
# Technological developments for NenuFAR*

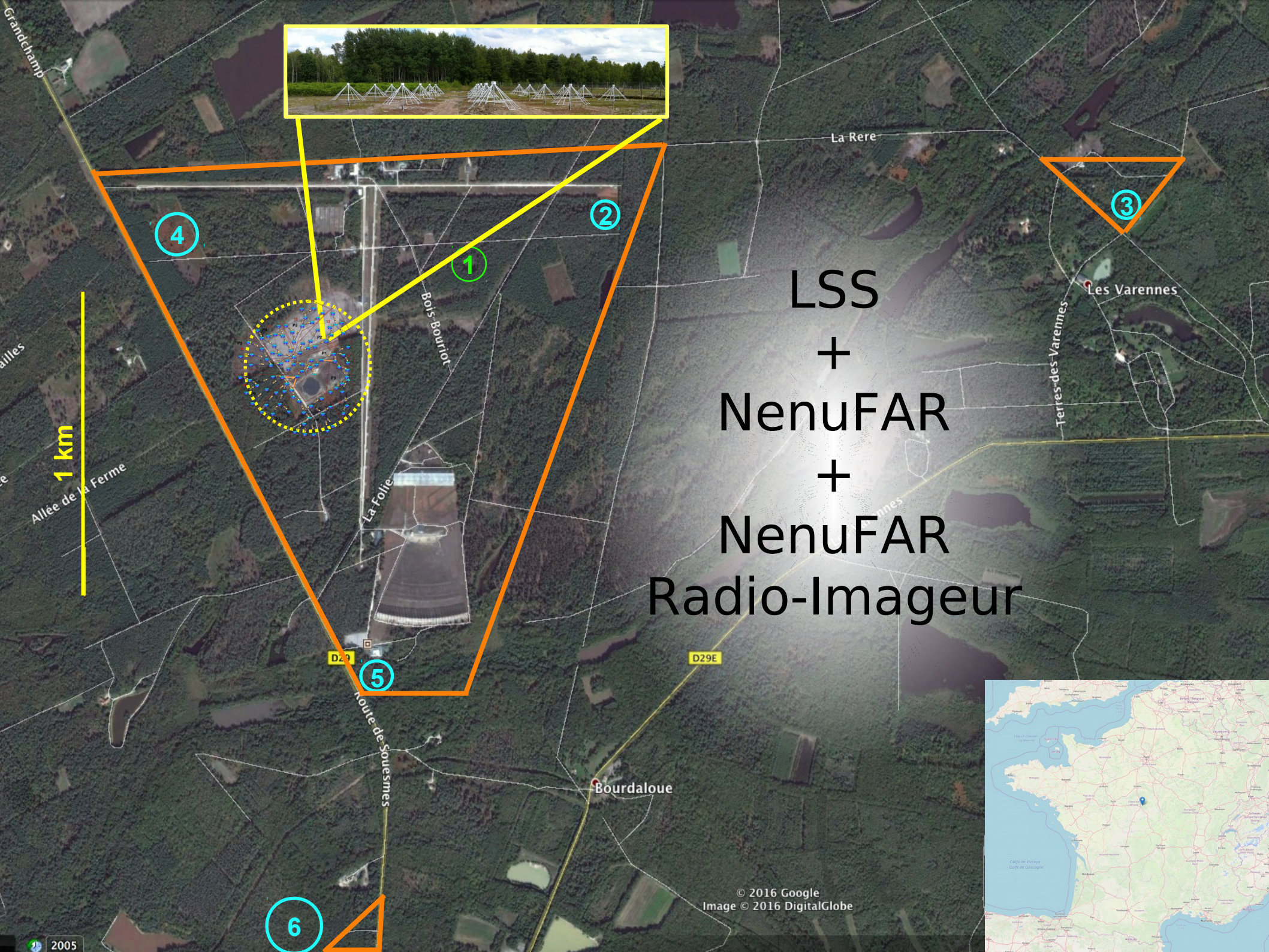
Cedric Viou

on behalf of the

**NenuFAR-France team****

***: LESIA-OP, LPC2E-Orléans, USN-OP, CEA-Saclay, GEPI, LERMA, ONERA, ENS/IAP, OCA, ...*

*New Extension in Nançay Upgrading LOFAR


LSS
+
NenuFAR
+
NenuFAR
Radio-Imageur
1 km
1
2
3
4
5
6
La Rere
Les Varennes
Terres-des-Varennes
Bois Bouriot
La Folie
Allée de la Ferme
Route de Souesmes
Bourdaloue
D29E
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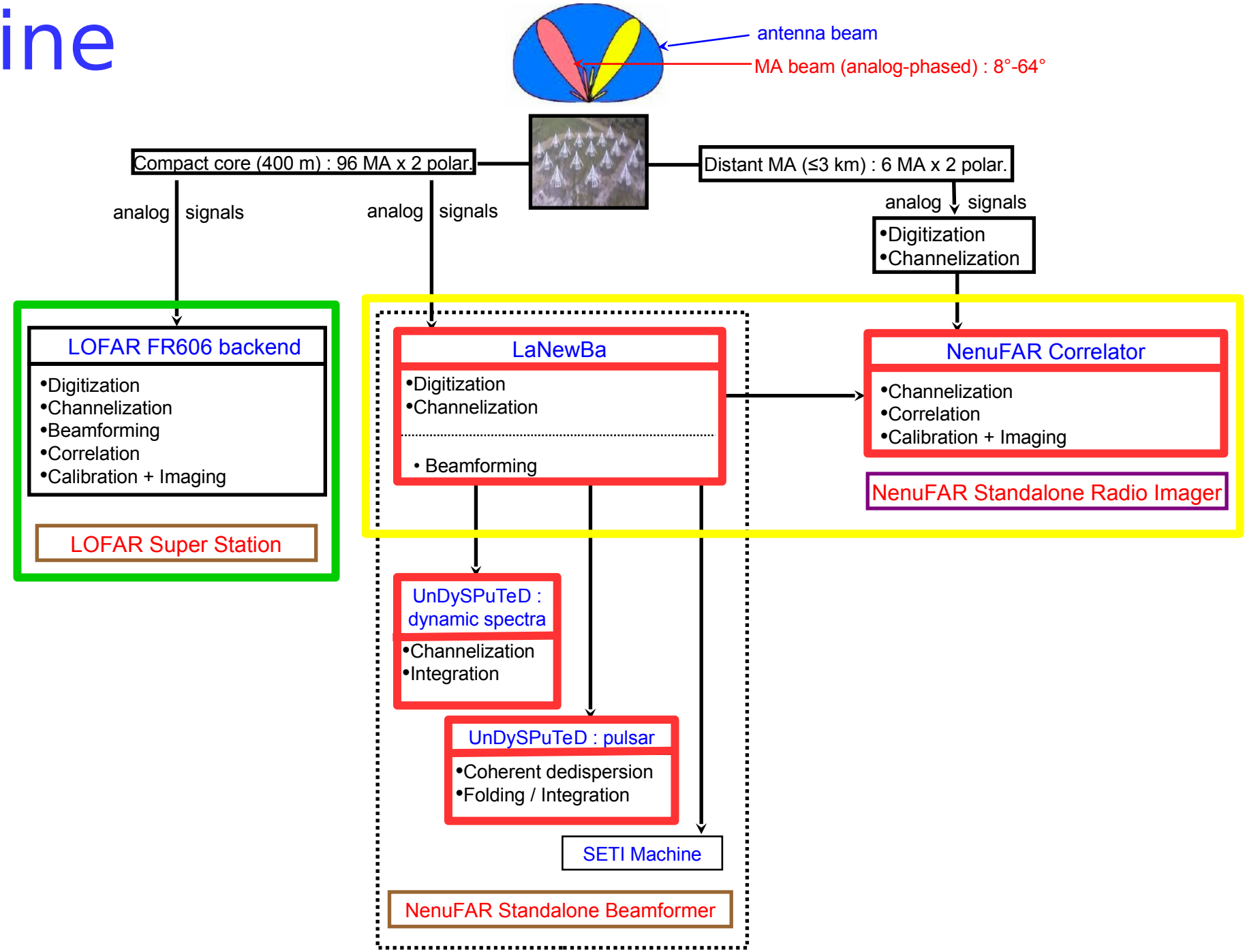
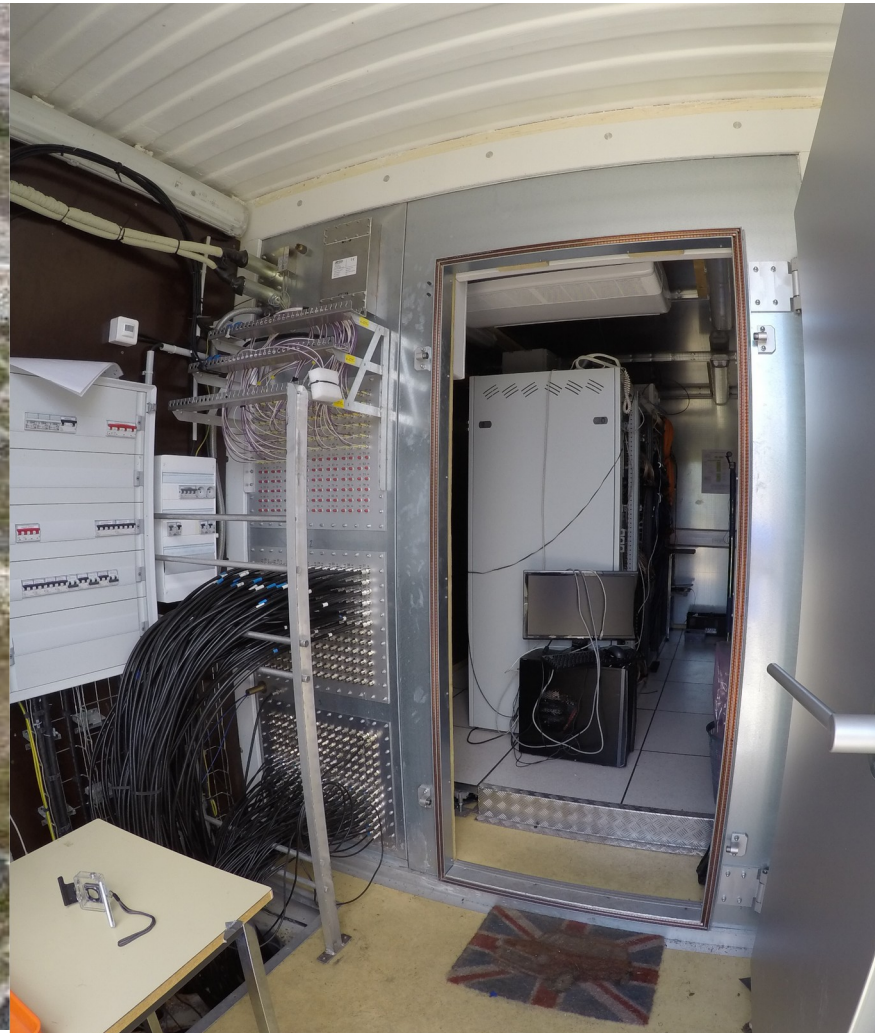
2005

