High Speed Data Transmission and Processing Systems for e-VLBI Observations

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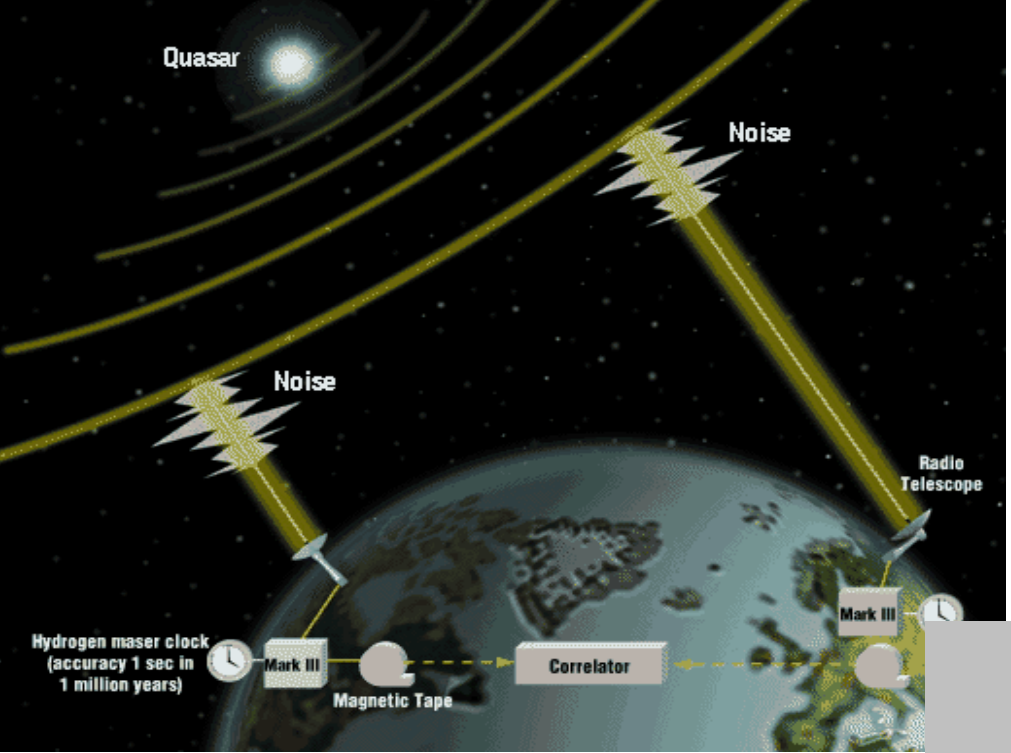
Outline

- What is e-VLBI?
- How?
  - K5 VLBI System
  - Network
- Test Experiments
  - Jan.31-Feb.1, 2003 KASHIMA-KOGANEI
  - Mar.25, 2003 KASHIMA-WESTFORD
- Future Plan



The Very-Long Baseline Interferometry (VLBI) Technique

(with traditional data recording)

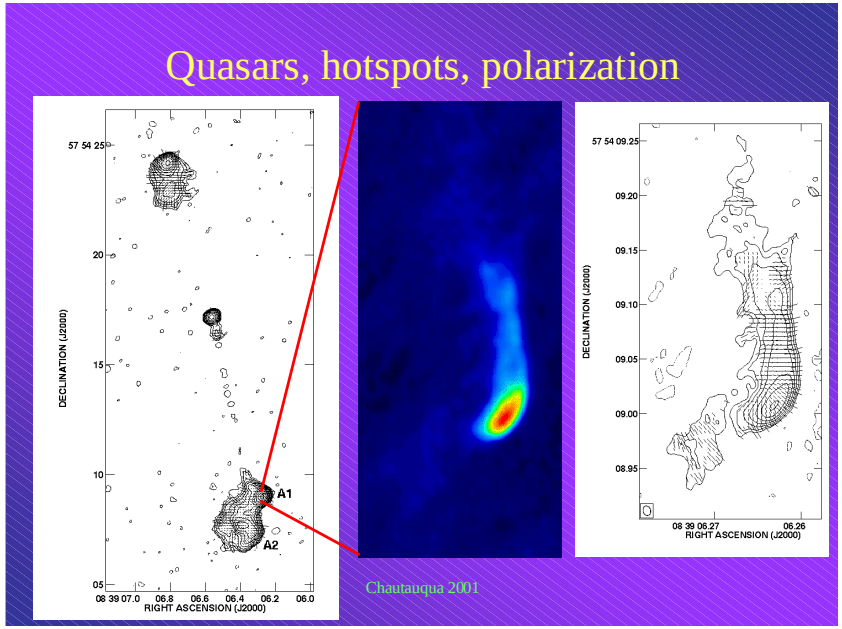
The Global VLBI Array

(up to ~20 stations can be used simultaneously)

