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HRTRs at VLBA Sites supporting Foundation CORS and beyond

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Overview

- What is the VLBA?
- What is the Foundation CORS network?
- What is a HRTR?
- Why locate HRTRs at VLBA sites?
- What new geodesy does this enable?

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Very Long Baseline Array (VLBA) Overview

- VLBA consists of 10 observing stations, spread over the United States
- Performs Very Long Baseline Interferometric (VLBI) observations of celestial radio sources using Earth-sized baselines (8,611km)
- Operated by the National Radio Astronomy Observatory (NRAO)
- Used for radio astronomy and geodesy scientific applications. e.g.
  - Earth Orientation Parameters (VLBA has been vetted to meet NGA EOP requirements)
  - International Celestial Reference Frame

Image Credit: NASA Goddard Space Flight Center

Each Very Long Baseline Array Site has:

- 25m diameter fully steerable parabolic dish antenna
- RF feeds from 0.3 – 96 GHz
- Hydrogen Maser Atomic Clock
- Digitizing / Recording equipment
- *(An electrical phase center whose location isn't as well-known at the millimeter level as we'd like … stay tuned)*

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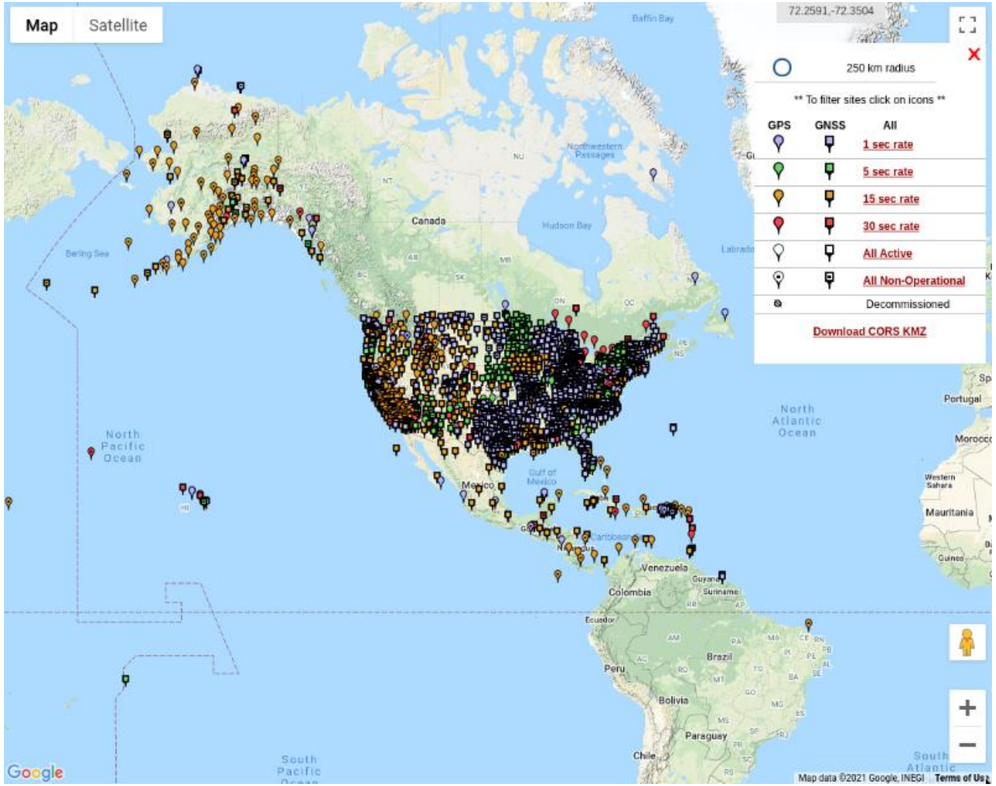
Person (for scale)

NGS Continually Operating Reference Stations

- CORS are fixed GNSS observation sites across U.S. and beyond
  - Data is publicly available
  - Enable GNSS precise positioning relative to U.S. National Spatial Reference System (NSRS)
  - Operated by NOAA National Geodetic Survey (NGS)
- Proposed "NGS Foundation CORS Network" is a subset of sites to be operated at highest standards
  - Signed formal agreements
  - Federally owned
  - Data submitted to IGS
  - Operational availability >90%, outages <14 days
  - Provides definitional support to ITRF
  - Site surveys conducted to IERS standards
  - Sites no more than 800km apart
  - Emphasis on supporting multi-GNSS



