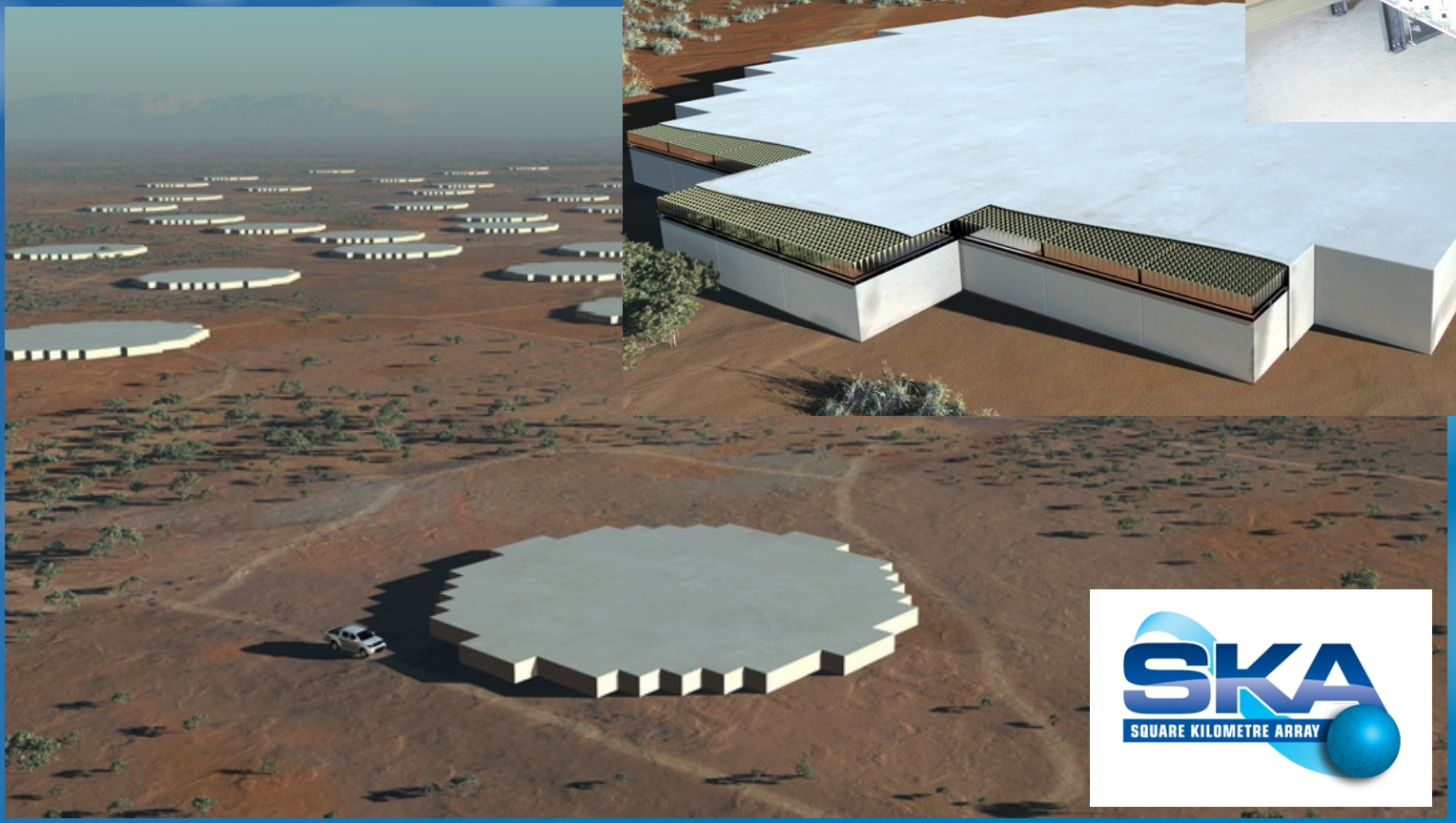
# Dense Aperture Array for SKA

**Steve Torchinsky**

Station de Radioastronomie de Nançay



SKA
SQUARE KILOMETRE ARRAY

# Why a Square Kilometre?

Station de Radioastronomie de Nançay

- Detection of HI in emission at cosmological distances
  - R. Ekers, SKA Memo #4, 2001
  - P. Wilkinson, 1991
  - J. Heidmann, 1966 !

# SKA Memo #4: 2001

Station de Radioastronomie de Nançay

**SKA Memorandum #4**

## SKA Technical Specifications

*Ron Ekers*

December 2001

The SKA specs have been evolved in a series of workshops over many years and in some cases the origin of the various specifics has been lost. In order to provide input to the science and engineering groups now looking at the scientific drivers and the specification trade-offs, I have provided this somewhat personal review of how we got to the present set of specifications. The specifications I have used and their definitions, which are repeated here, are from the 'SKA Science Case', p17.

$\underline{A_{eff}/T_{sys}}$ $(2 \times 10^4\ m^2/K)$
The effective collecting area divided by the system temperature. This may be a function of frequency.

- Sets the point source sensitivity and corresponds to 1 square kilometre collecting area, eg $A_{eff}$ = 50% total aperture with $T_{sys}$ = 25K. It is formulated this way to include the differences in aperture efficiency, and to allow different technologies to trade effective area for $T_{sys}$ .

- The spec is set by the HI brightness sensitivity at a moderate spectral resolution ($\nu/d\nu = 10^4$ corresponding to 30 km/sec). This enables detection of a normal galaxy like M101 at any z by using HI up to z = 4 and CO at any z > 4.

# The Hydrogen Array

Station de Radioastronomie de Nançay



*Radio Interferometry: Theory, Techniques and Applications,*
*IAU Coll. 131, ASP Conference Series, Vol. 19, 1991,*
*T.J. Cornwell and R.A. Perley (eds.)*

## THE HYDROGEN ARRAY

P.N. WILKINSON
University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire, SK11 9DL, United Kingdom

ABSTRACT The time is ripe for planning an array with a collecting area of 1 km² (14 times larger than Arecibo and 75 times larger than the VLA). In view of its major astronomical target I have dubbed this concept 'The Hydrogen Array', although 1$\mu$Jy continuum sources will also be reliably detected. I present some initial thoughts about the issues involved.

# 1966: 100x Nançay

Station de Radioastronomie de Nançay

## CENT FOIS NANÇAY ?

100x Nancay ≈ 700 000m$^2$

par J. HEIDMANN

*(Observatoire de Meudon)*

Le film qui vient d'être projeté a été terminé l'été dernier (1). Depuis, le grand radiotélescope de Nançay s'anime peu à peu. En 1966 il prendra progressivement sa pleine puissance. Sa portée sera énorme et le classera deuxième au monde, après l'interféromètre à synthèse d'ouverture de Cambridge, instrument très spécialisé mais rapidement construit ; le télescope de Nançay pourra observer des *quasars* paraissant s'éloigner de nous à dix fois la vitesse de la lumière. Selon le modèle d'univers d'Einstein-de Sitter, ces astres seront vus dans l'état où ils étaient 200 millions d'années seulement après le « gros boum » marquant le début de l'expansion (2).

Cet appareil étant près d'entrer en exploitation, on doit déjà envisager l'avenir. A ce propos, posons nous une question bien simple et essayons d'y répondre objectivement : quelle serait la situation si nous disposions d'un réflecteur de même qualité que celui de Nançay, mais ayant cent fois sa surface ?

Son pouvoir séparateur serait tellement fin, et sa puissance de captation serait si grande, qu'il pourrait observer effectivement, parmi la multitude d'astres parsemant la voûte céleste, 10 000 000 d'entre eux.

extragalactic survey: 10$^7$ sources

# SKA will give both huge FoV and exquisite resolution

Optical/near-IR survey machines have this sort of size

ALMA FoV (multiplied by factor ~10!)

- <1 GHz SKA realizations will give at least 10 deg$^2$ FOV
- ~100 deg$^2$ may be achievable!
- With this wide FOV the SKA will be a remarkable SURVEY MACHINE.
- ~3000km baselines gives <milli-arcsec resolution at ~30 GHz

**Steve Rawlings, 2005**

See Rawlings et al. 2004, in "Science with the SKA," Carilli & Rawlings, eds.

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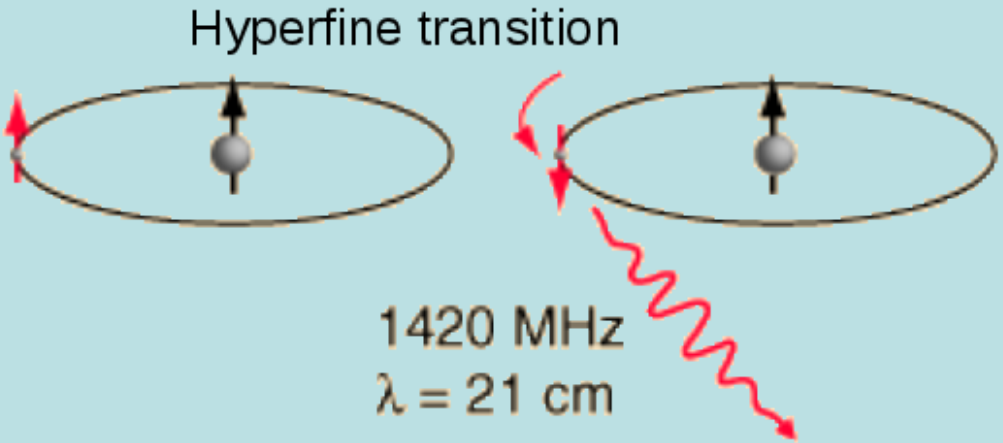
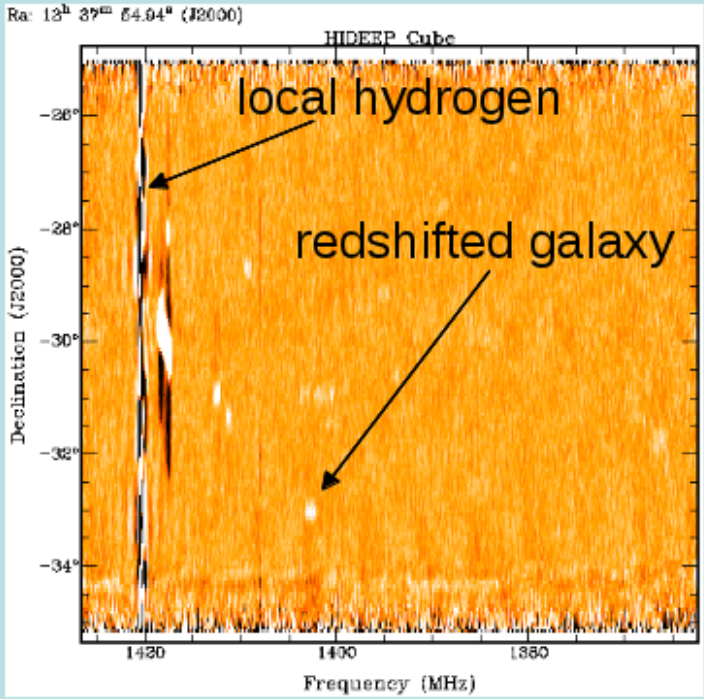
# KSPIV – Galaxies and Cosmology




SPECTRAL domain 0.5 to 1.4 GHz

An SKA sensitivity (100x current) needed to get from z=0.2 galaxies to z ~ 2

- Radio telescopes can have enormous fields of view (cf optical etc)
- Radio telescopes gain sensitivity on galaxies linearly with A (cf $\sqrt{A}$ optically)
- SKA will quickly pinpoint ~$10^9$ galaxies in 3D (cf ~$10^6$ galaxies in Sloan)

