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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

Introduction

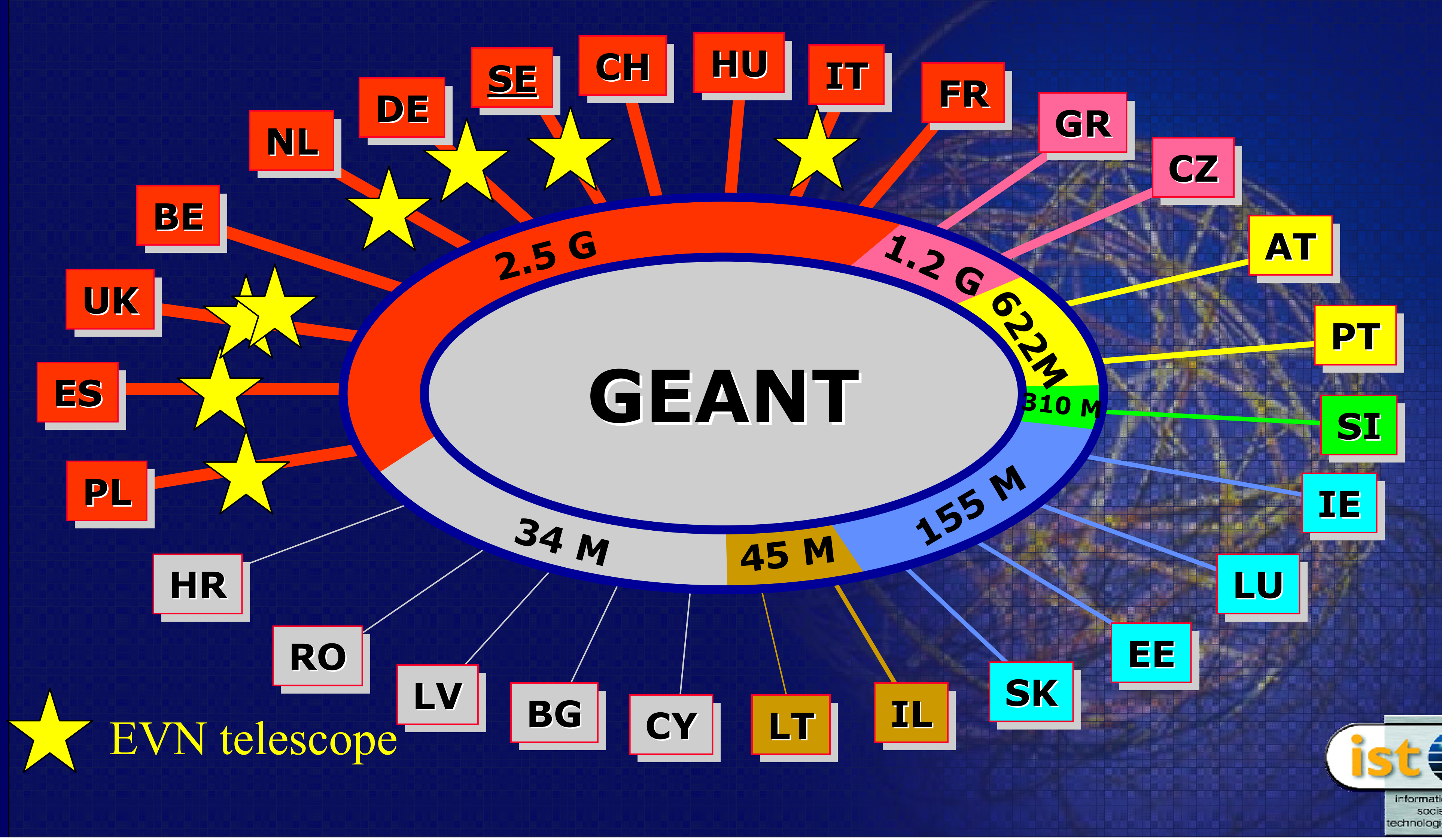
- Future of VLBI = e-VLBI
  - Recognized SKA pathfinder
- Future radio-astronomy = SKA
  - VLBI has complementary science case on an intermediate time scale

- EXPReS has demonstrated all VLBI can be e-VLBI
  - Competitive in bandwidth and resolution, robust, economic, fast

- e-VLBI is producing new science
  - And is an operational facility

- NEXPReS is funded to take next step
  - Buffering is needed in order to do all e-VLBI

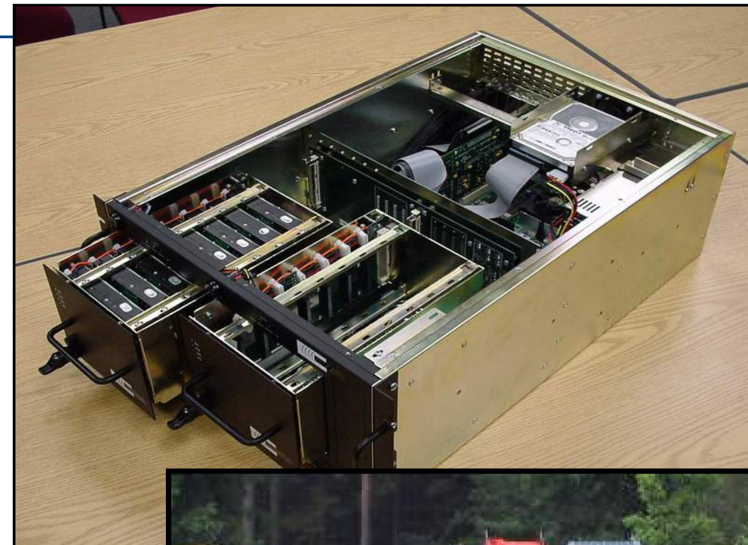
2002: first contact with DANTE and NRENs: EVN as application of GÉANT backbone



Move towards e-VLBI

FOR VLBI IN EUROPE

- Transmission via internet
  - Made possible by PC-based recording units
  - 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 Mbps limit
  - Bring in the big telescopes



- Now an operational facility
  - Guaranteed 10 x 24h per year
  - Many ways to get into e-VLBI:
    - Fast response
    - Triggered proposals
    - Short requests <2hr
    - Target of Opportunities
    - Or just because you feel like it..

