MULTIMESSENGER ASTRONOMY

The Mystery of the Brightest Bursts of Light in the Universe

JULY, 1967
CASE STUDY: GAMMA-RAY BURSTS

Gamma-Ray Bursts (GRBs) are the brightest flares of light in our Universe: a typical burst will emit more light than our Sun will in its entire 10 billion year lifespan! But what creates GRBs? We know that long GRBs (longer than 2 seconds) are associated with the deaths of massive stars (like supernovae), but we don't know what causes the short GRBs (less than 2 seconds).

HYPOTHESIS: Short GRBs could be created when very dense objects (like two neutron stars or a neutron star and a black hole) orbiting each other eventually merge.

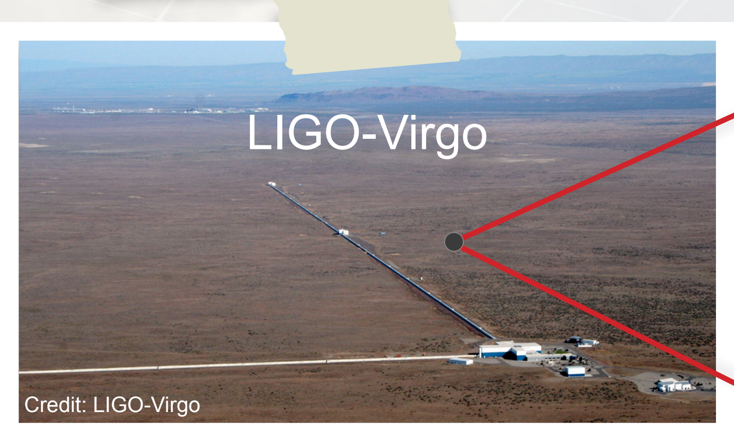
OBSERVATIONAL EVIDENCE: None from light of any wavelength.

NEEDED: A new way to observe (a new messenger from the Universe) to provide clues to illuminate the origin of short GRBs.

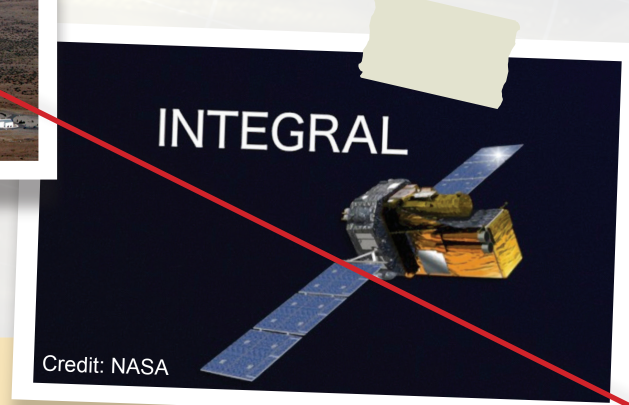
GRAVITATIONAL WAVES: A NEW DATA SOURCE

One hundred years ago Einstein predicted the existence of gravitational waves (GW), very small changes in gravity that travel throughout the Universe when mass moves. Encoded in every GW is information about the mass and movement of the objects that created it. In 2015, GWs were detected for the first time (winning the Nobel Prize!). If we detected GWs at about the same time and coming from the same area on the sky as a short GRB, we might finally learn something about what causes a GRB.

