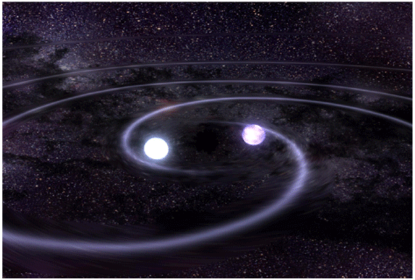
What Gravitational Waves and Gamma-Ray Bursts teach us about their progenitors

Merlin Kole, University of Geneva (DPNC)

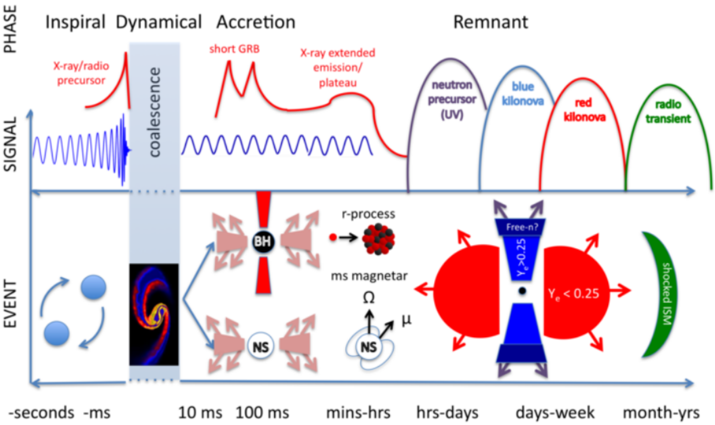


Credit: NASA

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

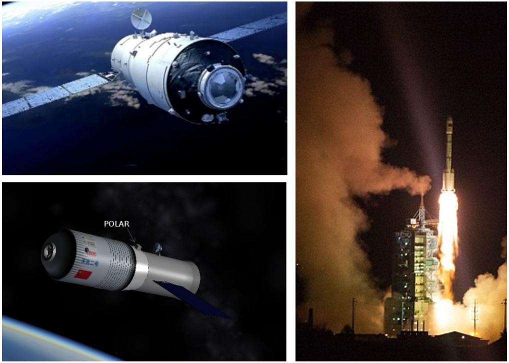
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

Overview



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

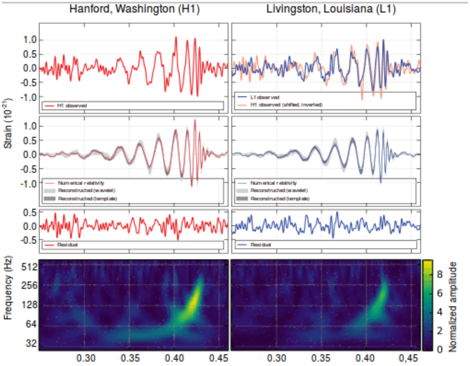
My Background



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 coming from Gamma-ray Bursts
- Closely connected to GWs

Gravitational Waves II: GW150914

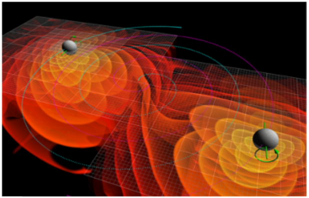


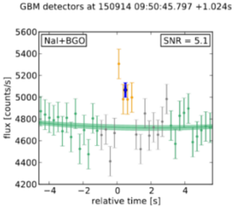
B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration)

- 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 larger than 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
- LIGO was upgraded saw more BH-BH mergers and finally could to see neutron star mergers