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Summary of CORS Receiver Requirements

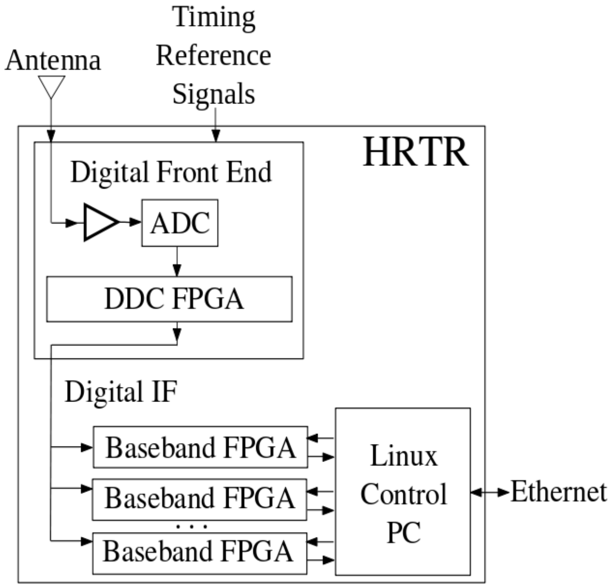
- Receiver
  - Dual frequency (e.g. L1 and L2)
  - At least 10 satellites
  - L1 C/A or P pseudorange
  - Full wavelength carrier phase
  - Receiver/Antenna registered in IGS
  - Data freely available for distribution
  - Recorded on 30 second or shorter interval

- Site
  - Antenna calibration
  - Long lasting, stable monument
  - Good sky view
  - Orienting/leveling
  - Metadata (station logs) provided

GNSS antenna on braced monument

High Rate Tracking Receiver (HRTR)

- The High Rate Tracking Receiver (HRTR)
  - Almost direct to digital software receiver [1,2]
  - Provides both GNSS and VLBI-like data from same digitized RF stream
  - Characteristics
    - 3 band configurations
      - 0.1-1 GHz, 1-2 GHz, 2-3 GHz
    - 1 GHz instantaneous direct sample bandwidth
    - FPGA-based digital downconversion and processing
    - Minimal analog front-end to minimize biases



1. J. York et al., "A Direct-Sampling Digital-Downconversion Technique for a Flexible, Low-Bias GNSS RF Front-end," ION GNSS Meeting, Sept. 2010

2. J. York et al., "A Novel Software Defined GNSS Receiver for Performing Detailed Signal Analysis," ION ITM meeting, Jan. 2012.

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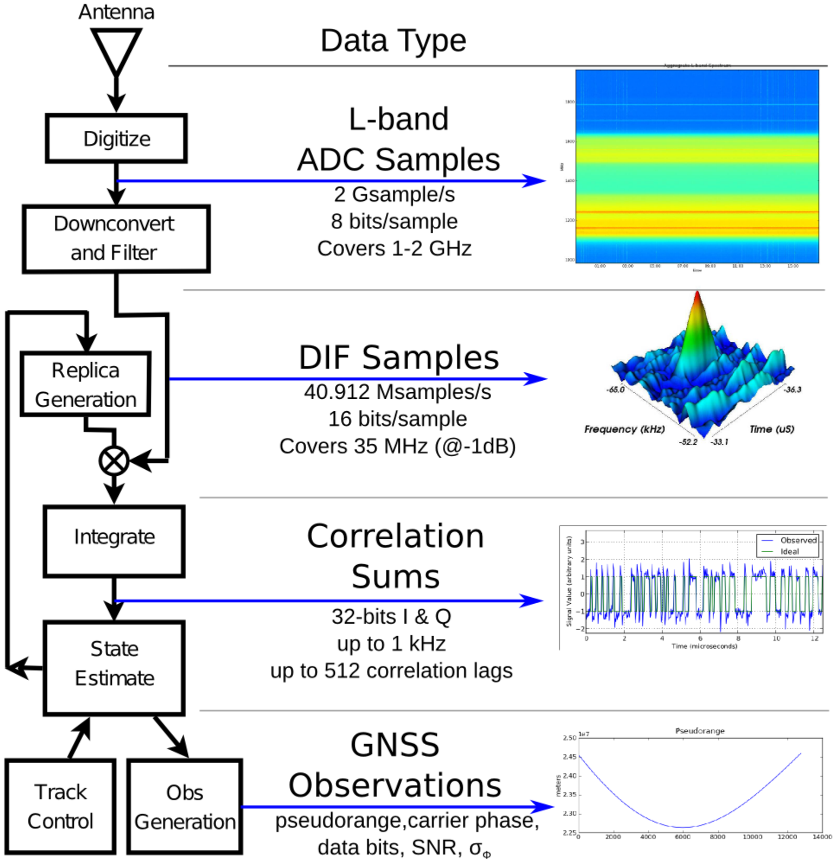
HRTR Signal Chain