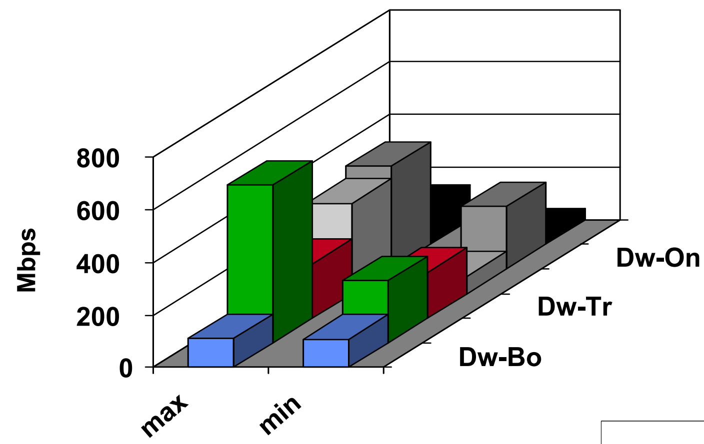
EXPReS

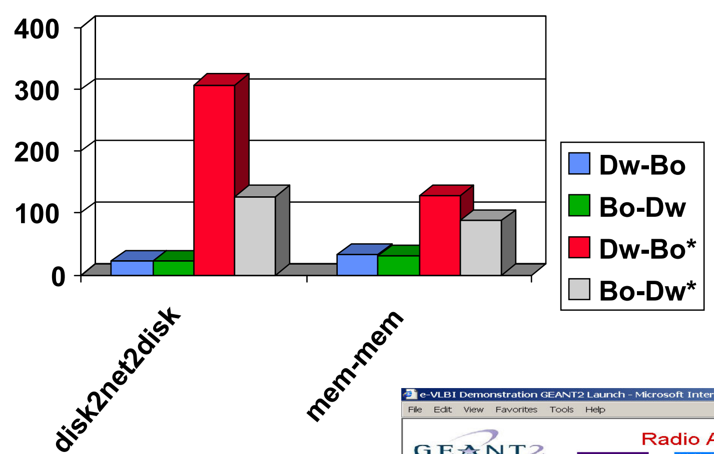
Express Production Real-time e-VLBI Service

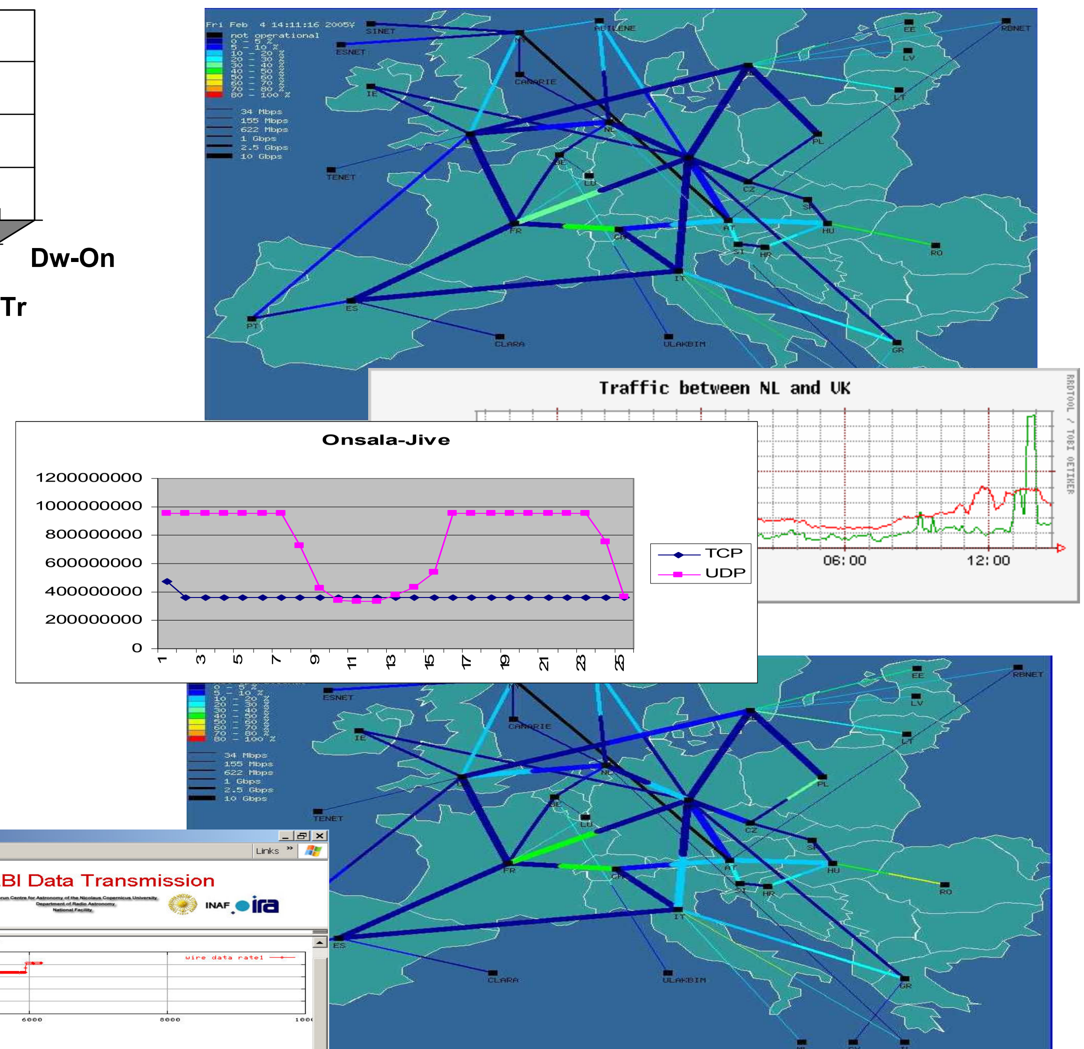
From Proof of Concept to reality

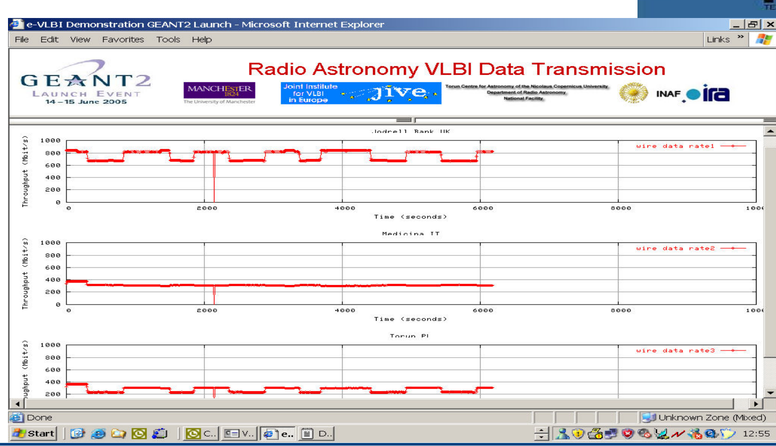
- Some of our original concerns. Would..
  - we be able to connect enough telescopes fast enough?
  - the bandwidth be high enough?
  - e-VLBI be as reliable as non-e?
  - long-haul intercontinental data transport be sustainable?
  - it produce new science?
  - it be cost effective? .....
  - we be able to accommodate all types of projects? *...eventually...*

