Generating Local Tie Vectors Between GNSS and VLBI by Co-Observing GNSS Satellites

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Introduction: the motivation – local tie vectors between GNSS and VLBI antennas

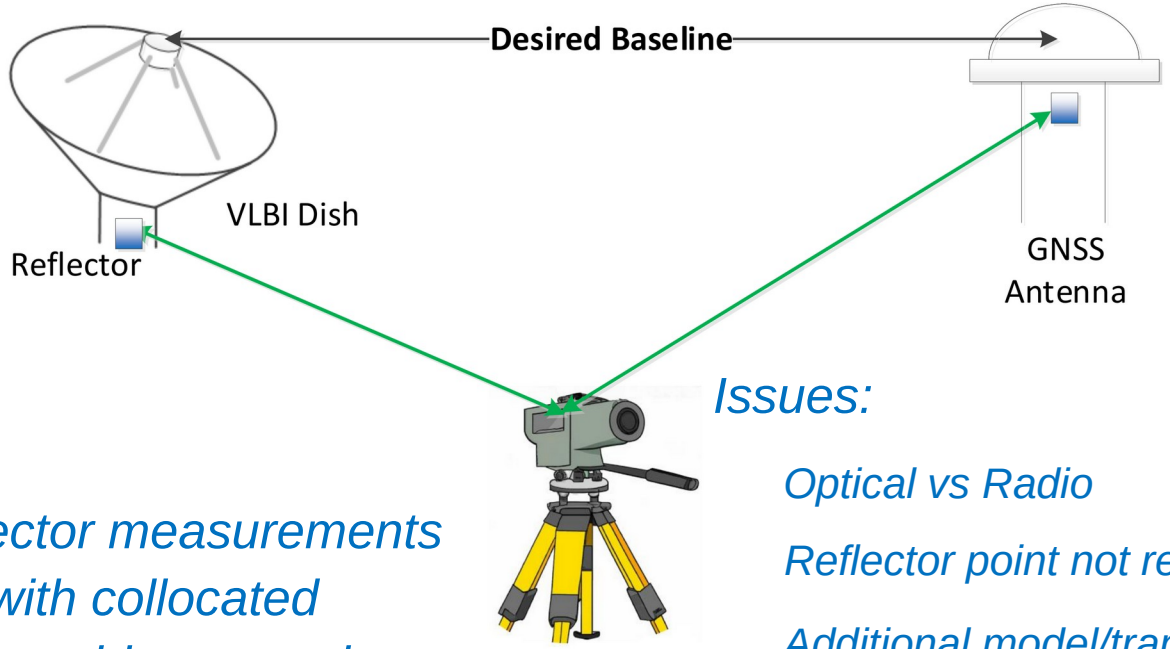
NRC recommendation for next generation TRF:

- 1 mm accuracy center of mass
- 0.1 mm/yr stability
- Providing this accuracy requires mm-level inter-technique local ties

We seek to generate mm-accuracy local tie vectors between GNSS and VLBI

- Use standard GNSS/VLBI processing chains
- Produce ties directly between geodetic reference points

Connecting the VLBI and GNSS frames (Conventional Approach)