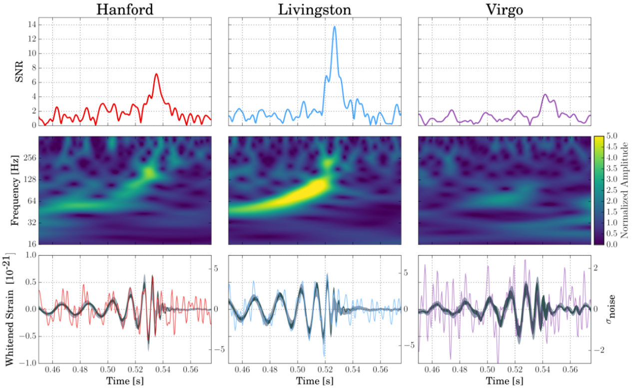




V. Connaughton et al. The Astrophysical Journal Letters, Volume 826, Number 1

Gravitational Waves IV: GW170817

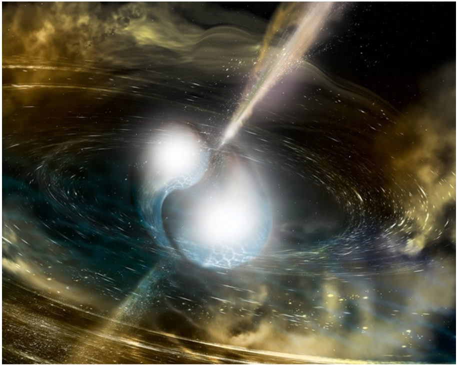
- GW170817: the first neutron star-neuton star merger
- Much slower inspiral than black holes
- Closest gravitational wave detection so far!
- Seen by both LIGO detectors, not really seen by VIRGO, but VIRGO data was used to improve position sensitivity
- And now there is matter in the merger...



LIGO Scientific Collaboration and Virgo Collaboration

Gamma-Ray Bursts I: Discovery

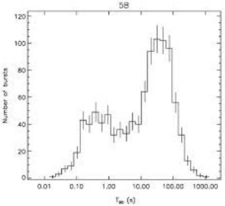
- Very bright bursts of x-/gamma-ray emission which last from fractions of a second to minutes
- Discovered July 2nd, 1967, at 14:19 UTC by US spy satellites
- Vela satellites designed to detect USSR nuclear tests found bright bursts of gamma-rays not coincident with solar flares or other activities



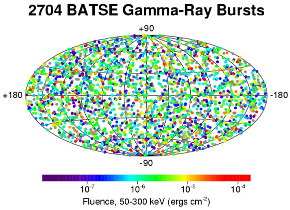
National Science Foundation/LIGO/Sonoma State University/A. Simonnet

Gamma-Ray Burst II: Scientific Measurements

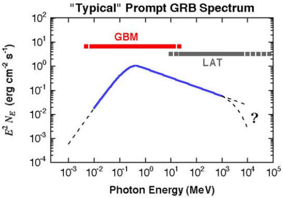
- Since the 70's they are being studied by scientific instruments
- Most energetic events in the universe since the big bang
- Timing, Direction and Energy spectrum measured in great detail
- Long bursts: Black hole formation by massive stars (extreme kinds of supernovae)
- Short bursts: Black hole formation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



Bing Zhang et al., IJMPA 2004



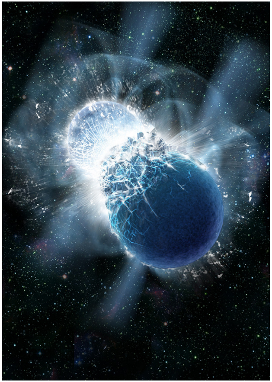
G. Fishman et al., BATSE, CGRO, NASA



source: http://polywww.in2p3.fr

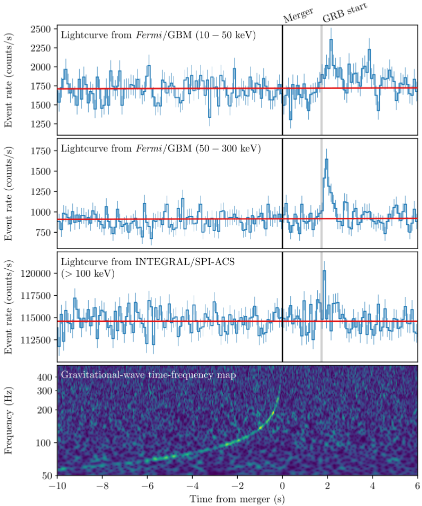
Gamma-Ray Burst III: Short Bursts

- 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 emmit 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



Gamma-Ray Burst IV: Origin confirmed!

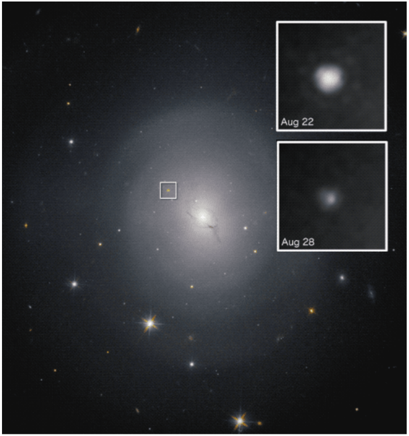
- GW170817 was followed by GRB170817A
- Gamma-radiation detected by two satellites at the same time
- Very weak GRB, but still fully compatible with a GRB
- Follow-up measurements by many many other instruments (not by mine...)