First European transfer tests

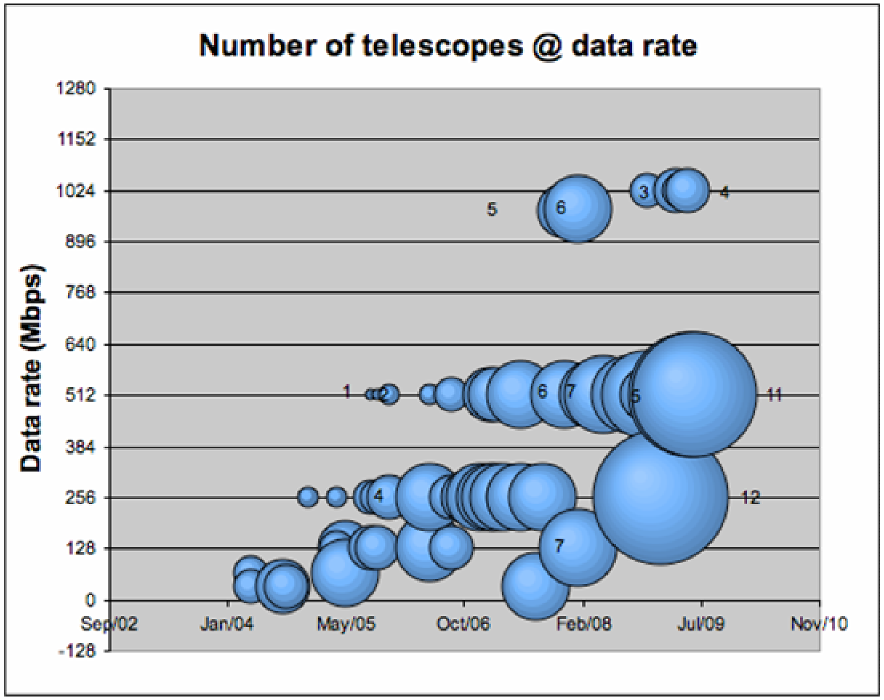


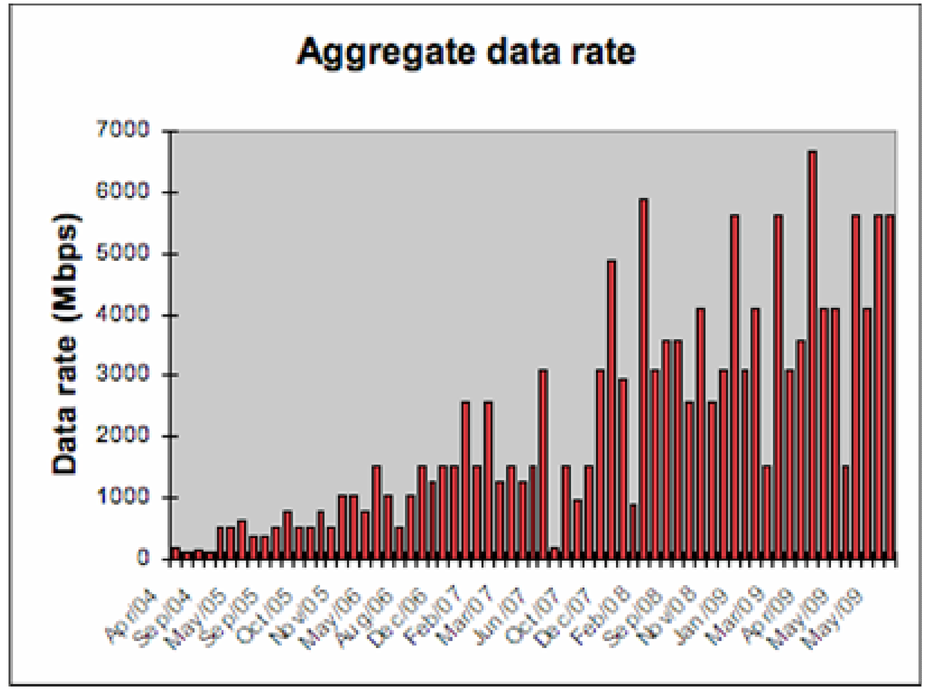


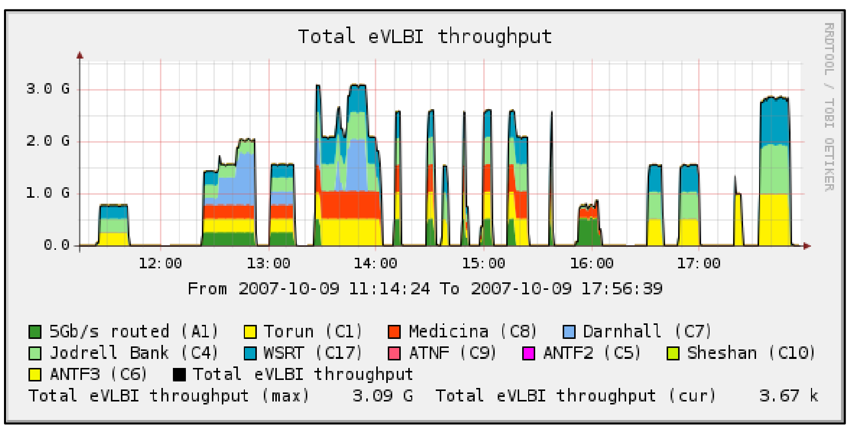


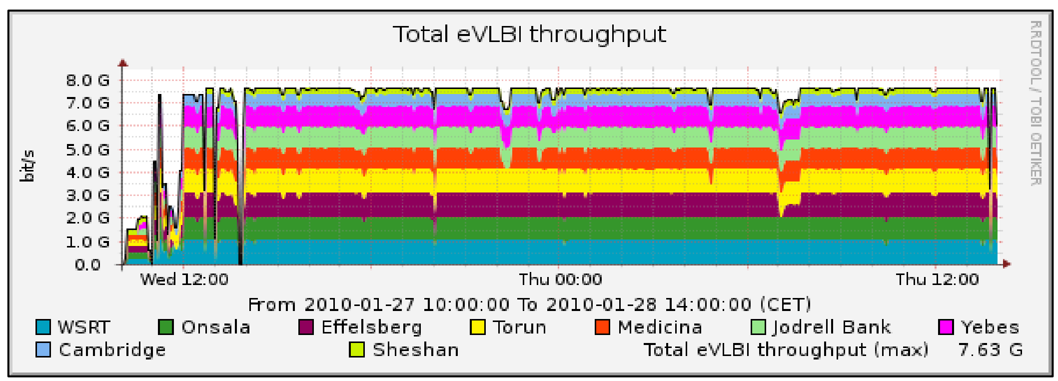


