SWIFT FOLLOW UP OF GW150914
**WHAT IS SWIFT**

**Burst Alert Telescope**
- **Aperture**: Coded Mask
- **Detecting Area**: $5200 \text{ cm}^2$
- **Detector**: CdZnTe
- **Detector Operation**: Photon Counting
- **Field of View**: $2.0 \text{ sr (partially coded)}$
- **Detection Elements**: 256 modules of 128 elements
- **Detector Size**: 4mm x 4mm x 2mm
- **Telescope PSF**: 17 arcminutes
- **Location Accuracy**: 1 - 4 arcminutes
- **Energy Range**: 15 - 150 keV
- **Burst Detection Rate**: >100 bursts/year

**UltraViolet/Optical Telescope**
- **Telescope**: Modified Ritchey-Chrétien
- **Aperture**: 30 cm diameter
- **F-number**: 12.7
- **Detector**: Intensified CCD
- **Detector Operation**: Photon Counting
- **Field of View**: 17 x 17 arcminutes
- **Detection Element**: 2048 x 2048 pixels
- **Telescope PSF**: 0.9 arcsec @ 350 nm
- **Location Accuracy**: 0.3 arcseconds
- **Wavelength Range**: 170 nm - 650 nm
- **Colors**: 6
- **Spectral Resolution (Grisms)**: $\lambda/\Delta\lambda \sim 200 @ 400 \text{ nm}$
- **Sensitivity**: $B = 24 \text{ in white light in 1000 sec}$
- **Pixel Scale**: 0.48 arcseconds
- **Bright Limit**: $m_v = 7 \text{ mag}$

**X-Ray Telescope**
- **Telescope**: Wolter I
- **Detector**: XMM EPIC CCD
- **Effective Area**: $135 \text{ cm}^2 @ 1.5 \text{ keV}$
- **Detector Operation**: Photon Counting, Integrated Imaging, & Rapid Timing
- **Field of View**: 23.6 x 23.6 arcminutes
- **Detection Element**: 600 x 600 pixels
- **Pixel Scale**: 2.36 arcsec/pixel
- **Telescope PSF**: 18 arcsec HPD @ 1.5 keV
- **Location Accuracy**: 3 - 5 arcseconds
- **Energy Range**: 0.2 - 10 keV
- **Sensitivity**: $2 \times 10^{-14} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ in } 10^4 \text{ sec}$

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**Swift**

Catching Gamma-Ray Burst on the Fly
GW150914 WITH SWIFT

Swift follow-up of the Gravitational Wave source GW150914

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Evans et al. 2016

LIB skymap

LIB convolved with galaxies

Swift probability map

LAL inference
5 pointings on high probability regions
~1,000 s exposure
Sep 16

37-tile automatic
1.1° radius
20-75 s exposure
Sep 17

2% of LIB
RESULTS

5 initial pointings: \(<1.5 \times 10^{-2} \text{ ct s}^{-1}, <6.5 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}\)

LMC tiling: \(<1.6 \times 10^{-1} \text{ ct s}^{-1}, <6.9 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}\)

\(<2.0 \times 10^{36} \text{ erg s}^{-1} \text{ @ LMC}\)

Observation in \(u\)-band

No transient brighter than

- 5 pointings \(u_{AB} < 19.8\)
- LMC \(u_{AB} < 18.8\)

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**Table 2.** Sources detected by *Swift*-XRT in follow-up of GW150914, with \(u\)-band magnitudes from UVOT.

<table>
<thead>
<tr>
<th>RA (J2000)</th>
<th>Dec  (J2000)</th>
<th>Error 90% conf.</th>
<th>Flux 0.3–10 keV, (\text{erg cm}^{-2} \text{ s}^{-1})</th>
<th>(u) Magnitude AB mag</th>
<th>Catalogued name</th>
</tr>
</thead>
<tbody>
<tr>
<td>09h 14m 06.54s</td>
<td>-60°32' 07.7&quot;</td>
<td>4.8&quot;</td>
<td>(1.9 \pm 0.5) \times 10^{-12}</td>
<td>N/A</td>
<td>XMMSL J091406.5-603212</td>
</tr>
<tr>
<td>09h 13m 30.24s</td>
<td>-60°47' 18.1&quot;</td>
<td>6.1&quot;</td>
<td>(5.3 \pm 2.0) \times 10^{-13}</td>
<td>15.44 \pm 0.02</td>
<td>ESO 126-2 = 1RXS J091330.1-604707</td>
</tr>
<tr>
<td>08h 17m 60.62s</td>
<td>-67°44' 03.9&quot;</td>
<td>4.7&quot;</td>
<td>(8.9 \pm 2.4) \times 10^{-13}</td>
<td>17.53 \pm 0.05</td>
<td>1RXS J081731.6-674414</td>
</tr>
</tbody>
</table>

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Motivated by short GRBs
Convolve LIB with GWGC galaxy catalog
- ASAP
search for an on-axis short GRB afterglow
short 50-100 s observations
- days after
search for an off-axis orphan
longer 500 s observations
Figure 12. The number of bursts (out of 100,000 simulated) detectable in a 50 s (black) or 500 s (red) observation, as a function of how long after the merger the observation begins. The solid lines are bursts viewed 'on-axis', that is the $10^\circ$ jet is oriented towards the observer. The dashed lines are the off-axis events. The different panels correspond to different values of jet energy ($E_{\text{jet}}$) and circumburst density ($n_0$). At early times, the on-axis bursts dominate the visible population, despite comprising only 1.5 per cent of all mergers. At late times, as the afterglow becomes visible off-axis, the off-axis population starts to dominate.

Beyond 2015 (or when considering NS–BH mergers), as the sensitivity of the GW network increases, galaxy catalogues that extend to greater distances (200–300 Mpc) while remaining highly complete will be necessary. One possibility is the 2MPZ catalogue (Bilicki et al. 2014); its advantages are large sky coverage and uniformity, its disadvantages are use of photometric redshifts and the current lack of detailed completeness analysis.

If Fermi-GBM also triggers on the event detected by the GW facilities, we can convolve the GBM and GW error regions, which reduces the amount of sky we need to cover, typically by a factor of $\sim 2$. 

DETECTABILITY
CONCLUSIONS

• Swift is the only sensitive **soft X-ray and UV** facility able to search for a GW counterpart (as well as a large FOV hard X-ray detector, BAT)

• Immediate search with short 50-100 s exposures looking for a short GRB afterglow (ALV+galaxy)

• Late time search (days) with long 1,000 s exposures looking for an orphan GRB afterglow (ALV+galaxy)

• Italian involvement: Swift team members & connections with GRAWITA