

# GLOBAL eVLBI

an evolution pathway for VLBI into the SKA era

*Huib van Langevelde*

*JIVE*

- **Programmatic aspects of e-VLBI**
  - EXPReS; introducing e-VLBI
  - Introducing NEXPReS
    - Objectives of the new program
  
- **Impact of e-VLBI on VLBI and radio astronomy**
  - Some discussion on policies
  - And applications
  
- **e-VLBI and the future**
  - SKA pathfinder
  - evolving VLBI = Global VLBI
  - Competitive in the SKA era

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Starts with a European perspective



Ends with a Global perspective

- **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



Zelenchukskaya



Yebes 40m



Kunming 40m



Miyun 50m

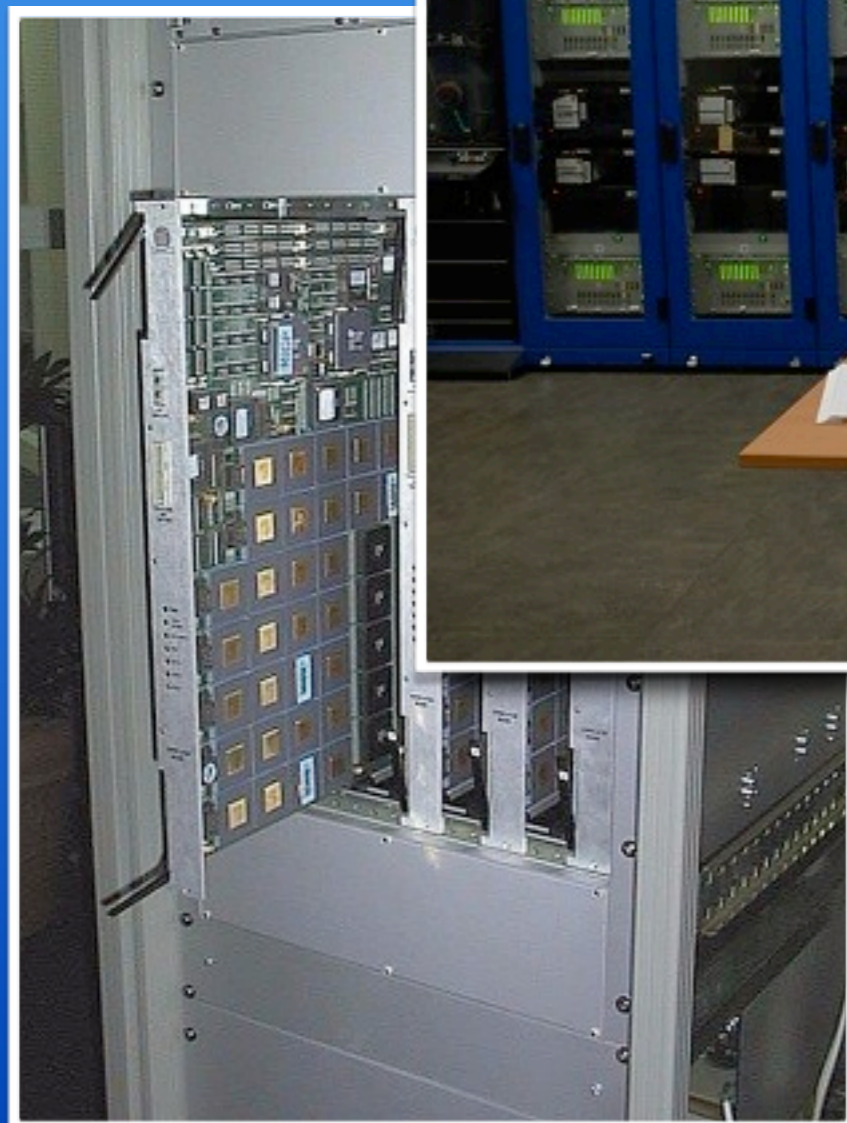
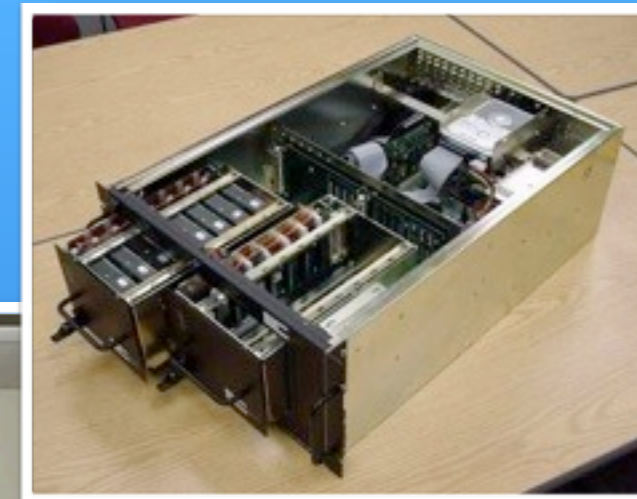


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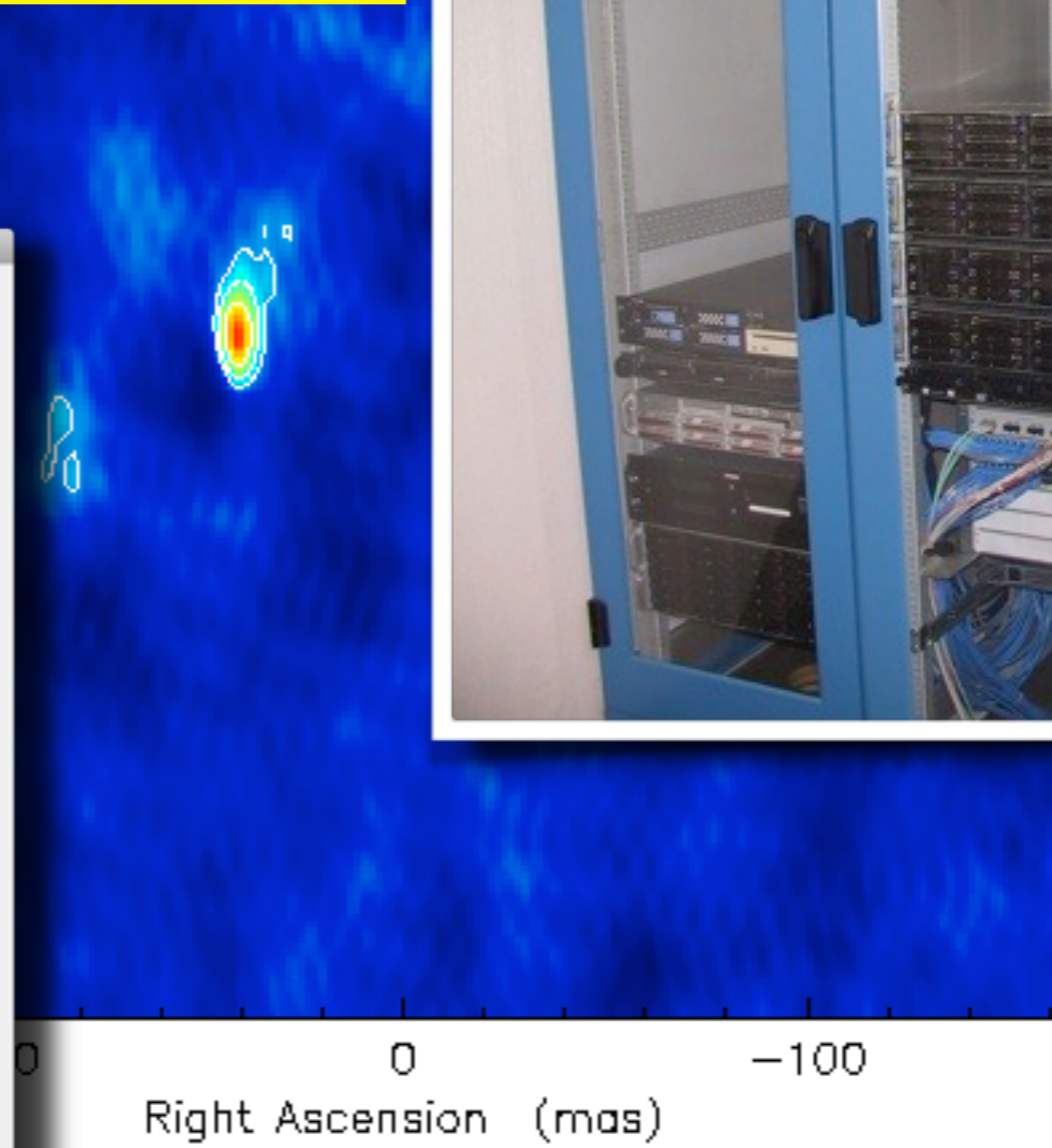
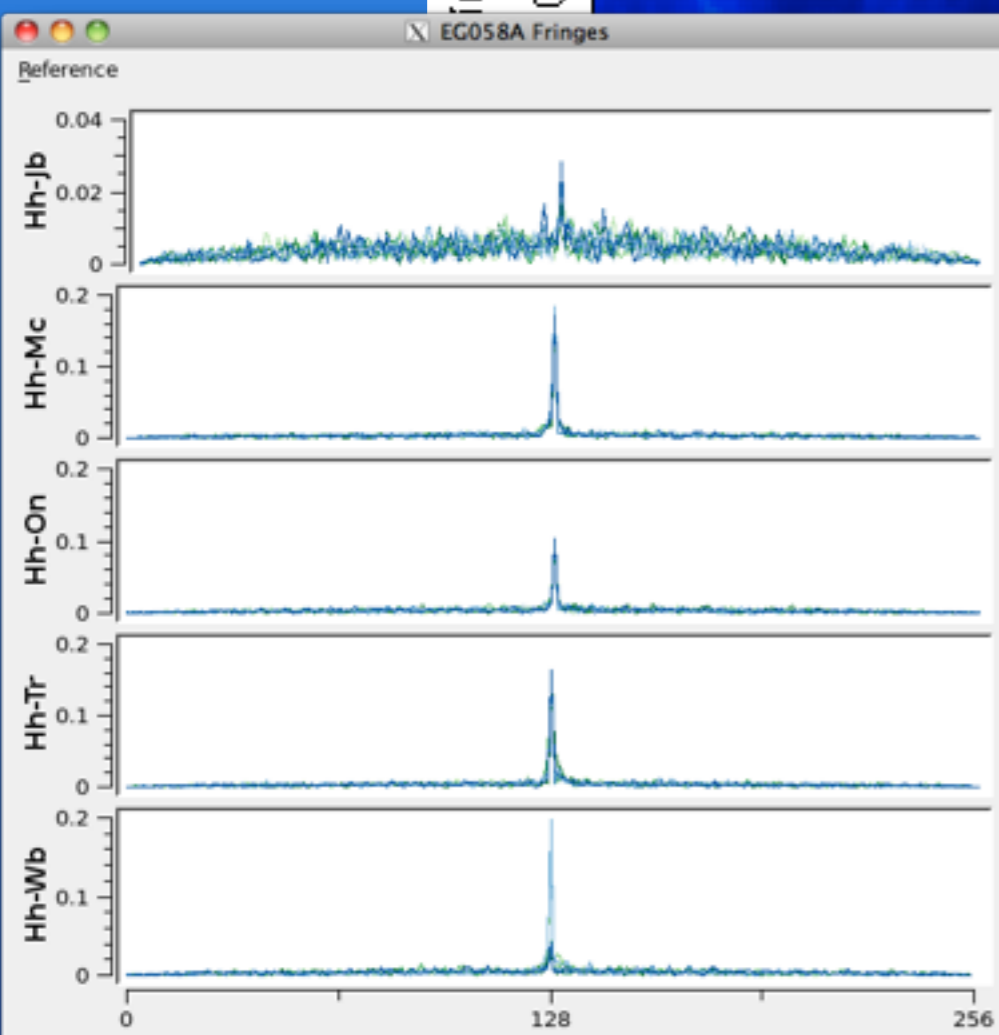
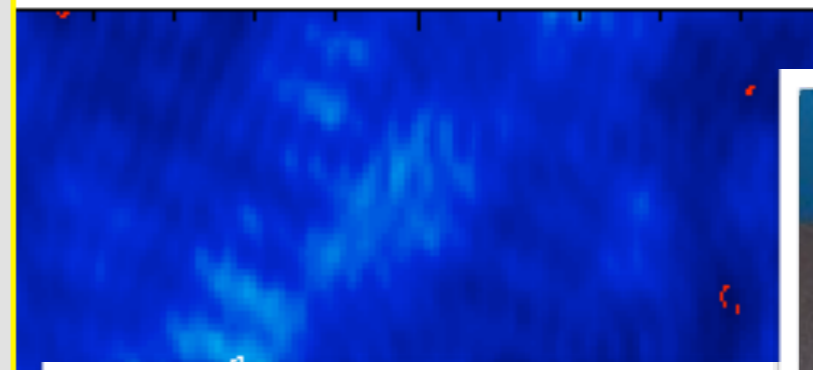
- **Promote the use and advance of VLBI for astronomy**
  - Central correlation
  - User services
  - Network support
  - Innovation
  - EC liaison/representation
- **Founded in 1993**
  - **Base budget from partners in 7 countries:**
    - China, France, Germany, Italy, Spain, Sweden, United Kingdom, the Netherlands
    - Some funding agencies, some institute contributions
  - **hosted by ASTRON**
  - **Large number of external projects**
    - Covering JIVE's R&D and science ambitions
  - **Preparing for new funding cycle MOU**
    - May take new form of European Research Infrastructure Consortium



- **Hardware correlator**
  - 1024 custom chips
  - 16x16 baselines, 0.25s



- The EVN software correlator at JIVE (SFXC)
- 9 stations 1Gbps real-time
  - Pulsar gating
  - Space craft applications
  - Spectral polarimetry
  - Many field of views



0 0 -100  
Right Ascension (mas)



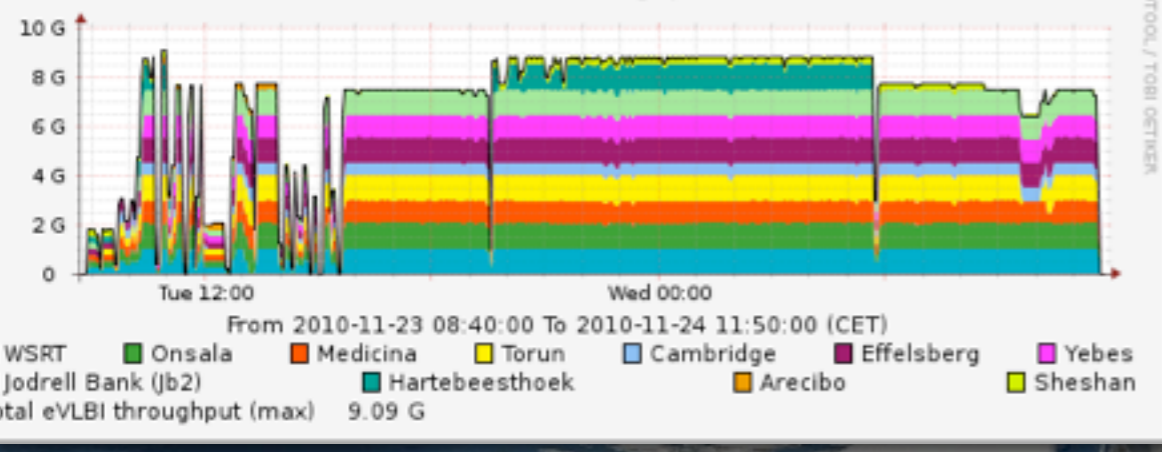
- **Started many times in many places**
  - Fringe verification, modem lines
  - For EVN started with a pilot in 2004



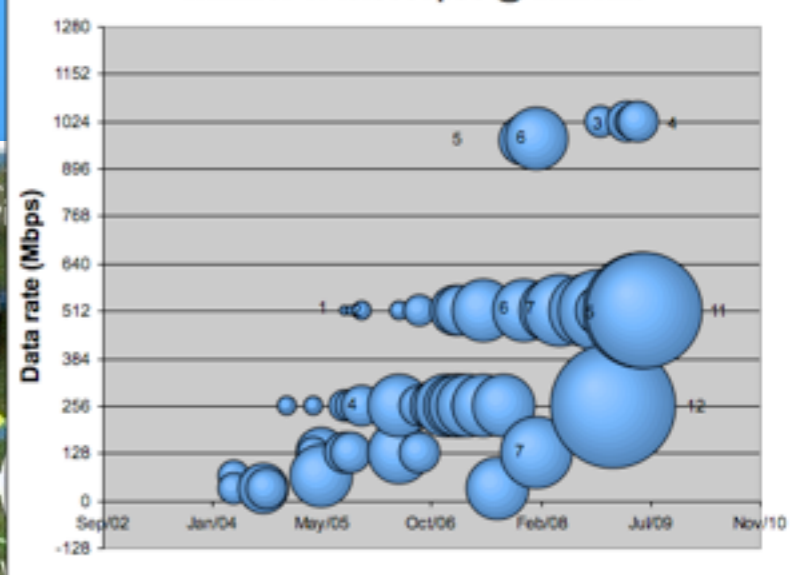
**3.9M€ project, with additional resources from partners and additional NRENs. Started Q3 2006 ended Q2 2010**

