SPECTROSCOPY OF CANDIDATE EM COUNTERPARTS TO GW SOURCES

http://telescope.livjm.ac.uk/
WHAT DO WE EXPECT TO SEE?

ELECTROMAGNETIC COUNTERPARTS

- binary mergers involving one or more neutron star (i.e. NS+NS or NS+BH) should show a transient EM signature due to energetic outflows:
  - If observer within jet opening angle could be similar spectral signature to “prompt” short GRB
  - Red kilo-nova emission from radioactive decay of heavy elements synthesised in merger ejecta
  - Low Lorentz factor jets - “failed GRBs” - orphan afterglow
- very nearby supernovae may also produce GW
WHERE TO LOOK?

TRIGGERS FROM ALIGO / VIRGO TO 63 MOU PARTNERS

- GCN Notices (machine interface)
- GCN Circulars (human interface)
- GraceDB (API and human interface)
- Burst Time
- Localisation (Sky Maps)
- False Alarm Rate (Hz)
- Email list for discussion/speculation

Final Sky Localisation map for GW150914
(Abbott et al 2016)
FINDING COUNTERPARTS

WIDE FIELD SURVEYS

- OPTICAL / IR
  - iPTF, PanSTARRS, SkyMapper, VISTA, MASTER, TOROS, TAROT, VST, DECam, Pi of the Sky

- High Energy
  - Fermi (LAT, GBM), MASTER, INTEGRAL, SWIFT

- Radio
  - MWA, ASKAP, LOFAR
GW150914

- 36 + 29 $M_\odot$ black hole merger at ~410 Mpc (z~0.09)
- PanSTARRS identified 56 candidates in northern error box (Smartt et al. 2016)
- Spectra by Keck, PESSTO, UH2.2 and Liverpool Telescope
ANOTHER BURST

GW151226 - $14.2 + 7.5 \, M_\odot$ AT $\sim 440 \, \text{MPC}$ ($Z=0.09$)
<table>
<thead>
<tr>
<th>Candidate ID</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPTF-15dki</td>
<td>No obvious transient detected. Emission from host galaxy with $z = 0.061$</td>
</tr>
<tr>
<td>iPTF-15dkm</td>
<td>Supernova Type II, $z = 0.03$, $t = +4$ d, 96.5 per cent template fit</td>
</tr>
<tr>
<td>iPTF-15dkn</td>
<td>No obvious transient detected. Emission from host galaxy with $z = 0.074$</td>
</tr>
<tr>
<td>iPTF-15dll</td>
<td>Some broad emission features, with evidence of contamination by the host galaxy. Consistent with Type Ic supernova.</td>
</tr>
<tr>
<td>iPTF-15dlm</td>
<td>No obvious transient detected. Spectrum shows host galaxy with $z = 0.051$</td>
</tr>
<tr>
<td>iPTF-15dmb</td>
<td>Supernova Type II, $z = 0.069$, $t = +2$ d, 98.1 per cent template fit</td>
</tr>
<tr>
<td>iPTF-15dmm</td>
<td>Narrow emission lines, consistent with AGN at $z = 0.056$</td>
</tr>
<tr>
<td>iPTF-15dni</td>
<td>No obvious transient detected. Emission from host galaxy with $z = 0.056$</td>
</tr>
<tr>
<td>iPTF-15dni</td>
<td>Weak H-alpha emission with host galaxy absorption at $z = 0.020$</td>
</tr>
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<td>iPTF-15fed</td>
<td>No transient detected to limiting magnitude of $R\sim19.1$</td>
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<tr>
<td>iPTF-15fel</td>
<td>Supernova Type Ia, $z = 0.038$, $t = +40$ d, 97.7 per cent template fit</td>
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<tr>
<td>iPTF-15fev</td>
<td>Supernova Type Ia, $z = 0.023$, $t = +50$ d, 94.7 per cent template fit</td>
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<tr>
<td>iPTF-15fhf</td>
<td>Possible supernova Type Ia, $z = 0.061$ $t = +15d$</td>
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<tr>
<td>iPTF-15fhi</td>
<td>Supernova Type Ia, $z = 0.085$, $t = +3$ d, 89.1 per cent template fit</td>
</tr>
<tr>
<td>iPTF-15ffk</td>
<td>Supernova Type Ia, $z = 0.102$, $t = +5$ d</td>
</tr>
<tr>
<td>iPTF-15ffm</td>
<td>Supernova Type Ia, $z = 0.094$, $t = +36$ d</td>
</tr>
<tr>
<td>iPTF-15ffz</td>
<td>Emission lines consistent with AGN at $z\sim0.07$</td>
</tr>
<tr>
<td>iPTF-15fgy</td>
<td>Supernova Type Ia, $z = 0.076$, $t = +20$ d, 84.7 per cent template fit</td>
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<tr>
<td>iPTF-15fhd</td>
<td>Possible supernova Type Ia, $z = 0.091$, $t = +11$ d</td>
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<tr>
<td>iPTF-15fhf</td>
<td>Possible supernova Type Ib, $z = 0.043$, $t = +18$ d</td>
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<tr>
<td>iPTF-15fhp</td>
<td>Possible supernova Type Ic, $z = 0.129$, $t = +1$ d</td>
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<tr>
<td>iPTF-15fhq</td>
<td>Narrow emission lines, consistent with AGN at $z = 0.043$</td>
</tr>
<tr>
<td>iPTF-15fib</td>
<td>Slow moving asteroid</td>
</tr>
<tr>
<td>LSQ15bvv</td>
<td>No transient detected to limiting magnitude $R\sim19.5$</td>
</tr>
<tr>
<td>MASTER OTJ020906</td>
<td>No transient detected to limiting magnitude $R\sim20$</td>
</tr>
<tr>
<td>UGC 1410 transient</td>
<td>No transient detected. ID’d as minor planet 2 606 Odessa (Cenko et al. 2015; D’Avanzo, et al. 2015c)</td>
</tr>
</tbody>
</table>
BASIC CONCLUSIONS

RATHER ENCOURAGING (GIVEN WE ONLY HAVE DETECTED BH+BH SYSTEMS SO FAR)

- Majority of transients were supernovae in the redshift range 0.02 - 0.13. Both GW candidates had z~0.09.
- aLIGO/Virgo at full sensitivity should reach to z~0.045 for NS+NS mergers
- We can eliminate candidates with 2 metre class telescopes at redshifts similar to the GW sources.
- Future aLIGO/Virgo observing runs will include a distance estimate (to ~30%) and a “EM-BRIGHT” flag if likely NS event. The localisations will also improve as more stations come on line. All of this will help with targeted followup of host galaxies in correct redshift range.
“THE CLASSIFICATION GAP”

- 77 candidate counterparts were announced for GW151226 via GCN
- 37 of these had a firm spectroscopic classification
- A further 18 had a more tentative classification based on photometric light curves
- 3 cases where the transient had faded into the host galaxy before spectroscopy was attempted
- 19 candidate counterparts were not followed up.
RESOLVING THE CLASSIFICATION GAP WITH TECHNOLOGY

NEW MODES OF OPERATION AND NEW FACILITIES

- All spectroscopic follow-up so far has been “manually” triggered. Technologies (e.g. RTML and VO standards) exist to automate this, reducing response times and increasing efficiency.

- A fast slewing, robotic, 4 metre class telescope dedicated to this kind of science would make a huge contribution, especially in the era of LSST.

Liverpool Telescope 2
http://telescope.livjm.ac.uk/lt2