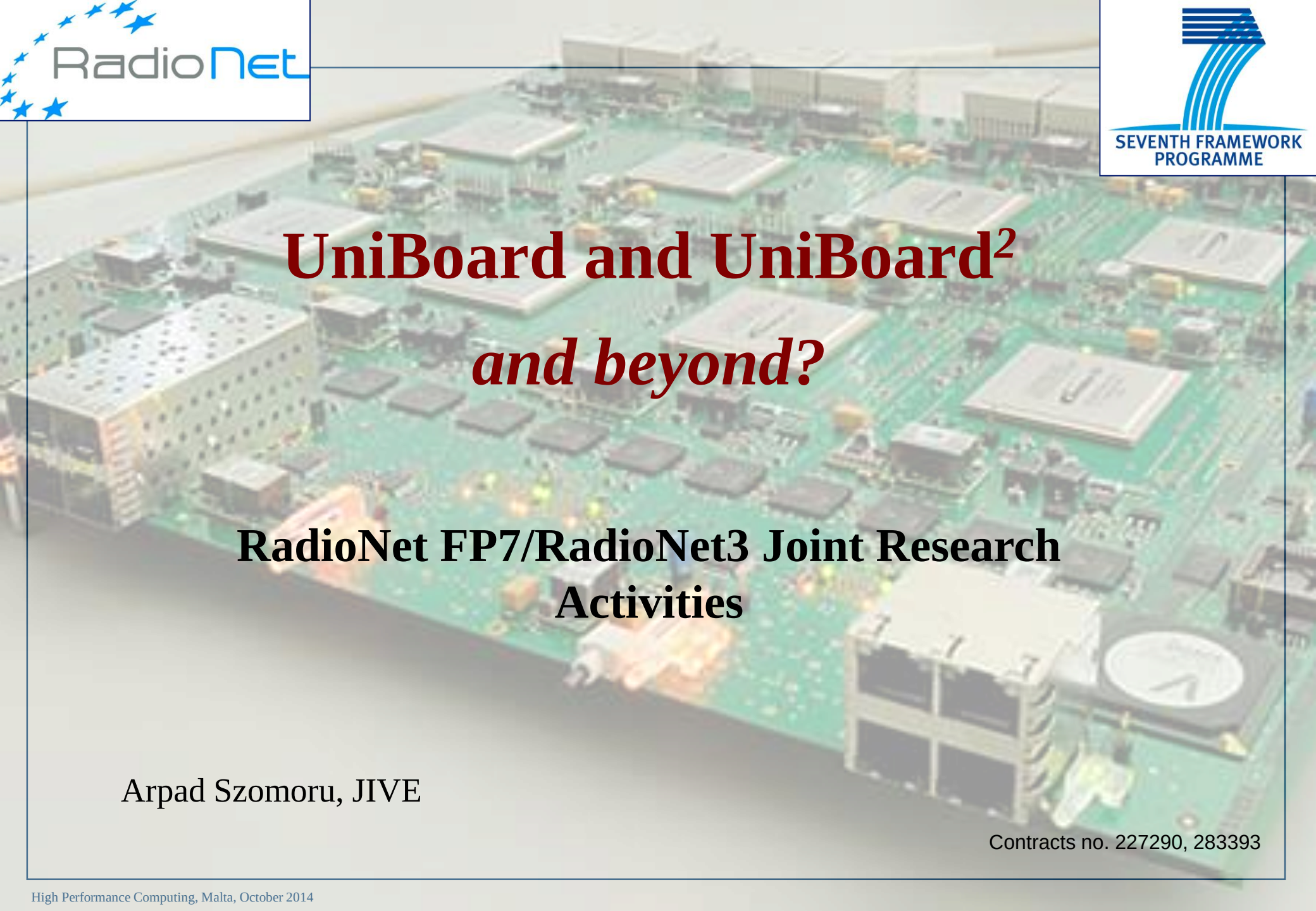


UniBoard and UniBoard^2

and beyond?

RadioNet FP7/RadioNet3 Joint Research Activities

Arpad Szomoru, JIVE

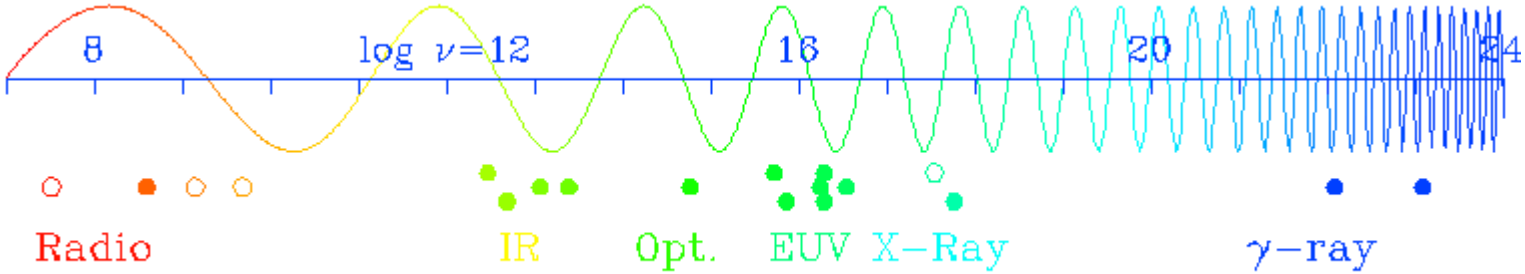
Contracts no. 227290, 283393

Joint Institute for VLBI in Europe

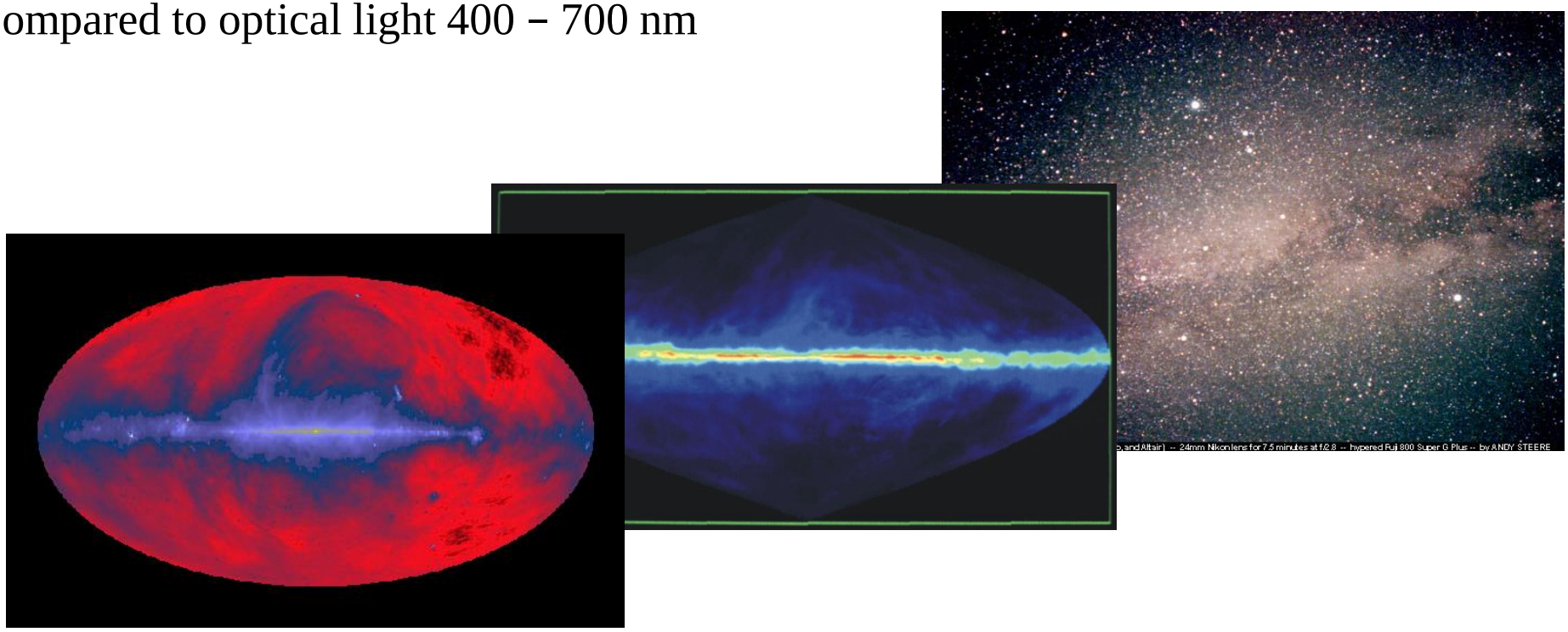
JOINT INSTITUTE FOR VLBI IN EUROPE

- Promote and advance the use of VLBI for astronomy
  - Central correlation for European VLBI Network
  - User support
  - Innovation
- Base budget from partners in 8 countries:
  - China, France, Germany, Italy, Spain, Sweden, United Kingdom, the Netherlands, South Africa
  - hosted by ASTRON
  - About to become an ERIC
- No R&D budget!
  - All R&D financed through EC and NWO projects