- **Really took off 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

Total eVLBI throughput



Number of telescopes @ data rate

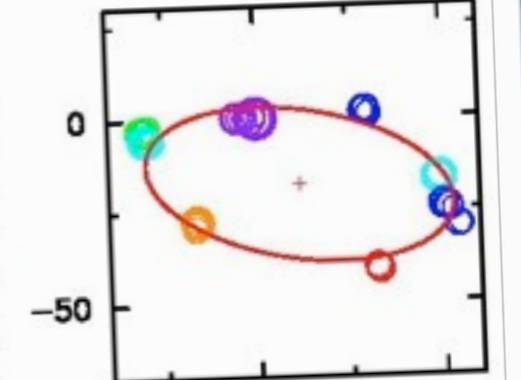
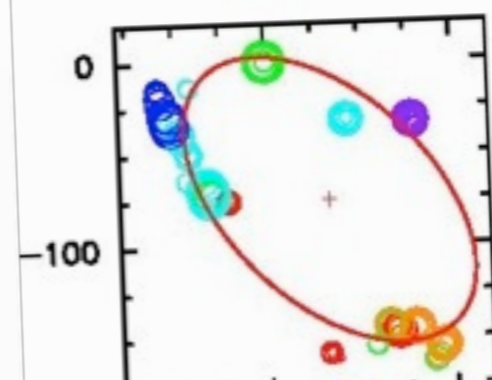
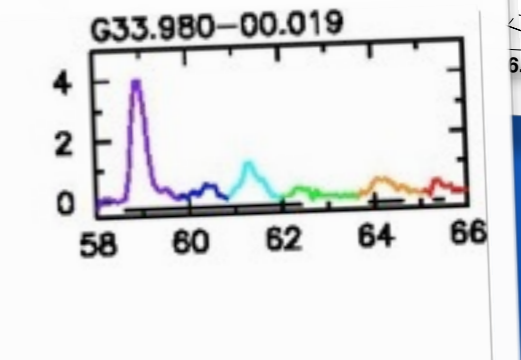
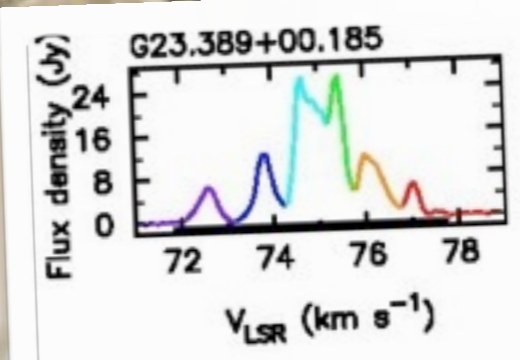
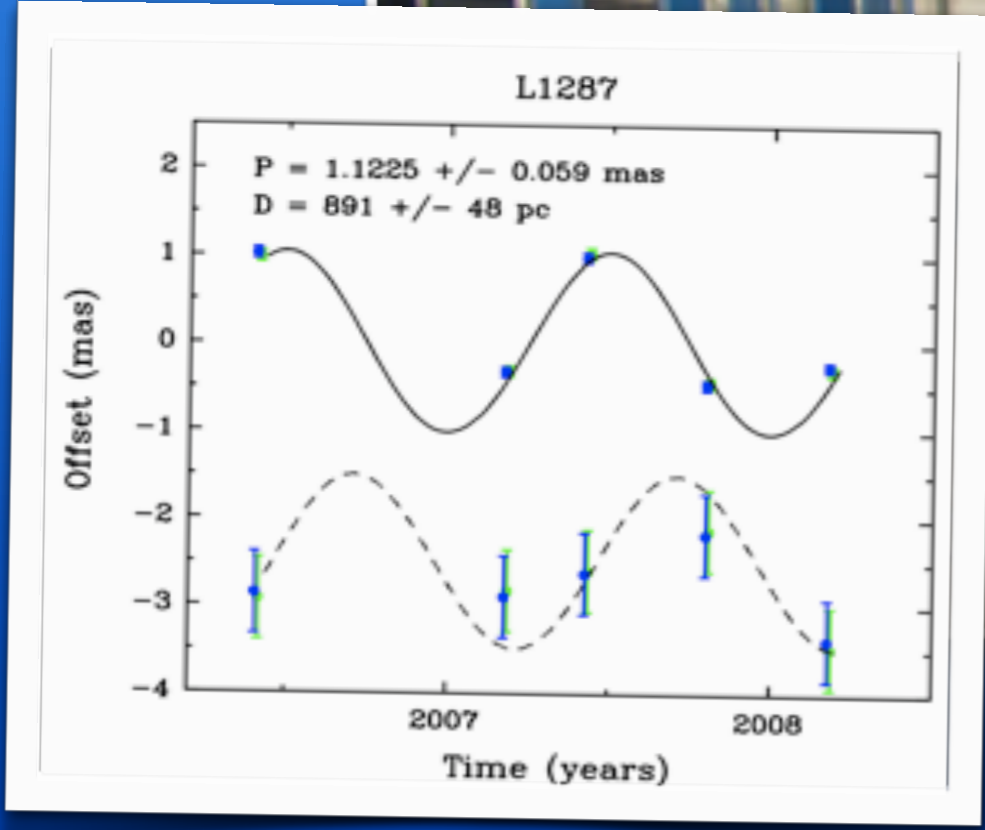
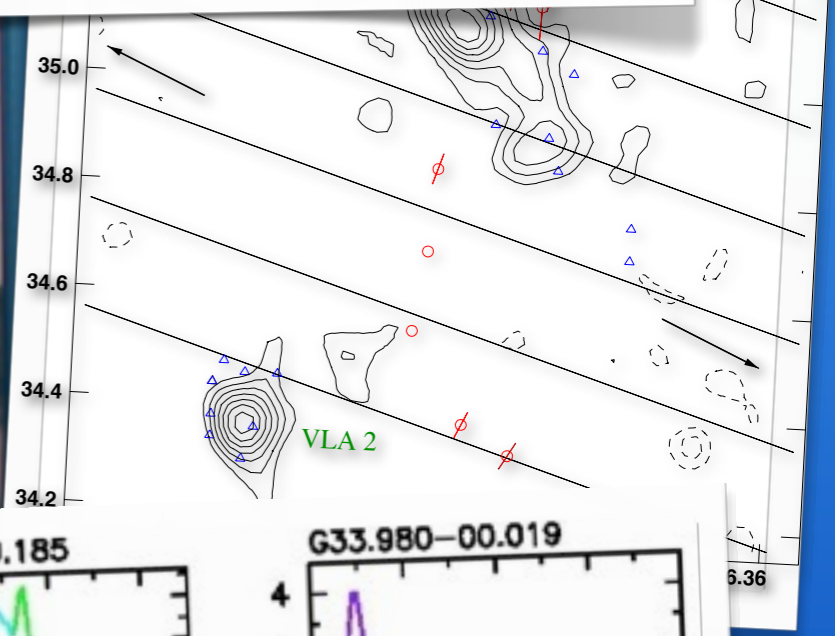
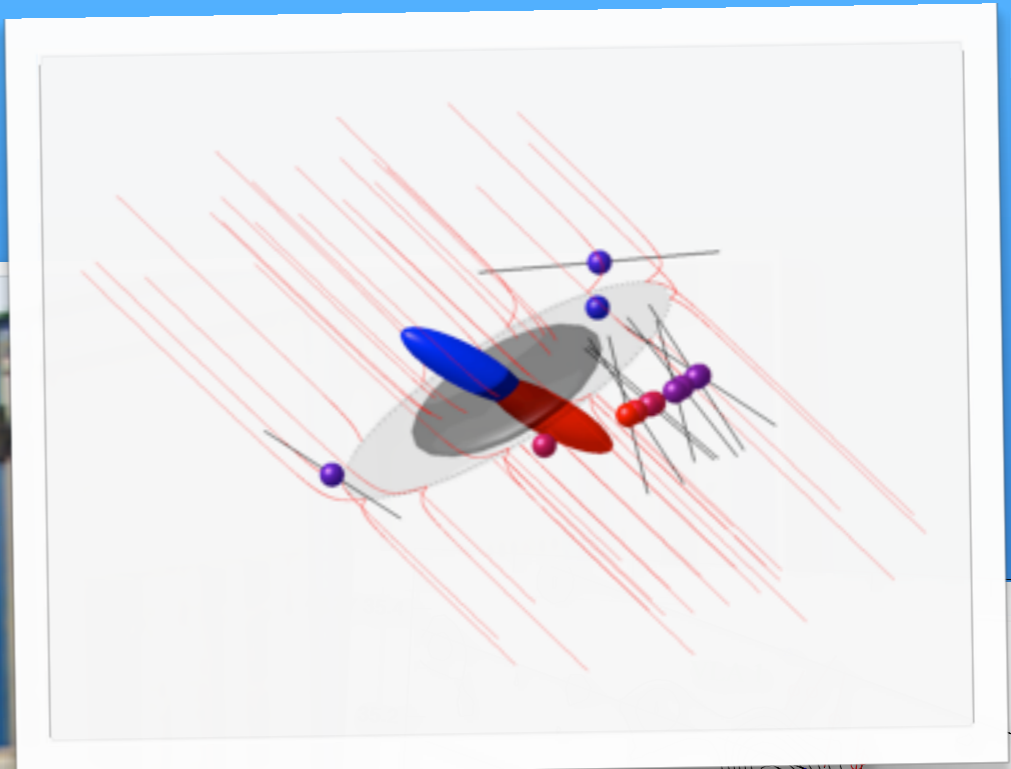
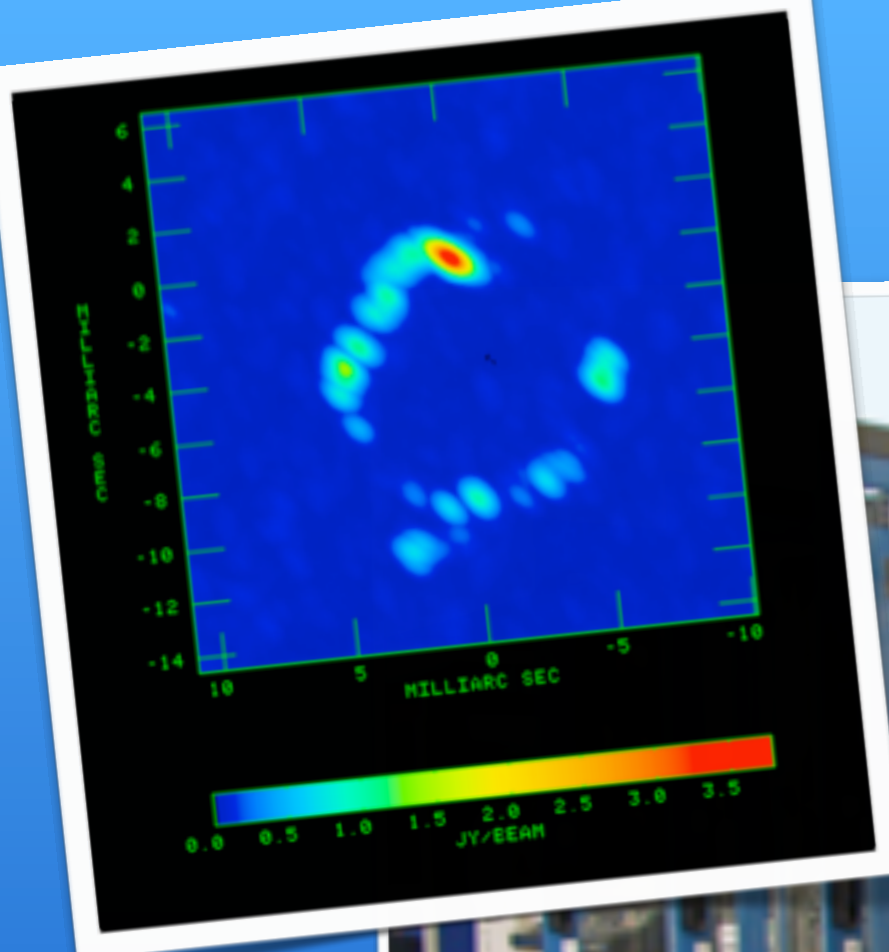


Network status as per 2008-05-02. Image created by Paul Boven <boven@jive.nl>. Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

- **Now an operational facility**
  - Guaranteed 10 x 24h per year
    - And quite bit more in practice (>30%)
- **Flexible ways to get into e-VLBI**
  - Request e-VLBI for fast response
    - Can be approved by PC for existing sessions
  - Or for triggered proposals
    - To be submitted at regular proposal dates
    - Requires specific trigger criteria
  - Short requests <2hr
    - e.g. calibrator checks
  - Target of Opportunities
    - EVN agreed to have substantially more of these
  - Or just because you prefer to e-VLBI
  - Or just because the EVN prefers to do e-VLBI
    - Because of logistics or (disk) resources

- **Besides building expertise and making new friends:**
  - Bandwidths of 1Gbps and above not a problem
  - e-VLBI is probably even more reliable
    - By closing the loop in real-time
  - It can be applicable to Global VLBI
    - Local connectivity often the more serious problem
  - It did produce new science
    - Moreover, users think it is exciting and convenient
- **But some questions remain**
  - Will it be cost effective?
    - In many places, notably NL, still has the nature of collaborative project
  - Cannot accommodate all projects
    - Spectral line, mixed bandwidth
    - Multiple correlator centres
    - Some antennas in some experiments (Noto, Russian, Chinese)
    - Globals including NRAO, DSN





# Cost effective?

- **Shipping much cheaper than bandwidth at commercial rates**

- Lucky with blessing at European level
  - Dante's Geánt
- Made local providers supportive
  - Fantastic infrastructure SURFNET
- Commitment of partners
  - Synergy with LOFAR

