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Proposal for an initial exchange of GEO, LIGO, and Virgo data

LIGO/Virgo joint data analysis working group

Draft

This is an internal working note of the
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CVS Id: T060079-00.tex,v 1.21 2006/06/14 04:18:11 shourov Exp — Processed with LaTeX on 2006/06/14

1 Introduction

With the LIGO detectors now at design sensitivity[1] and the Virgo detector in the final stages of commissioning[2], joint astrophysical searches are likely to start within the next year. At the same time, the LIGO/Virgo joint data analysis working group[3] is currently nearing completion of two detailed studies using simulated data and has now reached the point where it is ready to begin test exchanges of short segments of real detector data[1].

The purpose of this document is to describe the initial studies that the working group proposes to pursue using real detector data. To put this proposal in context, section 2 briefly reviews the progress made to date using simulated data. Section 3 then describes the proposed extension of these studies to real detector data, while the specific details of the proposed data to be exchanged are described in the appendices.

2 Previous studies on simulated data

The first project of the LIGO/Virgo joint data analysis working group focused on simulated data, and was carried out in two phases. Project 1a was performed using 3 hours of simulated single detector LIGO and Virgo data. Project 1b was performed using 24 hours of simulated coincident detector data from the LIGO Hanford and Livingston detectors and the Virgo detector.

2.1 Project 1a

The primary purpose of this first study was to develop a common language to describe our search procedures, and to understand, learn from, and build confidence in the various search algorithms brought forward by the LIGO and Virgo collaborations. At the same time, a secondary goal was to start to develop the necessary infrastructure to exchange and analyze data between the collaborations. This included addressing differences in sample frequency, differences in the storing of meta data, and differences in channel and frame file naming conventions.

The study consisted of a series of simulated inspiral and burst waveforms injected into 3 hours of simulated single detector LIGO and Virgo data. The results of this study were presented in two talks, one for burst and one for inspirals, at the 9th Gravitaional Wave Data Analysis Workshop in Annecy, France, and were published in the associated conference proceedings [5, 6].

[1] While this proposal focuses on searches for bursts and inspirals, a joint stochastic analysis effort has also been formed between the two collaborations[4]. The initial efforts of this group will also make use of the simulated detector data used in the initial burst and inspiral studies. Once these initial studies are complete, the joint stochastic analysis effort will then make use of real data proposed in this document.

2.2 Project 1b

The primary purpose of this second study was to quantitively study the benefits of coincident searches using LIGO and Virgo detector network a including increased detection confidence, greater sky coverage, and the ability to recover the sky position and waveform of candidate events.

The study consisted of astrophysically interesting populations of simulated inspiral and burst waveforms injected into 24 hours of simulated triple coincident LIGO (H1 and L1) and Virgo detector data. Both the inspiral and burst results of this study were presented in a joint talk at Amaldi 6 in Okinawa, Japan, and were published in the associated conference proceedings [7].

2.3 Further investigations

An additional two papers, one for inspirals[9] and one for bursts[8], are also nearing completion and will be submitted to Physical Review D. These more comprehensive papers expand on, and incorporate lessons learned from, our previously published studies on simulated data. For the burst search, the paper includes a more detailed discussion about the tuning of search algorithms for a targeted signal space, the robustness of search algorithms over the signal space, and the performance of various combinations of search algorithms. For the inspiral search, the paper includes a detailed comparison of the three available inspiral pipelines, including comparisons of their ability to recover the parameters of a signal.

In addition to these two papers, the triple coincident simulated data set from project 1B is also being used to benchmark coherent search algorithms for both burst and inspiral sources. It is expected that the results from these studies will be the topic of a future publication.

3 Proposed studies on real data

The proposed studies using real detector data will be analagous to the previous studies on simulated data. In particular they will be carried out in two phases. The first phase, project 2a, will be performed using 3 hours of single detector GEO, LIGO, and Virgo data from a previous science run. The second phase, project 2b, will be performed using 24 hours of data from GEO, LIGO, and Virgo detectors during a recent science run.

3.1 Project 2a

As a first step, a study is proposed using three hours of non-coincident calibrated data from the GEO detector, a single LIGO detector, and the Virgo detector.