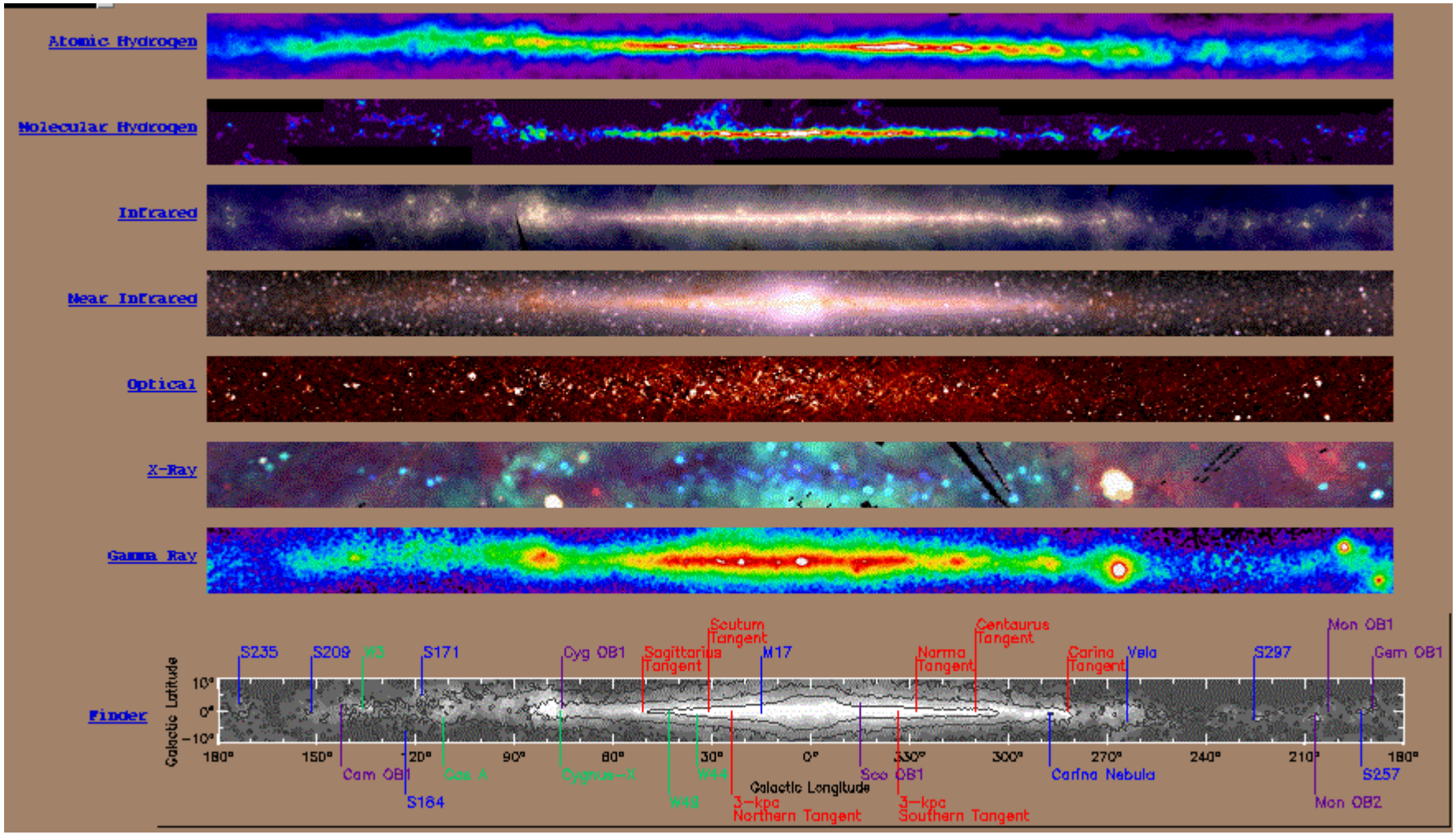
Radio vs. Optical Astronomy



- Radio waves with λ of 0.7mm to 90cm
- Compared to optical light 400 – 700 nm



And more wavelengths

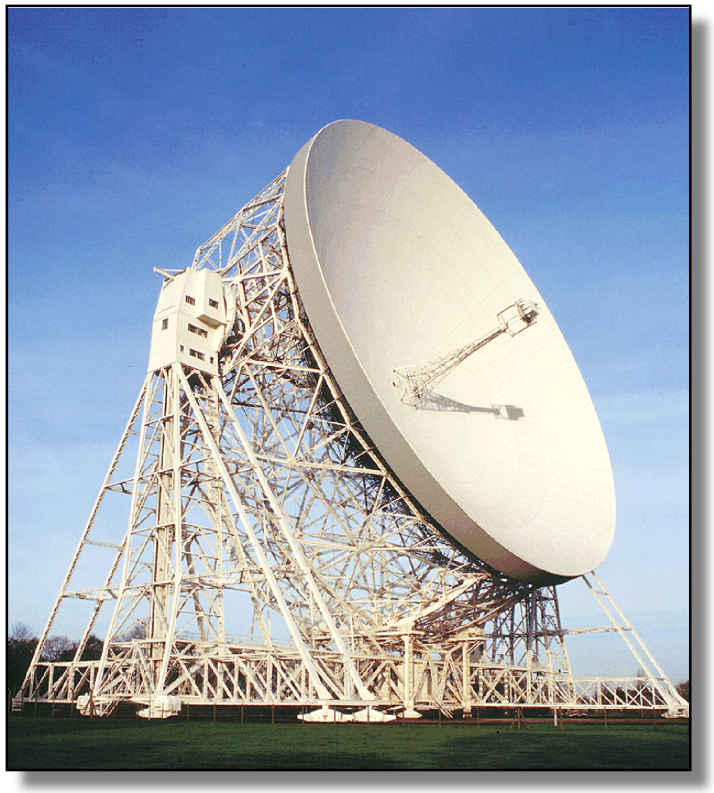


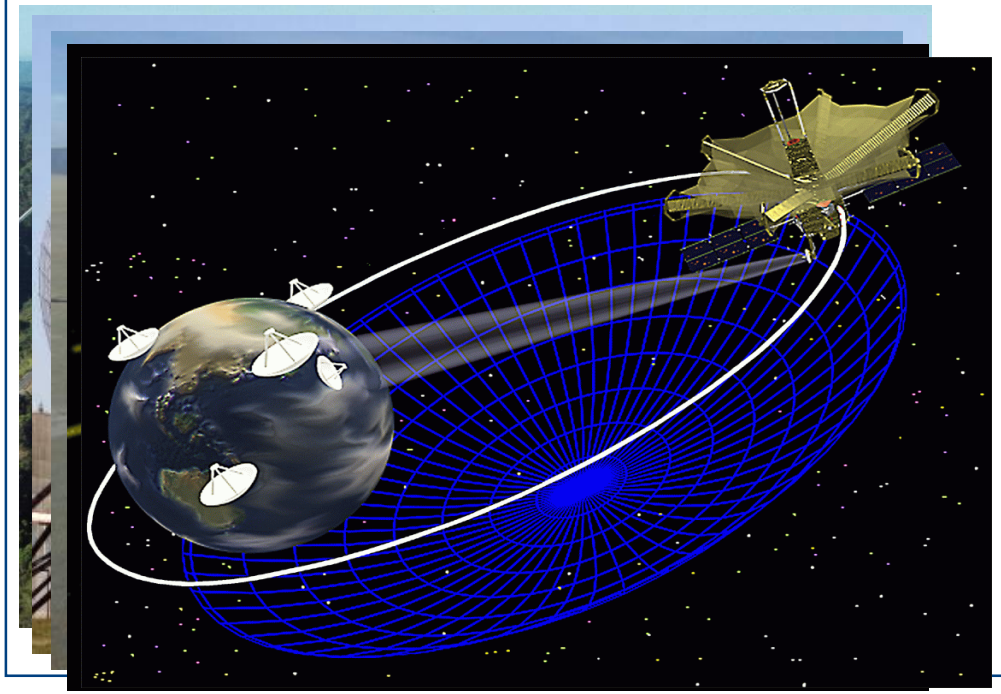
Radio Astronomy and VLBI

- Radio emission from astrophysical sources can be detected against the sky with telescopes larger than a few meters
- Resolution scales with size and wavelength:

$$q \approx \frac{l}{D}$$

- Solution: build larger telescopes!
  - Only goes so far....

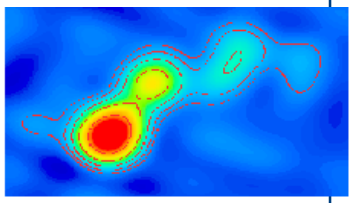


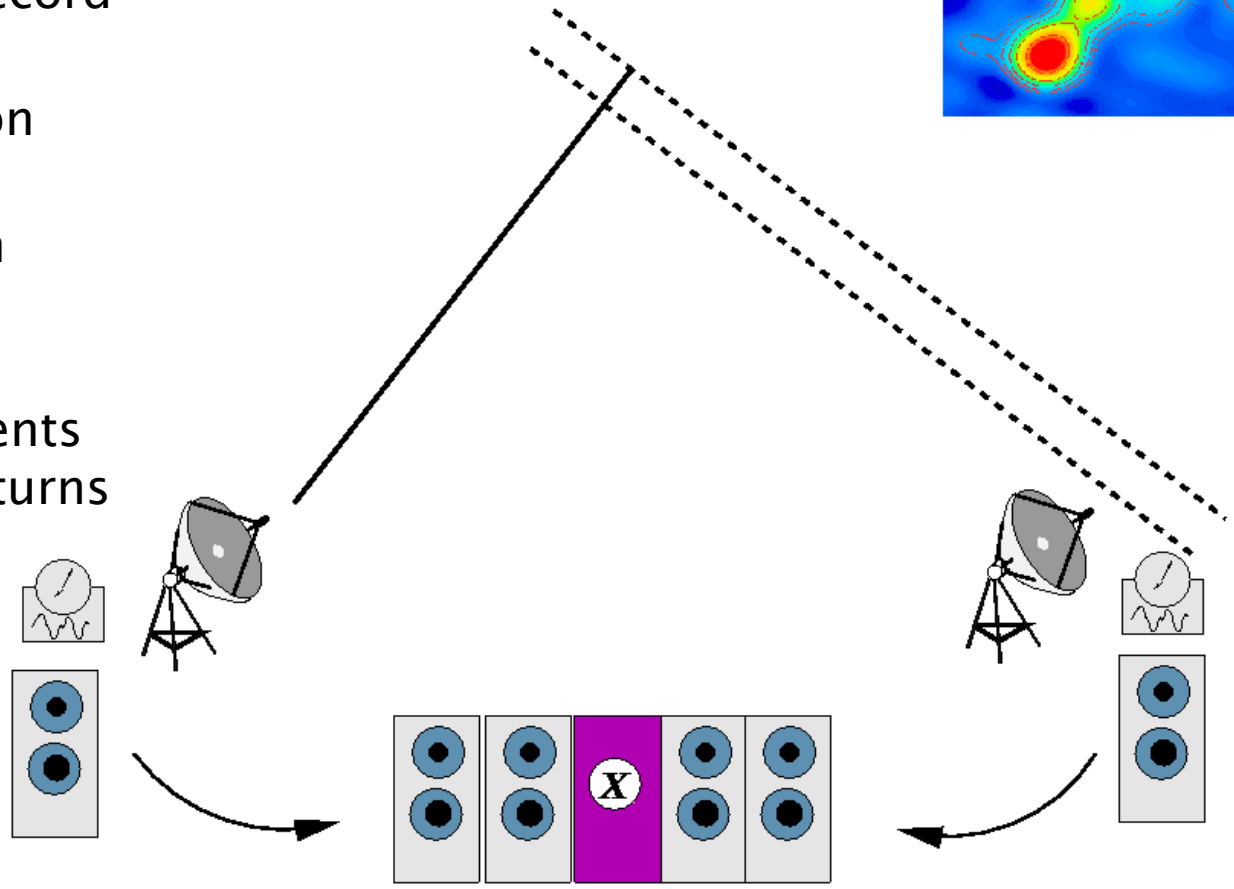


- Or: combine series of telescopes into radio-interferometer
- Not necessarily on same continent
- Or planet…

