VLBI With ARO-CHIME Baseline: Clock Stability for Localizations

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1- Motivation: What is VLBI and why do clocks matter?

- Very Long Baseline Interferometry (VLBI) is an essential tool in radio astronomy to get high resolution and perform precise localizations of sources. Fig 1. shows the general idea of how VLBI works. Signals from each station are cross correlated, and the delay shift needed to correlate the signal contains localization information. However, the measured delay contains contributions of other effects, such as clocks and ionosphere (Fig.1)
- Fast Radio Bursts (FRBs) are transient sources of unknown origin which we want to localize. Two telescopes separated by a baseline ideal for this are the ARO (Algonquin Radio Observatory) and CHIME (Canadian Hydrogen Intensity Mapping Experiment)To do reliable VLBI localizations with ARO-CHIME, we need to test the stability of new ARO clock system (see Fig. 3) relative to CHIME's clock system.

$$\tau = \tau_{\text{geo}} + \tau_{\text{clock}} + \tau_{\text{ions}} + \tau_{\text{inst}} + \ldots$$

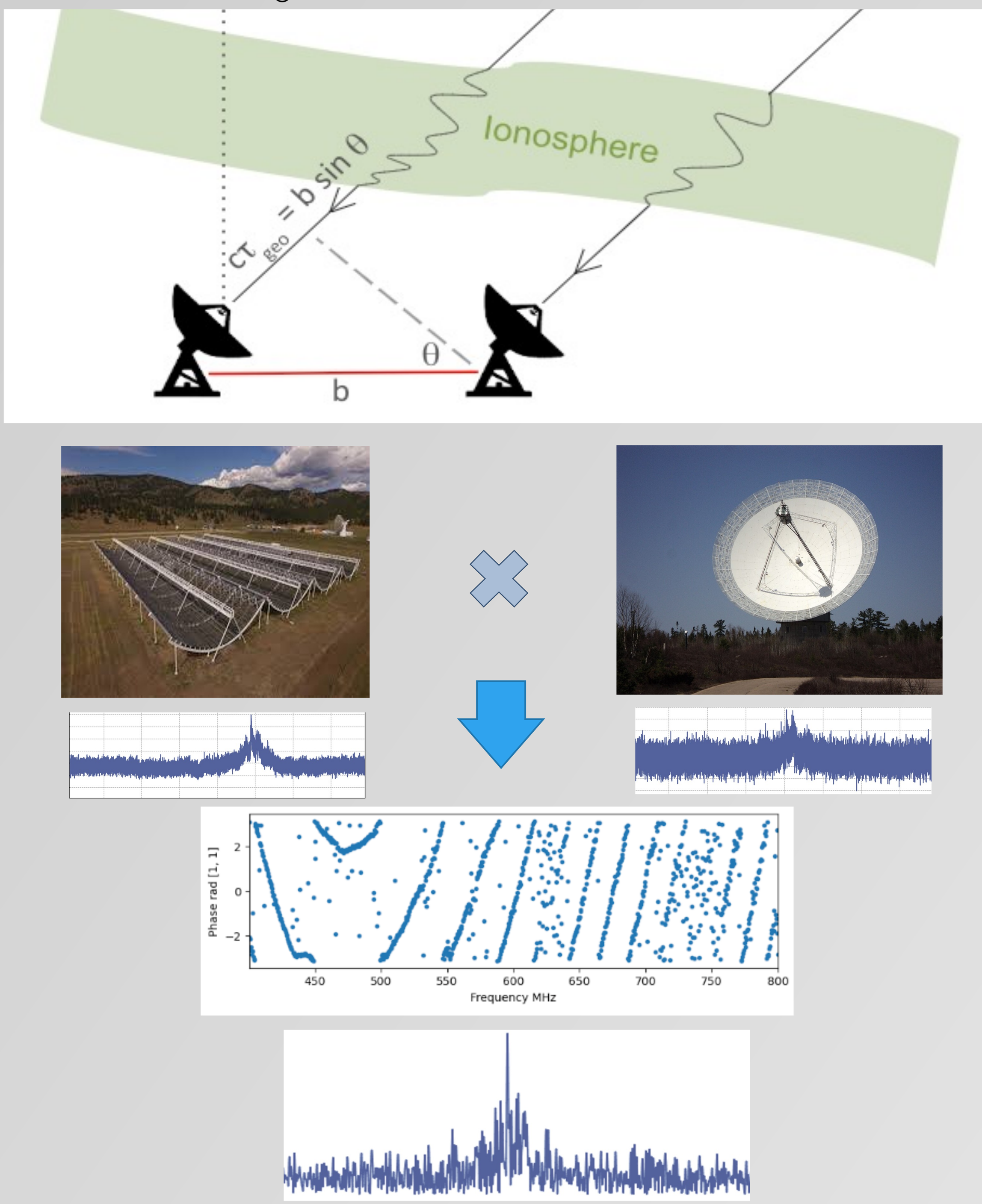


Figure 1: Visual representation of VLBI

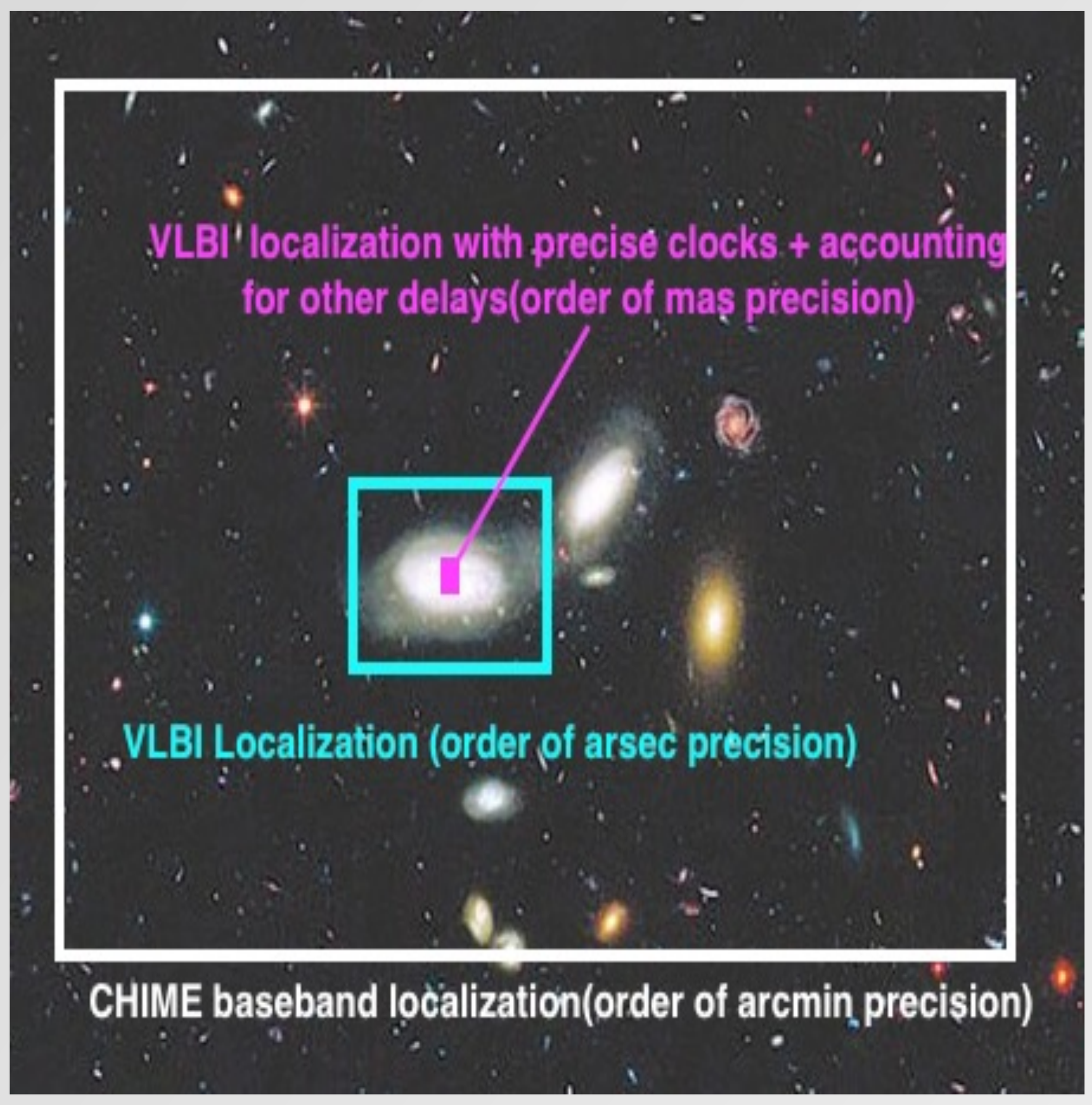


Figure 2: Demonstration of localization precision. Note this image was used for demonstration purposes, this is not an actual localization.

2 – Methods: Extracting Delays Using Pulsar Observations

- To test clock stability, we observed 9 pulsars concurrently at two stations. ARO and CHIME, run by two separate clocks. Their positions are known so we subtracted their geometric delay to extract any effects of clock asynchronization.
- The same pulses in two datasets were correlated to each-other, which allows us to extract the time delay between them

Lag correlation

- Align data sets within one frame , then find maximum correlation strength within frame to determine delay[1]

Fringe-fitting

- Use likelihood model to fit for delay, separating between ionospheric delays and other residuals

