

28^{ème} journée CASCIMODOT

Jeudi 21 Juin 2018

Polytech Tours

**HPC
Temps-Réel
pour le radiotélescope
NenuFAR***

Cedric Viou

on behalf of the

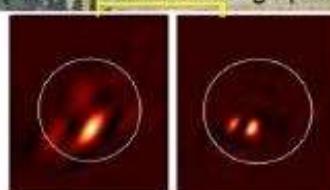
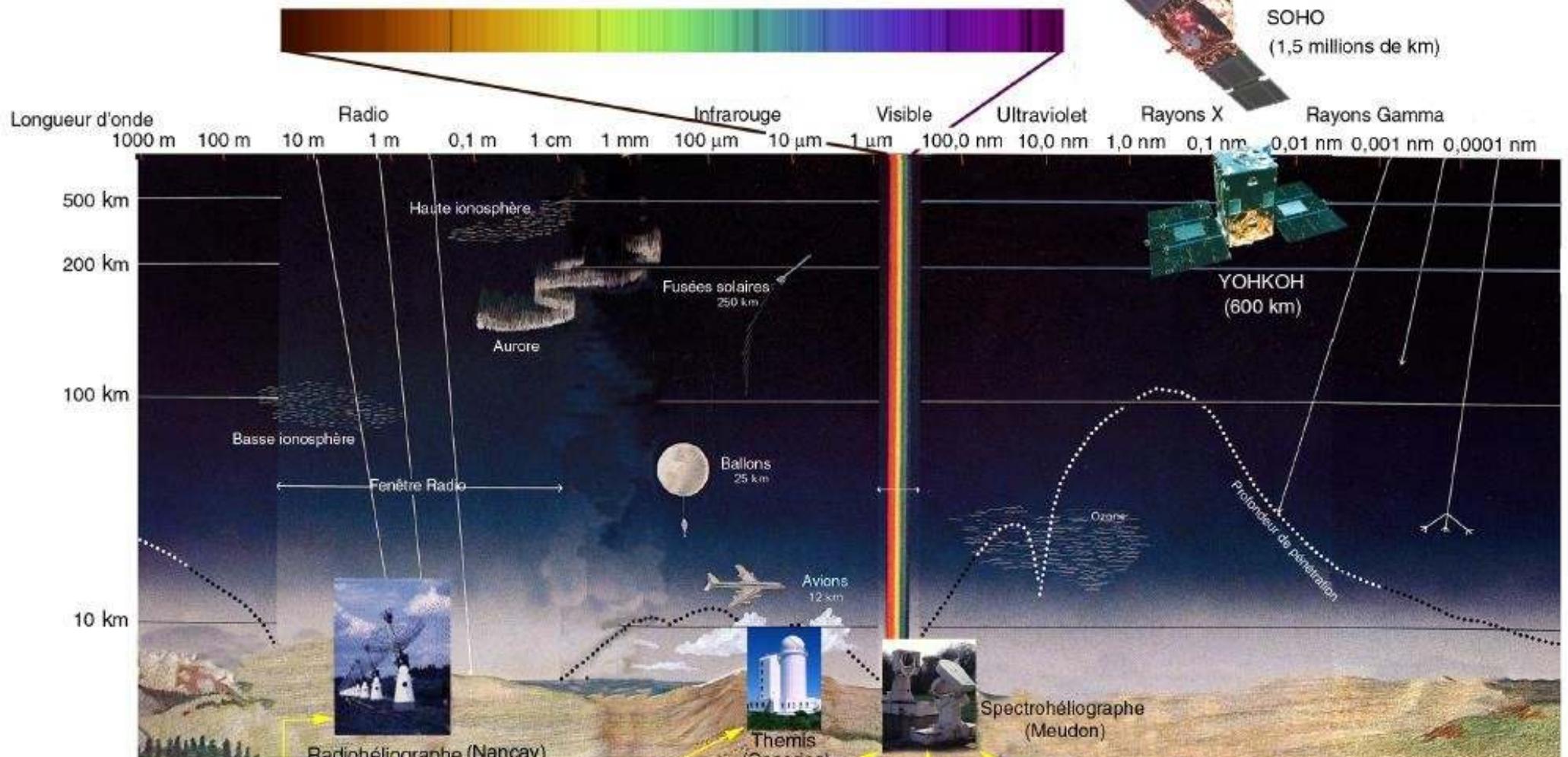
NenuFAR-France team**

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



- La radioastronomie
- Synthèse de faisceaux
- Analyse spectrale
- Dédispersion
- Imagerie par interférométrie

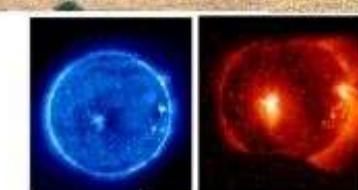
Les fenêtres de l'atmosphère



Observations radio



Observations optique (visible)