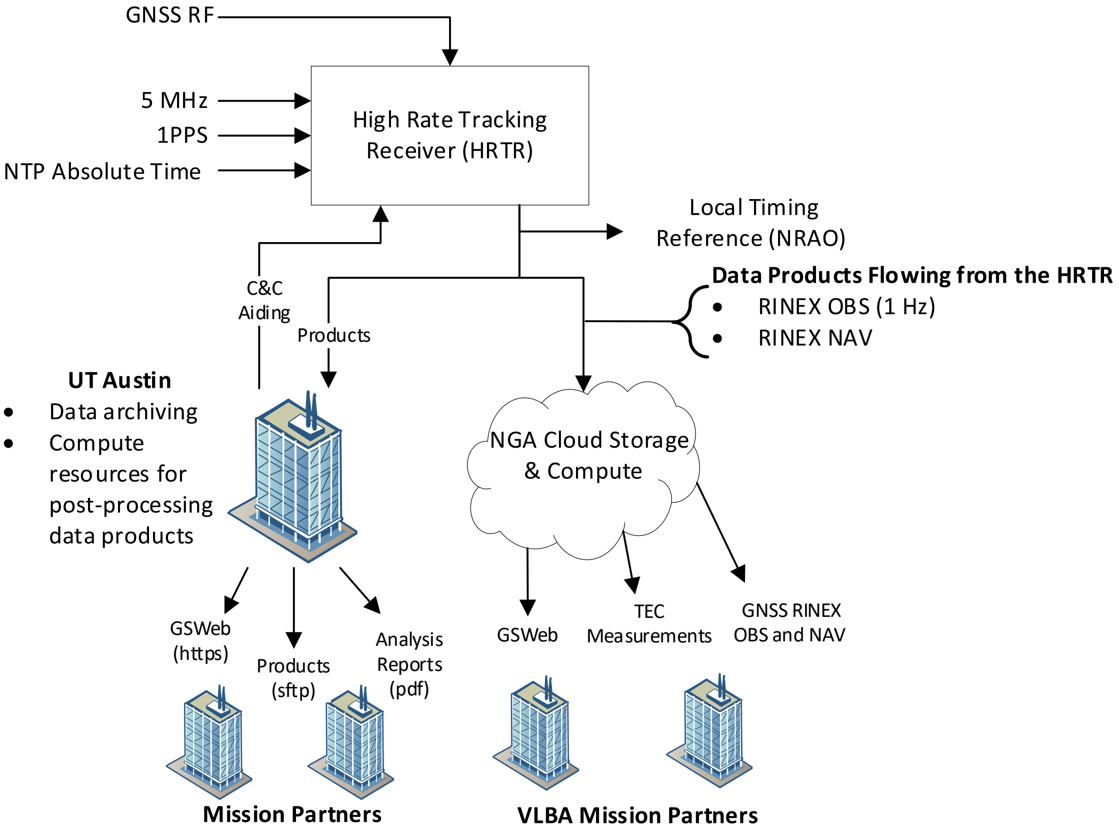
- HRTR provides multiple products from the same digitized RF data stream
- GNSS-like geodetic-quality data:
  - Pseudorange
  - Carrier phase
  - SNR
  - Navigation bitstream data
  - Supports all civil GNSS signals
  - Compatible with CORS requirements
- VLBI-like data for DiFX (et al)
  - 9 bands of ~36 MHz each (324 MHz total)
  - Converter to VDIF format standard for VLBI
- Well-characterized, stable timing subsystem, synchronizable to local atomic clocks



