

SA1: Production e-VLBI service

Arpad Szomoru
JIVE



Outline

- e-VLBI in practice
- Work packages
- Soft- and hardware developments

e-VLBI science/test runs

- 12 e-VLBI science projects accepted:
 - 2 failed
 - 3 Target of Opportunity (Cygnus X-3, GRS1915+105)
 - 3 determination of compactness of calibrator or target
 - 3 part of multi-wavelength campaign
 - 1 adaptive observation of 16 X-ray binaries (no detections..)
- Rapid access to EVN provides clear benefit to users (important for calibrator/multi-wavelength projects)
- Follow up of bursting transients only moderately successful
 - ❖ two week delay between proposal deadline and actual observations is simply still too long

e-VLBI: operational improvements

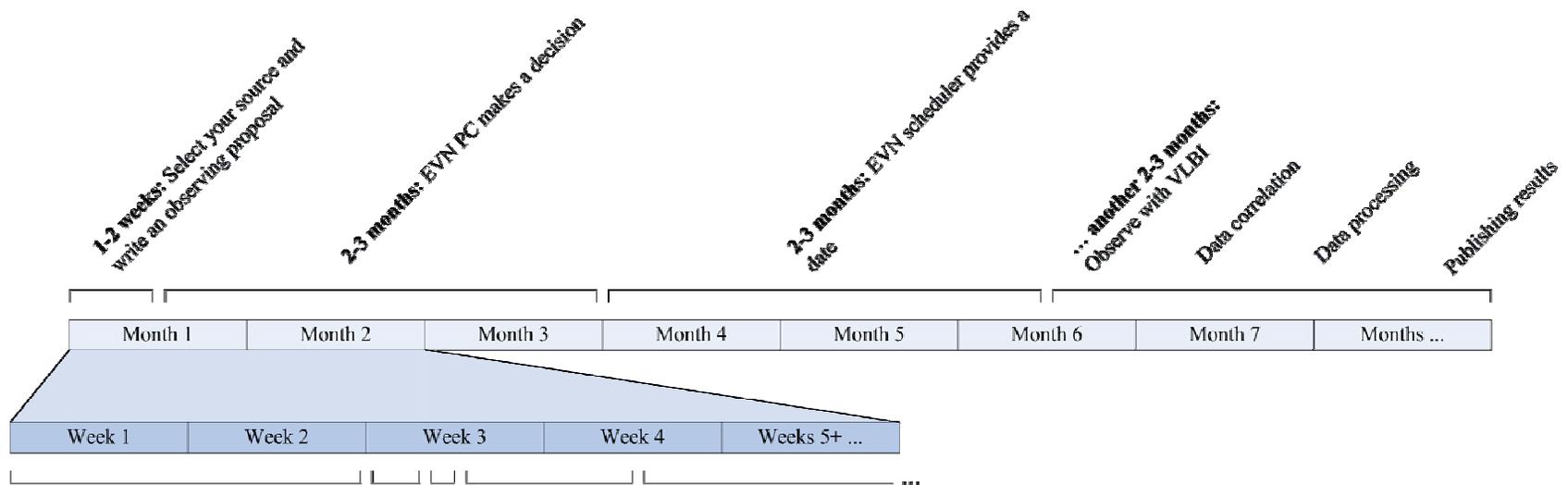
- Overall improvement in first year:

- Robustness
- Reliability
- Speed
- Ease of operation
- Station feedback

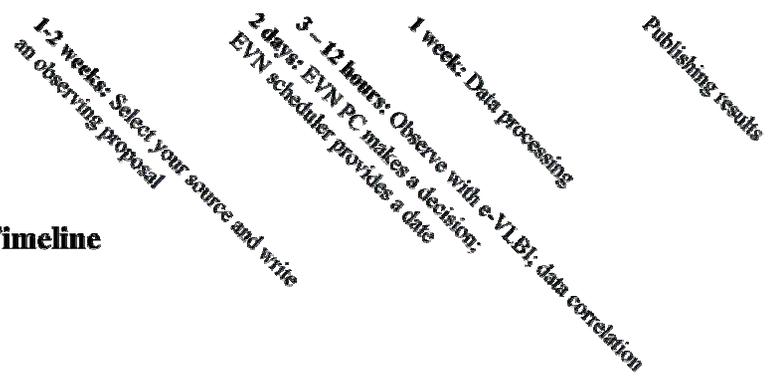


- Minimizing data loss by careful scheduling
- Increase of production data rate from 128 Mbps to 256 Mbps
- 5-station fringes at 512 mbps
- Inclusion of Metsähovi and Medicina telescopes

Traditional VLBI Timeline



e-VLBI Timeline

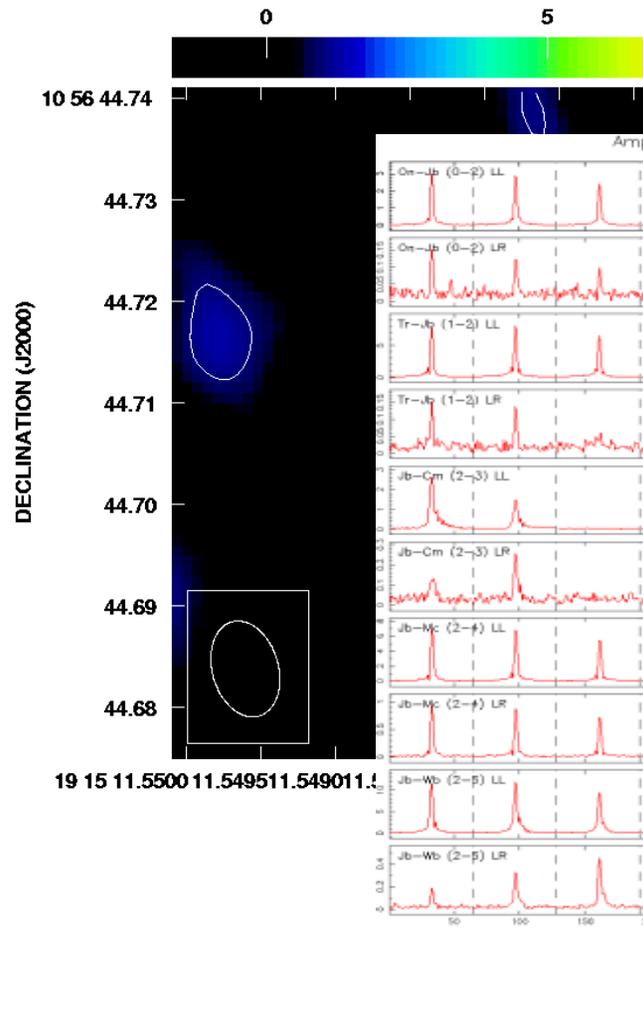


Test cases: black holes in outburst

- Data processing took 1-2 weeks with first images within 48 hours

- Publication took less than 2 months

e-VLBI results



Clean I map. Array: EVN
3C454.3 at 5.006 GHz 2007 Feb 02

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First e-VLBI observations of GRS1915+105

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Accepted XXXX XXXX. Received XXXX XXXX. Original form XXXX XXXX

ABSTRACT
We present results from the first successful open cell e-VLBI run on the X-ray binary GRS1915+105. e-VLBI scanner modes enable the rapid production of VLBI radio maps within hours of an observation rather than weeks, facilitating a decision for follow-up observations. 6 telescopes observing at 5 GHz across the European VLBI Network (EVN) were correlated at Jodrell Bank for VLBI in Europe (JIVE) in real time. Data rates of 128 Mbit s⁻¹ were transferred from each telescope, giving 4 TB of raw sampled data over the 12 hours of the whole experiment. Throughout this, GRS1915+105 was observed for a total of 3.5 hours, producing 2.6 GB of recorded visibilities of correlated data. A weak flare occurred during our observations, and we detected a slightly resolved dipole component of 2.7 by 1.2 millifarcs and was detected at a position angle of 140° ± 2°. The peak brightness was 10.2 mJy per beam, with a total integrated radio flux of 1.1 mJy.

Key words: ISM: jets and outflows - X-ray binaries: individual (GRS1915+105).

1 INTRODUCTION
The use of the Internet for VLBI data transfer offers a number of advantages over conventional recorded VLBI, including improved reliability due to real time operation and the possibility of a rapid response to new and transient phenomena. Decisions on follow up observations can be made immediately after the observation rather than delayed by potentially weeks due to problems in alignment of tapes/disks to the correlator. The first specific call with a suitable CPU range for observations of GRS1915+105 using the EVN (European VLBI Network), gave us the opportunity to test e-VLBI under operational conditions. A number of test runs over the past few years have shown that 128 Mbit sec⁻¹ data rates can be sustained reliably to four 6 telescopes. Cambridge, Jodrell Bank, Medicina, Onsala, Tverre and Westerbork, within Europe, currently constitute the national and international network available to the Jodrell Bank for VLBI in Europe (JIVE) operation. Currently following in

not contact to the e-EVN network, limiting the sensitivity and resolution of the current array. Scope are currently being taken to improve the reliability of 256 and 512 Mbit s⁻¹ connections, with EXPRES¹ used to develop a stable 1 Gbit/sec production capacity network.

Microquasars are ideally suited for study by e-VLBI real time techniques since they often have flares associated with the spectrum of radio emitting plasma in the form of jets. These flares are in the range of hours to days at our wavelengths, and decisions about subsequent observations, if for instance an eruption has been observed, needs to be taken quickly.

GRS 1915+105 was first discovered in 1992 (Castro-Tirado et al. 1992) by the WATCH instrument on the GLEAMST satellite. The system has a low mass K-M III star (Castro et al. 2003b) companion and 14 (±4) M_⊙ black hole (Gierke et al. 2003a). It was the first galactic source to display superluminal motion, and is well known for its rapid

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First e-VLBI observations of Cygnus X-3

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Accepted XXXXXX. Received XXXXXX. In original form XXXXXX

ABSTRACT
We report the results of the first two 5 GHz e-VLBI observations of the X-ray binary Cygnus X-3 using the European VLBI Network. Two successful observing sessions were held, on 2006 April 20, when the system was in a quasi-quiet state several weeks after a major flare, and on 2006 May 18, a few days after another flare. At the first epoch we detected faint emission probably associated with a fading jet, spatially separated from the X-ray binary. The second epoch in contrast reveals a bright, curved, relativistic jet more than 40 millifarcs in extent. In the first, and probably also second epoch, the X-ray binary core is not detected, which may indicate a temporary suppression of jet production as seen in some black hole X-ray binaries in certain X-ray states. Spatially resolved polarisation maps at the second epoch provide evidence of interaction between the ejecta and the surrounding medium. These results clearly demonstrate the importance of rapid analysis of long-baseline observations of transients, such as facilitated by e-VLBI.

