

# **EXPReS & NEXPReS**

**an evolution pathway for VLBI into the SKA era**

*Huib van Langevelde*

*JIVE*

- **EXPRReS; introducing e-VLBI**
  - Technological progress
  - Operational service
  - Scientific achievements
- **Introducing NEXPRReS**
  - Objectives of the new program
- **e-VLBI and the future**
  - economic aspects
  - SKA pathfinder
  - evolving VLBI

20 min talk, time for discussion

- **EVN consortium with 20+ possible antennas**
  - Ef, Mc, On, Jb, Nt, Tr, Wb, Sh, Ur, Hh, Ar, Mh, Ys, Sv, Ro, Ku, My, Wz, Sm, Ny, Ka
  - Ran by up to 14 different organizations
  - And 12 more antennas for “Globals” with NRAO
- **Covering range of frequencies**
  - Workhorse frequencies 18cm, 6cm,
  - Also available: SX, 5cm, 1.2cm
  - And at limited stations 90cm, 21cm, UHF, 50cm, 2cm, 0.7mm
- **Reaching mas resolutions**
  - From 15mas for 1.4 GHz EVN (can add MERLIN for brightness sensitivity)
  - To 1 mas at 5GHz with Asian, African or American baselines
- **Sensitivity of  $5\mu\text{Jy}$  in 8hr at 1.4 GHz**
  - Combination of Big Antennas and 1 Gbps bandwidth
  - Big antennas also vital for spectroscopy (mJy sensitivity)
- **Operational approximately 60 days/year**
  - 3 sessions augmented with e-VLBI once a month



Irbene 32m



Svetloe



Sardinia 64m

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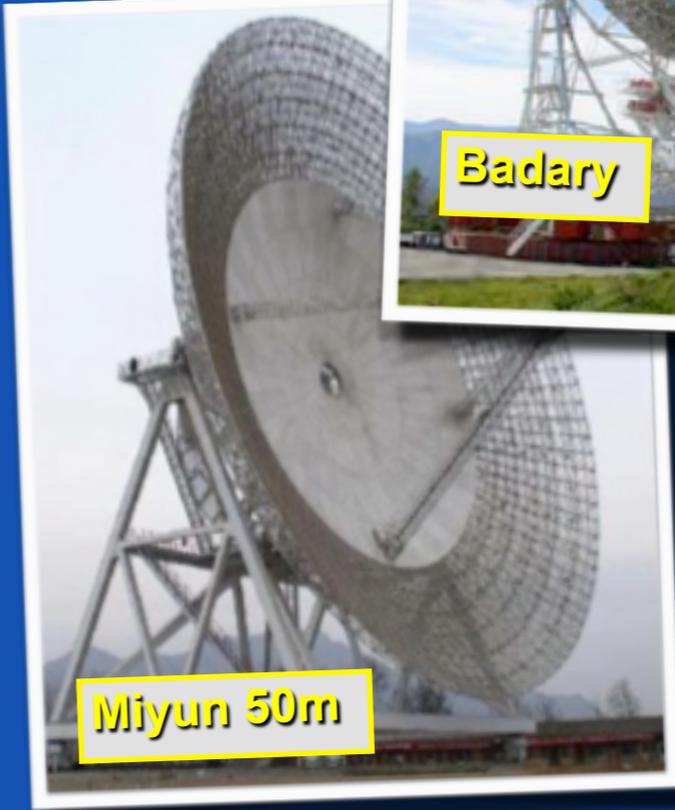
Zelenchukskaya



Yebes 40m



Kunming 40m



Miyun 50m



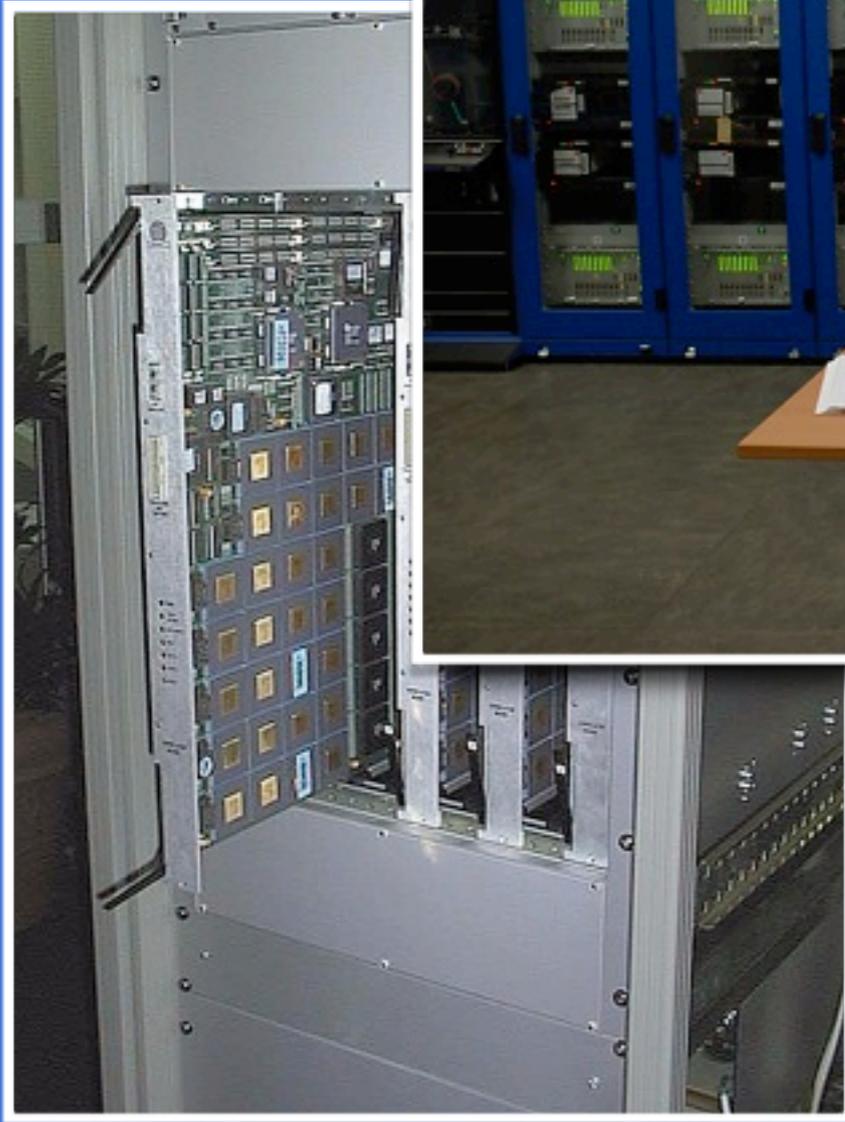
Badary

- **Promote the use and advance of VLBI for astronomy**
  - Central correlation
  - User services
  - Network support
  - Innovation
  - EC liaison/representation
- **Founded in 1993**
  - Base budget from partners in 7 countries:
    - China, France, Germany, Italy, Spain, Sweden, United Kingdom, the Netherlands
    - Some funding agencies, some institute contributions
  - hosted by ASTRON
- **Large number of external projects**
  - Many people with temp positions in R&D/Science
- **32 people, 12 nationalities**
  - 3.6M€ annual budget, 2.1 in local operations



# • Current correlator

- 1024 custom chips
- 16x16 baselines, 0.25s



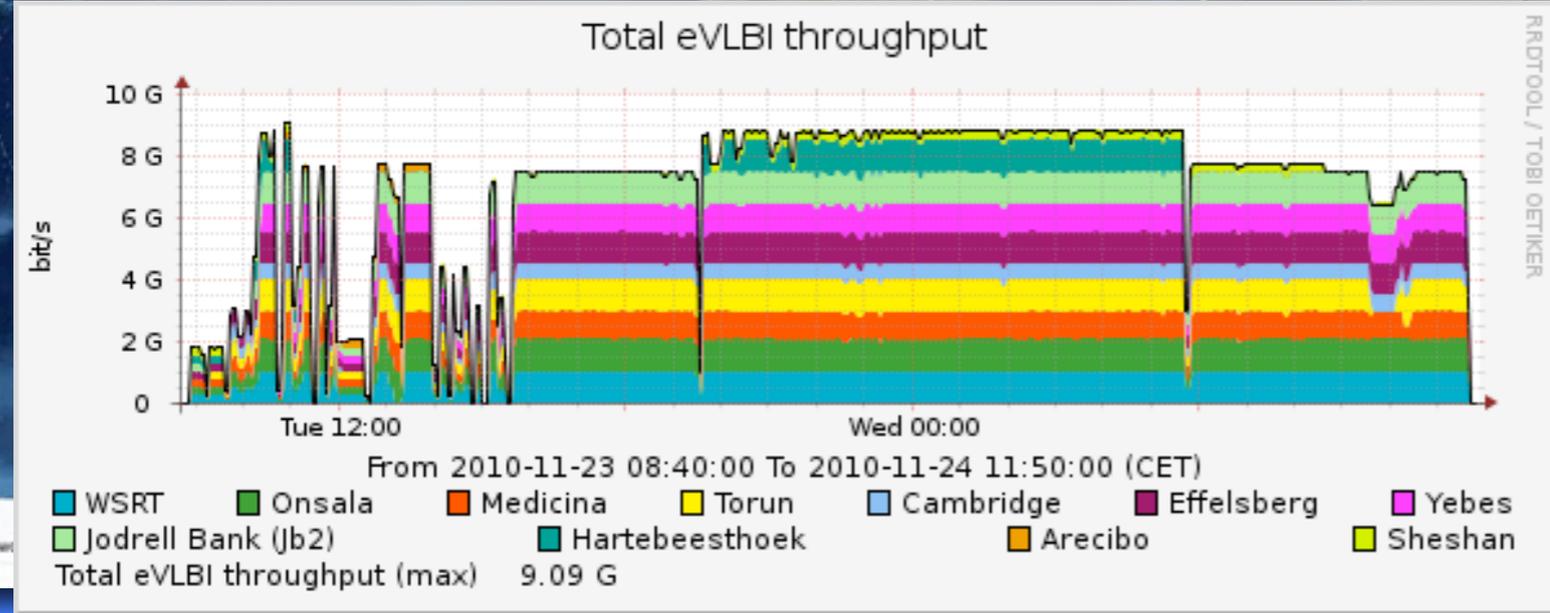
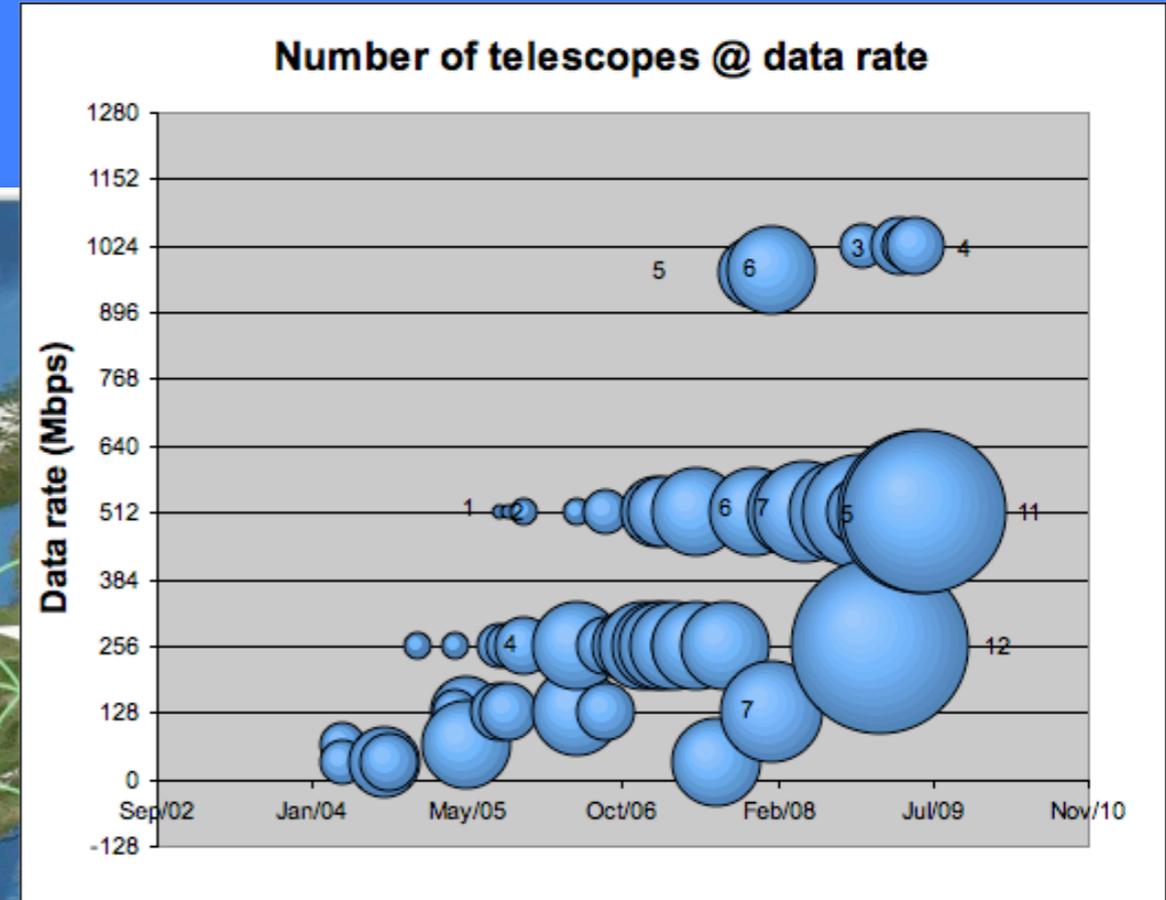
# Turned into e-VLBI

- **PC based recording**
  - Also allows Internet transmission
  - Started with a pilot in 2004
- **And was boosted with EXPReS**
  - 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
  - Change of VLBI culture in EVN
- **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!