VLBI Science

ASTRONOMY

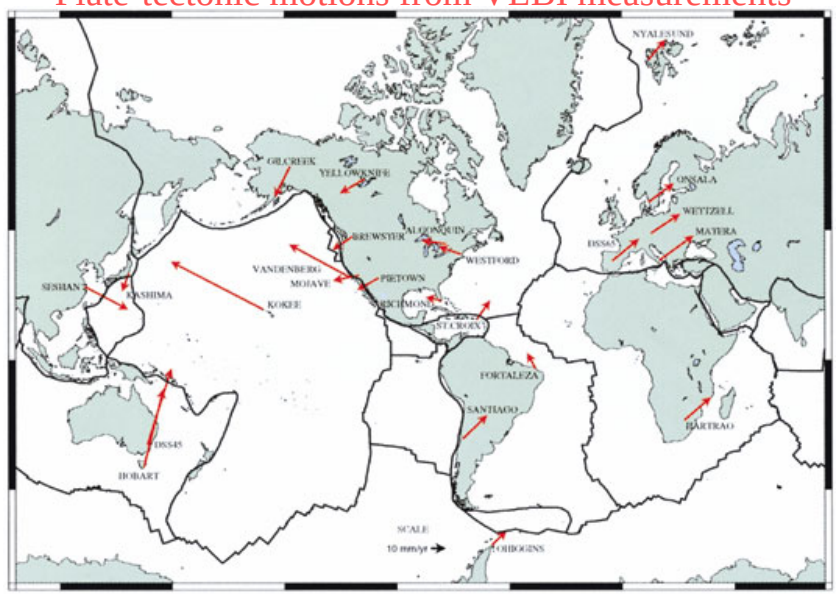
- Highest resolution technique available to astronomers – tens of microarcseconds
- Allows detailed studies of the most distant objects



GEODESY

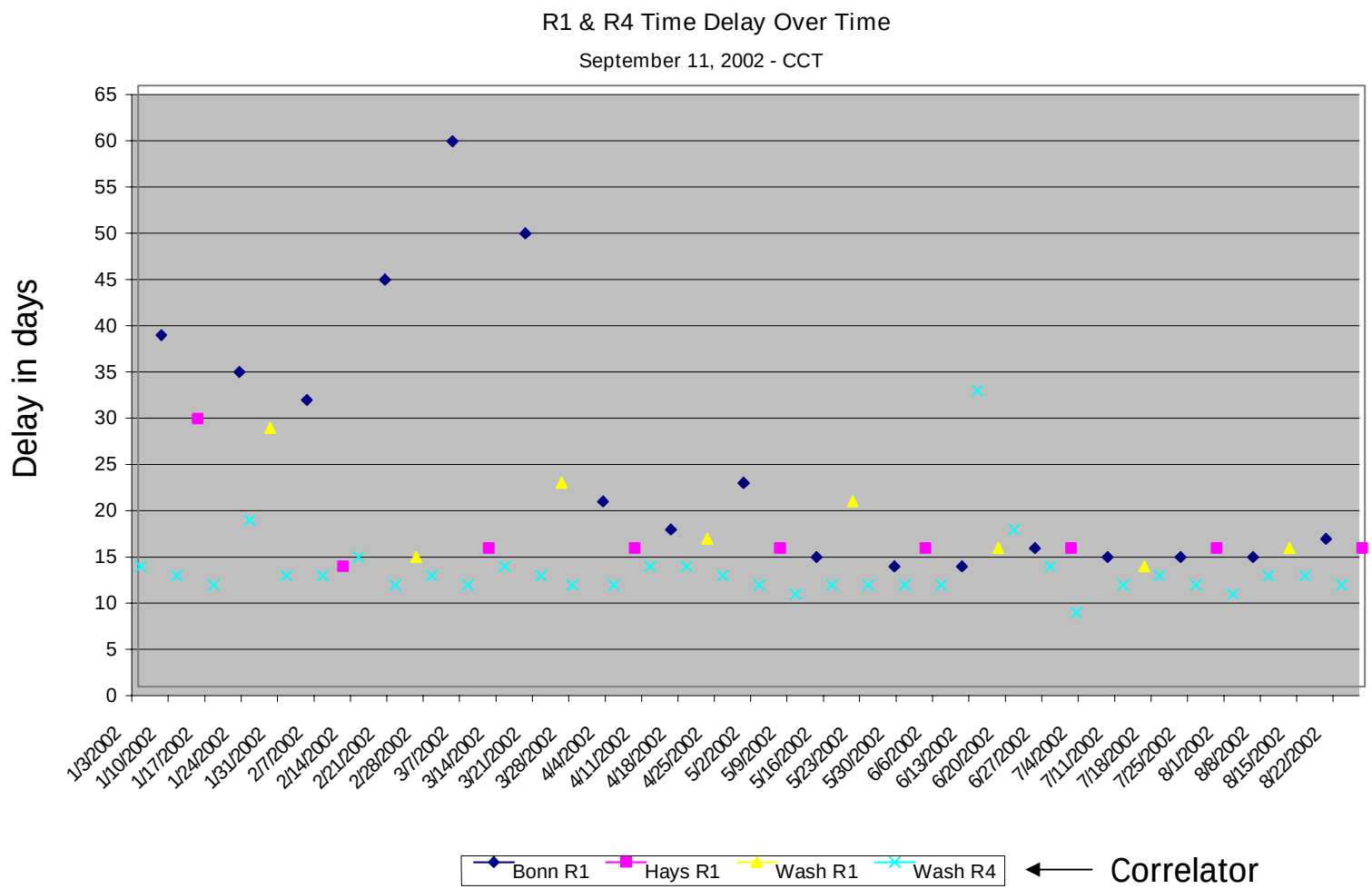
- Highest precision (few mm) technique available for global tectonic measurements
- Highest spatial and time resolution of Earth's motion in space for the study of Earth's interior
  - •Earth-rotation measurements important for military/civilian navigation
  - •Fundamental calibration for GPS constellation within Celestial Ref Frame

Plate-tectonic motions from VLBI measurements



Why e-VLBI?