The scope of this first exercise with real data will be to repeat the study that previously performed on 3 hours of simulated LIGO and Virgo data, as described in section 2.1. The goal is to come to an understanding of how both collaborations currently handle the details of real detector data (such as lock segment, data quality, and veto information), to develop a common language for describing this information, and to begin to develop the infrastructure to exchange this information. The inclusion of a number of burst and inspiral hardware injections will also permit a simple cross-validation study of search algorithm performance on real data. This will provide confidence in the ability of the various search algorithms to the handle non-stationarities of real detector data and enable comparisons of how they approach this task.

The deliverables from this project will be single detector trigger lists for each algorithm evaluated at a single detector false rate of 0.1 Hz. These will be compared to determine whether the different algorithms are sensitive to the same injections and/or the same non-stationarities. Initial results of these studies will be compared at a meeting of the working group on 23 June, 2006 in Orsay, France.

The details of the data to be exchanged are described in appendix A.

3.2 Project 2b

Following satisfactory progress in studying the initial 3 hours of real detector data, a second study will be performed using 24 hours of data from the GEO, LIGO, and Virgo detectors. The purpose of this study will be to develop and test the planned search strategies for the full network of detectors in a way that is as close as possible to a real joint astrophysical analysis.

The details of this study have not yet been finalized and are not being submitted for approval at this time. A proposal will be drafted at a meeting of the working group on 23 June, 2006.

The details of the data to be exchanged will be described in appendix B.

A Proposed data for project 2a

The following sections describe the details of the GEO, LIGO, and Virgo data to be exchanged for project 2a.

The exchanged information will be provided in the same format as it is currently used in each collaboration. It is up to individual analyses to convert this information to its native format. This includes changes in sample frequency and the conversion of meta information between plain ASCII, XML, and frame files.

A.1 GEO data for project 2a

The proposed GEO data set for project 2a consists of 3 hours of calibrated time-domain GEO science mode data from the 4th science run (S4). The start and stop times of the proposed data set are shown in Table 2.

Table 1: Start and stop time of the proposed GEO data set to exchange for project 2a.

	GPS	UTC
start time	795535213	2005 Mar 22 14:00:00
stop time	795546013	2005 Mar 22 17:00:00

The data will be transfered in the form that it is currently provided in within the LSC. Each frame file consists of 60 single second frames. The frame files will contain the gravitational-wave channel `G1:DER_DATA_H`, sampled at 16384 Hz, and the data quality channel `G1:DER_DATA_QUALITY`, sampled at 1 Hz.

Only a single data quality segment list will be provided. This data quality flag should be applied as an a posteriori veto to exclude coincident triggers. No a priori data quality flags are provided, nor is any distinction made between the burst and inspiral analysis. No hardware injections are provided.

Table 2 provides an accounting of the proposed science mode, data quality, veto, and injection segment durations. The duration of data to analyze is only a guide and assumes a minimum inspiral analysis duration of 2048 seconds and minimum burst analysis duration of 64 seconds. It is left up to the individual analysis algorithms to determine what data to analyze after excluding periods of poor data quality. This assumption is also included in the reported duration of good analysis time after the application of vetoes. As a result, the actual analyzed live time may vary slightly between algorithms.

The sensitivity of the GEO detector to optimally oriented 1.4 / 1.4 solar mass neutron star binaries during this time period is shown in Figure 1.

Since simulated burst and inspiral waveforms are not regularly injected into the GEO detector, no hardware injections will be provided.

Table 2: Details of science mode, data quality, veto, and injection segments for the proposed GEO data set.

segment type	total duration [hours]	number of segments
science mode	2.98	2
data quality	—	—
analyze	2.98	2
veto	1 second	1
good	2.98	3
injection	—	—

