Pre-Lab Reading: Mars Orbiters and the Search for Technosignatures

Introduction to Technosignatures

The question "Are we alone in the universe?" has fascinated humans for millennia. Following the advancement of science and technology over the years, we can now attempt to answer this question scientifically. Scientists approach this question using tools from astronomy, physics, chemistry, and data science. In the search for life beyond Earth, researchers look for two broad categories of evidence:

- **Biosignatures:** Signs of biological activity, such as oxygen or methane in an exoplanet's atmosphere, or pigments that could come from photosynthesis.
- **Technosignatures:** Signs of technology that might indicate the presence of advanced, intelligent life.

Technosignatures include anything that could be produced by and an advanced technological civilization, including but not limited to:

- Radio transmissions that are not easily explained by natural sources
- Pulsed lasers or optical beacons
- Atmospheric pollutants that don't occur naturally
- Large structures like Dyson spheres that surround stars to capture energy

In this lab, we'll focus on radio technosignatures, unusual radio signals that might suggest an artificial origin.

Why Radio Signals?

Radio waves are one of the most promising ways to detect intelligent life in the universe. They can travel across space with little interference, and are energy efficient to transmit. For these reasons, technosignature researchers typically search for:

- **Narrowband signals:** All the energy of the transmission is concentrated over a very small range of frequencies. Natural signals (e.g. stars, pulsars, quasars, etc.) are usually broadband, meaning they're spread across a wide range of frequencies. Narrowband signals stand out from the noise. Natural astronomical sources don't produce them easily, but technology might, especially if the goal is to communicate efficiently across large distances. Narrowband signals are also energy efficient. If you're an advanced civilization trying to send a detectable signal over large distances, concentrating your transmission energy into a very small frequency range would help maximize the chance of being noticed.
- **Frequency Drift:** If a signal gradually changes in frequency over time, that's called drift. This will happen if the transmitter and receiver are moving relative to each other, such as a planet rotating or orbiting its star, due to the Doppler effect. Sources of radio frequency interference from human technology, such as cell towers, WiFi, etc,

Signal Types and Classification

SETI researchers group signals into three broad categories:

- **Technosignatures:** Signals that might originate from intelligent life. These are likely to appear as narrowband signals that persist, repeat, or drift in frequency, and they usually don't match any known natural or human-made sources.
- **Natural Astronomical Signals:** These include things like pulsars, quasars, and spectral emission lines. They're typically broadband, noisy, or variable in shape, and they follow known astrophysical patterns.
- **Radio Frequency Interference (RFI):** Signals from human technology such as cell towers, satellites, radar, etc. RFI can sometimes look like a technosignature, so scientists must rule it out carefully.

In this lab, you'll practice classifying different types of signals based on their shape, frequency behavior, and source location. You'll learn to identify which features are consistent with natural signals, which point to RFI, and which might indicate something more unusual.

The Tianwen-1 Mars Orbiter

To help you explore how a real artificial signal appears in radio data, this lab includes observations of the Chinese Mars orbiter, Tianwen-1. The spacecraft transmits a continuous, narrowband signal that serves as a frequency reference for Doppler tracking, allowing ground stations to precisely measure its motion through space.

This signal doesn't carry any telemetry or information, but its artificial origin, narrow bandwidth, and sky-localized position make it a useful analog for studying potential technosignatures. By analyzing the signal with GNU Radio, you'll learn how to measure its characteristics and distinguish it from noise or natural background emissions.

Spectrum and Time-Series Plots

Radio signals can be analyzed in both the frequency and time domains, each providing different insights about the signal's behavior. In this lab, you'll encounter two common ways of visualizing radio data:

- **Spectrum Plot (Frequency vs. Power):** This plot shows how signal power is distributed across different frequencies. Narrowband signals appear as sharp peaks, while broadband signals spread across a wider range. Spectrum plots are especially useful for identifying signals that stand out from background noise.
- **Time-Series Plot (Time vs. Intensity):** This plot shows how the signal's strength changes over time. It's useful for identifying patterns like pulsing, fading, or sudden changes in intensity. A steady signal will appear relatively flat, while variable signals will show clear structure.

Understanding both types of plots is essential in radio signal analysis. While spectrum plots help you locate signals in frequency space, time-series plots help reveal how those signals behave over time.