EXPReS and NEXPReS

The future of European VLBI

Arpad Szomoru, JIVE

Research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° RI-261525

Acronyms / organisations involved

JOINT INSTITUTE FOR VLBI IN EUROPE

- VLBI: Very Long Baseline Interferometry
  - A radio-astronomical technique to obtain high resolution
- EVN: European VLBI Network
  - Consortium of (European) Telescopes
    - Arecibo (Puerto Rico), Cambridge (UK), Effelsberg (D), Hartebeesthoek (S-Africa), Jodrell Bank (UK), Medicina (I), Metsahovi (FI), Noto (I), Onsala (S), Robledo (ES), Shanghai (CN), Torun (PL), Urumqi (CN), Westerbork (NL), Wettzell (D), Yebes (ES)
- Joint Institute for VLBI in Europe
  - Institute established in Dwingeloo, the Netherlands
  - Funded by NWO (NL), ASTRON (NL), STFC (UK), INAF (I), ICN-IG (ES), OSO (S), CAS (CN), CNRS (F), MPG (D)
- EXPReS: EXpress PRoduction e-VLBI Service
  - EC-funded project, started in 2006
  - Partners: most radio-telescopes in Europe, some outside
  - DANTE and a number of NREN's, SURFNet, AARNET, PSNC


EUROPEAN
VLBI
NETWORK
Jodrell Bank Lovell (UK)
Onsala 20m (SE)
Onsala 25m (SE)
Dwingeloo (NL)
JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE
Jodrell Bank Mk2 (UK)
Metsähovi (FI)
Arecibo (PR)
Cambridge (UK)
Torun (PL)
Urumqi (CN)
Hartebeesthoek (ZA)
Westerbork (NL)
Wettzell (DE)
Seshan (CN)
Effelsberg (DE)
Medicina (IT)
Robledo (ES)
Yebes (ES)
Noto (IT)

Introduction

- Future of VLBI = e-VLBI
  - Recognized SKA pathfinder
- Future radio-astronomy = SKA
  - VLBI has complementary science case and intermediate time scale
- EXPReS has demonstrated all VLBI can be e-VLBI!
  - competitive, robust, economic, global
- e-VLBI is producing new science
  - And is an operational facility
- NEXPReS is funded to take next step
  - caching is necessary in order to do all VLBI
- e-VLBI is part of a long-term plan
  - new telescopes, global array, correlator, different telescopes

Move towards e-VLBI

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- PC based recording
  - Also allows Internet transmission
  - Upgrade EVN to e-EVN
    - Started with a pilot in 2004
- And was boosted with EXPReS (2006)
  - Retrofit correlator to work real-time
  - Help solve last mile problem at telescopes
  - Work with NRENs on robust connectivity
  - Push to 1024 Mb/s limit
  - Bring in the big telescopes
  - Cultural revolution in radio-astronomy
- Now an operational facility
  - Guaranteed 10 x 24h per year
  - Flexible ways to get into e-VLBI
    - Request e-VLBI for fast response
    - Or for triggered proposals
    - Short requests <2hr
    - Target of Opportunities
    - Or just because you prefer to e!

EXPReS

Express Production Real-time e-VLBI Service

From Proof of Concept to reality

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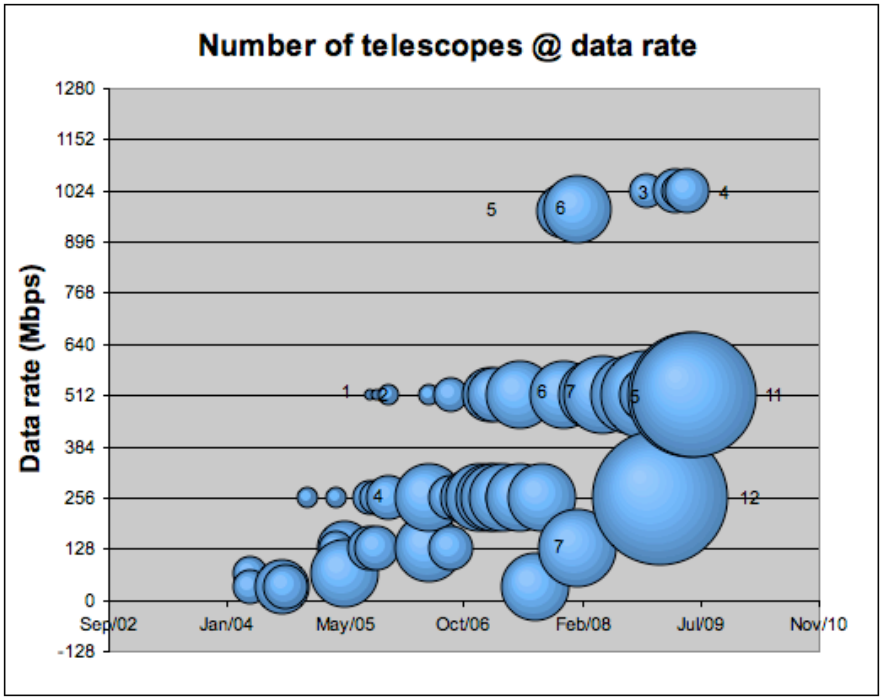
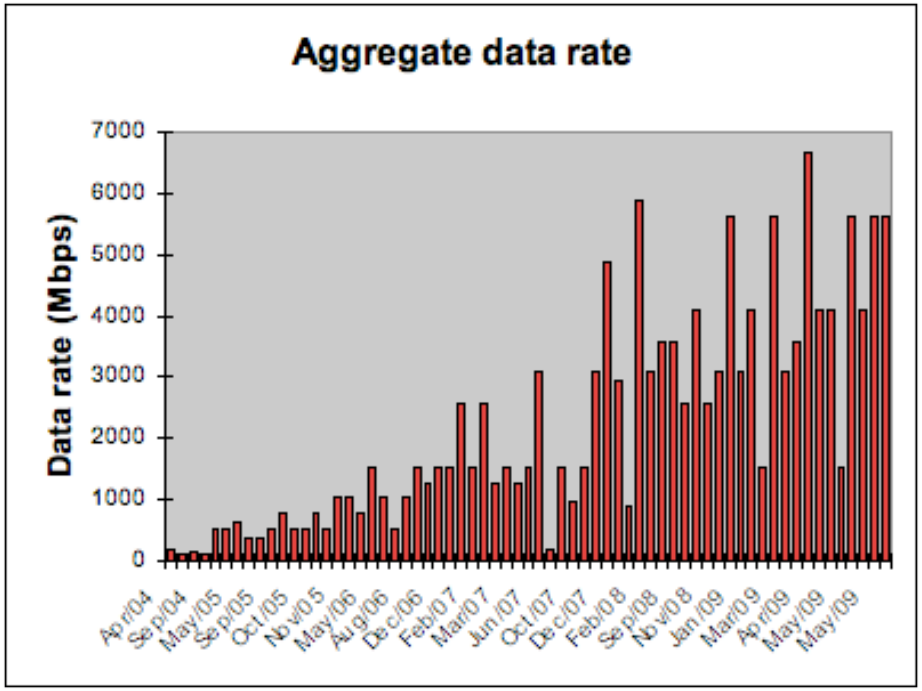
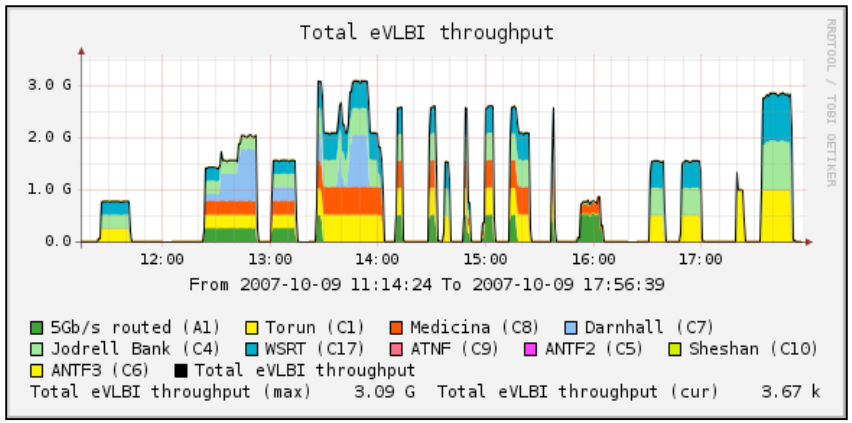
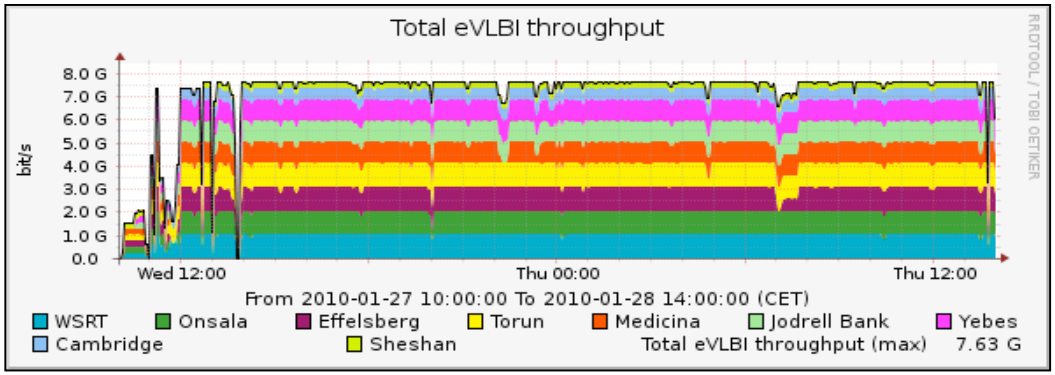
- Our original concerns. Would..
  - we be able to connect enough telescopes fast enough?
  - the bandwidth be high enough?
  - e-VLBI be as reliable as non-e?
  - it produce new science?
  - it be cost effective?
  - we be able to accommodate all types of projects?
- Judging from progress so far:
  - yes
  - yes
  - yes
  - yes
  - maybe
  - eventually