# Technological developments for NenuFAR

## Outline



# On-site computing facilities



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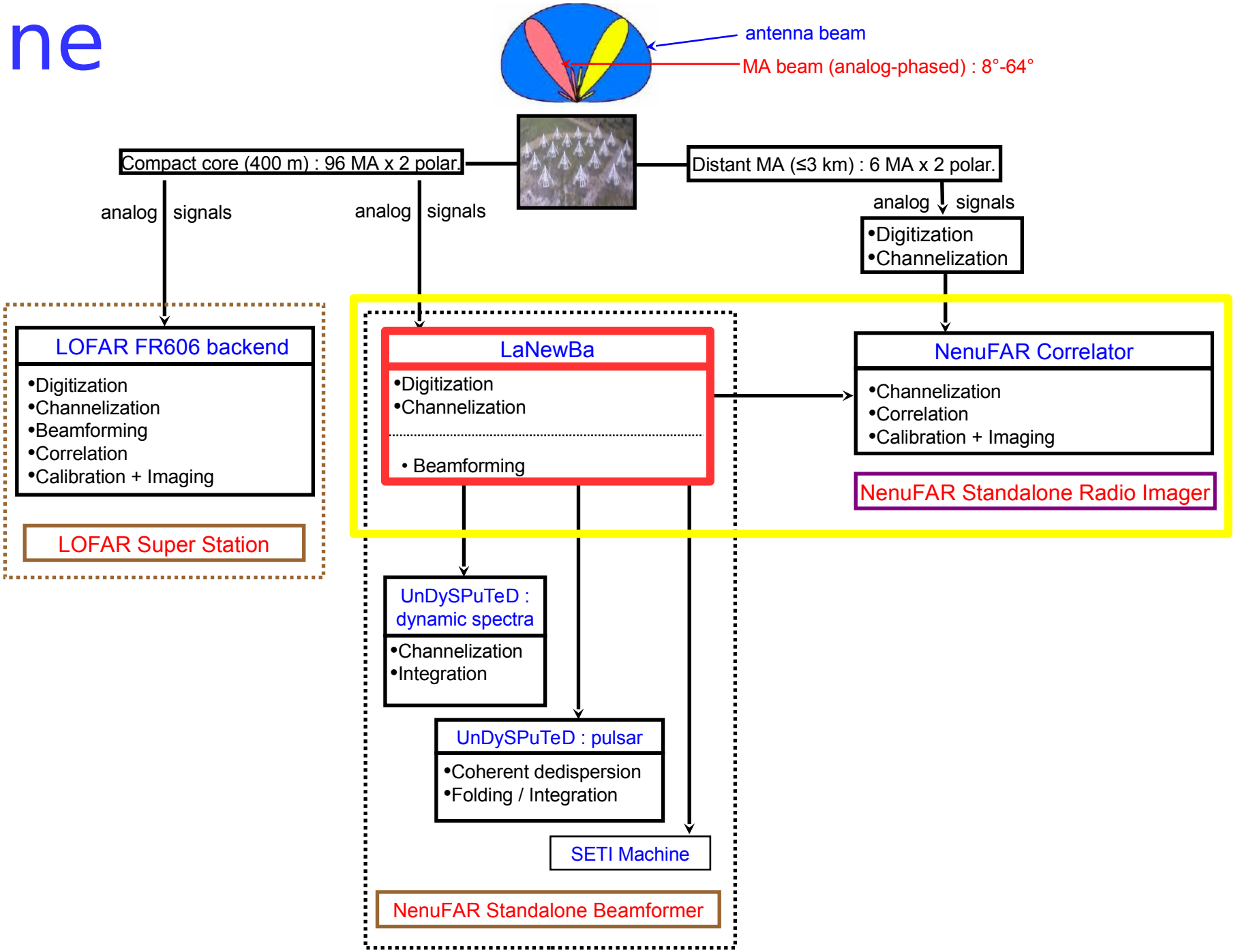
antenna beam
MA beam (analog-phased) : 8°-64°
Compact core (400 m) : 96 MA x 2 polar.
Distant MA (≤3 km) : 6 MA x 2 polar.
analog signals
analog signals
analog signals
•Digitization
•Channelization
LOFAR FR606 backend
•Digitization
•Channelization
•Beamforming
•Correlation
•Calibration + Imaging
LOFAR Super Station
LaNewBa
•Digitization
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NenuFAR Correlator
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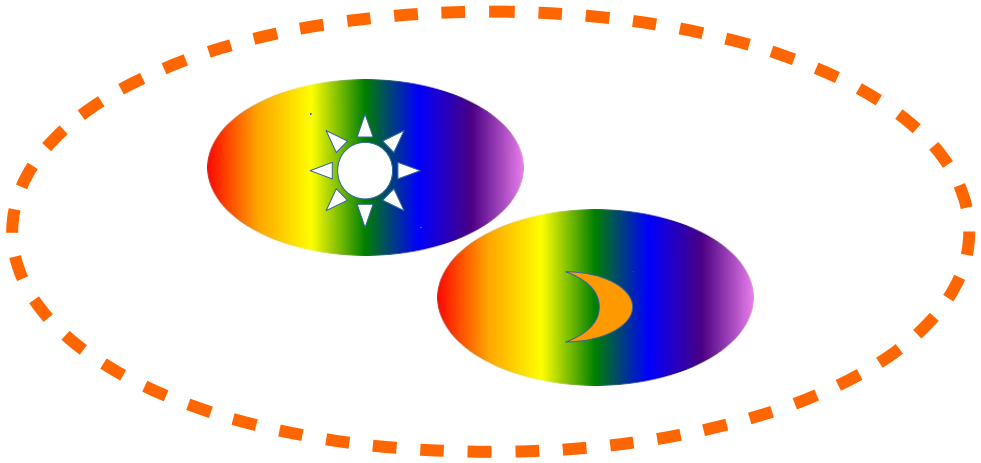
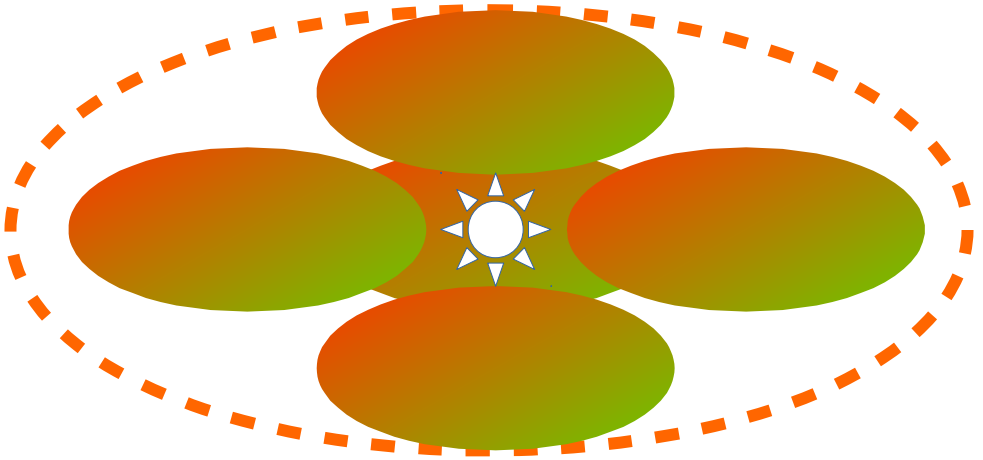
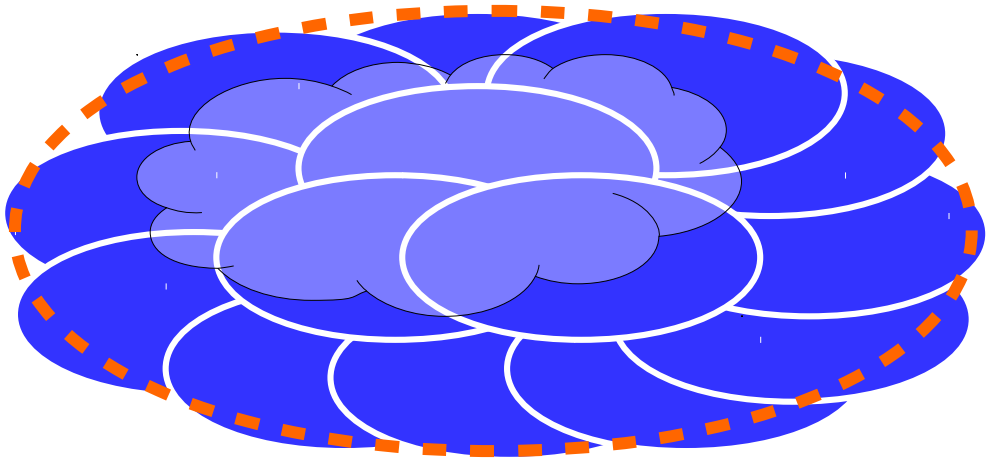
NenuFAR Standalone Radio Imager
UnDySPuTeD : dynamic spectra
•Channelization
•Integration
UnDySPuTeD : pulsar
•Coherent dedispersion
•Folding / Integration
SETI Machine
NenuFAR Standalone Beamformer

