Results from EMBRACE@Nancay

Steve Torchinsky

Station de Radioastronomie de Nançay

l'Observatoire de Paris

SKA SQUARE KILOMETRE ARRAY

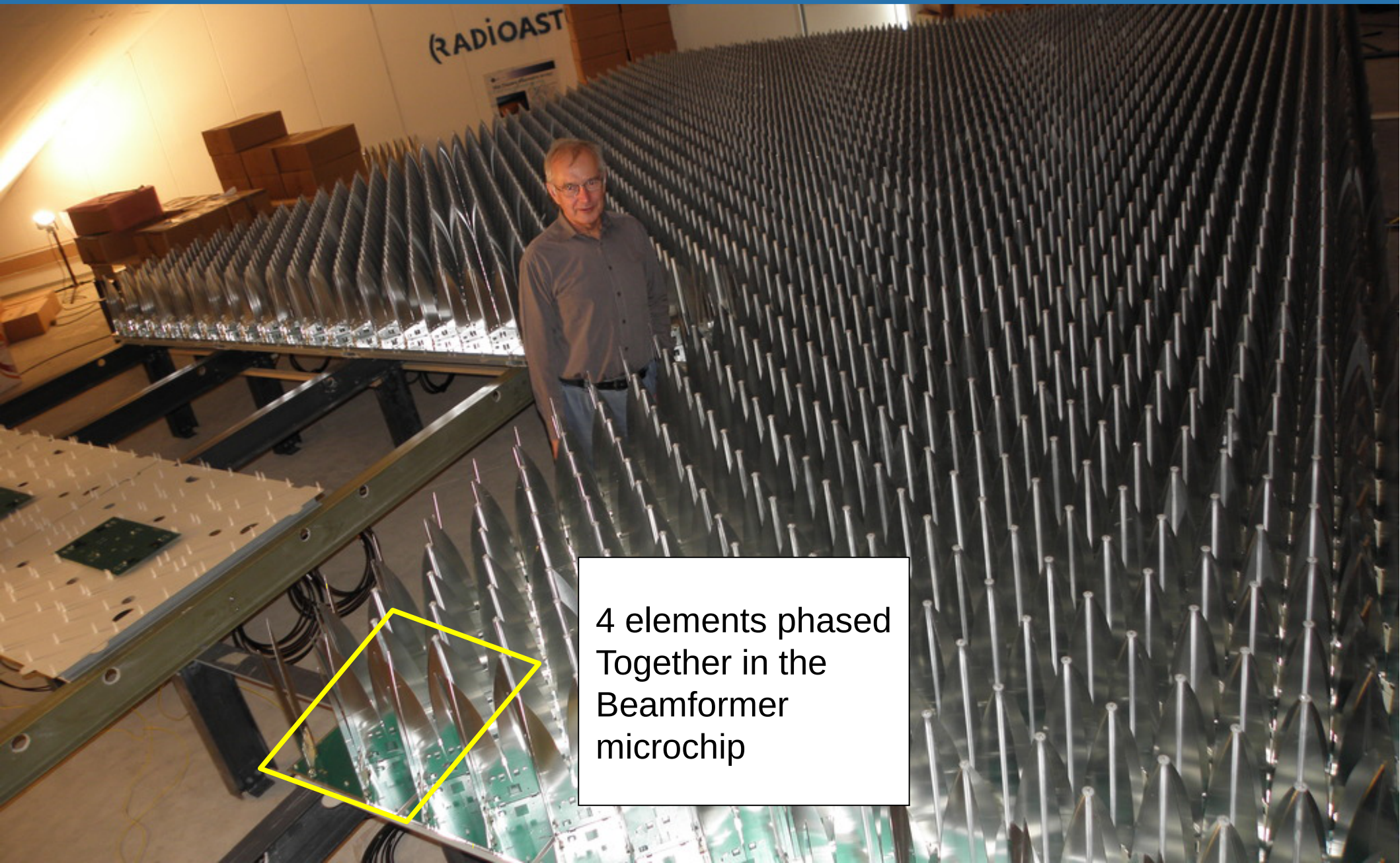
Outline

- A quick walk through the EMBRACE signal chain
- EMBRACE@Nançay results

Signal Chain

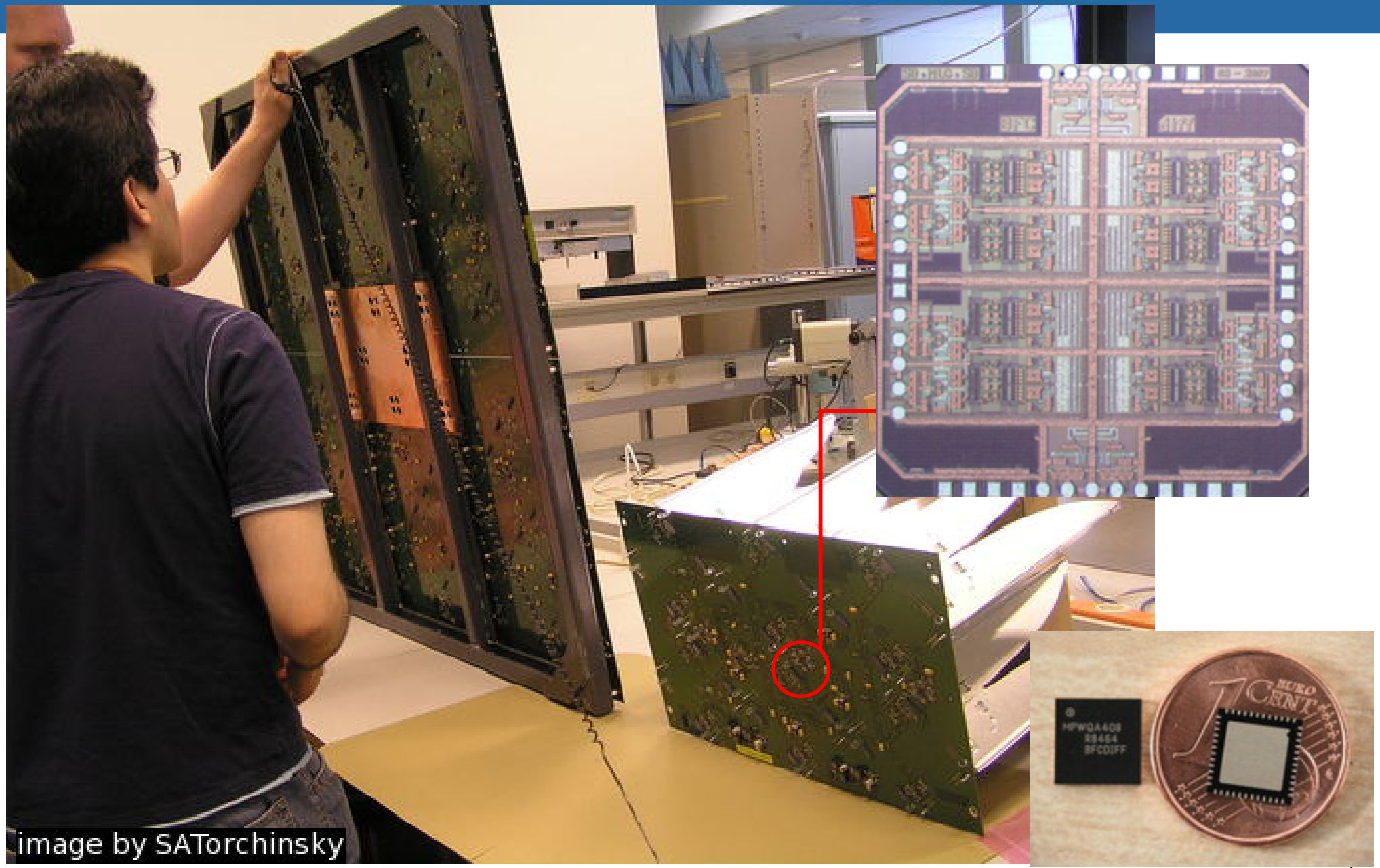
Hierarchical Beamforming

