EM Followup Observation of Gravitational Wave Events

[based on 1109.3498 & 1112.6005 by LVC]

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Introduction

- Detectable GW event rate for CBC [LVC, CQG '10]:
  - initial LIGO-Virgo network $\sim 1/100$ y
  - "advanced era" detectors $\sim 50/\text{y}$
- Detectable, transient GW signals in the LIGO/Virgo frequency band require bulk motion of mass on short time scales.
- Some transient GW sources may have corresponding EM counterparts which could be discovered with a low latency response to GW triggers. [Sylvestre, ApJ '03; Kanner et al., CQG '08]
- Finding these EM counterparts would yield rich scientific rewards. (e.g. parameter estimation, sky localization & GRB search)

Figure : LIGO Livingston [www.ligo.org]

GRBs as EM counterparts

- Short-hard GRBs may be powered by NS-NS or NS-BH mergers [Piran, RMP '04]:
  - Optical afterglows: a few tens of seconds $\sim$ a few days
  - At 1 day after the trigger time, for a source at 50 Mpc, the apparent optical magnitude: 12 $\sim$ 20
  - Another proposal for an (isotropic) optical afterglow known as a kilonova [Li&Paczyński, ApJ '98]
- Long-soft GRBs are believed to be associated with the core collapse of massive stars [Woosley, ApJ '93]:
  - A large variety of possible GW emitting mechanisms
  - In some models, GW spectra would be observable from a few Mpc with initial LV
  - The peak isotropic equivalent luminosity of LGRB afterglows is typically a factor of 10 brighter than SGRB afterglows [Nakar, PR '07]
- Since the network of GW detectors is essentially omni-directional, there is a strong case to undertake an observing campaign in which CBC candidates, identified in GW data, are rapidly followed up with EM observation.

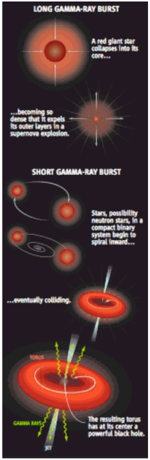

Figure : GRB [Covino, Science '07]

Telescopes participated in the project

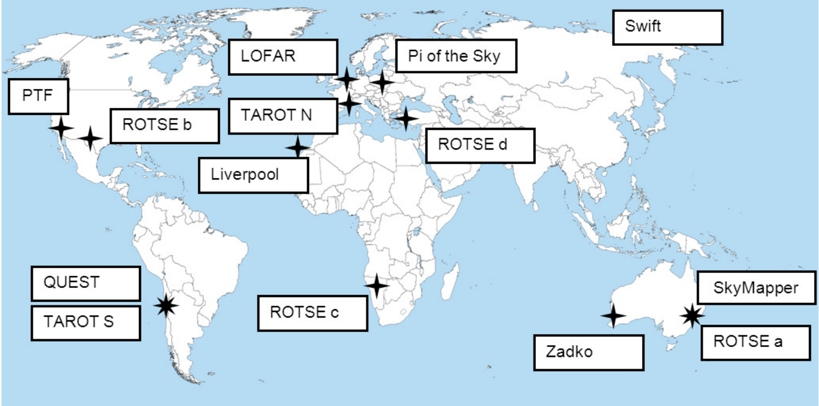

Figure : Telescope positions [LVC, 1109.3498]

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Pipeline

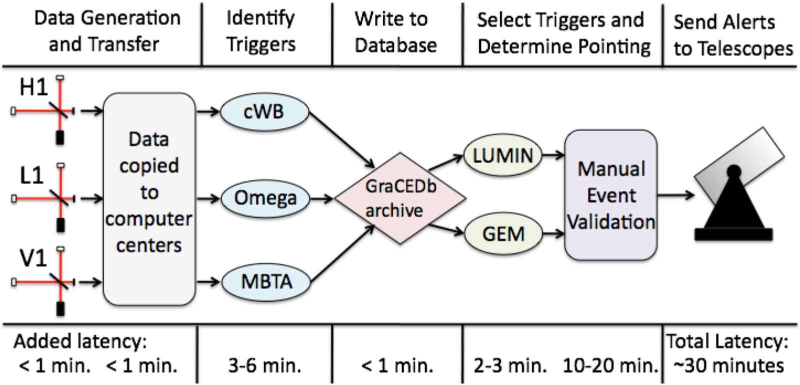


Figure : Pipeline [LVC, 1109.3498]

