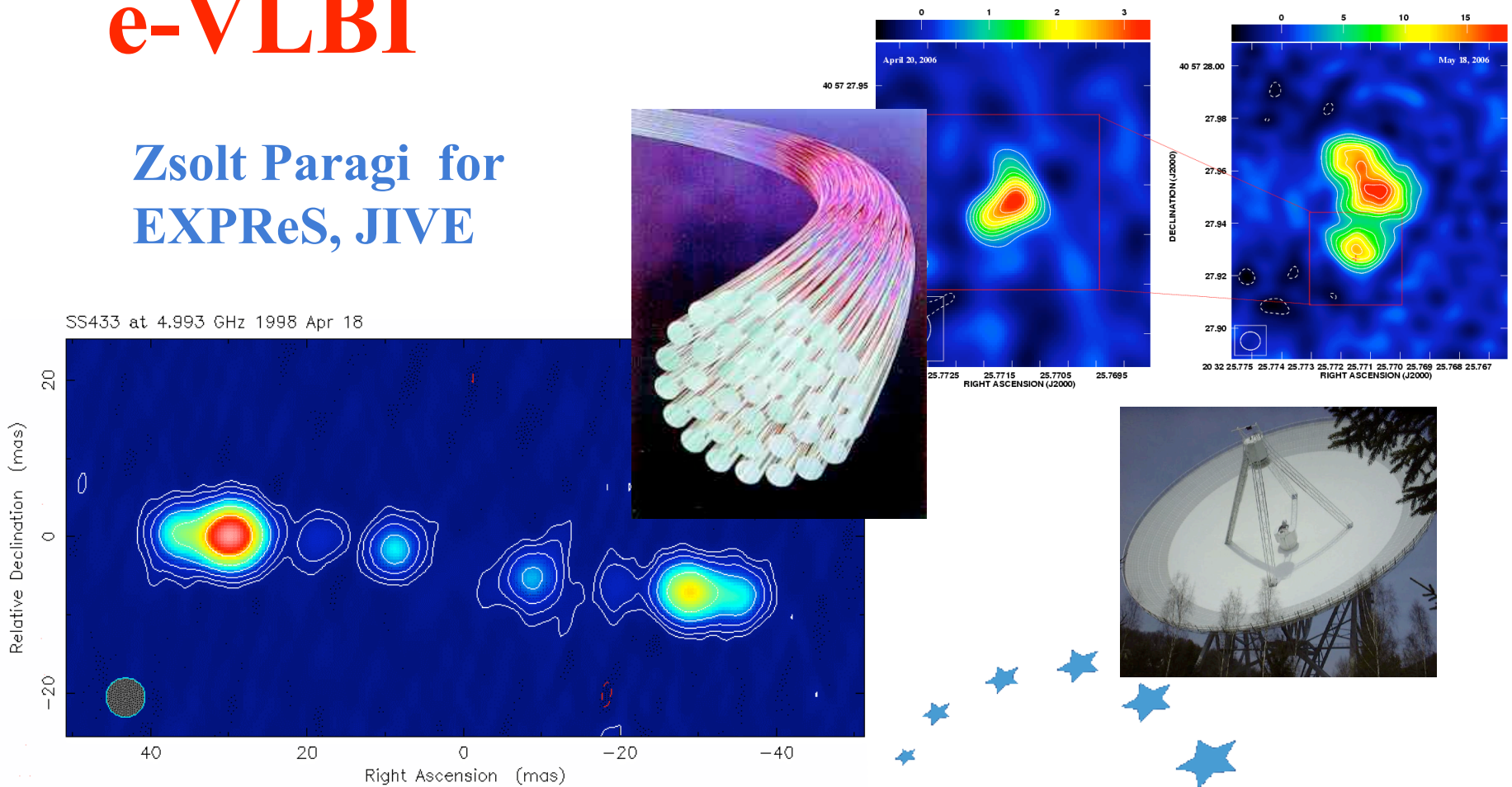


# New era in VLBI astronomy: e-VLBI

Zsolt Paragi for  
EXPR<sup>e</sup>S, JIVE



EXPR<sup>e</sup>S

# The European VLBI Network

- Some of the worlds greatest radio telescopes, e.g. Effelsberg 100m, Lovell 76m telescopes, Westerbork Synthesis Radio Telescope
- Outside Europe includes Hartebeesthoek (South Africa), Urumqi and Shanghai (China)
- Several telescopes are being built that will join the EVN: Yebes 40m (this year), telescopes in Sardinia, Latvia, Ireland and China
- Operating in three observing sessions per year, sometimes jointly with MERLIN (UK) and the VLBA (USA) – global VLBI
- Observing wavelength ranges from 92cm to 1.3cm
- The most sensitive standalone VLBI array (the so-called High Sensitivity Array formed occasionally by the VLBA, VLA, GBT and maybe Arecibo competes with it)
- The data are correlated in the EVN MkIV correlator at JIVE

