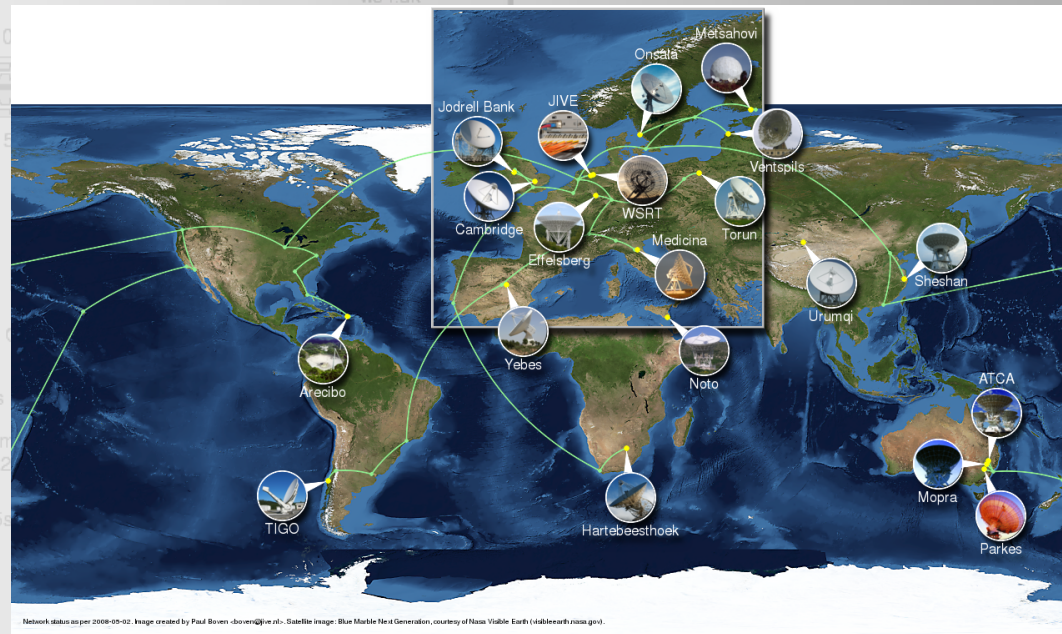


# From tape reel to intercontinental light paths

## Technical developments in the EVN

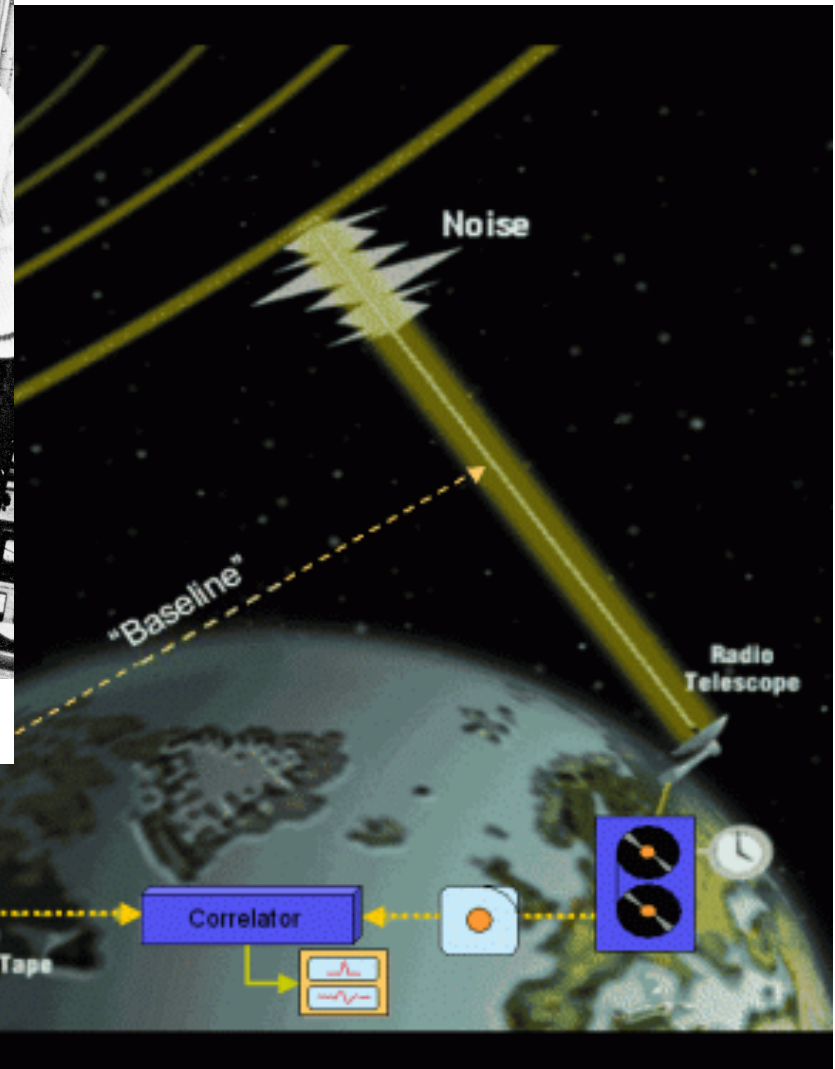


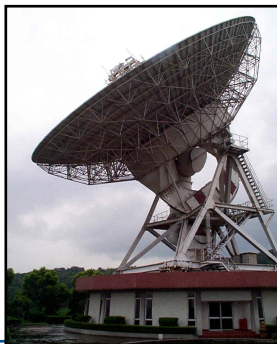
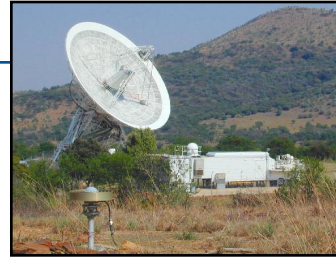
Arpad Szomoru, JIVE    Michael Lindqvist, OSO

# The olden days....



First transatlantic VLBI, Onsala, Sweden, 1968





# e-VLBI. Why?

- Rapid turn-around
- Rapid response
- Instant feedback
- Robustness
- Reliability
- Logistics
- No (less) dependence on magnetic media
- Cheaper (...?)
- Upgrade path for higher bandwidth

- *New science*

## Next decade developments in VLBI

- Data transport at even higher data rates (4 to 8 Gbit/sec)
  - ◆ magnetic recording or optical fibres
- second generation space VLBI
  - ◆ ARISE, ISS, HALCA -2
- next generation correlator
  - ◆ real-time?, ALMA/SKA/VLBI?

Schilizzi, NAC 1999

# First steps

## iGrid 2002

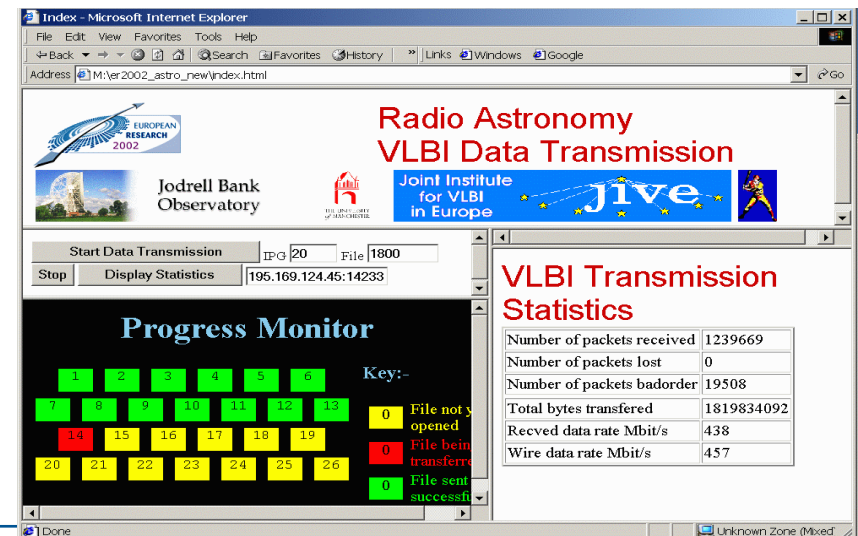
The International Virtual  
Laboratory

[www.startup.net/igrd2002](http://www.startup.net/igrd2002)  
[www.igrd2002.org](http://www.igrd2002.org)

24-26 September 2002  
Amsterdam Science and Technology Centre (WTCW)  
The Netherlands

### Call for Applications with Insatiable Bandwidth Appetites!

*“We hereby challenge the international research community to demonstrate applications that benefit from huge amounts of bandwidth!”*



Index - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address [M:\er2002\\_astro\\_new\index.html](http://M:\er2002_astro_new\index.html)

Radio Astronomy  
VLBI Data Transmission

Joint Institute for VLBI in Europe

Start Data Transmission IP:G 20 File 1800  
Stop Display Statistics 195.169.124.45:14233