Credit: NASA



Credit: LIGO-Virgo

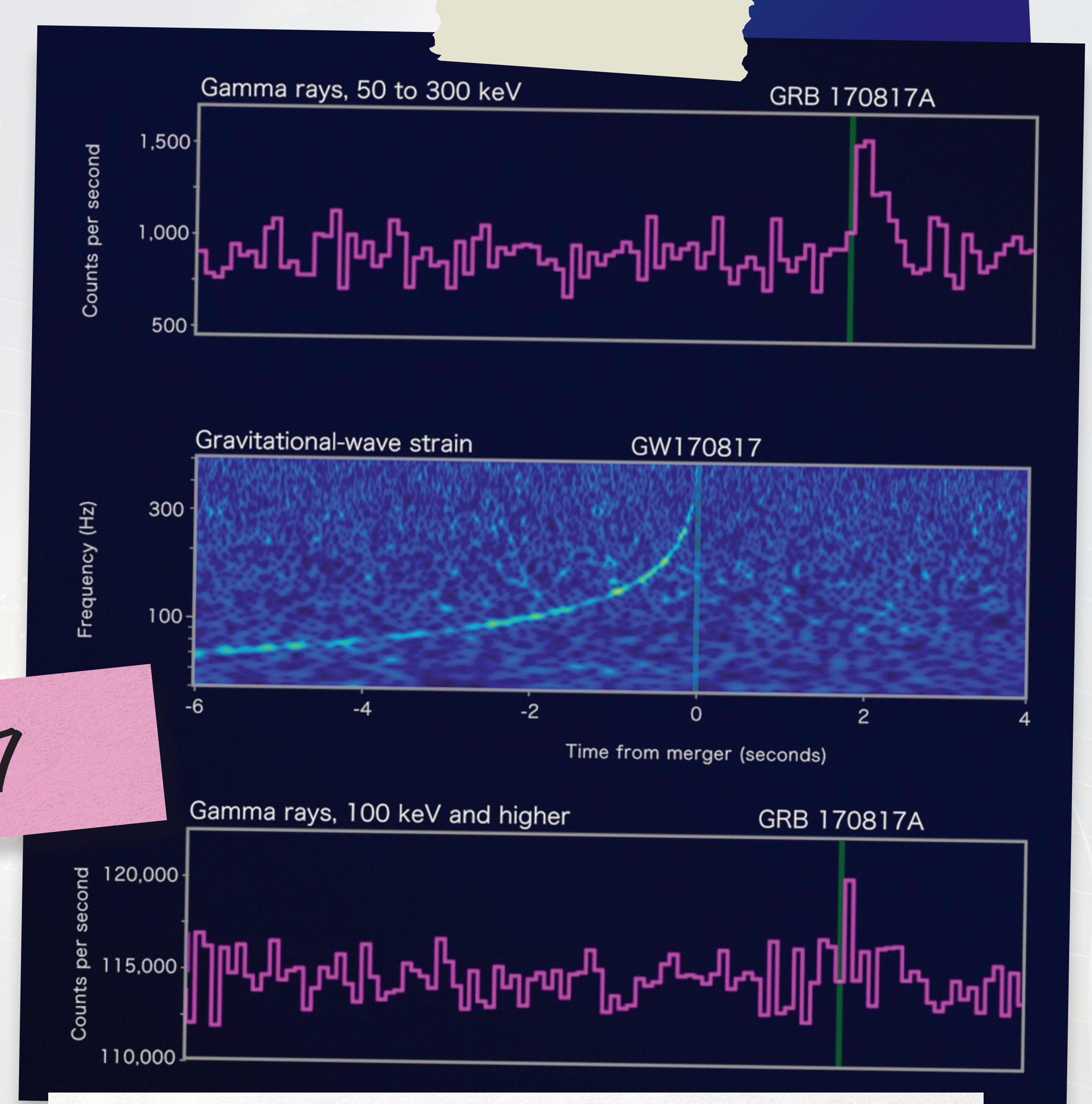


Credit: NASA

The Detection

In August 2017, GRB satellites Fermi and INTEGRAL detected a short GRB at about the same time that the Virgo and NSF-LIGO observatories detected a GW from two neutron stars orbiting and colliding with each other. All of these observations coincided with the same area of the sky. This was the first evidence that short GRBs could be produced by the merger of two neutron stars.