Station de Radioastronomie de Nançay

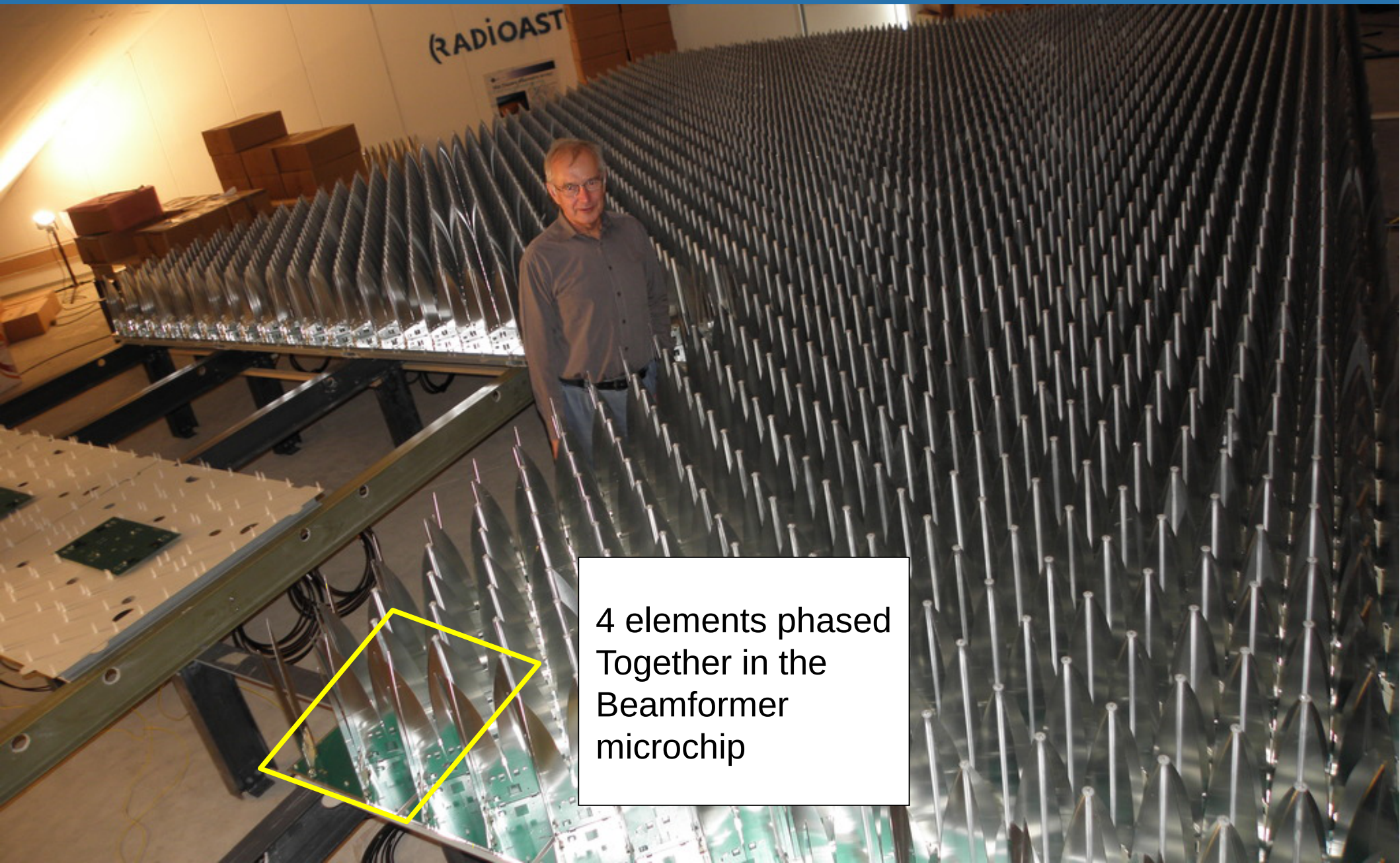


Beamformer Chip

Station de Radioastronomie de Nançay



Hierarchical Beamforming



Hierarchical Beamforming

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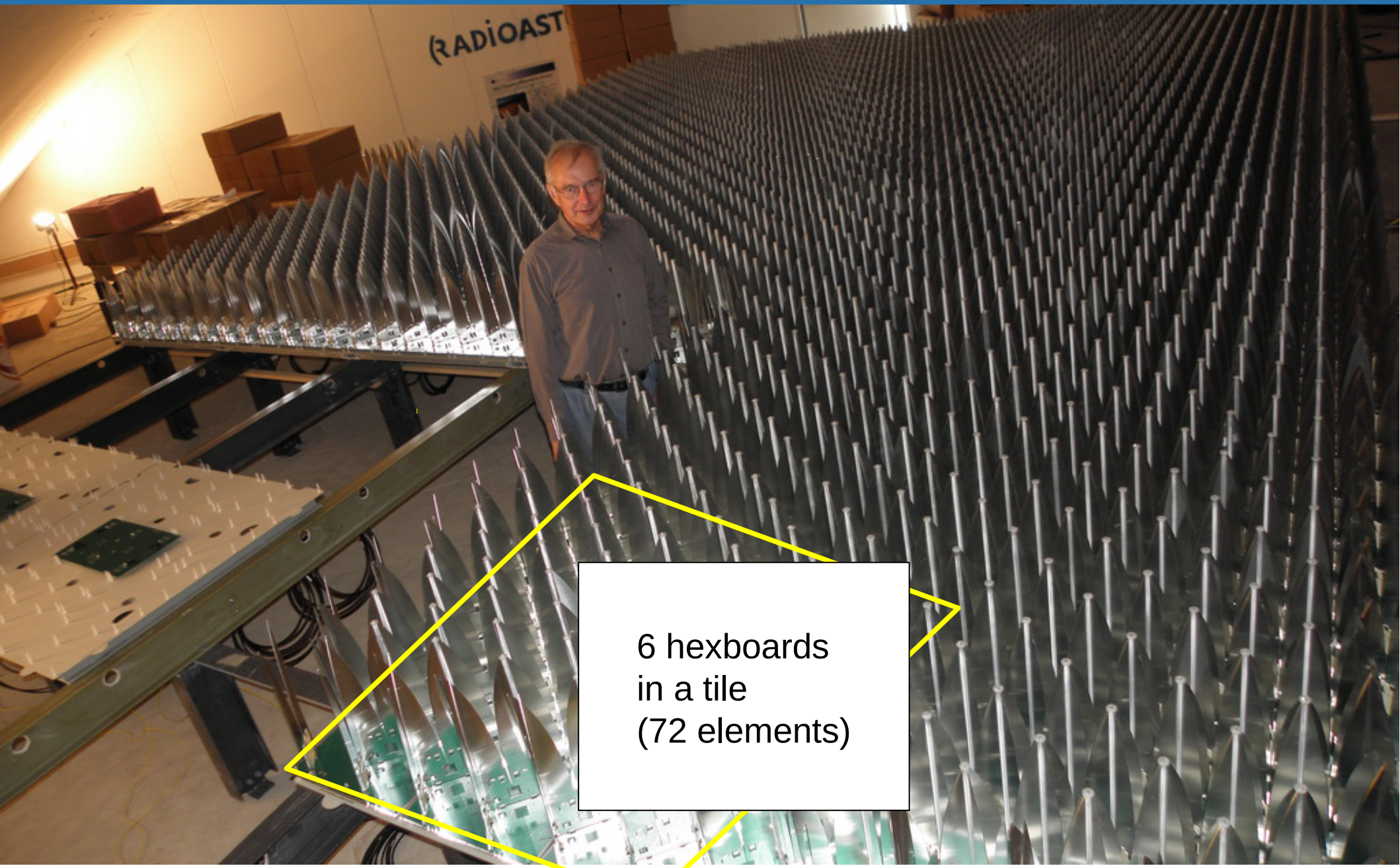
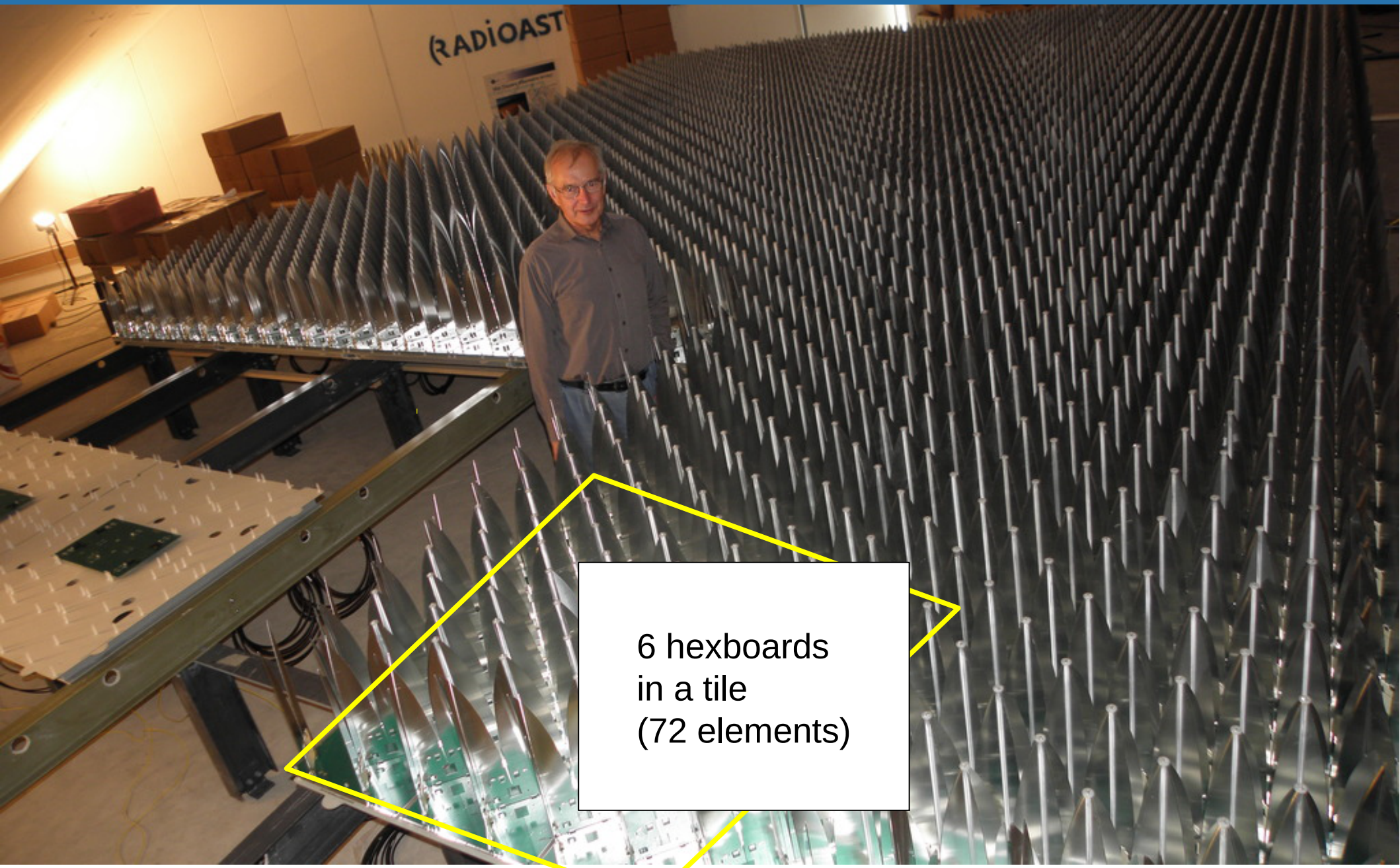
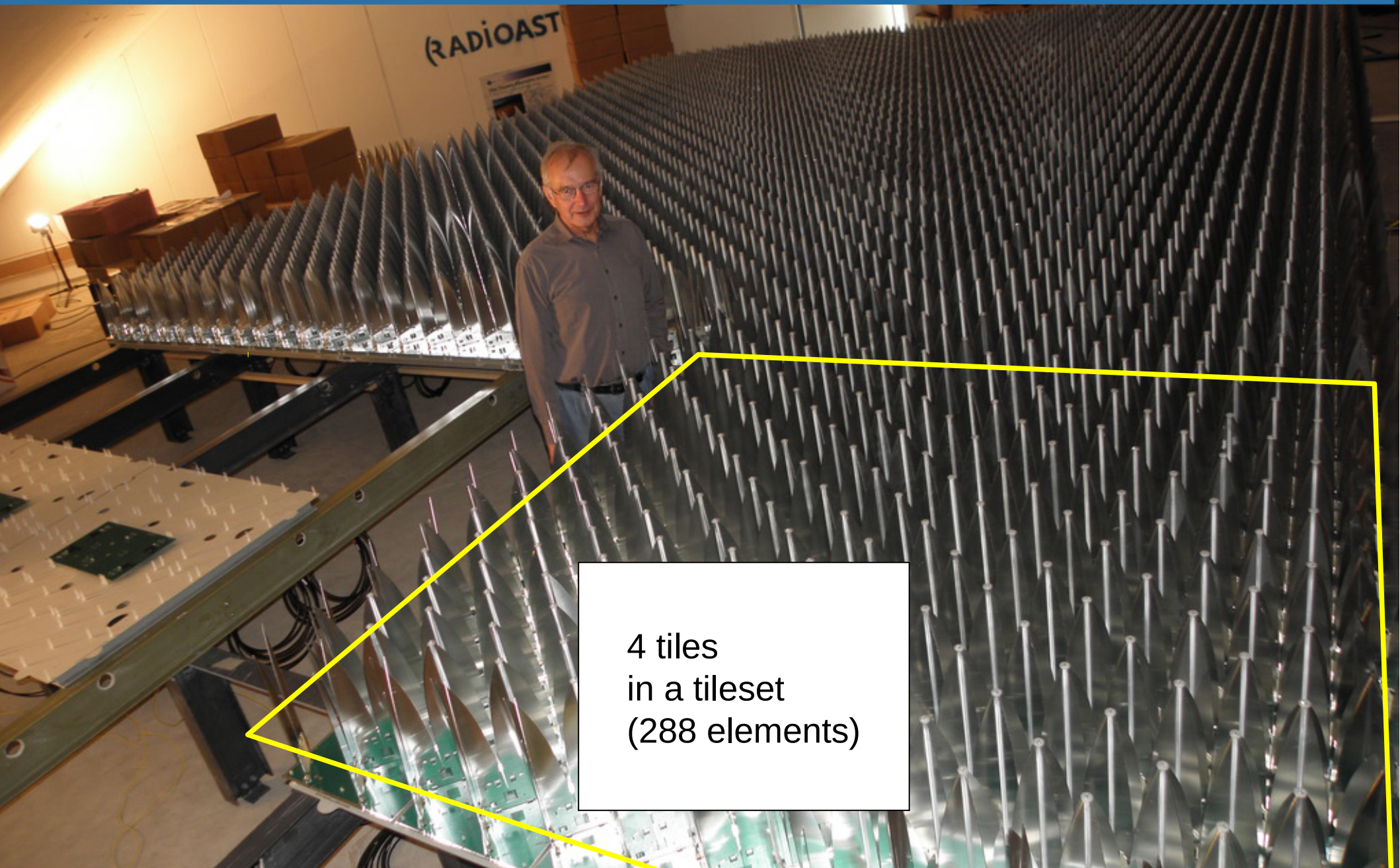


