The future of the European VLBI Network

Huib Jan van Langevelde
Joint Institute for VLBI in Europe, Dwingeloo NL

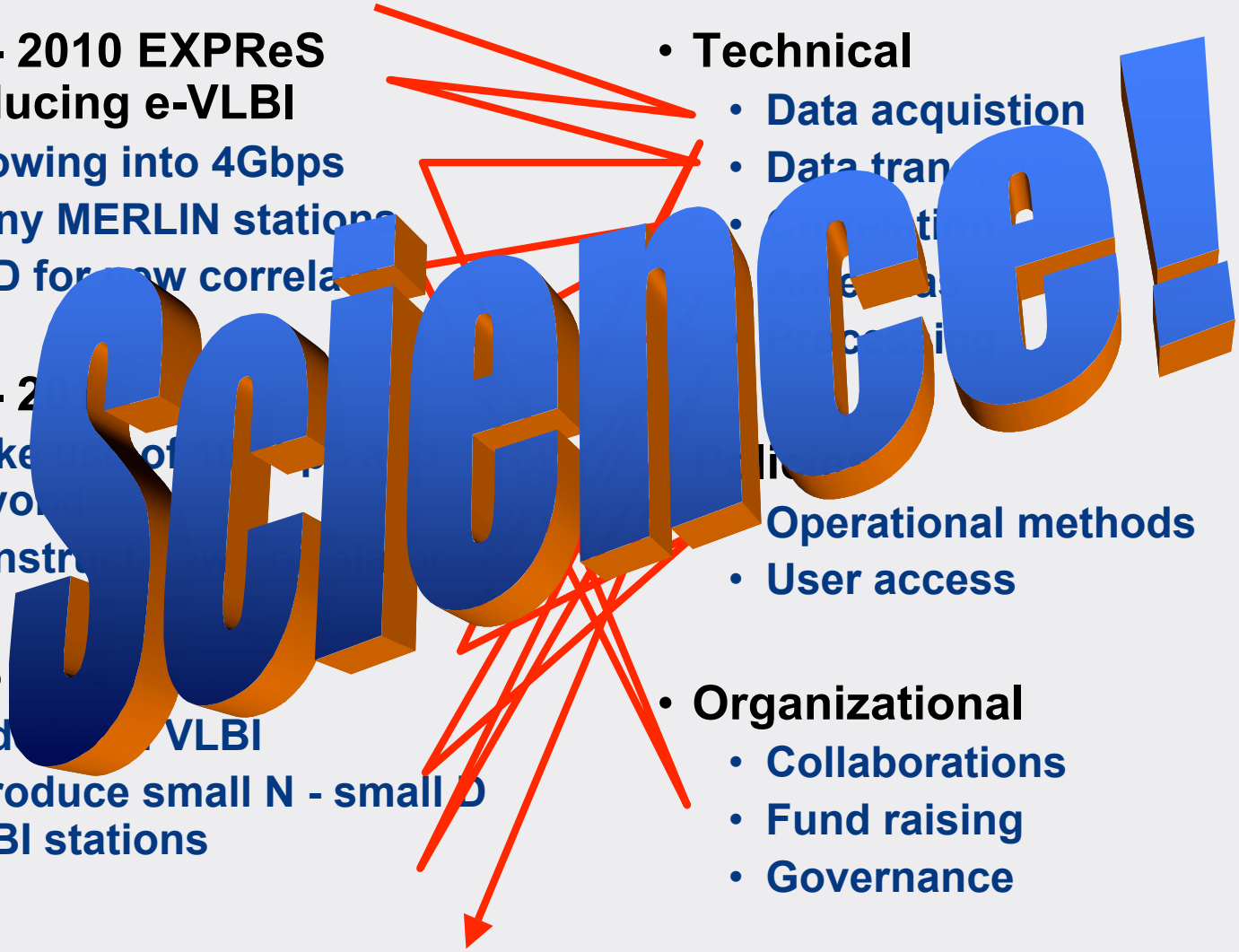
This talk

- View on the future of EVN with personal bias
- EVN CBD has started a road-mapping exercise
  - Following the issue of the EVN2015 science case
  - Various interesting concepts being discussed
  - And strategic issues
- This talk is very much open to discussion
  - “tackle” me after my talk
  - Or one of the following:
    - Walter Alef, TOG, Bonn
    - Paco Colomer, Yebes
    - Luigina Feretti, Bologna
    - Simon Garrington, Manchester
    - Huib van Langevelde, JIVE
    - Andre Lobanov, Bonn
    - Rene Vermeulen, ASTRON

Outline

Timeline

- 2006 - 2010 EXPReS introducing e-VLBI
  - Growing into 4Gbps
  - Many MERLIN statio
  - R+D fo w correla
- 2010 - 2
  - Make of
    beyo
  - Constr
- >2015
  - Wid VLBI
  - Introduce small N - small D VLBI stations

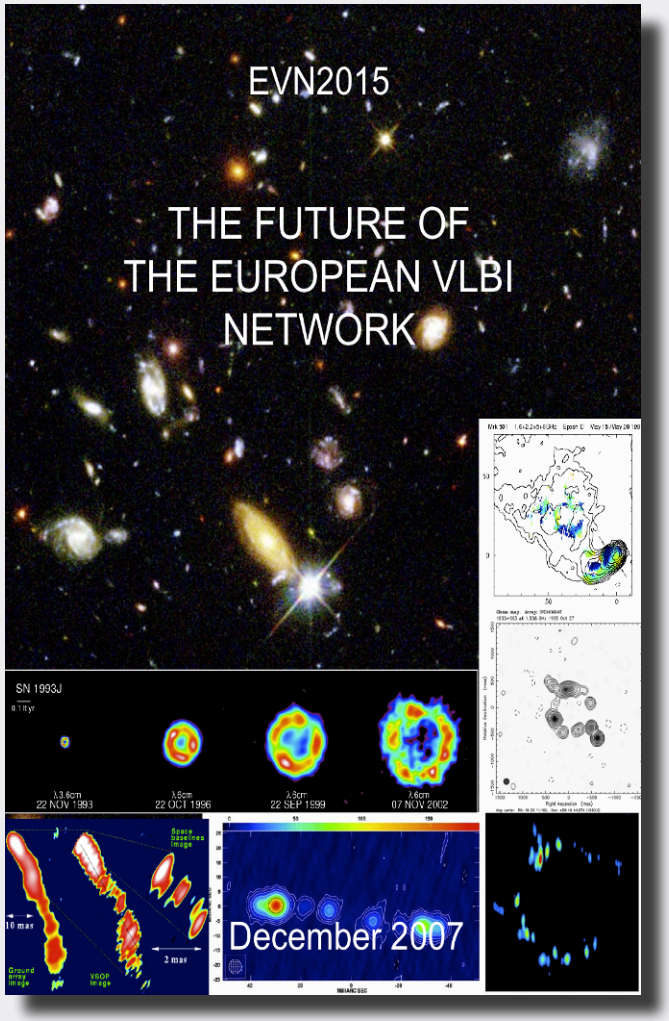


Topics

- Technical
  - Data acquistion
  - Data tran
  - Operational methods
  - User access
- Organizational
  - Collaborations
  - Fund raising
  - Governance

EVN2015 roadmap

- **Science case has been developed**
  http://www.evlbi.org/publications/publications.html



Some highlights include:

- **Nature of starburst/AGN in cosmological fields**
- **The fate of black holes/radio quiet AGN**
- **Jet physics close to the event horizon (VSOP2)**
- **Determining star burst activity, resolving SNR's**
- **The accretion physics in transient radio sources**
- **The detailed 3D kinematics of star formation**
- **The nature of the ISM in active galaxies**
- **Fundamental distances from astrometry**
- **Pulsar astrometry**
- **Monitoring spacecraft in the solar system**

Complement to new facilities

- **Science case will be complementary to other facilities**
  - **EVLA will reach new science with enhanced sensitivity**
  - **E-MERLIN will have fantastic bandwidth coverage**
  - **Will require VLBI to operate in same regime for follow-up**
- **LOFAR and E-LOFAR**
  - **Interesting input catalogues for VLBI follow-up**
  - **Cosmological sources at low frequency**
  - **Transients and variable sources**
- **Other SKA pathfinders**
  - **In particular follow up of pulsar surveys**
- **European Astronomy facilities outlined in ASTRONET effort**
  - **EVN recognized as addressing some of the major themes in astronomy**
- **There is a need for VLBI in SKA era**

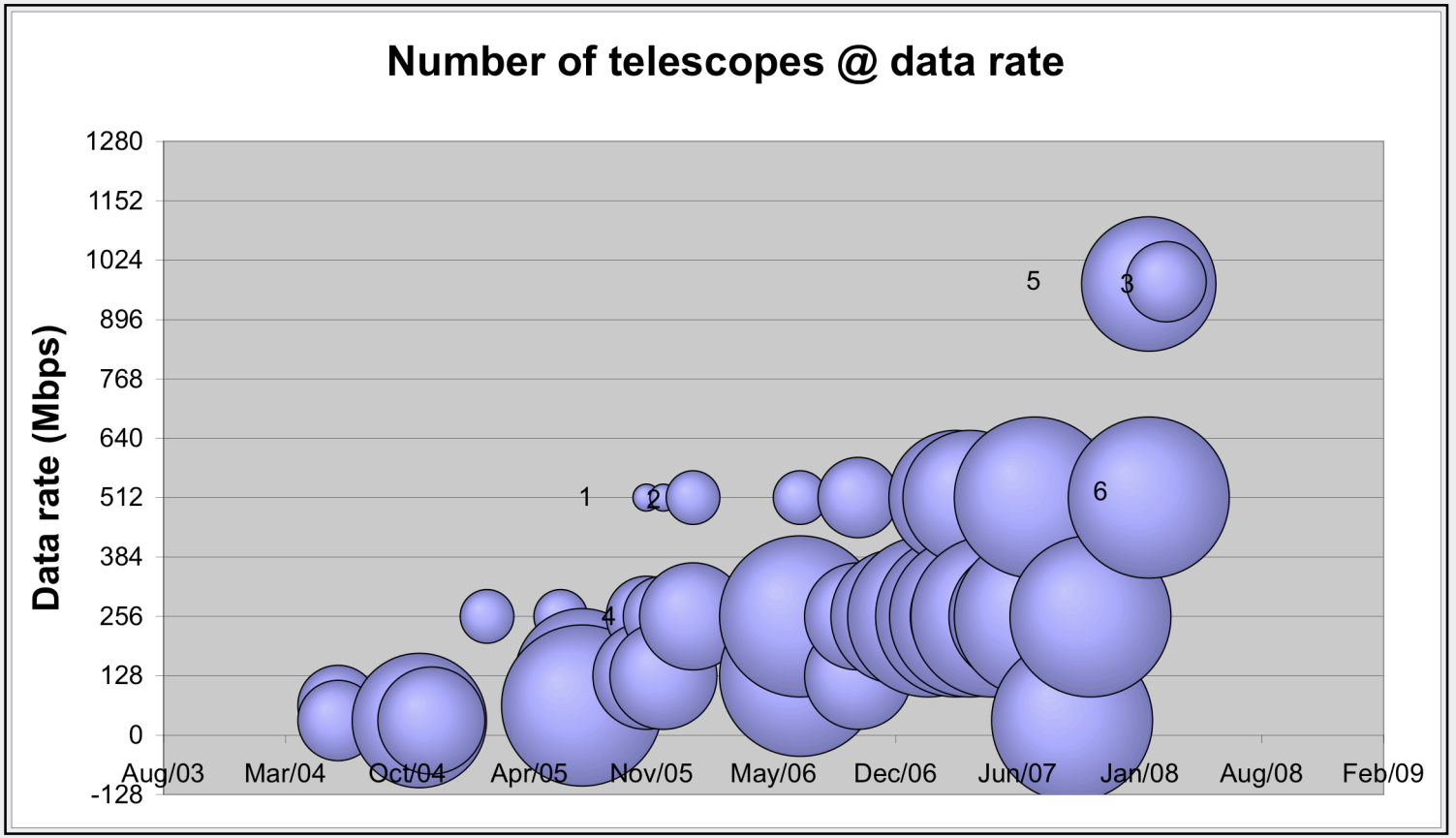
First point: it will be e-VLBI!