Principle of VLBI

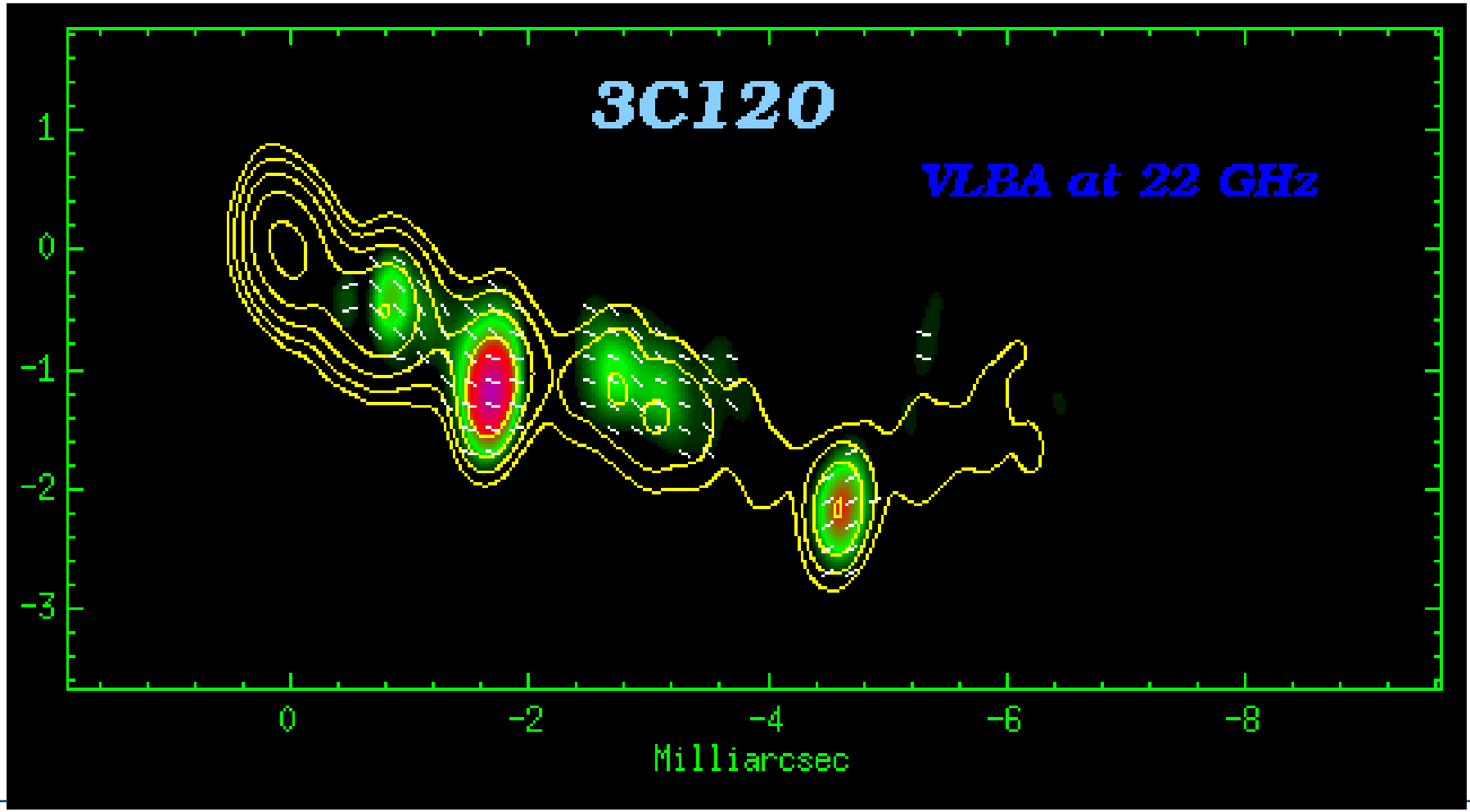
- Record same frequency band simultaneously at N telescopes
- Use best possible local clocks and frequency standard
- Sample and digitize and record (on magnetic medium)
- Find all ½N(N−1) correlation coefficients at correlator
- Compute back image from thousands of these measurements
- Builds up Fourier components of sky image as the earth turns





Astronomy in motion

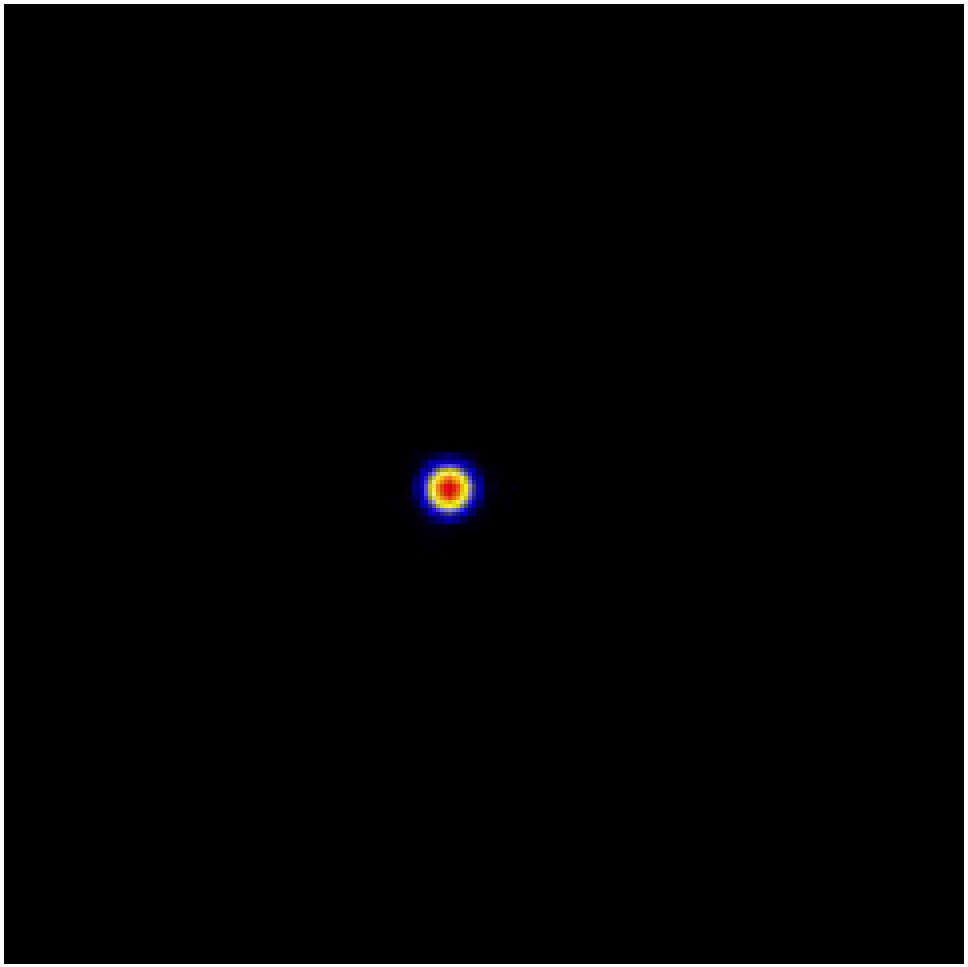
- A resolution which is high enough to see things move at cosmological distances
  - Like quasars at the edge of the Universe

