Interferometry in Radio Astronomy

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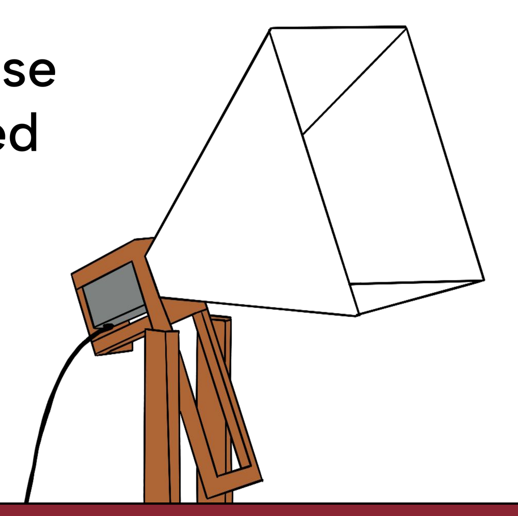
Background Information

Radio astronomy is a branch of astronomy that studies celestial objects by detecting and analyzing the radio waves they emit. These emissions arise from thermal radiation, synchrotron radiation, spectral line emission, and pulsed signals from sources like pulsars.

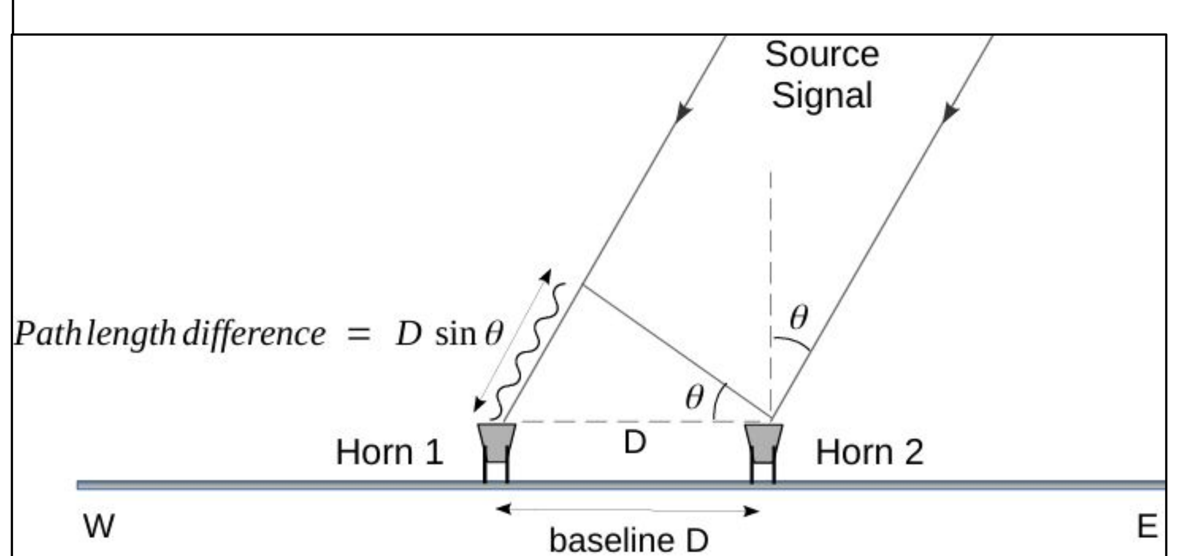
Horn telescopes are a type of radio telescope that utilize a flared, horn-shaped metal antenna to collect and direct radio waves into a receiver. In this setup, the receiver includes a low-noise amplifier (LNA) and a software-defined radio (SDR). The LNA amplifies weak signals with minimal added noise, while the SDR converts the analog signal into digital data for processing and analysis.



Interferometry

Interferometry is a technique in which signals from two or more telescopes are combined to act like a single, much larger telescope. The resulting interference patterns between the signals contain information about the position and motion of the radio source.

With more than one telescope, the geometry of the setup results in the radio waves not arriving at the same time.