Observations ultraviolet et X par satellites

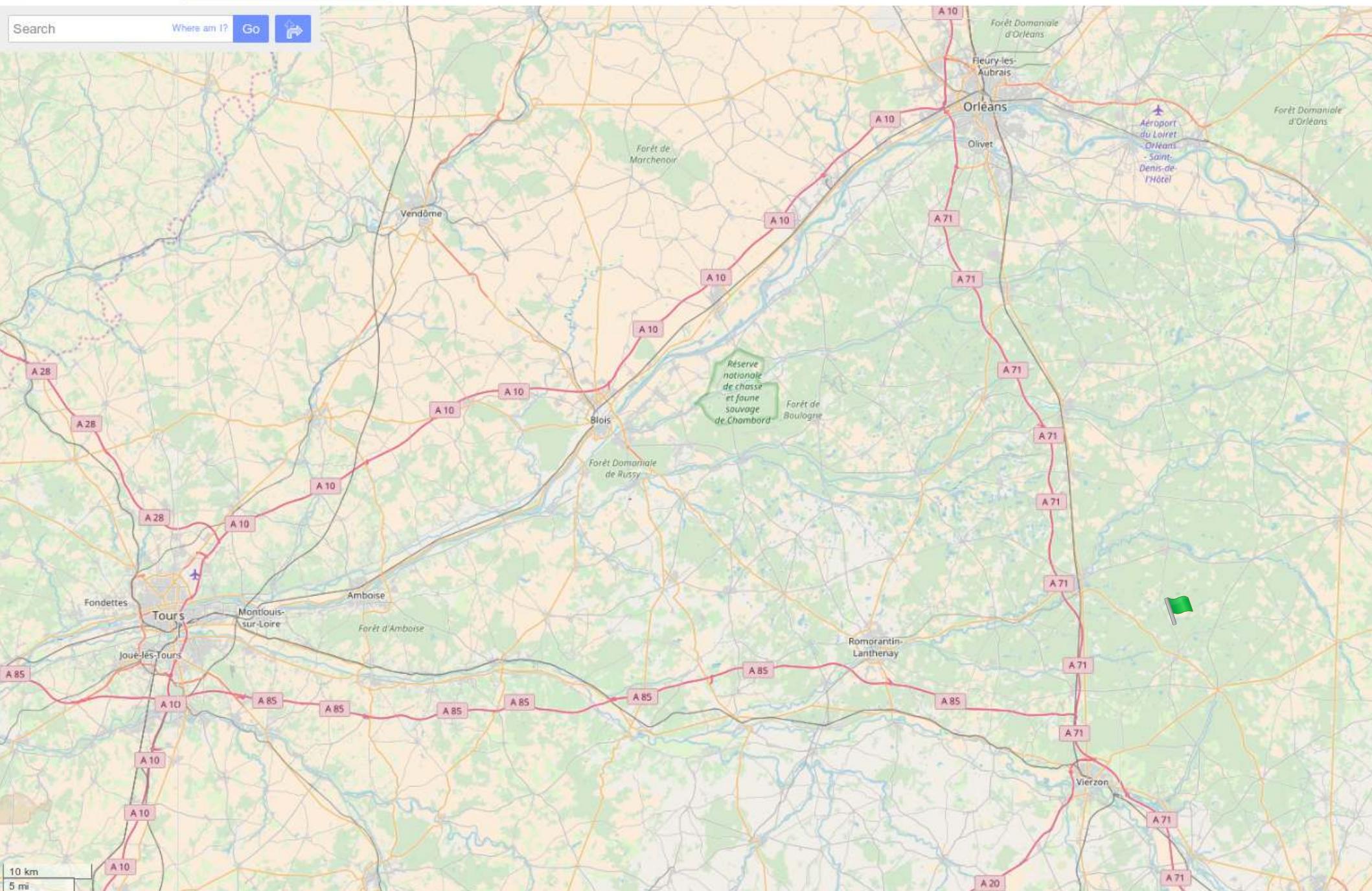
 OpenStreetMap

Edit History Export

Search

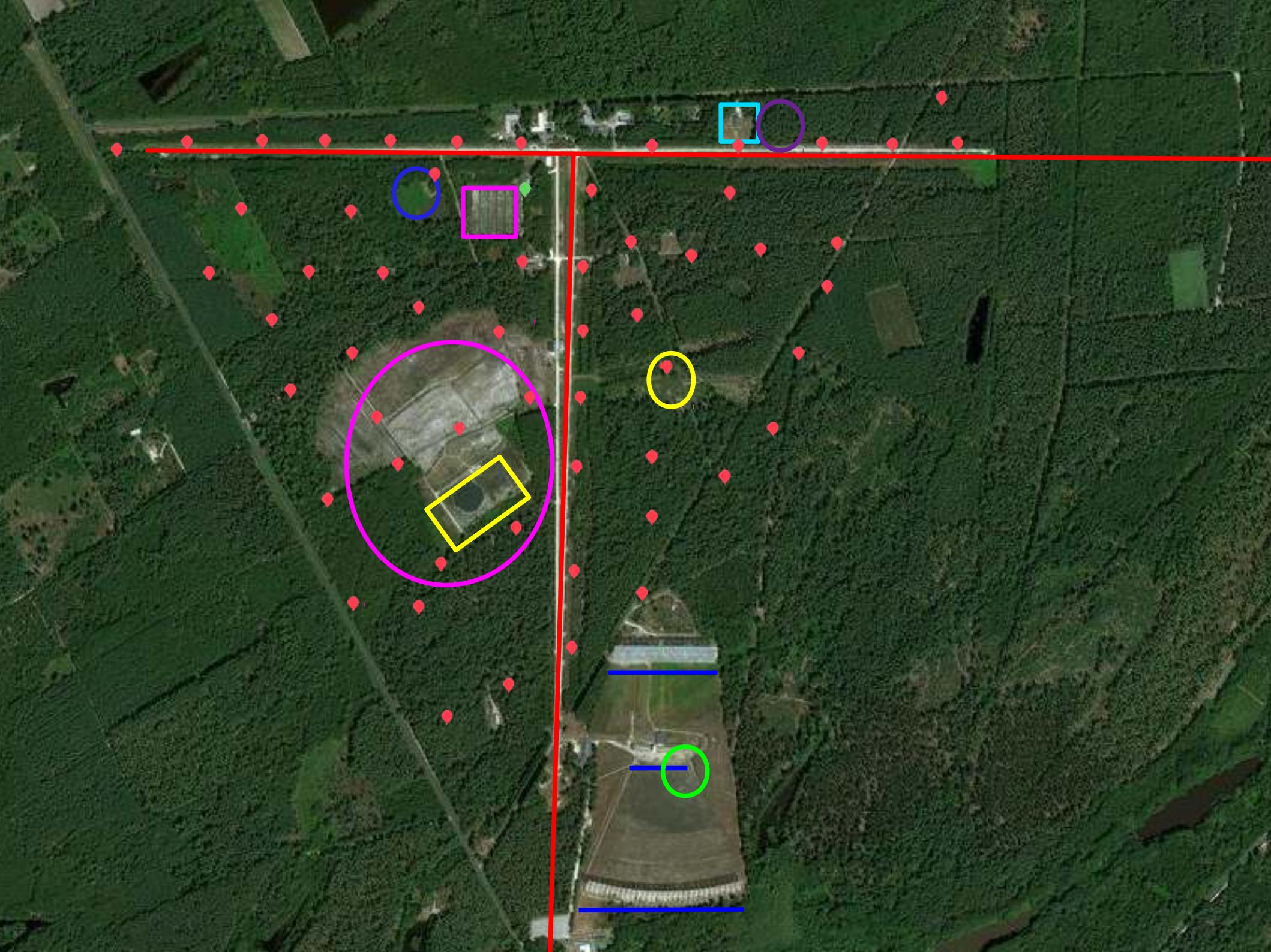
Where am I?

