Broadband and the Evolution of the VGOS Network

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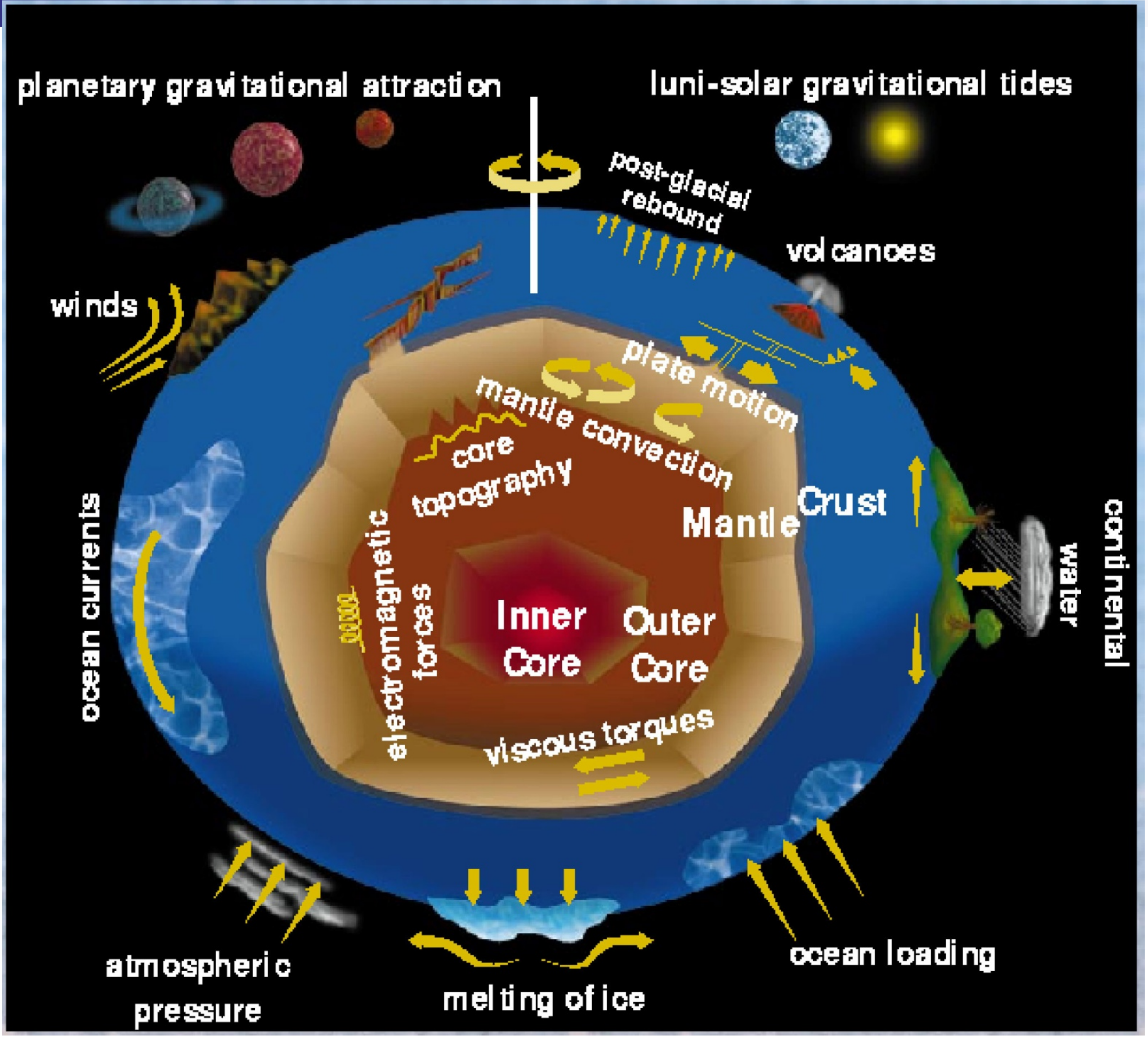
MIT Haystack Observatory

Geodesy

- Measurement of the shape of the Earth
  - Establishing a terrestrial reference frame
  - Plate tectonics
  - Crustal deformation near plate boundaries
  - Post-glacial rebound and other vertical motion
- Orientation of the Earth in space
  - Time and changes in length of day
  - Polar motion
  - Precession and nutation
- The data for understanding geodynamics