Two coaxial outputs per tile

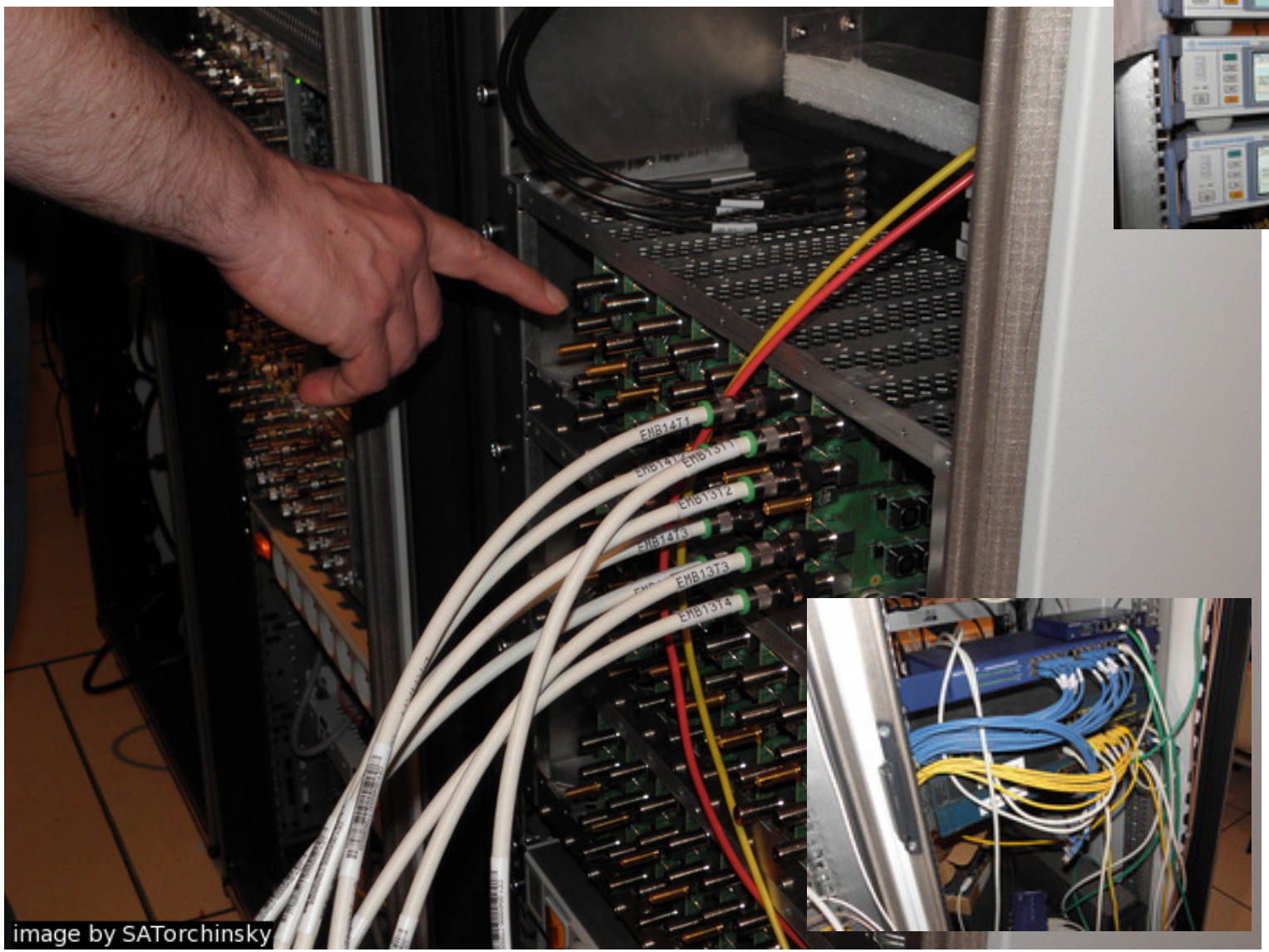
Hierarchical Beamforming



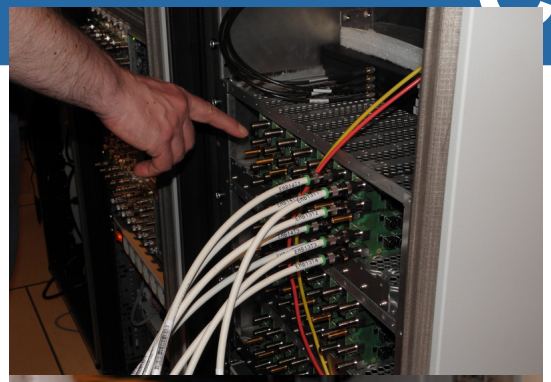
Hierarchical Beamforming

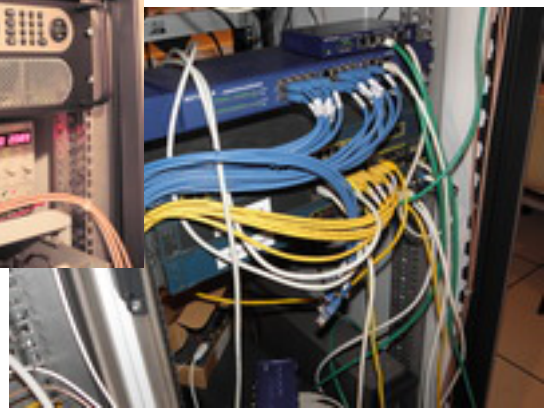


4th stage analog beam forming



Control and Down Conversion

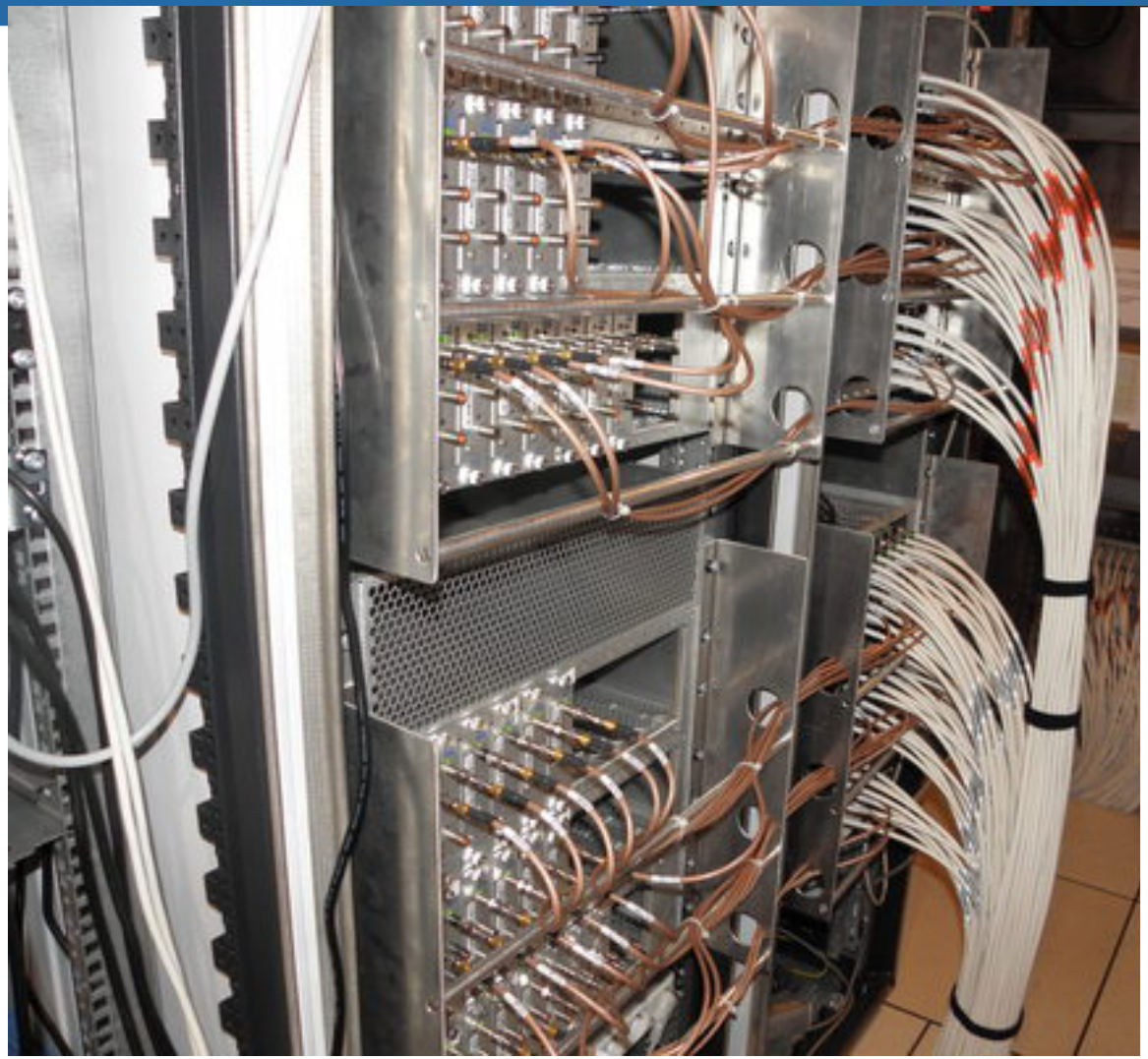




- Last stage analog summing of four tiles
- 2-stage mixing to convert RF down to 150 MHz +/- 50MHz
- Ethernet protocol for beamformer chip parameters and housekeeping
- 48V DC
- RF + Digital Commands + Power all on the same coax!

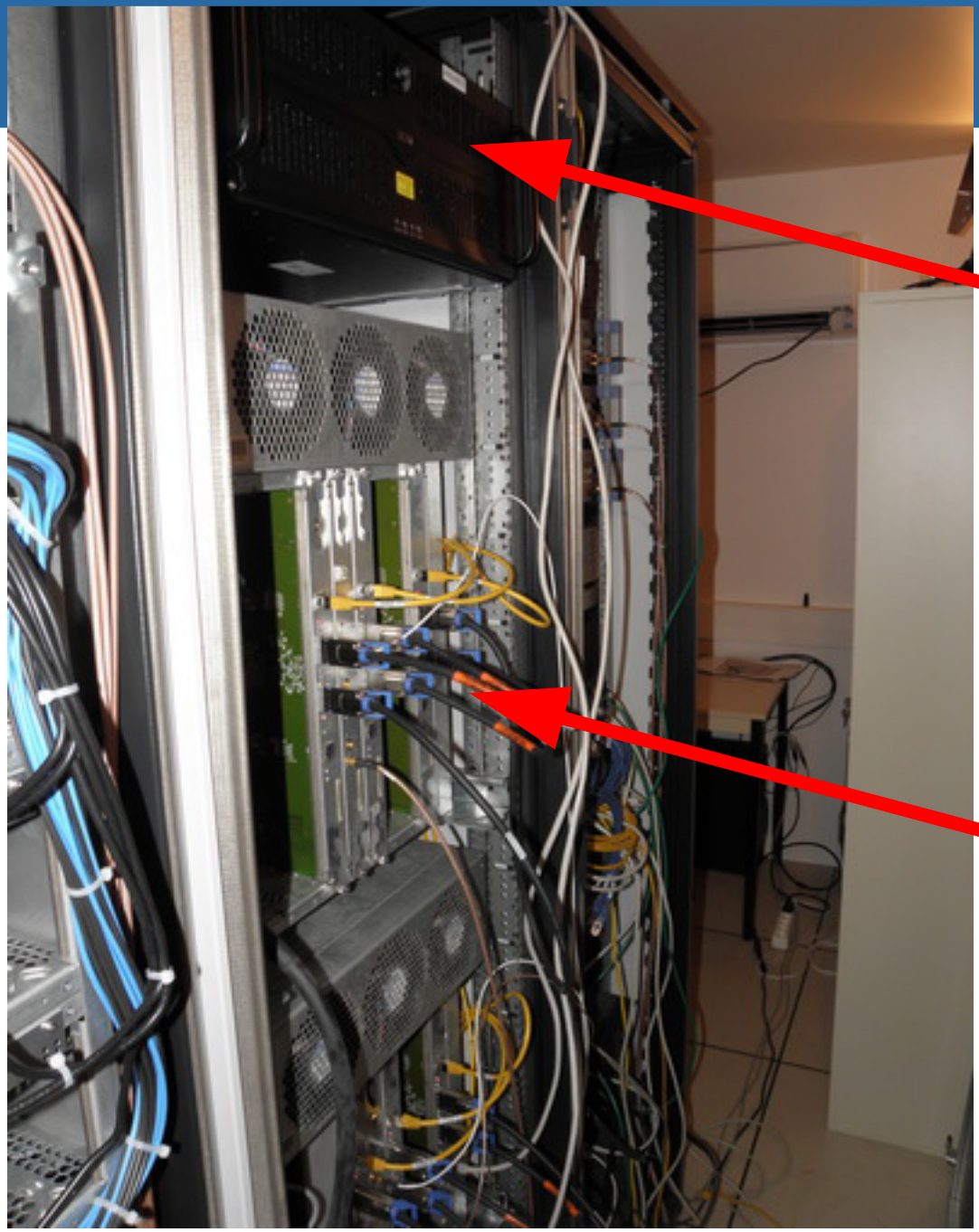
CDC cards designed by MPIfR/INAF-IRA/ASTRON

LOFAR Backend



- Output from CDC goes to LOFAR Receiver Unit (RCU) boards for digitization
- And then to LOFAR Remote Station Processing (RSP) boards for digital beamforming

High Speed Data Acquisition



ARTEMIS

Pulsar acquisition system provided by U. Oxford.
Aris Karastergiou

LOFAR Remote Station Processing Boards for digital beamforming

System Control and Data

- Enormous flexibility with the dense array
  - Multi-beam
  - Instantaneous reconfiguration
  - Real time calibration
  - Multiple observing mode possibilities with tradeoff between bandwidth, number of beams, field of view

