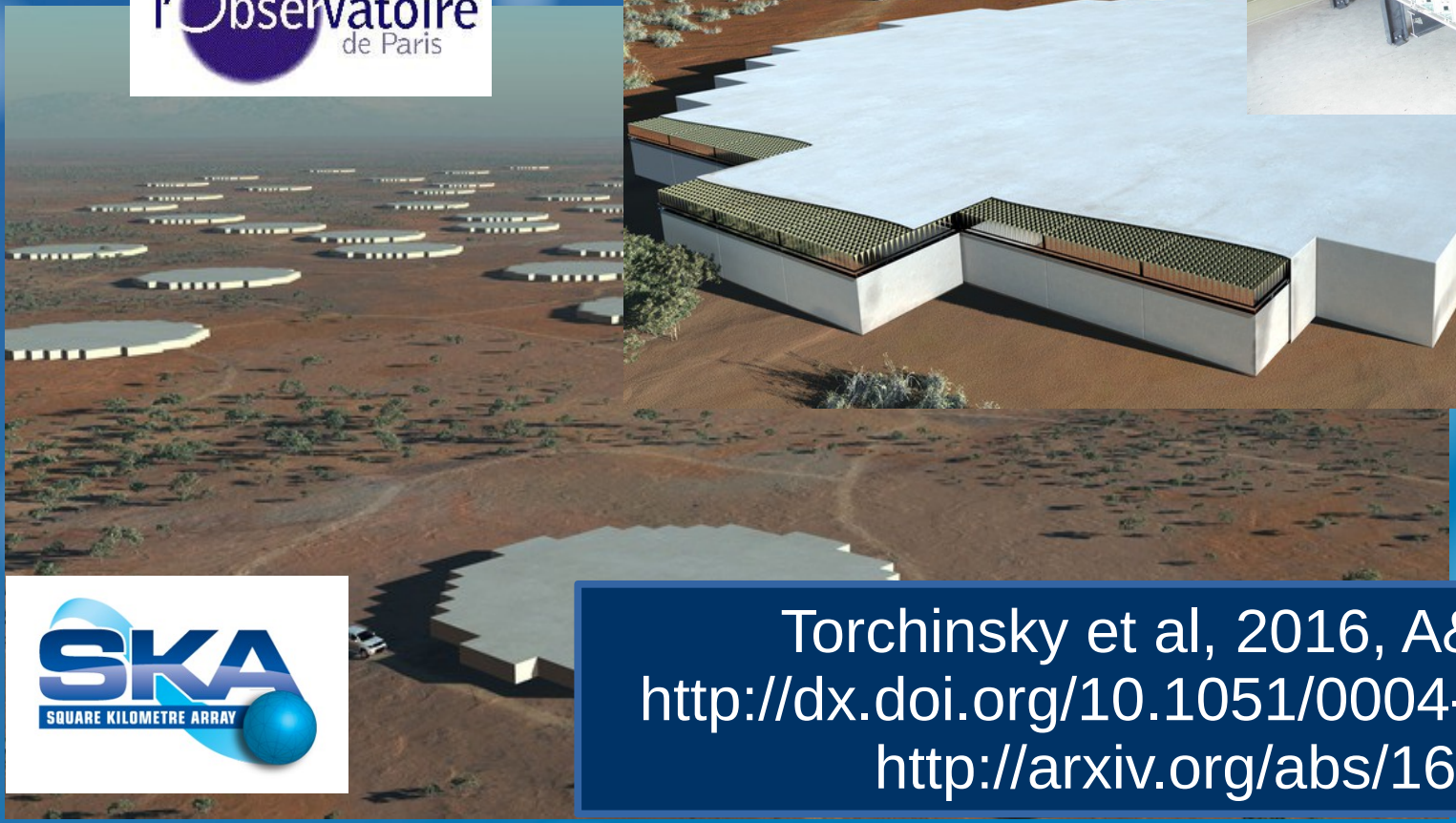
EMBRACE@Nancay



Station de Radioastronomie de Nançay

l'Observatoire de Paris

SKA SQUARE KILOMETRE ARRAY

Torchinsky et al, 2016, A&A, accepted
http://dx.doi.org/10.1051/0004-6361/201526706
http://arxiv.org/abs/1602.07976

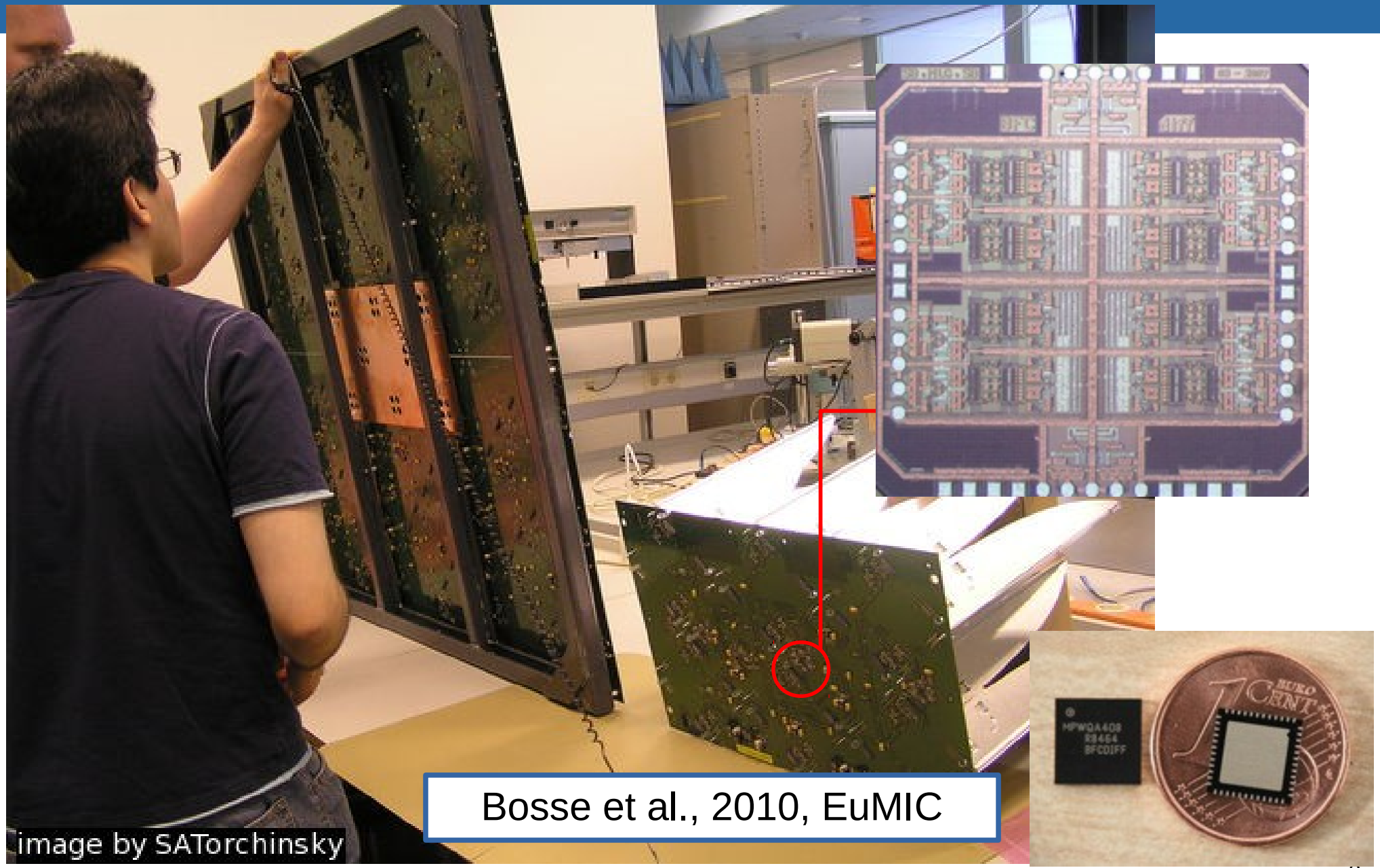
Electronic MultBeam Radio Astronomy ConcEpt

- **EMBRACE is an AAmid Pathfinder for SKA**
  - **Results from EMBRACE feed into SKA Mid Frequency design and SKA technology selection**
- 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