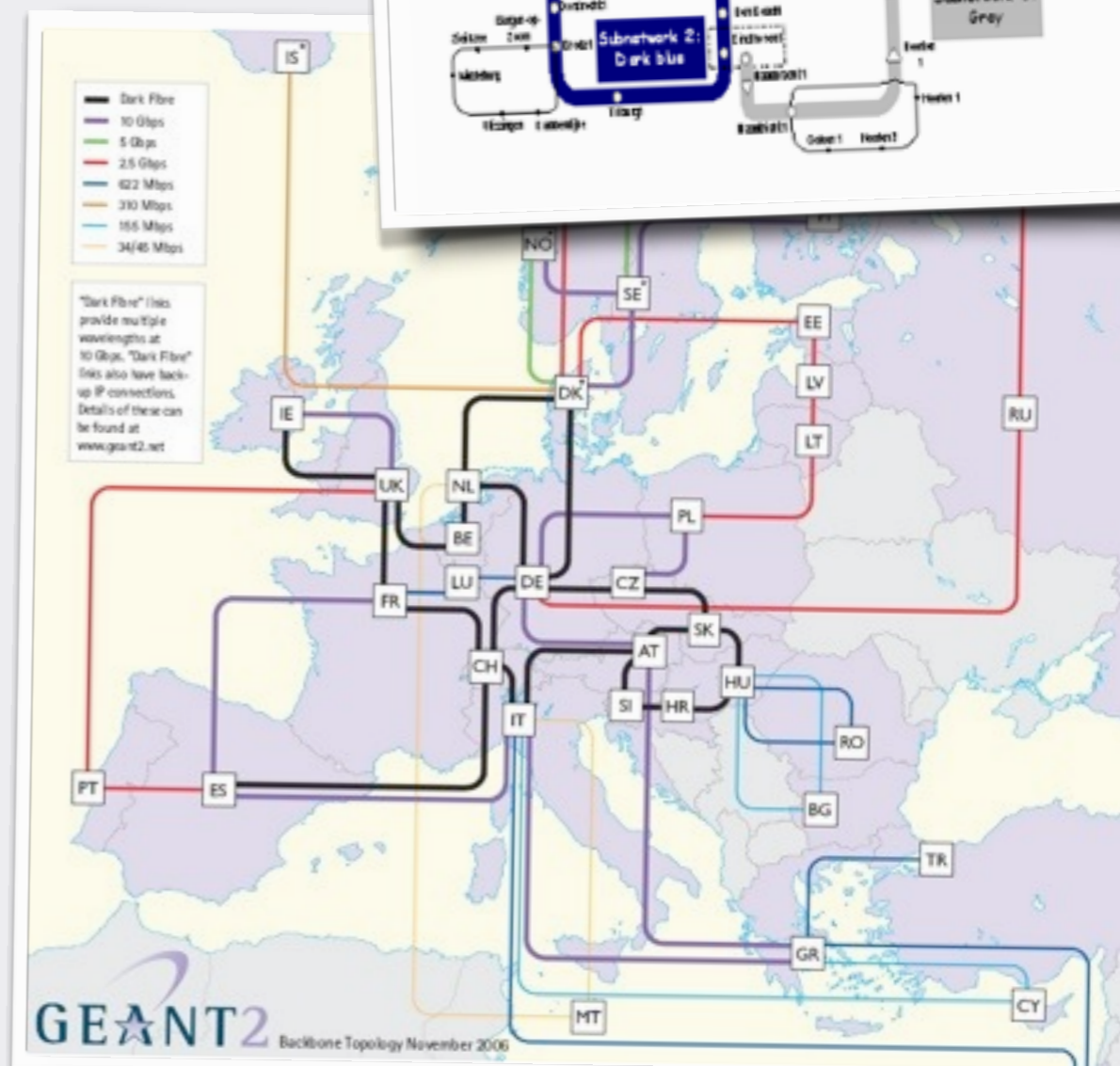
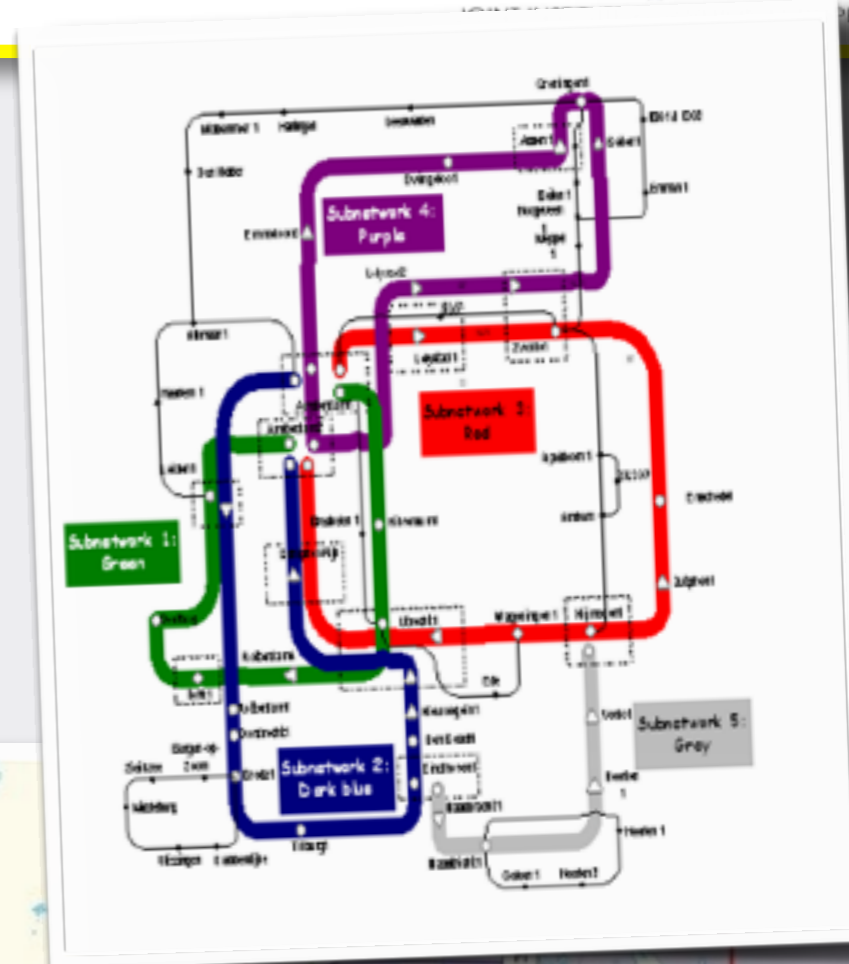
- **Strategic issue for NRENs**

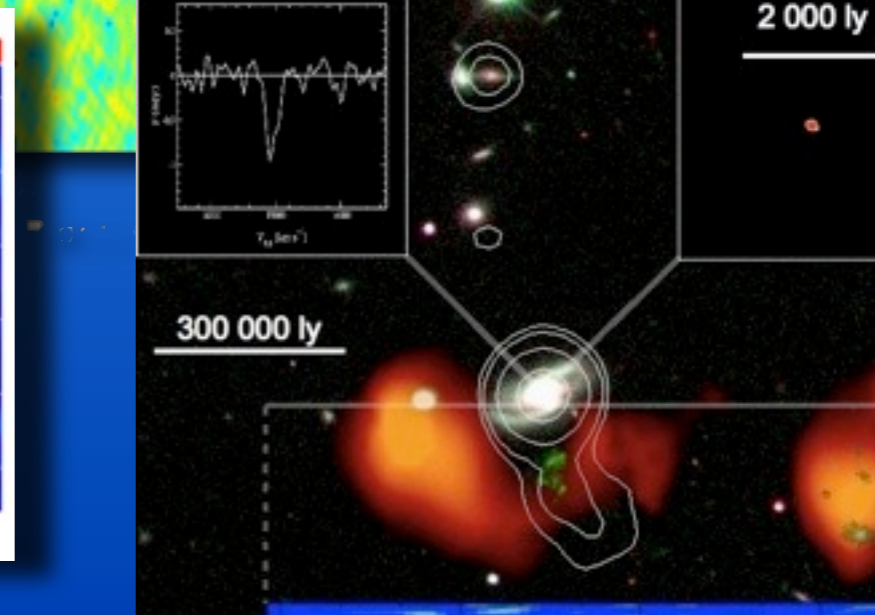
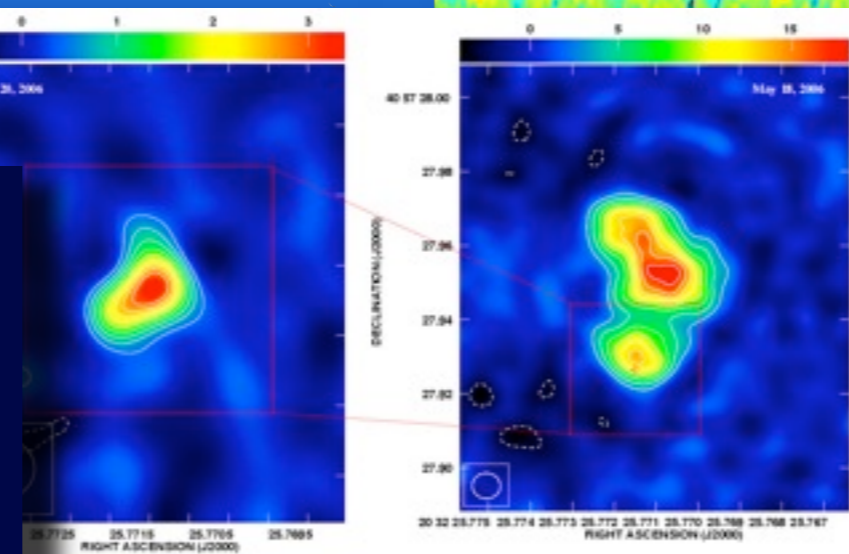
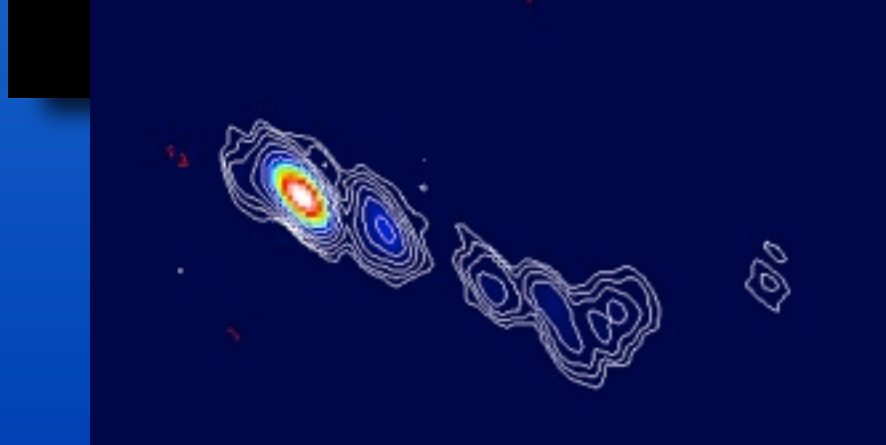
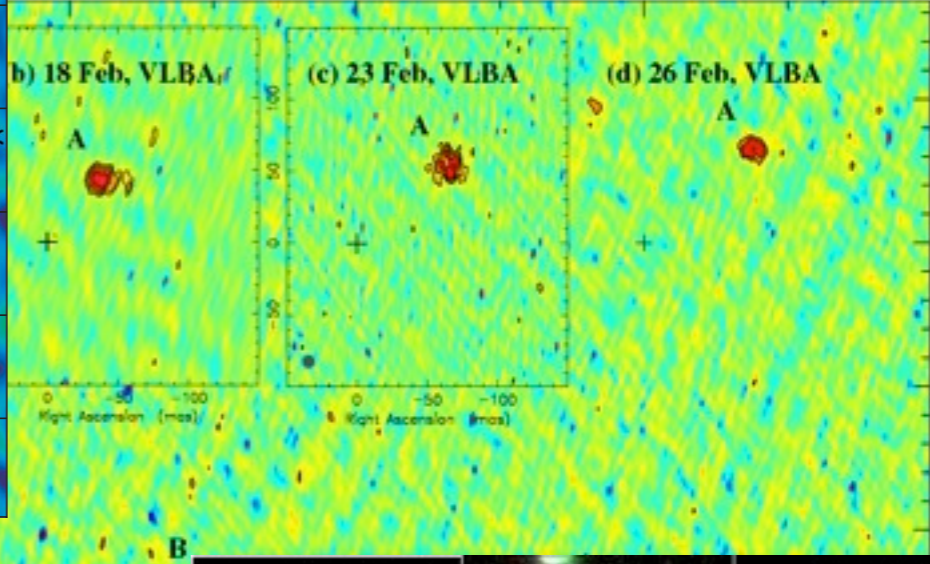
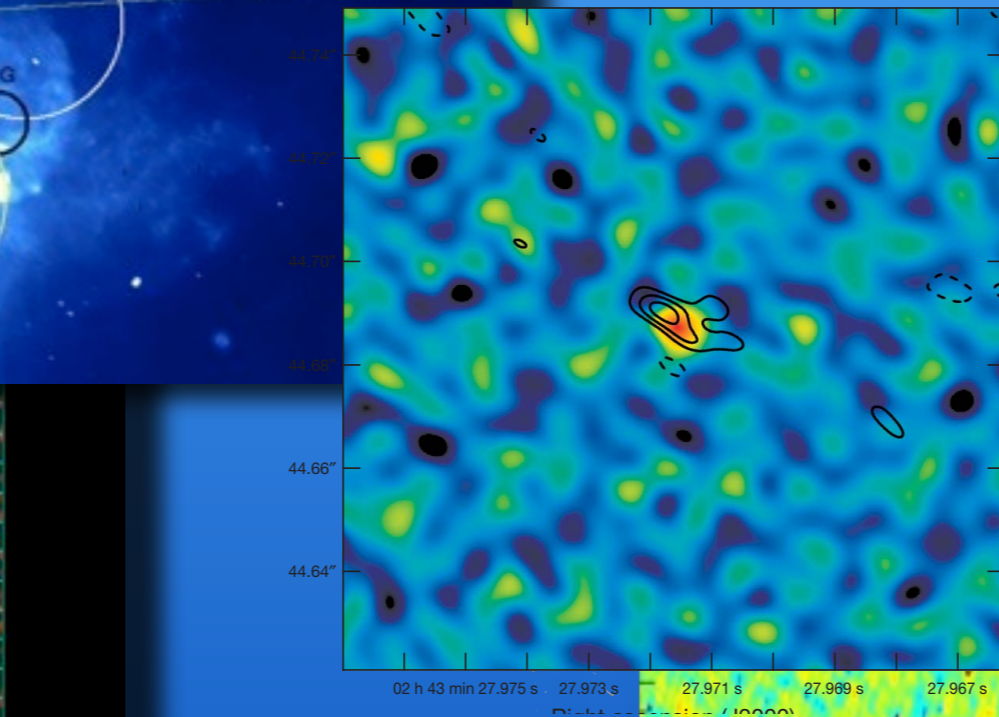
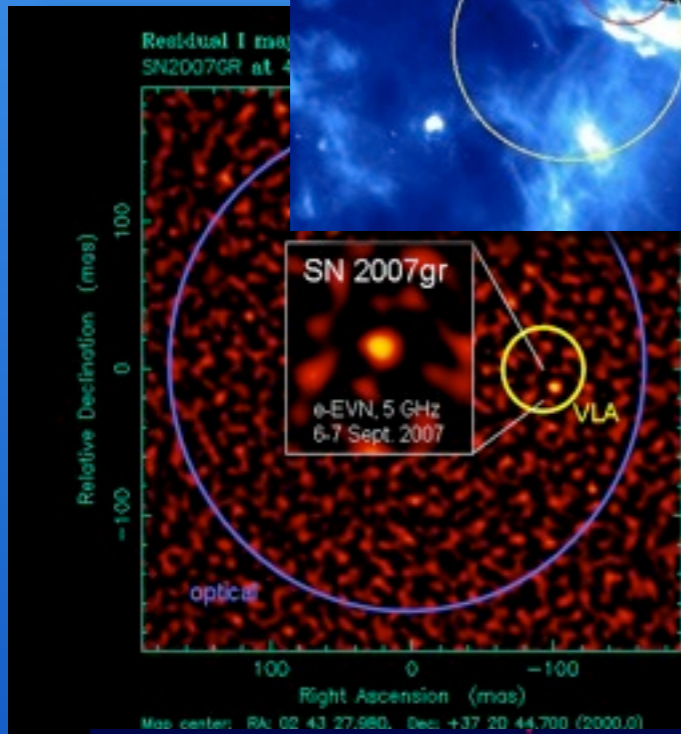
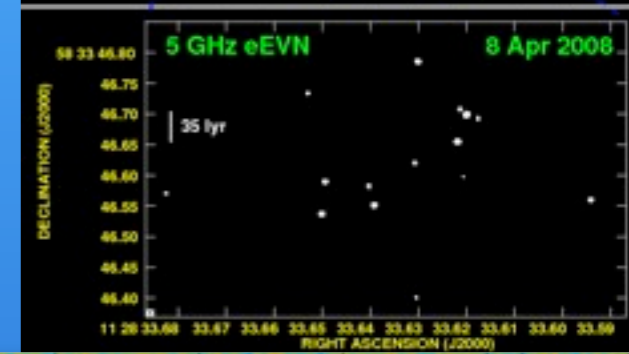
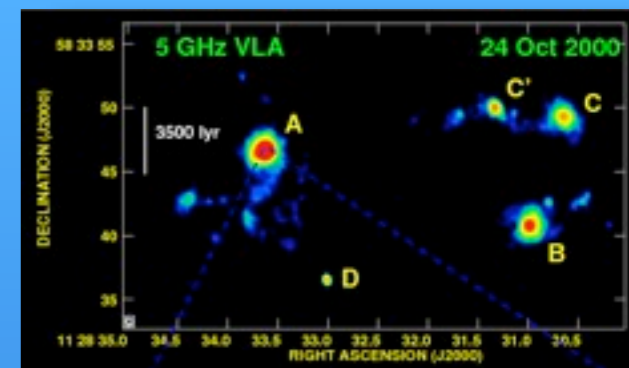
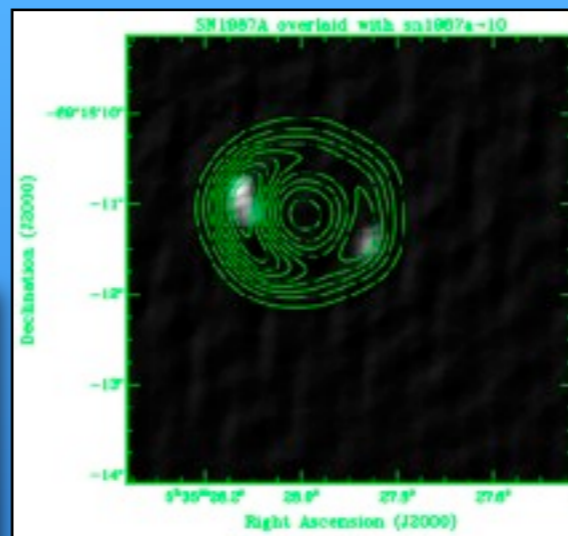
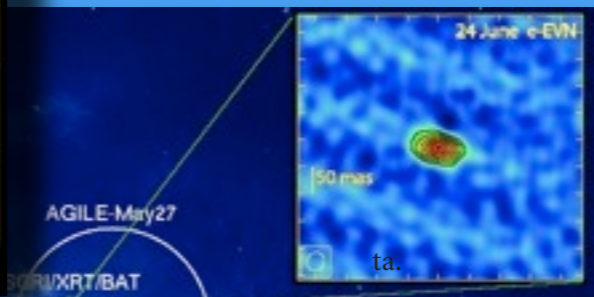
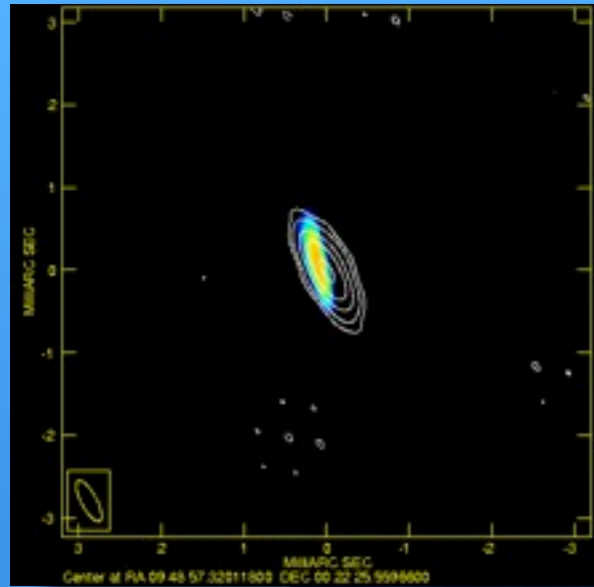
- Lightpath technology
- will be economic and green
- Link to SKA