Go

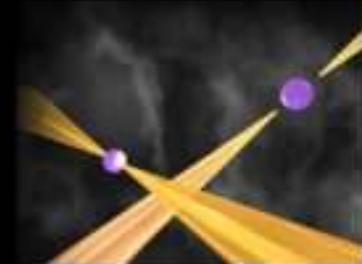


10 km

5 mi

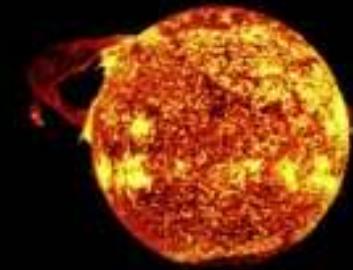


Sources observées à Nançay



10 MHz

Étoiles (dont le Soleil)
Planètes
Comètes
Pulsars
Nuages de gaz
Galaxies
Quasars
Mégamasers



100 MHz

Émission thermique (continuum)
Émission non-thermique

Raies spectrales

Rayonnement synchrotron (continuum)

Rayonnement “Bremßtrahlung” (continuum)

Absorption de raies spectrales

1 GHz

3,5 GHz

Le signal utile



Onde
électromagnétique

Domaine radio :
3 kHz à 300 GHz

Radiotélescope décimétrique de Nançay (1-3 GHz)

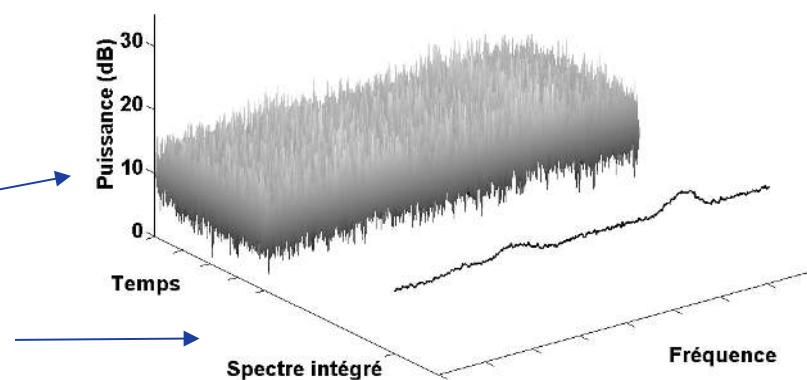


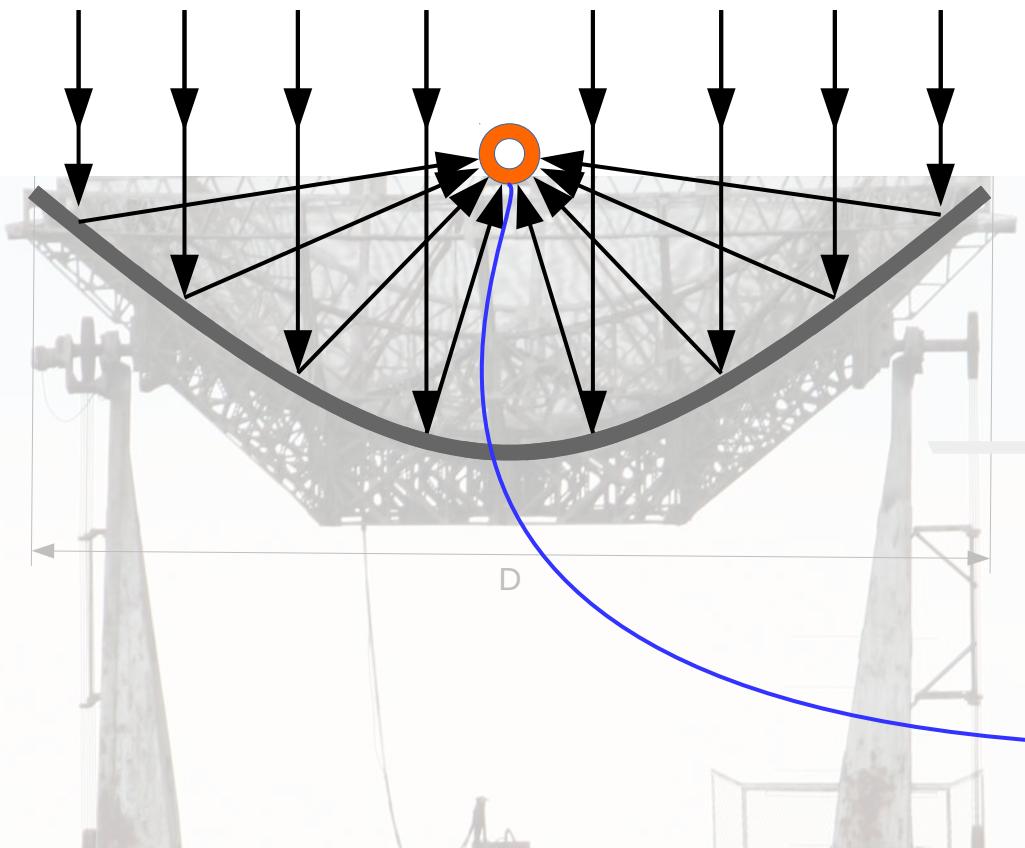
Signal observé :

