LEDA

LARGE-APERTURE EXPERIMENT TO DETECT THE DARK AGES

Detecting the Dark Ages With LEDA

Danny Price (et. al.), CfA

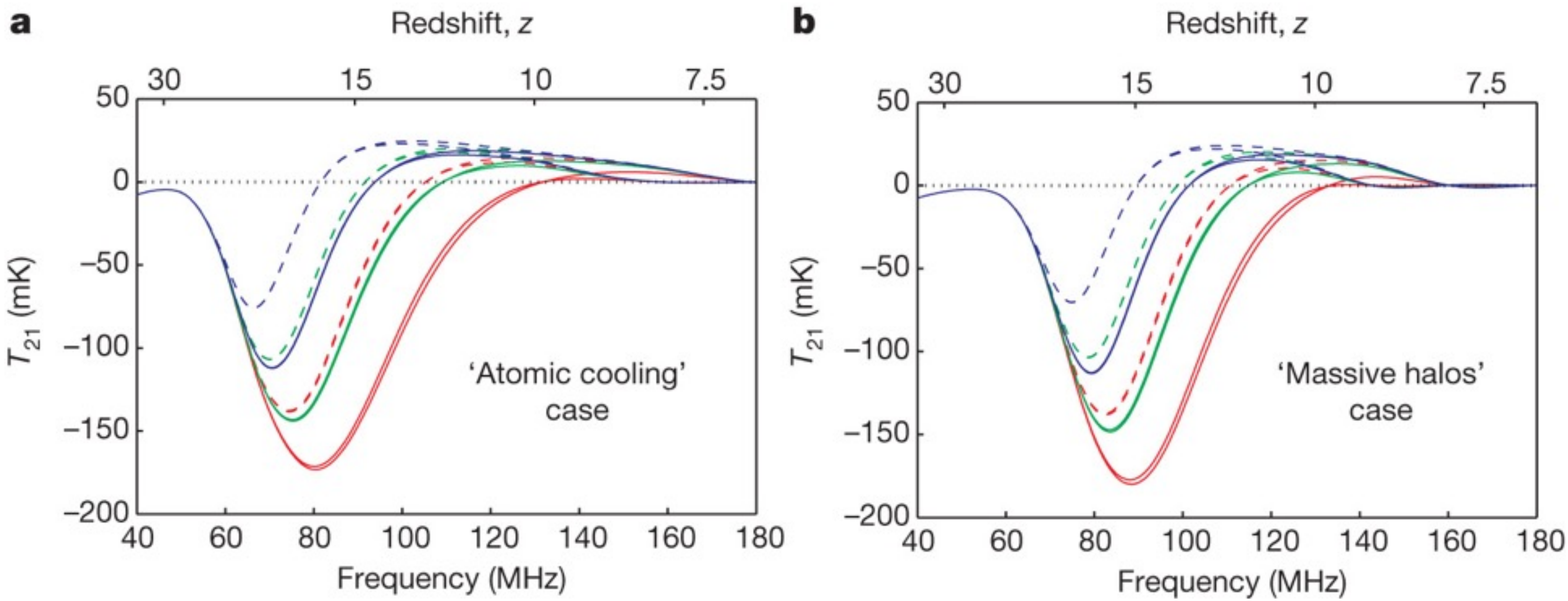
Oct 30, 2014

HPSP 2014, Malta

A Brief History of the Universe

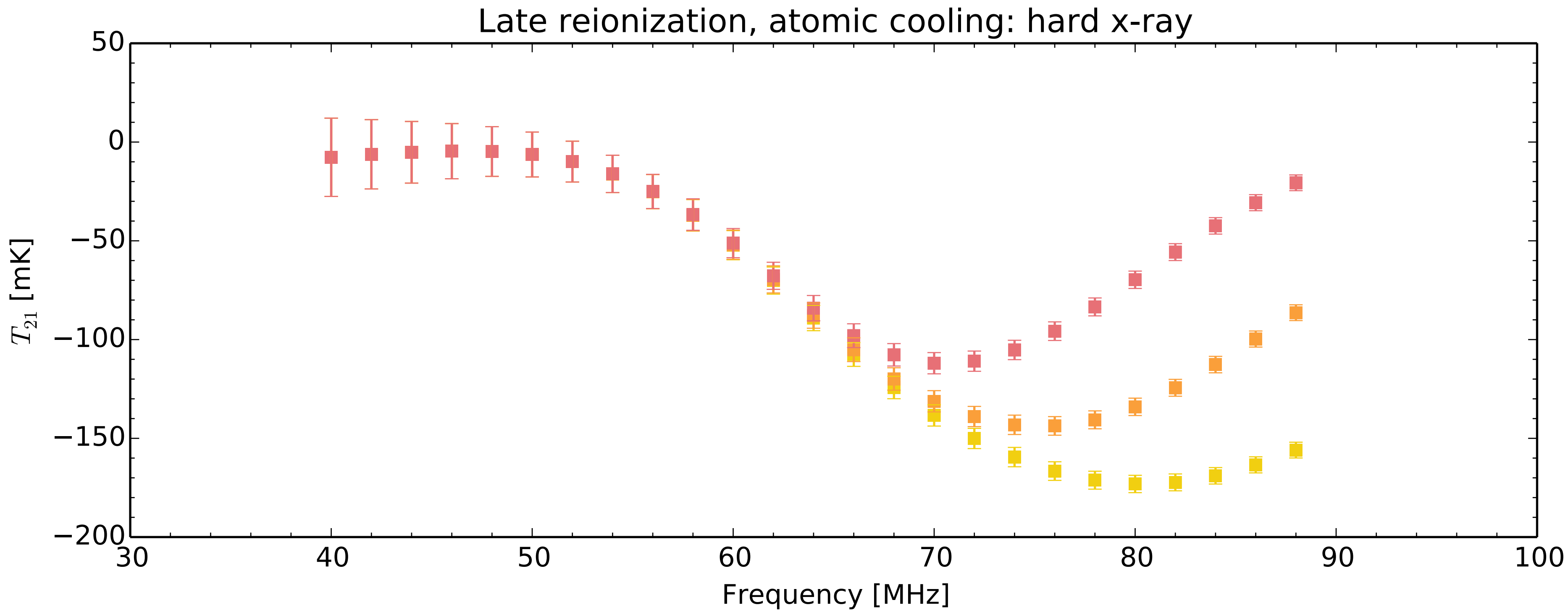
- Dark Ages (DA): 0.3 - 100 Myr *(after Big Bang)*
- Epoch of Reionization (EOR): 100 Myr - 1 Gyr

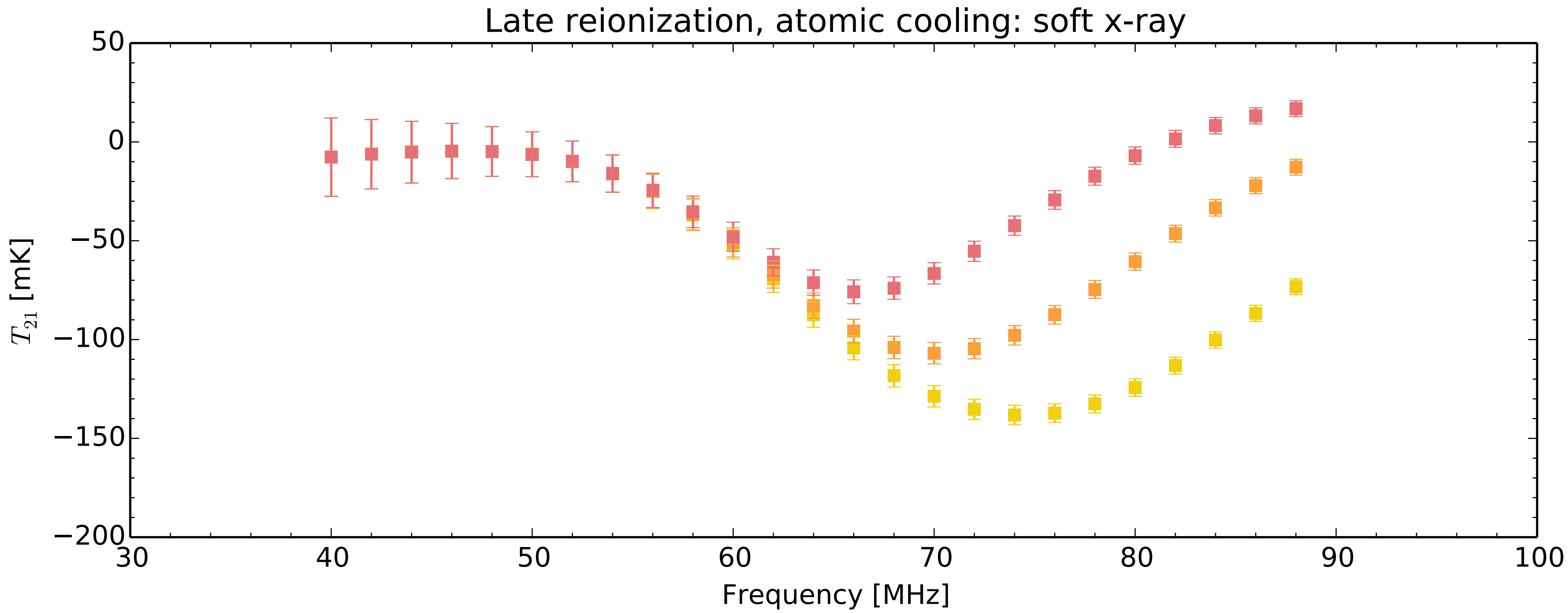
What are we looking for?



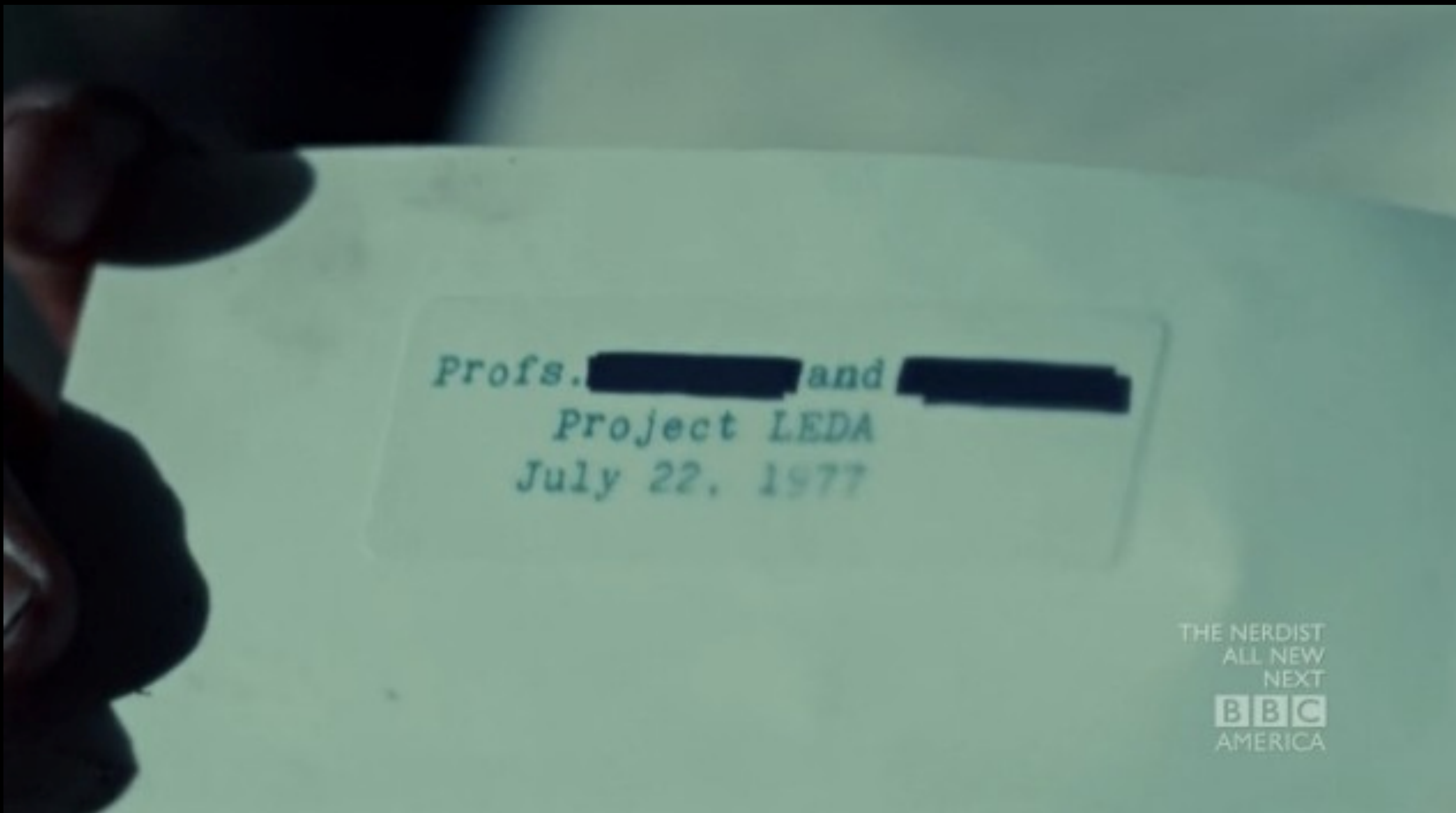
A. Fialkov et. al. (2014) doi:10.1038/nature12999

What are we looking for?





