Interferometry Using Very Affordable Radio Horn Telescopes

CSAAPT

Fall 2023

John Makous

Concord University

jmakous@concord.edu

Outline

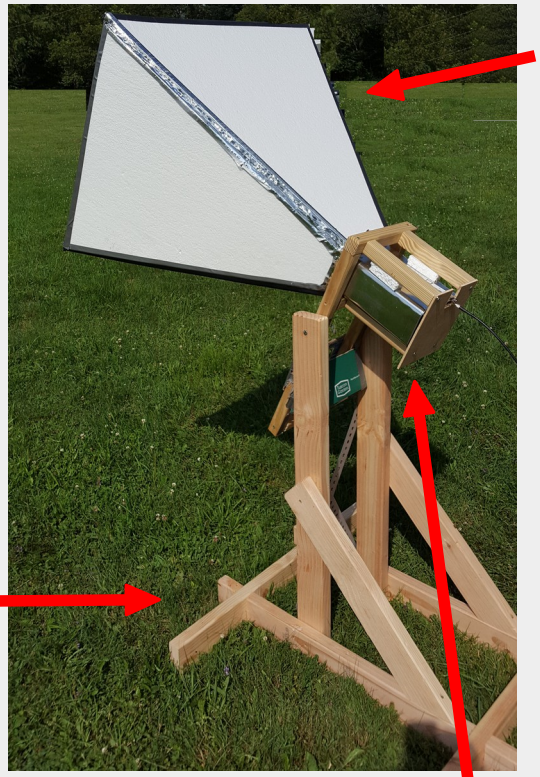
- Introduction
- DSPIRA RET program
- DSPIRA horns, experimental set-up
- Interferometry
  - Basic Theory
  - Results
- Future Work
- Summary

Digital Signal Processing in Radio Astronomy (DSPIRA)

- RET that began in summer of 2017
- Conducted at West Virginia University and the Green Bank Observatory
- Result: Lessons on how to build, operate, apply radio horn telescopes that are affordable on any budget
- developed by participating teachers
- Lessons can be found at: https://wvurail.org/dspira-lessons/

DSPIRA Radio Horn Telescopes

- Designed to detect 21 cm photons emitted during spin flip in H atoms
- The horn and stand:
  - Materials available at home project stores
  - Cost: $100-$200
- Amplifier and SDR



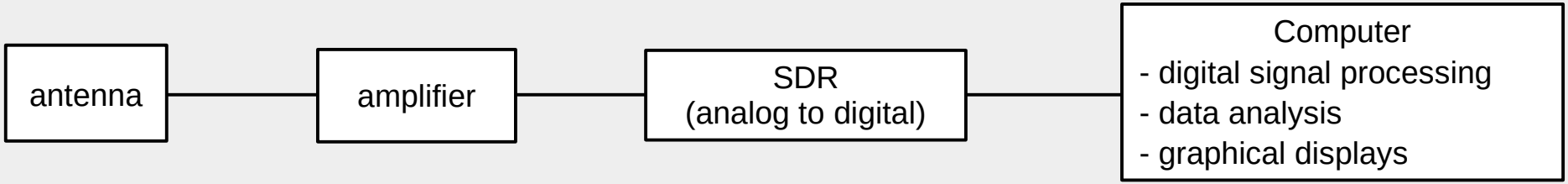
Horn
- aluminized insulation board
- 60 cm x 75 cm horn opening