Steady improvements

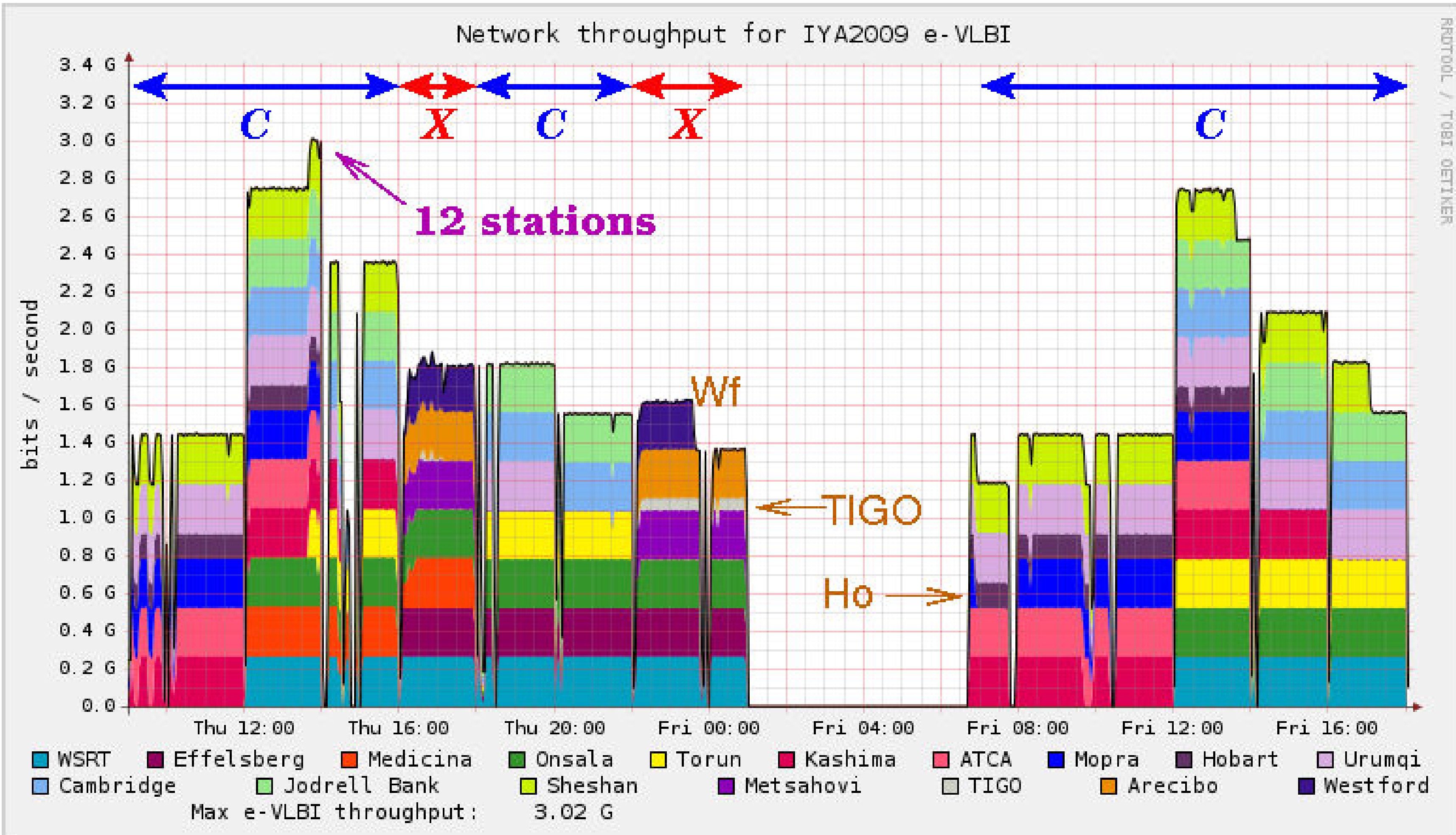






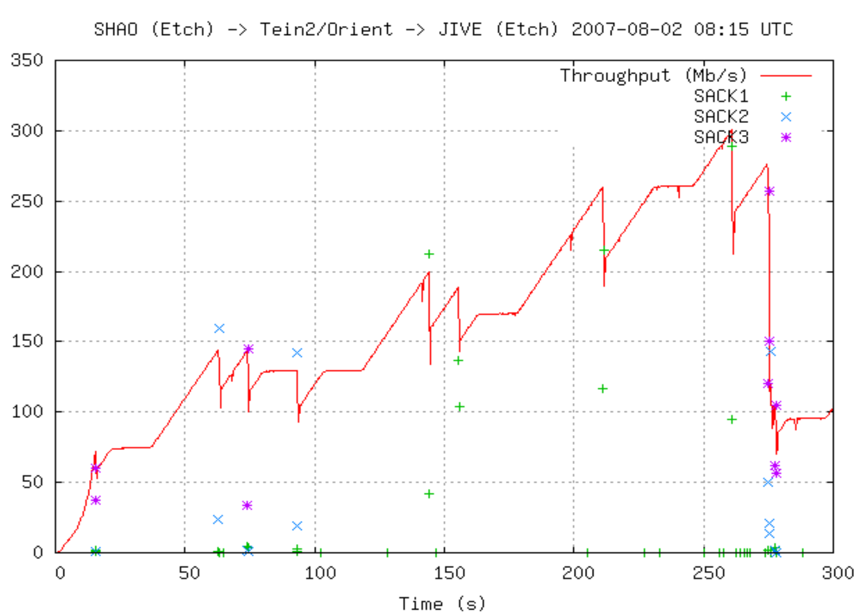


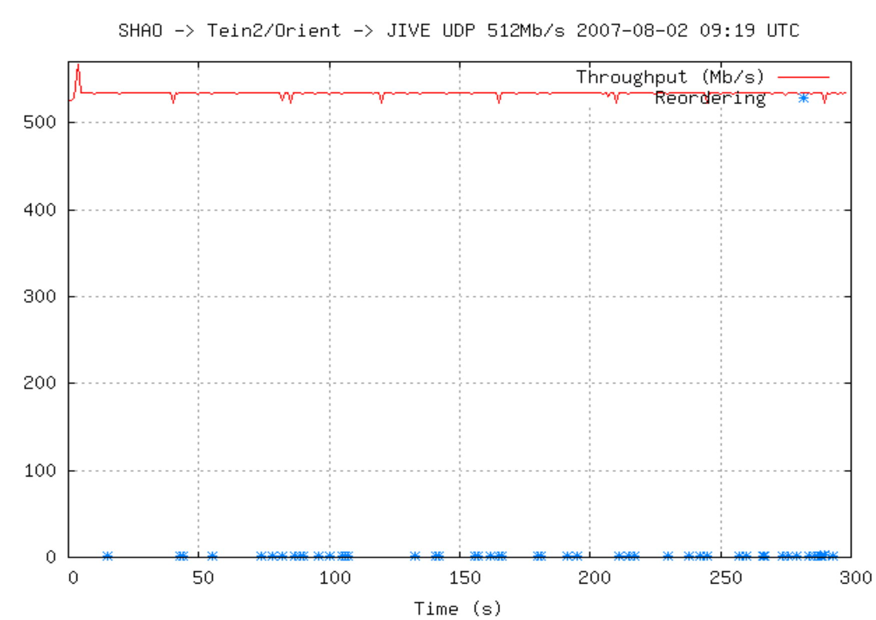
Demos leading to actual user experiments



