Electromagnetic Counterparts to Gravitational Waves

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Dawn of Gravitational Wave Astronomy
Sites of r-process nucleosynthesis?

A Resurgence in TDA Discovery Engines

Optical:
Evryscope, ASASSN, HATPI  ZTF, CSS-II, PS, BG, ATLAS  DECAM, HSC, LSST

Radio:
LOFAR, MWA and LWA: meter and decameter-mapping
Apertif, Meerkat and Askap: decimetric mapping
Infrared: SPIRITS, Palomar Gattini-IR, Polar Gattini-IR
Ultra-Violet: CUTIE & ULTRASAT
X-rays and Gamma-rays: Swift, Fermi, MIRAX, Lobster-ISS
Disk Wind Emission
UV (hours) + Optical (days)

Free Neutron Decay
UV + Optical (hours)

Kilonova
Infrared (weeks)

r-process radioactivity

Y_e > 0.25
Disk Wind

Y_e < 0.25
Dynamical Debris

Relativistic Jet
\gamma/X-ray (seconds)

Shocked ISM
Radio (months to years)
SPEED:
Speed of Response
Speed of Software
Speed of Follow-Up
Coarse Gravitational Wave Localizations

e.g. Kasliwal & Nissanke 2014, Singer et al. 2014
Optical Hardware

EM-GW Detectable Fraction of Mergers vs. EM Counterpart Luminosity (Absolute i-mag)

- LSST
- ZTF
- PS1
- BG4
- DECAM
- ATLAS
- HSC

Nickel peak and r-peak peak

January 5, 2017

Mansi M. Kasliwal
Software Speed

Palomar (Zwicky) Transient Factory

Oschin 48" Telescope

Mayer 60" Telescope

Hale 200" Telescope
Follow-Up is Key

Global Relay of Observatories Watching Transients Happen

January 5, 2017
Mansi M. Kasliwal
GW150914: All candidates classified in 2 hours!
127,676 candidates in subtraction images

78,951 do NOT have a quiescent stellar source

15,624 are detected twice and NOT asteroids

5,803 pass our machine learning threshold

1,007 are coincident with a nearby galaxy

13 were vetted by human scanners

8 were scheduled for follow-up spectroscopic observations

0 were associated with the gravitational wave
Census of the Local Universe (CLU Galaxy Catalog)

Narrowband Strategy

- New Galaxy
- H\(\alpha\) color (On – Off) = 1.5 mag
- at z \(\sim 0.017\) (~75 Mpc)
- H\(\alpha\) EW = 675 Å

SDSS gri

H\(\alpha\) off - 6563 Å
H\(\alpha\) on - 6630 Å

BOSS - spectra

6563 Å
6630 Å
6720 Å

Continuum

January 5, 2017
BUT...

What if even 2% of the neutrons fail to escape?
What if the ejecta mass is small and dominated by lanthanides?
What if the lifetime of the hypermassive neutron star is too short?
Deep I & z-band Searches

CTIO-DECAM
4m, 3 deg$^2$

Subaru HSC
8.2m, 1.8 deg$^2$

LSST
6.7m, 9.6 deg$^2$
BUT...

What if opacities push the emission entirely in the infrared beyond 1 micron?
**VIRCAM on VISTA**
0.6 deg$^2$ on 4.1m

**WFCAM on UKIRT**
0.16 deg$^2$ on 3.8m

**ETA (proposed)**

Space

*Stay Tuned: 25 deg$^2$ J-band imager at Palomar this summer!*
Caution is the better part of valor

It could be fast
It could be red
It could be temporally coincident
It could be next to a nearby galaxy

BUT unrelated!

“Spectrum is Truth”
Thank you
Furthest z=3.29. Faintest 20 mag.
TDA in the LSST era

**PTF:** $4 \times 10^4$ events/night  
**ZTF:** $3 \times 10^5$ events/night  
**LSST:** $2 \times 10^6$ events/night

<table>
<thead>
<tr>
<th>Technical</th>
<th>develop algorithms &amp; software for detection &amp; classification</th>
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</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>discover new transient &amp; variable phenomena</td>
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<tr>
<td>Organizational</td>
<td>organize collaborations and followup strategies with real data</td>
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**GROWTH builds a global community ready to contribute LSST time-domain science!**
SPIRITS: SPitzer InfraRed Intensive Transients Survey

Cycles 10-13
1410 hours of Spitzer mid-IR
190 Galaxies x 14 epochs
(PI Kasliwal)

Every Year:
110 nights of near-IR imaging
66 nights of optical imaging
33 nights of spectroscopy


A New Infrared Discovery Engine?