

# Real-time high volume data transfer and processing for e-VLBI

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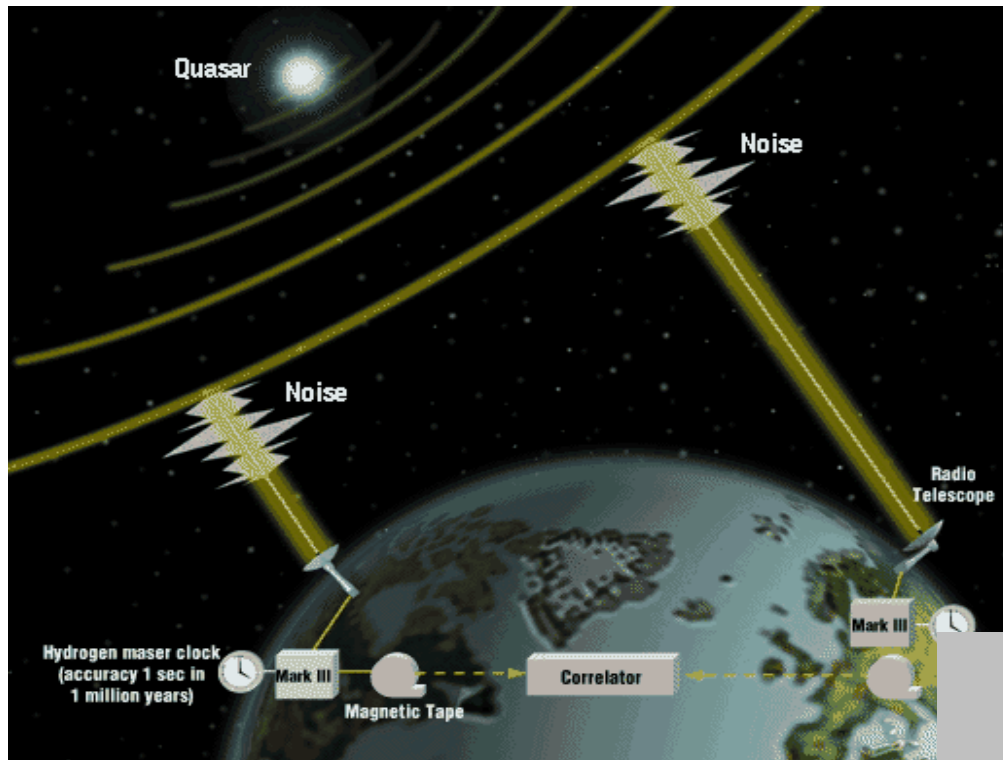
# Outline

- ◆ What is e-VLBI? Why e-VLBI is necessary?
- ◆ How?
  - K5 VLBI System ~ Standardization
  - Network
- ◆ Test Experiments
  - June 2004 : Near-Realtime UT1 Estimation
  - January 2005 : Realtime Processing Demo
- ◆ Future Plan

## Traditional VLBI

# The Very-Long Baseline Interferometry (VLBI) Technique

(with traditional data recording)



