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Proposal to the LIGO Scientific Collaboration (LSC)[1]

Entry of LIGO into the Supernova Nova Early Warning System (SNEWS) and Prototype Development of Real-Time LIGO Supernova Alert[2]

Present List of Proposers[3]:
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[1] As outlined by bullet points in the Data Analysis White Paper, Section 6, "LSC Organization of Data Analysis" and the LSC Proposal Review Guidelines at http://www.ligo.caltech.edu/LIGO_web/lsc/lsc.html.
[2] A comprehensive list of relevant hyperlinked references are given at our homepage at: http://www.ligo.caltech.edu/~smarka/SN/
[3] Other LSC members who will make a commitment to work on the project, please contact Szabolcs Márka (smarka@ligo.caltech.edu) to have your name added to the list.

1. Scientific and Technical Motivation

One of the major goals of LIGO is to develop and exploit gravitational wave detection in conjunction with other observations. The need for close collaboration with other gravity wave (GW) detectors and with other experiments capable to detect supernovae (neutrinos, GBR and optical) is particularly important for burst sources such as supernovae, therefore we propose that LIGO join the newly formed Supernova Early Warning System (SNEWS) and start developing its own real time supernova (SN) search/warning system.

SNEWS utilizes the prompt neutrino radiation from a supernova, to give advance real time warning to the scientific community. Neutrino observatories (e.g. Super-K) can provide accurate pointing information within our galaxy while gravity wave detectors such as LIGO II will be sensitive to supernovae at a significantly greater distance. Neutrino experiments are triggered and can distinguish an SN burst from background processes relatively easily, however, it might be very difficult to trigger directly on a gravity wave event. The gravity wave signature of supernovae is not well understood and the limiting sensitivity for LIGO interferometers has yet to be measured. Thus neutrino experiments and electromagnetic observatories are in a position to provide triggers, cross checks and verification for SN gravity wave searches. SNEWS and the neutrino experiments will also profit from the farther reach of advanced GW detectors, which can provide triggers in case of distant sources with low signal to noise ratio in the neutrino channel. However, the most exciting science can be learned from sources within our galaxy, which is the overlapping range of neutrino and gravity wave detectors for the near future and where correlated measurements are the most profitable. It will help us to draft a more solid picture of the dynamics of the collapse. The time when the neutrinos are released relative to the various phases of the motion inscribed in the gravitational wave, such as infall accelerations and bounce decelerations, would be absolutely fascinating and would give the collapse modelers really detailed information concerning the collapse. Especially for the neutrino watch, which strongly favors SN in our galaxy, the signal to noise of the gravitational waveforms may really be high enough to do some detailed dynamical fitting. We would also have a chance to measure various properties of neutrinos and GW, considering that the collapse is practically a "time of flight" experiment. Clearly, these measurements heavily rely on the less likely but much more spectacular close collapses. The observation of a close by SN event will completely revolutionize the way we understand core collapse, therefore it is worth waiting (even decades) for this opportunity to gain such exciting knowledge. To be ready we really need to learn how to keep the various instruments running with a minimum of downtime and maintenance.

Gravitational waves and neutrinos provide new windows on compact and difficult to study astronomical objects like stellar cores. Both types of radiation are emitted promptly during a supernova event and can travel to a distant detector with little attenuation, interaction, or deviation from a straight-line path. The need for cooperation and coordination among the gravitational wave, neutrino and astronomy communities is probably best illustrated by the observations associated with Supernova 1987A. On February 23, 1987 the Kamiokande and IMB experiments simultaneously detected a thirteen-second burst of a total of nineteen low energy (10-30 MeV) neutrinos. The neutrino signal preceded the arrival of visible light from SN1987A by three hours and was used to evaluate and test theories of supernovae dynamics and the corresponding energy flow and fusion processes. Unfortunately the neutrino signal was found after the supernova was discovered by astronomers. Timely warning for the optical, X-ray, ultraviolet and (especially) the radio astronomy communities would have allowed them to make detailed observations of this unique event from the very beginning. Luckily in this case the wide collaboration among different fields and nations resulted in observations, which were adequate to decipher a large part of the information conveyed by the burst. Clearly, better organization among collaborations, downtime coordination and prompt warning systems would have optimized the amount of information obtained from SN1987A. Some useful data, such as early UV satellite measurements, were obtained through luck rather than planning. In short, the sharing of information in the near term usually results in better science. It is highly desirable to make parallel observations of burst events with multiple detectors including those using various techniques and different bands and types of radiation. Each burst is a unique one-time episode. Comprehensive and complementary measurements are needed to make cross checks and to provide a complete scientific picture. Unfortunately the amount of neutrino data from SN 1987A and the resolution of the Kamiokande and IMB detectors was not sufficient to answer some important questions such as the neutrino mass. Parallel detection of neutrino and gravitational wave signals from a SN could allow us to measure fundamental properties of SN, GW and neutrinos. Using (more frequent) astronomical observations, we can measure or possibly extract an upper limit on the energy emitted through gravitational waves during the supernova explosion. To obtain such information close collaboration between related disciplines is an absolute necessity.