http://arxiv.org/abs/1602.07976

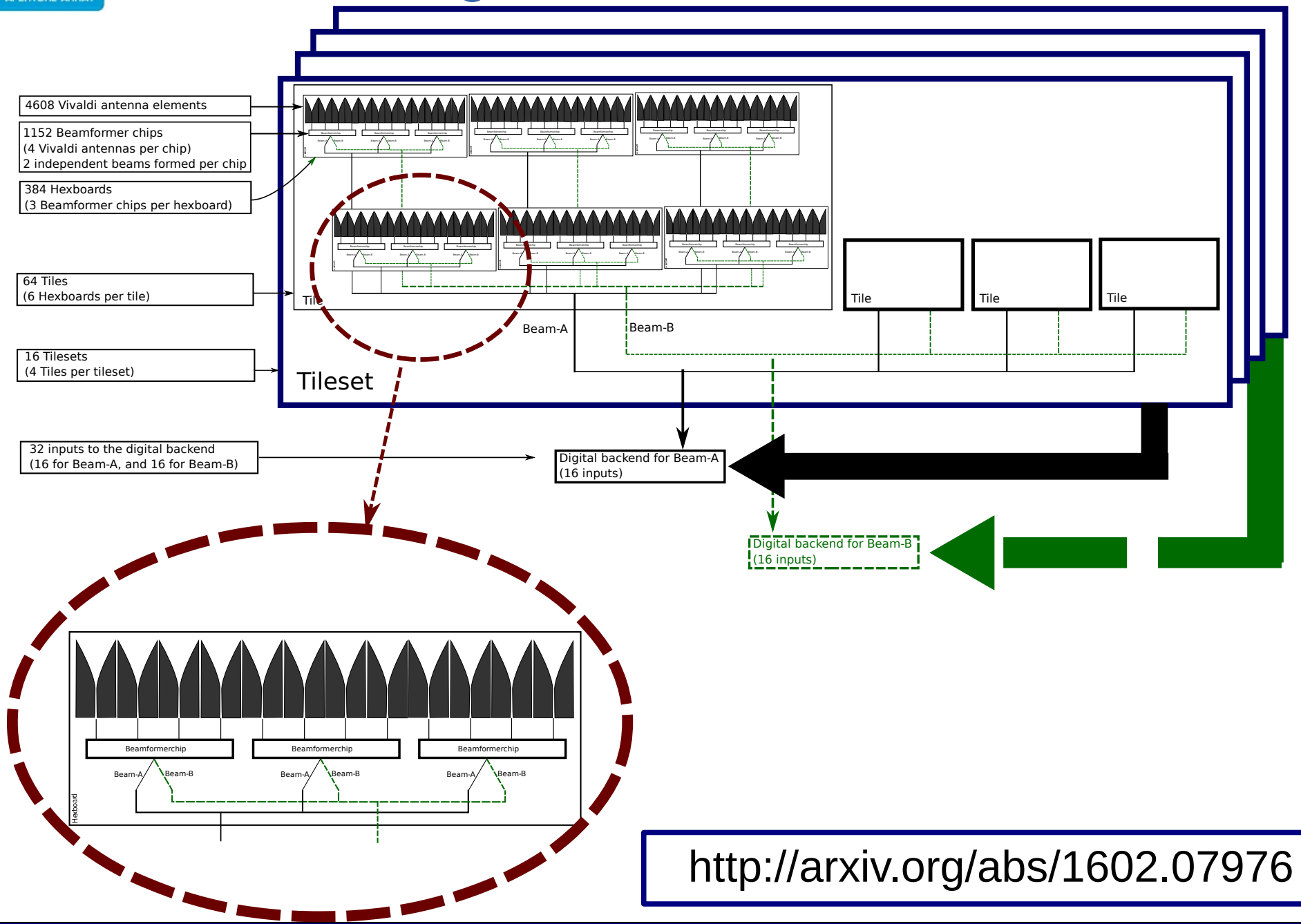
Beamformer Chip

Station de Radioastronomie de Nançay



Bosse et al., 2010, EuMIC

Beamforming Architecture



http://arxiv.org/abs/1602.07976

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)

http://arxiv.org/abs/1602.07976

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

http://arxiv.org/abs/1602.07976

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

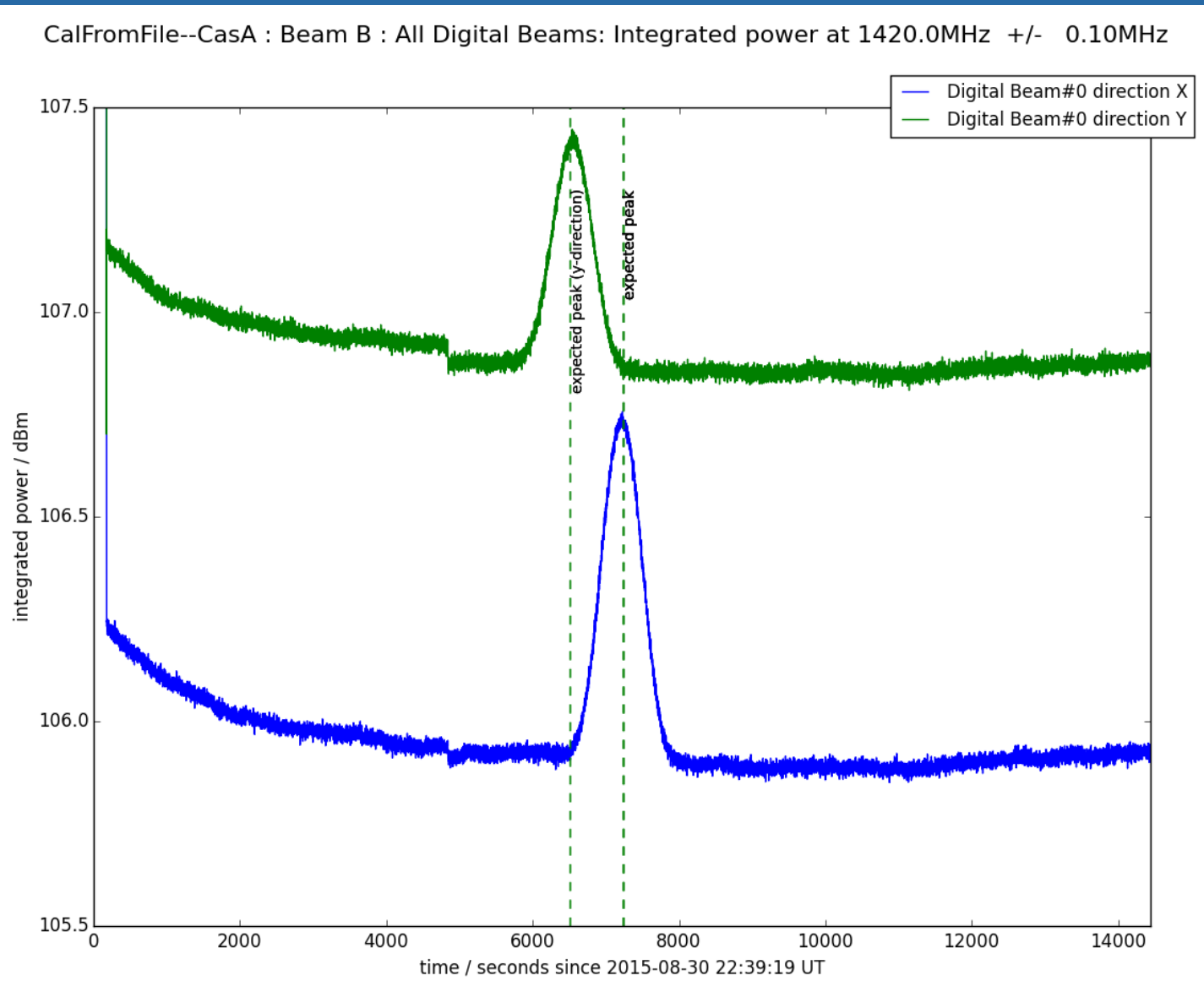
MAC developed at Nançay provides a friendly Python interface for the user to setup complicated observing runs.

http://arxiv.org/abs/1602.07976

Some results

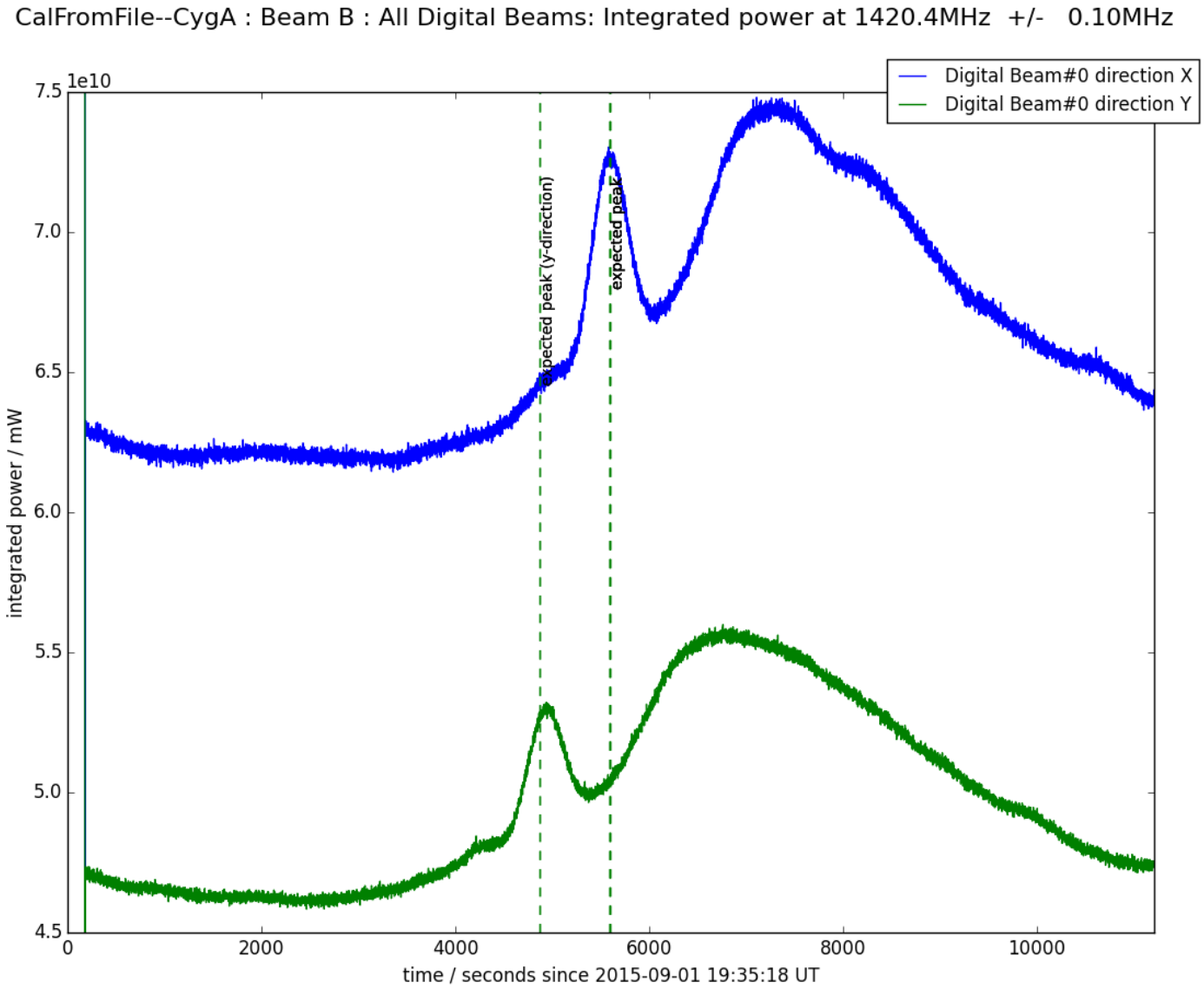
http://arxiv.org/abs/1602.07976
Torchinsky et al, 2016, A&A, accepted