Steady improvements



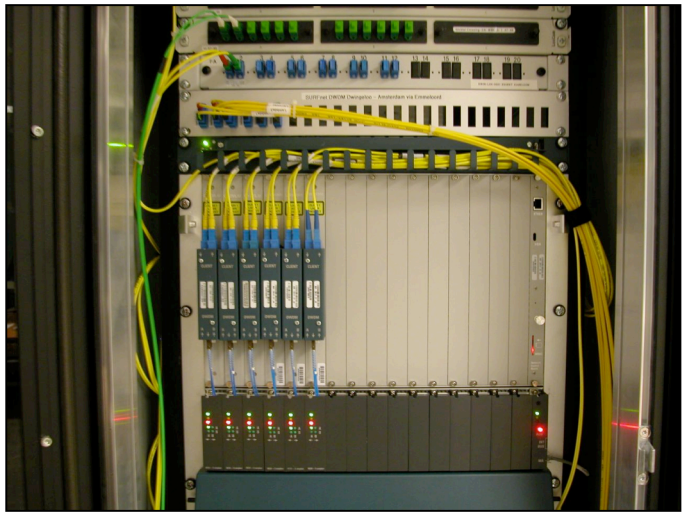


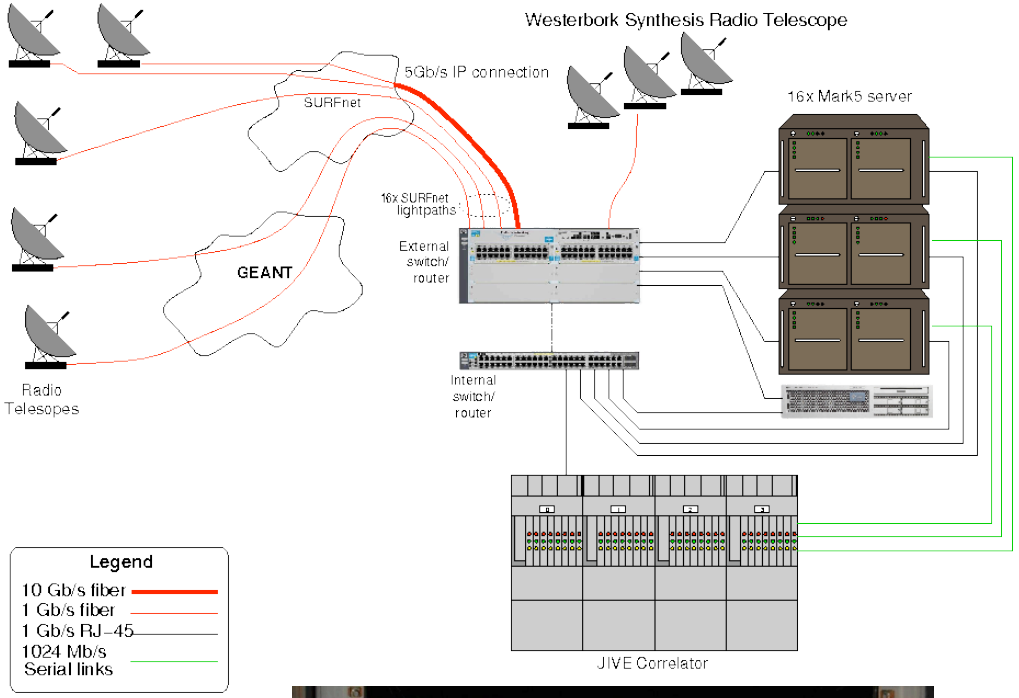


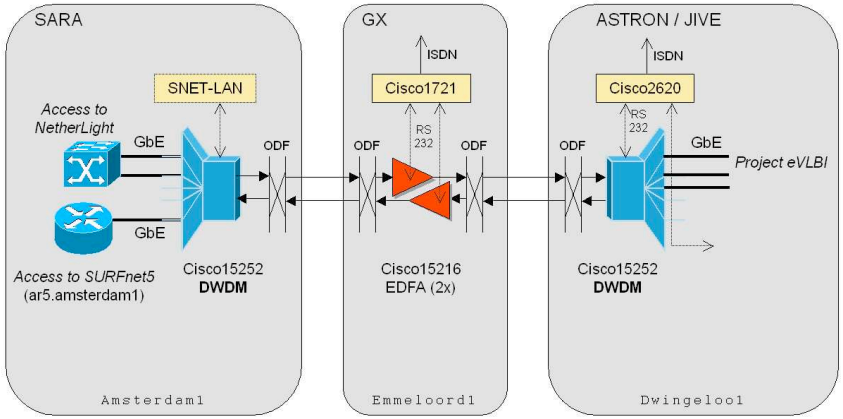


Intercontinental?

