USNO Prototype Software Correlator: Status Report

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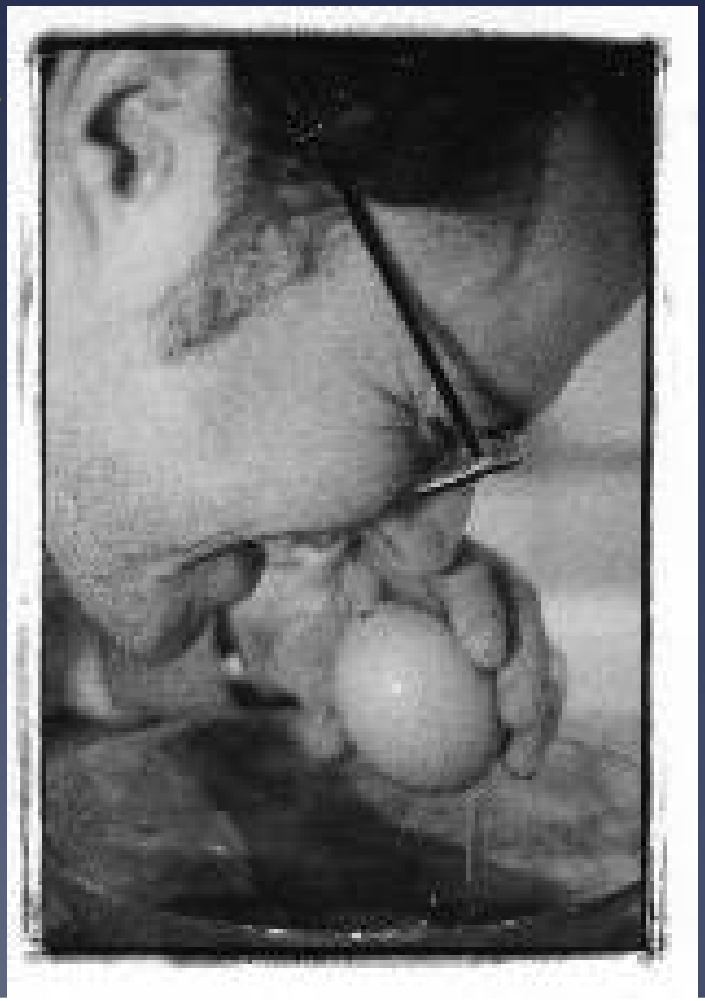
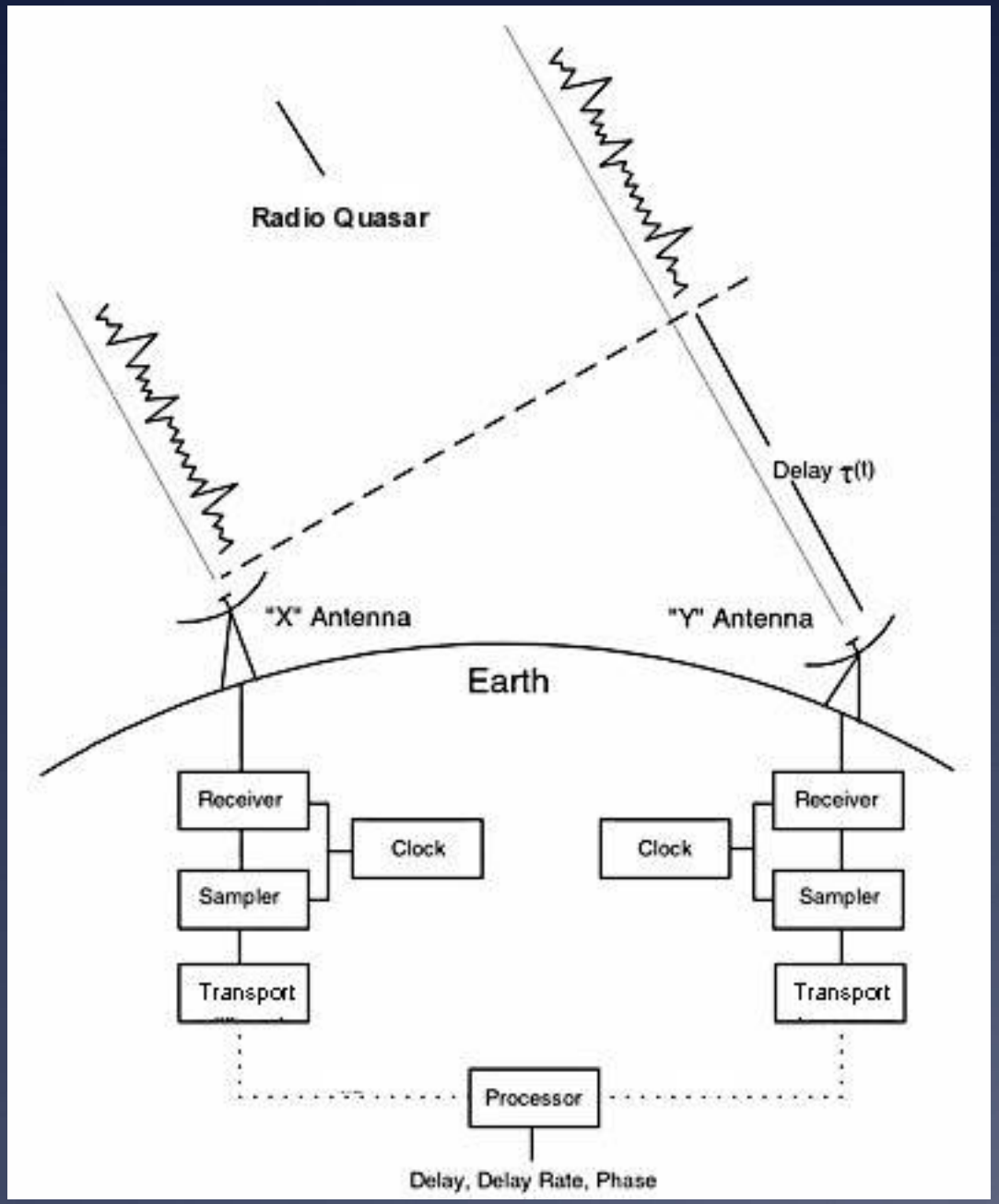
Outline