- **Test case for technology**

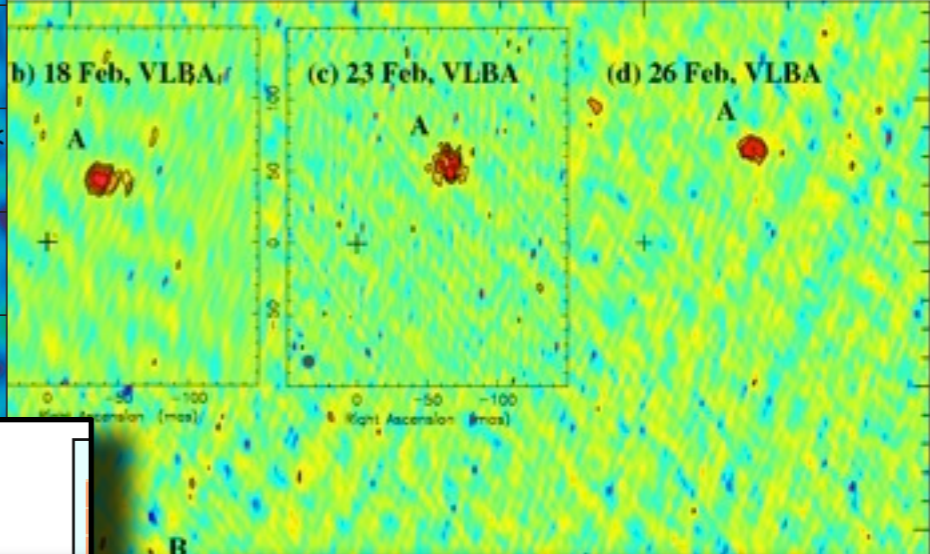
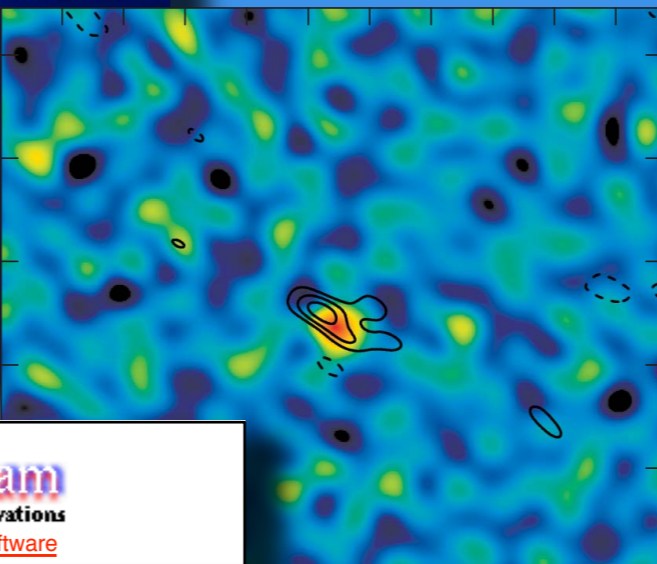
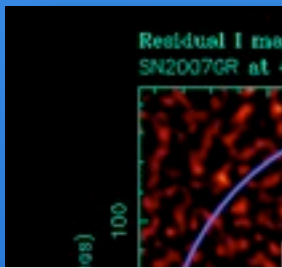
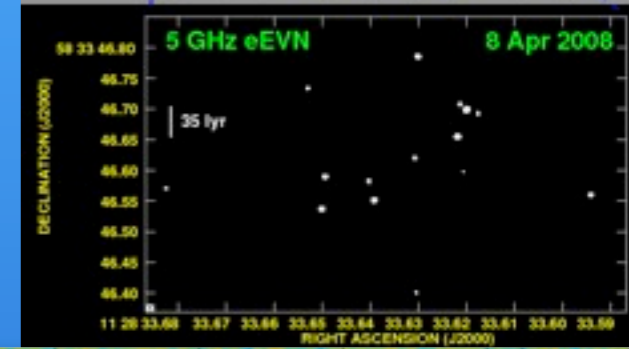
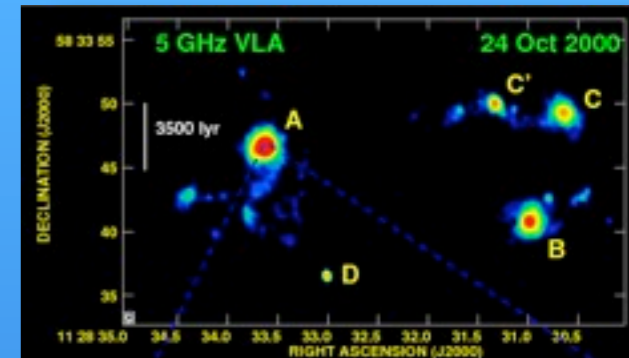
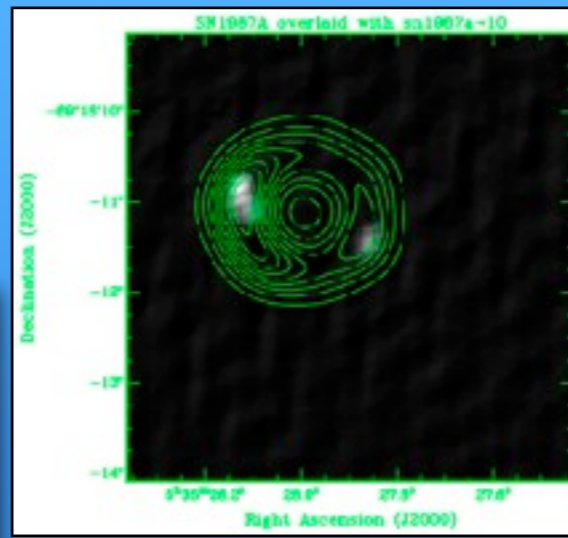
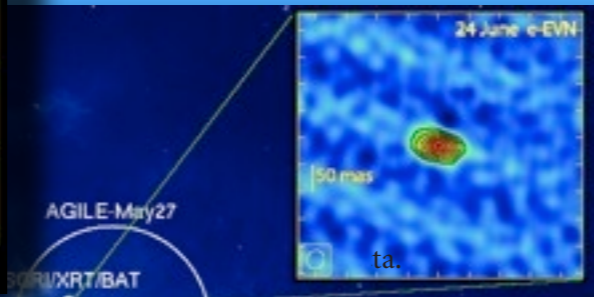
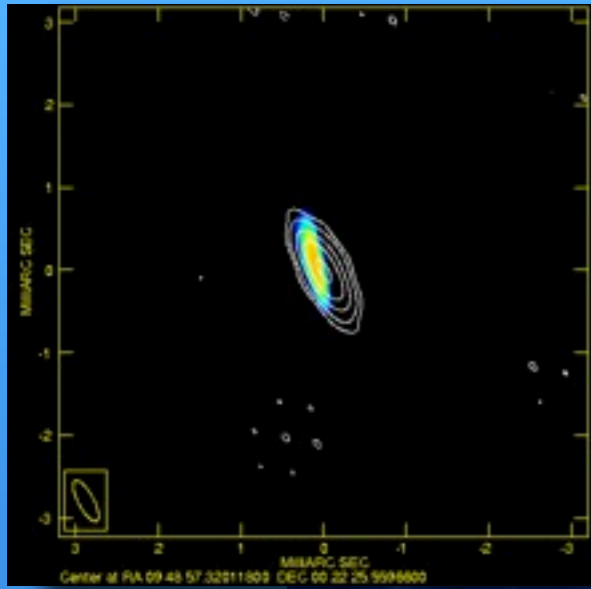
- **And policy issues**

- direct border crossings









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2 000 ly

**EVN observations of the**

ATel #2437; [M. Giroletti \(INAF/IRA\)](#), [E. CoRoian \(Washington Univ.\)](#), [A. Cesarini \(INAF/IRA\)](#)  
on 13 Feb 2010; 21:43 UT  
Password Certification: Catherine Brocksopp

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

ATel #2438; [Catherine Brocksopp \(MSSL\)](#), [Jun Yang \(Universite Paris Diderot\)](#), [Tasso Tzioumis \(ATNF\)](#), [Rolf S. J. van der Veen \(MNRAS\)](#)  
on 13 Feb 2010; 21:43 UT  
Password Certification: Catherine Brocksopp

Subjects: Radio, Binaries, Black Holes, Transients

Following the reported increased radio emission of XTE J1102-4542 (ATel. 2387, 2391, 2396), we have made observations with the European VLBI Network (EVN) in real-time e-VLBI mode.

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**VLBI detection of V407 Cyg**

ATel #2536; [Giroletti \(INAF/IRA\)](#), [E. Koerding \(Univ. Paris Diderot & CEA Saclay\)](#), [K. Sokolovsky \(MPIFR/ASC Lebedev\)](#), [L. Fuhrmann \(MPIFR\)](#), [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)

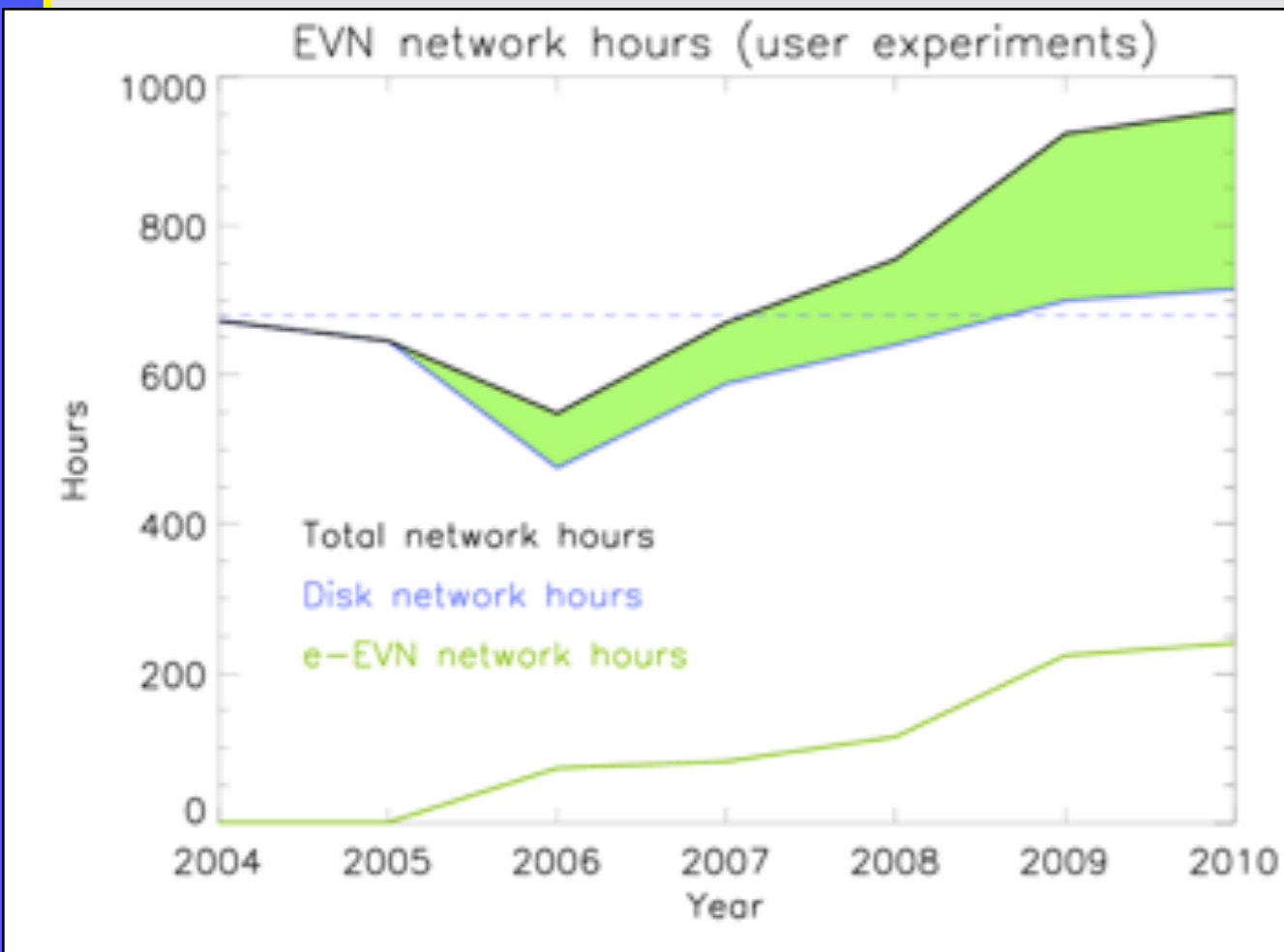
Subjects: Radio, Gamma Ray, Novae, Transients, Variables, Stars  
Referred to by ATel #: [2546](#)

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.

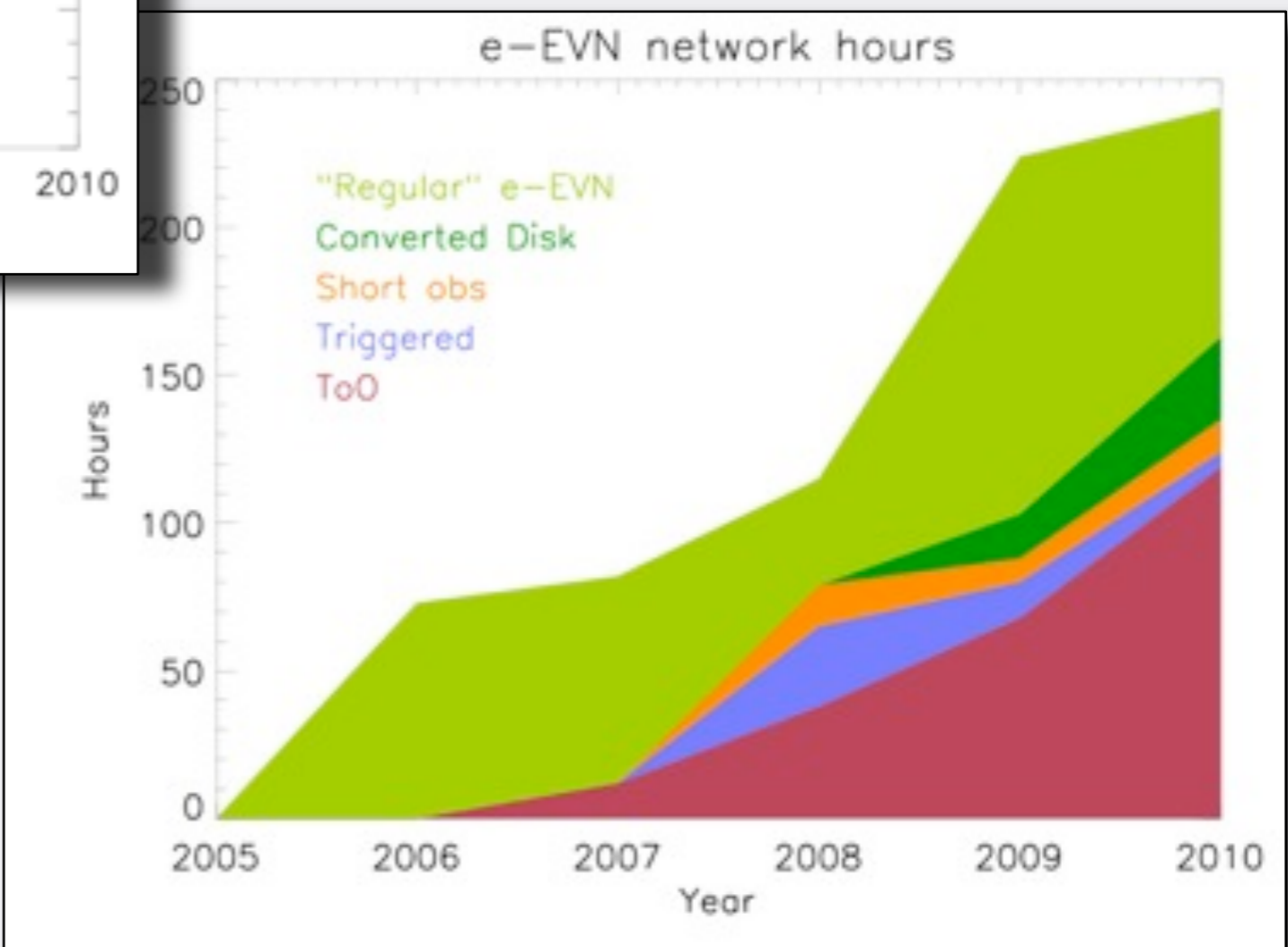
- Related**
- 2546 [Discovery of coronal emission lines in V407 Cyg](#)
  - 2536 [VLBI detection of V407 Cyg](#)
  - 2529 [V407 Cyg: Allen Telescope Array Observations](#)
  - 2514 [15-GHz flux density of V407 Cyg](#)
  - 2511 [Radio detection of V407 Cyg at 30GHz with OCRA-p on the Torun telescope](#)
  - 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 [INTEGRAL 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](#)