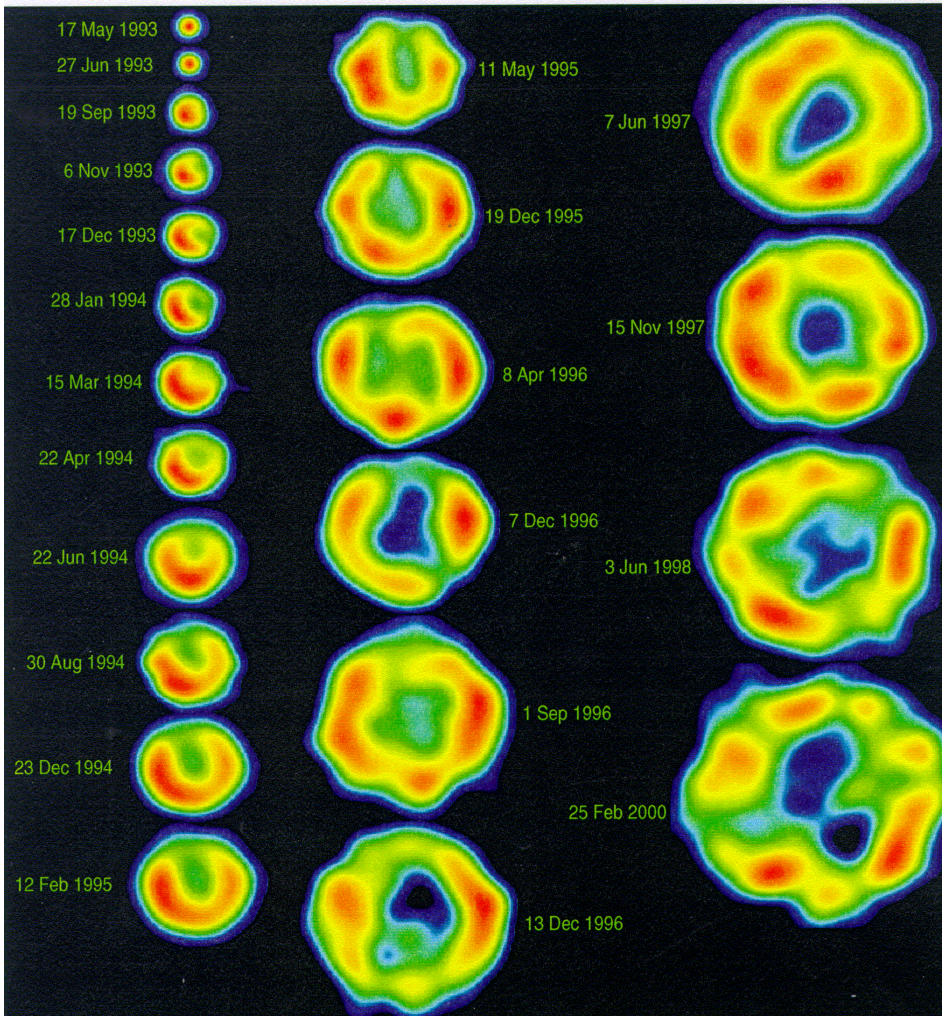


Exploding stars in other galaxies

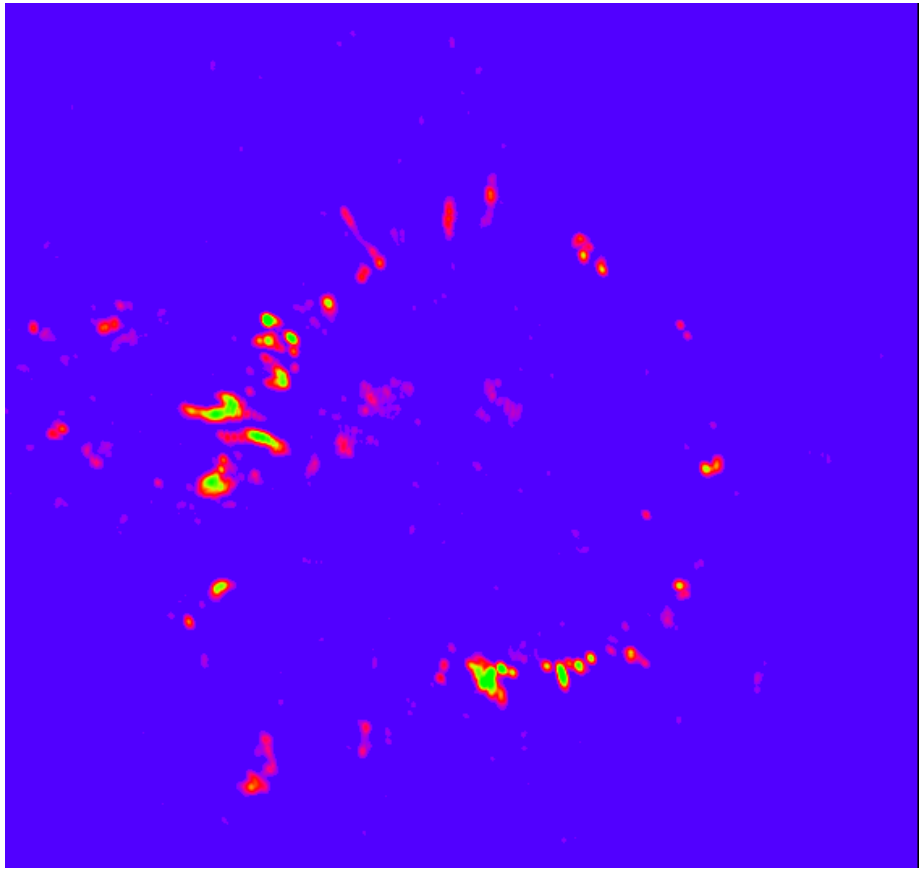
JOINT INSTITUTE FOR VLBI IN EUROPE

supernova in M81 (1993)





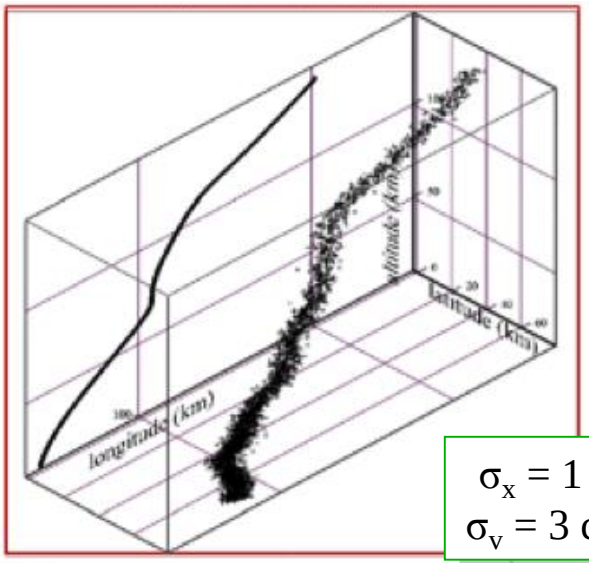
Mass loss around an old star



The birth of the JIVE software correlator

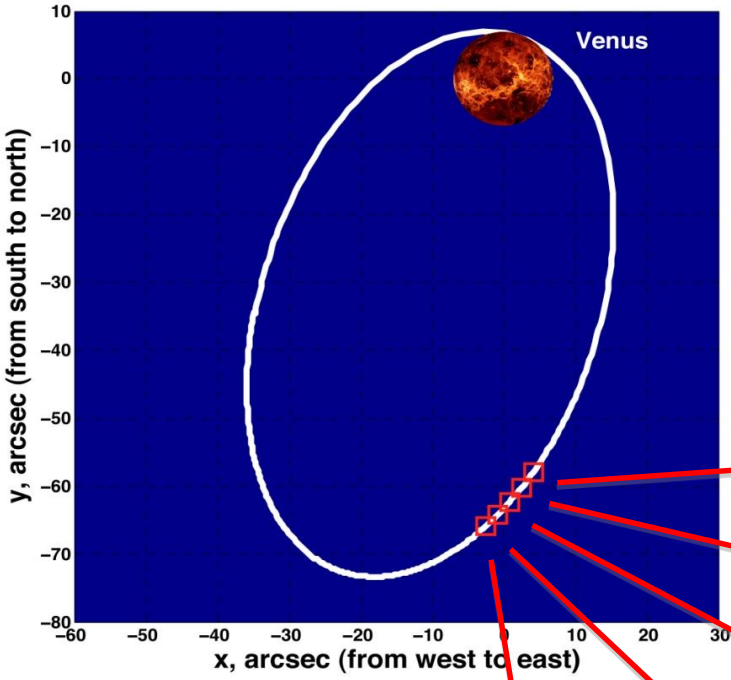
- Tracking of Huygens probe during descent to Titan
- Ad hoc use of the Huygens uplink carrier signal at 2040 MHz
- 17 radio telescopes around the world
- Salvage of Doppler experiment
  - *Special purpose, narrow band software correlator*

3D Huygens descent trajectory

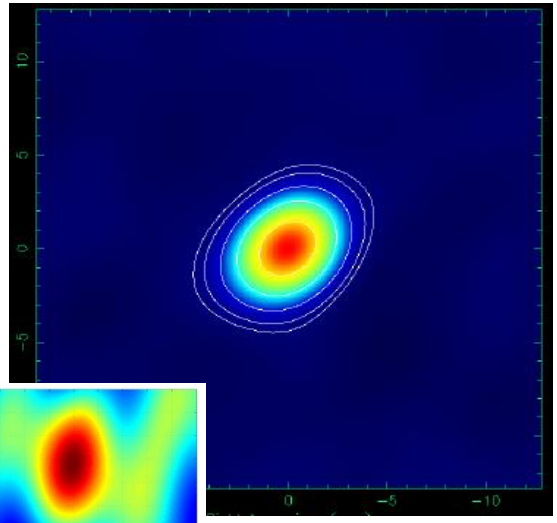


σ_x = 1 km
σ_v = 3 cm/s

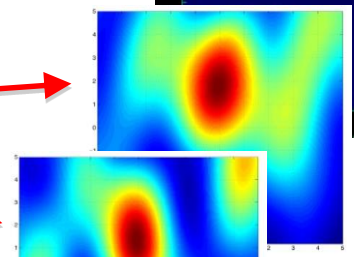
Space Science: tracking of VEX



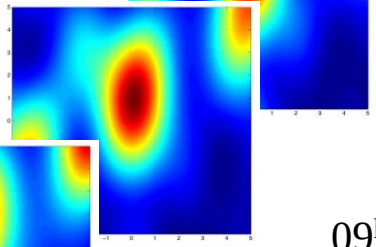
8.4 GHz
2011.03.28



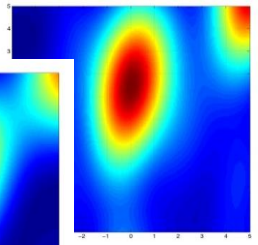
09^h05^m TDB



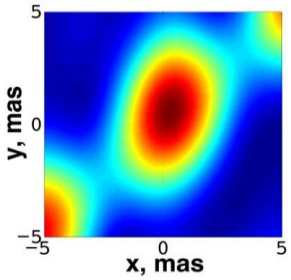
09^h30^m TDB



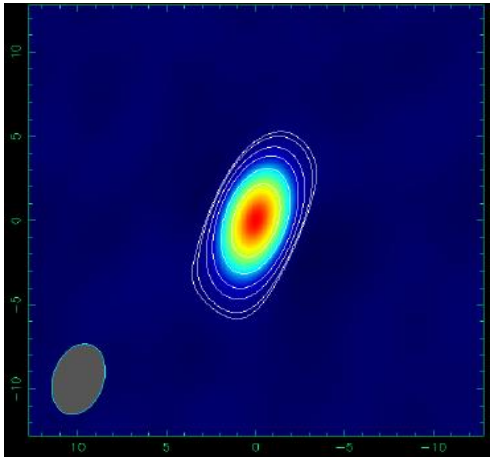
09^h55^m TDB



10^h20^m TDB



10^h45^m TDB



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

VLBI then

First transatlantic VLBI, Onsala, Sweden, 1968

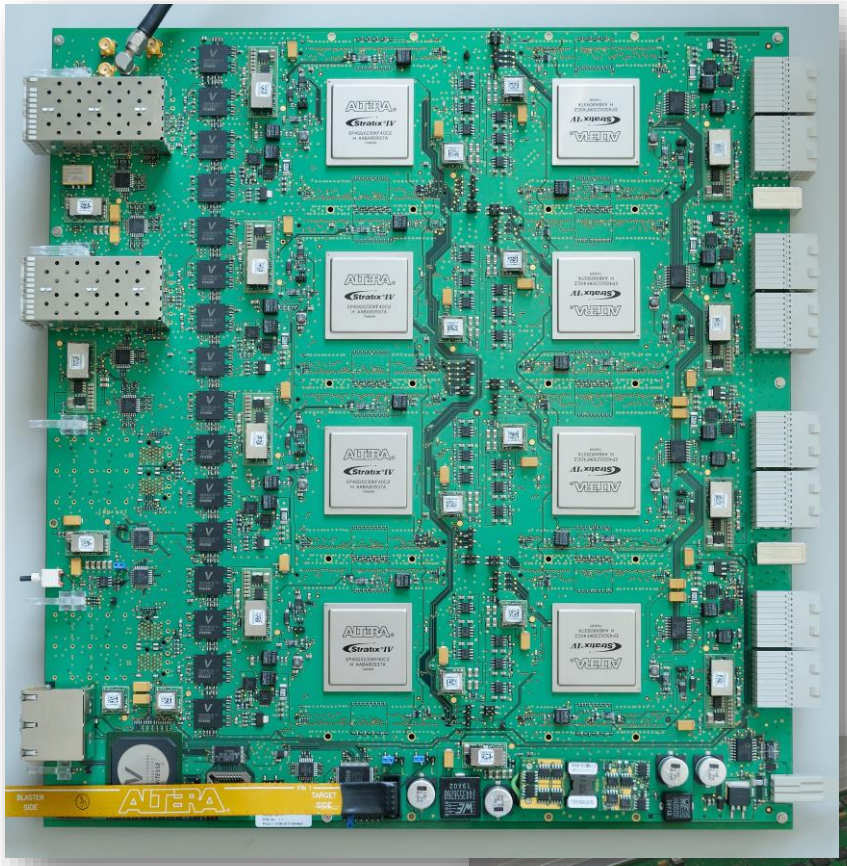
And now


Metsahovi
Onsala
Jodrell Bank
JIVE
Ventspils
Cambridge
WSRT
Torun
Medicina
Effelsberg
Sheshan
Urumqi
Yebes
Noto
Arecibo
ATCA
Mopra
TIGO
Hartebeesthoek
Parkes
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).