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
- Preferred use of “private” networks (lightpaths, VPN, dark fibre)
- Good agreements, and communications, needed with providers when using open networks

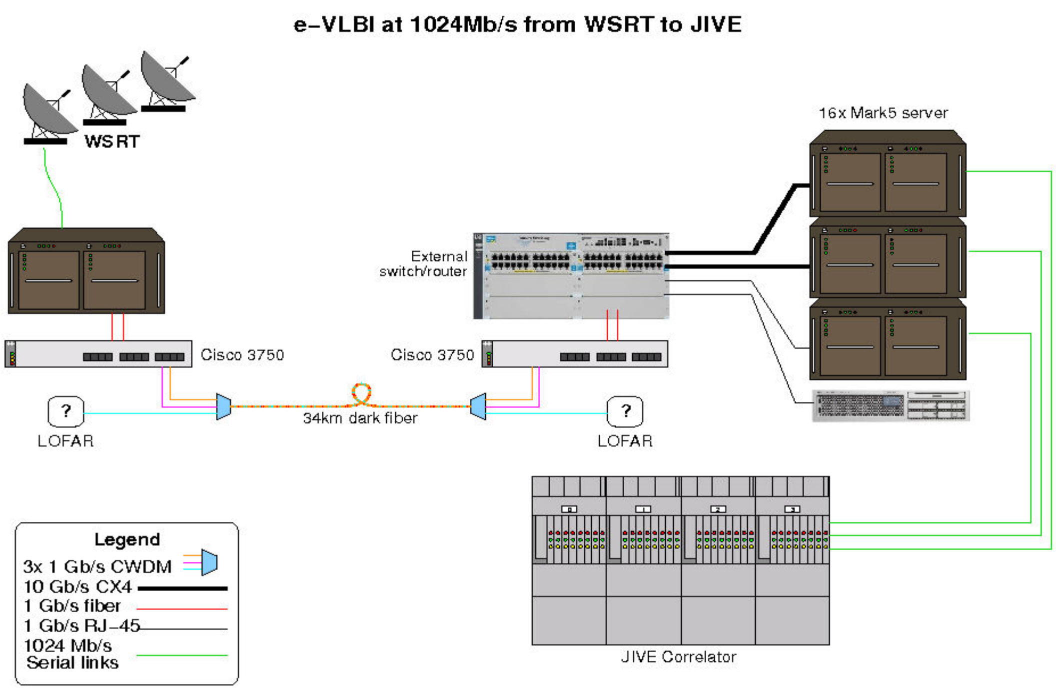




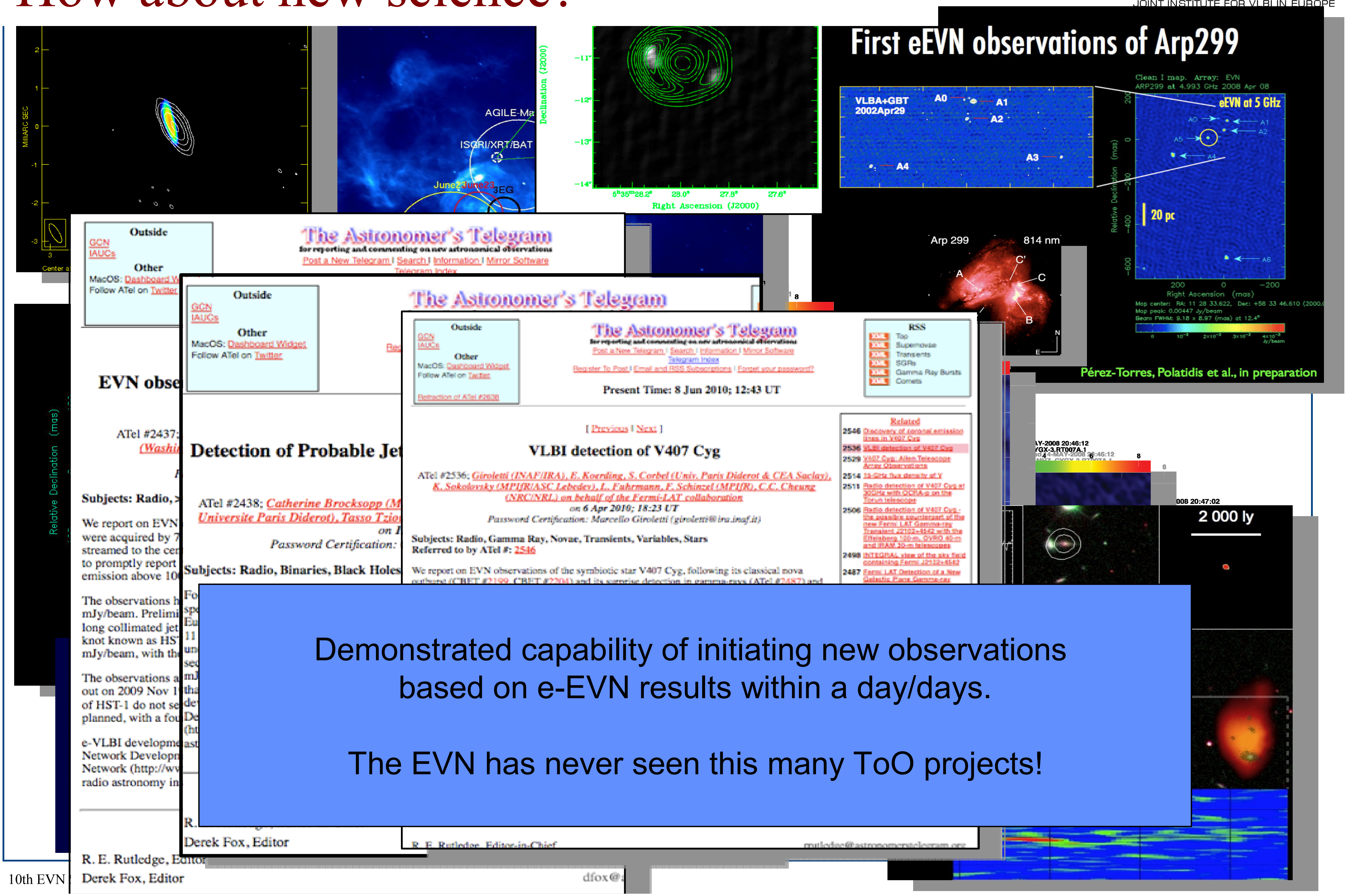
Beyond 1 Gbps

- 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)



How about new science?