- **When we started e-VLBI and the EXPReS project**
  - First pilots in 2004
  - EXPReS funded in 2006 by the EC, finishes in 1 year
- **Amongst our concerns:**
  - Can we connect all telescopes on competitive timescale?
  - Will we be able to deliver interesting bandwidth?
  - Will e-VLBI be just as reliable?
  - Will it be applicable to Global VLBI?
  - Will it produce new science?
  - Will it be cost effective?
  - Are we loosing options by not recording the data?
- **Looking at the progress with e-VLBI:**

Remarkable progress

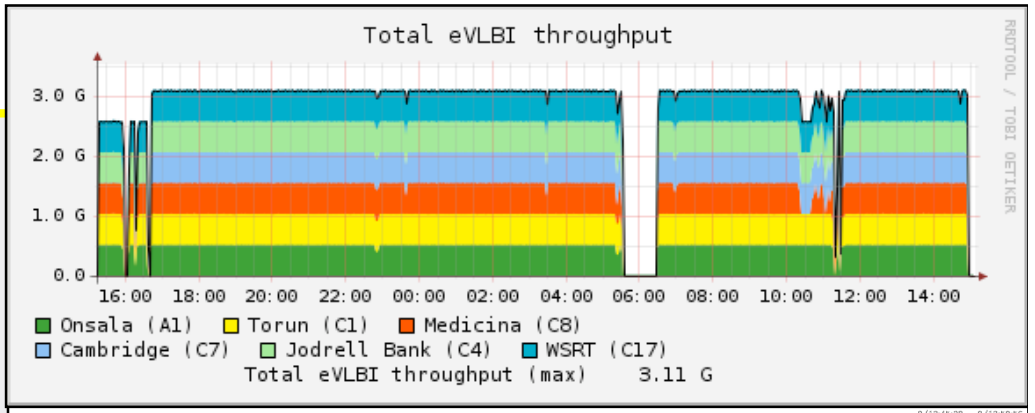
- 7 telescopes regularly on line, interesting for science
  - Sustained operations at 512Mb/s

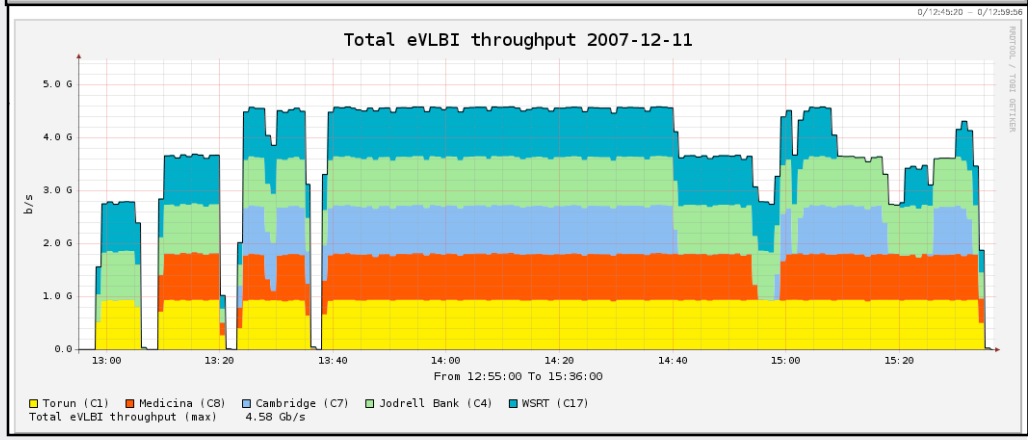
Size of bubble set by number of telescopes participating, height by station sustained bit-rate



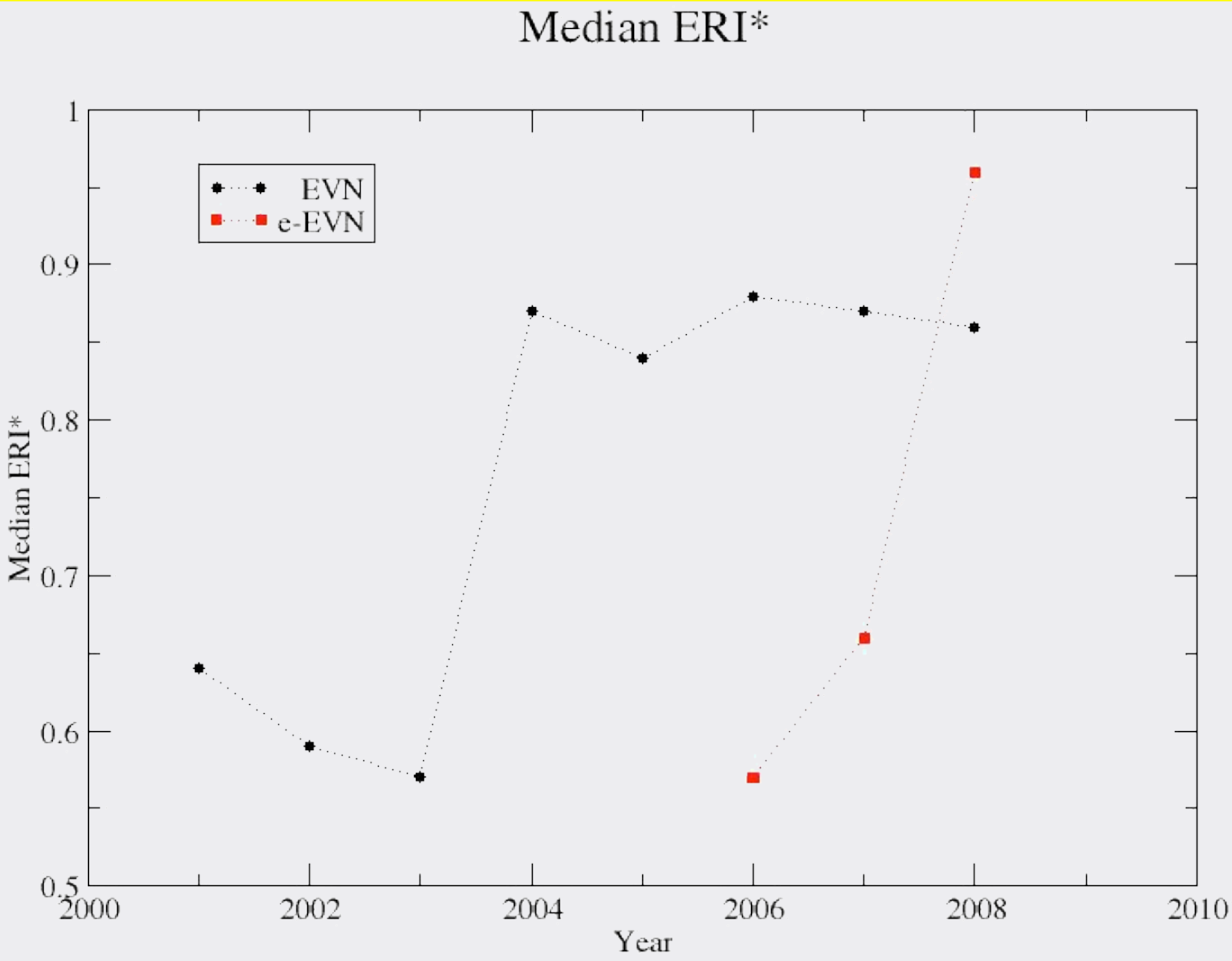
Progress in Europe

- As robust as normal VLBI
  - 24 hr long up-time:
- Managed to get almost full sensitivity at 1024 Mbps
  - Selectively dropping data
- Connectivity to Effelsberg
  - Major importance for sensitivity
  - Included in science runs