# 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



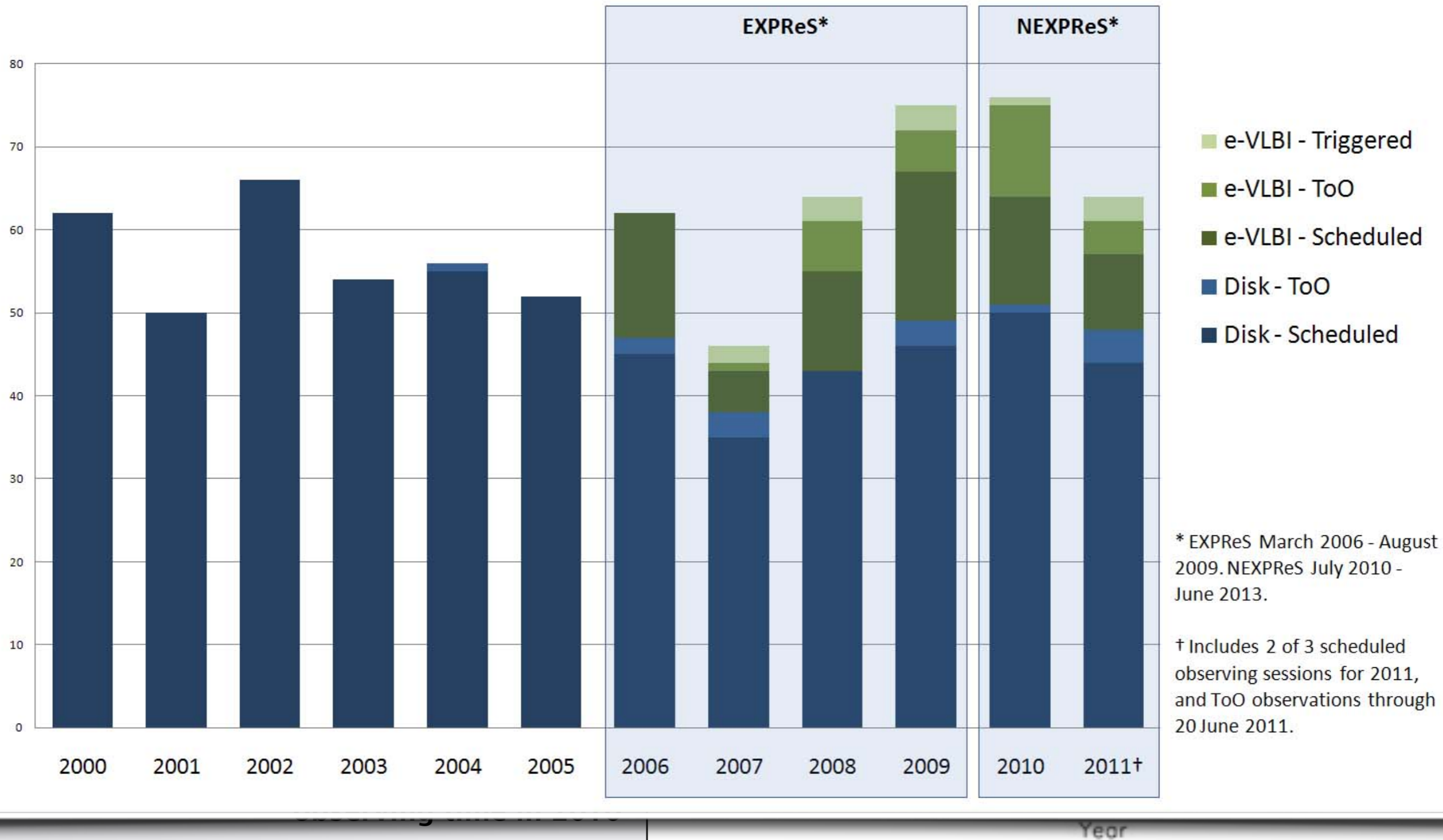
ToOs: half (49.5%) of the total e-EVN observing time in 2010

# e-EVN operations plots

• Disk-based network hours roughly constant

EVN network hours (user experiments)

EVN Observation Proposals



EXPRoS was concluded in Mar 2010



# NEXPRoS

*Novel EXplorations Pushing  
Robust e-VLBI Services*

Successful NEXPRoS proposal kicked off in July 2010



- Aims for
- Allow multiple correlator passes
- Buffer for more reliable operations
  - addressed by simultaneous recording
- Be more sensible about resource allocation
  - Bandwidth on demand, limit physical shipping
- Reach for higher bandwidths (10 - 40 Gbps)
- But also:
  - Continue to connect more telescopes
  - NEXPRoS maintains expertise
    - Collaborations with NRENs
  - 'owns' the e-VLBI operations and outreach
  - Also some LOFAR transport and storage issues
  - And link to SKA development

# New project: NEXPRoS

- Aims for

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

- Allow multiple correlator passes
- Buffer for more reliable operations
  - addressed by simultaneous recording
- Be more sensible about resource allocation
  - Bandwidth on demand, limit physical shipping
- Reach for higher bandwidths (10 - 40 Gbps)
- But also:
  - Continue to connect more telescopes
  - NEXPRoS maintains expertise
    - Collaborations with NRENs
  - 'owns' the e-VLBI operations and outreach
  - Also some LOFAR transport and storage issues
  - And link to SKA development

# NEXPRoS project info

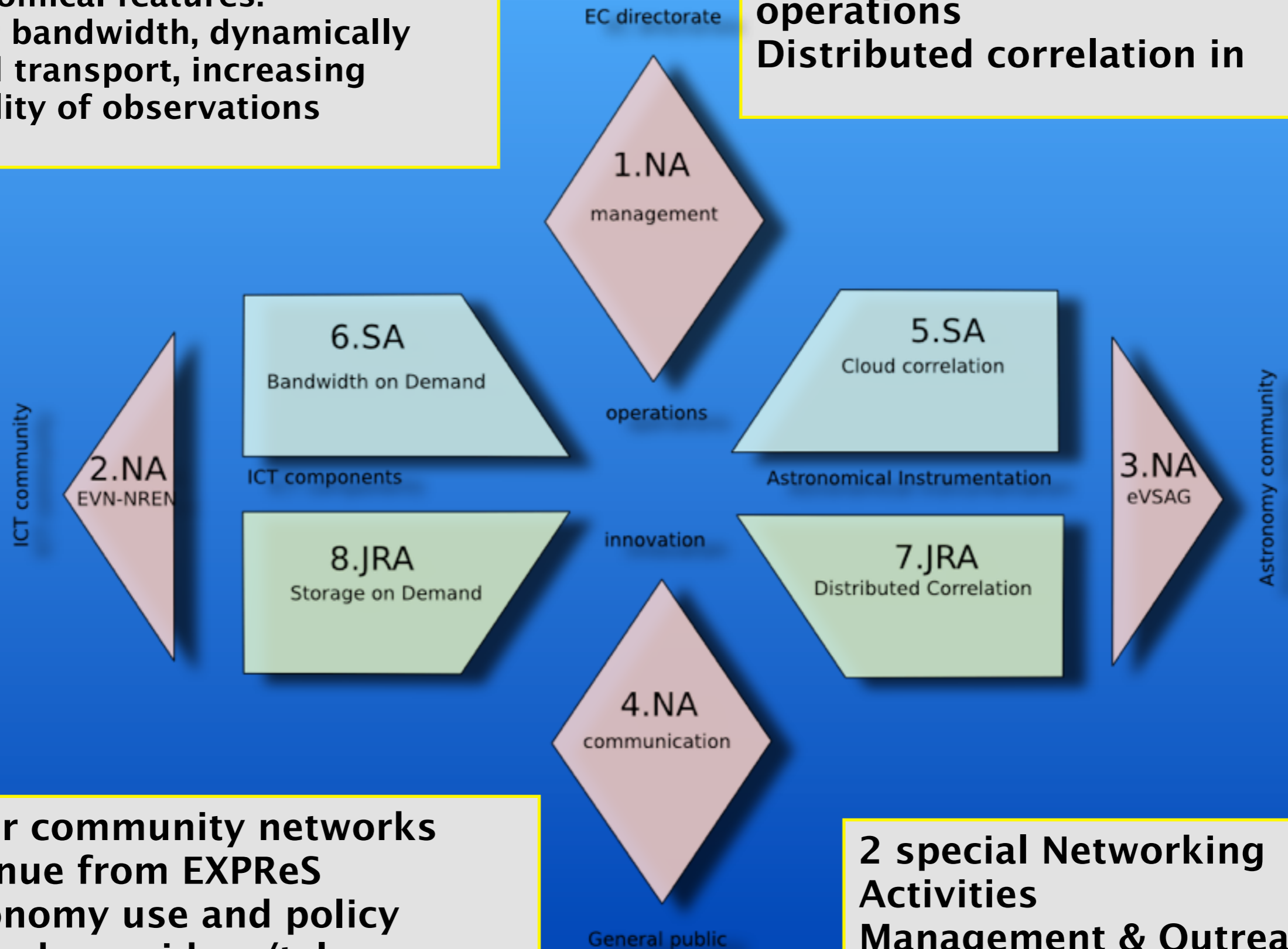
- **15 partners (cf. 19 in EXPRoS)**
  - Of which 3 choose not receive funds from EC
  - Good mix from astronomy-networking-HPC communities
  - High level of partner-contributed effort
- **Kicked off in 2010 with EVN symposium**
  - Had to fit project within 3.5 M€ envelope



- **Passed Year 1 review with good marks**
  - Some issues on spending profile
  - Metrics of success hard to define
  - And consortium agreement
- **NEXPRoS Consortium Agreement now done**
  - Money flowing any day now...

**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



**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

- Overhaul of local network
- Flexibly connecting playback,
- Fibres & correlators

## • Control code

- Allowing mixed rate operations
- Making various playback units flexibly usable
- Uniting correlator interfaces

## • Transparent buffering

- Working on JIVE Mk5 control code
- For use in the field
- And at the correlator

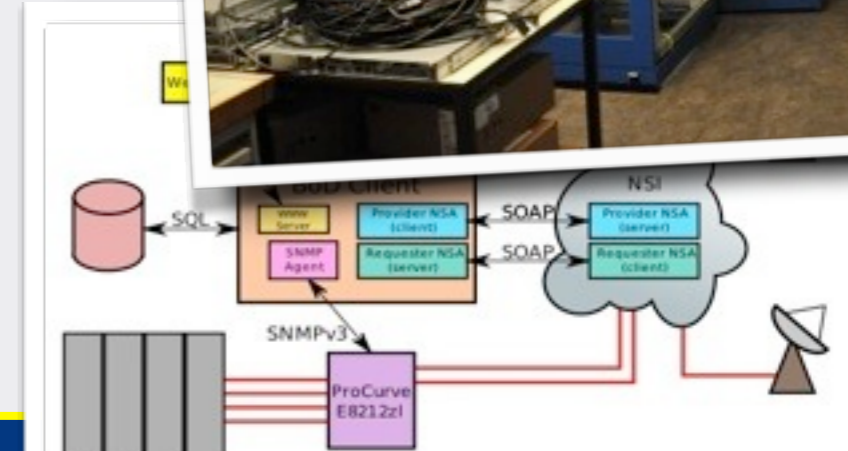
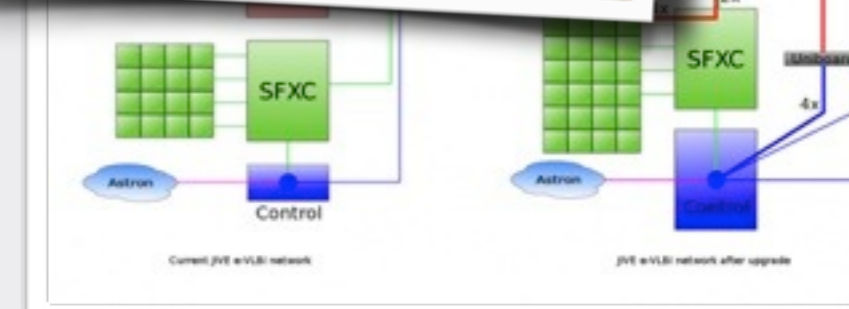
talk by Szomoru

## • Work on Bandwidth on Demand

- Enabling 4 Gbps
- And connectivity infrastructure

talk by Boven

talk by Huisman



# Joint Research Activities

- **Distributed correlation**

- Continued look at distributed correlation
- But moving away from Grid
- Looking at resources in own domain

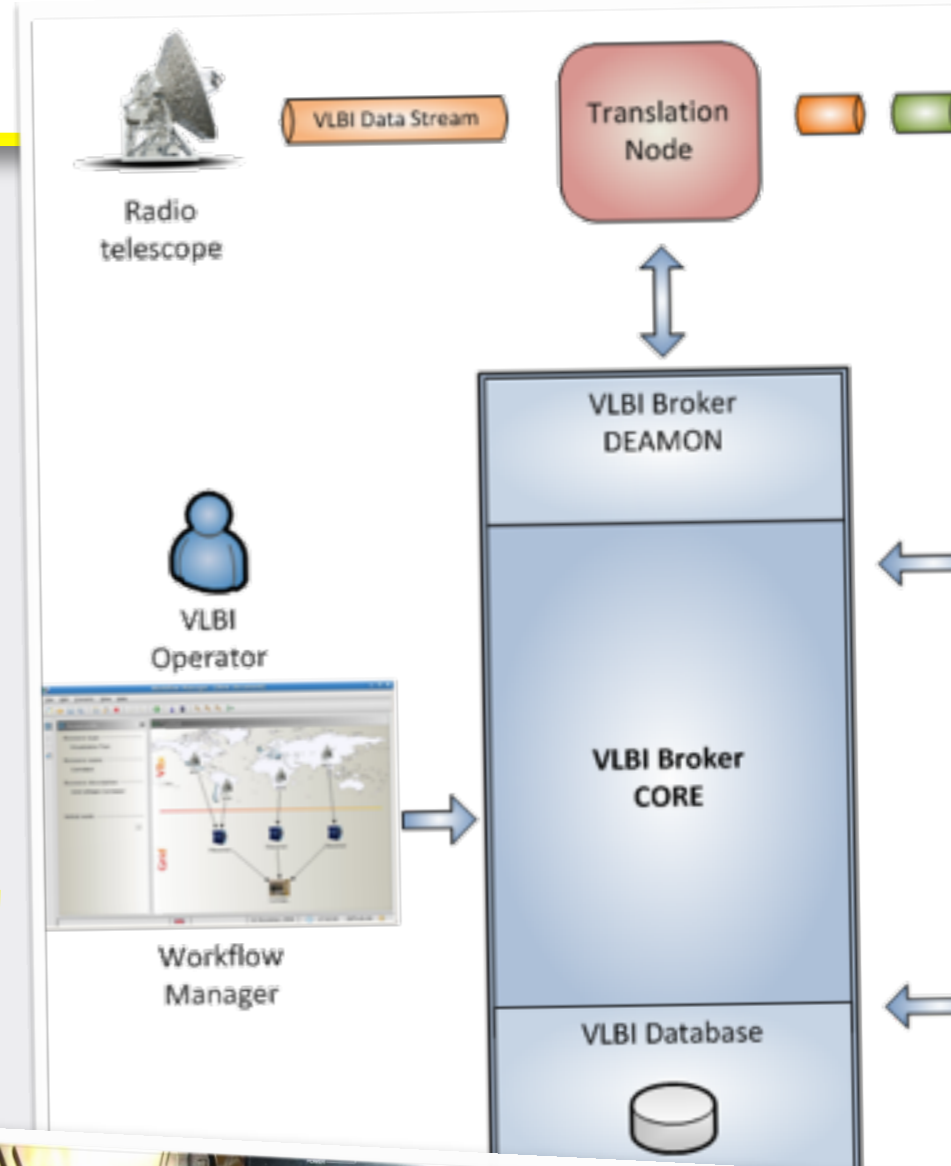
talk by Kettenis

talk by Jekabsons

- **High bandwidth storage**

- Feeding into the caching demands
- But also at massive (distributed) archives

talk by Mantovani



# Network activities

## • Management

- Doing all the nasty stuff
- Including dealings with EC
  - On finances for example