2017

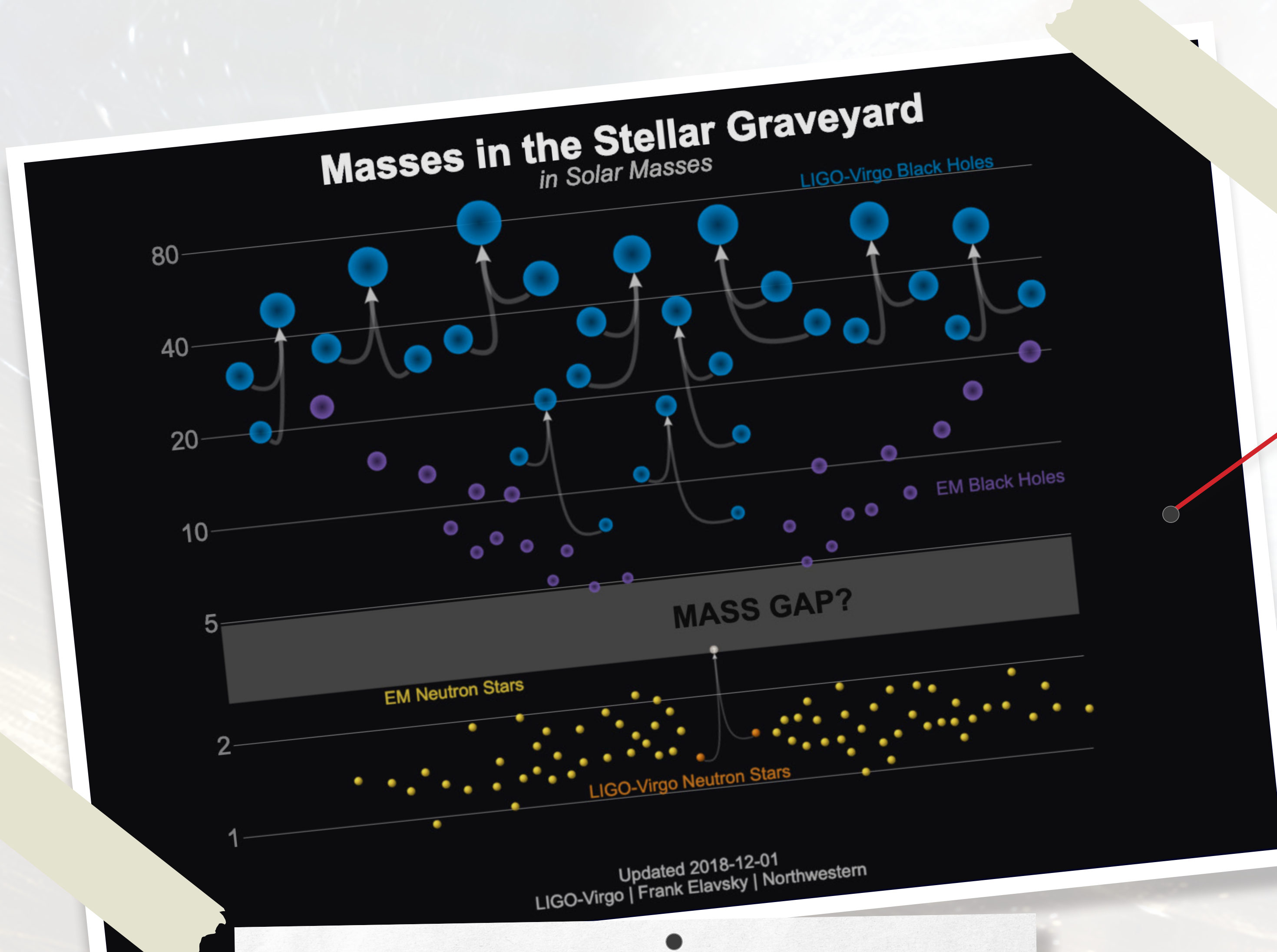


(top) The Fermi data collected in gamma-ray photons per second. (middle) The visual representation of the gravitational wave data LIGO and Virgo collected, showing the strength of the data at different frequencies over time. (bottom) The INTEGRAL data collected in gamma-ray photons per second. As expected, the GW arrived just before the gamma-rays.

Credit: NASA's Goddard Space Flight Center, Caltech/MIT/LIGO Lab and ESA

The Investigation

With the clues provided by LIGO-Virgo, Fermi, and INTEGRAL, thousands of astronomers from around the world turned their telescopes to the same area of the sky to try to detect any of the different forms of light that are typically emitted after a short GRB. They found optical, infrared, ultraviolet, X-rays, and radio light coming from the material that was ejected during an explosion called a kilonova. From these observations, they also found evidence that heavy elements were being created though the rapid neutron capture process, or r-process. This explains, for example, where a lot of the gold and silver in the Universe come from – another mystery solved!



The masses of stellar remnants are measured in many different ways. For details, visit this interactive site https://ligo.northwestern.edu/media/mass-plot/index.html

Remaining Mysteries

What is unknown is what was left behind after this merger. The remaining mass is estimated at 2.8 solar masses or less, based on the GW energy radiated away from the merger. No stellar remnants in the range of about 2-5 solar masses have ever been observed. If the remnant is a neutron star, it would be the most massive neutron star known to exist. If it collapsed into a black hole, then it would be the least massive black hole known. We will need more multimessenger observations like this one to solve this mystery!

NSF nsf.gov
LIGO ligo.org ligo.caltech.edu
VILLANOVA UNIVERSITY villanova.edu
APS physics aps.org

Content by Amber Stuver, Villanova/LIGO; Kathryne Sparks Woodle, APS; Monica Plisch, APS; Design by Ashley Mumford, APS; Background image credit: NSF/LIGO/Sonoma State University/Aurore Simonnet