Combined Gravitational and Electromagnetic observations of Gamma-ray Bursts

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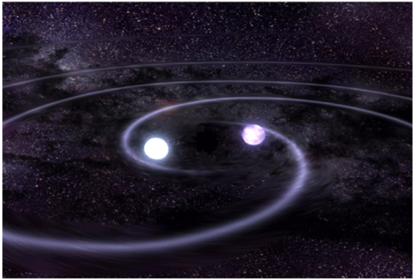

Credit: NASA

Credit: NASA/Swift/Mary Pat Hrybyk-Keith and John Jones

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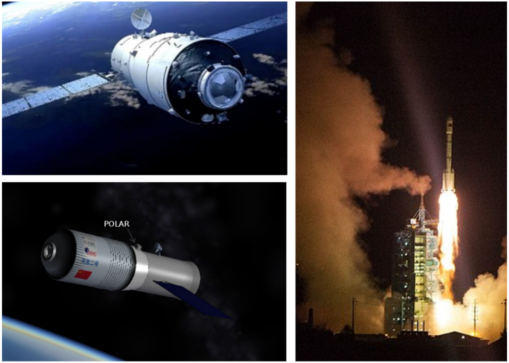
Overview

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

Figures taken from: https://www.ligo.caltech.edu/ and South China Morning Post

My Background

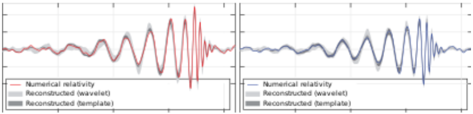


Credit: South China Morning Post

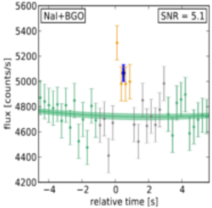
- Working on POLAR: Satellite to study X-ray emission from black hole formation
- Instrument was launched in September 2016 part of the Tiangong-2 Space Station
- Primary goal is measuing polarization of X-rays but scientific interest has shifted a bit...

Search for GWs and Exotic Matter

- First direct gravitational wave was detected end of 2015
- Potential measurement by Fermi sattelite → large interest in what this could be
- POLAR started searching for electromagnetic counter-parts of GWs
- Normal science: neutron star mergers
- Exotic science: finding exotic stars containing quark or boson matter



B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration)



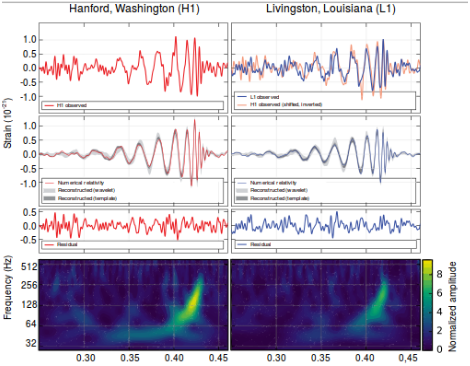
V. Connaughton et al. The Astrophysical Journal Letters, Volume 826, Number 1

Gravitational Waves I: The Detectors

- First direct detection of GWs was by LIGO
- Two large laser interferometers
- LIGO is stull being updated, VIRGO is now also running and more instruments are starting soon like KAGRA in Japan in 2018

Figures taken from: https://www.ligo.caltech.edu/

Gravitational Waves II: GW150914

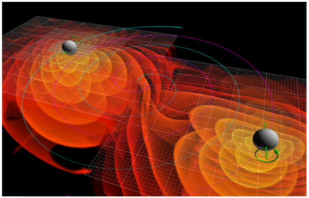


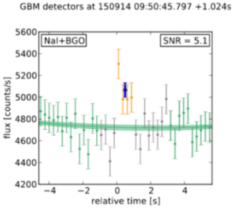
B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration)

- 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 5.1σ

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
- Upgrades to LIGO underway, moving towards possibility to see neutron star mergers





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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

Illustration from XKCD

Which of the following would be brighter, in terms of the amount of energy delivered to your retina:

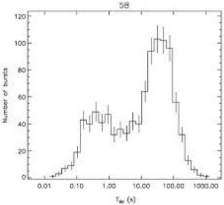
1) A supernova, seen from as far away as the Sun is from the Earth, or
2) The detonation of a hydrogen bomb pressed against your eyeball?

***Answer**: the supernova is brighter.*
... by nine orders of magnitude.

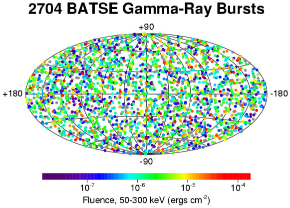
Per solid angle a GRB is another 10 order of magnitude brighter

Gamma-Ray Burst II: Scientific Measurements

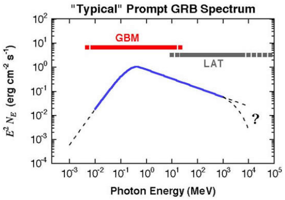
- Since the 70's they are being studied by scientific instruments
- Most energetic events in the universe since the big bang
- Timing, Direction and Energy spectrum measured in great detail