- The Washington Correlator (WACO)
  - USNO correlation requirements
  - Initial setup and testing
  - Current setup
  - Next steps
  - Long term plans



WACO



VLBI GOAL: TO MEASURE THE TIME-OF-ARRIVAL DIFFERENCE OF SIGNALS, THE DELAY, TO DETERMINE:

- Terrestrial Reference Frame (TRF)
- Celestial Reference Frame (CRF)
- Earth Orientation Parameters (EOP), VLBI data combined with SLR, GPS etc to produce final EOPs.

The Washington Correlator

- Mark IV Correlator was designed and constructed by MIT Haystack Observatory and is operated in cooperation with NASA
- USNO is the International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC) for Earth Orientation.
- As such, the USNO is responsible for determining and predicting the time-varying alignment of the Earth's terrestrial reference frame with respect to the celestial reference frame.
- The USNO provides daily, weekly, and long-term data products. Weekly updates (Bulletin A) are issued on Thursdays. Determinations of Delta TT (TT-UT1) are updated approximately quarterly, and long-term predictions are updated annually.

WACO: workload

- 5 days a week correlates 1 baseline, 1-hour experiments called “intensives”
- Every 2 weeks correlates a 3 station intensive
- Every week correlates a 24-hr “R4” experiment
- About 12, 24-hr CRF observations per year (2- 4 antennas)
- About twice a year, APSG (Asian-Pacific Space Geodynamics), 24-hr with 4 stations
- 4 to 6 24-hr “R1” experiments a year backing up Bonn
- 15 day CONT observation with 11 stations
- Etc

Why a Software Correlator?

- Backup
  - WACO is single point of failure
- COOP
  - Multiple instances at geographically different locations
- Cost effective
  - Can be implemented with COTS personal computers (PCs)
  - As few or as many CPUs as required for the job

Why a Software Correlator?