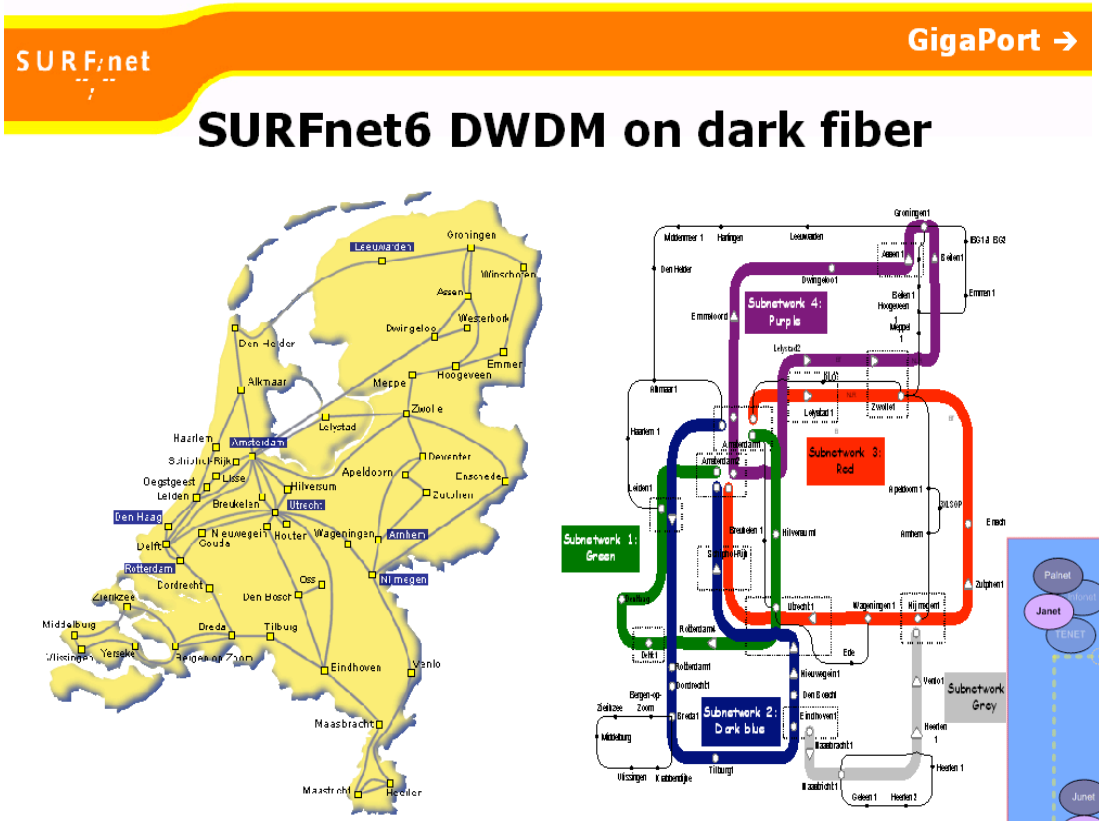
Local network upgrades

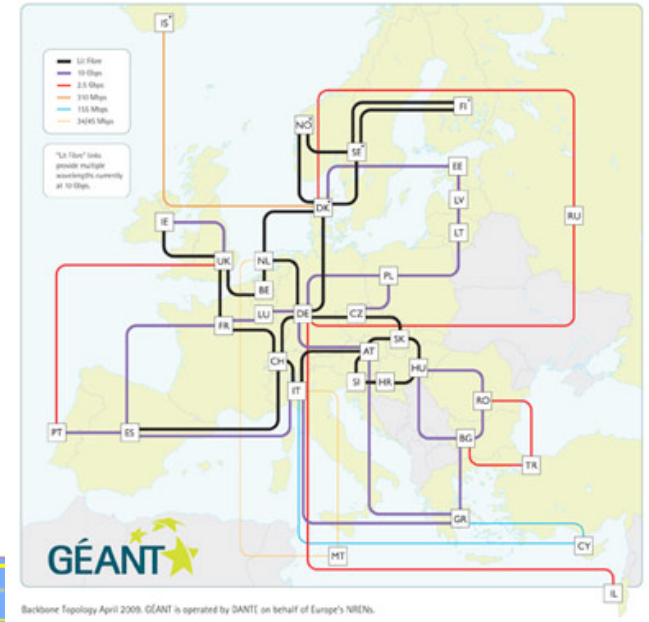


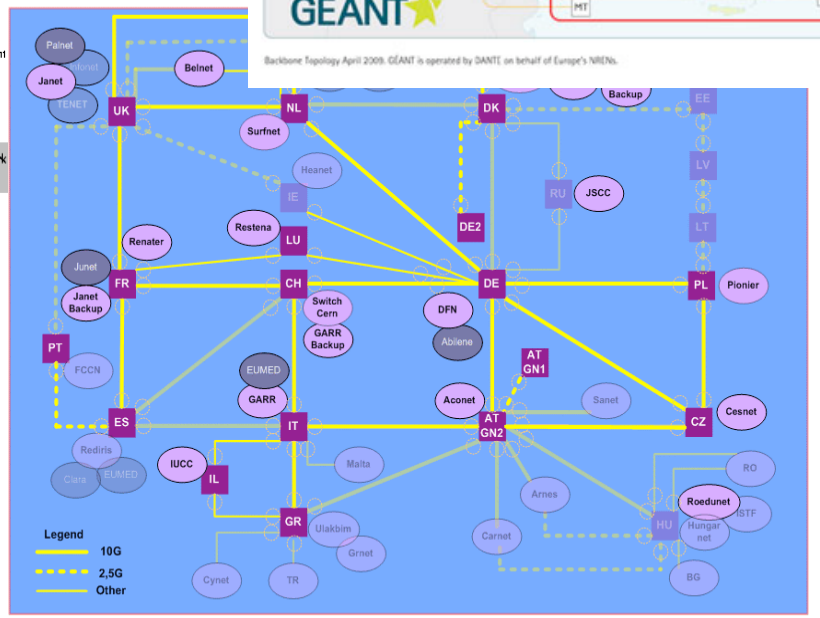




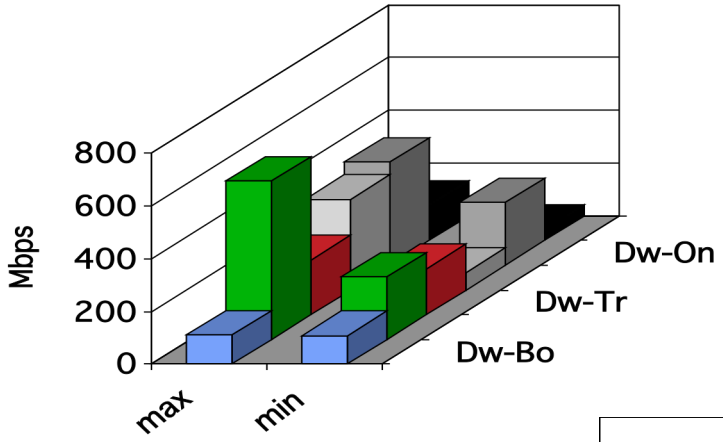
And international

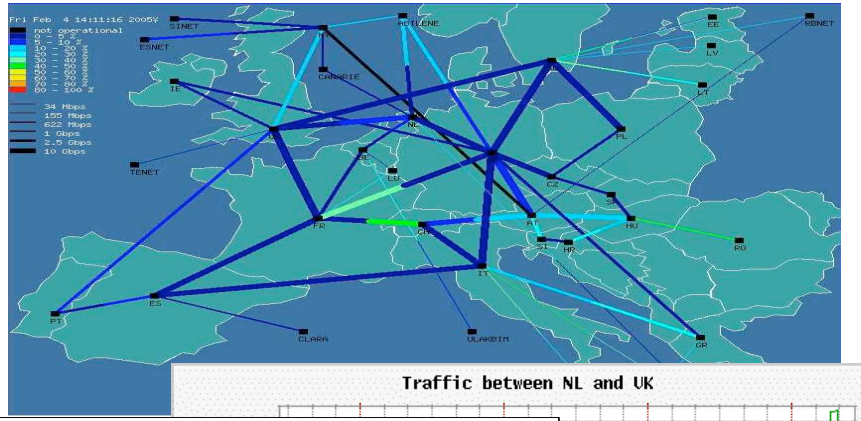


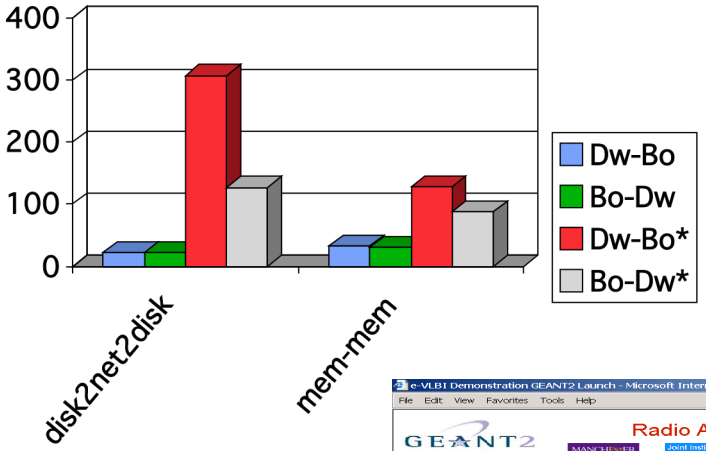


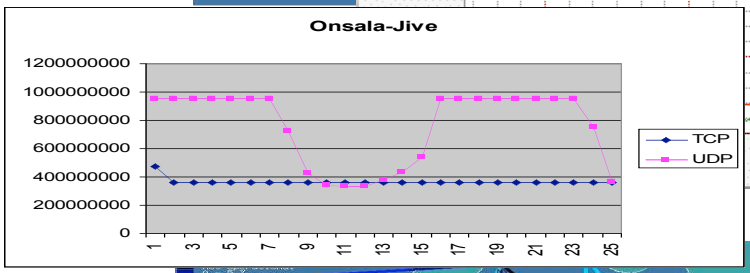


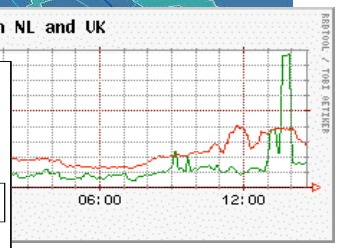
First European transfer tests

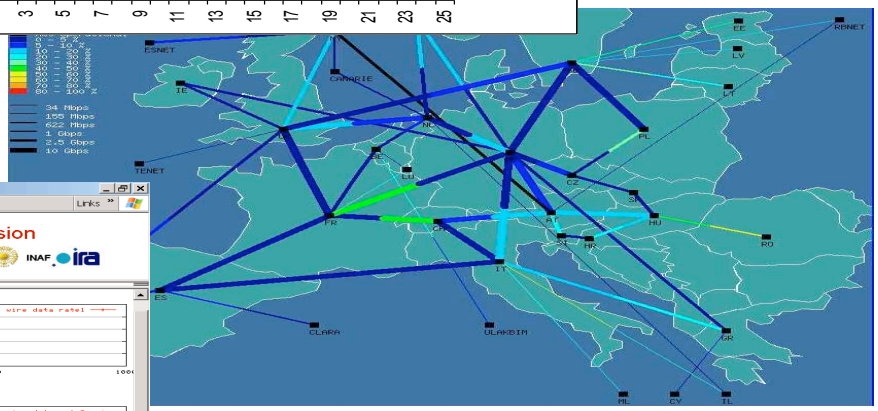


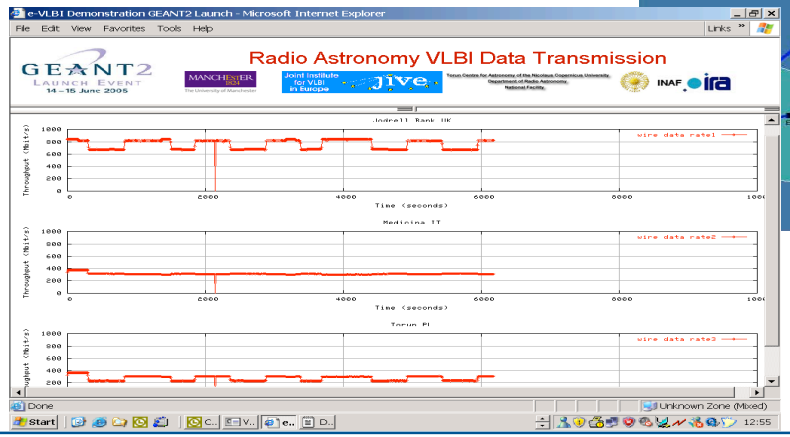






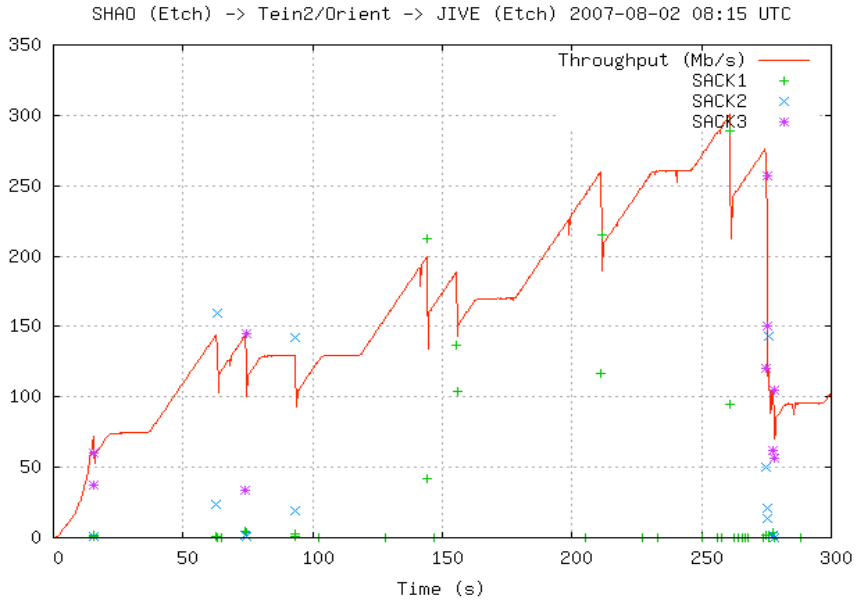


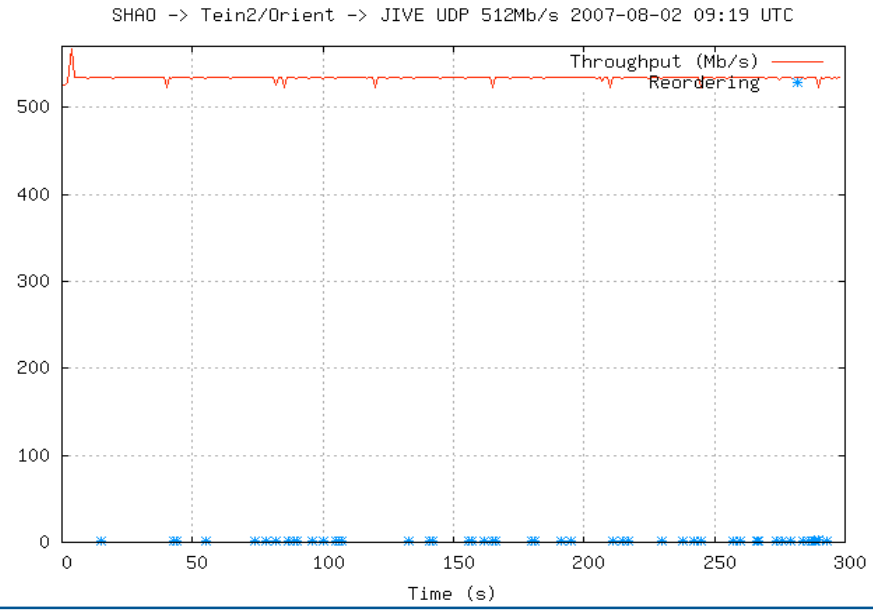




Long-haul high-bandwidth data transport