**Steve Rawlings, 2005**

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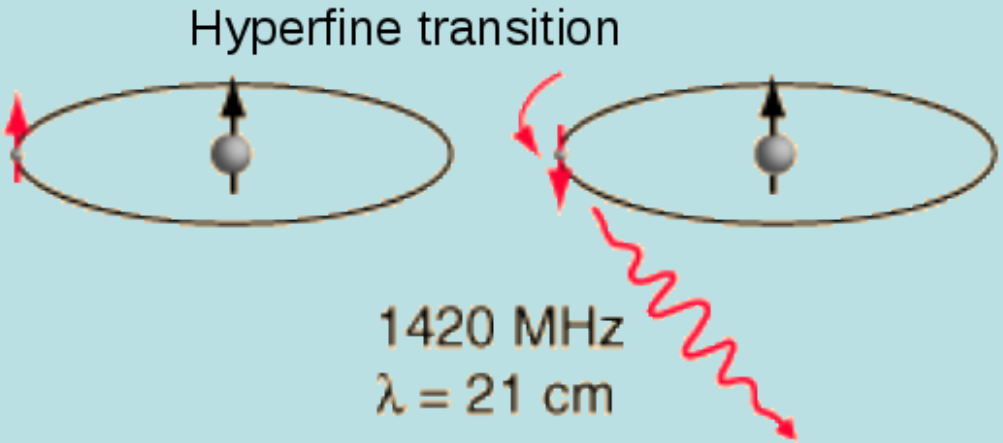
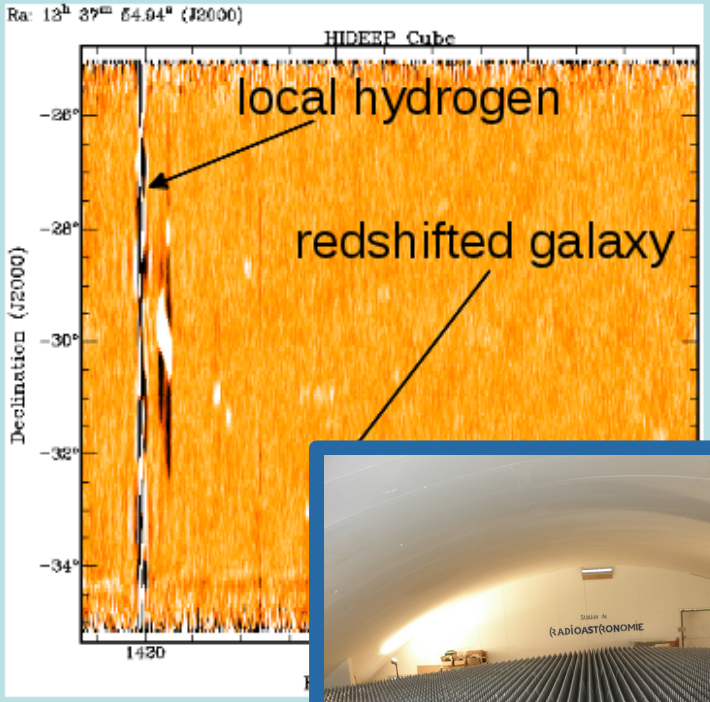
# KSPIV – Galaxies and Cosmology





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**Steve Rawlings, 2005**

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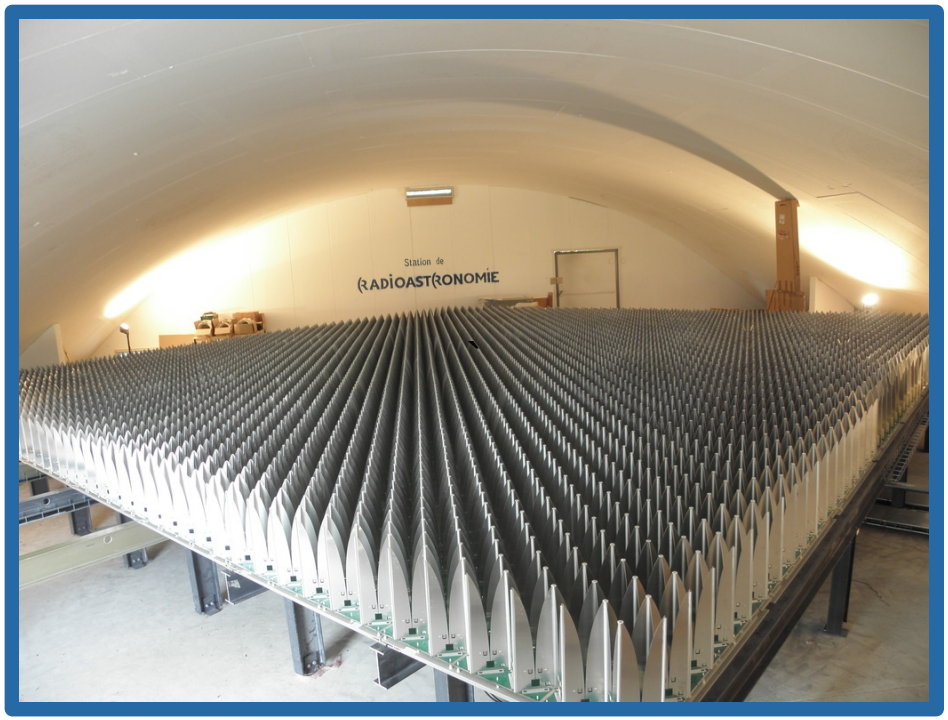
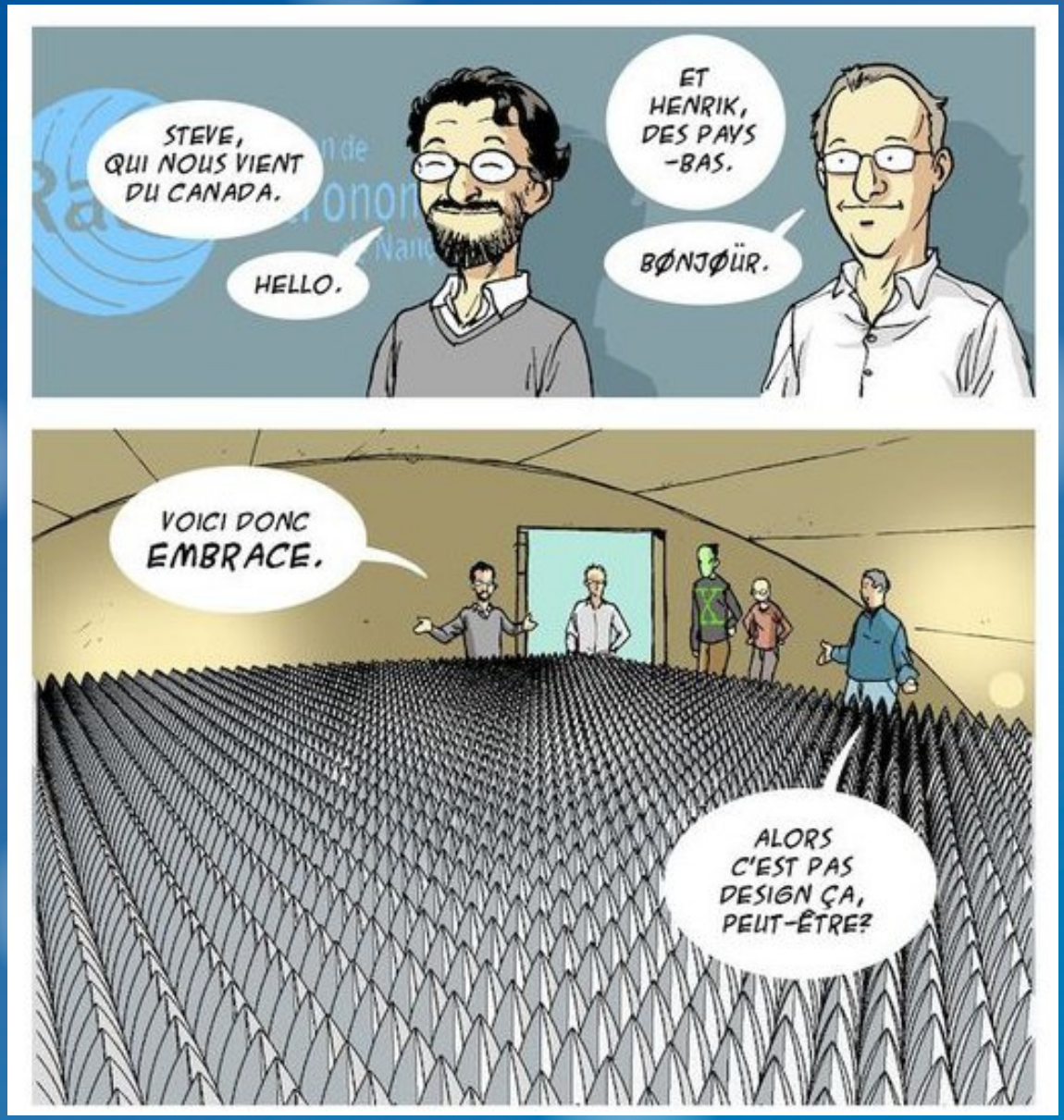
# Dense Aperture Plane Array




- Fully sampled, unblocked aperture
- Large field of view (~100 sq. deg)
- Extremely fast survey machine for HI at cosmological redshifts
- **Ideal for BAO survey by Intensity Mapping**