Bing Zhang et al., IJMPA 2004



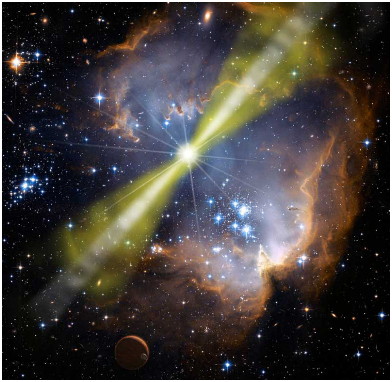
G. Fishman et al., BATSE, CGRO, NASA



source: http://polywww.in2p3.fr

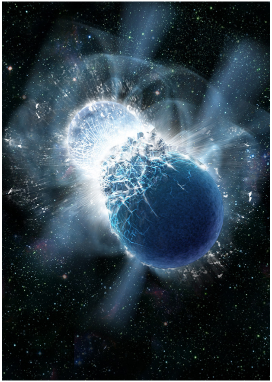
Gamma-Ray Burst III: Long Bursts

- Time scale and variabilities indicate size of the emitting area to be rather large
- Precise localization measurements indicate bursts occur in blue star forming parts of galaxies
- Several supernovae have now been found in the location of long GRBs
- Long GRBs thought to be connected to high energy collimated jets from black hole formation in special type of supernova



Gamma-Ray Burst IV: 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 emmit EM radiation
- Two candidates black hole/neutron star merger or neutron star neutron star merger
- Can be seen in coming years with LIGO/VIRGO



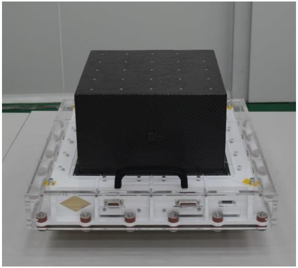
Gamma-Ray Burst V: Neutron stars

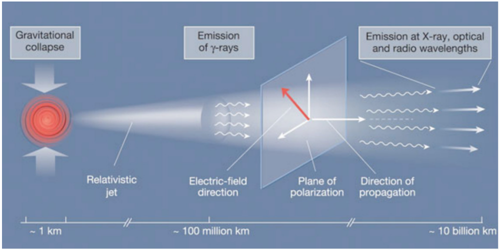
Credit X-ray: NASA/CXC/ASU/J. Hester et al.;
Credit Opitcal: NASA/HST/ASU/J. Hester et al.

- Remnants of massive stars
- Mass not large enough for gravity to overcome neutron degeneracy pressure
- Result: large ball of neutrons containing strange forms matter not producable on earth
- Size of about 15 km radius, mass of about 2 solar masses
- Most famous: the Crab pulsar resulting from a supernova detected in 1054

Joint Searches I: Short GRBs

- GWs provide info on the mass while EM measurements provide a precise location
- Jet emission studies: Number of measured EM counter parts gives indications on the emission angle of the jet
- Time difference between GW and EM gives the distance at which EM is radiated
- Combined detection would form clear proof of the progenitor of short GRBs

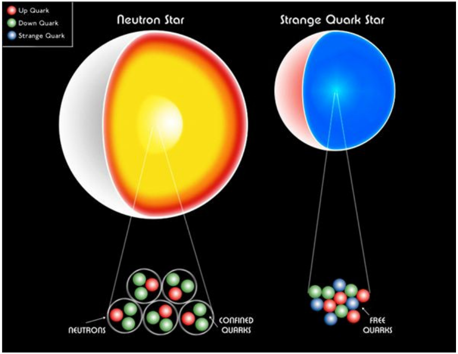




E. Waxman, Nature 423 (2006) 388

Joint Searches II: Quark stars

- Quark stars: theoretical stars consisting of (degenerate) quark matter
- Further collapse from neutron stars
- Many questions regarding the kind of matter
- Main problem is we don't know the equation of state for quark matter
- Collider studies produce hot quark matter
- Subgroup of: Strange stars as normal quark matter is unstable



Joint Searches III: Quark stars

- Theoretical studies of GW and EM signals now kicking-off
- Mass of especially strange stars can be much higher than neutron stars
- Between 4-6 solar masses if in 'Color-Flavor-Locked (CFL) phase'

Can stellar mass black holes be quark stars?

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Probing the internal composition of neutron stars with gravitational waves

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(Dated: November 5, 2015)

Discriminating hadronic and quark stars through gravitational waves of fluid pulsation modes

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Constraining color flavor locked strange stars in the gravitational wave era

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Joint Searches IV: More exotic stars

- Boson stars: theoretical stars consisting only of bosons
- Example is gravitationally bound axions
- Different size from black holes and neutron stars
- No fermionic matter so no EM counter part would be seen
- Preon stars, ElectroWeak stars...

Conclusions

- New era of astronomy has been started with GW detection
- EM measurements have been going on for long but many questions remain
- Joint studies would provide many new insights in standard astroparticle physics
- Opens new possibilities to study equations of state of quark/strange/xxx matter

Figures taken from: https://www.ligo.caltech.edu/ and South China Morning Post