**The Global VLBI Array**  
(up to ~20 stations can be used simultaneously)

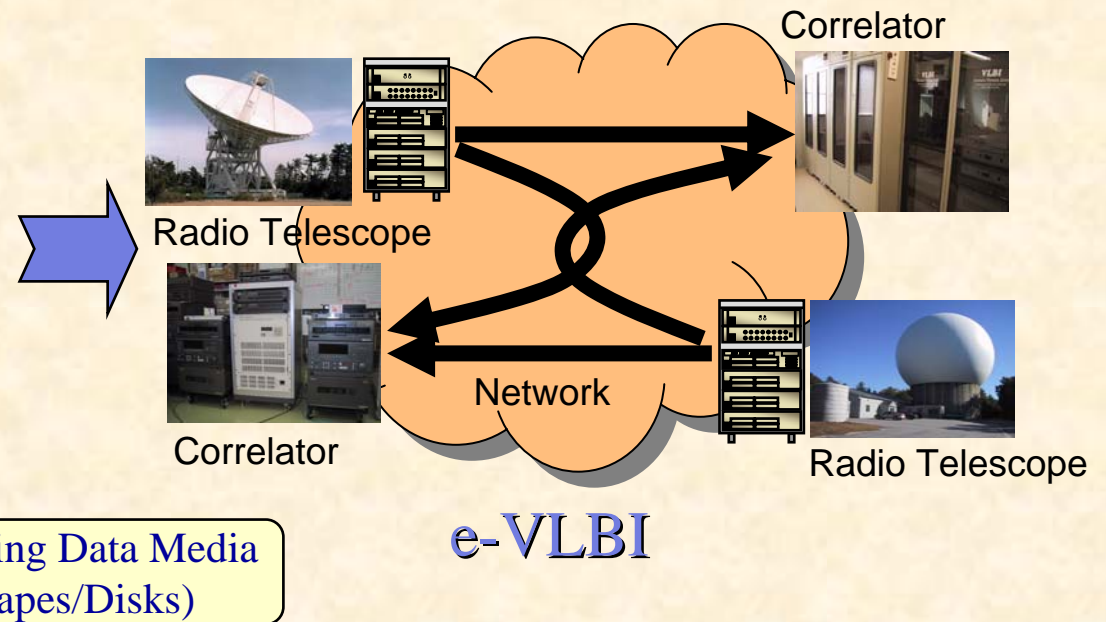


# What is e-VLBI?

VLBI=Very Long Baseline Interferometry

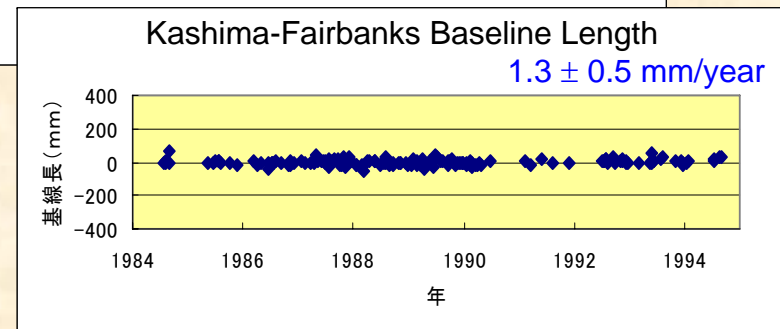
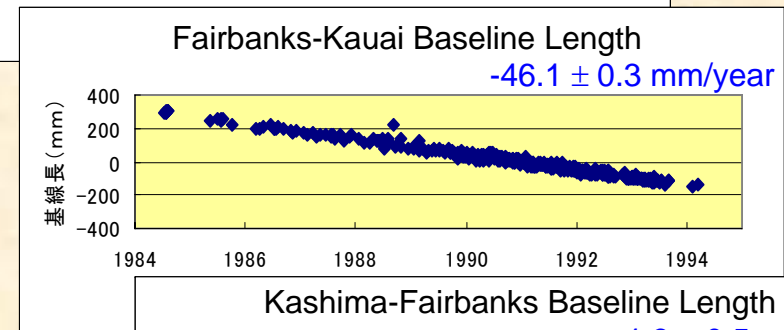
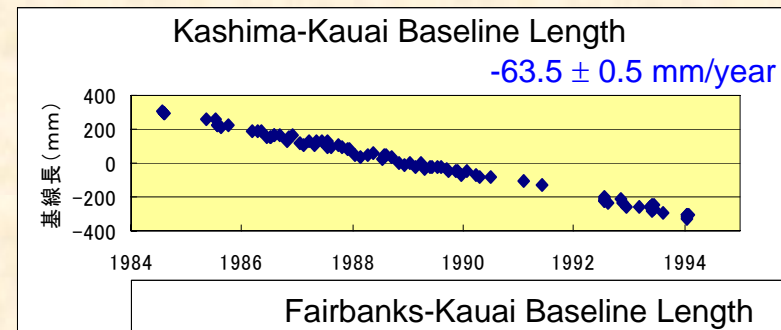
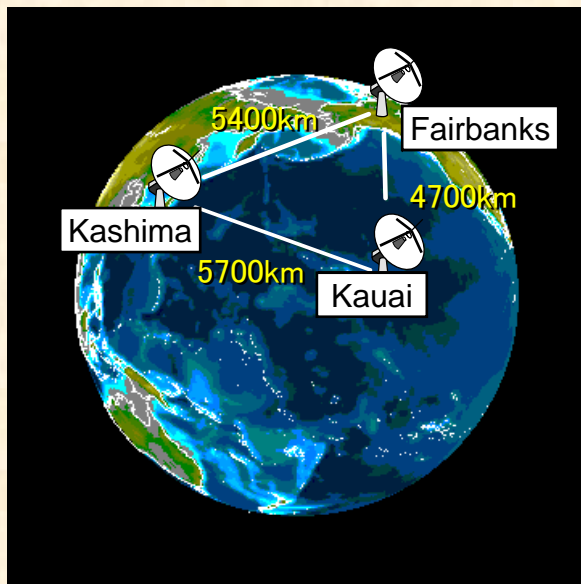


Conventional VLBI



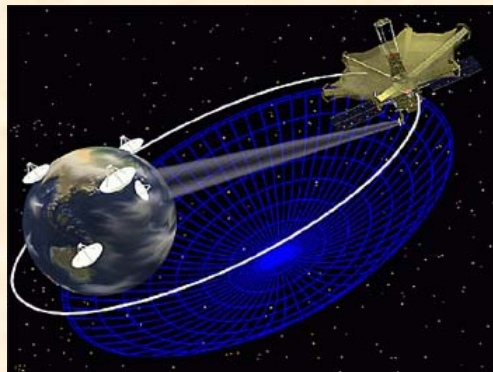
# VLBI Applications

- ◆ Geophysics and Plate Tectonics



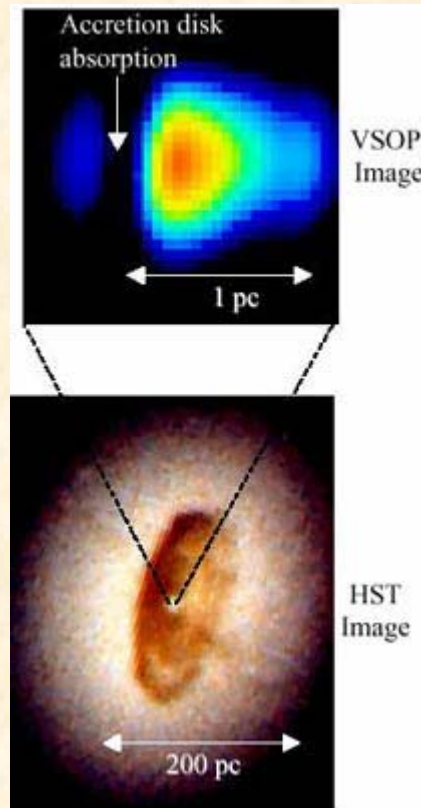
# VLBI Applications (2)

- ◆ Radio Astronomy : High Resolution Imaging, Astro-dynamics
- ◆ Reference Frame : Celestial / Terrestrial Reference Frame
- ◆ Earth Orientation Parameters, Dynamics of Earth's Inner Core