CasA



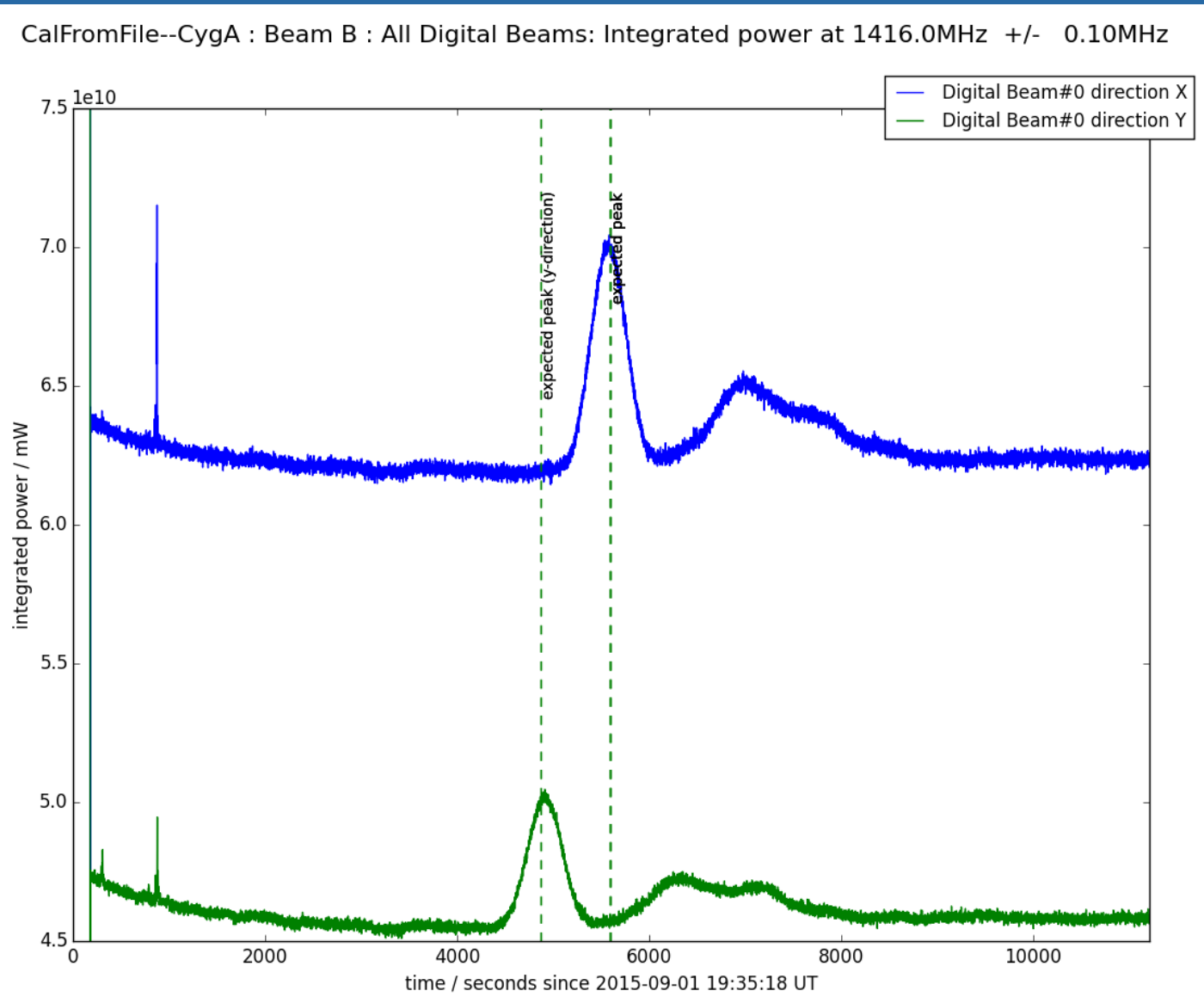
http://arxiv.org/abs/1602.07976

CygA 1420.4MHz



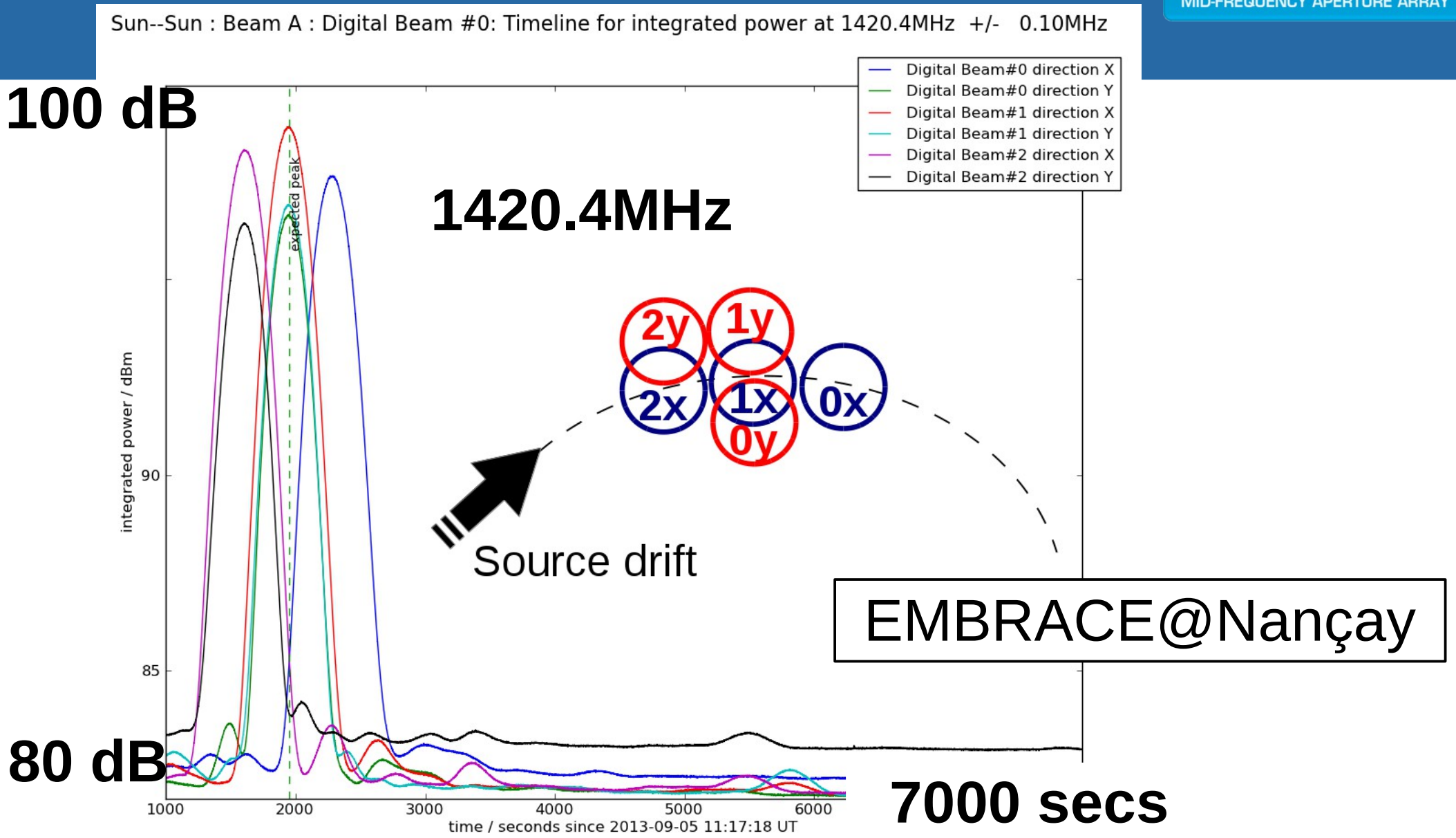
http://arxiv.org/abs/1602.07976

CygA 1416.0MHz



http://arxiv.org/abs/1602.07976

Multibeaming



100 dB

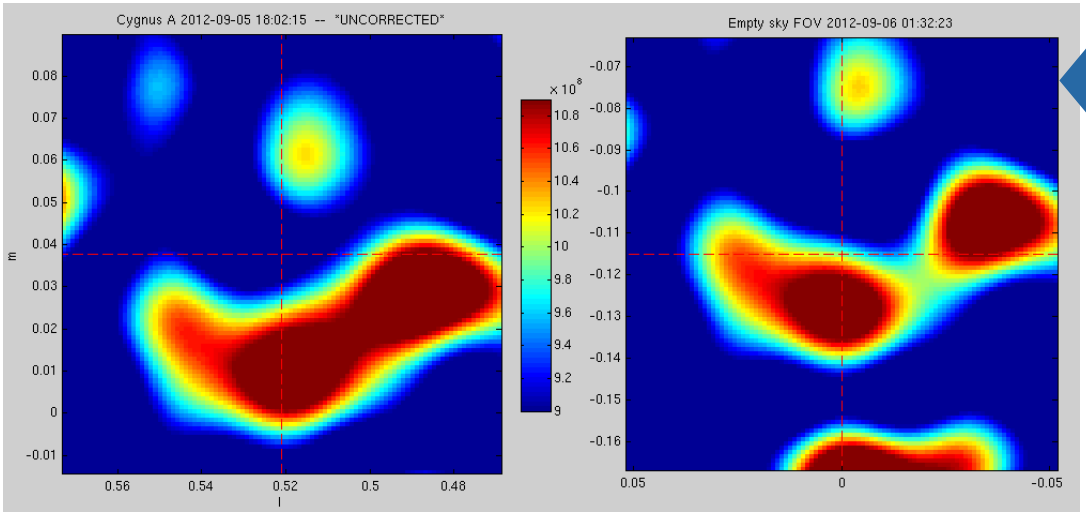
80 dB

EMBRACE@Nançay

7000 secs

http://arxiv.org/abs/1602.07976

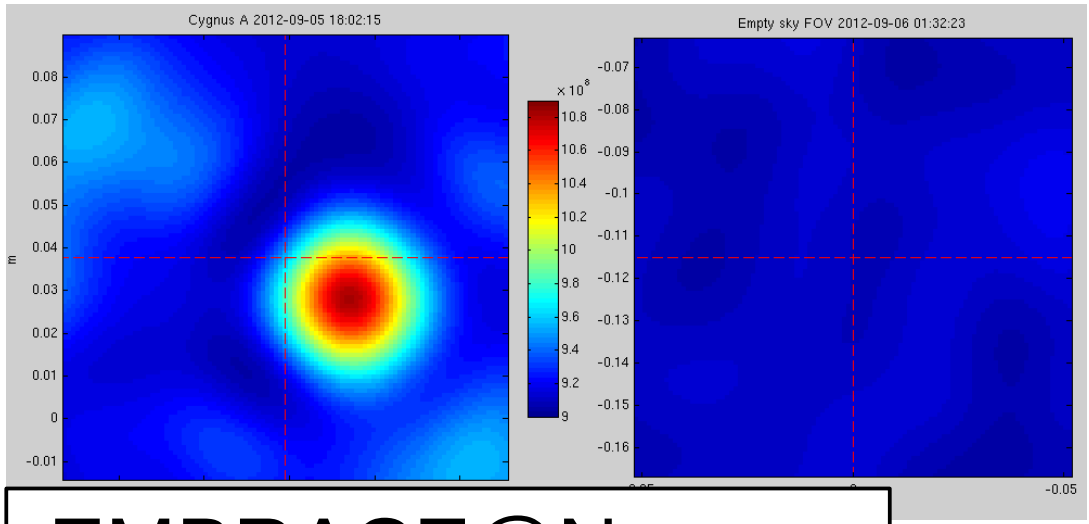
Correlator Offset: Flat Fielding



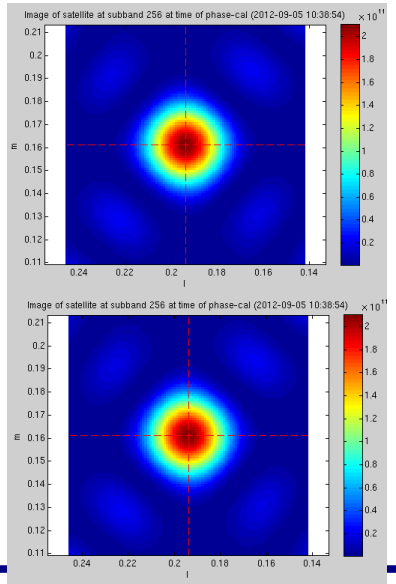
Stable background "image" due to correlator offset

Cygnus A
Same data!
(before/after fix)

GPS satellite
(strong source)