$$s(t) = u_{\text{sys}}(t) + u_{\text{source}}(t)$$

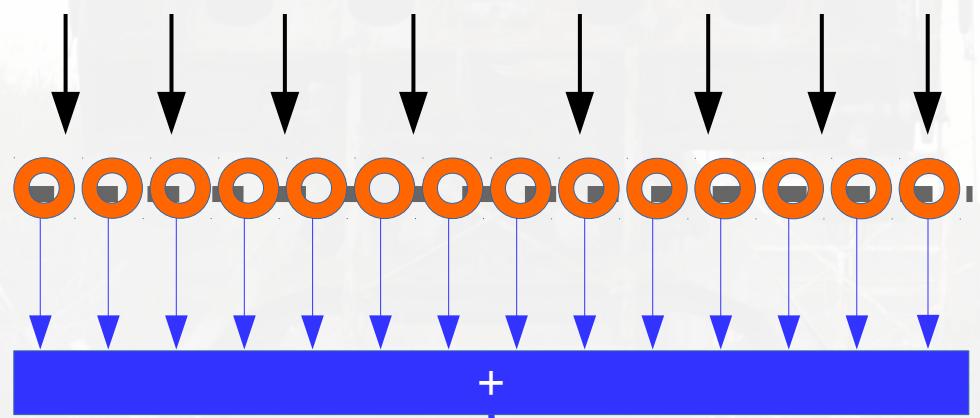
Gaussien

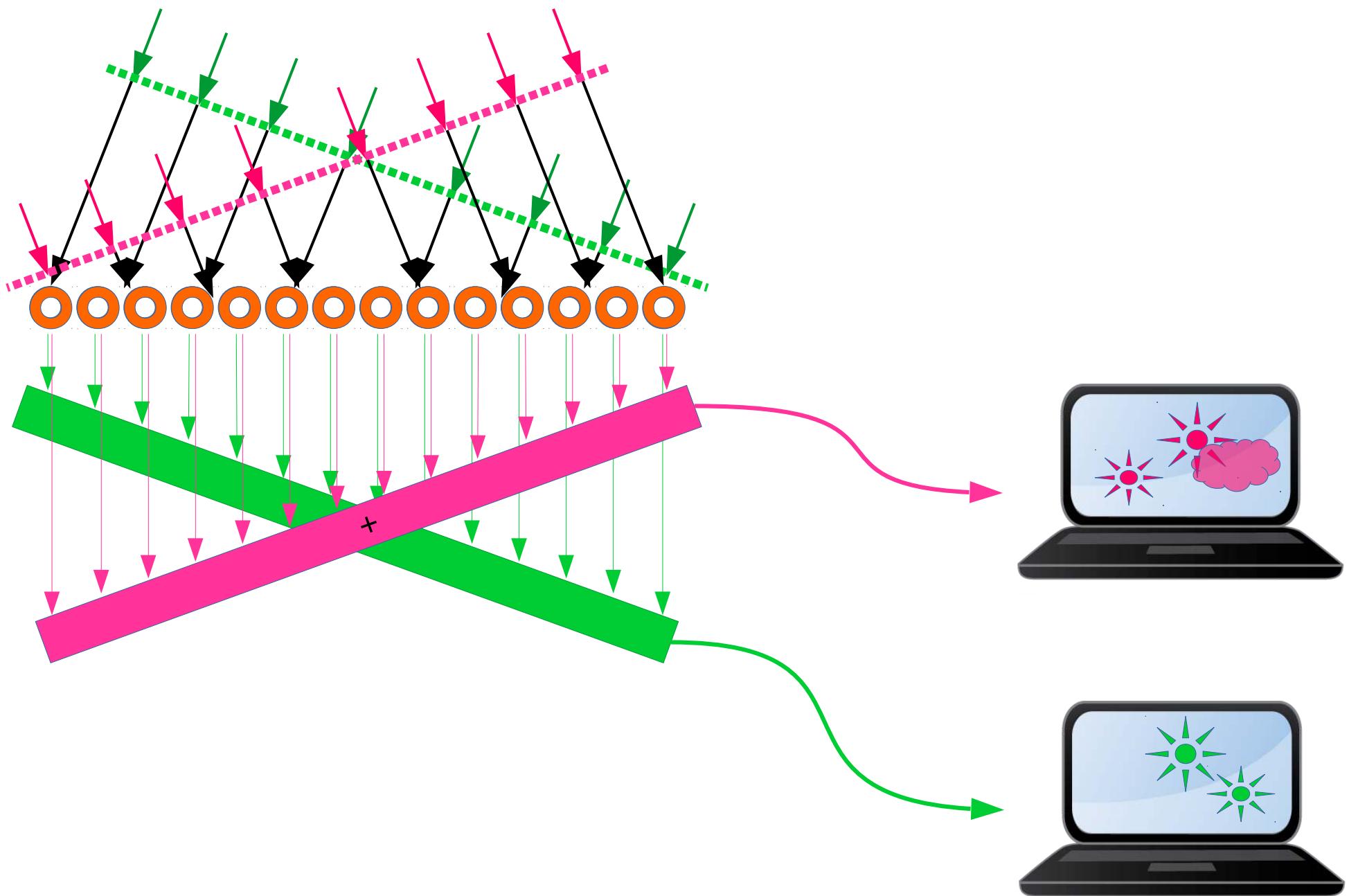
(Localement)
Stationnaire