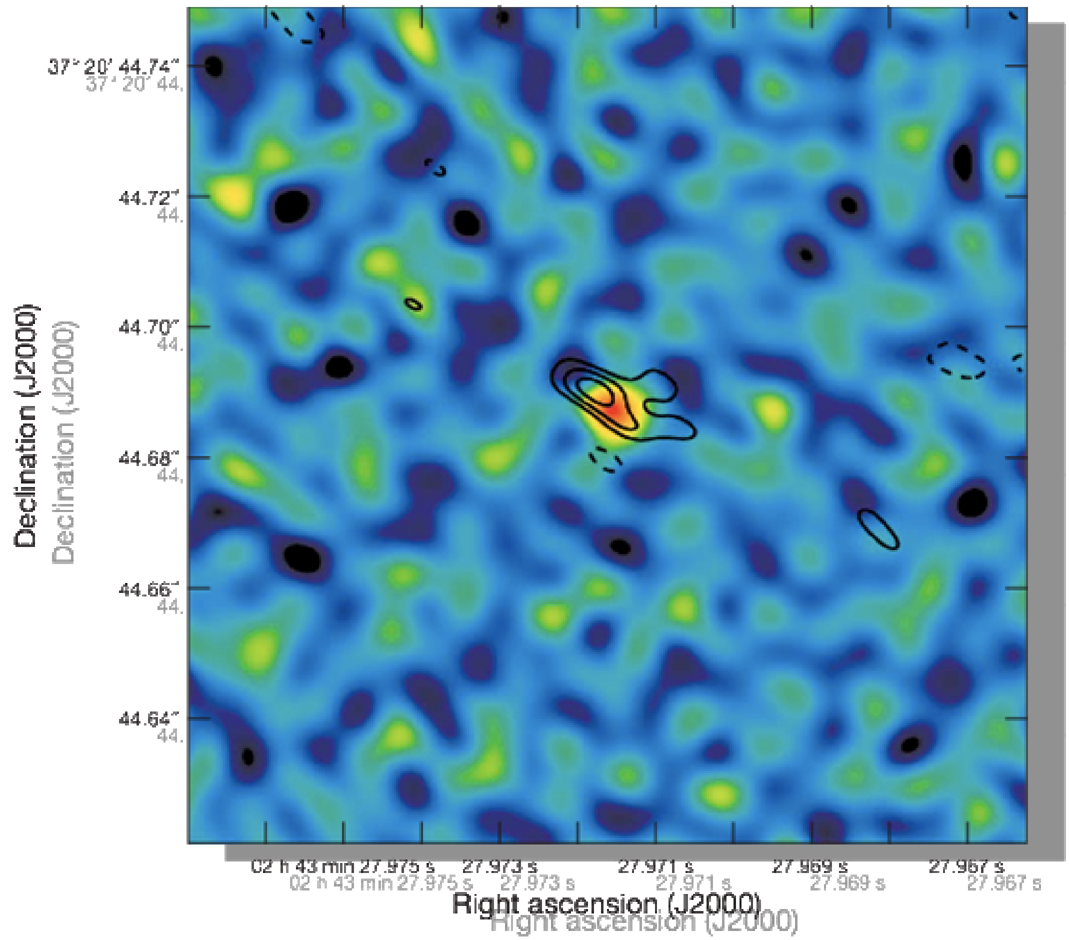
Demonstrated capability of initiating new observations based on e-EVN results within a day/days.

The EVN has never seen this many ToO projects!

Fame and fortune

SN2007gr

- Nearby type Ic supernova
- e-VLBI within 20 days
    - detection at 400 μJy/beam level
- First direct detection of relativistic expansion in a supernova
- Link with Gamma Ray burst



Paragi et al., Nature 2010, 463 516

Accepted for publication one day before EXPReS final review!!

A success story...

- Only made possible by the enthusiasm and hard work of a great many people, telescope operators and technicians, support scientists, project engineers, VLBI friends...

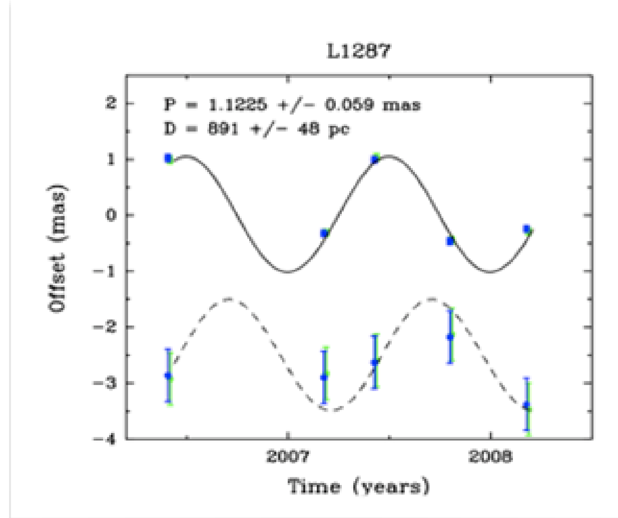
QuickTime™ and a
decompressor
are needed to see this picture.

Current limitations

- Correlator passes are a problem
  - Not a perfect correlator
  - Partly remedied by software correlator
- Not all telescopes connected
  - Noto, Urumqi
  - 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