- Flexible/Scalable
  - Software is easily adaptable to changing requirements
  - Number of CPUs can be increased/decreased with demand
  - Robust to failure of individual CPUs

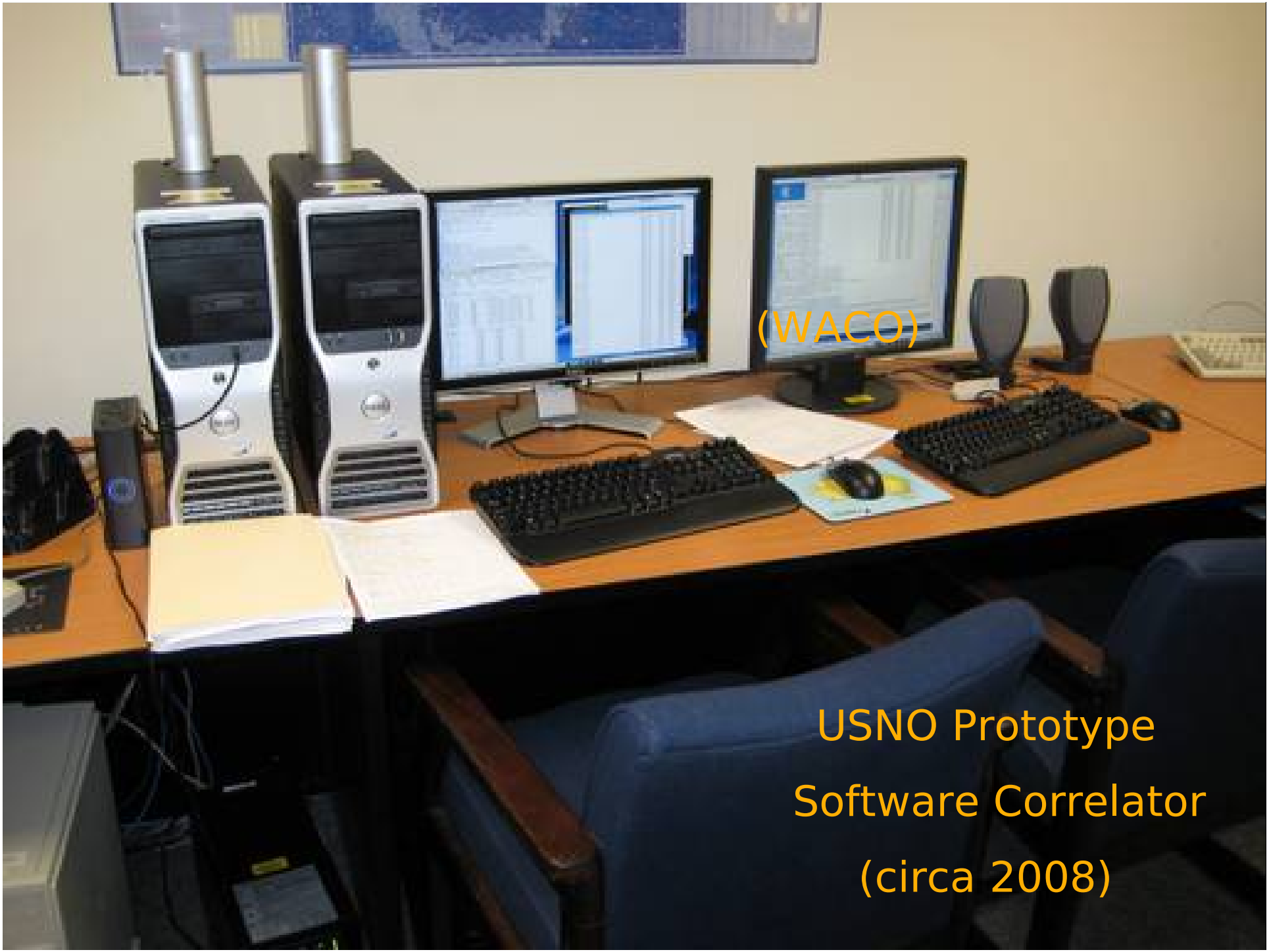
- Replacement for hardware correlator?