Wooden stand - 2”x2” and 2”x4” pieces

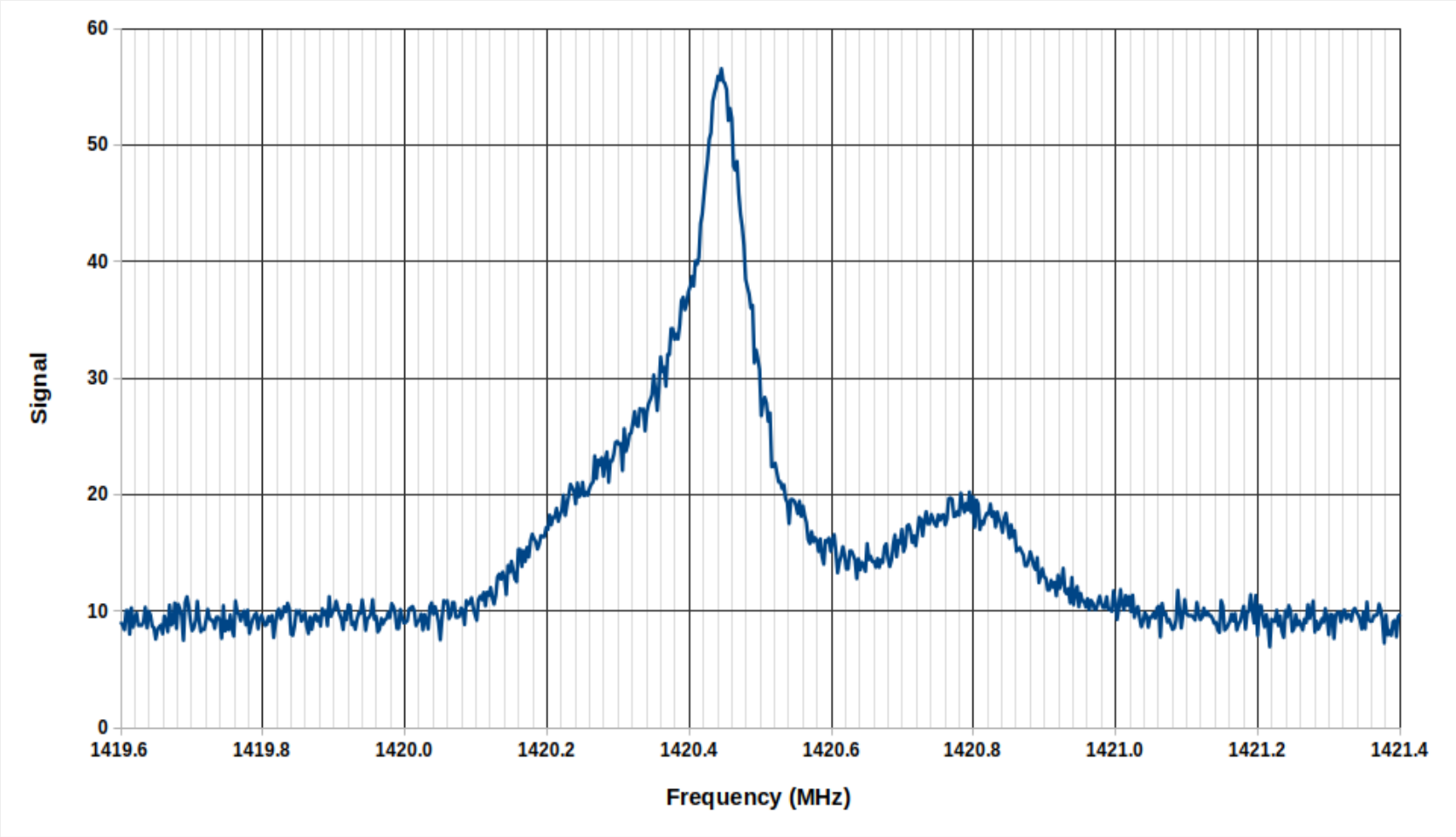
Antenna & LNA
- 4 ½ ” x 6 ½ ” metal can
- ¼ λ probe = 5.25 cm
- LNA optimized at 1420.4 MHz

Experimental Set-Up

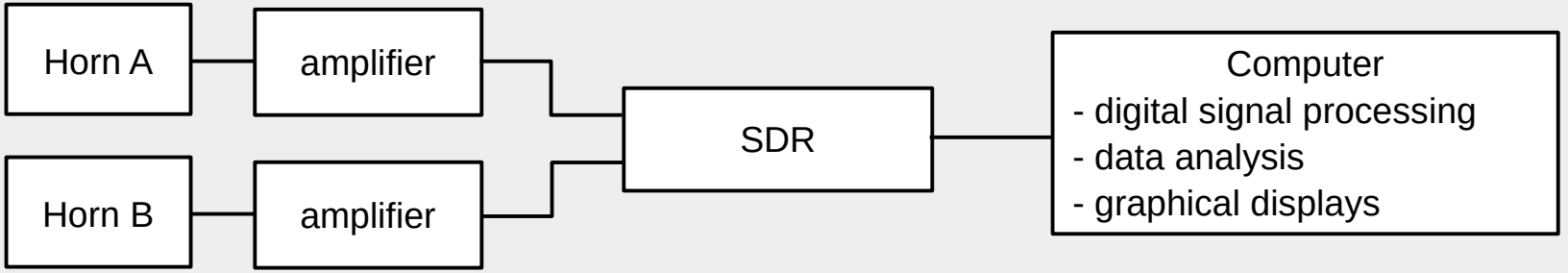
Used a radio horn telescope tuned for HI detection at $f = 1420\ MHz$