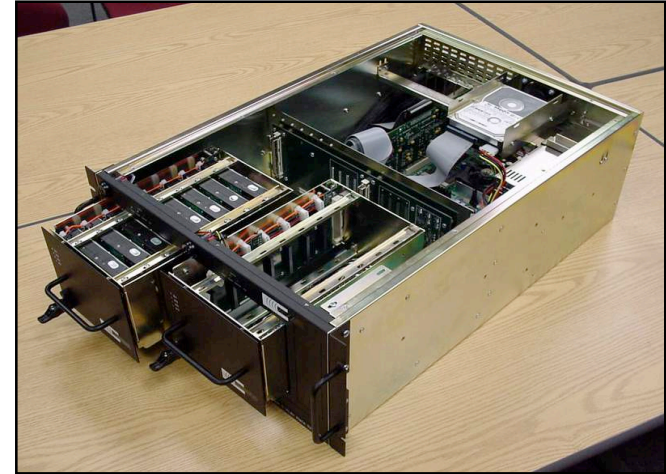


<http://www.evlbi.org/>

<http://www.jive.nl/>

# The end of the tape era

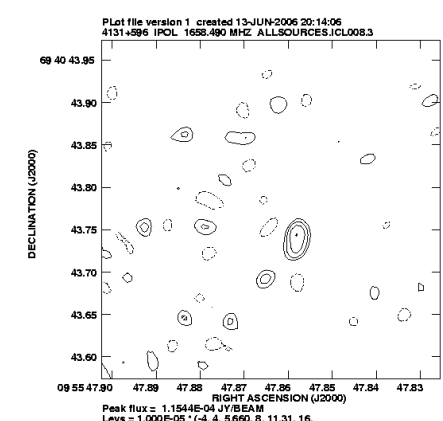
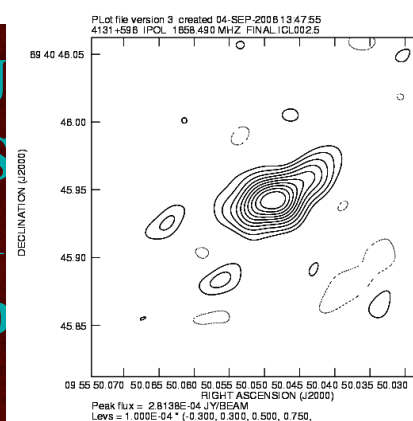
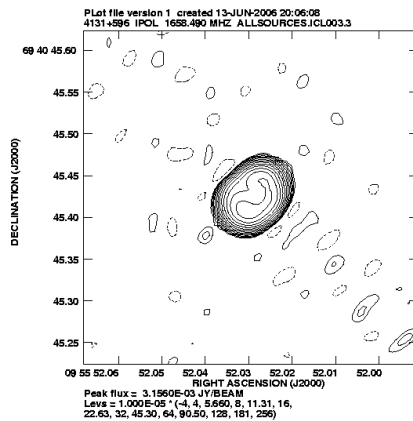
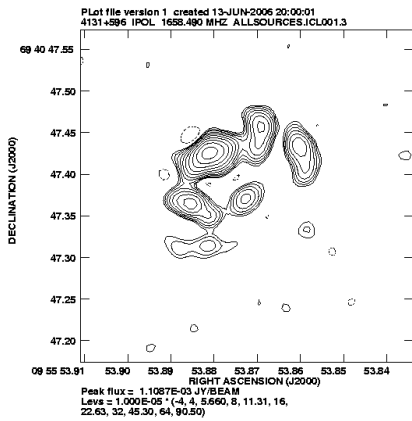
- Tape recording had limited performance (parity errors), and
- limited data rate (256 Mbps; 512 Mbps with two write heads).
- Tapes were expensive
- Tape playback units were not easy to maintain



- Disk based recording systems were developed at Haystack (Mark5A) and Metsahovi Radio Observatory (PC EVN)
- ← • And it worked!
- The EVN is fully disk operational (Mark5A) since early 2004
- Cheaper, off the shelf technology, perfect recording; data rate up to **1 Gbps**

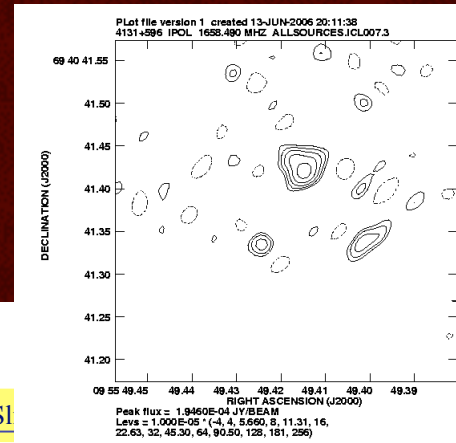
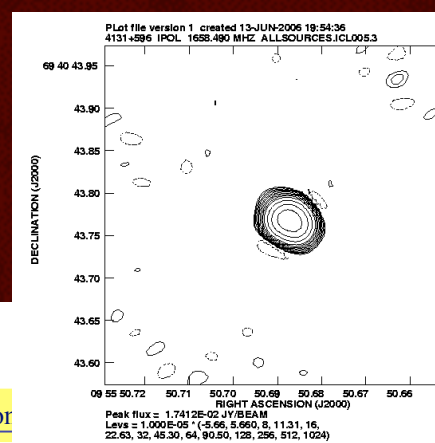
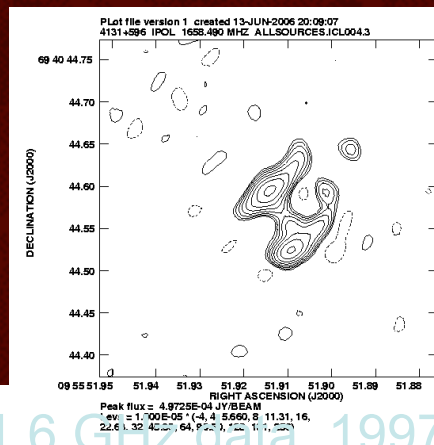
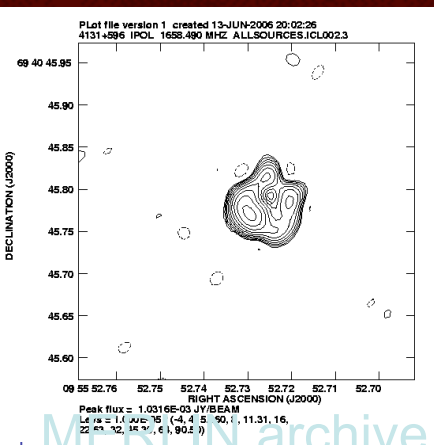
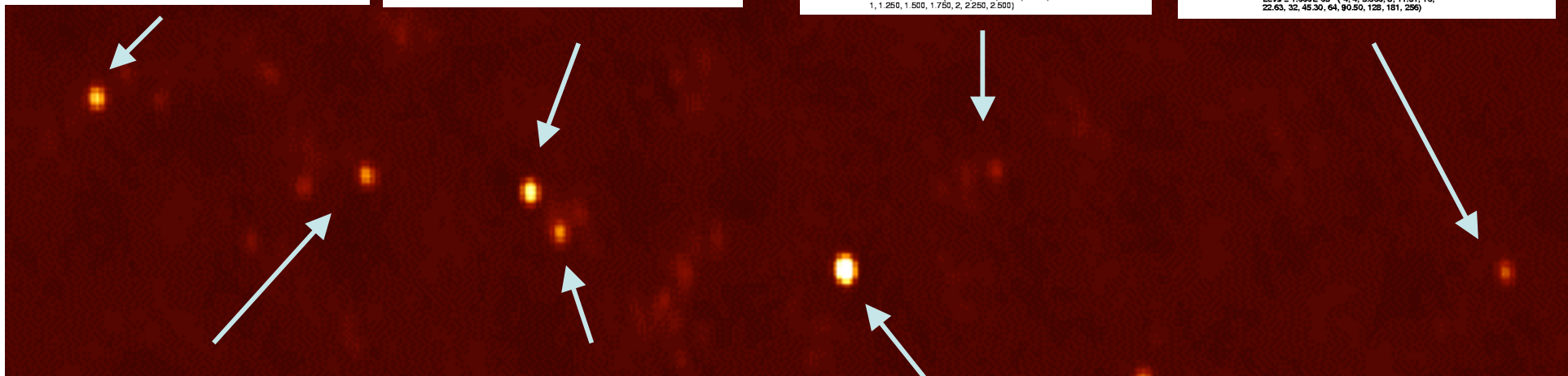
<http://www.haystack.edu/tech/vlbi/mark5/>





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MERLIN archive 1.6 GHz data, 1997