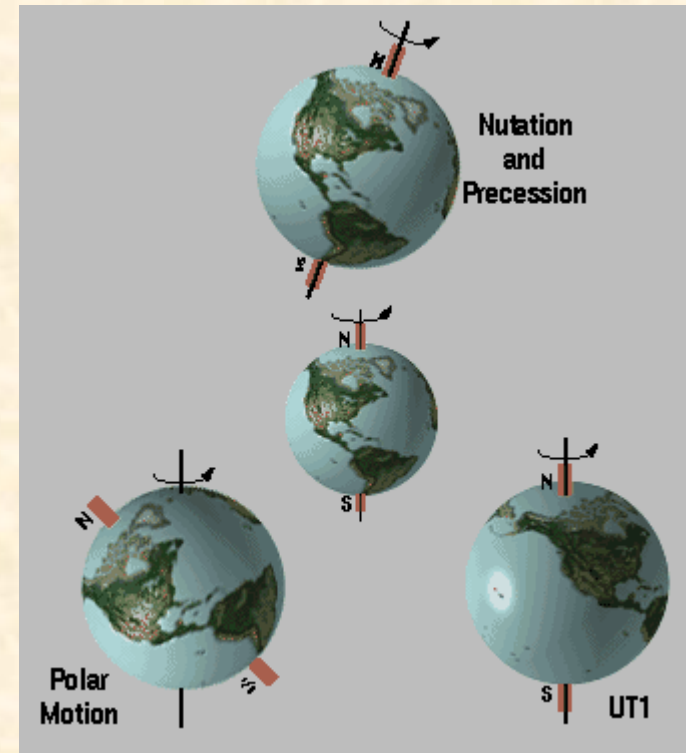


Halca (Muses-B)

Radio Telescope Satellite  
'Halca' and its images



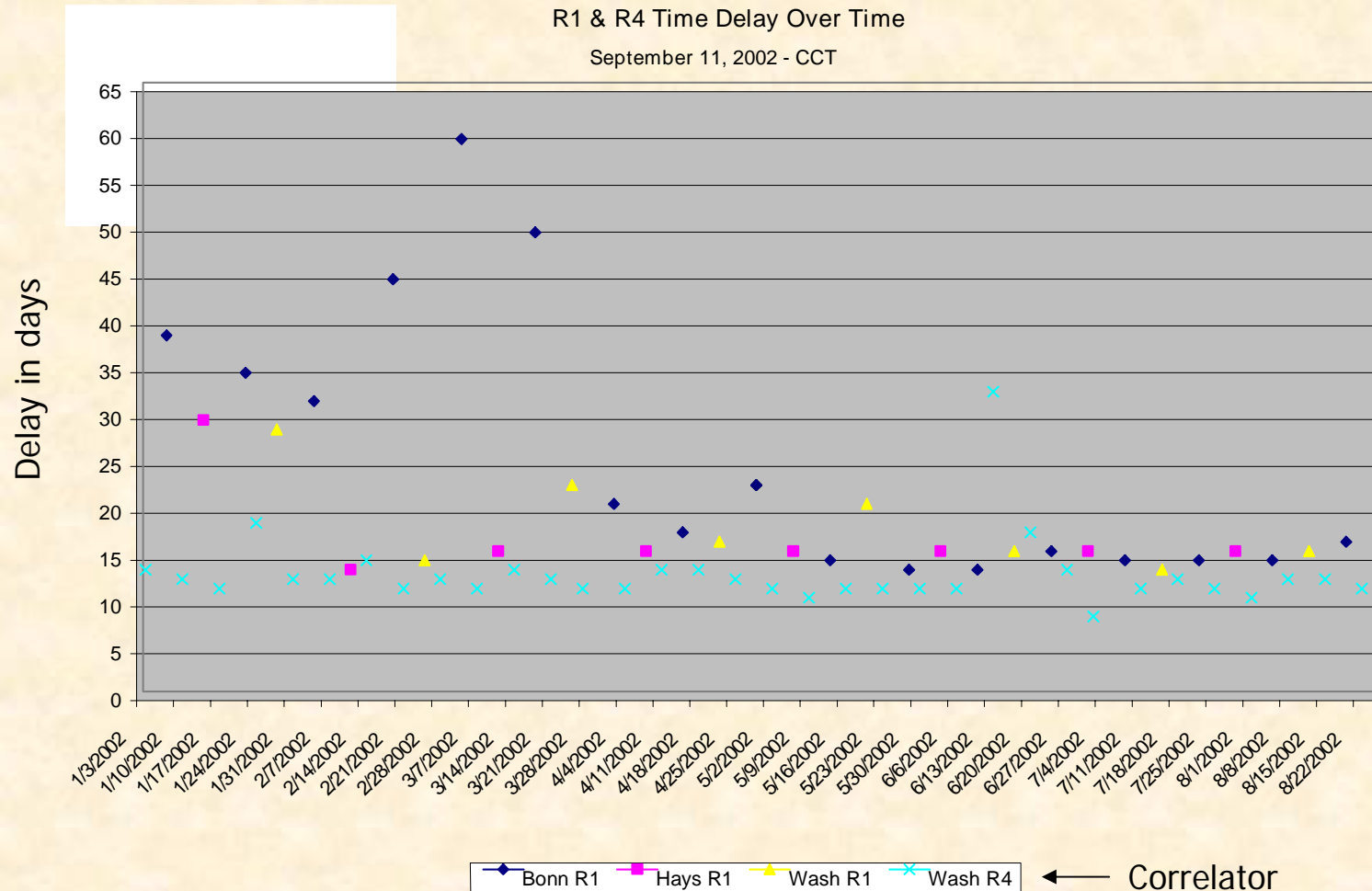
NGC4261



Earth Orientation Parameters

# Why e-VLBI?

To improve timeliness of global VLBI data processing



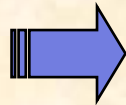
# Why e-VLBI?