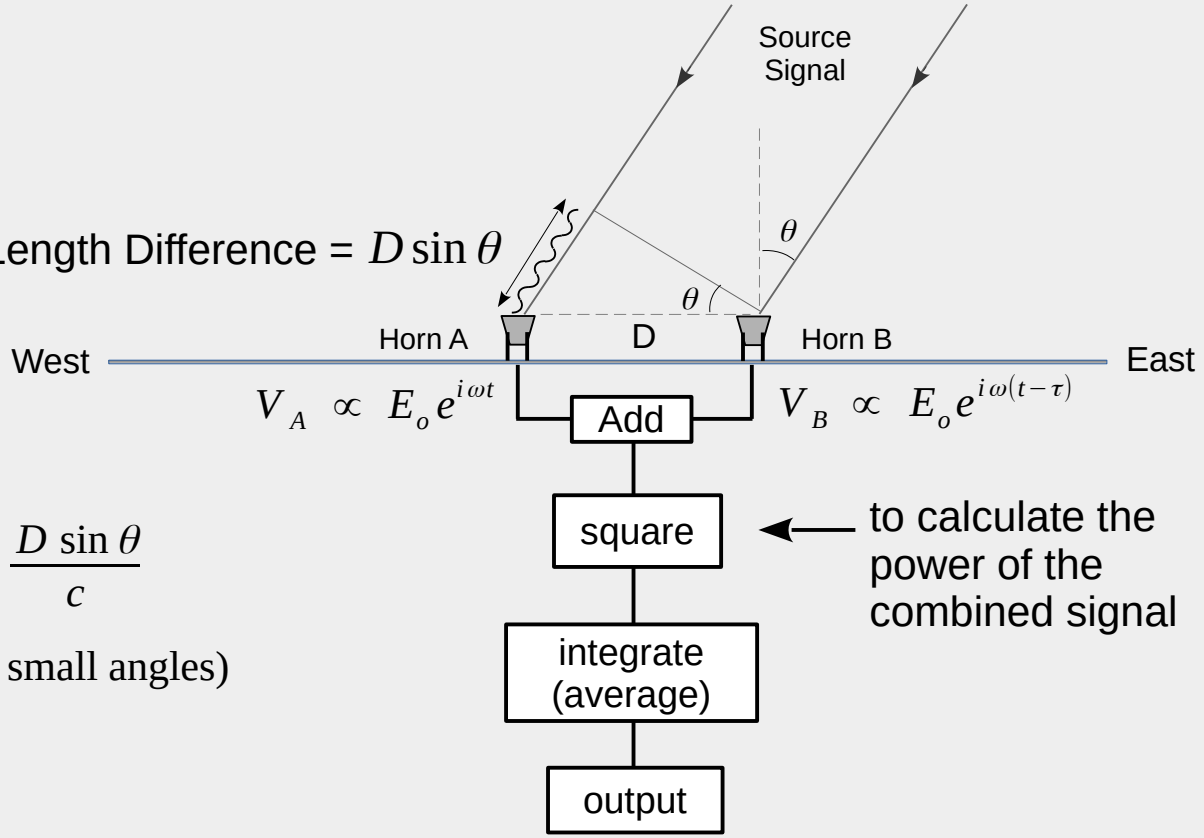
Sample Spectra from a Single Horn



Interferometry with Horns



Additive Interferometry



to calculate the power of the combined signal

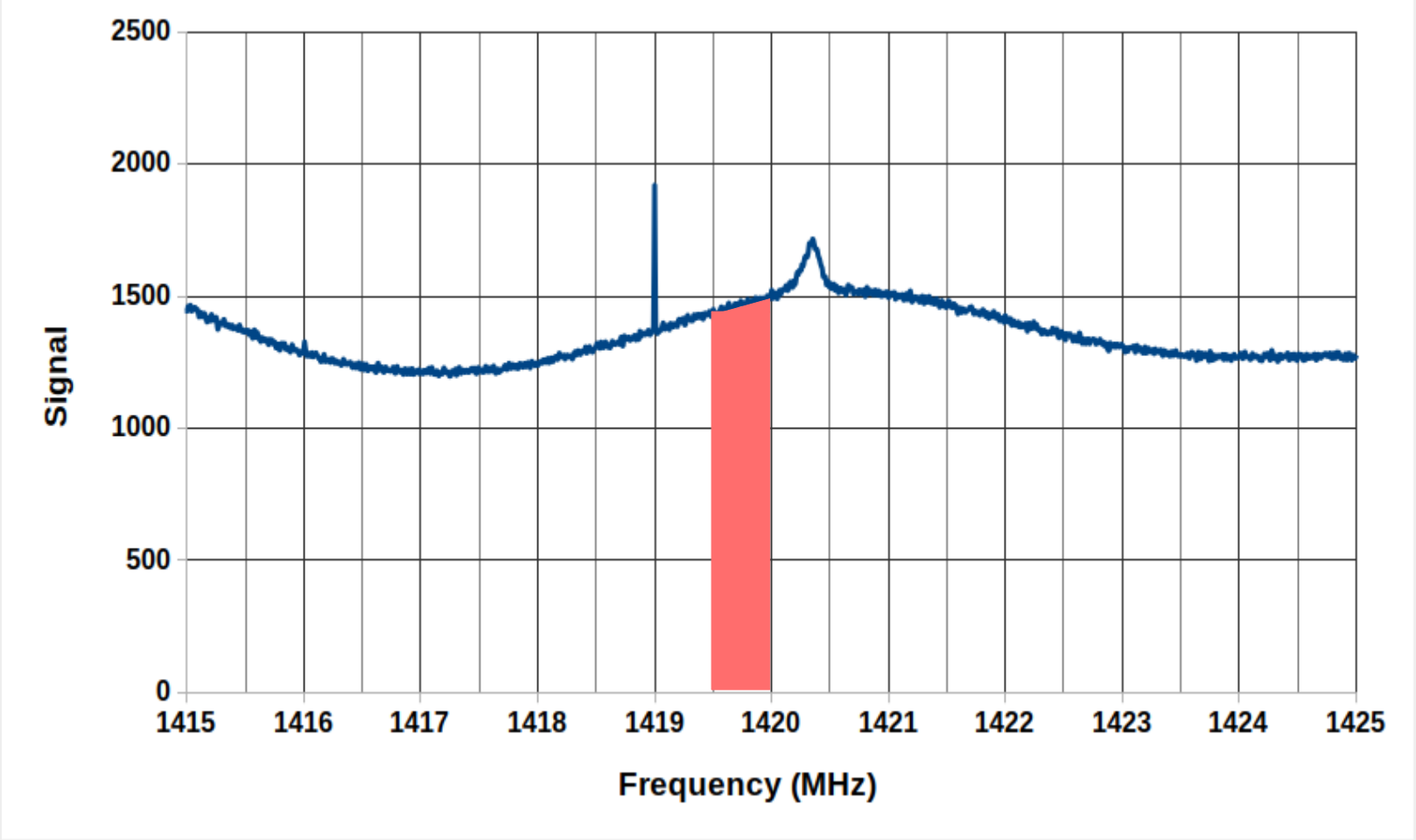
$$\tau_{delay} = \frac{PLD}{c} = \frac{D \sin\theta}{c}$$