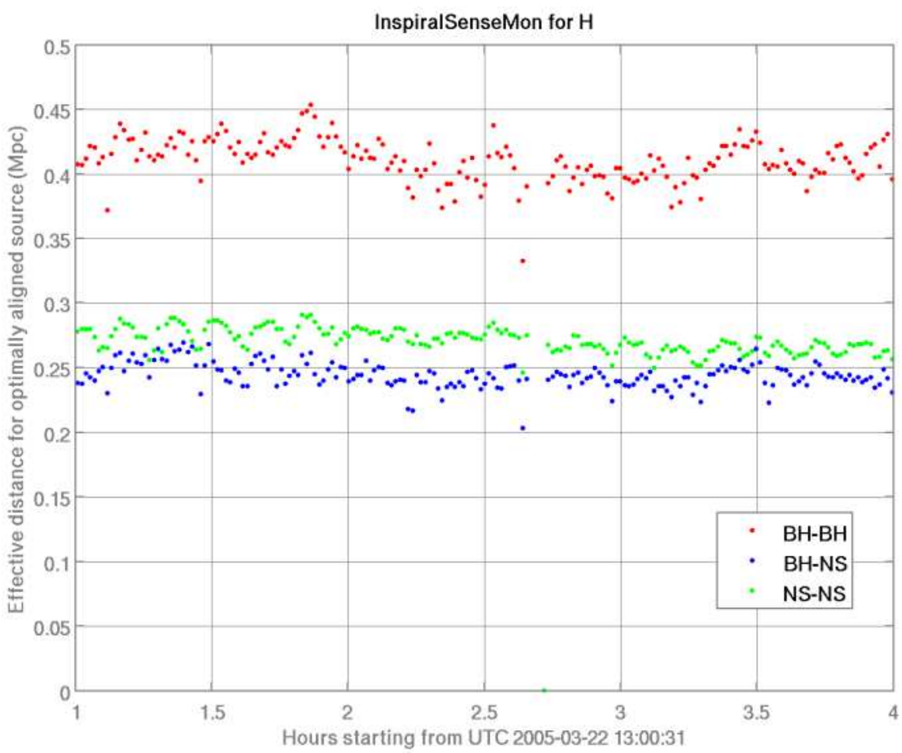

Figure 1: Sensitivity of the proposed project 2a GEO data set for optimally oriented 1.4 / 1.4 solar mass neutron star binaries.

Further details of the proposed data set, including segment lists, are provided in the working group e-notebook[10].

A.2 LIGO data for project 2a

The proposed LIGO data set for project 2a consists of 3 hours of calibrated time-domain science mode data from the 4 km Hanford detector (H1) during the 4th LIGO science run (S4). The start and stop times of the proposed data set are shown in Table 4.

Table 3: Start and stop time of the proposed S4 H1 data set to exchange for project 2a.

	GPS	UTC
start time	794685820	2005 Mar 12 18:03:27
stop time	794699230	2005 Mar 12 21:46:57

The data will be transfered in the form of 128 second long frame files with a sample frequency of 16384 Hz, as it is currently provided within the LSC. The frame files will contain the single channel `H1:LSC-STRAIN`.

In addition to the data, we will also exchange ASCII segment lists identifying periods of poor data quality, veto times, and injection times. These will be provided separately for the burst and inspiral searches, and are based on the data quality and veto flags used for the S4 burst and inspiral searches. Periods of poor data quality are to be excluded *a priori* from the initial analysis while vetoes are to be applied *a posteriori* to the resulting triggers.

Table 4 provides an accounting of the proposed science mode, data quality, veto, and injection segment durations. The duration of data to analyze is only a guide and assumes a minimum inspiral analysis duration of 2048 seconds and minimum burst analysis duration of 64 seconds. It is left up to the individual analysis algorithms to determine what data to analyze after excluding periods of poor data quality. This assumption is also included in the reported duration of good analysis time after the application of vetoes. As a result, the actual analyzed live time may vary slightly between algorithms.

A graphical summary of the proposed science mode, data quality, veto, and injetion segments is shown in Figure 2.

The sensitivity of the 4 km Hanford detector to optimally oriented 1.4 / 1.4 solar mass neutron star binaries during this time period is shown in Figure 3.

The proposed data set also includes a few of simulated burst and inspiral waveforms that have been physically injected into the instrument. The details of these hardware injections are listed in Table 5. Details of injections will also be provided in the form currently used within the LSC. Burst injections details will be provided in plain ASCII text. Inspiral injection details will be provided in XML.

