Internal proposal to LSC/Virgo data analysis council

Proposal to the LSC and Virgo: Follow-up observations with narrow field optical telescopes

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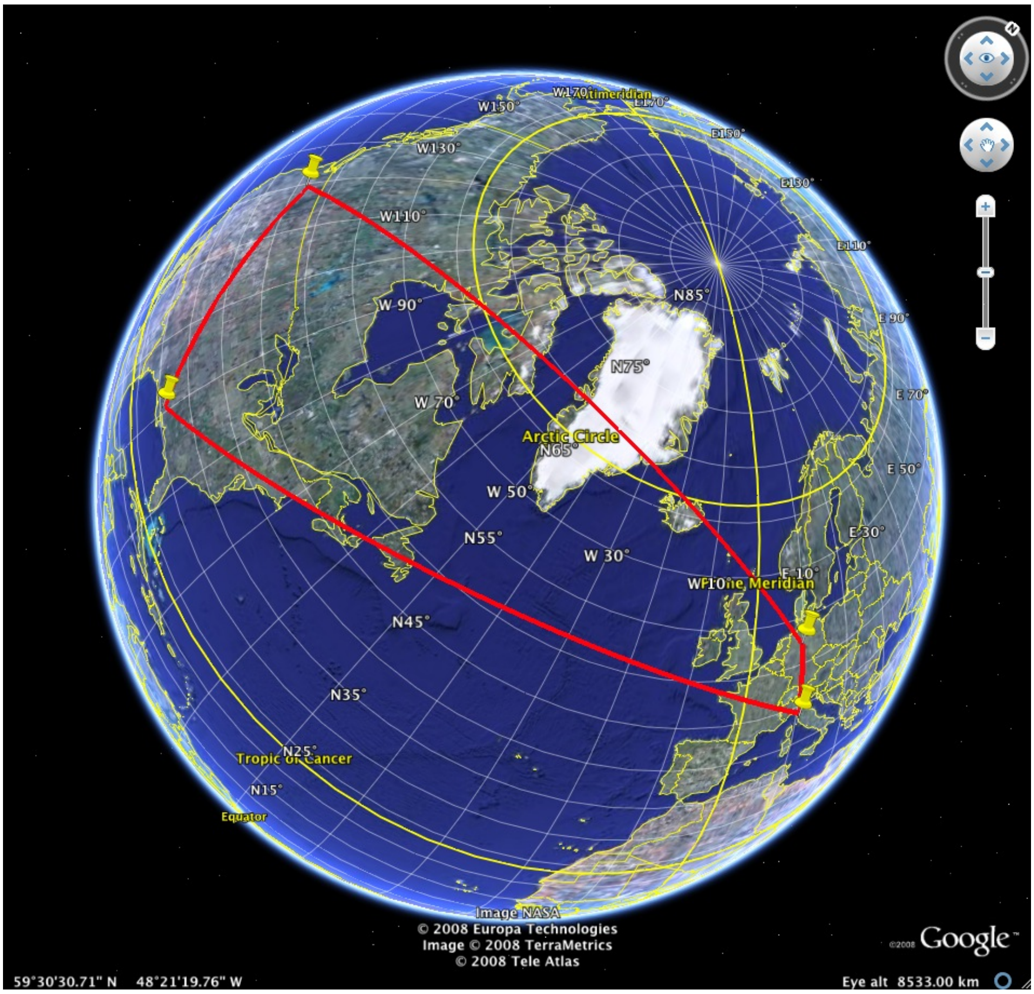
E. Daw



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1 Introduction

Many hypothesized sources of transient gravitational wave signals may have electromagnetic counterparts detectable by astronomical instruments. Considering the distinct possibility that the first identified transients may be weak, non repeating, and poorly modelled by existing phenomenology, the detection of an optical transient in coincidence is one of the best smoking guns for unambiguous direct detection of gravitational waves.

Optical counterparts to very close sources may be best sought using wide field optical instruments; this is the subject of a separate internal proposal [1]. Here we present the case for collaboration between LSC/Virgo and astronomers using narrow-field telescopes suitable for deep sky observations in the optical. The scientific arguments for narrow field optical follow-up is made in Section 2. Note also that preliminary investigations into narrow field optical follow-up have been made by members of the LOOCup group [2].