# Possible beam configurations







« Your » beam distribution

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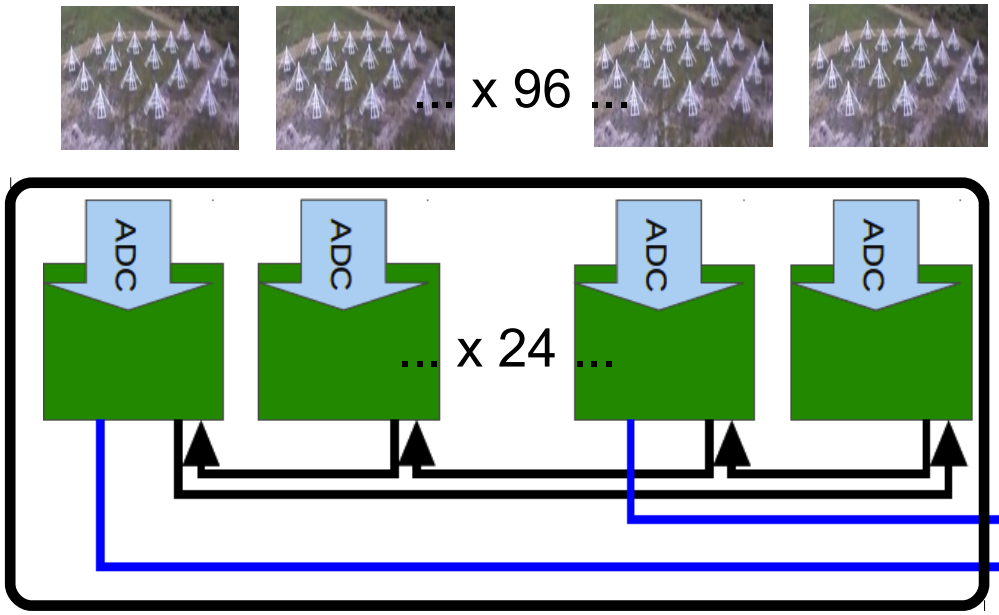
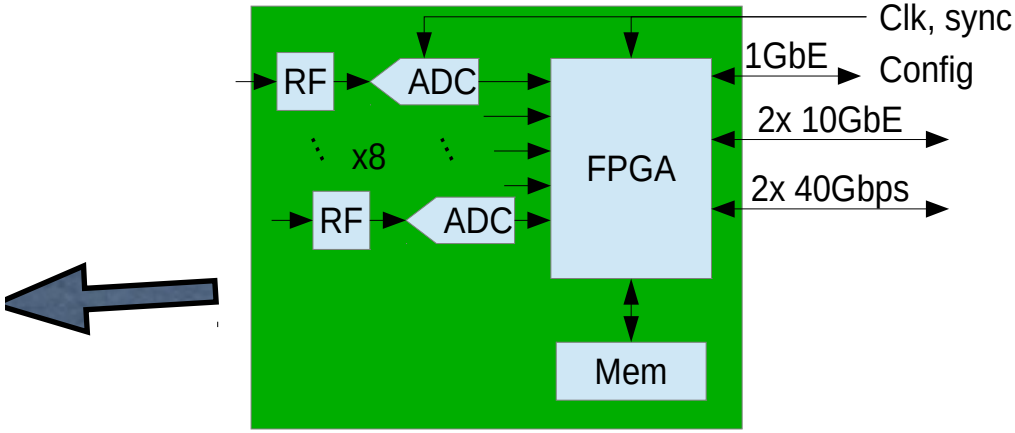
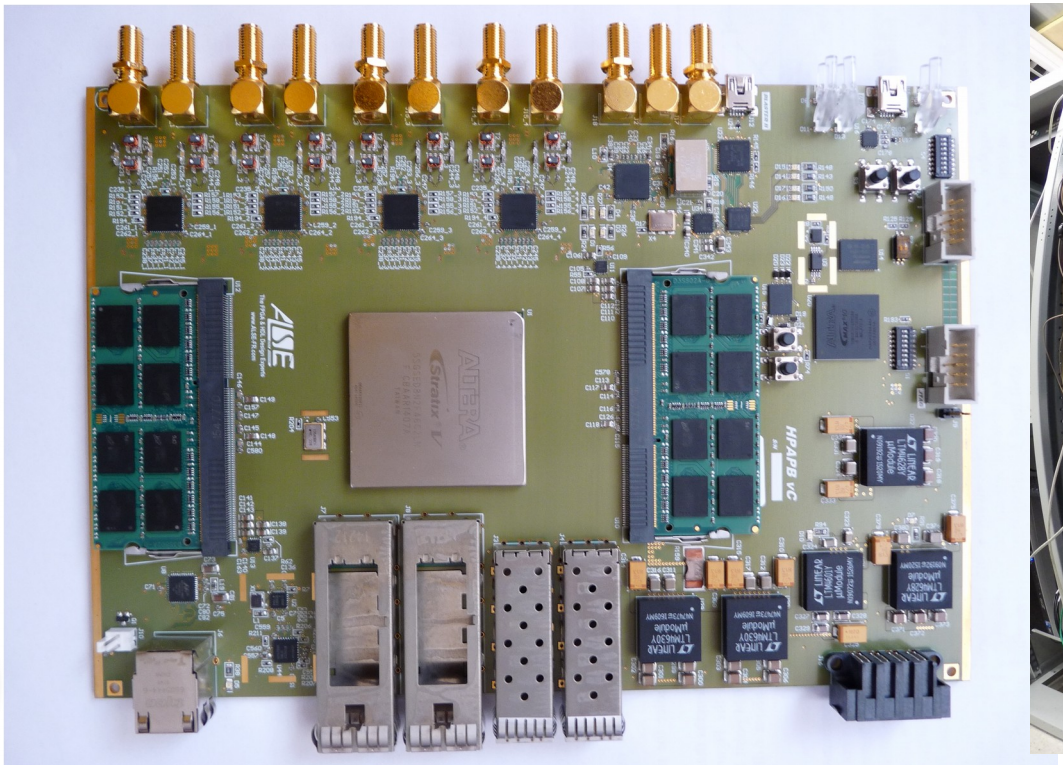
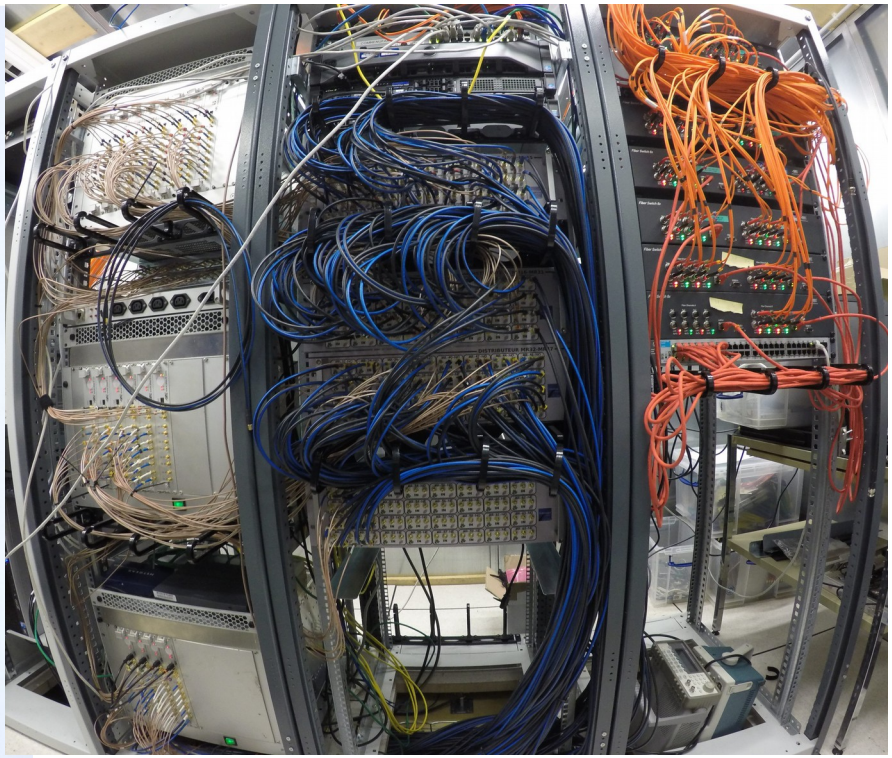



2 beams full-band (~10-85 MHz), full-polar.

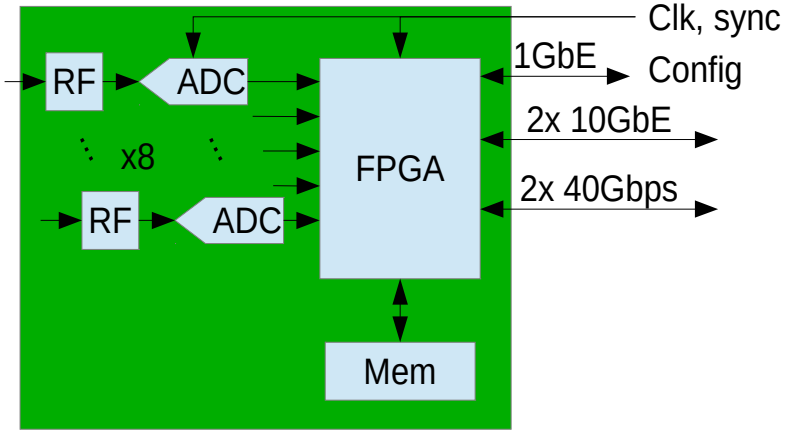




A.L.S.E
the FPGA Experts

# LANewBa

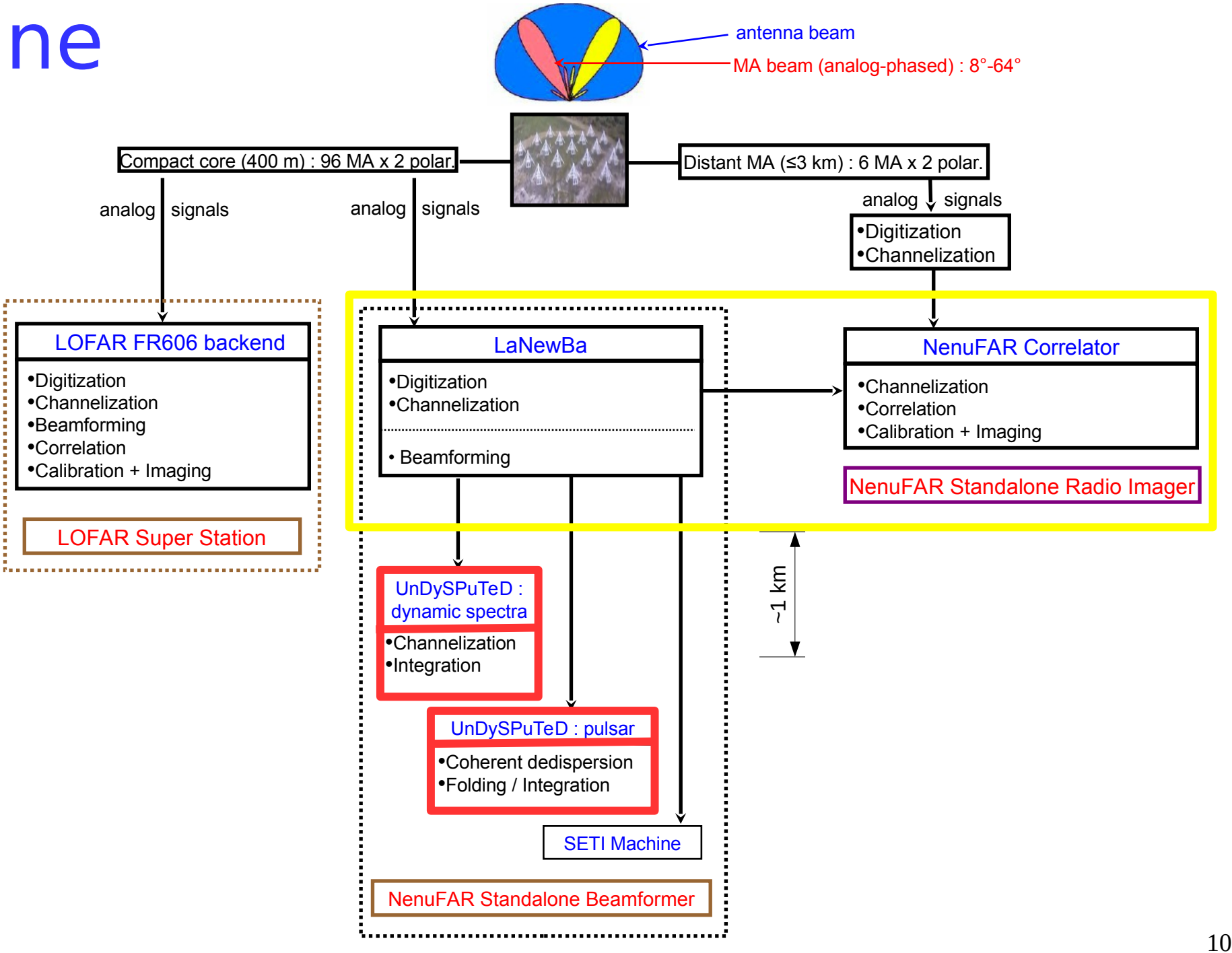
- Digitization
  - (96x2) x 200 MS/s - 14-bit ADCs (~400 MB/s/chan)
  - 48 GB/s today, 77 GB/s for full deployment, 24/7
  - Time synchronisation better than 0.1 ns
- Signal processing implemented within FPGAs (Stratix V Altera/Intel)
  - Hardware interfaces provided by ALSE (JESD for ADCs, DDR3, 1G, 10G, 40G,...).
  - Signal processing based on VHDL code from LOFAR RSPs
    - Multiple instanciations to increase processing capabilities.
  - 1300 GMAC/s distributed over 24 compute boards
- Channelization :
  - 512 x 0.195 kHz subbands
  - 16-taps PFB + 1k-FFT (614+192 GMAC/s)



# LANewBa

- Beamforming
  - Sub-band selection (768 from 512)
  - Delays implemented by phase rotation (Narrow band assumption)
  - Sommation within a ring connecting all FPGAs (14 Gb/s, 58 GAcc/s)
  - Export streams over 10GbE (2x 300-600 MB/s)
- Array calibration
  - Correlation observations of CasA, CygA (16 ssb/s -> 512 ssb/30s)
    - Sample distribution over the ring  (18 Gb/s)
    - MAC within all compute boards (90 MB/s x 2.2 GB/s)
    - 461 GMAC/s
- Health monitoring et diagnosis
  - Statistic Products computation (SST, BST)
  - Physical parameters of the compute units (T°C, U, I, flags)
- 1 cabinet, 1500 W