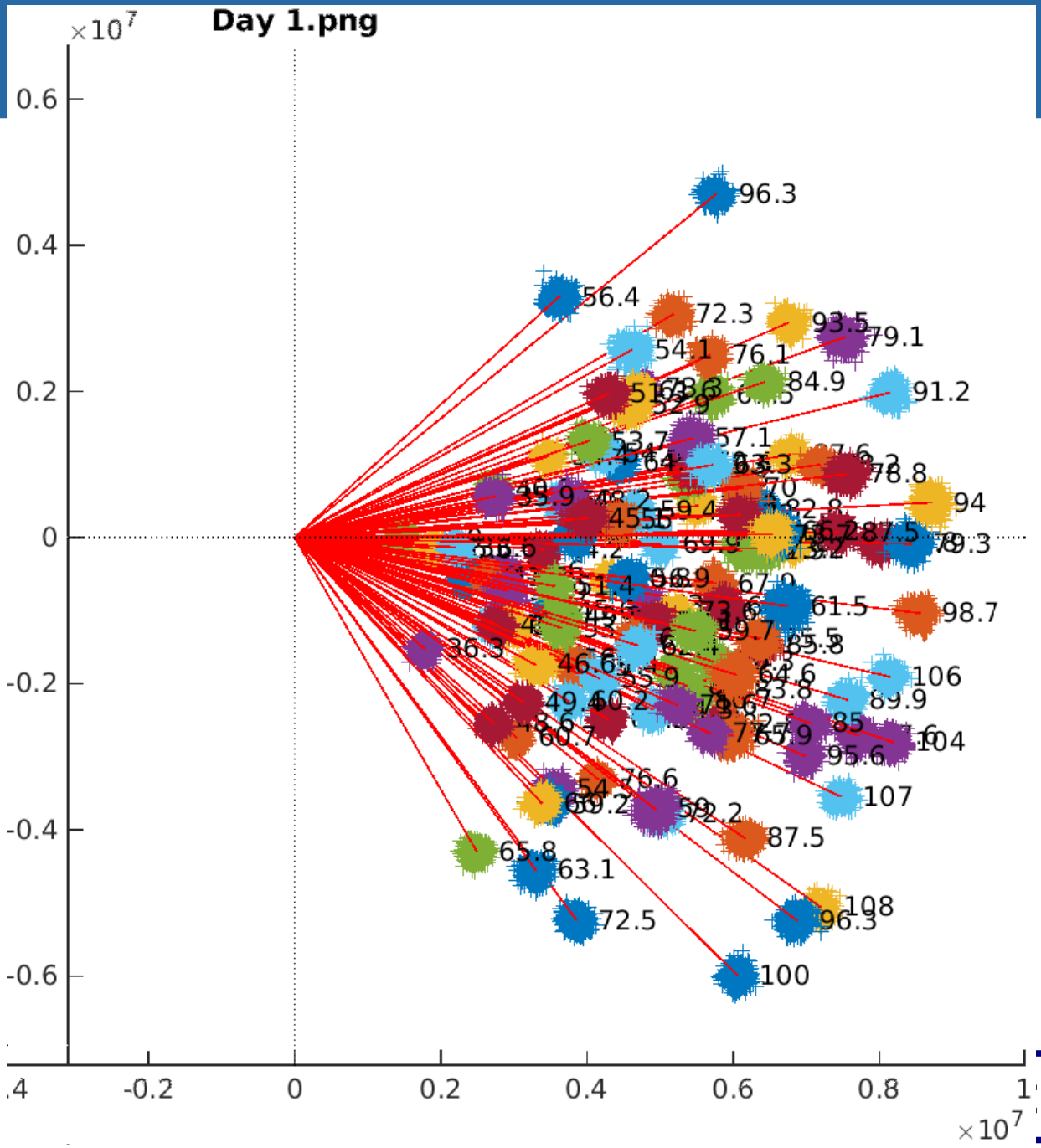
No change



EMBRACE@Nançay

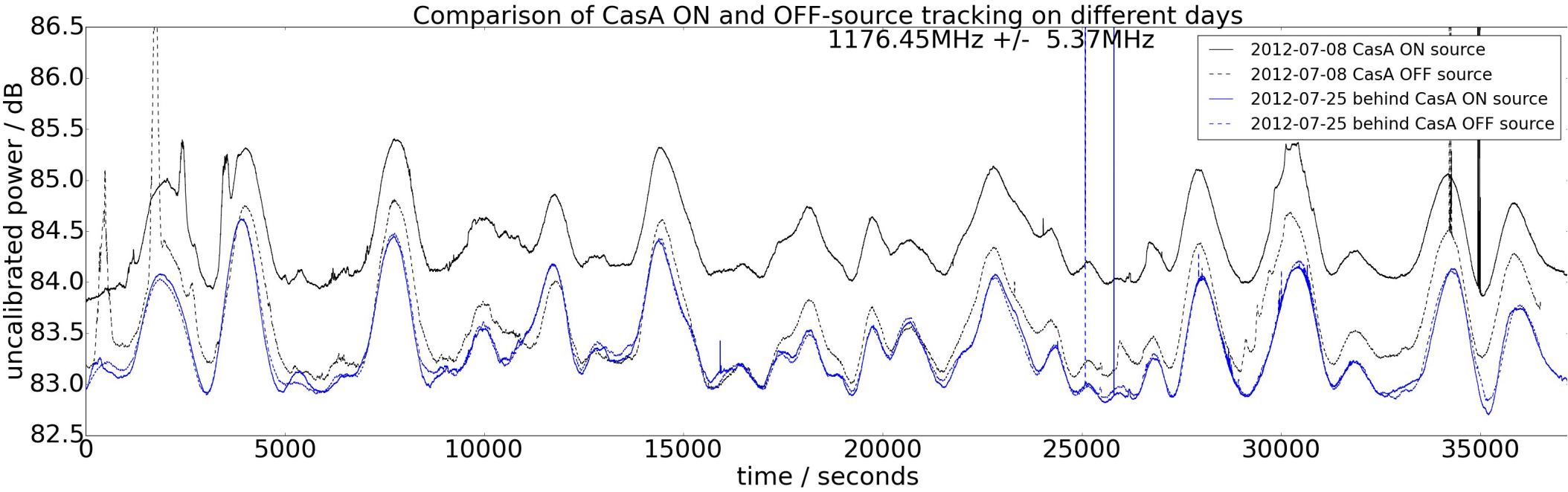
http://arxiv.org/abs/1602.07976

Correlator Offset



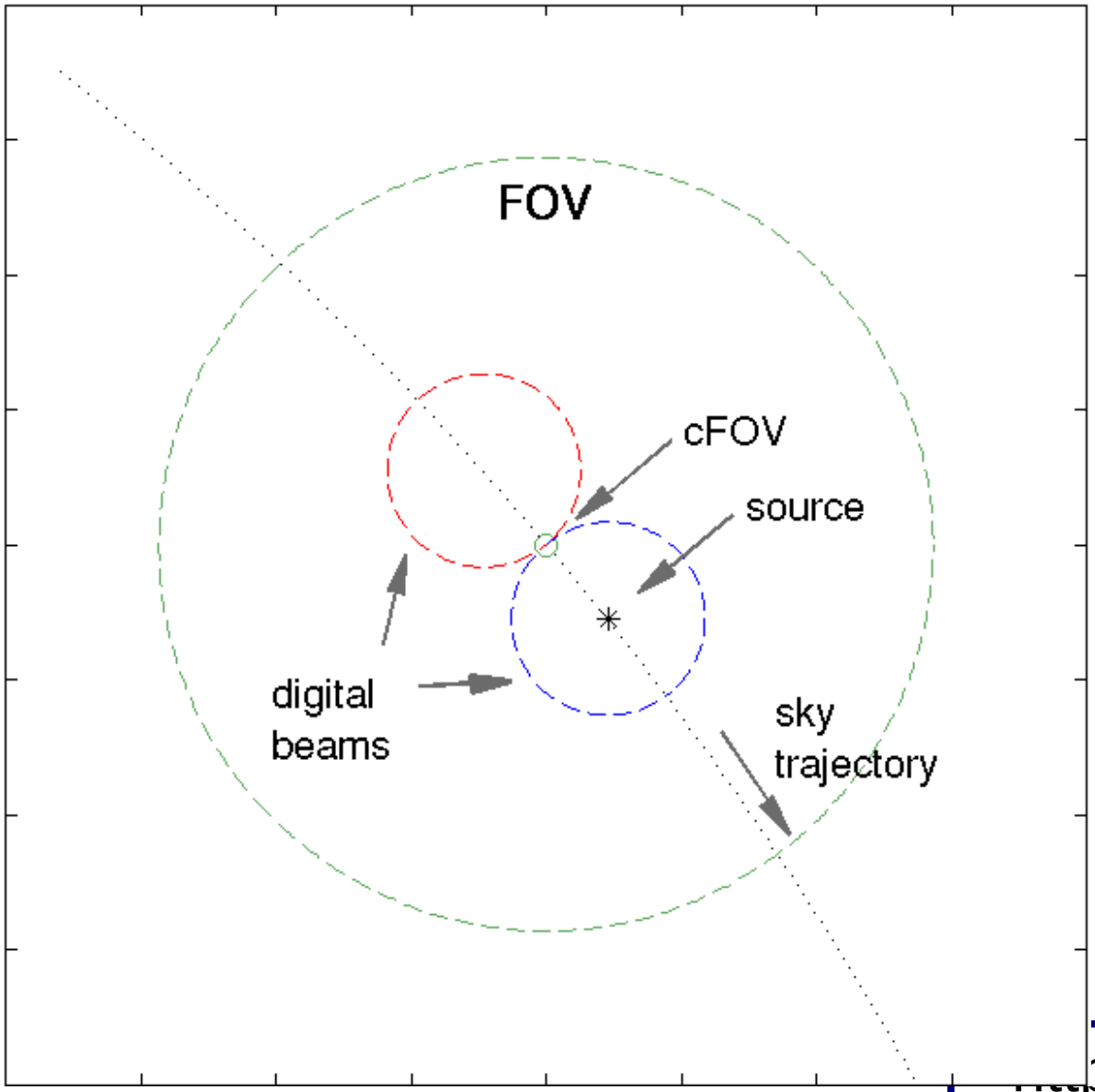
//arxiv.org/abs/1602.07976

Tracking with uncorrected Correlator Offset



http://arxiv.org/abs/1602.07976

ON-OFF pointing strategy

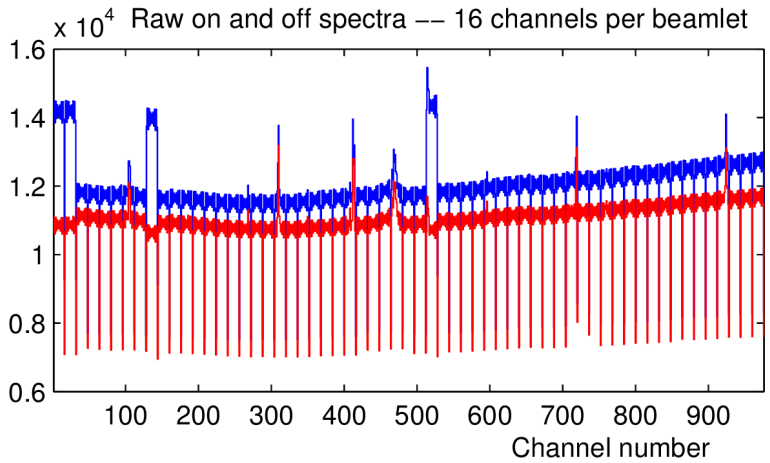


- On and Off observations can be done **simultaneously** with EMBRACE (multibeams)