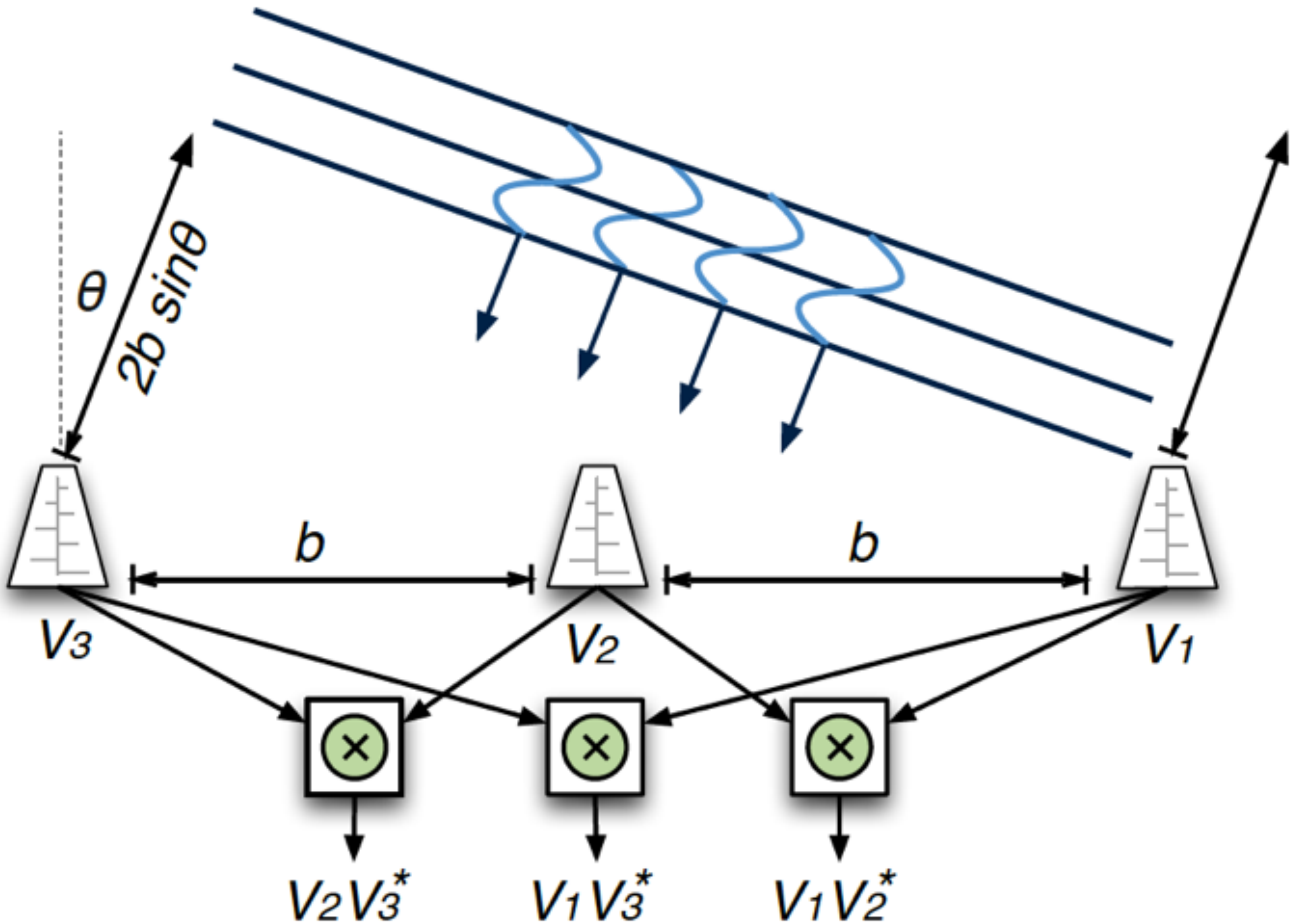
What is Project LEDA?



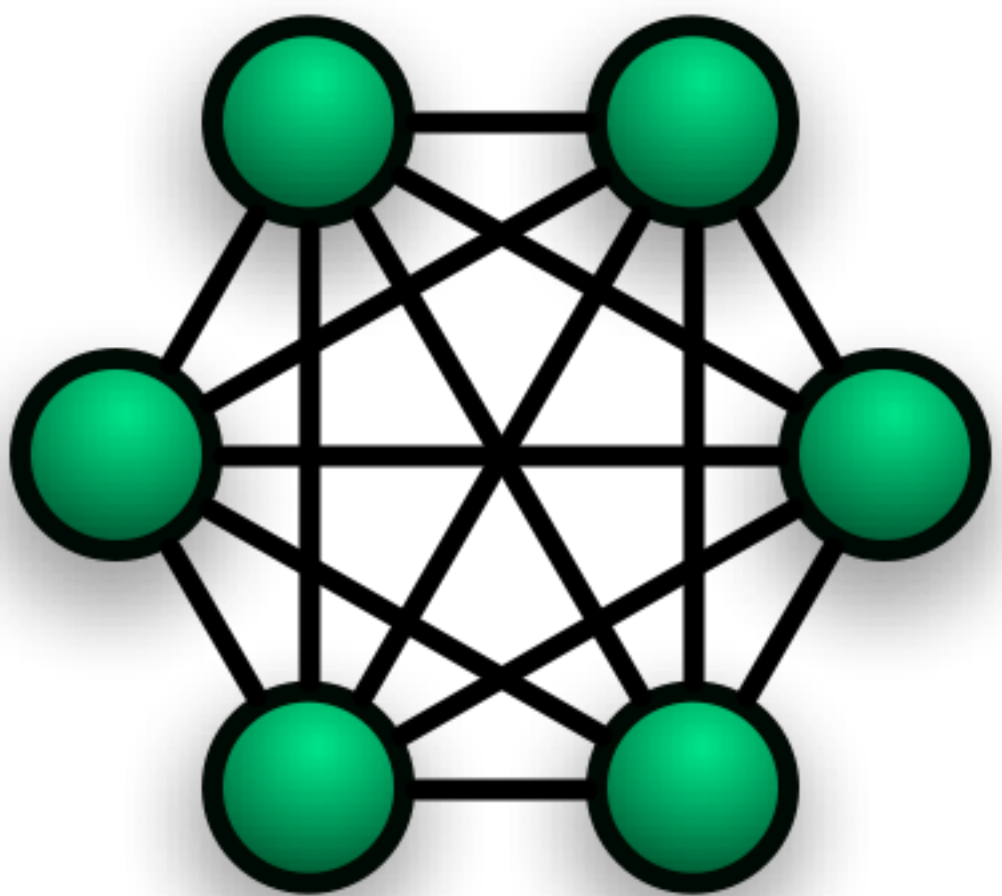
LEDA Concept

- LEDA is a total power measurement experiment
- Only “need” one antenna
- Correlator used for calibration (sky model + antenna gain)
- Correlator allows additional science: hot jupiters, transient monitoring

Radio Interferometry - lots of computations



Radio Interferometry - lots of computations



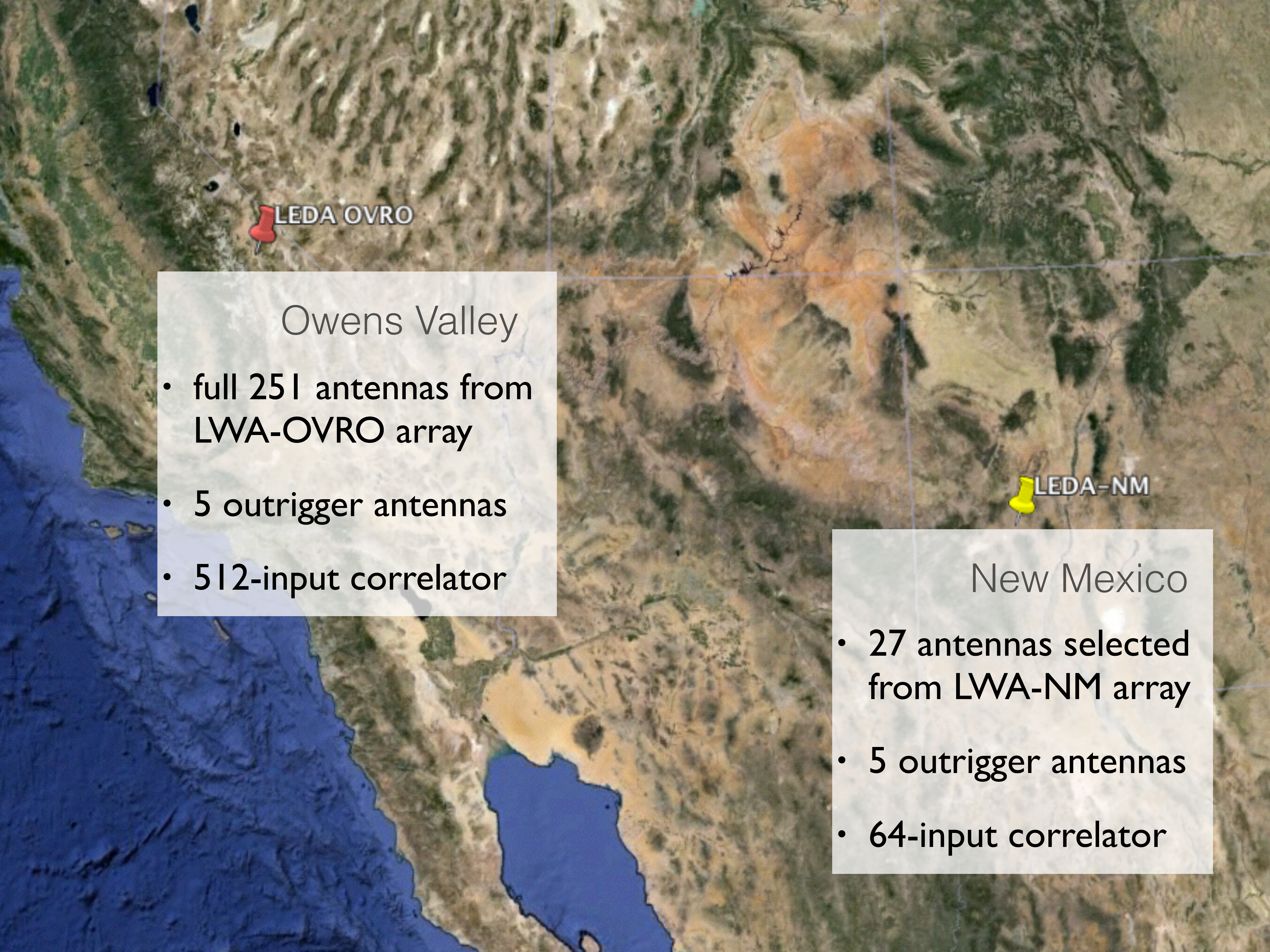
- More antennas = lots more baselines

$$N_B = \frac{N_A(N_A - 1)}{2}$$

for example, $N_A = 512 \Rightarrow N_B = 130816$

- Computations done on a frequency channel basis

- Trivially parallelizable: over frequency and baseline



Owens Valley

- full 251 antennas from LWA-OVRO array
- 5 outrigger antennas
- 512-input correlator

New Mexico

- 27 antennas selected from LWA-NM array
- 5 outrigger antennas
- 64-input correlator

LWA-NM

image: LWA Project (at UNM)

LWA-NM

image: LWA Project (at UNM)

LWA-OVRO

LWA-OVRO

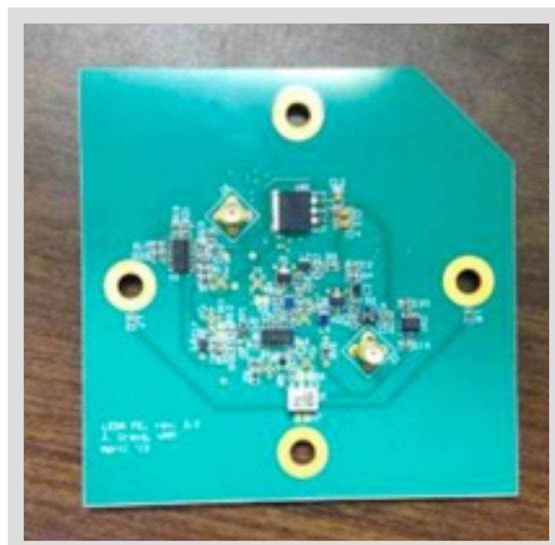
image: Barsdell (2013)