HASTE Effort

- HASTE - HRTRs for Awareness of Spectrum and Timing Enhancements
- Collaboration between NGA, NGS, and NRAO
- Goal: Co-locate HRTRs and geodetic monuments at VLBA sites to support time transfer, Foundation CORS and beyond
- Co-located geodetic observing techniques help each technique do geodesy better (e.g. Global Geodetic Observing System, NASA's Space Geodesy Project)
- Multiple monuments at each VLBA Site
  - Usable for GNSS antennas
  - Usable for optical survey equipment
  - Multiple monuments support maintainability, consistency
- Leverage HRTR as GNSS receiver
  - Provide improved time-transfer capability to VLBA system
  - Provide expanded GNSS data coverage
  - Enable geodetic research
- HRTR Data published to IGS

Conceptual HASTE Architecture



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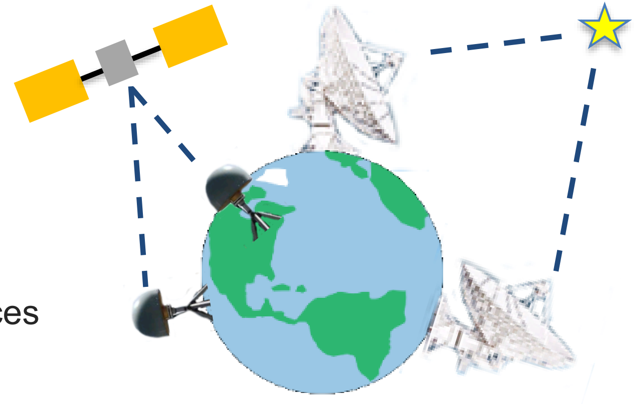
Why do this? Reference Frames!

- Geodetic Reference Frame - an abstract coordinate system, realized by physical references at known locations

- Examples:
  - Terrestrial Reference Frames (e.g. ITRF, WGS84)
    - Coordinates for the Earth, realized by points on the earth
    - Primarily derived and disseminated by GNSS observations
  - Celestial Reference Frames (e.g. ICRF)
    - Coordinates for the Stars, realized by extragalactic radio sources
    - Primarily derived by Very Long Baseline Interferometry
  - ICRF and ITRF are relatable via:
    - Earth Orientation Parameters
    - Observing Station Coordinates



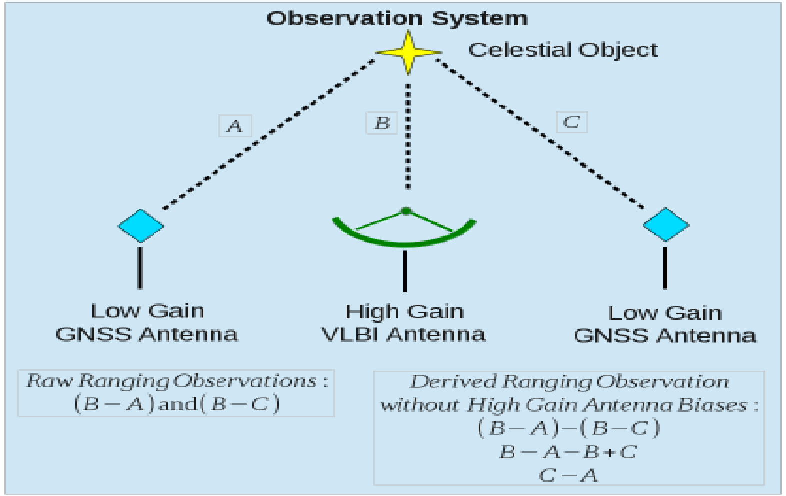
- Different techniques/frames are not as consistent as we'd like

  A current geodetic research frontier is co-locating observing instruments for multiple techniques, and measuring the baselines between them with goal of supporting ~1mm absolute accuracy, ~0.1mm/year drift

GNSS/VLBI Co-observation Concept

- Is it possible to measure GNSS/VLBI baseline by treating the GNSS as part of an interferometer?