MAC developed at Nançay provides a friendly Python interface for the user to setup complicated observing runs

Electronic MultBeam Radio Astronomy ConcEpt

- **EMBRACE is an AAmid Pathfinder for SKA**
- Largely funded within EC FP6 Project SKADS (2005-09)
- For EMBRACE:
  - ASTRON: Project Leader, overall architecture, antennas, industrialization,...
  - Nançay: Beamformer Chip, Monitoring and Control Software
  - MPI Bonn and INAF Medicina: design of multiplexing circuits for RF reception, down conversion, command/control, power supply

EMBRACE@Nançay signal chain

- 4608 Vivaldi antenna elements
- Single polarization (second polarization antennas are in place, but only one polarization has a complete signal chain)
- 4 level hierarchical analog beamforming/signal summing
  - Beamformer chip:
    - 4 inputs, 2 outputs (2 independent beams)
    - 45º phase steps
  - Analog summing output from 3 beamformer chips
  - Analog summing of 6 inputs = 1 tile (72 elements)
  - 15m cable → Analog summing of 4 inputs = 1 tileset
  - Down conversion
  - 32 inputs to LOFAR backend
    (16 A-beam, and 16 B-beam)

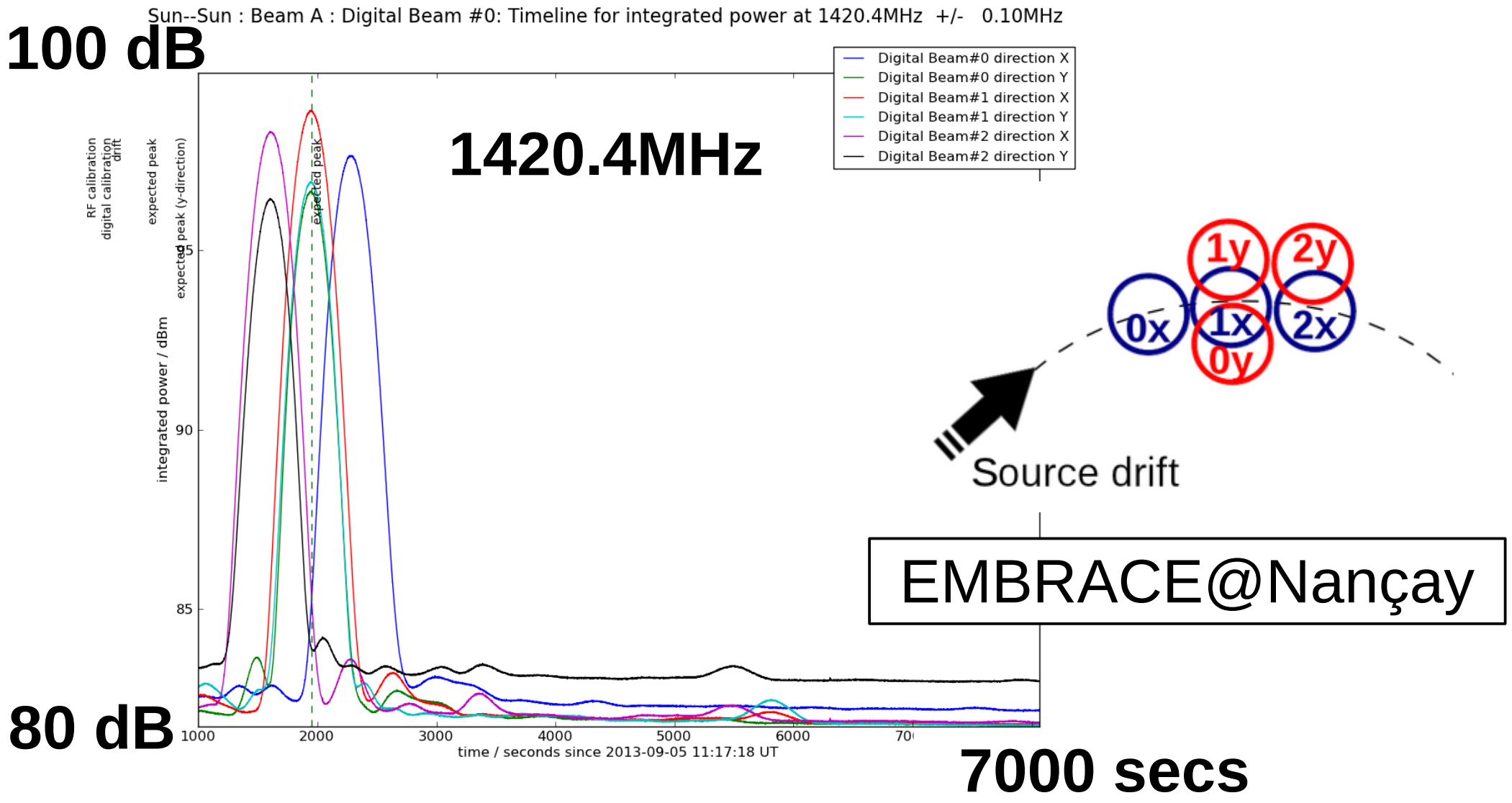
EMBRACE characteristics

- 500 – 1500 MHz
  - But high pass filter at 900 MHz to avoid digital television
- 70 m^2 (8.5m X 8.5m)
- Instantaneous RF band: 100 MHz
- Maximum instantaneous beam formed:
  - 36 MHz x 2 directions (single polarization)
  - 186 “beamlets” each of 195.3 kHz bandwidth
  - i.e. 3 “lanes” for high speed data from RSP
- Can trade off beam width vs. number of beams

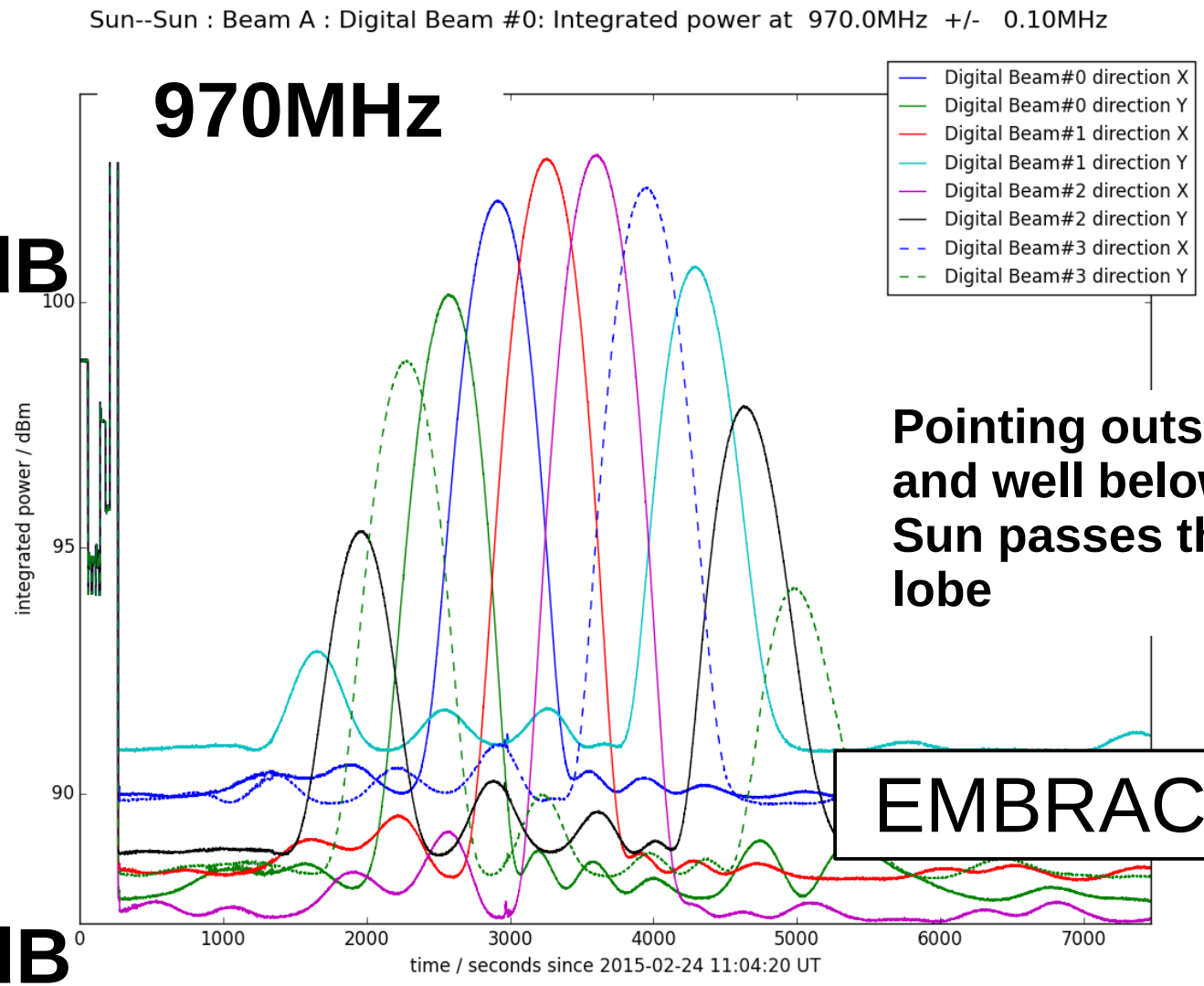
Some results

http://arxiv.org/abs/1504.03854
to appear in JINST
A more detailed paper will be submitted in June

Multibeaming



8 digital beams



100 dB

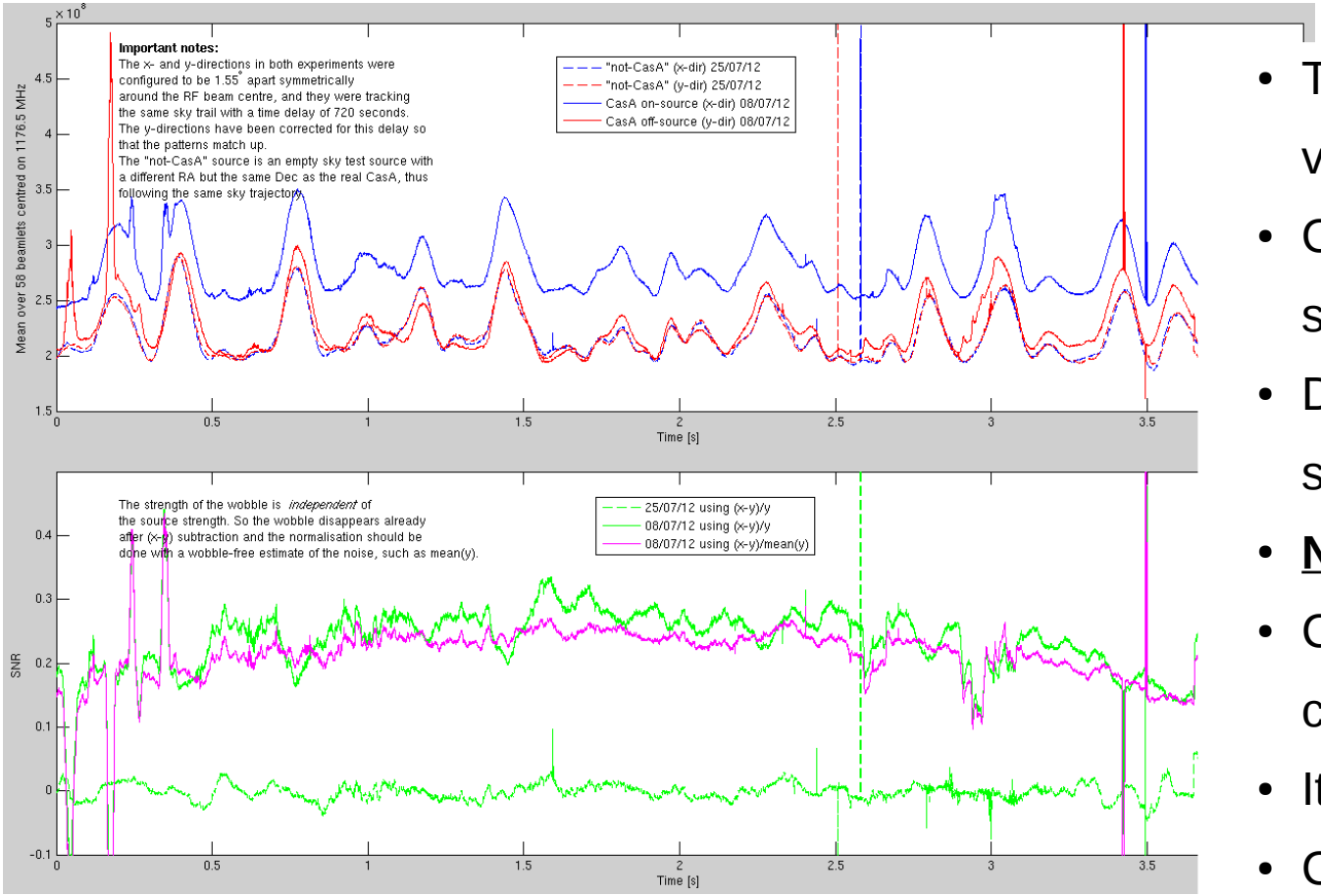
80 dB

Pointing outside the FoV, and well below 45° elevation: Sun passes through grating lobe

