Fast Radio Bursts: Hidden Cosmological Radio Sources

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We are constantly exposed to local radio waves, for example, from televisions, radios, cellular phones, and microwave ovens. In addition, we also absorb radio waves from the universe. Some messages might originate from extraterrestrial civilizations (of course, no one has found them so far) but the vast majority are astronomical phenomena called fast radio bursts (FRBs). FRBs are short duration (~ several milliseconds) luminous radio transients whose origin remains controversial.

The first detection of an FRB was in 2001[1]. Duncan Lorimer and his student David Narkevic found an enigmatic radio signal in their pulsar data survey. A pulsar is an astronomical object which periodically ejects pulse-like signals. Unlike the pulsars, the FRB radio signal was not repeated and was extremely energetic, emitting 30 Jy within 5 milliseconds (Jy (Janski) is a unit of flux). This value is almost the same as a light bulb with 1 Watt and a frequency range of 1 MegaHertz on the surface of the moon. Flux is proportional to (distance to the energy source)$^{-2}$, that is, the further the energy source is located, the smaller the flux is, even at the same luminosity. Radio astronomical phenomena such as fast radio bursts are thought to be located at cosmological distances and, therefore, the energy of FRBs is much larger than a light bulb on the moon.

At the time, Lorimer and Narkevic thought the burst signal might have been a kind of noise and decided not to release their discovery. However, the burst signal showed a curious characteristic: the arrival time depended on the observed frequency and was caused by a scattering of photons through a plasma. The observational data showed how much the signals were scattered, called the "dispersion measure (DM)". From the observed DM, they found the burst signal was propagated from 1 Giga parsec away (1 parsec is about 3 times 10^{16} m). Compared to the separation between the Earth and the Sun, about 1.5 times 10^{11} m, 1 parsec is about 10^{5} times larger. Six years later, they published a paper about the burst. After that, the signal became known as the "Lorimer burst" and such bursts eventually came to be detected by other researchers.

To date, more than 100 FRBs have been detected. The observed DM indicates FRBs propagated from cosmological distances such as 1 Giga parsec, and FRBs are a good probe for deep space distances. A small fraction of FRBs has been observed repeatedly and most researchers think they have a different origin from the non-repeated FRBs'.

What is the origin of FRBs? While most FRBs including the "Lorimer burst" have never been repeated, some bursts have, inferring the existence of different populations of FRBs, where the origin of the former group may be a catastrophic event and that of the latter group may not. No one has an answer to the question, but several scenarios have been suggested. One influential scenario for non-repeating FRBs is the merger of two binary neutron stars. A neutron star contains more neutrons than protons. In this scenario, gravitational waves (GWs) as well as FRBs are supposed to be observed at almost the same time. A gravitational wave is a distortion of space-time that propagates like a wave. Gravitational waves emitted by the merger of extremely dense and small "compact" objects such as black holes and neutron stars can be detected by current gravitational detectors. However, the problem is that the location of FRBs is too far away to observe their GWs. The amplitude of a GW gets smaller as the gravitational wave source is located farther away. The current sensitivity of gravitational wave detectors such as the Laser Interferometer Gravitational-Wave Observatory, Virgo interferometer, and KAGRA is several hundred Mega parsecs at most. Therefore, the simultaneous detection of FRBs and GWs remains a challenge.

One possible solution is to use the advantageous properties of FRBs, where their arrival time can be determined at a millisecond time scale. Within such a narrow time window, noise can be modeled and estimated more precisely. By extracting noise from the data, we may be able to obtain an embedded weak signal. Setting a time window may improve the effective sensitivities of gravitational wave detectors around the arrival time of FRBs.

In addition, there are interesting astronomical phenomena caused by neutron star mergers. In 2017, gravitational waves from a binary neutron star merger were observed and a kilonova and short gamma-ray burst were observed after that. A kilonova (or macronova) is a luminous phenomenon in the optical or infrared wavelength caused by the radioactive decay of heavy elements. A short gamma-ray burst is a short-time explosive phenomenon in the gamma-ray spectrum. The burst observed after gravitational waves from a neutron star merger is much fainter than ordinal short gamma-ray bursts, which indicates that it is another population of short gamma-ray bursts. This type of interdependent signaling is the dawn of multi-messenger astronomy, an interdisciplinary research field of astronomy. Identifying the origin of radio signals from the universe will enable us not only to understand the physics of cosmic progenitors, compact objects such as black holes and neutron stars, but also to prepare for receiving signals from extraterrestrial intelligence.

<Reference>

[1] D. R. Lorimer et al., *Science* 318, 777 (2007).

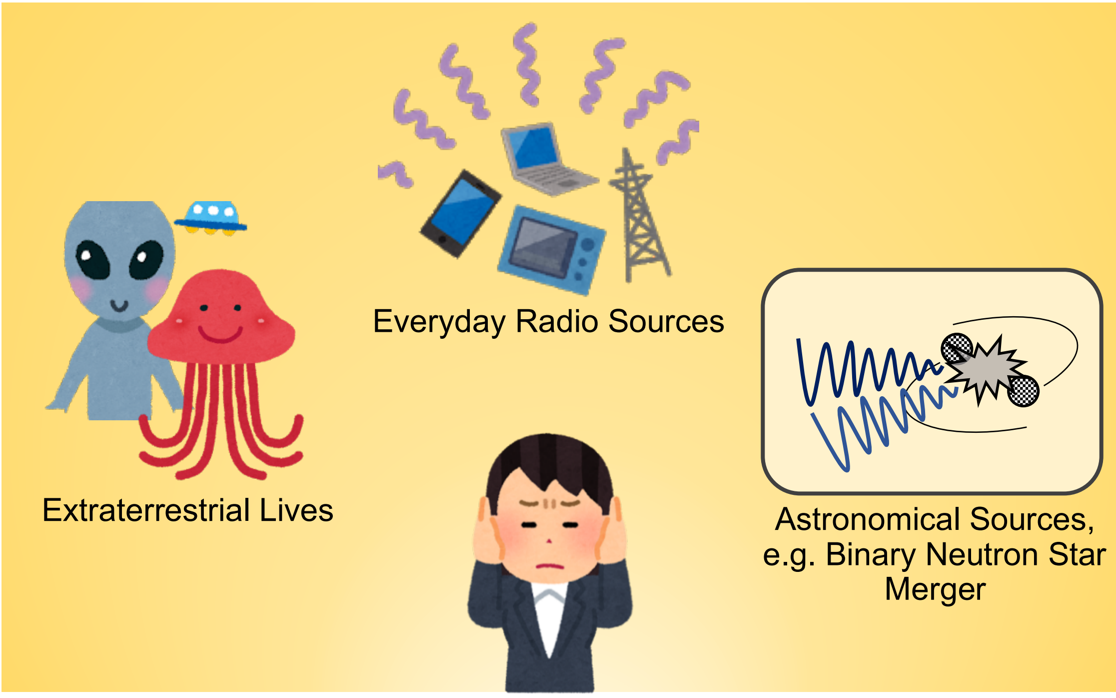

Fig 1 : We are surrounded by a various kind of radio signals, including local electronics such as cellular phones and televisions ("Everyday Radio Sources"), and from astronomical sources like binary neutron star merger, and (perhaps) messages from extraterrestrial lives. If we could hear them, will we frown and close our ears like the person in the figure does? (Source of individual images: https://www.irasutoya.com)