# EMBRACE@Nancay




SKADS

ASTRON

l'Observatoire de Paris

Station de Radioastronomie de Nançay

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

MAX-PLANCK-GESELLSCHAFT

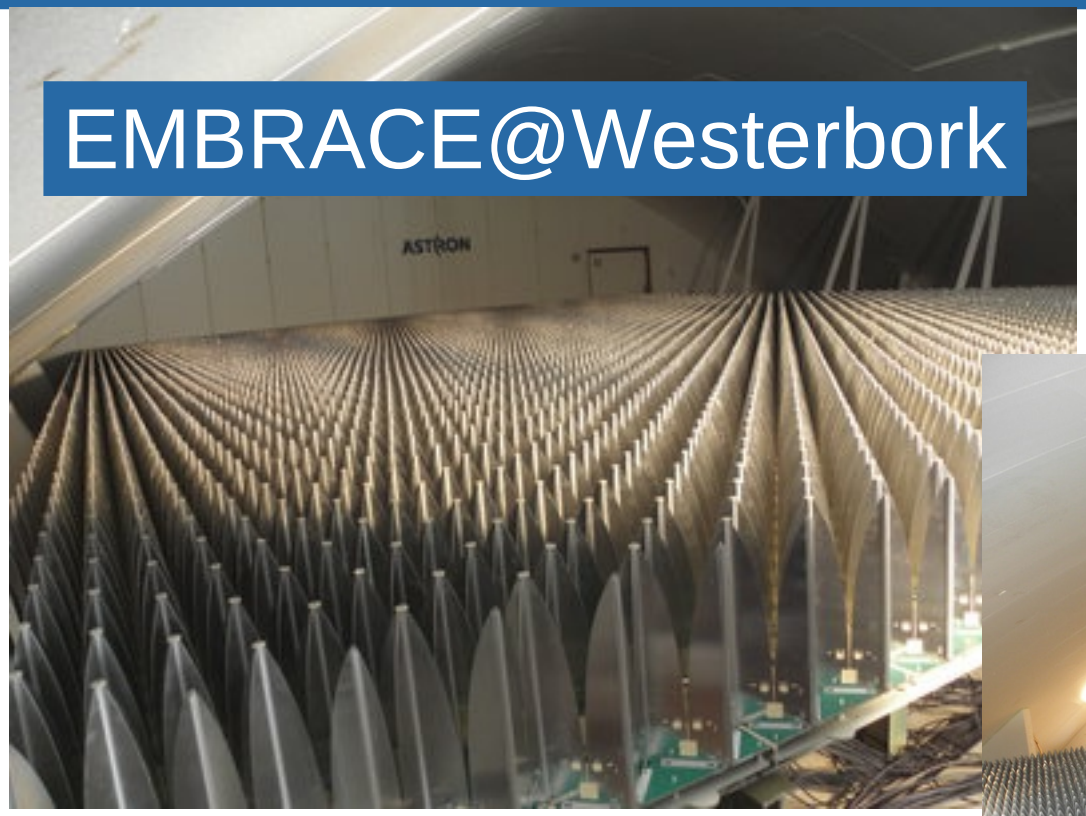
CHALMERS

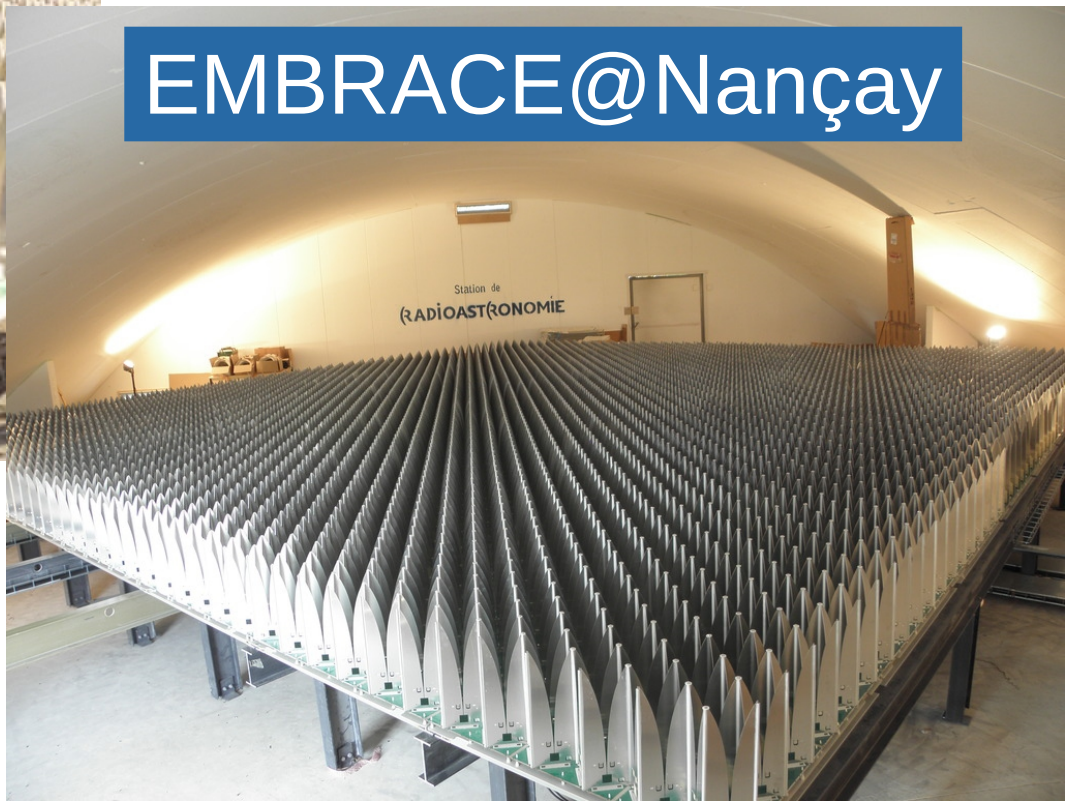
UNIVERSITY OF OXFORD

# 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
- Two demonstrators built.  One at Westerbork (132 tiles) and one at Nançay (64 tiles)

# Two EMBRACE sites



# EMBRACE@Nançay

- 4608 Vivaldi antenna elements
- Single polarization (second polarization antennas are there for a total of 9216 elements, 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)

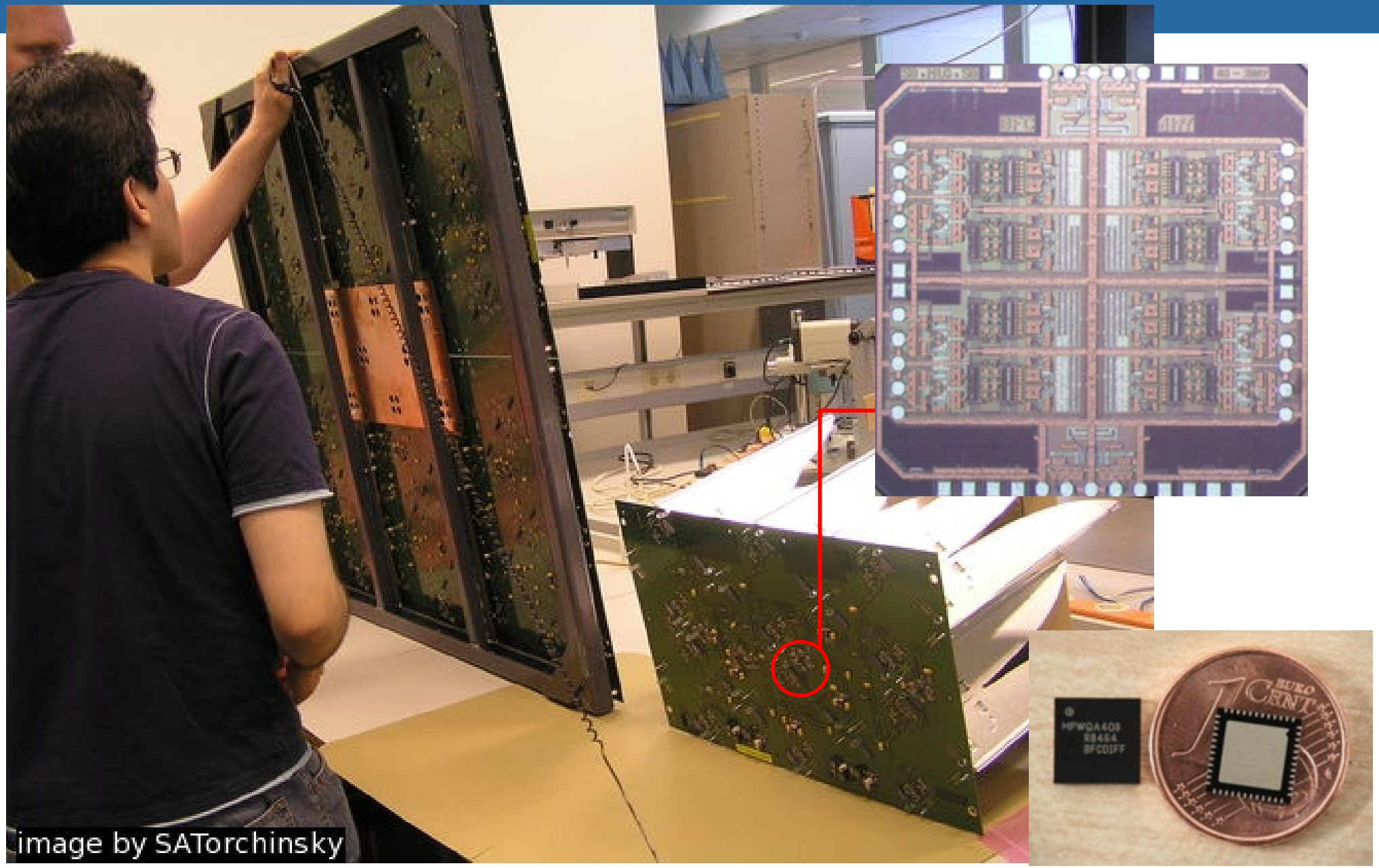
# EMBRACE@Nançay

Station de Radioastronomie de Nançay

- 500 – 1500 MHz
  - But high pass filter at 900 MHz to avoid digital television
- 70 $m^2$ (10.5m X 10.5m)
- Instantaneous RF band: 100 MHz
- Maximum instantaneous beam formed:
  - 36 MHz x 2 directions (single polarization)
  - 186 “beamlets” each of 195.3 kHz bandwidth
  - ie. 3 “lanes” for high speed data from RSP
  - Can trade off beam width vs. number of beams