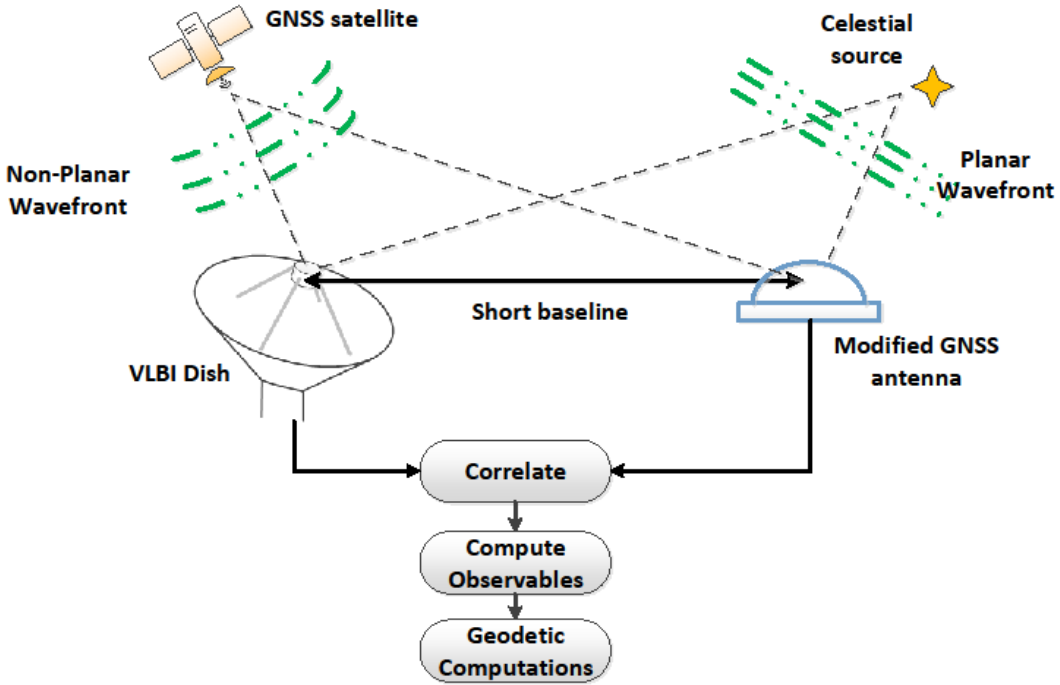


Optical tie vector measurements at locations with collocated instruments provide constraints.

Issues:

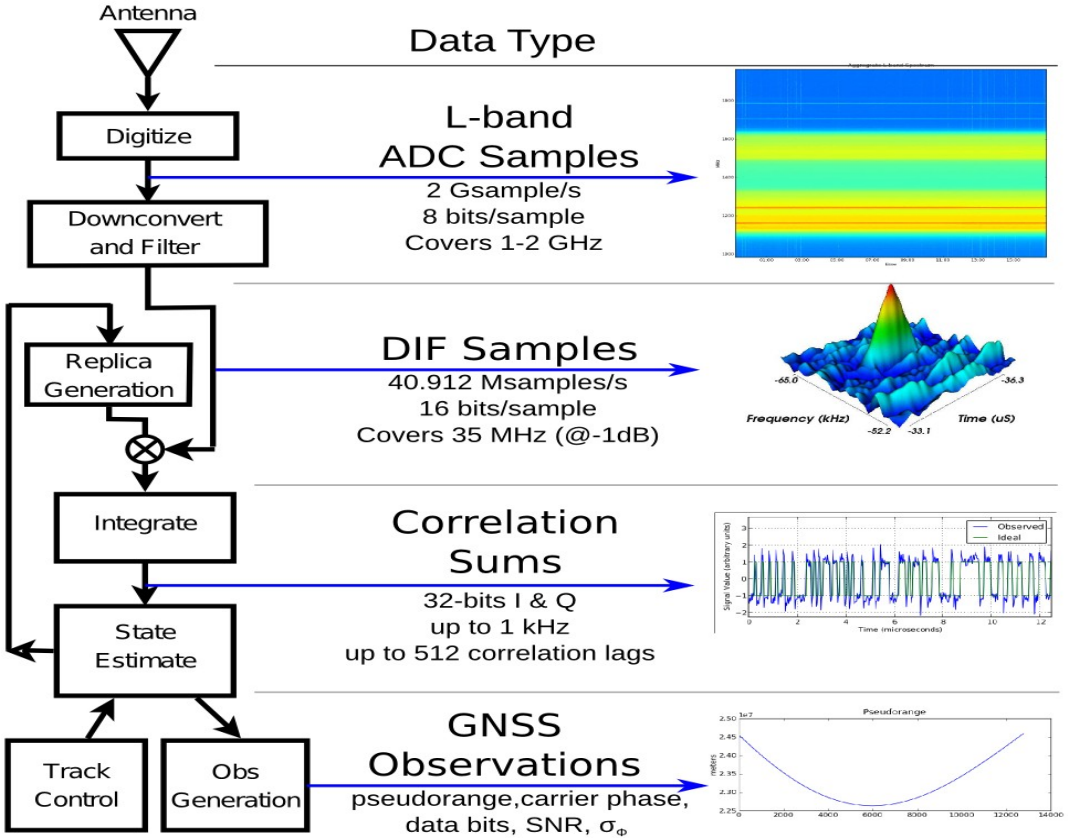
- *Optical vs Radio*
- *Reflector point not reference point*
- *Additional model/transformation required*
- *Physical survey required each time*