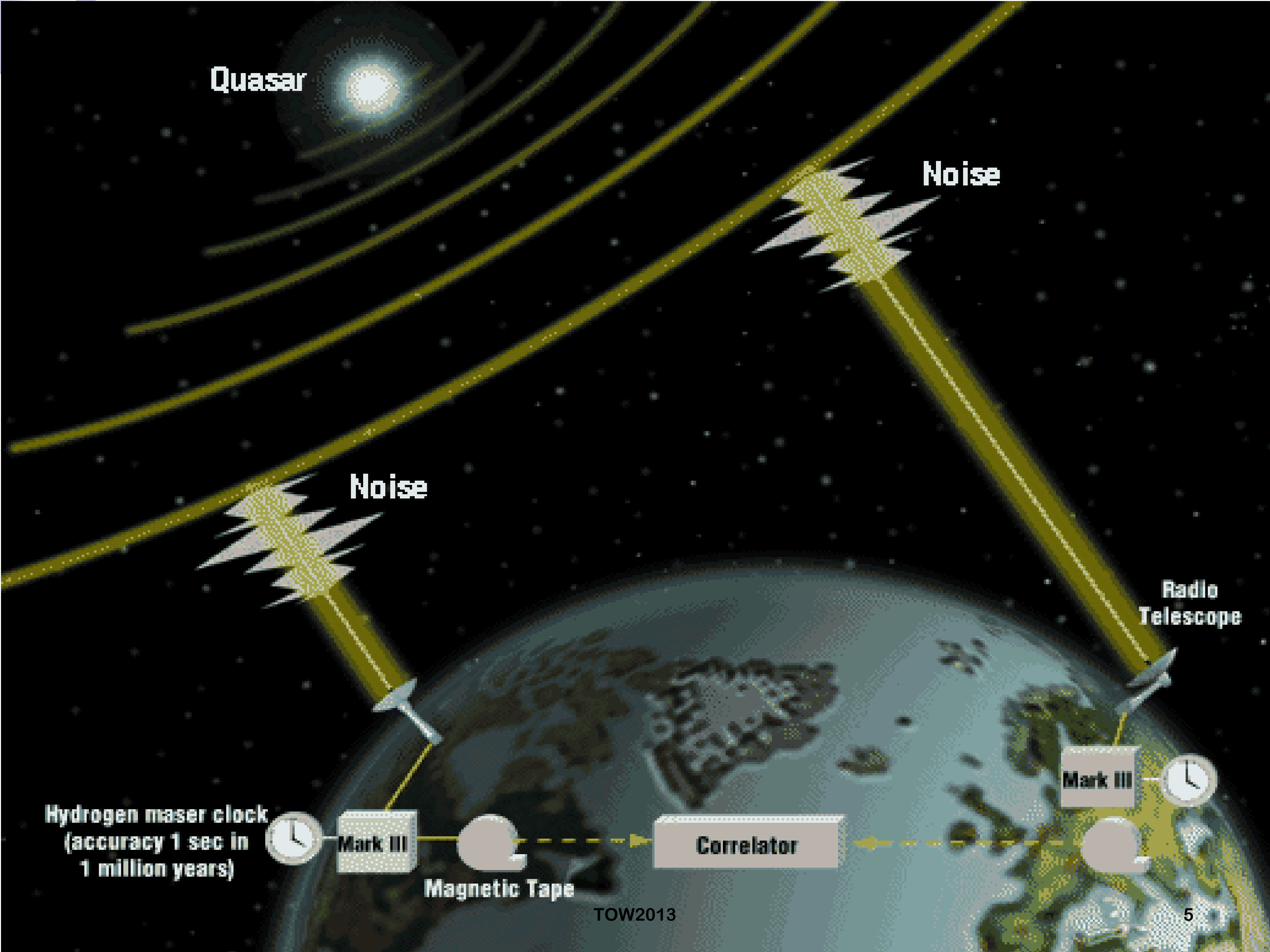


planetary gravitational attraction
luni-solar gravitational tides
post-glacial rebound
volcanoes
winds
plate motion
mantle convection
core topography
Crust
Mantle
ocean currents
electromagnetic forces
Inner Core
Outer Core
continental water
viscous torques
atmospheric pressure
melting of ice
ocean loading

Benefits of Geodesy to Society

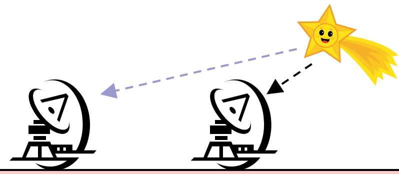
- Geodetic observing systems provide a significant benefit to society in a wide array of military, research, civil, and commercial areas
  - Sea level change monitoring
  - Autonomous navigation
  - Tighter low flying routes for strategic aircraft
  - Precision agriculture, civil surveying
  - Earthquake monitoring
  - Forest structural mapping and biomass estimation
  - Improved floodplain mapping

Precise Geodetic Infrastructure: National Requirements for a Shared Resource
NATIONAL RESEARCH COUNCIL **(2010)**


Quasar
Noise
Noise
Radio
Telescope
Mark III
Hydrogen maser clock
(accuracy 1 sec in
1 million years)
Mark III
Correlator
Magnetic Tape

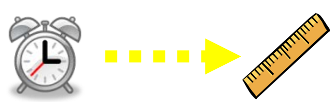
Geodetic VLBI: How does it work?

from Bill Petrachenko



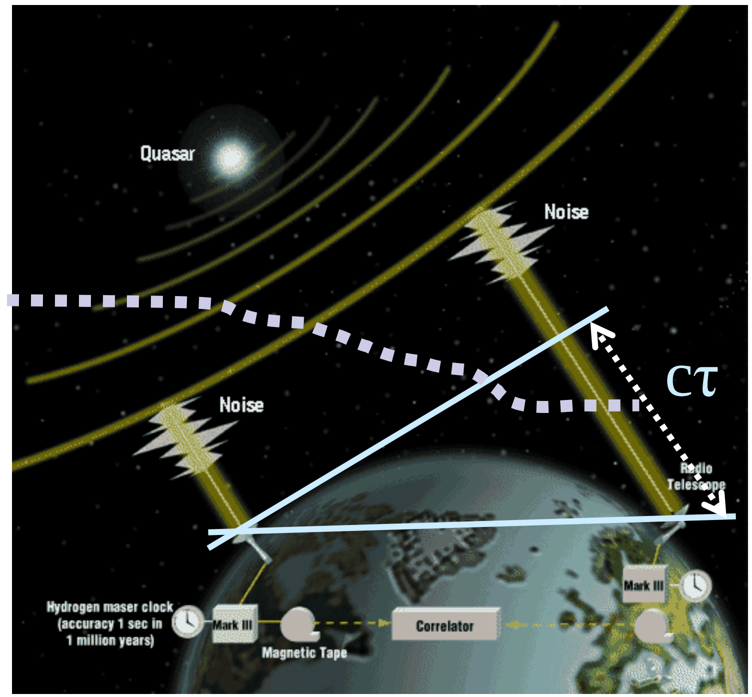
A network of antennas observes a Quasar

The delay between times of arrival of a signal is measured



Using the speed of light, the delay is converted to a distance

The distance is the component of the baseline toward the source



By observing many sources, all components of the baseline can be determined.

How good can we do?

- Distance:

  Better than 1 centimeter between continents

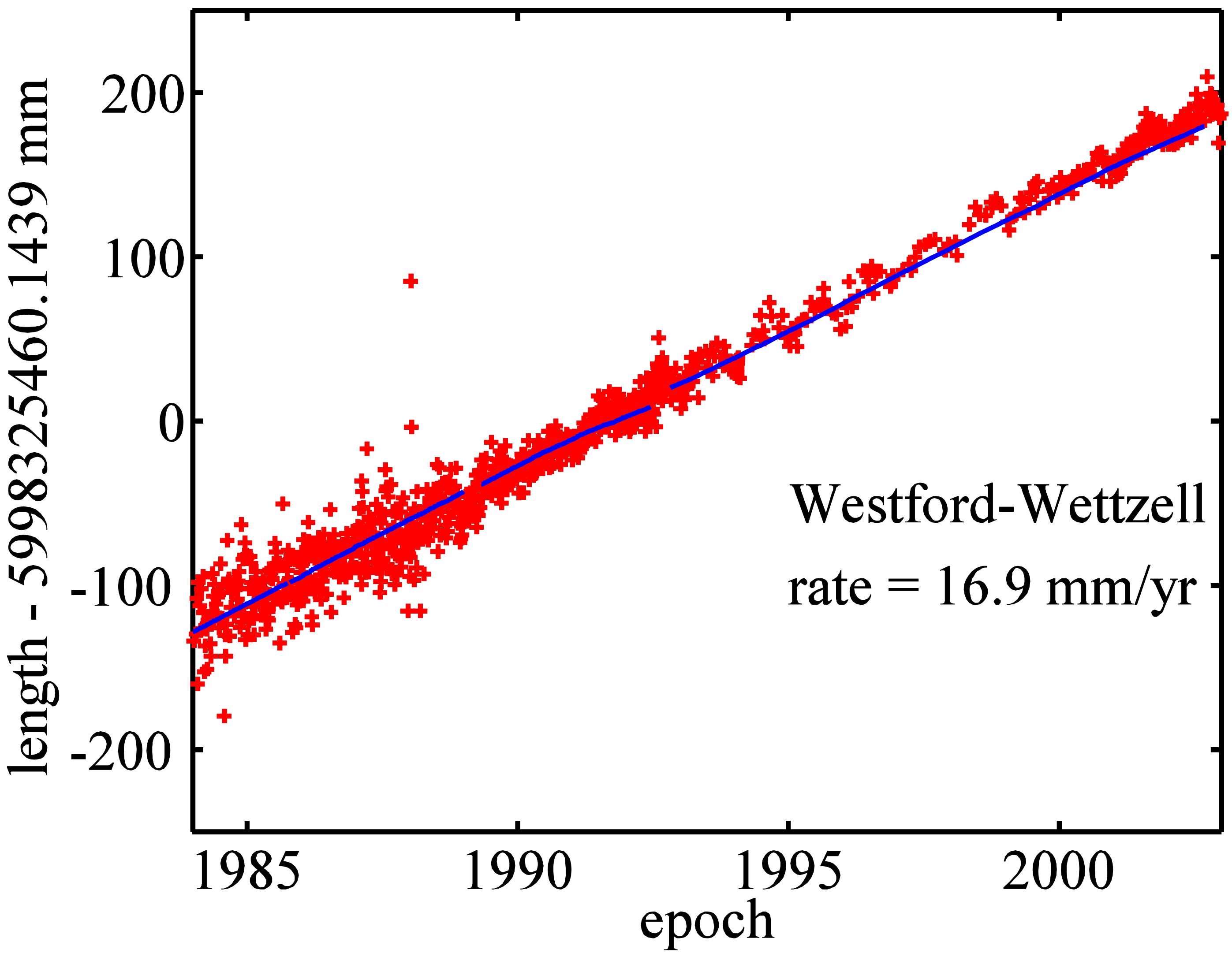
- Earth rotation (time of day):

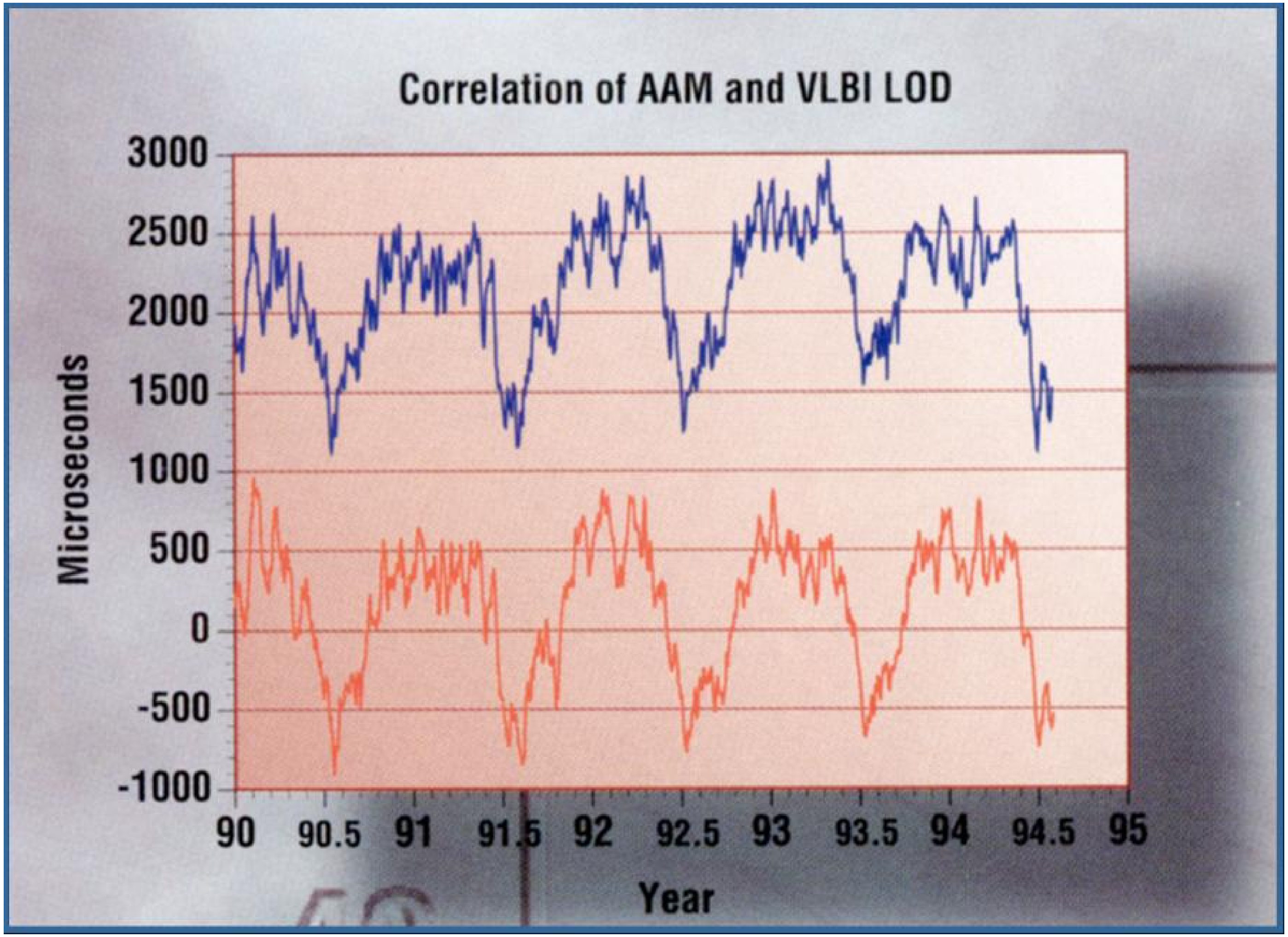
  Better than 1 one-thousandth of a second

  (about 20 microseconds)

- Wobble of the Pole:

  Better than 1 centimeter (moves 15m/year)

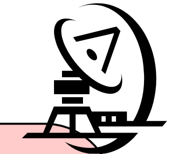

200
100
0
-100
-200
length - 5998325460.1439 mm
1985
1990
1995
2000
epoch
Westford-Wettzell
rate = 16.9 mm/yr


Correlation of AAM and VLBI LOD
Microseconds
3000
2500
2000
1500
1000
500
0
-500
-1000
90
90.5
91
91.5
92
92.5
93
93.5
94
94.5
95
Year

What makes it possible?