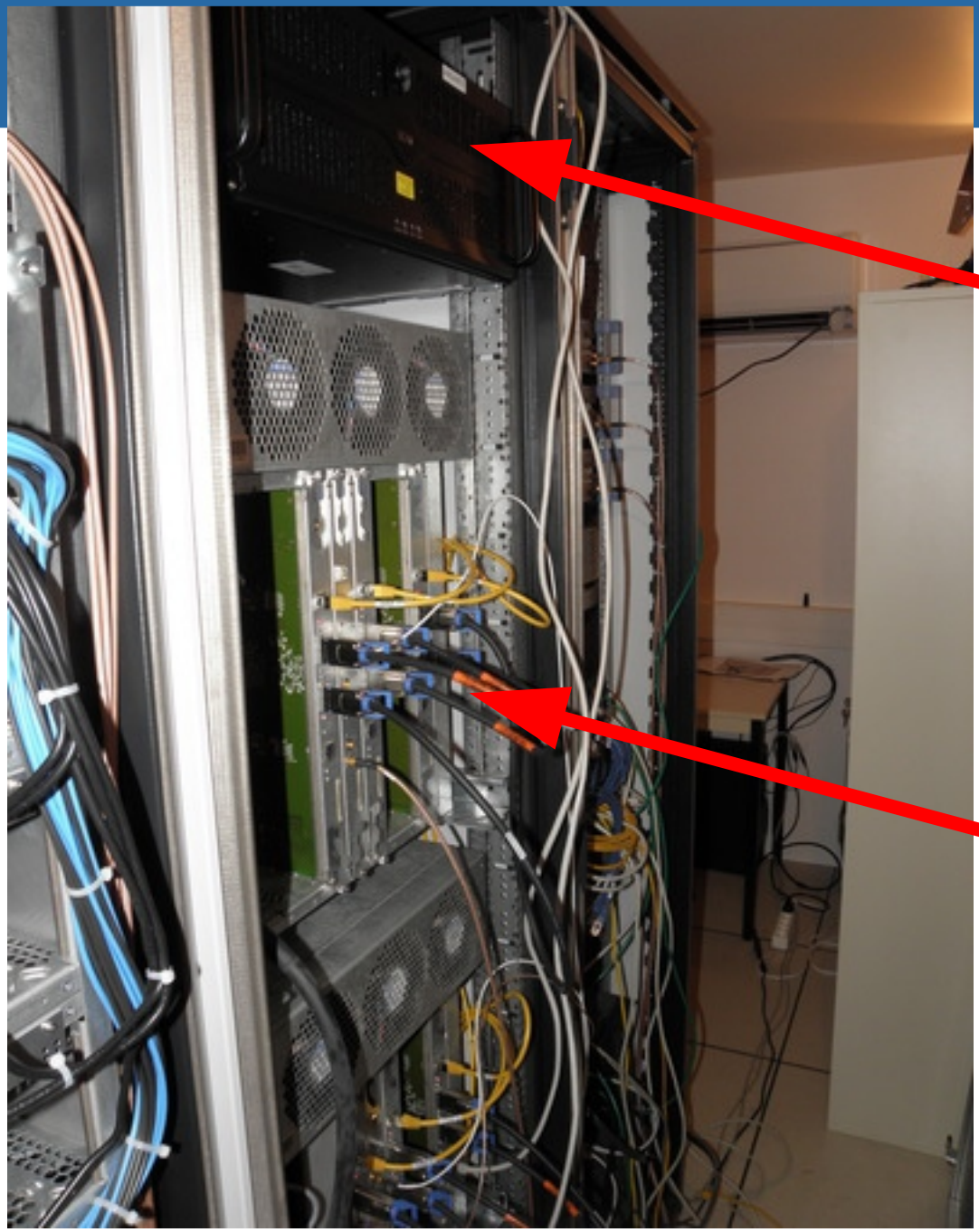
# Beamformer Chip

Station de Radioastronomie de Nançay



# High Speed Data Acquisition

UNIVERSITY OF OXFORD



ARTEMIS

Pulsar acquisition system provided by U. Oxford. Aris Karastergiou

LOFAR Remote Station Processing Boards for digital beamforming

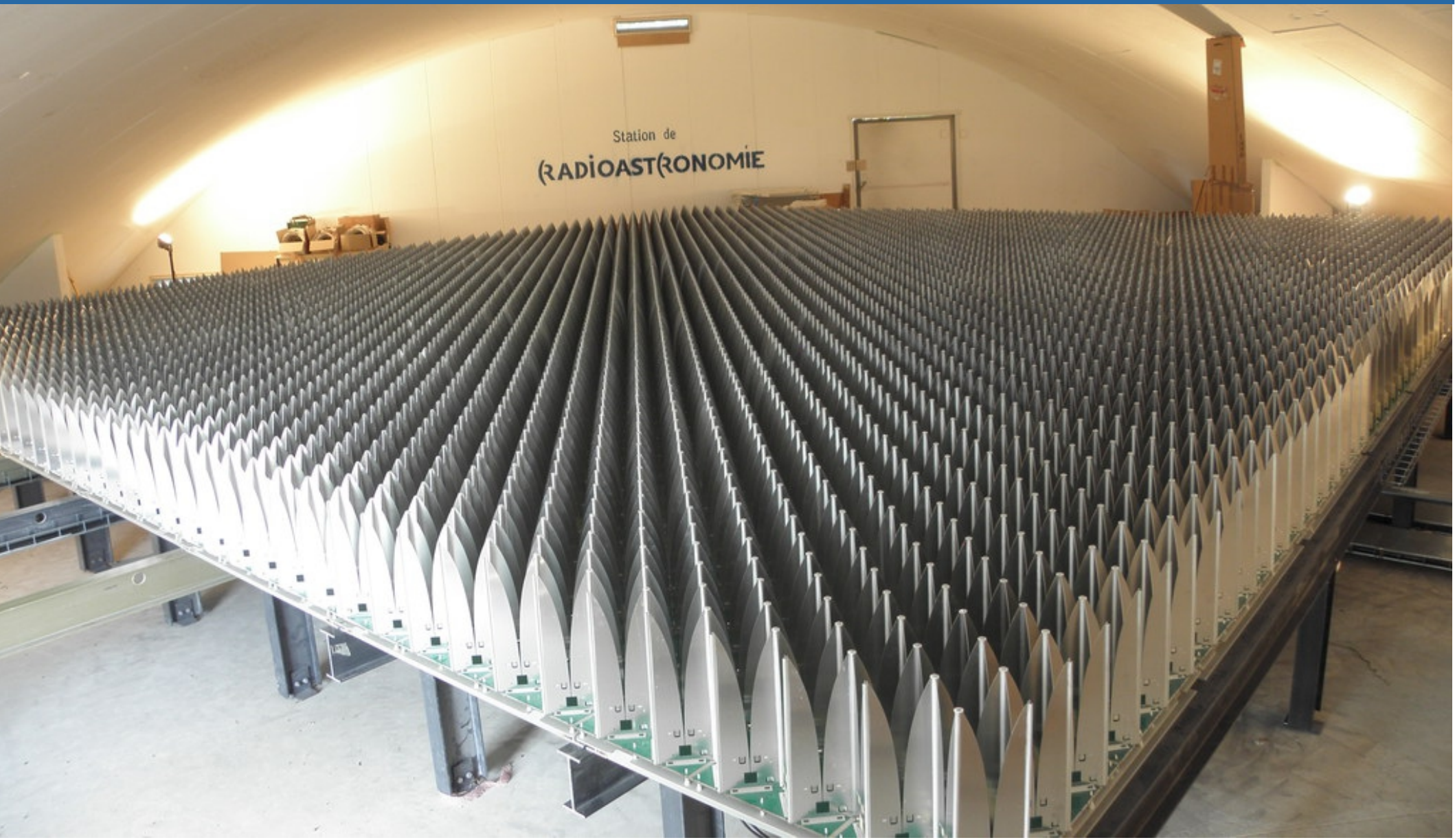
# System Control and Data

Station de Radioastronomie de Nançay

- 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

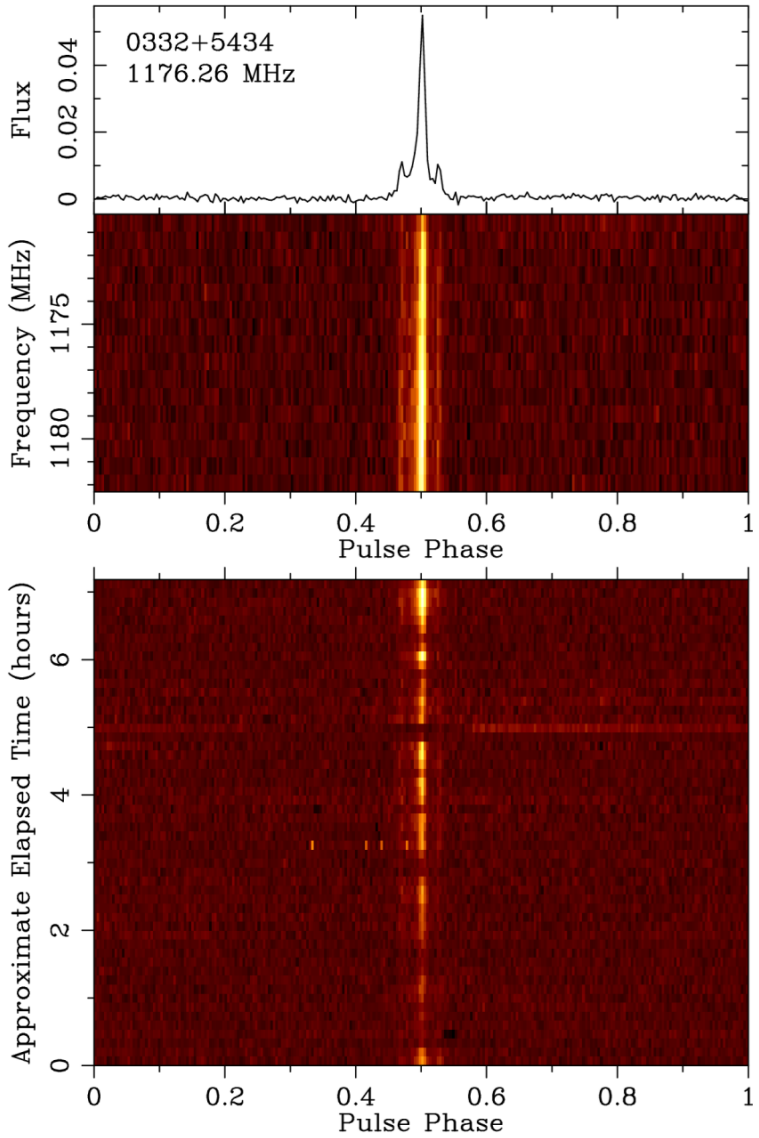
MAC developed at Nançay provides a friendly Python interface for the user to setup complicated observing runs

# Some results



# Pulsar B0329+54

Station de Radioastronomie de Nançay



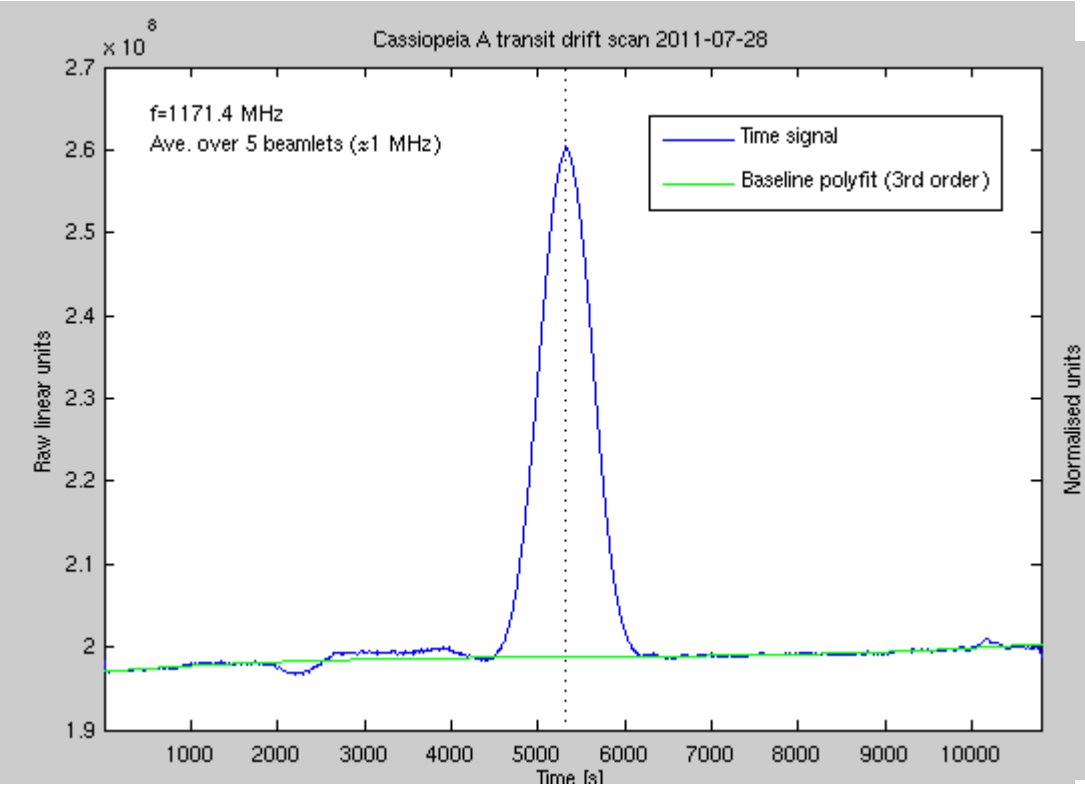

Pulsar B0329+54
1175.6MHz
6 November 2012
>9 hours tracking

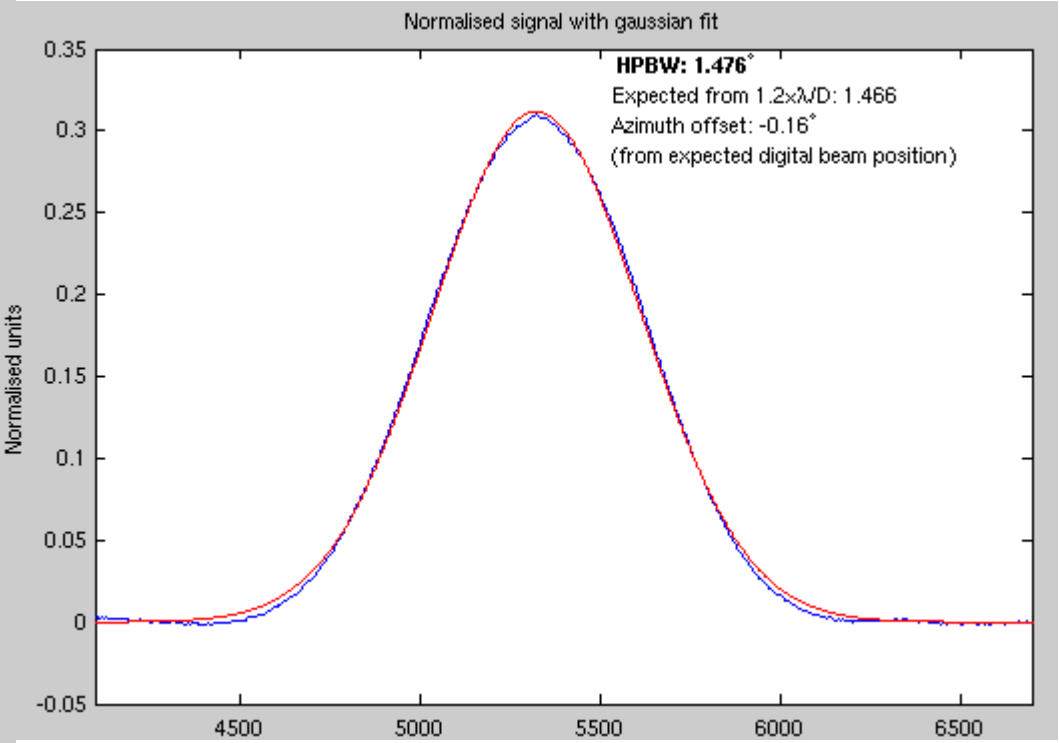
EMBRACE@Nançay
connected to
ARTEMIS backend
(courtesy U. Oxford)


