FIGURE 1. Strain sensitivity plot of the most sensitive LIGO detector during the five science. A large improvement over several orders of magnitude (depending on the frequency) can be seen when comparing the first and the latest science run. The solid line represents the design sensitivity, which is almost reached at low frequencies and slightly surpassed at higher frequencies.

GRB triggered searches for gravitational waves in LIGO data

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Abstract. The LIGO gravitational wave detectors have recently reached their design sensitivity and finished a two-year science run. During this period one year of data with unprecedented sensitivity has been collected. I will briefly describe the status of the LIGO detectors and the overall quality of the most recent science run. I also will present results of a search for inspiral waveforms in gravitational wave data coincident with the short gamma ray burst detected on 1st February 2007, with its sky location error box overlapping a spiral arms of M31. No gravitational wave signals were detected and a binary merger in M31 can be excluded at the 99 % confidence level.

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INTRODUCTION

Gamma-ray bursts (GRBs) are intense flashes of gamma-rays which are observed to be isotropically distributed over the sky [1, 2, 3] and which can be separated into two major groups. “Long” GRBs have a duration $\gtrsim 2$ seconds and are in general believed to be associated with stellar core-collapse events [e.g. 4, 5, 6, 7, 8].

“Short” GRBs (SGRB) with a duration of $\lesssim 2$ seconds are believed to have a different origin. The leading hypothesis is the merger of two compact objects, one of them a neutron star and the other either a neutron star or a black hole [see, for example, 9, 10, and references therein]. Such mergers are also sources of gravitational waves, accessible to ground-based detectors like LIGO, GEO-600, and Virgo [11, 12, 13, 14, 15, 16]. Another possible progenitor of short GRBs are soft gamma repeaters, but at most $\sim$15% of known short GRBs can be explained by these [17, 18].

The next section will give a brief overview of LIGO and the latest science run, followed by the results of the analysis of data taken around GRB 070201.

STATUS OF LIGO

The Laser Interferometer Gravitational-Wave Observatory (LIGO) consists of three instruments at two different sites, one located near Livingston, LA with a 4 km long detector (referred to as L1) and the other located near Hanford, WA, with a 4 km and 2 km long detector, (referred to as H1 and H2, respectively). Also part of the LIGO Scientific Collaboration is GEO600, a British-German instrument located near Hanover, Germany, a 600 m long detector.

These detectors use suspended mirrors at the ends of kilometer-scale, orthogonal arms to form a power-recycled Michelson interferometer with Fabry-Perot cavities. The interference of the light beams from the two arms recombining at the beam splitter depends on the difference between the lengths of the two arms. The LIGO detectors are sensitive in a frequency band of $\sim$40 Hz to $\sim$2000 Hz, with the greatest sensitivity at $\approx$150 Hz [see 19, for more details].

The first data-taking run took place in 2002. The last science run, referred to as S5, started on November 4th, 2005 and ended on October 1st, 2007 and collected more than 1 year of coincident data. In May 2007 the French-Italian VIRGO instrument [20], consisting of a 3 km long detector, joined the S5 data-taking effort. During the science runs of LIGO, the sensitivity of the detectors increased significantly. Figure 1 shows the strain sensitivity of the most sensitive LIGO detector for each of the five science runs, showing improvement in sensitivity by two orders of magnitude compared with the first science run in 2002. The figure also shows the design sensitivity, which has been reached with the latest S5 run. In figure 2 we plot the distance at which an optimal oriented and located source would create a signal-to-noise ratio of 8, the so-called horizon distance, as a function of the total mass of the source. The horizon distance for a neutron star binary merger is about 30 Mpc for H1 and L1.

No gravitational wave signals have been detected so far, and results of the analyses of previous science runs can be found in [15, 21, 22, 23]. See [24] for a review of the searches for Gravitational Waves from Binary Neutron Stars.

ANALYSIS OF GRB 070201 FOR INSPIRAL SIGNALS

This Section summarizes the analysis and results from data taken in coincidence with the occurrence of GRB 070201, a short-type gamma ray burst which might have occurred in M31. A more detailed description of the inspiral and burst analysis can be found in [25].

GRB 070201 was an intense, short duration GRB, which was detected and localized by five interplanetary Gamma-Ray Burst Timing Network spacecraft (Konus-Wind, Mars Odyssey, INTEGRAL and MESSENGER). The refined error-box of the location of this GRB overlaps with the spiral arms of M31 [26, 27], making this a possible close-by source of gravitational waves.