LWA-OVRO

LWA - Analog Overview

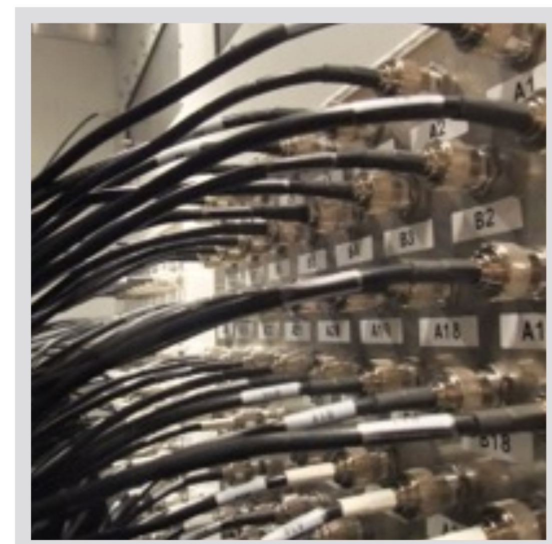
ANT

Antenna



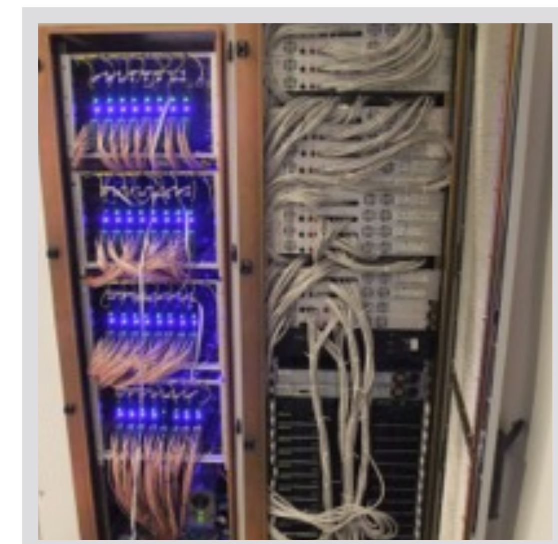
FEE

Front-end Electronics



COAX

Coaxial Cables

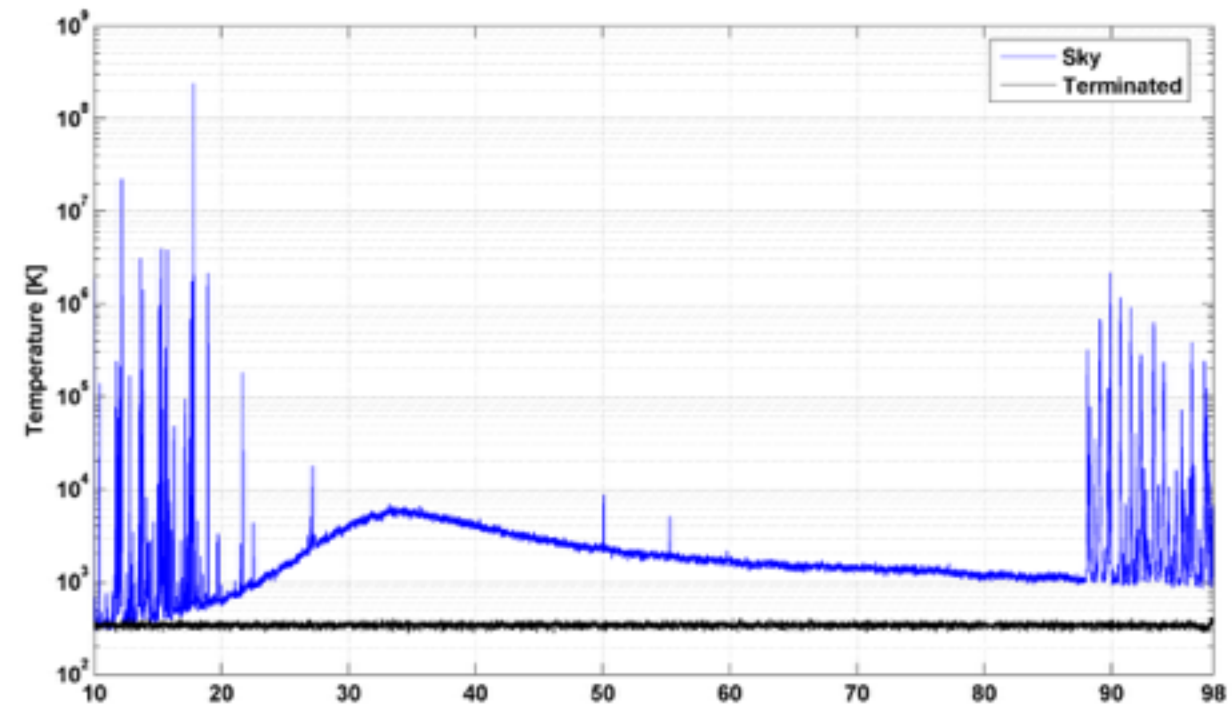


ARX

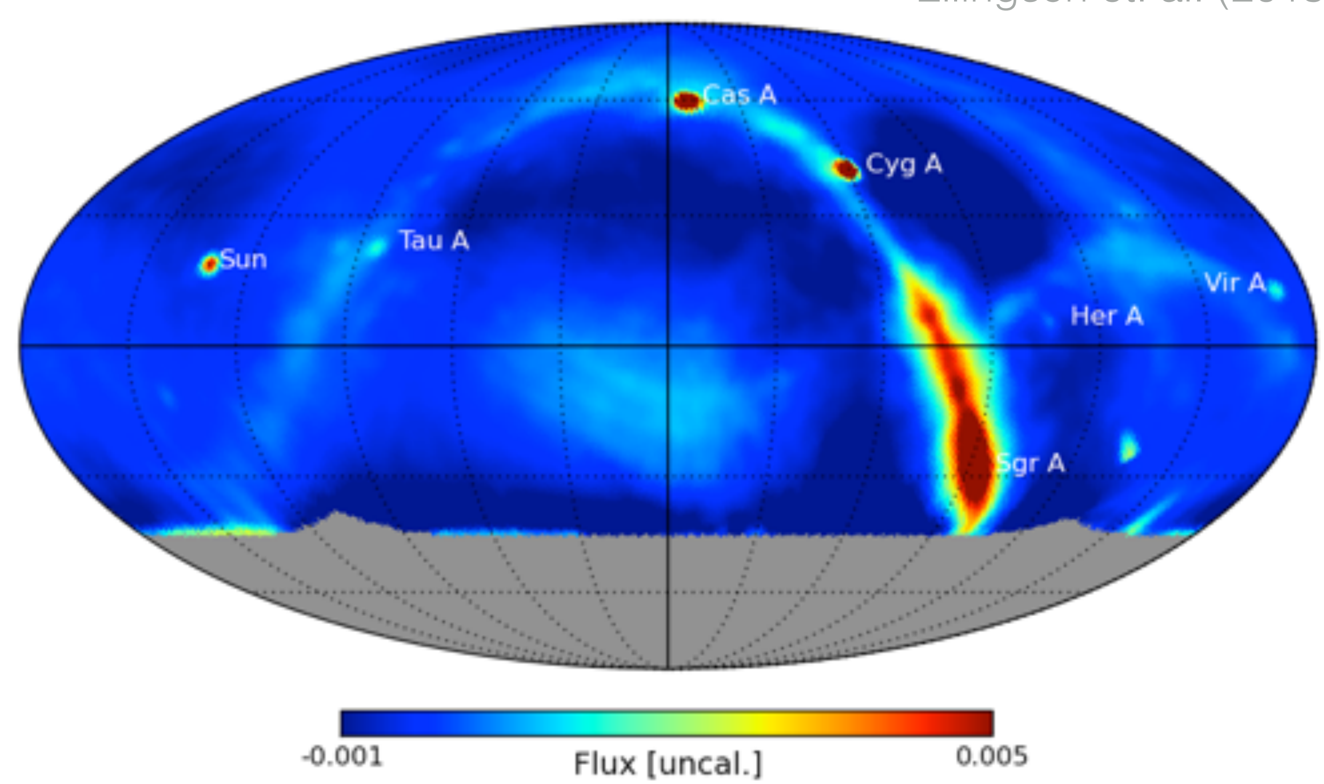
Analog Signal Conditioning

LWA - Analog Overview

- **ANT:** LWA antenna operates from 10-100 MHz. Dual-polarization wire “bow-tie” at 45 deg to sky
- **FEE:** amplifiers (~36 dB gain) and 5-pol lowpass filter (Butterworth). 300 K receiver temperature
- **Cables:** N-type (LMR 240), run underground (rabbits!). Enters RF shielded shelter via lightning arrester feedthroughs. Further assorted cables within shelter.
- **ARX:** Reconfigurable analog signal conditioning module. Tunable attenuator, 3 gain stages, additional filtering (10-88 MHz)



Ellingson et. al. (2013)



Dowell (LSL)

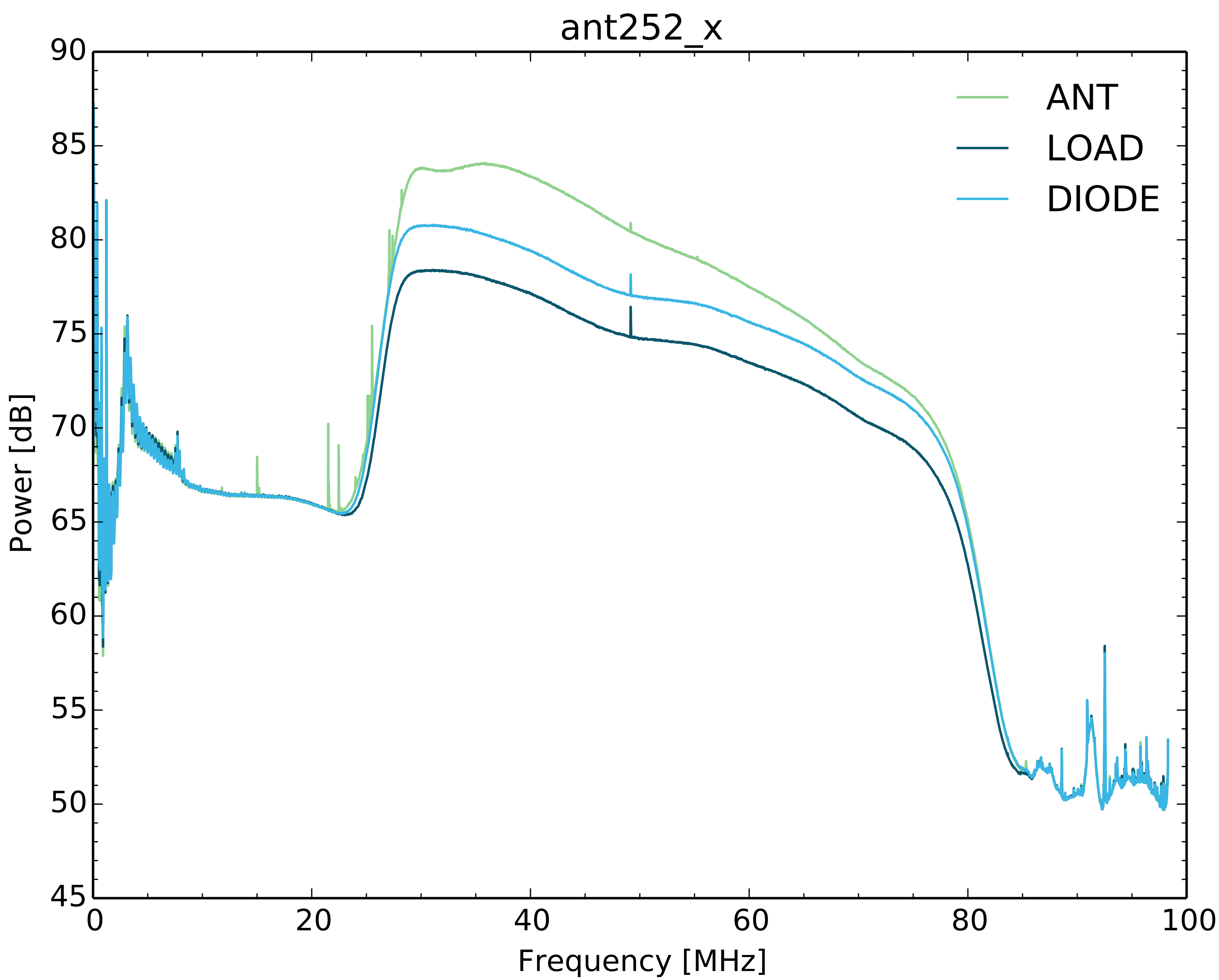
LEDA - Outrigger antennas

- Three-state frontend board (FEE) switches between antenna, load and noise diode + load
- Switching triggered by PPS, or can be controlled remotely
- LWA-OVRO has a modified FEE with a bandpass filter, LWA1-NM has lowpass