EMBRACE@Nançay

# Drift Scan of Cas-A

Station de Radioastronomie de Nançay




- Gaussian main lobe
- FWHM 1.476º
  - 1.2λ/D = 1.486º

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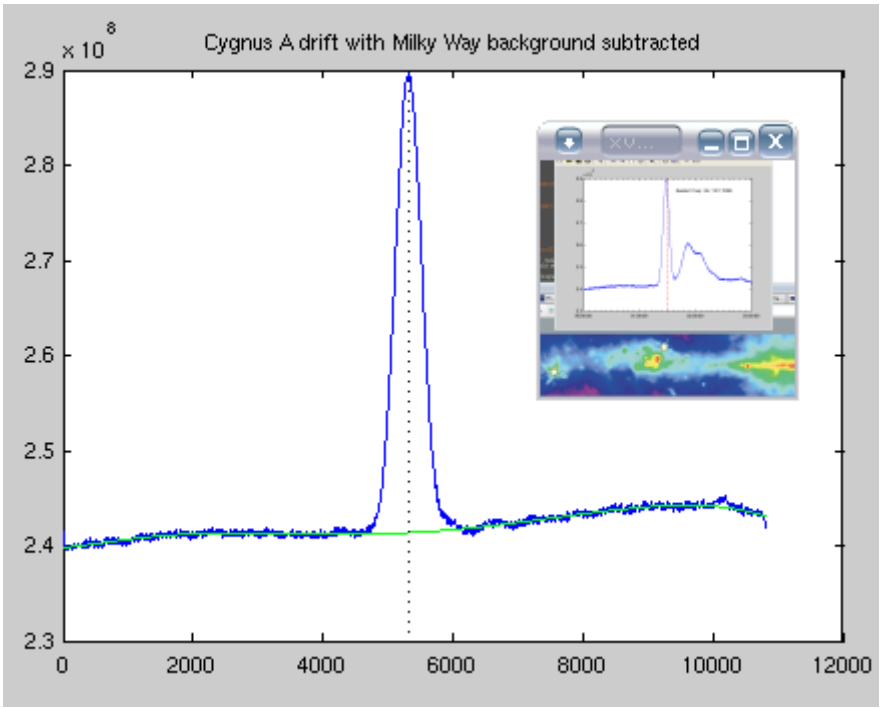
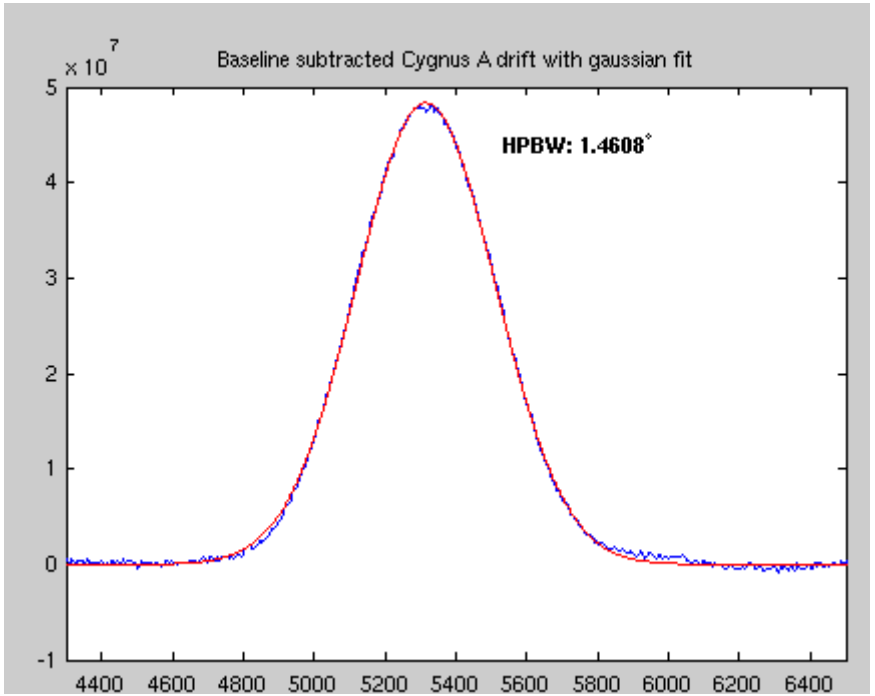
# Drift Scan of Cyg-A

Station de Radioastronomie de Nançay

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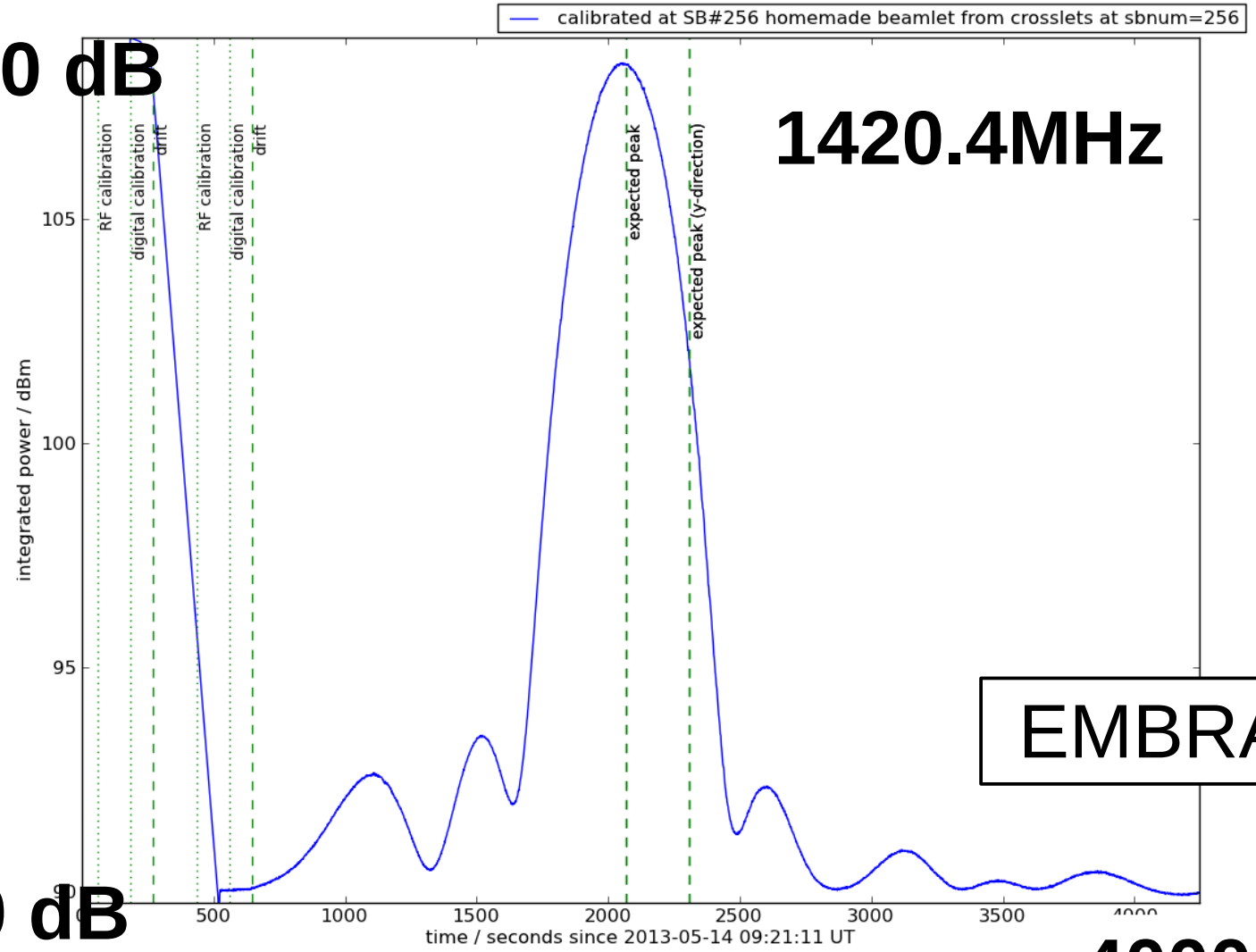
# Drift scan of the Sun

Station de Radioastronomie de Nançay

Sun : Beam A : calibrated at subband #256, power from crosslets: Timeline for integrated power




**110 dB**

**90 dB**

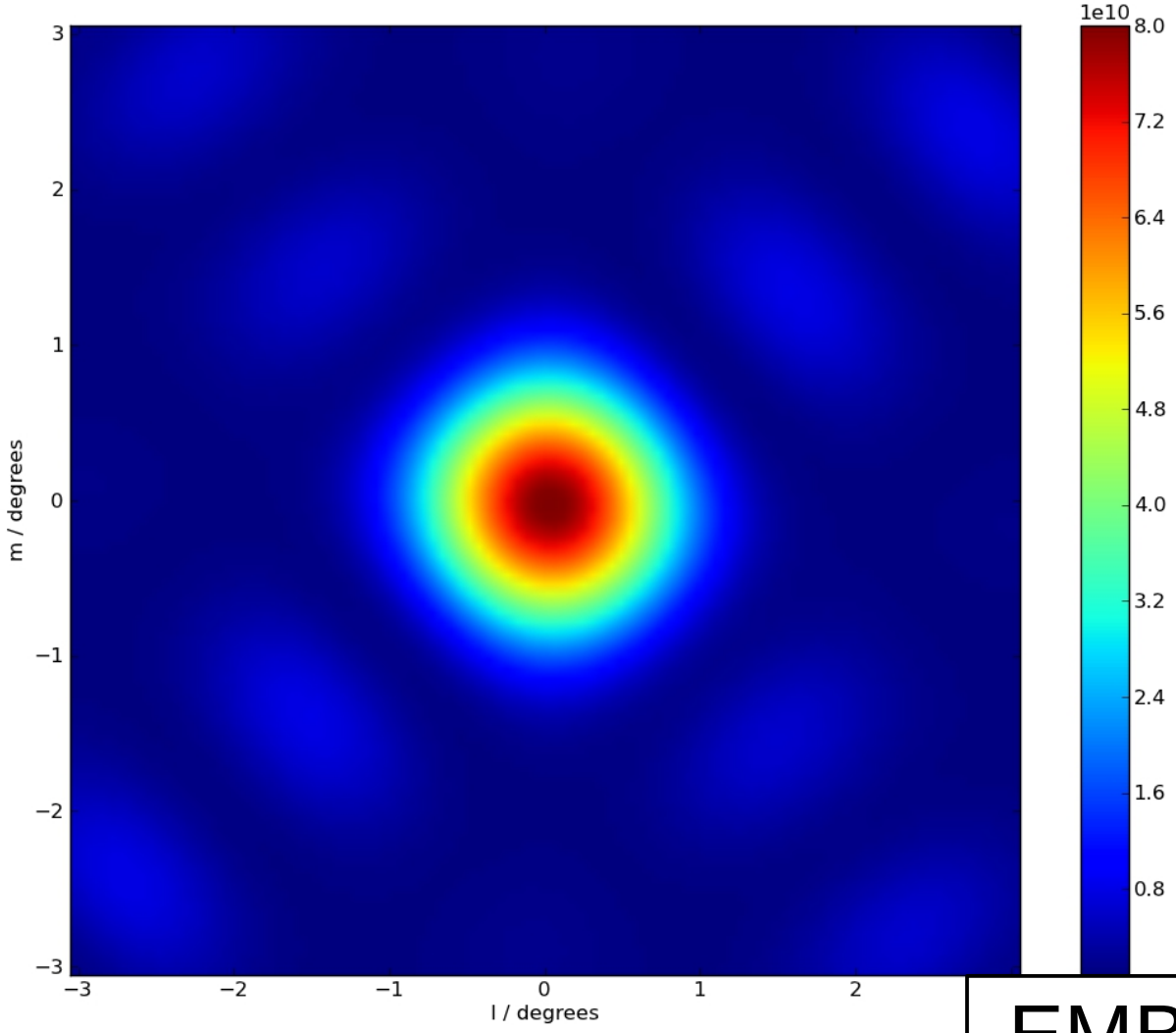
**1420.4MHz**

EMBRACE@Nançay

**4000 secs**

# Imaging using X-let statistics

: Beam A : calibrated at subband #256, subband #256 = 1420.41 MHz at integration #221 (2013-05-14 09:24:52