Key words: accretion, accretion discs – stars: individual: Cygnus X-3 – ISM: jets and outflows – radiation mechanisms: non-thermal – techniques: interferometric.

1 INTRODUCTION
The X-ray binary Cygnus X-3 was first detected in X-rays by Giacconi et al. (1967). The inflamed (e.g. Bevilacqua et al. 1973) and X-ray flares (e.g. Pongmanich et al. 1979) show a periodicity of 4.8 hours which is interpreted as the orbital period of the system. The nature of the compact object is not known (Schroeder, Gehrels & Schell 1996; Mirza 1999). As for the companion star, there is compelling evidence pointing toward a WN Wolf-Rayet star (van Kerkwijk et al. 1998; Fender, Hanson & Pooley 1999; Koch-Morén et al. 2002).

Great outbursts and large flares have been observed at radio wavelengths in Cygnus X-3 since 1972 (Gregory et al. 1972). In quiescence the soft X-ray emission is correlated with the radio emission, while the hard X-ray is anticorrelated with the radio. In a flare state, the situation is reversed: the hard X-ray correlates with the radio and the soft X-ray emission is anticorrelated (Watanabe et al. 1994; McLaughlin et al. 1995; Choudhury et al. 2002).

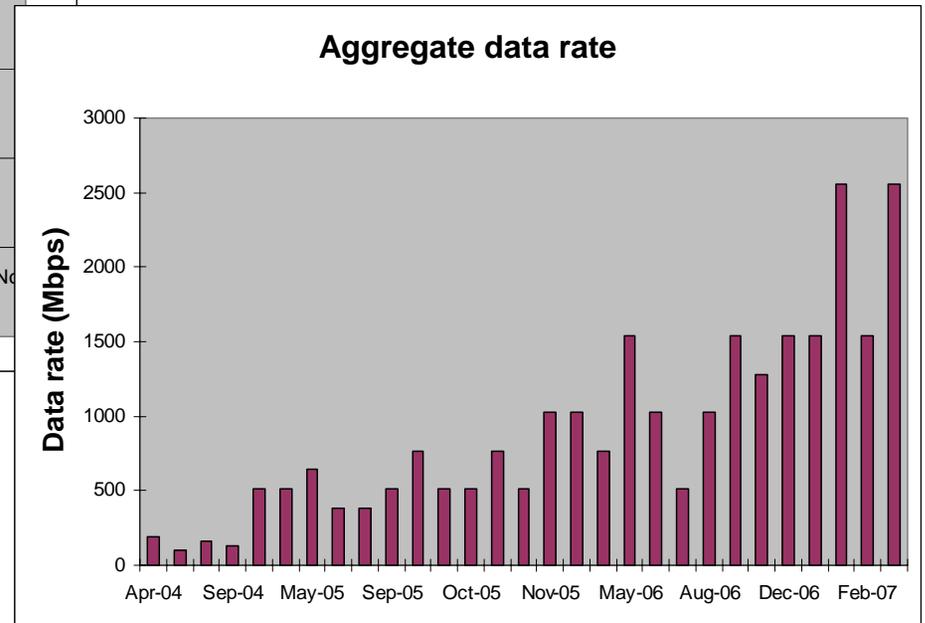
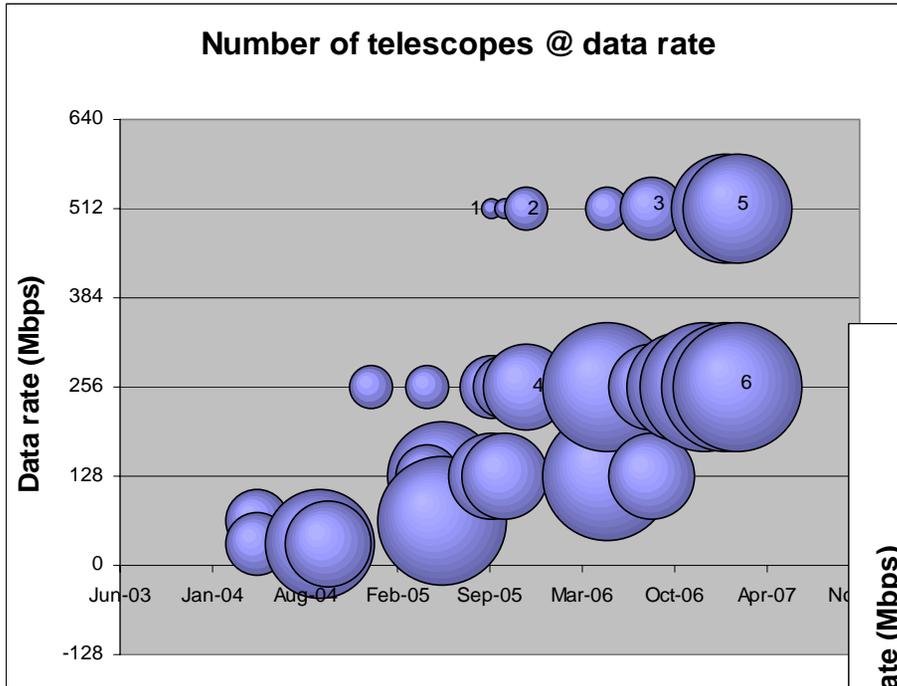
Great outbursts and large flares have been observed at radio wavelengths in Cygnus X-3 since 1972 (Gregory et al. 1972). In quiescence the soft X-ray emission is correlated with the radio emission, while the hard X-ray is anticorrelated with the radio. In a flare state, the situation is reversed: the hard X-ray correlates with the radio and the soft X-ray emission is anticorrelated (Watanabe et al. 1994; McLaughlin et al. 1995; Choudhury et al. 2002).

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e-VLBI: data rate improvements

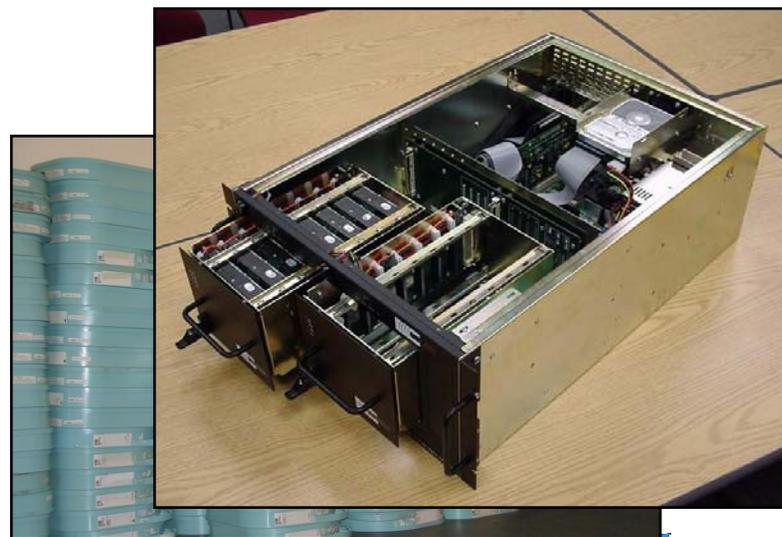


The EVN MarkIV correlator



Custom-made hardware,
~500000 lines of C++ code

Designed and built on tape
technology, only recently
adapted for disk-based
recording



Work packages

- Standard e-VLBI correlator mode:
 - Wall-clock time vs ROT
 - Centralized control
- Rapid response/ToO functionality:
 - Real-time monitoring/feedback/analysis
 - On-the-fly adjustment of observational/correlator parameters
 - Improved amplitude calibration
- Data transport issues
 - Lightpaths: guaranteed (high) bandwidth
 - Transport protocols (modified TCP, UDP-based, VSI-e...)
- Hardware issues
 - New control computers (reliability, speed)
 - Replacement of SUs (cause of much misery)
 - Networking hardware (router, interfaces)

e-VLBI correlator mode: control interfaces

controlstation at host: jaw0

Control MARK5 Unit at eVLBI stations

Help Dismiss

All 0 1 2 3 4 Jb 5 6 On 7 Cm 8 Wb 9 Tr 10 11 12 Mc 13 14 15

Start Mark5A Stop Mark5A Reboot Refresh Status

```

15:20:37 su 7: pingMark5 status = online
15:20:37 su 12: pingMark5 status = online
15:20:37 su 8: pingMark5 status = online
15:20:37 su 6: pingMark5 status = unknown
15:20:37 su 9: pingMark5 status = unknown
15:20:37 su 4: pingMark5 status = unknown
15:21:33 su 6: pingMark5 status = unknown
15:21:33 su 4: pingMark5 status = unknown
15:21:33 su 9: pingMark5 status = unknown
    
```

controlEvlbi at host: jaw0

Configuration and detection of eVLBI network parameters

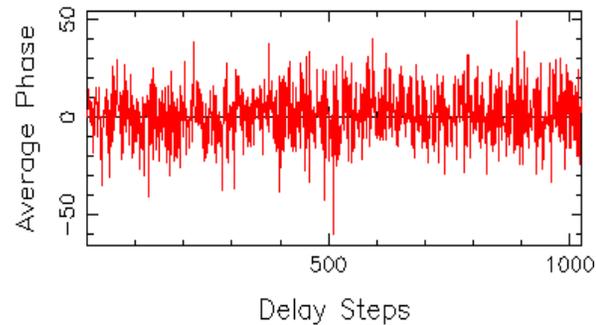
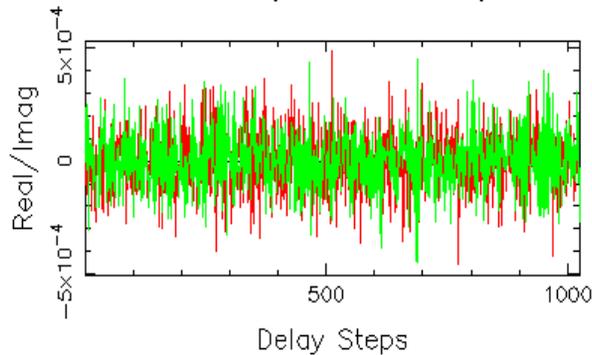
Help Send to database Dismiss

