PRESENTATION
Ames Area Amateur Astronomers (AAAA)
Saturday, April 20, 2019

TITLE
The aftermath of a neutron star merger

ABSTRACT
On August 17th, 2017, the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) registered tiny ripples in spacetime, produced by a pair of frantically orbiting neutron stars right before they collided (GW170817). A Gamma Ray Burst was observed at the same time from the same region of the sky. The unpresidented physics, astronomy, and cosmology coming out of these observations will be presented.

BIO
Sam Wormley is a retired Associate Scientist and Principal Investigator, CNDE/IPRT/AL at Iowa State. And for 17 years, an Adjunct Professor of Astronomy at Marshalltown Community College. Sam regularly teaches science and technology classes for OLLI at Iowa State.

STARS
- Compression increases temperature
- PP Chain (Neutrino confirmation)
- Main Sequence 0.076-0.8 M_s
- Main Sequence 0.8-8 M_s
- Main Sequence 8-30 M_s Type II Supernovae - Hydrogen Lines
- Main Sequence > 30 M_s Type II Supernovae - Hydrogen Lines

- Degenerate Matter & Degeneracy Pressure
- Chandrasekhar Limit 1.44 M_s
    Limiting mass of a White Dwarf
- Tolman-Oppenheimer-Volkoff limit ~2.27 M_s
    Limiting mass of a neutron star

- Type Ia Supernovae - No Hydrogen Lines

GW170817

On August 17th, 2017, the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) registered tiny ripples in spacetime, produced by a pair of frantically orbiting neutron stars right before they collided (GW170817). A Gamma Ray Burst was observed at the same time from the same region of the sky.

The excitement is fully justified--observing both gravitational waves and electromagnetic radiation from the catastrophic coalescence of two hyper-dense neutron stars provides astronomers with a wealth of new, detailed information.

The gravitational wave signal indicated that it was produced by the collision of two neutron stars with a total mass of 2.82 +0.47 -0.09 solar masses.

If low spins are assumed, consistent with those observed in binary neutron stars that will merge within a Hubble time (the age of the universe), the total mass is 2.74 +0.04 -0.01 solar masses.

Scientific interest in the event has been enormous, with dozens of preliminary papers (and almost 100 preprints) published the day of the announcement, including eight letters in Science, six in Nature, and 32 in a special issue of The Astrophysical Journal Letters devoted to the subject. The interest and effort was global: the paper describing the multi-messenger observations is coauthored by almost 4,000 astronomers (about one-third of the worldwide astronomical community) from more than 900 institutions, using more than 70 observatories on all seven continents and in space.

This is not the first observation that is known to be of a neutron star merger; GRB 130603B was the first observed kilonova. It is however, by far the best observation, making this the strongest evidence to date to confirm the hypothesis that mergers of binary stars are the cause of short gamma-ray bursts.

The event also provides a limit on the difference between the speed of light and that of gravity. Assuming the first photons were emitted between zero and ten seconds after peak gravitational wave emission, the difference between the speeds of gravitational and electromagnetic waves, vGW - vEM, is constrained to between -3x10-15 and +7x10-16 times the speed of light, which improves on the previous estimate by about 14 orders of magnitude.

In addition, it allowed investigation of the equivalence principle (through Shapiro delay measurement) and Lorentz invariance. The limits of possible violations of Lorentz invariance (values of 'gravity sector coefficients'') are reduced by the new observations, by up to ten orders of magnitude.

GW170817 also excluded some alternatives to general relativity, including variants of scalar-tensor theory, Horava-Lifshitz gravity, Dark Matter Emulators and bimetric gravity, the details of which are beyond the scope of this lecture.

Gravitational wave signals such as GW170817 may be used as a standard siren to provide an independent measurement of the Hubble constant. An initial estimate of the constant derived from the observation is 70.0 +12.0 -8.0 (km/s)/Mpc, broadly consistent with current best estimates.

Electromagnetic observations helped to support the theory that the mergers of neutron stars contribute to rapid neutron capture r-process nucleosynthesis and are significant sources of r-process elements heavier than iron, including gold and platinum.

Rising stars of multi-messenger astronomy
https://www.symmetrymagazine.org/article/rising-stars-of-multi-messenger-astronomy

Gravitational waves have been described as ripples in the fabric of spacetime. They are the wake left behind when an object with gravitational pull, in other words any object with mass, changes its speed. When two enormous neutron stars go through a particularly drastic change in speed by colliding and merging, the gravitational waves released are powerful enough for scientists to detect them on Earth, 130 million light-years away.

That's what happened at 12:41 universal time August 17th, 2017. The Laser Interferometer Gravitational-Wave Observatory detectors in Hanford, Washington, and Livingston, Louisiana, recorded gravitational waves the likes of which no one had ever seen. Previous gravitational-wave signals had lasted a few seconds; this one was in range for more than 100. Additional data from the Virgo gravitational-wave detector near Pisa, Italy, helped scientists triangulate the gravitational waves' origin in the sky.

Astrophysicist Wilson-Hodge, the principal investigator on the NASA's Fermi Gamma-ray Space Telescope's Gamma-ray Burst Monitor team, was in training, learning how to motivate her team. When she received the notification from LIGO-Virgo, she knew motivation wouldn't be hard to find: The GBM sent out an alert of its own that morning from a high-energy blast of light called a gamma-ray burst, recorded just two seconds after the gravitational-wave signal passed the Earth. "It was pretty clear it was something really exciting," she says.