A pulsar is a highly magnetized, rotating neutron star that emits “pulsating” beams of electromagnetic radiation from its magnetic poles. Pulsars are formed when a star is too massive to form a white dwarf but not massive enough to collapse into a black hole after it goes supernova. The resulting object is a small but incredibly dense object called a neutron star. A typical neutron star has a radius of approximately 10 km (roughly the size of a city), a mass of approximately 1.5 solar masses (up to 6.7 x 10^30 kg), and its density is roughly equivalent to the entire mass of the Earth compressed into a space the size of a sugar cube. A pulsar appears to pulse because its magnetic axis is offset from its rotational axis. When the pulsar spins about its rotation axis, the beams of radiation emitted from the magnetic poles sweep across the sky like a lighthouse (fig. 1). When one of the beams sweeps towards Earth, we see a “pulse” of electromagnetic radiation even though the beam is continuous. While pulsars emit radiation from radio to ultraviolet frequencies, they are most easily studied in radio waves.

**Gravity Waves**

Gravity waves can be used to detect gravity waves. Gravity waves, first predicted by Albert Einstein, are ripples in the curvature of spacetime generated by massive objects similar to electromagnetic waves. Gravitational waves have amplitude, wavelength, and move at light speed. These waves manifest as small sinusoidal variations in the distance between objects. They are very difficult to detect because their signal drops off as R^-3, where R is the distance from the source. When any mass accelerates, it produces gravitational waves, but they are only detectable when generated by supramassive objects like double neutron star systems. As these gravitational waves pass through Earth, they cause the Earth to stretch and squeeze in a very exact way (eq. 1). The problem is that the available pulsar data is not very precise, so the calculations are very approximate (fig. 2). The problem is that the available pulsar data is not very precise, so the calculations are very approximate (fig. 2).

**Some pulsars rotate extremely quickly about their axes. These “millisecond pulsars” have been found to rotate up to 716 times per second which translates to ~40000 pulses per minute. In addition to the pulses arriving very rapidly, they also arrive at very precise intervals (change in period ~10^-7 s). Because the arrival times of the pulsars are so precise, pulsars can be used as very precise “clocks in the sky.” By timing the pulse arrival times from several pulsars at various points in the sky, we can create a Pulsar Timing Array (PTA) which can be used to detect gravitational waves. If a gravitational wave were to pass through the region between Earth and the pulsars in the PTA, space itself would be warped causing the arrival times of the pulsars to be delayed in a very exact way (eq. 1). The scattering of the electromagnetic radiation off the scintillation layer (fig. 3) causes the data in the secondary spectrum is a coherent parabola (eq. 2) suggests that the data in the primary spectrum are related in some way. The large parabola appears in the secondary spectrum because delay depends on the square of the scattering angle whereas fringe frequency depends linearly on it. It also indicates that scattering occurs primarily in a thin plane-like structure between Earth and the pulsar.

**Objective**

If we plot the pulsar intensity over a range of frequencies versus time, we can see the interference pattern that the ISM causes (fig. 3a). After performing a 2D Fourier Transform on this primary spectrum, we get a secondary spectrum (fig. 3b). Although the primary spectrum seems random and uncorrelated to the naked eye, the fact that the secondary spectrum is a coherent parabola (eq. 2) suggests that the data in the primary spectrum are related in some way. The large parabola appears in the secondary spectrum because delay depends on the square of the scattering angle whereas fringe frequency depends linearly on it. It also indicates that scattering occurs primarily in a thin plane-like structure between Earth and the pulsar.

\[ \eta = \frac{D'}{D} = \frac{D(1 - s(\sin \theta))}{2\chi_{eff}} \bigg(1 + \frac{1}{4\pi D^2} \bigg) \]

\[ D' = \text{distance from pulsar to Earth} \]

\[ \lambda = \text{pulse wavelength} \]

\[ s = \text{fractional distance from pulsar to Earth where screen is located} \]

\[ \theta = \text{angle of light} \]

\[ V_{eff} = \text{effective velocity of pulsar at screen} \]

\[ \psi = \text{angle between } V_{psr} \text{ and the elongated pulse image (further explained in results section)} \]

**Modeling the Movement of the Pulsar and Earth**

In order to get an expression for the position of the screen, we need the effective velocity of the pulsar (V_{eff}) in eq. 2. The problem is that the available pulsar data is given in equatorial coordinates (a particular celestial coordinate system). The equatorial system’s configuration causes the Earth-Sun plane to vary sinusoidally making it difficult to combine the velocities of Earth and the pulsar. Ecliptic coordinates, on the other hand, hold the Earth-Sun plane at a fixed value, so we figured out a way to convert pulsar positions and velocity-vectors (eq. 4.5) from equatorial to ecliptic coordinates. The two systems are nearly identical except that their “0-altitude” axes are rotated 23.5° relative to each other. In fig. 5, each pulsar’s trajectory “cusp” because of the Earth’s orbit. Each pulsar has an component of its transverse velocity that is parallel to the Earth-Sun plane. The apparent velocity of the pulsar at the screen ranges between V_{psr} + V_{Earth} and V_{psr} - V_{Earth} which causes the “cusp” as the velocity varies during the Earth’s orbit.

**Discussion**

Through our analysis we were able to constrain the location of the screens. The pulsars we focused on were non-millisecond pulsars whose secondary spectra had one defined parabola. Future work could investigate pulsars with more complicated secondary spectra, or focus more specifically on the millisecond pulsars that are used in gravitational arrays. Our projections of the effective velocity could be improved by including the motion of the ISM by modeling the rotation of Earth and pulsar around the galactic center. Future work should focus on moving the s-value from a limit on the location of the screens to an exact location through further analysis. It may be possible to use analysis of a very nearby pulsar to isolate enough variables to find an exact location of the screen. This might tell us if there is a concentration of screens near Earth.

**References**


Stinebring et al. 2014, in preparation


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