Getting Started

- Program Objective:
  - Explore the feasibility of software correlation of VLBI data utilizing low cost *off the shelf* computer hardware
- Advantages:
  - Could provide near-term low cost, robust backup capability (COOP) for Washington Correlator (WACO) for key EOP products
  - Could provide longer-term lower-cost alternative for eventual replacement of existing WACO

Getting Started

- Collected existing PCs
  - 4 Linux PCs / 6 CPUs
  - Heterogeneous “cluster”
  - 2 TB hard drive storage
  - GigaBit ethernet links
- Installed NRAO implementation of Swinburne University DiFX software correlator
- Created USNO Prototype Software Correlator


(WACO)
USNO Prototype
Software Correlator
(circa 2008)

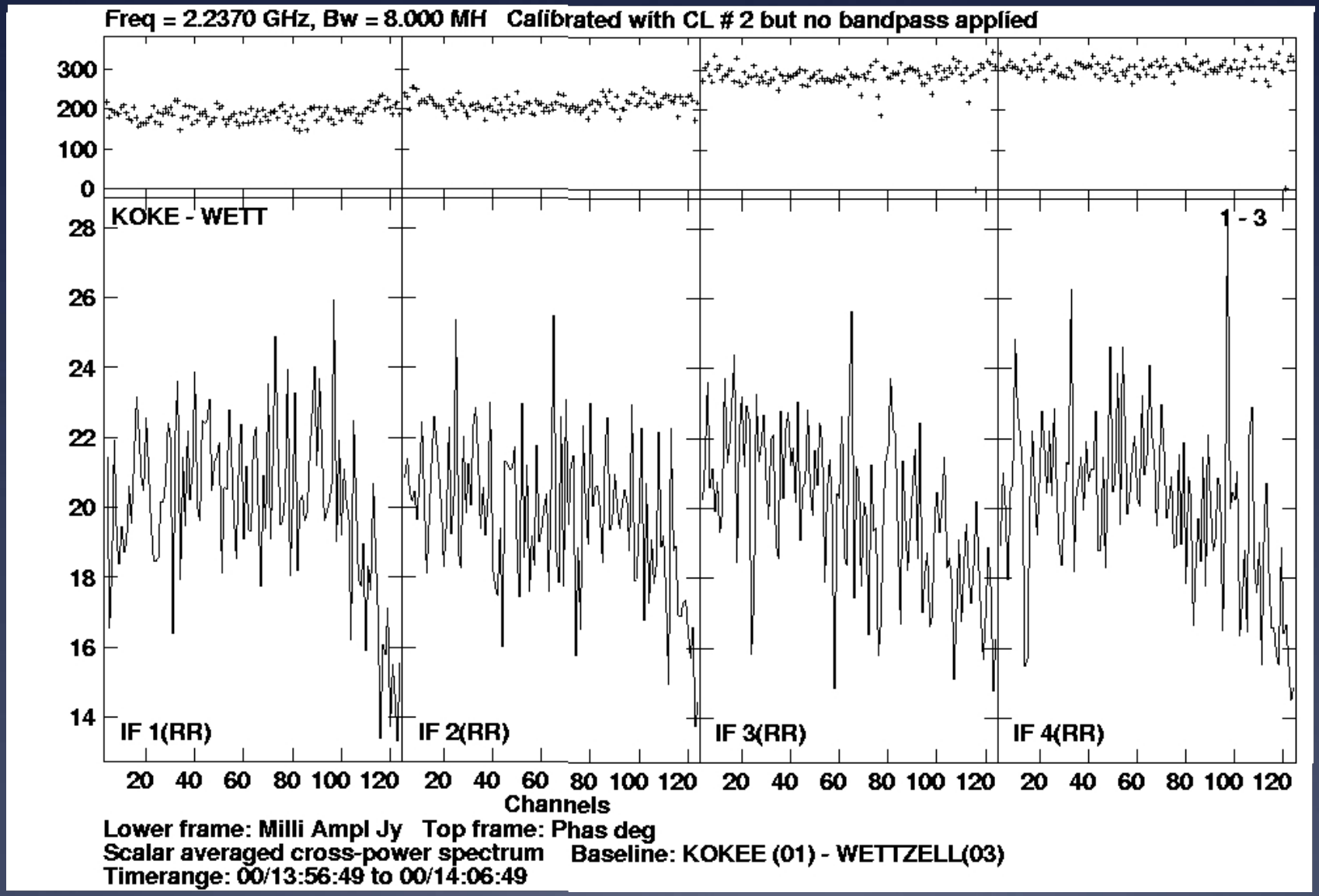
Getting Started

- Identified/implemented pre-processing data pathways
  - Different for UPSC than for WACO
- Identified/implemented post-processing data pathways
  - Different for UPSC than for WACO
- Attempted direct comparison between UPSC and WACO for EOP data
  - Unable to get valid data (via non-standard data path) due to problem in Mrk 5 formatter
    - Problem only revealed after exhaustive tests of parameter space (2 months)
- Decided to continue development with RDV data
  - Direct EOP comparison between UPSC and VLBA correlator