To improve timeliness of global VLBI data processing



Why e-VLBI?

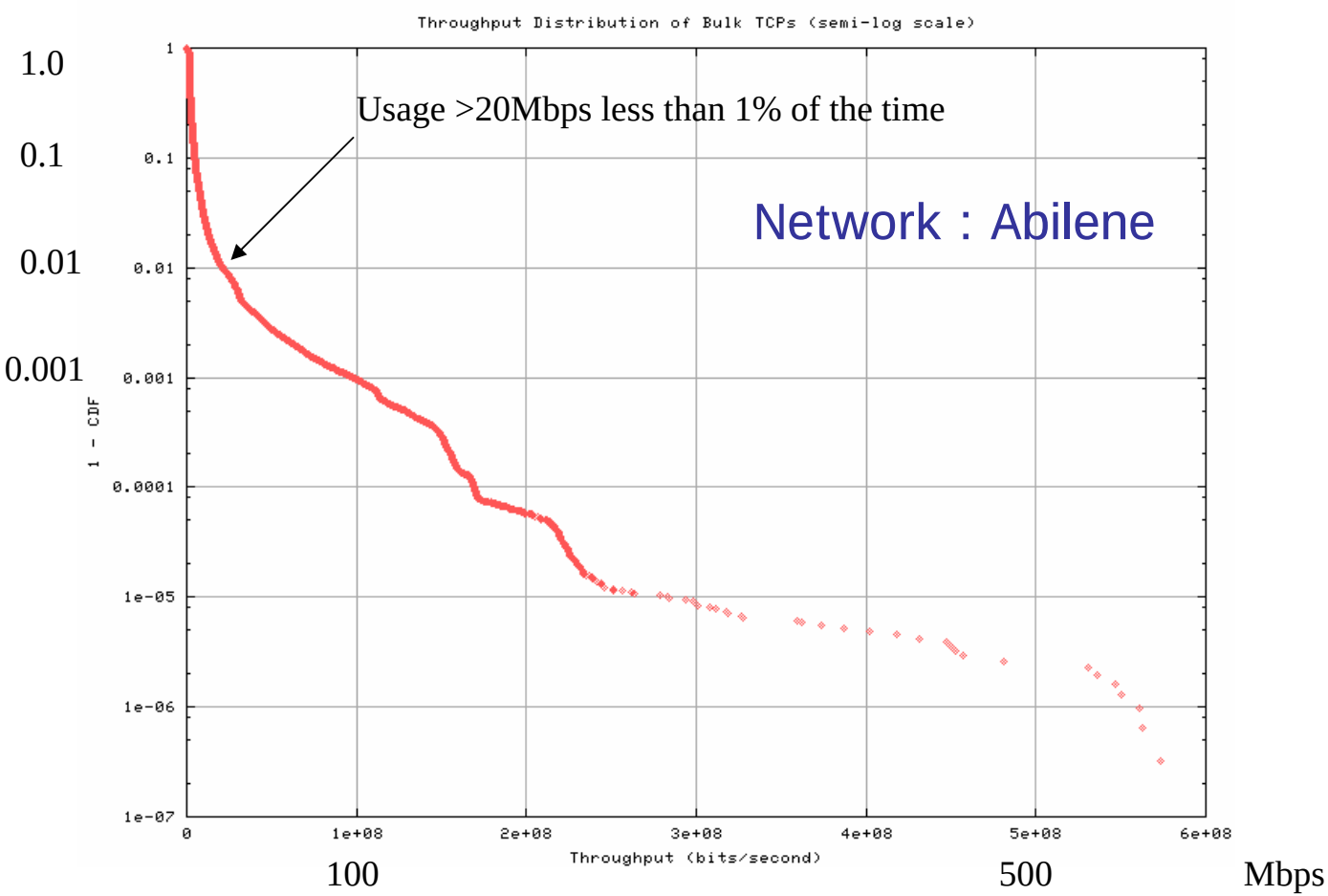
- Currently it takes at least 2 weeks to process (mainly shipping time)
- If it become 2 hours, it will improve accuracy of
  - positioning
  - navigation
  - real-time orbit determination of satellites and spacecrafts
- It potentially expands correlation/observation capacity
  - Currently ~8 stations with hardware correlator
  - Easy scalability with PC/distributed software correlator
  - No Recording Speed Limit with real-time correlation

e-VLBI with Satellite Link

- For Geodesy/Astronomy
  - e-VLBI with remote/isolated sites
  - distributed correlation processing

- For Network Research
  - ideal high volume data set for network research
  - research for adaptive transmission protocol
  - low QoS requirements
    - data loss
    - large/variable transmission delay

Typical bit-rate statistics on network



Conclusion: Average network usage is only a few % of capacity

VLBI Systems for e-VLBI


K3 Correlator (Center)
K3 Recorder (Right)