SU	Station	Ping control_ip	Ping data_ip	Congestion	Servo Error	Network	MTU	Sockbuf	Workbuf
4	Jb	Not online	Not online	0	No logfile	Restart	4470	8M	128K
6	On	1.000 ms	0.282 ms	0.036 MB	Not found	Restart	4470	8M	128K
7	Mc	31.000 ms	Not online	0	0 sec	Restart	1500	8M	128K
8	Wb	1.000 ms	0.266 ms	0.034 MB	Not found	Restart	9000	4M	128K
9	Tr	Not online	Not online	0	No logfile	Restart	4470	8M	128K
11									
12	Cm	1.000 ms	0.251 ms	0.004 MB	Not found	Restart	1500	8M	128K

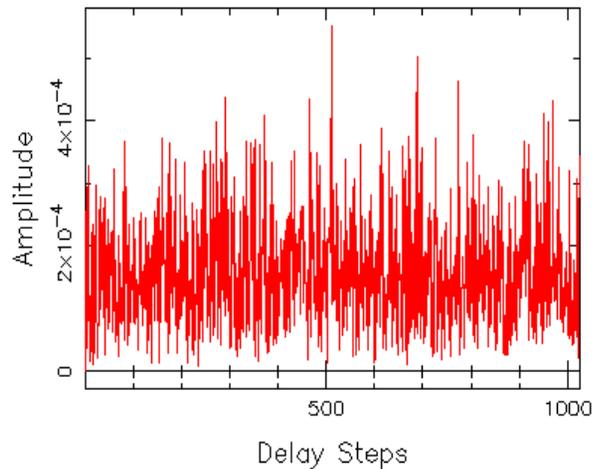
Set all buffers

Monitoring tools: Integrating fringe display

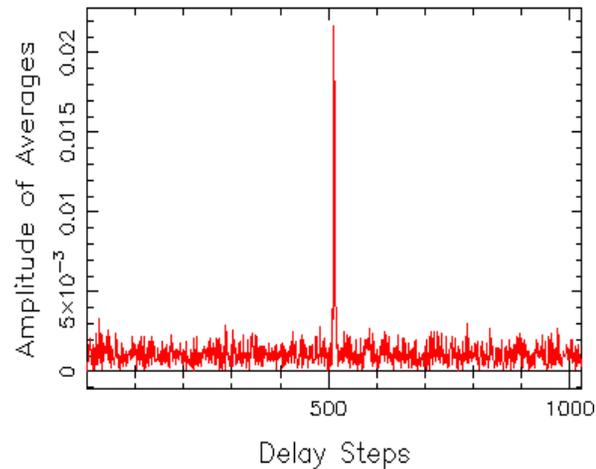
Plot 0: Intf 23 #Integrations 46; Time Tue Aug 22 09:06:54 2006
Subb 0; X Ant 0 Pol 1; Y Ant 5 Pol 1; Systck 1127262; Err 0



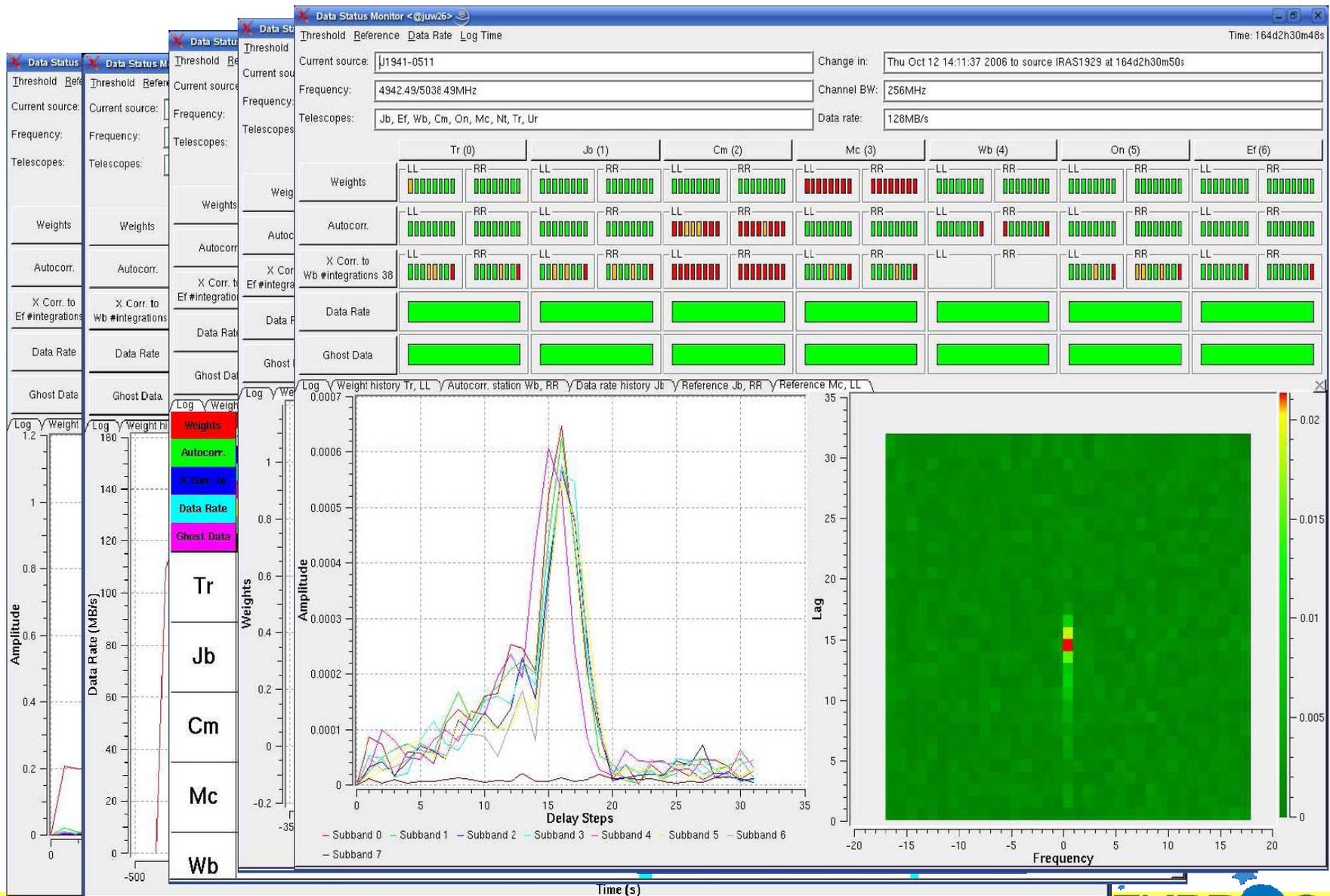
Max. amp @ lag=511.23 (after fit)



Max. amp @ lag=511.00 (after fit)