EVN Reliability Index



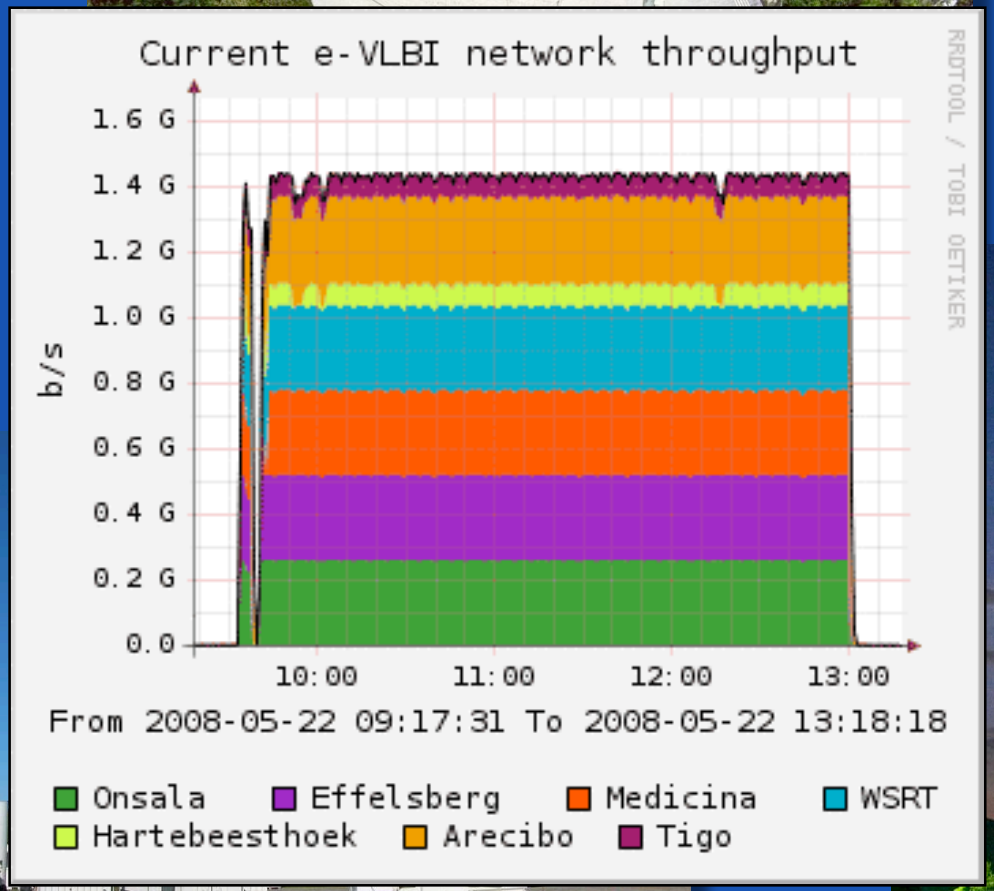
2008: Africa and the Americas

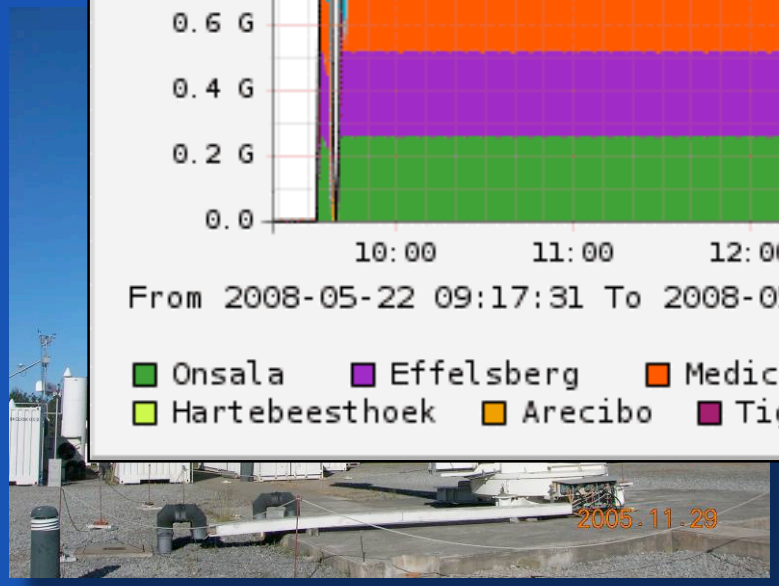
Network status as per 2008-05-02. Image created by Paul Boven <boven@jive.nl>. Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