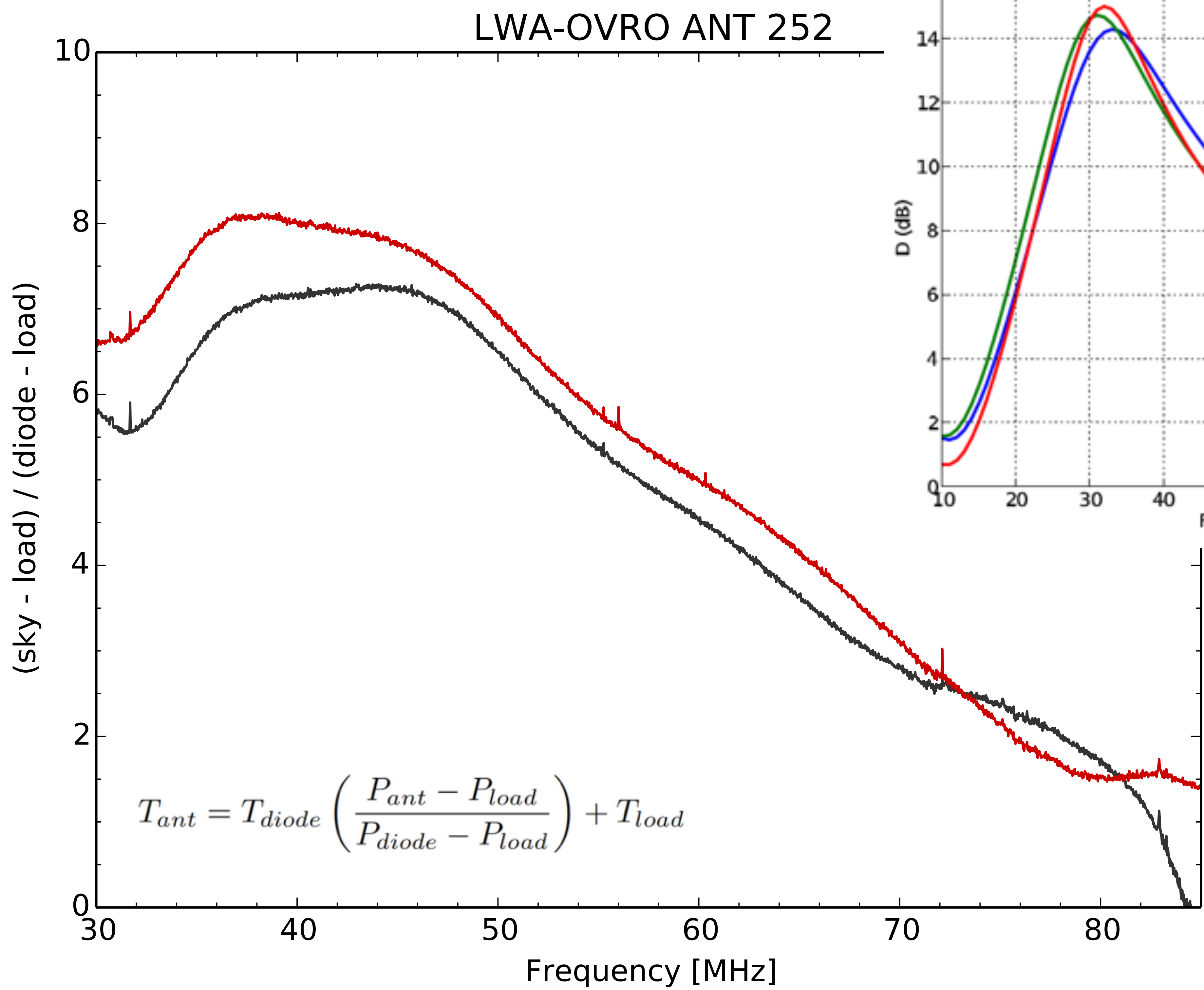
$$T_{ant} = T_{diode}\left(\frac{P_{ant} - P_{load}}{P_{diode} - P_{load}}\right) + T_{load}$$

$$\begin{aligned} P_{ant} &= G k_B \Delta\nu T_{ant} \\ P_{load} &= G k_B \Delta\nu T_{load} \\ P_{diode} &= G k_B \Delta\nu (T_{diode} + T_{load}) \end{aligned}$$

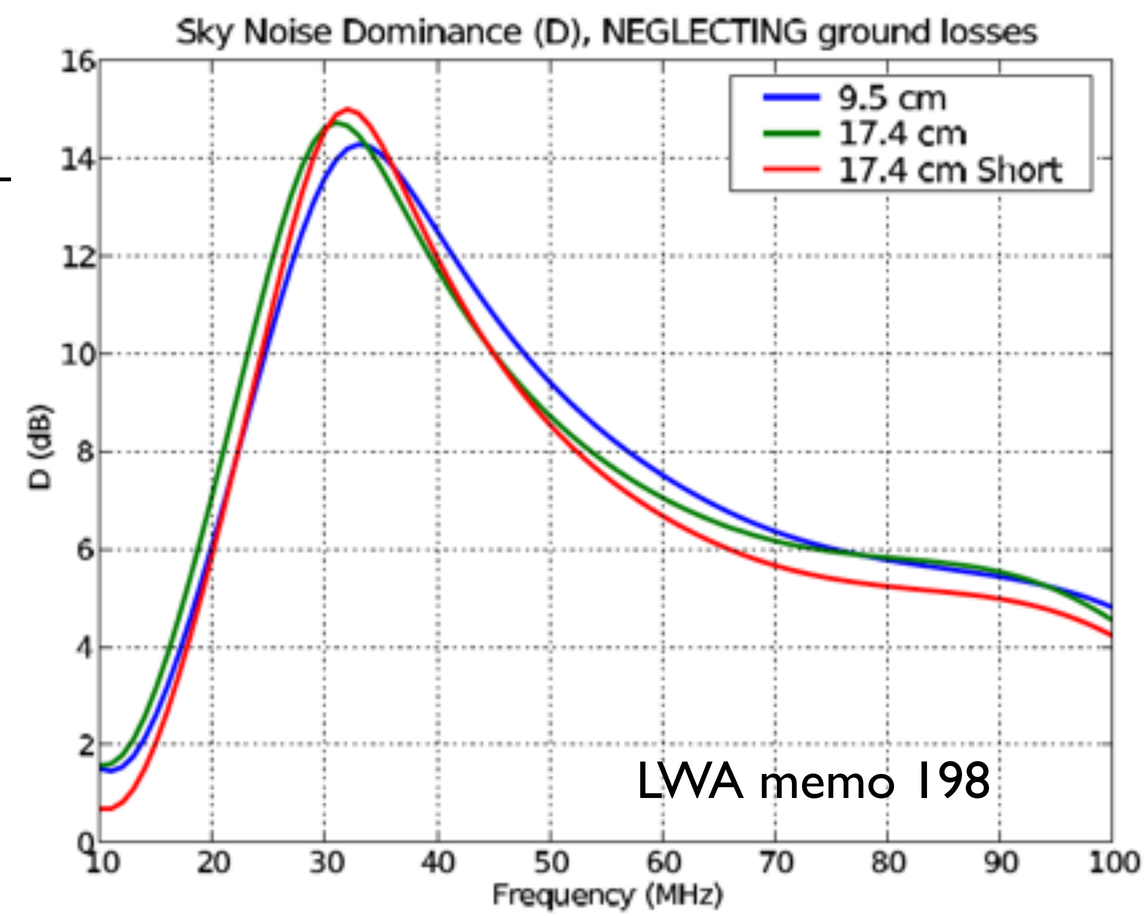
LEDA - Outrigger antennas



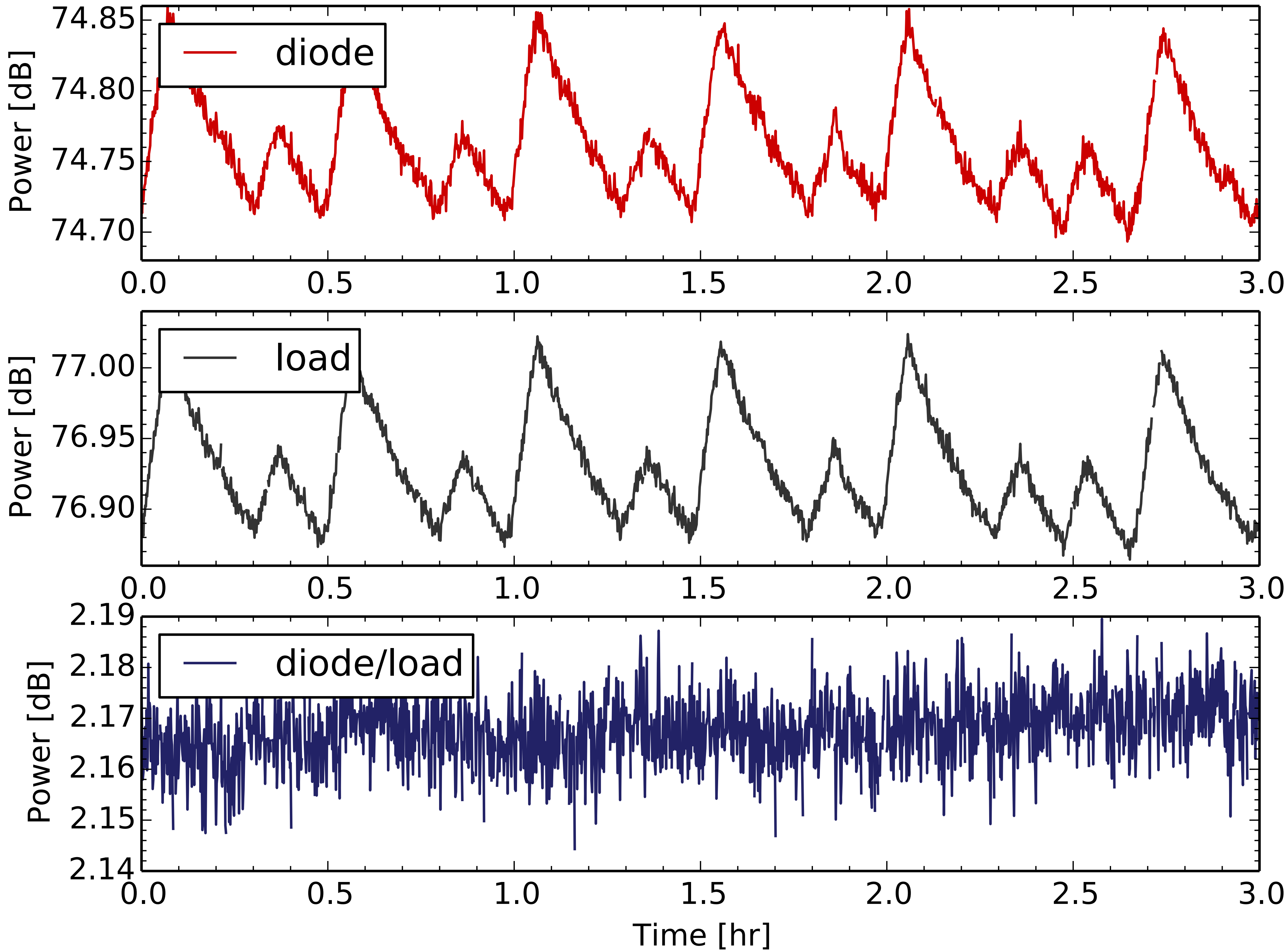
LEDA - Outrigger antennas



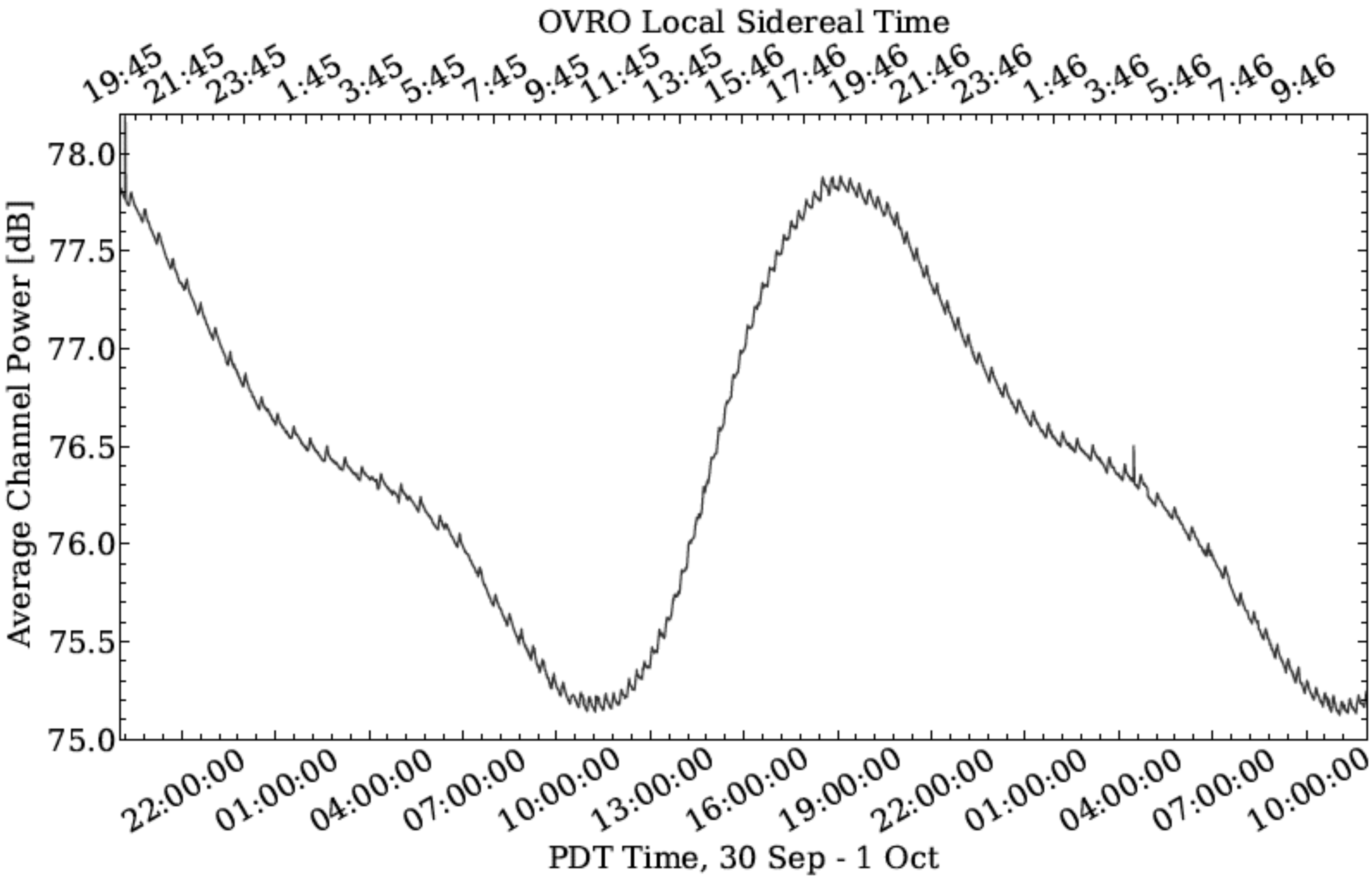
$$T_{ant} = T_{diode}\left(\frac{P_{ant} - P_{load}}{P_{diode} - P_{load}}\right) + T_{load}$$