Monitoring tools: Data status monitor

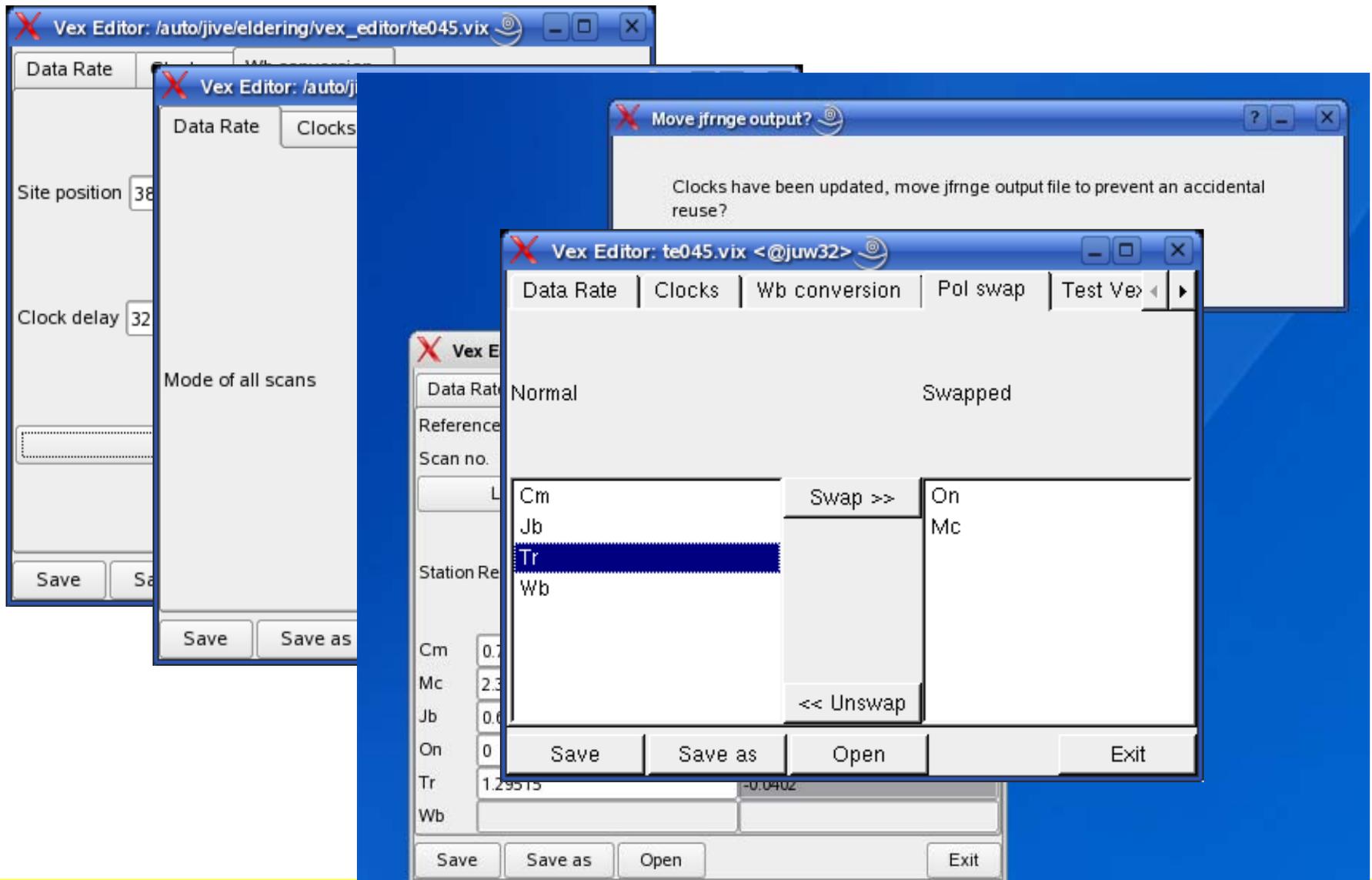


Monitoring tools: Data status monitor

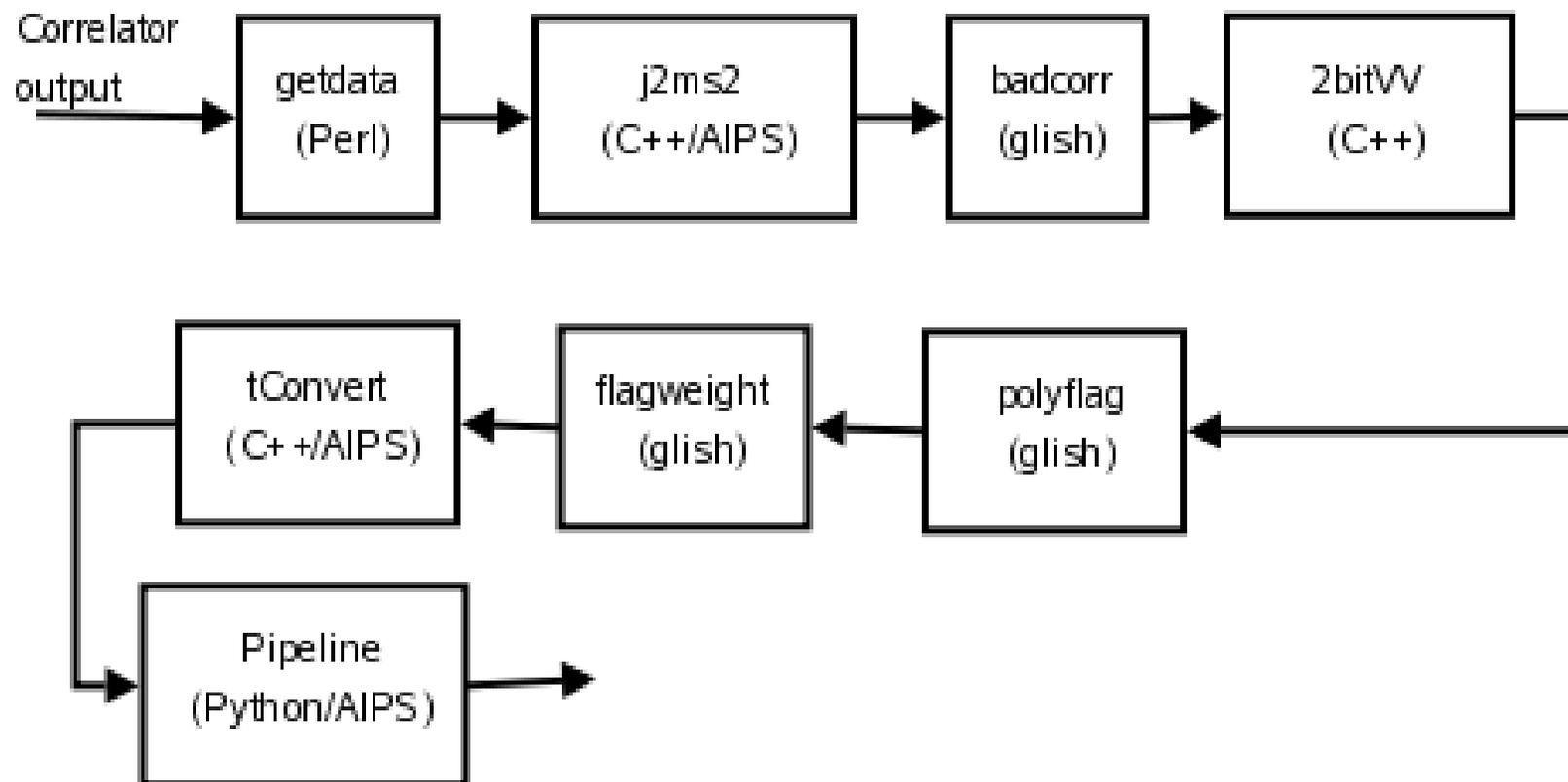
The screenshot shows a Mozilla Firefox browser window displaying the 'eVLBI Telescope Summary' page. The page features the JIVE logo (JOINT INSTITUTE FOR VLBI IN EUROPE) and a table of data generated on Friday, February 2, 2007, at 14:14:01. The table lists various parameters such as Temperature, Wind Speed, Pressure, Humidity, Zenith, Azimuth, Elevation, Hour Angle, Declination, Right Ascension, Epoch, and Source.

	Tr	On	Jb	Cm	Wb
Temperature °C	-1.59	5.9			7.30000
Wind Speed m/s	4.88	6			5.60000
Wind Direction °	221.57				
Pressure hPa	997.74	1011			1024.40002
Humidity %	100.00	99			92.90000
Zenith	24.676				
Azimuth	0.479		156.61	159.65	
Elevation			51.12	52.63	
Hour Angle					-0.476923
Declination	28:25:12		15:52:54	15:52:54	50.0769
Right Ascension	14:07:18		22:51:29	22:51:29	
Epoch	B1950		B1950	B1950	
Source			3c454.3	3c454.3	

Rapid adjustment of correlator params: vex editor



(near) Real-time analysis: streamlining of post processing



Web-based Post-processing

The image shows a series of overlapping Mozilla Firefox browser windows. The top-most window displays a web interface for a project named 'EP056A'. The interface includes a sidebar with a 'Projects' list, a 'Choose disk' section, and a main content area with a 'Submit' button and a 'StandardPlots' section. The main content area contains a code block with the following text:

```
Experiment: EP056A
Submit
Flagweight('jw27_0/CD2/EP056A/ep056a.ms', 0.2)
NORMAL: successful readonly open of default--locked table /jw27_0/CD2/EP056A/ep056a.ms: 22 columns, 236160 rows
NORMAL: successful readonly open of default--locked table /jw27_0/CD2/EP056A/ep056a.ms/ANTENNA: 8 columns, 9 rows
NORMAL: successful readonly open of default--locked table /jw27_0/CD2/EP056A/ep056a.ms/DATA_DESCRIPTION: 3 columns, 8 rows
NORMAL: successful readonly open of default--locked table /jw27_0/CD2/EP056A/ep056a.ms/POLARIZATION: 4 columns, 1 rows
NORMAL: successful readonly open of default--locked table /jw27_0/CD2/EP056A/ep056a.ms/SPECTRAL_WINDOW: 14 columns, 8 rows
NORMAL: successful readonly open of default--locked table /jw27_0/CD2/EP056A/ep056a.ms/FIELD: 9 columns, 4 rows
NORMAL: successful read/write open of default--locked table /jw27_0/CD2/EP056A/ep056a.ms: 22 columns, 236160 rows
dot 944640 weights
dot 122368 bad points
T
- : print "Wibble"
```

Below the code block is another 'Submit' button and a footer that reads 'Maintained by Des Small'. The browser's address bar shows the URL 'http://op46.nrao.edu/pipe/cgi-bin/gdcontroller.py:2732'. Other overlapping windows show similar interfaces for different projects like 'j2ms2', '2BitVV', and 'PlyFlg'.

Protocol work in Manchester:

- Protocol Investigation for eVLBI Data Transfer
- Protocols considered for investigation include:
 - TCP/IP
 - UDP/IP
 - DCCP/IP
 - VSI-E RTP/UDP/IP
 - Remote Direct Memory Access
 - TCP Offload Engines
- Work in progress – Links to ESLEA UK e-science
 - Vlbi-udp – UDP/IP stability & the effect of packet loss on correlations
 - Tcpdelay – TCP/IP and CBR data

Protocols (1)

Mix of High Speed and Westwood TCP (Sansa)

2.2.4 Our Proposed Algorithm (HTCP with Bandwidth Estimation)

Basing on the observations from the above stated algorithms [2, 4, 11, 6, 9, 8] as well as some comparative studies [1, 3], we propose an algorithm that combines the strengths of HTCP and TCPW. With this algorithm a connection will be established following HTCP-like rules, however at a packet loss, we propose that the TCPW's adaptive decrease be evoked. From our simulations with NS2 [7], on a packet loss event a TCPW flow sets its $CWND$ to a value averagely 17% greater than that set by an HTCP flow. The increase factor will be controlled by the HTCP adaptive increase, which controls increment relative to the elapsed time since the last packet loss event. From our simulations the HTCP increase function yields much faster growth of the $CWND$ than that obtained with TCPW. The aim is to use the tested bandwidth estimation mechanism employed by TCPW algorithm and combine it with adaptive increase mechanism of HTCP. The expectation is that this will ensure higher link utilisation than what is possible with any of TCPW or HTCP. The weaknesses of HTCP in short RTT flows as well as parallel flows revealed in [3] we propose to solve by employing the tested TCPW adaptive backoff. The non-adaptive nature of TCPW increase factor will be taken care of by the HTCP adaptive increase factor. Our proposed algorithm is summarised in (17) and (19).

On Acknowledgement:

$$CWND \leftarrow CWND + \alpha/CWND \quad (17)$$

Where

$$\alpha_i \leftarrow \begin{cases} 1 & \Delta_i \leq \Delta^L \\ 1 + 10(\Delta_i - \Delta^L) + \left(\frac{\Delta_i - \Delta^L}{2}\right)^2 & \Delta_i > \Delta^L \end{cases} \quad (18)$$

Where Δ_i is the elapsed time since the last congestion event experienced by the flow i , Δ^L is the time duration used as the threshold for switching from the low to high speed regimes.

On Packet Loss event:

$$CWND \leftarrow B \times RTT_{avg} \quad (19)$$

Where

$$B = CWND/RTT_{avg} \quad (20)$$

Protocols (2)

Circuit TCP (Mudambi, Zheng and Veeraraghavan)

Meant for dedicated end-to-end circuits, fixed congestion window

No slow start, no backoff:
finally, a TCP rude enough for e-VLBI?