EMBRACE@Nançay

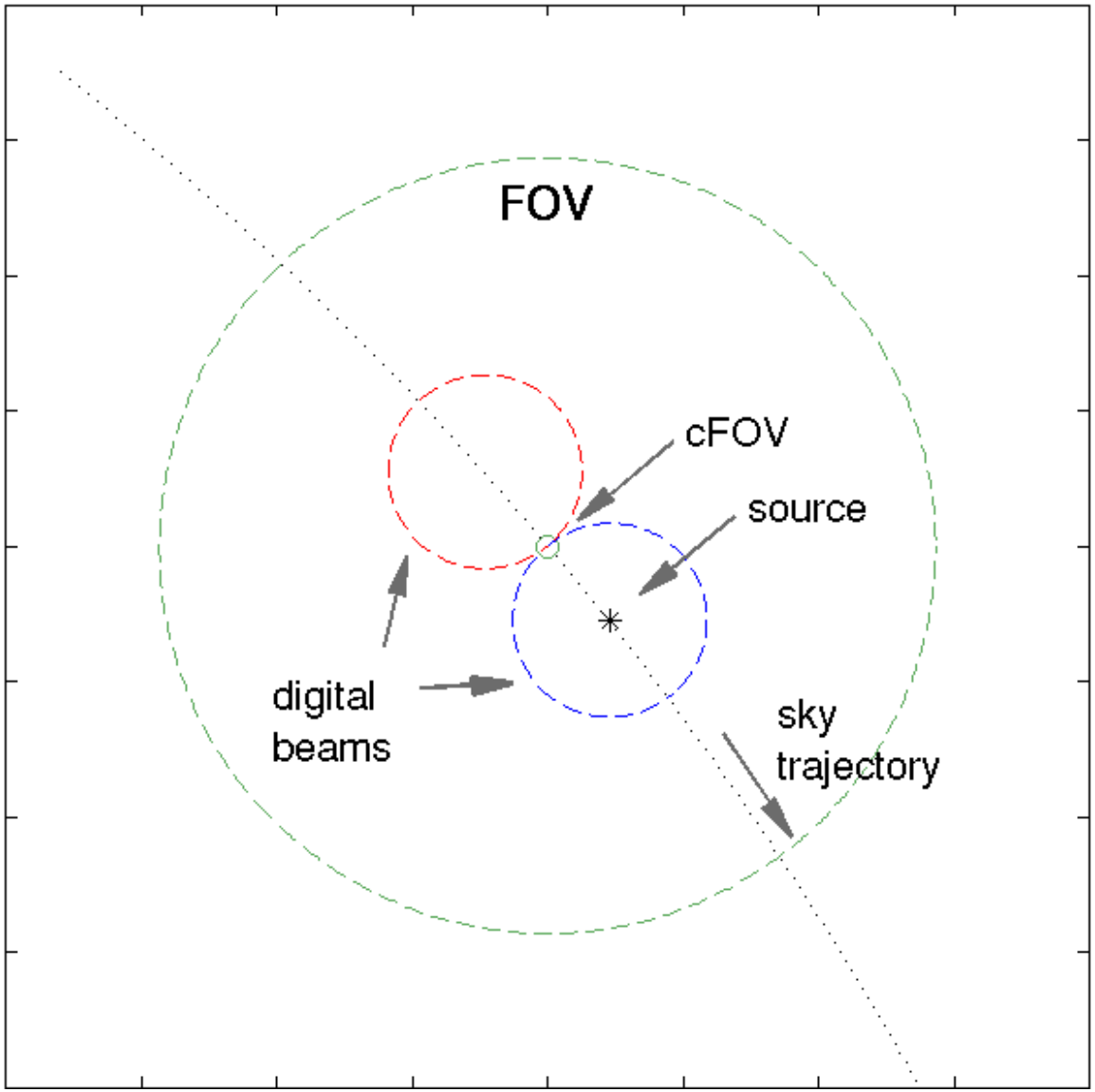
7000 secs

Correlator offset



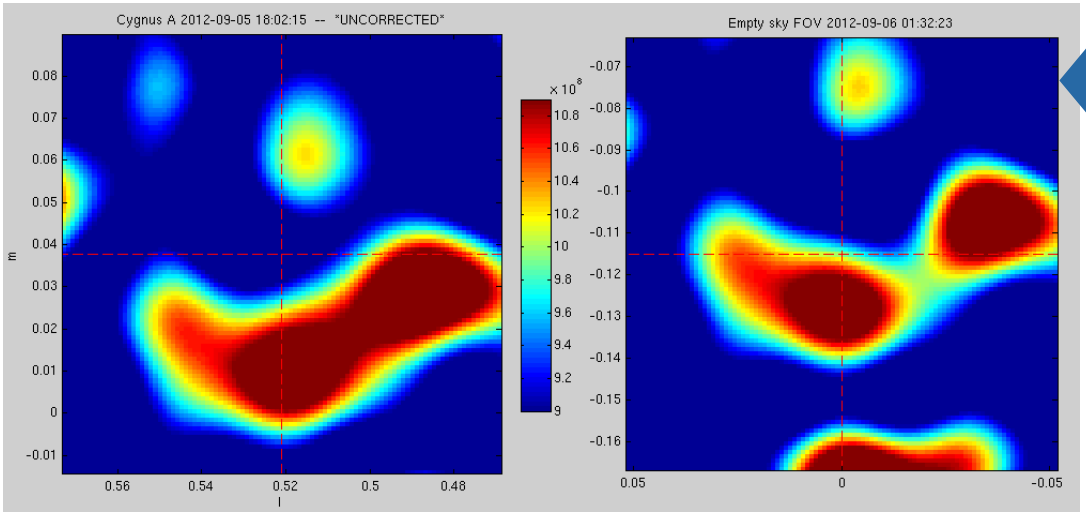
- Tracking a source shows a variation in the power.
- Off-source tracking shows the same pattern
- Does not scale with source strength
- **Not** a gain variation
- Can correct by subtracting constant UV matrix (empty sky)
- It's a consant “correlator offset”
- Can also correct by classic ON-OFF measurements

ON-OFF pointing strategy



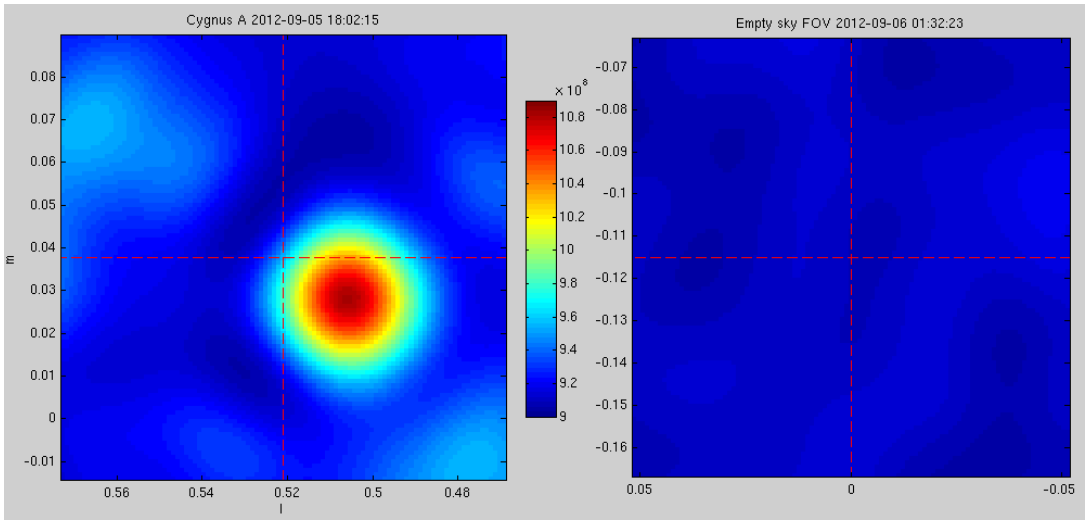
- On and Off observations can be done **simultaneously** with EMBRACE (multibeams)

Correlator Offset: Flat Fielding



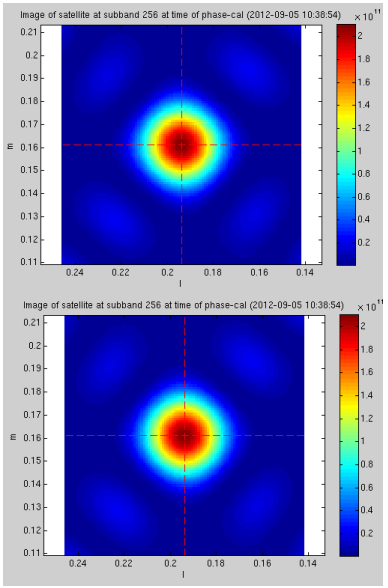
Stable background “image” due to correlator offset

Cygnus A
Same data!
(before/after fix)



No change

GPS satellite
(strong source)



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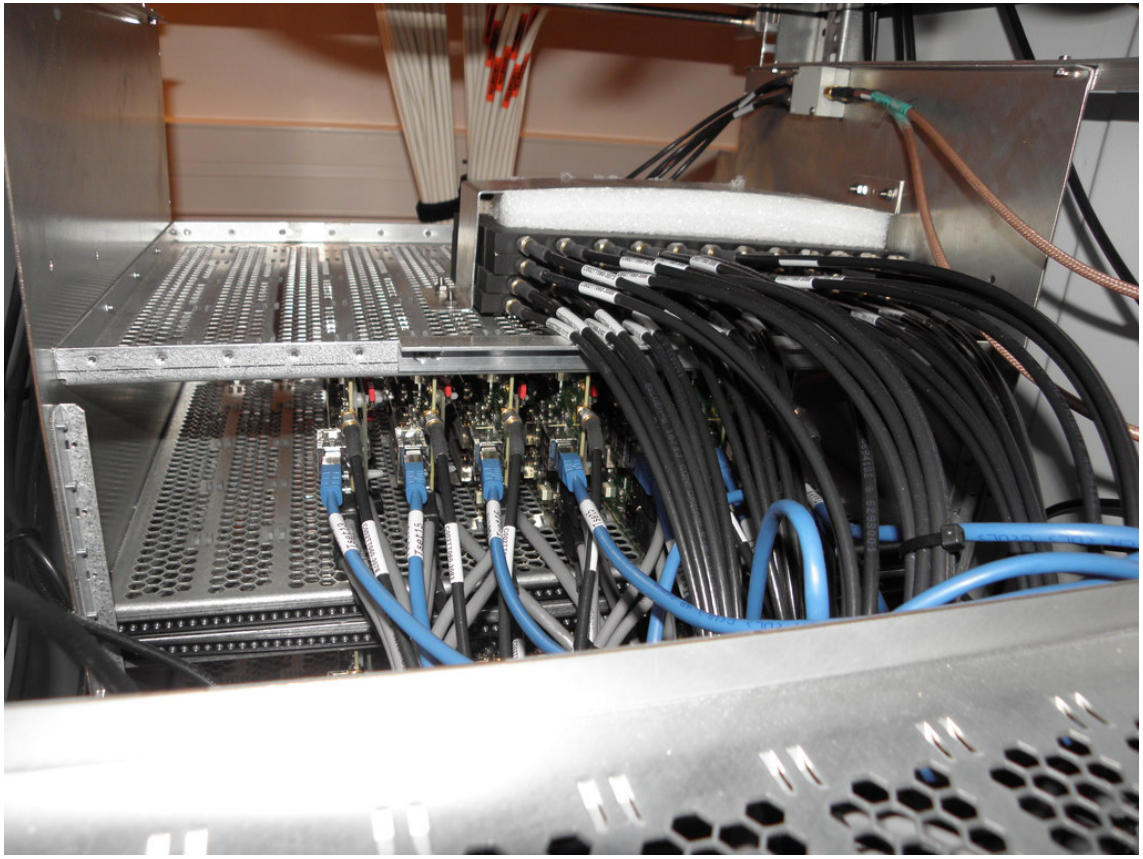
LO distribution