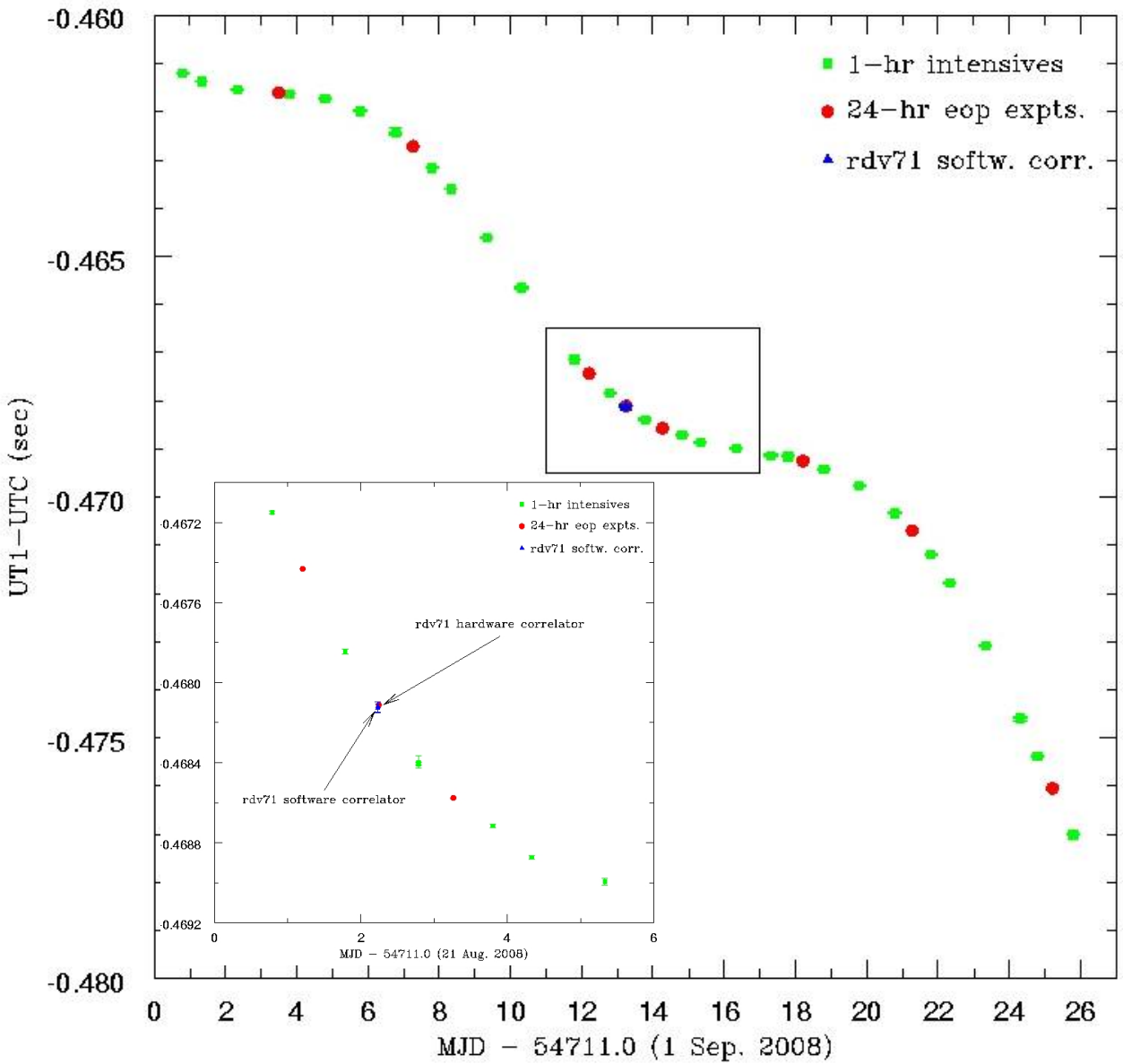
Getting Started

- RDV = Research and Development VLBI
  - Standard 24-hr geodetic experiments
  - VLBA + up to 10 geodetic antennas
- Chose RDV data due to availability
  - Selected data for 3 geodetic stations
    - Kokee Park, Ny Alesund and Wettzel
    - Core stations used for USNO Intensives
- Also processed at VLBA hardware correlator
  - Ideal for comparison with UPSC

Fringes on the Kokee/Wettzell baseline!