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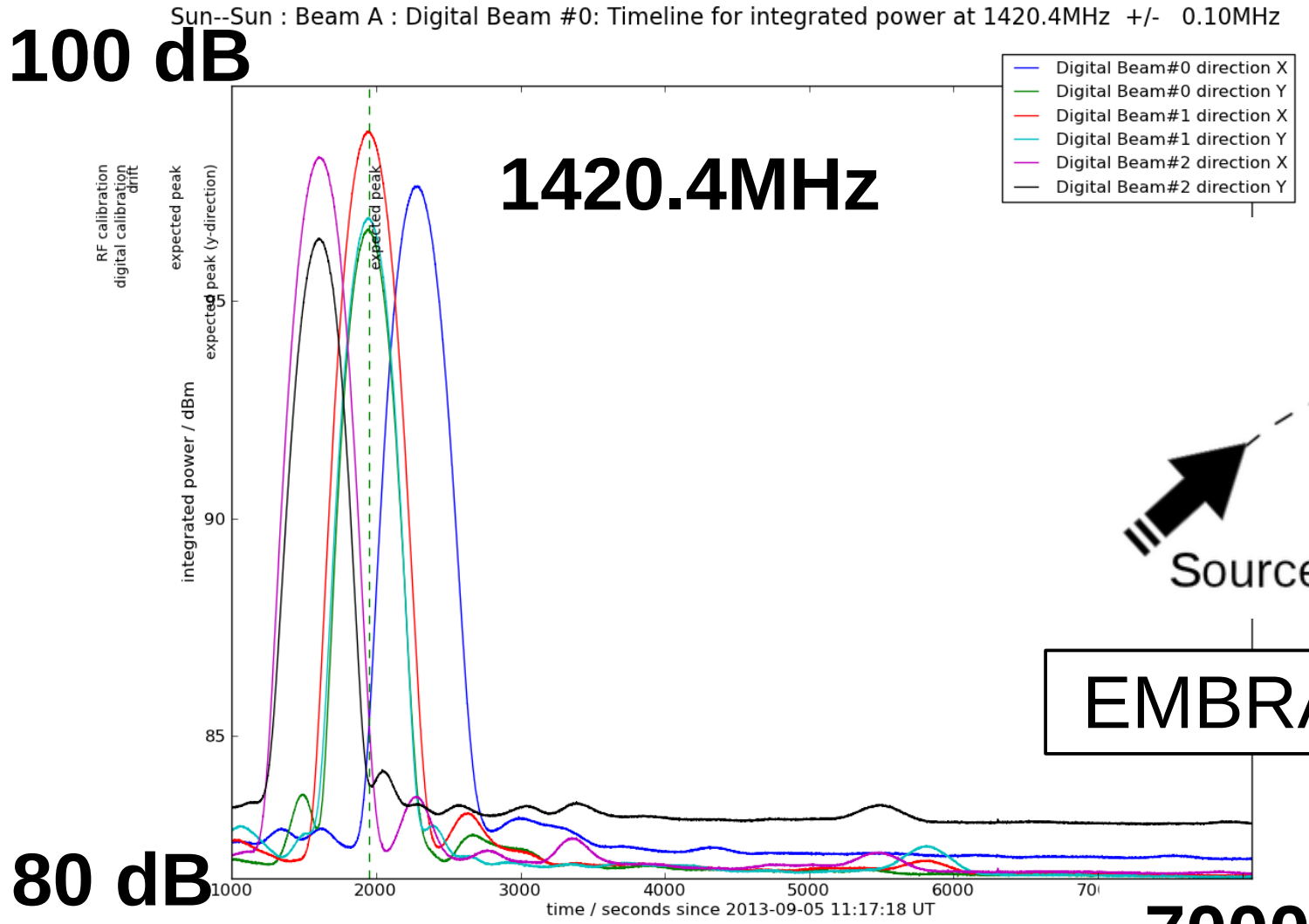
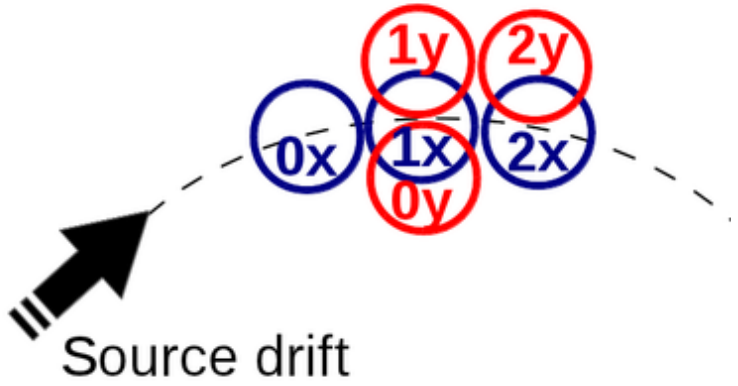
# Multibeaming

Station de Radioastronomie de Nançay

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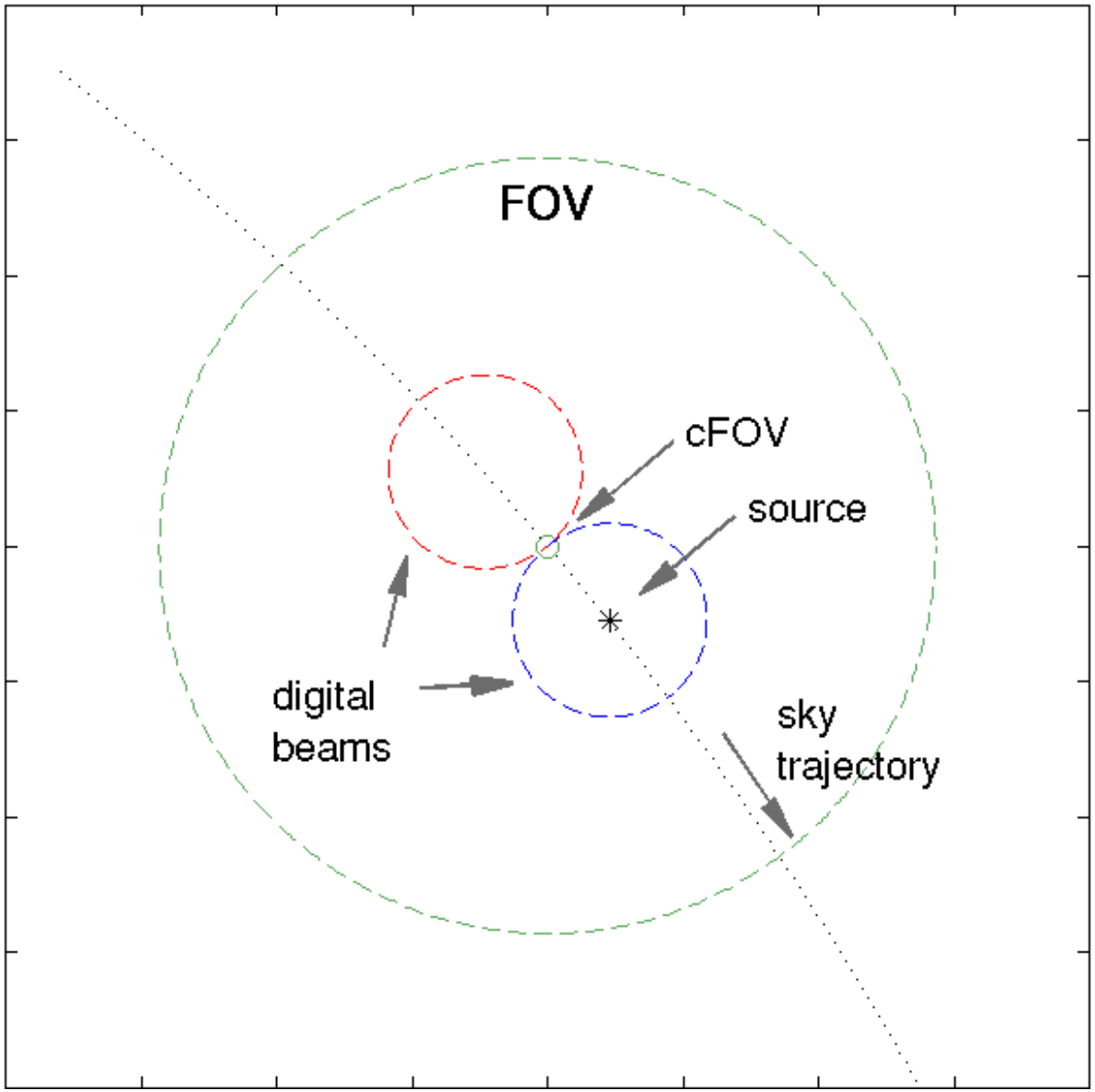
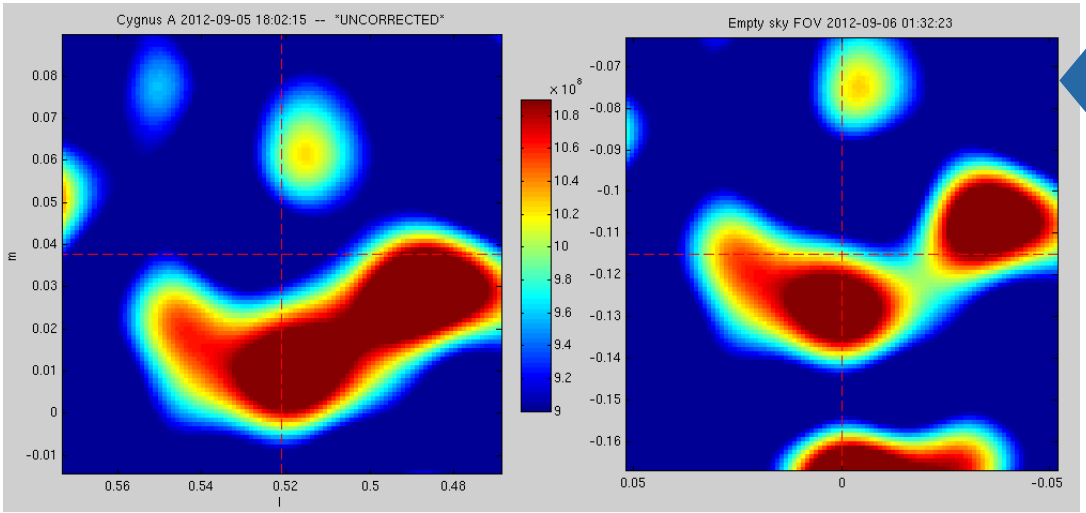
# ON-OFF pointing strategy



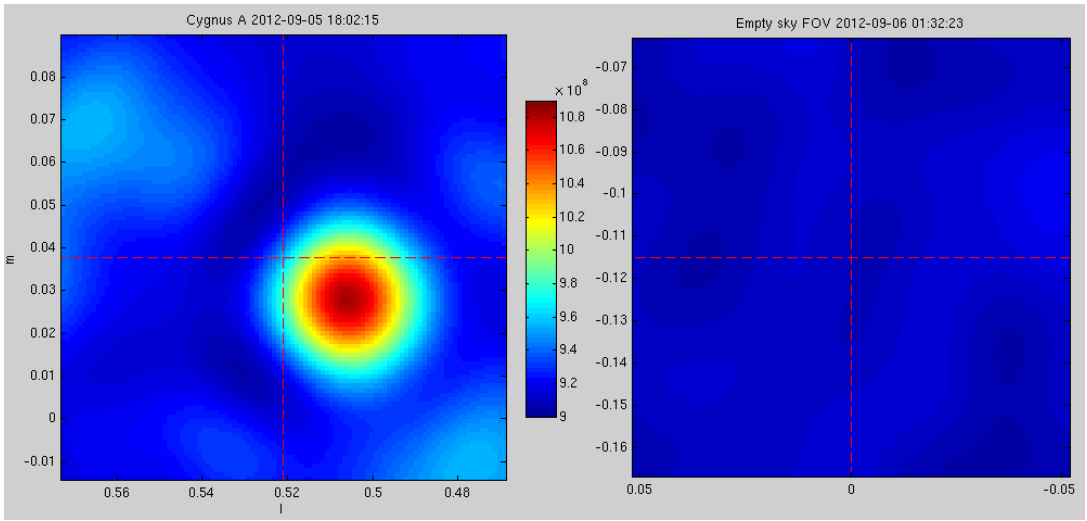

- On and Off observations can be done **simultaneously** with EMBRACE (multibeams)

# Another fix: Flat Fielding



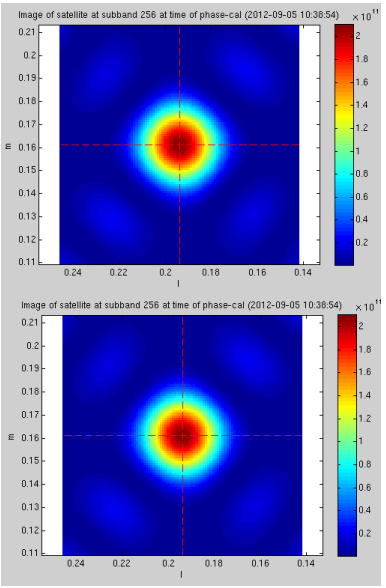

Stable background “image” due to correlator offset

Cygnus A
Same data!
(before/after fix)