- Why do this?
  - Provide direct measurement between VLBI dish and GNSS antenna phase centers
  - Phase center stability of GNSS antennas is good



The goal is measurements of the baselines at reference frame co-location (fundamental) sites directly through the instruments

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Early GNSS/VLBI Co-observing Experiment

- Under a NASA grant, ARL:UT conducted an early experiment using HRTRs to detect celestial sources on a baseline involving a GNSS antenna
- Antenna elements
  - Three meter dish
  - GNSS antenna (Topcon)
- Next slides detail results from 2018
- Work is ongoing…

3 meter dish

GNSS antenna (w/ modified preamplifier)

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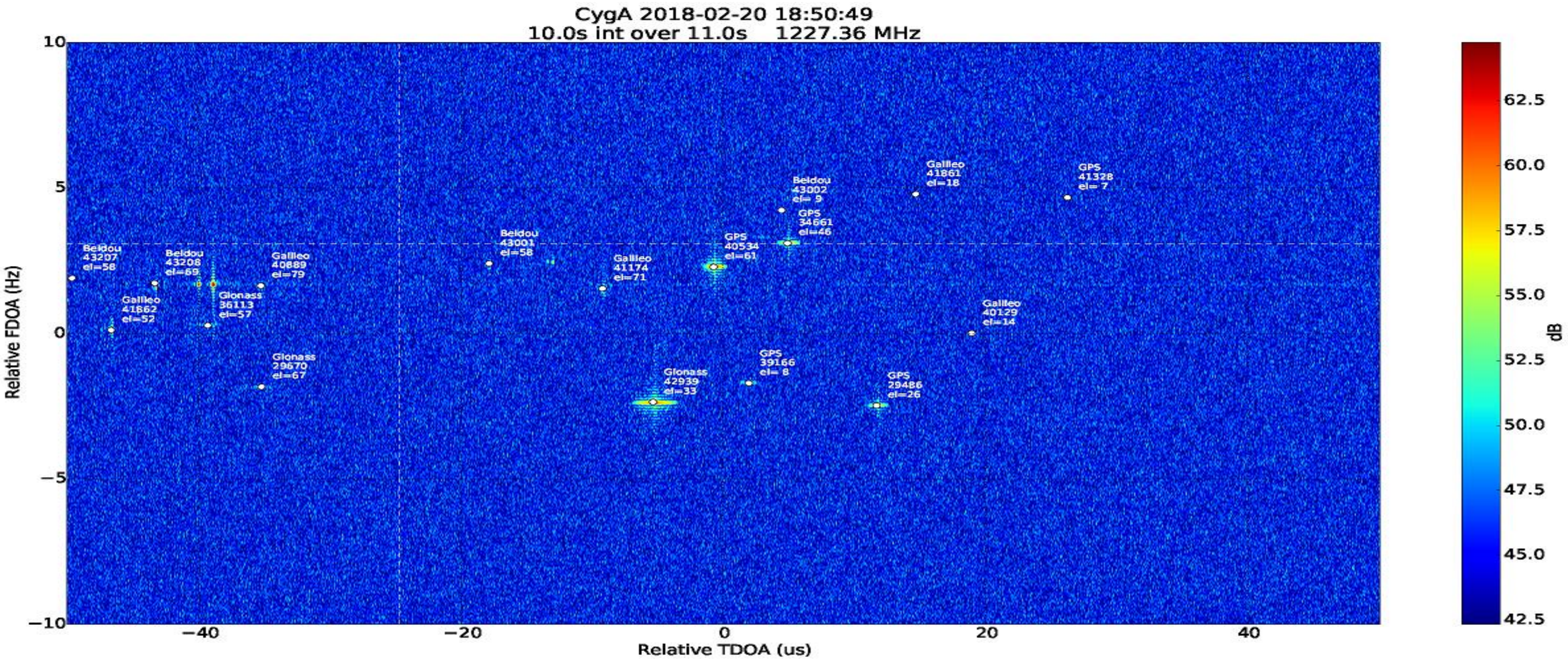
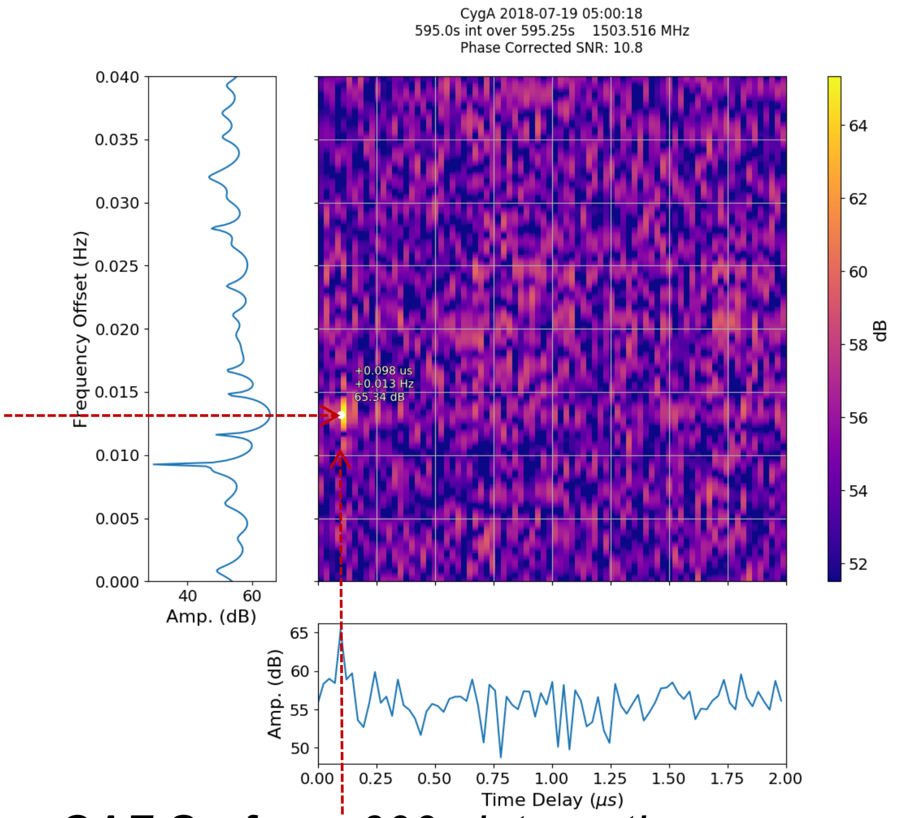
High Power (GNSS) Sources