Connecting the VLBI and GNSS frames (New Approach)



Determine the baseline between reference points directly through RF hardware

High Rate Tracking Receiver (HRTR) data



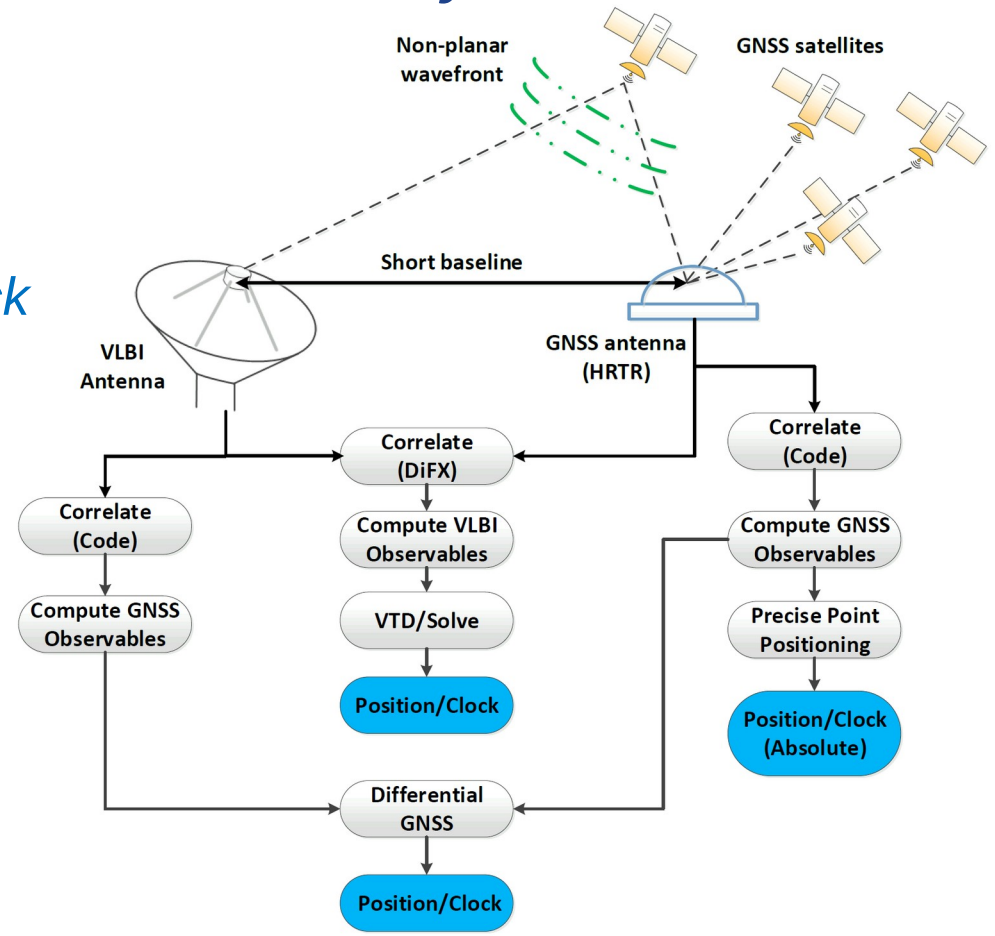
Equivalent To:

VDIF data

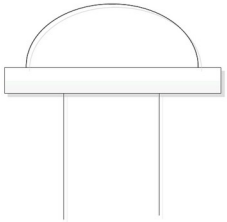
RINEX data

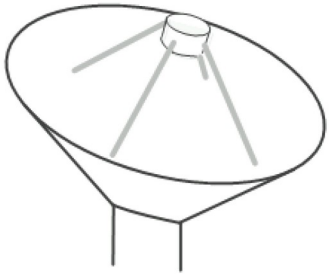
Processing GNSS satellite-only data

- *Absolute positioning for GNSS antenna with PPP*
  → get a priori position/clock
- *Correlation against code*
  → GNSS processing
- *Correlation against signal from other antenna*
  → VLBI processing



Planned processing setup





HRTR Baseband Samples

Convert to VDIF

GNSS Tracking

Convert to RINEX

Position and Clock Estimation (PPP)

In Development

GNSS Single Difference Estimator

Convert to HDF5

IGS (COD) Ephemerides

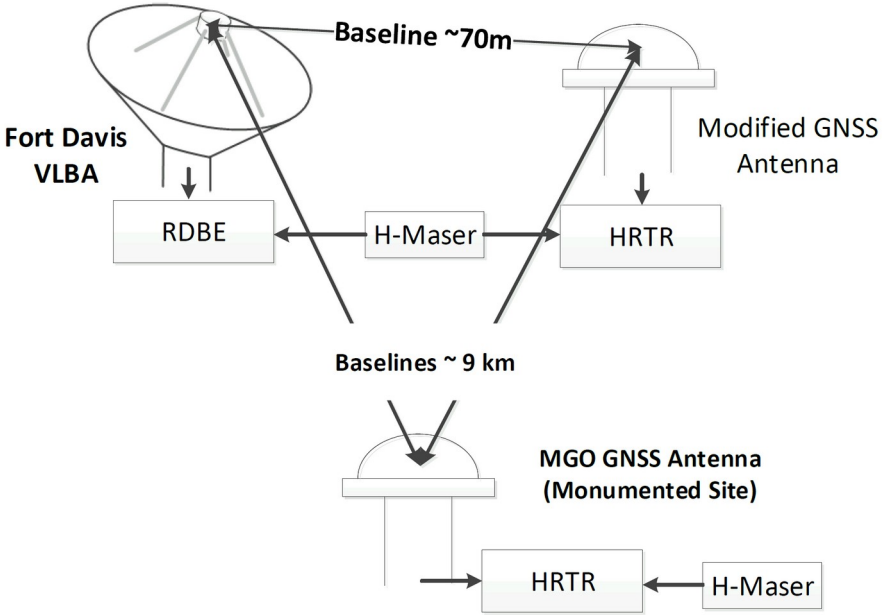
VLBA Baseband Samples

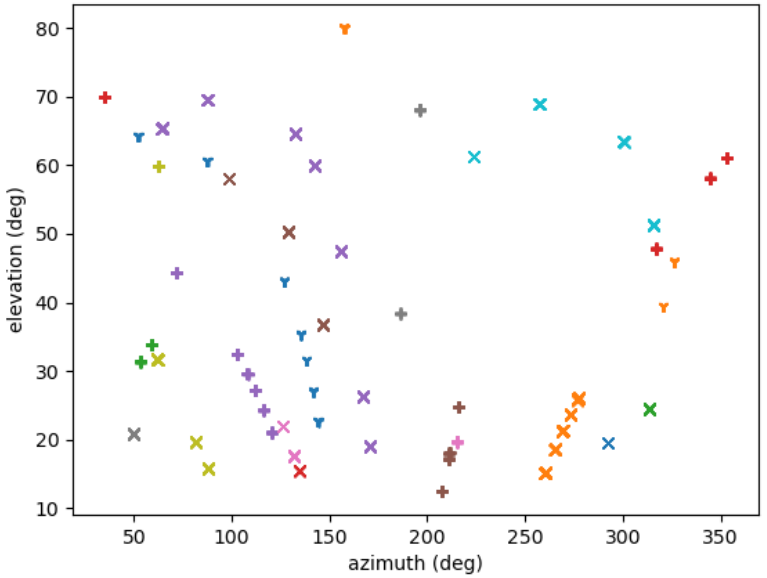
DIFX

PIMA

Solve

GNSS data collection (1/25/23)