# Outline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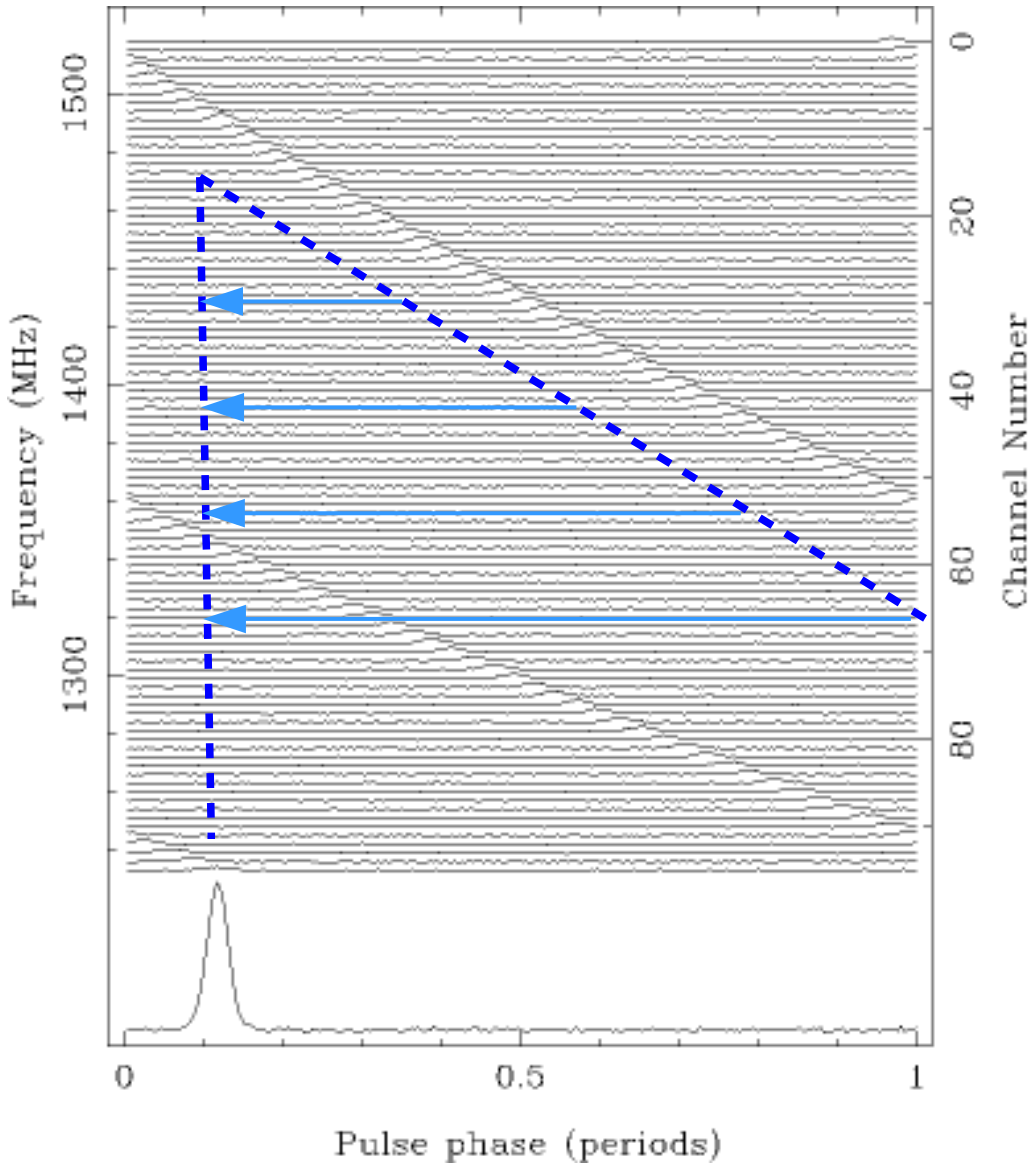
# UnDySPuTeD

- 2x Servers :
  - 2x Intel Xeon E5-2620v4 8cores
  - 32 GB DDR4
  - 2x GPU Nvidia GTX 1080
  - 13 TB HDD storage

# UnDySPuTeD dynamic spectra

- Dynamic Spectra
  - Processes 1 to 4 streams of 2.4 Gb/s each, B=195 kHz, dt = 5.12 µs
  - FFT + $<|x_i.x_j|^2>$ to provide continuous Full Stokes in real time
    - $B_{min}$ = 762 Hz, $dt_{min}$ = 1 ms
    - $B_{max}$ = 195 kHz, $dt_{max}$ = 1 s
  - Input stream : 300-600 MB/s (int8-int16) → 1.2 GB/s (float32)
  - FFT : ~ 2 GFLOPS

# UnDySPuTeD pulsar : LUPPI




- Narrow time domain pulse scattered over frequency (dispersed) by interstellar medium ($e^-$)
- Correction required before t-f integration => Dedispertion

$$H(\nu+\nu_0)=\exp\left(i\,2\pi\,D\frac{\nu^2}{\nu_0^2(\nu+\nu_0)}\right)$$

- Chromatic time delay (linear filter) cheaper to implement in the frequency domain. But we want time domain to study pulsars => TF, filter, $TF^{-1}$

$$x[n]$$
$$X[k]=\boldsymbol{TF}(x[n])$$
$$X_{dedis}[k]=X[k].H[k]^{-1}$$
$$x_{dedis}[n]=\boldsymbol{TF^{-1}}(X_{dedis}[k])$$

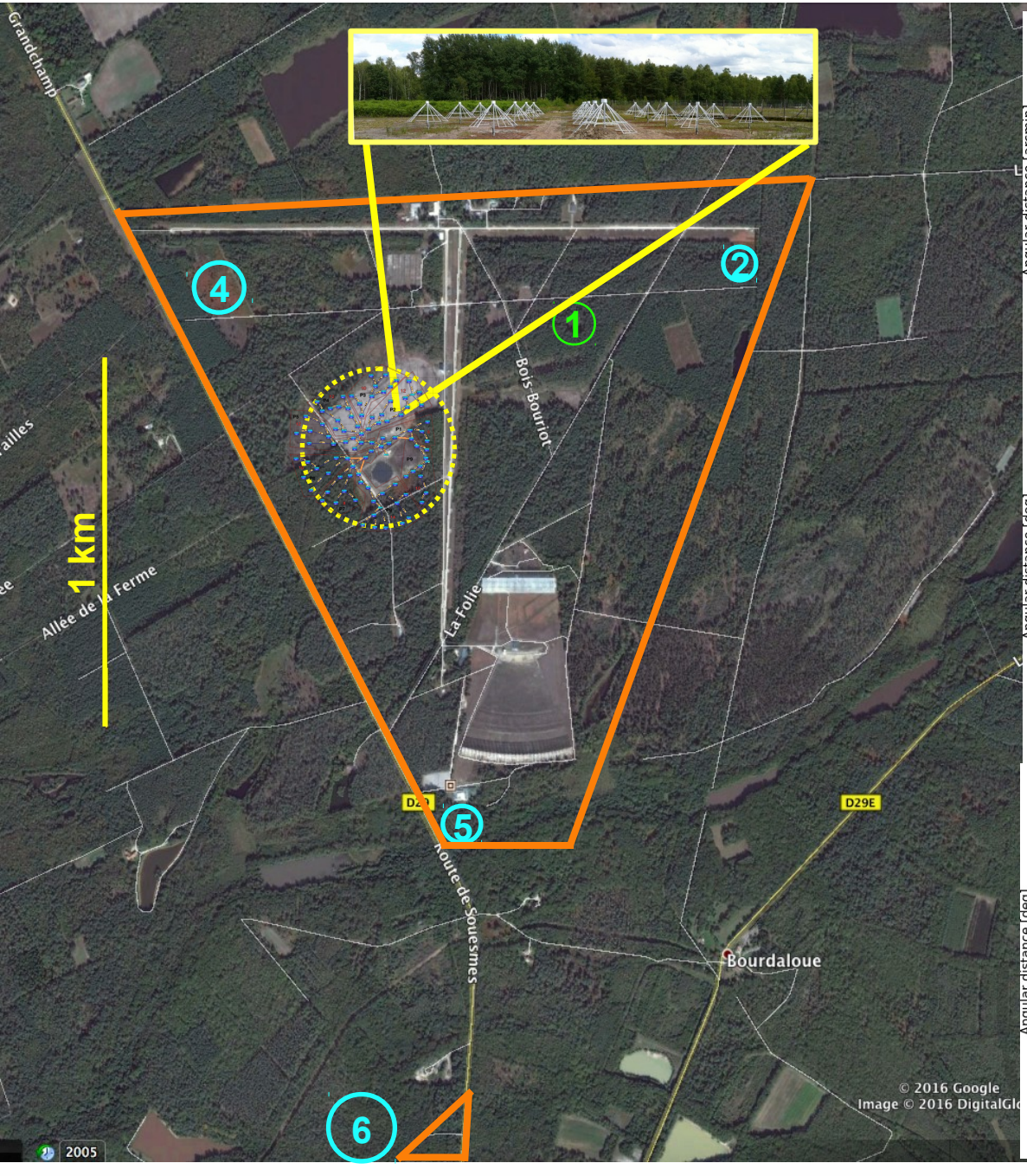
From the Handbook of Pulsar Astronomy, by Lorimer & Kramer

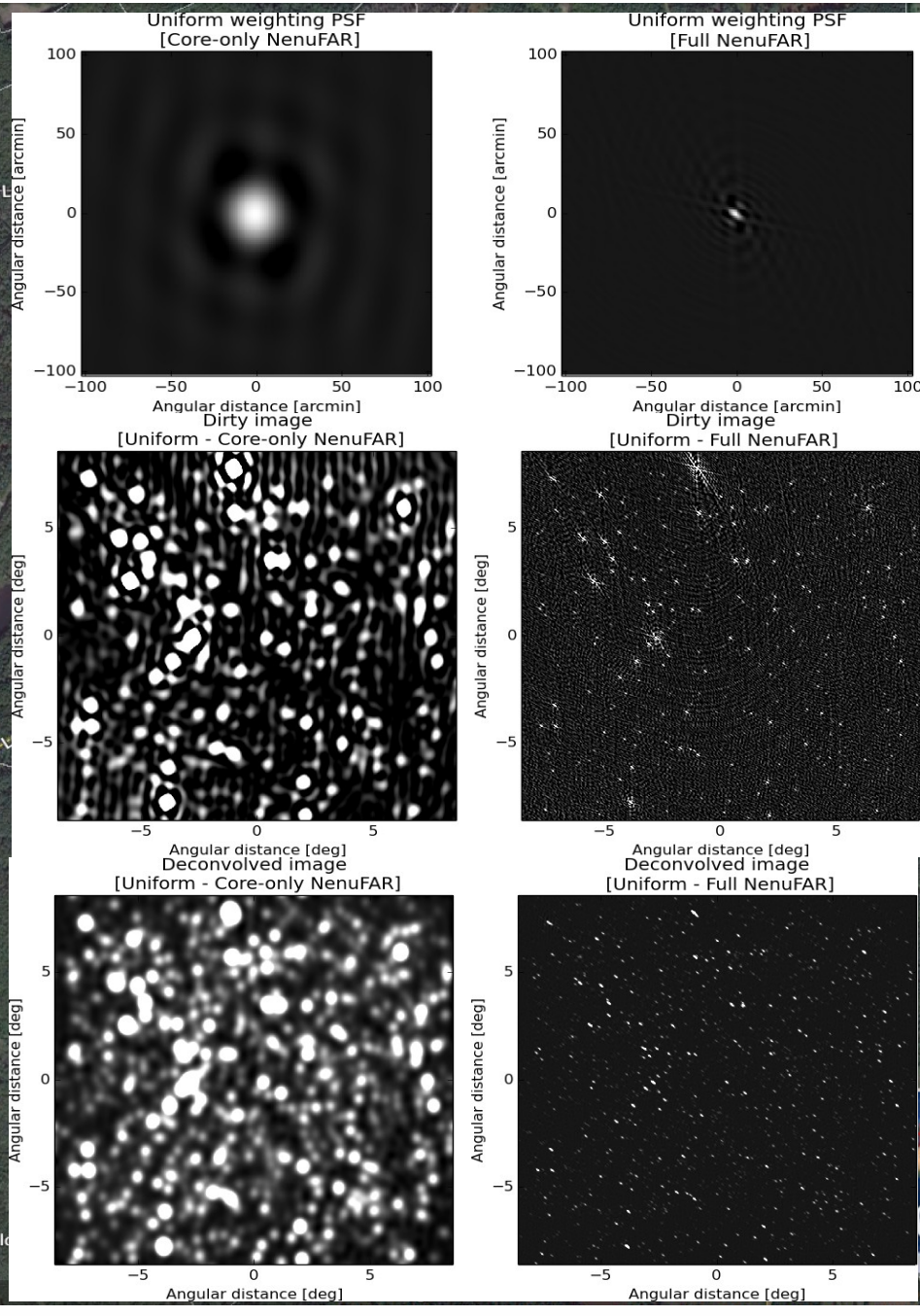
# UnDySPuTeD pulsar : LUPPI

- Input stream (300-600 MB/s) for several hours
- At low frequency, dispertion can be large (sometimes > $T_{pulsar}$)
  => large chunck of data to process (few seconds)
  - FFT size: 2M à 16M samples
  - Need to store 256 H[k] pre-computed over $10^6$ samples
  - Memory-bounded problem
  - ~25 % GPU usage => not compute-bounded
- Production-oriented HPC
  - High availability
  - Configuration tightly coupled to VCR system
  - 2-pulsar-simultaneous observations (2x75 MHz)
  - Up to 4 pulsars reobserved simultaneously (2x37.5 MHz)