- Large radio telescopes to collect energy from weak Quasars
- Atomic clocks for accurate frequency and timing (Hydrogen maser)
- High rate of data recording
  - Initially tapes - 720 kilobits/second (0.000720 Gigabits/second)
  - Now disks - 16 Gigabits/second

Why do we need a next generation VLBI observing system?

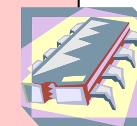


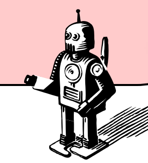
Aging systems (now ~35 years old):

- Old antennas
- Obsolete electronics
- Costly operations
- RFI

Emerging Technology:

- Fast antennas
- Digital electronics
- Hi-speed networks
- Automation





New system

New requirements:

- Sea level rise
- Earthquake processes
- 1-mm accuracy
- GGOS

What’s gone wrong?

- Fairbanks – too expensive to maintain
- Failing azimuth rail support – several antennas
- Mk4 formatter & video converter – obsolete parts
- Phase cal - obsolete part
- Better accuracy needed
- Almost all antennas too slow for atmosphere estimation

Long Term Goals for VGOS

VGOS Goals

1-mm position accuracy

Acquire many more observations per day by using:

- fast slewing, compact antennas (12°/s Az; 6°/s El)
- short on-source integrations (5-10 sec)
- very high data rates (16 Gbps or more)
- new "Broadband" systems to get high delay precision

Continuous measurements of station position and EOP

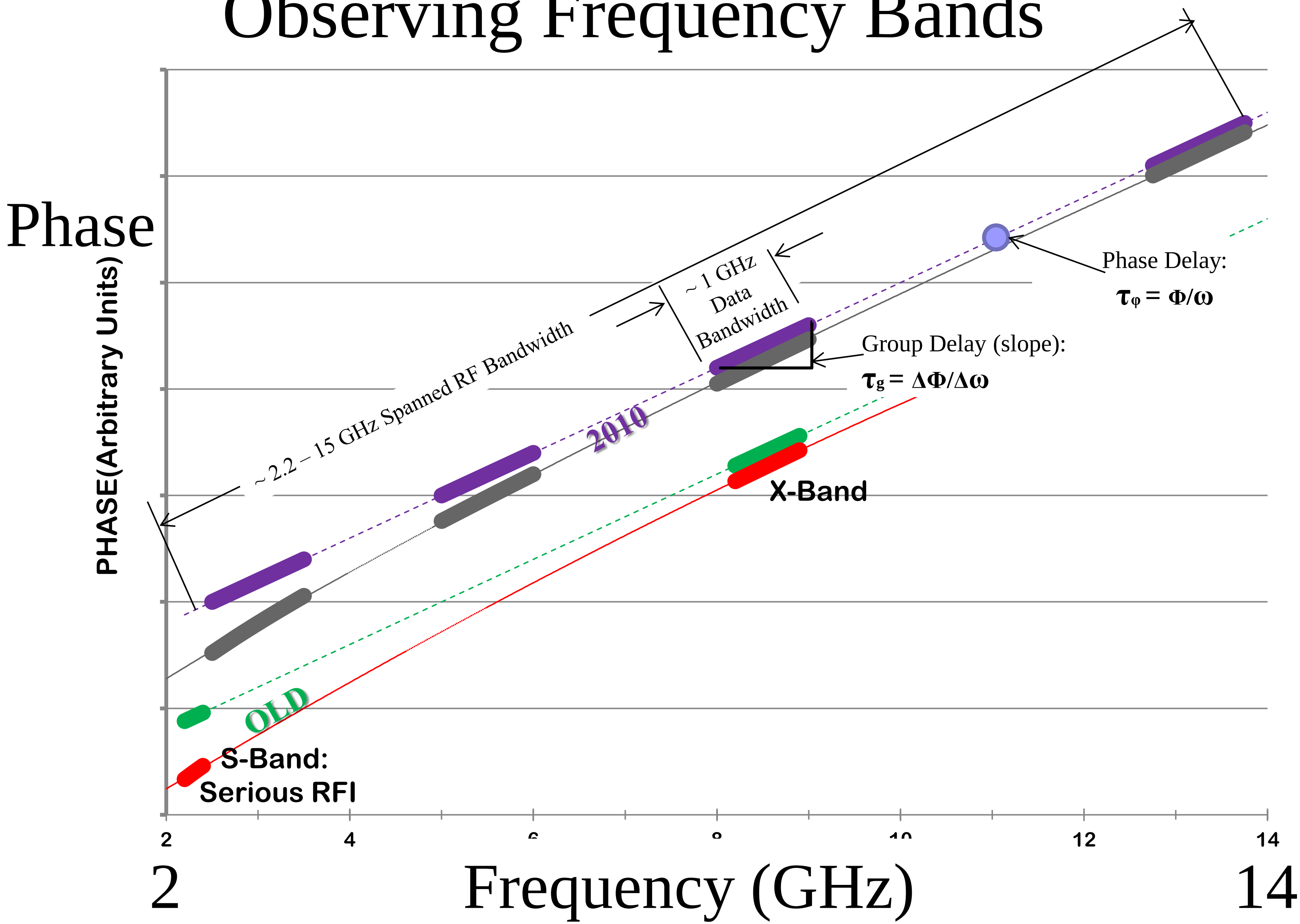
- Increase remote control of stations
- Increase automation of both stations and analysis

