Description of Trigger Data File Contents to Accompany *GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs*

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Abstract

This document describes the contents of trigger data files used in the catalog of compact binary mergers observed by LIGO and Virgo during the first and second observing runs produced by the LIGO and Virgo Collaborations, GWTC-1 [1], generated by the PyCBC [2, 3] and GstLAL [4, 5] searches.

1 Overview

LIGO and Virgo data collected in the first and second observing runs, O1 and O2, were analyzed by the PyCBC [2, 3] and GstLAL [4, 5] template-based matched-filter search pipelines to detect gravitational wave signals resulting from coalescences of compact binaries with both components having mass greater than 1 $M_\odot$, the total mass of components less than either 500 $M_\odot$ (PyCBC) or 400 $M_\odot$ (GstLAL), and the ratio of the larger mass component to the smaller mass component less than 98. These searches form *triggers* corresponding to times when the matched filter signal-to-noise ratio exceeds a certain threshold simultaneously (within a small time window) in at least two detectors in a network that includes the LIGO Hanford Observatory detector (H1), the LIGO Livingston Observatory detector (L1) [6], and the Virgo detector (V1) [7]. The eleven confident detections and the fourteen marginal candidates published in the Gravitational Wave Transient Catalog GWTC-1 [1] are among the thousands of triggers generated by the GstLAL and PyCBC searches. Here we provide the entire set of triggers generated by those searches, including not only the set used to produce GWTC-1, but also sub-threshold triggers, to enable searching for coincidences between sub-threshold triggers and events recorded in other astronomical datasets.

1.1 Trigger Selection

The PyCBC triggers are generated at times when the matched-filter signal-to-noise ratio in a template exceeds the threshold of 5.5 in both the H1 and L1 detectors. This resulted in 21931 triggers recorded over the O1 and O2 runs, including a special period of analysis around the time of GW170608 when the H1 detector was in a low-noise state but was not in a nominal observational period. At this threshold, the overall rate of false alarms in the trigger set is approximately 80 000 per year, so nearly all the triggers provided are not produced by astrophysical signals (internal clustering of triggers within the pipeline results in fewer triggers recorded).

The GstLAL triggers are generated at times when the matched-filter signal-to-noise ratio in a template exceeds the threshold of 4.0 in at least two of the H1, L1, and V1 detectors. A further requirement in the selection of triggers released here is that the GstLAL log-likelihood-ratio ranking statistic exceeds 14.0. This resulted in 4992 triggers. At this threshold, the overall rate of false alarms in the trigger set is approximately 10 000 per year, so nearly all the triggers provided are not produced by astrophysical signals.

2 Trigger Files

The triggers are stored in the HDF5 file format [8] in the files listed below.

GW170608_triggers_gstlal.hdf5
GW170608_triggers_pycbc.hdf5

GstLAL and PyCBC triggers produced during a specially identified period between 2017-06-07 and 2017-06-09 comprising 1.2 days of coincident H1-L1 data [9]. During this time H1 was not in nominal observing conditions due to commissioning activities but was in a stable, low-noise configuration. Times during which commissioning activities could have resulted in broadband disturbances are excluded from this period.

O1_triggers_gstlal.hdf5
O1_triggers_pycbc.hdf5

GstLAL and PyCBC triggers produced during the first observing run (O1) of Advanced LIGO, which took place from 2015-09-12 to 2016-01-19. During O1, a total of 51.5 days of coincident analysis time were accumulated when H1 and L1 were both operating in their nominal state.

O2_triggers_gstlal.hdf5
O2_triggers_pycbc.hdf5

GstLAL and PyCBC triggers produced during the second observing run (O2) of Advanced LIGO, which took place from 2016-11-30 to 2017-08-25. On 2017-08-01 the Advanced Virgo detector joined the observing run and generated triggers in the GstLAL search. During O2, approximately 118 days of data suitable for coincident analyses were collected, of which approximately 15 days were collected in coincident operation with Virgo.

3 Datasets

Each file contains a subset of the following datasets. These datasets contain triggers that were found above threshold simultaneously in at least two operating detectors. Each dataset in a file will contain values indexed by an ordinal trigger number. The datasets all have the same length. If data is missing for a particular trigger in one of the datasets, for example, if a trigger is produced in H1 and L1 data but not in V1 data, then the value in the dataset for which there is no value for that trigger index will be set to NaN. A description of the dataset contents is provided below.

`false_alarm_rate`

> The rate of false alarms (year^{-1}) expected above the trigger ranking statistic. See [3] for PyCBC and [4] for GstLAL. Note: for GstLAL, a prior distribution (a power law distribution in signal-to-noise ratio with a large negative exponent) is assumed for the background distribution where no measurable background is available; consequently, the false alarm rate value assigned to highly significant signals in the GstLAL search is determined by this prior distribution [10].

`h1_chisq`

> Signal consistency test value χ^2 (PyCBC) or ξ^2 (GstLAL) for the trigger in H1.
>
> For GstLAL this quantity is given by Eq. (4) of [4]. Note that this is a reduced quantity so there is no `h1_chisq_dof` dataset for GstLAL (treat as 1).
>
> For PyCBC this quantity is given by Eq. (7.10) of [12]; see also Eq. (9.4) and (C1) of [11].

`h1_chisq_dof` **(PyCBC Only)**

> Degrees of freedom associated with the χ^2 test for the trigger in H1. See Eq. (7.11) of [12].

`h1_end_time`

> GPS time (seconds since 1980-01-06T00:00:00Z) of the trigger coalescence time in H1. See Eq. (3.2) and Eq. (8.14a) of [11] where it is called the *termination time*.