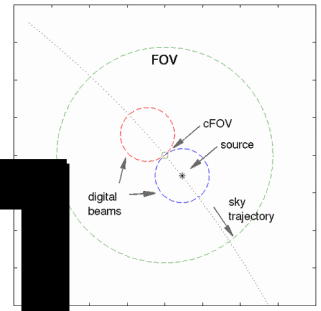
http://arxiv.org/abs/1602.07976

Galaxy Detection: M33

Integrated ON and OFF spectra

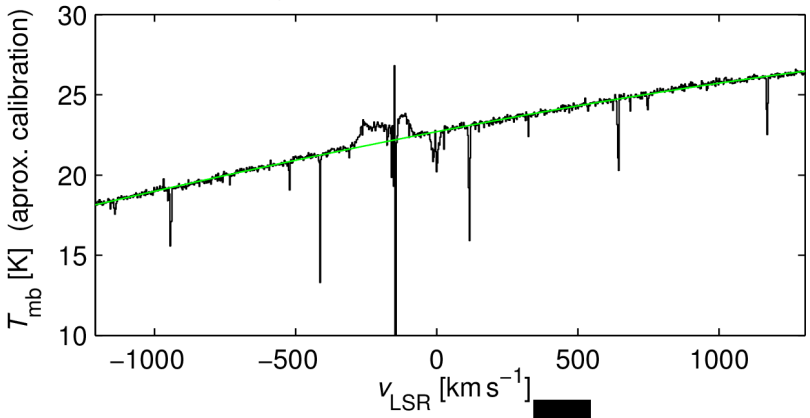


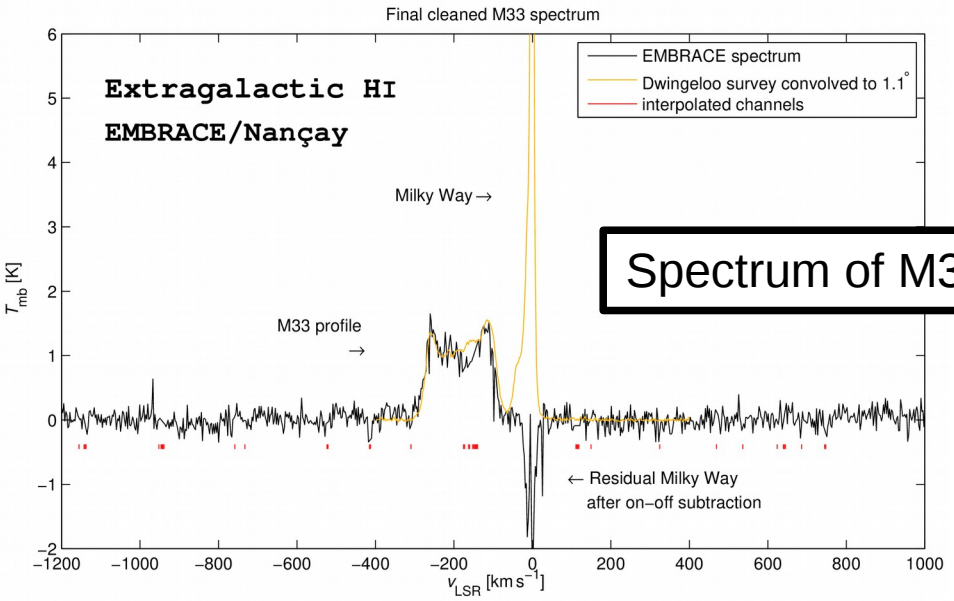
EMBRACE@Nançay



(ON – OFF)/OFF

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



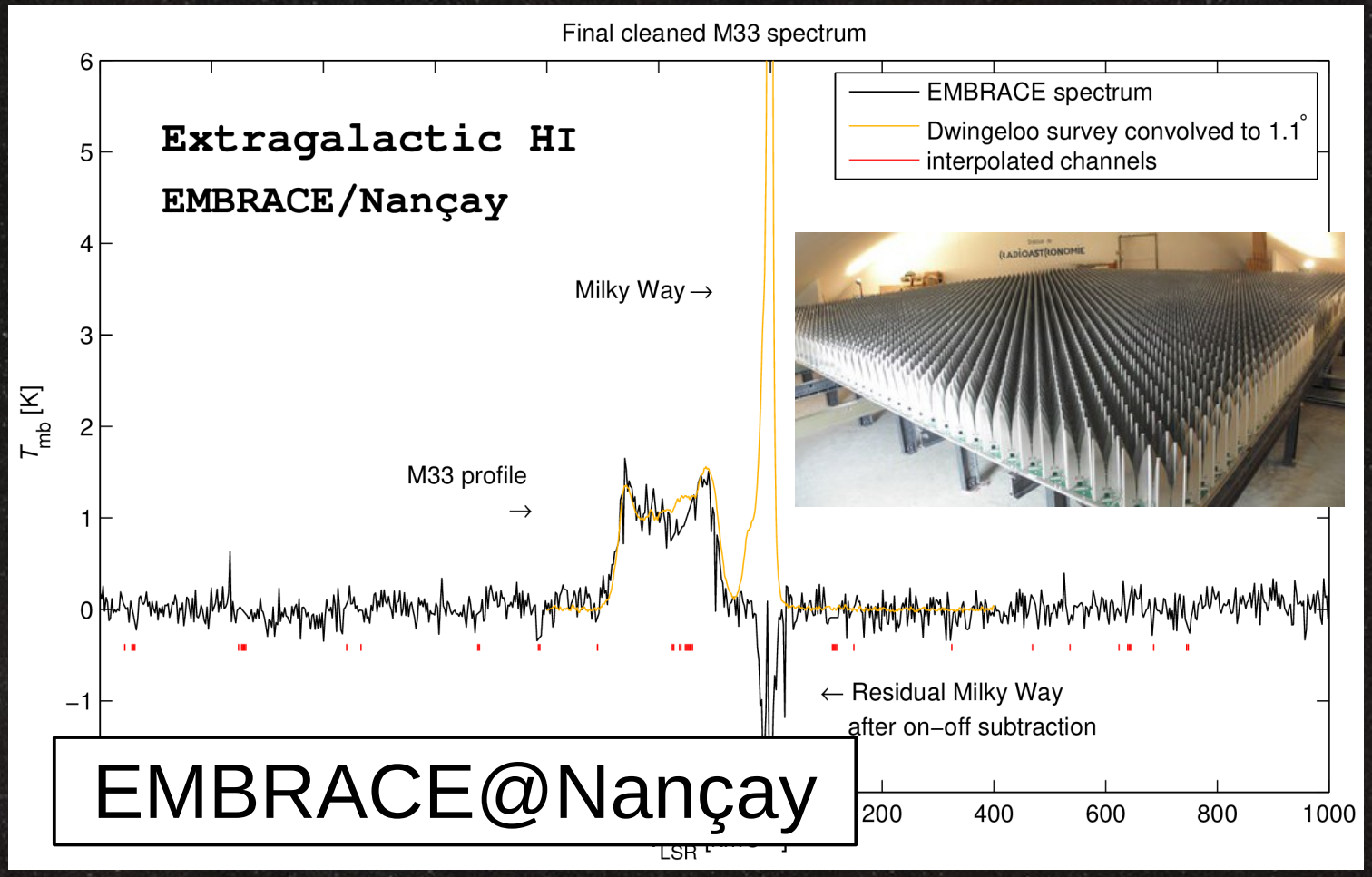


Spectrum of M33

Baseline fit and interpolate past RFI channels

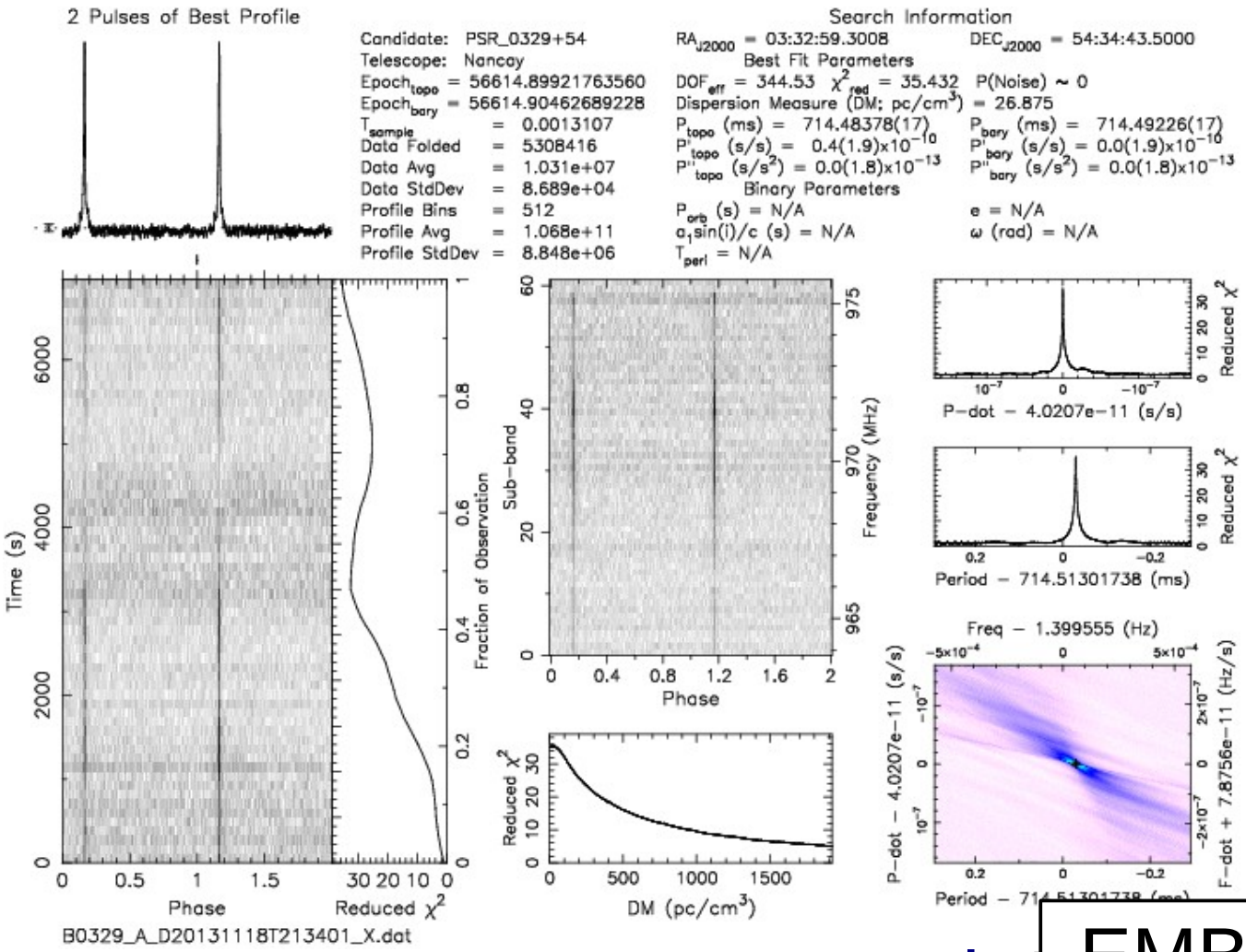
http://arxiv.org/abs/1602.07976

Galaxy Detection



EMBRACE@Nançay

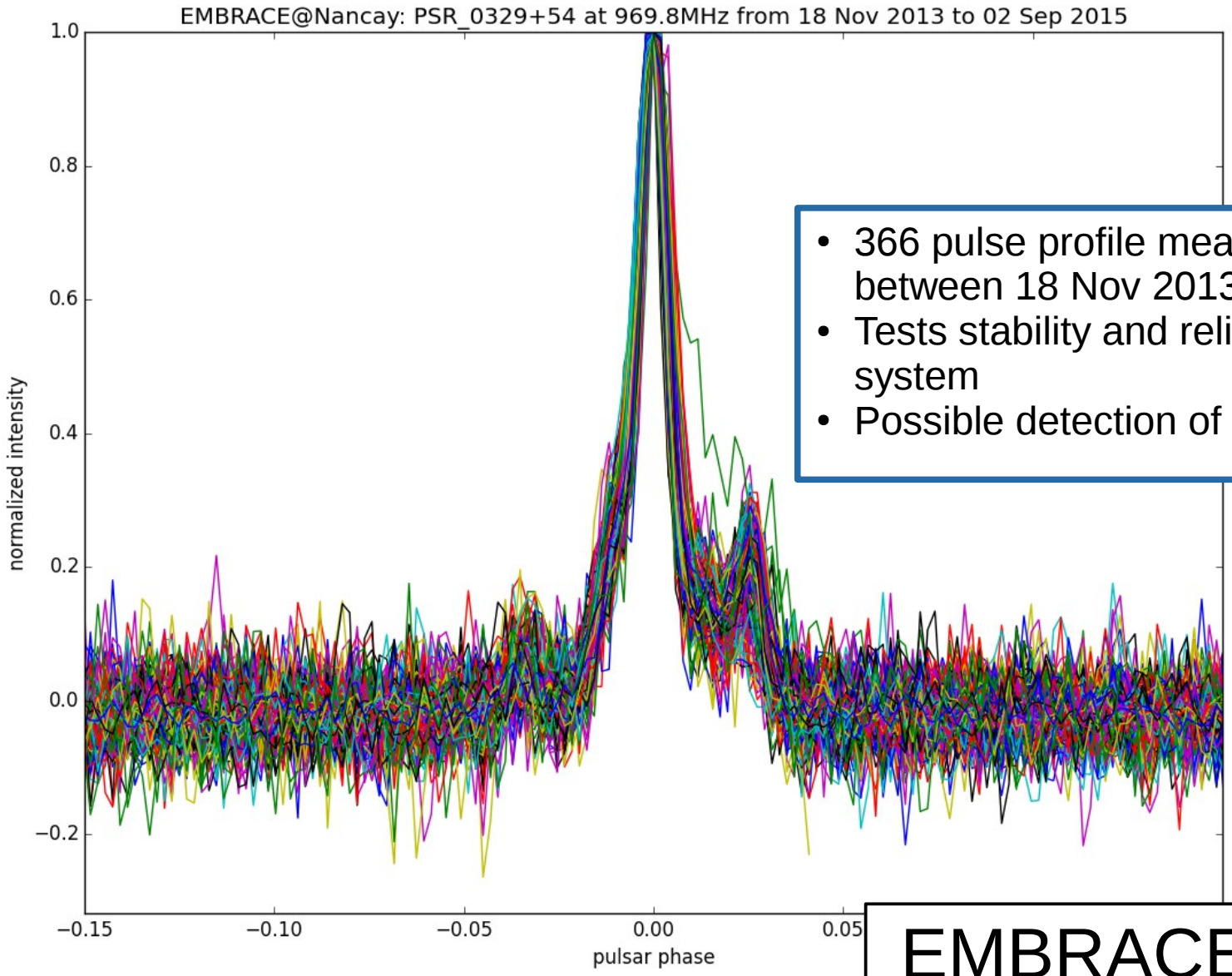
Pulsar monitoring



- 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)

EMBRACE@Nançay

B0329+54 at 970MHz



- 366 pulse profile measurements between 18 Nov 2013 and 2 Sep 2015
- Tests stability and reliability of the system
- Possible detection of solar wind