Turn-around time <24 hours

- e-VLBI wherever possible using improved networks

Strive for good global distribution of stations

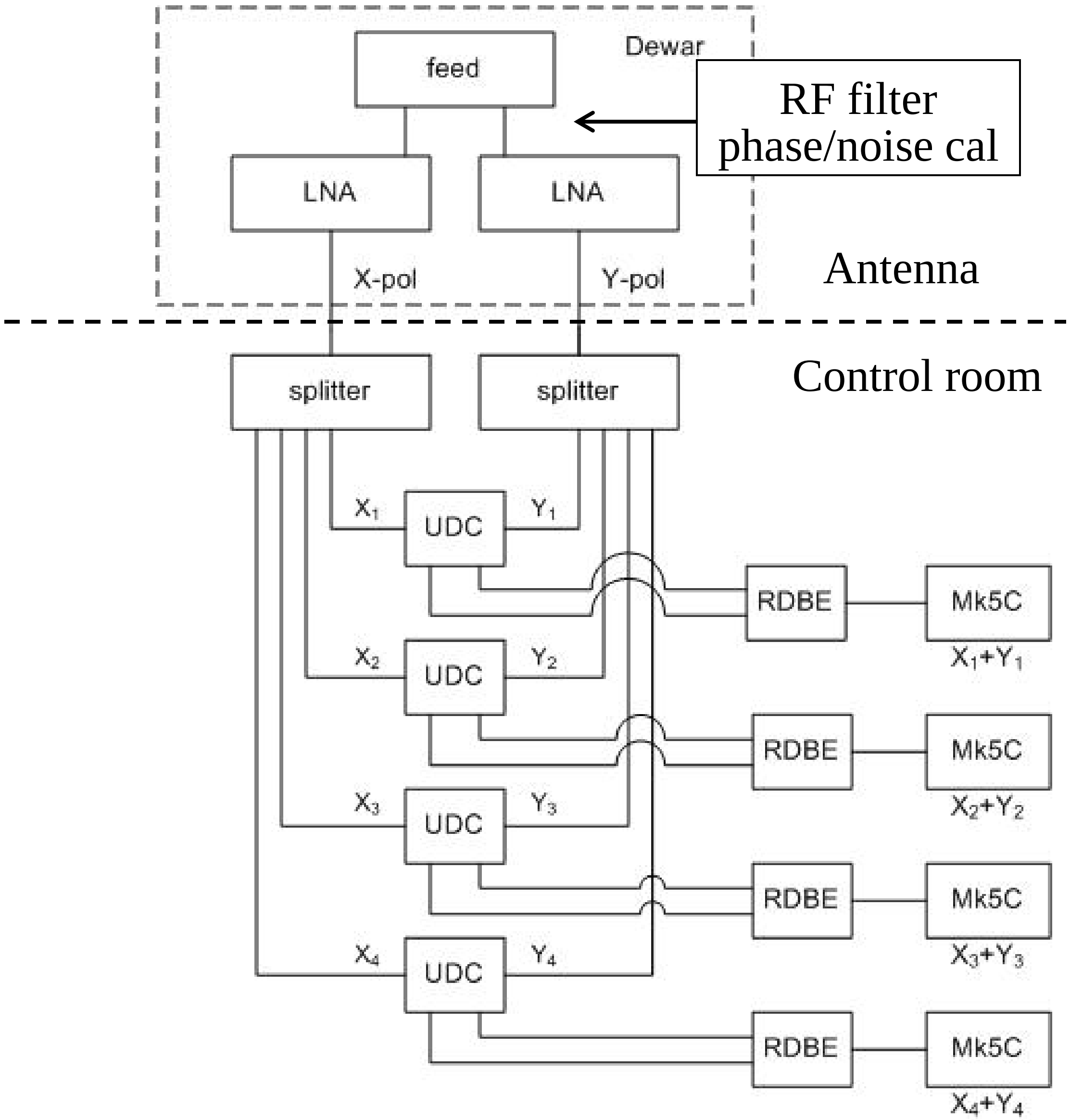
Observing Frequency Bands



Next generation VLBI = VLBI2010 = VGOS

Other points

- More data faster from less equipment
  - Four RDBEs and one Mark6 recorder in one rack for 16 Gbps
- Digital electronics more stable and reliable
- Smaller antennas can be more stable and robust



Feed and LNAs cooled to ~20K

Both senses of linear polarization used

Odd channels from each pol'n for one band output to each Mk5C.

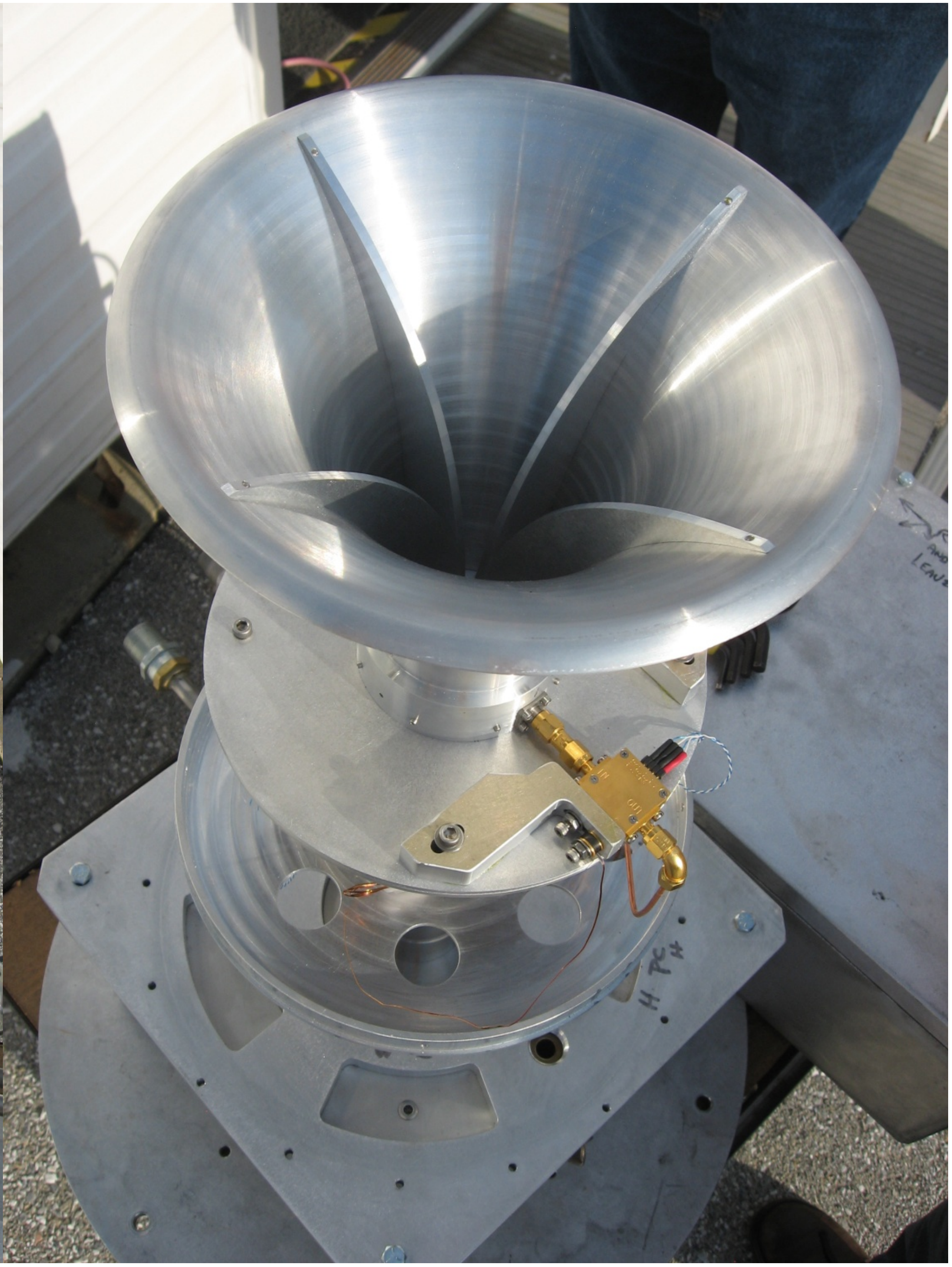
2 Gigabits/sec recorded on each Mk5C.

