Searching for EM counterparts to neutron star mergers

David Coward
Presentation Outline

• Motivation for coincident observations of gravitational waves and optical counterparts from neutron star mergers

• emissions from a short gamma ray burst

• How an automated follow-up should work: GRBs as a superb example

• first attempts of an EM follow-up of a gravitational wave source

• Considerations for the first EM follow-up of a neutron star merger
Motivation for chasing EM signatures from neutron star mergers

- Combining GW and EM observations of transients will unleash a new era of astronomy
- **Optical data will pinpoint the location of the GW sources, enabling an understanding of their environment and formation history (even if they are not connected to GRBs)**

- Gamma ray bursts: the “smoking gun” for the existence of binary neutron star mergers?

- Rates of short gamma ray bursts and NS mergers are compatible but uncertain:

- realistic estimates of some tens of mergers per year, and a GRB optical afterglow coincidence rate of at least several yr$^{-1}$ (see Coward et al. 2012).
gamma ray burst emissions
An ideal automated follow-up: GRB example

Swift 2-3 degree error

XRT location X-ray light curves 2 arcmin localisation

Robotic Telescopes: Transient optical source identified Photometry of early emissions > 10 seconds

Redshift obtained from spectroscopy of the host galaxy or directly from the afterglow about 1 hour

First GRB optical counterpart localised in 1997 (in X-ray)…after thousands of GRBs were detected in the early 1990s….many years to achieve localisation and redshifts
Anatomy of a GRB (note for short GRB emission time is < 1 sec)
Gamma ray (prompt emission) + x-ray + optical afterglow (Zadko Telescope)
**Latency for EM follow-up of the first GW source**

<table>
<thead>
<tr>
<th>Initial GW Burst Recovery</th>
<th>Initial GCN Circular</th>
<th>Updated GCN Circular (identified as BBH candidate)</th>
<th>Final sky map</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fermi</strong> GBM, LAT, MAXI, IPN, <em>INTEGRAL</em> (archival)</td>
<td><em>Swift</em></td>
<td><em>Swift</em></td>
<td><em>Swift</em></td>
</tr>
<tr>
<td></td>
<td><em>XRT</em></td>
<td><em>XRT</em></td>
<td><em>Fermi</em> LAT, MAXI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BOOTES-3</th>
<th>MASTER</th>
<th><em>Swift</em> UVOT, SkyMapper, MASTER, TOROS, TAROT, VST, iPTF, <em>Keck</em>, Pan-STARRS1, Pan-STARRS1, KWFC, QUEST, DECam, <em>LT</em>, <em>P200</em>, Pi of the Sky, PESSTO, UH VST</th>
<th>TOROS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Low latency (but low sensitivity all sky) from “shadowing” same sky as LIGO. Fermi (all sky) candidate also from shadowing.
The Good, the Bad and the Ugly

Compared to the first identification of a GRB optical counterpart, huge localisation uncertainty for the first GW detections

There is reason to be optimistic

Significant global facilities are eager to participate in the first detections

strong international interest: e.g. China
Validation bottleneck for O1 and improved for O2
For GRBs this is automated from the SNR of detector, seconds latency

Motivation
• Validate found events
• Inform noise hunting
• Enable Multi-messenger astronomy
From Alert to follow-up, the brute force pipeline

LIGO Validation (Human) → GCN type alert to EM partners → Human receives alerts

Human

Download sky probability maps

Optimized algorithms for scheduling

Human schedules telescope
Example implementation of code

- Probability map
- Tile observation

GW150914 Bayestar Probability Map
Issues from the first EM follow-up of a GW alert

- Repeated imaging of the same sky location in the optical at similar sensitivities.

- Considerable delay (days) before a GW Alert sent, because of human vetoing of the signal.

- Despite over 60 participating facilities, less than a third managed to acquire data.

- Negative declination localisation region is less sampled.

- Evidence for a geographic bias in follow-up capabilities. Australia can capitalise on this window!
Summary

• EM counterparts to NS mergers are transients: implications - a global distribution of follow-up facilities is required.

• Several deep and wide field facilities do not cover the temporal space required.

• Coordination between follow-up facilities optimal: non-trivial (political and technically).

• Australia: follow-up opportunities - Southern sky and temporal niche.

• Western Australia is close to the geographic antipode of LIGO, follow-up of the brightest GW sources observable from the southern hemisphere.

• Automated alerts and robotic pipelines for optimal imaging may be essential.

• EM counterparts to GWs from neutron star mergers will revolutionise astronomy: Let’s go!
ASKAP 36 identical antennas, each 12 metres in diameter, 0.7 to 1.8 GHz, FoV 30 square degrees

MWA 2048 dual-polarization dipole antennas 80-300 MHz frequency, FoV 200 - 2500 sq. deg.

Zadko Telescope - optical, 1m robotic dedicated follow-up of transients, FoV 0.5 x 0.5 deg

SkyMapper optical 1.35m robotic, FoV about 3 x 3 sq. deg.
Exciting Post Doctoral position at UWA

Theme: Multi-Messenger astronomy
GW data analysis
Coincident detection of gamma ray bursts and GWs
Fast Radio Bursts
Important update

OzGrav is born:

September 2016: Australian Government provides funding for a Centre of excellence for gravitational wave Astronomy

A consortium of national and international partners, OzGrav, (including Italy participants) is born, to consolidate Australia’s role in gravitational astronomy

Goal: to unite individual GW research groups into a single collaboration

Research themes include:

• multi-messenger astronomy
• GW source modelling
• Pulsar timing
• data analysis
• 3rd generation detector technology
From shaking mirrors to sky positions

many “events” in O1 data rejected because the False Alarm Rate (FAR) too high
…some of these could be mergers… beyond horizon distance

EM counterparts?

NS mergers detected within a smaller horizon compared to BH mergers 300 Mpc

LIGO + Virgo needed to reduce localisation
Probability for imaging optical counterpart of a NS binary merger assuming short GRB afterglow

Probability depends on FoV, sensitivity limit and localisation

Assuming a 100 square degree uncertainty as an example