Search for gravitational waves associated with GRB050915a using the VIRGO detector during C7 run

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on behalf of VIRGO collaboration

Gravitation – Moriond 2007
Gamma-Ray Bursts

Two classes of bursts: short / long, \( E_{\gamma,\text{iso}} \) as high as \( 1 M_\odot c^2 \)

Prompt emission followed by an “afterglow”: time decreasing multi-wavelength emission. Optical counterpart allows redshift measurements.

BeppoSAX: first discovery of the afterglow GRB 970228
How to power a GRB?

Merger of compact binaries (short GRBs) or collapse of massive rotating stars ("collapsar", long GRBs): the result is a black hole + disk, where disk accretion powers the GRB.

Merger of two blobs of $1M_\odot$ each, under the (optimistic) assumption $E = 1-5\% (4\mu/M)^2 M c^2$
GRBs during VIRGO 2005 runs

**VIRGO C6**

<table>
<thead>
<tr>
<th>GRB</th>
<th>GPS Time (s)</th>
<th>Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRB 050730</td>
<td>806788716</td>
<td>Swift</td>
</tr>
<tr>
<td>GRB 050801</td>
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<td>Swift</td>
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<tr>
<td>GRB 050802</td>
<td>807012495</td>
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<td>GRB 050803</td>
<td>807131655</td>
<td>Swift</td>
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<tr>
<td>GRB 050807</td>
<td>810447538</td>
<td>HETE</td>
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**VIRGO C7**

<table>
<thead>
<tr>
<th>GRB</th>
<th>GPS Time (s)</th>
<th>Detector</th>
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<tbody>
<tr>
<td>GRB 050915a</td>
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<td>GRB 050915b</td>
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<td>GRB 050916</td>
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<td>Swift</td>
</tr>
</tbody>
</table>

Good position in one of the data stretch of the run, z unknown (no host galaxy identified), $T_{90} = 53$ s (15-350 keV), long GRB $\rightarrow$ we expect the progenitor to be a collapsar and search for a burst type event in VIRGO data.

15-150 keV fluence of $(8.8 \pm 0.9) \times 10^{-7}$ erg cm$^{-2}$

The GRB electromagnetic study is performed in collaboration with IASF-Rome/INAF: Luigi Piro, VESF member

http://heasarc.gsfc.nasa.gov/docs/swift/bursts/index.html
VIRGO sensitivity during C7 run

- $h = 8.1 \times 10^{-22} \text{ Hz}^{-0.5}$ @ 203 Hz
- $h = 9.4 \times 10^{-22} \text{ Hz}^{-0.5}$ @ 1503 Hz
Run filter to search for burst-like events

Select a **signal region**: data segment around the GRB trigger time

Select a **bkg region**: long data segment around the signal region (~ 16500 s)

Run filter to search for burst-like events

Define bkg statistical properties: estimate false alarm rate and set a threshold for "good" events. Calibrate filter response: using software injections, estimate for each event strength the detection efficiency and the corresponding hrss

Select "good" events

Some "good" events are found

No "good" events

Coincidence search: estimate corresponding hrss

Set corresponding hrss upper limit

Some "good" events are found

No "good" events

Coincidence search: estimate corresponding hrss

Set corresponding hrss upper limit
The method

- **Source region**: a time window 180 s long (about 10 times GRB duration), 2 min before the trigger and 1 min after. Covers most astrophysical predictions, trigger uncertainty and accounts for the favored ordering where GW precede the GRB.

- **bkg region**: stretch of data of 16500s around the source region.

- **On both source and bkg region**, we run the “Wavelet Detection Filter” (WDF) by Elena Cuoco (VIR-NOT-EGO-1390-305 & VIR-NOT-EGO-1390-110), selecting all events with SNR > 4.

- **We calibrate our pipeline using sine Gaussian software injections** (by A. Vicere’), in the hypothesis of circular polarization (we expect to be observing the GRB on-axis, i.e. along the rotation axis of the progenitor star, and we take a model best scenario of GW emission from a triaxial ellipsoid rotating around the same axis as the GRB).
Background region:
defining a threshold for “good” events
and calibrating the filter response
Event strength distribution in the bkg region
f.a. rate in the bkg region: defining a threshold for “good” events

Assuming Poisson statistics, a mean rate of f.a. of $5 \times 10^{-4}$ Hz corresponds to a chance of about 10% for one false alarm in a time window 180 s long. We thus select SNR=26 as our “good events threshold”.
Filter efficiency evaluation for Sine Gaussian Waveforms

For a $40 \text{ ms} (\pm 20 \text{ ms})$ time window, we can conservatively estimate the expected number of false coincidences as: $1 \text{ Hz} \times 40 \text{ ms} = 0.04$, where $1 \text{ Hz}$ is the rate of f.a. with SNR$>4$ (SNR$=4$ is our threshold for event definition). This implies a 4% error on the filter efficiency evaluation.
Calibrating the filter response for Sine Gaussian Waveforms

The error-bars are the $\pm 2\sigma$ intervals. Those contain more than 90% of data.