K3 System

1983~
Longitudinal Recorder
Open Reel Tapes
Hardware Correlator

KSP Backend

KSP Correlator

K4 (KSP) System

1990~
Rotary Head Recorder
Cassette Tapes
Hardware Correlator
e-VLBI with ATM

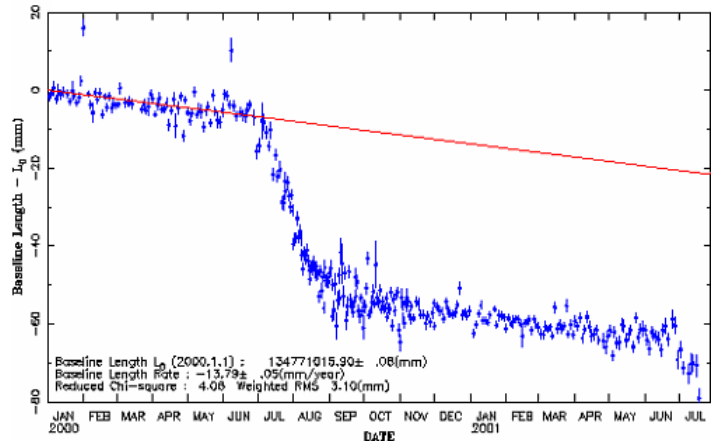

K5 Data Acquisition Terminal

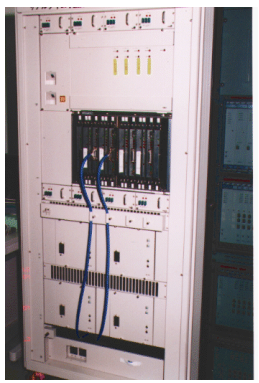
K5 System

2002~
PC based system
Hard Disks
Software Correlator
e-VLBI with IP

e-VLBI with ATM Network (1998~2001)

Distance between Kashima and Tateyama



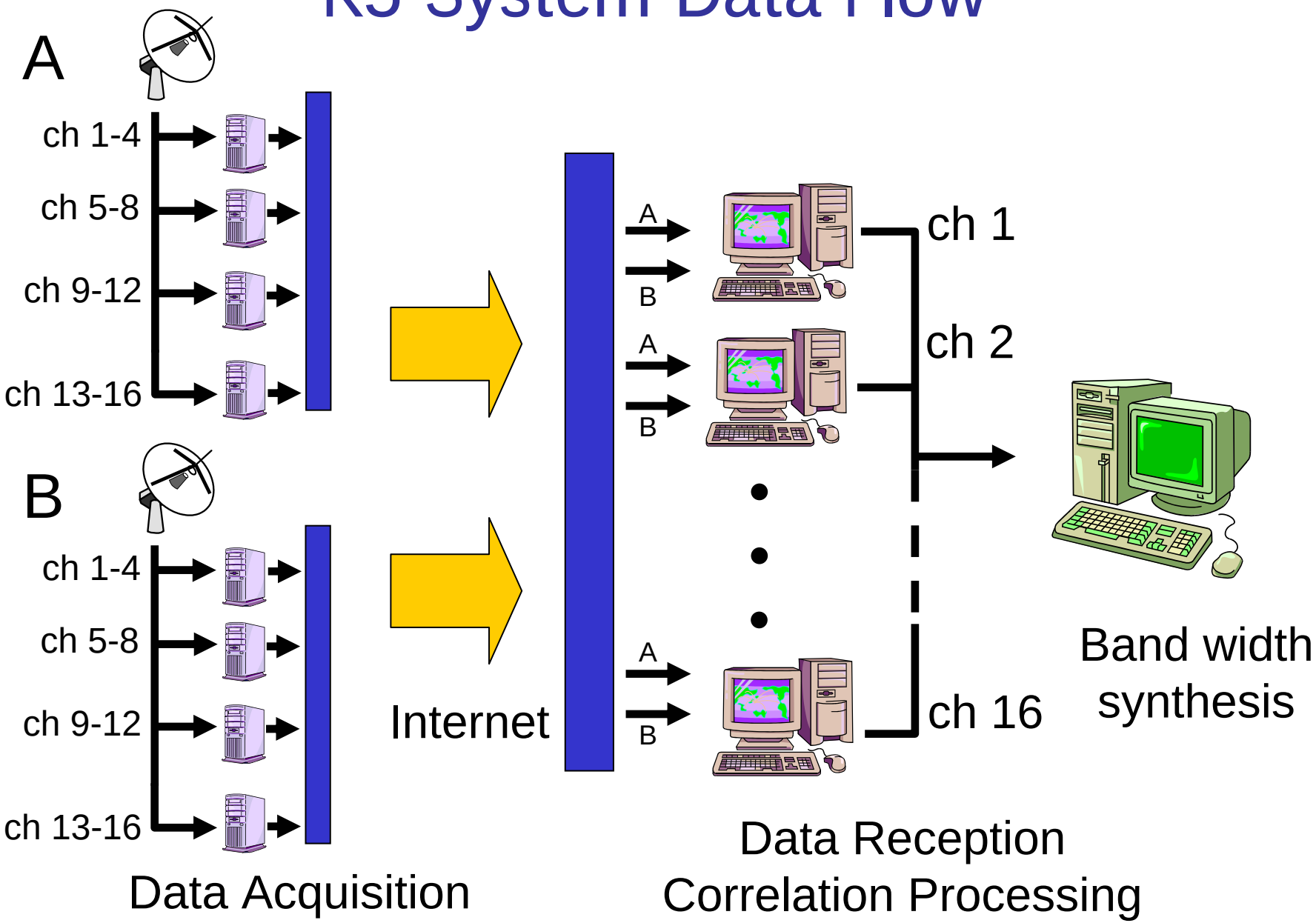


ATM VLBI interface (left)
and Correlator (right)

