GRAVITATIONAL WAVES AND MULTI-MESSENGER ASTRONOMY

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2 December 1915:
Einstein completes General Relativity
(A. Einstein,
- December 1915, 844-847)

June 1916:
Gravitational Waves are predicted
(A. Einstein,
- June 1916, 688-696
- January 1918, 154-167)
Understanding Gravitational Waves

- Strong analogies with EM radiation
  - Two transverse polarisations
  - Move at the speed of light, follow geometrical optics
  - Same behaviour with gravitational lensing, cosmological redshift
...but GWs are different...

- Coupling of GW to matter is very different from EM
- Very weak
  - $h \approx \delta L / L \approx 10^{-21} \ldots 10^{-24}$
  - $h \approx 1 / r$
- Weakness
  - negligible scatter, absorption
  - perfect messengers!
- Huge energy flux
  - luminosity scale is $(c^5/G) \approx 3.6 \cdot 10^{59}$ erg/s
Evidence:
Hulse – Taylor Binary Pulsar discovered in 1974

- Orbital decay of PSR 1913 + 16 binary pulsar systems
  - from data points represent the cumulative shift of periastron time measured whereas the parabola curve shows the same quantity predicted by the General Relativity.
- Mass of both pulsars of about 1.4 solar masses.
- Orbital period: 7.75 hours.
Existing Ground Based GW Detectors
Existing/ Planned Ground Based GW Detectors

- LIGO Hanford
- LIGO Livingston
- GEO600
- VIRGO
- KAGRA
- LIGO India

Gravitational Wave Observatories

- Operational
- Under Construction
- Planned
Gravitational wave signal of 14 September 2015
Event of 14 August 2017: $30 + 25$ solar masses, final mass $53$ solar masses
Artist’s illustration of two merging Neutron stars.

Discovery of the optical image by the Swope Telescope.
Host galaxy NGC 4993.
Top: 10.9 hr after the merger.
Bottom: 20.5 days before.
Lightcurve from *Fermi/GBM* (10 – 50 keV)

Lightcurve from *Fermi/GBM* (50 – 300 keV)

Lightcurve from *INTEGRAL/SPI-ACS* (> 100 keV)

Gravitational-wave time-frequency map
Time line of the discovery of GW170817 in the various electromagnetic bands.
LISA sensitivity and Black Hole science
LISA PATHFINDER (ESA MISSION)
Launch: 3 December 2015 - End mission: 18 July 2017

LISA Pathfinder is the first step in the observation of gravitational waves from space

LISA Pathfinder provides us with:

- A better understanding of the physics of the forces acting on a free-falling test mass
- Industrial experience in the development, manufacture, and testing of technologies required for GW detection
- Data analysis algorithms and tools dedicated to the analysis of the system as a whole
- Essential experience in the commissioning of a LISA-like mission

LPF essentially shrinks one arm of LISA from ~million km down to ~40cm

- Giving up the sensitivity to gravitational waves
- Maintaining the instrument noise which could dominate the GW signal
Floating test masses: 46 mm gold-platinum cubes
Within ESA’s Cosmic Vision plan:

The Gravitational Universe was identified in 2013 as the Theme for the L3 Large-class mission

On 20 June 2017 LISA has been selected as the third (L3) Large-class mission in ESA’s Science programme. Following this selection the mission design and costing can be completed and will be then proposed for “adoption” (early 2020s) before construction begins.

Currently launch is foreseen for 2034, however could be also anticipated.

The LISA Consortium includes also NASA participation.

GRAVITATIONAL WAVE ASTRONOMY HAS STARTED