EMBRACE@Nançay

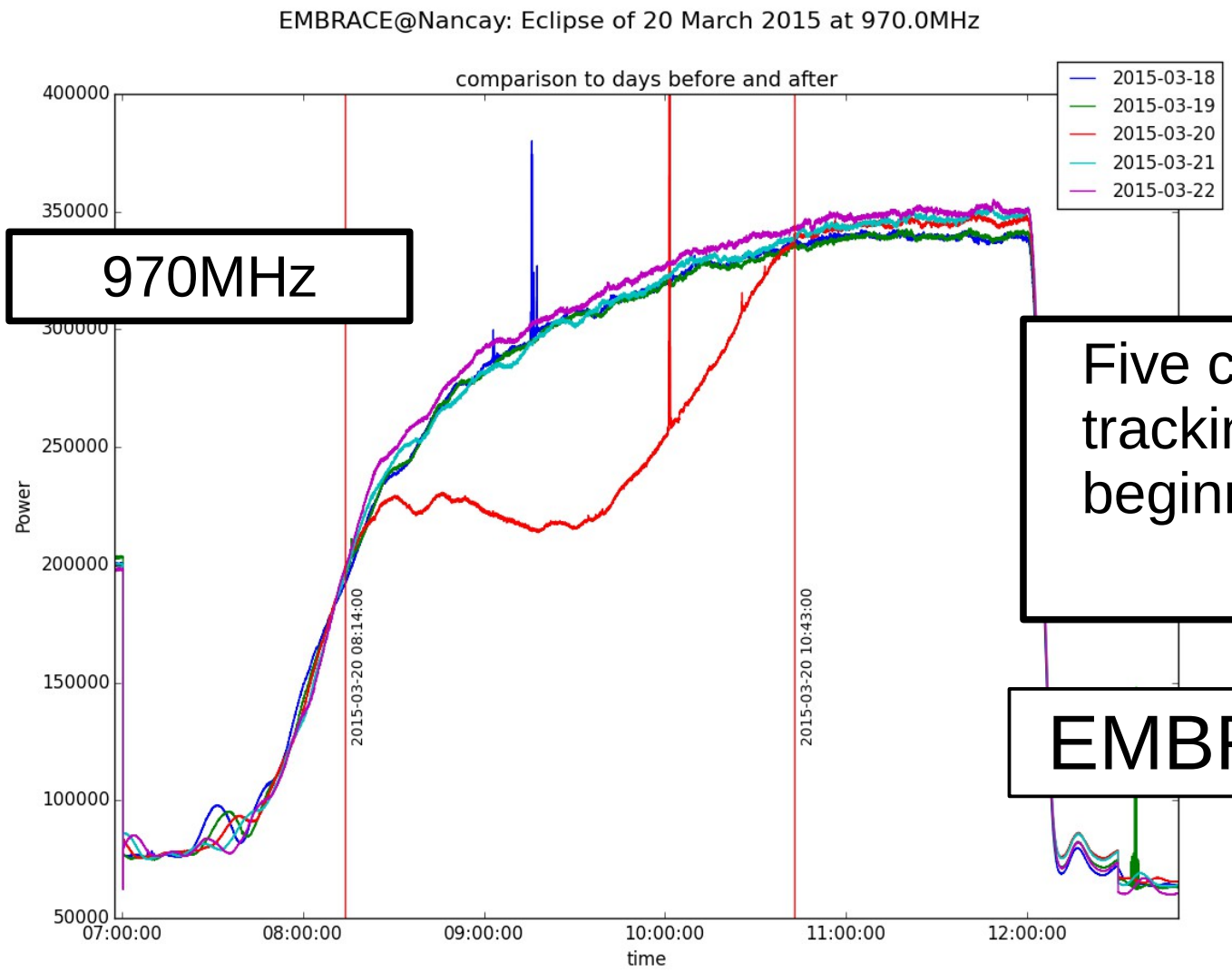
Partial Solar Eclipse 20 March 2015

Bourges

Photo by Steve T.