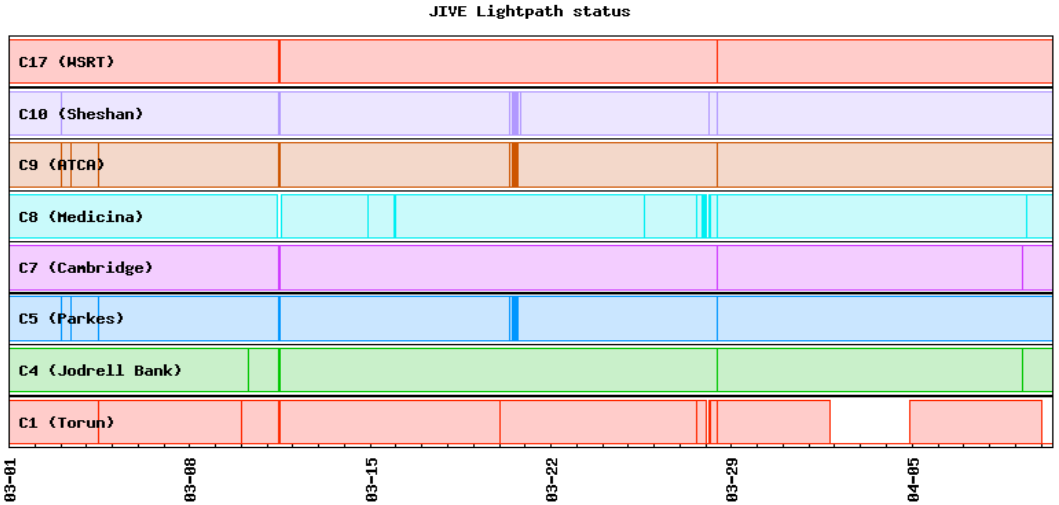
- Up to 375 ms RTT
- TCP on old linux kernels completely inadequate
- Parallel TCP, TCP tuning defeat fairness principle
- UDP logical choice but can be hostile to other users on open network
- Preferred use of “private” networks (lightpaths, VPN, dark fibre)
- Good agreements, and communications, needed with providers when using open networks

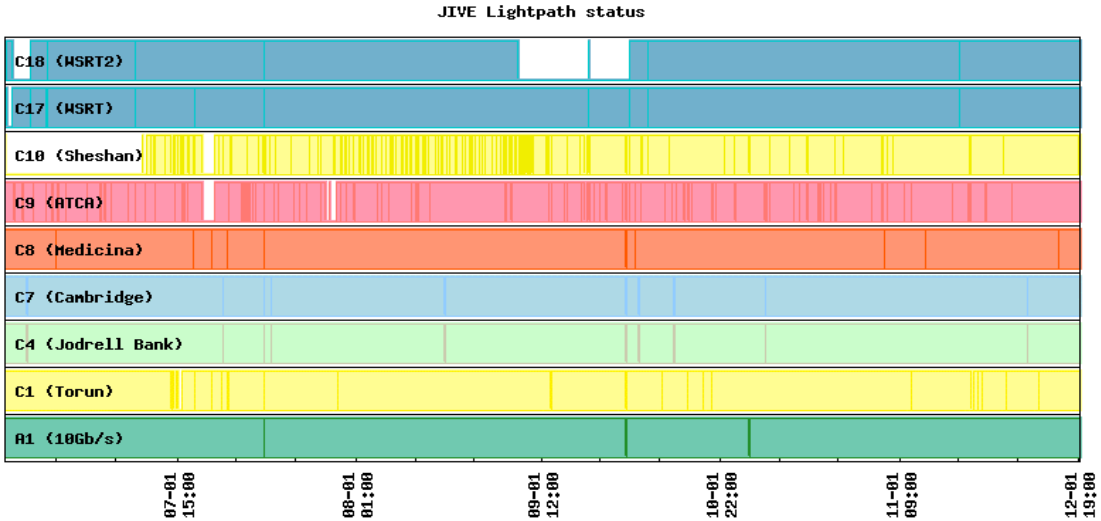




Lightpaths

- Dedicated point to point circuits
- Based on SDH/Sonet timeslots (NOT a lambda)
- Stitched together at cross-connects
- Guaranteed bandwidth
- But also: a string of SPFs