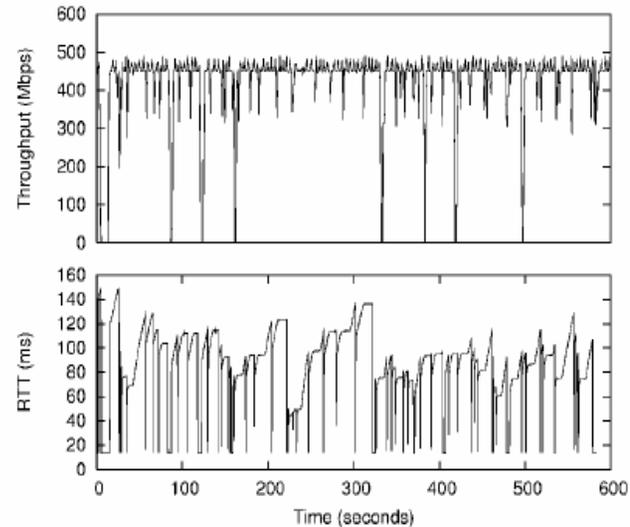


Figure 4. Throughput and RTT using BIC-TCP

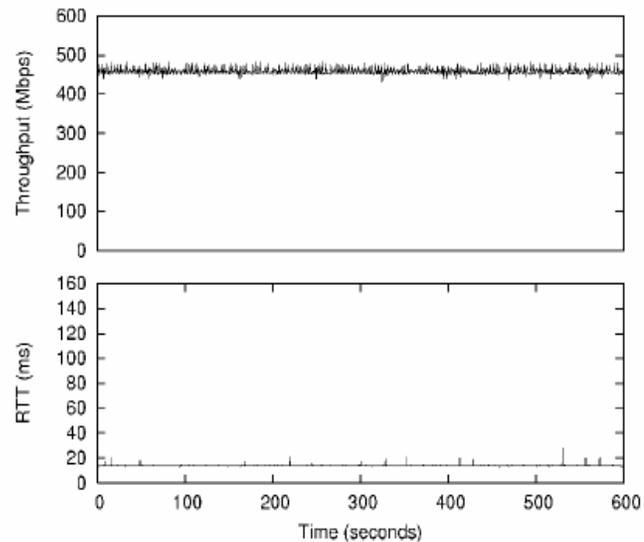


Figure 5. Throughput and RTT using C-TCP

Protocols (3)

Home-grown version of CTCP using pluggable TCP congestion avoidance algorithms in newer Linux kernels (Mark Kettenis)

Rock-steady 780 Mbps transfer using iperf from Mc to JIVE

Problem with new version of Mk5A software under newer kernels; should be solved by the end of May..

Hardware

New control computers

- Solaris AMD servers, redundant power supplies
- Interchangeable for maximum reliability
- Cut down dramatically on (re-)start time
- Removal of single points of failure

Mark5 upgrade

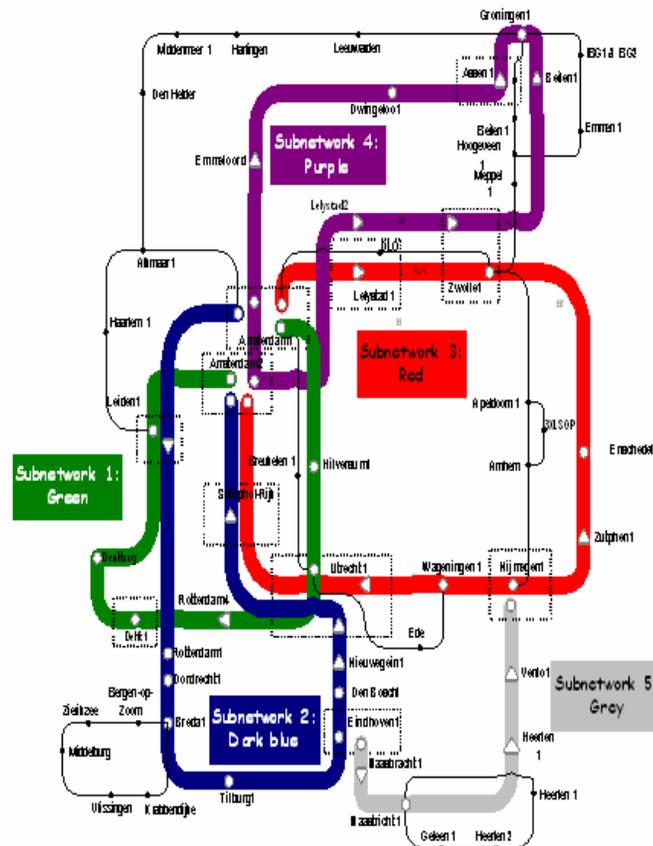
- Original Mark5s woefully under-powered (Pentium PIII...) New dual processor motherboards, memory, power supplies
- Immediate result: Mc and Tr now sustain 512 Mbps
- Mark5A→B: new streamstor cards, new serial links (optical and coax), Correlator Interface Boards
- Elimination of Station Units, VSI compliance

Hybrid networks in the Netherlands..

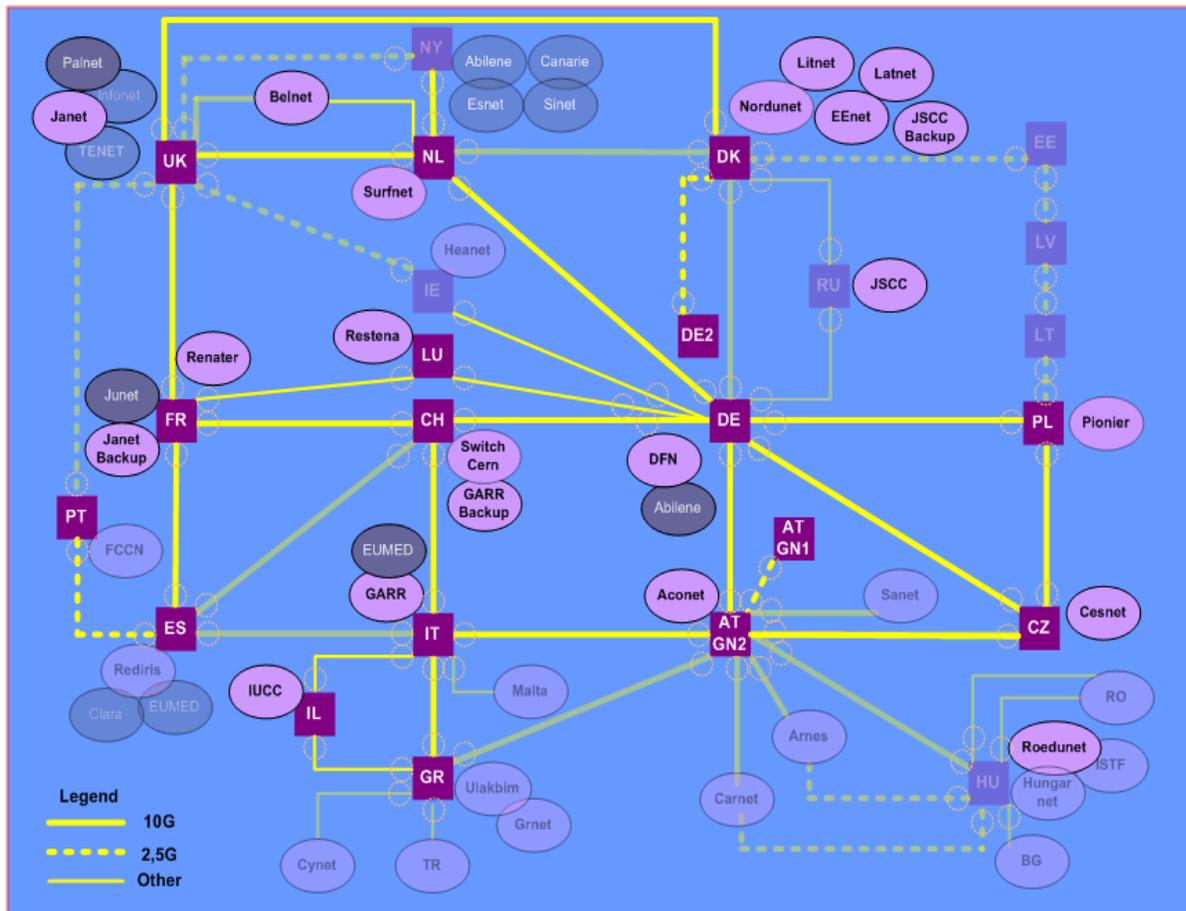
SURFnet

GigaPort →

SURFnet6 DWDM on dark fiber



..and across Europe: GÉANT2 network upgrade



Local solutions: Tr connectivity bottleneck (partially) solved

Black Diamond 6808 switches:

New interfaces (10GE) system in old architecture (1GE)

- Originally 8x1GE interface per card
- 10GE NIC served by 8 x 1GE queues
- Queuing regime – RR (packet based) and flow-based