Express Production Real-time e-VLBI Service

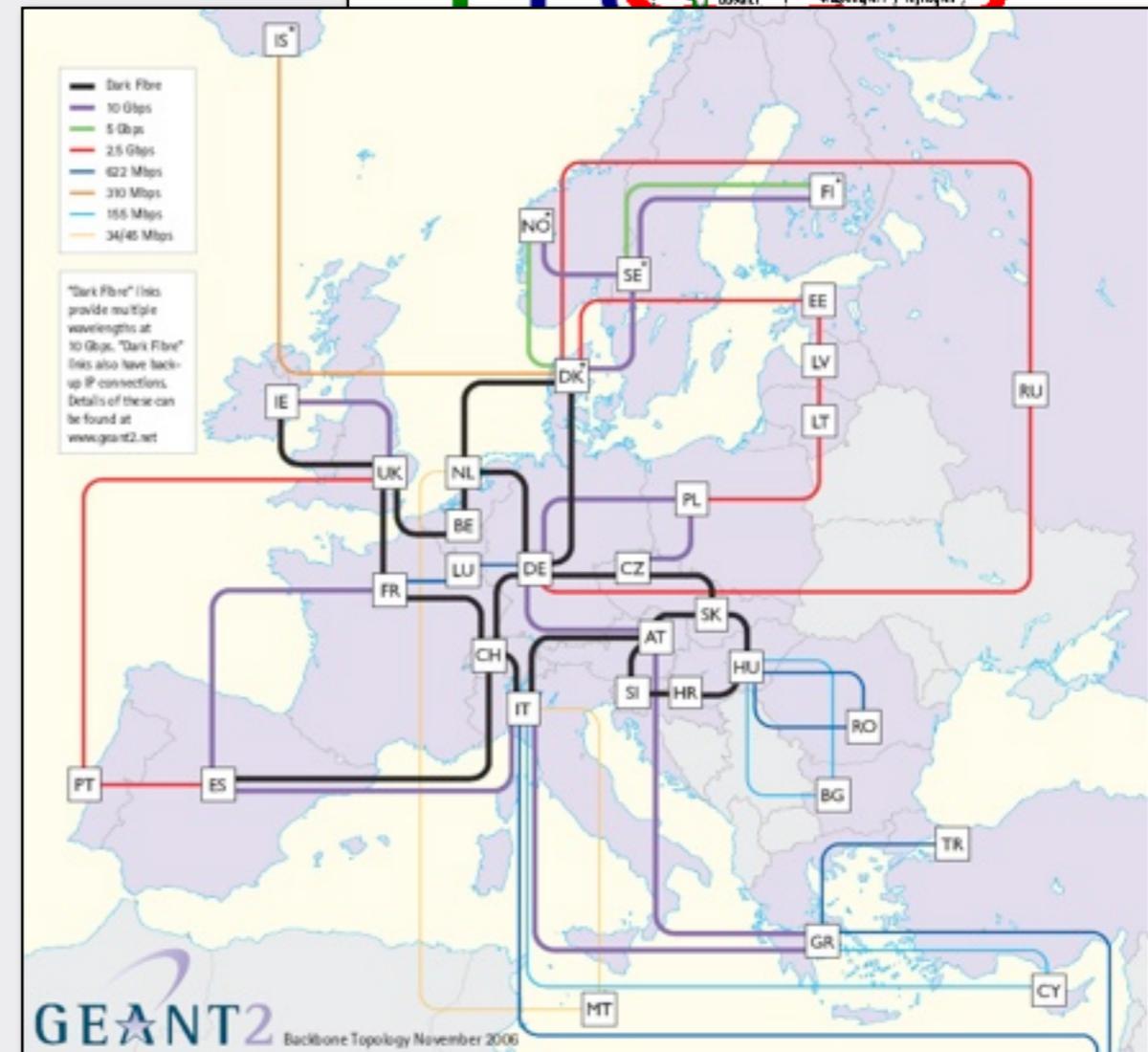
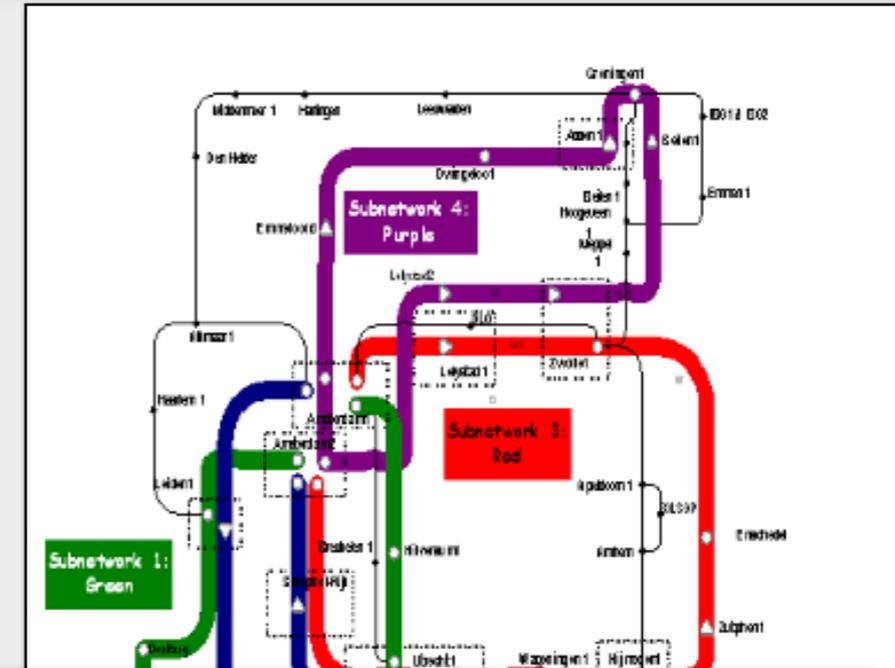
- **Connections work great!**
  - often dedicated light paths
  - Use optimized protocols
- **Closed feedback loop makes e-VLBI more robust**

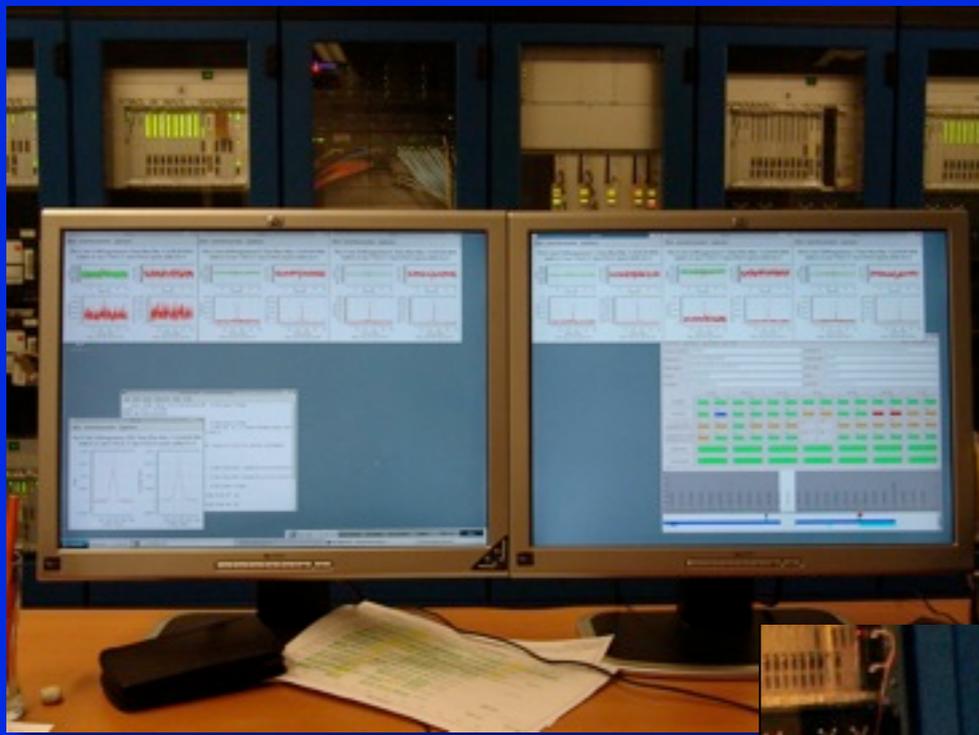


- **When we started e-VLBI and the EXPReS project**
  - First pilots in 2004
  - EXPReS funded in 2006 by the EC, finishes in September
- **Amongst our original concerns:**
  - Can we connect all telescopes on competitive time-scale?
  - Will we be able to deliver interesting bandwidth?
  - Will e-VLBI be just as reliable?
  - Will it be applicable to Global VLBI?
  - Will it produce new science?
  - Will it be cost effective?
  - Can we accommodate all types of projects?
- **Looking at the progress with e-VLBI:**
  - yes
  - yes
  - yes, even more robust
  - yes

# Cost effective?

- Shipping much cheaper than bandwidth at commercial rates
  - Lucky with blessing at European level
  - Made local providers supportive
  - Commitment of partners (also LOFAR)
- Strategic issue for NRENs
  - Lightpath technology
  - will be economic and green



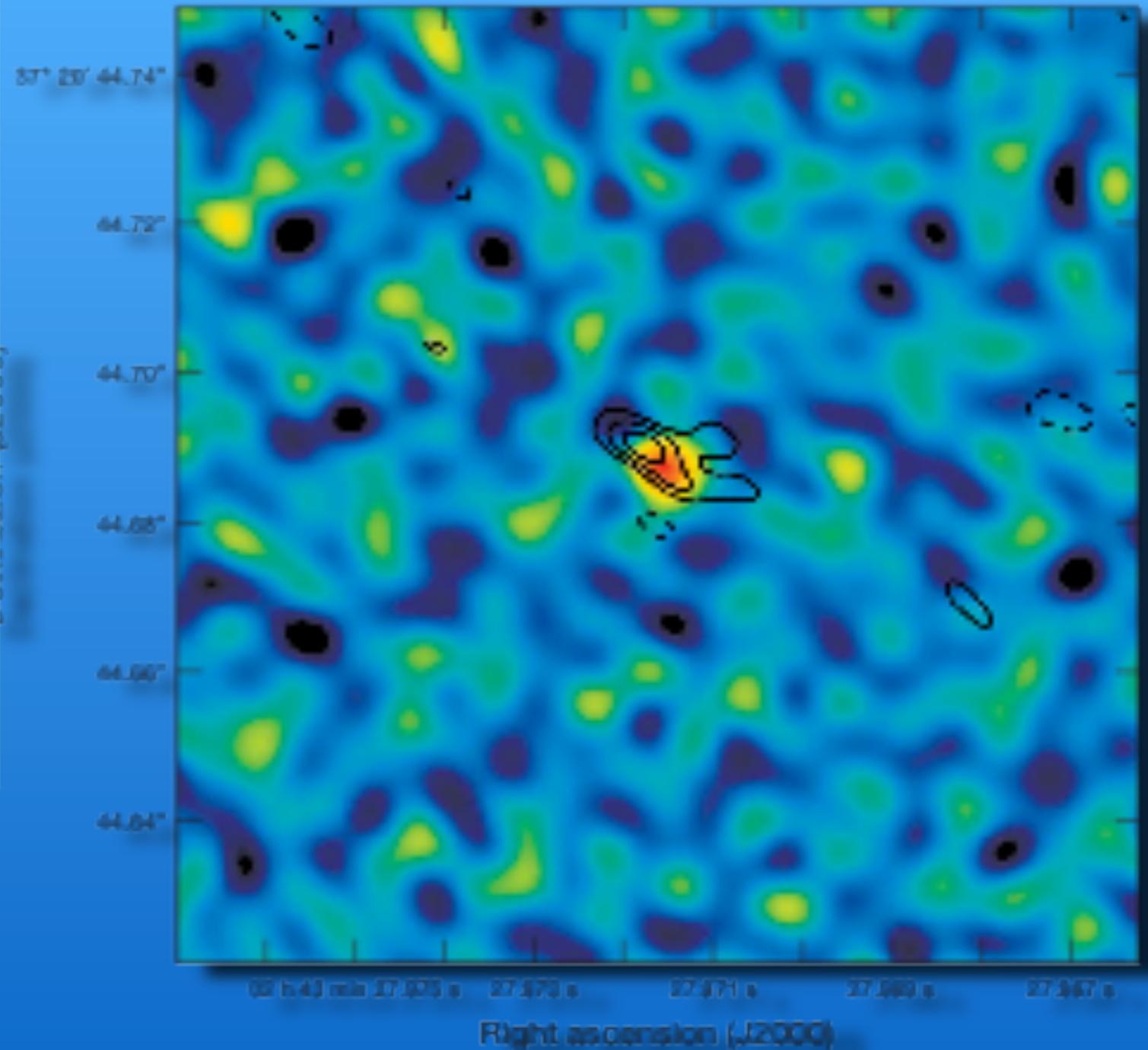


- Now sustained 24hr observing runs now possible
- Can be run by a single person
- Can be rewarding experience!