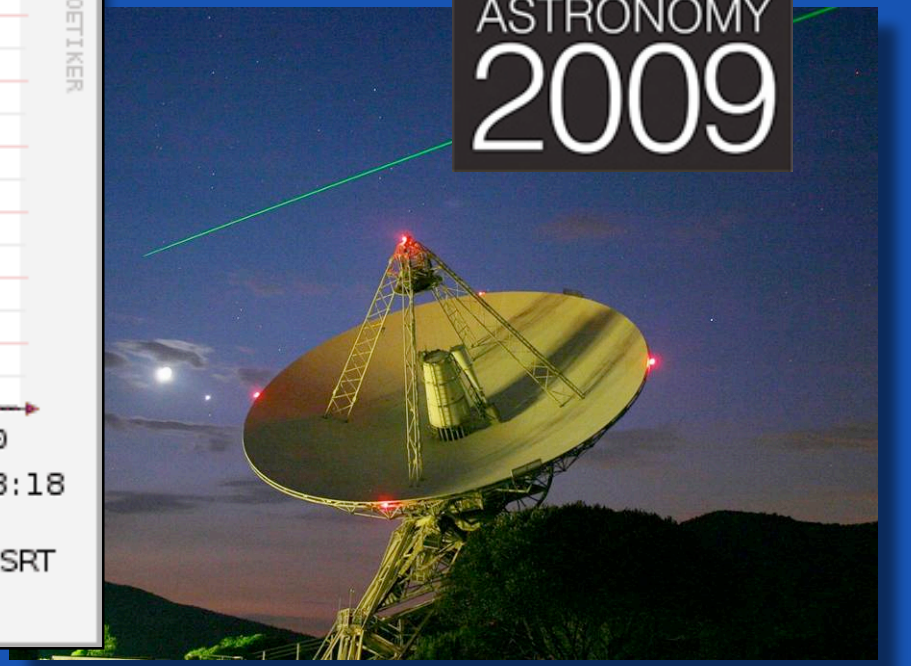
Demo in 2008 at TERENA

- **Arecibo, Puerto Rico**
- **TIGO Chile**
- **Hartebeesth**

Challenge: 5 c
Internationa
Astronomy 2

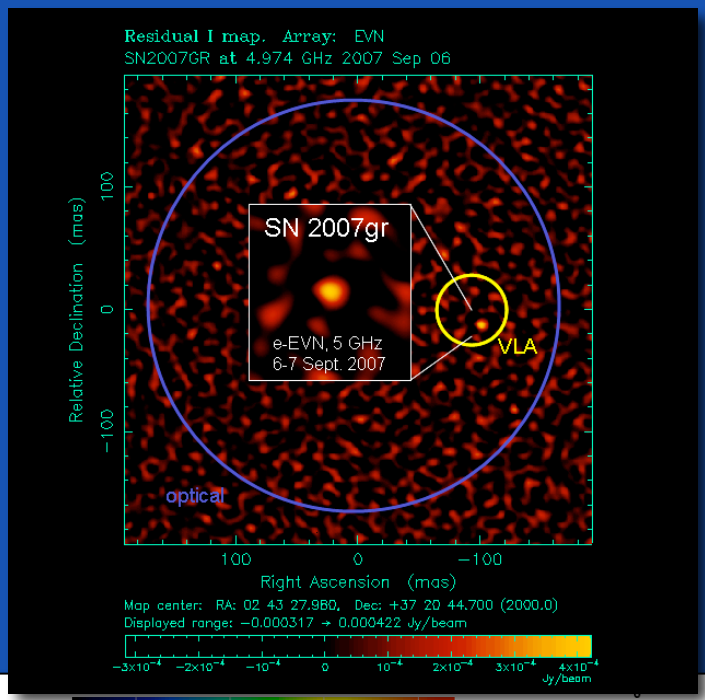


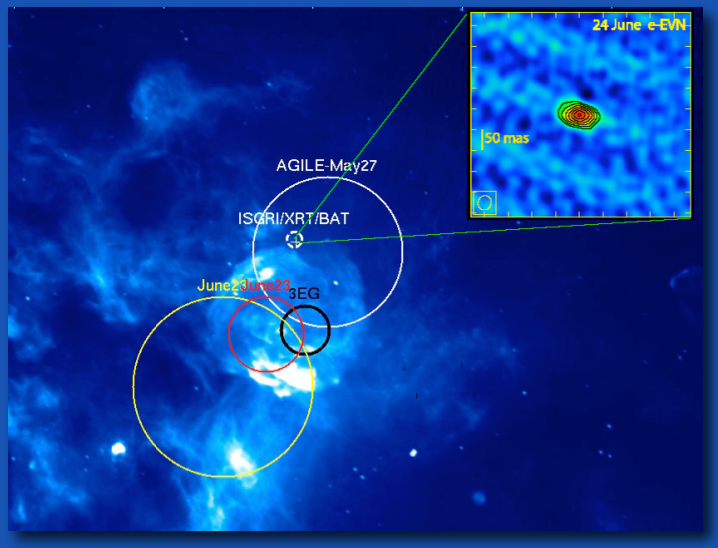


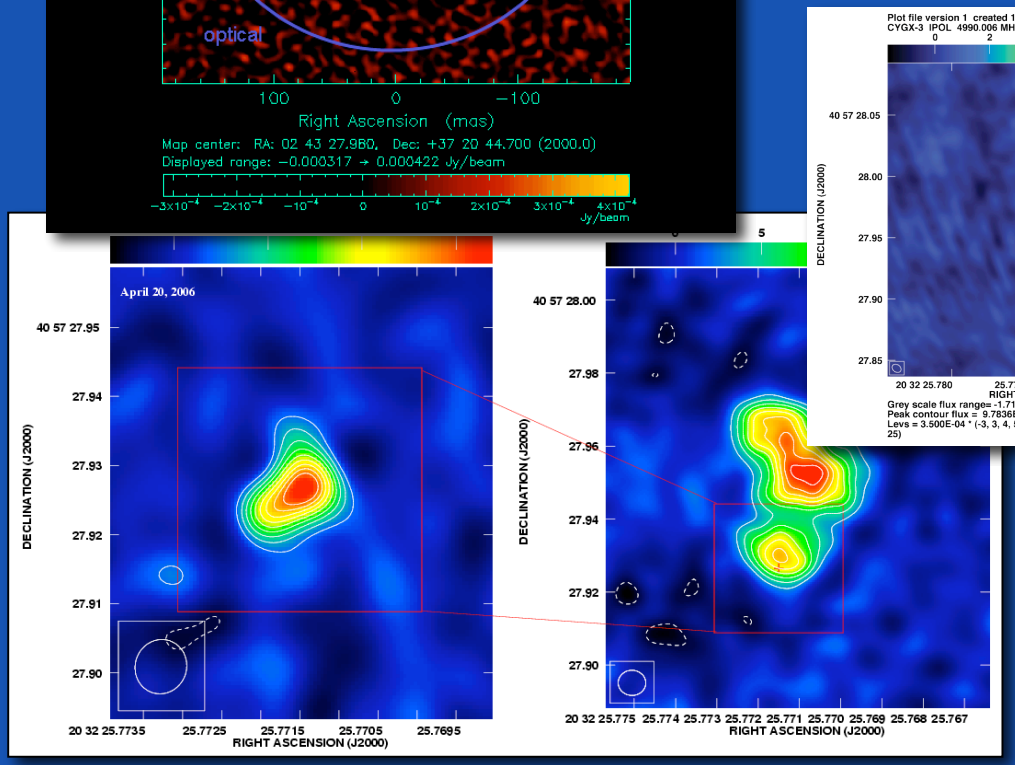


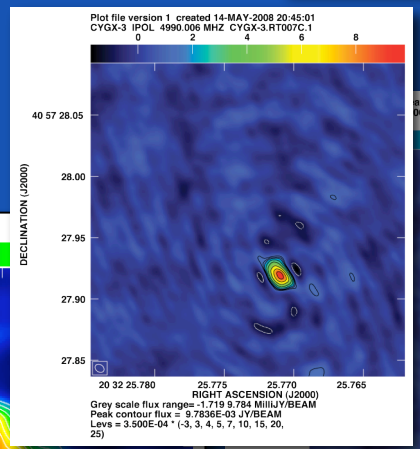
THE UNIVERSE
YOURS TO DISCOVER
INTERNATIONAL YEAR OF
ASTRONOMY
2009

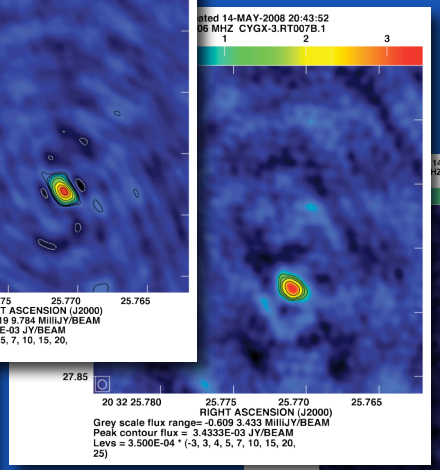
New e-VLBI science

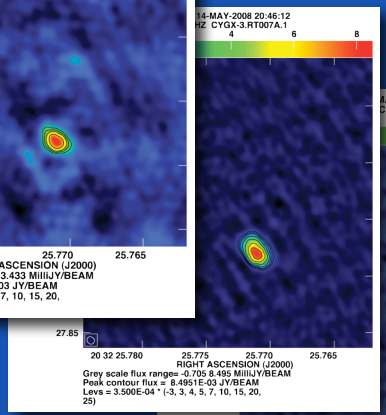


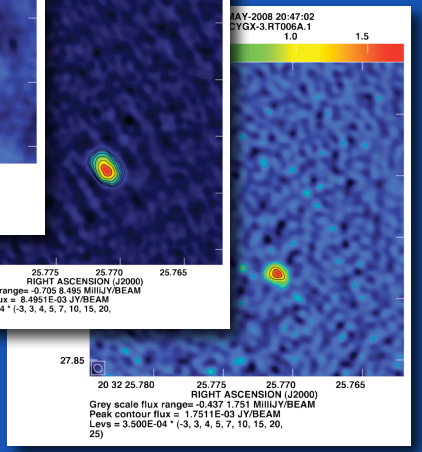












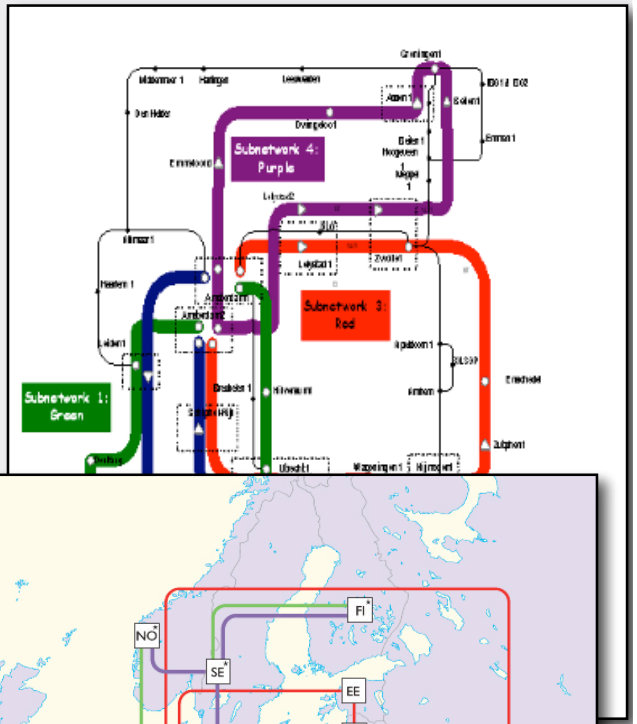
Scientific output:

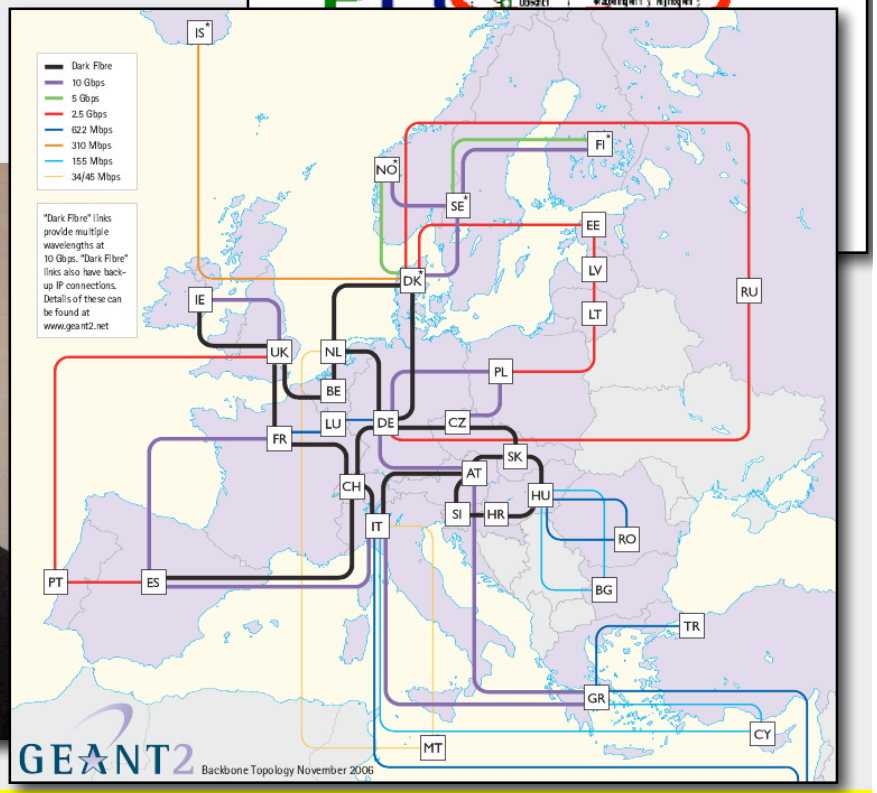
- Operational facility from 2006
  - Available on scheduled dates throughout year
    - For normal proposal and short observations
    - And special class of triggered proposals
  - Increasing use for Target-of-opportunities

- Cultural change requiring quite some discussion in the EVN

Cost effective?

- **Shipping still cheaper than bandwidth at commercial rates**
  - **International connectivity provided by Geant as part of project**
  - **Local providers quite supportive of the project**
  - **Continue to lobby for continuity**





Buffered VLBI data

- **Are we loosing options by correlating real time?**
  - **Considerable fraction EVN proposals have multiple passes**
    - **For different resolution on line channels**
    - **High resolution pass for spectra-polarimetry**
    - **To collect all baselines for 16+ stations**
  - **Just means the correlator is not up to user requirements**
- **Still, buffering data could be advantageous**
  - **To include telescopes that cannot connect**
  - **Real time results and full array results later**
- **Could be important step in guaranteed quality level for EVN observations**

EXPReS follow-up

- e-VLBI wish-list for Network providers
  - Dynamically allocation of light-paths
    - To accommodate distributed correlation
    - And around the globe in some uniform manner
  - Must continue close collaboration with NREN
  - Buffering data at telescopes and correlator for robustness
- Make use of 10Gb/s infrastructure!
- Requiring upgrades on the VLBI side:
  - Implement new digital data-acquisition system
  - And expand the usable IF bandwidth
  - Decide on correlator architecture for next generation
- Synergy with E-LOFAR connectivity

Scientific motivation

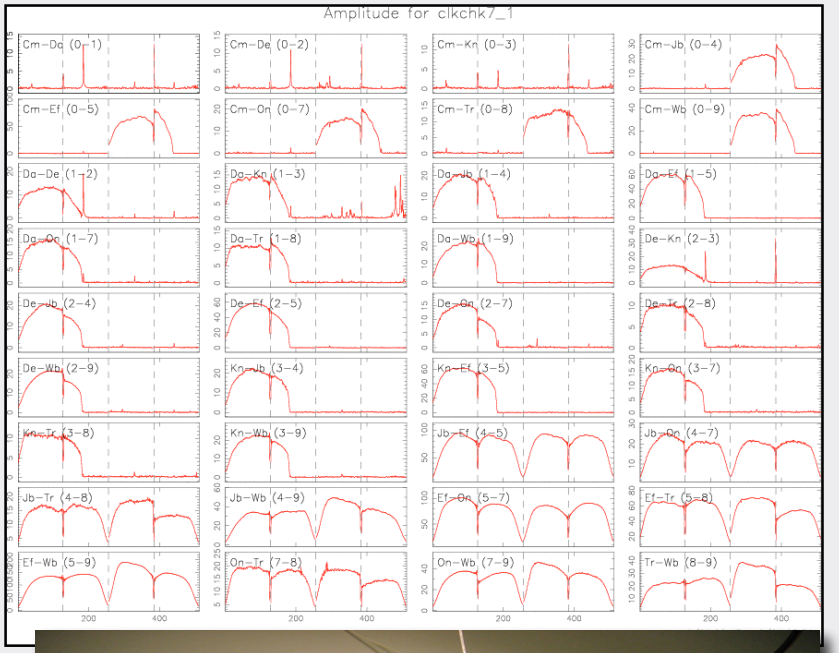
- Rapid response for rapid variability
  - Fast response to requests
  - Immediate analysis of data, adapt observing parameters
  - Coordination with current and future observatories
    - GLAST, LOFAR
- Immediate feedback
  - More robust data
- Fewer consumables, logistics
  - Constantly available VLBI network
    - Monitoring: for example astrometry
    - Spacecraft tracking
- Growth path for more bandwidth
  - More sensitivity
- European SKA pathfinder

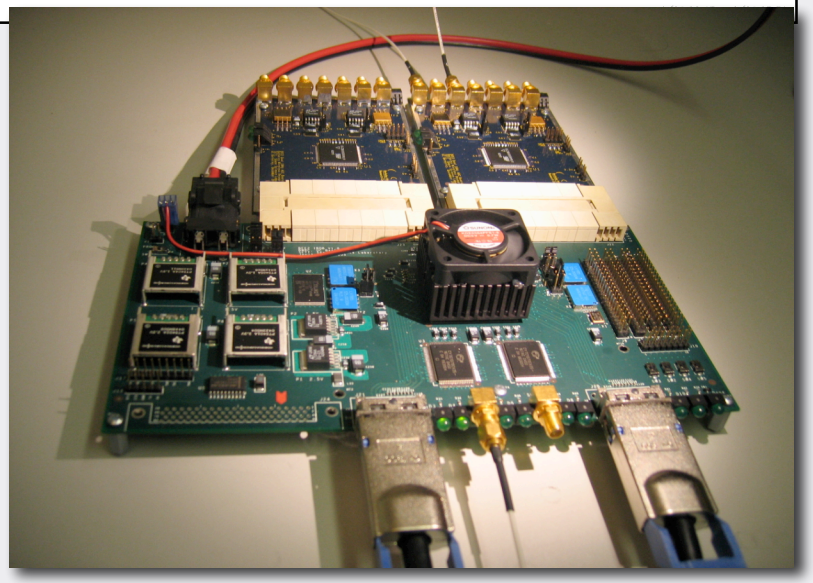
Data acquisition

- First DBBC systems being commissioned
  - Improves data quality
  - And provides path to larger bandwidth
  - EVN aiming for 4Gbps pilot
- Mk5B systems ready for use
  - Necessary to overcome outdated playback capability
  - Mk5C being adopted by VLBA
  - Global compatibility at 1 Gbps and beyond
- Use requires upgrade of telescope IF bandwidth
  - Limited at lower frequencies by available allocation

MERLIN telescopes in the EVN

- Recent EVN experiment had fringes from 5 UK dishes
  - In 1 pol and limited by MERLIN link bandwidth
- Supposedly much better in eMERLIN
  - Work on digital interface defined in EXPReS
- eMERLIN interfaces make you think again about chanellization
  - Could all be in correlator





Yebes, new 40m telescope

- **Now available at S,X,K**
- **First ever telescope to have first fringes without recording**