Events detectable with high confidence in a 180 s time window are in the yellow corner: 90% confidence of not being a false alarm and about 90% filter efficiency.
Distribution of detected SNR

For the lowest injected $h_{rss} (9 \times 10^{-21} \text{ Hz}^{-0.5})$, the $\pm 2\sigma$ interval contains more than 90% of data (94.6%).
Analysis of the GRB window
Comparing GRB window and bkg region: toward an upper-limit

The events distribution has SNR<9. No events above the "good events threshold" of SNR=26 are found in coincidence with the GRB: we can only set an upper-limit.
Defining the UL \( h_{rss} \)

Red line: for each detected SNR, it gives the highest possible value of \( h_{rss} \) (considering the \( 2\sigma \) range of detected SNR).

Since there are no events above threshold in the GRB window, this gives the upper-limit: \( h_{rss} < 5.3 \times 10^{-20} \) Hz\(^{-0.5}\).
Summary of UL \( h_{rss} \) for Sine Gaussians waveforms

GRB 050915a seen from VIRGO: \( F_+ = 0.32 \) \( F_x = 0.21 \)
If optimally oriented, upper-limits would be lower of a factor of \((F_+^2 + F_x^2)/2)^{0.5} = 3.69\)

<table>
<thead>
<tr>
<th>( f_0 ) (Hz)</th>
<th>UL ( h_{rss} ) (Hz(^{-0.5}))</th>
<th>( Q=5 )</th>
</tr>
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<tbody>
<tr>
<td>203</td>
<td>( 5.3 \times 10^{-20} )</td>
<td></td>
</tr>
<tr>
<td>497</td>
<td>( 4.2 \times 10^{-20} )</td>
<td></td>
</tr>
<tr>
<td>803</td>
<td>( 5.0 \times 10^{-20} )</td>
<td></td>
</tr>
<tr>
<td>1001</td>
<td>( 5.8 \times 10^{-20} )</td>
<td></td>
</tr>
<tr>
<td>1503</td>
<td>( 6.9 \times 10^{-20} )</td>
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<table>
<thead>
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<th>( f_0 ) (Hz)</th>
<th>UL ( h_{rss} ) (Hz(^{-0.5}))</th>
<th>( Q=15 )</th>
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<td>203</td>
<td>( 6.9 \times 10^{-20} )</td>
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</tr>
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Astrophysical interpretation

We can use the hrss upper-limit to set constraints on the energy emitted in gravitational waves by the GRB progenitor. For Sine Gaussian waveforms:

\[ E_{gw} \sim 4.2 M_\odot c^2 (d_L/100 \text{ Mpc})^2 (f_0/100 \text{ Hz})^2 (h_{rss}/10^{-21} \text{ Hz}^{-0.5})^2 \]

For \( f_0 = 203 \text{ Hz}, Q = 5 \), \( h_{rss} = 5.3 \times 10^{-20} \text{ Hz}^{-0.5} \) and assuming the distance of GRB 980425 (\( d_L = 40 \text{ Mpc} \)):

\[ E_{gw} < 7.8 \times 10^3 M_\odot c^2 \]

For optimal orientation we would have:

\[ E_{gw} < 571 M_\odot c^2 \]

When running at nominal sensitivity, \( E_{gw} \) will improve of about a factor 1000: start constraining at least the really most optimistic GRB models (\( E_{gw} < 0.1 M_\odot c^2 \))
Conclusions and future developments

- Given the lack of events above the “good events threshold” in the GRB window, we are going toward the definition of an upper-limit.

- We are actually analyzing a larger set of waveforms: Gaussian and damped sinusoids, in addition to sine Gaussian.

- After C7 analysis will be concluded, we will start analyzing WSR data: GRB 070219a during WSR9. The sensitivity during this run was: $1.9 \times 10^{-22}$ @ 203 Hz (vs $8.1 \times 10^{-22}$ during C7) and $2.8 \times 10^{-22}$ @ 1503 Hz (vs $9.4 \times 10^{-22}$ during C7).