# SN2007gr

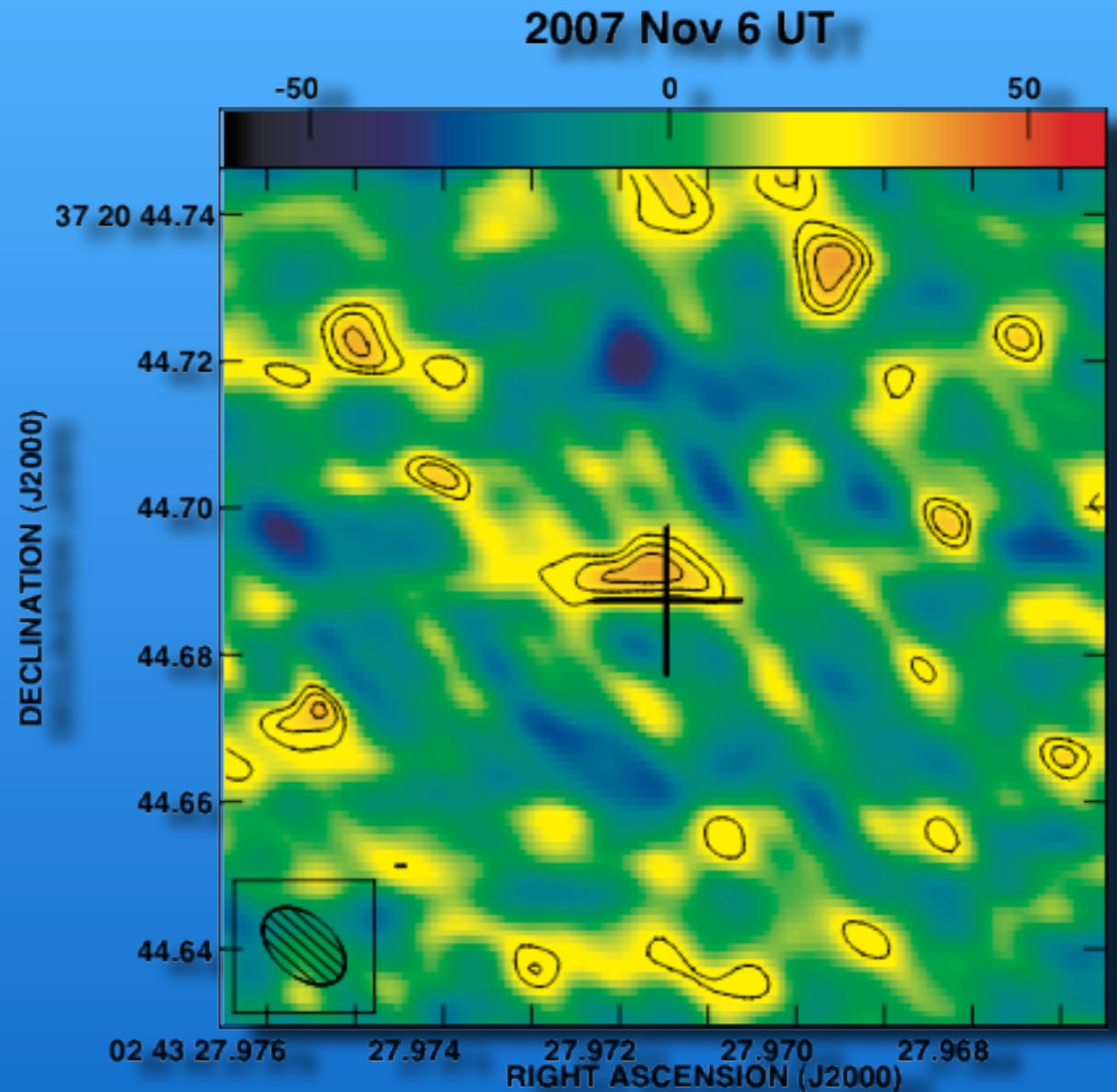
- Nearby type Ic supernova
- e-VLBI within 20 days
  - detection at  $400 \mu\text{Jy}/\text{beam}$  level
- Two months later EVN+GBT:
  - Weaker detection
  - VLBI vs. WSRT total flux
  - mildly relativistic ( $>0.6c$ ) expansion!
- First direct detection of relativistic expansion in a supernova
- Link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



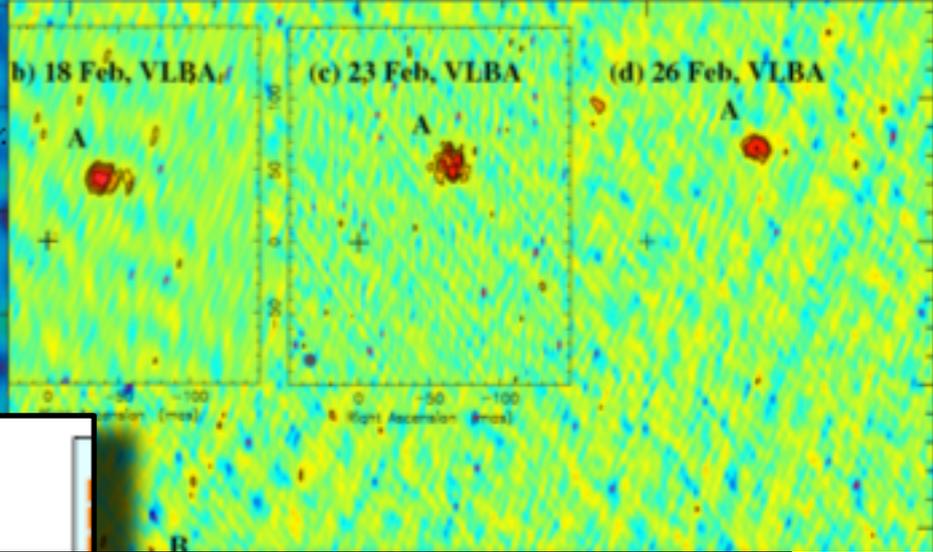
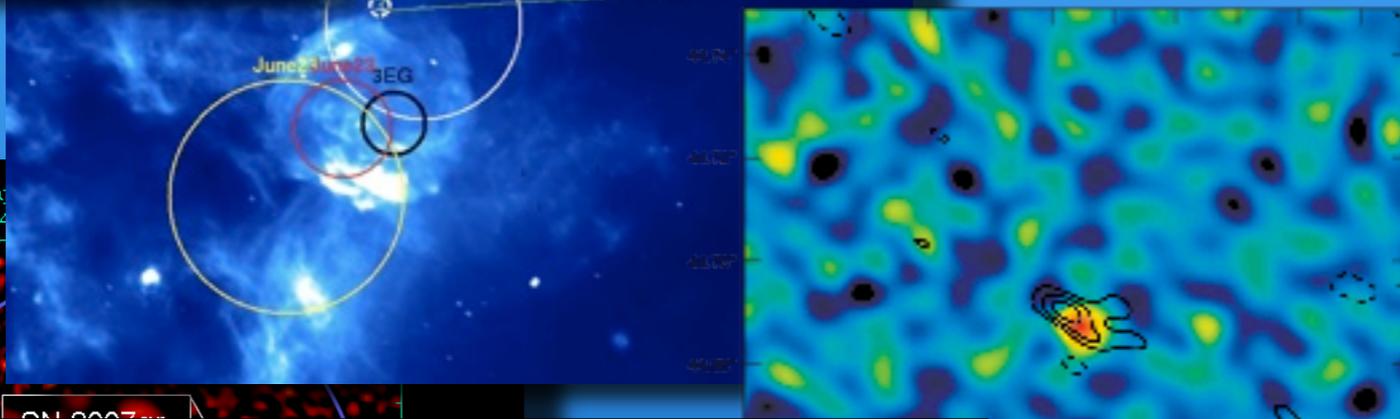
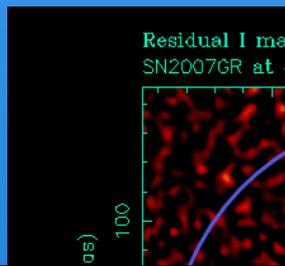
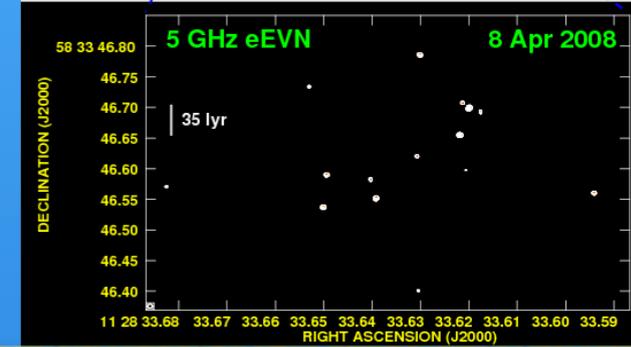
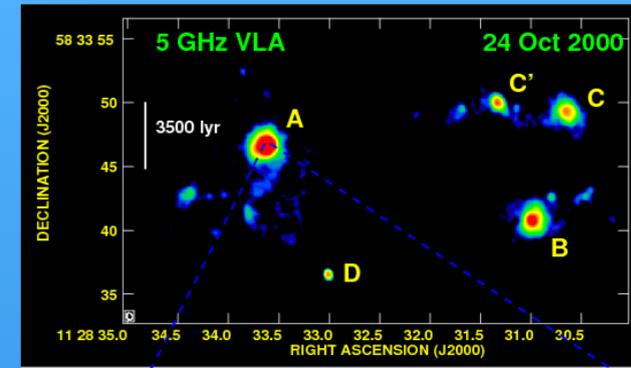
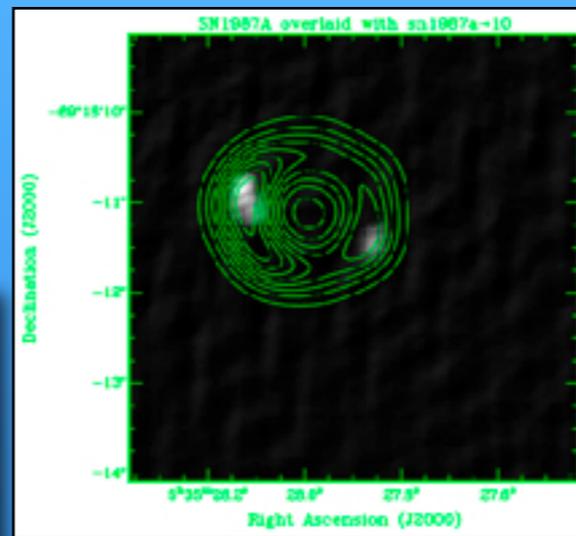
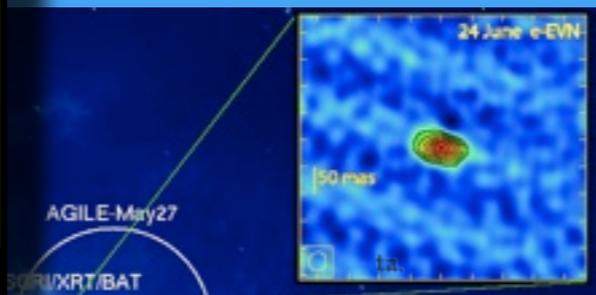
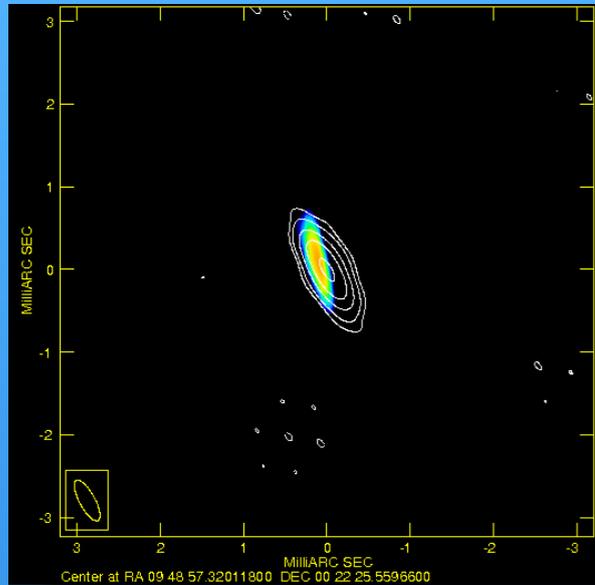
Paragi et al., Nature 2010, 463 516

# SN2007gr

- Nearby type Ic supernova
- Detailed modelling
  - And use of VLA light-curve
- Argue for ordinary SNe Ibc
- Confirm e-VLBI detection
  - But question the overall calibration
- Two months later EVN+GBT:
  - Also weak detection
  - But question resolved nature
  - No need for relativistic expansion



Soderberg et al, 2010 ApJ 725 922



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XML SGRs  
XML Gamma Ray Bursts  
XML Comets

**EVN observations of the**

ATel #2437; [M. Giroletti \(INAF/IRA\)](#), [E. Koerding \(Univ. Paris Diderot & CEA Saclay\)](#), [S. Corbel \(Univ. Paris Diderot & CEA Saclay\)](#), [K. Sokolovsky \(MPIJR/ASC Lebedev\)](#), [L. Fuhrmann \(MPIJR\)](#), [E. Schinzel \(MPIJR\)](#), [C.C. Cheung \(NRC/NRL\)](#) on behalf of the Fermi-LAT collaboration  
on 13 Feb 2010; 21:4  
Password Certification: Catherine Brocksopp

Subjects: Radio, >GeV, AGN, Black Holes, Transients, Variables, Stars

We report on EVN observations of the symbiotic star V407 Cyg, following its classical nova outburst (CBET #2199, CBET #2204) and its surprise detection in gamma-rays (ATel #2487) and radio cm and mm bands (ATel #2506, ATel #2511, ATel #2514). The radio continuum observations were carried out at 5 GHz by 9 telescopes for about 9 hours between 23h March 30 and 13h March 31, 2010.