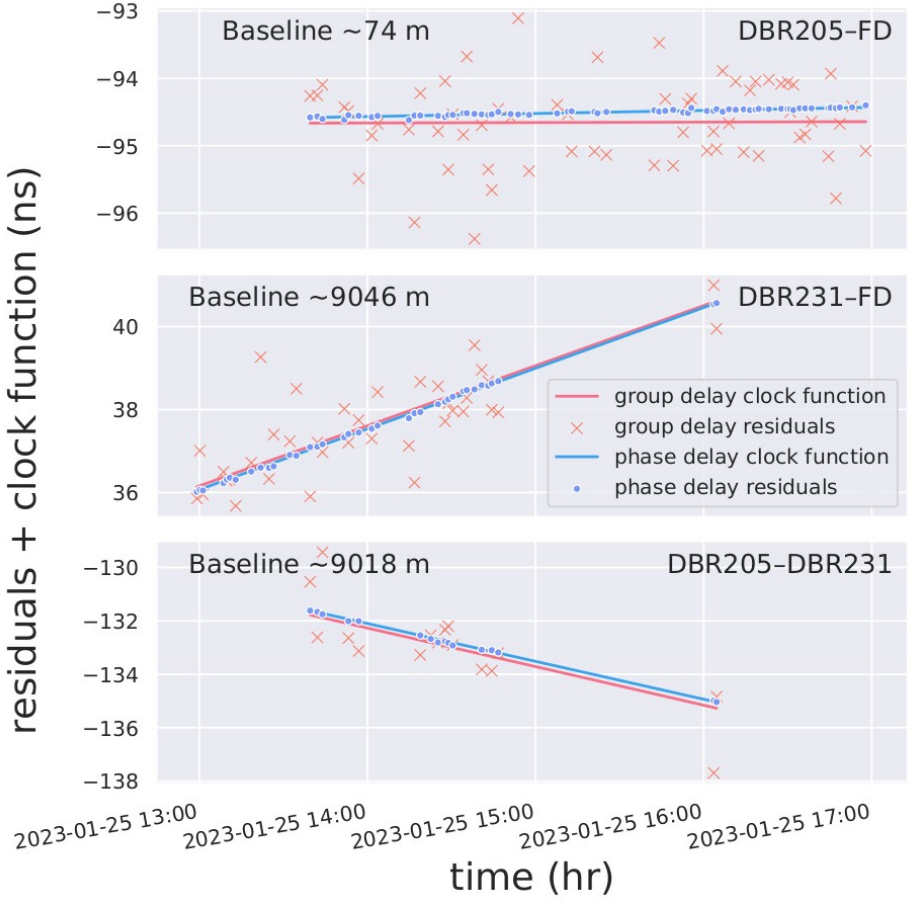
- *GNSS: 1 Hz data, VLBI: 1 measurement per scan (~30 s)*
- *19 satellites (GPS+GAL+BEI)*
- *~4 hours of data, L1 only (VLBI), L1 + L2 (GPS antennas)*