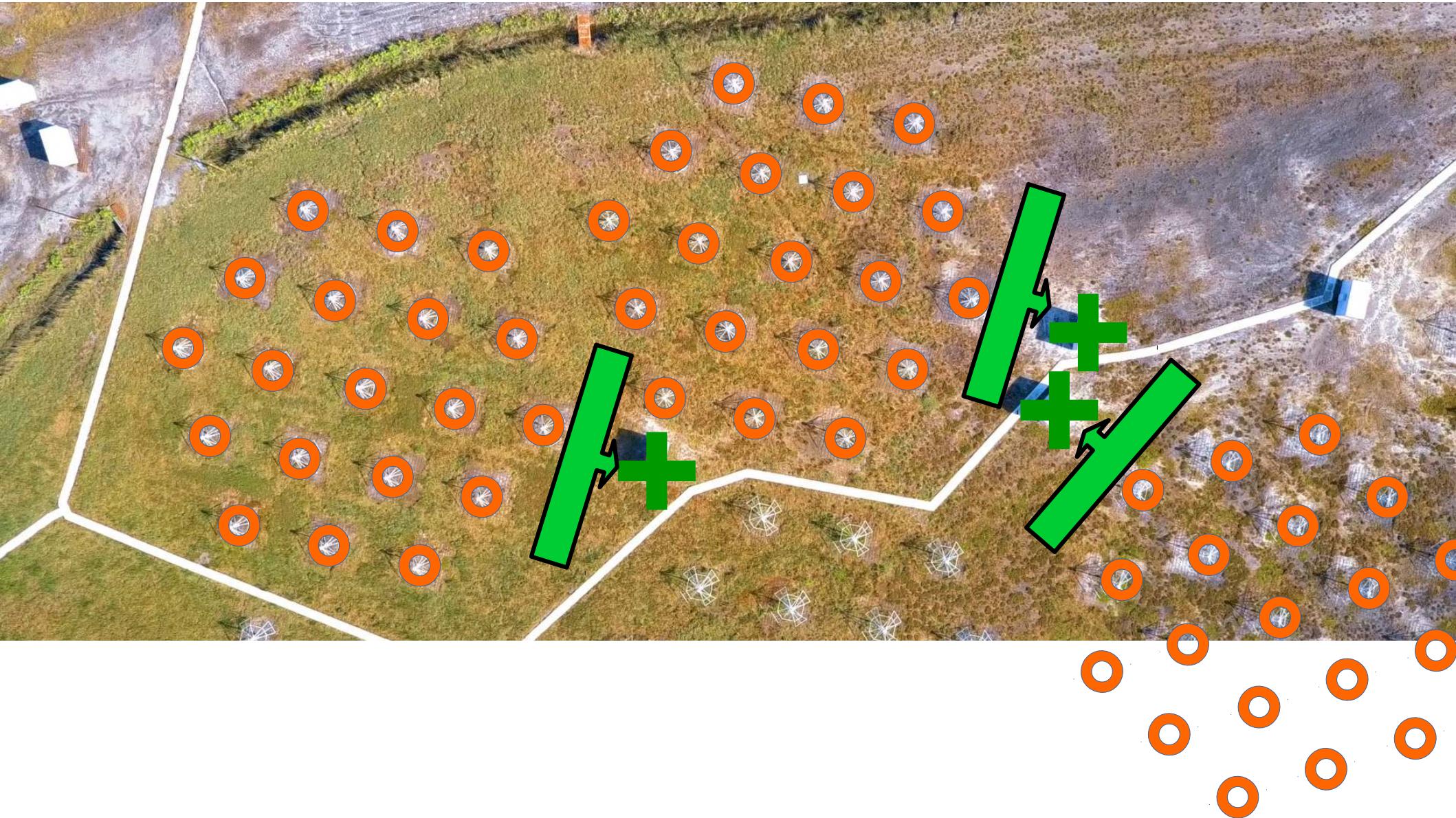




- Grande surface collectrice
→ sensibilité $\propto D^2$
- Grande extension
→ résolution spatiale $\propto \frac{\lambda}{D}$