**Progress Monitor**

Key:-

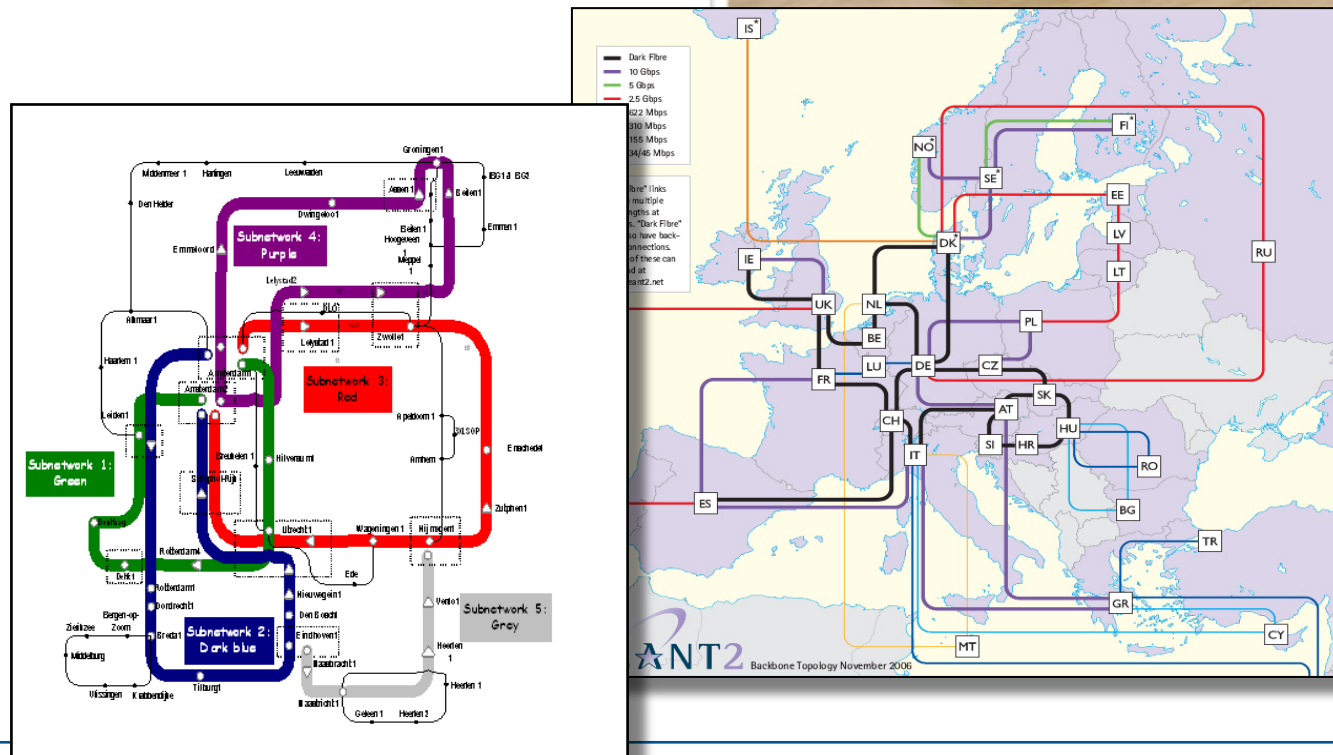
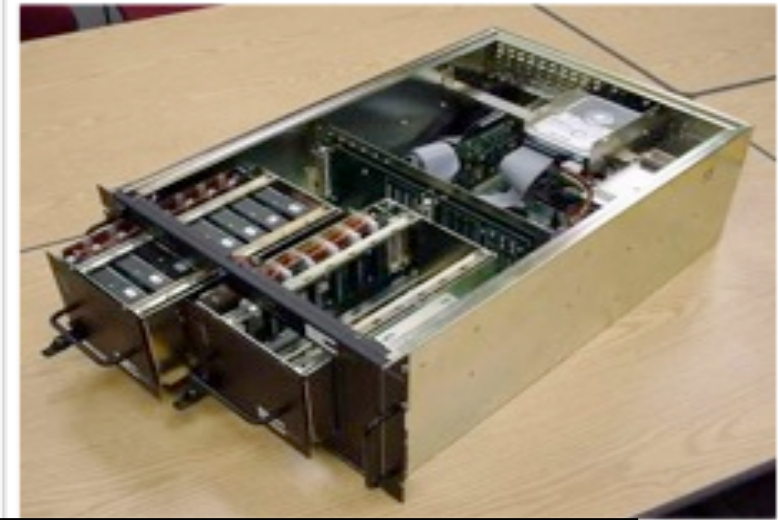
1	2	3	4	5	6	
7	8	9	10	11	12	13
14	15	16	17	18	19	0 File not opened
20	21	22	23	24	25	26
						0 File being transferred
						0 File sent successfully

**VLBI Transmission Statistics**

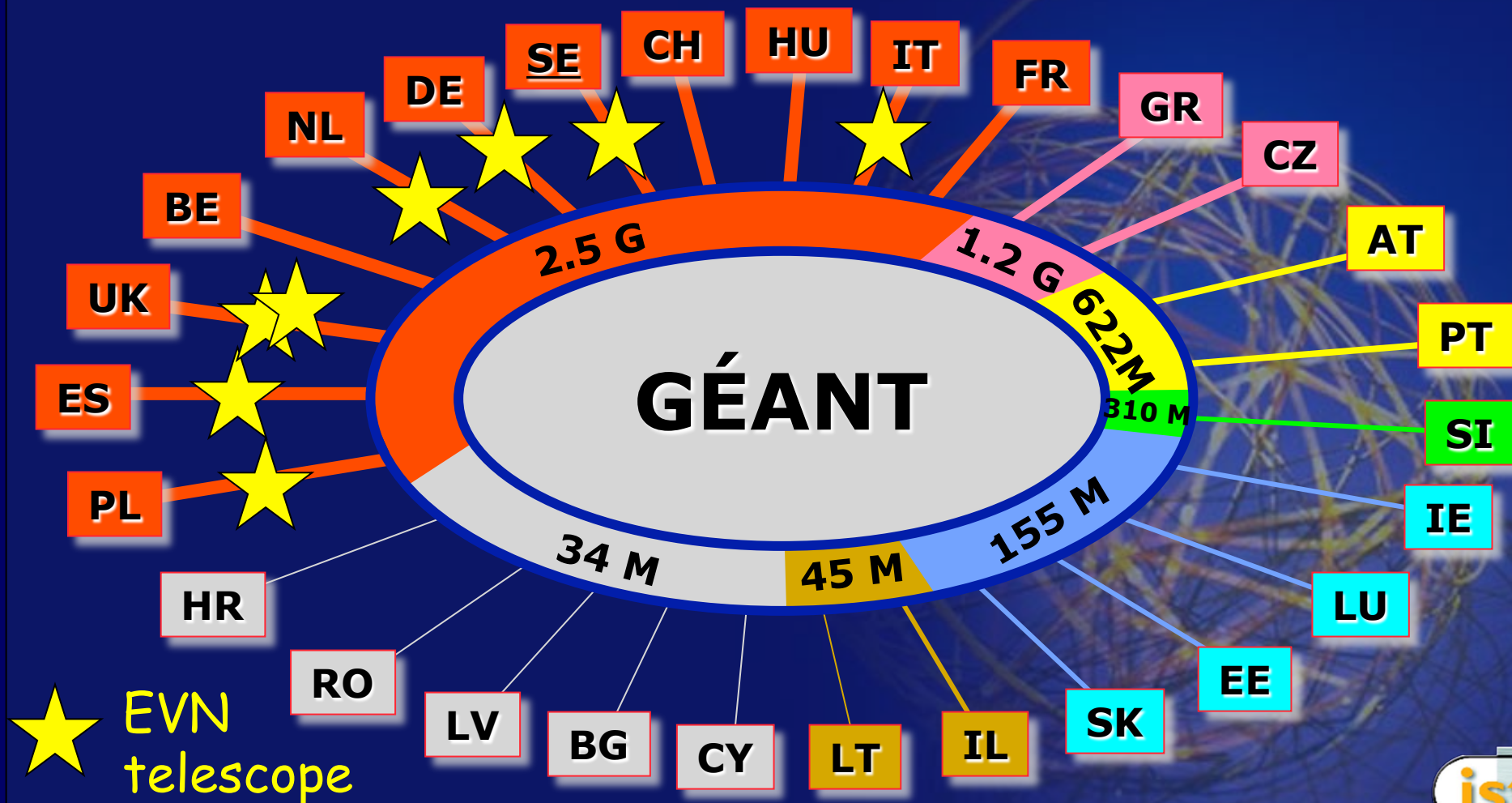
Number of packets received	1239669
Number of packets lost	0
Number of packets badorder	19508
Total bytes transferred	1819834092
Recvd data rate Mbit/s	438
Wire data rate Mbit/s	457

# Pieces falling into place

- Introduction of Mark5 recording system (game changer)
- Emergence of high bandwidth optical fibre networks