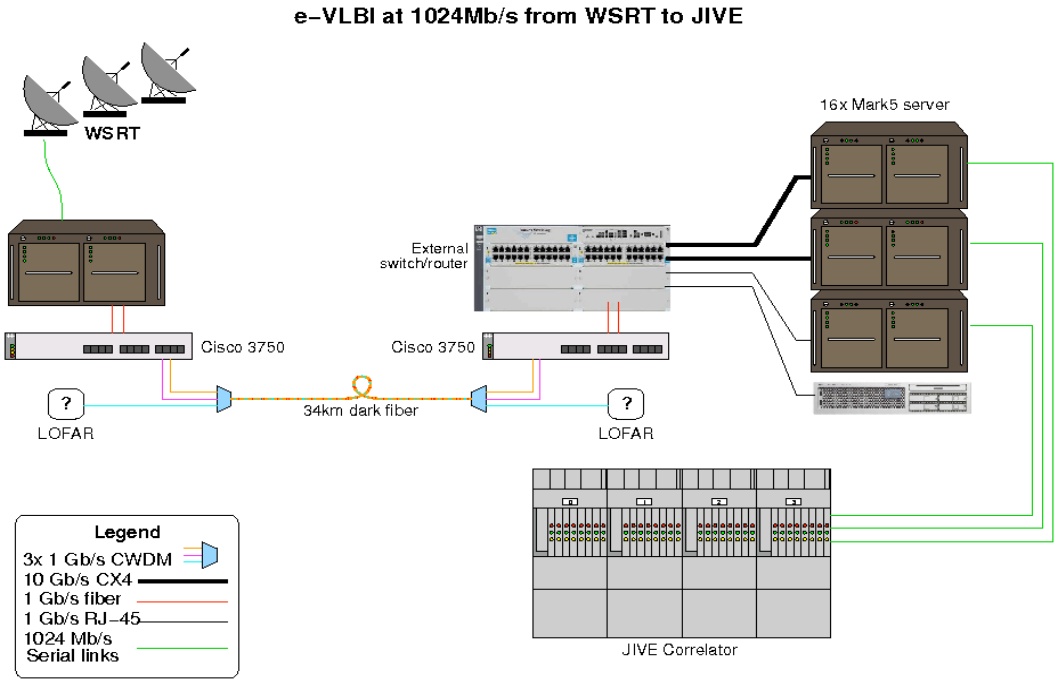




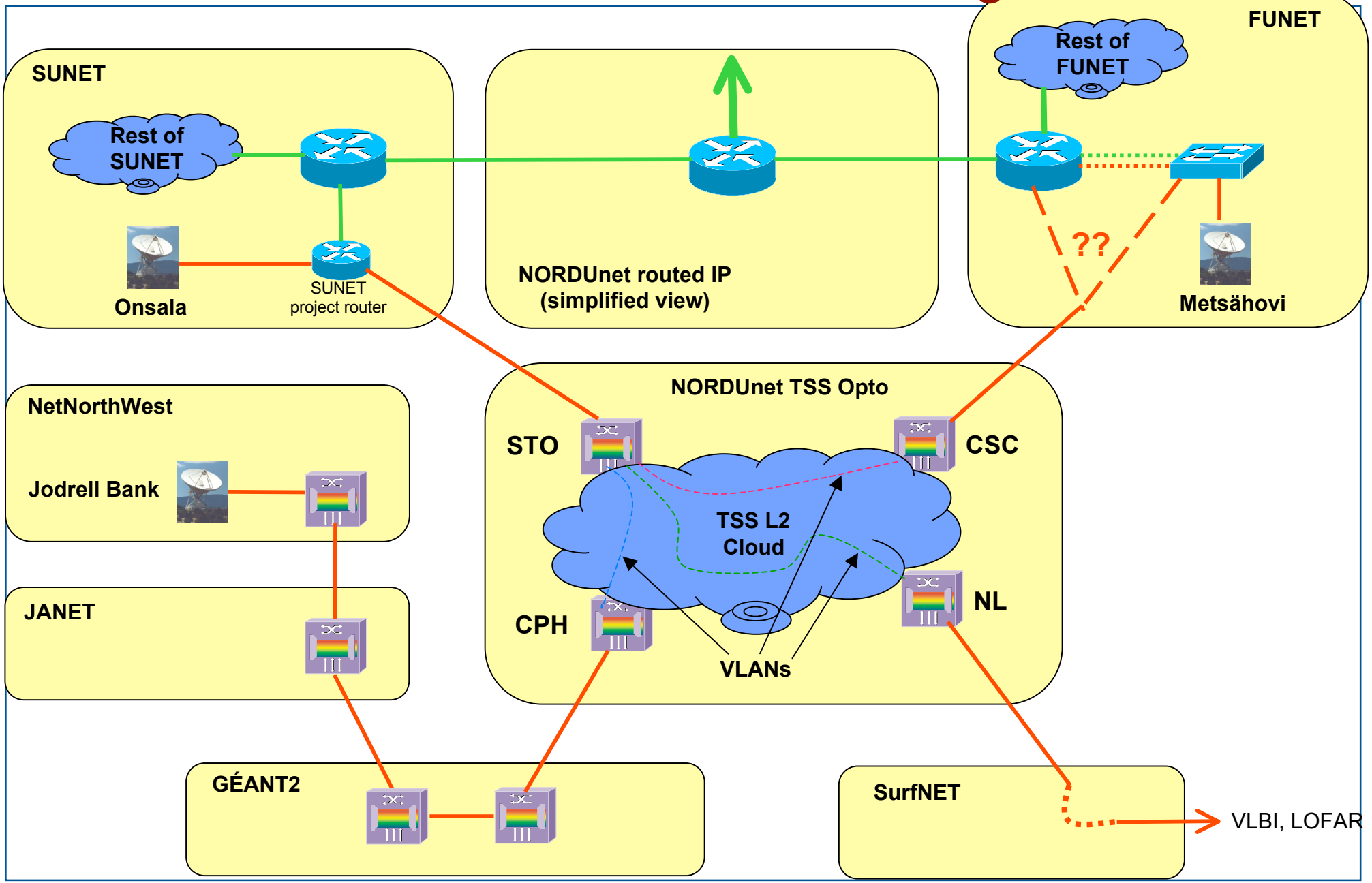
Beyond 1 Gbps

- Current maximum data rate in VLBI 1024 Mbps (1030 including headers)
- Does not fit on 1 Gbps
- Dropping packets possible, but not optimal
- Dropping channels works, but loss of sensitivity
- Lightpaths come in “quanta” of 150 Mbps, Ethernet does not