$$\tau_{delay} \approx \frac{D\ \theta}{c} \text{ (for small angles)}$$

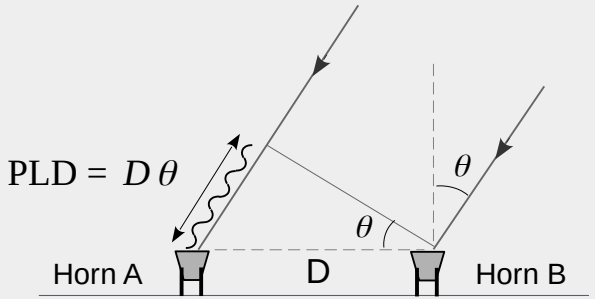
$$P \approx \cos\left(\omega \tau_{delay}\right)$$

Data Processing of Spectra for Interferometry

- $t_{integration} = 10\ s$
- Average signal over Δf
- 4 hrs = 1440 files



Additive Interferometry Results



Adjacent peaks: $\Delta(PLD) = D\,\Delta\theta = 1\,\lambda$

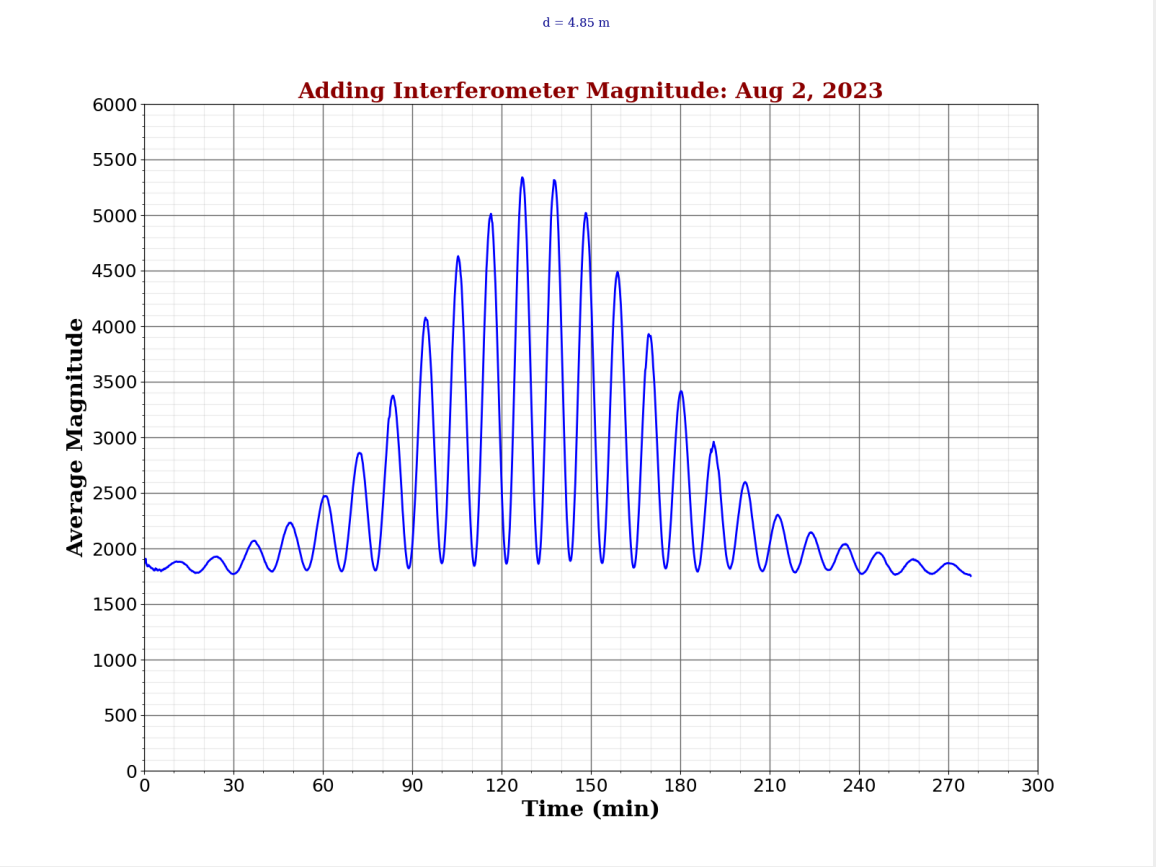
So: $D\,\Delta\theta = \frac{c}{f}$

$$\theta = \left(\frac{1^o}{4\ min}\right) t(min)$$

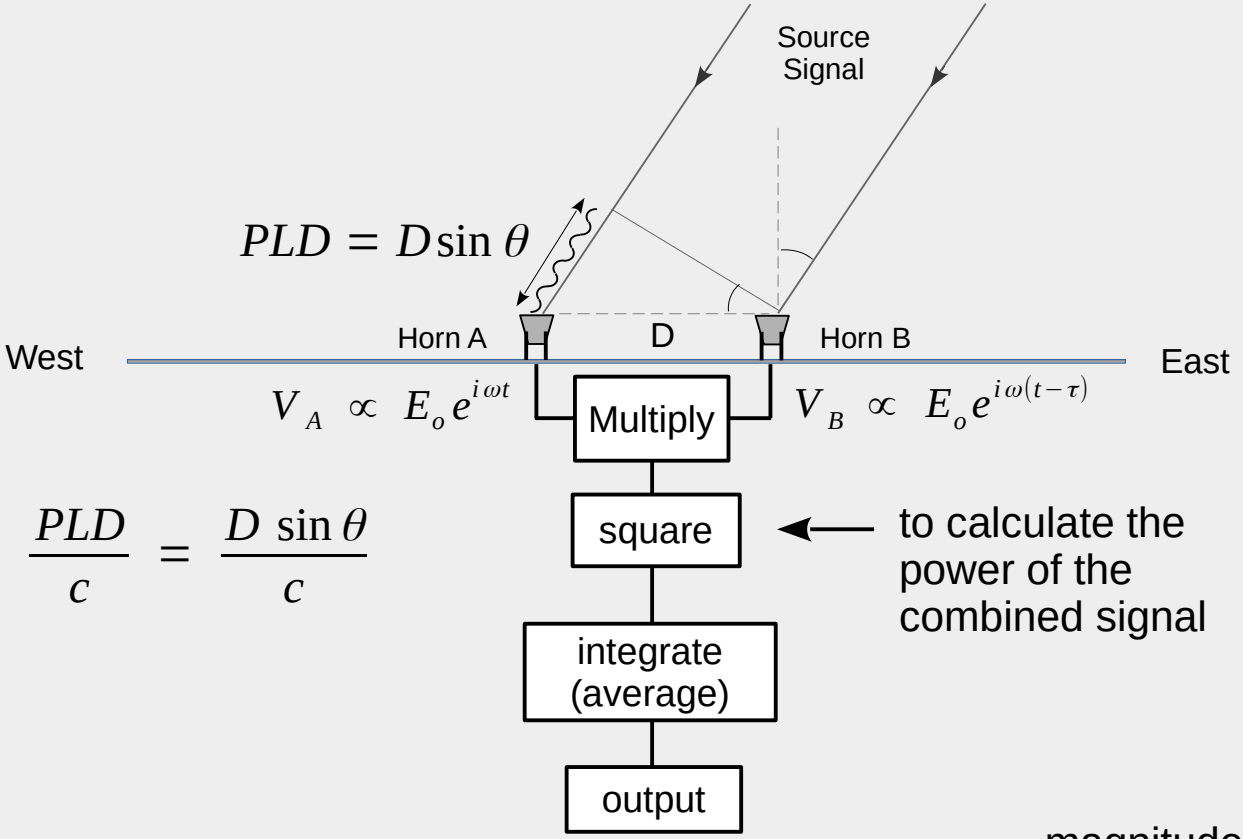
$$\Delta t_{peaks} = 10.66\ min$$

$$\rightarrow\ c = 3.00 \times 10^8\ \frac{m}{s}$$

Target: Transiting Sun
D = 4.85 m



Multiplicative Interferometry