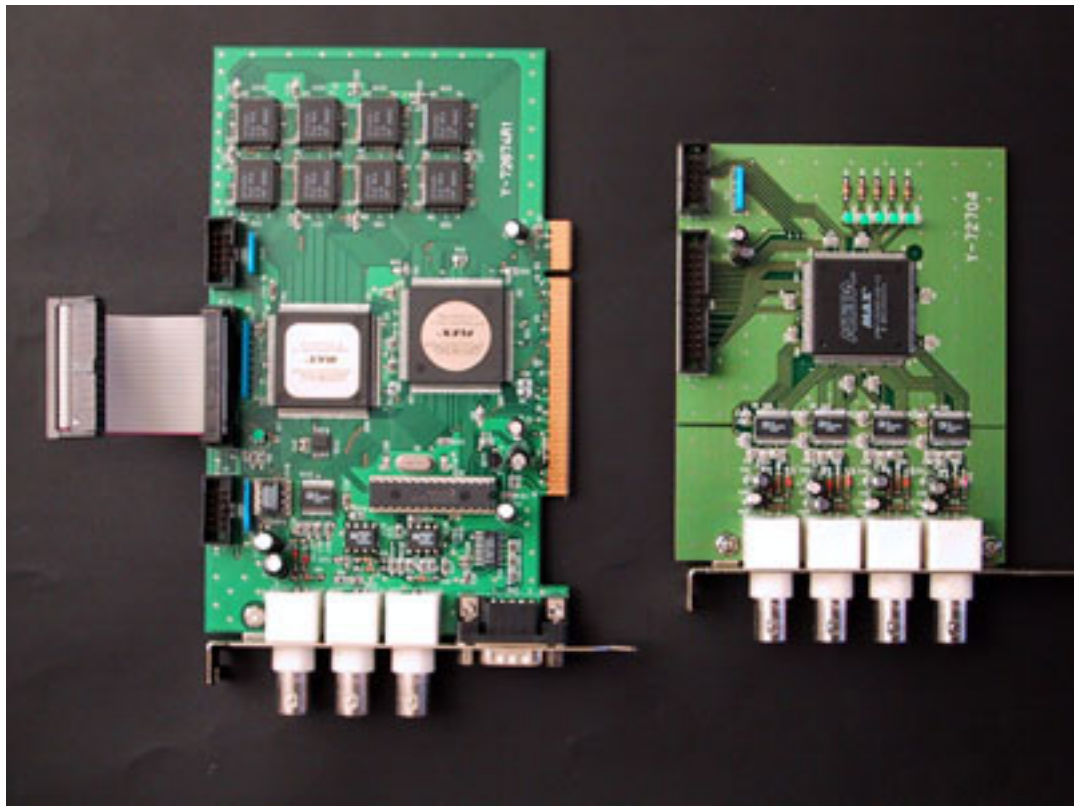
K5 Data Acquisition System for e-VLBI with IP

- 4 Pentium PCs
  - CPU : Pentium-4
    - 1.2GHz (1st Unit)
    - 2.4GHz (2nd Unit)
  - OS : FreeBSD (Linux is also possible)
  - An IP-VLBI board (PCI) in each PC
  - 120Gbyte HDx4x4 ~ 2.8days@64Mbps
- 16ch base-band signal amplifier
- Standard Signal Distributor
  - 10MHz and 1PPS signals for 4 units

K5 System Data Flow



PCI Data Sampling Board (IP-VLBI Board)