- ◆ Currently it takes 1 week or more 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



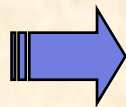
# VLBI - Characteristics

- ◆ Observing Bandwidth  $\propto$  Data rate  
 $\propto$  (Precision of Time Delay)<sup>-1</sup>  
 $\propto$  (SNR)<sup>1/2</sup>



Faster Data Rate = Higher Sensitivity

- ◆ Wave Length / Baseline Length  $\propto$  Angular Resolution
- ◆ Baseline Length  $\propto$  (EOP Precision)<sup>-1</sup>



Longer Distance = Better Results

# History of VLBI System R&D



K3 Correlator (Center)  
K3 Recorder (Right)

## K3 System

1983~  
Longitudinal Recorder  
Open Reel Tapes  
Hardware Correlator



KSP Backend

## K4 (KSP) System

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



KSP Correlator



K5 Data Acquisition Terminal

## K5 System

2000~  
PC based system  
Hard Disks  
Software Correlator  
e-VLBI with IP

# K5 system

ADS3000  
(2048Msample/sec 1ch 8bits + FPGA)



ADS1000  
(1024Msample/sec 1ch 1 or 2bits)



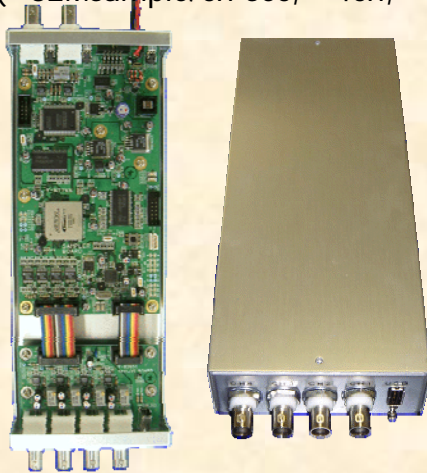
ADS2000  
(64Msample/ch·sec, 16ch, 1 or 2bits)

PC-VSI Board  
(~2048Mbps)



VSI

K5/VSSP32 Unit  
(~32Msample/ch·sec, ~4ch, ~8bits)



VSI = VLBI Standard Interface  
(or Versatile Scientific Interface)

VSI

Correlator  
other DAS

Internet



PC : Data Acquisition  
Correlation

# e-VLBI with the K5 system

- ◆ Flexible combination of component units
  - Supports variety of observation modes
    - 40ksps~2048Msps, 1bit~8bits/sample, 1ch~16ch~
  - Scalable, extensible, and sustainable system
  - Maintain and promote compatibility and connectivity by adopting various standards
    - VSI-H, VSI-S, VSI-E, file naming convention
- ◆ Being developed to realize global e-VLBI
  - near real-time VLBI : already in practice for IVS sessions ~ data transfer, parallel correlation processing
  - real-time VLBI : IP, VSI-E

# Recent developments of K5 system

- ◆ USB2.0 version of K5/VSSP = K5/VSSP32
  - up to 64Msps sampling each channel
  - supports up to 1024Mbps with 16 channels
  - no need to have PCI extension bay
- ◆ VSI-S implementation to K5/VSI system
  - succeeded to control the unit from fs9 by developing VSI-S command interpreter program modules (N. Takahashi at Yamaguchi Univ.)

# Concept of the K5 System

	K3	K4	K5
Data Recorders	Magnetic Tapes Longitudinal Recorders	Magnetic Tapes Rotary Head Recorders	Hard Disks
e-VLBI	Telephone Line	ATM	IP
Correlators	Hardware	Hardware	Software
	1983~	1990~	2002~
	M96 Recorder, K3 Formatter, K3 VC, K3 Correlator	DIR-1000, -L -M, DFC1100, DFC2100, K4 VC (Type-1, 2), TDS784, ADS1000, GBR1000, GBR2000D, K4 Correlator, KSP Correlators, GICO, GICO2	K5/VSSP, K5/VSSP32, K5/VSI, ADS1000, ADS2000, ADS3000, Software Correlatos (cor, fx_cor, GICO3)

# K5 Family : Selection of Samplers (1)

	K5/VSSP	ADS1000	ADS2000
Sampling Speed	40, 100, 200, 500kHz, 1, 2, 4, 8, 16MHz,	1024MHz	64MHz
Sampling Bits	1, 2, 4, 8	1, 2	1, 2
No. Channels	1, 4, 16 (with 4PCs)	1	16
Max. Data Rate	512Mbps (with 4PCs)	2048Mbps	2048Mbps



K5/VSSP



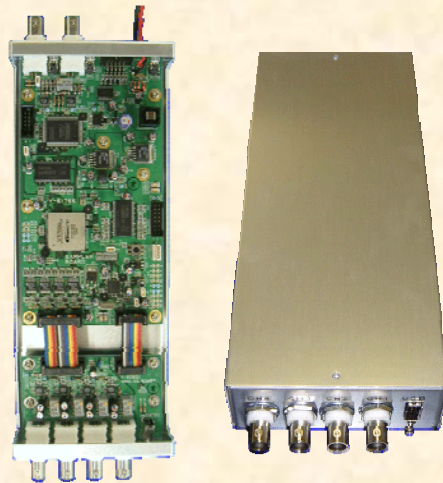
ADS1000



ADS2000

# K5 Family : Selection of Samplers (2)

	K5/VSSP32	ADS3000
Sampling Speed	40, 100, 200, 500kHz, 1, 2, 4, 8, 16, 32, 64MHz,	2048MHz
Sampling Bits	1, 2, 4, 8	8
No. Channels	1, 4, 16 (with 4PCs)	Programmable with FPGA
Max. Data Rate	1024Mbps (with 4PCs)	2048Mbps



K5/VSSP32



ADS3000



# K5 Data Acquisition System

- ◆ 4 Pentium PCs
  - CPU : Pentium-4
    - 1.2GHz (1<sup>st</sup> Unit)
    - 2.4GHz (2<sup>nd</sup> 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