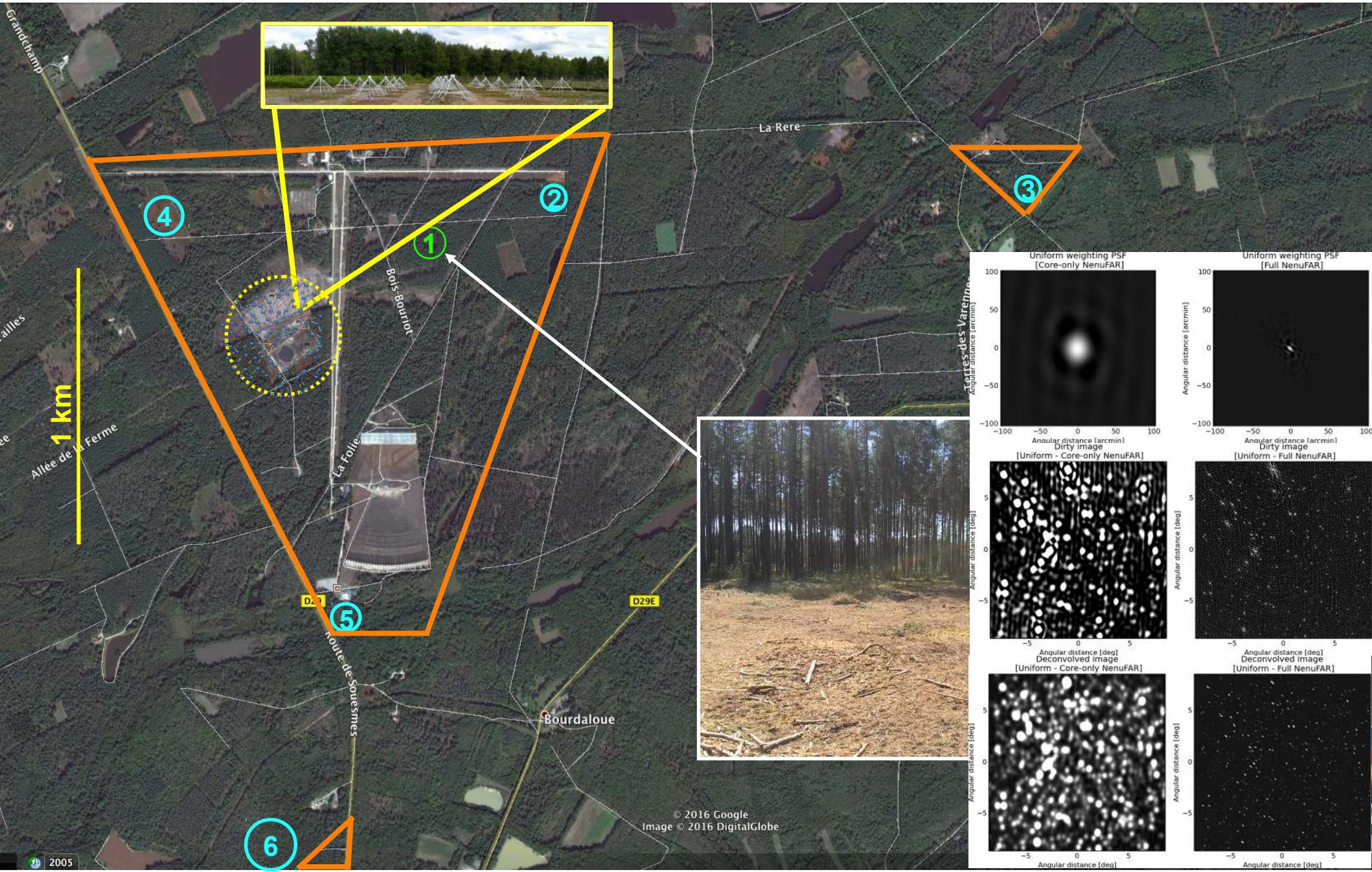






NenuFAR-Radio-Imageur

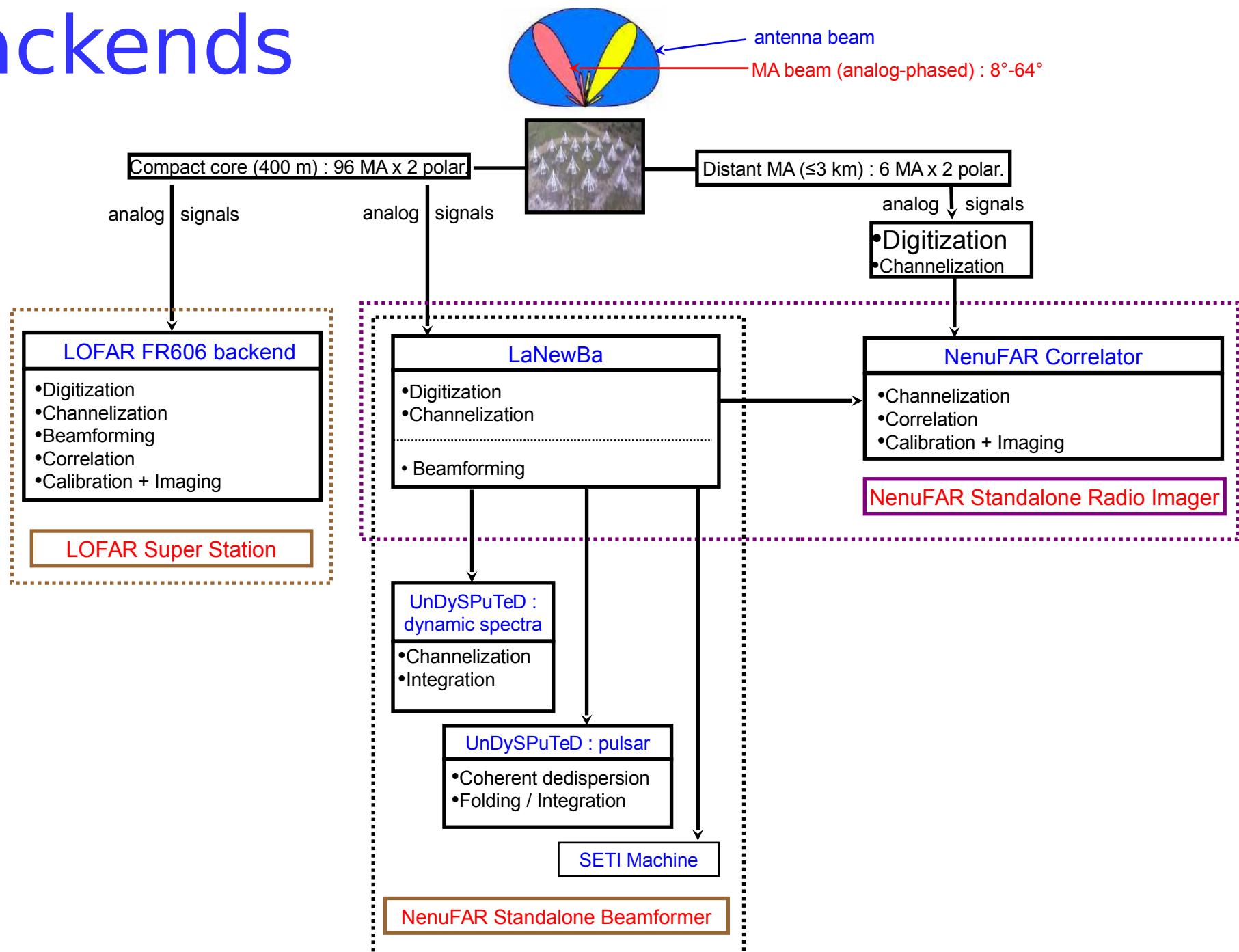
ANR «NRI» 2017-2019