- Local Oscillator distributed to all CDC cards via cascaded power-splitters
- Correlated mixing products between tilesets could explain correlator offset

Galaxy Detection: M33

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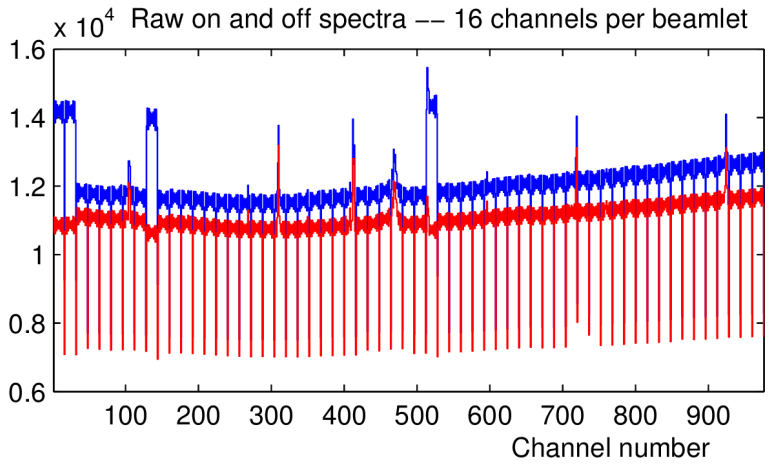
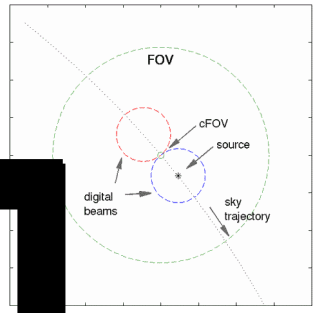
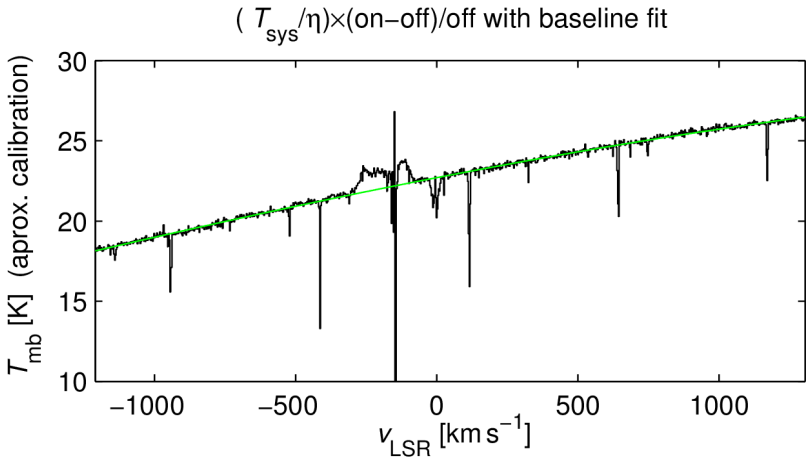
MID-FREQUENCY APERTURE ARRAY

Integrated ON and OFF spectra

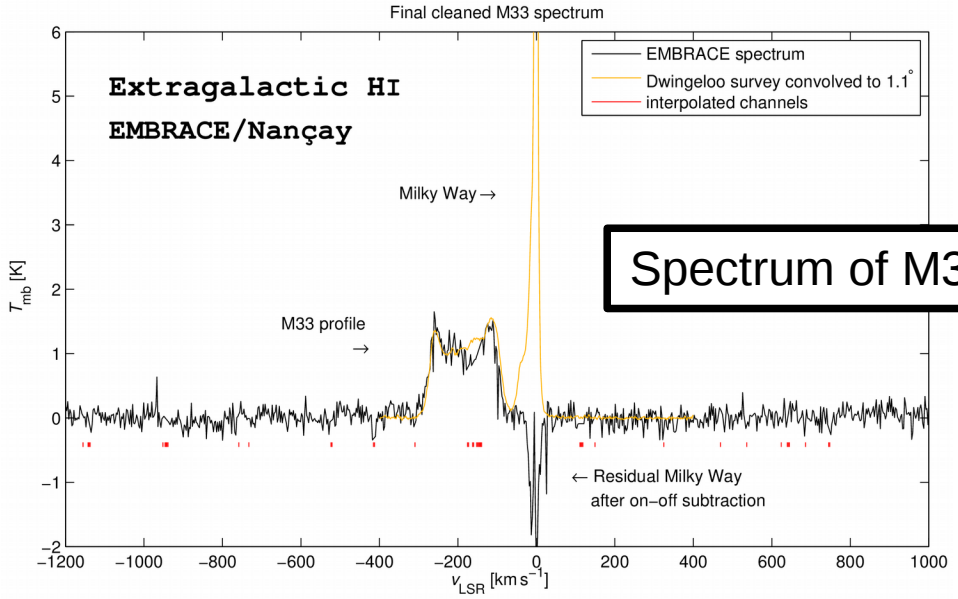




(ON – OFF)/OFF



Baseline fit and interpolate past RFI channels



Spectrum of M33

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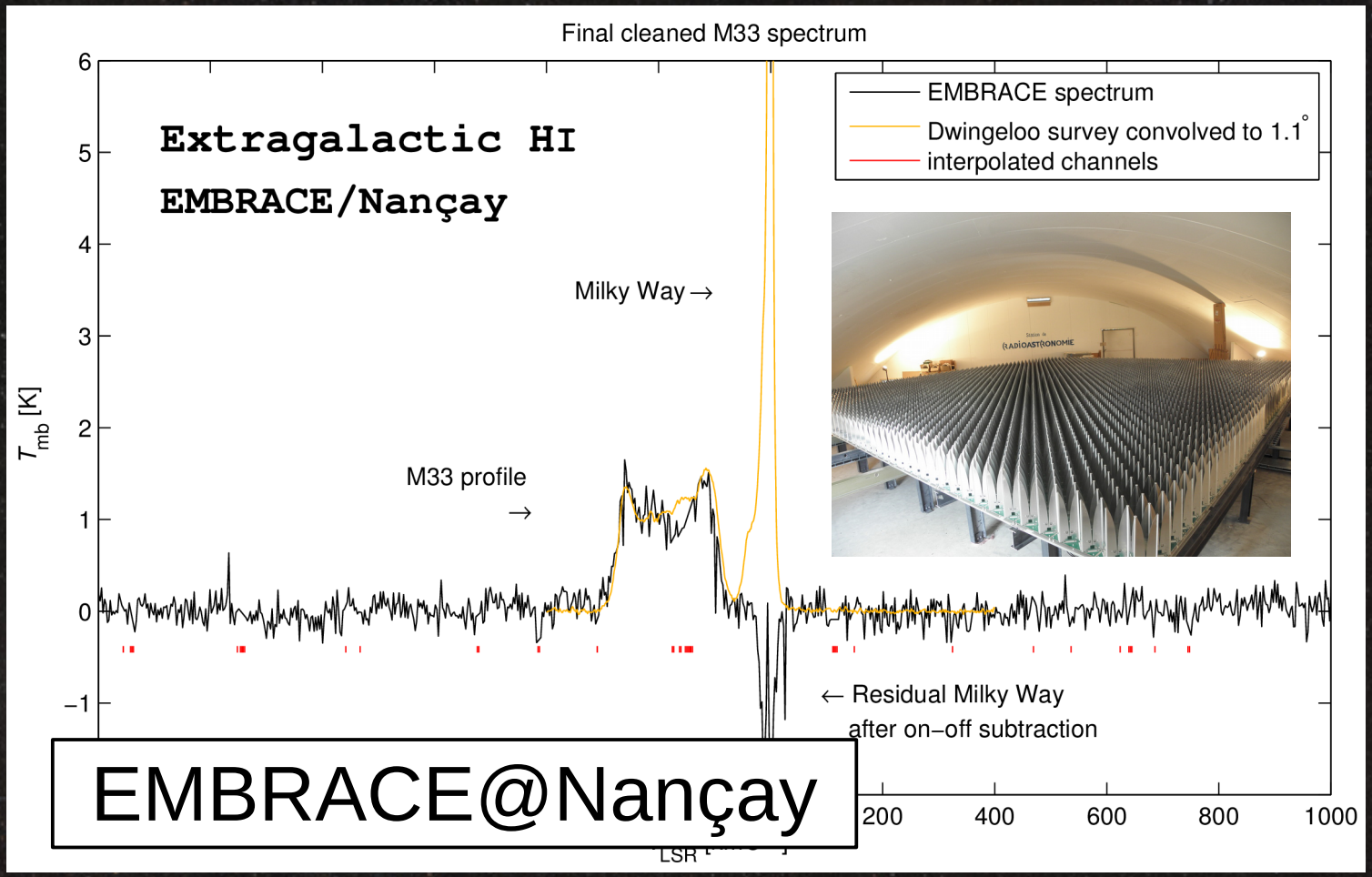
Galaxy Detection



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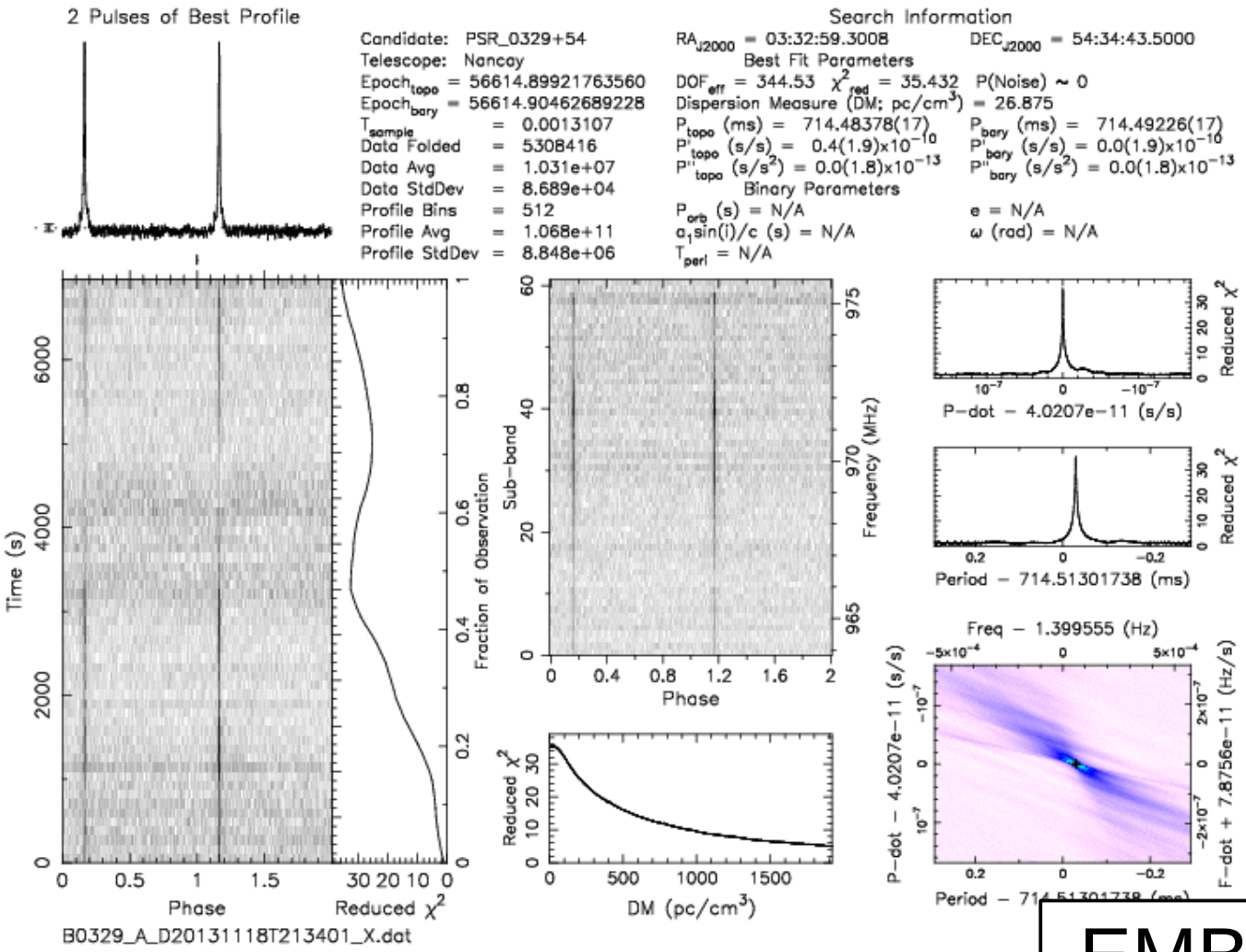
Billion galaxy survey: Only 999 999 999 to go ...