# CPU array for Software Correlation

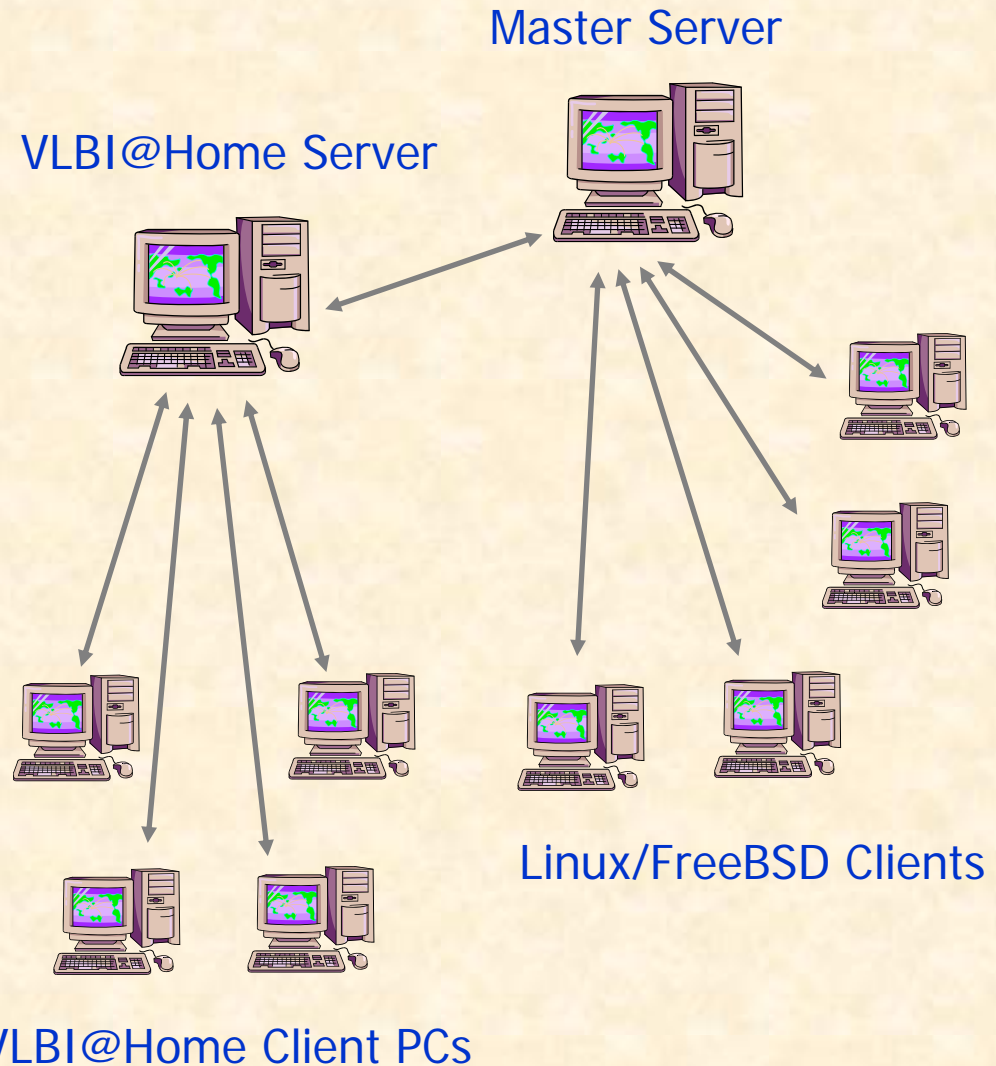
K 5 相関処理ステータス

通信総合研究所 島宇宙通信研究センター  
Communication Reserach Laboratory


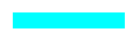


実験コード名	データ総数	処理済	処理中	処理待ち
JD0306	28	3	3	22

Obs	Baseline	Apri file	Mark	host	Start	Stop
1	KASHIMA-OIFU11	ape19702000RYc.bt	●	byakko	031118180719	031118183127
2	KASHIMA-OIFU11	ape197020610RYc.bt	●	seinyuu	031118180733	031118211308
3	KASHIMA-OIFU11	ape197021950RYc.bt	●	byakko	031118183128	031118113510
4	KASHIMA-OIFU11	ape197022640RYc.bt	●	seinyuu	031118211309	*****
5	KASHIMA-OIFU11	ape19702305RYc.bt	●	byakko	031118213511	*****
6	KASHIMA-OIFU11	ape19702305RYc.bt	●	K5la	031118213623	*****
7	KASHIMA-OIFU11	ape19702305RYc.bt	●	*****	*****	*****
8	KASHIMA-OIFU11	ape19702305RYc.bt	●	*****	*****	*****