Total data rate: 8 Gbps

NASA-Haystack VGOS System

- Observation components
  - Patriot-Cobham 12m antenna near Washington, D. C.
  - Westford 18m antenna near Boston, Massachusetts
  - Feed: QRFH
  - LNAs: Caltech
  - UpDown Converters: Haystack Observatory
  - Digital Backend: RDBE-H from Digicom
  - Recorders: Mark5C from Conduant
- Observable extraction and estimation
  - Correlator: DiFX at Haystack Observatory
  - Post-correlation: *fourfit*
  - Estimation: nuSolve at GSFC


Courtesy Wendy Avelar



QRFH feed

2 – 14 GHz

Developed by
Sandy Weinreb
and
Ahmed Akgiray
of Caltech

Signal Chain
from Quasar signal to bits

- New developments
  - Front end (on antenna)
    - Feed and Low Noise Amplifiers
    - Phase and delay calibration system
    - Signal transport to control room over optical fiber
  - Backend (in control room)
    - Frequency down-conversion
    - Digital back end
    - High data rate recorders

Observation Chain
from bits to baseline

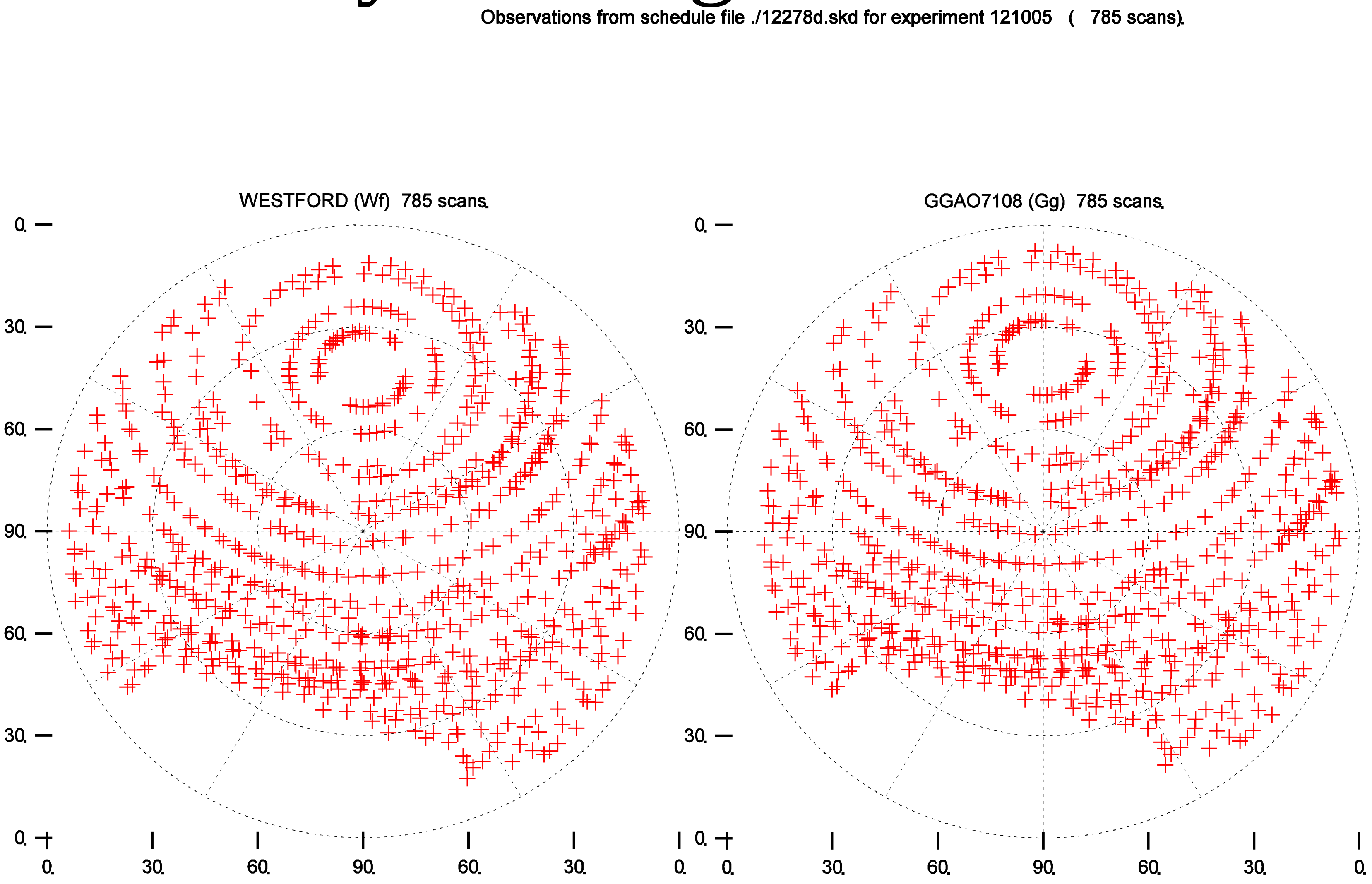
- New developments and challenges
  - Scheduling of observations for four bands (tbd)
    - Astronomy: characteristics of the quasars
    - Antennas: sensitivity differences
  - Correlation of data from the antennas
    - DiFX software correlator
    - Estimation of delays: 4 bands and 2 polarizations
  - Estimation of geodetic parameters
    - Many more observations
    - Feedback of astronomical information to scheduling (tbd)