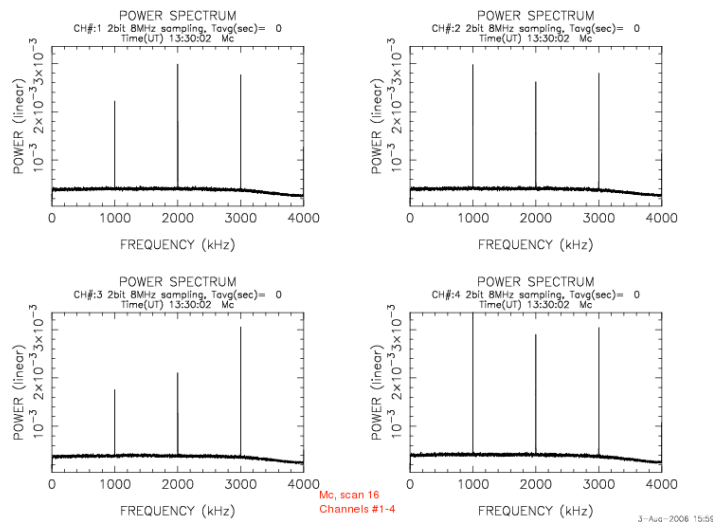
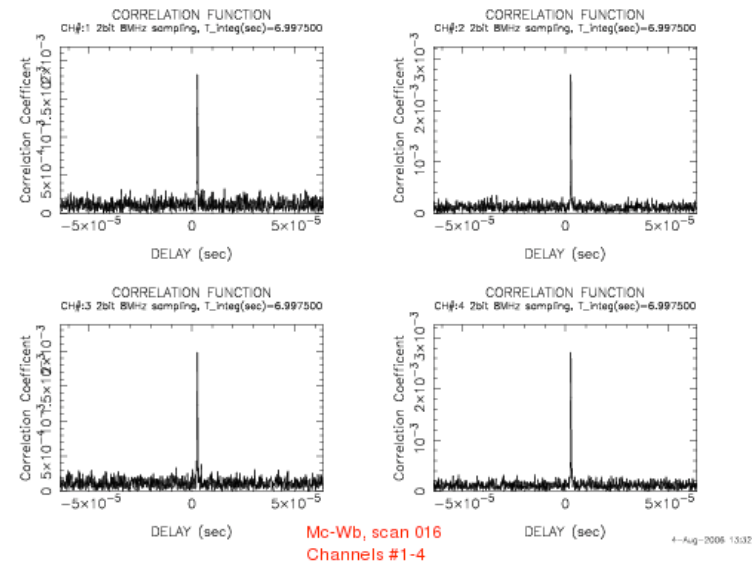
2007 April 24

A new era in VLBI astronor

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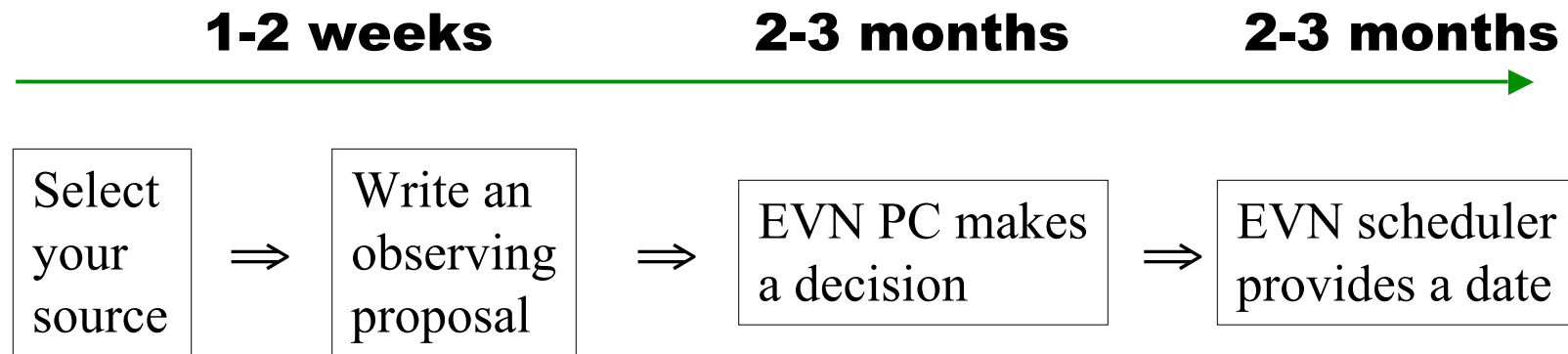
# The reliability

- Disk recording is better quality, but it also provides a way to quickly check telescope performance: ftp tests
- 2-4s data at 256 Mbps  $\Rightarrow$  64-128 MB files, may be transferred through the Internet!
- Data processed by a software correlator developed in NICT, Japan



- Since late 2004 there are regular ftp tests during EVN sessions.
- The software correlator runs on a PC cluster
- Feedback to telescopes used to take at least a week, now it is a matter of minutes
- OK, let us see what else can we improve...

# VLBI observations timeline



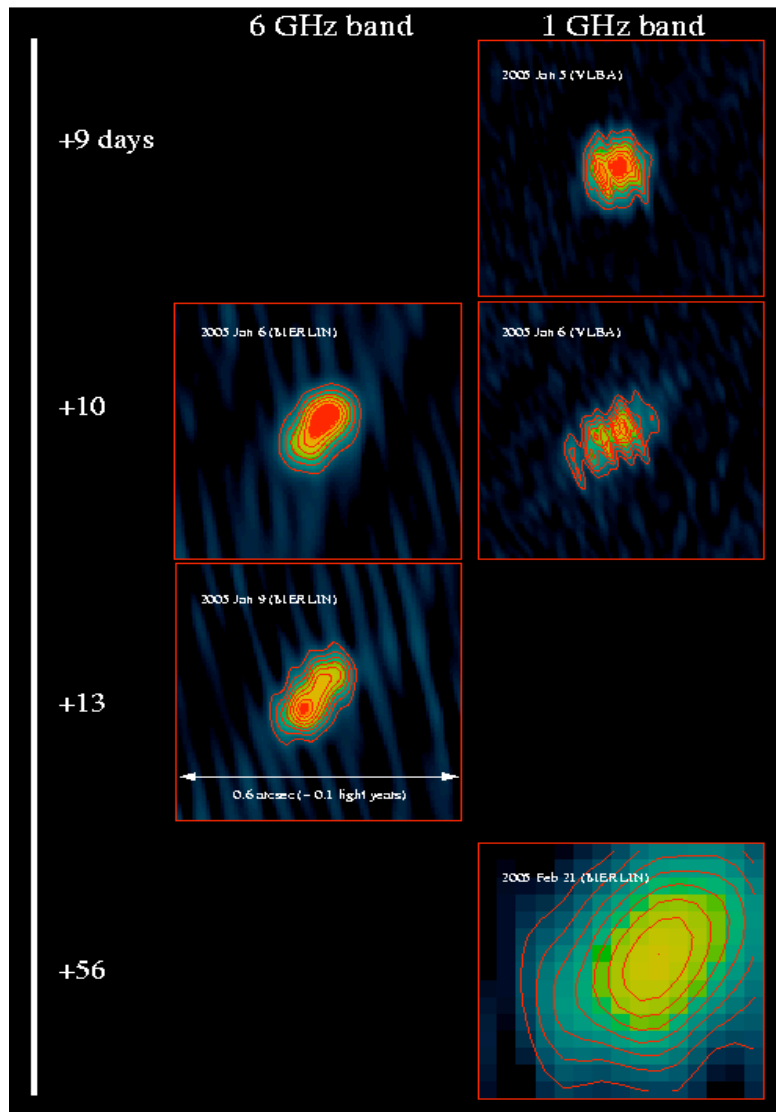
**... another 2-3 months**                      **well, why would you hurry?**

```
graph LR; E[Observe with VLBI] --> F[Data correlation]; F --> G[Data processing]; G --> H[Publishing results];
```

The diagram shows a horizontal timeline with a green arrow pointing right. The text above the arrow indicates a duration of '... another 2-3 months' and a rhetorical question 'well, why would you hurry?'. The steps are: 'Observe with VLBI', 'Data correlation', 'Data processing', and 'Publishing results', connected by right-pointing arrows.