GPS satellite
(strong source)

No change



EMBRACE@Nançay

# Galaxy Detection: M33

Station de Radioastronomie de Nançay

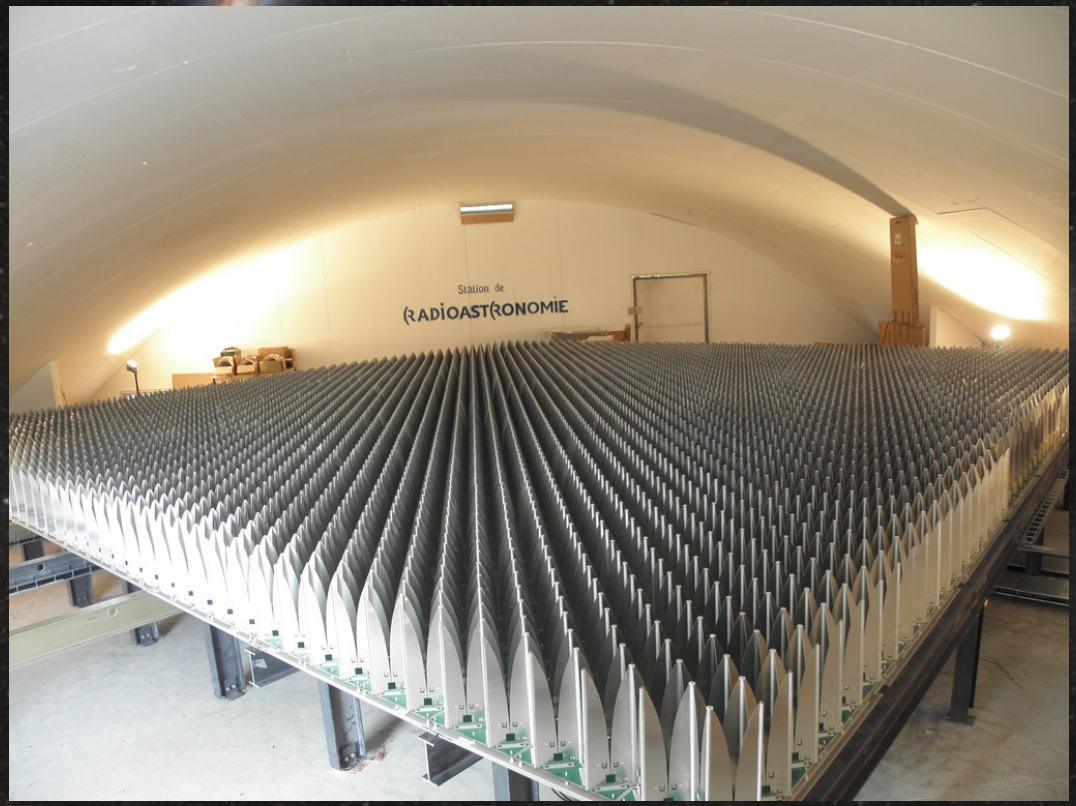
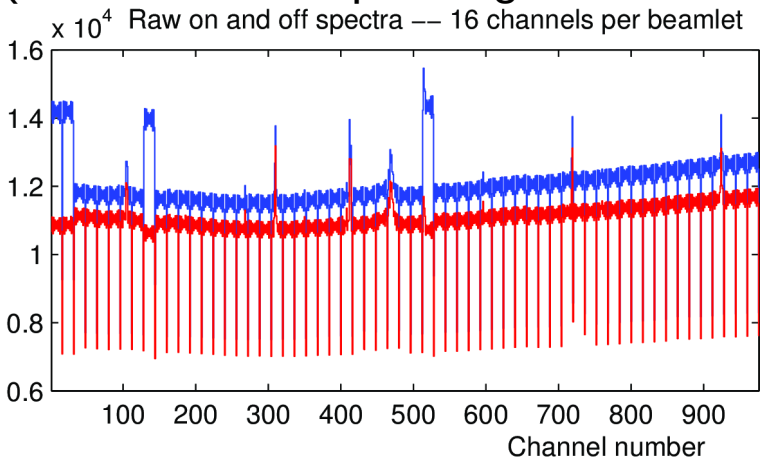


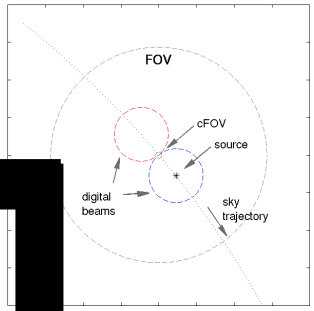

Image by deepskycolors.com

# Galaxy Detection: M33

Station de Radioastronomie de Nançay

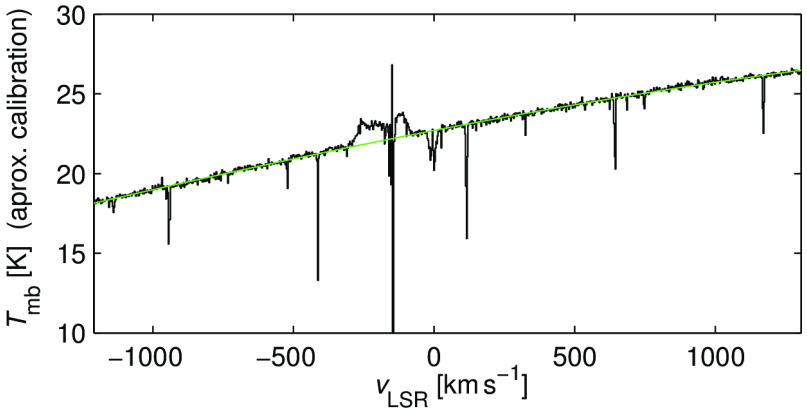
OFF timeline shifted to align with ON
(i.e. same Az-El pointing, earlier time)

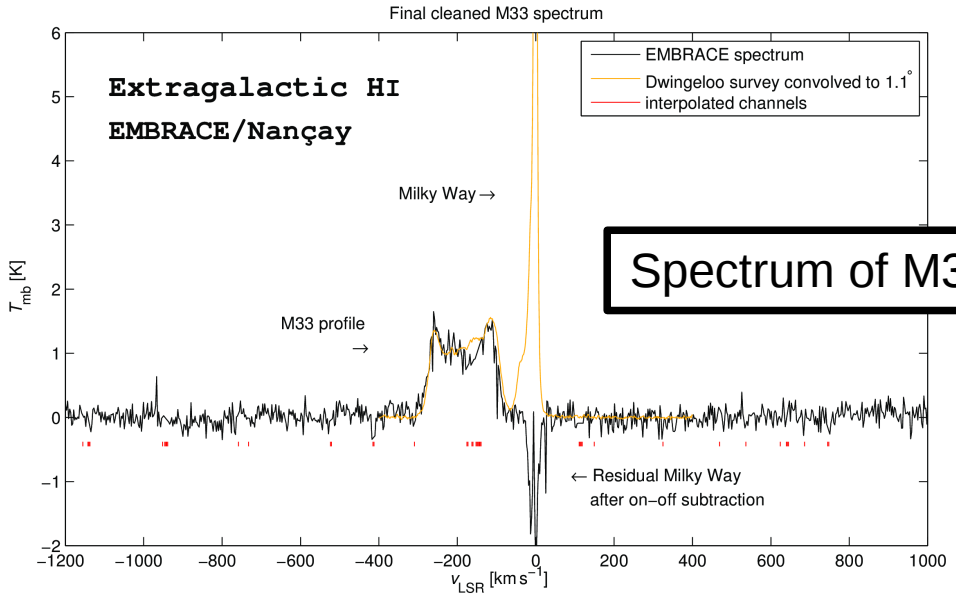



(ON – OFF)/OFF

( $T_{sys}$/η)×(on–off)/off with baseline fit




Spectrum of M33

Baseline fit and interpolate past RFI channels

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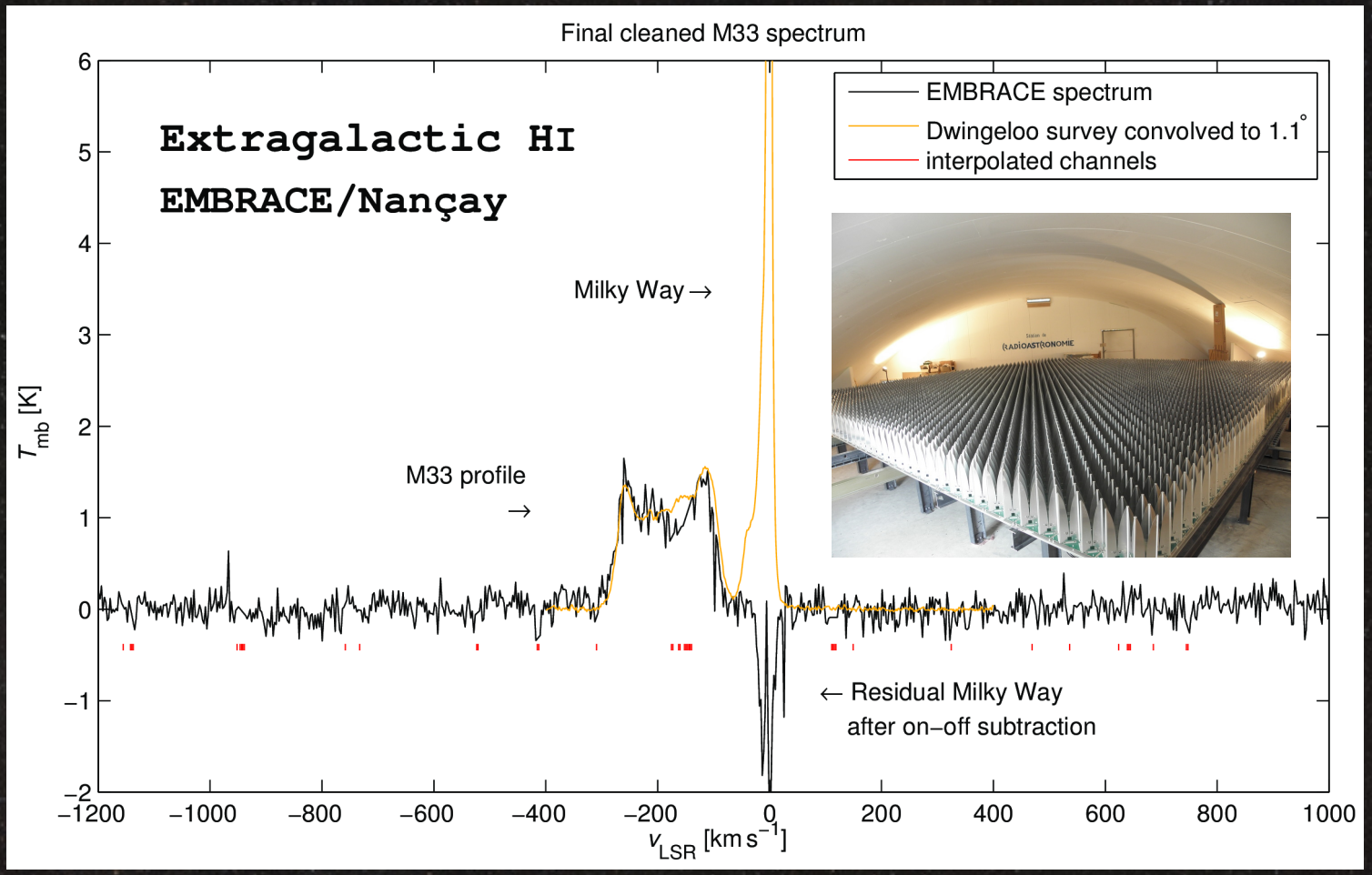
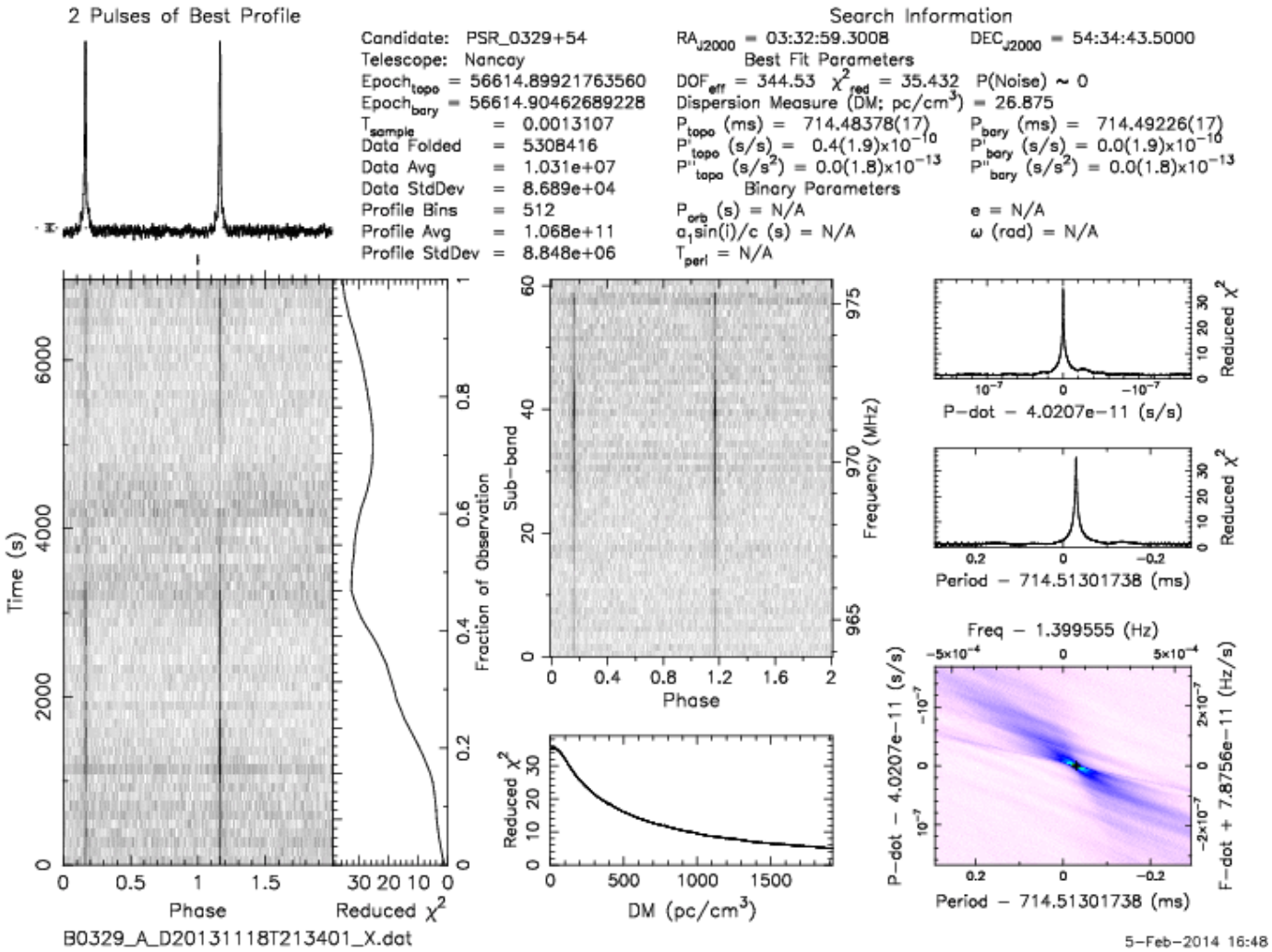
# Galaxy Detection