On-field computing facilities

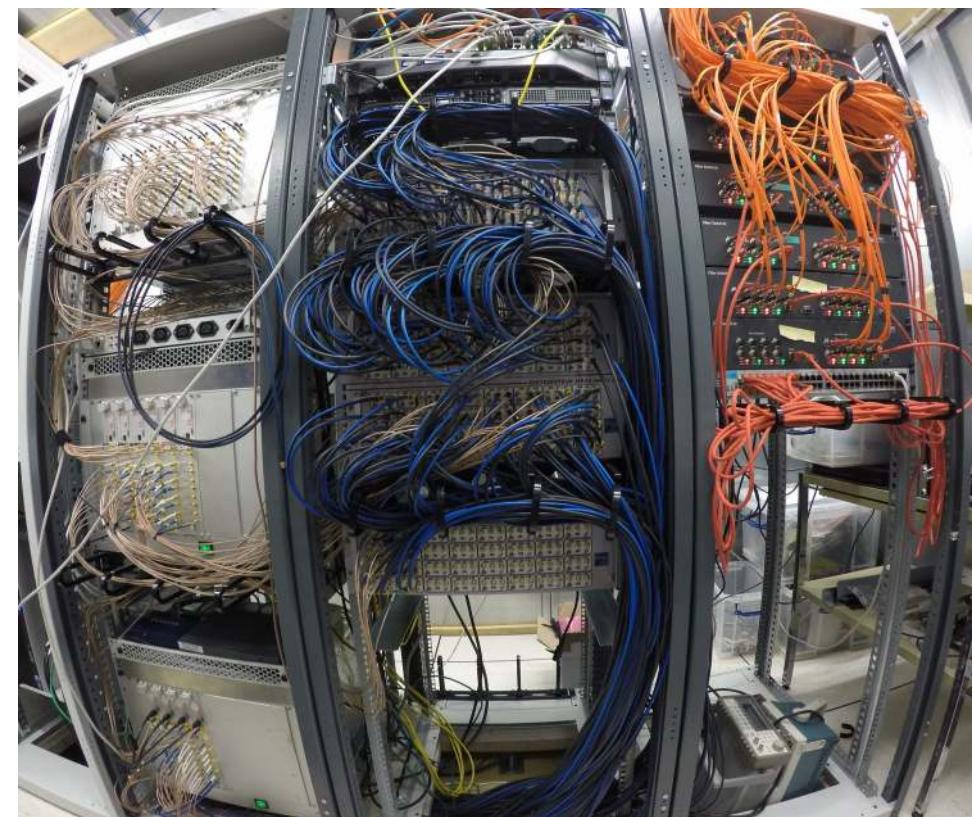
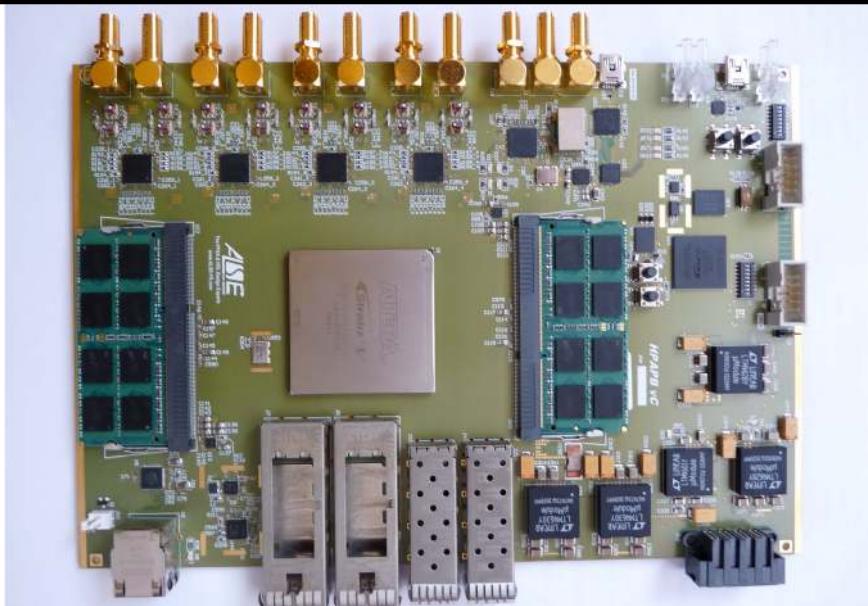
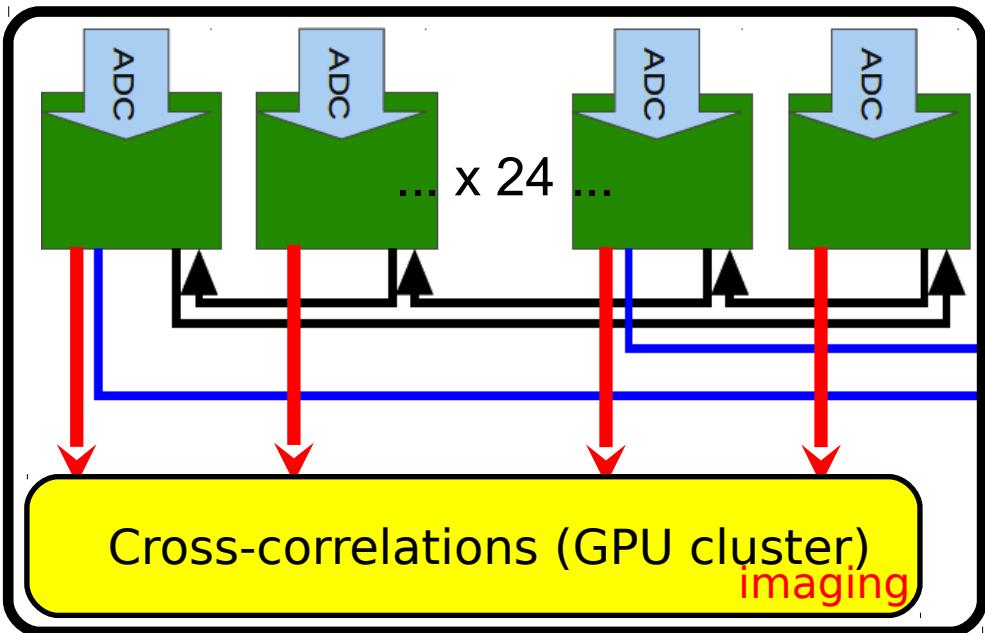