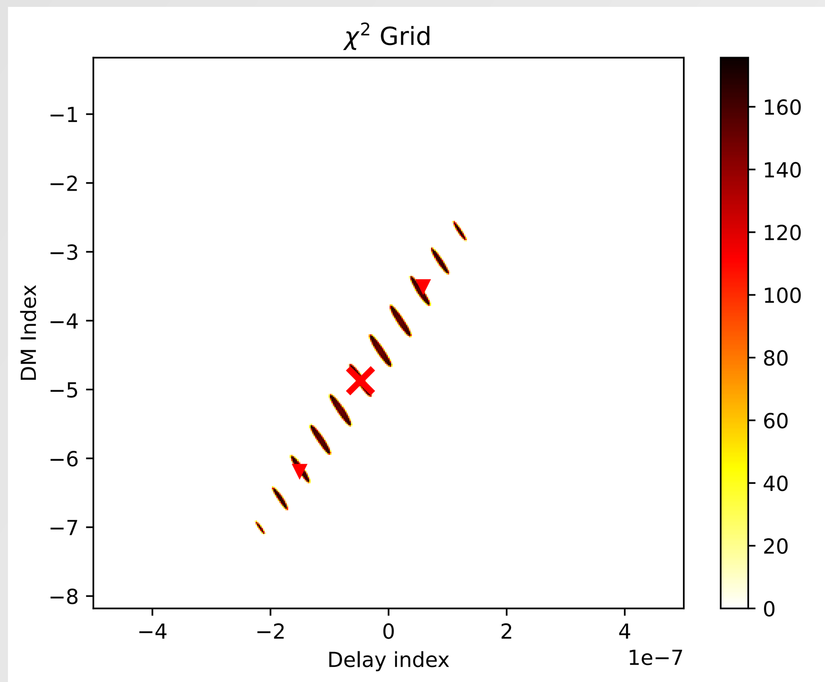
