Opening the Gravitational Wave Window

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Newtons’ gravity

“Newton’s law”: \( F = G \frac{m_1 m_2}{r^2} \)

Explains why apples fall, why the planets move around the Sun,…
Einstein’s gravity

sciencebulletins.amnh.org
And in YouTube!
When masses move, they wrinkle the space time fabric, making other masses move...

Explains just as well as Newtons’ why things fall and planetary motion...

.. but it also predicts gravitational waves traveling away from moving masses!
Where do gravitational waves come from?
Where do gravitational waves come from?

Supernova explosions (that form a BH or a NS)

From stars living in galaxies…

Credits: Animation: NASA/CXC/D.Berry & A.Hobart
From stars living in galaxies…

Where do gravitational waves come from?

Rotating stars (pulsars)

Credit: NASA/CXC/ASU/J.Hester et al.
LIGO-G1301143
Where do gravitational waves come from?

- Supernova explosions
- Rotating stars (pulsars)
- Binary systems coalescing into a black hole

Credit: John Rowe
LIGO-G1301143
Where do gravitational waves come from?

From stars living in galaxies...

Supernova explosions

Rotating stars (pulsars)

..and from the beginning of the Universe!

Binary systems coalescing into a black hole

LIGO-G1301143

Credit: NASA/WMAP
How to detect gravitational waves with an interferometer

Einstein’s messengers,
National Science Foundation video
http://www.einsteinsmessengers.org/
Gravitational waves: how big?

Gravitational waves are quadrupolar distortions of distances between freely falling masses. They are produced by time-varying mass quadrupoles.

\[
G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} (= 0 \text{ in vacuum})
\]

\[
g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \quad h_{\mu\nu} = \frac{2G}{c^4 r} \ddot{I}_{\mu\nu}
\]

\[
h(t) = \frac{\Delta L}{L}
\]

\[
h \approx \frac{4\pi^2 GMR^2 f_{\text{orb}}^2}{c^4 r}
\]
• 900+ members, 86+ institutions, 17 countries

https://www.zeemaps.com/map?group=245330

roster.ligo.org
Find all LSC results and publications in [www.ligo.org](http://www.ligo.org) - science tab
Some interesting results 2005-2011

Horizon distance for a binary neutron star system (with $m=1.4$ solar masses)

- L1
- H1
- H2
- V1

Horizon distance for GRB070201

GW100916


atlasoftheuniverse.com
In progress: Advanced LIGO

Vacuum system – same as initial LIGO

Neutron Star Binaries:
Initial LIGO:
  Average BNS reach \(\sim 15\) Mpc \(\rightarrow\)
  rate \(\sim 1/50\)yrs
Advanced LIGO: \(\sim 200\) Mpc
  “Realistic rate” \(\sim 40/\)year (but can be 0.4-400)

Other binary systems:

NS-BH: 0.004/yr \(\rightarrow\) 10/yr
BH-BH: 0.007/yr \(\rightarrow\) 20/yr

Class. Quant. Grav. 27, 173001 (2010)
Coming soon near you: Advanced GW Detectors running!

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Estimated Run Duration</th>
<th>Burst Range (Mpc)</th>
<th>BNS Range (Mpc)</th>
<th>Number of BNS Detections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$E_{GW} = 10^{-2}M_\odot c^2$</td>
<td>LIGO</td>
<td>Virgo</td>
</tr>
<tr>
<td>2015</td>
<td>3 months</td>
<td>40 – 60</td>
<td>–</td>
<td>40 – 80</td>
</tr>
<tr>
<td>2016–17</td>
<td>6 months</td>
<td>60 – 75</td>
<td>20 – 40</td>
<td>80 – 120</td>
</tr>
<tr>
<td>2017–18</td>
<td>9 months</td>
<td>75 – 90</td>
<td>40 – 50</td>
<td>120 – 170</td>
</tr>
</tbody>
</table>

arXiv:1304.0670
Multi-messenger astronomy

The astrophysical events we expect produce electromagnetic waves, gravitational waves, neutrinos… we need all eyes and ears open!
Gravitational waves are coming!

www.ligo.org