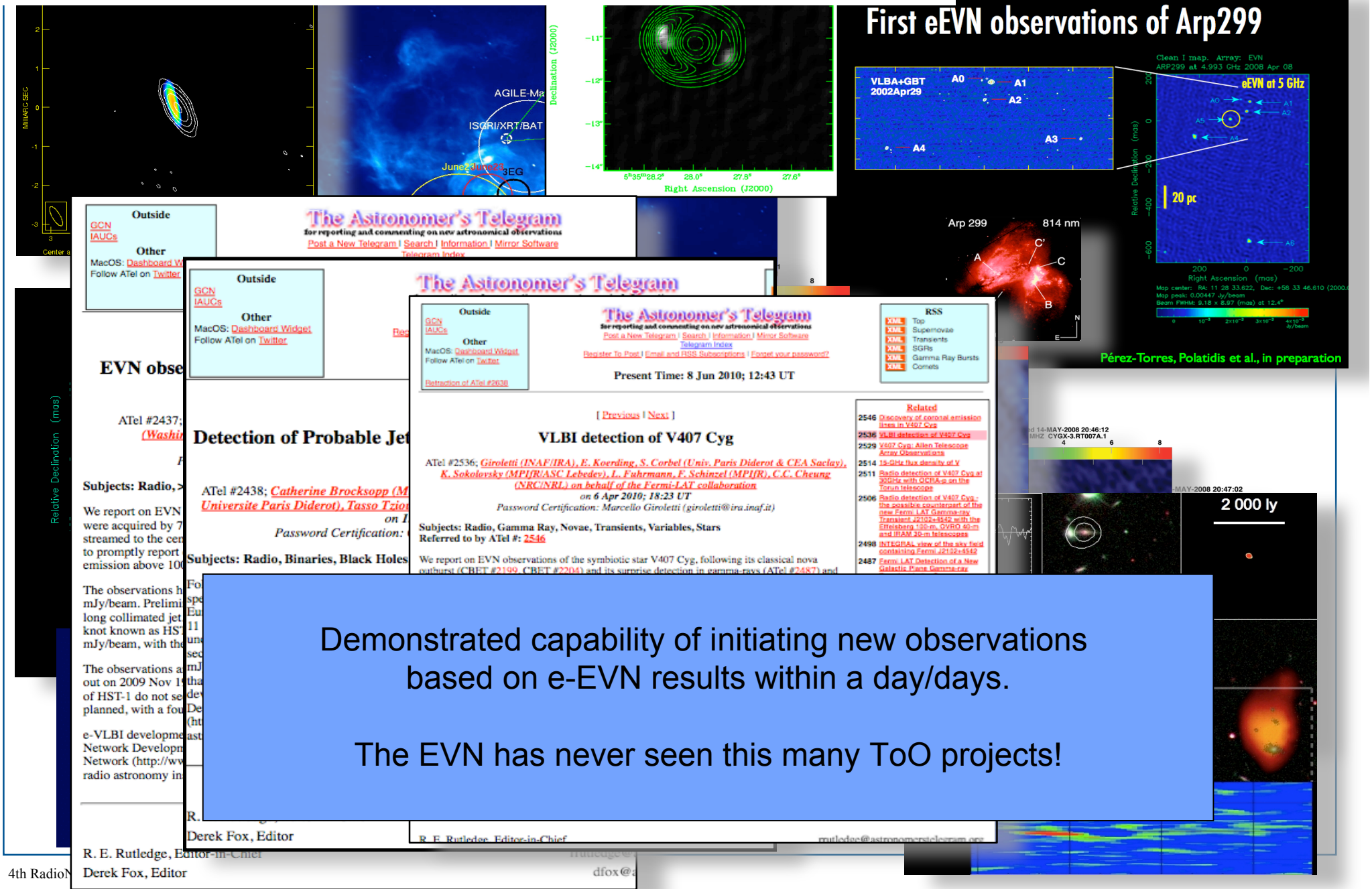
- One solution: Round Robin distribution of data over two connections using bonding, both halves through separate VPNs
- Used on Westerbork-Dwingeloo CDWM connection (much cheaper than upgrading to 10 Gbps)
- Also used for connecting Merlin telescopes over two 1 Gbps lightpaths
- With multicast + Elliptical Robin, up to 5 Merlin telescopes simultaneously (Merlincast)



Onsala to Manchester, JIVE, Groningen



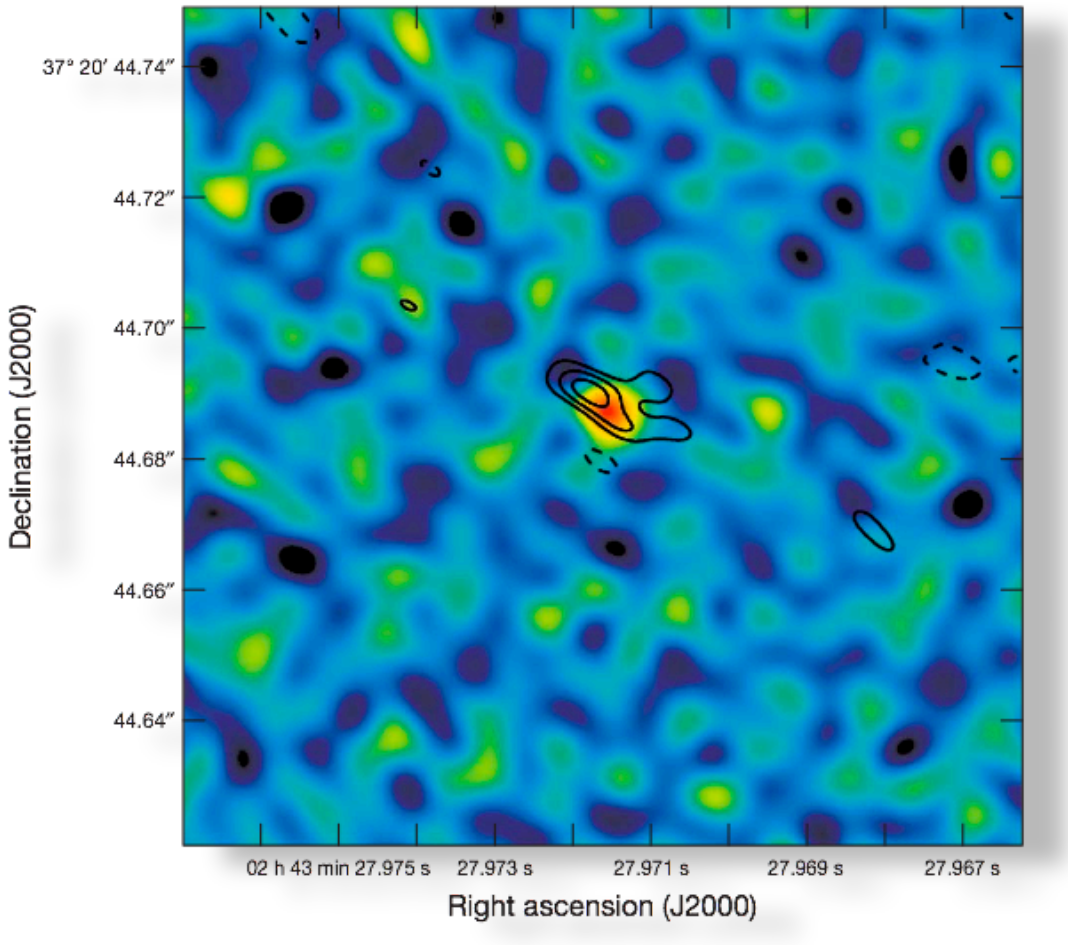
How about new science?



Fame and fortune

SN2007gr

- Nearby type Ic supernova
- e-VLBI within 20 days
  - detection at 400 μJy/beam level
- Two months later EVN+GBT:
  - Weaker detection
  - VLBI vs. WSRT total flux
  - mildly relativistic (>0.6c) expansion!
- First direct detection of relativistic expansion in a supernova
- Link with Gamma Ray burst



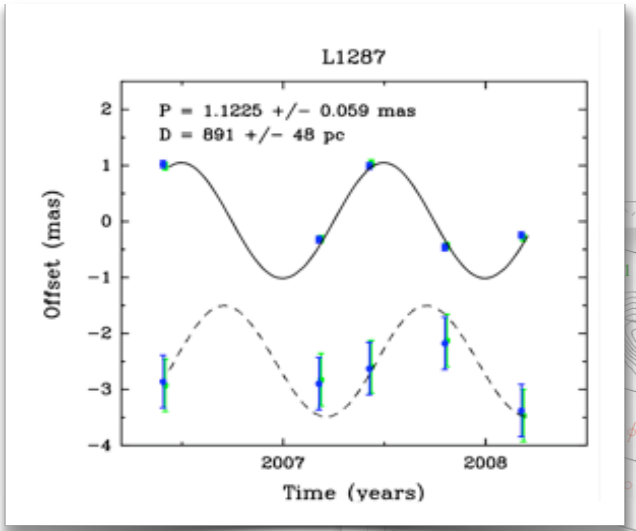
Paragi et al., Nature 2010, 463 516

Current limitations

- Correlator passes are a problem
  - Not a perfect correlator
  - Partly remedied by software correlator
- Not all telescopes connected
  - Noto/Sardinia
  - Newly added Russian telescopes
  - Global baselines with VLBA

- Reliable operations
  - Of all components in the chain
- Could be addressed by simultaneous recording!
  - And get the best of both worlds!