NEXPReS

Novel EXplorations Pushing Robust e-VLBI Services

NEXPReS: EXPReS follow-up

- 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

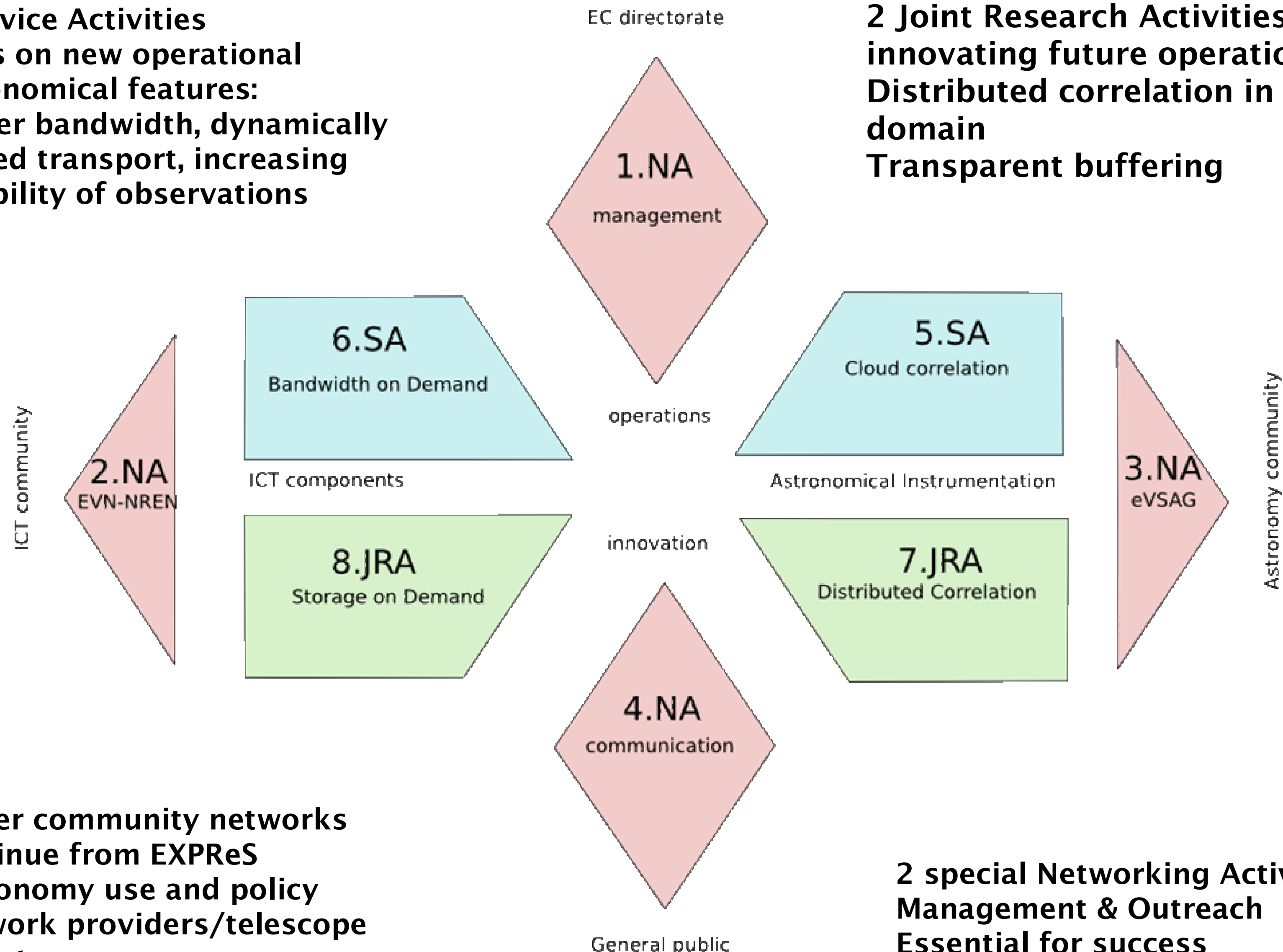
- Project has started July 1, 2010
  - Had to fit project within 3.5 M€ envelope (3.8 requested)
  - Relatively painless

- 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

Service activities

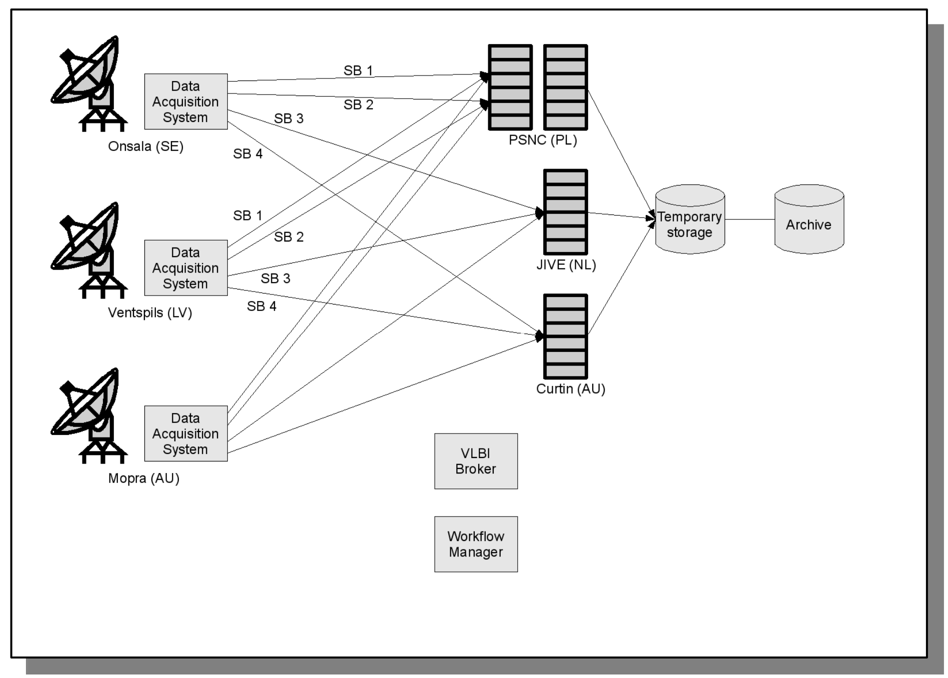
- Cloud correlation
  - Transform complete VLBI observational chain:
    - Scheduling, observing, buffering, real-time - delayed correlation, use of hardware/software correlators
  - Enable modification of observational parameters on the fly
  - Implement 4 Gbps recording/transmitting/playback
  - Implement flexible buffering at stations and correlator
  - Continuous quality and network monitoring, station remote control
  - Automated network-dependent correlation

- High bandwidth on demand
  - Permanent, static links are very convenient, but under-used, and limited to 1 Gbps
  - Integrate e-VLBI with existing BoD techniques
  - 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
  - Prepare EVN for real-time 4 and 10 Gbps operations

