Pulsars and Millisecond Pulsars

A pulsar is a rotating neutron star that emits a beam of radio waves. The beams are emitted from the poles of the strong magnetic field surrounding the pulsar. These poles are often misaligned with the rotational axis. This creates a “lighthouse effect” as the beam sweeps across the line of sight of the Earth; the beam is detected as pulses of radio waves. Pulsars with the shortest periods are millisecond pulsars which have periods of 1 to 10 milliseconds. These are formed during a supernova as a neutron star just like all pulsars. Their very short periods come from two sources: The conservation of angular momentum when the star collapses means the smaller, denser neutron star must spin much faster; and when these pulsars are in a binary system with another star they can pull matter away from the larger star causing the pulsar to “spin-up” or increase its rotational speed.

Another interesting aspect of millisecond pulsars is their place in the lifespan of a pulsar. Millisecond pulsars that undergo the “spin-up” process often do so towards the end of their original pulsar life. After they are formed, pulsars lose energy over time (due to their rotating magnetic field); they slow down and stop radiating their beams. Most pulsars in binary systems undergo the “spin-up” process at this point in the process to form millisecond pulsars. (Lyne 14)

The reason these pulsars are useful to scientific research is that when many pulses from the same pulsar are superimposed on top of one another, the resulting pulse profile is very consistent over time. This comes from the fact that pulsar rotation is extremely steady. This consistency, especially of the very short timescales of millisecond pulsars, allows for detection of many subtle phenomena which effect the pulse arrival times, including gravitational waves and the make-up of the interstellar medium.

Introduction to Pulsars, the Interstellar Medium, and NANOGrav

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The Interstellar Medium

The Interstellar Medium is basically defined as all the space and free particles between the stars and other bodies in our universe.

These free particles interfere with EM waves traveling between two bodies, such as radio waves traveling from a pulsar to the Earth. The interference in the signal due to the free electrons is called dispersion and it is proportional to the number of electrons in the path of the signal. The dispersion of a signal causes it to arrive at different times for different frequencies. The graph to the right shows the influence on the timing of a pulsar signal. The pulse was emitted at one time but the interference caused by the free electrons delayed the lower frequencies more than the higher frequencies (Lyne).

Gravitational Waves are disturbances in space-time that travel as waves away from a gravitational source. A good way to think of them is as “ripples” in space-time which decrease in magnitude the farther they travel just as ripples in water die out farther from the source. By studying the influence of the interstellar medium on the signals for different pulsars, one may hope to create a power spectrum model of its influence and be able to remove that influence from the data. Once that is removed, it’s possible that long-term variation in the timing of the pulsar signal could be observable gravitational waves.

Sources:


NANOGrav

Our work is part of the NANOGrav project. NANOGrav is a collaboration of physicists who hope to use pulsar timing to detect gravitational waves. The name stands for North American Nanohertz Observatory for Gravitational waves because the goal is to detect gravitational waves with frequencies on the order of nanohertz. This corresponds to periods of a few years. By attempting to detect gravitational waves, NANOGrav is complimenting other gravitational wave projects done by ground detectors such as LIGO (kilohertz frequencies) and proposed space mission detectors (millihertz frequencies).

NANOGrav uses the Arecibo Telescope in Puerto Rico and the Green Bank Telescope in West Virginia. The people involved in NANOGrav also collaborate with observatories around the world involved with the International Pulsar Timing Array.

Much of the timing data were collected remotely but we were fortunate enough to take a trip down to the actual telescope and collect the data on site for a few days. The data collected was used by us and will also be used by all the NANOGrav collaborators.

The large “dish” shaped telescope on the bottom right is the Arecibo Observatory in Arecibo, Puerto Rico where NANOGrav collects a large amount of data on pulsars and their arrival times. Our Excel Research work came out of a lot of this data.

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