Pulsar monitoring



- Programme of daily monitoring of pulsar B0329+54 at 970MHz and 1420MHz simultaneously
- Possibility to detect accretion events in the long term (see e.g. Brook et al. ArXiv:1311.3541v1)

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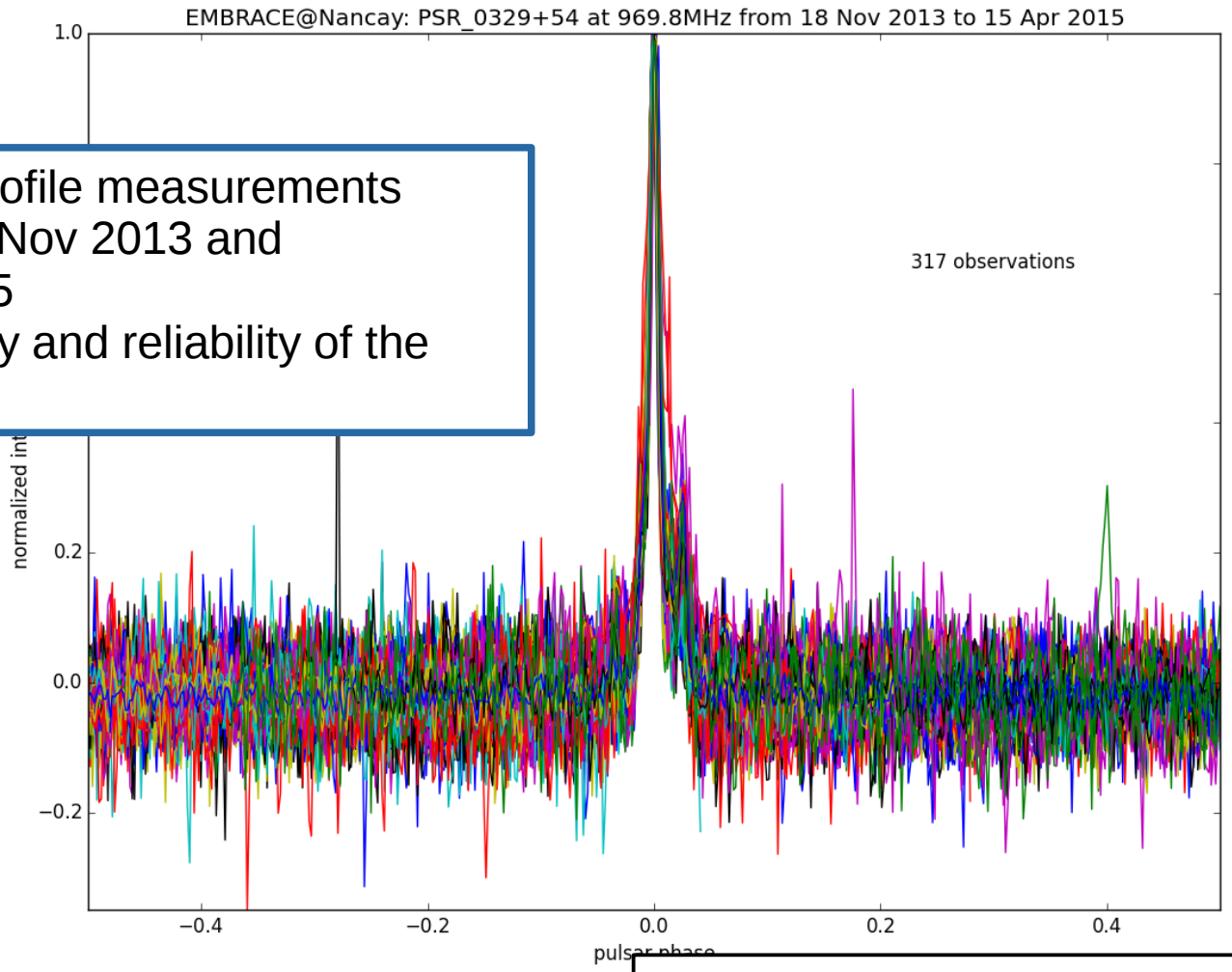
B0329+54 at 970MHz

- 317 pulse profile measurements between 18 Nov 2013 and 15 April 2015
- Tests stability and reliability of the system



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Dispersion Measure

- Dispersion by the plasma between observer and source (Interstellar Medium)
- DM is a measure of the plasma column density
- DM is indirectly a measure of distance
- DM varies with frequency (and is therefore subject to the Doppler Effect)

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DM Seasonal Variation

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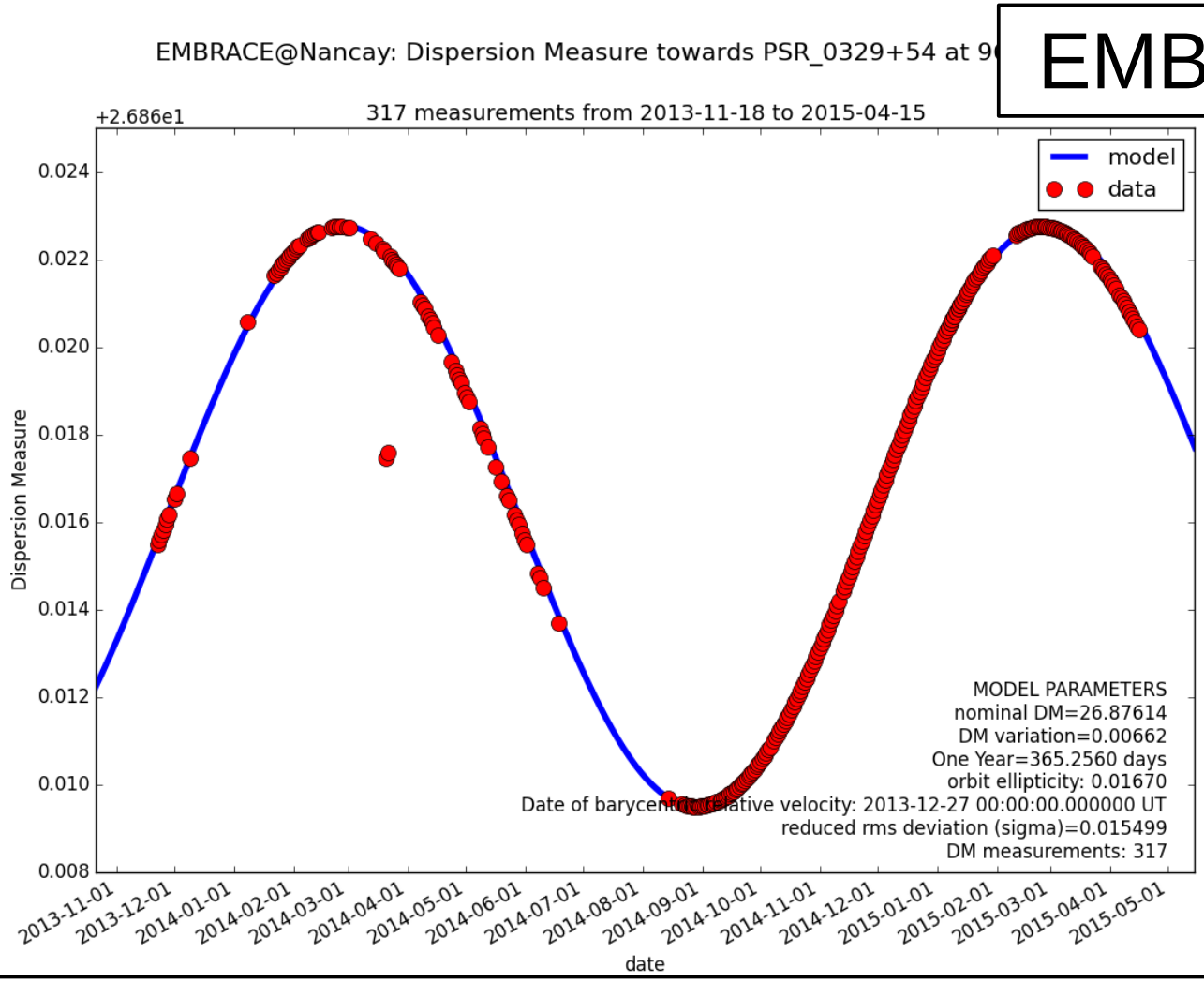


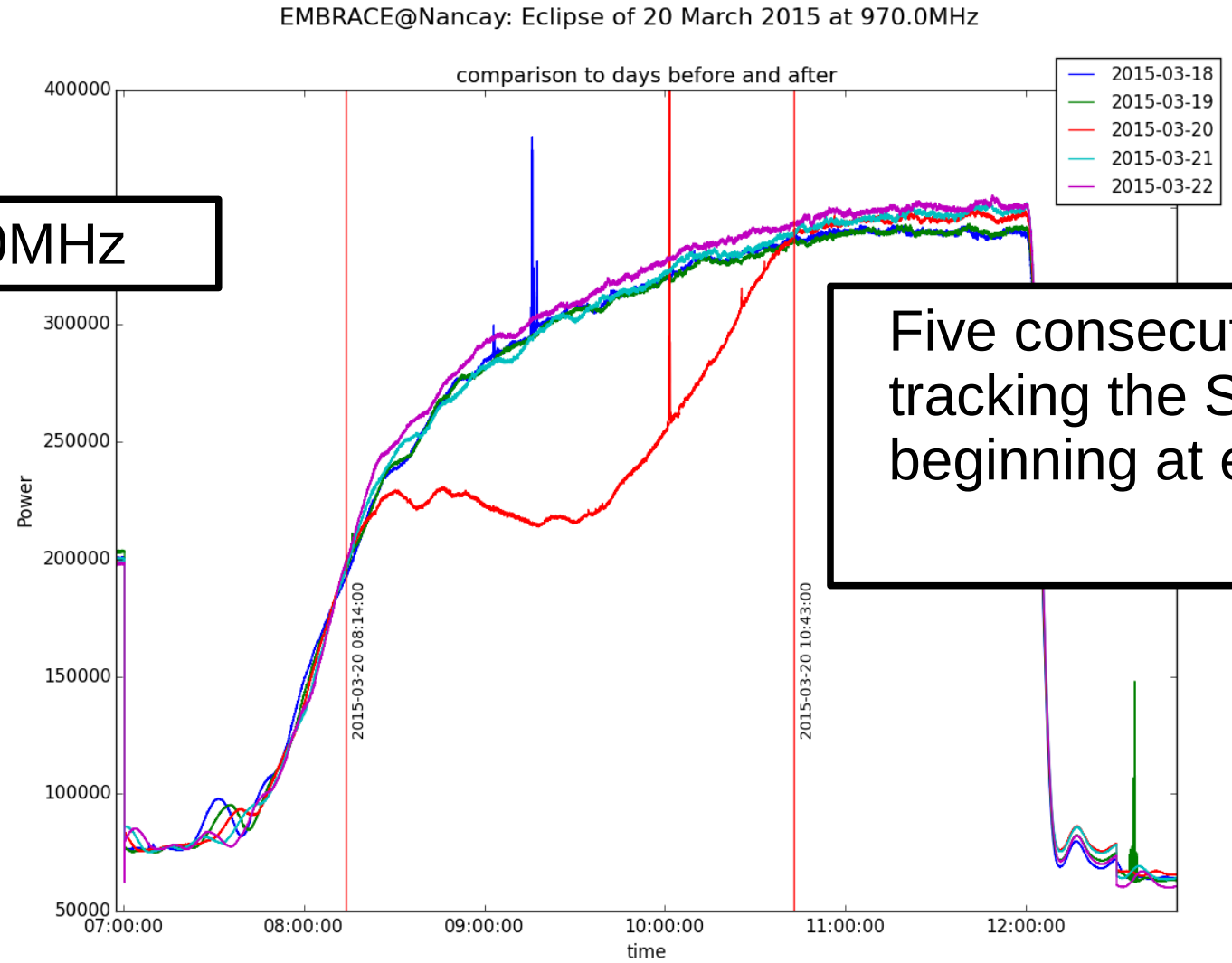
The Earth goes around the Sun in one year!