Correlation Master Table



# Network Connection in Japan

-  GEMnet2/GALAXY
-  JGN2
-  Super Sinet
-  Future Plan

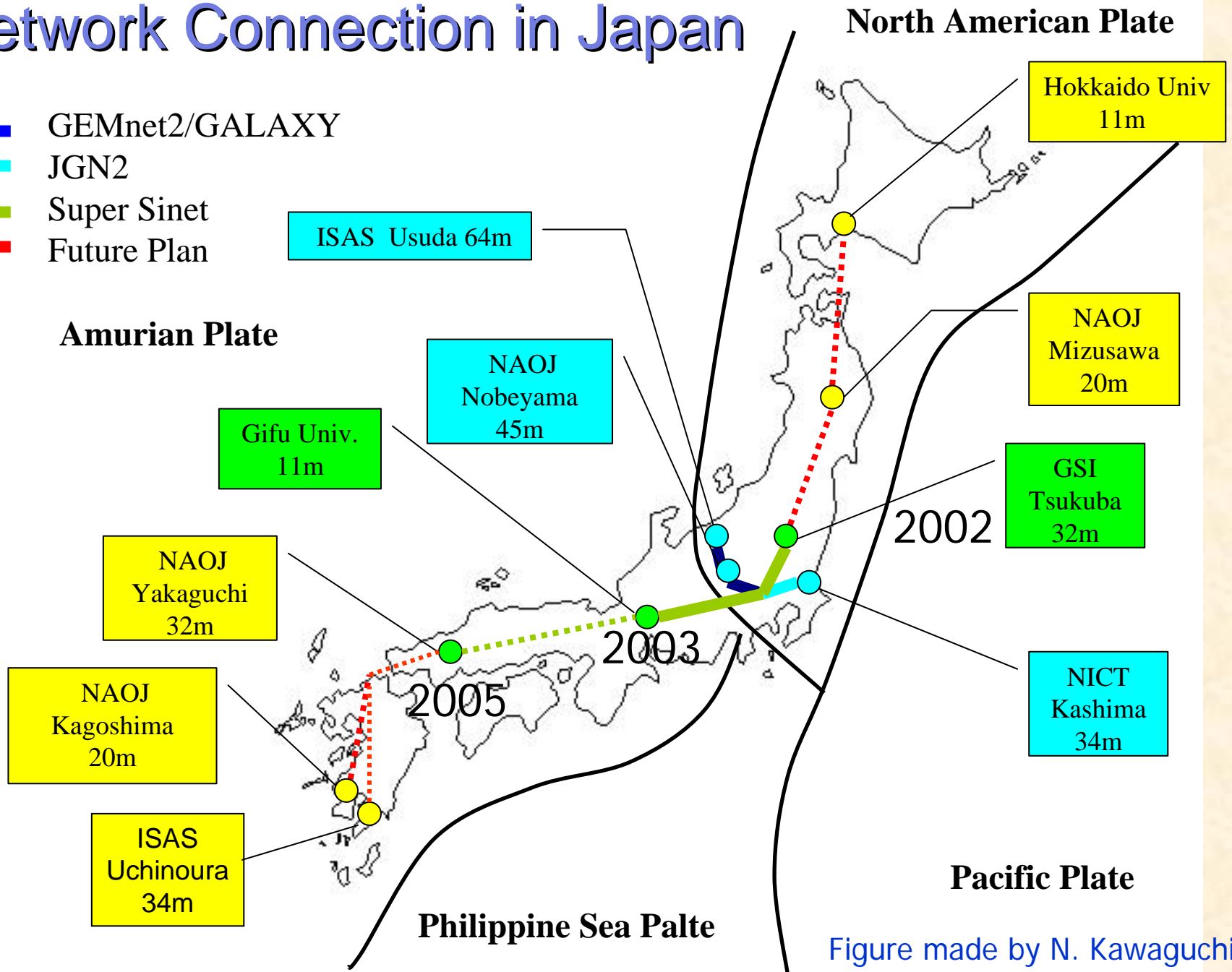


Figure made by N. Kawaguchi

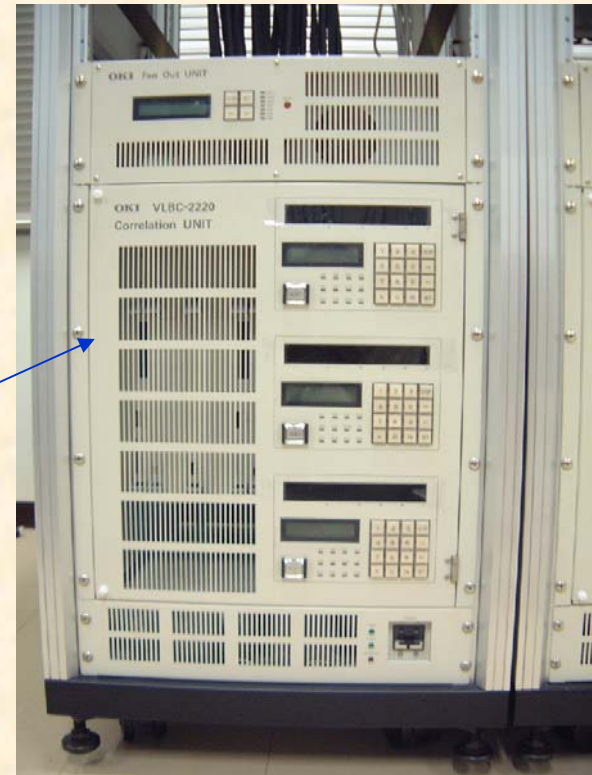
# ATM based real-time VLBI system



ADS-1000  
(A/D Sampler)  
: 1024Msps, 2bits AD

Distributed Correlator  
: 1024Msps, 2bits,  
3baselines  
(developed by NAOJ)

Network Access Unit  
(VOA-100) : OC48 x 2 (developed by NAOJ)