# NenuFAR-Radio-Imageur

*ANR «NRI» 2017-2019*

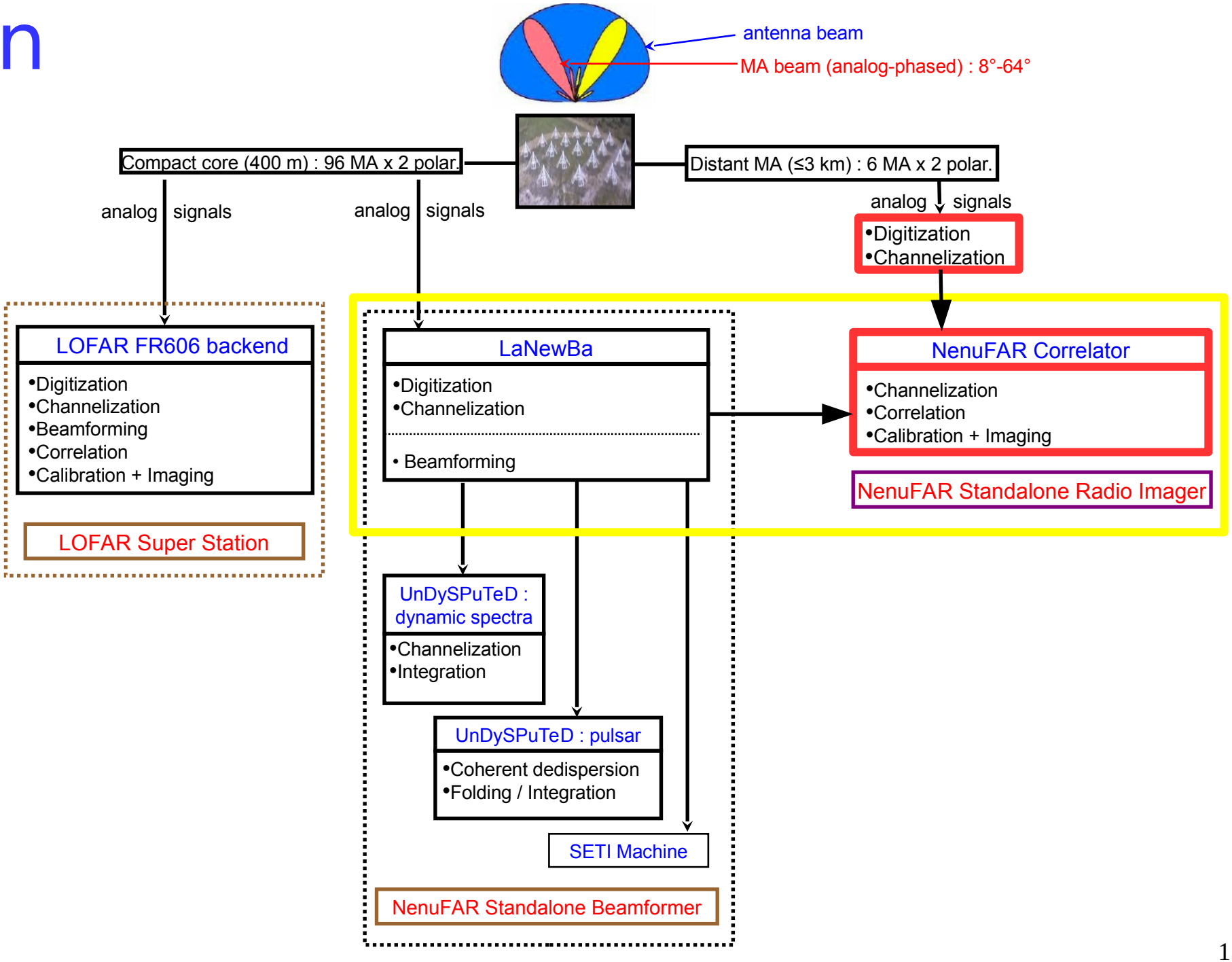


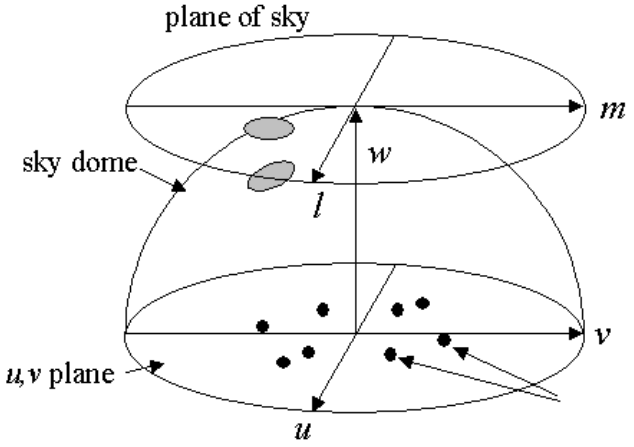
# Technological developments for NenuFAR

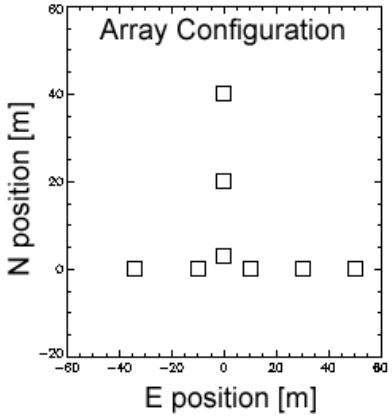


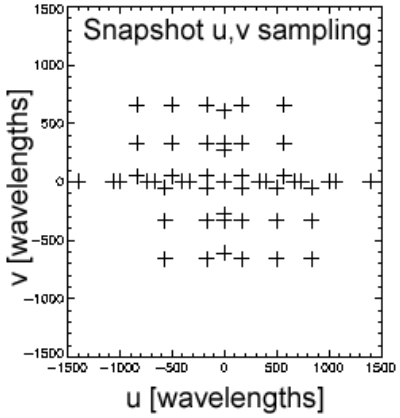
## Plan

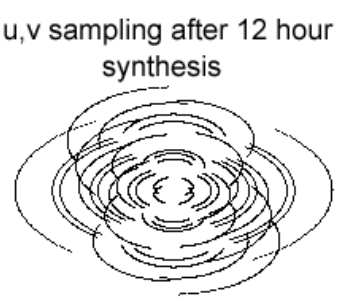


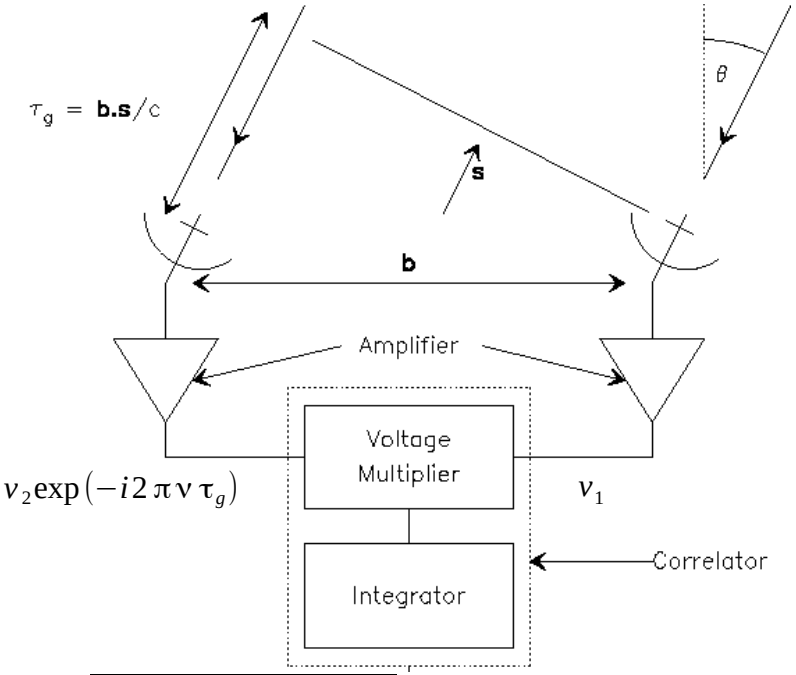
# Radio-interferometric imaging



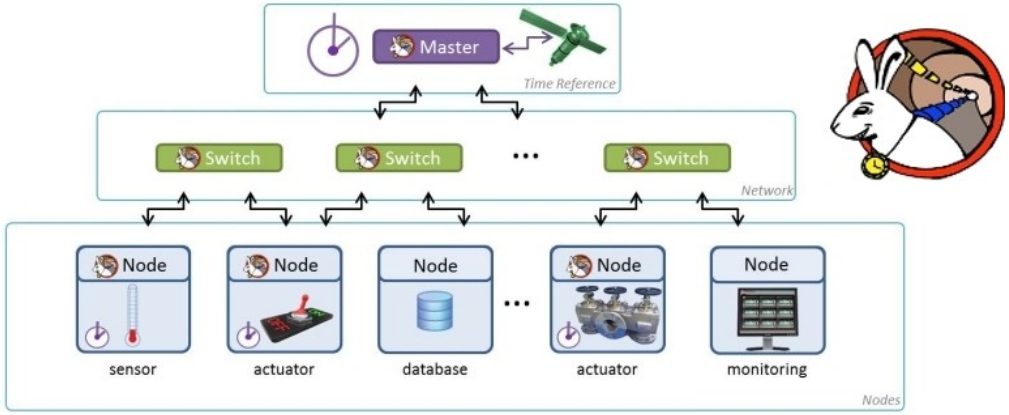




$$V = \langle v_1 \overline{v_2 \exp(-i 2\pi\nu\tau_g)} \rangle = |v_1 v_2| \exp(i 2\pi\nu\tau_g)$$

- Instrumental stability required for Distant MAs
- N feeds → N(N+1)/2 visibilities
  - 96 polarized MAs → 18528 visibilities
  - Each visibilities cost 4 $B_{Hz}$ MAC/s (or FLOPS)
  - 96 MAs within 75 MHz → 5 TFLOPS
- Signal transport is costly (several 100Gb/s)