TTW
Wettzell Twin Telescopes

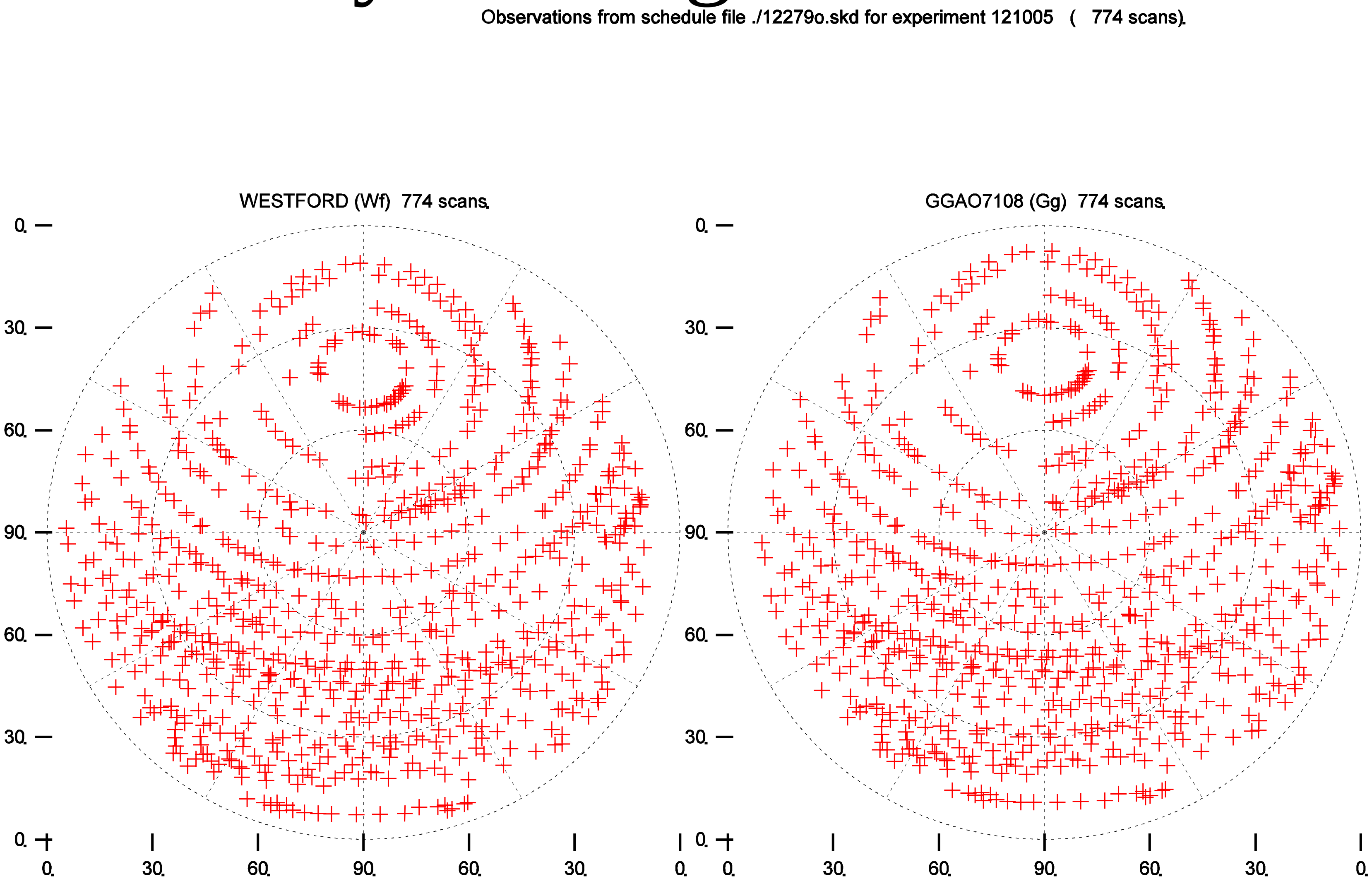
Radio Frequency Interference

- External sources of RFI
  - Usual S-band sources (e.g. cell phones, Sirius XM)
  - Unknown 4 GHz at GGAO (NSA or CIA?)
  - Local communication link at 6 GHz at Westford
- Intra-technique RFI for geodetic Core Sites
  - Satellite Laser Ranging aircraft avoidance radar at 9.4 Ghz
    - Potential to damage LNAs
    - Coordinated observing appears difficult
    - Attempting to mitigate by physical blockage near radar
  - DORIS transmission near 2 GHz