Partial Solar Eclipse 20 March 2015

Bourges

Photo by Steve T.

Simultaneous Observations at 970MHz and 1420MHz

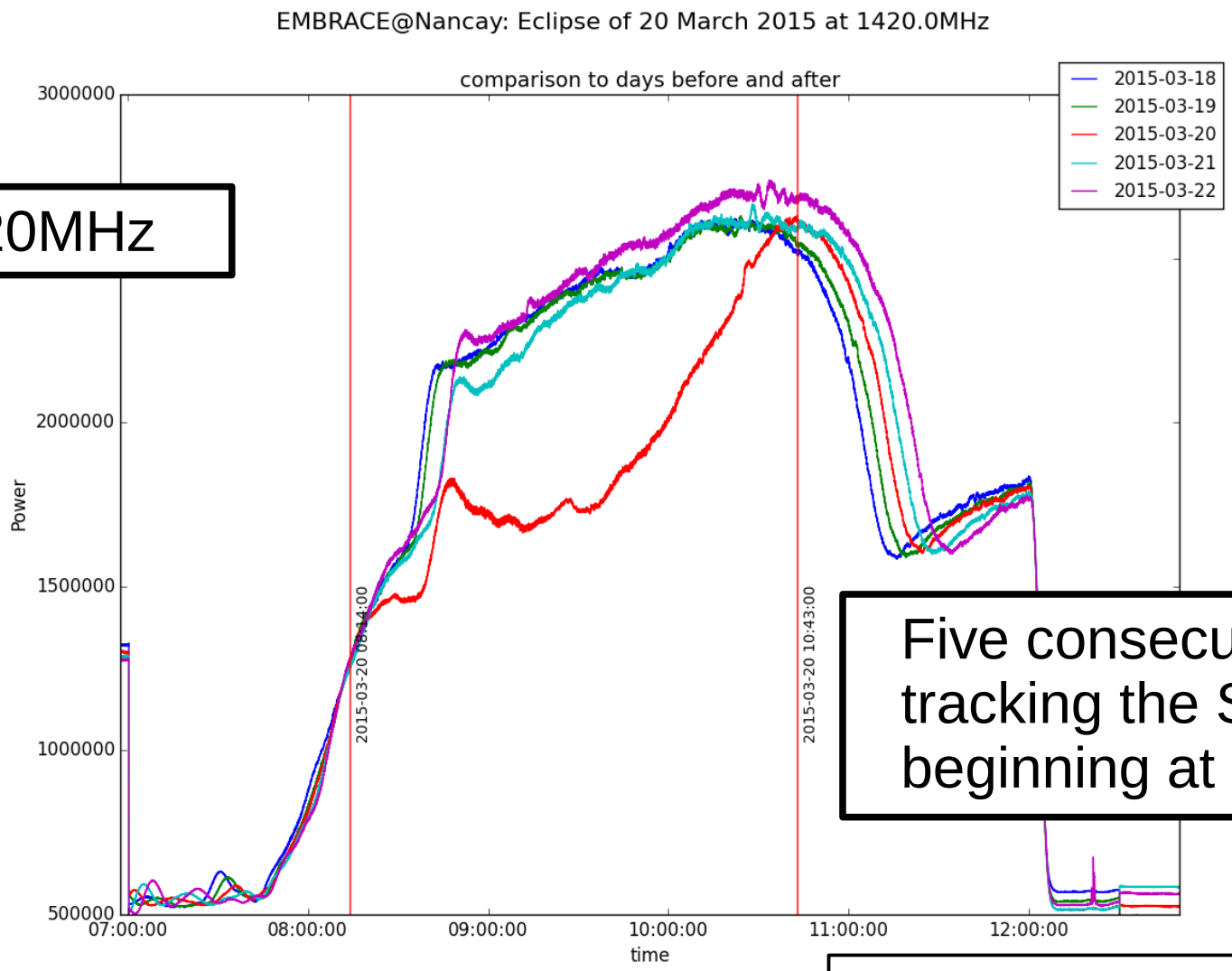


970MHz

Five consecutive days of tracking the Sun, beginning at elevation 10°

EMBRACE@Nançay

Simultaneous Observations at 970MHz and 1420MHz

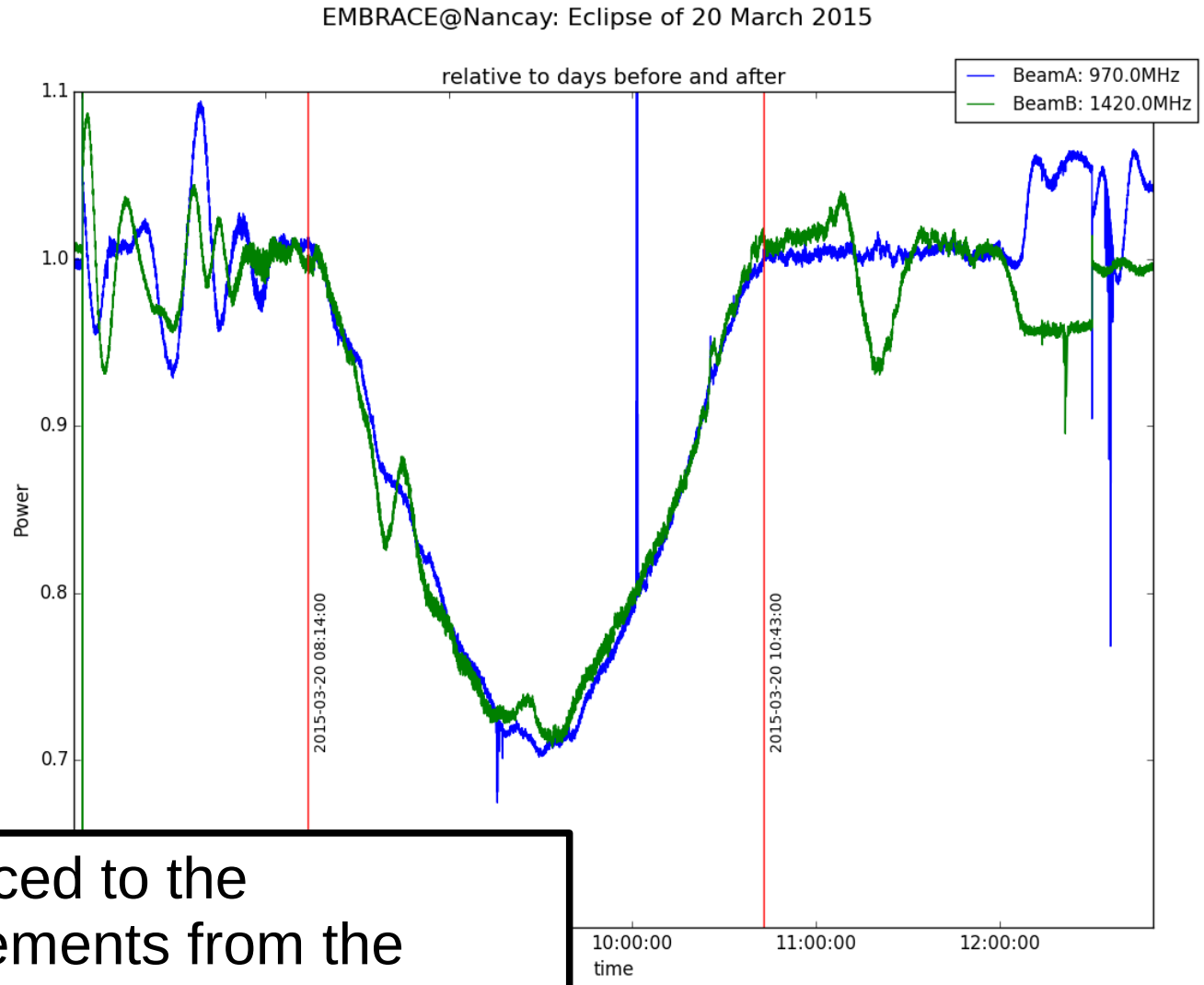


1420MHz

Five consecutive days of tracking the Sun, beginning at elevation 10°

EMBRACE@Nançay

Solar Eclipse at 970MHz and 1420MHz



Referenced to the measurements from the days before and the days after

EMBRACE@Nançay

Results from EMBRACE@Nancay

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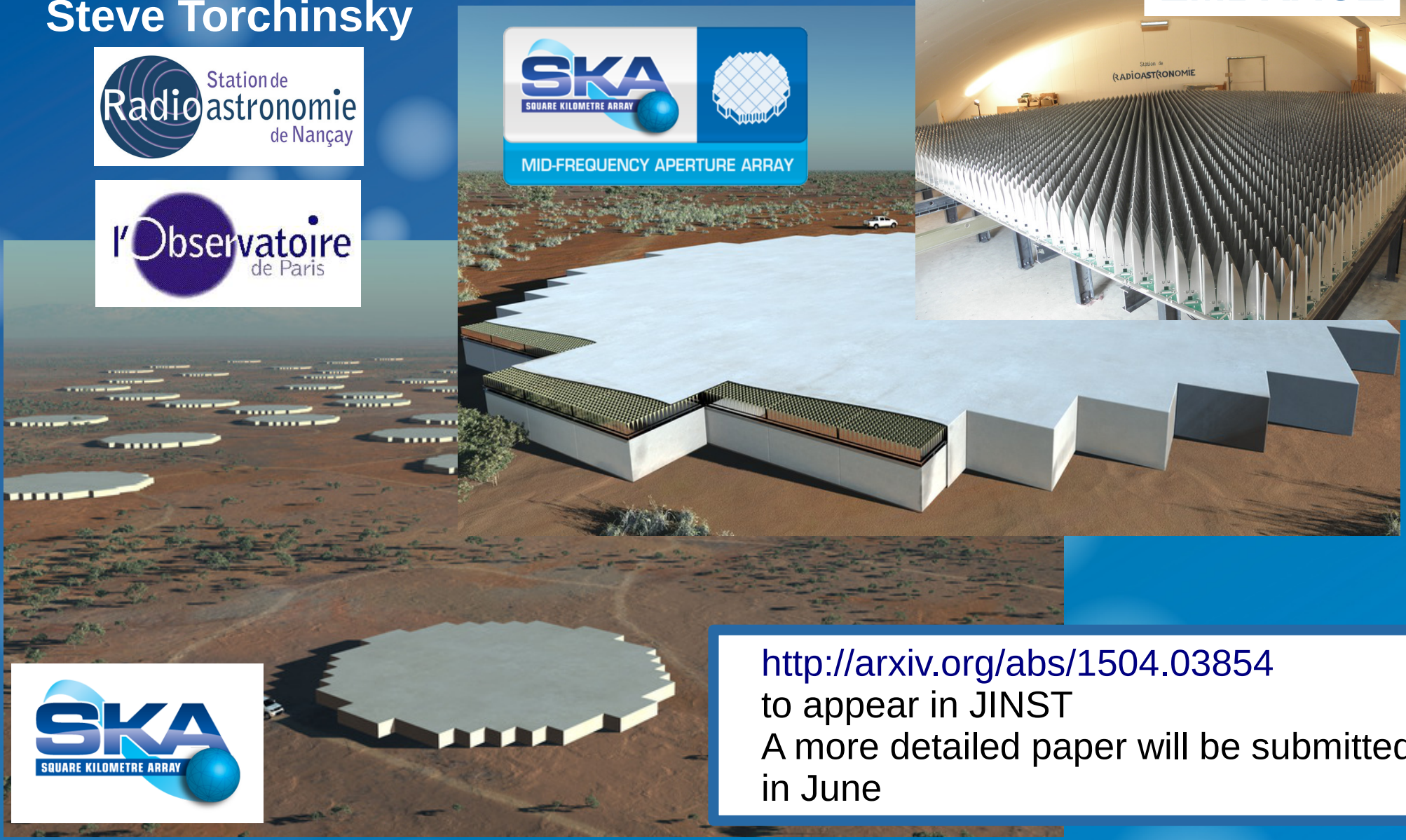

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