JUNKERS
Irbene 32m

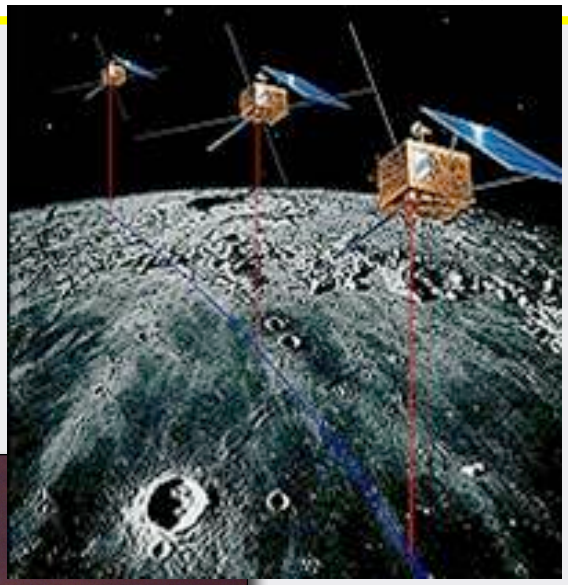

Miyun 50m

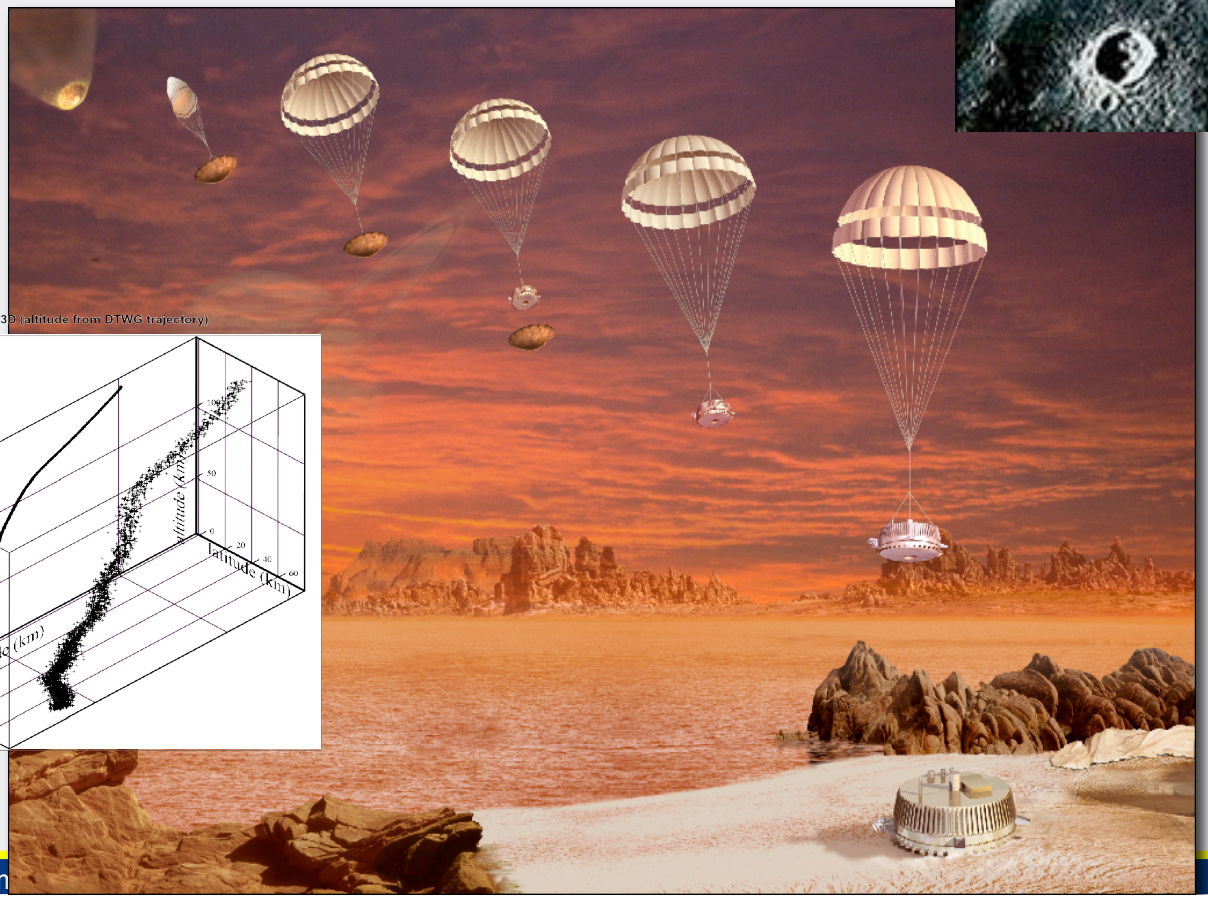

Sardinia 64m


Kunming 40m

Relation with space

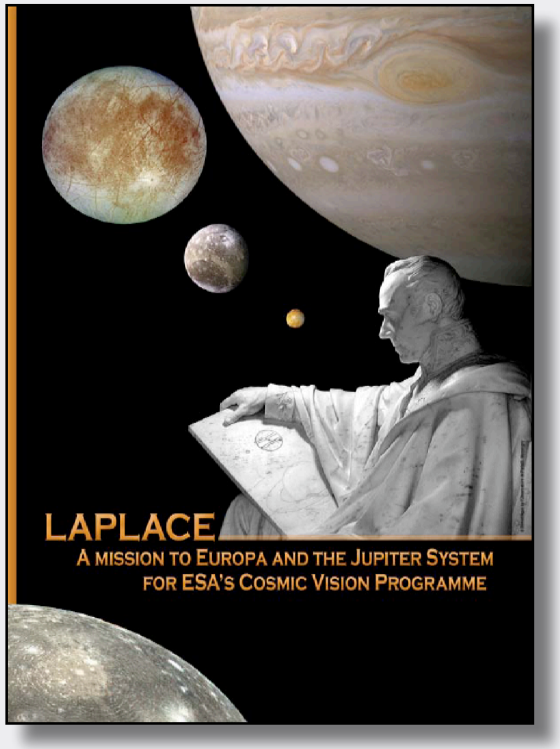
- Chinese telescopes in Chang'E project
- Similar to Huygens application

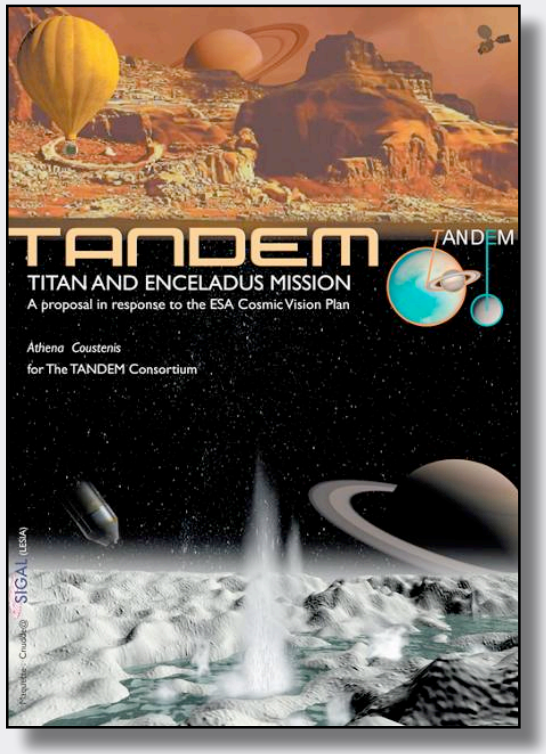




More spacecraft tracking

- **LAPLACE and TANDEM (former names)**
  - **accepted by ESA for study for 2015-2025**
  - **Earlier projects may include Bepi-Colombo**





LAPLACE: a mission to Jupiter and Europa:

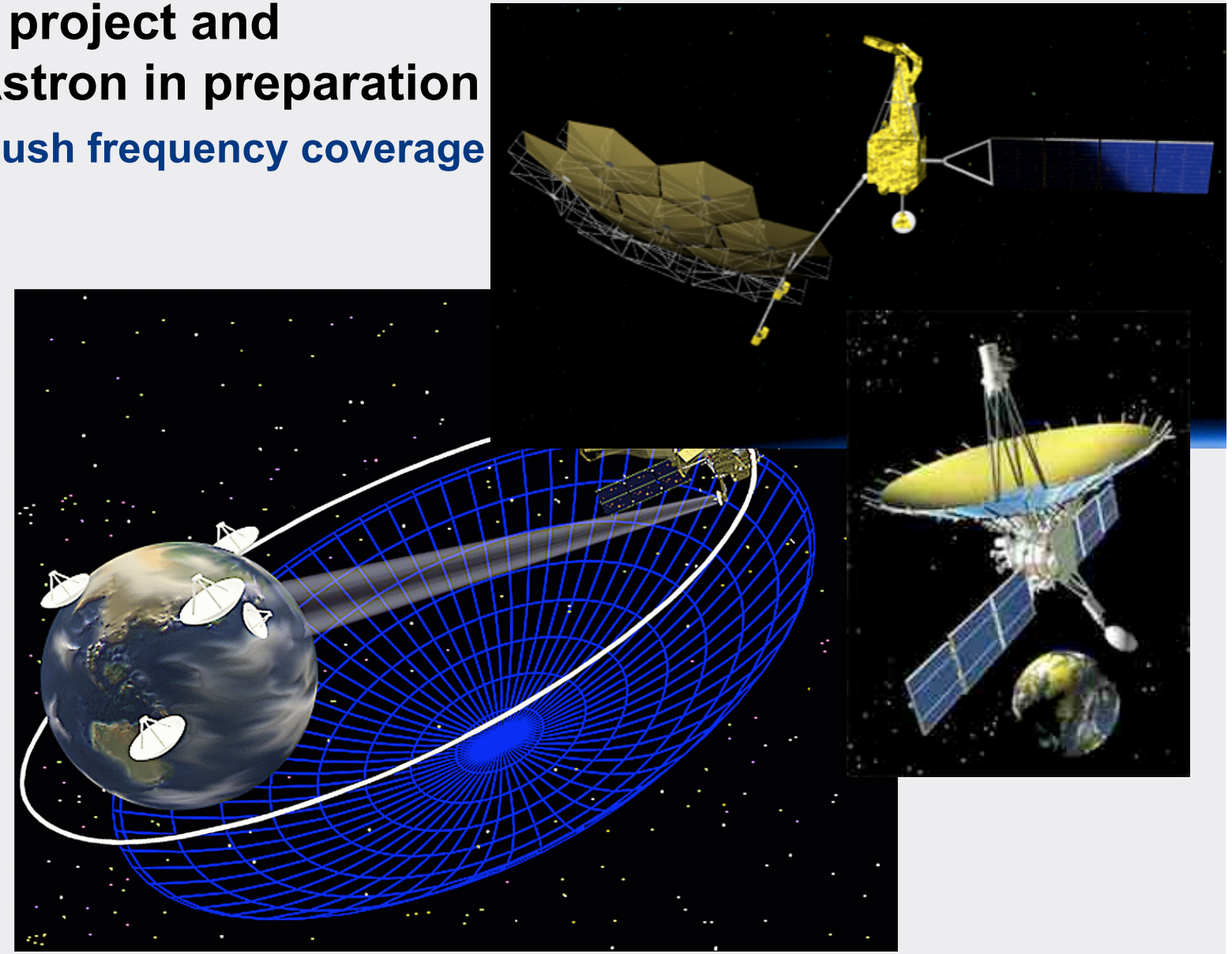
- **VLBI experiments with Europa landers/orbiter**
- **Radio astronomy experiments Jovian orbiter**