# January 2002: Proof-of-Concept e-VLBI over GÉANT



★ EVN telescope

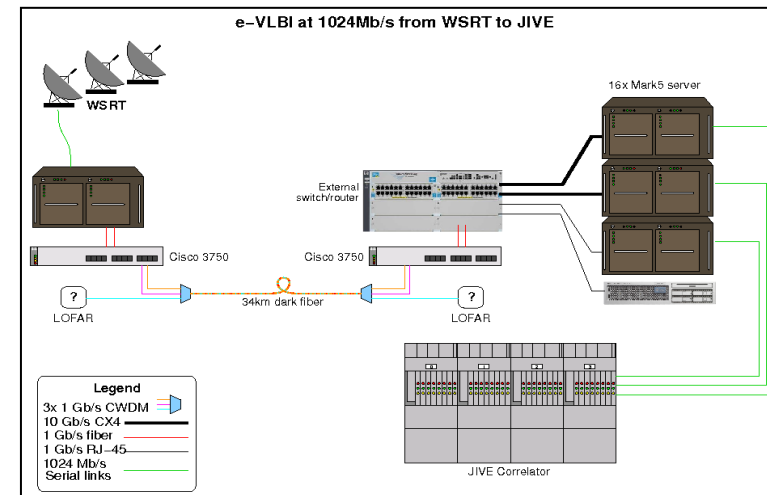
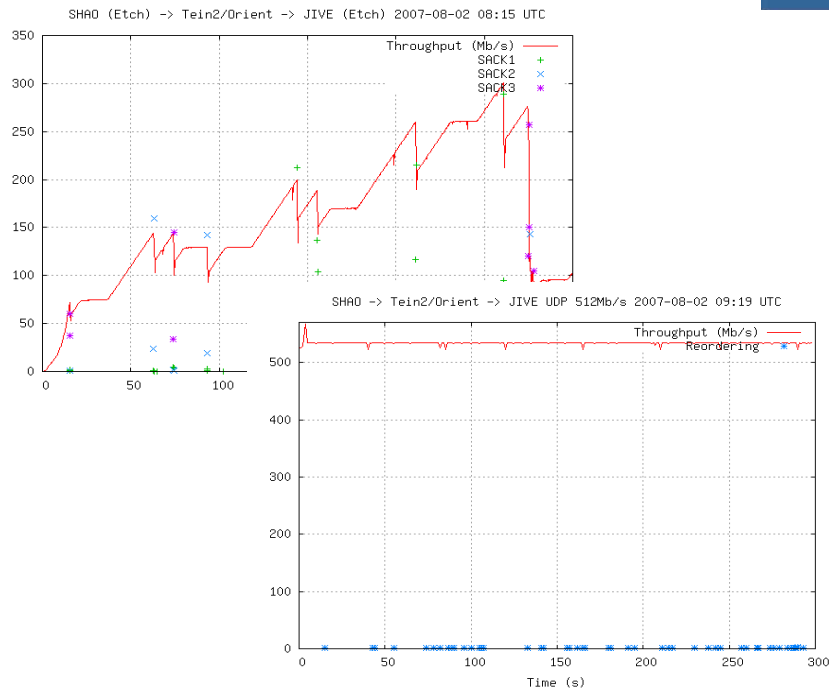
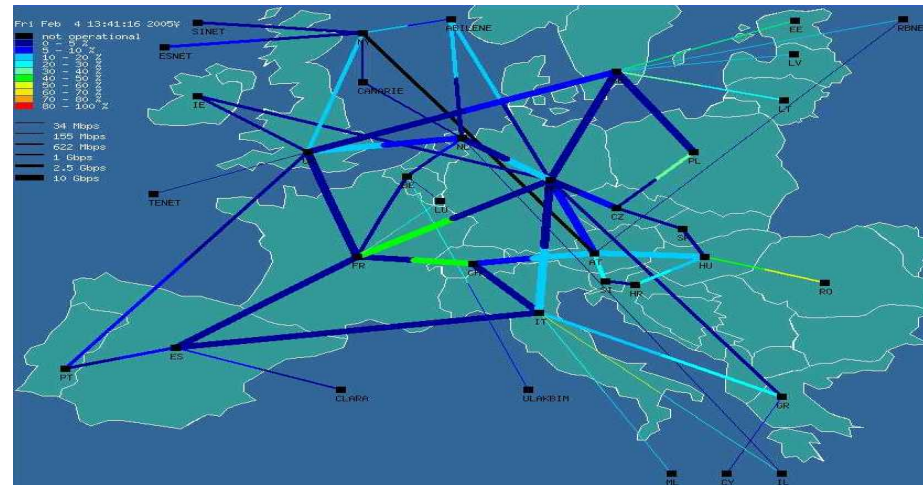
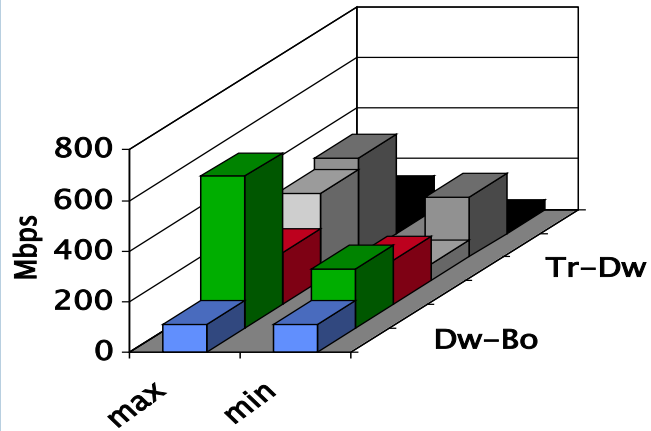
# From Proof of Concept to reality: EXPReS

- EXPReS proposal submitted on 17 March 2005 to Research Infrastructures Call - Communication and Network Developments
- Project kicks off 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





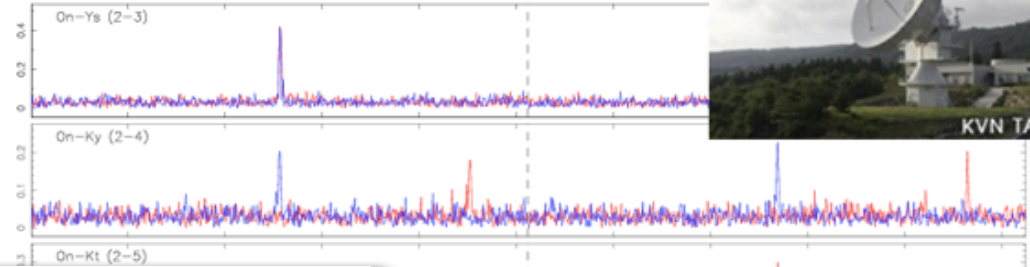
# First European transfer tests



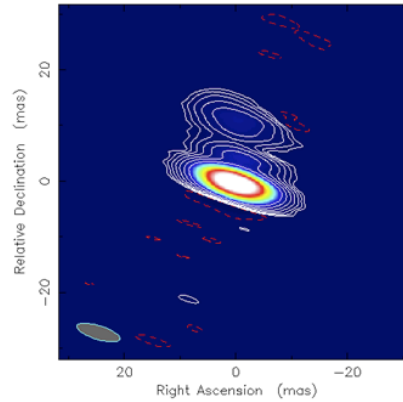
# Continuously adding new e-stations



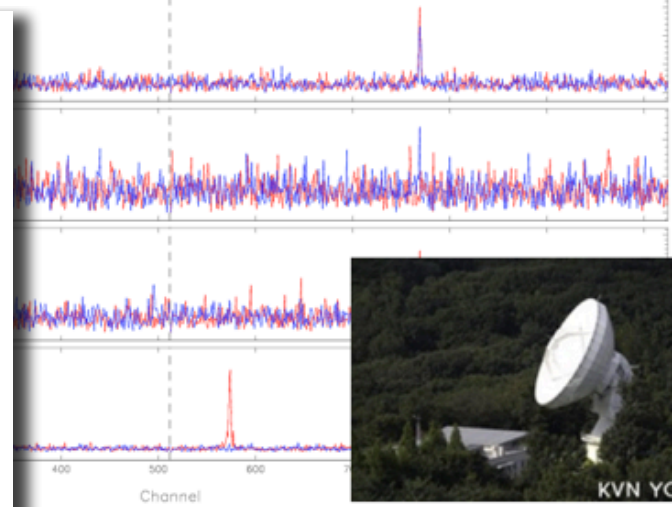
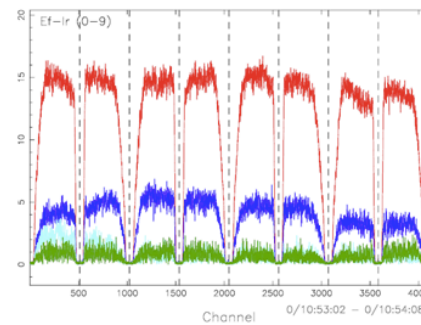
Amplitude for kvn.2sbl