$\tau_{delay} = \frac{PLD}{c} = \frac{D\sin\theta}{c}$

← to calculate the power of the combined signal

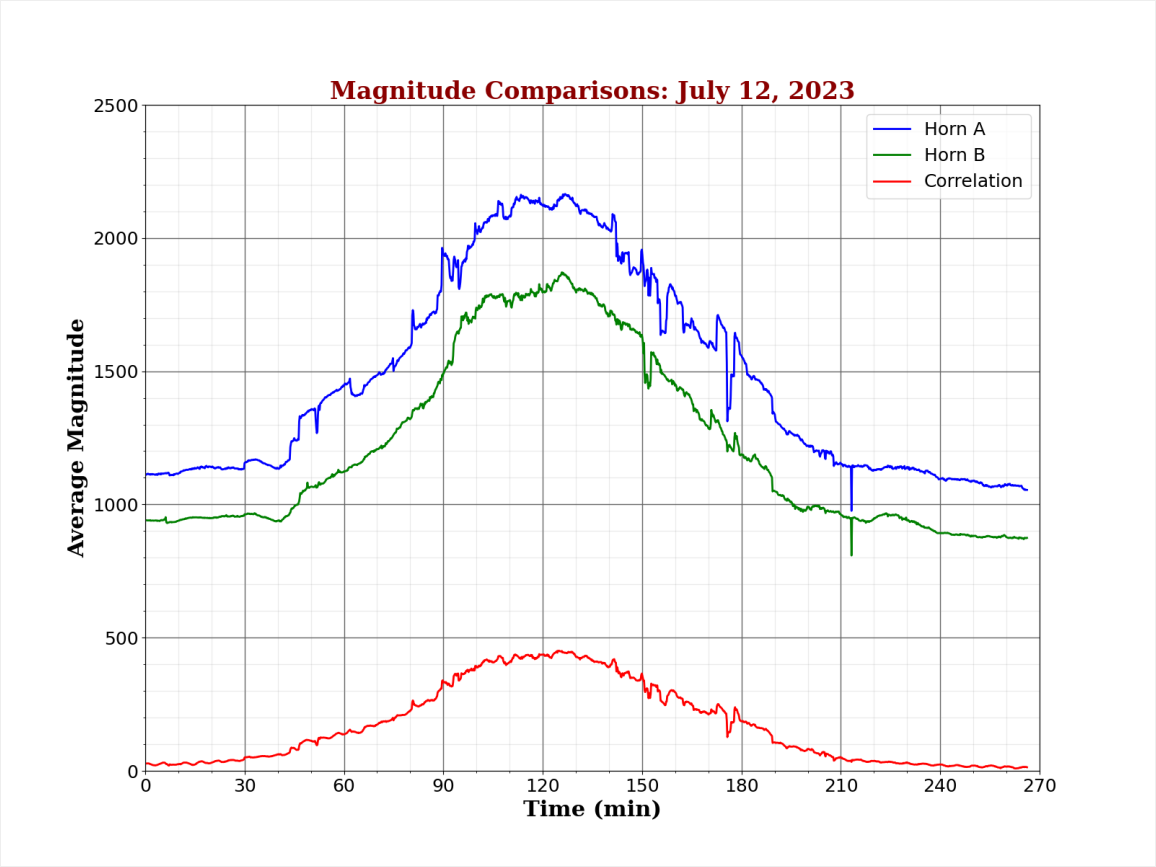
$P \approx constant$

magnitude phase

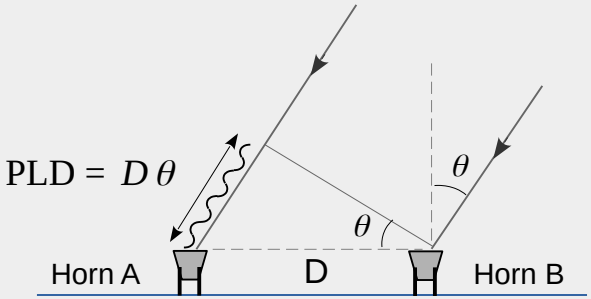
$$R(\tau) \propto \int V_1 V_2^* \, dt = \int E e^{i\omega t} E e^{-i\omega(t-\tau)} \, dt = E^2 e^{i\omega\tau}$$