Table 4: Details of science mode, data quality, veto, and injection segments for the proposed LIGO data set.

segment type	total duration [hours]	number of segments
science mode	3.00	2
data quality burst	0.28	2
data quality inspiral	0.01	1
analyze burst	2.72	3
analyze inspiral	2.99	2
veto burst	0.16	310
veto inspiral	0.51	6
good burst	2.63	286
good inspiral	2.49	6
injection burst	0.11	1
injection inspiral	0.15	1

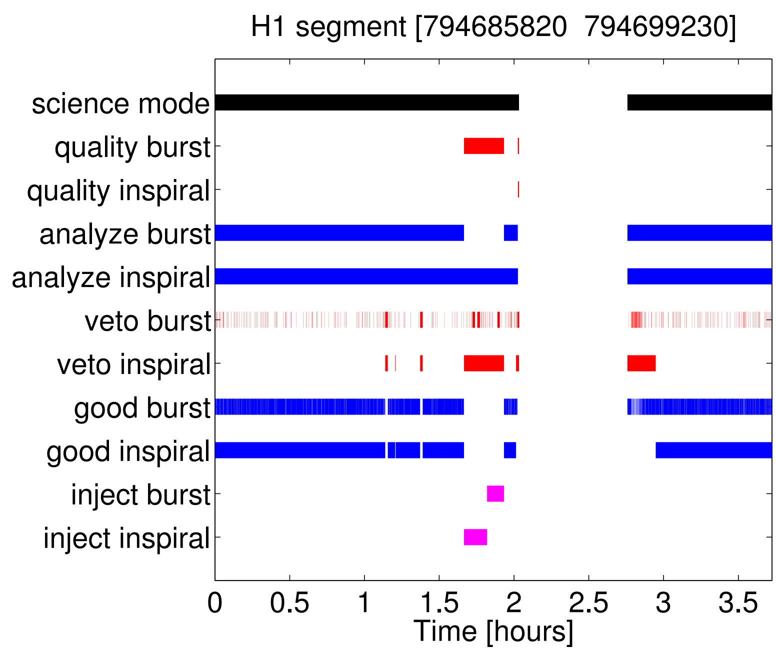

Figure 2: Graphical summary of the proposed LIGO data set for project 2a.

Further details of the proposed data set, including segment lists and hardware injection parameters, are provided in the working group e-notebook[11].

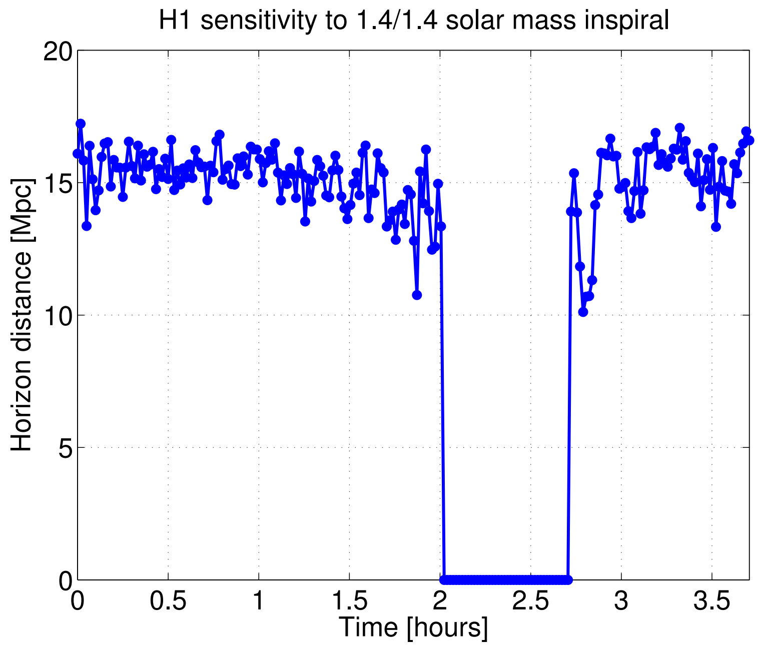

Figure 3: Sensitivity of the proposed project 2a LIGO data set. The sensitivity is specified in terms of the detectable range to optimally oriented 1.4 / 1.4 solar mass neutron star binaries at an SNR threshold of 8.