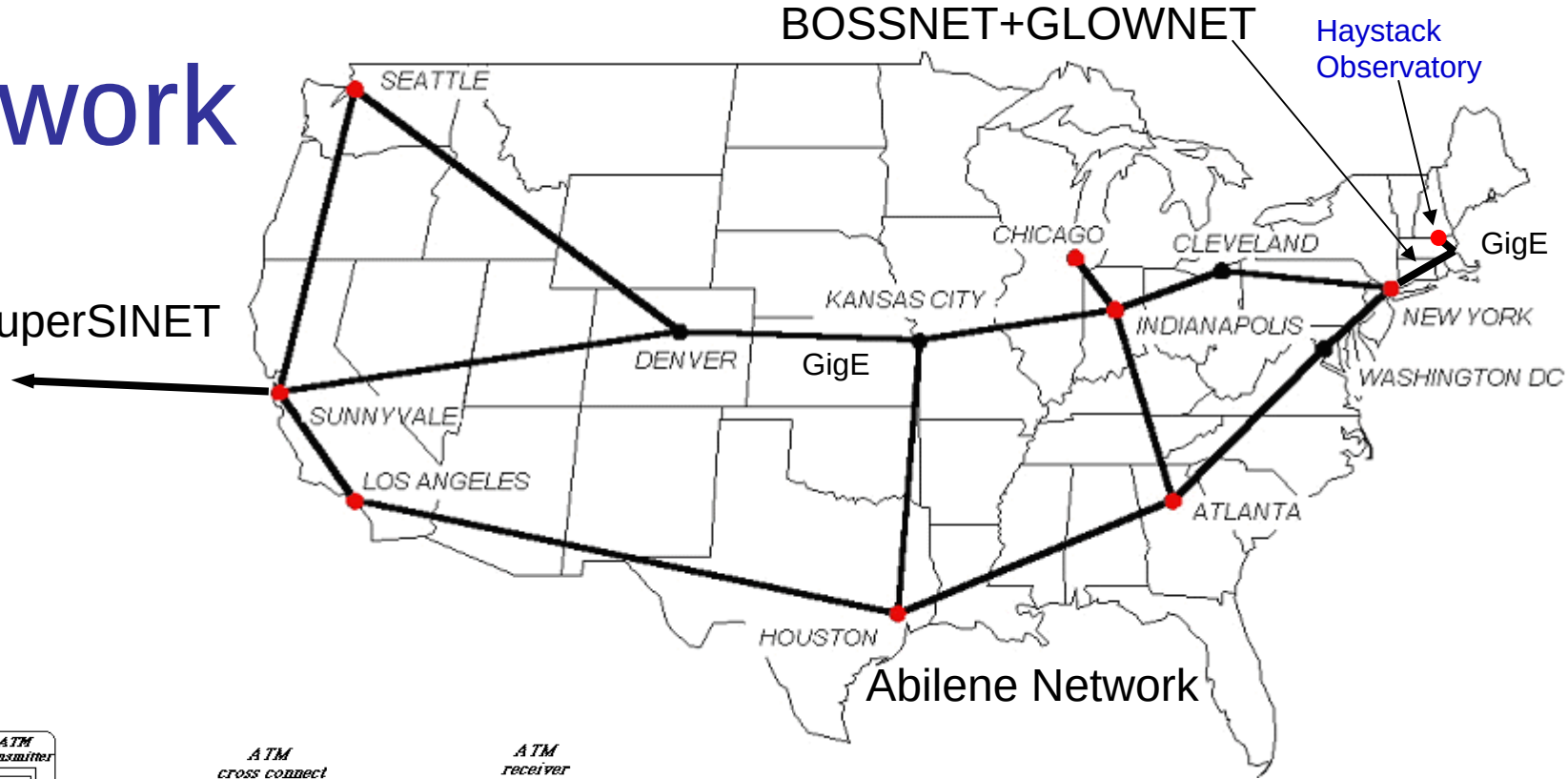


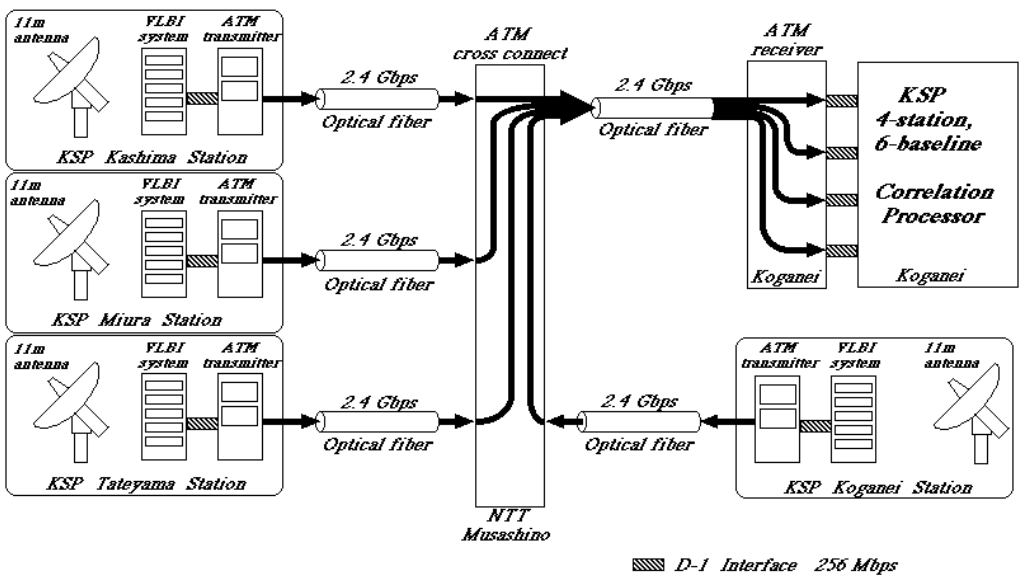
Left : Main board
Right : Auxiliary board

Specifications of the board

Reference signals	10MHz +10dBm, 1PPS
# of INPUT CH	1 - 4ch
A/D	1, 2, 4, 8 bits
Sampling Freq.	40kHz, 100kHz, 200kHz, 500kHz, 1MHz, 2MHz, 4MHz, 8MHz, 16MHz