In Section 3.2 we discuss possible collaborators to be considered seriously in the very near term, ie before the S6/VSR2 run, and others regarded as possibilities for the future beyond S6/VSR2.

2 Scientific Case

2.1 Detection of faint optical counterparts

For many nearby sources, a wide field instrument may be ideal to observe the optical counterpart of a gravitational wave signal. The scientific case for wide field instruments is made in [1]. An example of wide field instruments for optical follow-up is the ROTSE III robotic telescopes [3]. These instruments, designed for detecting optical afterglows of gamma ray bursts, currently have a limiting magnitude of around 19 and a field of view of 1.85° squared. To place this in context, an object at a distance of 30 Mpc would be visible in ROTSE at optical luminosities exceeding $30 \times 10^6 L_\odot$. Sources known to have high optical luminosities such as supernovae would certainly be observable in ROTSE at this distance; had SN1987A occurred at 30 Mpc its apparent visible magnitude would have been 16.8.

Other possible sources of gravitational wave transients have poorly understood, and perhaps far smaller, optical luminosities. Large aperture telescopes suitable for deep observations naturally have smaller fields of view. One instrument that may be considered for narrow field follow-up is the Liverpool robotic telescope, having a field of view of 4.6 arcmin squared [4]. The limiting magnitude of the Liverpool telescope is about 24. At 30 Mpc an object having a luminosity of around $3 \times 10^5 L_\odot$ would be seen by the Liverpool telescope. Therefore narrow field instruments can potentially detect optical counterparts at least 1/100 the luminosity of those detectable in a good wide field instrument.

Since the best achieved gravitational wave source position reconstruction results have an accuracy of approximately a square degree, there is a significant mismatch between the field of view of these telescopes and the area where reconstruction algorithms place the putative gravitational wave source. One possible way of increasing the probability of prompt optical counterpart identification is to use a catalogue of nearby galaxies to narrow down the likely source positions within the field identified with the gravitational wave event. Such catalogues are already available [7, 8], and could be used to automate selection of image fields for a narrow field telescope.

2.2 Secondary optical follow-up

A second application for narrow-field instruments is to obtain higher quality images and spectroscopic information on sources located in wide field instruments. For example, special purpose high-speed multi-colour imagers and spectrographs such as ULTRACAM and ULTRASPEC [5] mounted on large aperture telescopes, such as the New Technology Telescope in Chile [6], could be scheduled for target-of-opportunity time on optical counterparts identified in a wide field instrument. Such instruments could provide spectroscopic and high time resolution information on the source superior to that obtainable in a wide field instrument.

2.3 Source identification

In the case where there is no phenomenological model of the transient waveform, it may be difficult to identify the source from the gravitational wave signal alone. One problem is that the resolving power of a gravitational wave interferometer network is very poor; for a burst having a central frequency of 100 Hz the wavelength is 3×10^6 m, about half of the Earth's radius and hence comparable with the baseline for the network. Therefore the resolving power is of order 1 radian. It is therefore impossible to obtain anything more than the average position of the source on the sky. The resolving power of the Liverpool telescope, for instance, is approximately 1 arc second; thus the optical image of an electromagnetic counterpart may be significantly more useful than the graviational wave signal in identifying the source.

2.4 Sources

Several classes of sources of gravitational wave transients are likely to possess optical counterparts. Supernovae are most often mentioned in this context. In enhanced LIGO, with its range of 30 Mpc or so, most optical supernovae would be observed in a wide field instrument. Narrow-field instrument follow up observations for improved imaging and spectroscopy will yield extra information. A second possible class of source is associated with the progenitors of gamma ray bursts (GRBs). If short, hard GRBs are emitted during the merger of compact objects, and the associated gamma-rays are beamed away from Earth, only the gravitational wave and optical/radio emission would be detectable here. Orphan afterglows of gamma ray bursts may be detectable by this method, and knowledge of the rate of orphan afterglows to gamma ray burst afterglows would give an indication of the extent to which GRBs are beamed from their sources. Narrow field instruments will be necessary to detect the fainter afterglows from these sources at the limits of the range of enhanced LIGO/Virgo.