Charles Yun



## • EVN-NREN

- Interactions with Networking experts
- Had first meeting in Aveiro, PI

Richard Hughes-Jones



## • EVSAG

- e-VLBI Science Advisory Group
- On policies and operational issues
  - Overlaps with EVN-PC
- Meeting in Madrid last week

Paco Colomer



## • Outreach & Dissemination

- Maintains internal information
- And external outreach material
  - Display booth
  - e-VLBI/JIVE film

Kristine Yun



- **Still some real-time issues under consideration**

- More dedicated e-VLBI sessions required
  - For normal proposals, triggered proposals
- More readiness for ToO opportunities
  - Not necessarily e-VLBI
- In NEXPRoS more, new options may occur:
  - Same real-time/transient opportunities
    - But including those that require multiple correlations
    - And reaching 4Gbps data rates

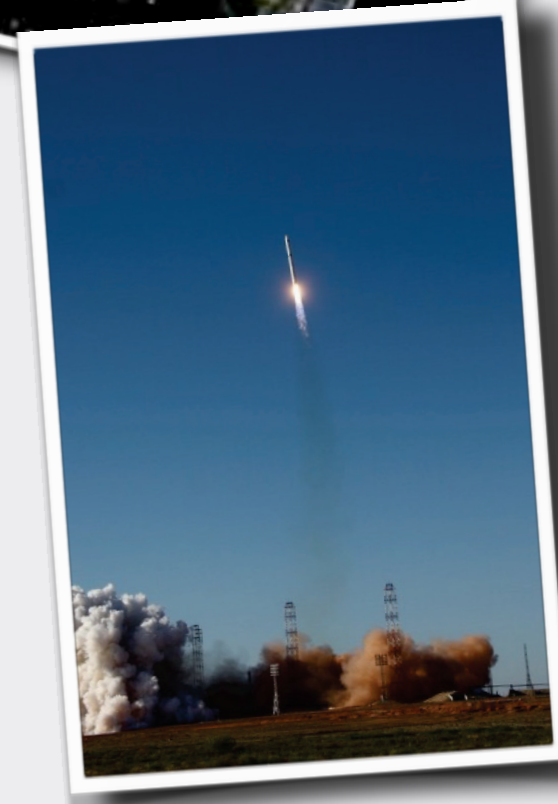


- **And in the future:**

- Distinction between real-time and disk recording will vanish
  - Must define when science objectives are met
    - Release data and re-correlate decisions
- Consumables bottleneck/logistics disappear
  - Can have continuous array, small telescopes, distributed correlation
- Flexibility of array improves
  - Can adapt schedules to observing conditions
  - Or react to automated, external triggers!

# New opportunities

- **In addition, new requests from (new) user communities**
  - Could impact on policy discussions
    - RadioAstron, space applications
    - Monitor programmes/astrometry/joint observations
    - Triggers set by other observatories (link with LOFAR)
- **Worried about exploding the procedures?**
  - Already complex for telescope & correlator operators
  - Also complex for users!
  - Data ownership for triggers, concurrent observations
- **Can we address this by (yet) new services?**
  - Offer smaller sub-arrays?
  - More e-VLBI days, leading to “VLBI every Friday”
    - And some telescopes on Thursday as well?
  - Central scheduling?



# VLBI for Space applications...

JUICE-Laplace ?

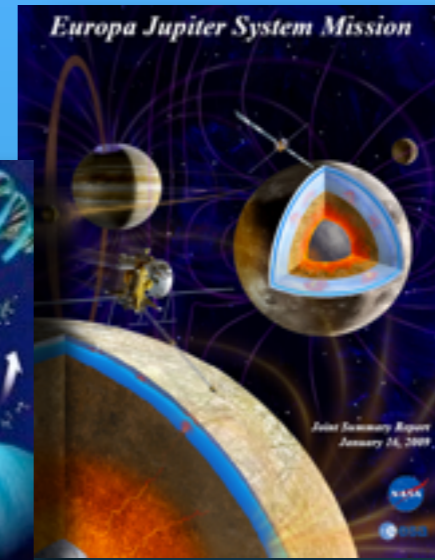
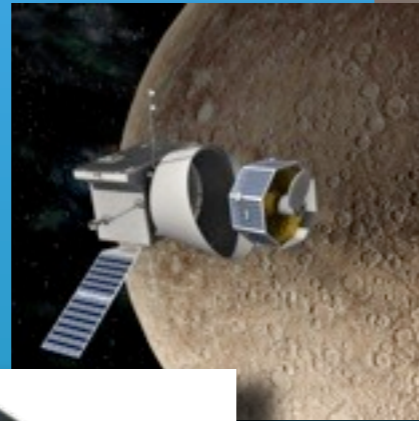
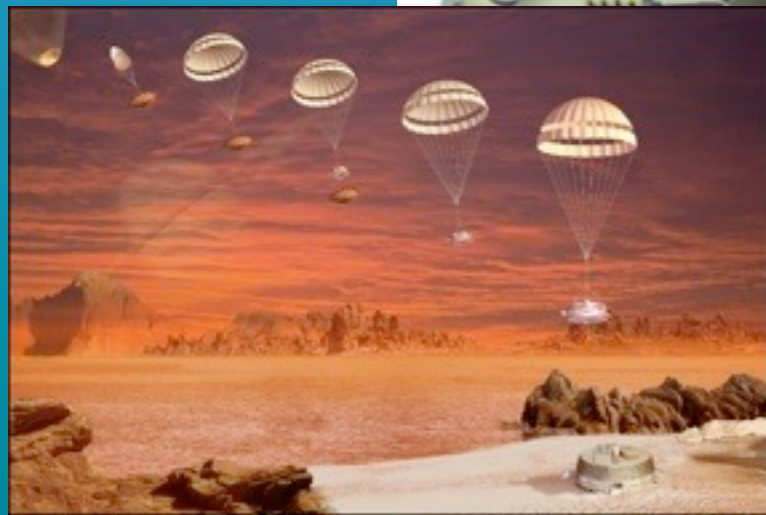
MarcoPolo-R?

ExoMars

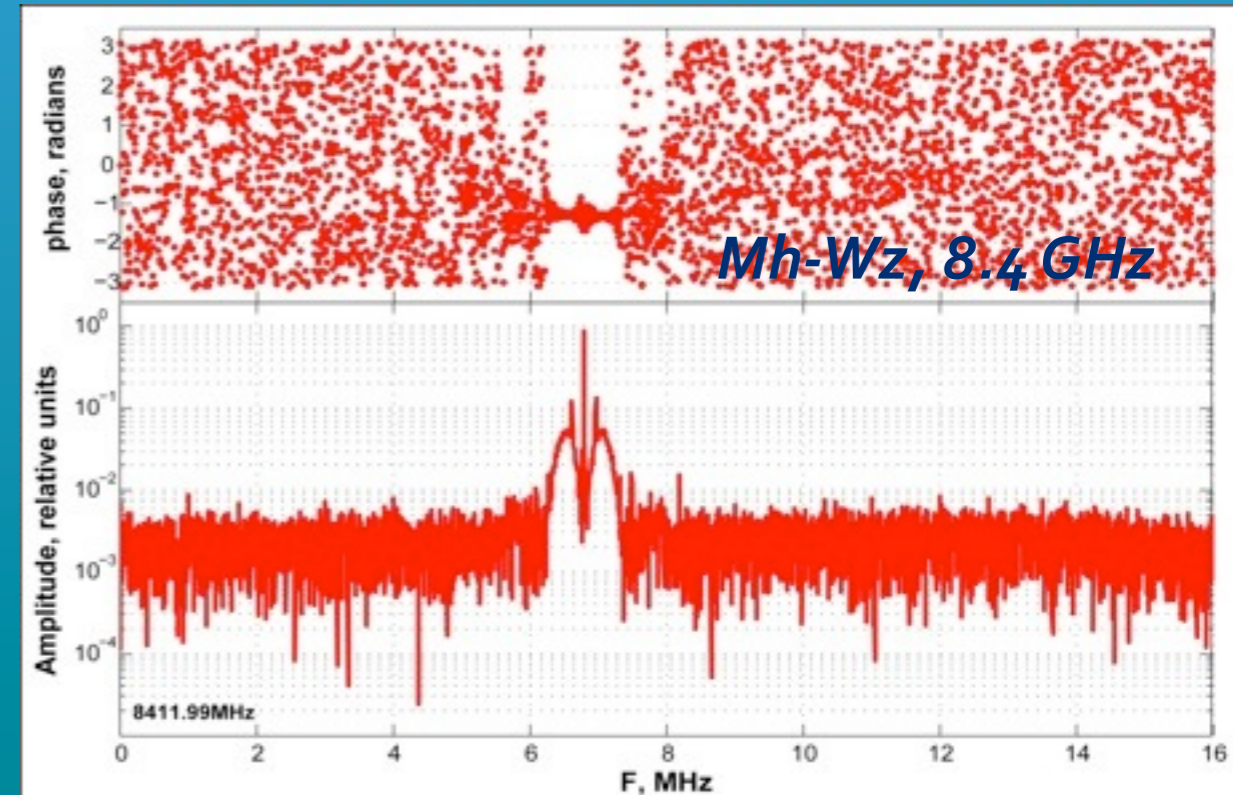
BepiColombo

Phobos-Soil

Huygens



VEX SFXC near-field fringes Duev, Keipema et al. 2011



PRIDE: Planetary Radio Interferometry & Doppler Experiment

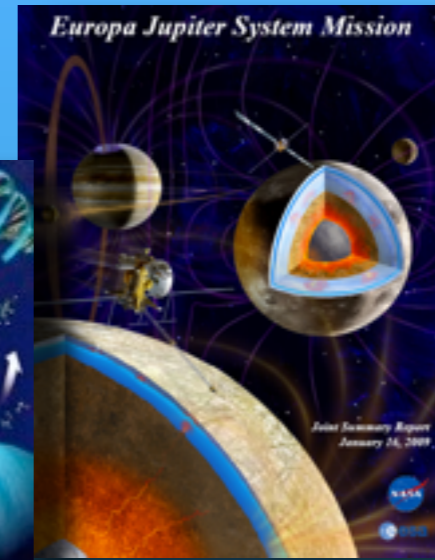
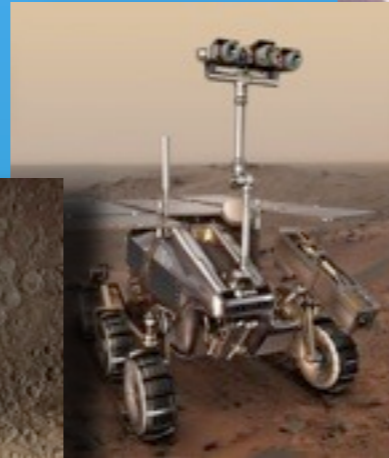
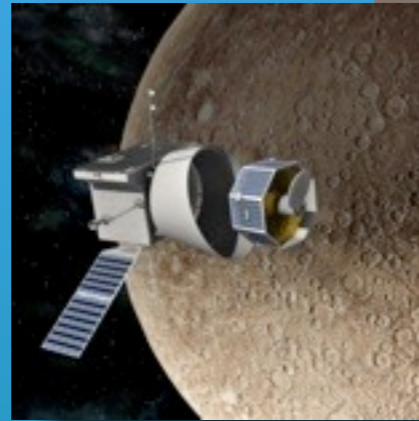
# VLBI for Space applications...

JUICE-Laplace ?

MarcoPolo-R?

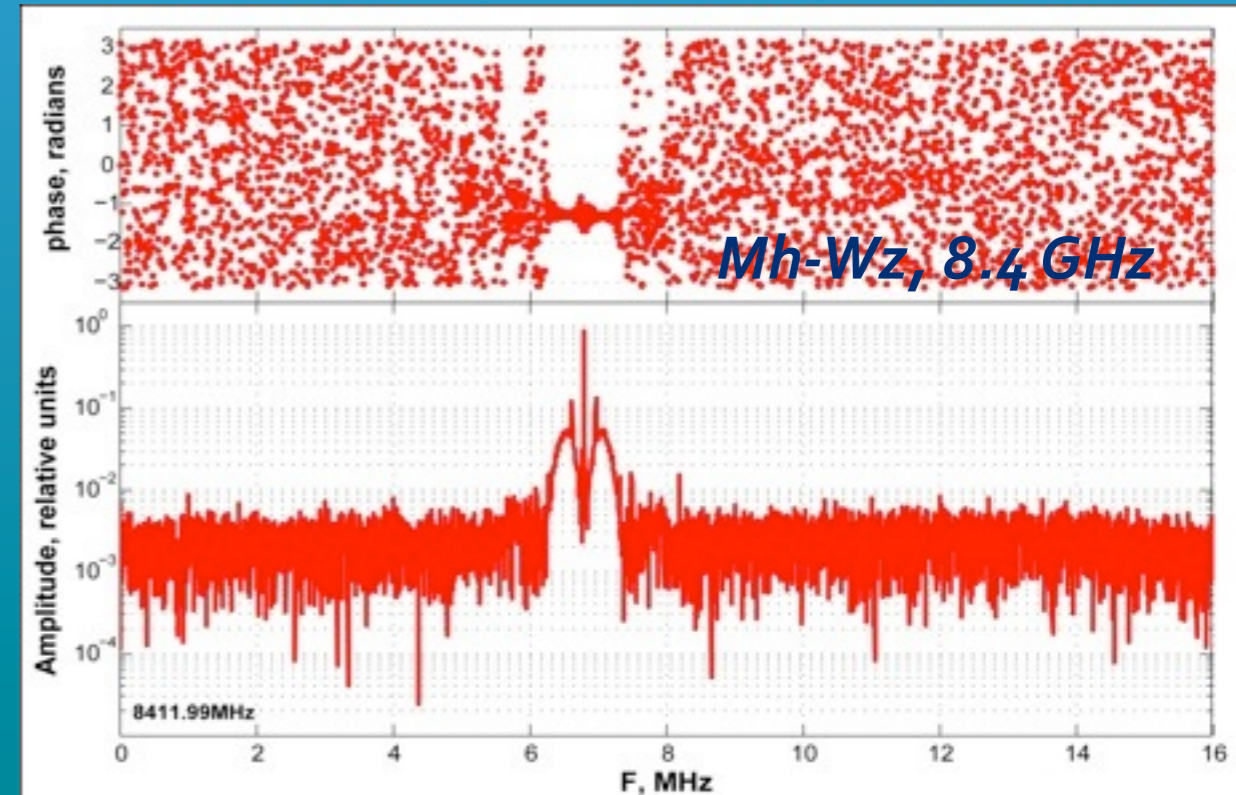
ExoMars

BepiColombo



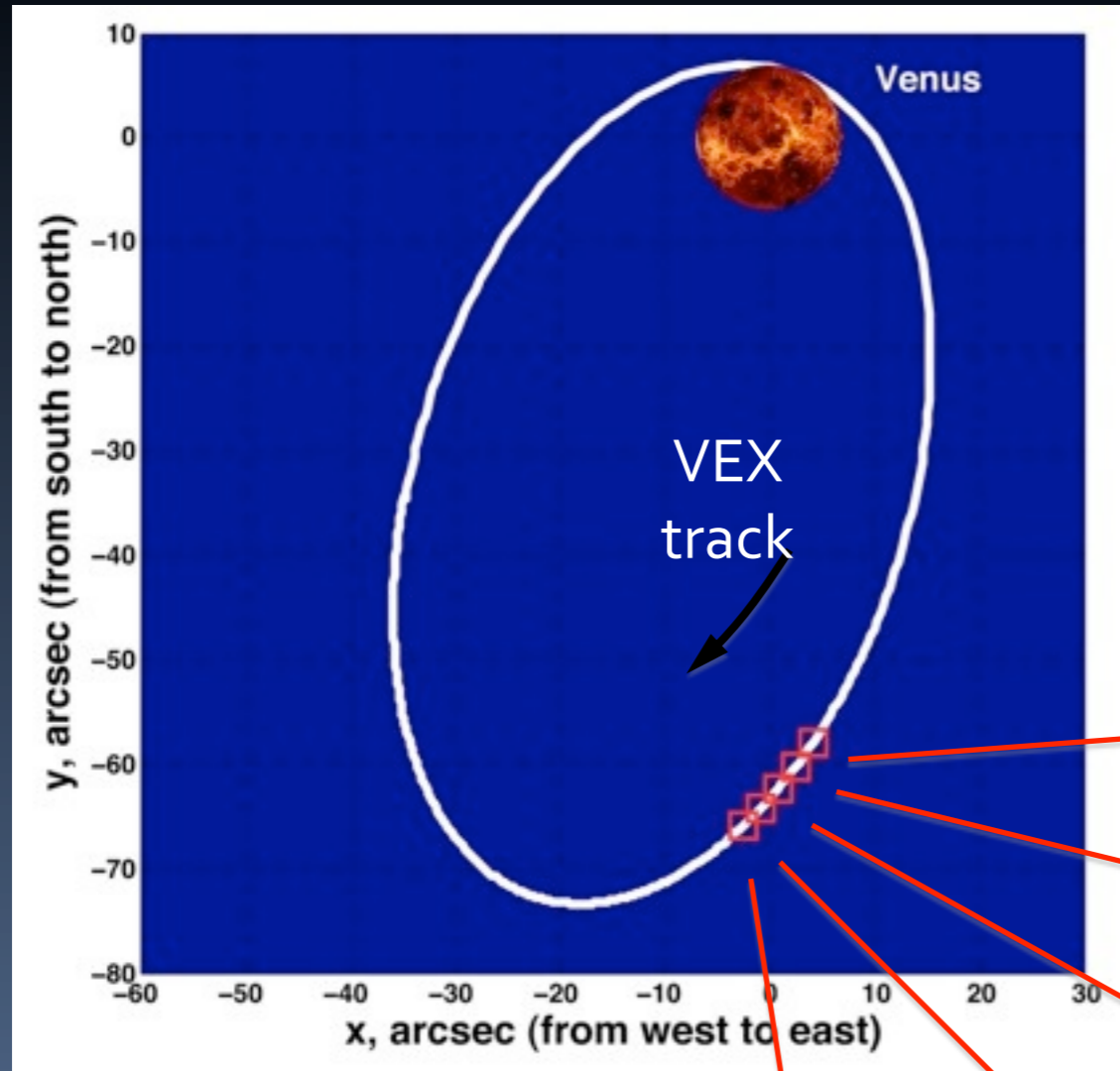
VEX SFXC near-field fringes Duev, Keipema et al. 2011