A.3 Virgo data for project 2a

The proposed VIRGO data set for project 2a consists of 3 hours of calibrated time-domain VIRGO data from the C7 VIRGO commissioning run. The start and stop times of the proposed data set are shown in Table 7.

The data will be transfered in the form of 1 hour long frame files each containing 360 ten second long frames, as it is currently provided within the Virgo collaboration. The frames contain the time domain calibrated gravitational-wave strain channel decimated to 4 different sample frequencies of 20 kHz, 16384 Hz, 4 kHz, and 4096 Hz.

The frames contain four different time-domain calibrated gravitational-wave strain channels, which differ only in their sample frequency. The channels commonly provided within Virgo are `V1:h_20kHzNo50` (20000 Hz) and `V1:h_4kHzNo50` (4000 Hz), while `V1:h_16384HzNo50` (16384 Hz) and `V1:h_4096HzNo50` (4096 Hz) are also provided for the benefit of joint data analysis. All four gravitational-wave data streams have been filtered to remove the 50 Hz power line and its harmonics.

In addition to the data, we will also exchange information that identifies periods of poor data quality, vetoes, and injections. These will be provided separately for the burst and inspiral searches. Periods of poor data quality are to be excluded *a priori* from the initial analysis while vetoes are to be applied *a posteriori* to the resulting triggers. Virgo data quality information are also provided in the frame files to be exchanged as the 1 Hz sample frequency channels `V1:dataQuality`, `V1:ScienceMode`, `V1:LockState`, `V1:TimeSinceLastRelock`, `V1:Hrec_quality`.

Table 5: Details of simulated burst and inspiral hardware injections into the proposed LIGO data set. For inspiral waveforms, the listed time is the end time at the Hanford detector. For burst waveforms, the listed time is the center or peak time at the Hanford detector. For inspiral waveforms, amplitude is specified in terms of effective distance. For burst waveforms, amplitude is specified in terms of the hrss observed by the Hanford detectors.

time	waveform		amplitude
794692372.350000000	sine-gaussian	235 Hz Q 9	$5 \times 10^{-22}\,\mathrm{Hz}^{-1/2}$
794692382.350000000	sine-gaussian	235 Hz Q 9	$1 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692392.350000000	sine-gaussian	235 Hz Q 9	$2 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692402.350000000	sine-gaussian	235 Hz Q 9	$4 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692412.350000000	sine-gaussian	235 Hz Q 9	$8 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692422.350000000	sine-gaussian	914 Hz Q 9	$5 \times 10^{-22}\,\mathrm{Hz}^{-1/2}$
794692432.350000000	sine-gaussian	914 Hz Q 9	$1 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692442.350000000	sine-gaussian	914 Hz Q 9	$2 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692452.350000000	sine-gaussian	914 Hz Q 9	$4 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692462.350000000	sine-gaussian	914 Hz Q 9	$8 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692472.350000000	gaussian	1 ms	$5 \times 10^{-22}\,\mathrm{Hz}^{-1/2}$
794692482.350000000	gaussian	1 ms	$1 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692492.350000000	gaussian	1 ms	$2 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692502.350000000	gaussian	1 ms	$4 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692512.350000000	gaussian	1 ms	$8 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692522.337365723	supernova	ZM A3B3G1	$5 \times 10^{-22}\,\mathrm{Hz}^{-1/2}$
794692532.337365723	supernova	ZM A3B3G1	$1 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692542.337365723	supernova	ZM A3B3G1	$2 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692552.337365723	supernova	ZM A3B3G1	$4 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794692562.337365723	supernova	ZM A3B3G1	$8 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
794691919.920935404	inspiral	10, 10 $M_\odot$	60 Mpc
794692046.141423857	inspiral	3, 3 $M_\odot$	10 Mpc
794692184.429062010	inspiral	1.4, 1.4 $M_\odot$	5 Mpc

Table 7 provides an accounting of the proposed science mode, data quality, veto, and injection segment durations. The duration of data to analyze is only a guide and assumes a minimum inspiral analysis duration of 2048 seconds and minimum burst analysis duration of 64 seconds. It is left up to the individual analysis algorithms to determine what data to analyze after excluding periods of poor data quality. This assumption is also included in the reported duration of good analysis time after the application of vetoes. As a result, the actual analyzed live time may vary slightly between algorithms.