**THIS MUST CHANGE!**

# Target of Opportunity projects



An example: the huge flare of SGR1806-20

- SGR1806-20 is a soft gamma-ray repeater a neutron star with very strong magnetic fields, a **magnetar**
- Produced the greatest explosion witnessed by humans in our Galaxy, on 27 December 2004
- Observations with various instruments, also VLBI (with the VLBA array)
- Could not image reliably because of lack of known calibrator in the vicinity of the target!

Is there a way to do these projects more efficiently?  
Is there a way to get the data and analyze them quickly???

*Fender et al. (2005), MNRAS 367, L6*

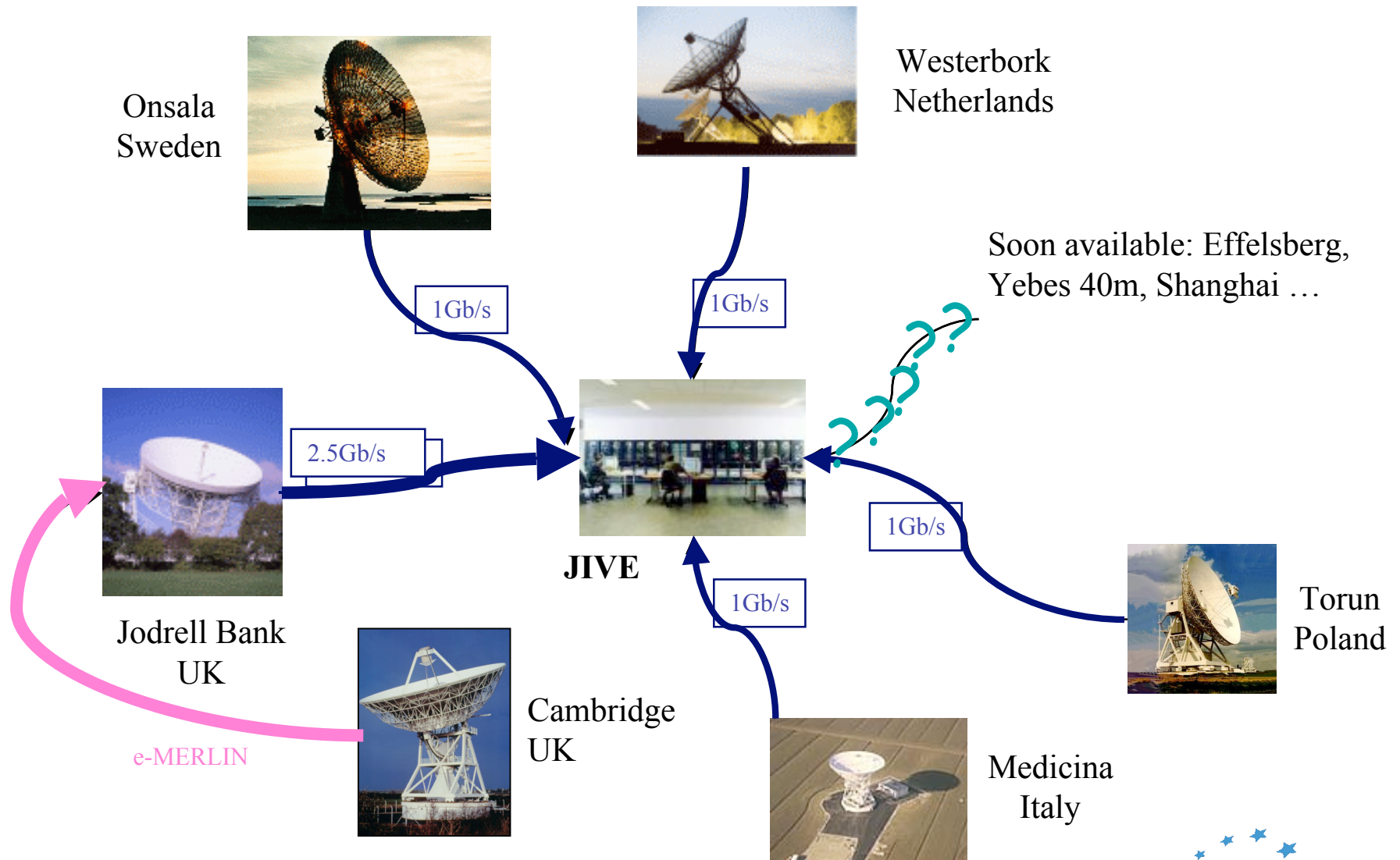
# What is EXPReS?

- EXPReS = Express Production Real-time e-VLBI Service
- Three year project, started March 2006, funded by the European Commission (DG-INFSO), Sixth Framework Programme, Contract #026642
- Objective: to create a distributed, large-scale astronomical instrument of continental and inter-continental dimensions
- Means: high-speed communication networks operating in real-time and connecting some of the largest and most sensitive radio telescopes on the planet