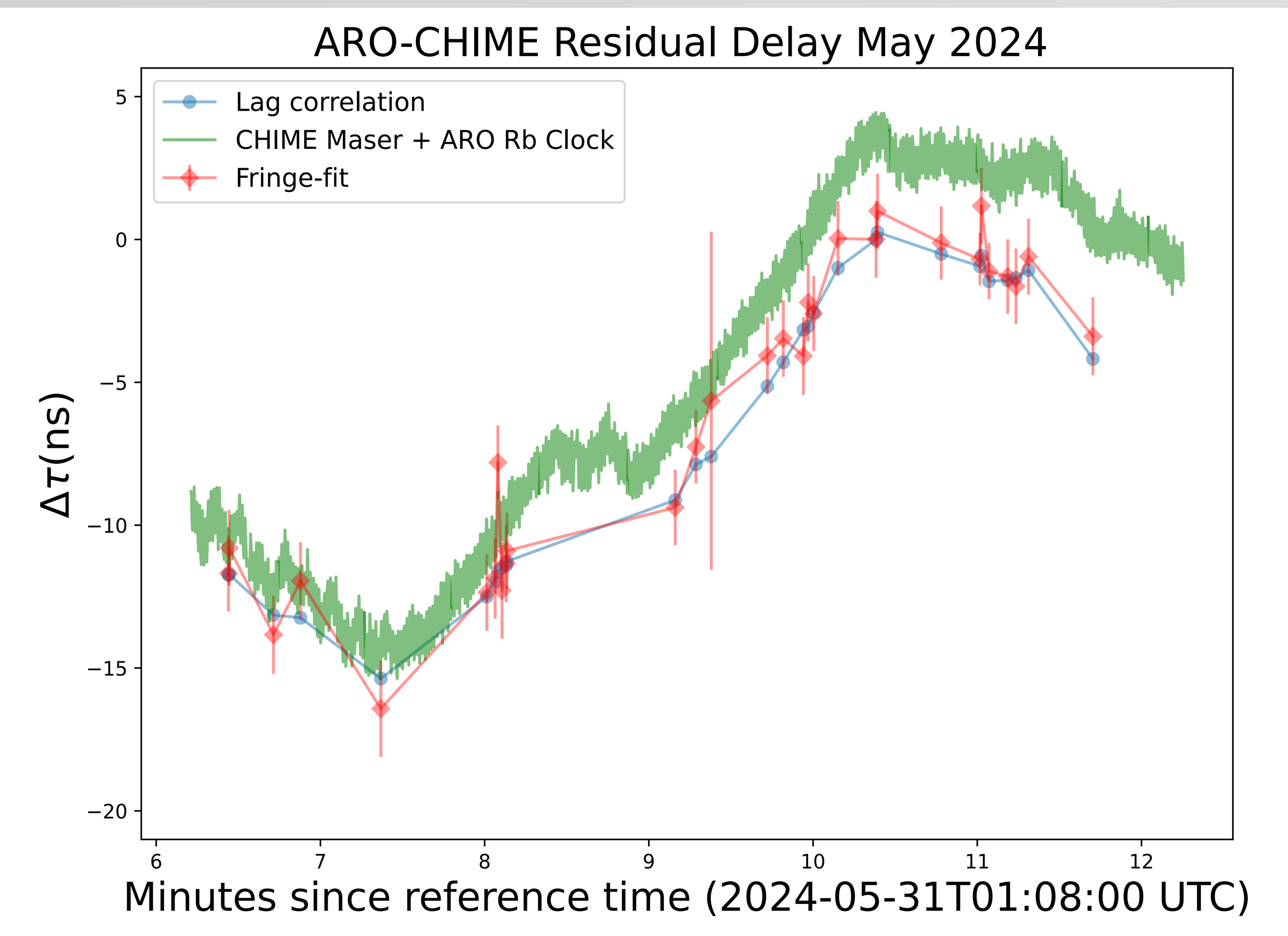