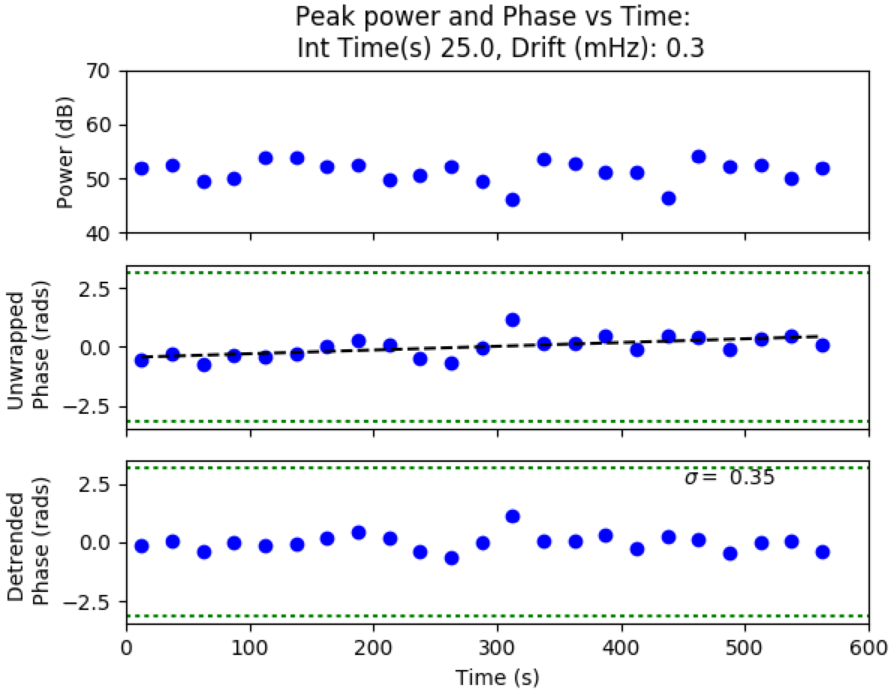


16 km baseline, 10 s integration, GPS L2

Successful HRTR detect of celestial source



CAF Surface: 600s integration



Peak power and phase at 25 s integration time through period

Recap

High Rate Tracking Receivers will be fielded to VLBA sites over coming years supporting:

- Time transfer within VLBA
- Precision Geodesy
- Foundation CORS mission
- Emerging geodetic research applications

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