The VLBI parameter estimation setup

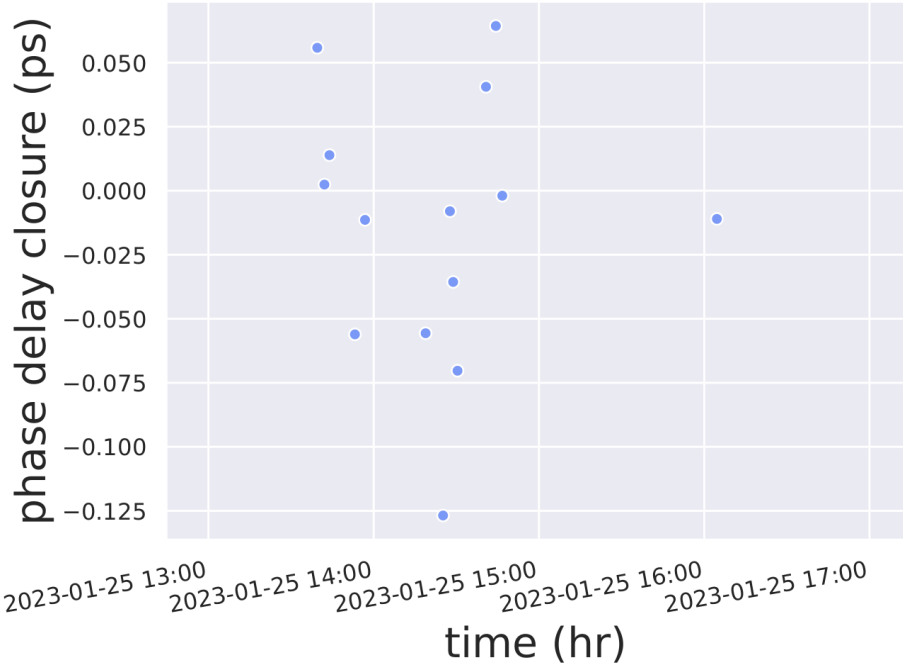
- *Estimate position, clock, and clock rate for DBR205, FD-VLBA, DBR231 set as reference station (10 parameters total)*
- *A priori position for DBR205/DBR231 from PDP*
  - *Network solution with IGS monuments MDO1, MGO2, MGO3, MGO4, MGO5; MDO1 used as reference station*

Parameter	Station(s)	Estimated	Description
Satellite orbits	All	No	COD multi-GNSS precise ephemerides
Measurement model	All	N/A	Jaron, Nothnagel (2019) analytical delay model
Position	DBR231	No	Reference station, a priori from PDP
	DBR205	Yes	A priori from PDP
	FD-VLBA	Yes	A priori from VLBI network solution
Clock/clock rate	DBR231	No	Reference station
	DBR205, FD-VLBA	Yes	No a priori, one clock interval
Atmospheric delay/gradients	All	No	Saastamoinen (1972) model used

Residuals on all baselines, closure measurements

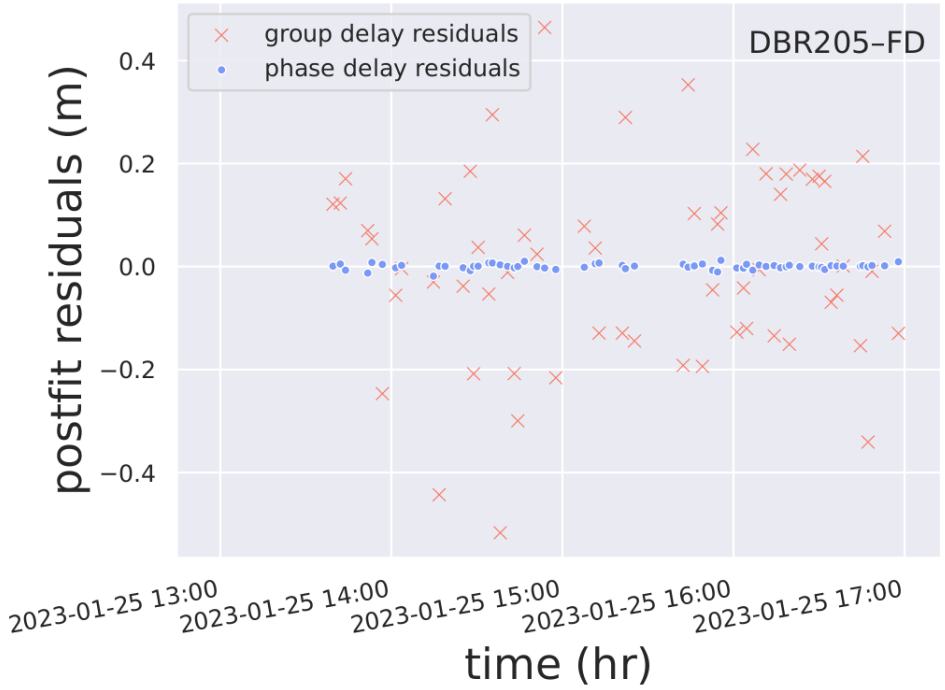


Closure RMS 0.05 ps (0.015 mm)