Network



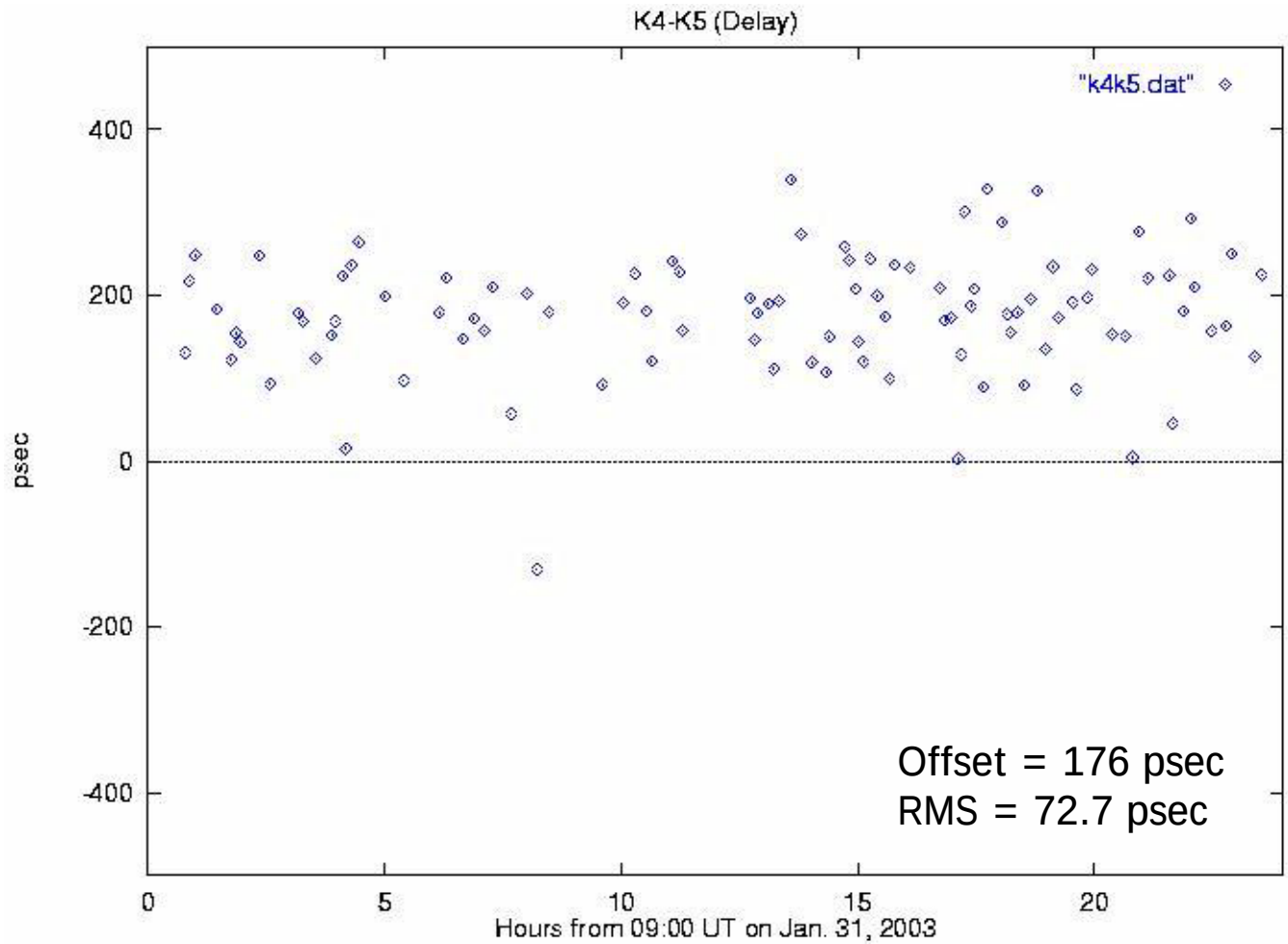


Galaxy Network

Test Experiments 1

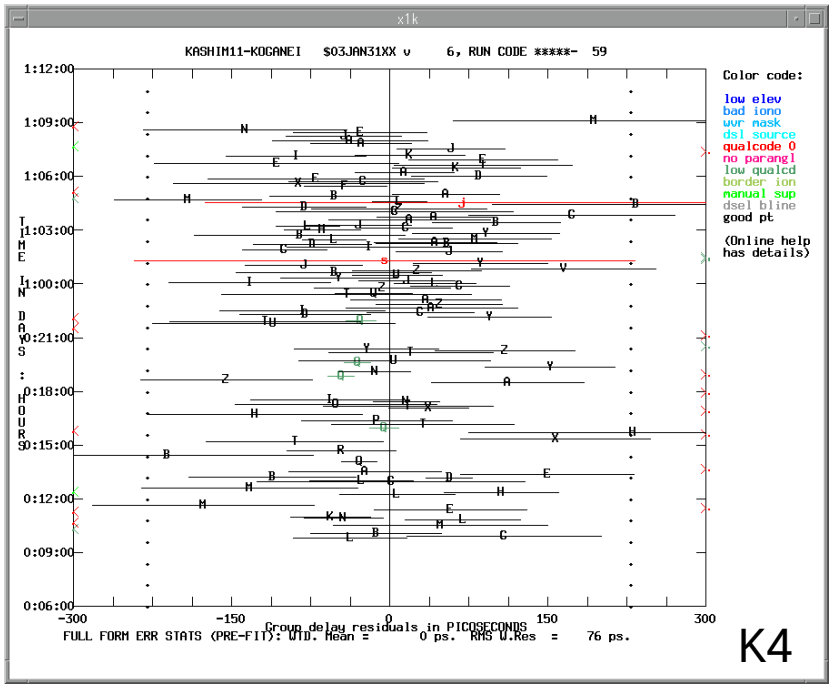
- Jan.31-Feb.1, 2003
  - Kashima11m(K5)-Koganei11m(K5)
  - 24 hours, 56Mbps
  - Comparison with K4