# UT1 Challenge with e-VLBI : June 29, 2004



Kashima 34m

Baseline Length : 9502km



Westford 18m

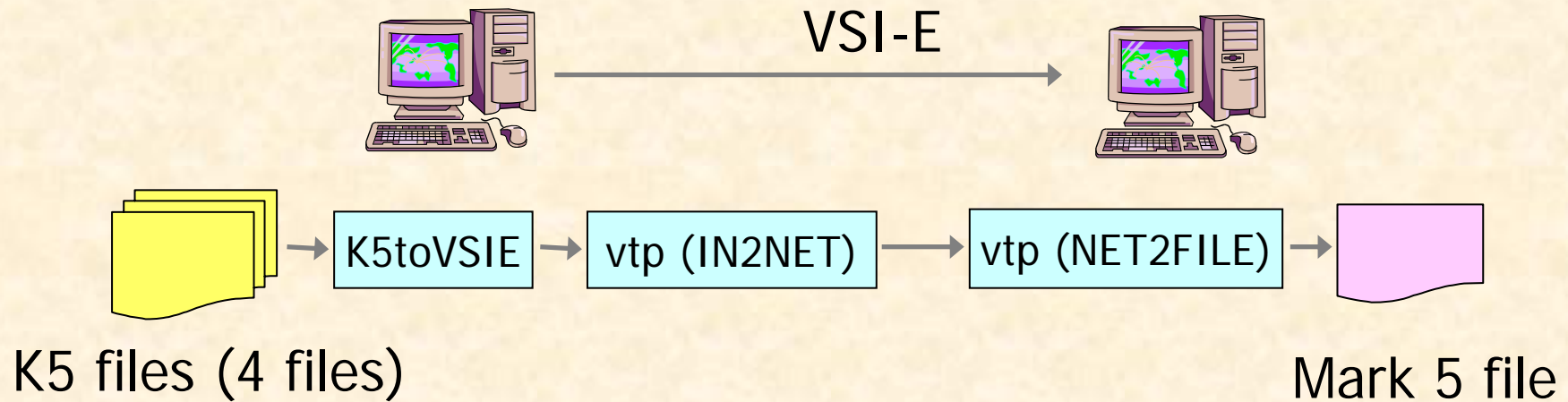
## ◆ Time Sequence (JST)

- 4:00 Observing Started
- 5:00 Observing Finished
- 5:13 Data Transfer Started (from Haystack to Kashima)
- 6:28 Data Transfer Finished (~30Mbps)
- 9:16 Correlation Processing Completed (used 20 CPUs)
- 9:30 Data Analysis Completed : UT1-UTC sigma=22 microsec.

New World  
Record!!