TANDEM – Titan and Enceladus mission:

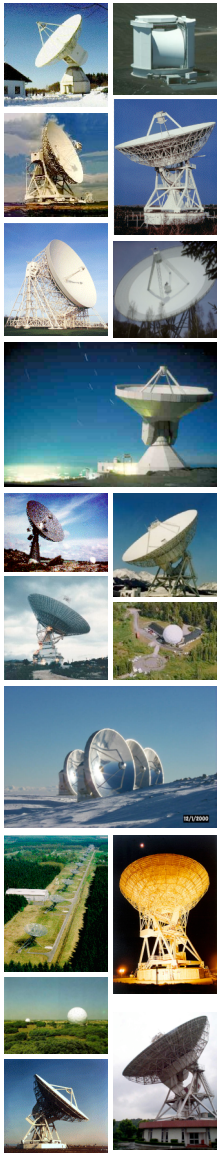
- **VLBI experiments with Titan probes/balloons**
- **Radio astronomy exps Enceladus orbiter**

And prepare for Space VLBI

- **VSOP2 project and RadioAstron in preparation**
  - **Will push frequency coverage**



RadioNet FP7



- **RadioNet-FP7 has ~ 20 partners: all of the major radio astronomy facilities and the laboratories involved in technology development**
- **10 M€ over 3 years**
- **In negotiation phase**

IRAM
Jodrell Bank Observatory
jive
KOSMA
l'Observatoire de Paris
Science & Technology Facilities Council
INAF
FG IGN
ESO
ASTRON
Max-Planck-Institut für Radioastronomie
mecsa
SRON
CCLRC
JCMT
UNIVERSITY OF OXFORD
TKK
Korea Astronomy and Space Science Institute
TU Delft
IAF
Institut Angewandte Festkörperphysik
THE UNIVERSITY of NEW ORLEANS
VENTSPILS AUGSTSKOLA
UNIVERSITY OF CAMBRIDGE
NRAO

RadioNet activities

- Trans National Access
  - MERLIN
  - EVN + Global VLBI
  - WSRT
  - LOFAR
  - Effelsberg
  - APEX
  - IRAM PdB
  - IRAM PV
  - SRT

- Networking Activities
  - Management
  - Science workshop
    - Supports EVN symposium
  - Engineering Forum
    - Supports EVN TOG
  - Training Radio Astronomers
    - Schools and YERAC
  - Radio Frequency Management

Joint Research Activities

- ALBiUS
- AMSTAR+
  - Mm receivers
- APRICOT
  - Radio cameras
- UniBoard

EVN TNA program

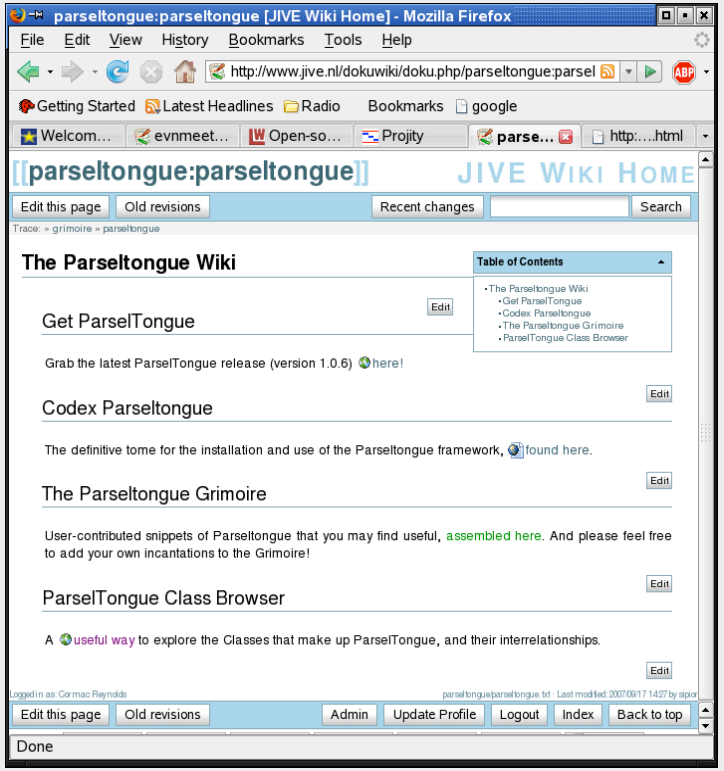
- **EC support for outside access to EVN facility**
  - Directly benefits data quality through support team at JIVE
  - Support to visit the EVN (for help with data reduction)
  - Support for the EVN-PC

- **Includes more EVN (new and affiliated telescopes)**
  - And now also the VLBA for Globals
    - Important signal for the future of VLBA
    - Step to International VLBI Network (IVN)
    - Necessary for the SKA era

Please acknowledge funding support...

ALBUS to ALBiUS

- ALBUS: Advanced Long Baseline User Software
  - Europe doing software development in FP6
- Efforts at JIVE, ASTRON, MPI, JBO
  - Enhance data product
    - calibration info
    - external atmospheric calibration
    - archive selection methods
  - Large Data Volumes
    - research parallel processing
    - wide band data processing
    - wide field processing
  - ParselTongue: common interface
    - AIPS talking Python



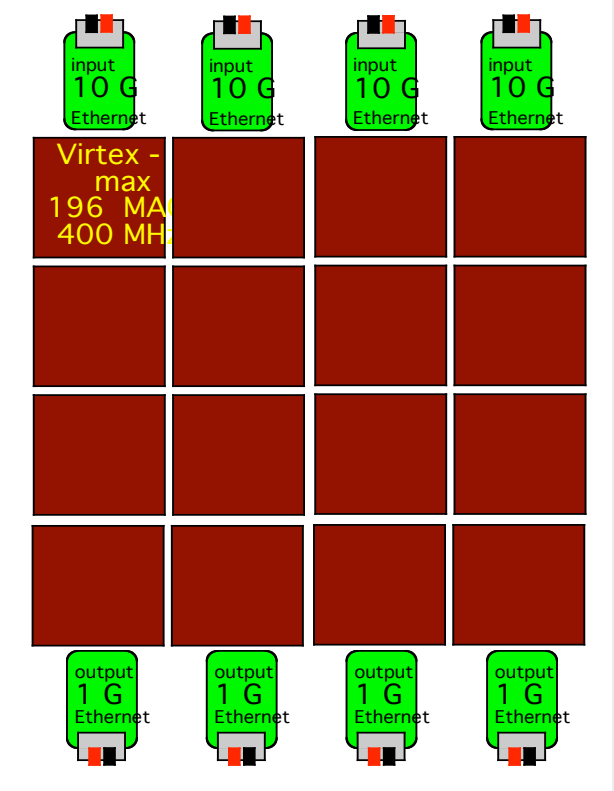
FP7: ALBiUS

- Advanced Long Baseline Interoperable User Software
  - Bring trusted and proven algorithms to new environments
  - Allow new packages to run on data from RadioNet facilities
- Synergy with LOFAR, ALMA, EVLA
- New collaboration includes
  - All old partners
  - Cambridge, Oxford, Bordeaux
  - ESO and NRAO

- Workpackages include
  - Interoperability, python interfaces calibration model
  - Calibration: fringe fitting, image plane effects, parallel processing
  - Automated processing, data quality control, source fitting

Uniboard

- FPGA processing platform for digital processing
  - Put as many computing power as possible on 1 board
- Several applications:
  - Correlator
  - Pulsar machine
  - Digital backend
- Participants:
  - ASTRON
  - JIVE
  - INAF
  - Bordeaux
  - Orleans
  - Manchester
  - KVN (Korea)



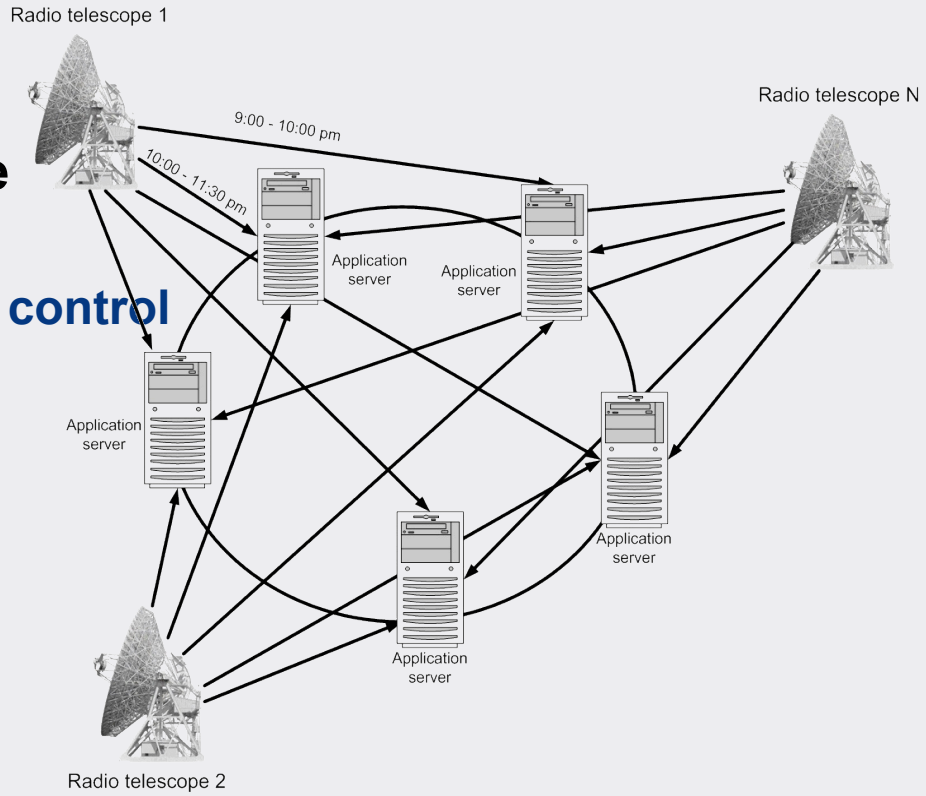
Important R+D covered in these projects.