rg/abs/1602.07976

Simultaneous Observations at 970MHz and 1420MHz



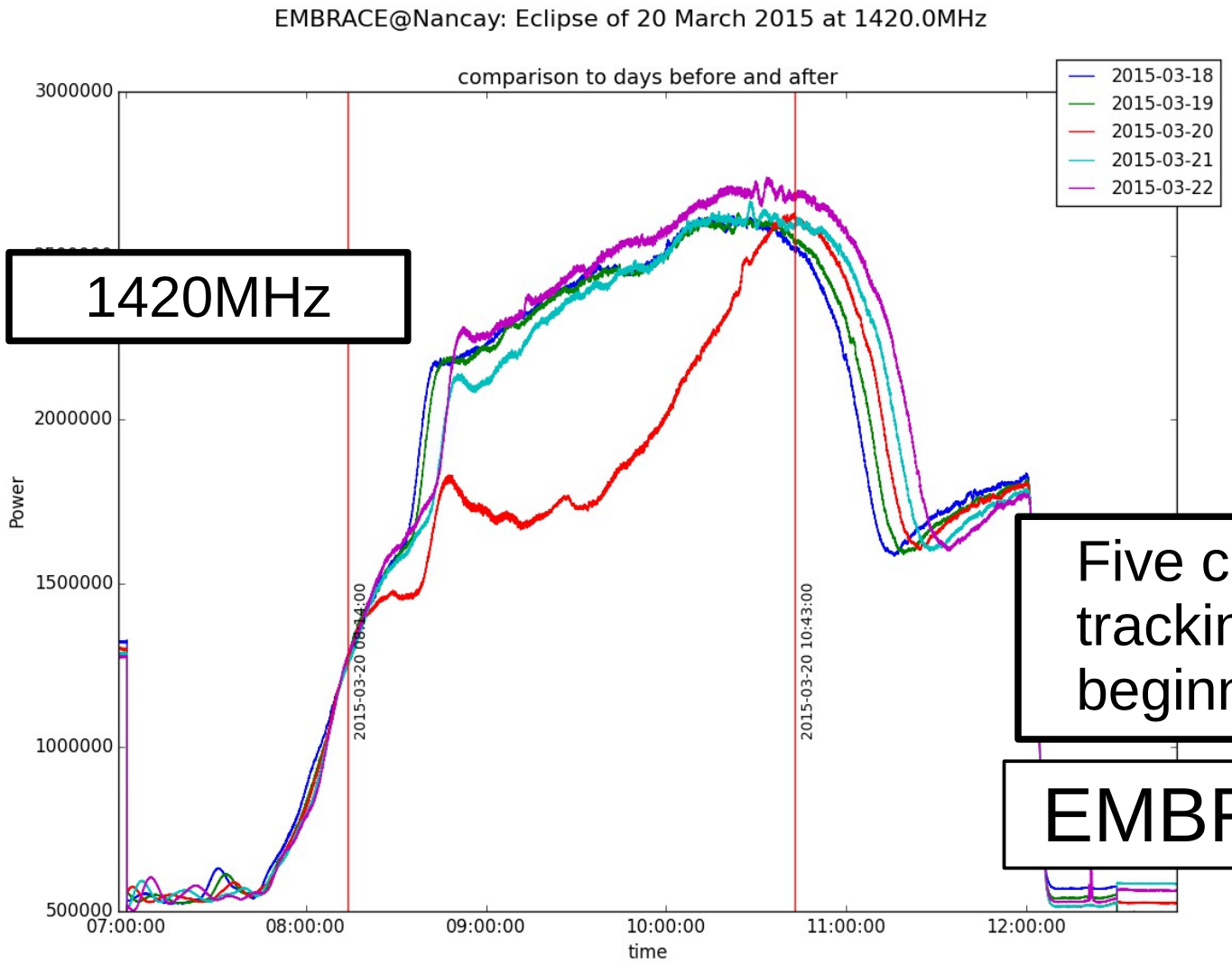
970MHz

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

EMBRACE@Nançay

http://arxiv.org/abs/1602.07976

Simultaneous Observations at 970MHz and 1420MHz



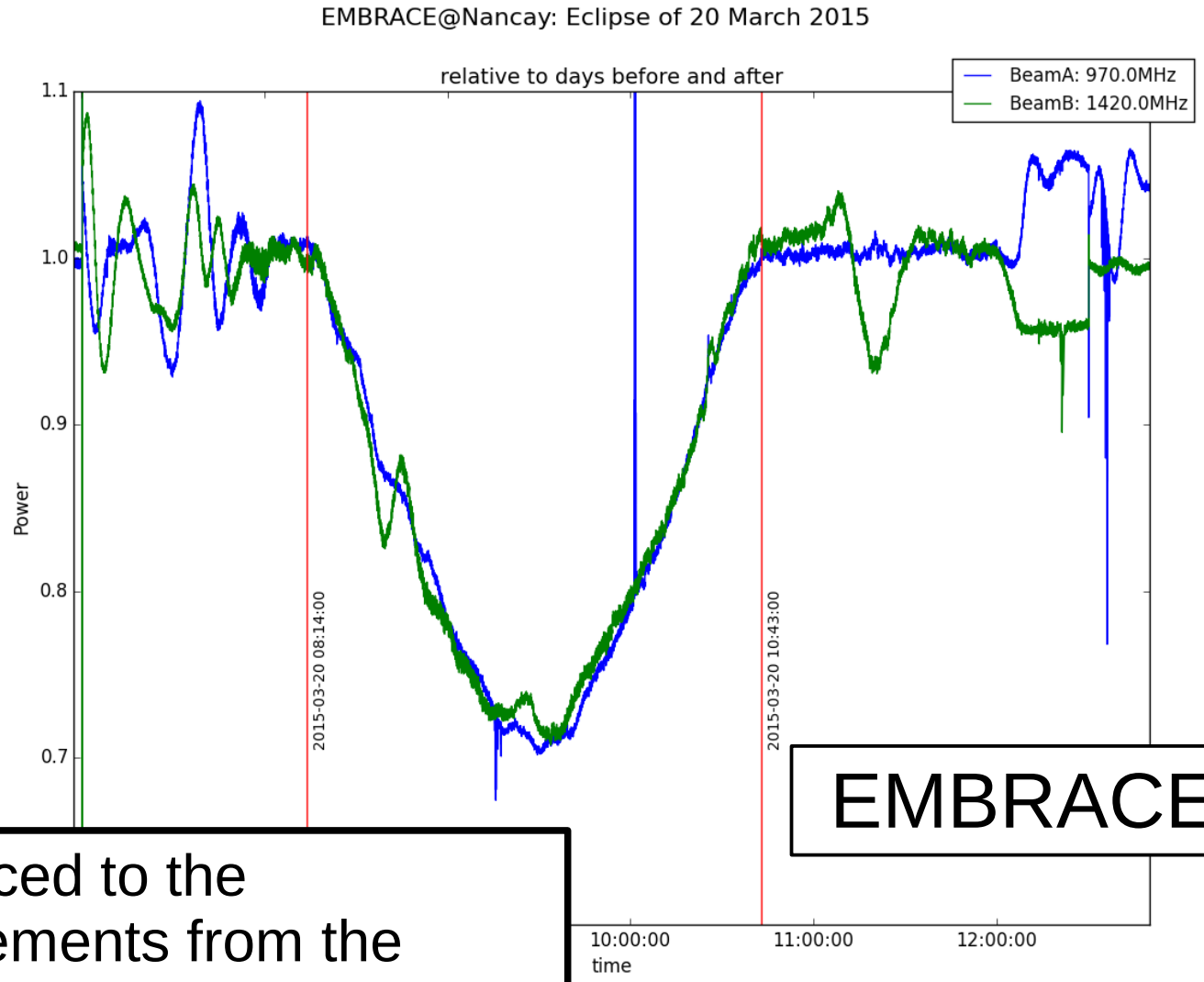
1420MHz

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

EMBRACE@Nançay

http://arxiv.org/abs/1602.07976

Solar Eclipse at 970MHz and 1420MHz

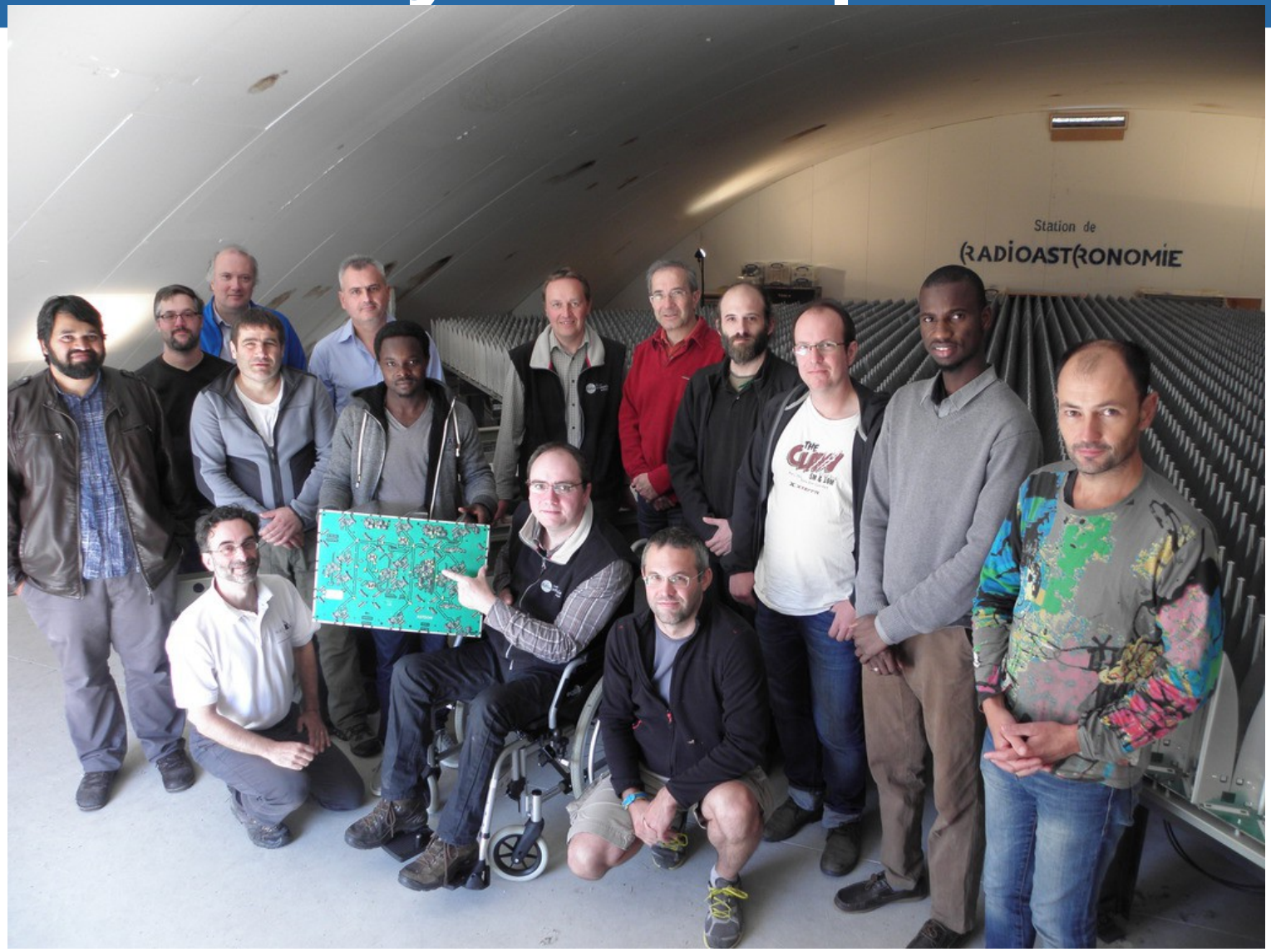


EMBRACE@Nançay

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

http://arxiv.org/abs/1602.07976

EMBRACE Workshop at Nancay 7-11 September



http://arxiv.org/abs/1602.07976

Lessons Learned

- Long term stability
  - Calibration parameters can be used for many months (years?)
  - Repeatability: characteristics the same from one day to the next
- Reliability
  - Many components, but few hardware failures. In fact, the large number of components is an advantage for reliability: If one signal chain fails, it makes little difference to the whole system.
- Custom components work well over the long term
  - Beamformer chip extremely reliable, and stable. All chips still performing well after 5 years nearly continuous operation
  - LNA, ditto
  - Mean time between failures > 5 years (and counting)
- Use direct sampling!
  - Correlator offset due to frequency conversion
- Cross correlation statistics are extremely useful for debugging!