The proposed data set also includes a few of simulated burst and inspiral waveforms that

Table 6: Start and stop time of the proposed VIRGO data set to exchange for project 2a.

	GPS	UTC
start time	811131950	2005 Sep 19 02:25:37
stop time	811146350	2005 Sep 19 06:25:37

Table 7: Details of science mode, data quality, veto, and injection segments for the proposed VIRGO data set.

segment type	total duration [hours]	number of segments
science mode	2.86	4
good burst	2.77	5
good inspiral	2.53	10

have been physically injected into the instrument. The details of these hardware injections are listed in Table 8. Details of both burst and inspiral injections will also be provided in the form of FrSimEvent structures (with names `V1:HI_CB` and `V1:HI_Burst`), as is currently used within the Virgo collaboration.

Table 8: Details of simulated burst and inspiral hardware injections into the proposed VIRGO data set. For inspiral waveforms, the listed time is the end time at the Hanford detector. For burst waveforms, the listed time is the center or peak time at the Hanford detector. For inspiral waveforms, amplitude is specified in terms of effective distance. For burst waveforms, amplitude is specified in terms of the hrss observed by the Hanford detectors.

811139954.645400000	gaussian	1 ms	$1.59761 \times 10^{-20}\ \mathrm{Hz}^{-1/2}$
811139964.261450000	sine-gaussian	920 Hz Q 15	$8.20703 \times 10^{-21}\ \mathrm{Hz}^{-1/2}$
811139970.459700000	sine-gaussian	460 Hz Q 15	$5.98009 \times 10^{-21}\ \mathrm{Hz}^{-1/2}$
811139977.059100000	gaussian	1 ms	$1.59761 \times 10^{-20}\ \mathrm{Hz}^{-1/2}$
811140017.679450000	sine-gaussian	920 Hz Q 15	$8.20703 \times 10^{-21}\ \mathrm{Hz}^{-1/2}$
811140070.716800000	sine-gaussian	460 Hz Q 15	$5.98009 \times 10^{-21}\ \mathrm{Hz}^{-1/2}$

time	waveform		amplitude
811140120.269200000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140135.068450000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140157.154600000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140158.154700000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140162.747300000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140227.993850000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140228.805300000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140291.610000000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140293.515350000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140305.504900000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140346.440500000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140350.797550000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140359.230400000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140369.944500000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140396.400350000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140398.152200000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140415.088100000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140439.030250000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140472.146900000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140476.088400000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140480.344050000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140505.868900000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140512.350900000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140533.598250000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140540.729300000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140562.700600000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140565.086150000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140584.734900000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140588.810700000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140603.969050000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140614.301800000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140641.254100000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140645.350150000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140686.721700000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140695.127200000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140716.033250000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140722.011000000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140723.618800000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140739.565050000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811140761.858000000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140787.202100000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140794.085150000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$

time	waveform		amplitude
811140795.894900000	sine-gaussian	460 Hz Q 15	5.98009×10^{-21} Hz$^{-1/2}$
811140803.229700000	gaussian	1 ms	1.59761×10^{-20} Hz$^{-1/2}$
811140833.287250000	sine-gaussian	920 Hz Q 15	8.20703×10^{-21} Hz$^{-1/2}$
811135866.094500000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811135903.243300000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811136639.047300000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811136875.421800000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811138112.690800000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811138418.264600000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811138833.247800000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811138919.968200000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc
811138977.656900000	inspiral	1.32 / 1.36 $M_\odot$	0.43696 Mpc

Further details of the proposed data set, including segment lists and hardware injection parameters, are provided in the working group e-notebook[12].

B Proposed data for project 2b

This section is a placeholder for a future 24 hour coincident study of GEO, LIGO, and Virgo data. The details of the data to be exchanged for this study have not been finalized.

B.1 GEO data for project 2b

To be determined.

B.2 LIGO data for project 2b

To be determined.

B.3 Virgo data for project 2b

To be determined.

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