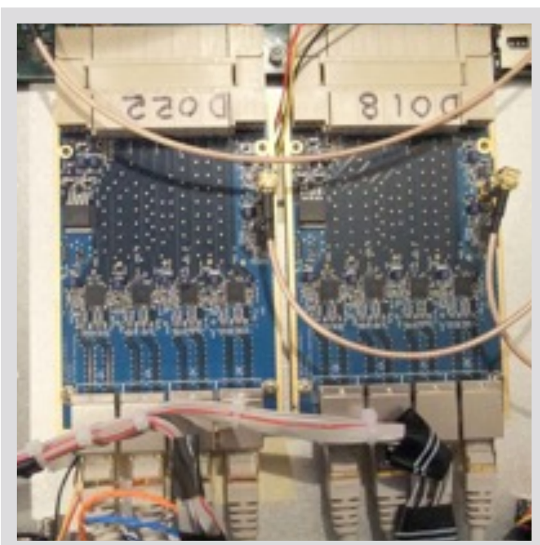
LEDA - Airconditioning switching



LEDA - Airconditioning switching



LEDA-OVRO - Digital Overview



ADC-16

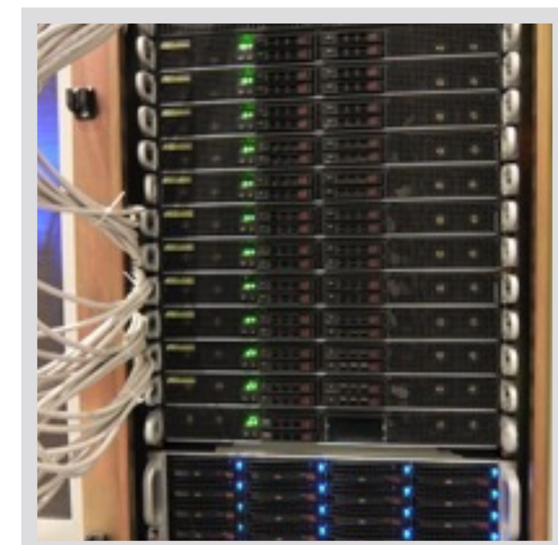
Signal digitization

F-ENGINE

CASPER ROACH2

10/40 GbE

Ethernet Switch

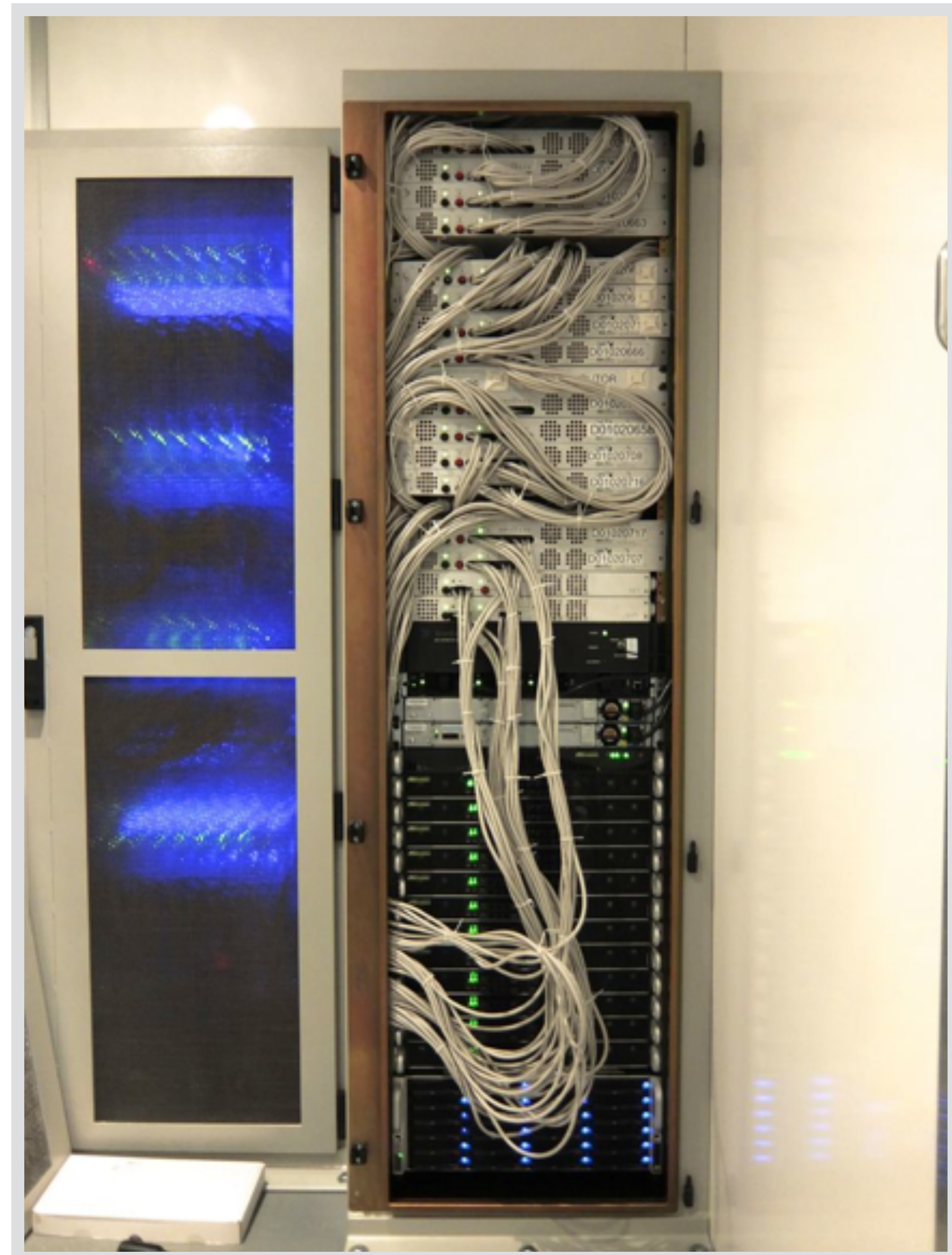


X-ENGINE

K20X GPU Servers

LEDA-512 Correlator

Correlator	N	B (MHz)	N^2B (GHz)
ALMA	66	8000	34800
eVLA	27	8000	5830
LEDA	**256**	**58**	**3800**
CARMA	23	4000	2120
PAPER	128	30	819
MWA	128	30	492
SMA	8	32	256
pdBI	288	1	829
AARTFAAC	288	1	829
LOFAR	48	32	737



LEDA-512 Correlator

ACCELERATING RADIO ASTRONOMY CROSS-CORRELATION WITH GRAPHICS PROCESSING UNITS

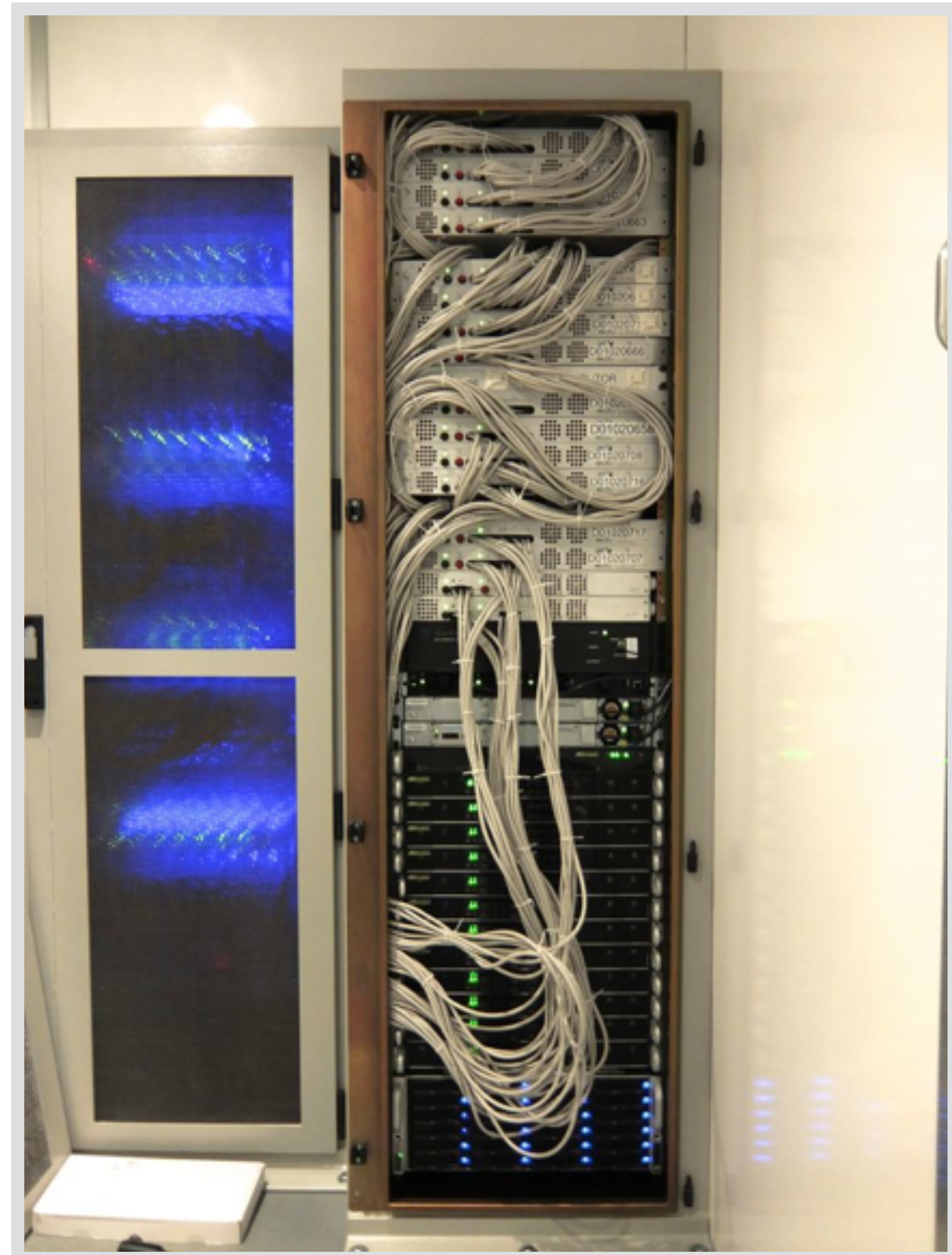
M.A. CLARK, P. C. LA PLANTE, L. J. GREENHILL
[arXiv:1107.4264 [astro-ph]]