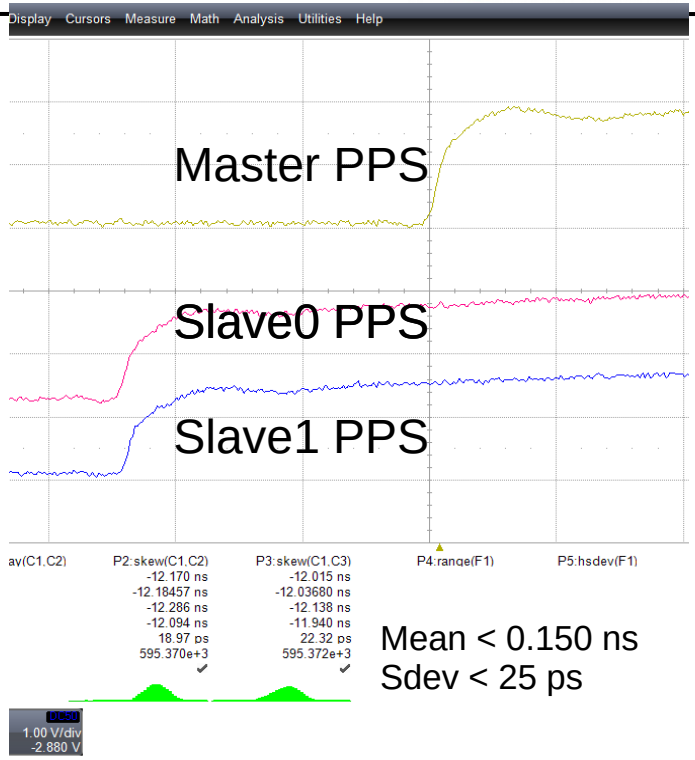
# NenuFAR-Radio-Imageur



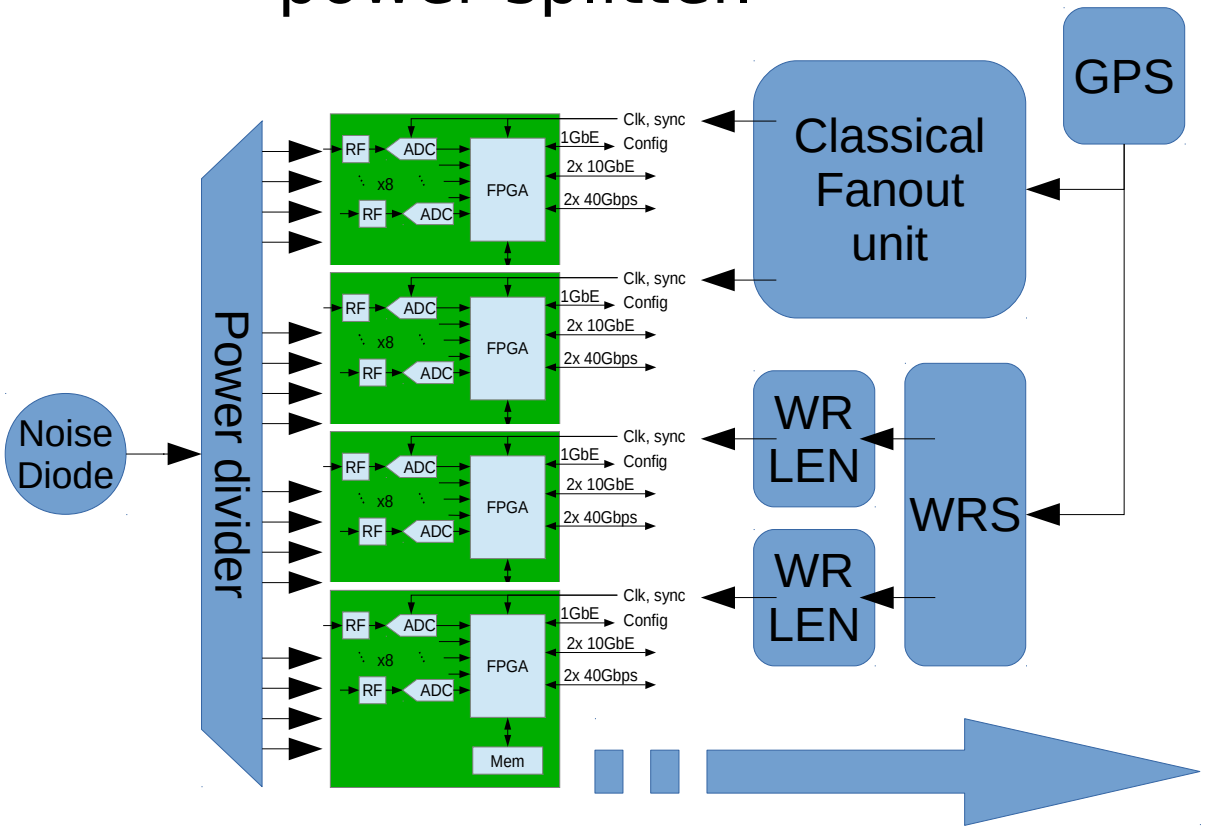

- Remote Digitization
  - WhiteRabbit network (WRS + WR-LEN)
    - Sub-ns fiber-based timing distribution (next IEEE 1588)
    - PPS and 10 MHz refclock regenerated on-site
  - 10GbE streams of beamlets towards the correlator
  - On-field constraints (cooling, RFI shielding,…)
  - One unit deployed, ready for correlation

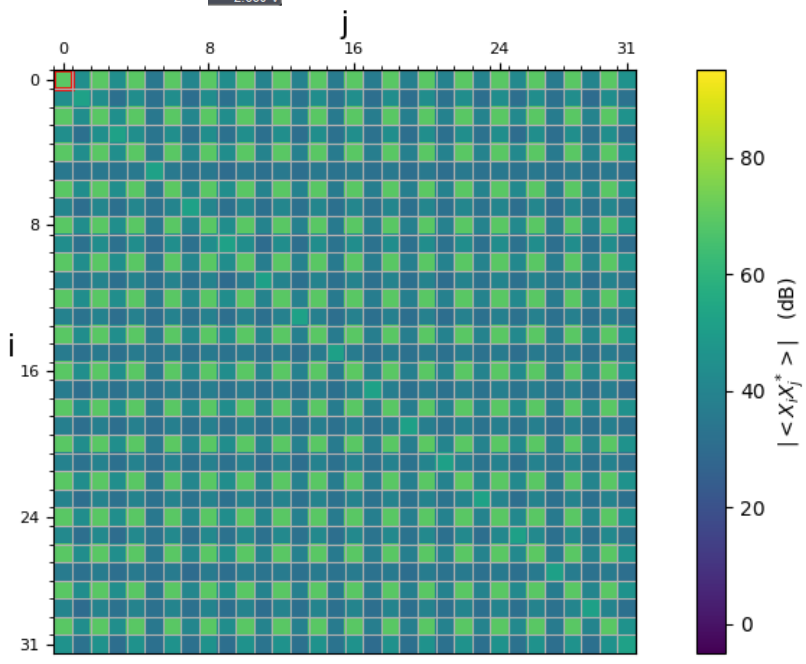
# Technological developments for NenuFAR

- Time-frequency distribution testing
  - Time domain with high speed scope
  - RadioAstronomy method
    - Correlation of a single noise diode distributed in-phase by a power splitter.




Mean < 0.150 ns
Sdev < 25 ps



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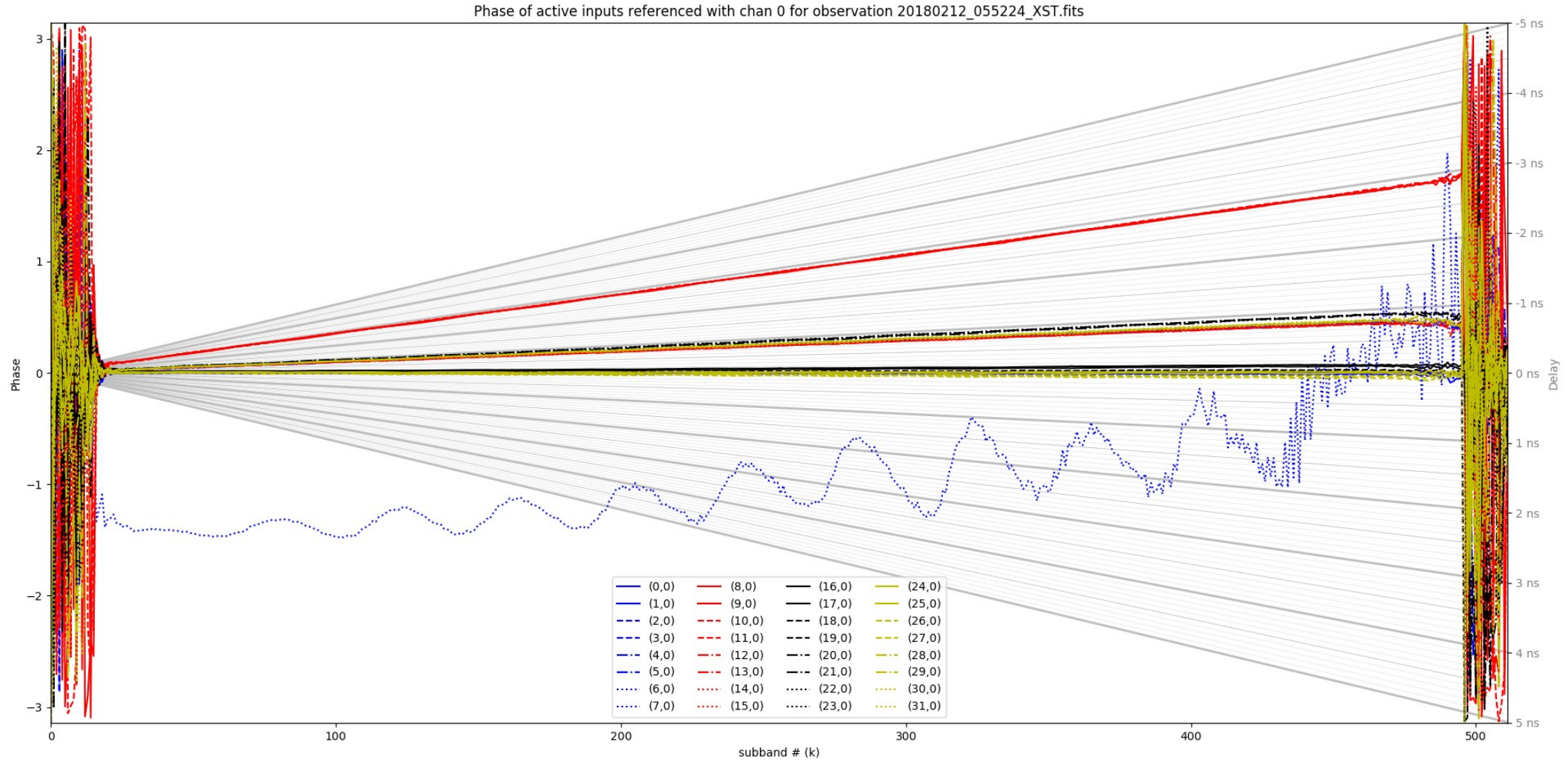

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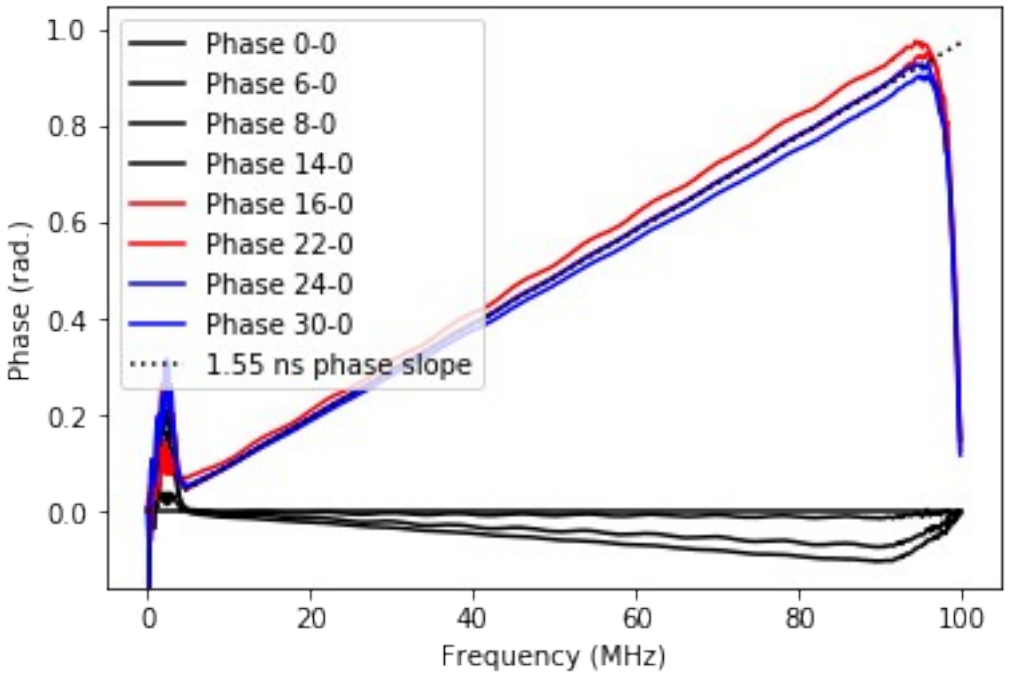