USNO UT1-UTC series over 27 days



USNO UT1-UTC series over 27 days derived from 1-hr intensives (green squares), 24-hr eop experiments (red circles) and the RDV71 data correlated with the UPSC (blue triangle). Note the excellent agreement.

Getting Started

- Yet to be done
  - Exhaustive comparisons with WACO results
  - Correlate multiple-station experiments
  - Procure additional PCs
    - Existing CPUs are oversubscribed

UPSC Today

- Acquired new PCs
  - 1 Linux PC with 8 CPUs
  - 4 linux PCs with 2 CPU each
  - Heterogeneous “cluster”
  - 2 TB hard drive storage
  - GigaBit ethernet links
- Current version of NRAO implementation of Swinburne University DiFX software correlator

UPSC Today

- Used scripts originally from John Morgan for input file preparation for intensives (vex format) and correlated intensive data
- Correlated several 5-antenna VLBA experiments with nice fringes on all 10 baselines (see next talk)
- Wrote script to streamline creating input files for VLBA experiments
- Correlated other single baseline experiments
- Playing with fake data generator (courtesy Chris Phillips) to test current setup


USNO Prototype
Software Correlator
(today)

Constraints on UT1 Estimation

- The USNO routinely schedules, correlates and analyzes dedicated VLBI observations to estimate the UT1 component of the Earth Orientation Parameters.
- Biggest constraint on UT1 predictions is the delay in shipping the data to the correlator
- Near real-time transfer to VLBI data over optical fiber networks to WACO will dramatically reduce the latency of UT1 estimation.

Constraints on UT1 Estimation

- Pre-2006 this delay was 4 days
- The shipping delay has been reduced to 2 days (Kokee delay only). As a result the observational accuracy and extrapolations to 2 days have been halved and the prediction error at 7 days has been reduced by 32%.
- By the end of 2009, data transfer will be fully e-VLBI. It is estimated that this will bring prediction error at 7 days to just 40% of its pre-2006 level.

Near Real-Time UT1 Estimation Using e-VLBI

- Observations are made using the 20m telescope at Wettzell, Germany and the 20m telescope at Kokee Park, Hawaii

- Wettzell (right) records its data onto a RAID array and sends it to the High Speed Internet over a 600 Mb/s line.

Near Real-Time UT1 Estimation Using e-VLBI

- Kokee Park (right) records data to a Mk5. This is sent over a microwave link at 150 Mb/s to Oahu from where it is sent at 600 Mb/s to the High Speed Internet. The microwave link will be replaced by a 1 Gb/s fiber in early 2010.

Near Real-Time UT1 Estimation Using e-VLBI

- Data is transferred from the High Speed Internet to a Mk5B at the USNO at 600 Mb/s. It is then copied to a Mk5 via a disk and fed into the correlator (next slide). By the end of 2009 either the data will go directly from the Mk5B to the correlator or from a Mk5A to the correlator.