A SCALABLE HYBRID FPGA/GPU FX CORRELATOR

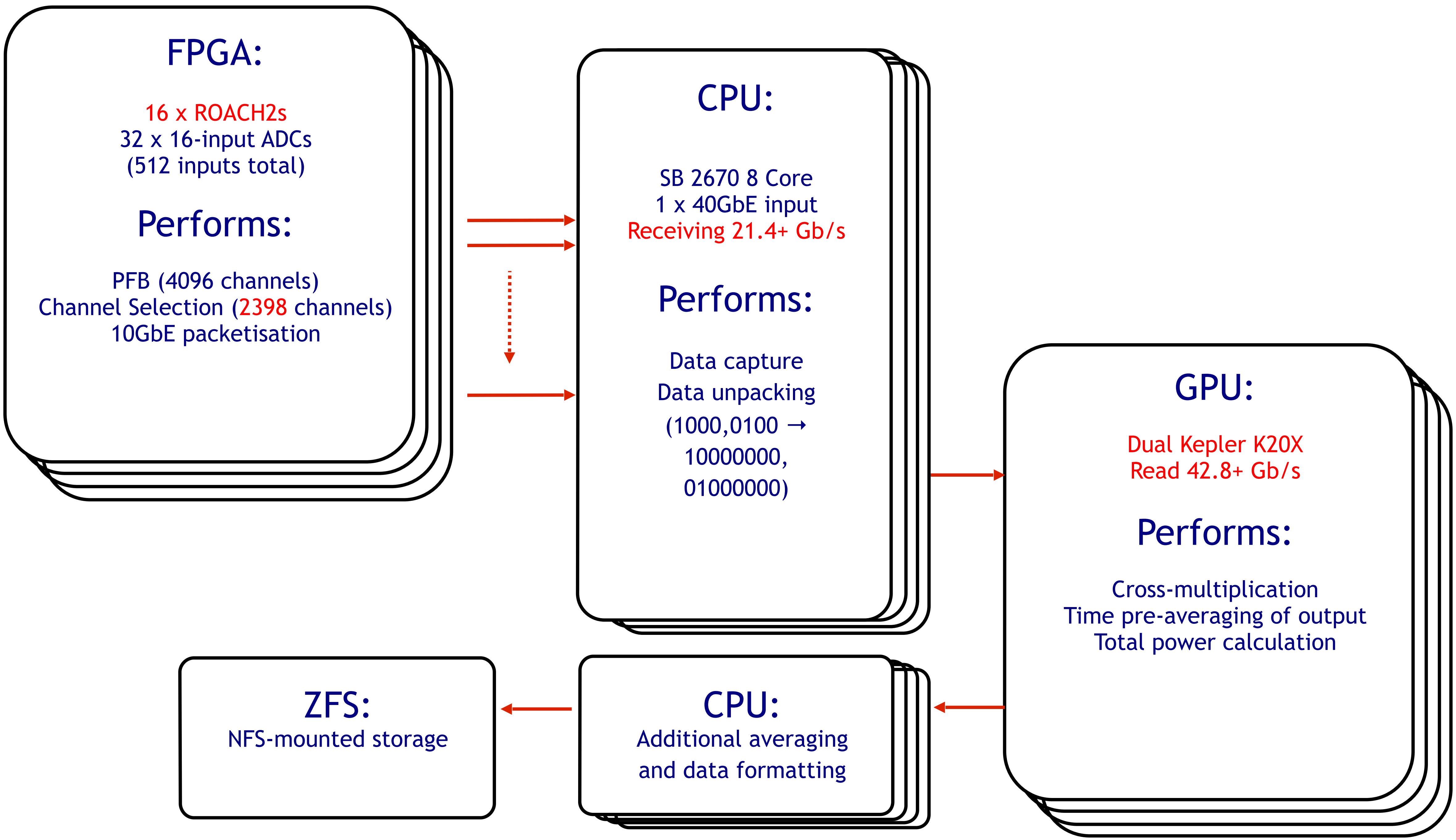
J. KOCZ, L. J. GREENHILL, B. R. BARSDELL, G. BERNARDI, A. JAMESON, M.A. CLARK, J. CRAIG, D. PRICE, G. B. TAYLOR, F. SCHINZEL, D. WERTHIMER
JAI (2014)

DIGITAL SIGNAL PROCESSING USING STREAM HIGH PERFORMANCE COMPUTING: A 512-INPUT BROADBAND CORRELATOR FOR RADIO ASTRONOMY

J. KOCZ et. al. (in prep)



LEDA-512 Correlator



CASPER ROACH-2

FPGA:

2 x ROACH2
4 x 16-input ADCs
(64 inputs total)

Performs:

PFB (4096 channels)
Channel Selection (2398 channels)
10GbE packetisation

- Standard F-engine
- ADC Capture
- 4-tap PFB
- Equalization coefficients applied
- Output of PFB (18 + 18 bits) reduced to 4 + 4 bits.
- User selects 2398 channels blocks, to go to different 40GbE connections.

Channels packed in channels order, followed by antenna order

10/40 GbE Switch

Mellanox SX1024:

48x SFP+

12x QSFP

- 32x ROACH2 SFP+
  - 7.36Gb/s
- 11x Server QSFP
  - 2x10.71Gb/s

•235.62 Gb/s input

•Flow control required

PSRDADA

Receiving:

- Create a series of data buffers
- Capture to RAM
- 21.4 Gb/s required

Achieved:

- Input capture up to 9.9Gb/s per 10GbE
- 30Gb/s+ using 40GbE (full pipeline).
- 40Gb/s (capture only).

CPU:

2 x 8 core
1 x 40GbE inputs
Receiving 21.42 Gb/s

Performs:

Data capture
Data unpacking
(1000,0100 → 10000000, 01000000)

Processing:

- Unpacker:
  - Calculation
  - Lookup table
- Write to different output buffer

CPU:
Additional averaging
Writes data to disk

Input from GPU, write to disk efficiently

GPU X-Engine

Processing:

- Read in input through texture memory
- Perform correlation using memory tiling to gain maximum performance
- Results accumulate in registers before write
- Effective data reuse leading to high arithmetic intensity

Output to memory buffer.
[Integrated with PSRDADA]

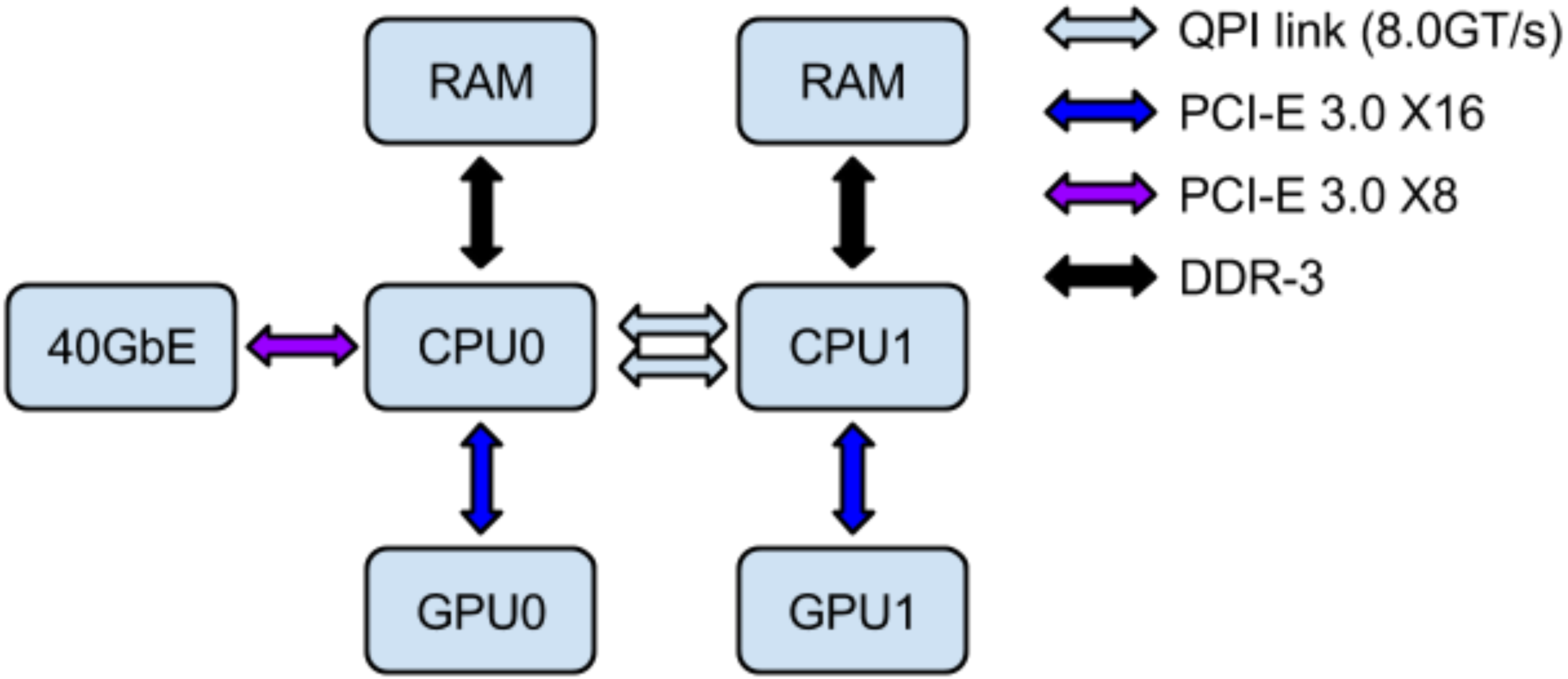
GPU:

Dual Kepler K20X
Read 42.8+Gb/s

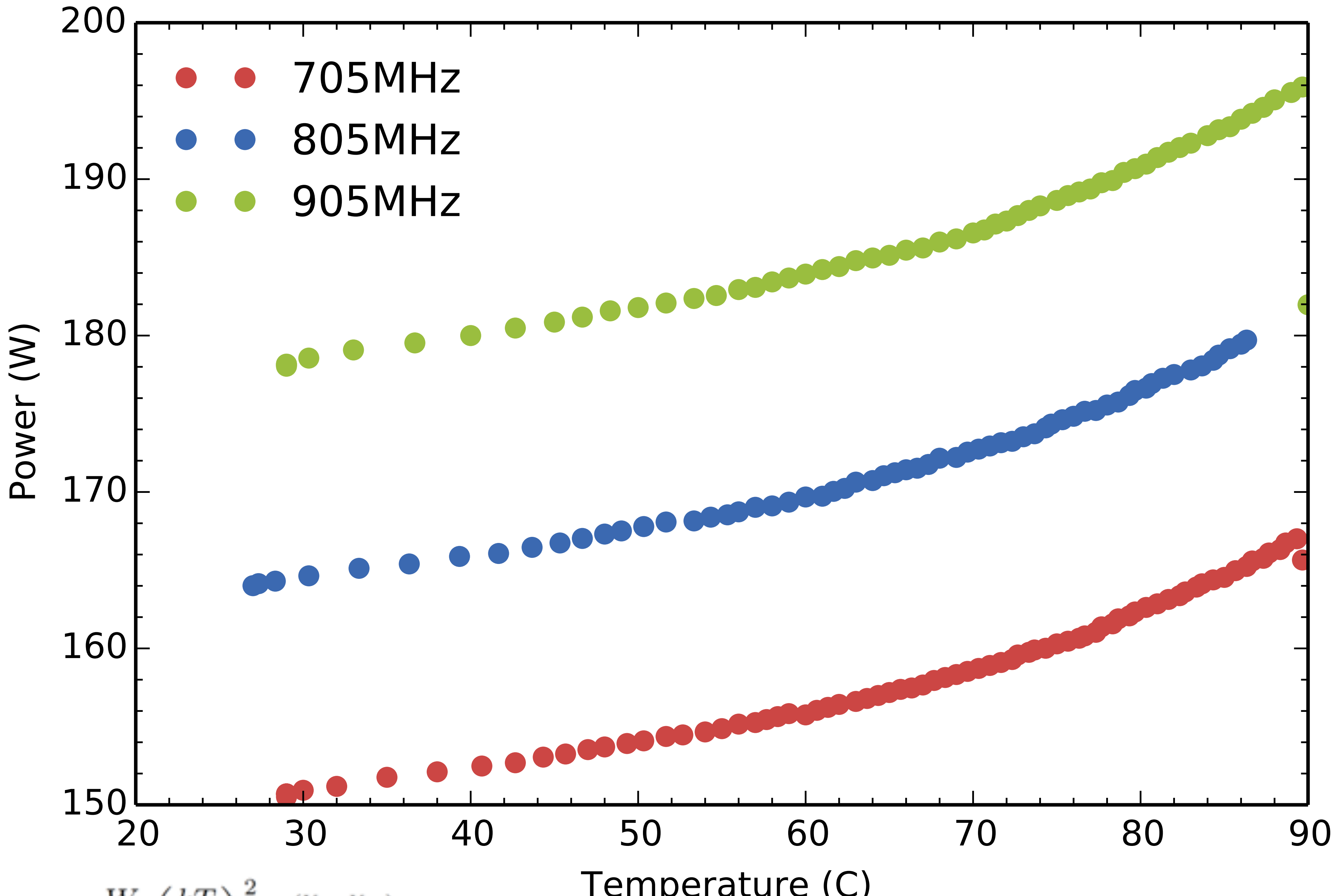
Performs:

Cross-multiplication
Time pre-averaging of output
Total Power Calculation

GPU X-Engine


RAM
RAM
40GbE
CPU0
CPU1
GPU0
GPU1
QPI link (8.0GT/s)
PCI-E 3.0 X16
PCI-E 3.0 X8
DDR-3

Measured power vs temperature

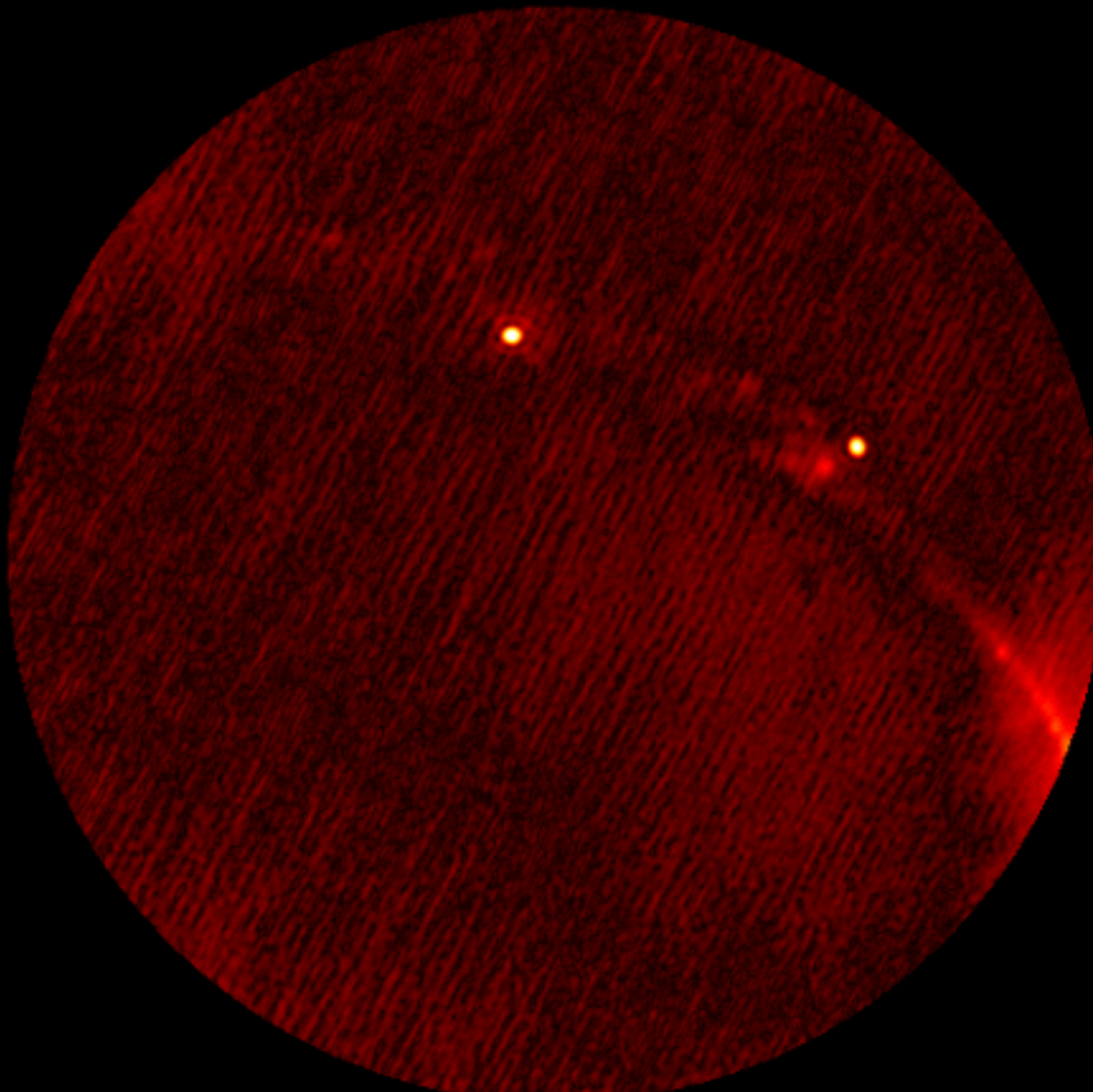


$$I_{subthreshold} = A_s \frac{W}{L} \left(\frac{kT}{q}\right)^2 e^{\frac{q(V_S - V_{th})}{nkT}}$$