- Correlate in real time what you can,
- Correlate later what you need



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Novel EXplorations Pushing Robust e-VLBI Services

NEXPReS: EXPReS follow-up

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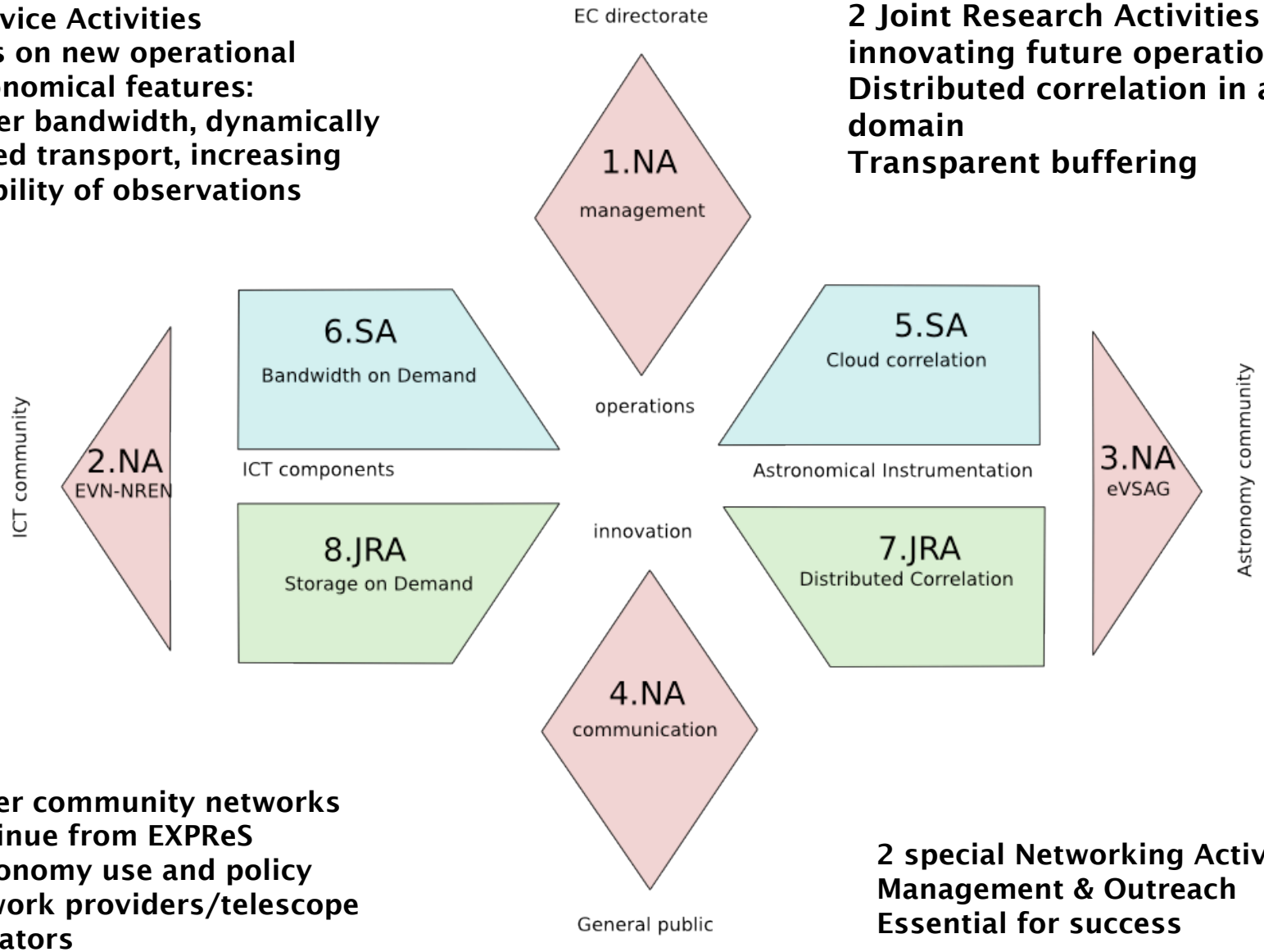
- Main objective to introduce transparent caching
  - Bring increased sensitivity, flexibility and robustness of real-time VLBI to all EVN experiments
  - Deploy a high-speed, flexible caching system
    - allow transparent re-transmissions and/or re-correlation
  - Remove distinction between VLBI and e-VLBI operations
  - Continue collaboration with NRENs
  - Explore common technology questions with Lofar, SKA
- 15 partners (cf. 19 in EXPReS)
  - Of which 3 will not receive funds from EC
  - Good mix from astronomy-networking-HPC communities
  - High level of partner-contributed effort
- Project has started July 1, 2010
  - Had to fit project within 3.5 M€ envelope (3.8 requested)
  - Relatively painless
- Continuity for e-VLBI operations
  - Will allow us to keep key expertise, personnel
  - And assures continued connectivity in collaboration with SURFnet

NEXPReS structure

2 Service Activities
focus on new operational astronomical features:
Higher bandwidth, dynamically cached transport, increasing flexibility of observations

2 Joint Research Activities aiming at innovating future operations
Distributed correlation in astronomy domain
Transparent buffering



2 user community networks continue from EXPReS
Astronomy use and policy
Network providers/telescope operators

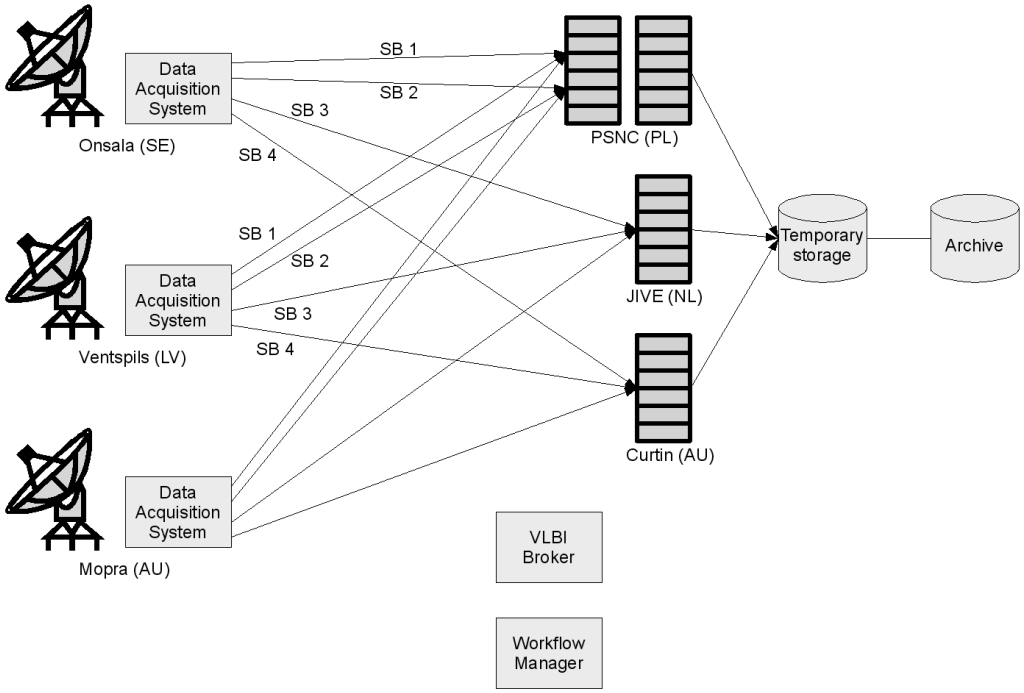
2 special Networking Activities
Management & Outreach
Essential for success

NEXPReS workpackages

- 4 Network Activities:
  - similar to EXPReS, NA1:Management NA4: Outreach
  - continuation of highly successful eVSAG and EVN-NREN fora
- Service Activity 1: Cloud correlation
  - flexible buffering at stations and correlator, automated network-dependent correlation, continuous quality monitoring and remotely controlled operations
- Service Activity 2: High bandwidth on demand
  - integrate e-VLBI with existing BoD, investigate on-demand access for large archives, establish international multi-Gbps on-demand services, position EVN to take full advantage of emerging 100 Gbps technology
- Joint Research Activity 1: Computing in a shared infrastructure
  - Use existing network and computing resources within EVN for distributed correlation, real-time stream processing, develop generic Grid alternatives
- Joint Research Activity 2: High-bandwidth, high-capacity networked storage
  - Develop multi-Gbps storage elements with simultaneous I/O streaming, investigate use of such elements as LTAs, investigate allocation methods

Distributed correlation

- Real-time stream processing; disk is slow, keep data on network/in memory. Relies on VDIF/VTP
- Workflow manager to assist telescope operators, correlator operators and PI
- Broker to do resource allocation and manage the correlation process
- Middleware to allow real-time scheduling of jobs
- All aimed at allowing additional VLBI observations with (a subset) of the EVN and global VLBI arrays with a minimal impact on scarce resources (disk, manpower)