At the time of GRB 070201, only the two Hanford detectors were taking data. The horizon distances at this time were 35.7 Mpc and 15.3 Mpc for H1 and H2, respectively. However, M31 was located sub-optimally at this time so the actual reach is only $\sim 43\%$ of the horizon distance in the direction of M31. If this GRB were due to a binary binary

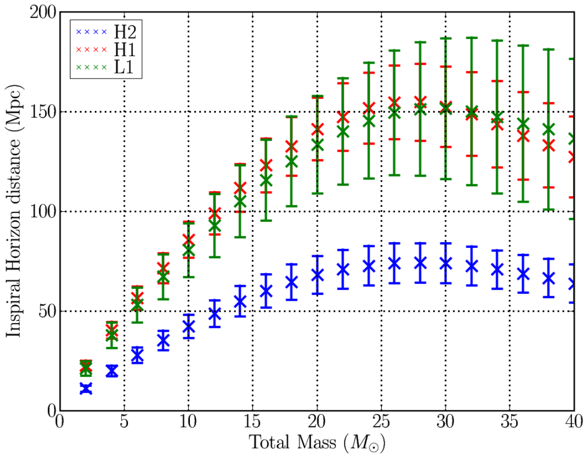

FIGURE 2. Plot showing the horizon distance to an inspiral signal for the three LIGO detectors, as a function of total mass of the merging system.

merger in M31, the gravitational wave signal would be easily detectable by LIGO. A 180 second long on-source segment was chosen around the time of the GRB as in previous analyses (see e.g. [28]) starting 120 seconds before the trigger and lasting 60 seconds after it. Two off-source segments of the same length were chosen one on each side of the on-source segments to estimate the rate of accidental background events. Also, simulated signals were added to the data and analyzed to estimate the efficiency of this search.

The search for inspiral signals from compact binaries involves matched filtering [29] the data with theoretical waveforms [30] of two inspiraling objects, with masses in the range $1\,M_\odot < m_1 < 3\,M_\odot$ and $1\,M_\odot < m_2 < 40\,M_\odot$. One of the objects must be a neutron star in order to create a GRB [31, 32], but the other can be either a neutron star or a black hole, which is the reason for the selected mass ranges. Details of the inspiral search can be found in [24, 15, 21, 22, 23], and details for this particular search are given in [25].

No candidates were detected in the on-source time, and therefore no plausible gravitational wave signals were identified around the time of GRB 070201. However, due to the lack of detection of gravitational waves two upper-limit results can be drawn from this analysis.

The first result is shown in Figure 3; here an exclusion area is shown on a space spanned by the more massive compact object m_2 and the physical distance D, including all errors and uncertainties.

The second result is a constraint on the nature of the source if it were located in M31, at a distance of 0.77 ± 0.05 Mpc. Since no plausible gravitational wave signal was found in the on-source data, a compact binary progenitor of this GRB can be excluded at the $> 99\%$ confidence level at the distance of M31.

If, however, the origin of this GRB was a soft-gamma repeater located in M31, the expected gravitational wave signal would be too weak to be detected by LIGO, so we cannot exclude it [33]. A model independent analysis looking for a burst of gravitational

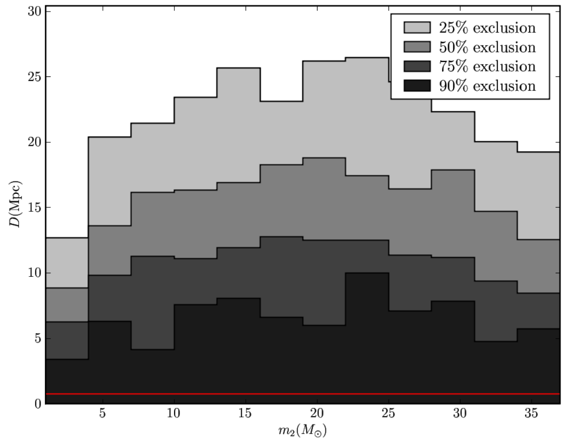

FIGURE 3. Plot showing exclusion areas for an inspiral merger signal from the direction of GRB 070201. The x-axis shows the more massive component of the merger, and the y-axis shows the physical distance. The shaded regions represent 90%, 75%, 50%, and 25% exclusion regions, from darkest to lightest, respectively. The distance to M31 is indicated by the horizontal grey line at $D = 0.77$ Mpc.

waves was also performed on the same data, but it could not exclude a possible SGR at the distance of $d_{\mathrm{M31}} \simeq 770$kpc [25]. Therefore, our non-observation of a gravitational wave signal associated with GRB 070201 suggests that the progenitor could be an SGR in M31 or a binary merger at a much greater distance.

DISCUSSION

The LIGO detectors have recently finished a science run at design sensitivity, collecting one year of coincident data. During this period, the short GRB 070201 was detected by several missions, which the sky location error box overlapping M31. Data from the LIGO H1 and H2 gravitational-wave detectors were analyzed around the time of GRB070201, looking for inspiral waveforms over a range of component masses. No plausible gravitational-wave signal was identified. Based on this search, a compact binary progenitor (neutron star + black hole or a binary neutron star) located in M31 with masses in the range $1\ M_\odot < m_1 < 3\ M_\odot$ and $1\ M_\odot < m_2 < 40\ M_\odot$, could be excluded at the 99 % confidence level. A burst search looking for an un-modeled burst of gravitational waves on the same data was performed, with the conclusion that less than $7.9\times\ 10^{50}$ ergs was emitted within any 100-ms-long time interval inside the on-source region at the most sensitive frequency of LIGO ($f \approx 150$ Hz), if the source were located in M31.

The search for inspiral gravitational wave signals, associated with short GRBs will continue on all (short) GRBs detected during S5. In total 213 GRBs were discovered during this time, 32 of them classified as a “short“ GRB. Since only 7 of them have a redshift estimation, the real distance to the GRBs is not known and could be within the reach of the LIGO/VIRGO detectors. Results from our search will be reported in the following months.

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