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Class. Quantum Grav. **23** (2006) S705–S707 doi:10.1088/0264-9381/23/19/S08

# Overview of LIGO Scientific Collaboration inspiral searches

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Received 31 March 2006
Published 15 September 2006
Online at stacks.iop.org/CQG/23/S705

**Abstract**
We describe the effort of inspiral searches with LIGO data from the third and fourth science runs, which took place in 2003/2004 and 2005, respectively. Although the analysis pipeline is the same for all searches, there are significant differences between the three major ongoing searches: for primordial black hole binaries, binary neutron stars and binary black holes. The horizon distance for all searches significantly increased with respect to earlier LIGO science searches.

PACS numbers: 04.80.Nn, 95.85.Sz

The search for gravitational waves has entered a new era with the operation of kilometre-scale laser interferometers. These L-shaped instruments are sensitive to the minute changes in the relative lengths of their orthogonal arms that would be produced by gravitational waves [1]. The Laser Interferometer Gravitational-Wave Observatory (LIGO) [2, 3] consists of three Fabry–Perot–Michelson interferometers: two interferometers are housed at the LIGO Hanford Observatory, Washington and a single interferometer is housed in the LIGO Livingston Observatory, Louisiana. In 2003–2005, all three interferometers simultaneously collected data under stable operating conditions during two science runs: the third science run from 31 October 2003 to 9 January 2004 (S3) and the fourth science run from 22 February 2005 to 24 March 2005 (S4). Even though the interferometers were not yet performing at their design sensitivity, the data represented the best broadband sensitivity to gravitational waves that had been achieved to that date [4, 5]. In this paper, an overview is given on the searches for signals from binary systems of compact stars, in the late inspiral stage of their evolution before coalescence. The searches include data from the third and fourth science runs of LIGO, including data from the GEO600 detector [6], which is located near Hannover, Germany.

The first stage of an inspiral search consists of the creation of a bank of templates, which are used for matched filtering (a cross-correlation function between the data and the assumed waveform of the signal, see [7, 9]). Those templates, spanning the region in parameter space that is searched, defined by the binary component masses, are created in such a way that the loss in SNR between any putative signal and its nearest template is no more than a few per cent, taking into account the detector noise spectrum measured in the segment of data to be searched [8]. In the second step, the data are searched with those templates using matched filtering techniques [9].

Three major inspiral searches are performed using S3 and S4 data: the search for primordial black hole binaries (PBHB) with component masses between $0.35M_\odot$ and $1.0M_\odot$, binary neutron stars (BNS) with component masses between $1.0M_\odot$ and $3.0M_\odot$ and binary black holes (BBH) with component masses between $3.0M_\odot$ and $40.0M_\odot$ in S3 and up to $80.0M_\odot$ in S4. In each case the component masses are assumed to be non-spinning. Although the basic algorithm for these searches is the same and they use the same pipeline and the same data segments, they differ significantly in details [9–11].

The signal expected from a primordial black hole binary will spend a relatively long time in the LIGO frequency band because of its low chirp mass and therefore high coalescence frequency. The longer the duration of this signal, the more precise the waveform must be to not lose a large fraction of the signal-to-noise ratio (SNR), because small differences in the chirp masses create phase errors, leading to a mismatch between the signal and the waveform. Therefore, the number of templates would become too large if the low-frequency cut-off is chosen to be too low. For this reason, the low-frequency cut-off is set to 100 Hz for this search while it is set to 70 Hz for the other two searches. This way, the number of templates for the PBHB and BNS searches is comparable (between 1000 and 3000 per 2048 s long data segment).

The searches for PBHB and BNS use second-order post-Newtonian waveforms [12] for an approximation of the inspiral waveform and they also use a $\chi^2$-test as a signal-based veto to discriminate a real signal from background noise (which is a waveform-consistency test [9, 13]), as well as a newly developed '$r^2$' veto (which looks at the time the $\chi^2$-value spends above some threshold, see [14]).

The search for binary black holes, however, is much more challenging since the post-Newtonian approximation starts to lose validity and different versions of approximations differ from one another. For this reason, phenomenological templates are used for the filtering (see [15] and the paper on the BBH search in the second LIGO science run [11]). We do not implement a $\chi^2$-test for this search because accurate waveforms are not available for this case to date, we only use phenomenological templates for the matched filtering; therefore, also only phenomenological parameters are used instead of physical parameters (the component masses).

We only accept candidate events when they are seen in at least two detectors, whose parameters (coalescence time, masses and distances for PBHB and BNS, phenomenological parameters for BBH) are consistent within reasonable windows. These coincident windows are chosen by performing simulated injections in the data and optimizing their recovery. Therefore, the horizon distance of the searches is limited by the least sensitive interferometer used for the coincidence.

Compared to the analysis of the S2 data, the horizon distance for S3 has improved significantly by a factor of 3–5 (which corresponds to an increase of a factor of 30–100 in volume). For S4, the horizon distance again increased by another factor of at least 2 (depending on the search). Figure 1 gives an example of the distribution of the horizon distance for $5.0/5.0M_\odot$ binary black holes, which would give a signal-to-noise ratio of 8 in the interferometer, when the binary is optimally located and oriented. When accepting only coincident triggers, the maximum horizon distance in S3 for BBH is 5 Mpc, for BNS it is 1.5 Mpc (for a $1.4/1.4M_\odot$ binary) and for PBHB it is 0.6 Mpc (for a $0.7/0.7M_\odot$ binary).

Besides the searches already described, we are searching for spinning black holes and for the ringdown phase after the merger of a binary black hole. We are also looking for

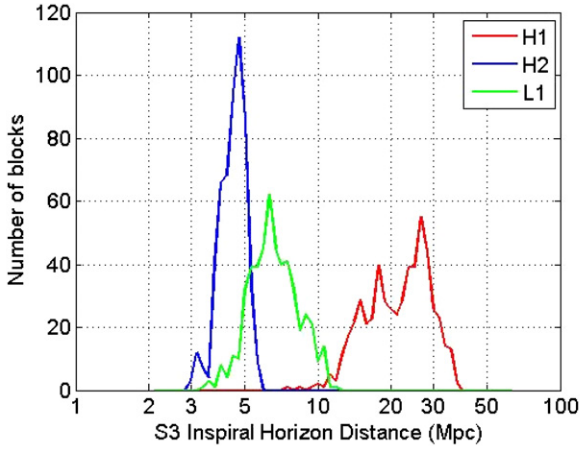


**Figure 1.** Distribution of the horizon distance for the BBH search in S3 data. Shown is the distance for each 'block' of data. L1 refers to the Livingston interferometer, H1 and H2 refer to those located at Hanford.

coincidences between inspiral triggers resulting from this search, and gamma ray bursts and also between inspiral triggers and burst triggers, resulting from other searches [16]. We also plan to search for the inspiral phase of high mass ratio binaries in the future.

At the end of 2005, we started our fifth science run (S5), which will collect triple coincident data for 1 year, with a horizon distance larger than 10 Mpc for BNS systems in all interferometers. We are also performing searches during this run for BBH and BNS systems.

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