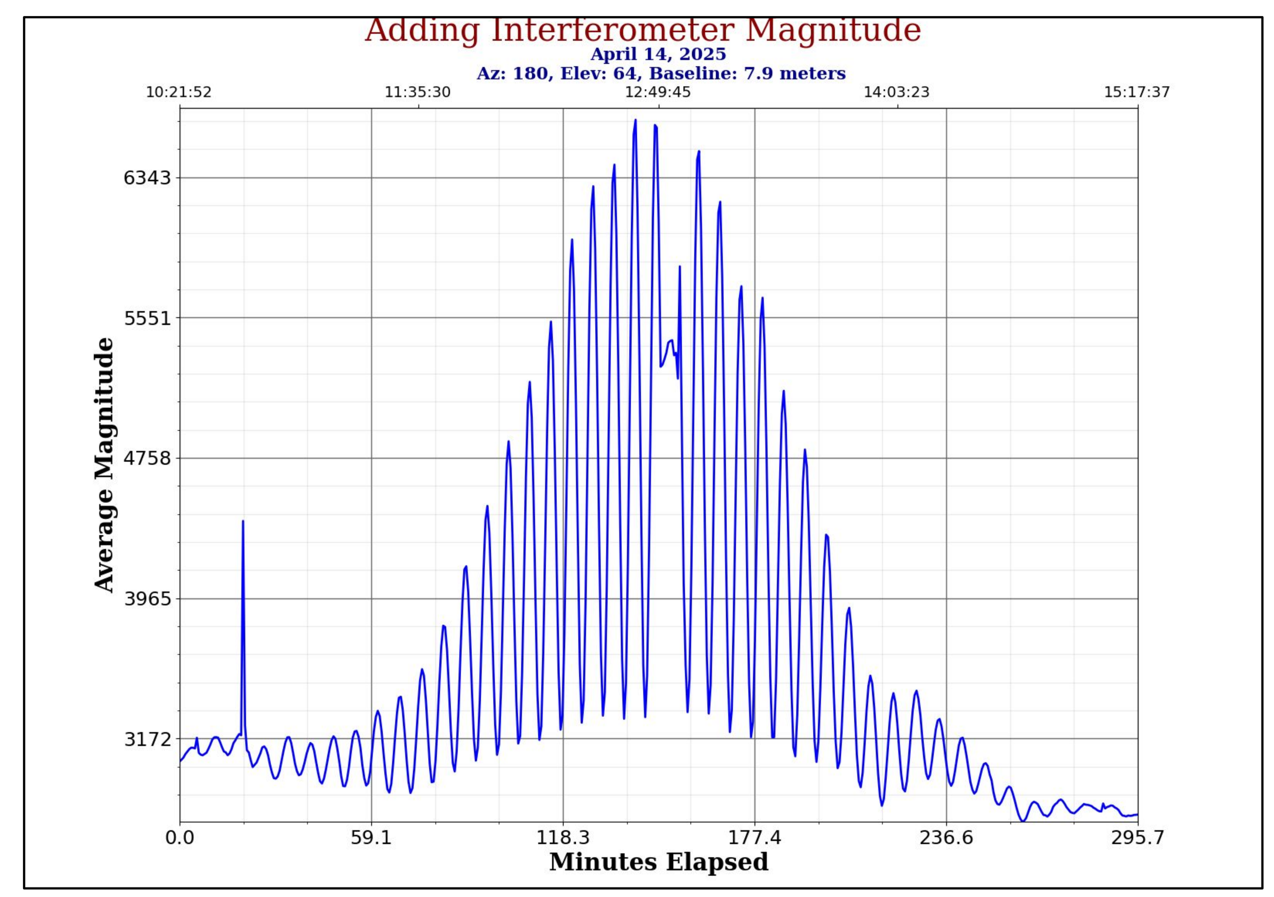
One wave may have to travel farther, and this extra travel distance is called the path length difference.

That difference causes a phase shift, or a change in where the wave is in its cycle. $\Delta\phi = \frac{2\pi}{\lambda}\Delta L$

If the waves arrive in-phase with each other, they will form constructive interference, strengthening the signal. If they arrive out of phase, they undergo destructive interference, weakening or canceling the signal.