<http://www.expres-eu.org/>



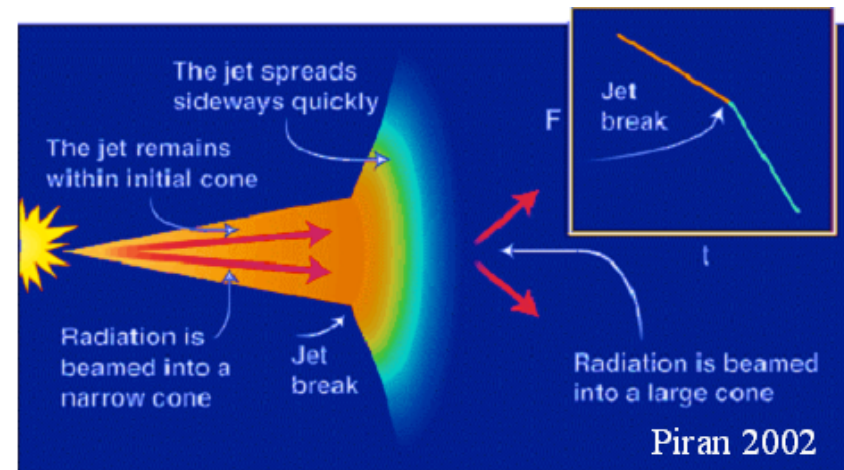
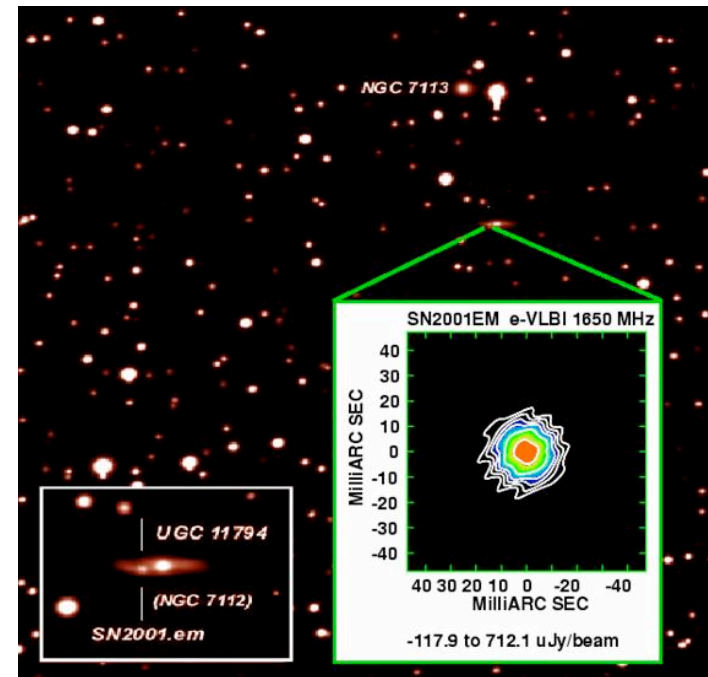
# Telescopes connections (early 2007)



# The first e-VLBI science result (continuum)

- SN2001em was discovered on 15 September 2001 in UGC11794 galaxy (Pepenkova 2001).
- Redshift  $z \sim 0.02$  corresponding to a distance of 80~Mpc.
- Filippenko and Chornok (2001) classified it as type Ib/c, most likely Ic.
- Exceptional radio and X-ray luminosities (off axis GRB, developing late radio emission due to jet break?),
- Not quite a 1 mJy radio source
- EVN observations: Cm, Jb2, On, Tr, Wb (128Mbps), +Arecibo 300m (64 Mbps) at 18cm, on 2005 Mar 11
- Tentative detection ( $4.5 \sigma$ ) of the first real faint target with e-VLBI

*Paragi et al. (2005), MSAIt 76, 570*



# e-VLBI activities in 2006

- There are regular e-VLBI test observations in every six week (on average)
- Normal operations at 256 Mbps (Cm, Jb2, Mc, On, Tr, Wb)
- Fringes to several telescopes at 512 Mbps, most recently to Mc
- 24h time is pre-allocated for science observation during each e-VLBI test
- Observing proposals may be submitted two weeks before the advertised date
- More info at <http://www.evlbi.org/evlbi/evlbi.html>

## Science projects observed in 2006:

Cyg X-3, 20 Apr/18 May, 128 Mbps, Tudose et al.

GRS1915, 20 Apr, 128 Mbps, Rushton et al.

LSI +61.303, 256 Mbps, 26 Oct, Perez-Torres et al.

Algol, 26 Oct/14 Dec, 256 Mbps, Paragi et al.

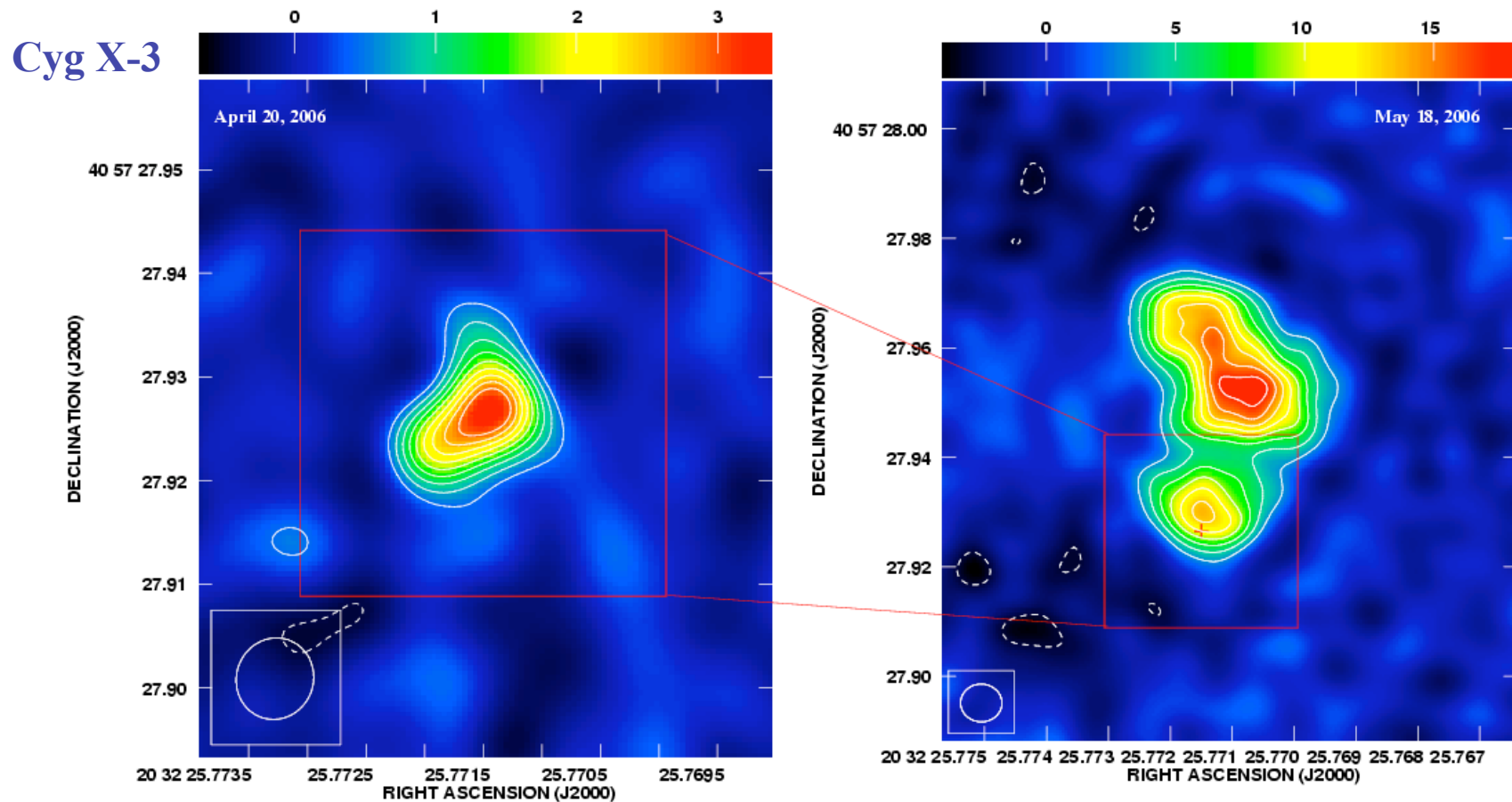
Calibrators near M81, 14 Dec, 256 Mbps, Brunthaler et al.