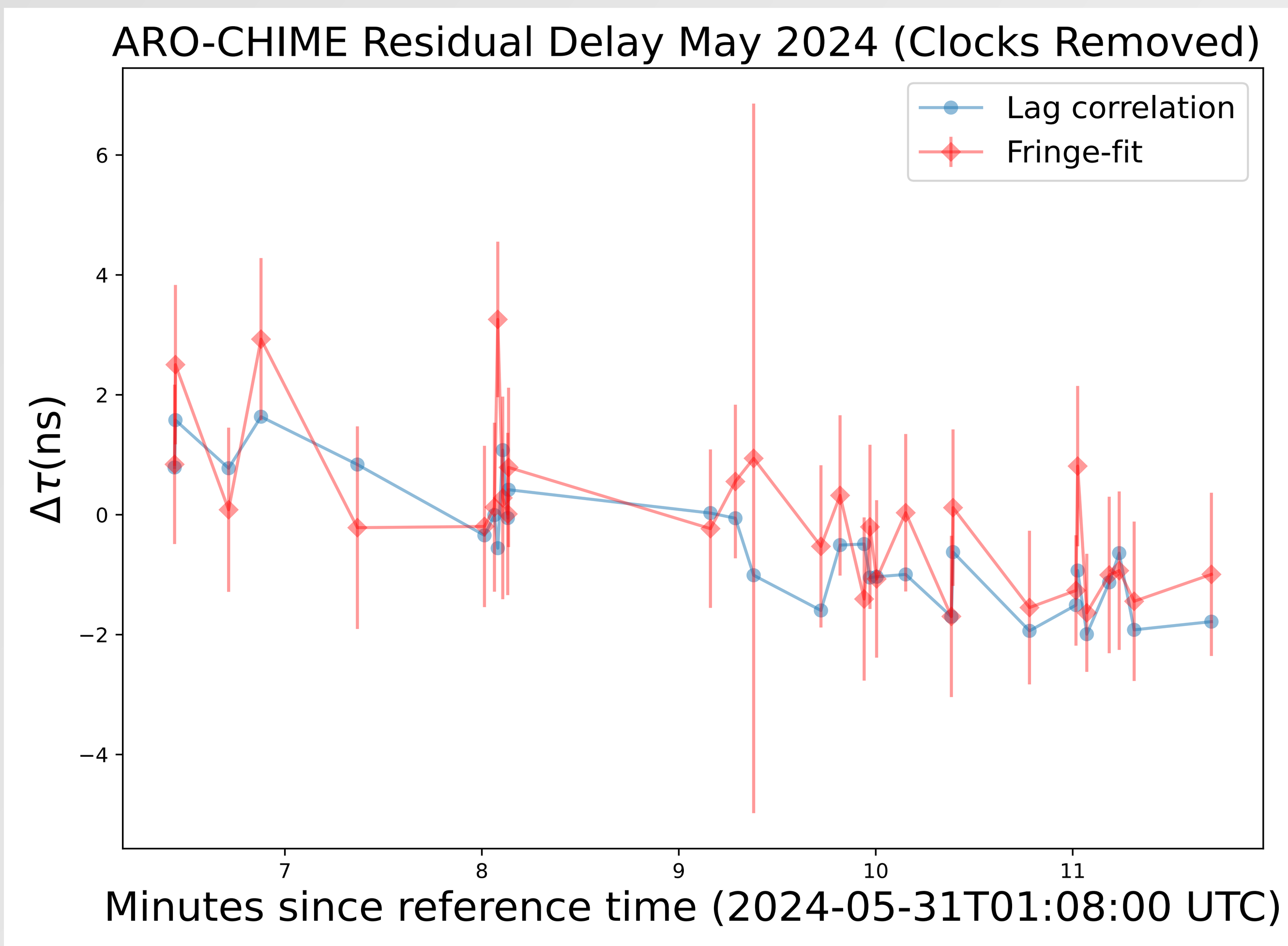