**Detection of Probable Jet Component in the e-EVN**

ATel #2438; [Catherine Brocksopp \(MSSL\)](#), [Jun Yang \(Univ. Paris Diderot\)](#), [Tasso Trioumis \(ATNF\)](#), [Roberto Corbelli \(INAF\)](#)  
on 13 Feb 2010; 21:4  
Password Certification: Catherine Brocksopp

Subjects: Radio, Binaries, Black Holes, Transients

Following the reported increased radio emission of XTE J1401.9-22019 (ATel. 2387, 2391, 2396), we have made observations with the European VLBI Network (EVN) in real-time e-VLBI mode.

**VLBI detection of V407 Cyg**

ATel #2536; [Giroletti \(INAF/IRA\)](#), [E. Koerding \(Univ. Paris Diderot & CEA Saclay\)](#), [S. Corbel \(Univ. Paris Diderot & CEA Saclay\)](#), [K. Sokolovsky \(MPIJR/ASC Lebedev\)](#), [L. Fuhrmann \(MPIJR\)](#), [E. Schinzel \(MPIJR\)](#), [C.C. Cheung \(NRC/NRL\)](#) on behalf of the Fermi-LAT collaboration  
on 6 Apr 2010; 18:23 UT  
Password Certification: Marcello Giroletti (giroletti@ira.inaf.it)

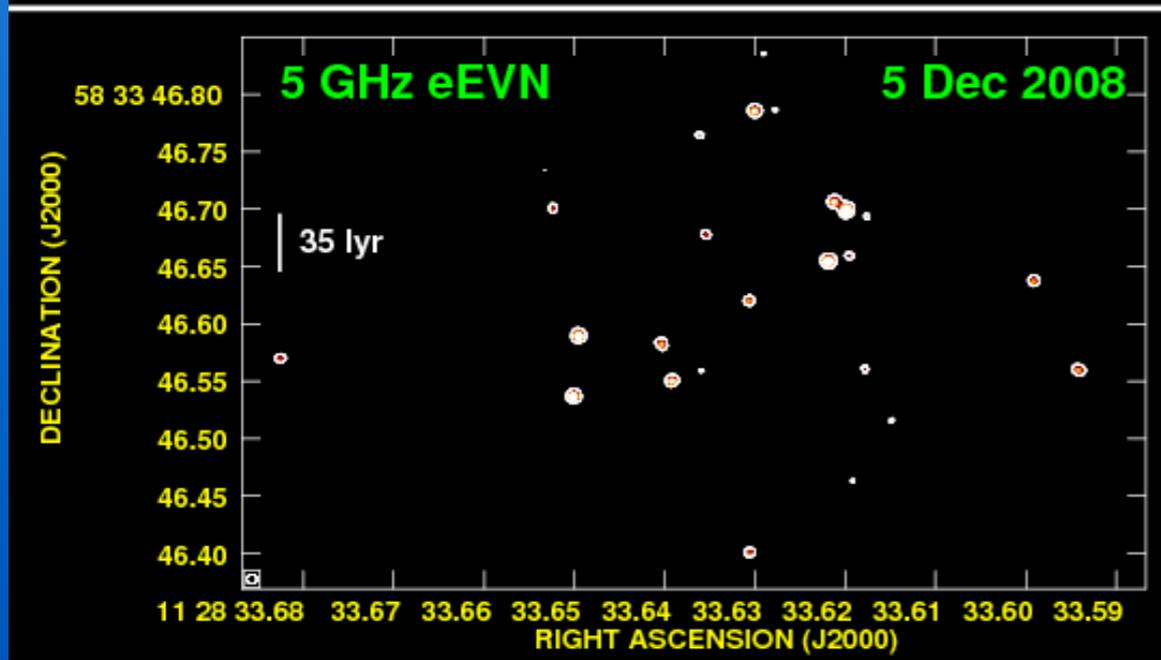
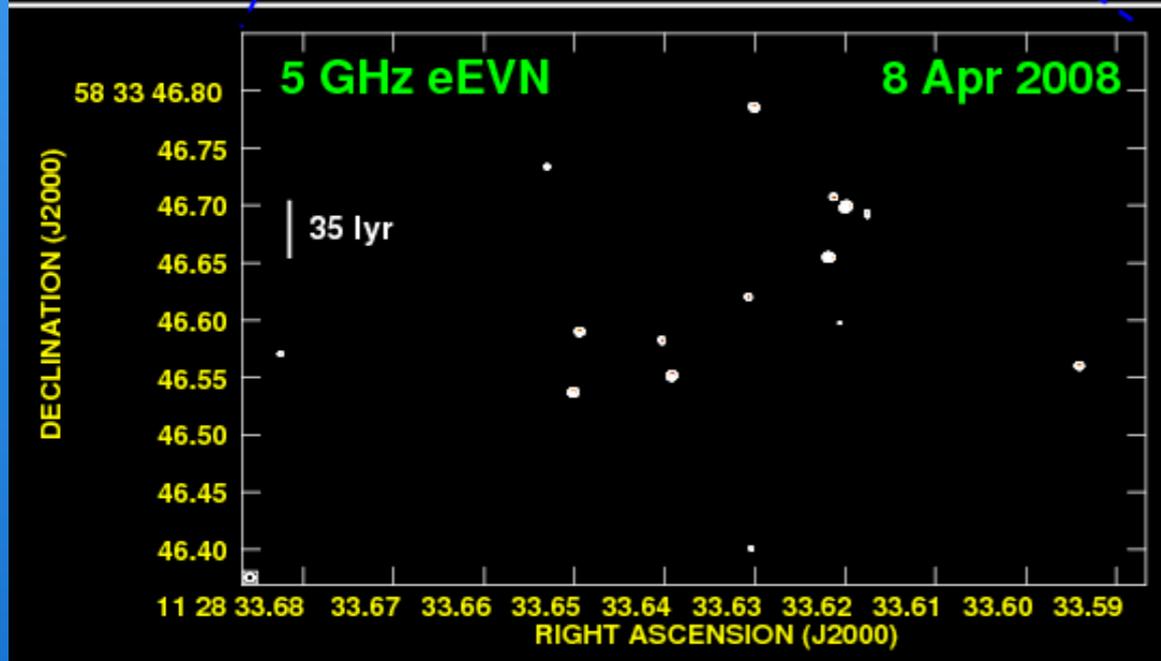
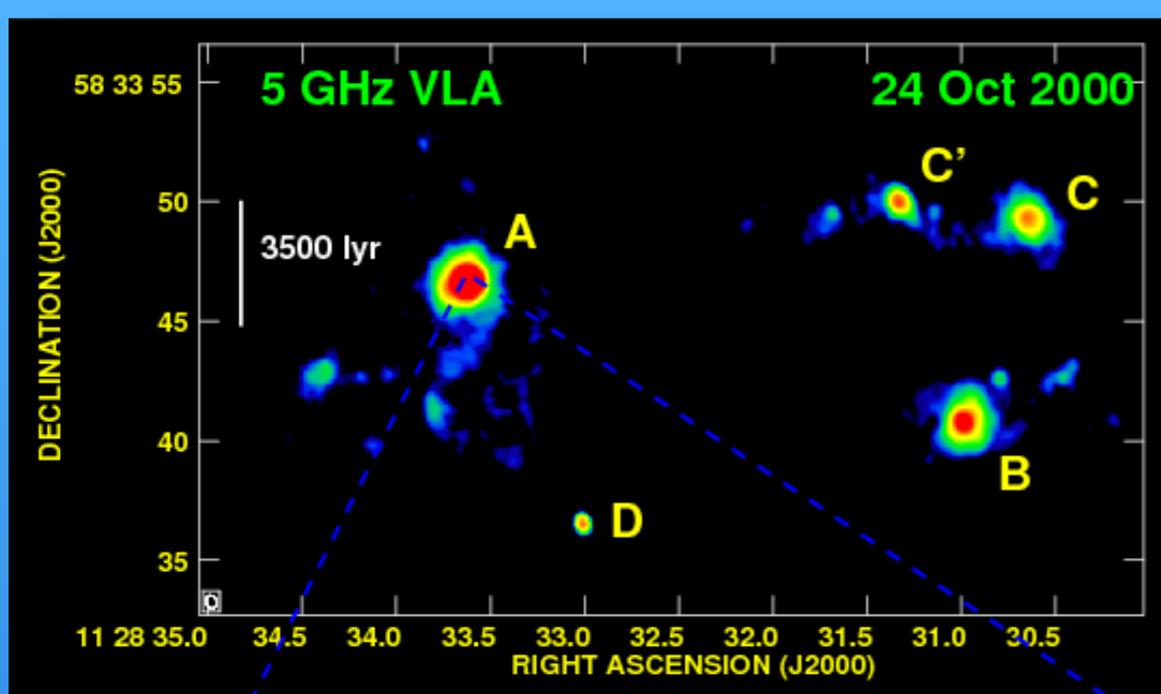
Subjects: Radio, Gamma Ray, Novae, Transients, Variables, Stars  
Referred to by ATel #: [2546](#)

We report on EVN observations of the symbiotic star V407 Cyg, following its classical nova outburst (CBET #2199, CBET #2204) and its surprise detection in gamma-rays (ATel #2487) and radio cm and mm bands (ATel #2506, ATel #2511, ATel #2514). The radio continuum observations were carried out at 5 GHz by 9 telescopes for about 9 hours between 23h March 30 and 13h March 31, 2010.

Related

- 2546 [Discovery of coronal emission lines in V407 Cyg](#)
- 2536 [VLBI detection of V407 Cyg](#)
- 2529 [V407 Cyg: Allen Telescope Array Observations](#)
- 2514 [15-GHz flux density of V407 Cyg](#)
- 2511 [Radio detection of V407 Cyg at 30 GHz with OACA-2 on the Torii telescope](#)
- 2506 [Radio detection of V407 Cyg: the possible counterpart of the new Fermi-LAT Gamma-ray transient J2102+4542 with the Effelsberg 100-m, OVRO 40-m and IRAM 30-m telescopes](#)
- 2498 [INTERCAL view of the sky field containing Fermi J2102+4542](#)
- 2487 [Fermi-LAT Detection of a New Galactic Plane Gamma-ray Transient in the Cygnus Region: Fermi J2102+4542 and its Possible Association with V407 Cyg](#)