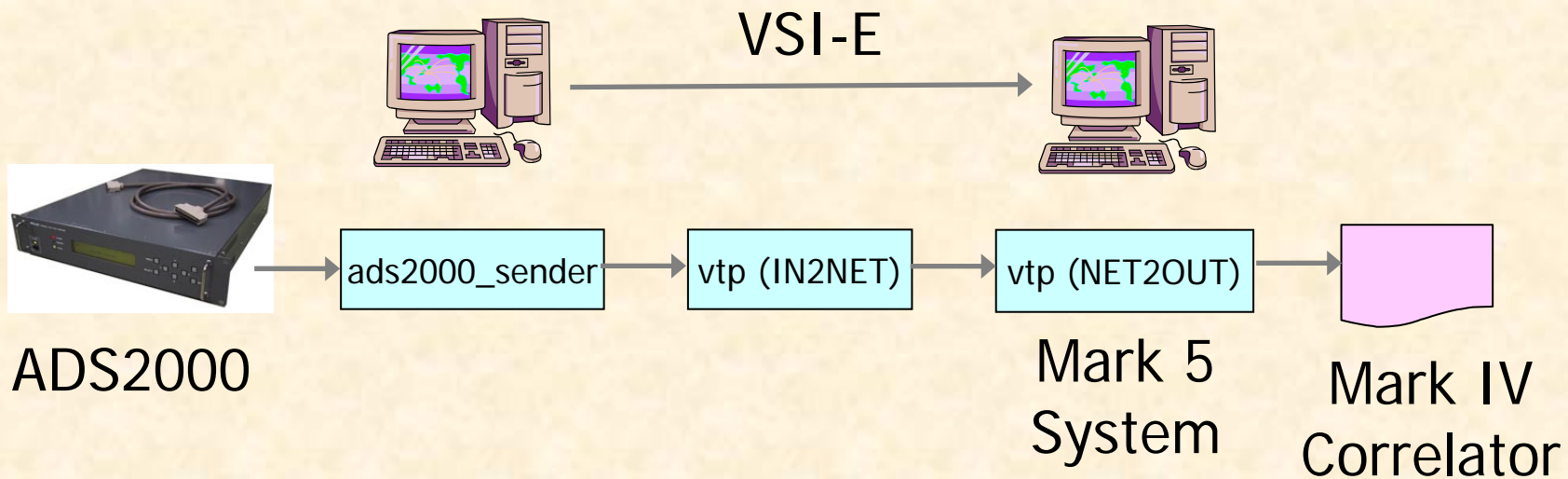
4.5 hours

# K5 - Mark 5 file conversion through VSI-E



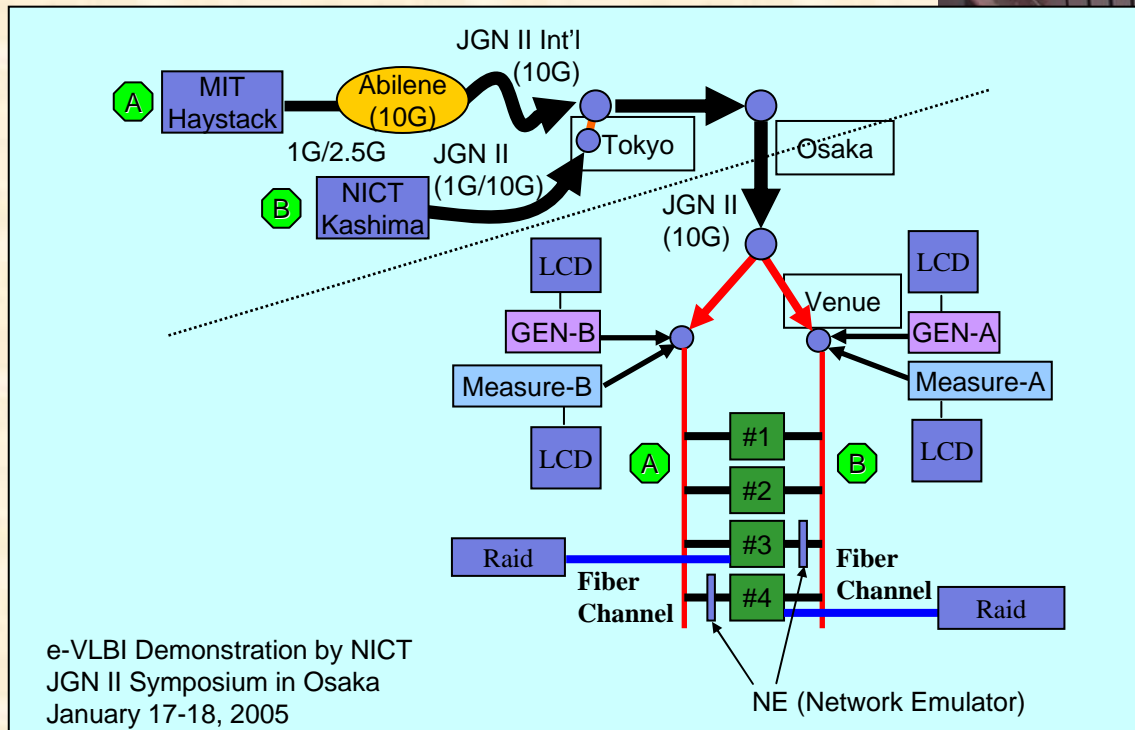
\* 'vtp' codes have been developed by David Lapsley and his colleagues at Haystack Observatory

# K5 - Mark 5 real-time correlation (in progress)



# Real-time software correlation demo

Real-time software distributed correlation was demonstrated at JGN2 symposium in Osaka (January 17-18, 2005). Fake random data were generated at Kashima and at Haystack and transferred to Osaka by using Abilene and JGN2.



The data were correlated by using 8 CPUs (Apple X-serve G5) and about 400Mbps throughput without fringe rotation processing was achieved (the speed was limited by the network data transfer).

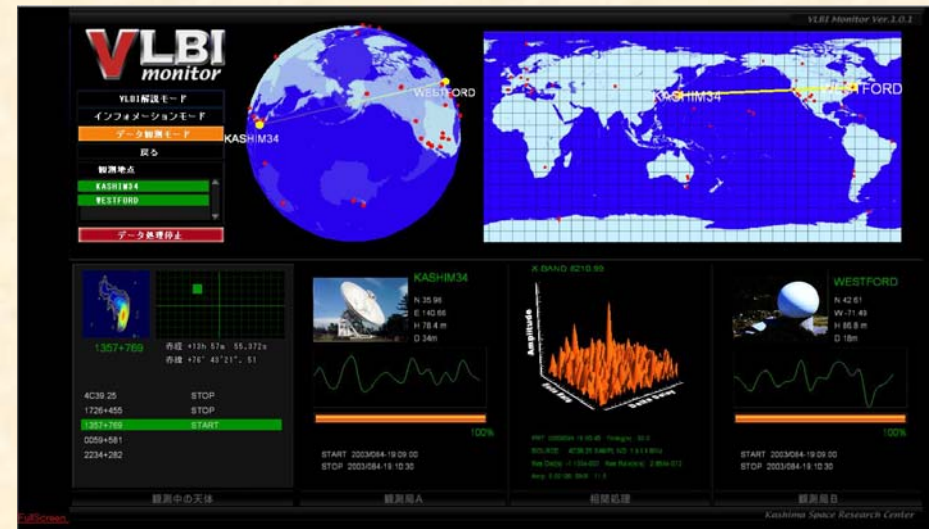


# Another recent event at Kashima

Emperor and Empress of Japan visited Kashima and they learned about e-VLBI (June 5, 2005)



Demonstration software was developed. The software was designed to be useful for actual operation.



# Huygens Probe Tracking : January 14, 2005

- ◆ Huygens probe was tracked by global VLBI network during its descent to the atmosphere of Titan on January 14, 2005.
- ◆ Purpose was to investigate atmosphere of Titan.
- ◆ The new network connection was established between Shanghai and Kashima and was used for data transfer (average transfer rate was 22.2 Mbps).
- ◆ Participated VLBI Stations
  - China (Shanghai and Urumqi)
  - Japan (Kashima)
  - Netherlands (Westerbork)
  - USA (Green Bank and 8 VLBA stations)
  - Australia (Ceduna, Hobart, Mopra, Parkes and ATCA)



# Remaining Issues

- ◆ Realize global-scale 'real-time' operation of e-VLBI
- ◆ Promote standardized data transfer protocol (VSI-E)
- ◆ Remove bottle-necks for high-speed AD sampling and real-time processing
  - Faster AD sampling
  - Faster interfacing (PCI=>PCI Express=>Optical Link)
  - Efficient data transfer over the shared networks
  - Global GRID data processing
- ◆ Expand the experiences learned with e-VLBI to other scientific applications

# Acknowledgements

- ◆ Haystack Observatory for various e-VLBI activities
  - Jason SooHoo : routine administration for data transfer
  - Chester Ruszczyk, Kevin Dudevoir, Mike Titus, and Alan Whitney : developments for VSI-E data transfer of K5 system
- ◆ JIVE, Univ. Tech. Vienna, ATNF CSIRO, Istituto di Radioastronomia INAF, NRCAN, KVN, Shanghai Observatory CAS, and MERLIN for valuable feedbacks to improve software correlator
- ◆ NAOJ, GSI, JAXA/ISAS, NIPR, NTT Lab., KDDI Lab., Yamaguchi Univ., Gifu Univ., Kagoshima Univ., and Hokkaido Univ. for e-VLBI collaboration in Japan
- ◆ JGN2, TransPAC2, Abilene, GEMnet2/GALAXY, SuperSINET, and APAN networks for their supports to e-VLBI