Pipeline latency for MBTA

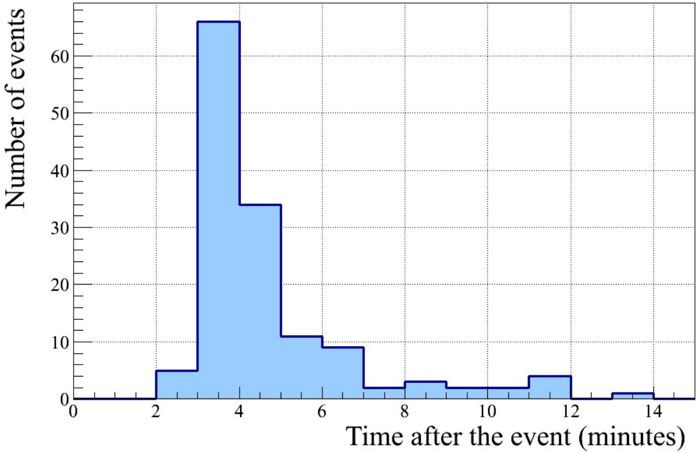


Figure : Pipeline latency for MBTA [LVC, 1112.6005]

Sky localization performance for MBTA

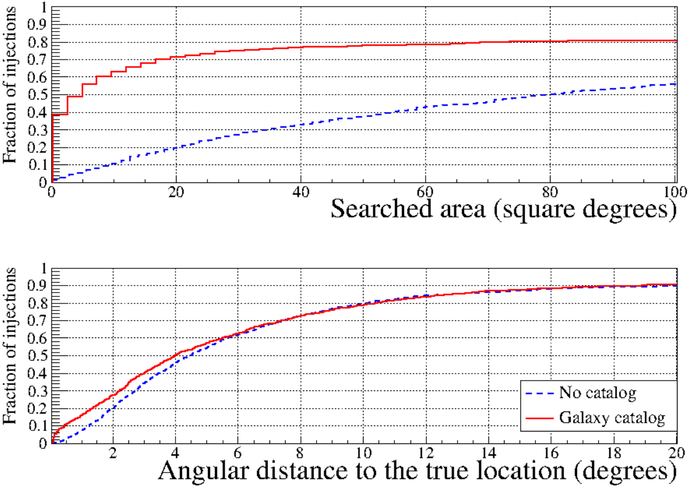
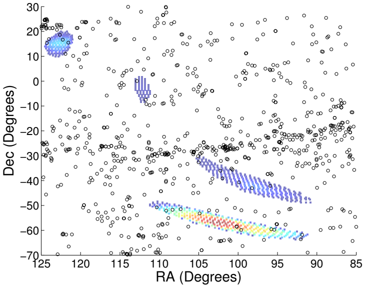


Figure : Sky localization performance for MBTA [LVC, 1112.6005]

Tiling process



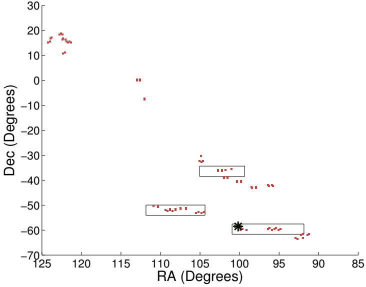


Figure : The weighting and tiling process for a simulated signal reconstructed by cWB [LVC, 1109.3498]. The right panel shows the location and approximate size of the three chosen QUEST tiles, along with the locations of pixels that are retained after weighting by the galaxy catalog.

Skymap for the G20190 trigger

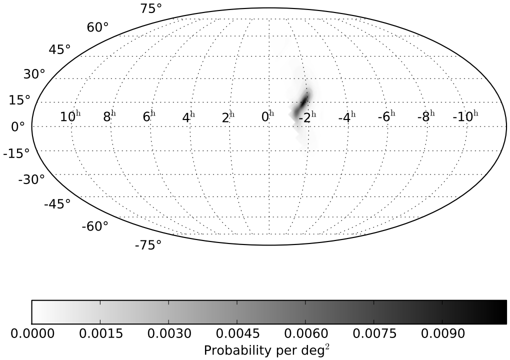


Figure : Skymap for the G20190 trigger on 19 Sep. 2010 [LVC, 1112.6005]. The application of the galaxy catalog reduces the 90% confidence region from nearly 600 square degrees to 3.3 square degrees.