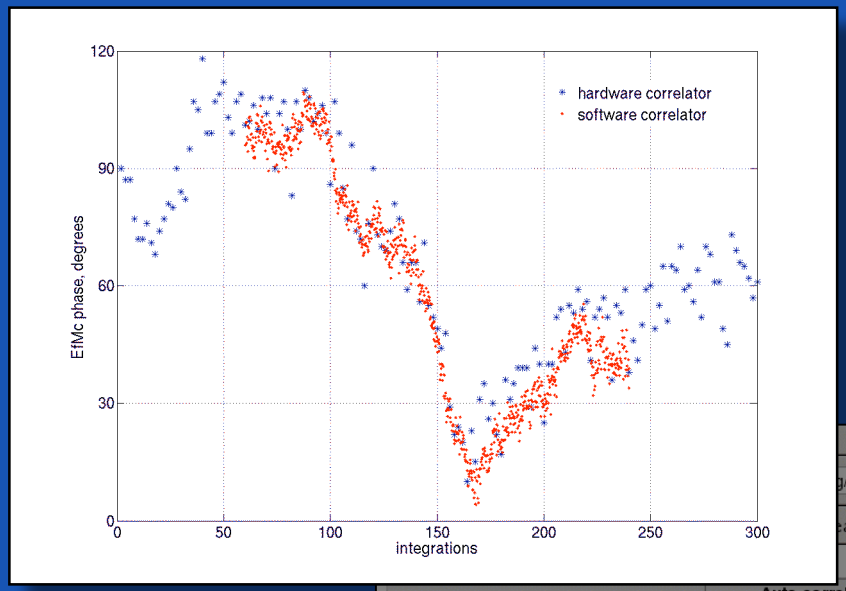
BUT....

- Not all EVN priorities can be addressed in externally funded projects
  - Calibration issues must be addressed by consortium
    - Amplitude calibration
    - Phase transfer schemes
    - Polarization purity
  - Frequency agility
  - Telescopes in strategic places
- Also operational issues that must be adressed
  - More time coverage than 3 fixed sessions
  - Guaranteed quality level, rapid re-observation
- Let's look at correlators...

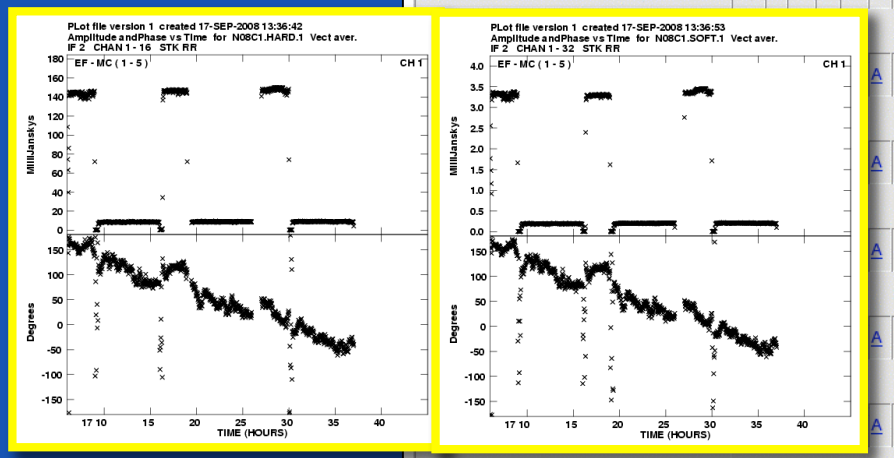
EXPReS: FABRIC

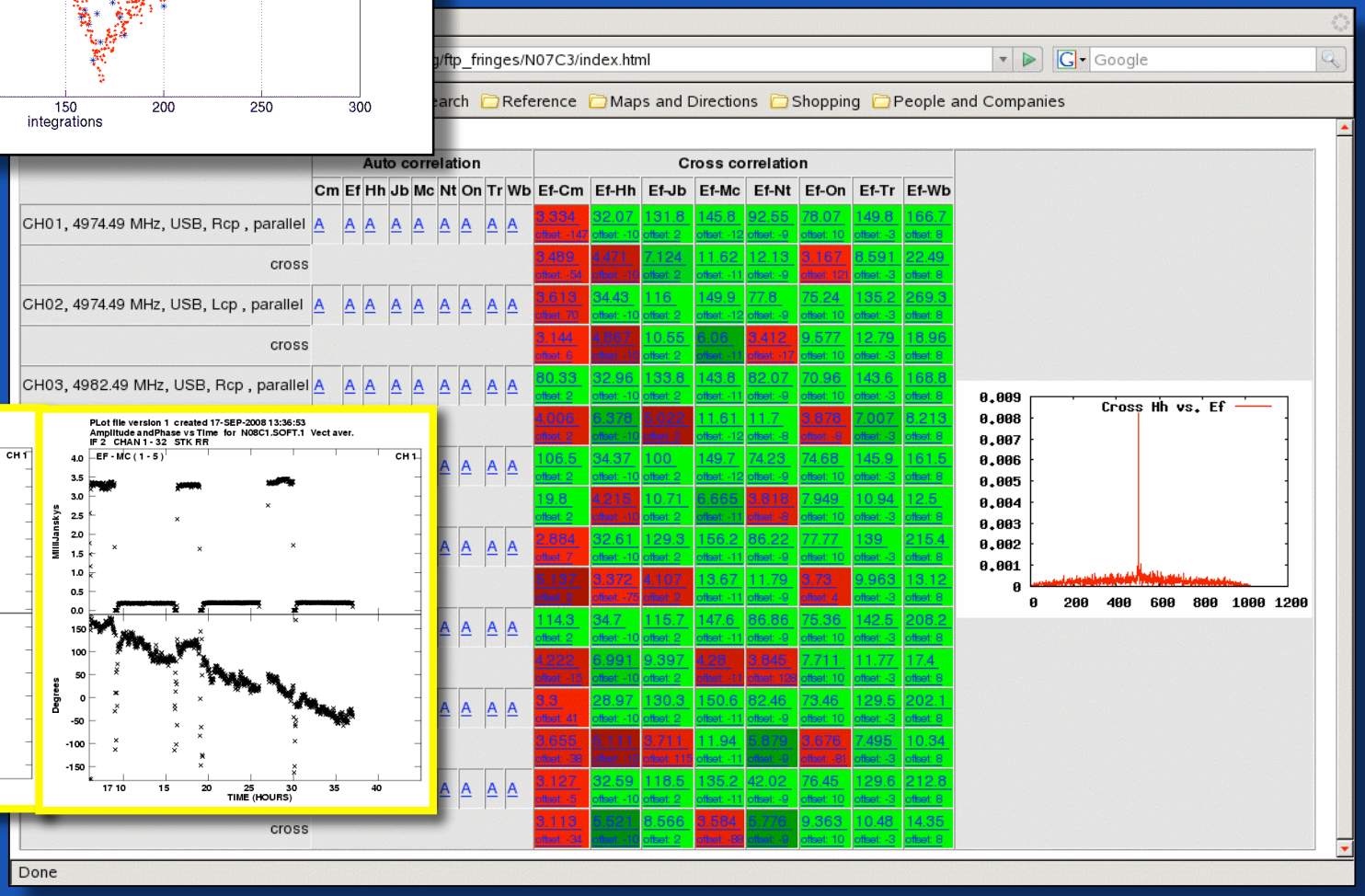
- 10 Gbps connectivity coming up
  - Development of data acquisition system required
  - Interface to UK eMERLIN system
  - Connectivity to Onsala (SE) telescope
  - And Metsahovi (FI)
- Working on distributed software correlator
  - Prototype operational for quality control
  - Grid enabled
  - Looking for P-ops regime
  - Not sure this is cost effective
    - Power and cooling bill





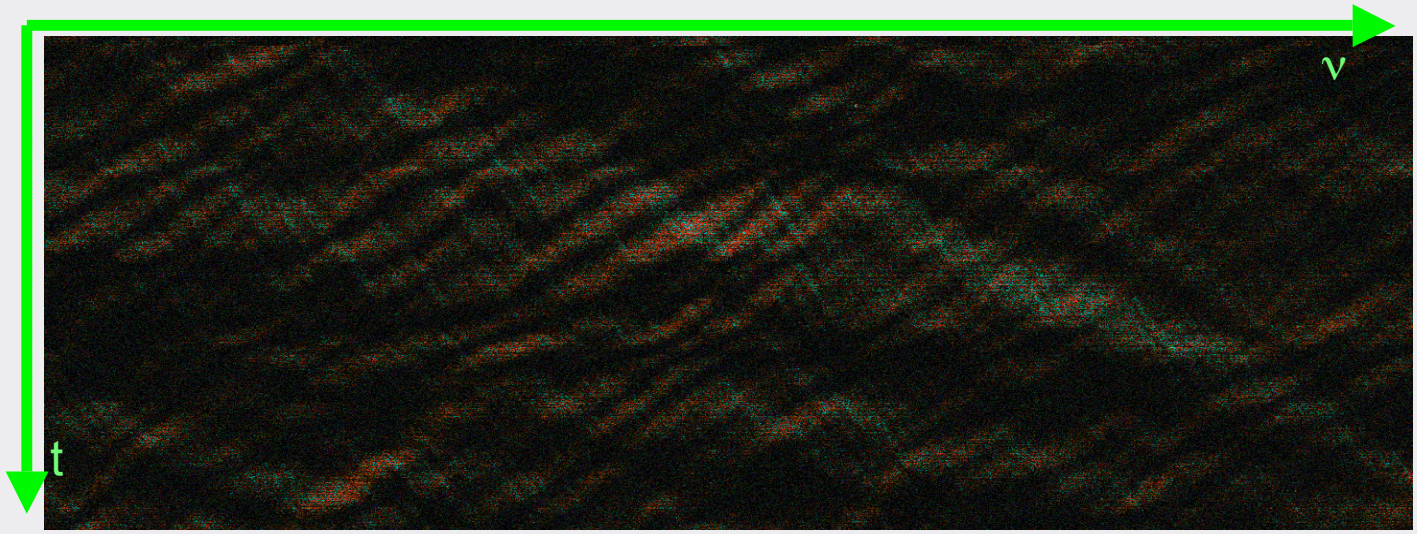
- **Software correlator outperforms hardware in data quality, not in speed**
- **Operational for real-time data quality checks**





DiFX

- **Software correlator developed at Swinburne**
  - **Operational for LBA**
  - **Adopted by VLBA**
  - **And being deployed at MPIfR Bonn**
- **Flexibility of software correlator is major asset**
  - **Replacing current correlator power on moderate size cluster**