- Failures of Off-the-shelf hardware
  - Problem with communication to some tiles
    - Network switches
    - Cables and connectors
  - Remember: consumer electronics are programmed to fail after 3 years (is this a controversial statement?)

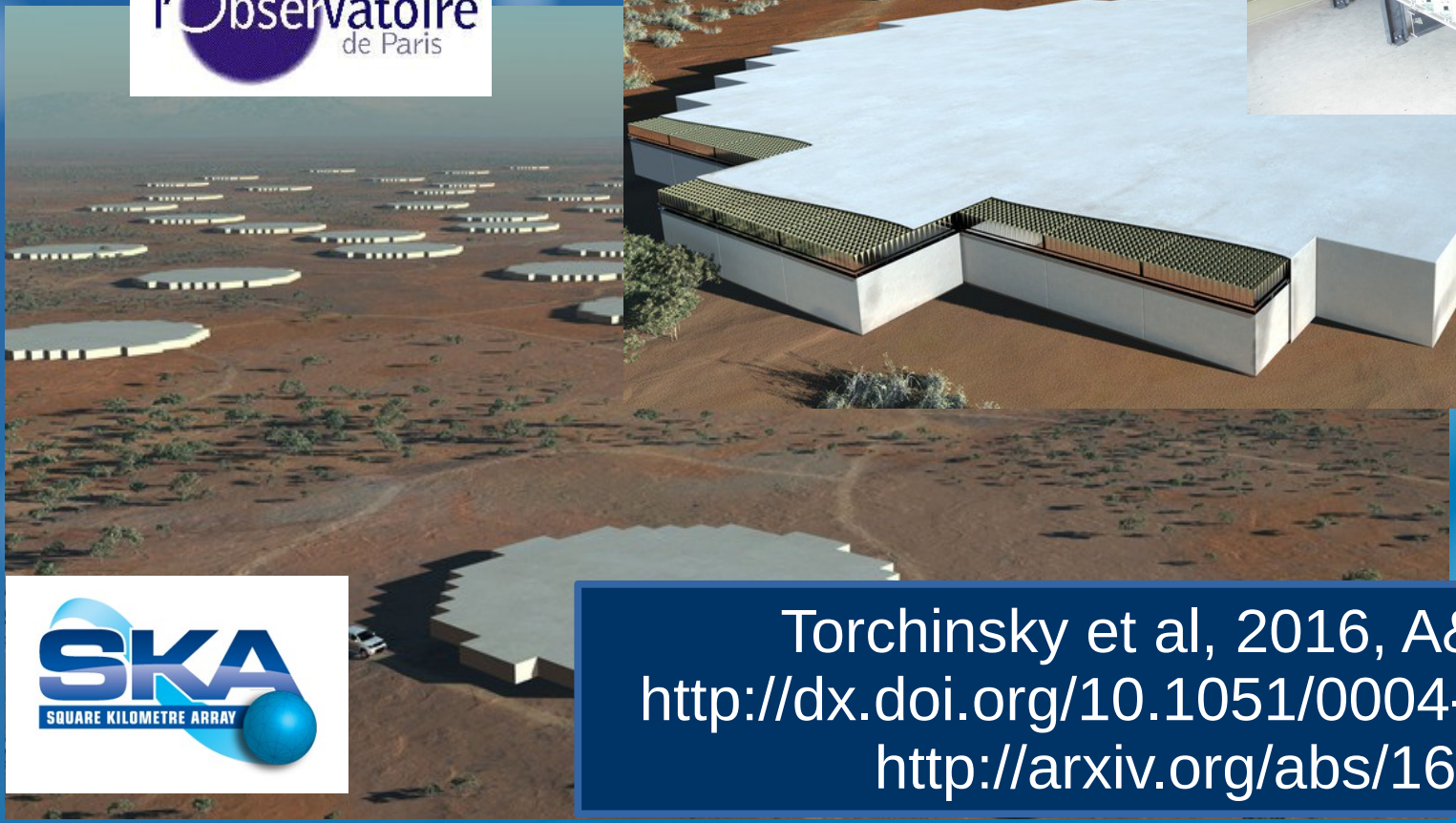
http://arxiv.org/abs/1602.07976

EMBRACE contribution to SKA Development

- Demonstrate that dense aperture array technology can be used for radio astronomy
  - Calibration
  - Ease of operation
    - setup, pointing, multibeaming, mapping, etc
  - Operation as a facility instrument
    - Long term programme of observation with regular (daily) observations
    - Robustness and reliability
    - Hardware “mean time between failures”
  - Test Bench
    - Real time RFI filtering algorithms implemented on UNIBOARD
    - Fast Radio Burst algorithms implemented on GPU
  - Training
    - Student projects on Aperture Array astronomy
    - workshops
  - Possible scientific results despite modest collecting area
    - Survey for Fast Radio Bursts
    - Solar wind monitoring with pulsar observations
    - Targets of opportunity (e.g. solar eclipse)

http://arxiv.org/abs/1602.07976

EMBRACE@Nancay



Station de Radioastronomie de Nançay

l'Observatoire de Paris

SKA SQUARE KILOMETRE ARRAY

Torchinsky et al, 2016, A&A, accepted
http://dx.doi.org/10.1051/0004-6361/201526706
http://arxiv.org/abs/1602.07976