## Supernova factory in Arp229A

Burst of star-formation leading to numerous

- SNe hidden by dust

Closely spaced EVN e-VLBI observations

- new radio sources appear, SNe or remnants

- 26 radio sources in the central 150pc

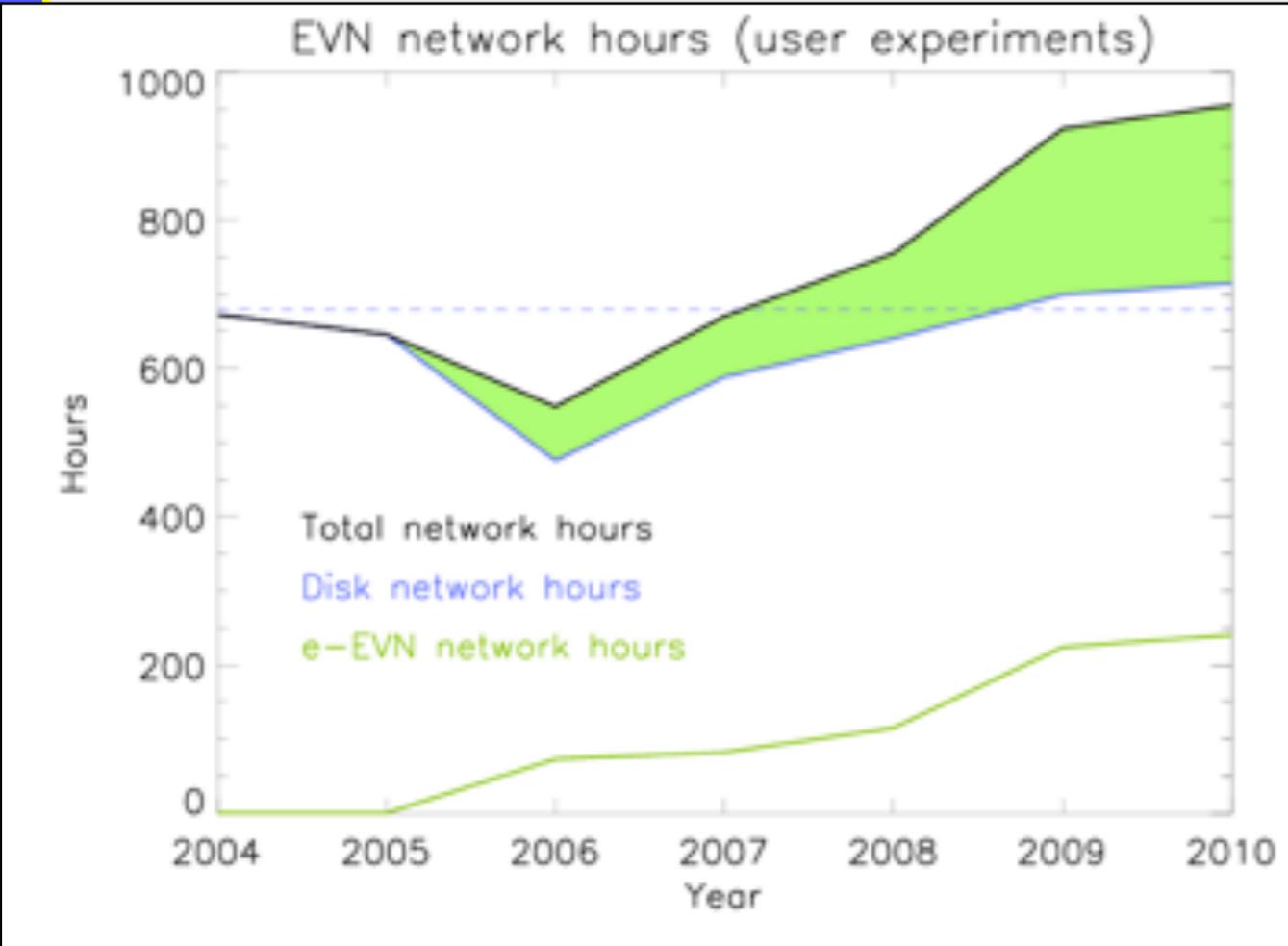
Further monitoring constrains

- the star-formation rate

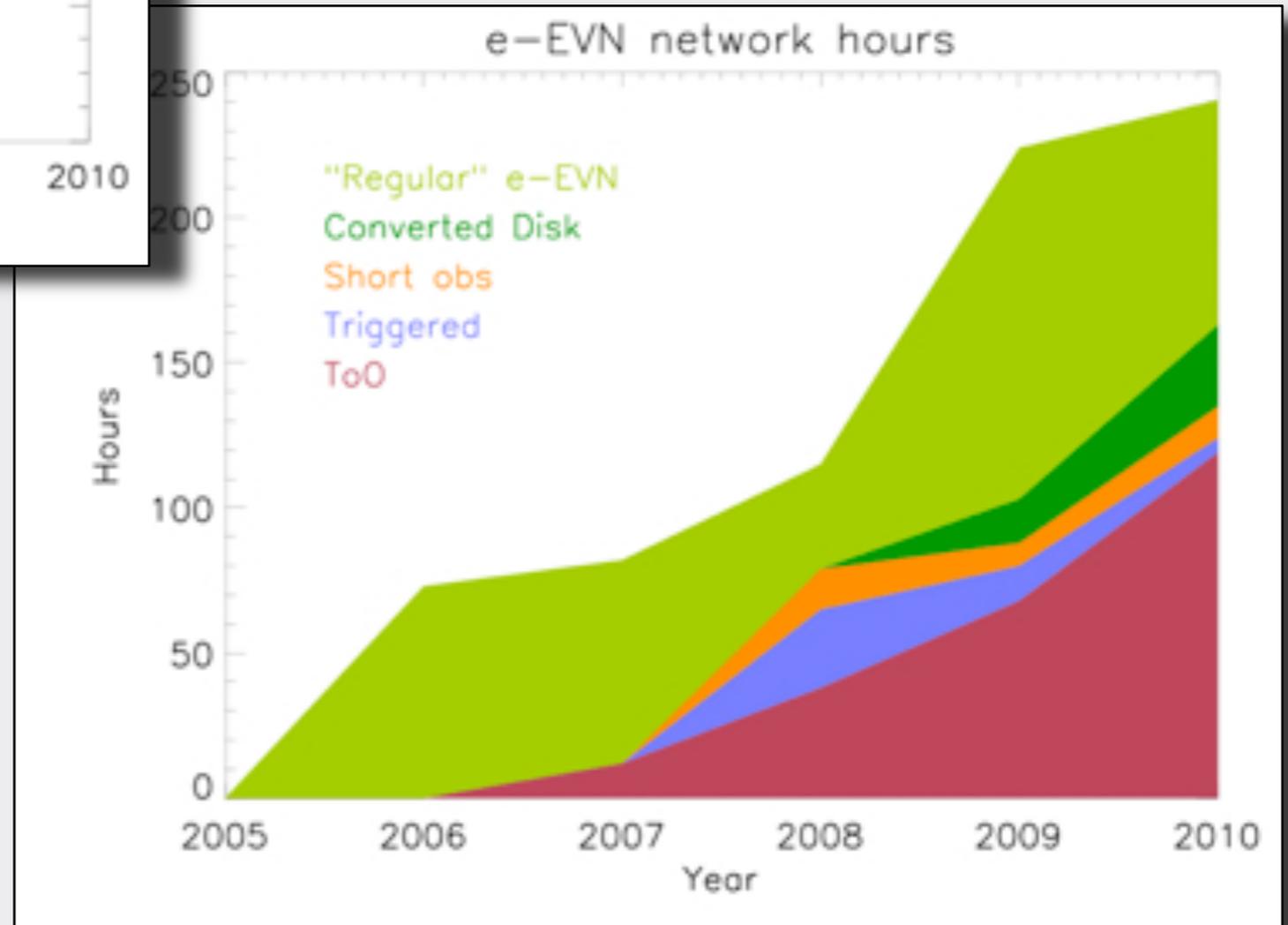
- initial mass-function

Perez-Torres et al. (2009). A&A 507 L17

# e-EVN operations plots



- Disk-based network hours roughly constant
- 2010 e-EVN network hours now at 240.5
- Total network hours 2010 at 999



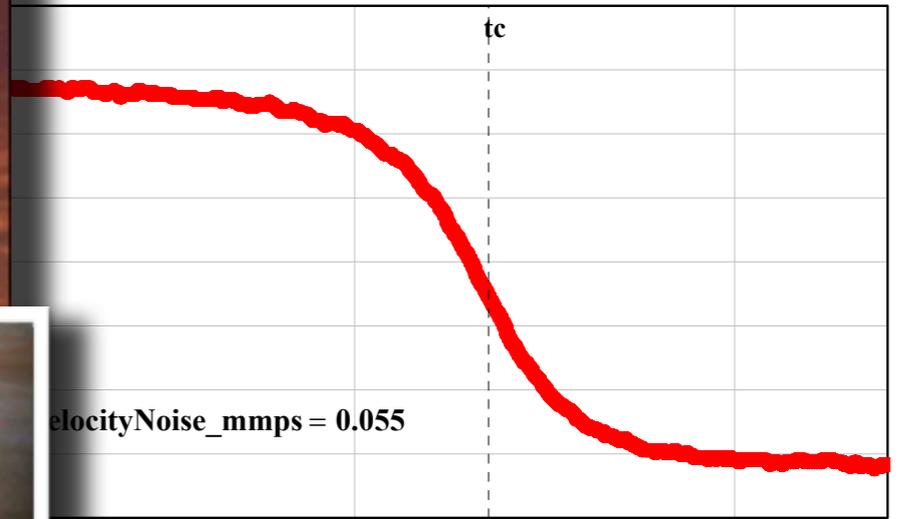
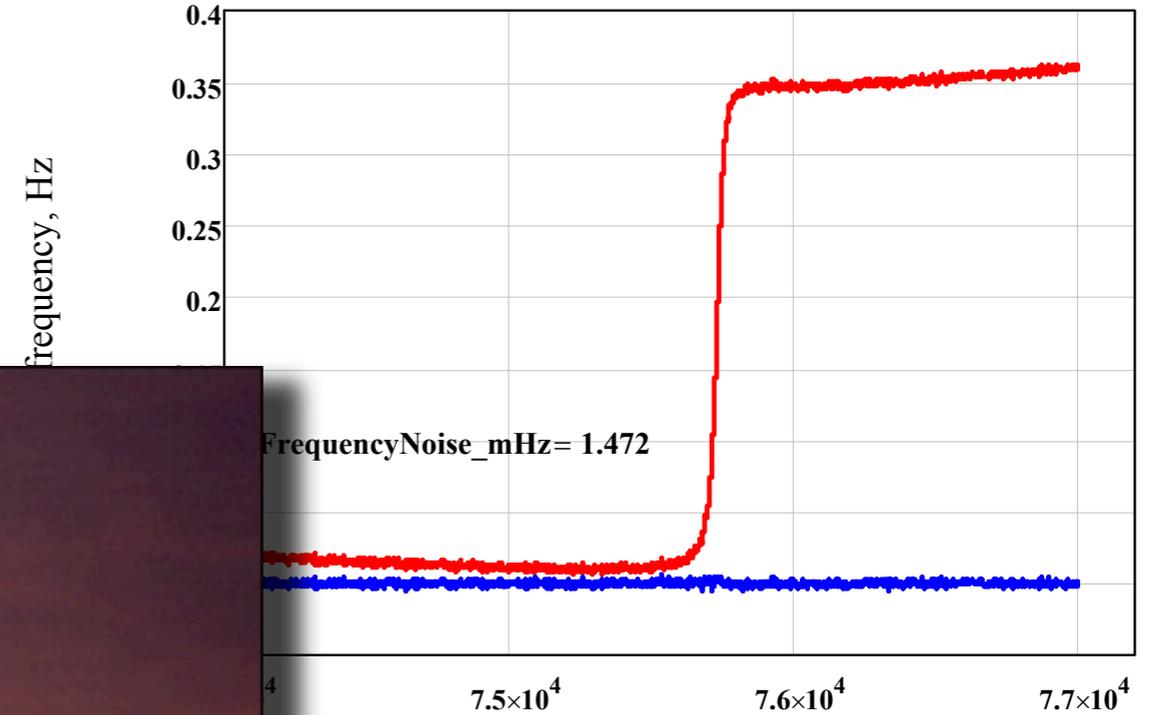
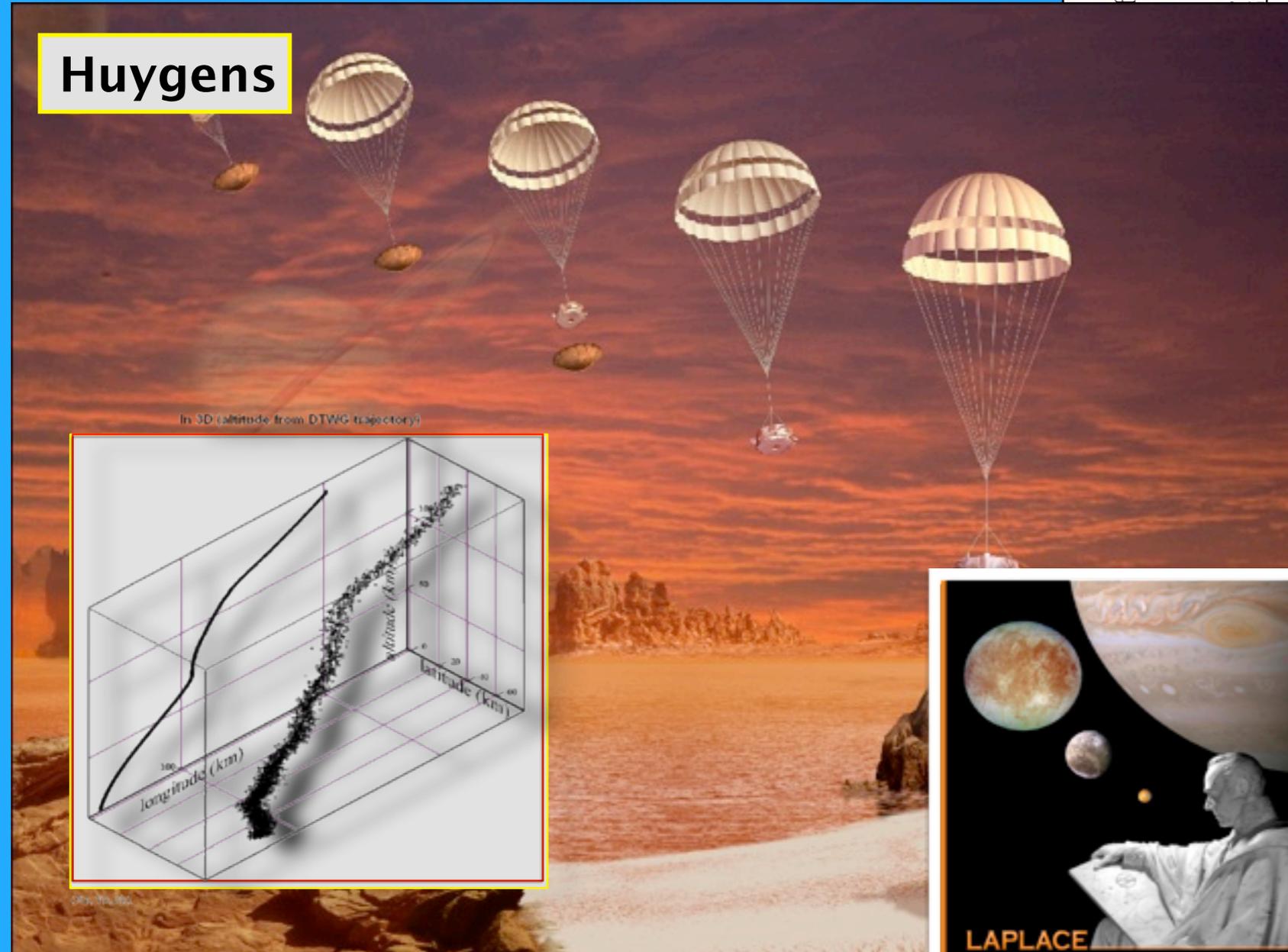
ToOs: half (49.5%) of the total e-EVN observing time in 2010 so far.