Clean RR map. Array: EVN  
0234+285 at 4.990 GHz 2013 Mar 19

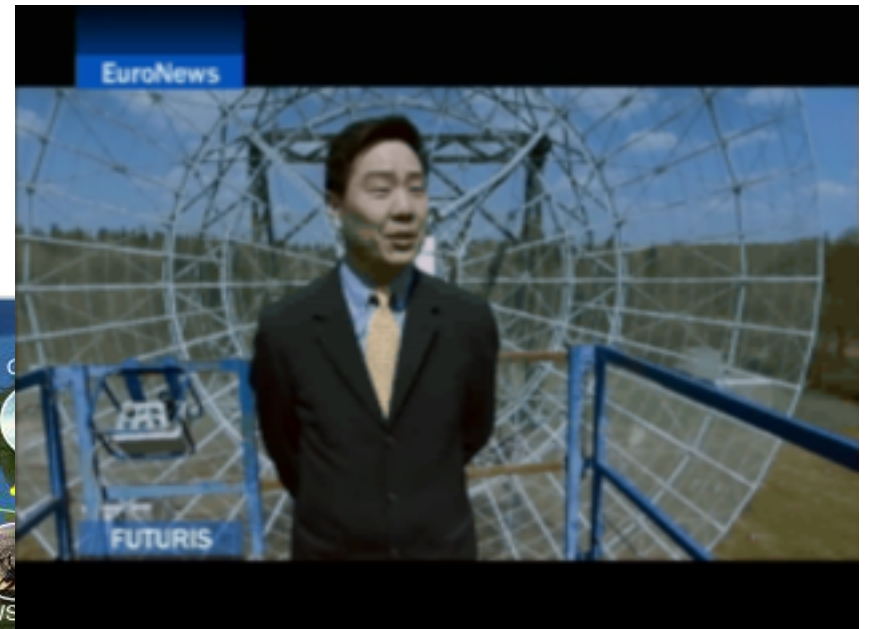


Amplitude for No0008.ms



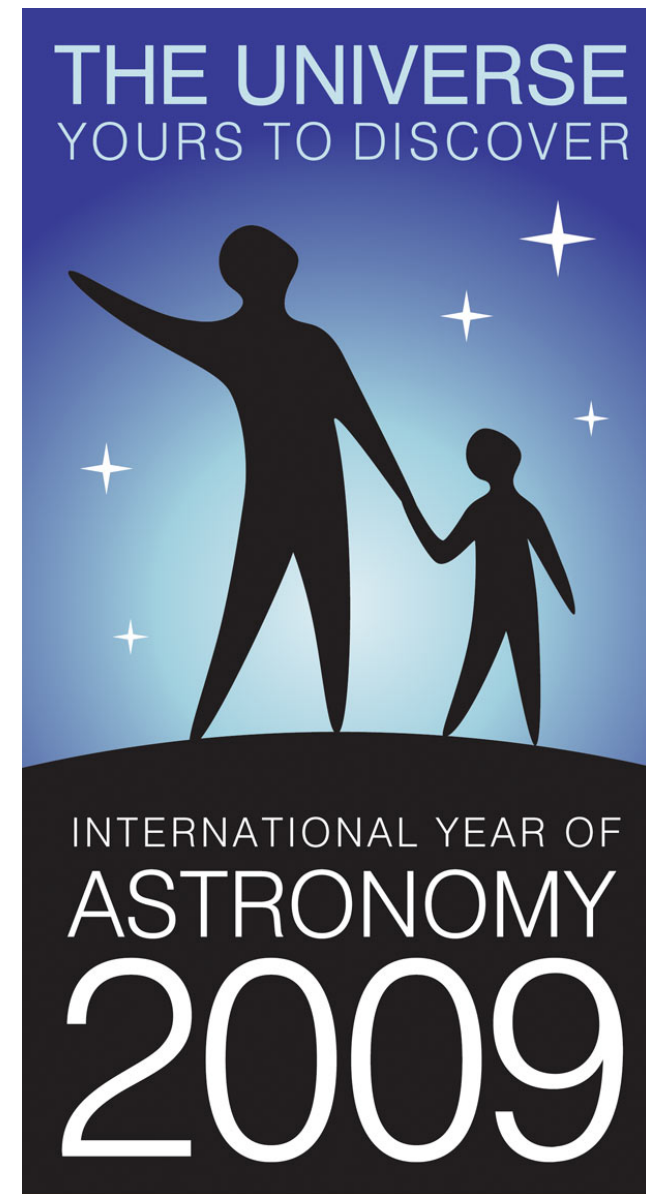
# Demonstrations and visibility

- Fantastic way to focus effort
- But can be really disruptive and time-consuming...

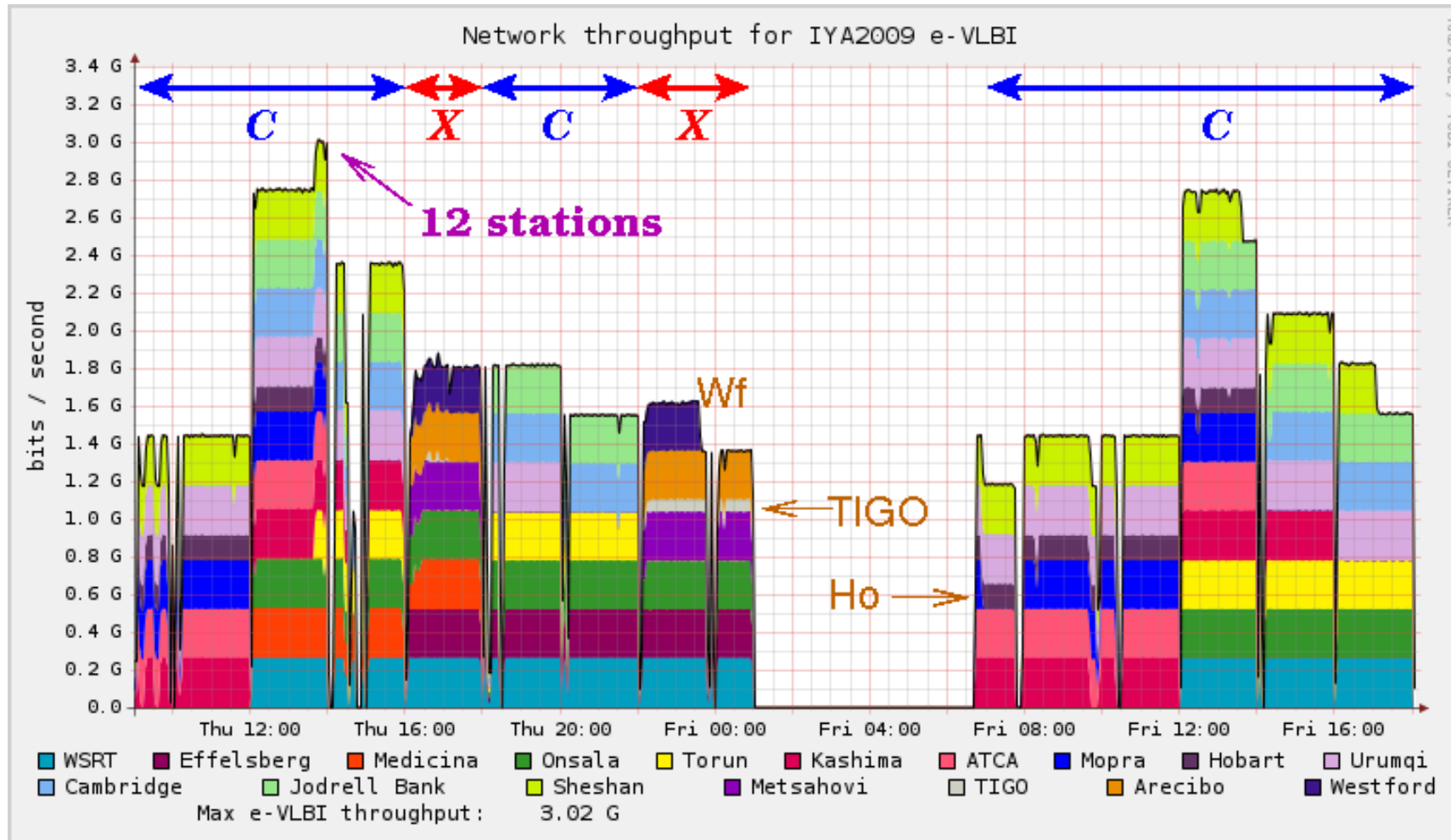


# PR which led to science

- Real-time demo during opening ceremony of IYA, 15-16 January 2009 in Paris
  - UNESCO building in Paris
  - ~800 invitees
  - Many dignitaries, Nobel prize winners, students
- 24 (33) hours real-time tracking of one (three) source(s)
- 6 (5) - continent e-VLBI
- 17 telescopes, 4 of which new for us
- 4 data acquisition systems,
- 2 frequencies