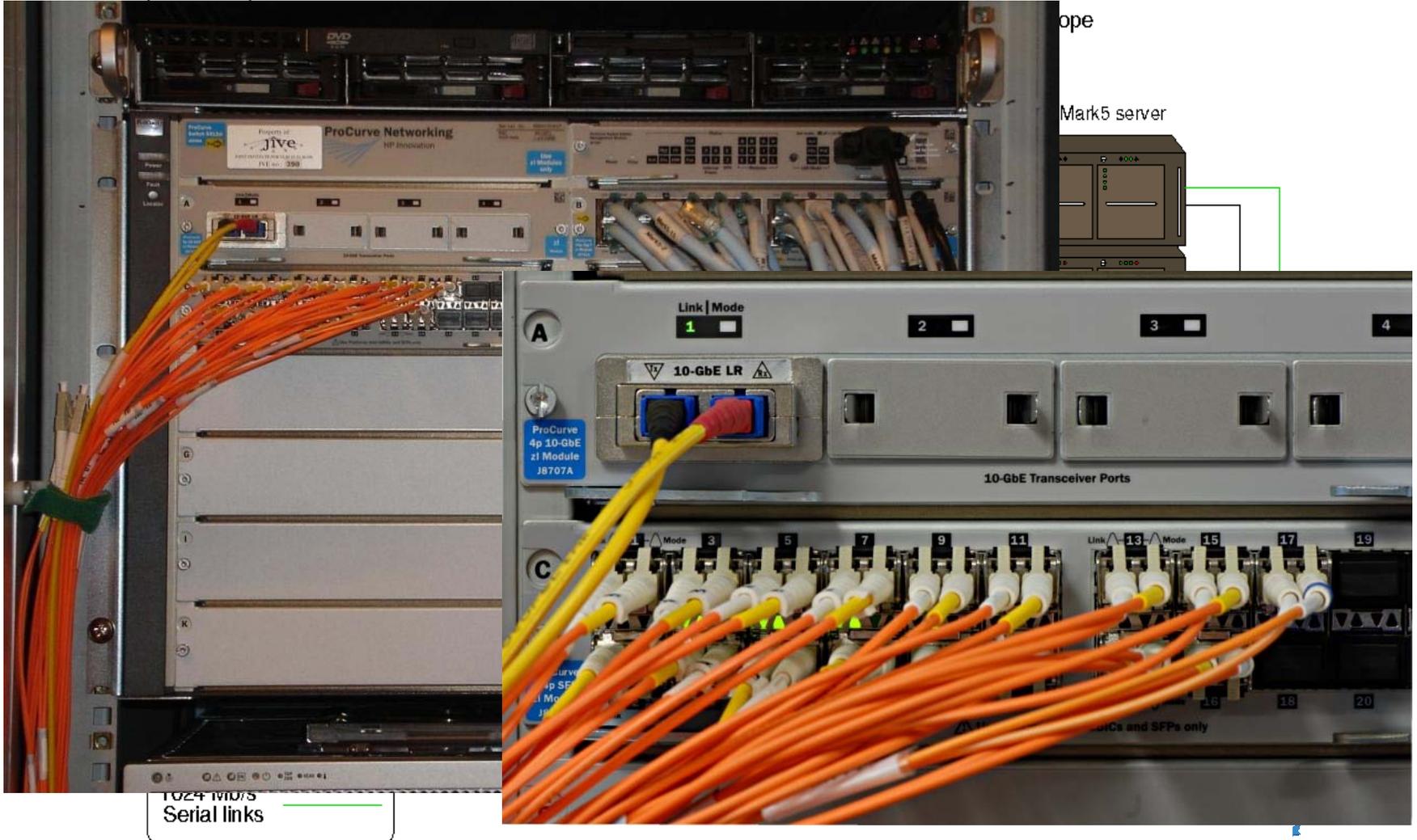
Flow based:

Max. flow capacity – 1Gbit/s – background traffic.

There is no known reordering workaround to solve this problem.

But, re-routing of traffic between Poznan and Gdansk has made a big difference.

Upgrade of network at JIVE

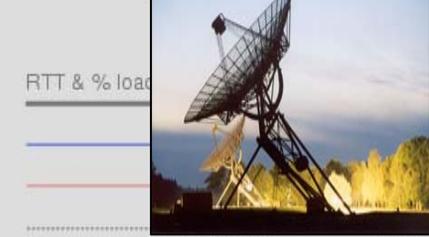


Routes across GEANT

used by eXPLIMkVc

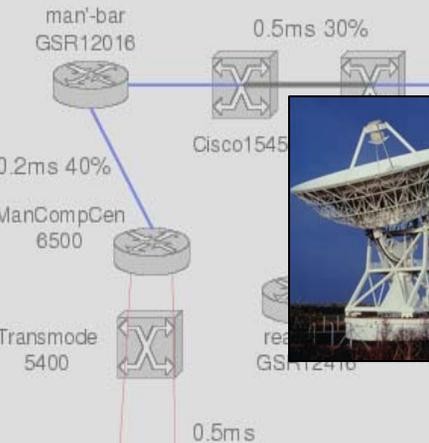
RTT & % load

% load is approx daily high value

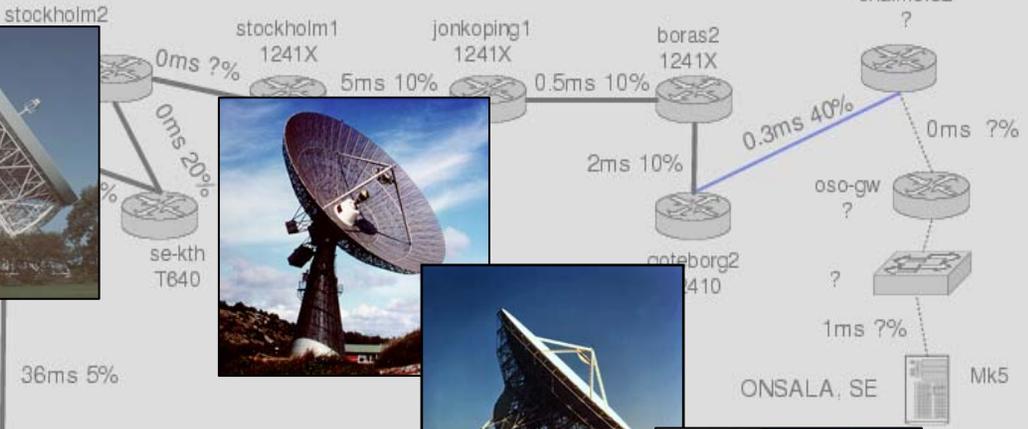
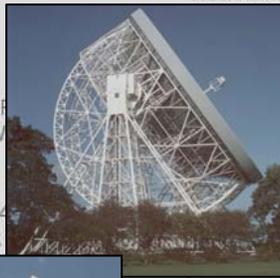


- ment
- Cisco 3508
- Cisco 6500
- Cisco 15216 EDF
- Cisco 15252 DW
- Juniper M160
- Juniper T640
- X - Cisco GSR 12416
- Extreme Black

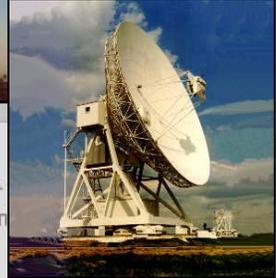
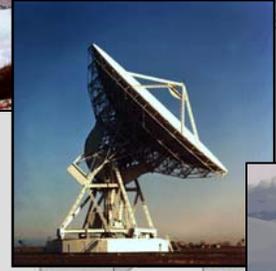
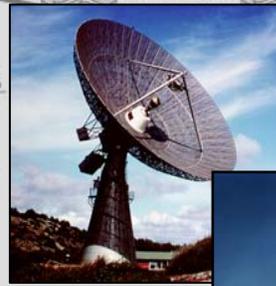
3812 - 30
AT-9816



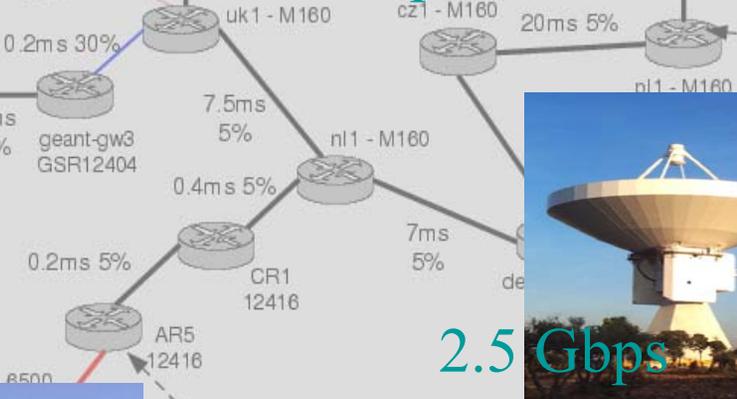
155 Mbps



1 Gbps



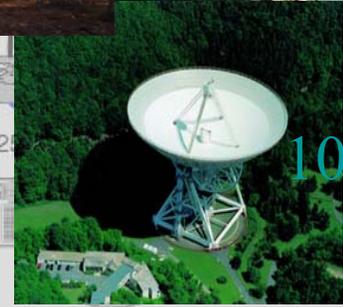
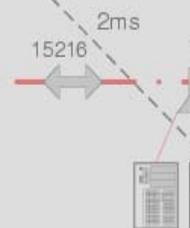
ONSALA, SE



2.5 Gbps



TORUN, PL



Bologna M320

10 Gbps

SA1: the next 18 months

All personnel in place, at JIVE and JBO

Main focus:

- Adaptive scheduling
- Increasing the operational data rate
- Improving flexibility and robustness of correlation
- New telescopes

- Inclusion of eMERLIN telescopes

- Re-assessment/refinement of deliverables

Specific tasks

Crucial:

- fast/adaptive (re-)scheduling
 - Transform EVN into a truly flexible instrument
 - Reaction time of hours
 - Remote control of widely different telescope control systems
 - Safeguard local operational constraints
- hard/software upgrade
 - Phase out aging Station Units, main cause of operational instability
 - Involves large software effort
 - VSI compliance

Fine-tuning of deliverables

- Use of WSRT synthesis data for e-VLBI calibration (absolute flux calibration, polarization calibration, source selection)
- Space craft tracking correlator mode
- On-the-fly fringe fitting
- Real-time download and extraction of station information
- Automated correlator diagnostics
- Removing/adding stations from the correlation process on the fly
- Investigating a 1024M sub-array

Connectivity improvements:

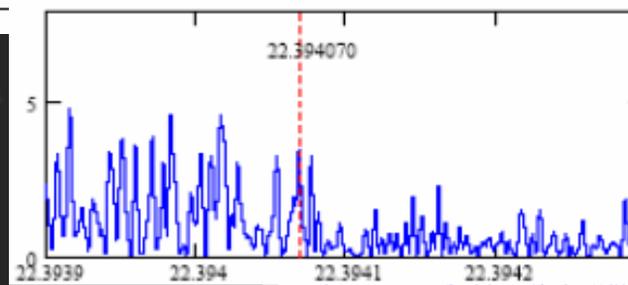
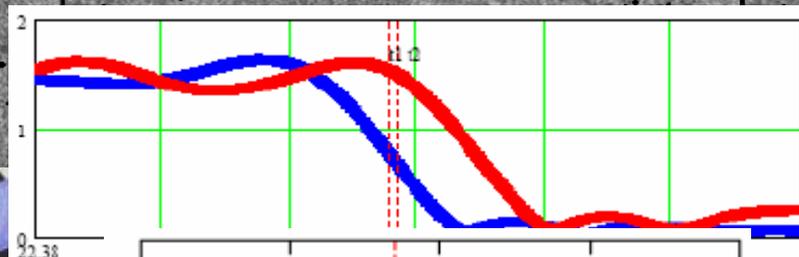
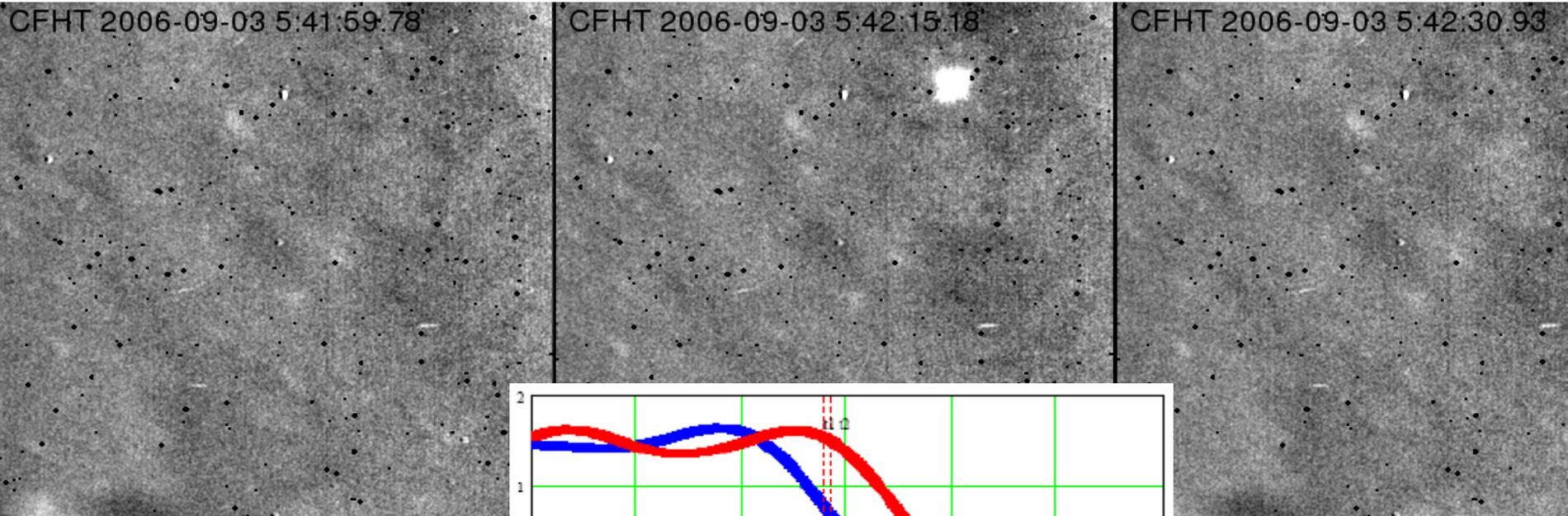
- Use of new/modified transport protocols, lightpaths across Europe
- Increase granularity of data streams to optimize utilization of available bandwidth
- Increase of sensitivity and resolution through addition of telescopes: Effelsberg, Yebes, Shanghai
- Improving global connectivity: South-America, Puerto Rico, China, Australia

Global connectivity:

- Arecibo: 64 Mbps real-time operations in the past, currently < 32 Mbps. New submarine cable facilities in near future...
- Australia: 4 LBA telescopes connected at 1 Gbps. AARNET currently investigating transport to Europe. Issues with format conversion, command interfaces. First test planned before summer 2007
- South Africa: local situation improving, connection to Europe remains problematic

e-VLBI to South America: SMART-1

SMART-1 factsheet



ember 2004. Conducting lunar

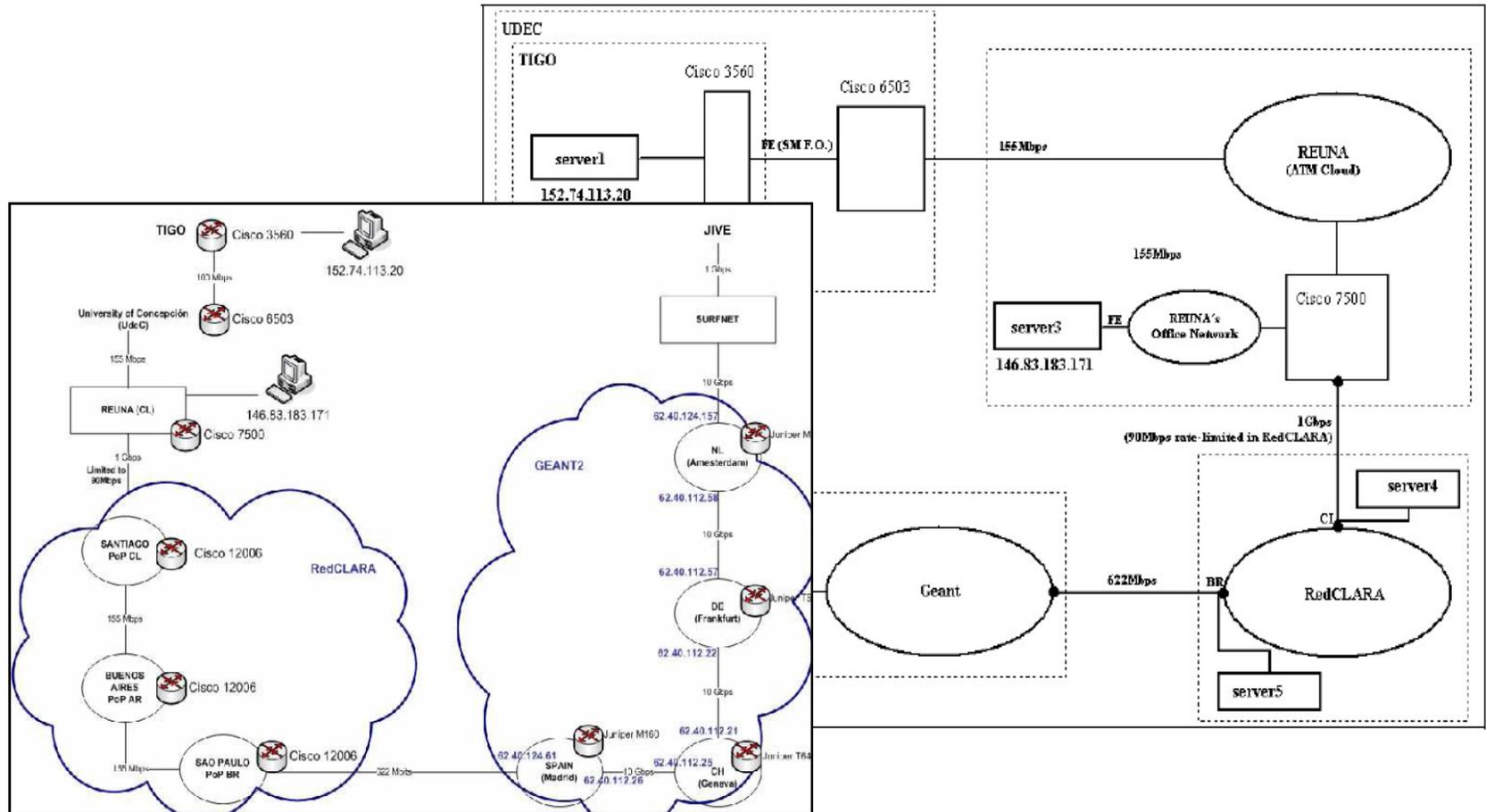
uropean spacecraft to travel to and

tion propulsion has been used as a stem (the first was NASA's Deep ber 1998).

(in the form of ice) on the Moon.

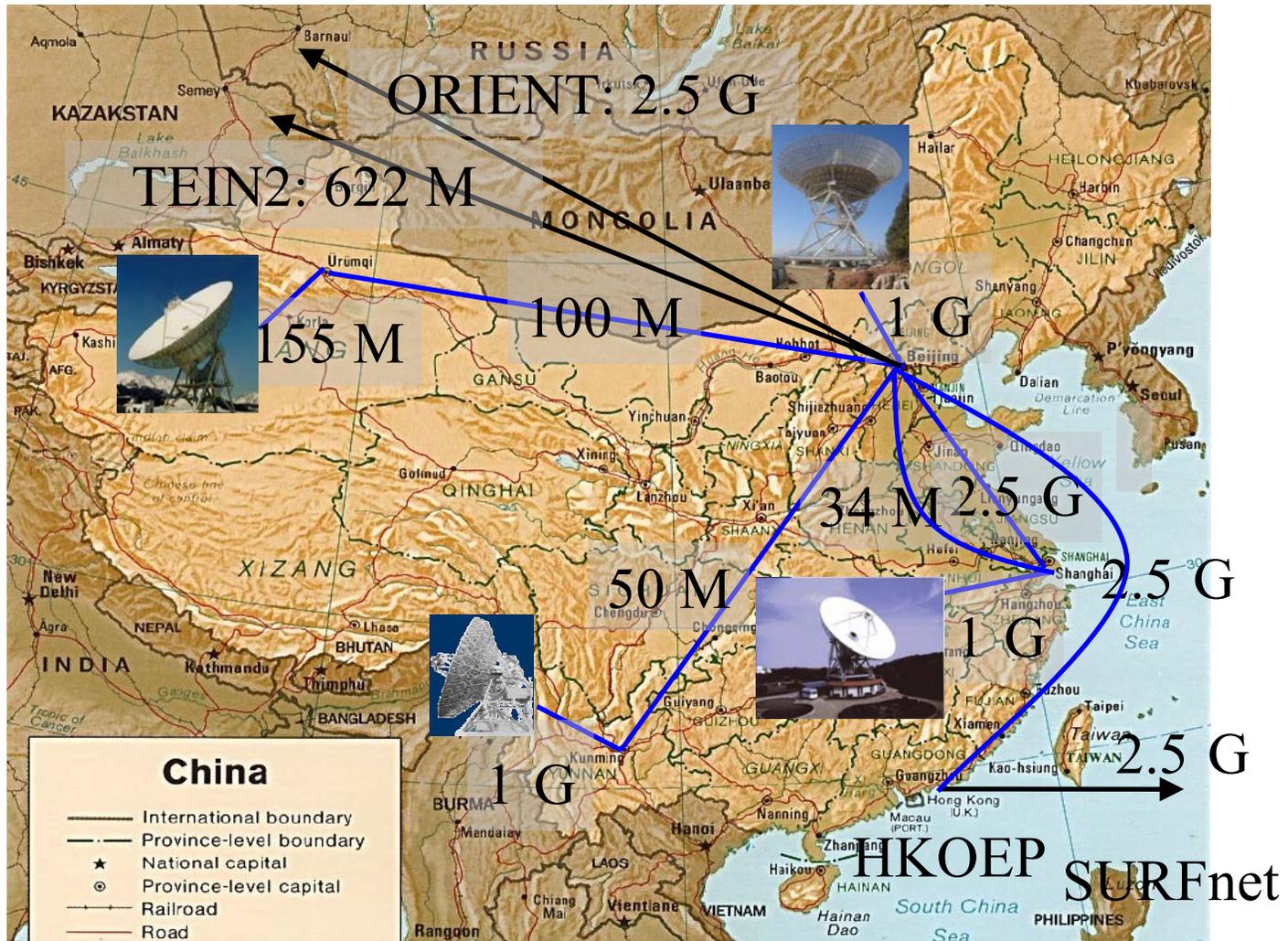
To save precious xenon fuel, SMART-1 uses 'celestial mechanics', that is, techniques such as making use of 'lunar resonances' and flybys.