Additive vs Multiplicative

In additive interferometry, signals are combined by directly adding their values at each point in time. We use the open-source signal processing platform GNURadio to perform this operation: the signals are summed, squared to calculate power, integrated to average the result and reduce noise, and then output as a single stream. Whether these signals reinforce or cancel each other depends on their phase relationship, resulting in the fringe pattern illustrated in the graph.

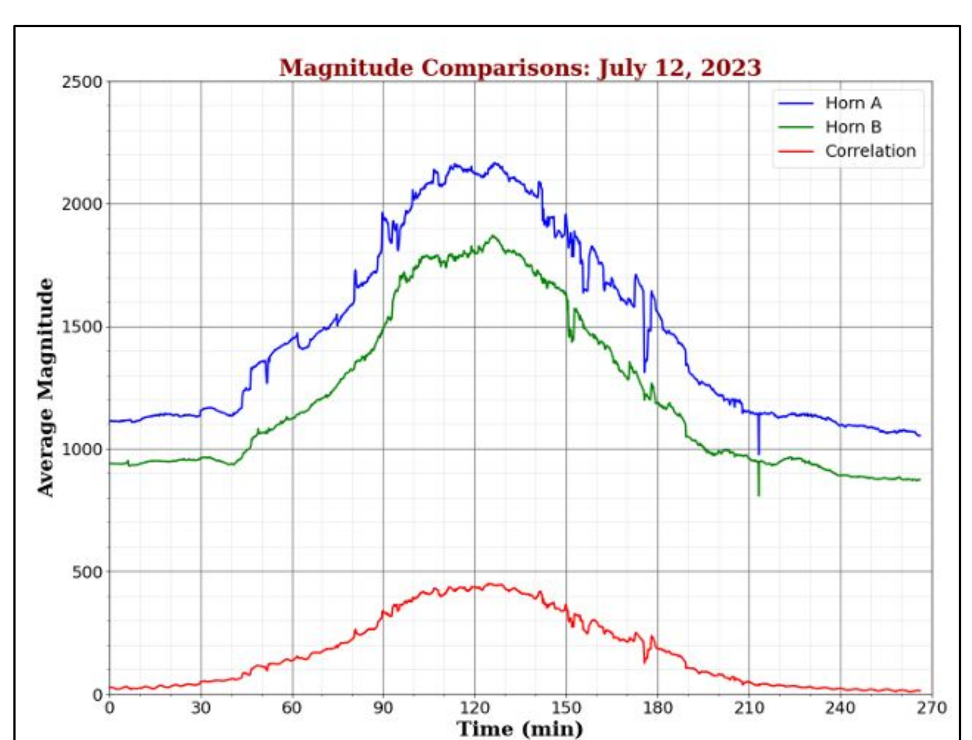


Data taken at Concord University on a windy day.

In multiplicative interferometry, the complex-valued signals from each telescope are multiplied by the conjugate of the other, preserving both the amplitude and relative phase between the signals. The result is a complex number where magnitude reflects signal strength, and the phase angle represents how aligned the signals are. This is outputted to two separate magnitude and phase files.

Each wave signal can be represented as: $s = Ae^{i\phi}$

When multiplied by the complex conjugate: $s_1 \cdot s_2^* = A_1 A_2 e^{i(\phi_1 - \phi_2)}$



Magnitude result:

$$\left|s_1 \cdot s_2^*\right| = A_1 \cdot A_2$$

Phase result:

$$arg(s_1 \cdot s_2^*) = \phi_1 - \phi_2$$

These complex results allow you to represent phase vs time, magnitude vs time, and instantaneous signal on a complex plane.

Future Work

Physical

- Build sturdier, weather-resistant bases with adjustable elevation angles for horn antennas.
- Use longer data transmission cables for an increased baseline separation and centralized hardware and power supplies.
- Improve imaging resolution with more horn antennas.
- Expand Wi-Fi range so hardware can establish a connection.

Software

- Integrate version control for efficient development.
- Package into executable applications for streamlined operation.
- Implement a PyScript-based GUI to make the system more accessible.
- Host on an external site for remote access and monitoring, regardless of local network connection.

Technologies Used

Acknowledgements

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References

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