UniBoard: project setup

- UniBoard: Joint Research Activity in RadioNet FP7
  - Kick-off January 2009
- 7 partners at first, 2 joined in later
  - JIVE, ASTRON, INAF, Bordeaux, Orleans, UMAN, KASI
  - Followed by Oxford and ShAO
- Board development + four separate applications
  - VLBI correlator
  - digital backend
  - pulsar binning machine
  - RFI mitigation for pulsar binning
- Followed by
  - APERTIF beamformer
  - all-dipole LOFAR correlator
  - Filterbank for Effelsberg pulsar machine

Results: hardware



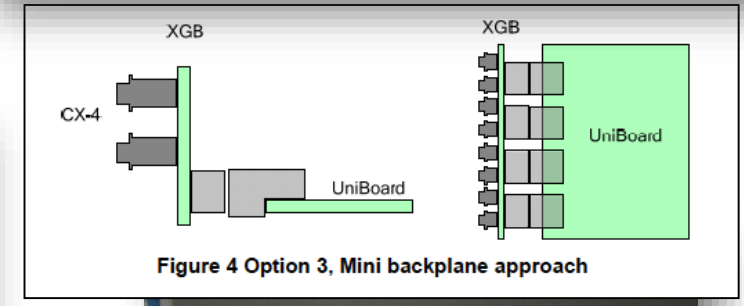
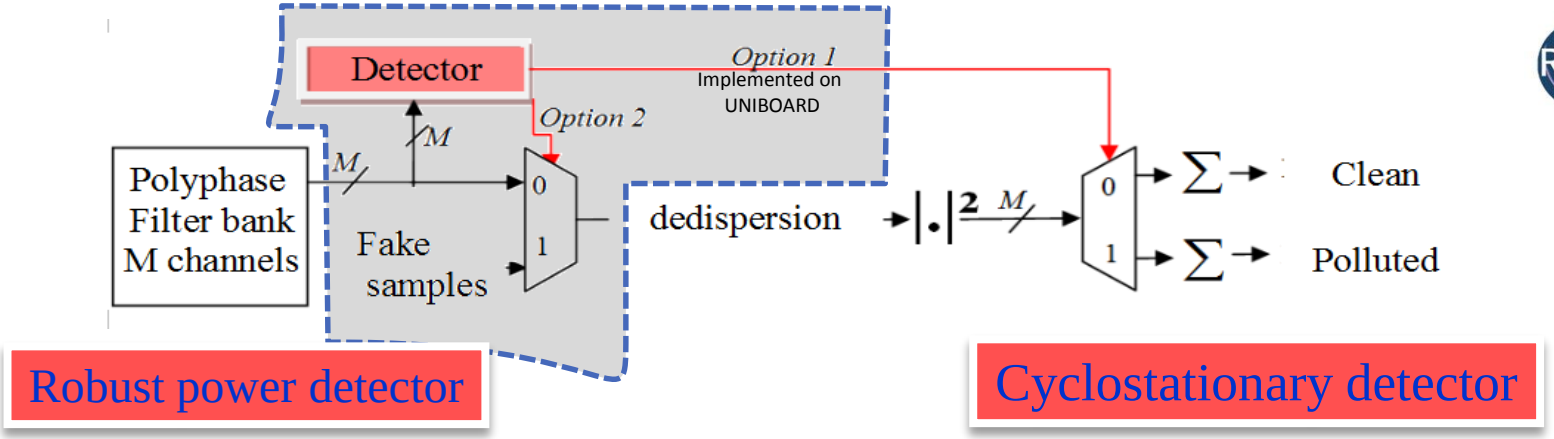
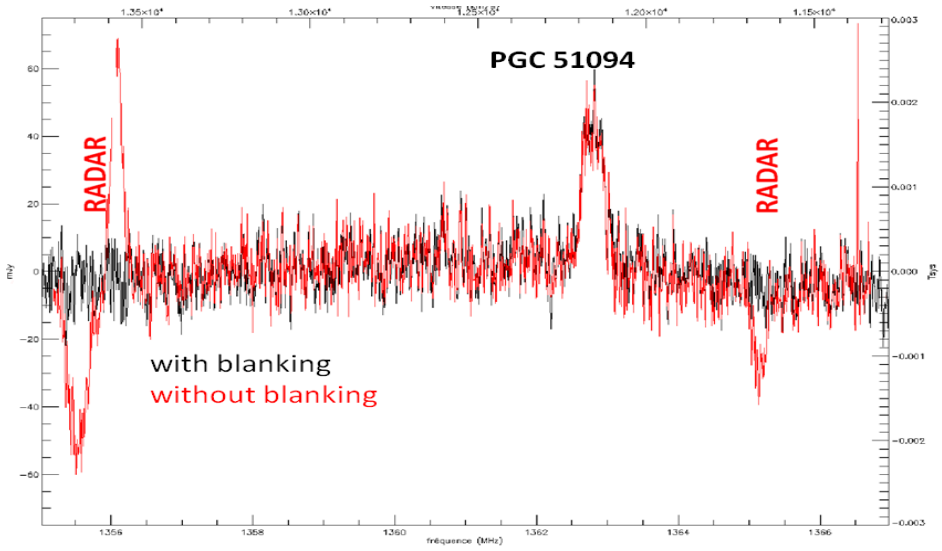


Figure 4 Option 3, Mini backplane approach

And more hardware

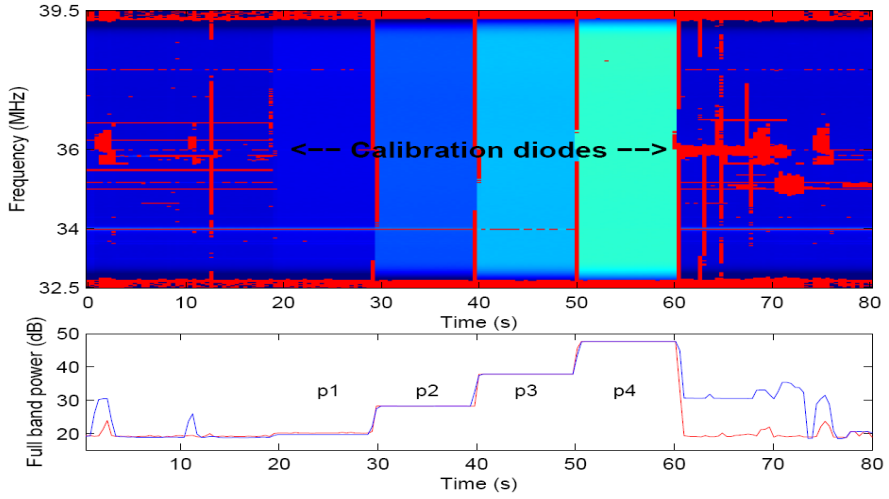
RFI mitigation for pulsar binning machine





Calibration diodes simulating pulsar pulses

Red = flagged T-F slots



Blue= initial total power profile (with RFI)

Red= power profile after blanking

•**D. AIT-ALLAL, R. WEBER, C. DUMEZ-VIOU, I. COGNARD, AND G. THEUREAU**
Rfi Mitigation Implementation For Pulsar Radioastronomy EUSIPCO'10, Aalborg, DN, August 2010.

•**D. AIT-ALLAL, R.WEBER, C.DUMEZ-VIOU**
RFI mitigation at Nancay Observatory: Impulsive Signal Processing in proceedings of "RFI mitigation workshop - RFI2010", PoS(RFI2010)021, 2010

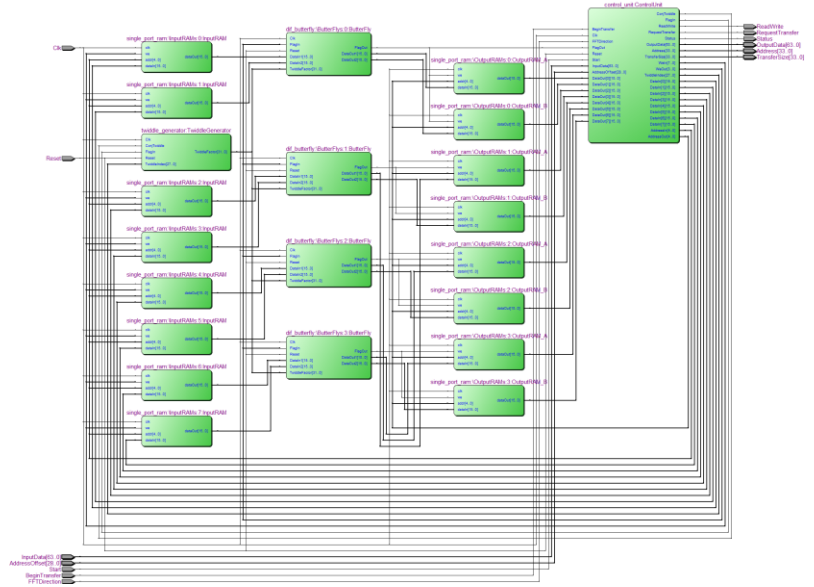
•**R. WEBER, S. CHANGUEL ,C. DUMEZ-VIOU ;C. DUMEZ-VIOU** Real-time RFI mitigation on a new generation digital board: UNIBOARD, JS 2011, Ursi France, 29-30 March 2011, Paris

Pulsar binning machine development

JOINT INSTITUTE FOR VLBI IN EUROPE

FFT module for large transforms:

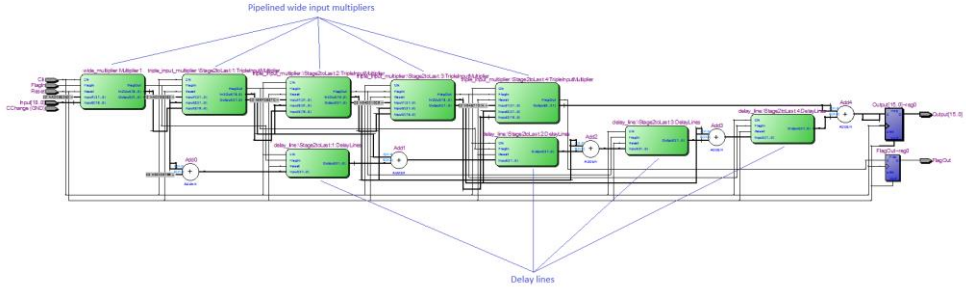
- Technology independent: The core can be used for ASICS or FPGAs from any vendor
- Transform size: From 16 to several Giga points. Limited by the size of the external memory



FFT module with 4 parallel butterfly units

Polynome module for pulsar timing and dedispersion coefficients calculation:

- Completely customisable at compile time via a number of constants
- MATLAB script for auto pre-processing of the coefficients and generating a VHDL package for them
- Minimal use of multipliers

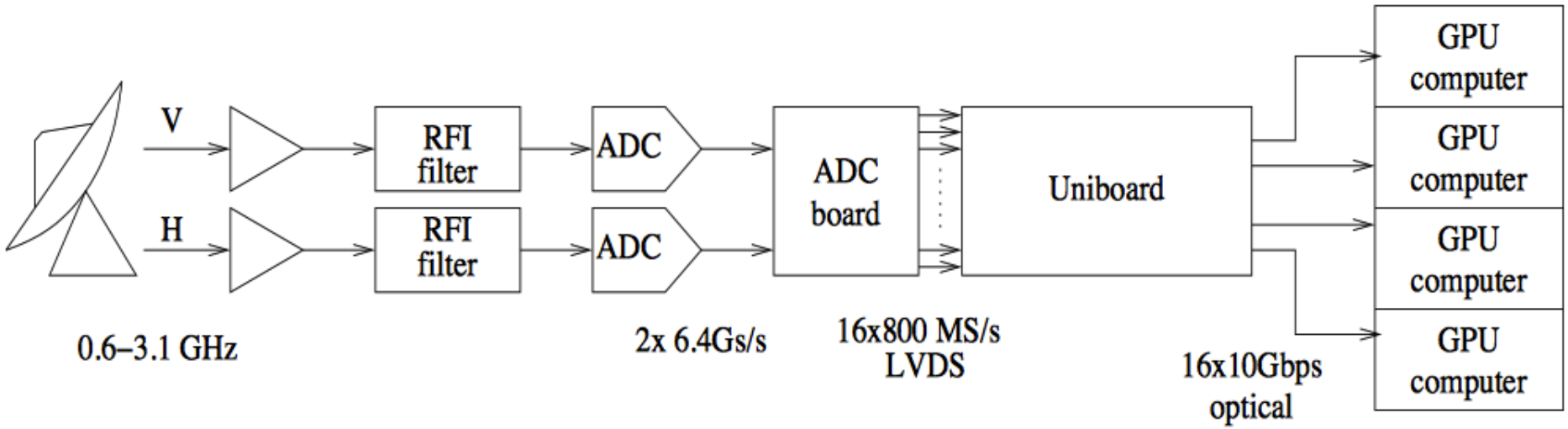


Schematic for order 5 polynome

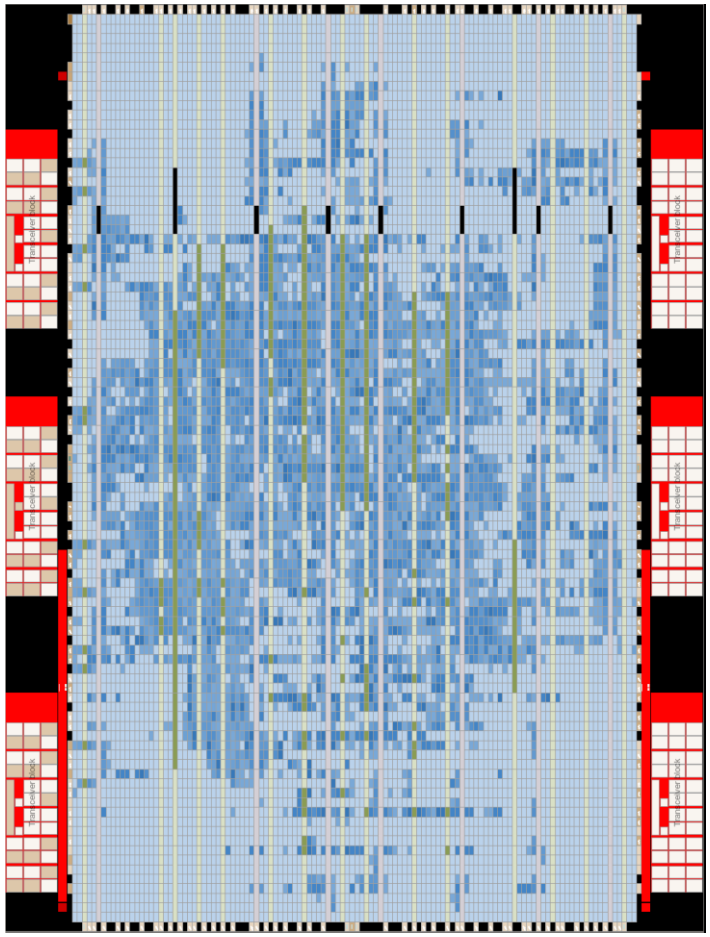
And something we did not think of

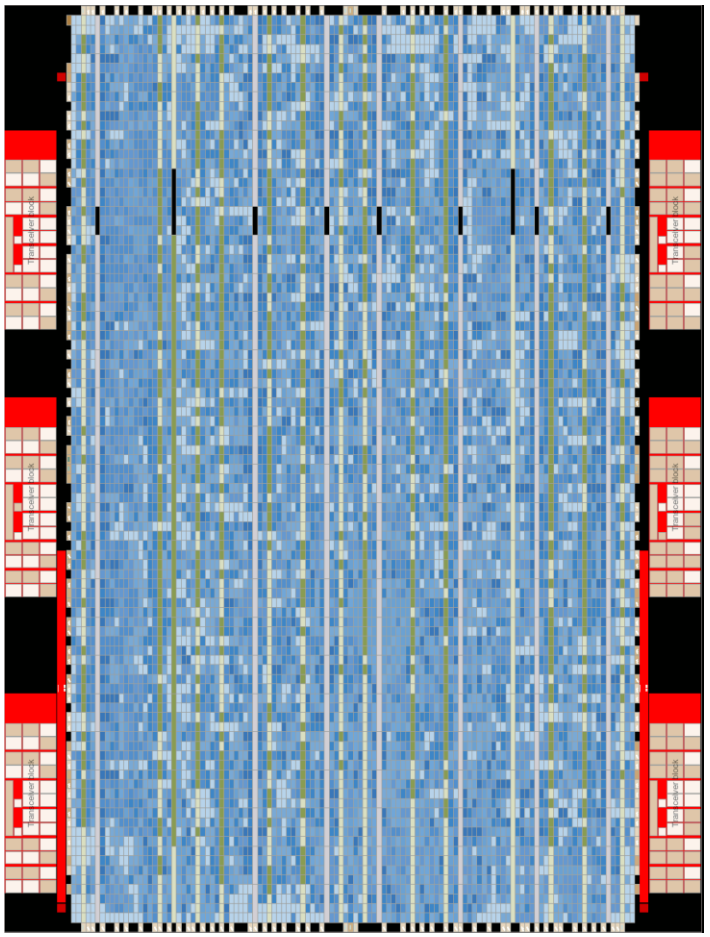
- Wideband pulsar receiver
  - 2 x 3.125 GHz rec. BW
  - 2x1.5 GHz usable BW
  - 144 dBBC bank
- GPU based processor
  - 16 dual core ATI GPUs

Work by G. Comoretto (INAF) and Guenther Knittel (MPG)



Overkill?





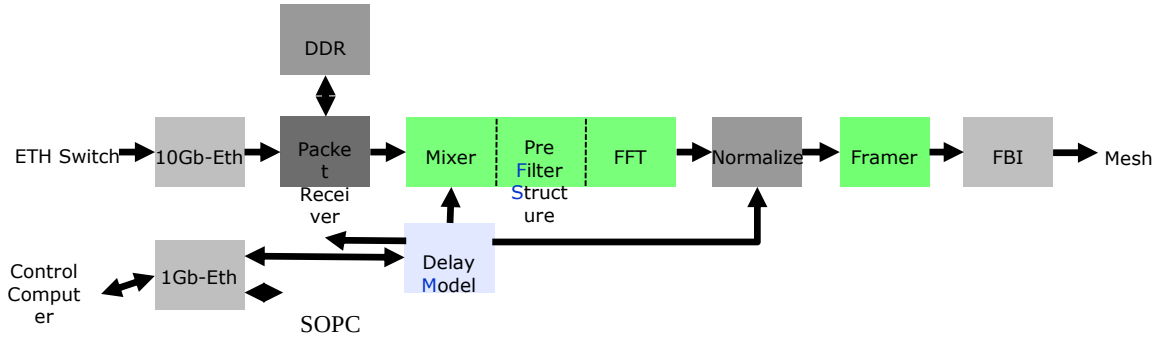
- Back node:
  - 922 multipliers (72%)
  - 2.4 Mbit (16%)
  - 43K (24%) of logic elements
- Front node
  - 1272 multipliers (99%)
  - 1.6 Mbit (11%)
  - 96K (53%) of logic elements

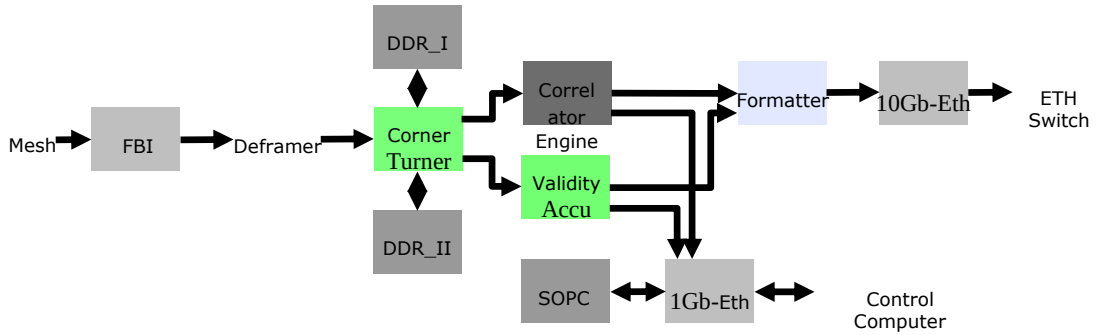
JUC (JIVE UniBoard Correlator)