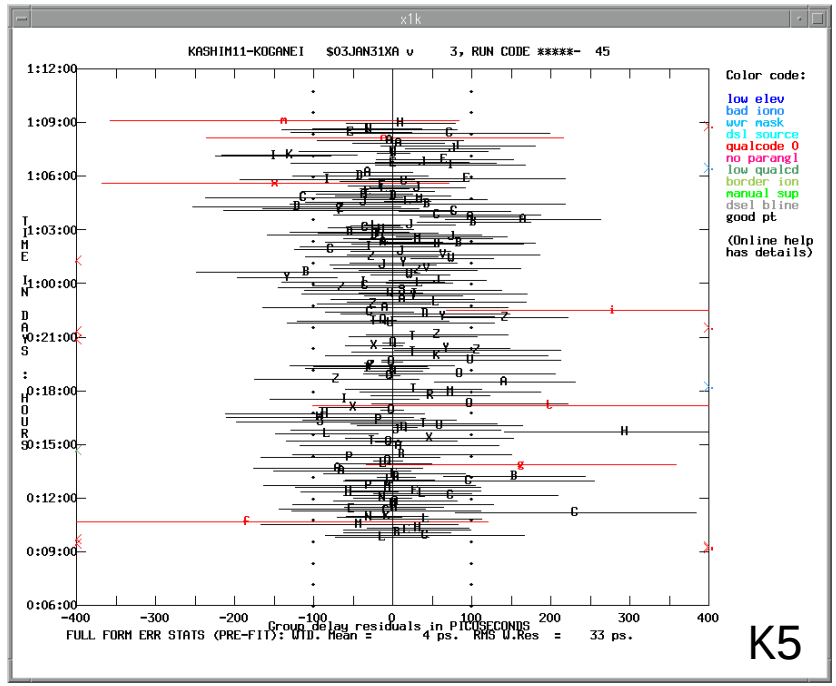
K4-K5 comparison



K4-K5 comparison

Delay Residual





Data Analysis Results

	Baseline Length	Delay RMS	Delay Rate RMS
K4	109099657.0±6.7mm	76 psec	136 fsec/sec
K5	109099641.2±3.2mm	33 psec	92 fsec/sec

Test Experiments 2

- Mar. 25, 2003 (evlbi4)
  - Westford (Mk5)-Kashima34m(K5), 2 hours, 56Mbps
  - Fringes were found on Mar. 27!

	Source Name	Duration (sec)	File Size (Mark5)	File Size (K5)
1	4C39.25	90	1,620 Mbytes	180 Mbytes x 4
2	1736+455	200	3,600	400 x 4
3	1357+769	90	1,620	180 x 4
4	0059+581	250	4,500	500 x 4
5	2234+282	310	5,580	620 x 4
6	1300+580	140	2,520	280 x 4
7	0955+476	90	1,620	180 x 4
8	2113+293	300	5,400	600 x 4
9	1739+522	500	9,000	1,000 x 4
10	1357+769	90	1,620	180 x 4
11	0059+581	270	4,860	540 x 4
12	2234+282	510	9,180	1,020 x 4
13	1044+719	784	1,4112	1,568 x 4
14	1128+385	180	3,240	360 x 4
15	1300+580	130	2,340	260 x 4
16	0955+476	90	1,620	180 x 4
17	2113+293	390	7,020	780 x 4
18	1739+522	530	9,540	1,060 x 4
19	1357+769	90	1,620	180 x 4
Total		5,034	90,612 Mbytes	40,272 Mbytes

File Transfer ~ 20 hours

Delay = 234 msec
Buffer Size = 64 kbytes
Speed
= 2.2 Mbps / Connection
= 11 Mbps (5 connections)

Correlation ~ 20 hours with 1 PC

Bandwidth Synthesis ~ 10 min.

Data Analysis ~ 1 hour

UT1-TAI
= -32338.7280 +/- 23.90
(micro sec)

Future Plan

- Repeat ftp-VLBI with Kashima-Westford a few times
  - Speed up by expanding buffer size
  - Try 256 Mbps observations
- Develop Correlator CPU Array System in 2003
- Software developments for real-time data transfer in 2003
- Regular (weekly) Mk5-K5 e-VLBI using Tsukuba-Westford baseline in 2004

Acknowledgements

- Internet2
- SuperSINET
- Galaxy team (CRL, NTT, NAO, and ISAS)
- Haystack Observatory, MIT