Figure 3: Sample chi-squared fit of a PSR B0950+08 pulse observed at ARO and CHIME

3- Results : Short Timescale Stability Using PSR B0950+08





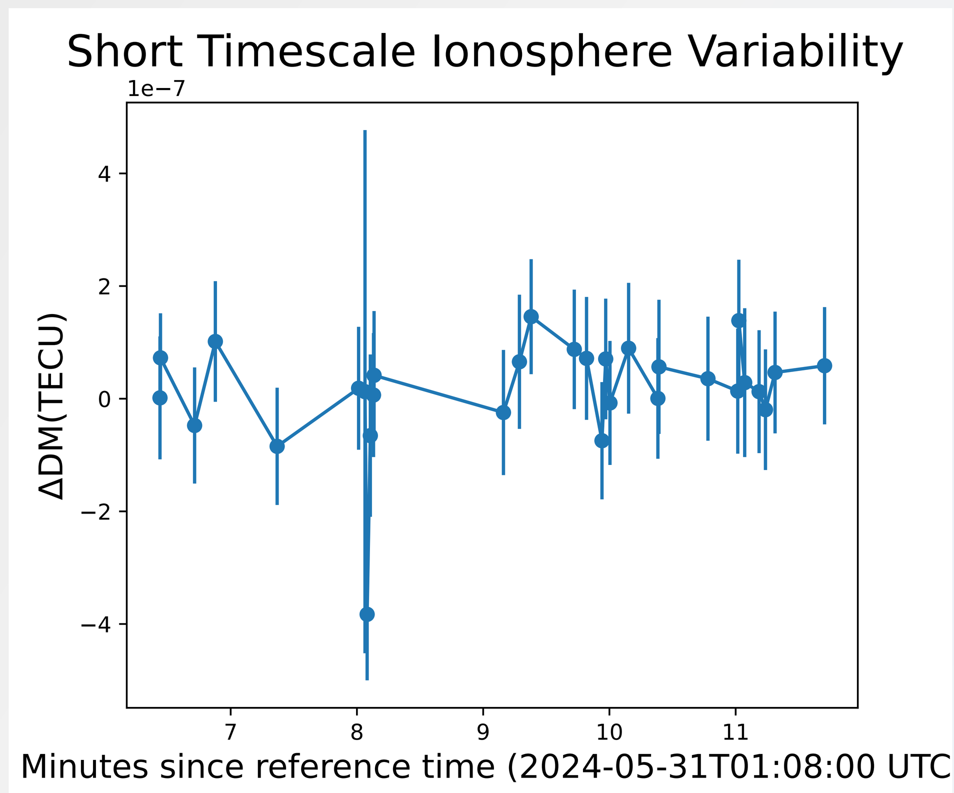


Figure 6: Ionospheric delay found by fringe fitting

Figures 4 and 5: Residual Delay of the ARO-CHIME baseline over about 5 minutes. The green shows the correction of the GPS clock at both sites, which visually we see causes most of the delay. The left shows the residual delay after the correction being applied.

Measured time drift is ~ 10.7 $\pm$0.1ns in 20 mins, which corresponds to a localization precision[2] of 220mas, which is enough to unambiguously identify the host galaxy of FRBs. Analyses of other pulsars in the dataset have yielded similar results. The drift measured on PSR B2021+25 pulsar one day later is in agreement with the drift measured here, indicating it is not just an artifact of this observation.

4- Future Work

- Validation of clock stability over longer timescales
- Localize pulsars , using ARO46m/10m to as proof of concept, then LPDA (Long Periodic Dipole Array)
- **Localize FRBs with LPDA!**

5 -Acknowledgements and References

References:

1- Cassanelli, T., Leung, C., Rahman, M., et al. 2022, AJ, 163, 65, doi: 10.3847/1538-3881/ac3d2f

2- J. Mena-Parra *et al* 2022 *AJ* **163** 48

3- Adam E. Lanman et al 2024 AJ 168 87

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