Multiplicative Interferometry Results - Correlation Magnitude

Target: Transiting Sun
D = 12 m



Multiplicative Interferometry Results - Phase



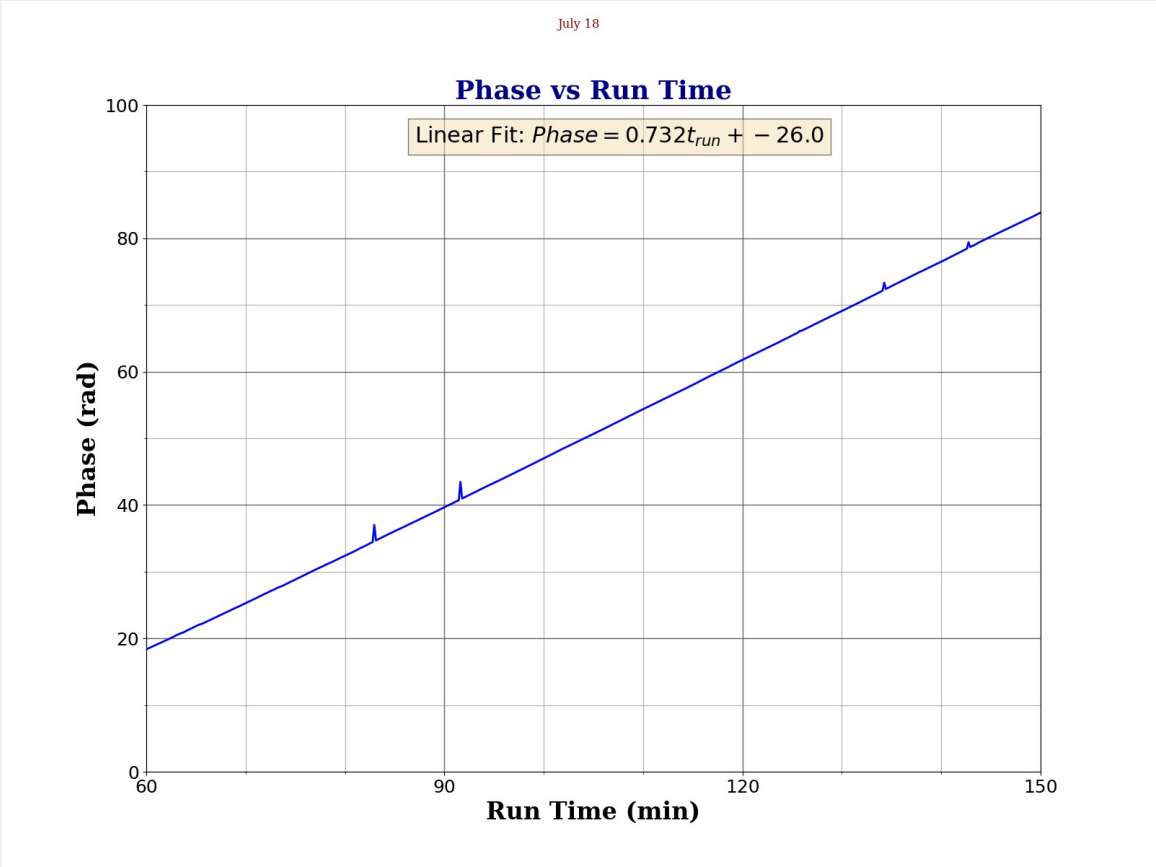
$$\phi = \frac{2\pi D\theta}{\lambda}$$

$$\phi = \frac{2\pi D}{\lambda}\left(\frac{1^0}{4\,min}t\right)$$

$$slope = \frac{2\pi Df}{c}\frac{1^0}{4\,min}$$

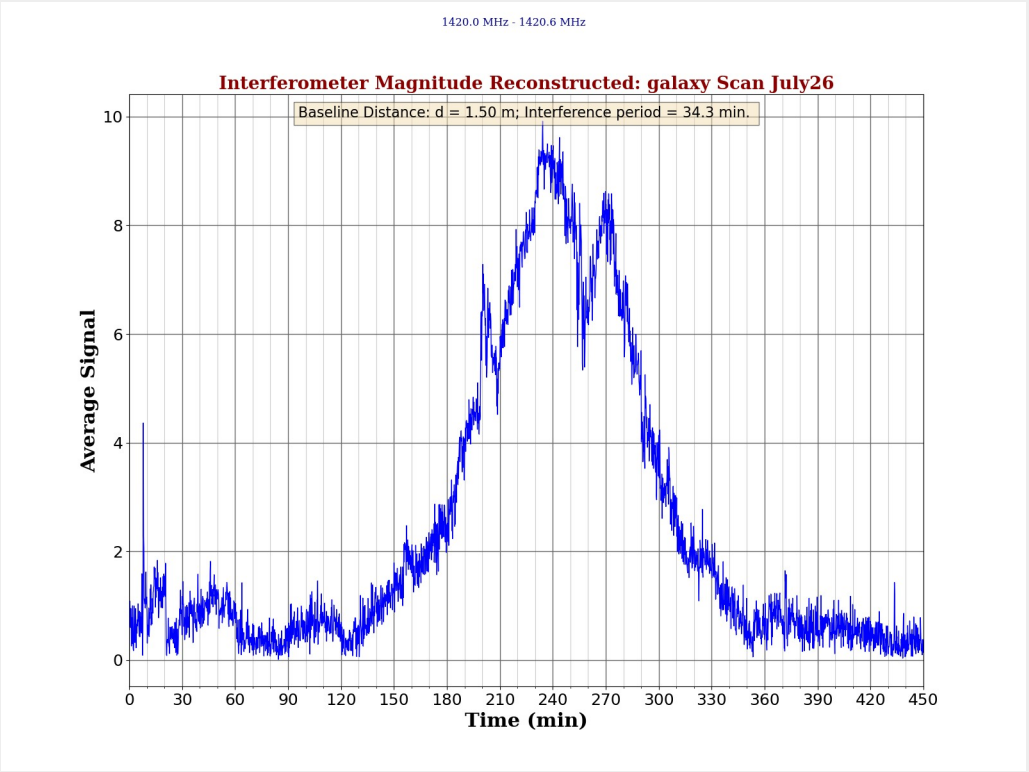
$$\rightarrow \quad c = 3.04 \times 10^8 \ \frac{m}{s}$$

Target: Transiting Sun
D = 6.12 m

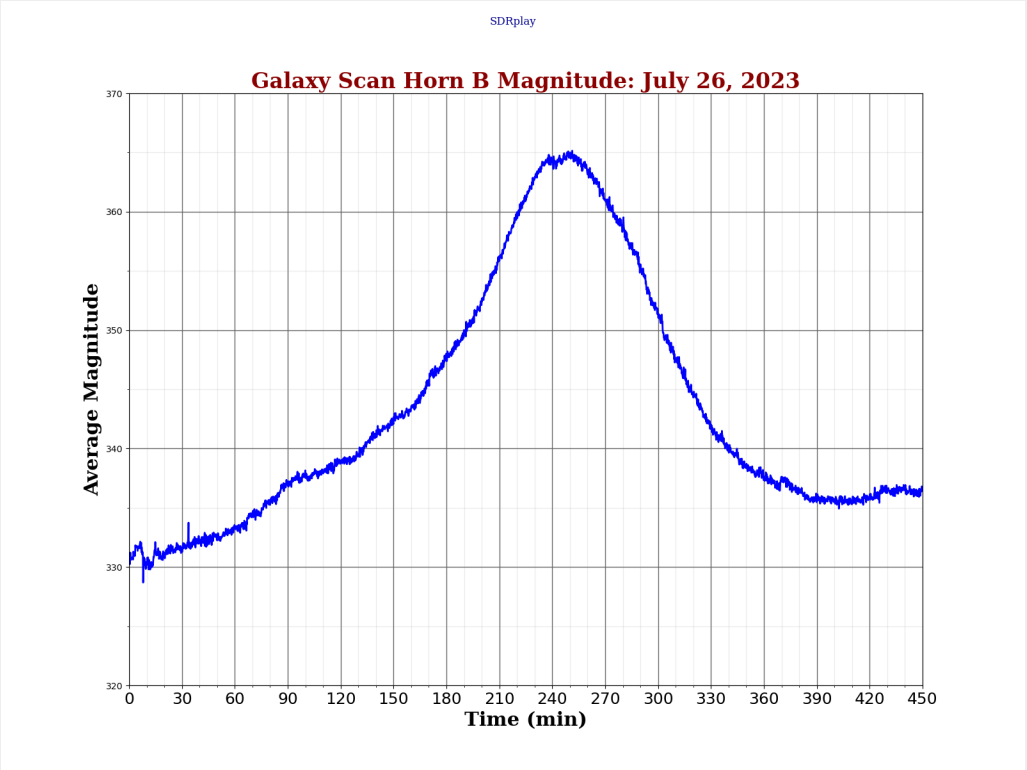


Drift Scan of Galaxy

Correlation Magnitude



Horn B



Future Projects with Interferometry

- Further investigations – what can we observe with these horns?
- Continue testing systems
- Develop software for easier use
- Develop investigations for undergraduate/graduate labs

Acknowledgements

Thanks goes to the following for their expertise, patience, and support:

- Dr. Kevin Bandura, West Virginia University
- Pranav Sanghavi, Yale University
- RET colleagues: Howard Chun and Robert Baker

Thanks also goes to the following for their generous support and contributions to the Research Experience for Teachers in Digital Signal Processing in Radio Astronomy program:

- National Science Foundation
- West Virginia University
- Green Bank Observatory