Huygens

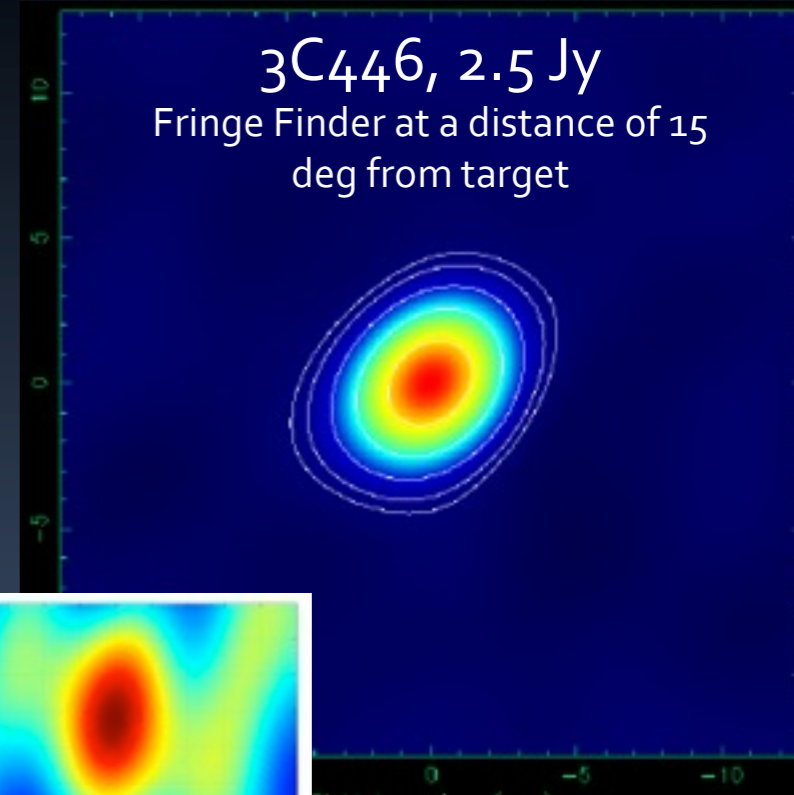


PRIDE: Planetary Radio Interferometry & Doppler Experiment

# EM081c: On, Wz, Mc, Ma, Ys, Mh, Sv, Zc



8.4 GHz  
2011.03.28



09<sup>h</sup>05<sup>m</sup> TDB  
OnWzMaMcMhSvZc  
+Ys

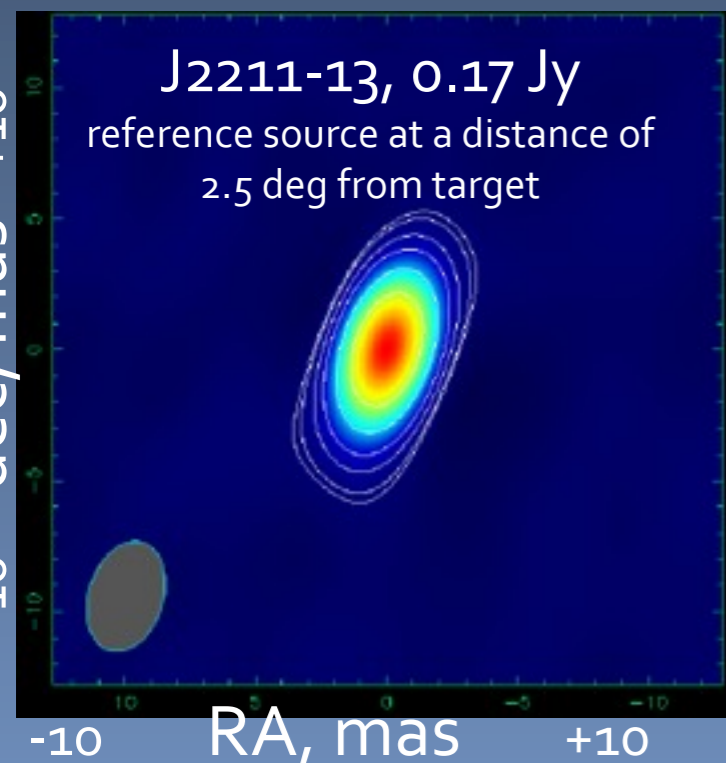
09<sup>h</sup>30<sup>m</sup> TDB  
OnWzMaMcYsMhSvZc

09<sup>h</sup>55<sup>m</sup> TDB  
OnWzMaMcYsMhZc

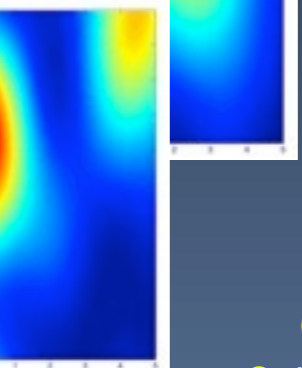
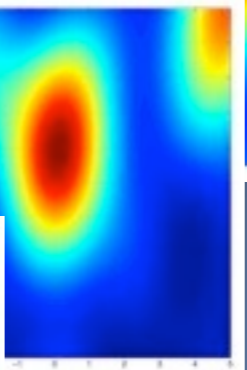
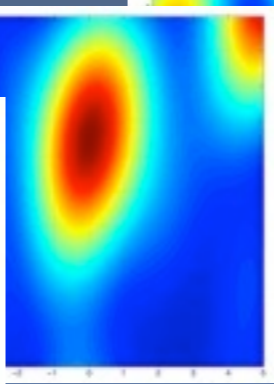
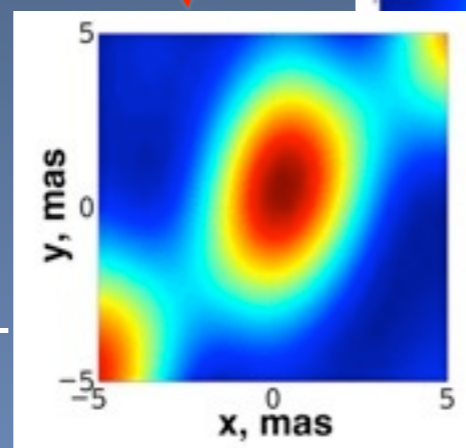
10<sup>h</sup>20<sup>m</sup> TDB  
OnWzMaMcYsZc

10<sup>h</sup>45<sup>m</sup> TDB  
OnWzMaMcYs

*Cimo, Duev, Molera et al.  
2011, in preparation*



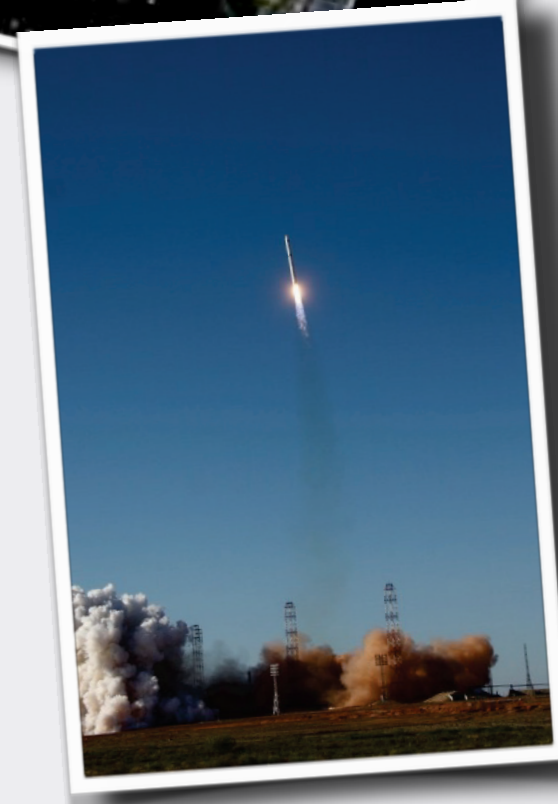
-5 dec, mas 5





# New opportunities

- **In addition, new requests from (new) user communities**
  - Could impact on policy discussions
    - RadioAstron, space applications
    - Monitor programmes/astrometry/joint observations
    - Triggers set by other observatories (link with LOFAR)
- **Worried about exploding the procedures?**
  - Already complex for telescope & correlator operators
  - Also complex for users!
  - Data ownership for triggers, concurrent observations
- **Can we address this by (yet) new services?**
  - Offer smaller sub-arrays?
  - More e-VLBI days, leading to “VLBI every Friday”
    - And some telescopes on Thursday as well?
  - Central scheduling?



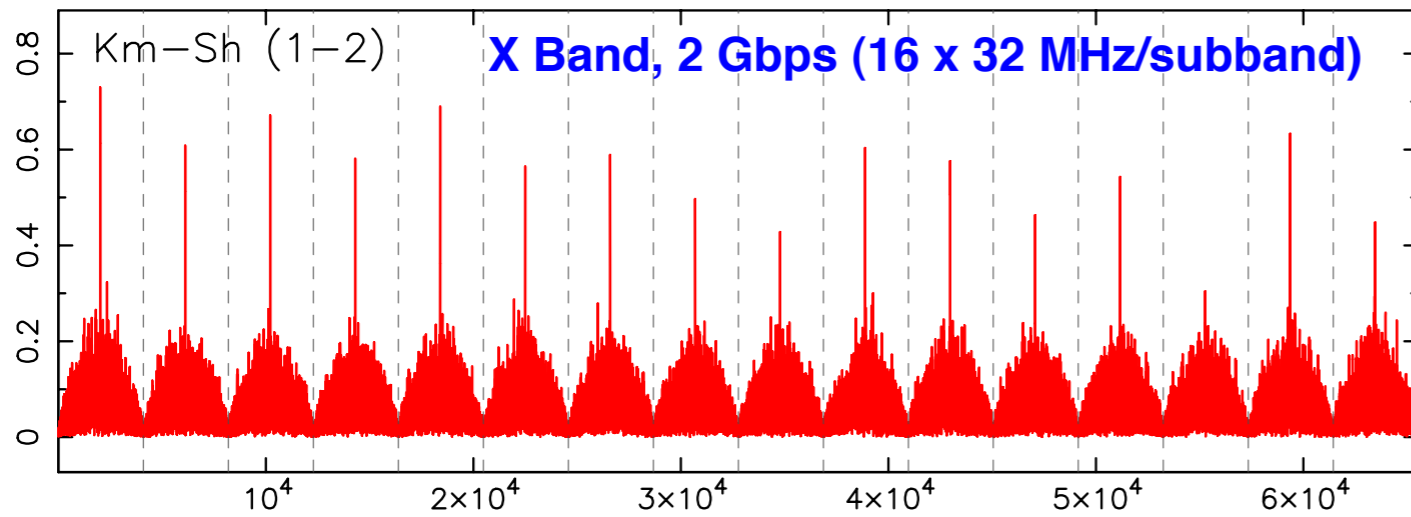
# Next? More VLBI!

- **Increasing data rate will not stop any time soon:**
  - New stations: Africa, Goonhilly, Madeira, Brasil....
  - Joint observations with e-MERLIN
  - Joint observations with ALMA
- **Need for better sensitivity, more digital bandwidth**
  - with more bit sampling against interference
- **And increasing number of space applications**
- **Science synergy with new survey instruments**
- **For aperture arrays much more data**
  - eg APERTIF@WSRT 25 interferometers simultaneous

