ratio set to 1.5
  - simulations — CSG/SG at 100, 150, 250, 500, 1000 Hz

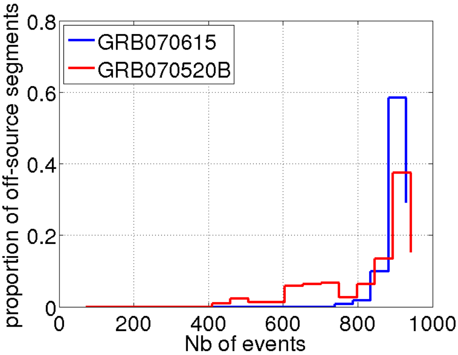
Analysis of 9 GRBs

- 9 GRBs in May/June 2007 with various network configurations (LIGO - Virgo - GEO)

0520	0520B	0521	0529	0531	0610	0615	0616	0621
$H_1 H_2 VG$	$H_1 LVG$	$H_1 H_2$	$H_1 H_2 LV$	LVG	$H_1 LG$	$H_1 H_2 L$	$H_1 H_2 VG$	$H_1 LVG$

- analysis with both HC and gSL to compare performance

- a “typical” GRB 070615
- a GRB with “glitchy” detectors 070620B
- less clusters, larger clusters (clusters cover 1% of TF map)

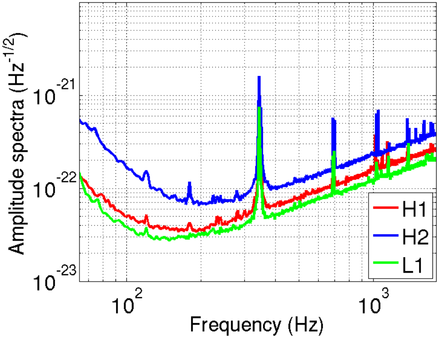


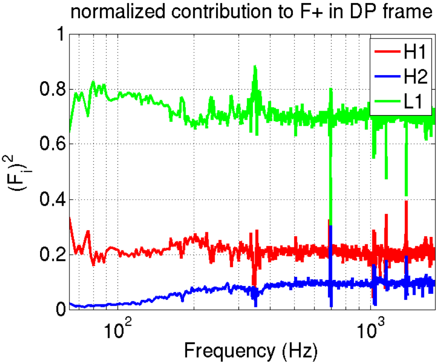
GRB070615 — “typical” GRB

- Network

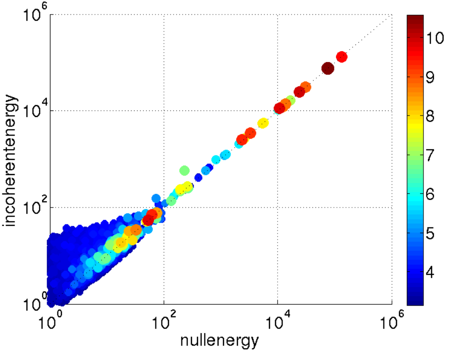
IFO	H_1	H_2	L
$F_+^2 + F_\times^2$	0.356	0.356	0.753

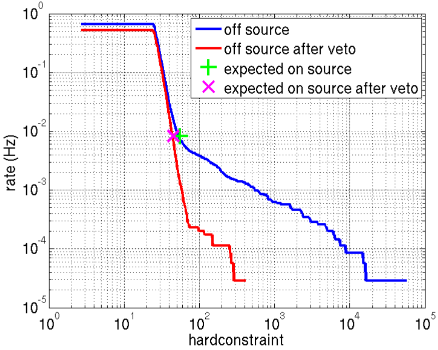
- null stream : $H_1 - H_2$





GRB070615 — background

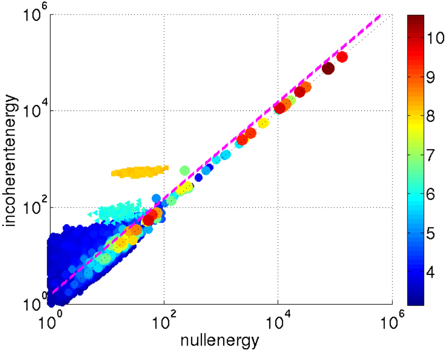




- color shows ln(hardconstraint)

- tail cut by veto
- on source event estimated from median loudest off-source background

GRB070615 — CSG 150 Hz Q=9 injections



- veto — $E_{inc}/E_{null} < 1.5$
- hrss = $1.3 \cdot 10^{-21}$
- hrss = $4.6 \cdot 10^{-22}$

- hrss 90% UL, against median :

HC without veto	—	$2.3 \cdot 10^{-22}$
HC with veto	—	$2.1 \cdot 10^{-22}$
gSL	—	$2.5 \cdot 10^{-22}$

- hrss 90% UL, against 90 percentile :

HC without veto	—	$5.6 \cdot 10^{-22}$
HC with veto	—	$2.6 \cdot 10^{-22}$
gSL	—	$2.6 \cdot 10^{-22}$