  - Keen interest in networking community, not all NRENs in agreement

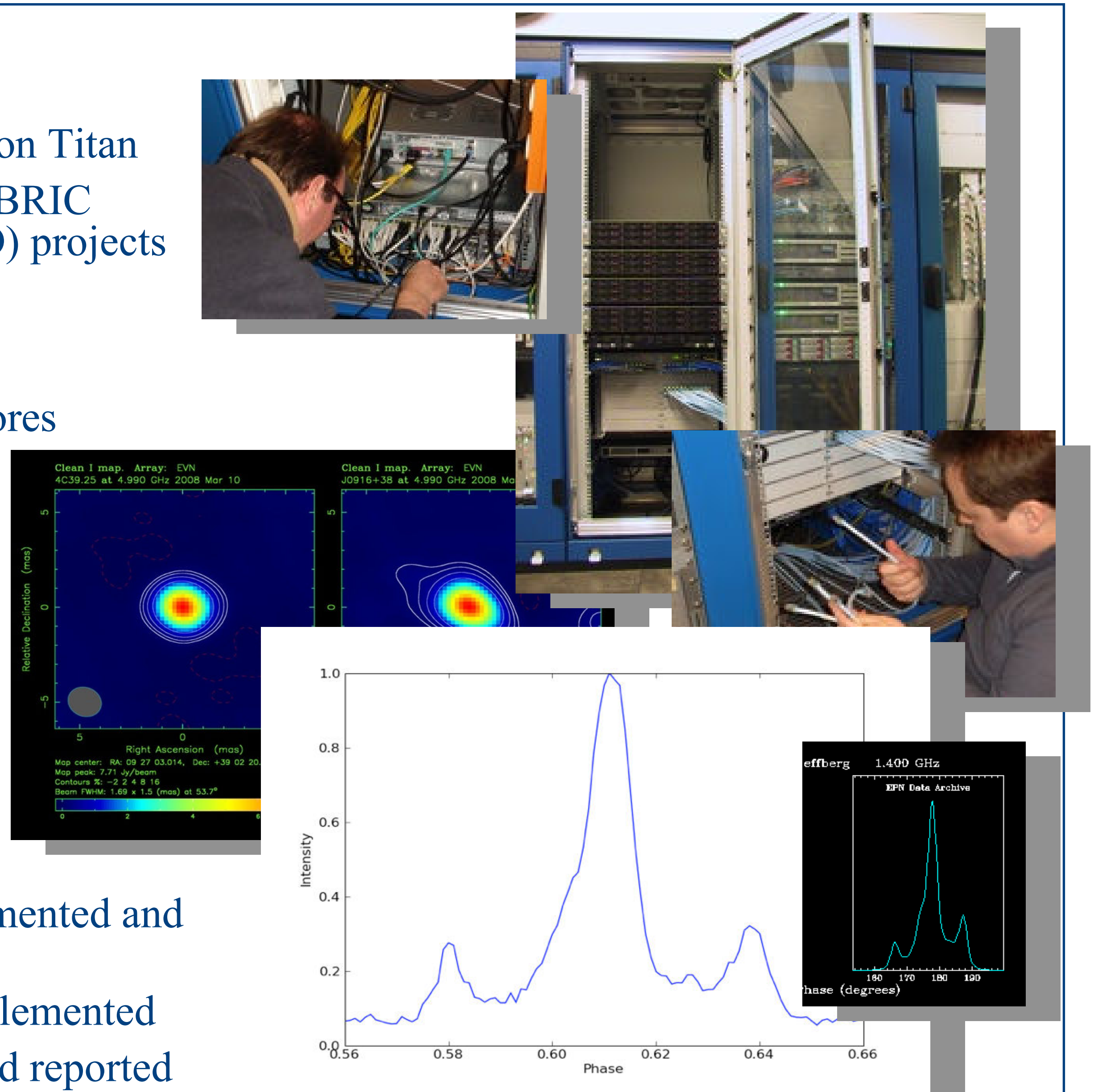
Research activities

- Computing in a shared infrastructure
  - Real-time stream processing; disks are slow, keep data on network/in memory
  - Make use of EVN infrastructure, develop generic Grid alternatives
  - Allow additional VLBI observations with (a subset) of the EVN and global VLBI arrays with a minimal impact on scarce resources (disk, manpower)
- High-bandwidth, high capacity networked storage
  - Develop buffering solutions capable of multi-Gbps simultaneous I/O streaming
  - Investigate use of LTAs, allocation of resources
- Both activities:
  - Focus on generic solutions
  - capable of supporting different applications



SFX Software correlator

- Developed at JIVE
  - First used in Huygens descent on Titan
  - Further developed through FABRIC (EXPReS) and SCARIe (NWO) projects
- 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

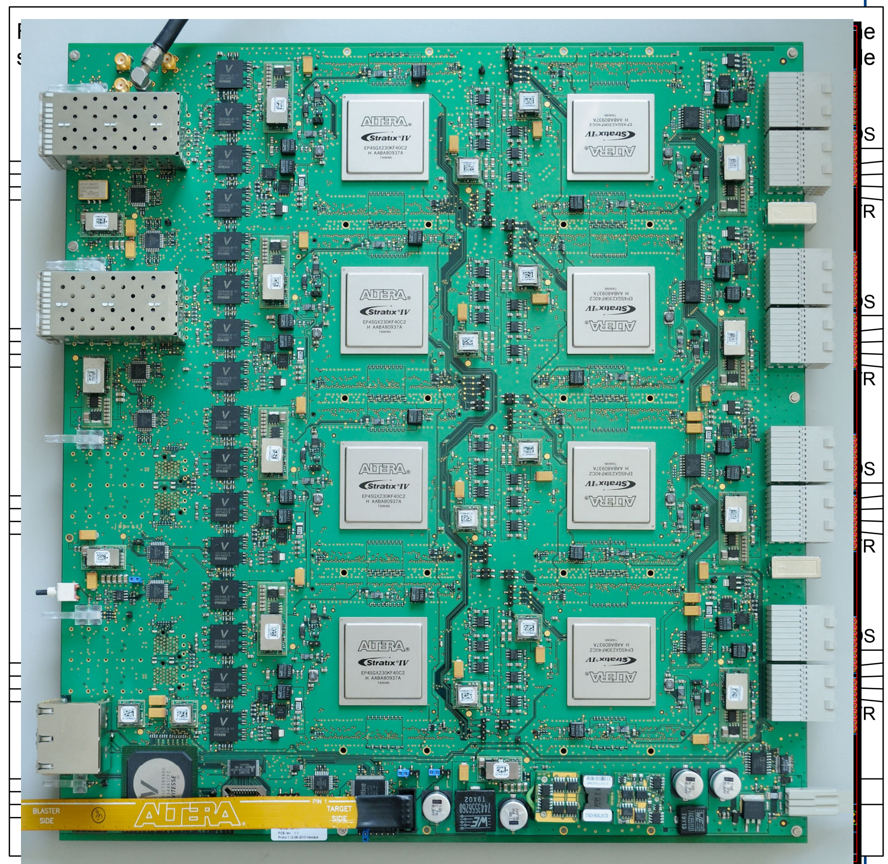


Data from 2008 NME C band 10 stations

Next Generation Correlator: UniBoard

JOINT INSTITUTE FOR VLBI IN EUROPE

- Raised considerable budget:
  - RadioNet: UniBoard, NWO: ExBoX, NWO-ShAO collaboration
  - Link to APERTIF correlator project
- Aims at 100-fold more powerful machine
  - 32 station,10 - 64 Gbps
- Scalable, generic, high-performance FPGA-based computing platform for radio astronomy
  - RadioNet FP7 research activity:
    - Jive: project lead, VLBI correlator
    - Astron: hardware
    - Inaf, Bordeaux: digital receiver
    - Uman, Uorl: pulsar binning, RFI mitigation
    - Kasi: VLBI correlator
    - ShaO, Oxford: VLBI correlator, all-station Lofar correlator
- Much interest from different groups
  - obviously maps well onto current problems (NG EVN, Apertif)
  - Future applications: Apertif beam former, correlator, 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

- 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