e-VLBI to South America (2)

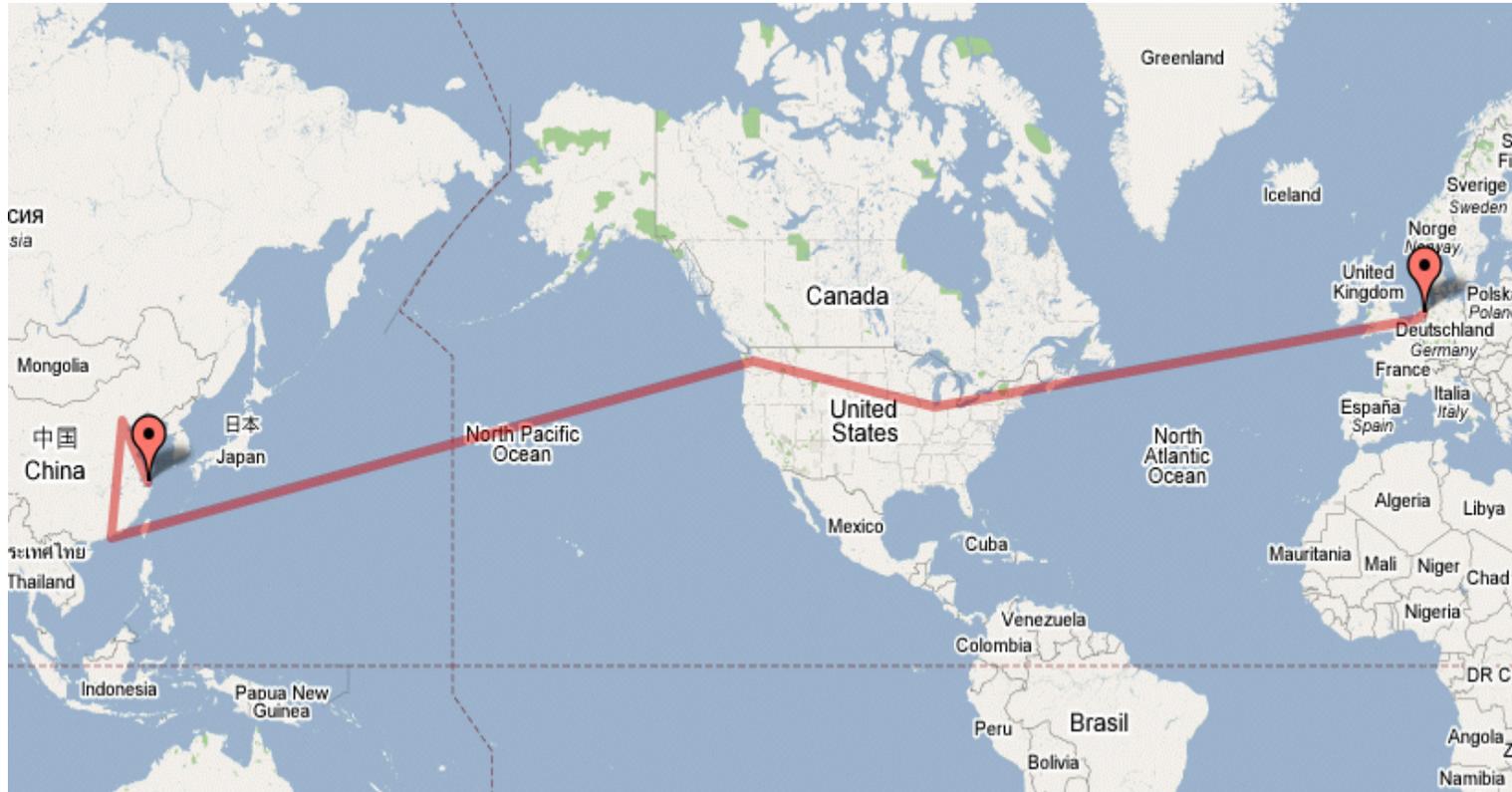


Server3 to server2: 274ms
 Server4 to server2: 273ms
 Server5 to server2: 226ms

e-VLBI to China

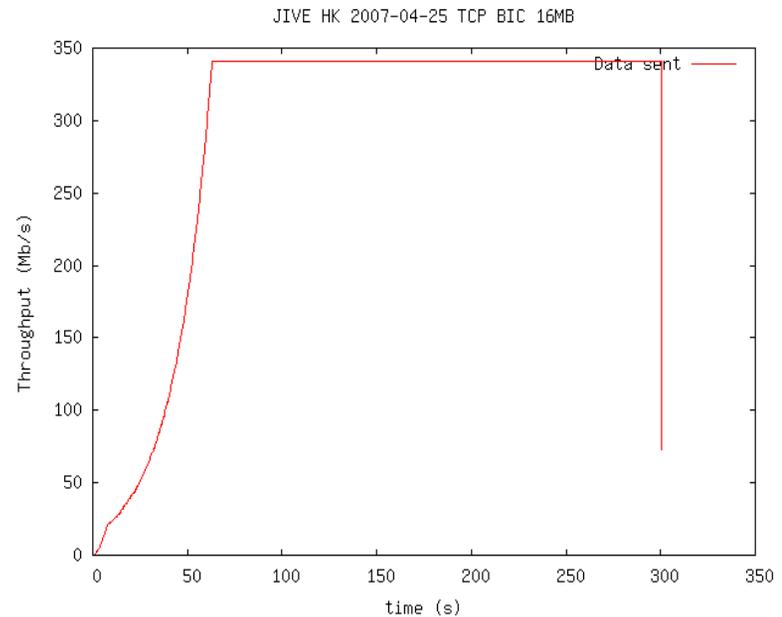
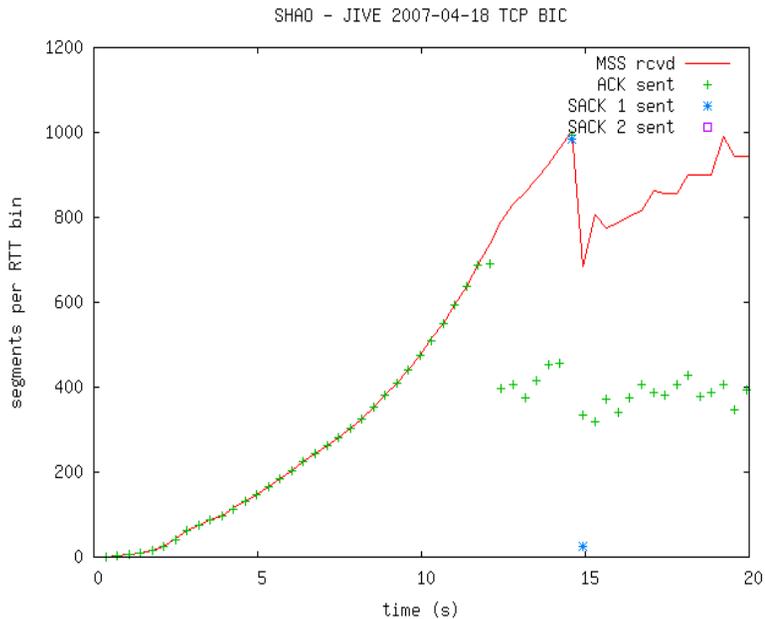
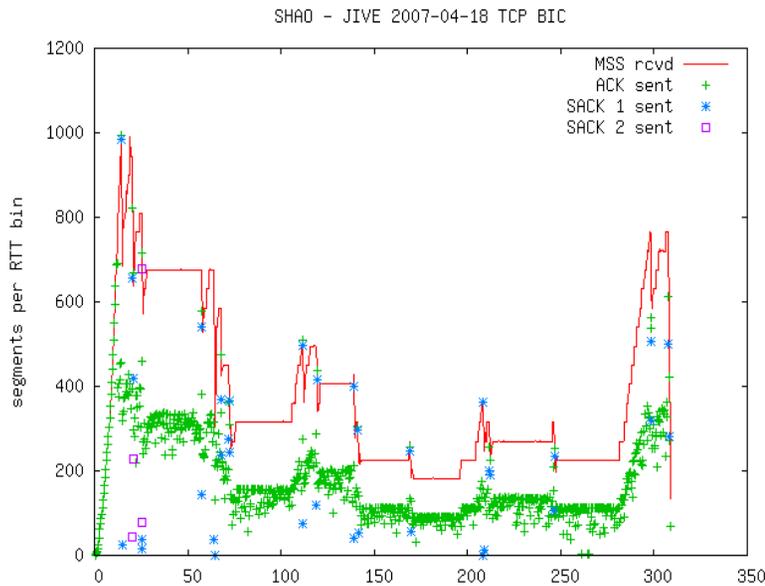


e-VLBI to China (2)



Connection Sheshan (near Shanghai) – JIVE (via HongKong, Chicago).
RTT 360 ms, real distance 8800 km, path length 27500 km

e-VLBI to China (3): Connectivity tests Sheshan-JIVE



e-VLBI to China (4)

- First tests (iperf with UDP, to rule out tuning issues):
 - HongKong – JIVE: 577 Mbps (lightpath 622 Mbps)
 - Sheshan – Beijing: 560 Mbps (822 Mbps with TCP!)
 - Beijing – HongKong: 1.85 Mbps (!)
- Follow-up
 - HongKong – JIVE: steady 320 Mbps with TCP
 - HongKong – Beijing: most lossy part of connection
- Latest result: nearly 800 Mbps SHAO-Hong Kong with TCP