2. Character of the Proposed Efforts

"Proof of principle" component: The proposed work has the goal to demonstrate that it is possible to develop a real time "automatic" system, which is able to receive, use and provide SN alarms with high efficiency and low false alarm rate, based on cooperation with other fields and coincident use of the LIGO detectors. Our initial goal for LIGO false alarm rate is less than 1/week after double/triple coincidence, which is consistent with SNEWS input requirements and ensures that the SNEWS false alarm rate will be less than 1/century. We believe that this is possible for a real time system with limited analysis resources, considering that the LIGO design goal is one accidental coincidence per decade for full analysis.

Prototype development activity: A secure system with very high duty cycle will be developed, utilizing existing resources and relying on the coincidence among LIGO detectors. This fully functional prototype system will be capable of receiving, matching to the relevant GW data and later providing SN alarms. It will be able to derive a prompt estimate on SN, GW and neutrino properties, therefore providing important preliminary information for LSC scientists shortly after the event. It is expected that the prototype phase will end after the thorough testing with engineering data.

LAL software development activity component: Although it is probable that the first prototype tests will be conducted using existing algorithms tuned for SN search, it is expected that the effort will produce effective SN specific search algorithms supplementing the current LAL effort.

LDAS/LAL/GDS subsystem tests: Since excellent resources are available both in LDAS and GDS, the system will fully utilize both existing infrastructure and build on them. Therefore every test of the real time warning system will be a real life test of the underlying structure. The special real time nature of the system is expected to initiate/help/support the development of new LDAS features and one of the first objective of the proposed work is to find the optimal way to use the available resources.

Data analysis side: To efficiently find SN signatures and promptly extract accurate data necessitates the use and/or development of sophisticated but fast analysis techniques, therefore helping the LIGO data analysis effort.

3. Technical Approach

3.1 SNEWS The basic strategy of SNEWS is to limit false alarms through the coincidence of two or more experiments. This is very effective for neutrino detectors since individual detector false alarms are due almost entirely to instrumental problems. These false alarms are nearly always uncorrelated among different experiments. The SNEWS criterion for a single detector is that it must have a false alarm rate of less than one per week. The coincidence is formed over a time period of ten seconds (characteristic time of SN neutrino signal), therefore, the coincidence of only two detectors with uncorrelated false-alarm rates results in a net false alarm rate of less than 1 per century rather than the individual rate of one per week.

All active members of SNEWS are clients for a central server operating at Super-K. In case of observation, clients automatically provide the server with TCP/IP sockets containing basic information about the event and the contributing detector. This socket can be delayed by a maximum of ~30 minutes relatively to the event. If coincidence is detected SNEWS issues an alarm, which is sent out to registered and qualified parties in the form of a authenticated (PGP signed) e-mail message and/or TCP/IP socket. A confidentiality agreement assures the privacy of all parties involved in case of false alarms. Only the advisory board, including a prominent member from each collaboration, and the core developmental group has access to submitted data. People in these group agreed not to disseminate any information submitted to SNEWS to ensure privacy, however, they are still capable to ensure that the submission rules are observed. This will also prevent the dissemination of information on the Supernova candidate other than that contained in the socket in case of detection. Information on the source location is relayed to SNEWS members, other cosmic ray observatories, the Hubble Space Telescope (HST) and a representative of amateur astronomers throughout the world (from Sky and Telescope magazine).

3.2 LIGO in SNEWS: LIGO's involvement in SNEWS will be realized through two major somewhat parallel subtasks. *First*, we will set up a system within LIGO to receive and to immediately react upon a supernova warning. *Second,* we will develop a real time coincidence system to scan LIGO data from all working LIGO IFOs and detect internal double/triple coincidence, providing prompt SN alarm for the LSC. Ultimately, this system will be able to issue triggers for the SNEWS coincidence server at the required rate of less than one false alarm per week. However, we will not send alarms to outside of the LSC until we are sure that the system is reliable from both analysis and computational viewpoint and received the approval of the LSC. We plan to accomplish these tasks in close collaboration with LSC members presently working[4] on burst detection and integrate/build the system on top of the existing LIGO Data Analysis System (LDAS) and GDS structures. We do and will actively encourage these experts and site scientists to join and/or help us with the project.

3.3 Other sources: Since the reception of and reaction to warnings from Gamma-Ray Burst (GRB) (e.g. GCN network) detectors as well as from astronomical surveys (e.g. AstroAlert, sky surveys) are very similar to those of from SNEWS, it makes sense to develop our system so it will be capable of receiving alerts from multiple sources in multiple formats. This will ensure that a wide range of (possibly) SN related channels are conveyed to the LSC, the relevant trigger information will be entered into the LDAS database and, most importantly, LIGO can start a customized and sensitive real time search for the signature of the supernovae.