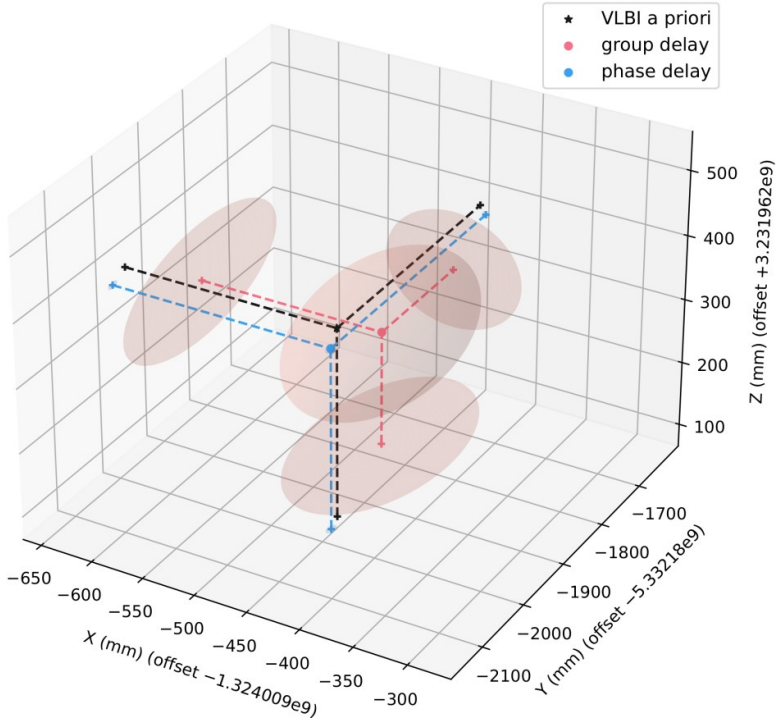


Postfit residuals and FD-VLBA position

Phase delay WRMS 5 mm (18 ps)
Group delay WRMS 18.4 cm (614 ps)