High Bandwidth on Demand

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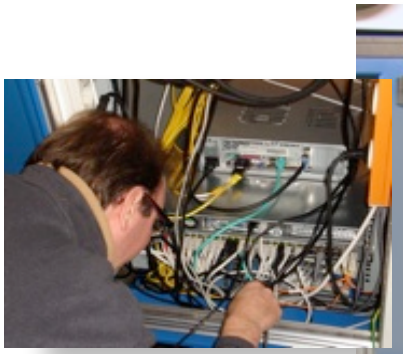
- Aim: to establish inter-domain dynamic circuits for e-VLBI and LOFAR Long-Term-Archive data-distribution
- Integration of scheduling, testing and observations

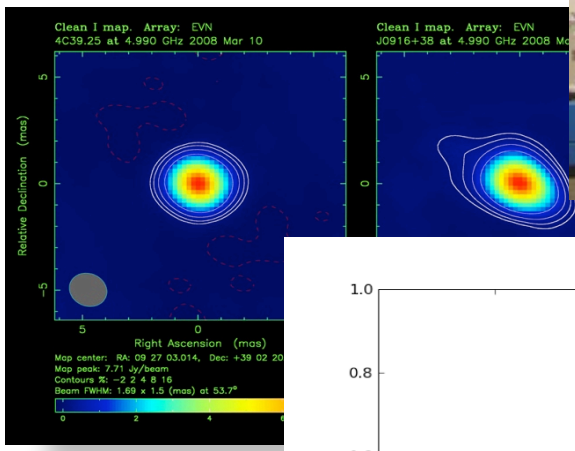
- Various transport techniques:
  - SDH/Sonet (dynamic lightpaths, fixed timeslots)
  - MPLS (Multi Protocol Label Switching)
  - (Metro) Ethernet
- Reservation methods:
  - DRAC (Nortel and SURFnet), now OpenDRAC
  - OSCARS, DCN
- Inter-domain controllers:
  - AutoBahn
  - Fenius

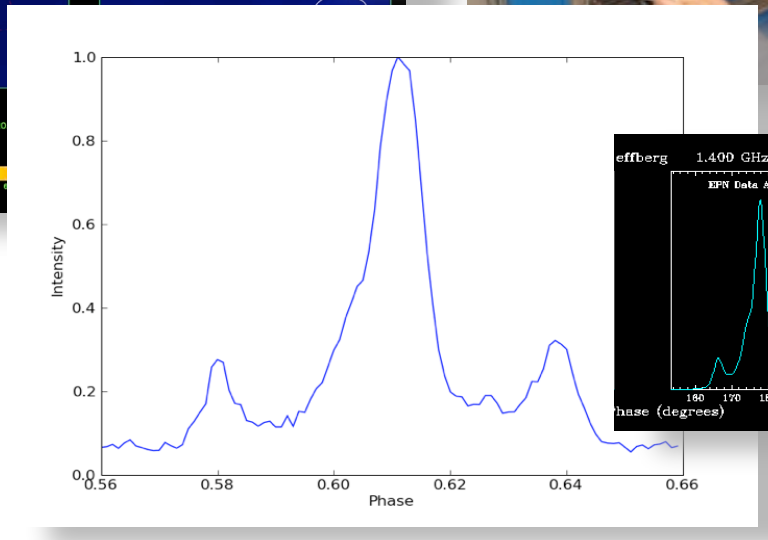
- Service Activity, which means should deliver service to community
- BoD has been demonstrated to work in previous projects, but
  - No standards
  - No recent developments
  - No clear agreement in networking community
- Should this not rather have been a Research Activity....?

SFX Software correlator

- Local JIVE correlator
  - Huygens, FABRIC and SCARIe
  - Used in ftp tests
- JIVE/EVN 16 cluster nodes
  - each 2 quad core CPUs: 128 cores
  - Direct 1GE/2GE to Mark5s
  - Test: 9 stations at 512 Mbps
    - 1024 spectral points
    - 1s integration
    - 10 minutes observations
  - Done in 9m20s wall time
- New functionality:
  - Pulsar gating/binning is implemented and tested
  - Preliminary VDIF support implemented
  - Sampler stats are calculated and reported during FTP fringe tests







Data from 2008 NME C band 10 stations

Next Generation Correlator

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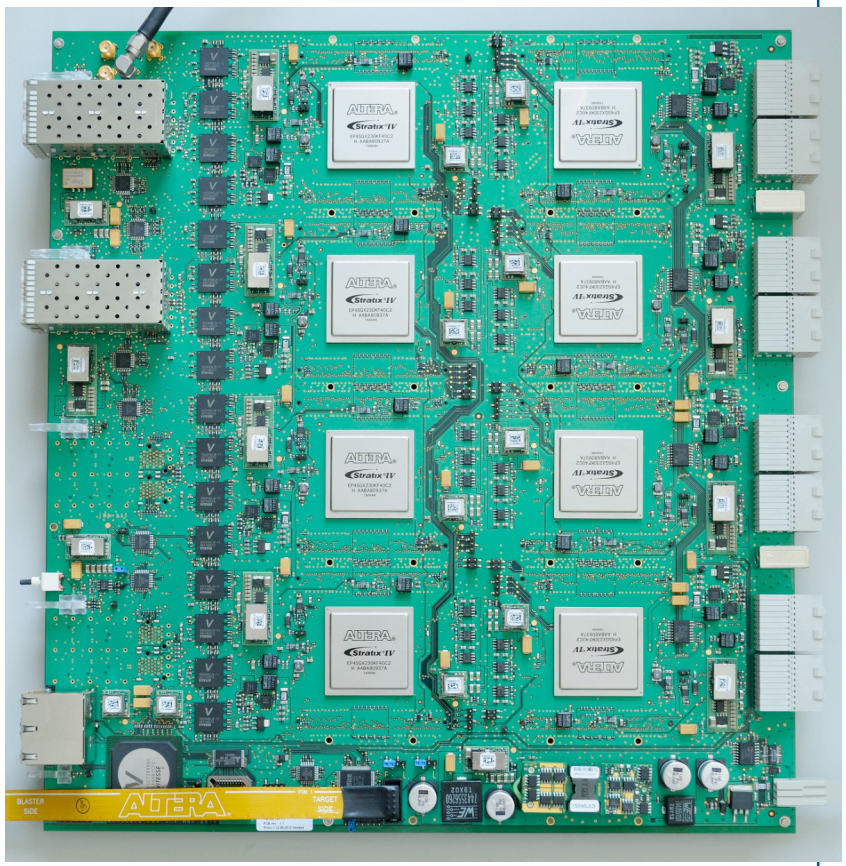
- Raised considerable budget:
  - RadioNet: UniBoard, NWO: ExBoX, NWO-ShAO collaboration
  - Link to APERTIF correlator project
- Scalable, generic, high-performance FPGA-based computing platform for radio astronomy
  - Several personalities:
    - correlator, beamformer, digital receiver, pulsar binning machine
  - Uses 40nm Altera StratixIV
  - First prototype has arrived and being tested
- Aims at 100-fold more powerful machine
  - 32 station,10 - 64 Gbps
- Much interest from different groups
  - obviously maps well onto current problems (NG EVN, Apertif)
  - possible use as building block of all-station LOFAR correlator



NEXPReS impact on EVN

- Step towards use of real-time high-bandwidth e-VLBI for EVN
  - Must increase interoperability with other VLBI networks
- Raise level of availability
  - Continuous data quality monitoring
  - Continuous network monitoring
  - More remote control, immediate feedback
- Should consider more frequent, more evenly spaced observing sessions
  - Move to VLBI every Friday... eventually
- Introduction of observations with sub-sets of EVN telescopes
  - semi-automatically generated schedules and control
  - transient response, multi-epoch campaigns
- High degree of automation in operations
  - Scheduling (network and correlator)
  - Network monitoring
  - Automated pipelines
- Increased use of software correlator
  - Parallel operations soft- and hardware correlators
  - Mixed 1Gbps-4Gbps operations

VLBI in the SKA era

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- Unique science case for VLBI during SKA operations
  - Definitely during SKA phase I and II
  - Providing global baselines
  - Located predominantly in Northern hemisphere
  - With a focus on the higher frequencies
- Requires a VLBI technology roadmap
  - And a strong international collaboration
- Will need to set ambitious goals
  - Not just new correlator, also new receptors
- Possible other innovations:
  - Many more telescopes that operate at higher frequencies
  - Maybe stations consisting of small clusters of antennas
- Upgrade of EVN correlator, receiver systems will lead to a massive increase of bandwidth and sensitivity
- Will keep EVN competitive and complementary in the era of SKA