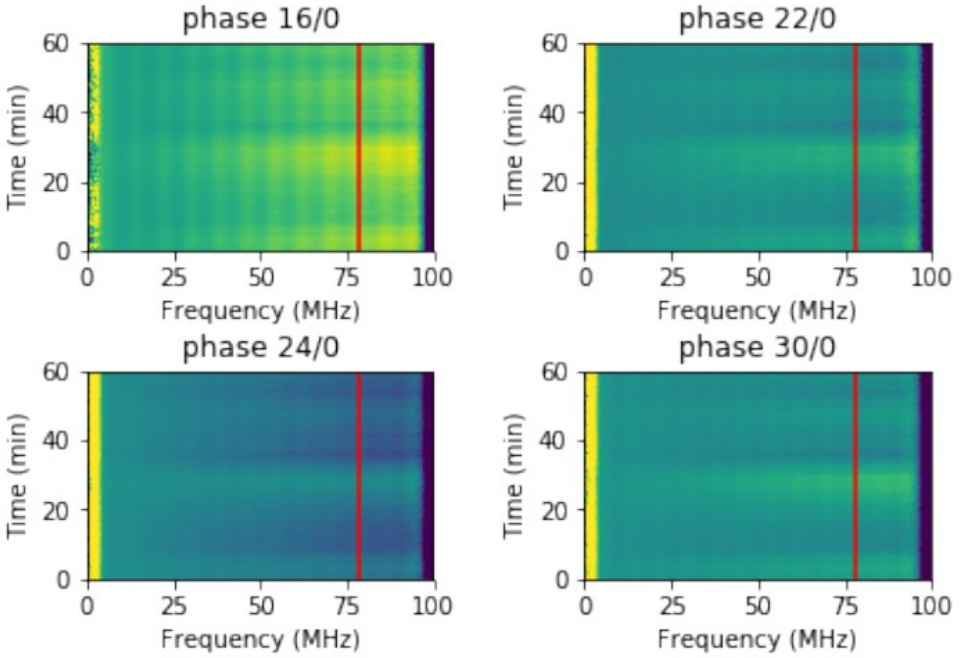


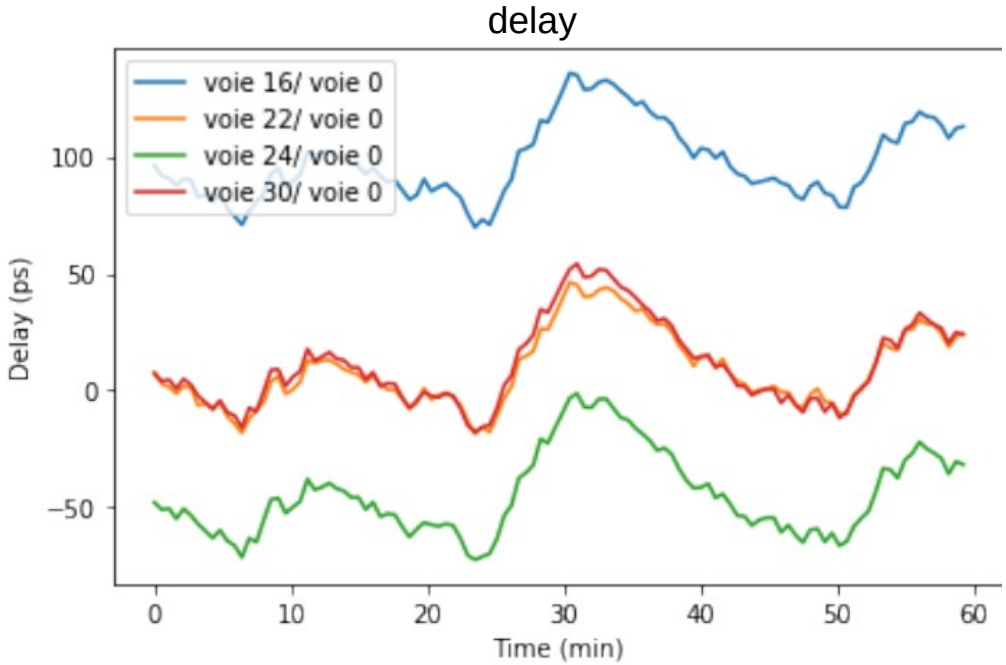


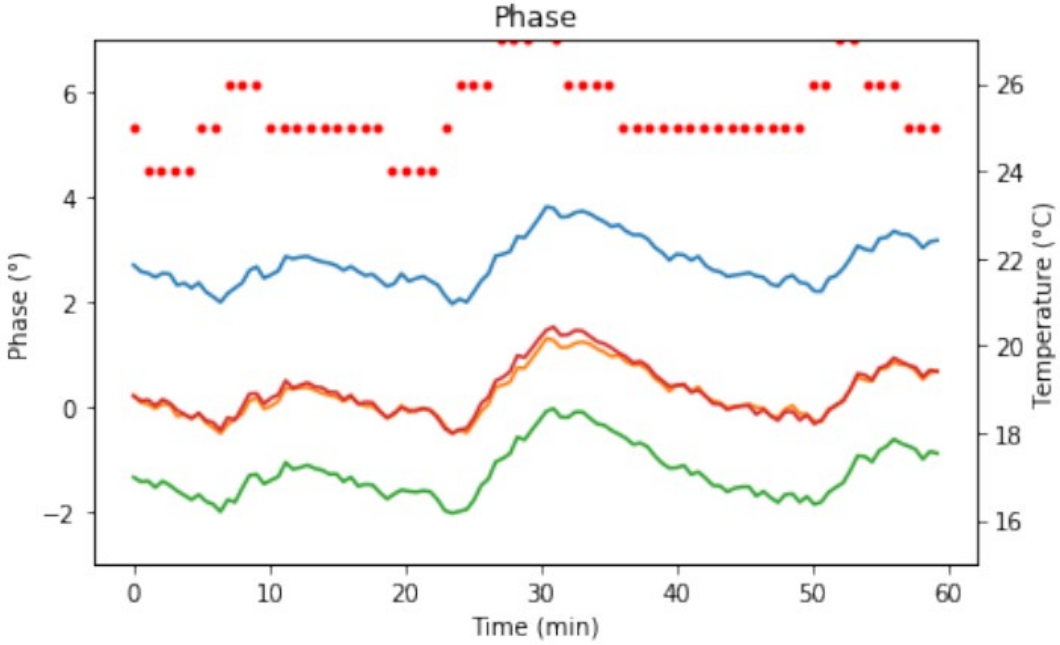

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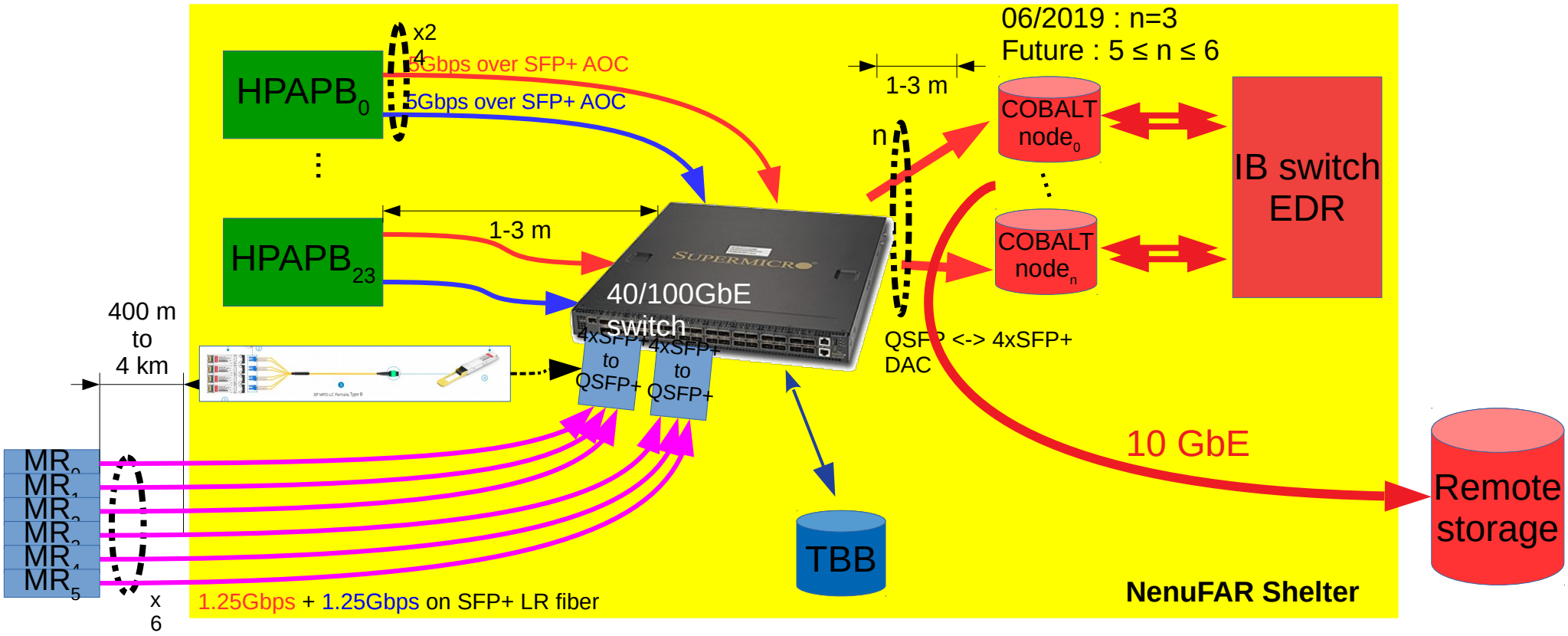


- NICKEL (**N**enuFAR **I**maging **C**ompute **K**luster **E**laborated from **L**OFAR's)
  - LOFAR COBALT2.0 based (with ASTRON support)
  - Local work to adapt correlator for NenuFAR :
    - 96 antenna fields
    - 384 subbands (75 MHz), 8 bits.
  - System configuration to be adapted for our instrument.

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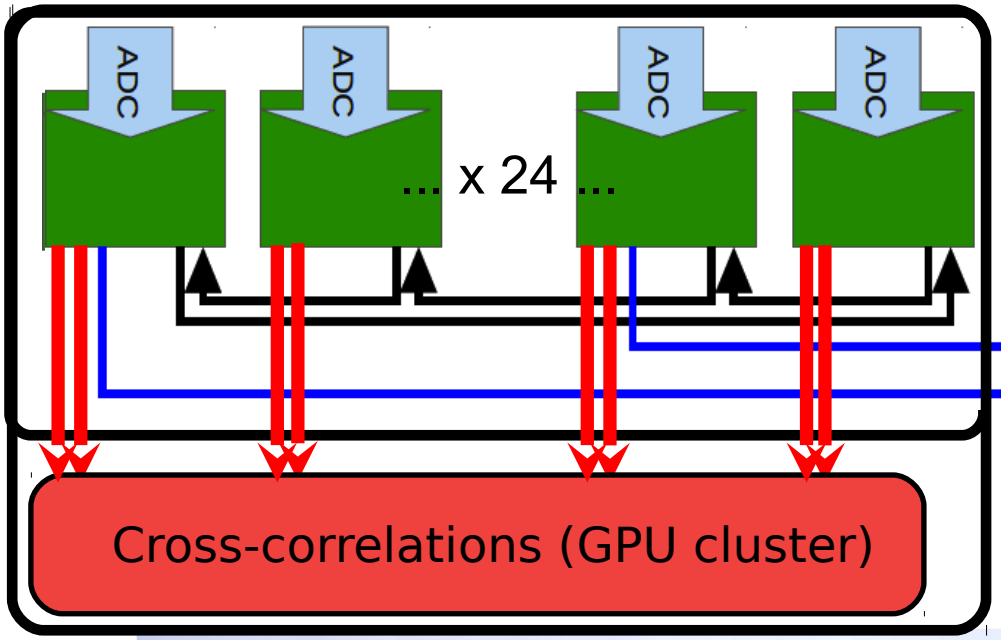


