What Gravitational Waves and Gamma-Ray Bursts teach us about their progenitors

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- Gravitational Wave Detection
- Gamma-Ray Bursts Detection
- What can we learn from joined observations?
My Background

- Working on POLAR: Satellite to study X-ray emission from black hole formation
- Instrument was launched in September 2016 part of the Tiangong-2 Space Station
- Primary goal is measuring polarization of X-rays coming from Gamma-ray Bursts
- Closely connected to GWs
Gravitational Waves II: GW150914

- The very first direct detection of a GW
- ‘Chirp signal’ as the binary system comes closer and closer, frequency increases from 35 Hz to 250 Hz before the merging occurs
- Detected by both LIGO detectors
- Time difference in detection of 7 ms is consistent with distance between detectors
- Detection significance larger than $5.1\sigma$
Gravitational Waves III: EM counter-part?

- Analysis indicates merger was of two black holes of around 30 and 35 solar masses
- Deduced from frequency/distance and amplitude of the signal
- No matter → no charges to emit electromagnetic radiation → no electromagnetic counter-part
- But something was seen... or not
- LIGO was upgraded saw more BH-BH mergers and finally could to see neutron star mergers
Gravitational Waves IV: GW170817

- GW170817: the first neutron star-neutron star merger
- Much slower inspiral than black holes
- Closest gravitational wave detection so far!
- Seen by both LIGO detectors, not really seen by VIRGO, but VIRGO data was used to improve position sensitivity
- And now there is matter in the merger...

![Graphs showing data from Hanford, Livingston, and Virgo detectors.](image-url)
Gamma-Ray Bursts I: Discovery

- Very bright bursts of x-/gamma-ray emission which last from fractions of a second to minutes
- Discovered July 2nd, 1967, at 14:19 UTC by US spy satellites
- Vela satellites designed to detect USSR nuclear tests found bright bursts of gamma-rays not coincident with solar flares or other activities
Gamma-Ray Burst II: Scientific Measurements

- Since the 70’s they are being studied by scientific instruments
- Most energetic events in the universe since the big bang
- Timing, Direction and Energy spectrum measured in great detail
- Long bursts: Black hole formation by massive stars (extreme kinds of supernovae)
- Short bursts: Black hole formation by compact objects
Gamma-Ray Burst III: Short Bursts

- Time scale and variabilities indicate size of the emitting area to be small
- Burst often in ‘old regions of galaxies’ indicates compact binary systems
- Object needs to have matter or no charge to emit EM radiation
- Two candidates black hole/neutron star merger or neutron star neutron star merger
- Theorized more than 25 years ago but no clear evidence
GW170817 was followed by GRB170817A

Gamma-radiation detected by two satellites at the same time

Very weak GRB, but still fully compatible with a GRB

Follow-up measurements by many many other instruments (not by mine...)
GWs provides the clear message something happened

Gamma-ray detectors check if they saw something and give a rough location if they saw something

GRB measurement gave a location for other instruments to point

Exact location was found: NGC 4993 (130 MLy away (not that far))

Emission in X-ray/optical/radio compatible with emission from neutron enriched ejecta
Based on GW signal we can get lots of info
GRB measurement gives location and an indication on the pointing direction of the GRB
Mass of progenitors in the expected mass range
Final product a bit heavy to be a neutron star
Depends on EOS
The progenitors I: from GW

- As the neutron stars get closer together, the gravitational distortion of the star itself becomes significant: tidal distortions.
- Tidal effects add a mass quadropole moment, energy of the system is lost at a faster rate, acceleration of the inspiral.
- Acceleration is proportional to the tidal deformability of neutron star matter.
- We get an upper limit on \( \Lambda \), directly connected to radius and mass of neutron star.
The final product: from EM I

- What do we know about the final product?
- From GRB we know that the black hole was formed less than 1.7 seconds after merger
- We can look at afterglow emission at lower energies
- Mass is lost by neutron star merger during inspiral
- The material is ejected at certain velocities and later irradiated to form heavy elements
The final product: from EM II

- A final state neutron star will have an accretion disk, a final state black hole does not.
- Accretion disk will lose matter which again will be irradiated to form heavy elements.
- The first early emission and second emission will have different properties, can be distinguished based on emission.
- 170817 shows both types, not enough of the second kind to favour a stable neutron star.

The final product: from EM II

- So something in between: a super massive neutron star or a hyper massive neutron star
- SMNS is kept from collapsing by rotation, can support a mass 1.2 times the maximum neutron star mass
- HMNS is kept from collapsing by differential rotation, can support a mass 1.3 times the maximum neutron star mass
- 170817 seems compatible with a either SMNS or HMNS
- We know final mass from GW = 2.74 solar mass, so maximum neutron star mass below 2.17 solar masses
GW 170817A was only the first
We can expect more measurements
More sensitivity at higher frequencies gives more info on Λ
Sensitive EM measurements needed for more precise measurements of delay
LIGO VIRGO being updated, KAGRA and IndiGO will come soon
But EM detectors are slowly dying...