INTEGRAL microquasar candidates, 14 Dec, Pandey et al.

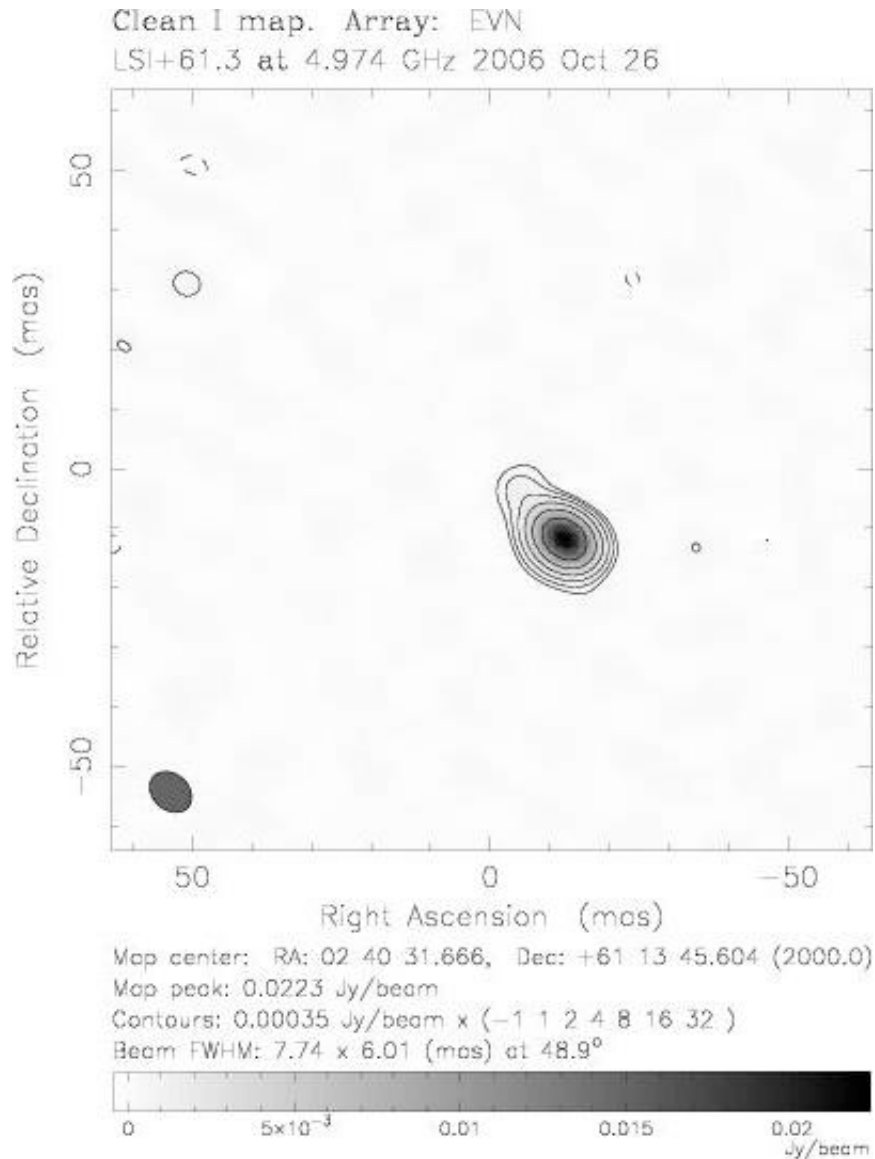
# First refereed journal papers:

*Rushton et al. (2007), MNRAS 374, L47*

*Tudose et al. (2007), MNRAS... very soon*



# LSI 61+303 preliminary results:



Gamma-detected XRB candidate;

Recent VLBA observations  
(Mioduszewski et al.) suggest  
interacting pulsar wind...

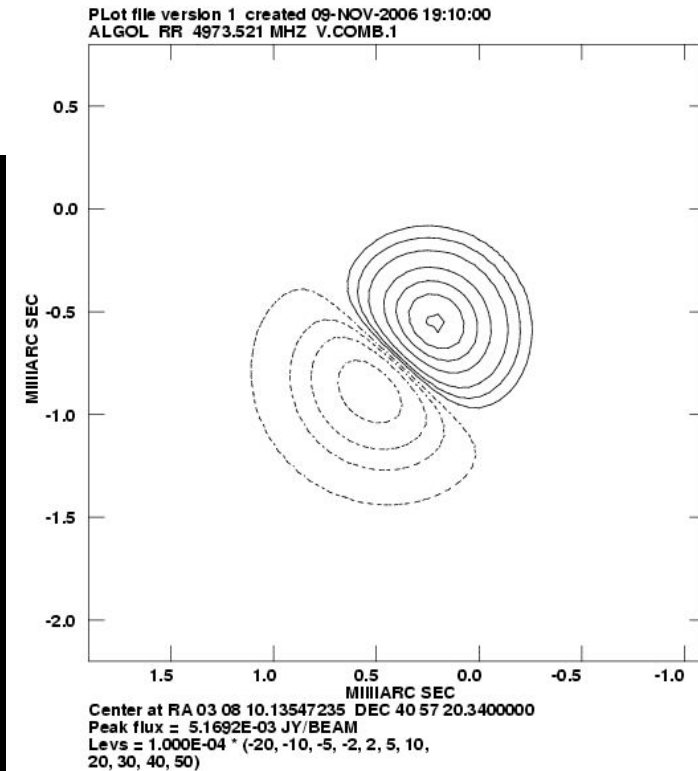
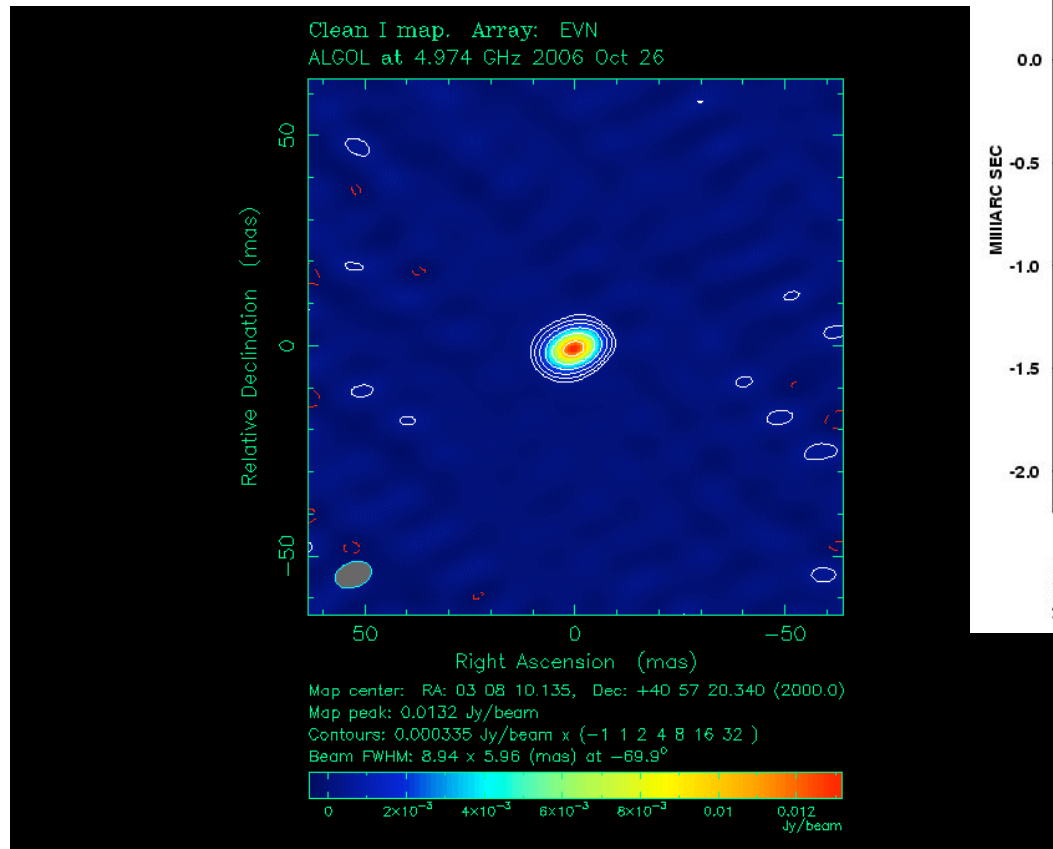
e-EVN, MERLIN, CHANDRA  
Observations on 26 October 2006