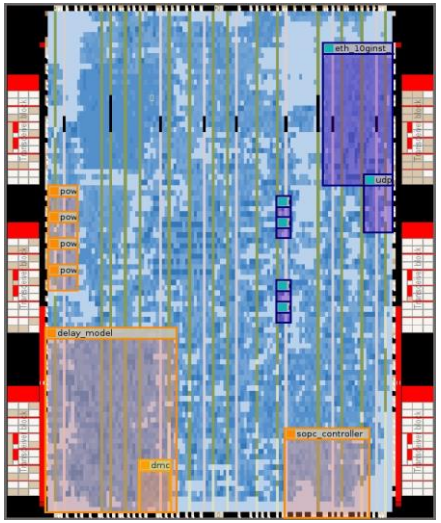
- FX correlator
- Data format: VDIF
- Delay model: CALC10 (same as SFXC), computed on external control computer
- PFB: Blackman Harris window, 6 taps/spectral channel
- VEX driven, with JSON configuration file
- 32 stations, 2 polarizations, 4*16 MHz subbands
- Freq. resolution 15.625 kHz
- 32 MHz personality available, not yet tested
- 1- and 2-bits, 4 and 8 to follow
- All products are calculated all the time, selection at ouput

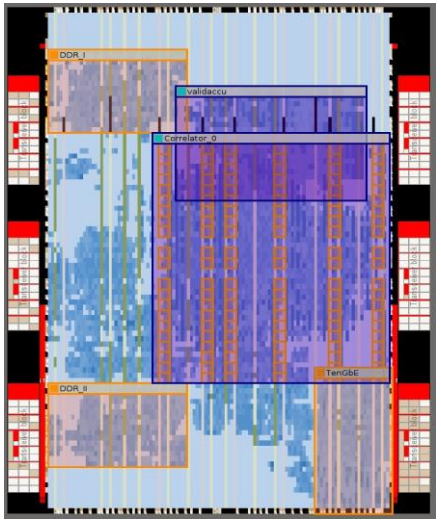
Status

- Front and Back Node designs operational
- 32 MHz design meets timing, needs testing



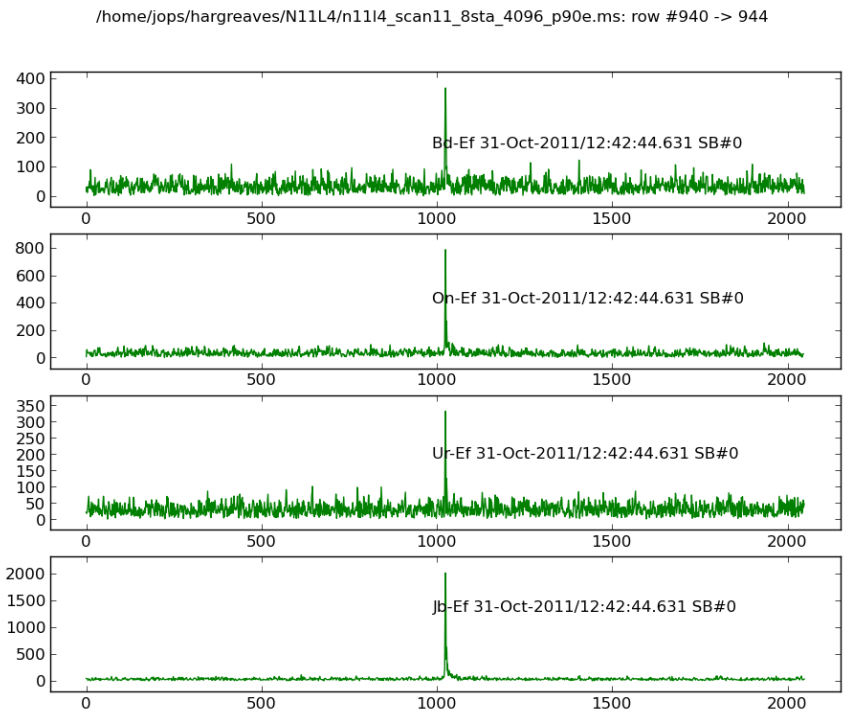


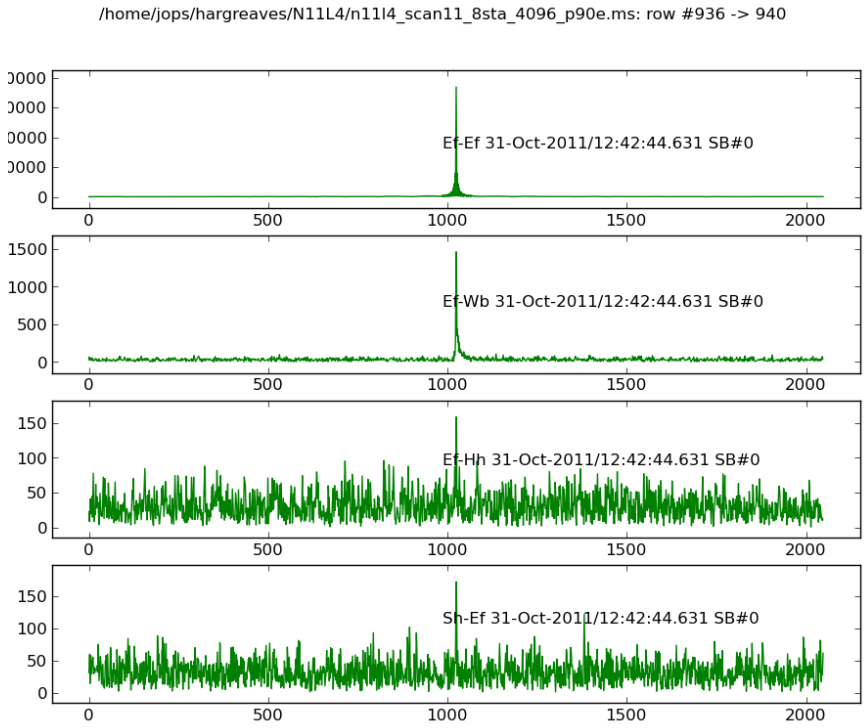




UniBoard Correlator

- One board roughly equivalent to MarkIV hardware correlator
  - At 250 Watt power consumption…
- Real results
- Close to commissioning





Lessons learned

- Number of MUXes definitely not equivalent to available computing power
- Big chips with lots of multipliers are great, but, to use all of them one needs more of everything else: registers, SRAM, routing resources
- Simple things work great on FPGAs, anything slightly more complicated does not
- Plenty of space left on FPGA, but correlator design at (cutting) edge of what is possible
- Modularization of VHDL code blocks for re-use by other parties is only possible in limited cases and for limited functionality
  - And a waste of time in other cases
- But good agreements on level and type of documentation very useful

Next: UniBoard^2

JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE

- Joint Research Activity in RadioNet3, start date July 2012
- Generic hardware complemented by a number of applications
- Consolidate and build on expertise obtained through UniBoard project
- Aimed at large instruments of the future, SKA

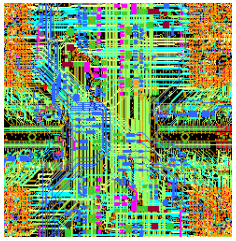
- **Power efficiency** (green computing)
- Complete re-design, using **the newest generation FPGAs**, 20nm?
- **Non-leaded** components
- Possible use of **40GE, 100GE**
- Investigation into effects of **hard-copy** and **partial hard-copy**
- **Tuning of algorithms and firmware design** to minimize power consumption
- **Balancing of system parameters and performance** to minimize power consumption
- **Standardized interfaces and coding conventions** to facilitate sharing and re-use of firmware

UniBoard^2, wishlist

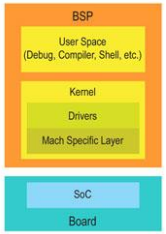
JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE