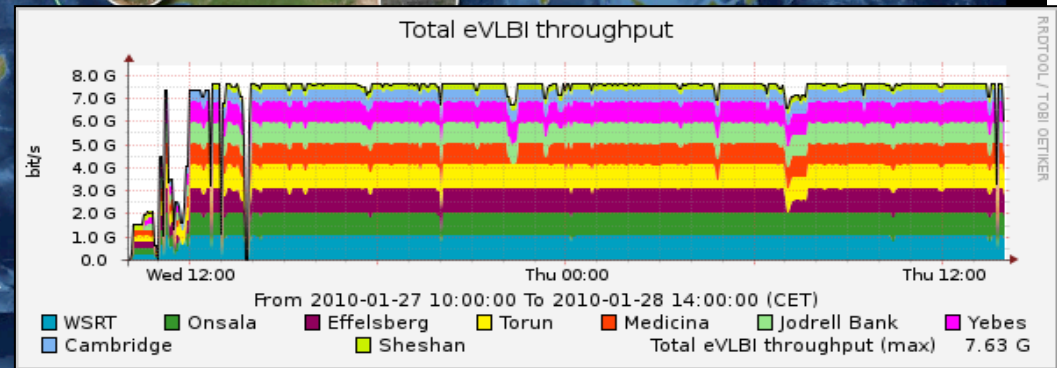
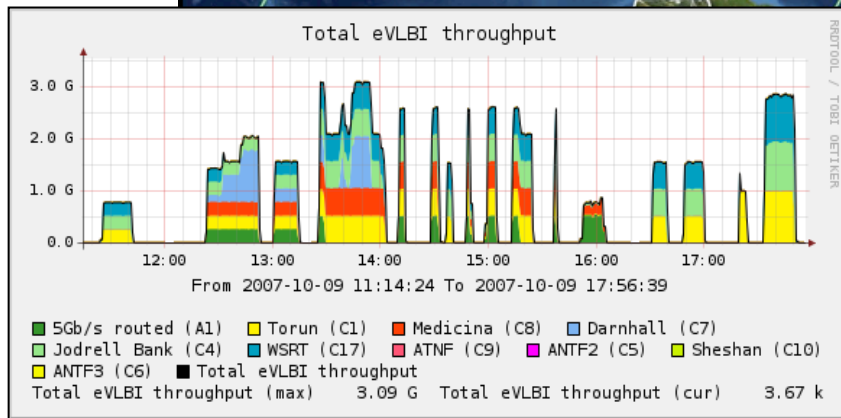
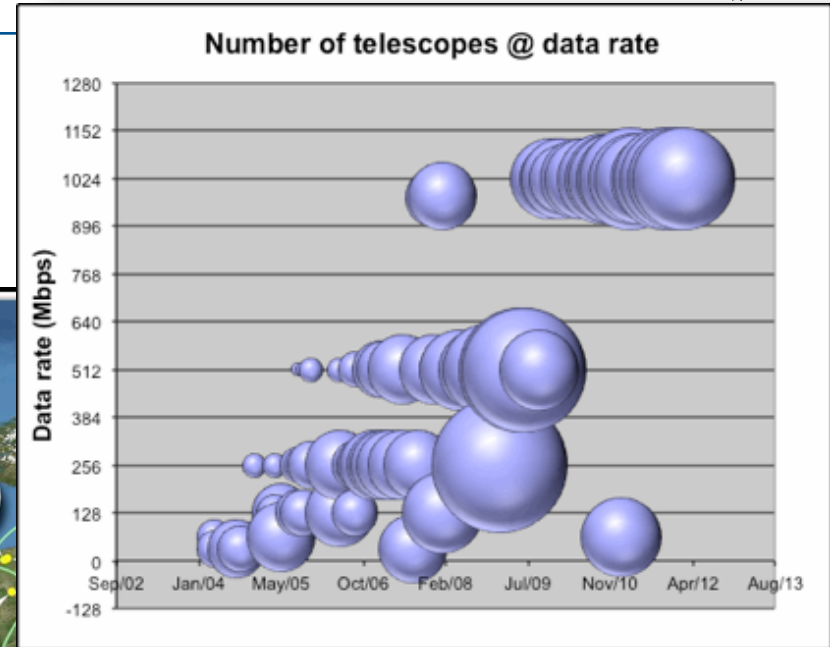
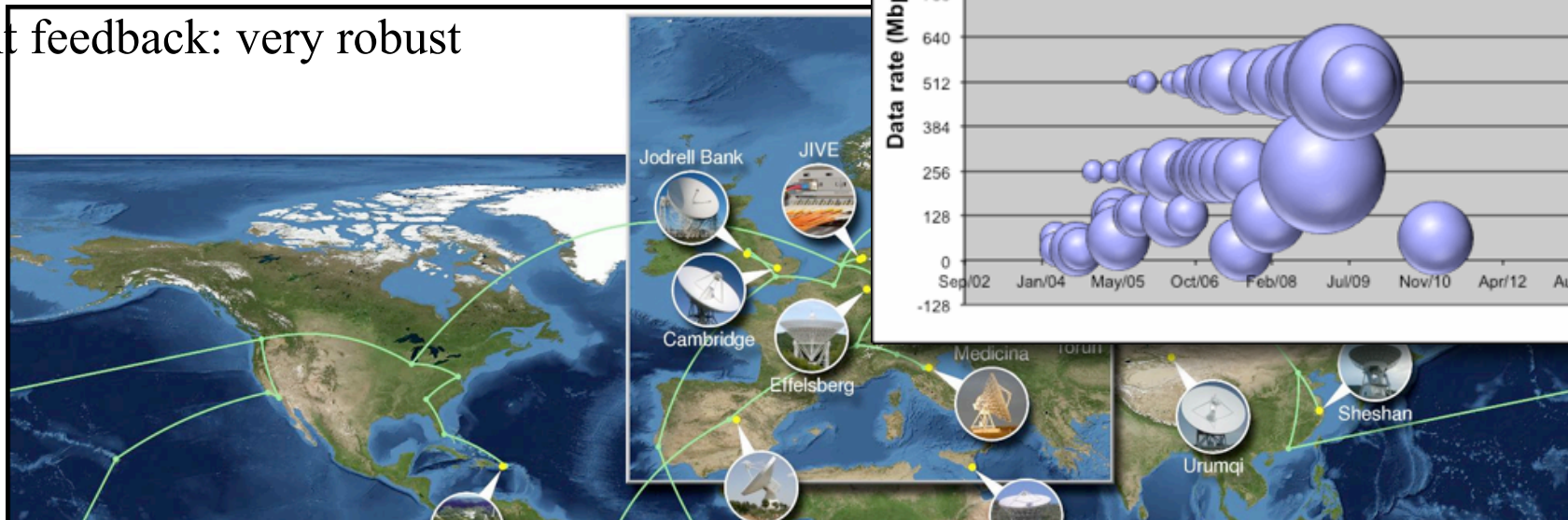


# The result



# A truly global result

- Connections work great!
- Dedicated lightpaths, VPNs, routed connections
- Optimized transport protocol
- Instant feedback: very robust