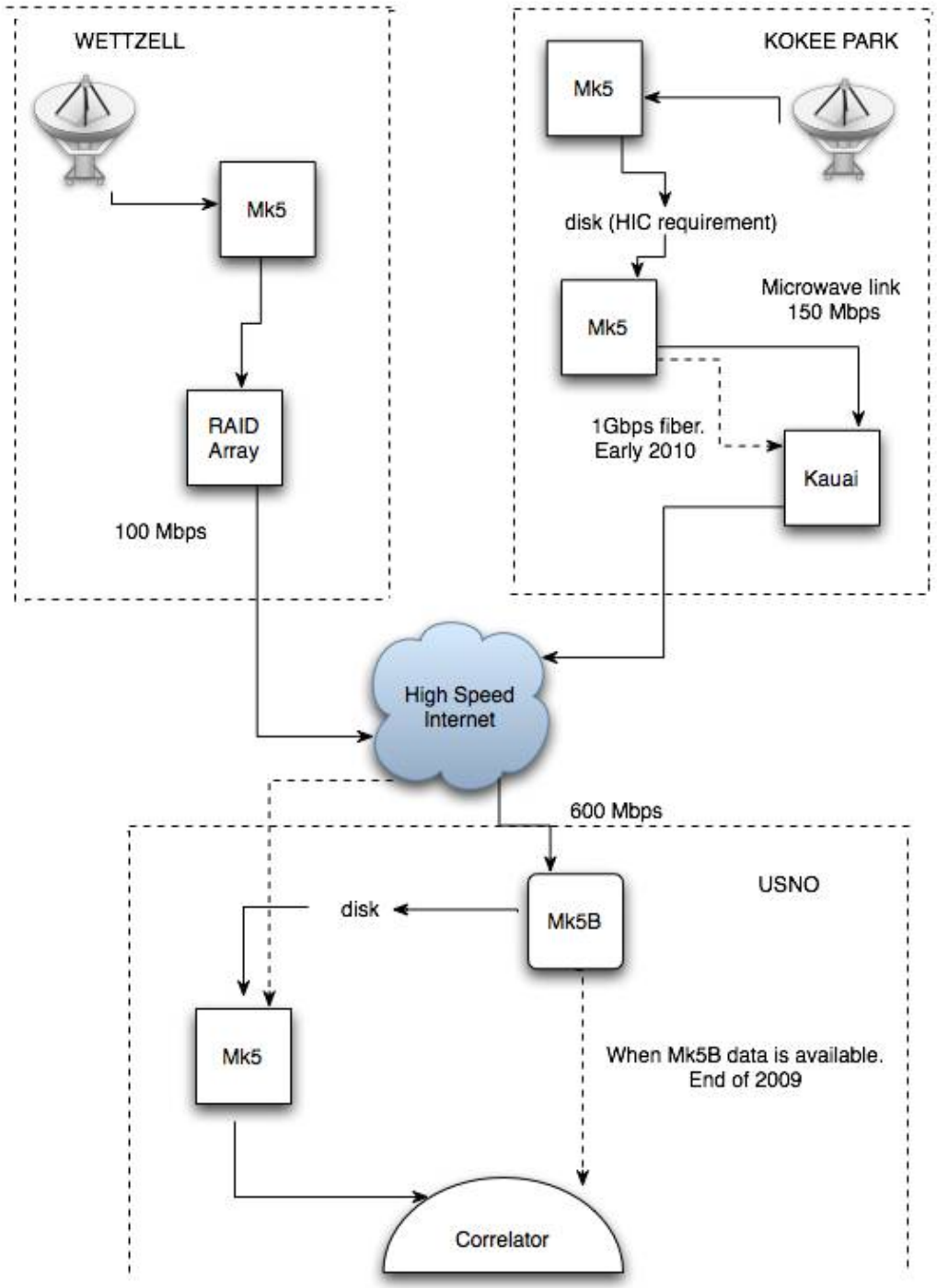


Illustration of the data flow
Solid arrows indicate operational elements.
Dotted arrows indicate planned elements.

Development

- Investigate and develop optimal pre-processing data pathways
- Investigate and develop optimal data input pathways
  - Magnetic media?
  - Optical fiber?
  - Other?
- Explore/evolve PC/CPU configuration for USNO requirements
- Investigate and develop optimal post-processing data pathways
  - NRAO Astronomical Image Processing System?
  - Haystack Observatory Post-processing System?
  - Other ?

Development

- Develop graphical user interface (GUI)
  - Hide complexity and make it possible for an operator to run the correlator with little intervention from a scientist
  - Robust error reporting and recovery
- Settle on stable PC/CPU configuration
- Robust software/hardware correlator comparisons
  - explore parameter space

Verification

- Side-by-side operation with WACO
  - Daily comparison of results ~ 1 year
  - Robustness
  - Reliability
- Additional software development as required

Conclusions

- UPSC pathway for EOP data has been validated via comparison with same dataset correlated with VLBA hardware correlator
- Series of pseudo-intensives correlated and analysed further validate UPSC
- Next major step is near-real time correlation of intensive data from Kokee and Wettzell. With Kokee upgraded to 600 Mb/s and improved transfer techniques we expect to achieve near real-time results in future. Near real-time observations at 128 Mb/s may be possible by early 2010

Conclusions

- Excited about detailed exploration of parameter space leading to approval for routine use. This will be enabled by development of pathway from DiFX to HOPS