Sky coverage mask on

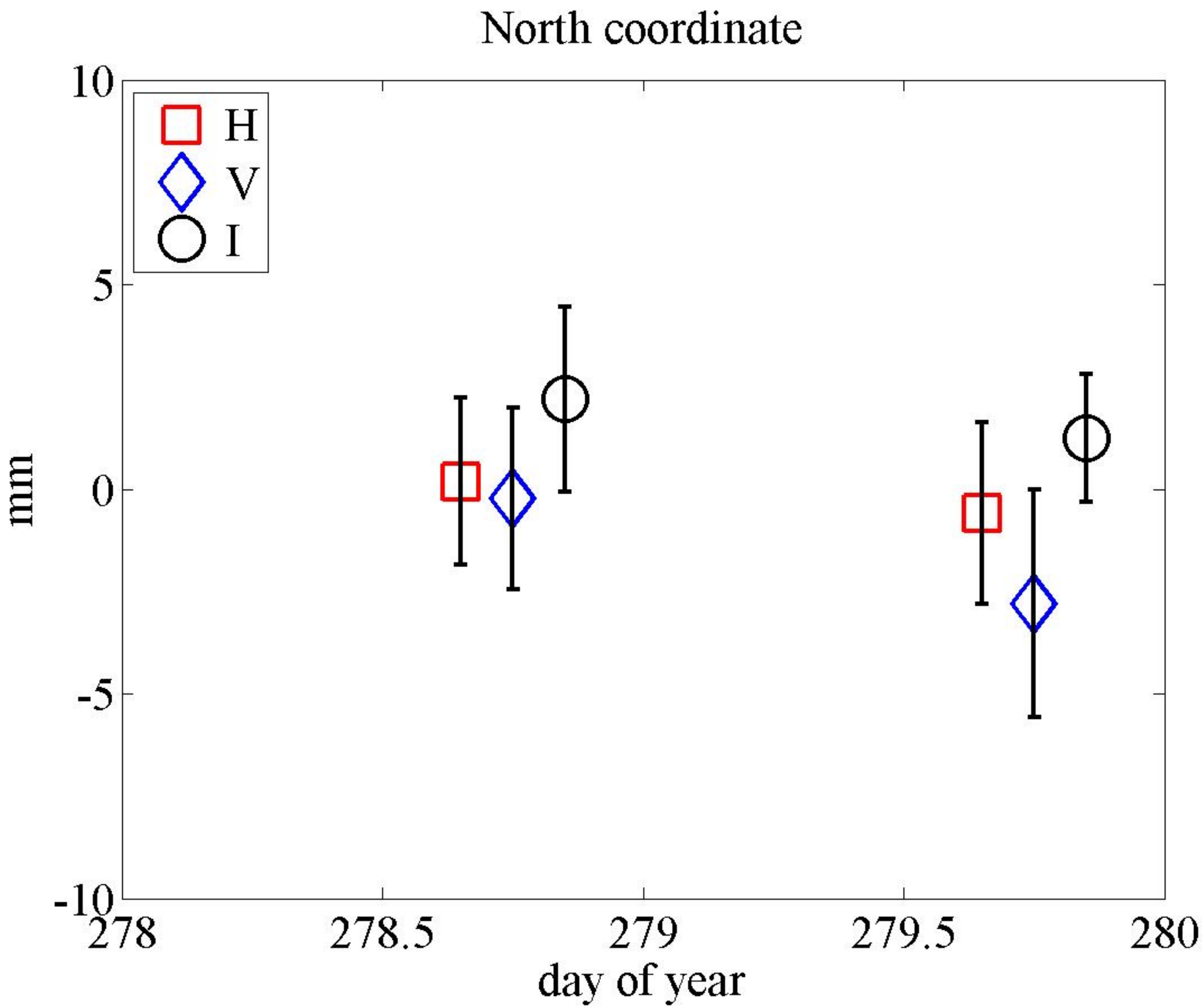


Sky coverage no mask



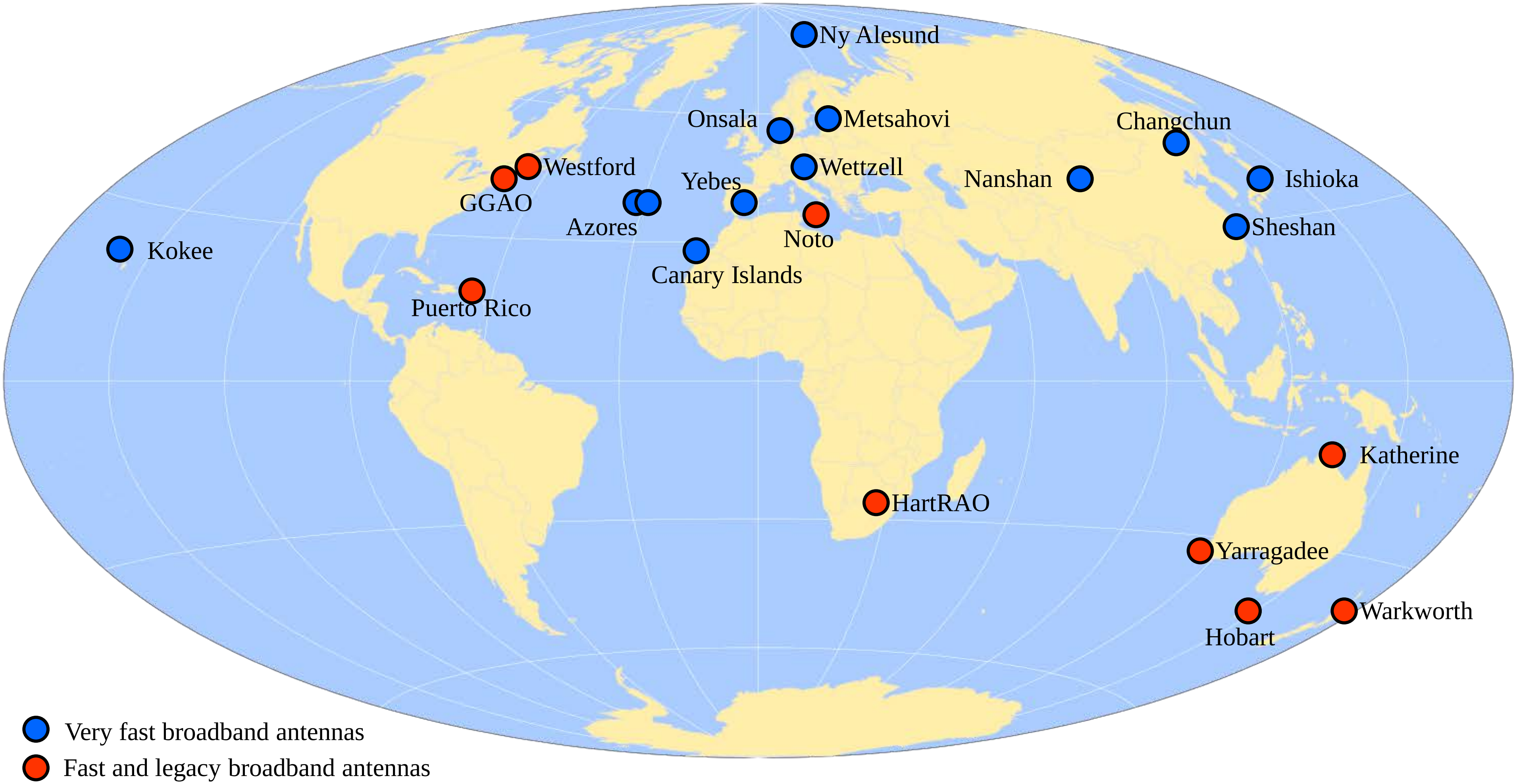
Geodetic Sessions

- 2012 October 4-5
  - Two 6-hour sessions
  - 34 scans per hour at 30 seconds per scan
  - Oct 4: SLR radar active: VLBI observation-mask ON
  - Oct 5: SLR radar off: VLBI observation-mask OFF
- Observing bands
  - Frequencies
    - 32 MHz channel bandwidth
    - 3.2 GHz 5.2 GHz 6.3 GHz 9.3 GHz
  - Polarization
    - Dual linear
    - Data from H-pol’n and from V pol’n for each scan


North coordinate
H
V
I
10
5
0
-5
-10
mm
278
278.5
279
279.5
280
day of year

VGOS Network anticipated for 2017

Strong in the North Polar Region
Weaker in the Americas and Pacific Region



IVS continues to promote VGOS growth

Effect of hypothetical expansion into the Americas and Pacific Region

Very fast broadband antennas
Fast and legacy broadband antennas
Hypothetical network expansion - very fast broadband antennas


Courtesy Wendy Avelar

GGAO12M Development Team

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