# Important links to Space applications

## Phobos fly by

on Metsähovi

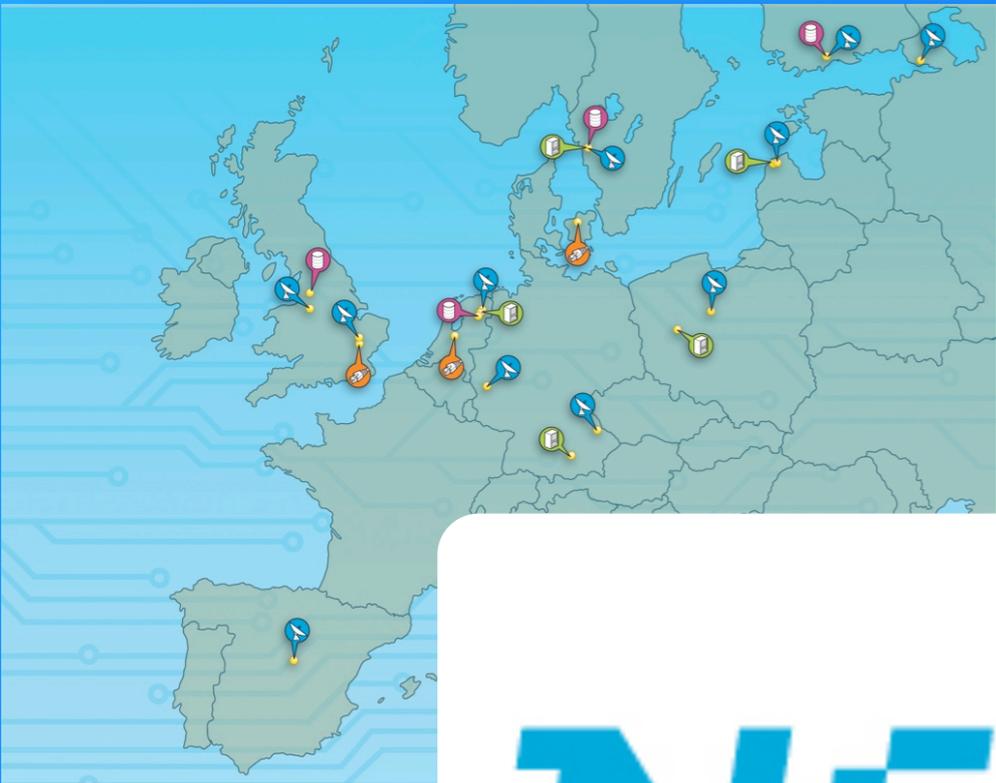
## Huygens



Time, seconds of the day 2010.03.03



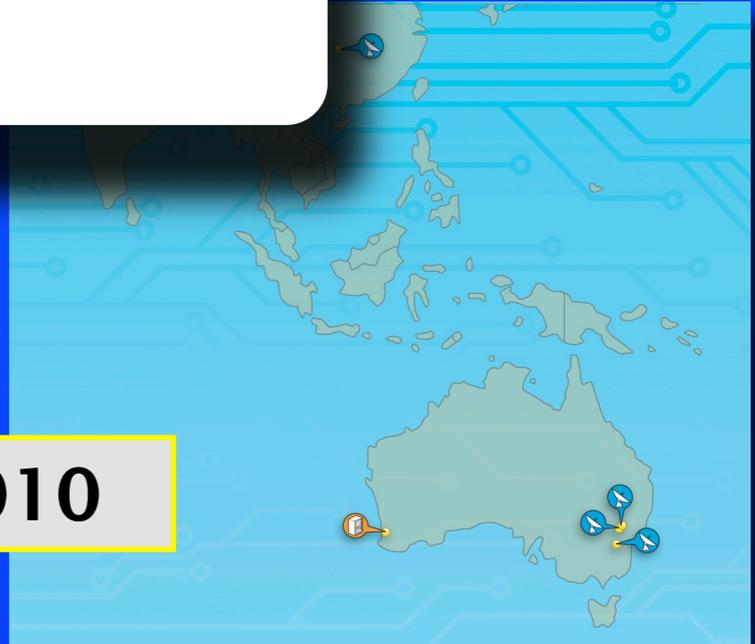
**EXPReS was concluded in Mar 2010**



# **NEXPR***e***S**

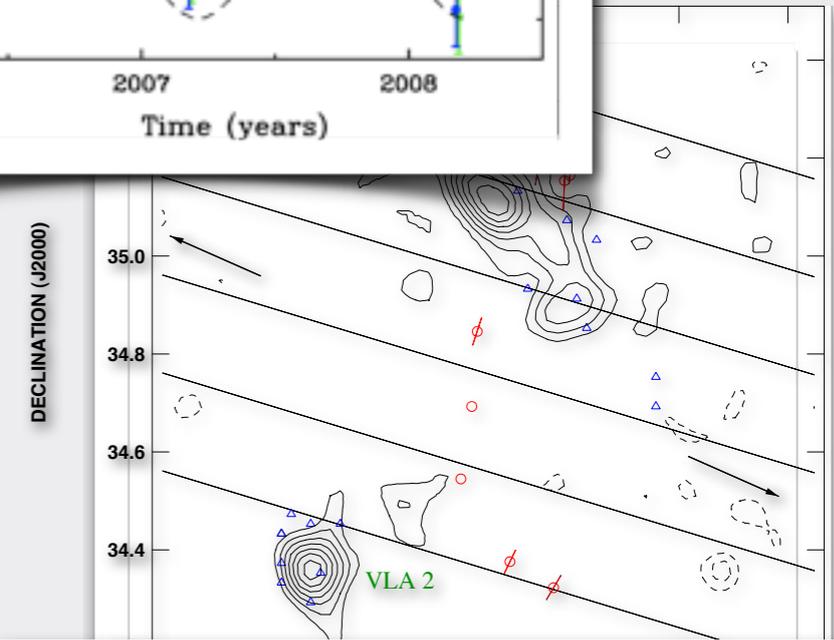
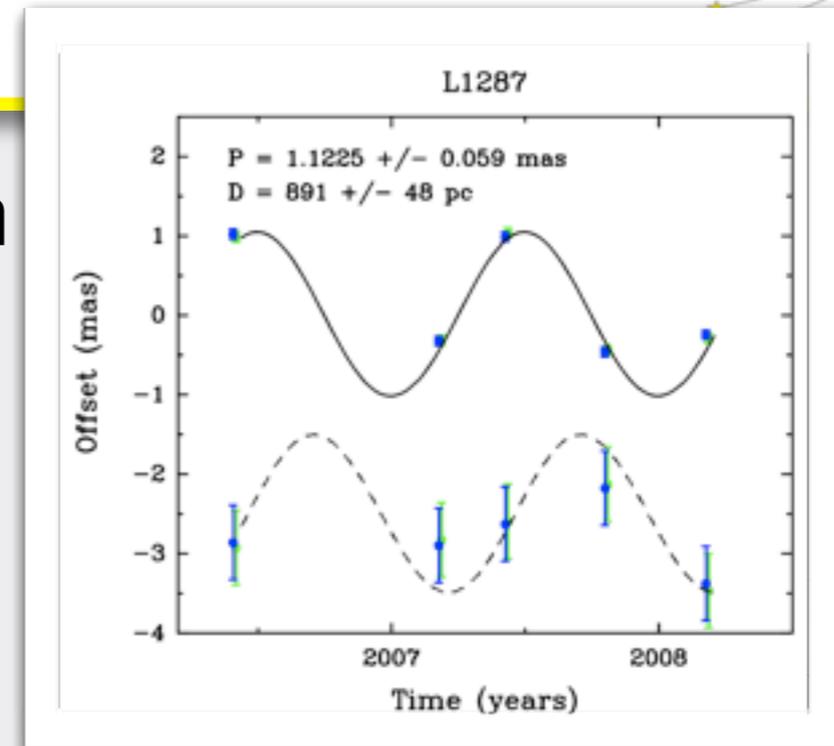
*Novel EXplorations Pushing  
Robust e-VLBI Services*

**Successful NEXPReS proposal kicked off in July 2010**



# Addressing issues:

- 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



- **Main objective to introduce transparent caching**
  - Lift distinction between VLBI and e-VLBI operations
  - Continue collaborations with NRENs
    - Bandwidth on demand allocation
  - Common technology questions with LOFAR and SKA
    - Broadband storage
- **15 partners (cf. 19 in EXPRoS)**
  - Of which 3 choose not receive funds from EC
  - Good mix from astronomy-networking-HPC communities
  - High level of partner-contributed effort
- **Kicked off in September at EVN symposium**
  - Had to fit project within 3.5 M€ envelope
  - Relatively painless, good progress
- **Continuity for e-VLBI operations**
  - Keep key expertise, discussion on shaping eVLBI in eVSAG
  - And assures continued connectivity in collaboration with NRENs

- **Step towards exclusive 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

# NEXPREs consequences for JIVE

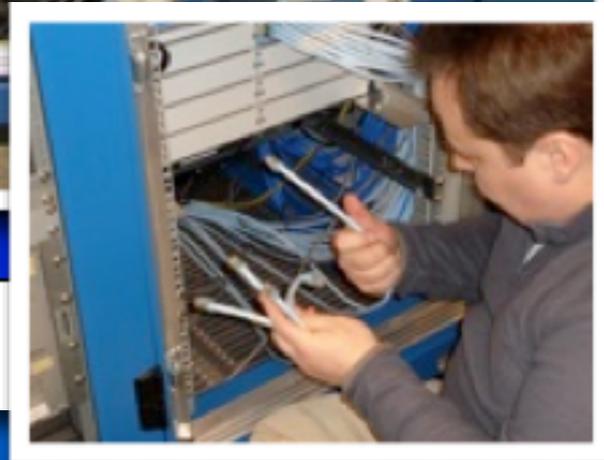
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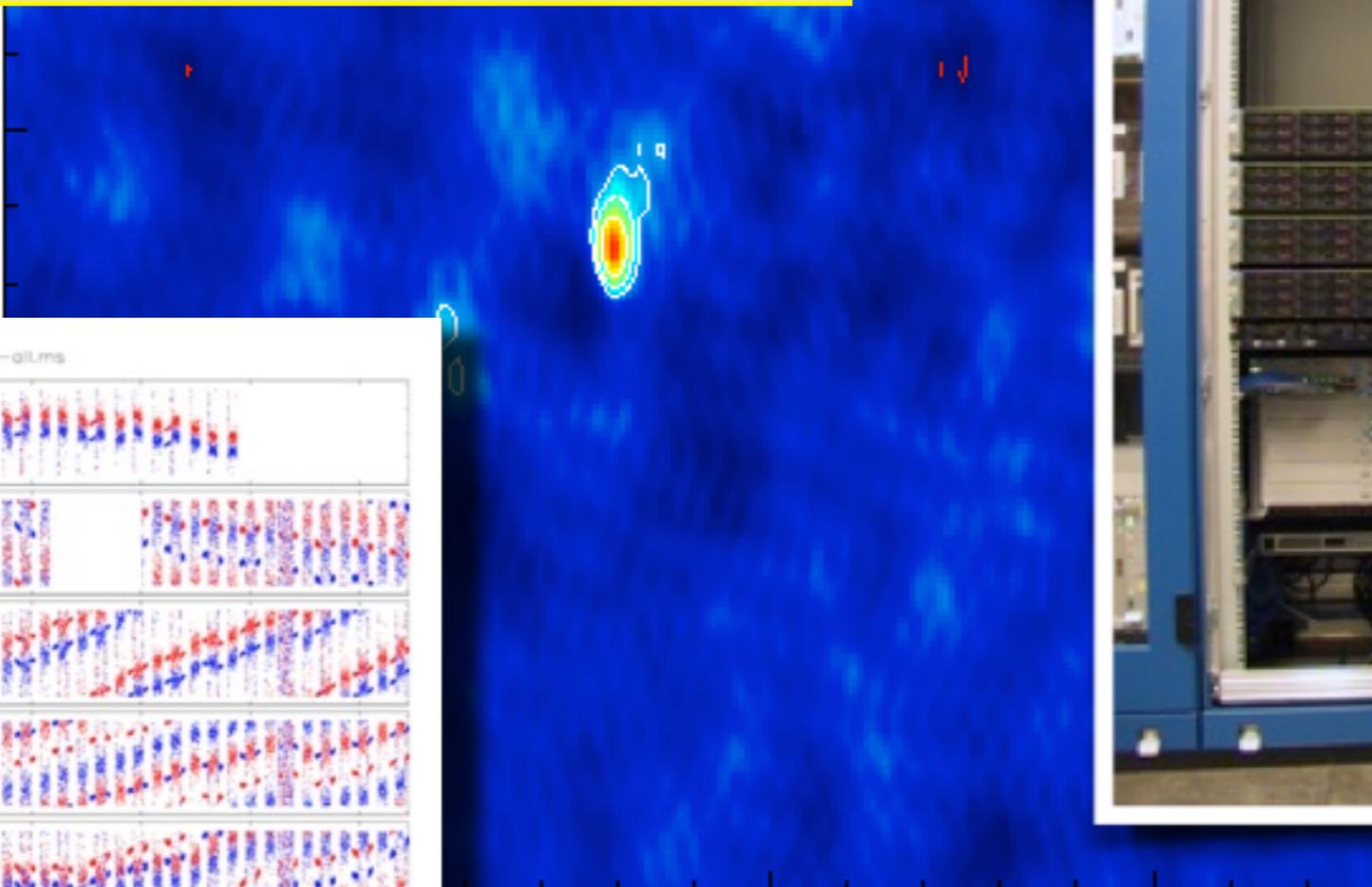
- **Good to be on the forefront of technology & science**
  - Consistent with recognition of e-EVN as an SKA Pathfinder

# • SFX Correlator

- Homegrown, based on Huygens
- **16 cluster nodes** Each 2 quad core CPUs: 128 cores Direct 1GE/2GE to M
- Pulsar gating/binning operational Preliminary VDIF support implemented