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

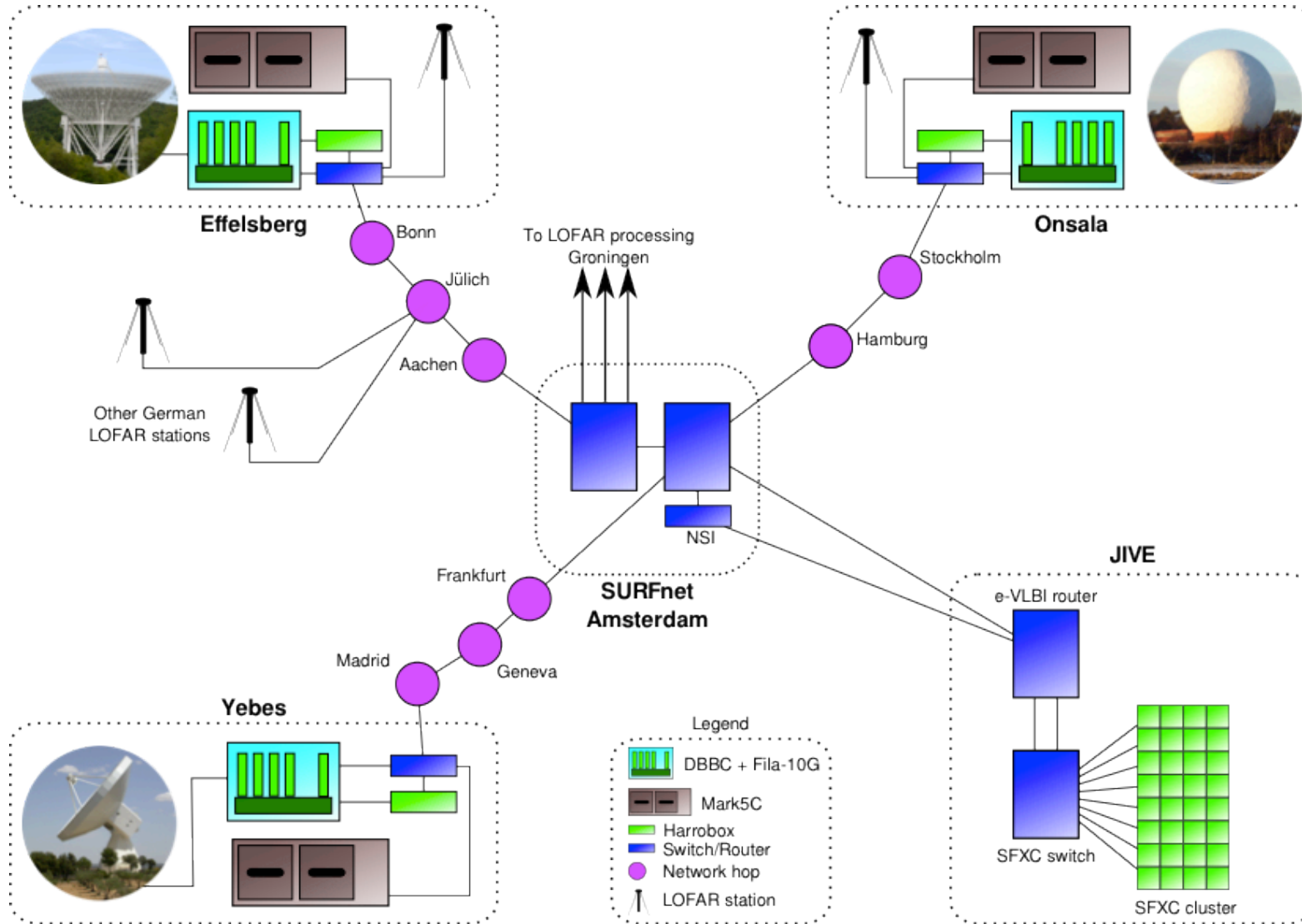
# Stuff breaks

**NEXPR<sup>es</sup>**  
Novel EXplorations Pushing  
Robust e-VLBI Services

**jive**  
JOINT INSTITUTE FOR VLBI IN EUROPE



# 4 Gbps simultaneous recording/real-time

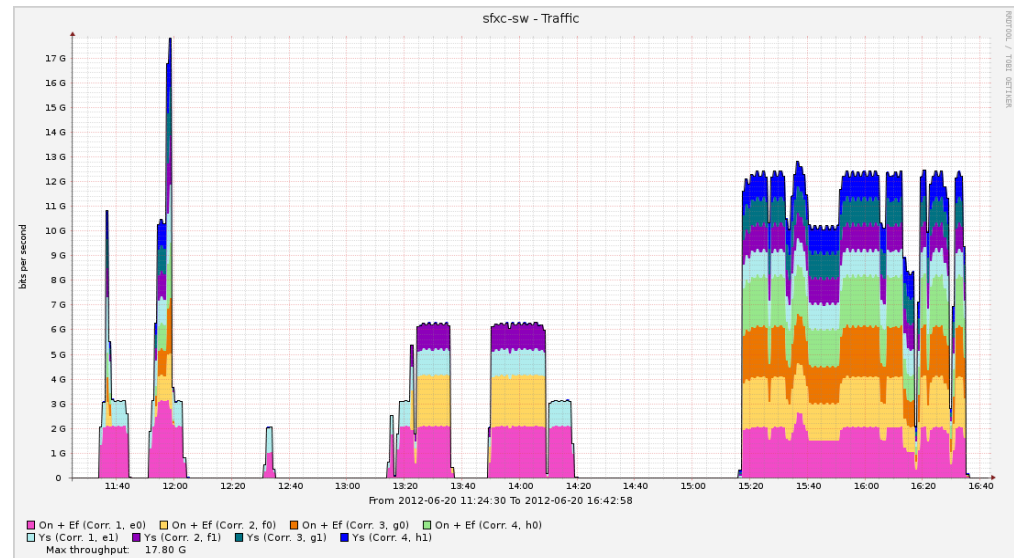


2nd NEXPreS Board Meeting– Copenhagen June 20, 2012



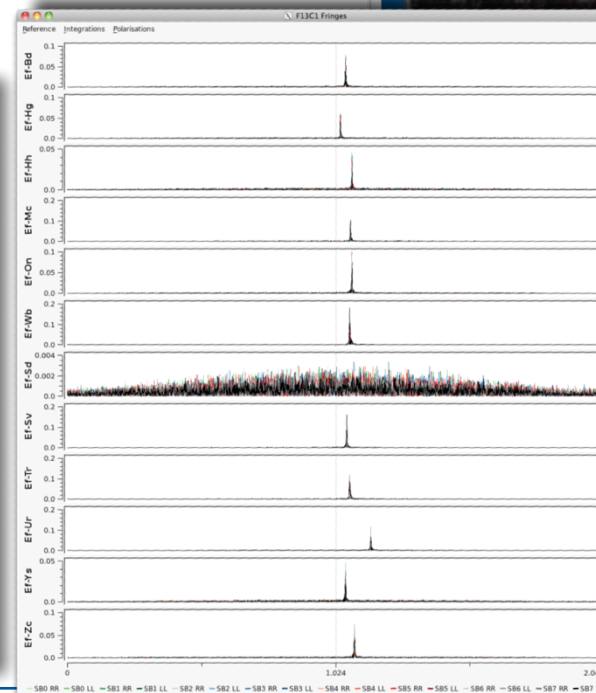
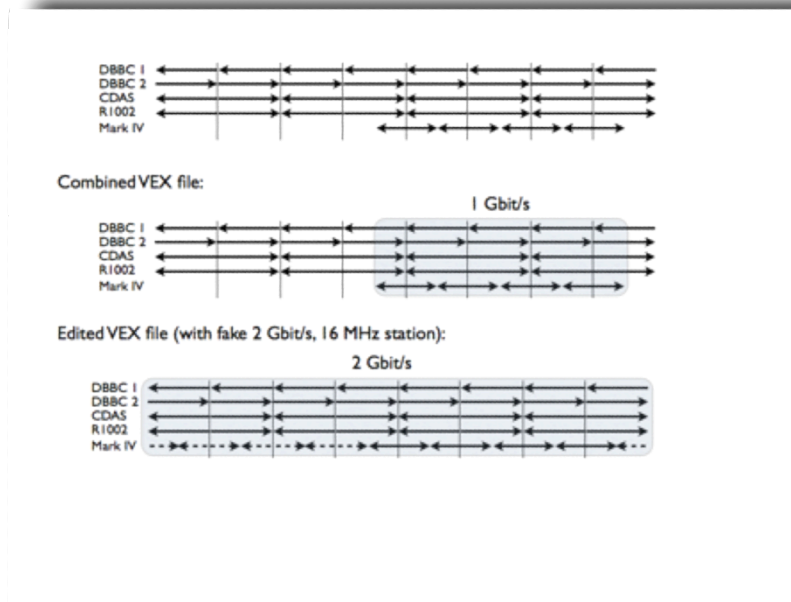
# 4 Gbps demo: results (June 20)

- Technically everything just worked!!!
- All equipment keeping up
- Networks stable and performing flawlessly
- But..... No fringes
- DBBC configuration, Fila10G time synchronization?
- Completely new equipment, need to learn
- Next attempt live during final NEXPreS review
- What could possibly...



# SFXC Software correlator

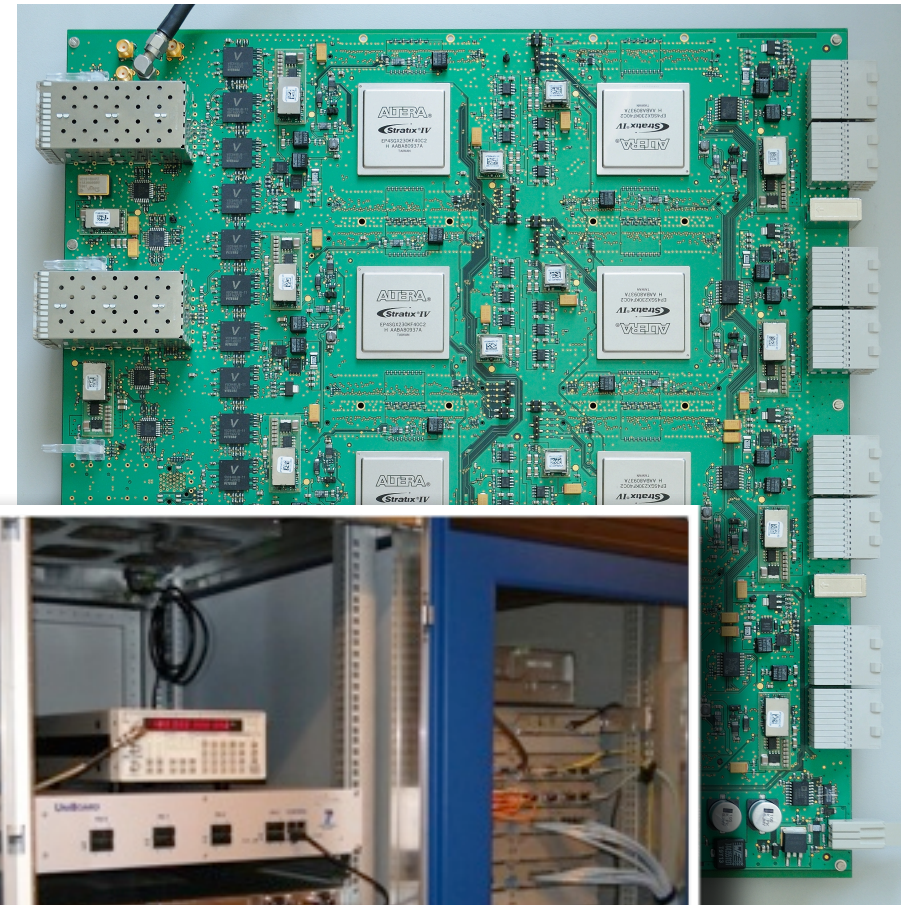
- Home grown
- Now used for *all* correlation at JIVE
- Increasing functionality:
  - Pulsar gating/binning
  - Multiple phase centers
  - VDIF support
  - Mixed bandwidth correlation
  - Phased array mode