B. P. Abbott et al.

Joint Measurement I

- 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



Hubble Space Telescope, NASA and ESA

Joint Measurement II

PRL **119,** 161101 (2017) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

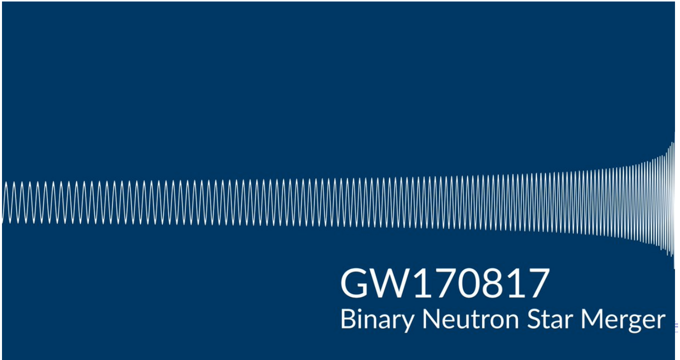
TABLE I. Source properties for GW170817: we give ranges encompassing the 90% credible intervals for different assumptions of the waveform model to bound systematic uncertainty. The mass values are quoted in the frame of the source, accounting for uncertainty in the source redshift.

	Low-spin priors ($\lvert\chi\rvert \leq 0.05$)	High-spin priors ($\lvert\chi\rvert \leq 0.89$)
Primary mass m_1	1.36–1.60 $M_\odot$	1.36–2.26 $M_\odot$
Secondary mass m_2	1.17–1.36 $M_\odot$	0.86–1.36 $M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0	0.4–1.0
Total mass $m_{\rm tot}$	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
Radiated energy $E_{\rm rad}$	$> 0.025 M_\odot c^2$	$> 0.025 M_\odot c^2$
Luminosity distance $D_{\rm L}$	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc
Viewing angle Θ	$\leq 55°$	$\leq 56°$
Using NGC 4993 location	$\leq 28°$	$\leq 28°$
Combined dimensionless tidal deformability $\tilde{\Lambda}$	≤ 800	≤ 700
Dimensionless tidal deformability $\Lambda(1.4 M_\odot)$	≤ 800	≤ 1400

- 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

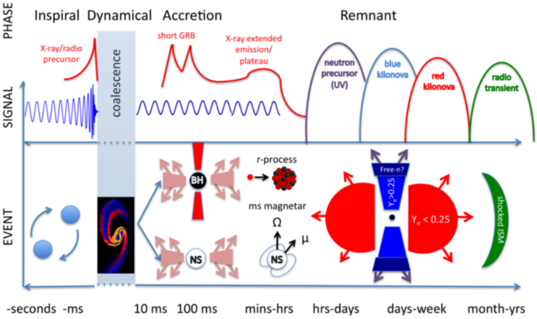
The progenitors I: from GW

- Ass 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, accaleration of the inspiral
- Accaleration is proportional to the tidal deformability of neutron star matter
- We get an upper limit on Λ, directly connected to radius and mass of neutron star



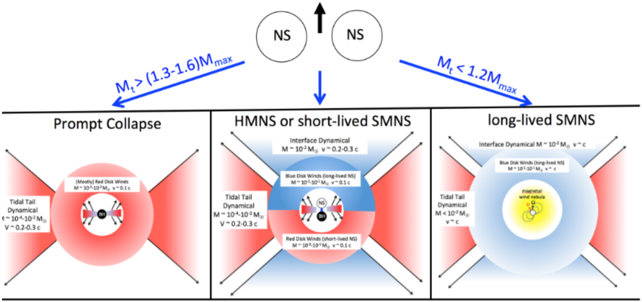
The final product: from EM I

- 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 after glow 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

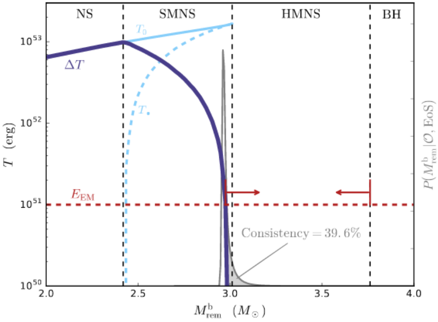
- A final state neutron star will have an accretion disk, a final state black hole does not
- Accretion disk will lose matter which again will be irradiated to form heavy elements
- The first early emission and second emission will have different properties, can be distinguished based on emission
- 170817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



Margalit, B., & Metzger, B. D. 2017, Astrophys. J., 850, L19, 1710.05938

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
- details: Margalit, B., and Metzger, B. D. 2017, Astrophys. J., 850,



Future

- 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...

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