3 External collaborations

3.1 Memoranda of understanding

Any external collaborator requires a memorandum of understanding with LSC/Virgo before collaborative work can proceed. Drafts of memoranda of understanding should be informed by the following guidelines.

- Any partnership involving LSC and/or Virgo GW strain data must be part of the approved scientific program of the Collaborations, i.e. not just a personal project.
- As such, any decision to enter into a partnership should be based on scientific merit, LSC/Virgo priorities, and practical considerations and must be made after a transparent

and open evaluation process. All such collaborative agreements should be approved by the LSC council for LSC and VSC for Virgo. Agreement should also be obtained with whatever science board or equivalent committee is tasked with approval of such collaborations for the collaborating party. The approving entities should be explicitly named.

- The collaborative work should be a specific, well-defined project. The project and its duration must be governed by written and clear understanding among the involved parties, which should be in place before committing the Collaborations to the project and before any proprietary data can be shared or exchanged.

- The Collaborations will not enter into "exclusive" agreements. For example, a partnership with one particular astronomy team does not prevent the Collaborations from forming a partnership with another astronomy team doing similar work, if scientific merit and the other principles above call for it.

- Arrangements for approval of publications stemming from the collaborative work should be discussed in detail. These arrangements should include the requirement of approval of the publication by the LSC and Virgo publications committees. Such agreements should address, in particular, the policies for approval and publication of discovery, upper limit, and technical papers. Working definitions of these publication types should also be included in the MOU.

3.2 Collaborations with astronomers

Large astronomical telescopes are commonly operated as general purpose facilities, for which individual astronomers, or small groups, apply for observing time. The resulting data are then the property of the principal investigator, typically for a period of one year before being made public. Therefore the most logical model for external collaboration would be for MOUs to be arranged with individual astronomers rather than the organizations that run the observatories, though there may be exceptions to this rule.

Some astronomers have expressed interest in collaborating with LSC/Virgo on deep optical observations. An example is Prof. Vik Dhillon of the University of Sheffied, an observer specializing in transients, compact objects and high speed imaging. Dhillon built the ULTRACAM and ULTRASPEC instruments mentioned above, he has good contacts in transient astronomy, and he has a successful track record in obtaining observing time. We propose that Dhillon should be approached as an external collaborator with LSC/Virgo as soon as it is clear that this is approved by the LSC/Virgo data analysis council. Dhillon's role would be to apply for target of opportunity observing time on a variety of facilities available to the U.K., possibly including the Liverpool robotic telescope and the William Herschel telescope on La Palma, and the telescopes of the European Southern Observatory in Paranal-La Silla, Chile.

We anticipate that similar arrangements will be proposed in connection with other astronomers who have access to other large aperture telescopes.

4 Estimate of resources required

We estimate that on the LSC/Virgo side, a single FTE would be fully occupied in maintaining a programme of narrow-field optical follow-up observations with a suite of external collaborators. This work would involve development of the pipeline from LSC/Virgo to each telescope, setting and monitoring of event thresholds and event rates to external instruments, and analysis of results in collaboration with astronomers. Each of these external collaborators would require of the order of 0.5FTE to maintain automated links to triggers from LSC/Virgo, and to analyze the resulting image data. These resource estimates do not include the manpower necessary to maintain the gravitational wave trigger generation and position reconstruction software; it is assumed that manpower in these areas is considered predominantly common between a range of electromagnetic follow-up analysis streams.

References

[1] Wide field optical DCC number.

[2] J. Kanner, T. L. Huard, S. Marka, D. C. Murphy, J. Piscionere, M. Reed and P. Shawhan, Class. Quant. Grav. **25**, 184034 (2008) [arXiv:0803.0312 [astro-ph]].

[3] http://www.rotse.net/equipment/

[4] http://telescope.livjm.ac.uk/Info/TelInst/Inst/RATCam/

[5] http://www.vikdhillon.staff.shef.ac.uk/ultracam/ultracam_home.html

[6] http://www.ls.eso.org/lasilla/Telescopes/NEWNT/

[7] http://darrenwhite.postgrad.shef.ac.uk/

[8] R. K. Kopparapu *et al.*, Ap. J. **675**, 1459-1467 (2008)