4. Deliverables

Robust and secure system: The proposed project will produce a **robust and secure system capable to receive and react upon receiving a SN warning** from SNEWS, GCN (GRB) and/or astronomers, which is fully compatible with LSC and LDAS standards. Reaction to warning will include real time automatic search for SN in LIGO data in coincidence from all available IFOs, prompt estimates of SN, GW and neutrino properties and immediate relaying of the alarm, IFO data summary, results and parameters to registered LSC members. It will be capable to serve users with e-mail and e-mail enabled phones/pagers.

LIGO's real time SN search system: The effort will also produce a prototype of **LIGO's own real time SN search system**. This search will utilize the data available from all IFOs to provide prompt warning with a false alarm rate less than 1/week. Ultimately the alarm will be conveyed to SNEWS, however until full LSC approval the warning will only be circulated inside LSC.

LDAS database update: The system will promptly and automatically update the LDAS database with up to date information on supernovae detected in the neutrino, GRB and optical channels.

Reduced dataset: We will work on the **development of a reduced dataset** standard for real time multi-detector analysis and utilize the results for real time SN search.

Tested system: The systems will be **tested** on available engineering data, therefore helping the characterization effort.

Prototype: The project can also serve as a **prototype** of working collaboration among different fields and detectors, therefore pioneering the way for future cooperative agreements.

Papers, talks: Several **papers and talks** are expected to result from the effort: describing the system, the results of the engineering run tests and summarizing search results. It is feasible, based on the estimated SN

[4] Late Note: This proposal and initial work predates in time the Burst Data Analysis Working Group, formed at the 08/2000 LHO LSC meeting. We plan to coordinate our effort with the working group to obtain limits from the engineering run data and also to develop optimal search algorithms. Members of the LIGO-SNEWS group are also members of the Burst group and will significantly contribute to its efforts.

rate within the reach of LIGO I, that the effort will produce a significant limit on the SN energy emitted in the GW channel. Detailed technical documentation of the system will be produced parallel to the development effort. A comprehensive online library of relevant SN related literature with special emphasis on GWs will be produced and maintained.

5. Required Resources

Software: The warning system will be based on the efficient use of software available or being developed at LSC, including standard Unix tools, root and DMT libraries and LDAS and LAL software. We may require minor extension of software being developed if acceptable.

Hardware: A single modern SUN workstation with sufficient storage capacity is needed to coordinate the SN alarm activities (LIGO SN server) and to temporarily store the reduced datasets. Otherwise no special hardware is required for the initial prototype implementation.

> **Computing:** Access to DMT computing power for reduced dataset generators and on-demand availability 1-2 processors on the LDAS Beowulf clusters for real time monitors will be required . It is very likely that as the system evolves and the load on the DMTs increases, a dedicated workstation on the GDS gigabit net will be required.
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> **Storage:** Access to LDAS database will be required. Short period storage of the reduced dataset will require 2 standard 30Gb disks installed on the SN server, which will be accessible to LIGO nodes.

Data: We need real time access to the detector data at the sites (DMT or equivalent machines on the GDS gigabit net) and also to the LDAS clusters/databases at the IFO sites and at CIT. Engineering data from the IFO sites will be used for further testing, if allowed.

Personnel: We estimate that the full prototype development will require 0.7 FTE postdoc (Szabolcs Márka) and 0.5 FTE from a visiting scientist (Benoit Mours). We expect to receive significant effort from UCSDH (Ken Ganezer 0.3 FTE). We will also try to recruit students.

Travel: System set up will require presence at the sites, which will be coordinated with travel required by other reasons. We will also try to recruit interested personnel at the sites. Travel to specialized workshops and meetings as well as to LSC members developing useful detection algorithms might be required.

6. Work Plan (until 06/2001)

- Secure (skeleton) communication code from/to SNEWS, from GRB and optical networks and data transfer system between IFOs and SN server: Márka (ongoing, 01/15/01)
- Develop reduced dataset writer: Mours (ongoing, 12/01/00)
- Set up SN server (supernova.ligo.caltech.edu): (ongoing, 11/20/00)
- Communication with LDAS systems (set, retrieve database entry): Márka, Mours (01/01/01)
- Robustness issues of alarm reception, distribution and transmission: Márka (01/01/01)
- Build SN reduced dataset from E2 data: Mours Márka (12/01/00)
- Examine possible SN related upper limits from E2 (03/01/01)
- Access to reduced dataset developed for multi-detector analysis. Real time data transfer to the LIGO-SN server: Mours, Márka (01/15/01)
- Efficiency test and implementation of available transient search algorithms from LAL for real time SN search: Ganezer, Márka, Mours (04/15/01)
- Specialized search algorithm issues, hierarchical search: Mours, Márka, Ganezer (05/01/01)
- Test system during the spring engineering run: (06/2001)
- Examine possible SN related upper limits from the spring engineering run (06/2001)
- Real time estimator/measurement issues (e.g. radiated energy in the GW channel): TBD
- SNEWS and LIGO pointing issues: Ganezer TBD
- Use of modeled/known properties of SN GW signature: Márka, Mours (TBD)
- Coincidence issues: Márka, Mours (06/01/01)

Test false alarm rate: Márka, Mours (06/01/01)