Station de Radioastronomie de Nançay




Only 999 999 999 to go ...

# Pulsar monitoring




- Programme of (nearly) daily monitoring of pulsar B0329+54 at 970MHz and 1176MHz simultaneously
- Possibility to detect accretion events in the long term (see e.g. Brook et al. ArXiv:1311.3541v1)

30 observations at 970MHz to date

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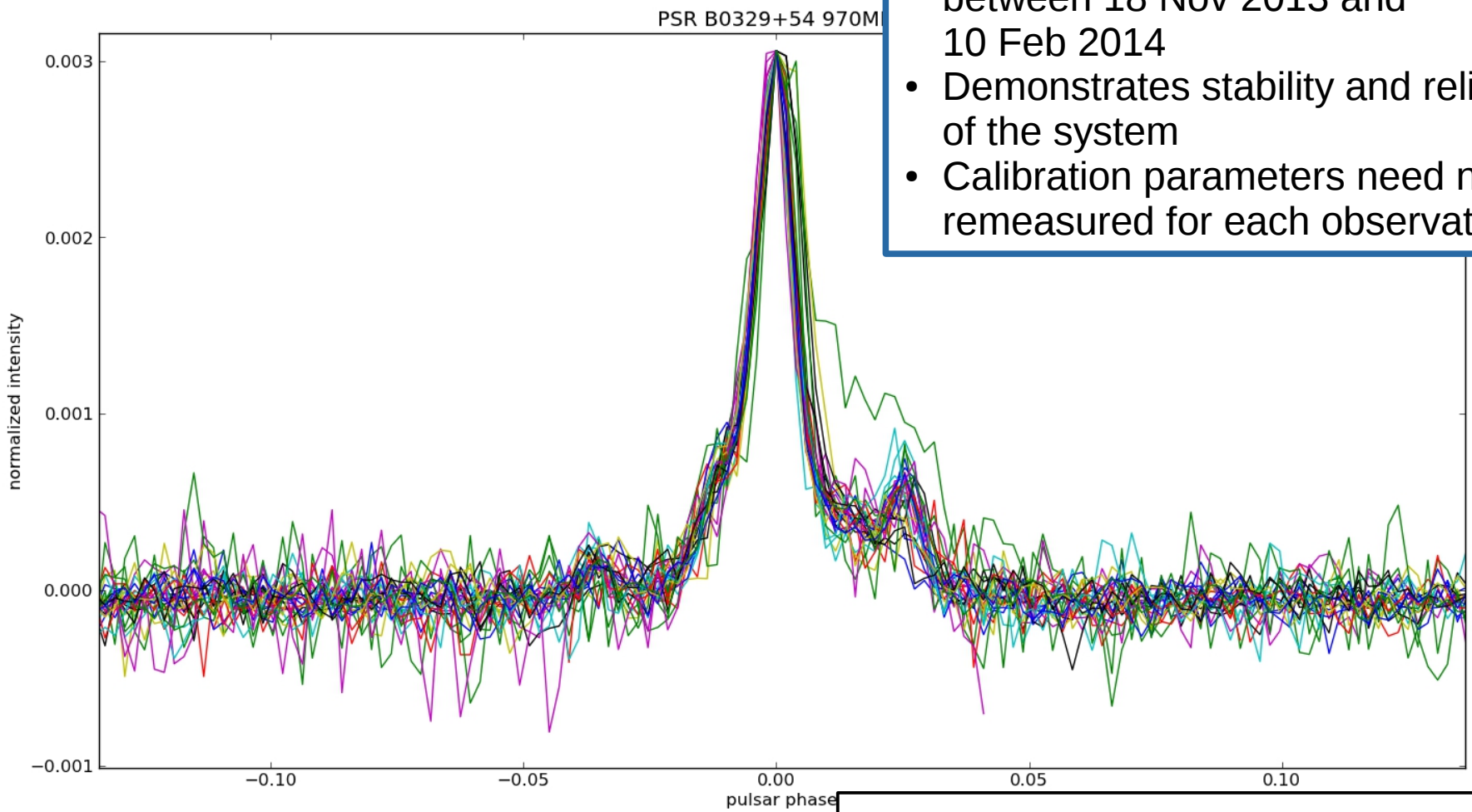
# B0329+54 at 970MHz

Station de Radioastronomie de Nançay




- 30 pulse profile measurements between 18 Nov 2013 and 10 Feb 2014
- Demonstrates stability and reliability of the system
- Calibration parameters need not be remeasured for each observation

EMBRACE@Nançay

# Future developments

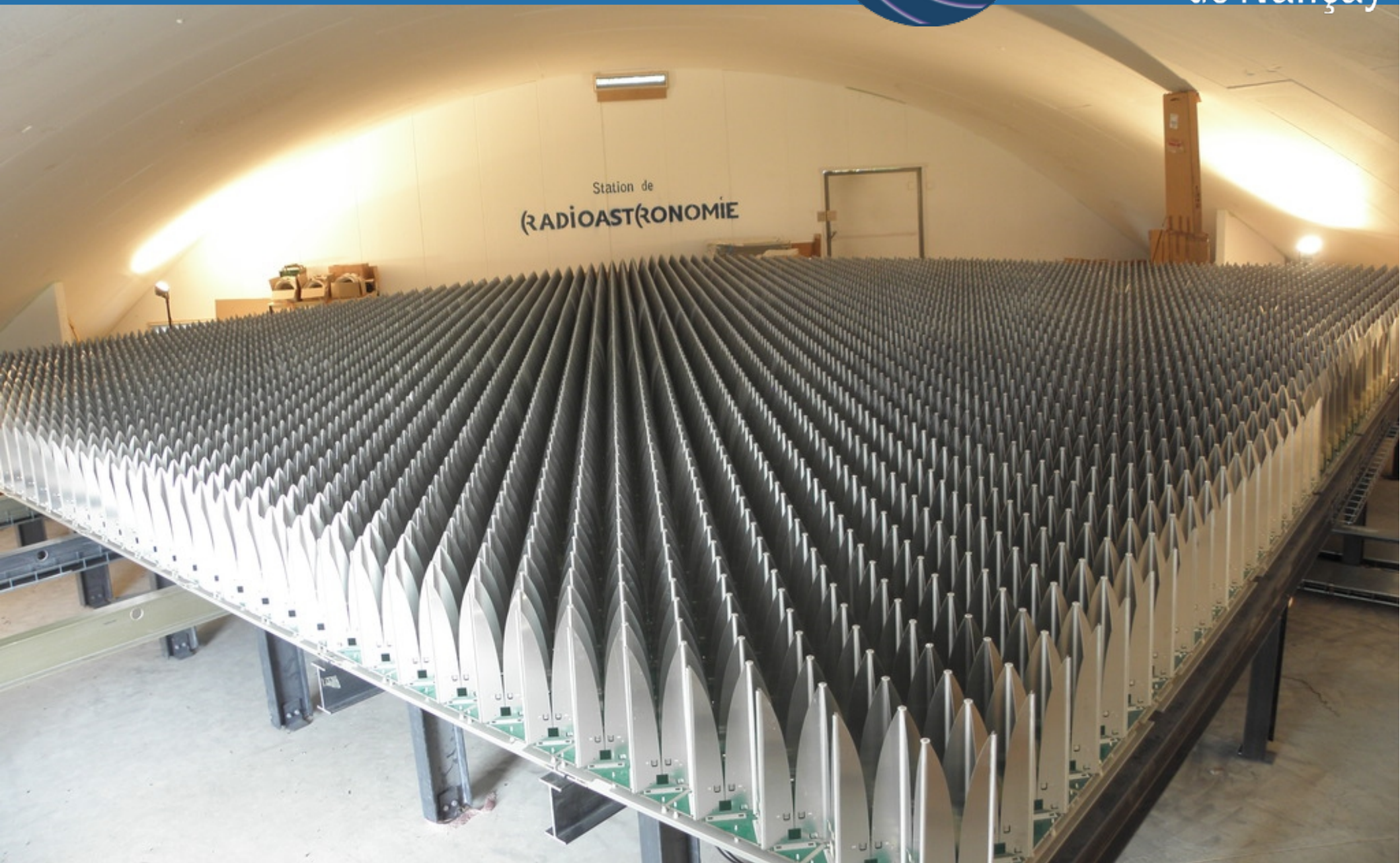
- Continued testing/characterization of EMBRACE
  - Long term stability, robustness, multimode observing...
  - Testing new calibration algorithms
  - UNIBOARD backend with real-time RFI filtering
- Hardware development: further integration “System on chip”
  - Reduce power consumption, cost of manufacture
  - Digital output from the tile
- Next generation: dual polarization EMBRACE
  - Proposal for a large prototype
    - Looking for funding... possibly AERAP
    - Perhaps at SKA site SA
    - Ideal for Intensity Mapping for BAO!

# EMBRACE@Nancay


http://tinyurl.com/nancaycomicbook

# EMBRACE@Nançay

Station de Radioastronomie de Nançay



# B0329+54 2014-Feb-01

Station de Radioastronomie de Nançay