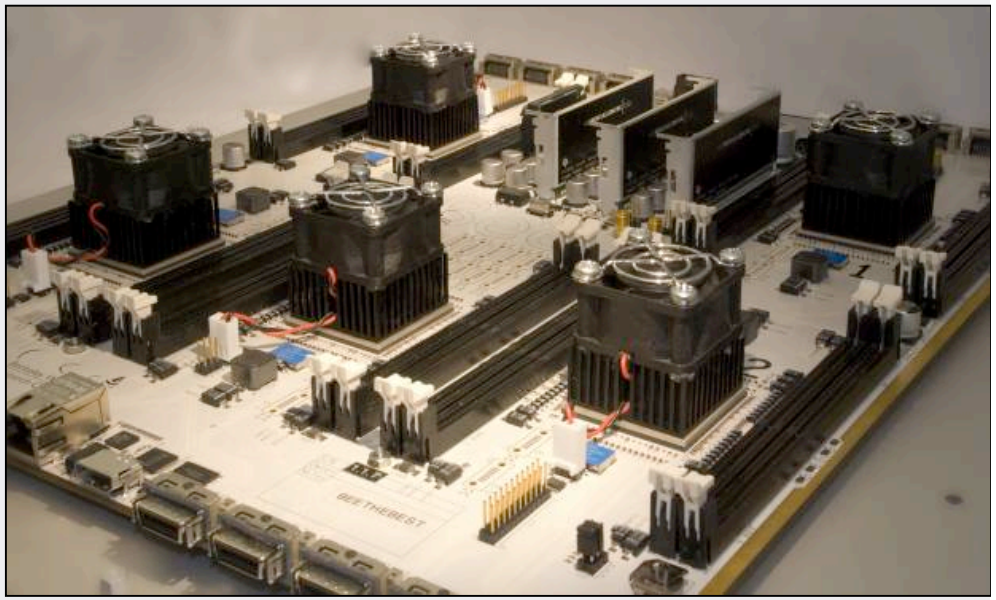
Pulsar scintillation (Brisken) requires extreme frequency resolution (244 Hz channels over 32 MHz bandwidth)

Next generation correlator

- **Requirements set by EVN2015 science case**
  - Multiple data streams of 10 - 100 Gbps
  - 32 stations, or at least more than 16
  - Multiple bit representation
  - High bandwidth at higher frequency
- **Calls for a hundred fold more powerful correlator**
  - Compares to EVLA correlator
  - Similar size as some (other) SKA pathfinders
- **Seems to require FPGA based power**
  - Software correlators can be intermediate solution
    - Distributed correlation attractive in Europe
    - Seeking synergy with WSRT APERTIF system
    - Ground-work starts in RadioNet FP7: UniBoard

FPGA based correlation

- FPGA based boards with standard connections
  - And high speeds samplers, multiple 10Gb/s in
- Several modern FPGA/board
  - Few Tops per board
    - Could rebuild current EVN correlator on 8 boards
  - New correlator requires a few racks
- For total few 10s kW
  - compared to MW range for supercomputers
- High level development possible
  - with Simulink (CASPER Berkeley)

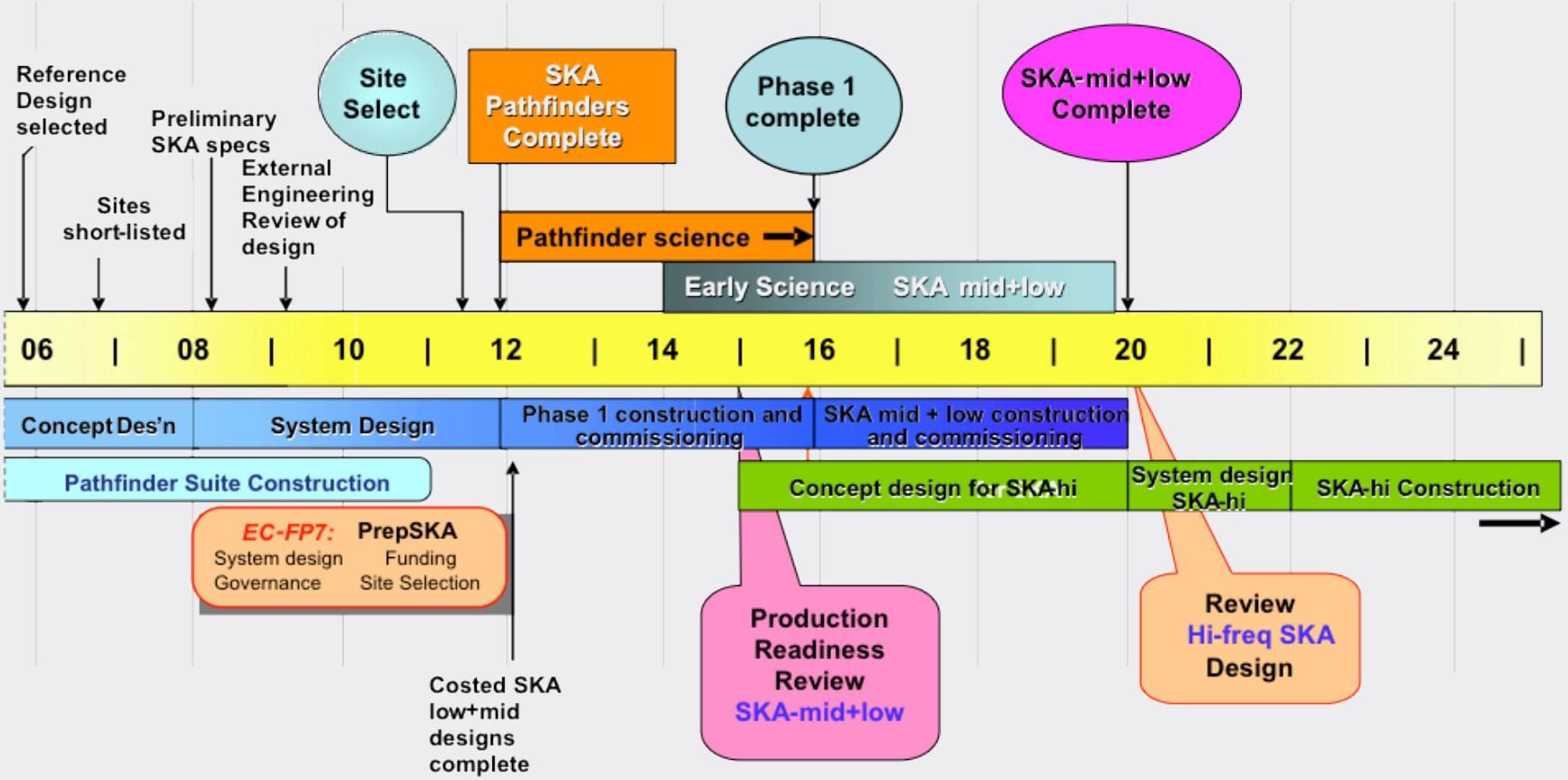


FPGA = Hybrid correlator

- FPGA based approach allows high level programming
  - Has some of the advantages of software correlator
    - Some level of scalability
- High accuracy, better signal to noise
  - RFI robust high bit representation
- Can have all the required flexibility
  - High spectral resolution, even for Space applications
  - Mixed bandwidth mode for spectral line phase ref
    - Make selection at the correlator?
  - Pulsar gating
  - Support for more than 1 beam per telescope

Longer term

- Time to compare to the SKA timeline
  - 2012 pathfinders complete
  - <2015 pathfinder science
  - >2015 phase 1 science



- LOFAR and SKA have simpler antennas
- But many more, more connectivity, more correlation

- e-VLBI is pioneering the development of signal transport for the SKA
- Can also be important in developing correlator solutions

Relation to SKA project

- Current EVN developments have a lot of synergy with SKA
  - E-VLBI is a recognized SKA pathfinder
    - For long-range connectivity, real-time radio-astronomy
  - Shares a lot of technology interests
    - Correlators and digital processing
    - Calibration algorithms and data processing
    - Telescopes…
  - Overlap in science expertise and training
    - Explored in MC Training network Path2SKA

- Also challenges
  - In continuity of funding
  - In training the right number of people

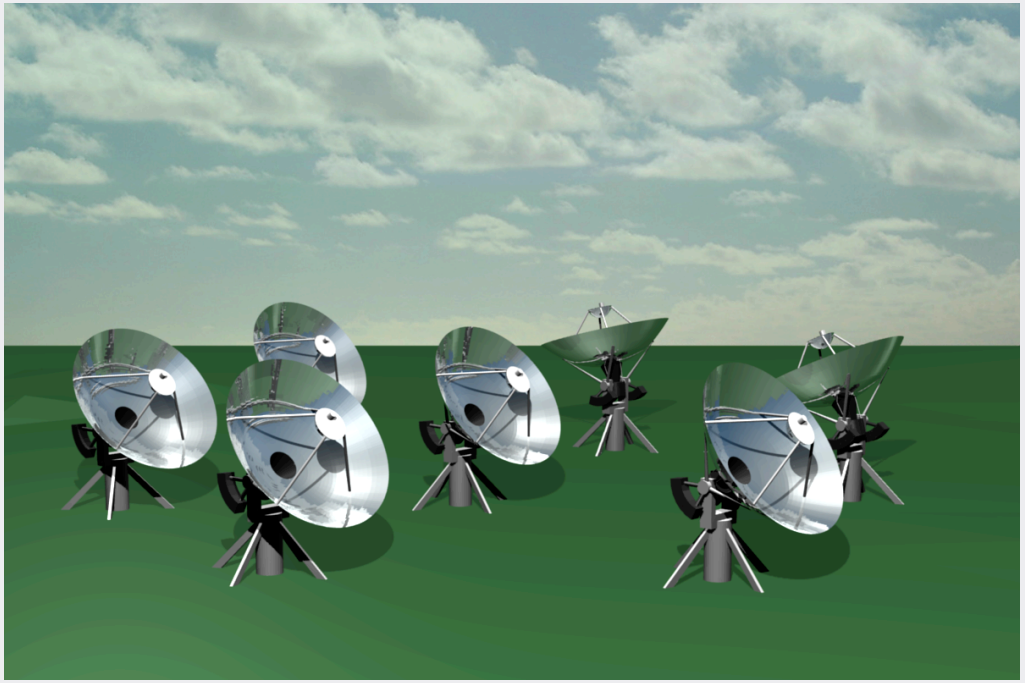
- Important for Europe to have its own pathfinder scale facilities
  - To maintain forefront facilities in the process
  - And train generation of radio-astronomers for the SKA

VLBI in the SKA era

- **Unique science case for VLBI during SKA operations**
  - Definitely during SKA phase I and II
  - **Especially with Global baselines**
  - **And a focus on the higher frequencies**
    - Limited overlap with SKA parameter space
- **Requires a VLBI technology roadmap**
  - **And a strong international collaboration**
- **Will set ambitious goals**
  - **Not just new correlator, also new receptors**

EVN2015 innovations

- **Obvious: higher bandwidth at higher frequency**
  - **Demanded by EVN2015 science case**
- **Possible other innovations:**
  - **Many more telescopes that operate at higher frequencies**
    - **To improve image fidelity dramatically**
  - **Maybe station will be small clusters of antennas**



Funding

- Competitive, Interesting times ahead
  - even more so with SKA on horizon
    - Radio-astronomy will have to present consistent story
    - Or even come to more formal, tighter collaboration model
- Long term case for VLBI look good
  - European based pathfinder for training and expertise
  - Outreach on a local basis

- **Produce fantastic science!**
  - Aim for the stars!
    - No room for conservatism wrt innovations!
  - Good prospect of synergy with new facilities

Summary

- **e-VLBI is operational and works as reliable as recorded VLBI**
  - And can even be used for intercontinental VLBI
  - Requiring new operational models and policies
  - Short-term projects secure
- **Clear upgrade path for VLBI**
  - Requiring new data acquisition equipment
  - and matching correlator
  - In synergy with the SKA technology
  - Should be done on a global scale
- **VLBI has a role in the SKA era**
  - With global baselines and high frequencies