*Perez-Torres et al. (in prep.)*



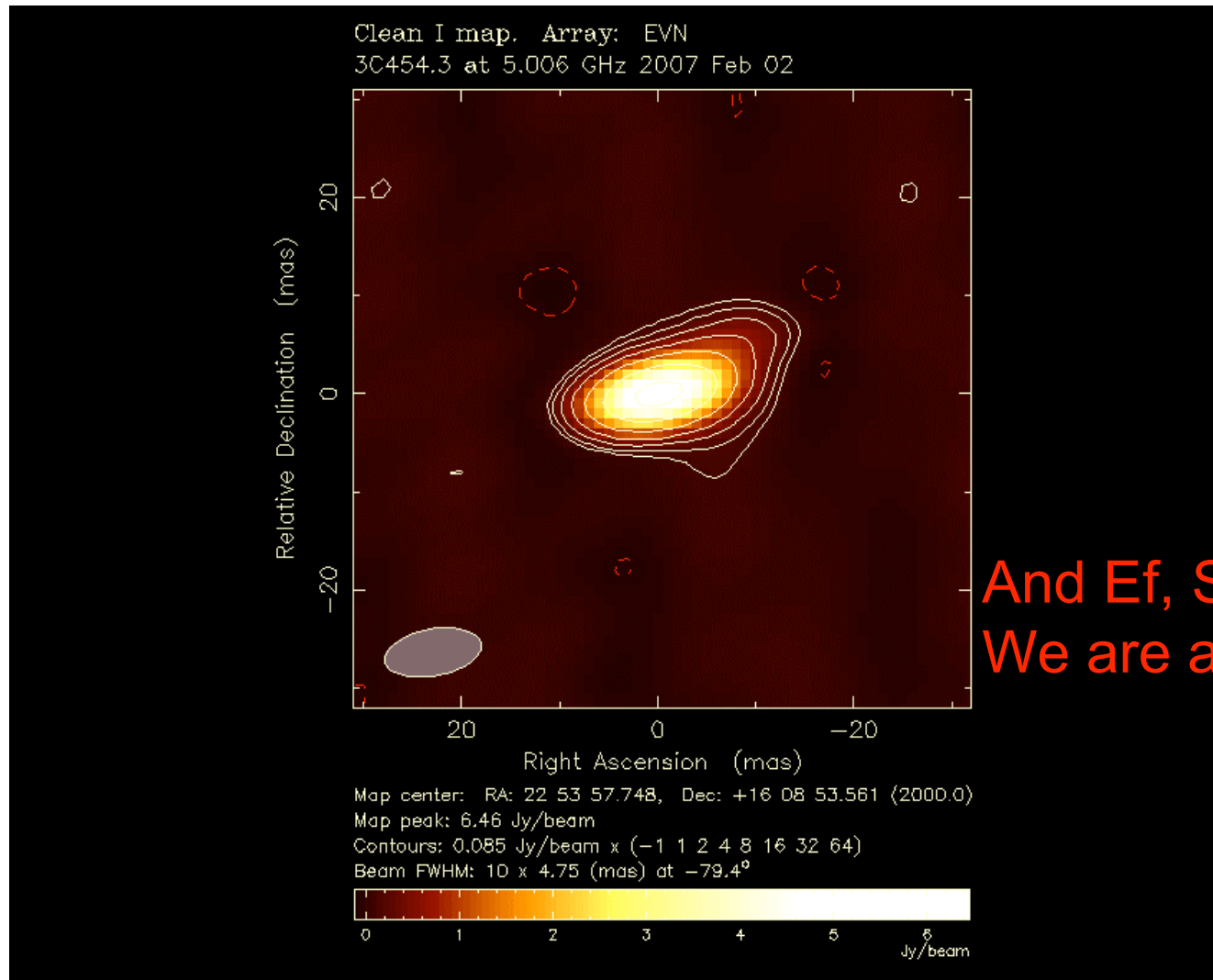
# Algol preliminary results:

26 October 2006



*Csizmadia et al. (in prep.)*

# 512 Mbps e-VLBI run



1/2 February 2007

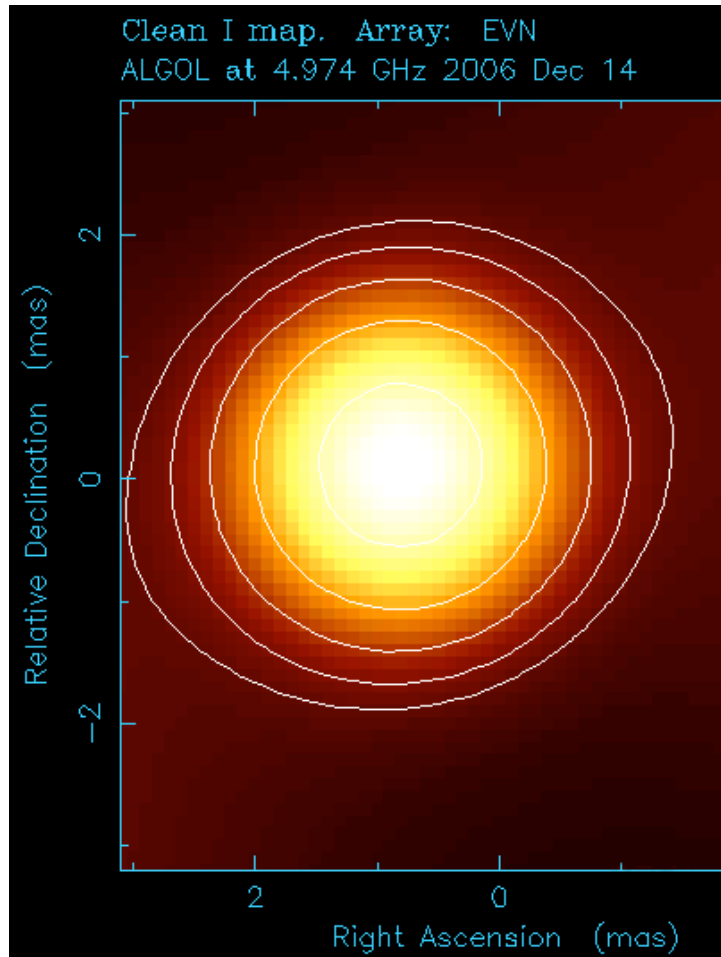
(Cm),Jb2,On,Mc,Wb

And Ef, Sh, Yb ... coming:  
We are almost there!!!

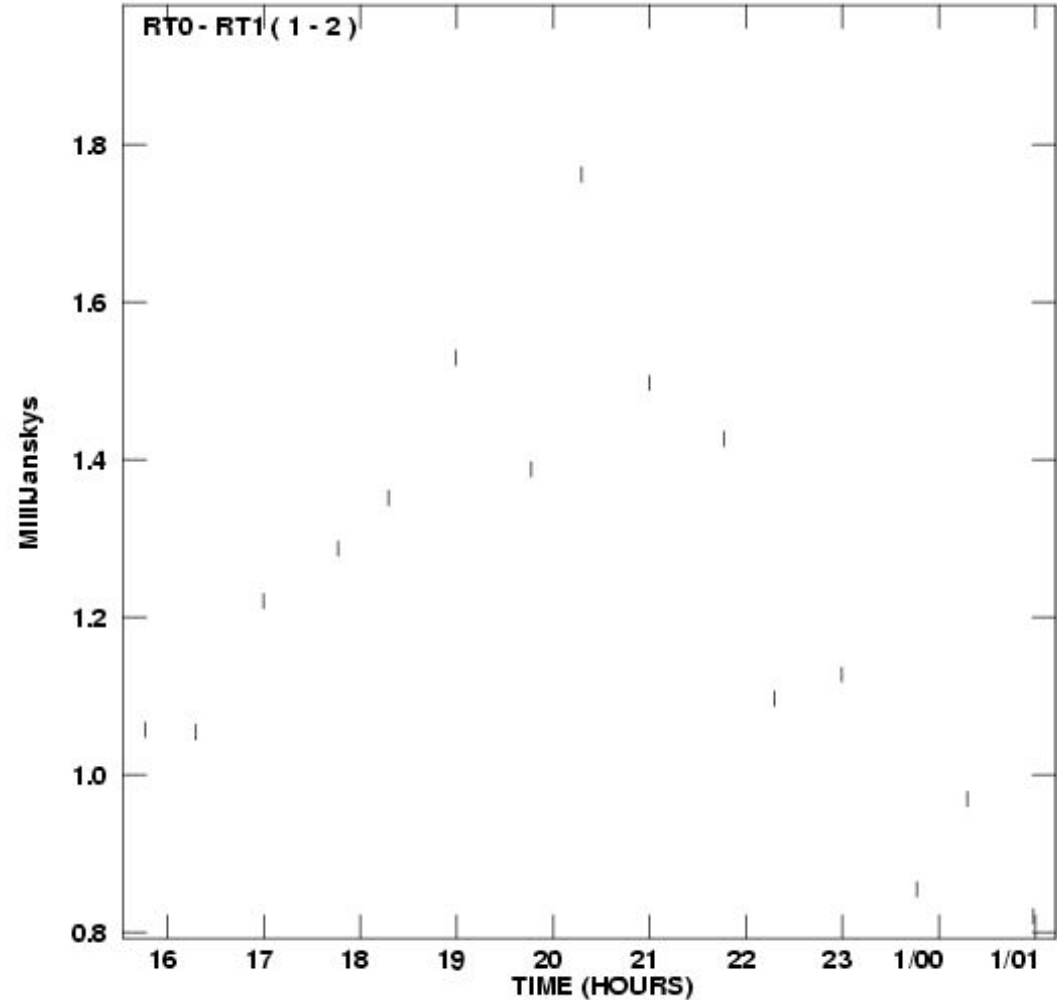
# Westerbork – e-EVN as a unique instrument

- Westerbork Synthesis Array data may help in calibration (amplitude, linear and circular polarization)
- May help to confirm detection/non-detection of weak targets
- Could be used as a ‘built-in’ alert instrument for the e-EVN
- Wb can help improving coordinates of new transients... (note that there are cases when we cannot afford time to get this information from an external instrument, e.g. the VLA)
- ...with **adaptive scheduling**, this could be immediately used for the VLBI array
- Not to mention the additional information on the very large-scale structure (which we normally waste when we do not reduce Wb data along with the EVN)

# Back to Algol, 14 December 2006 run:



Plot file version 2 created 19-APR-2007 15:23:48  
Amplitude vs Time for ALGOL.TBAVG.1 Vect aver.  
IF 1 CHAN 1 STK U



# Summary –is e-VLBI useful for science?

- First of all, it works! Significantly reduces science turnaround time.
- e-VLBI is easy and practical for users with little or no experience with VLBI. Data analysis pipeline does most of the work! Additional PI support is available at JIVE.
- **Westerbork + e-EVN** will be a unique instrument: calibration, WSRT alert for e-VLBI, position information on new transients
- Yes, these developments are mainly driven by technical/logistical considerations, but there is the possibility of doing new type of VLBI science ...
- ...especially when **adaptive scheduling** is becoming a reality
- May contribute significantly to follow-up observations of GLAST Galactic transients and maybe GLAST GRBs.



# Want to propose e-VLBI observations?

e-VLBI proposals must be submitted through a web proposal tool.

e-VLBI proposals are just like other EVN proposals, but you must take additional care to

- justify properly why urgency is needed (target of opportunity, e.g. known transient flares, or need to check calibrators quickly for another project, taking part in an observational campaign)
- give accurate coordinates (sub-arcsecond accuracy)
- specify all the details of the proposed observations – schedule will be made by JIVE staff
- contact **Bob Campbell** ([campbell@jive.nl](mailto:campbell@jive.nl)), to find out if preferred correlation mode is OK
- keep in mind the limited resolution ( $\sim 6 \times 8$  mas at 6cm), uv-coverage and sensitivity at the moment
- When 512 Mbps is possible and Effelsberg joins the array, the sensitivity will improve greatly; with Shanghai joining during 2007, the resolution will be better as well
- Be ready to travel to JIVE for quick data processing
- Think creatively, find projects that make appropriate use of this unique service!