and 10 stations

# FPGA-based UniBoard Correlator

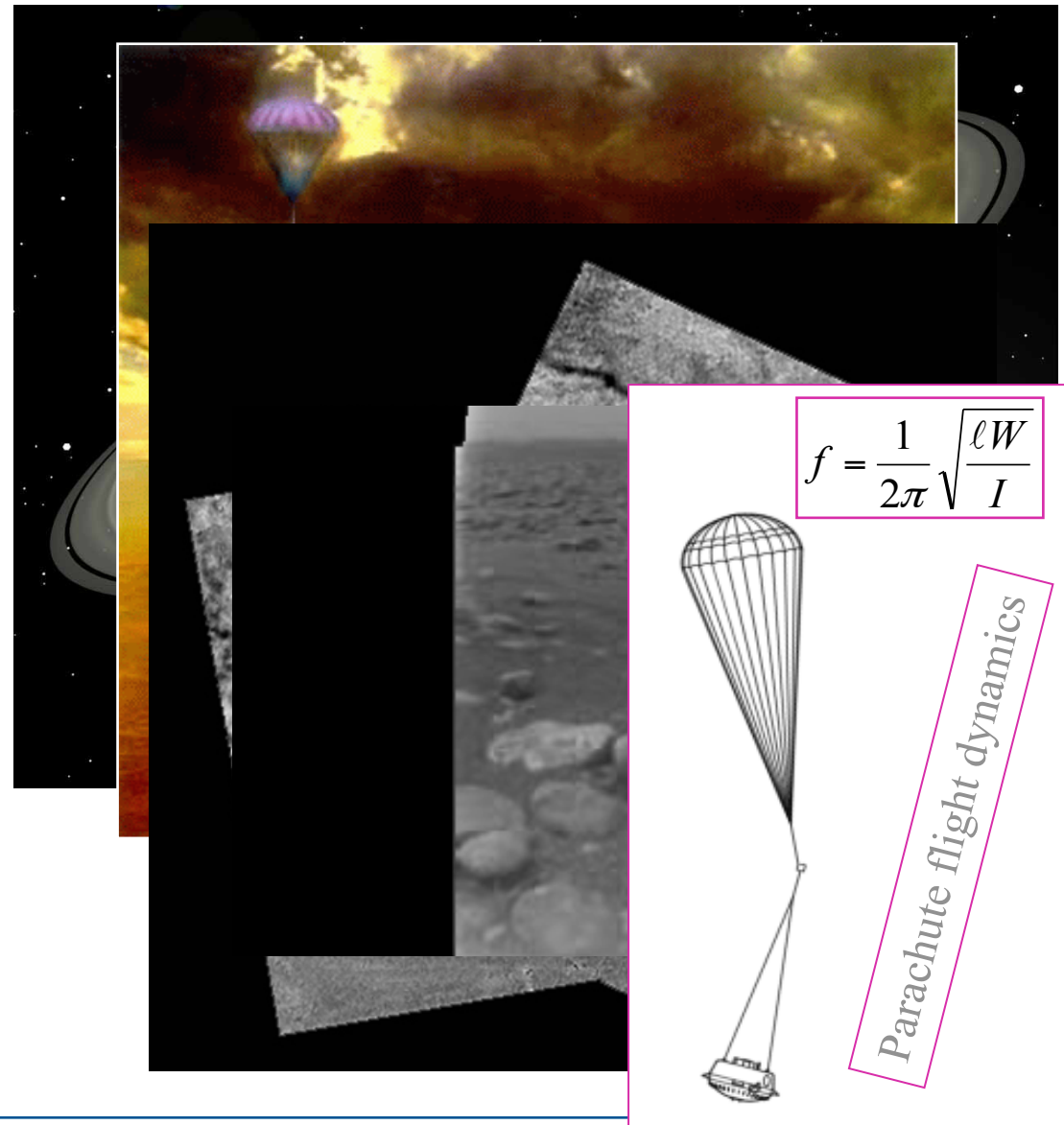
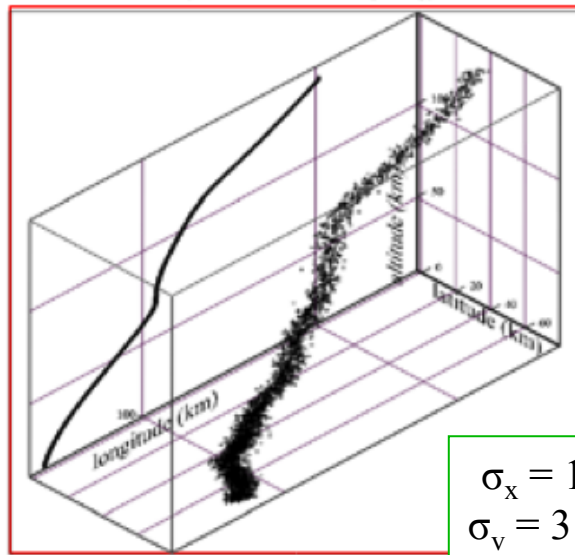
- EC-funded, JIVE-led project
  - Create generic, high performance computing platform for radio astronomy
- One board roughly equivalent to MarkIV hardware correlator
  - At 350 Watt power consumption...
- UniBoard<sup>2</sup> considered in several SKA work packages



# Space science VLBI

- Tracking of Huygens probe during descent to Titan
- Ad hoc use of the Huygens uplink carrier signal at 2040 MHz
- 17 radio telescopes around the world
- Salvage of Doppler experiment
  - Special purpose, narrow band software correlator which evolved into SFXC

