Multi-Messenger Astronomy: A new era

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March 28, 2020

1 Introduction

On February 24, 1987, a spectacular, never-before-seen signal was detected from a source 165,000 light years away. It was a signal from a recently destroyed star— a core-collapse supernova. The first signal from this celestial phenomenon didn't come in the form of light, but rather in the form of a signal never measured before: neutrinos.

It wasn't hours later till the light arrived, corresponding to the extra time it took for the shock wave occurring in the star's interior to reach the surface. Where light interacts with the material composing the progenitor star, neutrinos simply pass through it, giving them a significant head start. For the very first time, a celestial event was detected through light and particles and with this, the era of Multi-Messenger Astronomy was born [1].

Although particles detected from cosmic rays and solar bursts cast new light on how we viewed the Universe, the last decade brought about another fundamental breakthrough in the field of astrophysics and astronomy as gravitational waves were detected for the very first time.

On August 17, 2017, the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo gravitational wave detectors detected ripples in the fabric of space-time from a source 130 million light years away— a neutron star merger. Immediately, observatories around the world scrambled to point their telescopes in the direction predicted by LIGO and Virgo and sure enough, in about 11 hours after the gravitational wave-detectors sounded the alarm, astronomers had their first glimpse of this never-before-seen celestial event. According to estimates made by observations across the spectrum, the collision produced around 200 earth masses of pure gold and 500 earth masses of pure platinum [2]. This was the first time gravitational waves were detected with an electromagnetic counterpart.

2 Motivation

For millennia, people have observed the night sky through their naked eye. With the invention of the telescope, we were able to see beyond what was visible with our naked eye, but were restricted only to the visible region of the electromagnetic spectrum. It was not until almost a century ago that we started observing the universe in different regions of the electromagnetic spectrum.

Looking at celestial bodies in different wavelengths reveals entirely new classes of information about the celestial body ranging from composition to age as shown in Figure 1.

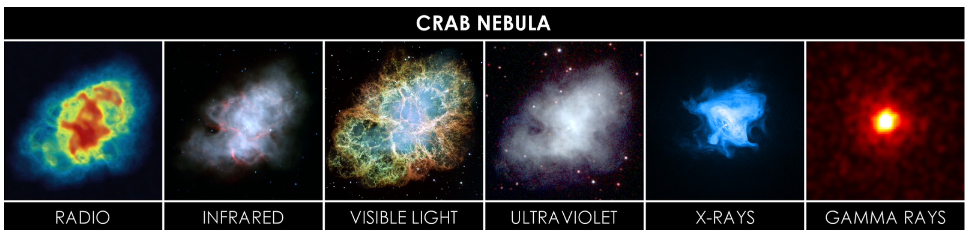

Figure 1: Multi-wavelength image of Crab Nebula [3].

From a Physics point of view, the observation of the universe in different regions of the spectrum is just the collection of photons emitted by these celestial bodies. In other words, doing astronomy by collecting light of any type always involves the same type of messenger: the same type of information-carrier. However, the objects in the Universe do not just emit light but emit a variety of fundamentally different signals as they undergo different astrophysical processes, as allowed by the universe. These signals carry different kinds of information about the body as with different types of electromagnetic radiation.

The different types of cosmic messengers that are used in astronomy today are:

- Photons (Electromagnetic radiation)
- Cosmic rays (High energy particles like electrons, positrons, protons, anti-protons and even atomic nuclei travelling at near-light speeds.)
- Gravitational waves
- Neutrinos and anti-neutrinos

3 Significance

So far, humans have learnt to take advantage of three fundamentally different messengers (photons, particles and gravitational waves) to glean information

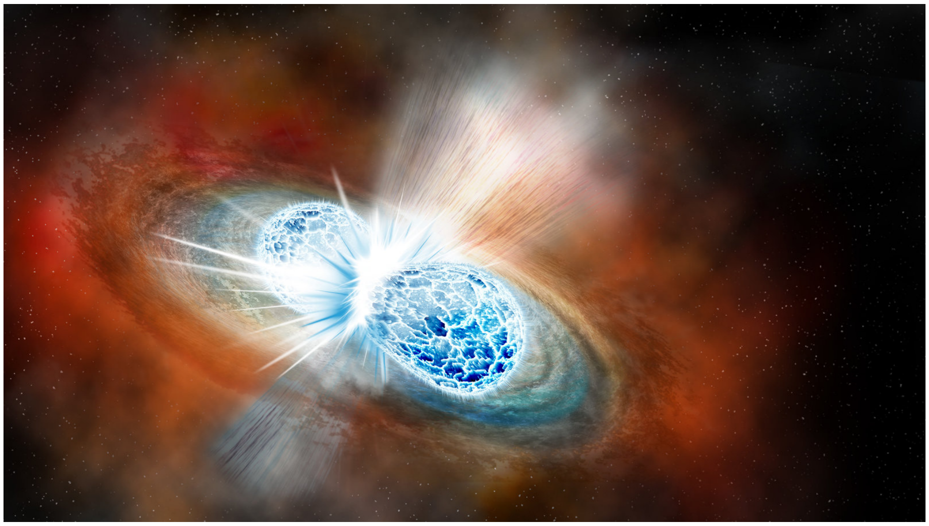

Figure 2: Neutron star merger: Kilonova [4].

about different faces of the Universe, but the most powerful examples of astronomical techniques occur when we are able to make use of more than one of these messengers at the same time. A striking example of this is the 2017 neutron-star merger or kilonova, where the gravitational waves were detected first and 1.7 seconds later gamma rays were detected. This gave ample time for other observatories around the world working in different wavelengths of light to be ready for the visible light and radio waves which arrived about 11 hours later. The advanced heads-up given by the gravitational wave sensors made it possible to obtain much deeper information than what would have been possible without us knowing when and where to look at the night sky.

When astronomers use the term 'multi-messenger astronomy' this is exactly what they mean—coordinated observation and interpretation of disparate messenger signals [5]. By combining the most precise observations we can make with each of these, we can learn more about our cosmic history than any one of these signal types alone.

4 Future

Already the Supernova Early Warning System (SNEWS), which combines multiple neutrino detectors to generate supernova alerts and the Astrophysical Multi-Messenger Observatory Network (AMON), a broader and more ambitious project to facilitate the sharing of preliminary observations and to encourage the search for "sub-threshold" events have been established on the foundations of Multi-Messenger astronomy [6].

We have learned about the generation of neutrinos in supernovae and linked kilonovae to neutron star mergers. It is only a matter of time before we actually see a neutron star colliding with a black hole and understand the astrophysics behind it. The technologies involved in the detection of these different messengers can only evolve with time and keep getting better and better. With multi-messenger astronomy still in its infancy we can expect an overwhelming number of new observations and discoveries as this science progresses.

An apt analogy that can be made about multi-messenger astronomy is that we were once limited to only one sense organ. But now, as we keep growing newer and newer sense organs we keep getting better and better at achieving a 'feel' of the Universe.

References

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