Outline

KGWG activity

- People: Hyung Mok Lee, Yong Bum Kim (SNU)
- We are trying to apply ROTSE pipeline to QUEST (followup) images.
- Current status in LVC:
  - Analysis of images underway by a number of LVC members
  - Methods papers describing EM follow-up program are published in [A&A 539, A124; 541, A155 (2012)]
  - Results paper happening on longer timescale

LaSilla-QUEST

- Name: ESO 1-metre Schmidt telescope
- Camera:
  - a mosaic of 112 CCDs
  - a total of 160 million pixels
- Aperture: 1.02m (40", La Silla)
- FOV: 4x4 deg
- Location: 33.356242, -116.86492
- Altitude: 2375 m
- For more details, see http://www.eso.org/public/teles-instr/lasilla/1mschmidt.html

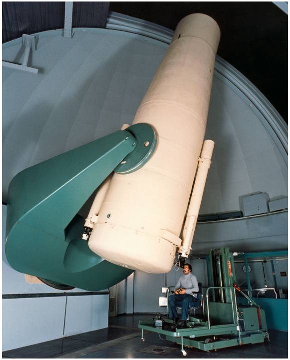


Figure : ESO 1-metre Schmidt telescope [www.eso.org]

X-Convolution: ROTSE Pipeline

- Cross convolution is a part of the ROTSE pipeline to find transient objects.

$$R \otimes K_R \approx T \otimes K_T$$

- To demonstrate the results, three artificial "variable" stars were added to the test image (a) and the reference image (b) with PSFs appropriately matched to their respective fields. The locations are shown by black arrows.
- The subtracted image obtained by cross-convolution is depicted in (c) and the Alard-Lupton results are shown in (d).

$$R \otimes K = R^*$$

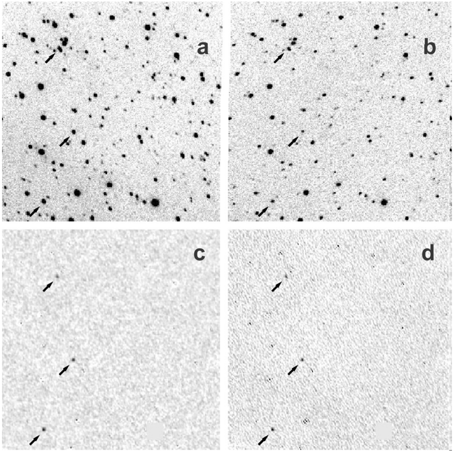


Figure : Image subtraction by X-convolution
[Yuan&Akerlof, ApJ '08]

X-Convolution: ROTSE Pipeline

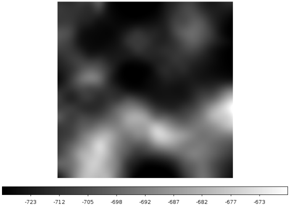


Figure : Call tree of XCONVOLVE image subtraction code [Yuan&Akerlof, ApJ '08]

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Advanced era

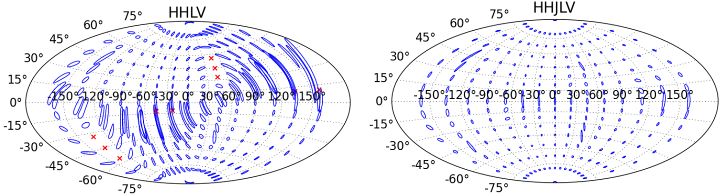

Figure : The localization accuracy for face on BNS at 160 MPc [Fairhurst, CQG '11]

- KAGRA should improve the localization accuracy.
- To reduce the latency of the pipeline, the manual validation might be omitted.
- Then, some GW triggers may play the role of premonitions of GRBs.

THANK YOU!