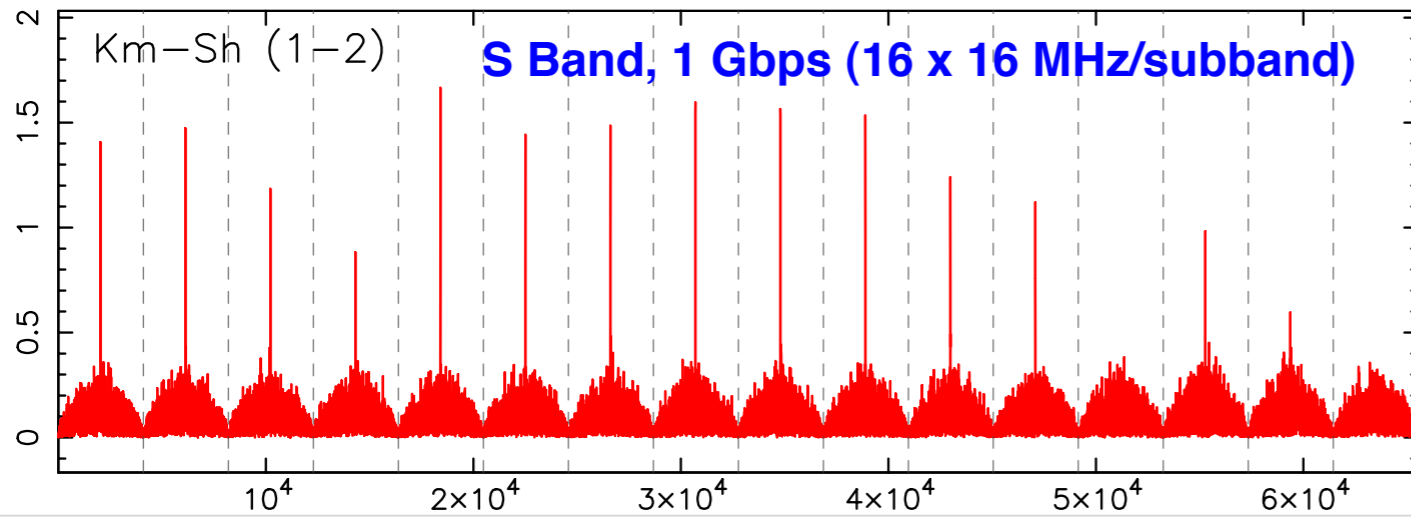


Focal plane array

# Amplitude for chin06a.ms

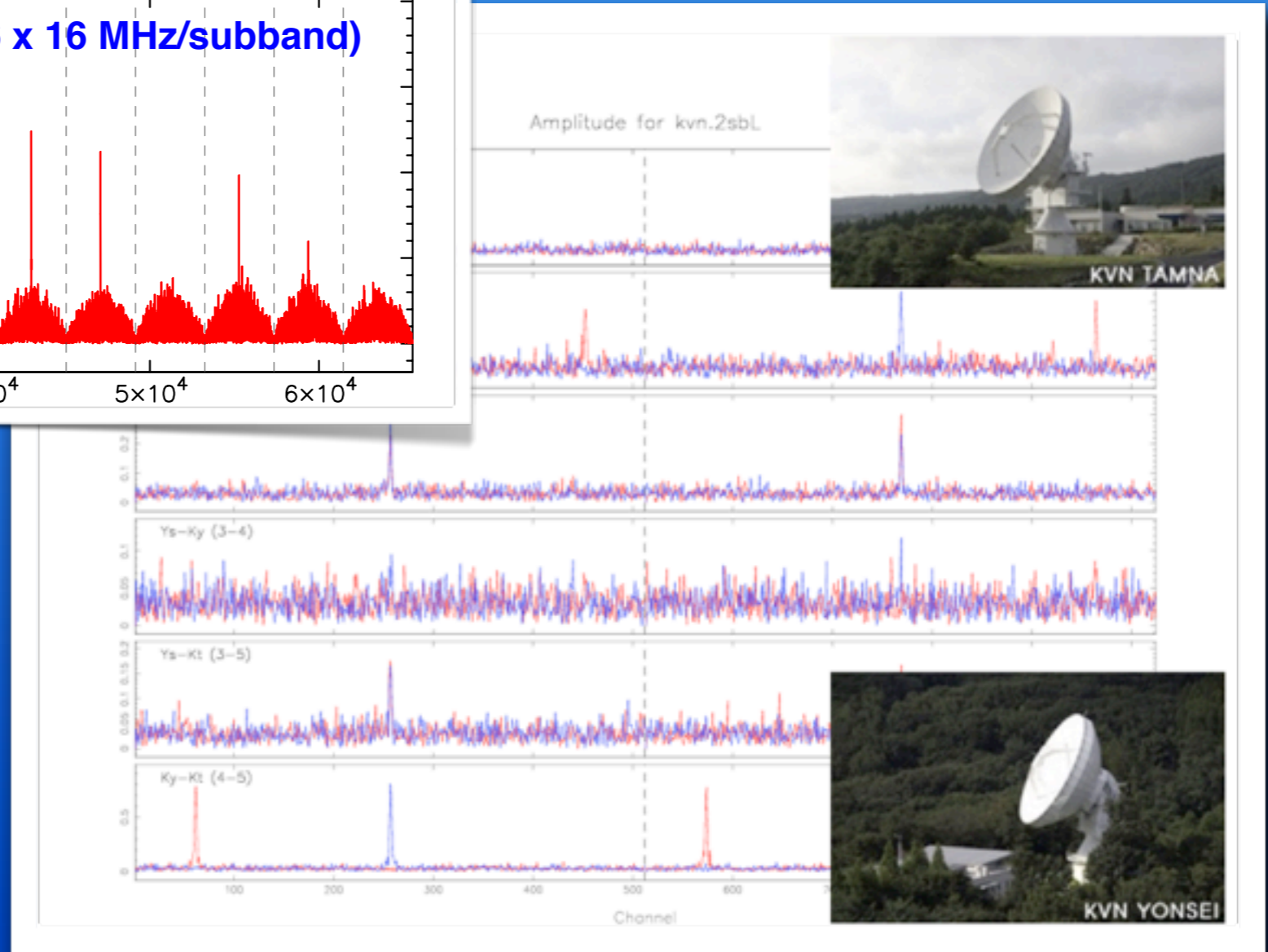


# Amplitude for chin06b.ms



**First 3Gbps fringes with Chinese tels. Combining CDAS and Mk5**

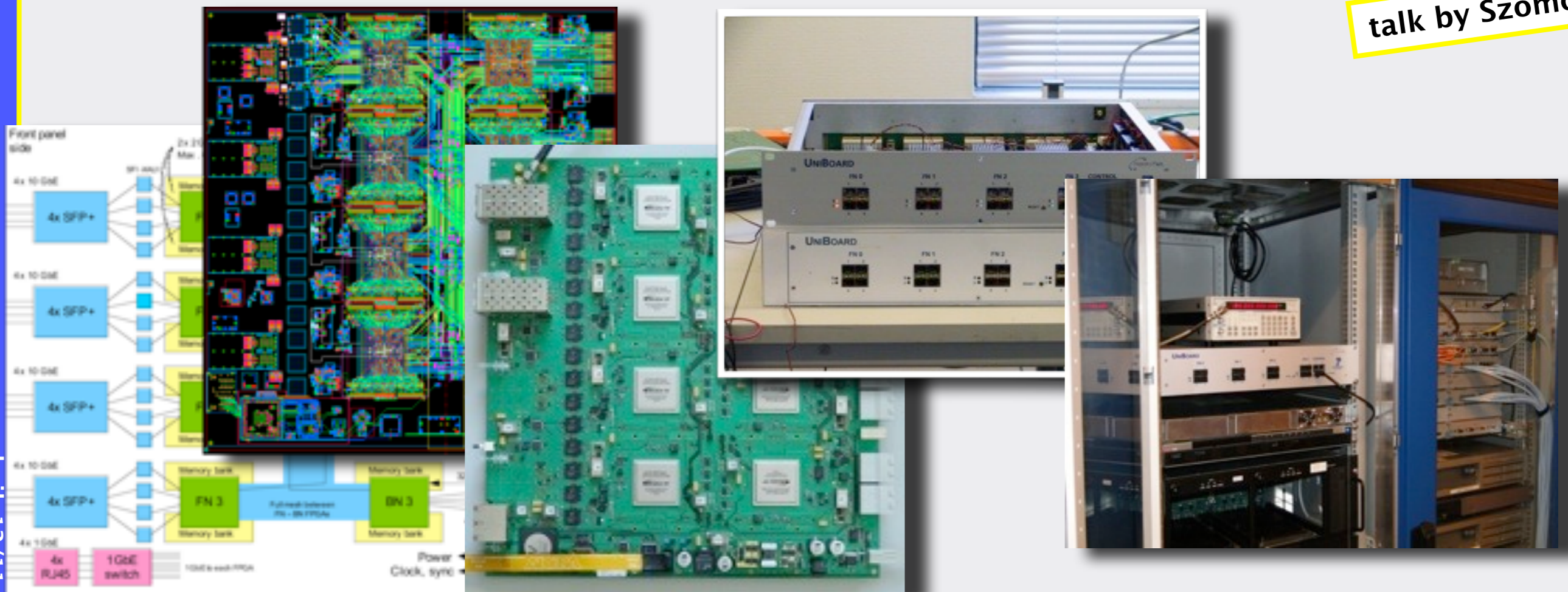
**First correlation of European - Korean baselines at K-band**



# Needed: next generation correlator

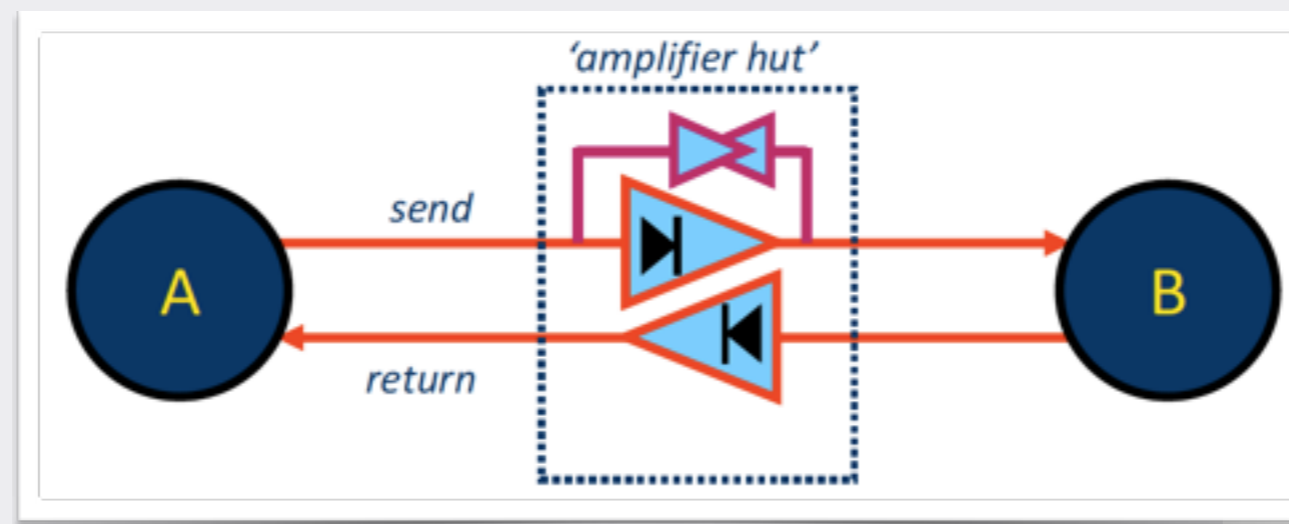
- Aiming for 32 station 10+ Gbps FPGA correlator
  - Flexibility of software correlator
  - Power consumption should be much better
- Currently funded for EVN correlator prototype (2012)
  - Also WSRT Apertif and LOFAR beam-forming
  - And feeding into the SKA programme
  - Continued development in RadioNet3 for new chip technology

talk by Szomoru



# Future 2: clock distribution

- VLBI depends on availability of extremely accurate clock and frequency standard ( $10^{-15}$ )
  - All telescopes must have 100k€ maser clock
    - In principle can be distributed over dedicated fibre
- Investigate clock distribution on public network
  - Requires dedicated wavelength and stable amplification
  - To measure return loop



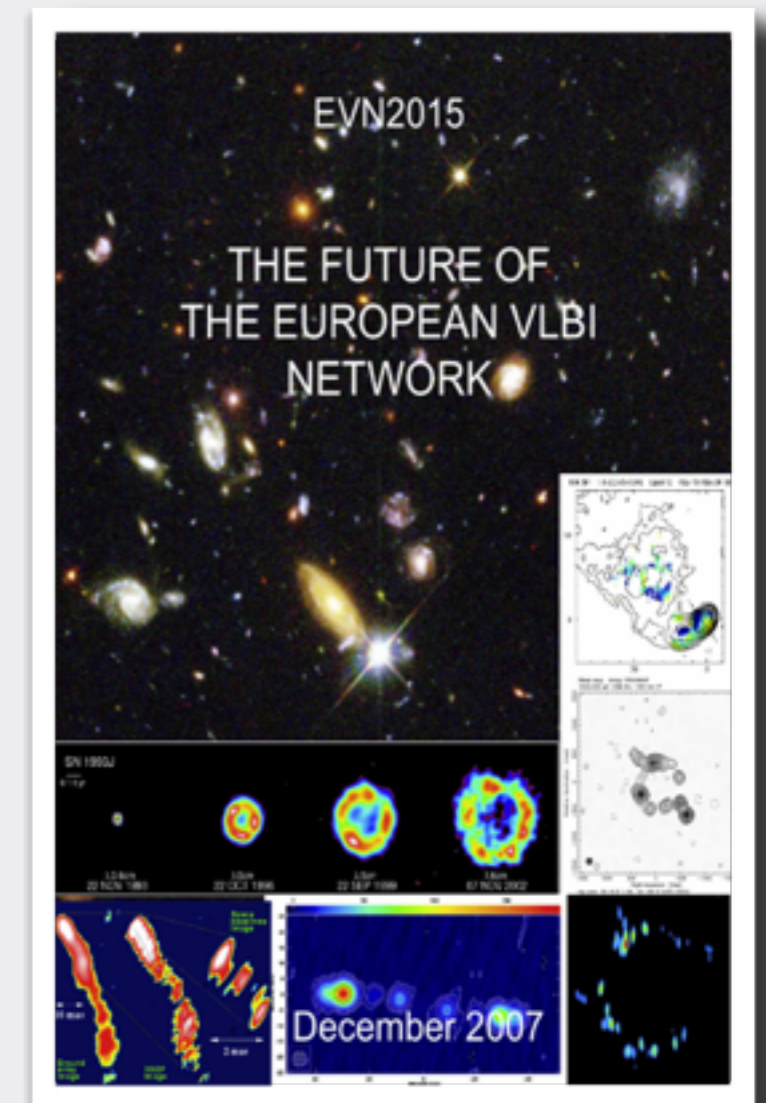
- Will improve stability, operations
- And many more VLBI sites!

quote by Brisken

- **While VLBI is ever greater....**
  - ... some of us are encountering some issues
  - Maybe these issues are getting larger during the SKA process
    - Certainly with the current economic developments
- **In Europe we do not run VLBI on national levels**
  - Besides the baseline length...
  - The critical mass user community is not on national level
- **Some of this discussed in context VLBA future**



- **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
  - Determining star burst activity, resolving SNR's
  - The accretion physics in transient radio sources
  - The detailed 3D kinematics of star formation
  - The role of magnetic fields in stellar life cycle
  - The nature of the ISM in active galaxies
  - Fundamental distances from astrometry
  - Pulsar astrometry
  - Monitoring spacecraft in the solar system



- **Unique science: long baselines and high frequencies**
  - Keep up with EVLA/MERLIN sensitivity
    - Going for 4Gbps in 2011
  - Follow up LOFAR, MeerKAT, ASKAP
- **Even in the SKA era**
  - At least for phase I
  - Most certainly phase II
    - And this molecular astrophysicist is very worried about phase III
  - Spacecraft applications (and geodesy) need Northern Hemisphere coverage
- **Global baselines for better images**
  - And better time coverage
  - Data quality and image fidelity for SKA users
- **Only single (or two) user communities for all of us**
  - Critical mass reached on continental scale or larger





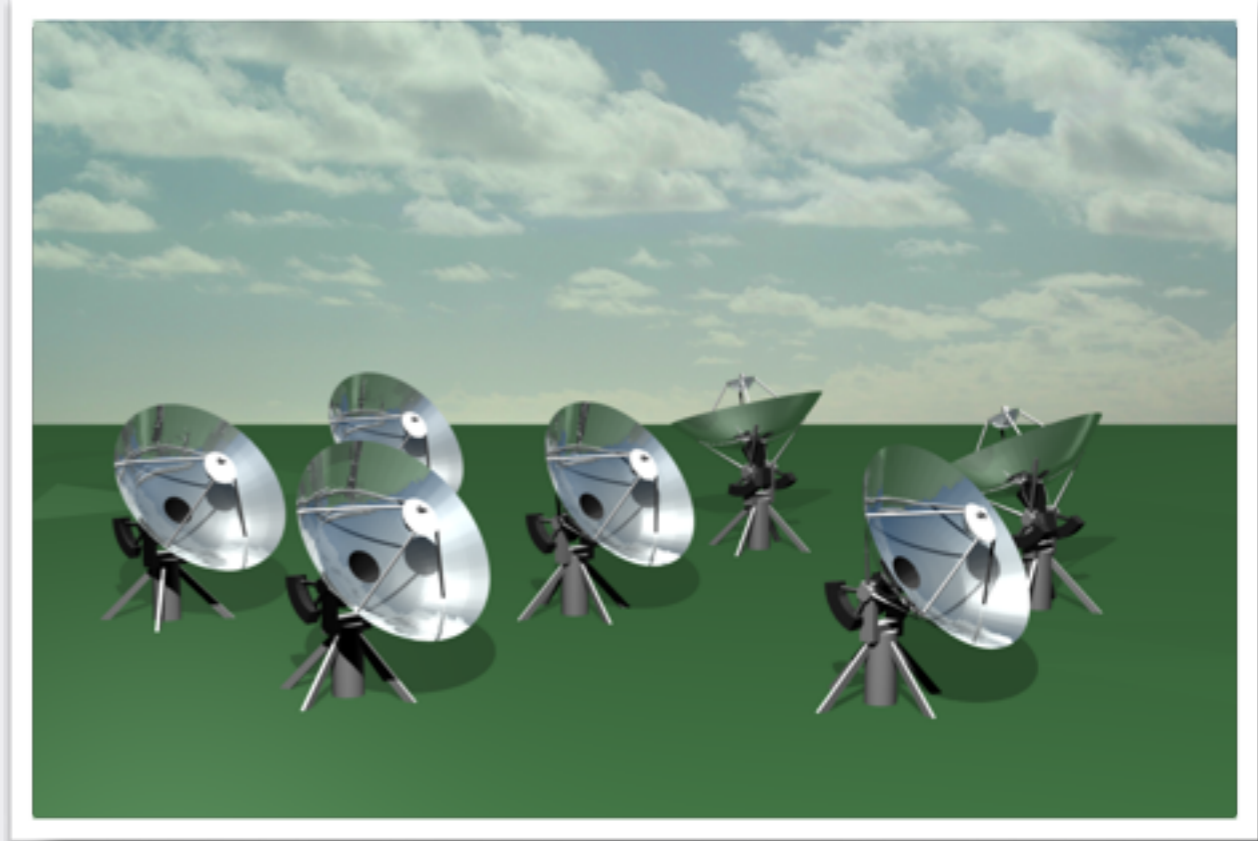
# Synergy with the SKA

- **Future VLBI to be based on e-VLBI 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



- **Need SKA story to maintain funding...**

- Training aspects, home telescope, outreach

- **User community is the most precious asset**
  - Make sure the interfaces are uniform and robust
    - User software, User support, Training, Proposal handling, Scheduling
  - Do not increase number of interfaces to different networks
    - 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
- **Should build on these e-VLBI meetings**
  - Could have a wider topic, they already have
  - BTW, next EVN symposium is in Bordeaux, October 2012
- **Pushing technology is part of the mission**
  - e-VLBI has helped keeping us visible
- **Long-term common goal?**
  - Global VLBI array which react flexible on user demands
    - Needed to satisfy scientists used to SKA/ALMA

**The End**