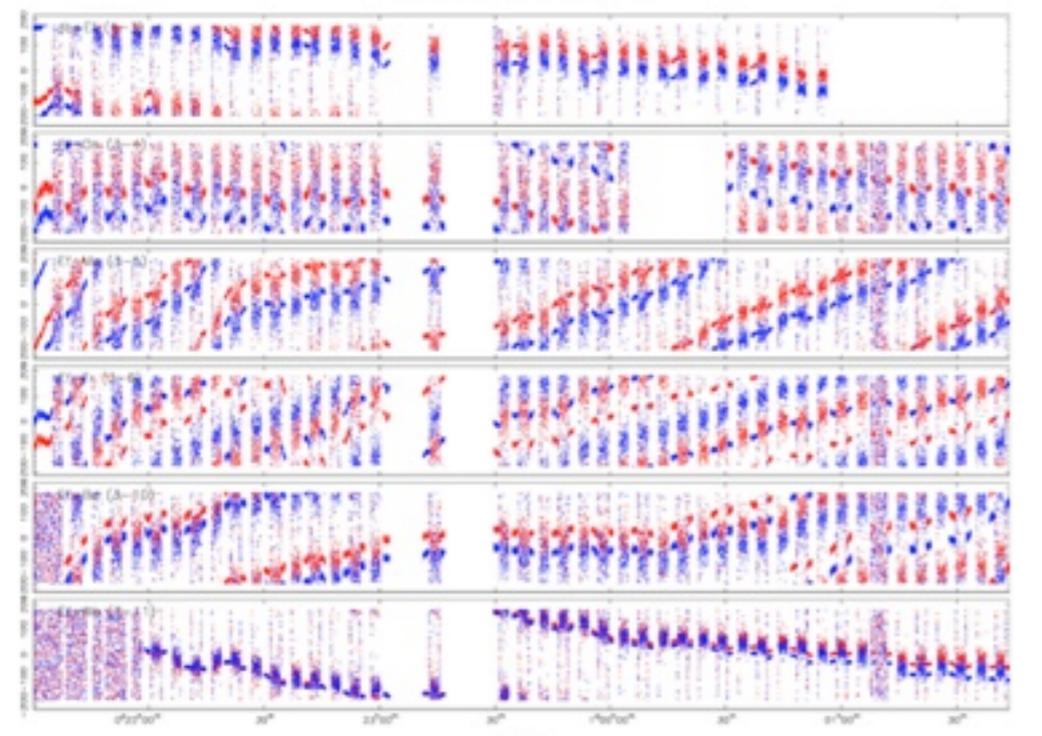


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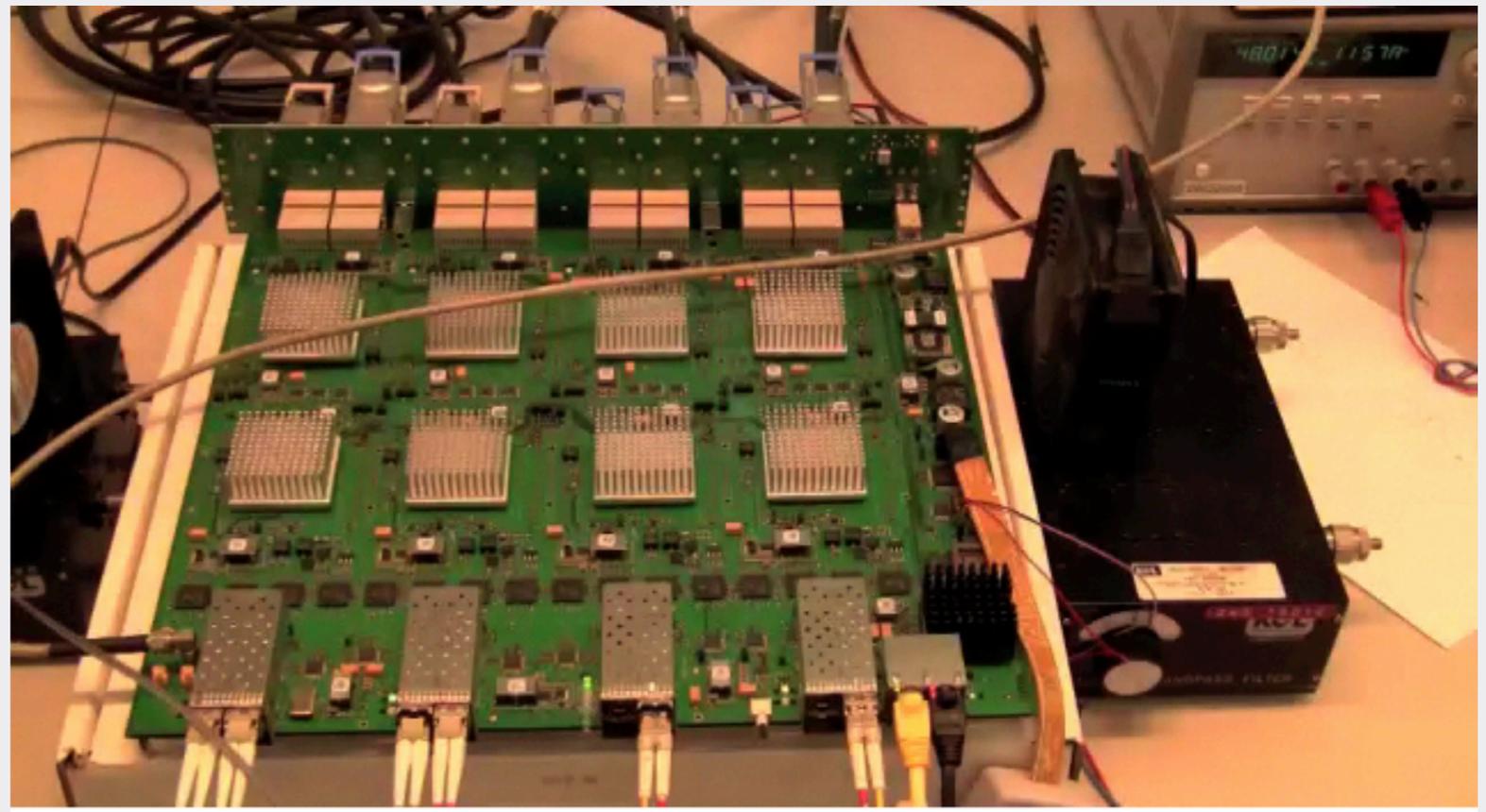
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Right Ascension (mas)

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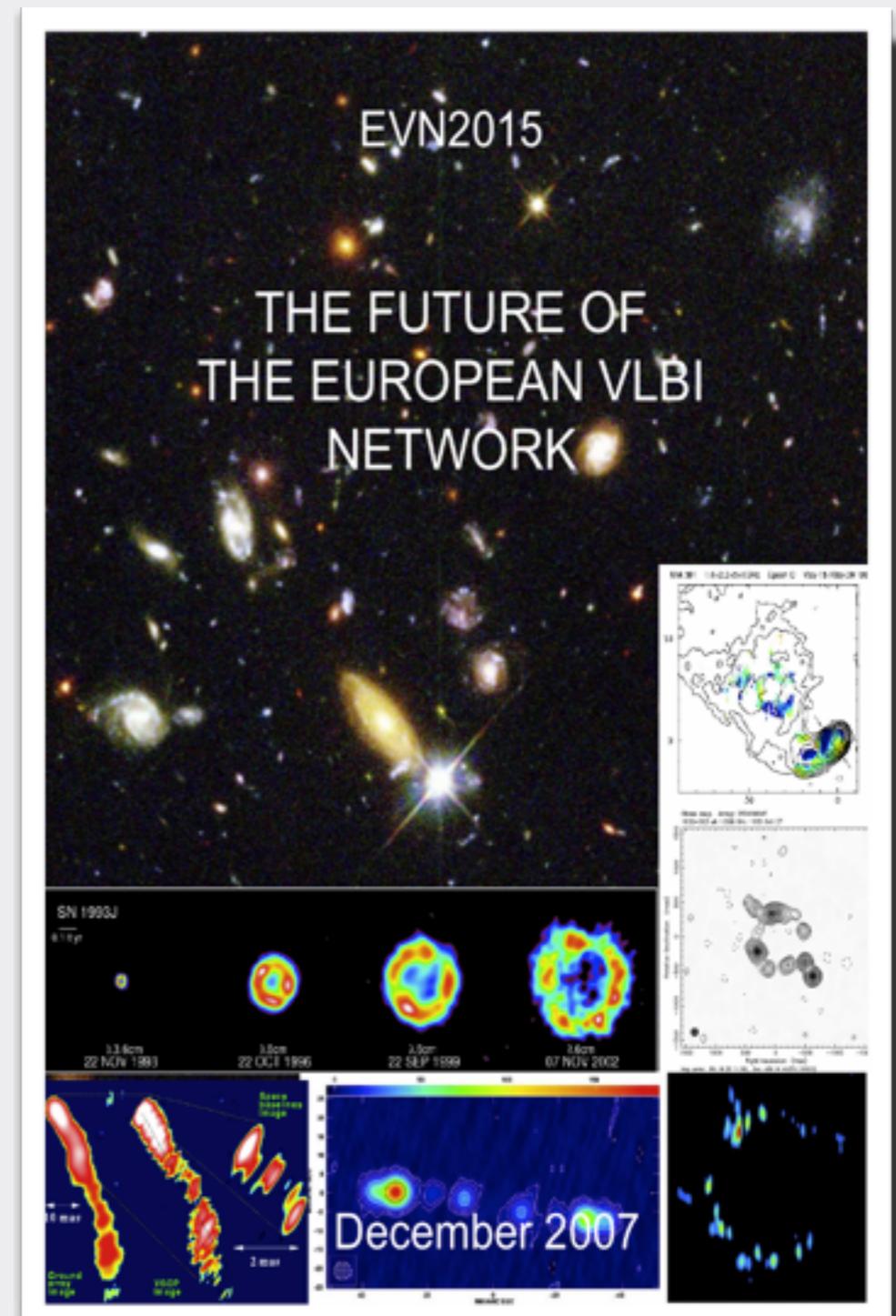


# Next: FPGA based correlator

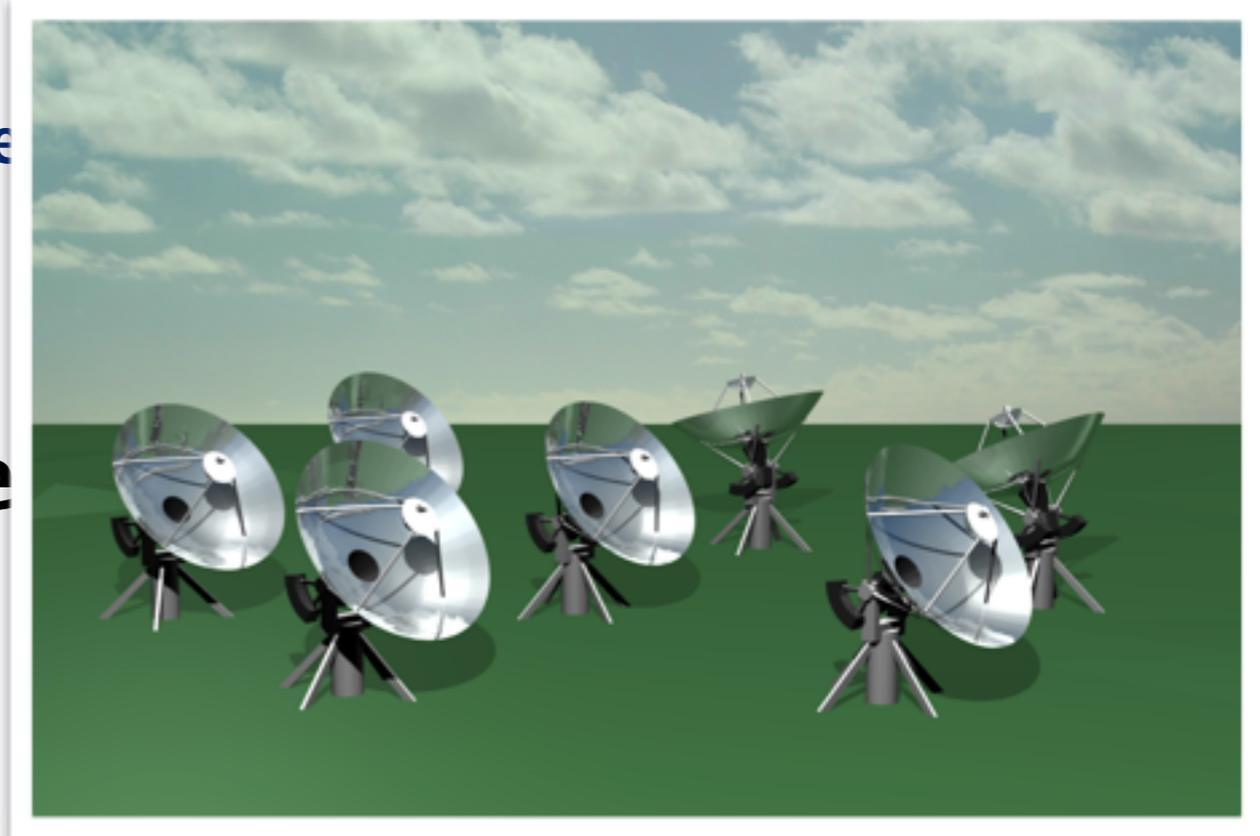
- Raised about 765k€ for NGC
  - From RadioNet UniBoard
  - In the Netherlands, link with Apertif @ WSRT
  - In collaboration with ShAO
- Will deliver prototype for EVN correlator
  - 2 boards deliver Mk4 capacity
  - Scale up to modest rack
- Will have the advantages of software correlator
  - But should be more economic



- **Unique science: long baselines and high frequencies**
  - Keep up with EVLA/MERLIN sensitivity
    - Going for 4Gbps in 2011
  - Follow up LOFAR, MeerKAT results
  - Even in the SKA era
  - Science case has been developed
    - <http://www.evlbi.org/publications/publications.html>
  - Better images? More telescopes!
    - MeerKAT, African array, Azores, eMERLIN
    - 100-fold bigger correlator