`h1_sg_chisq` **(PyCBC Only)**

> High frequency sine-Gaussian reduced χ^2 discriminator value $\chi^2_{r,sg}$ for the trigger in H1. See Eq. (5) of [13].

`h1_sigmasq` **(PyCBC Only)**

The value of the variance of the matched filter for a template signal at effective distance of 1 Mpc in H1. See Eq. (4.3) and Eq. (8.8) of [11].

`h1_snr`

Signal-to-noise ratio of trigger in H1. See Eq. (4.4b) and (8.12) of [11].

`l1_chisq`

Signal consistency test value χ^2 (PyCBC) or ξ^2 (GstLAL) for the trigger in L1.

For GstLAL this quantity is given by Eq. (4) of [4]. Note that this is a reduced quantity so there is no `l1_chisq_dof` dataset for GstLAL (treat as 1).

For PyCBC this quantity is given by Eq. (7.10) of [12]; see also Eq. (9.4) and (C1) of [11].

`l1_chisq_dof` **(PyCBC Only)**

Degrees of freedom associated with the χ^2 test for the trigger in L1. See Eq. (7.11) of [12].

`l1_end_time`

GPS time (seconds since 1980-01-06T00:00:00Z) of the trigger coalescence time in L1. See Eq. (3.2) and Eq. (8.14a) of [11] where it is called the *termination time*.

`l1_phase_minus_h1_phase`

Difference between twice the termination phase of the trigger in L1 and twice the termination phase of the trigger in H1 (radians). See Eq. (3.2) and Eq. (8.14a) of [11] for the definition of termination phase.

Attention: For both the PyCBC and GstLAL triggers in the GW170608 files, the differences in the L1 and H1 termination phases were originally miscalculated when adjusting for the higher-than-normal low-frequency cutoff needed to avoid known instrumental artifacts in the H1 data. The values provided in the datasets are those erroneous values that were used in constructing the search ranking statistics; they should not be used for any purpose other than reproducing the search results.

`l1_sg_chisq` **(PyCBC Only)**

High frequency sine-Gaussian reduced χ^2 discriminator value $\chi^2_{r,sg}$ for the trigger in L1. See Eq. (5) of [13].

`l1_sigmasq` **(PyCBC Only)**

The value of the variance of the matched filter for a template signal at effective distance of 1 Mpc in L1. See Eq. (4.3) and Eq. (8.8) of [11].

`l1_snr`

Signal-to-noise ratio of trigger in H1. See Eq. (4.4b) and (8.12) of [11].

`log_likelihood_ratio` **(GstLAL Only)**

The natural log of the likelihood ratio used as the GstLAL trigger ranking statistic. See Eq. (9) of [4]. Note that the distributions used in forming the numerator and denominator are not normalized, so the `log_likelihood_ratio` has an unspecified constant offset.

`mass1`

Primary detector-frame mass m_1 ($M_\odot$) of the template signal.

`mass2`

Secondary detector-frame mass m_2 ($M_\odot$) of the template signal.

`spin1z`

Primary z-component of spin $c\hat{\mathbf{L}} \cdot \mathbf{S}_1/(Gm_1^2)$ (dimensionless) of the template signal where $\hat{\mathbf{L}}$ is the unit vector in direction of the orbital angular momentum vector and $\mathbf{S}_1$ and m_1 are the spin vector and the mass of the primary component. The templates used had spin vectors aligned with the orbital angular momentum vector.

`spin2z`

Secondary z-component of spin $c\hat{\mathbf{L}} \cdot \mathbf{S}_2/(Gm_2^2)$ (dimensionless) of the template signal where $\hat{\mathbf{L}}$ is the unit vector in direction of the orbital angular momentum vector and $\mathbf{S}_2$ and m_2 are the spin vector and the mass of the secondary component. The templates used had spin vectors aligned with the orbital angular momentum vector.

`v1_chisq` **(O2 Only, GstLAL Only)**

Signal consistency test value ξ^2 (GstLAL) for the trigger in V1.

This quantity is given by Eq. (4) of [4]. Note that this is a reduced quantity so there is no `v1_chisq_dof` dataset (treat as 1).

`v1_end_time` **(O2 Only, GstLAL Only)**

GPS time (seconds since 1980-01-06T00:00:00Z) of the trigger coalescence time in V1. See Eq. (3.2) and Eq. (8.14a) of [11] where it is called the *termination time*.

`v1_phase_minus_h1_phase` **(O2 Only, GstLAL Only)**

Difference between twice the termination phase of the trigger in V1 and twice the termination phase of the trigger in H1 (radians). See Eq. (3.2) and Eq. (8.14a) of [11] for the definition of termination phase.

`v1_phase_minus_l1_phase` **(O2 Only, GstLAL Only)**

Difference between twice the termination phase of the trigger in V1 and twice the termination phase of the trigger in L1 (radians). See Eq. (3.2) and Eq. (8.14a) of [11] for the definition of termination phase.

`v1_snr` **(O2 Only, GstLAL Only)**

Signal-to-noise ratio of trigger in V1. See Eq. (4.4b) and (8.12) of [11].

4 Tutorial

The following Python code `tutorial.py` demonstrates how to read the trigger files and prints out certain information about the triggers.

```python
import h5py

# open trigger file
fname = 'O2_triggers_pycbc.hdf5'
trigger_set = h5py.File(fname, 'r')

# print the properties of the most significant triggers
print('Properties of most significant triggers in file {0}'.format(fname))

for i, far in enumerate(trigger_set['false_alarm_rate']):

    # only consider triggers with false alarm rate < 1/year
    if far < 1.0:
        print('')
        print('Trigger number {0}:'.format(i))

        # print all the properties of the found triggers
        for key in trigger_set.keys():
            print('... {0}: {1}'.format(key, trigger_set[key][i]))
```

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