$\Longrightarrow$ need to reject glitches for unlucky case

$2 \cdot 10^{-22} \rightarrow$ total SNR in network $= 7$

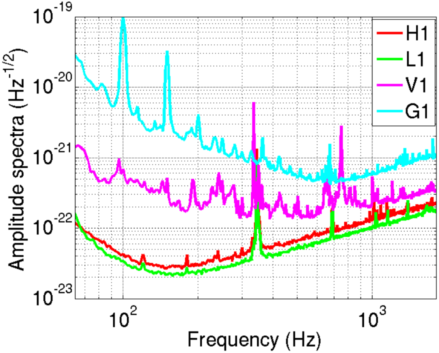
$(\text{total SNR})^2 = \sum_\alpha \text{SNR}_\alpha^2$

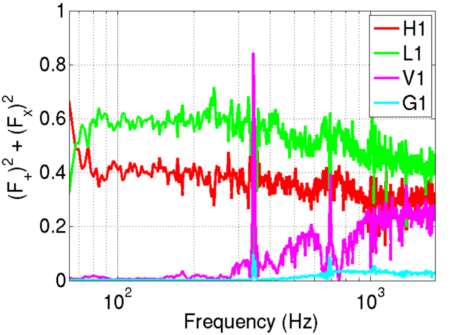
GRB070520B — “glitchy” GRB

- Network

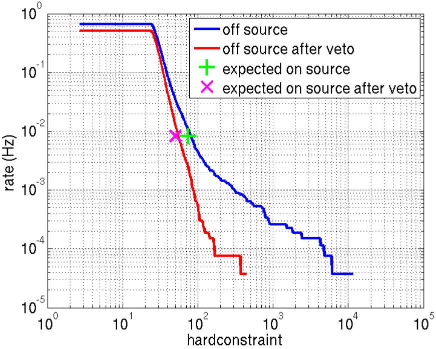
IFO	H_1	L	V	G
$F_+^2 + F_\times^2$	0.411	0.372	0.828	0.889

- Virgo and GEO are favored by GRB sky position
- null streams : 2 linear combination of Virgo and GEO
- poor null stream at low frequencies



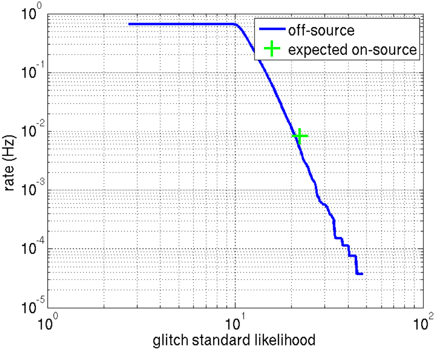


hardconstraint



- tail cut by veto
- wider separation between with/without veto

glitch SL



- no tail

GRB070520B — CSG 150 Hz Q=9 injections

- hrss 90% UL, against median :

HC without veto	—	$2.8 \cdot 10^{-22}$
HC with veto	—	$3.7 \cdot 10^{-22}$
gSL	—	$2.7 \cdot 10^{-22}$

- hrss 90% UL, against 90 percentile :

HC without veto	—	$5.6 \cdot 10^{-22}$
HC with veto	—	$3.7 \cdot 10^{-22}$
gSL	—	$2.9 \cdot 10^{-22}$

- null stream not sensitive enough $\rightarrow E_{inc}/E_{null}$ random value around 1 $\rightarrow$ veto reject injections
- $2 \cdot 10^{-22} \rightarrow$ total SNR in network $= 7$, same as for GRB070615

GRB070201 — open box results

- V3 calibration
- calibration/statistical errors are not accounted for
- cross-correlation — GRB070201 draft July 2, P070081-02-Z

circular SG frequency	T=25ms 90% UL $\times 10^{-22}$	T=100ms 90% UL $\times 10^{-22}$	HC with veto 90% UL $\times 10^{-22}$	gSL 90% UL $\times 10^{-22}$
100 Hz	17.5	16.0	7.0	9.5
150 Hz	10.3	10.3	4.4	6.6
250 Hz	10.9	11.6	5.0	7.1
554 Hz	19.3	20.7	9.8	12.0
1000 Hz	33.8	37.1	18.7	21.6

$\Longrightarrow$ factor 2 improvement

- $4 \cdot 10^{-22} \rightarrow$ total SNR in network = 7 at 150Hz

Summary

- Preliminary study of 10 S5 GRBs with X-Pipeline.
- Study relative performance of different likelihoods for different networks
  - hard constraint + null vs. incoherent energy test
  - glitch standard likelihood
- Null versus inc. test works well if null stream sensitive enough
  - Use H1-H2 null stream (when available)
  - Do not use null stream from non-aligned detectors (HLV or HLG), except at high frequencies
- Glitch SL — new statistic, robust against glitches
  - Not as sensitive as hard constraint for most GRBs.
  - Better for very glitchy GRB times (e.g. 070520B) when H1-H2 null stream not available
- Next steps
  - Find good estimates of likelihoods performance
  - Finalize choice of likelihoods to be used for each GRB/network configuration
  - Large-scale analysis of S5 GRBs