## 3D Huygens descent trajectory



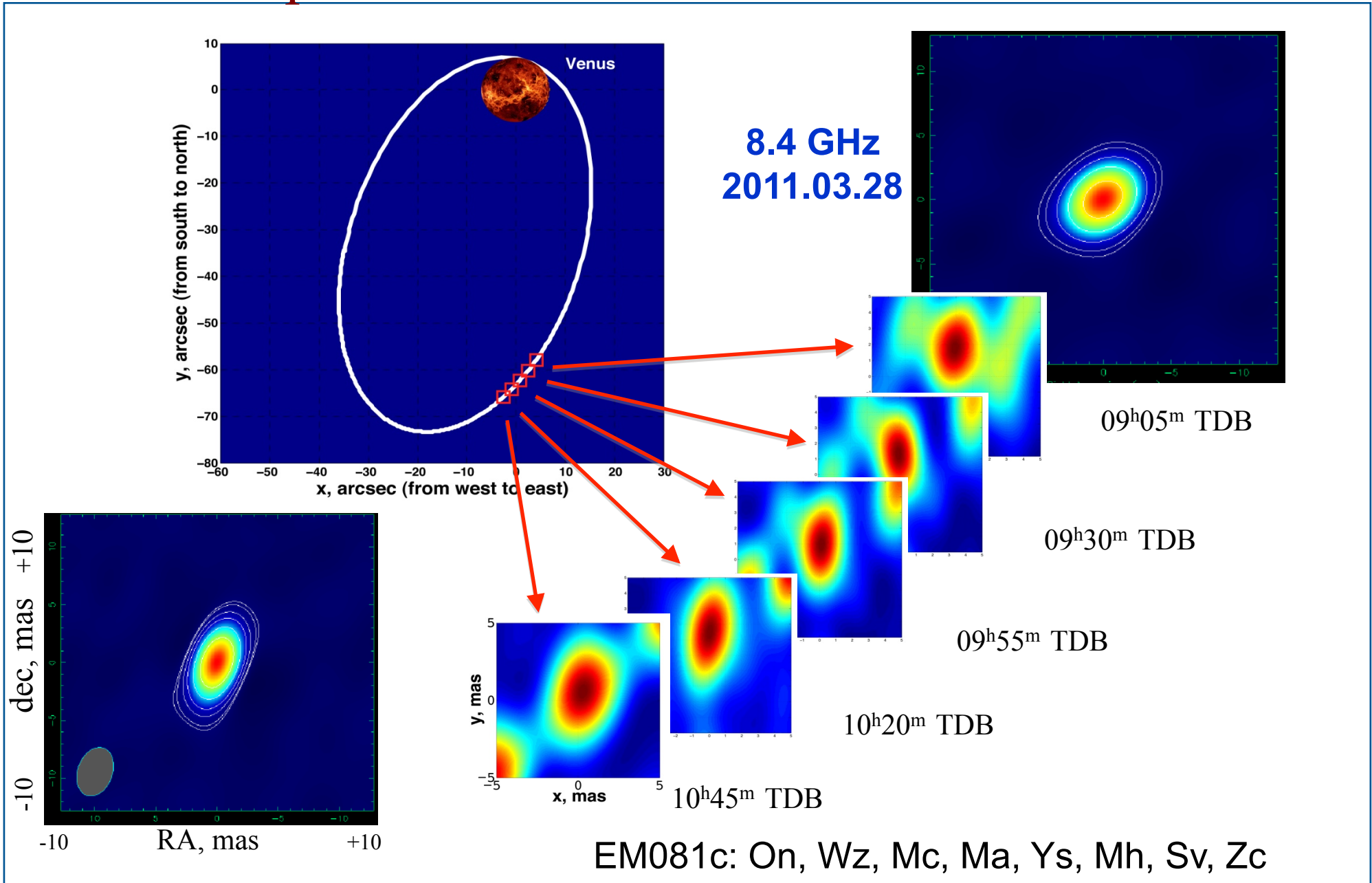
# PRIDE

**PRIDE**: a multidisciplinary enhancement of the mission science return with minimum on-board instrumentation

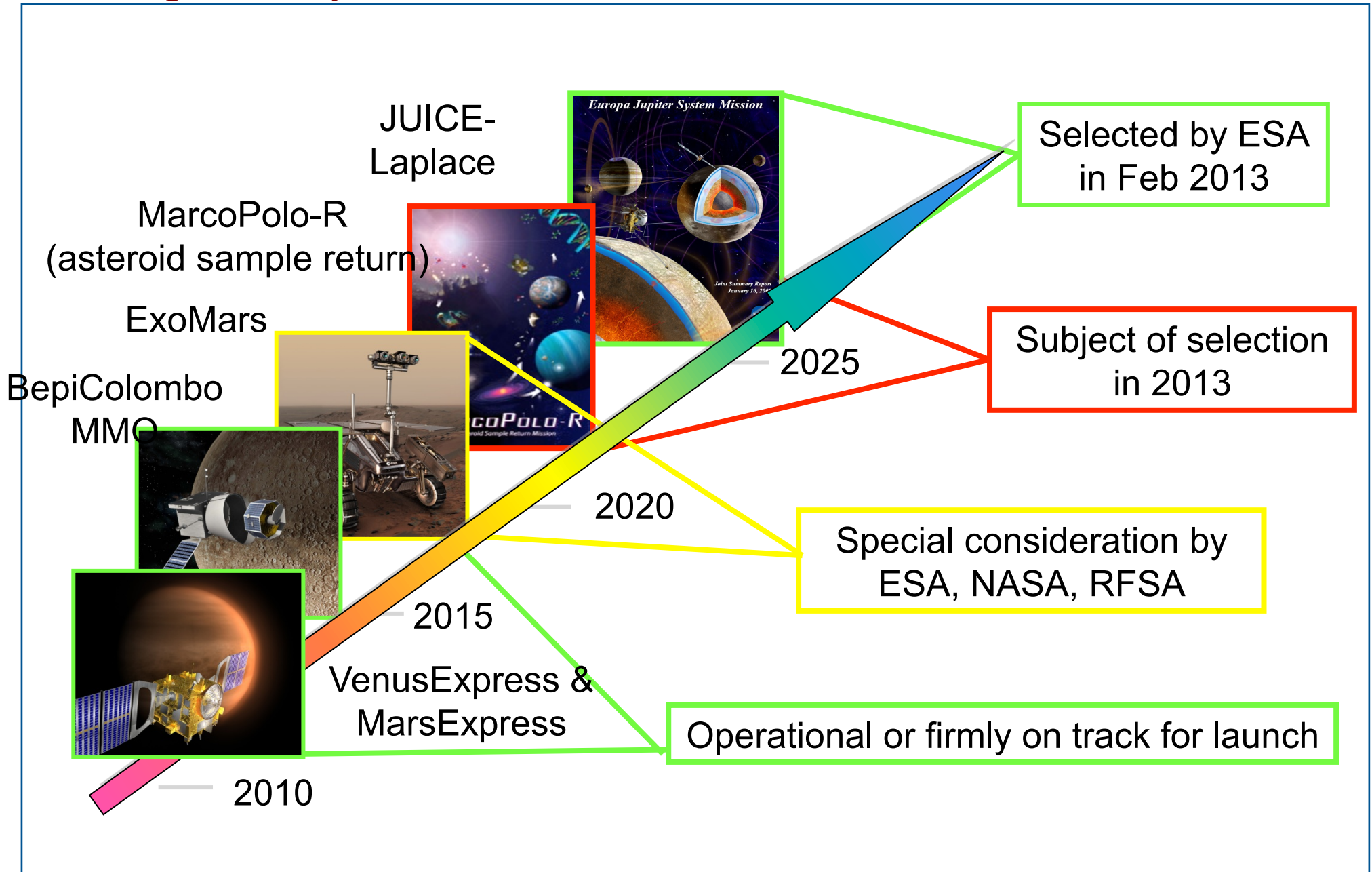
**Planetary  
Radio  
Interferometry &  
Doppler  
Experiment**

$$R_{nf} \propto \frac{B^2}{\lambda}$$

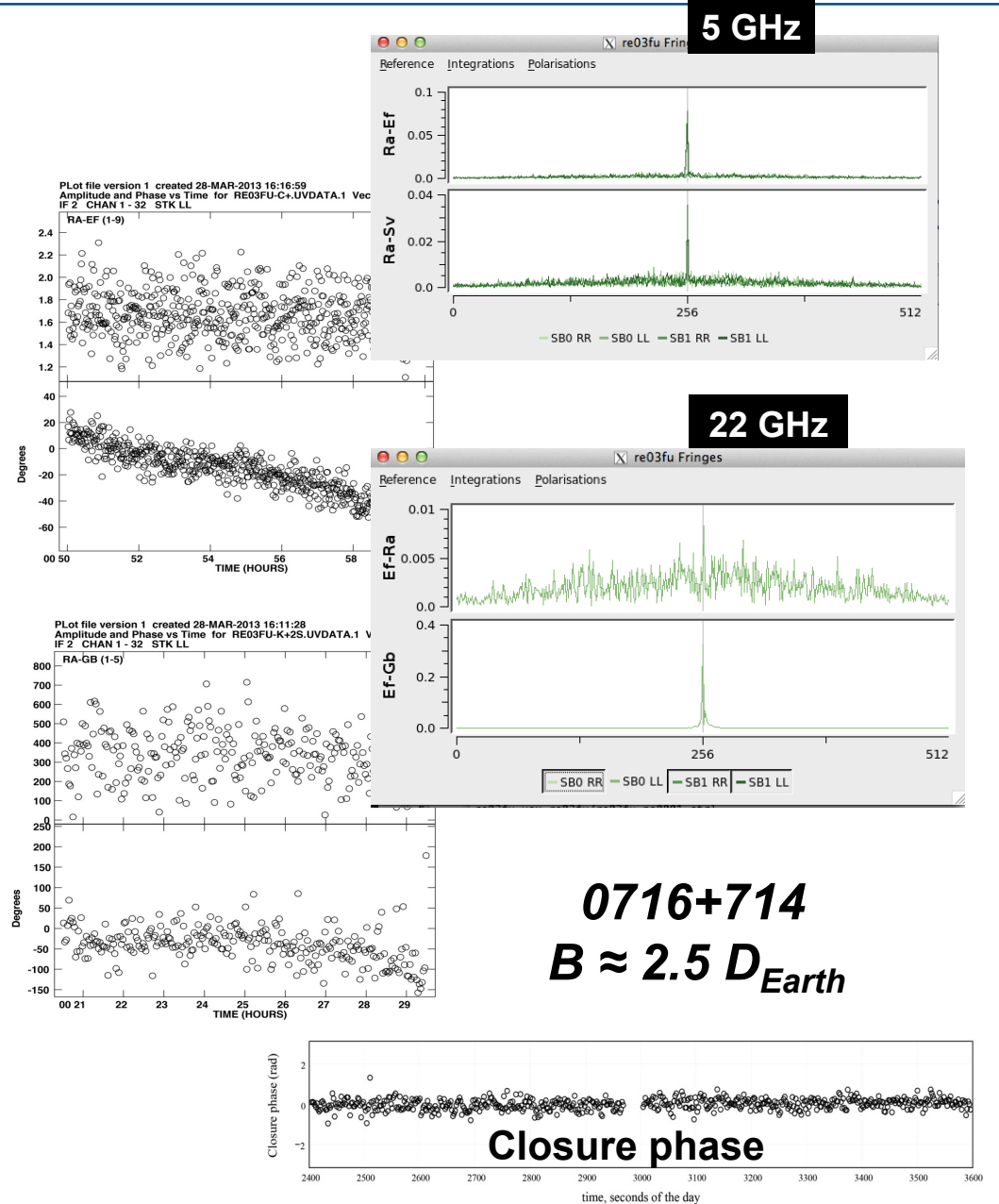
# PRIDE in practice



# ESA planetary missions – VLBI “customers”



# RadioAstron fringes on SFXC at JIVE





# The future.....



## *Just about to happen.....*

- Digital Base Band Converters becoming operational in EVN
  - Opening the way for 2Gbps, 4Gbps, .....
- Automated triggered observations (EVN-light?)
- BoD standard to be implemented by NRENs
- 100Gbps technology rolled out
- KVN will become member of EVN
- KVAZAR telescopes should get high-speed connectivity any moment
- New Shanghai and Sardinia telescopes nearly operational
- KAT7 participation in first (e)VLBI with EVN this fall (?)
- e-Merlin getting ready to re-join the e-EVN
- Disk-less operations in EVN



# The future.....

## And further along

- More telescopes, higher sensitivity
- Clocks, frequency via commercial networks?
- 1 APERTIF beam of 12 WSRT dishes each added to EVN
- VLBI with ALMA, MeerKAT, African VLBI Array, SKA,...

## Telescopes Participating in EXPReS



Copyright: EXPReS  
Telescope photos used with permission