Phase delay formal uncertainty ~1 cm
Difference from VLBI a priori ~3 cm



Conclusion/summary

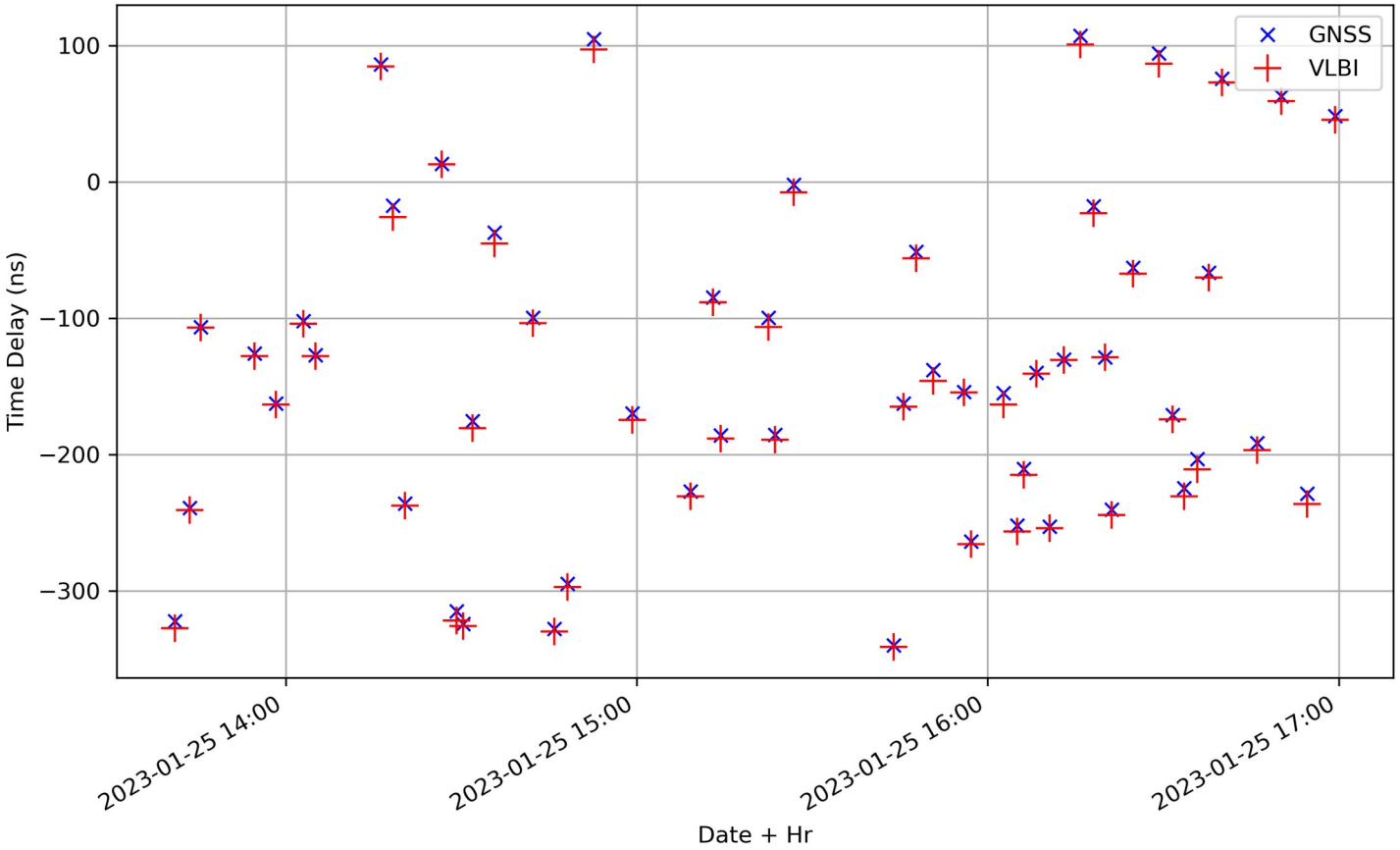
- *Implemented the Jaron, Nothnagel (2019) analytical model with IGS multi-GNSS precise ephemerides in software correlation and parameter estimation*
- *Constrained FD-VLBA position to ~1 cm in IGS-distributed TRF with only 4 hours of data → longer collections and repeatability analysis planned*
- *Work ongoing to develop a parallel pseudorange/carrier phase analysis pipeline*

More details at:
Radio Science – First observations with a GNSS antenna to radio telescope interferometer
REFAG Proceedings– Precise VLBI/GNSS ties with micro-VLBI

Backup – DiFXVTD: Earth-orbiting satellites support

- *Testing is ongoing for Earth orbiting satellites*
  - *Uses Jaron, Nothnagel (2019) analytical delay model for satellites*
    - *Analytical partial derivatives implemented in VTD, NASA memo forthcoming*
  - *Plan to acquire test dataset, finish testing in 2024, create test suite*
    - *Rigorously compare to GNSS analysis*
- *Ingests tabulated orbits in various formats (NZO, soon SP3)*
  - *Working on direct support for IGS ephemerides*
- *Ingests two-line element orbits (under testing)*

Backup – observables comparison (GNSS vs. VLBI, preliminary result)



$$\tau_{\text{gnss}} = \frac{\rho_2 - \rho_1}{c}$$

$$\tau_{\text{vlbi}} = \frac{1}{2\pi}\frac{\partial \phi}{\partial \nu}$$