- **Unique science case for VLBI**
  - Definitely during SKA phase I and II
  - Global baselines northern hemisphere
- **Based on eVLBI advances**
  - Sensitivity, Robustness, Flexibility
- **Lots of overlap with SKA technology**
  - Benefit from digital components
  - And even antennas
  - And processing software
  - Synergy with other SKA pathfinders
- **Requires a Global approach**
  - With a common technology roadmap
    - e-VLBI could be the vehicle for doing that
- **Need SKA story to maintain funding...**
  - Training aspects, home telescope, outreach



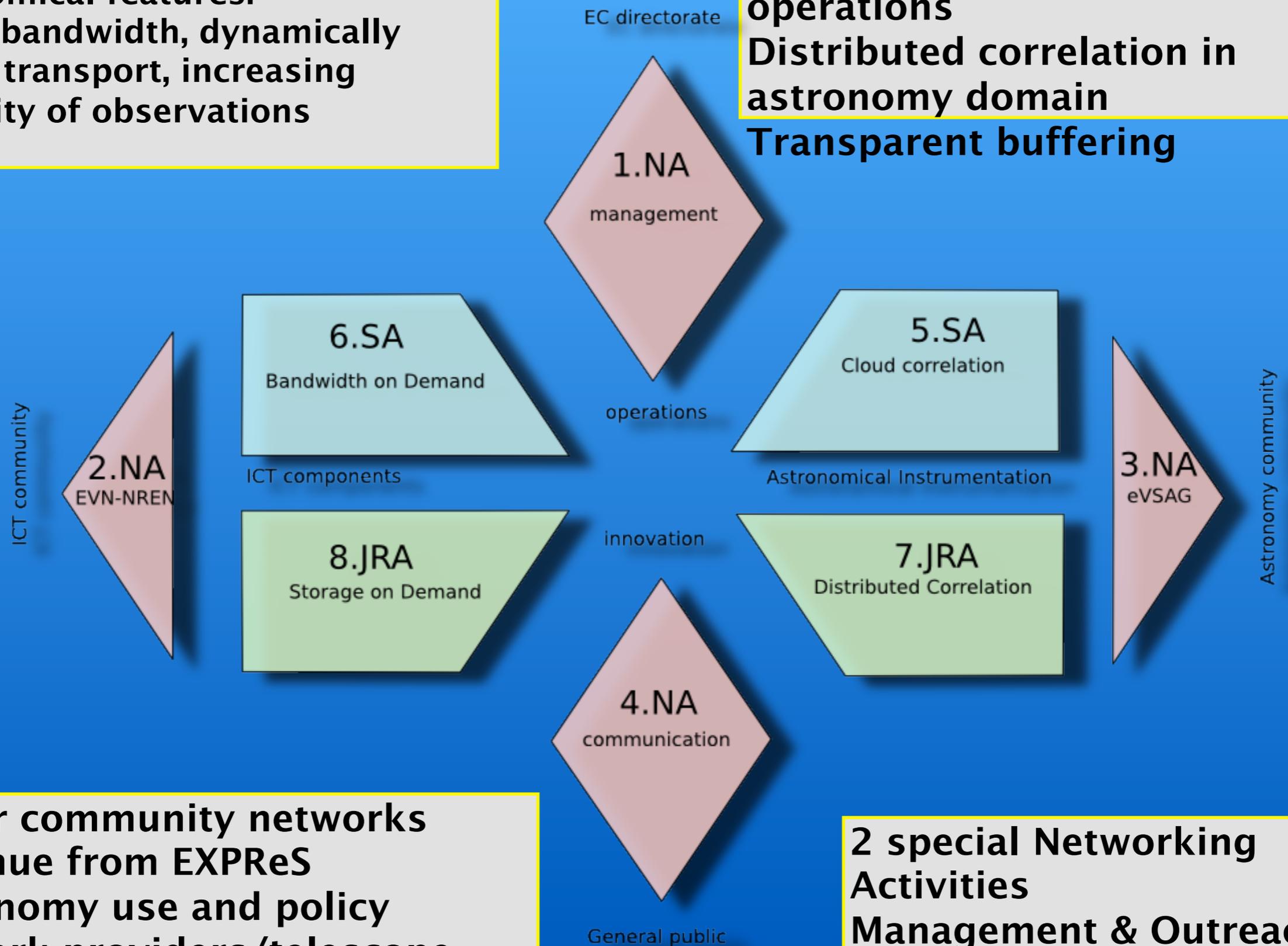
- **Too few interaction with US/Eu user communities**
  - Surely the VLBI science meetings should be joint
- **User community if the most precious asset**
  - Make sure the interfaces are uniform and robust
    - More important to get it accountable than to make it easy
    - User software, User support, Training, Proposal handling, Scheduling
  - Do not increase number of interfaces, but reduce and simplify
    - We do not have a user community to run 6 different networks
  - e-VLBI is helping us to foster user involvement
    - Gets the excitement of astronomical observation into VLBI
  - Dropping antennas does not help, reducing observing time may
- **Pushing technology is part of the mission**
  - e-VLBI has helped keeping us visible
    - Internet2 opportunities?
- **Long-term common goal?**
  - Global VLBI array which react flexible on user demands
    - Needed to satisfy scientists used to SKA/ALMA

**BTW: the Dutch Network provider is very interested in distributing clocks over public fiber**

**The End**

**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**



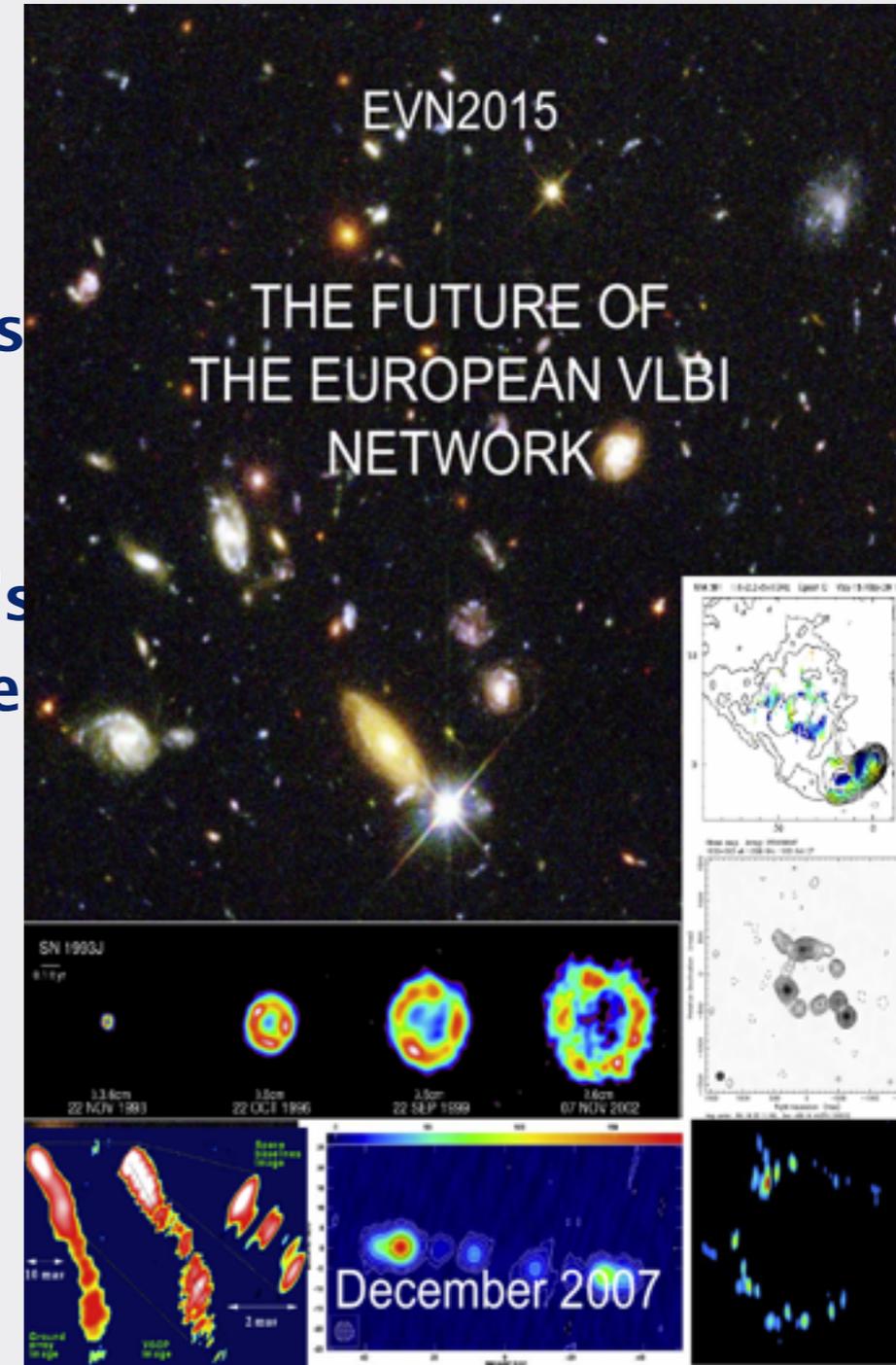
**2 user community networks**  
 continue from EXPRoS  
 Astronomy use and policy  
 Network providers/telescope  
 operators

**2 special Networking  
 Activities**  
**Management & Outreach**  
**Essential for success**

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

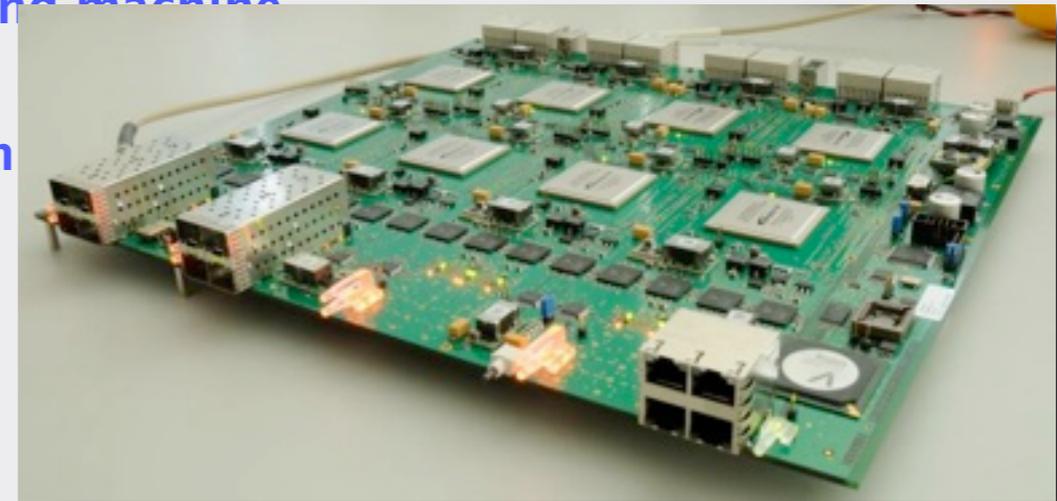
- **Some highlights include:**

- 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 source
- 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



# Next Generation Correlator

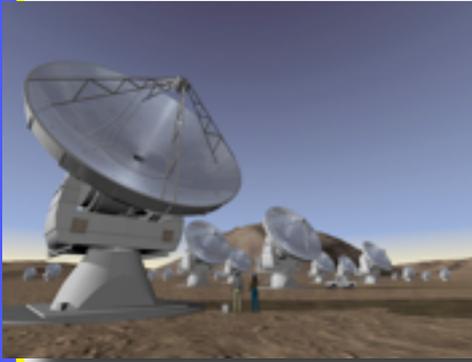
- **Raised considerable budget for prototype**
  - RadioNet: UniBoard, NWO: ExBoX, NWO-ShAO collaboration
  - Link to APERTIF correlator project
- **Scalable, generic, high-performance FPGA-based computing platform for radio astronomy**
  - **Several personalities:**
    - correlator, beamformer, digital receiver, pulsar binning machine
  - **Layout finished**
    - Various control software systems under construction
  - **Hardware purchase: Altera StratixIV**
    - First hardware has arrived and being tested
  - **Aims to deliver single crate prototype**
    - Same power as current correlator
- **Aims at 100fold 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



# Common issue: software



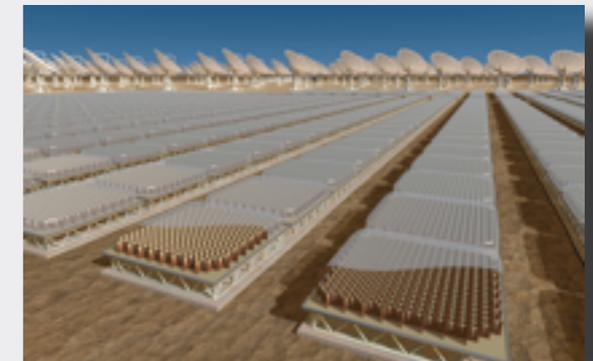
- **Trying to address with small steps**
  - EC sponsored contribution
    - Across quite different range of facilities
  - Channel collaboration & meetings
  - A platform for exchanging experiences
  - A place to train new specialists



- **A set of related work-packages**
  - A way to structure progress
  - And enforce communication



- **Addressing hot topics**
  - Interoperability
    - Includes support for ParselTongue
  - Calibration algorithms
    - Large fields, directional dependence
  - Automated processing
    - Data quality, automated flagging





**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**