Local parallel (12) optical interface

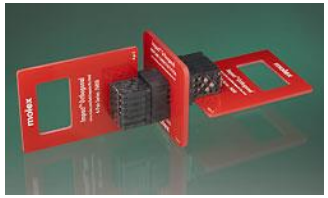
Liquid cooling



Copper mesh @ 14Gbps



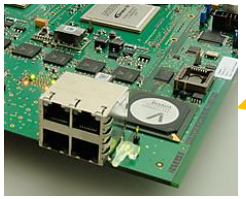
on chip Processor



Orthogonal backplane interface

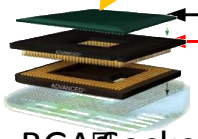
QSFP+ 2x4x10/25Gbps

DDR4 SODIMM

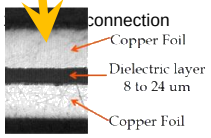


On board 1GbE switch

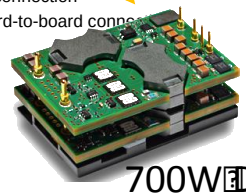
Green Assembly



BGA Socket

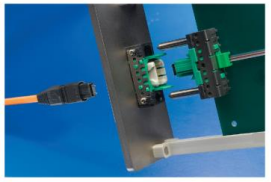


Embeded passives

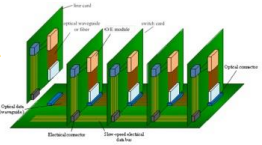


700W DC/DC

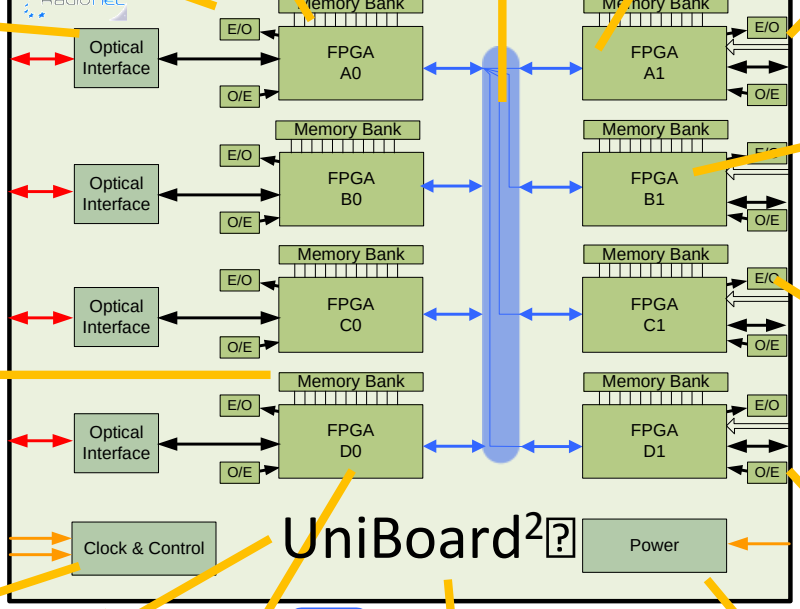
Stratix VI 20nm FPGA



Optical Interface



Optical backplane



UniBoard^2

JOINT INSTITUTE FOR VLBI IN EUROPE

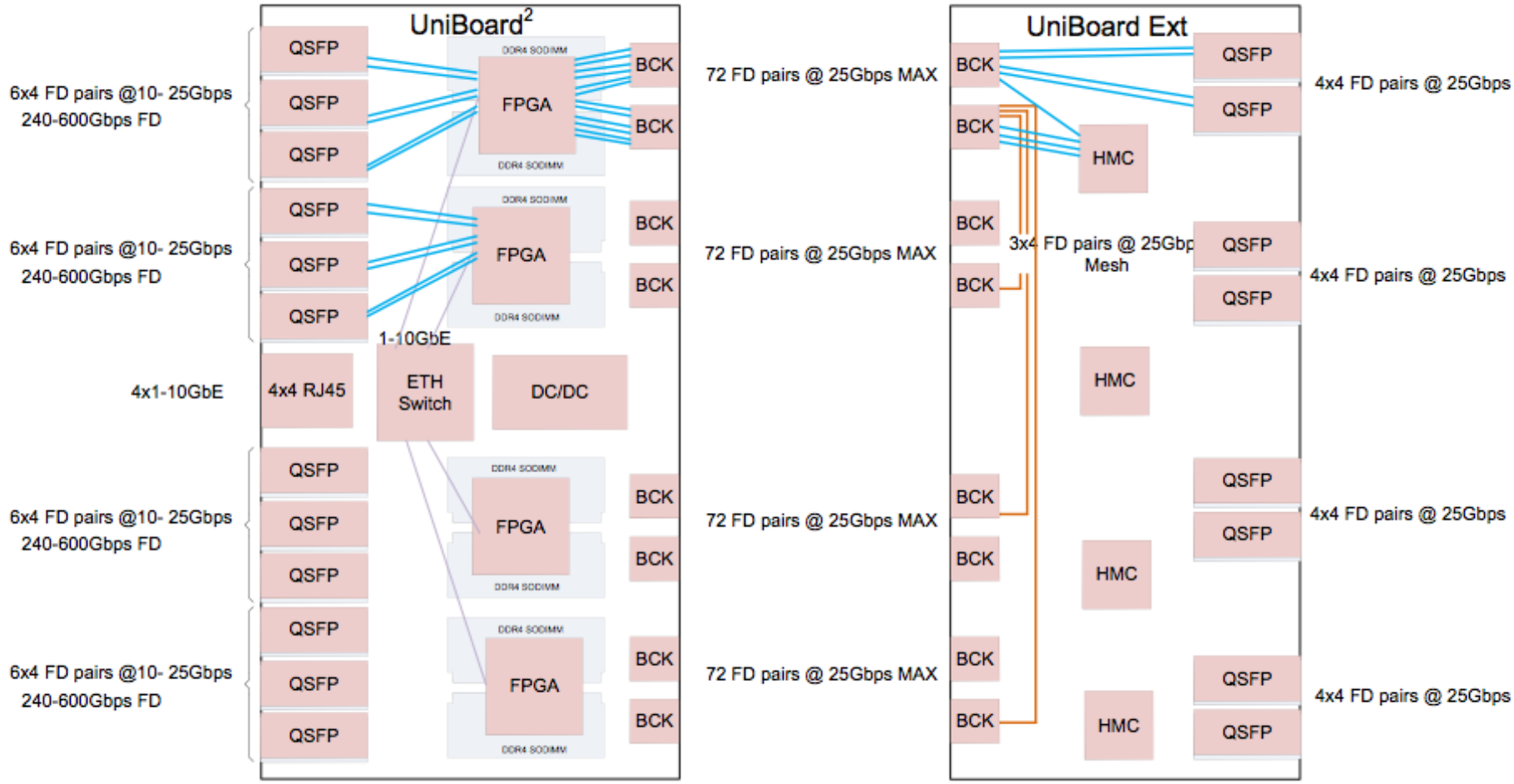
- Prototype on 20nm (Altera Arria10)
- Production on 14nm (Altera Stratix10) (>10000 multipliers)

- Focus was on SKA AAlow beam forming
  - SKA AAlow correlator?

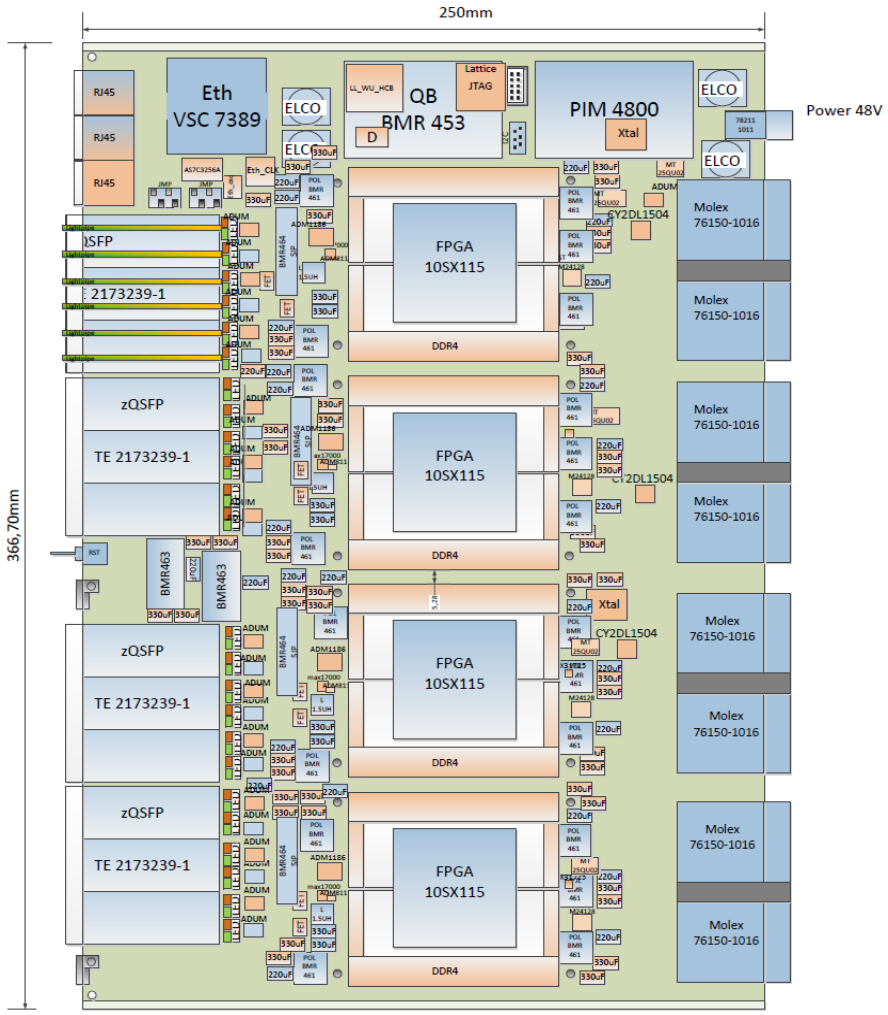
- Main board: single column of 4 FPGAs
- QSFP cages one side, backplane connector other side
- Only transceivers, no LVDS, no mesh
- Need for many transceivers to feed all the multipliers on Stratix10
- Limits number of I/O pins: *not enough DDR memory!*

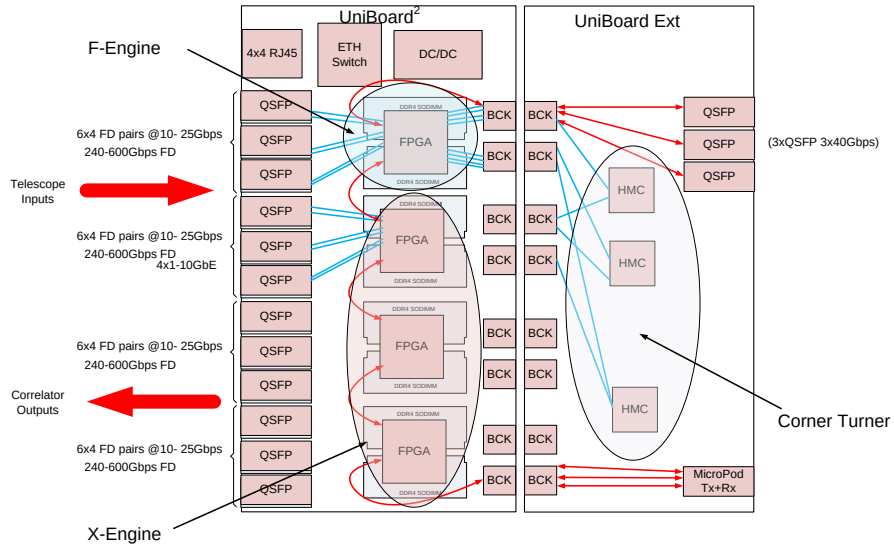
- Full mesh, Hybrid Memory Cubes and QSFP on break-out board

UniBoard^2: possible setup



UniBoard^2: high-level design





UniBoard^2: what is happening

- Lay-out nearly completed
- Companies selected for assembly and PCB production
- Arria10 engineering samples ordered for prototype
- Availability/affordability of Stratix10 may become an issue

- Much effort into pinning and test design at JIVE and ASTRON
- UMAN, UORL: continue algorithm development
- BORD: new digitizers
- MPG: beam former

And next?

- RadioNet will most likely be continued
- UniBoard projects provided opportunity to work with latest technology
  - Valuable whether or not the board itself gets incorporated in SKA
- Go on, and on, towards UniBoard^N...?

- Speed (or rather lack of) of development killing projects
  - Get overtaken by software correlators, CPU and GPU
- Devices ever larger, more complex
  - Inordinate amount of time needed for synthesizing

- OpenCL? Big devices, can afford hit in efficiency if it buys *real* ease of programming
- Combinations GPU-FPGA-ADC on one board?

Third International VLBI Technology Workshop

- Hosted by JIVE
- November 10 -13 2014
- Groningen + Dwingeloo, the Netherlands

- www.jive.nl/ivtw2014