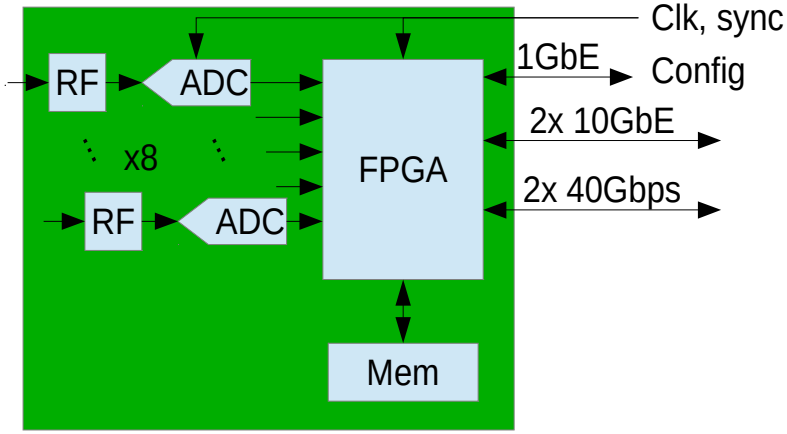


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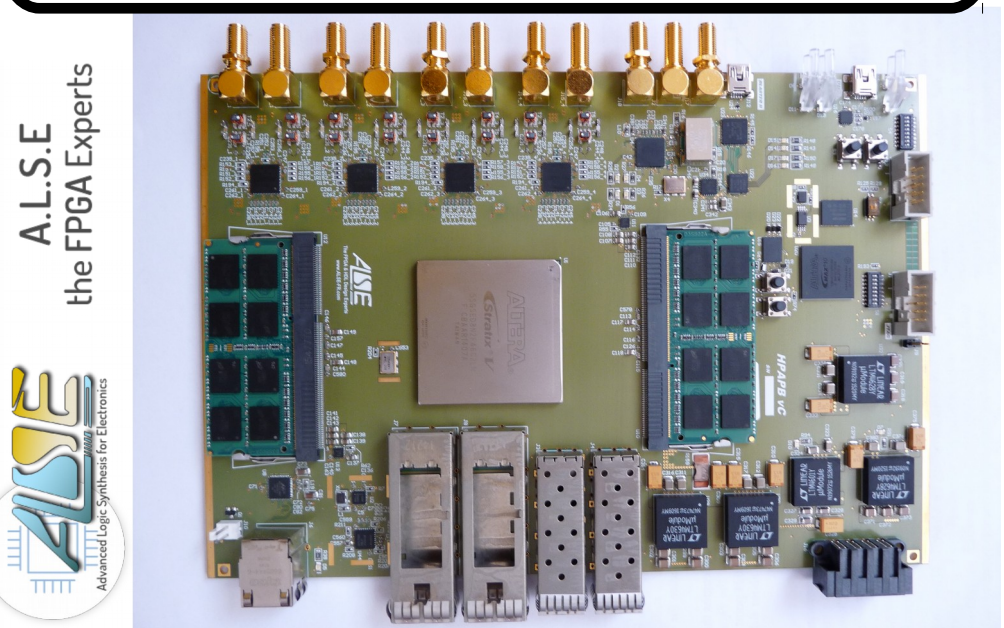


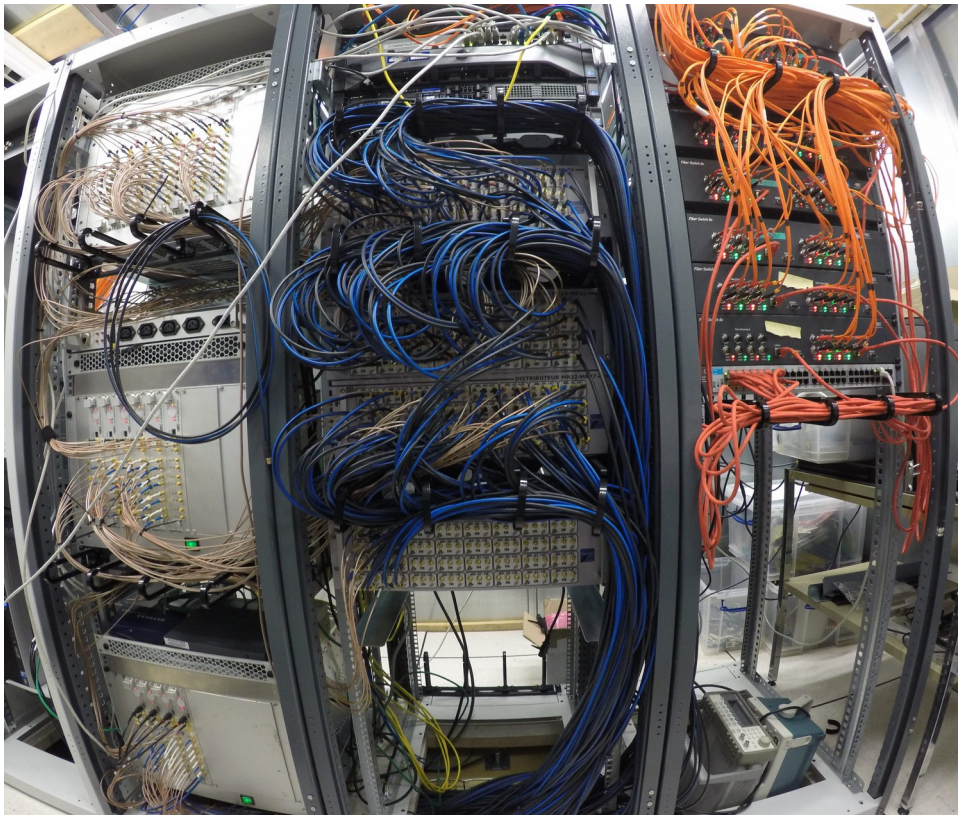

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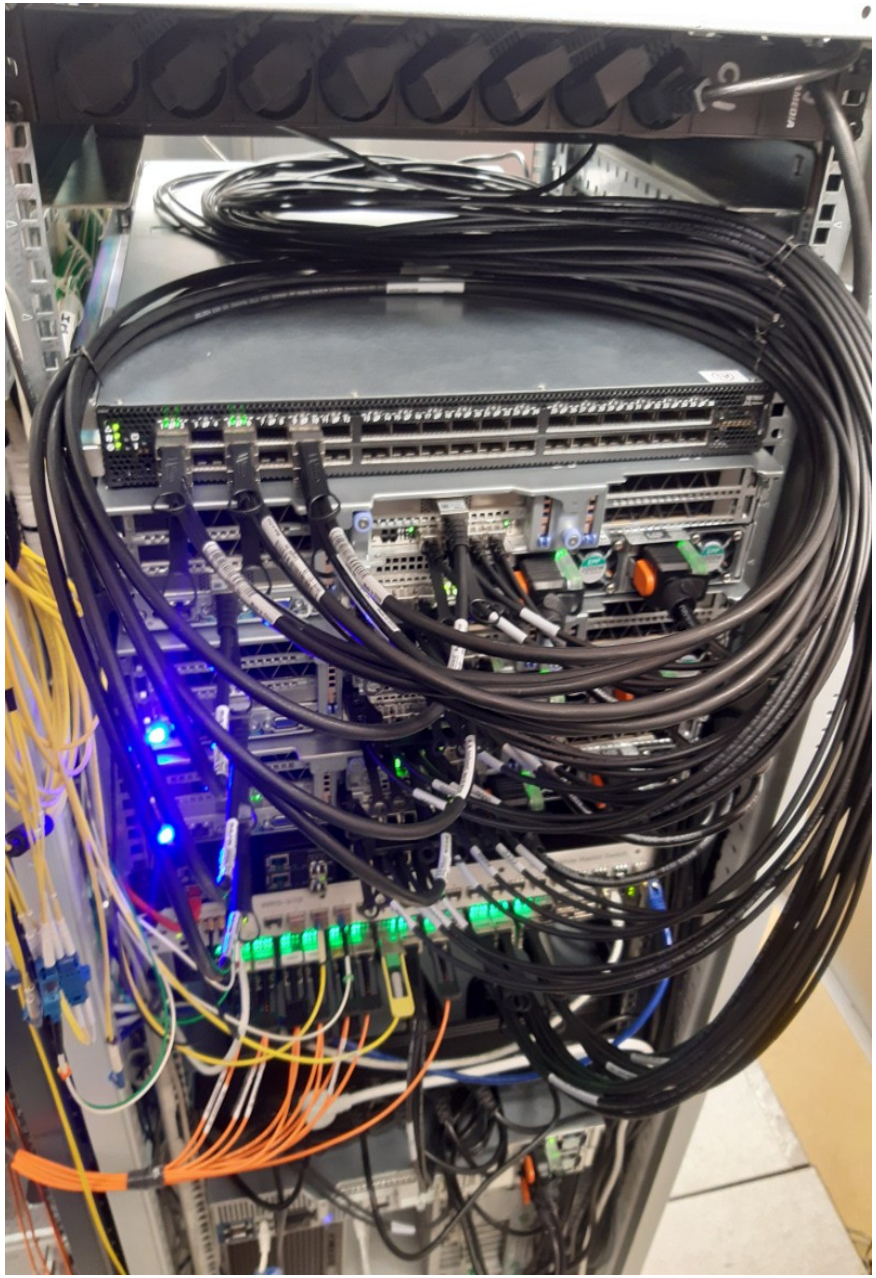
Front



Back

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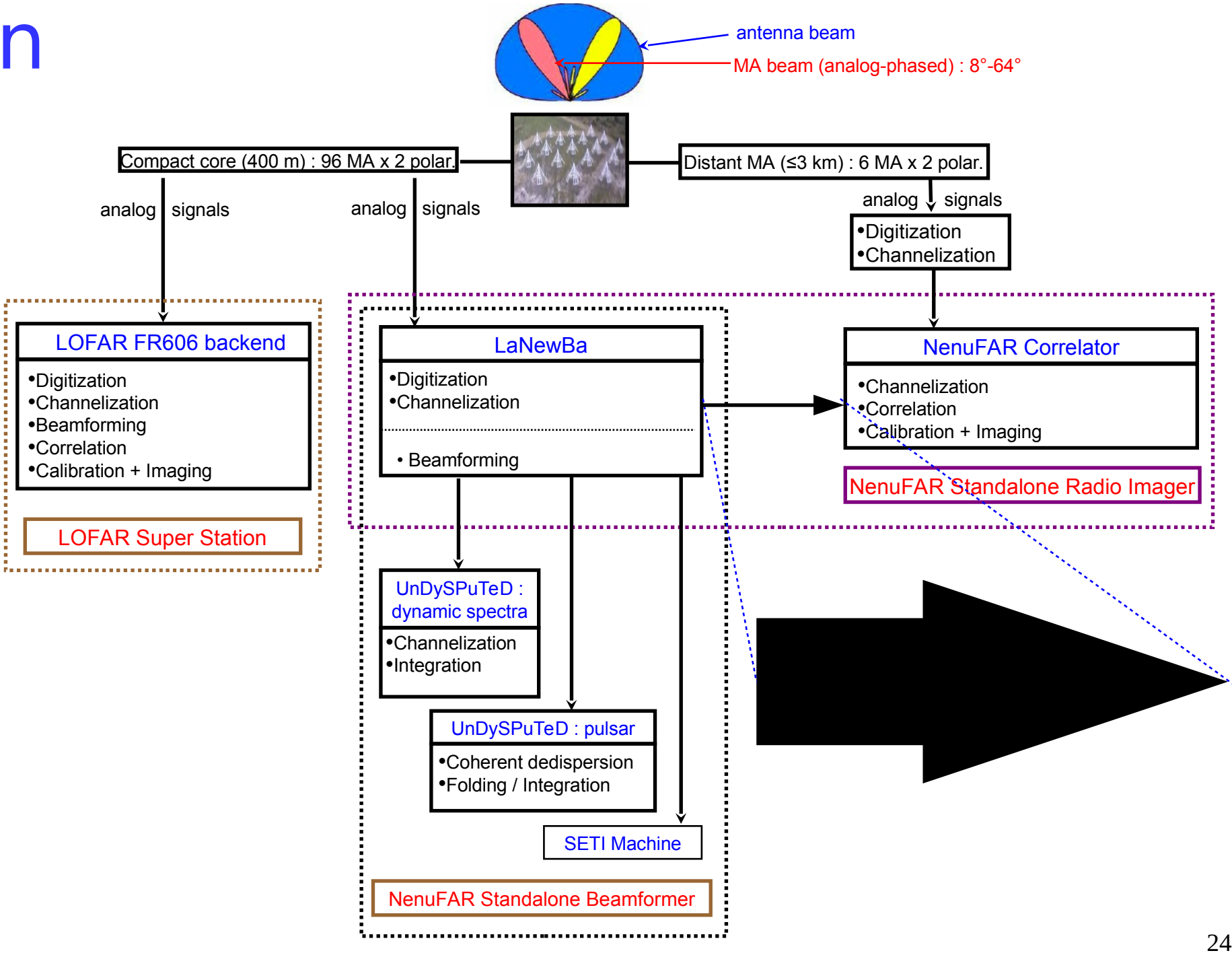
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# Questions ?