LEDA-512: 24hr simulation

LST: 22:49:29.06

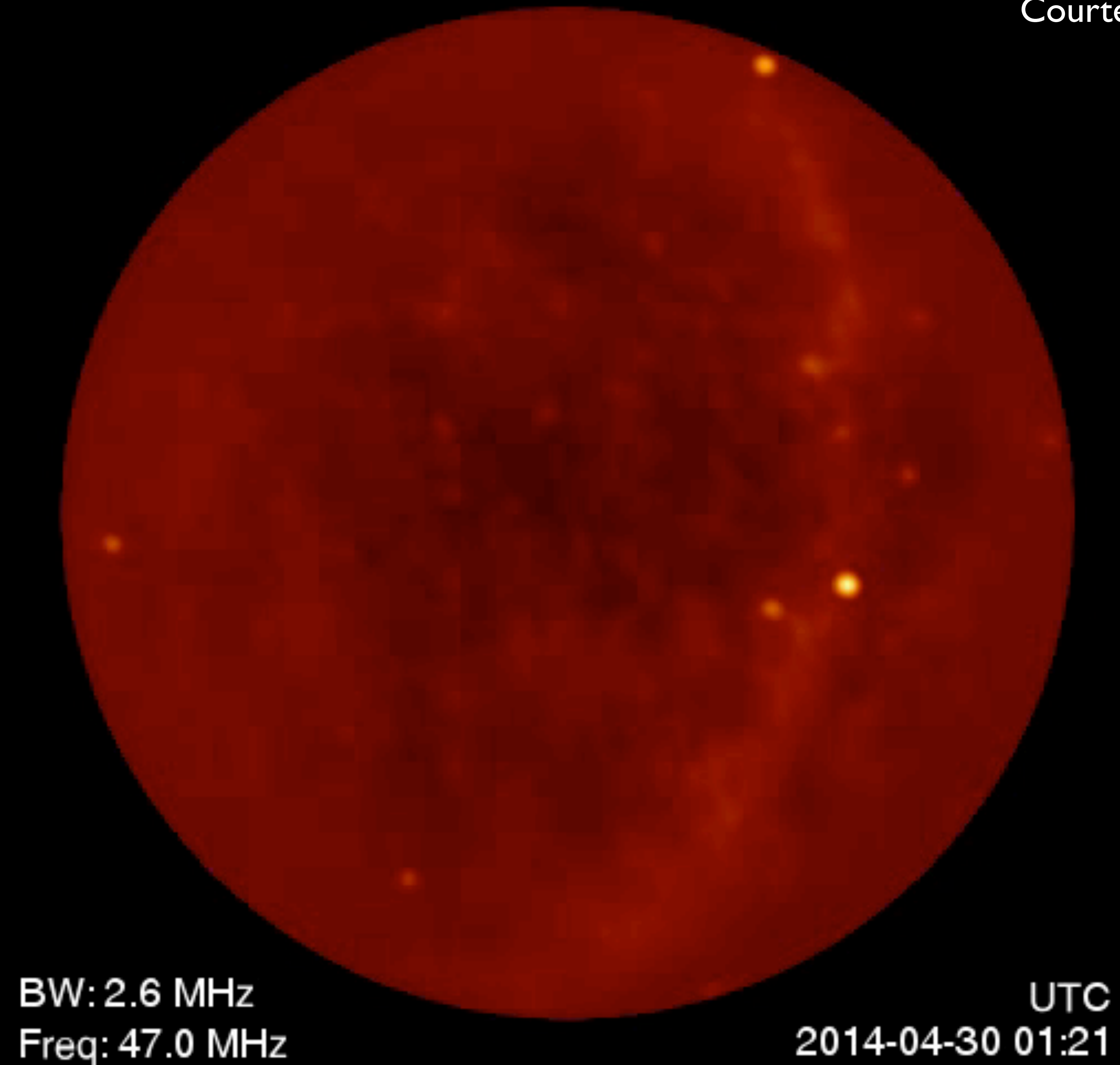
OSKAR2 + GSM



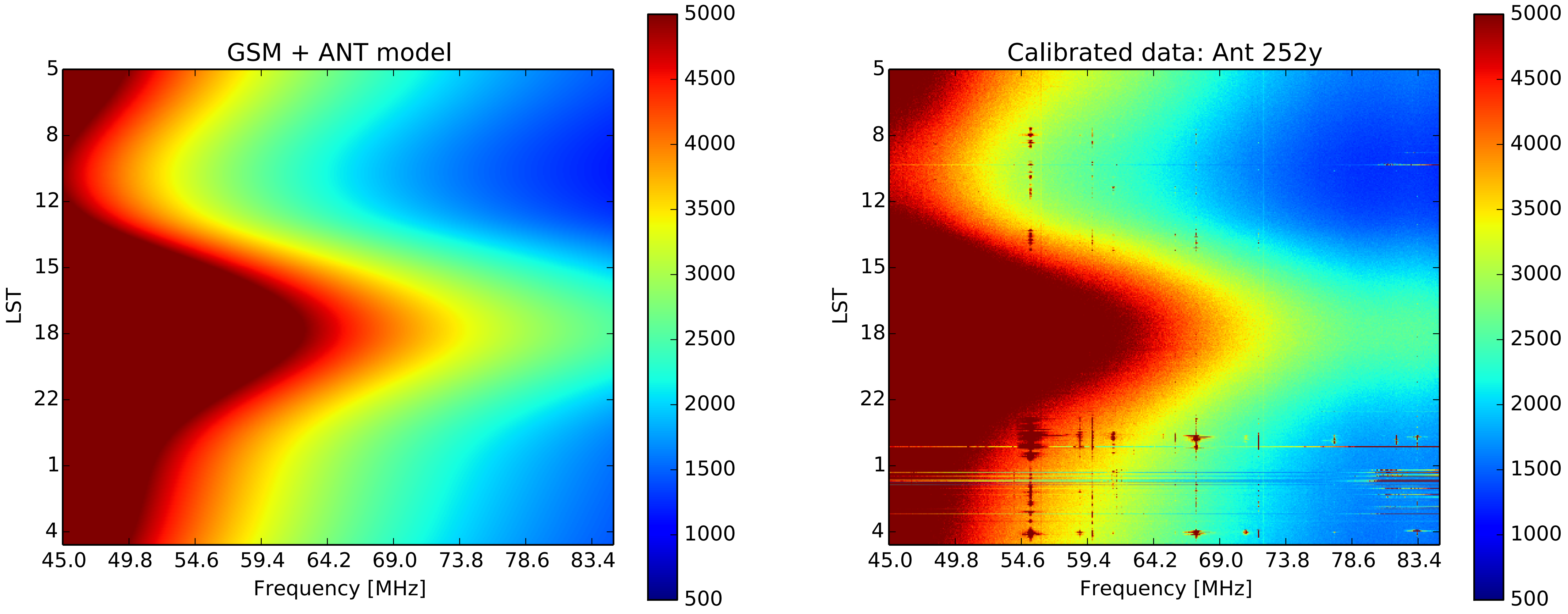
Single channel
47 MHz

LEDA-512: 24hr timelapse

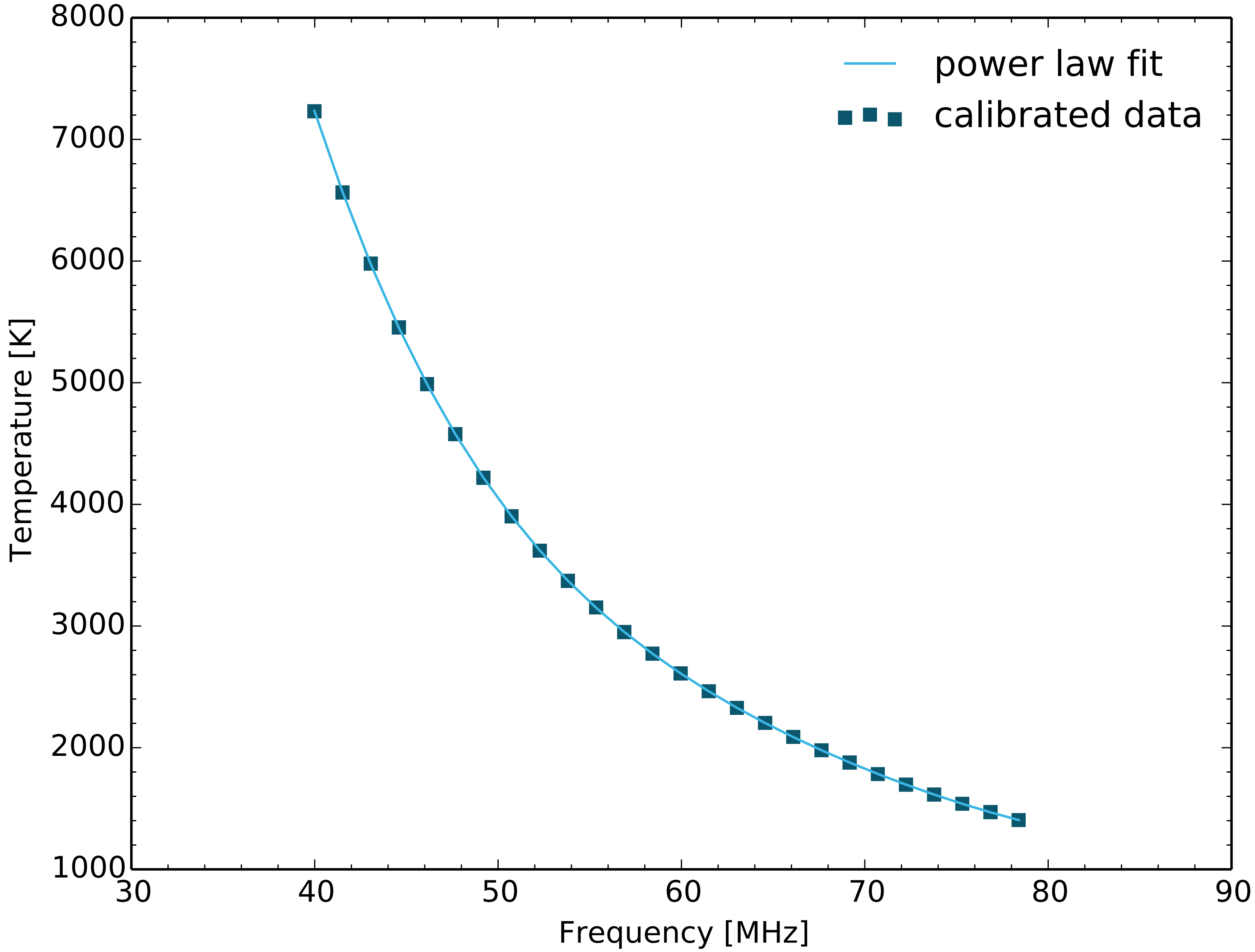
Courtesy Stephen Bourke



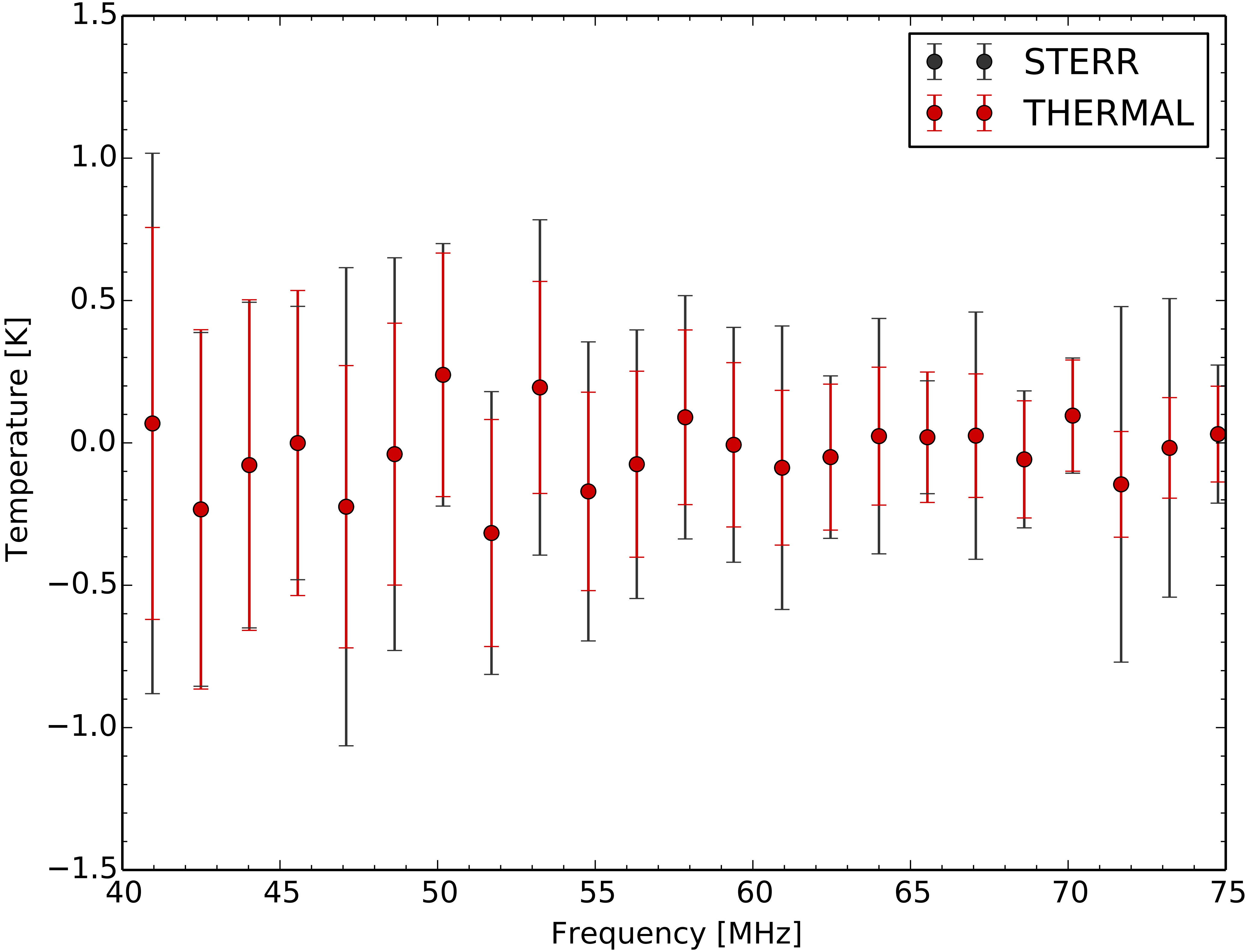
LEDA - Outrigger antennas



LEDA - Calibrated Spectrum



LEDA - Calibrated Residuals



Future plans / investigations

Science observations in December 2014

Upgrade to 576 inputs

Neater pipeline (redis, ZMQ, msgpack)

Data compression & storage format (bitshuffle, HDF5)

RDMA over Ethernet (FPGA -> GPU)

Low power ARM + GPU systems


Thank you

Connecting Great Minds

JAI Journal of Astronomical Instrumentation

Call for papers

The Journal of Astronomical Instrumentation (JAI) publishes articles that describe instruments being proposed, developed, under construction and in use, e.g. on ground-based, airborne, balloon-borne, and space telescopes. JAI also publishes articles that describe algorithms, their implementations, and techniques, such as calibration, that shape and advance instrument capabilities.

JAI was launched in December 2012 as a bi-annually journal, with production increasing in 2014 to meet demand. In this time, there have been two special issues, and the editors solicit proposals for more. JAI is distinctive in the Astronomy and Astrophysics literature, offering a high-quality, peer-reviewed venue devoted entirely to topics bearing on instrumentation, with fast turnaround and an Open Access option for authors. JAI works to provide first reviews in four weeks, and within a few weeks of being accepted, articles are cross-referenced in the NASA Astrophysical Data System (ADS) and receive DOI numbers. JAI also supports free hosting for a growing array of supplemental online information attached to articles and subject to review, including animations and movies, calibration and other data, and research notes.

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Access JAI at http://www.worldscientific.com/JAI. For more information about submissions, please refer to guidelines at http://www.worldscientific.com/page/jai/submission-guidelines. If you would like to propose a special issue, or if you have questions, please contact us at jai@wspc.com.

Thank you.

Sincerely,

Giovanni G. Fazio (Editor-in-Chief)
Harvard-Smithsonian Center for Astrophysics, USA

Associate Editors

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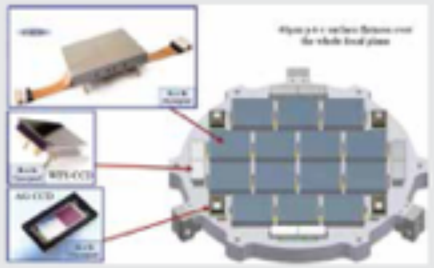
ICP Imperial College Press www.icpress.co.uk
Preferred Publisher for Leading Thinkers

JAI Journal of Astronomical Instrumentation www.worldscientific.com/jai
Latest issue: Vol. 3, No. 01 (March 2014)

JPCam: A 1.2 Gpixel camera for the J-PAS survey

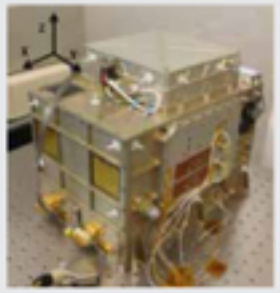
by **K. Taylor** *(Universidade de Sao Paulo)*, et al.
DOI: **10.1142/S2251171713500104**



JPCam is a 14-CCD mosaic camera, using the new e2v 9k-by-9k 10 μm-pixel 16-channel detectors, to be deployed on a dedicated 2.55 m wide-field telescope at the OAJ (Observatorio Astrofisico de Javalambre) in Aragon, Spain. We will present an overview of JPCam, from the filter configuration through to the CCD mosaic camera. A brief outline of the main J-PAS science projects will be included.

GIADA: Its status after the Rosetta cruise phase and on-ground activity in support of the encounter with comet 67P/Churyumov-Gerasimenko

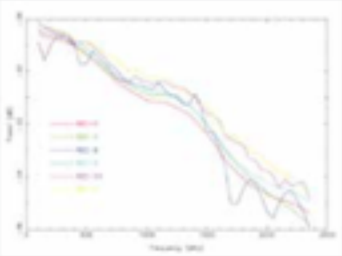
by **V. Della Corte** *(INAF)*, et al.
DOI: **10.1142/S2251171713500116**



GIADA (Grain Impact Analyser and Dust Accumulator) on-board the Rosetta mission to comet 67P/Churyumov-Gerasimenko was designed to study the physical and dynamical properties of dust particles ejected by the comet during the encounter. In this paper we report the results of the analysis of data collected by GIADA during the past seven years of the cruise phase.

Characterizing the performance of a high-speed ADC for the SMA digital backend

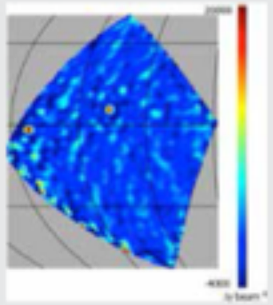
by **N. A. Patel** *(Harvard-Smithsonian Center for Astrophysics)*, et al.
DOI: **10.1142/S2251171714500019**



We report on tests of a 5 Gs/s analog-to-digital converter (ADC) used in the new Submillimeter Array (SMA) Digital Backend (DBE). The ADC is e2v EV8AQ160, with 8-bit resolution and 4 interleaved cores, operated in single-channel mode. We measured the frequency response, Signal to Noise and Distortion (SINAD), Spurious Free Dynamic Range (SFDR), Noise Power Ratio and intermodulation distortion over the bandwidth of 2.25 GHz. The performance of this ADC is found to be adequate for our application in the SMA DBE.

A scalable hybrid FPGA/GPU FX correlator

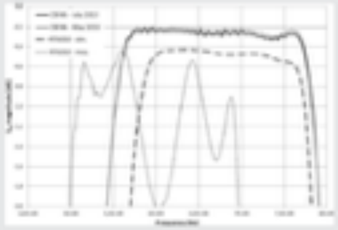
by **J. Kocz** *(Harvard-Smithsonian Center for Astrophysics)*, et al.
DOI: **10.1142/S2251171714500020**



Radio astronomical imaging arrays comprising large numbers of antennas, O(102–103), have posed a signal processing challenge because of the required O(N2) cross correlation of signals from each antenna and requisite signal routing. This motivated the implementation of a Packetized Correlator architecture that applies Field Programmable Gate Arrays (FPGAs) to the O(N) "F-stage", and Graphics Processing Units (GPUs) to the O(N2) "X-stage". Fringes, visibility amplitudes and sky image results obtained during field testing are presented.

A high temperature superconductor microwave filter working in C-band for the Sardinia Radio Telescope

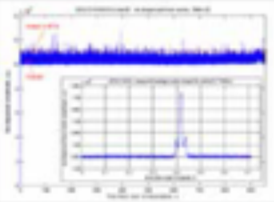
by **P. Bolli**, et al.
DOI: **10.1142/S2251171714500032**



A planar band-pass filter based on High Temperature Superconductor (HTS) has been designed for possible implementation in the cryogenic front-end of the C-band receiver for the Sardinia Radio Telescope. The band-pass filter is designed to operate at relatively high frequencies: center frequency 6.7 GHz with 30% bandwidth. Seven nominally identical filters have been fabricated to test different carrier materials and connector types aimed to keep the fabrication of the HTS filter simpler and more cost competitive.

A multi-beam radio transient detector with real-time DE-dispersion over a wide DM range

by **N. Clarke** *(Curtin University)*, et al.
DOI: **10.1142/S2251171714500044**



Isolated, short dispersed pulses of radio emission of unknown origin have been reported and there is strong interest in wide-field, sensitive searches for such events. To achieve high sensitivity, large collecting area is needed and dispersion due to the interstellar medium should be removed. To survey a large part of the sky in reasonable time, a telescope that forms multiple simultaneous beams is desirable. We have developed a novel FPGA-based transient search engine that is suitable for these circumstances.