Backends

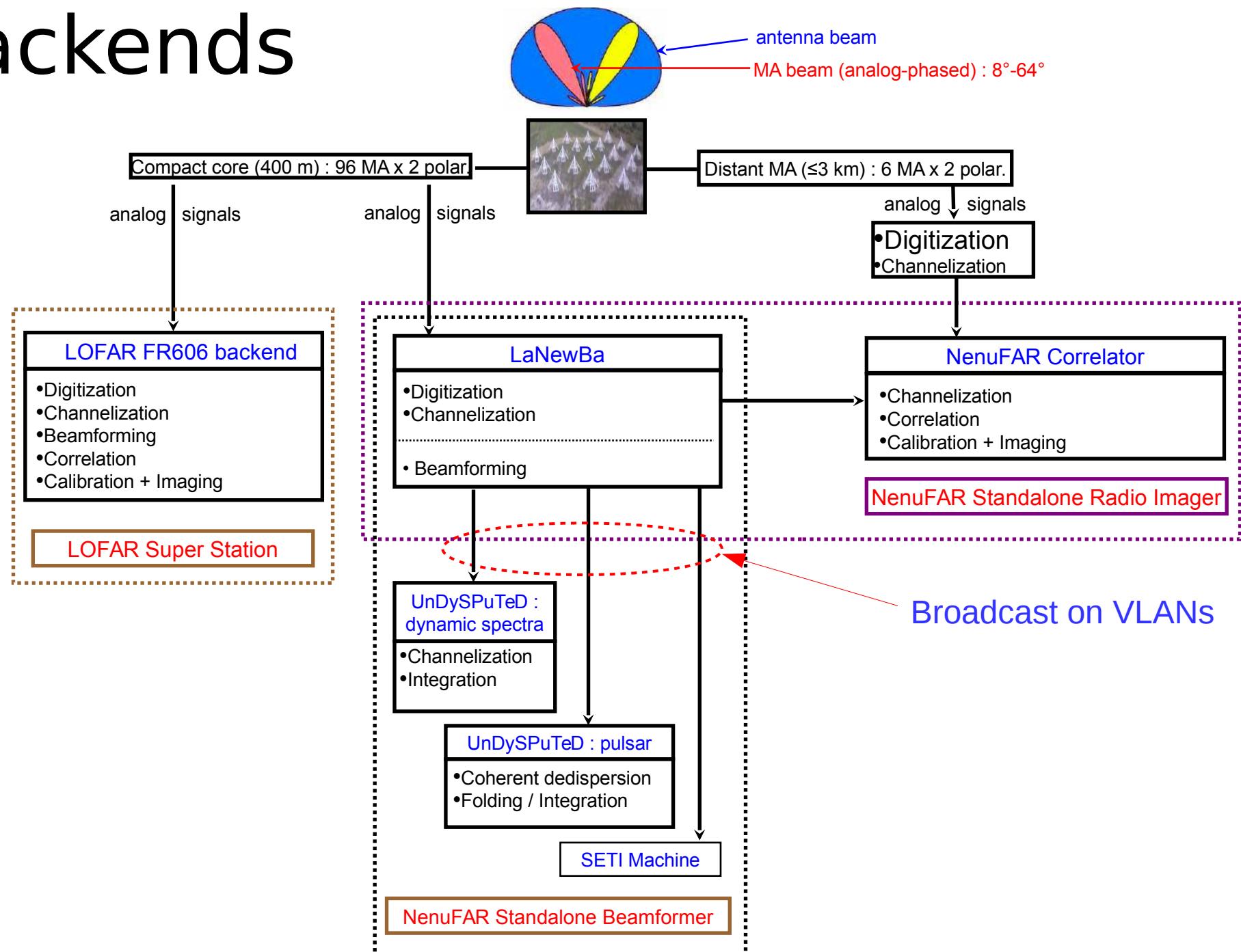


LANewBa

- Numérisation
 - $(96*2) \times 200$ MEch/s - 14 bits ADCs (~ 400 Mo/s/chan)
 - 45 Go/s aujourd'hui, 77 Go/s pour l'instrument complet, 24/7
 - Synchronisation meilleure que 0.1 ns
- Traitement du signal implémenté en FPGA (1.3 TMAC distribués sur 24 cartes de calcul)
 - 512 x 0.195 kHz subbands : 16-taps PFB + 1k-FFT (614+192 GMAC/s)
 - Formation de faisceau
 - Sélection des sous-bandes à phaser
 - Phasage par rotation de phase
 - Sommation dans un anneau (14 Gb/s, 58 GMAC/s)
 - Export par 10GbE (2x 4.8 Gb/s)
 - Mesure de déphasage par corrélation (calibration)
 - Échange de données dans un l'anneau (18 Gb/s)
 - MAC au sein de chaque cartes (90 Mo/s x 2.2 Go/s)
 - 461 GMAC/s
 - Calcul de statistiques sur les flux haut-débits
- 1 baie, 1500 W



Backends

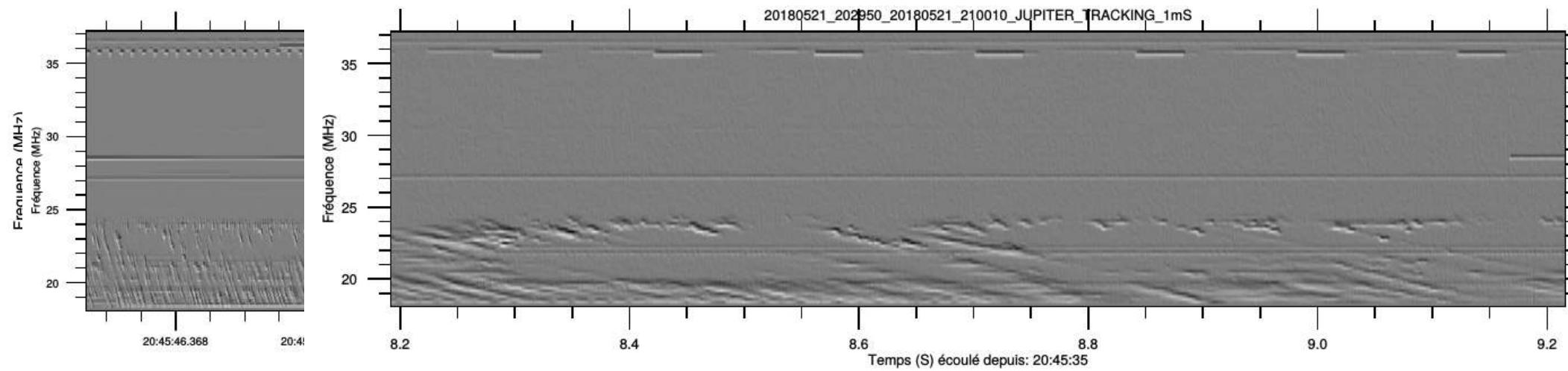
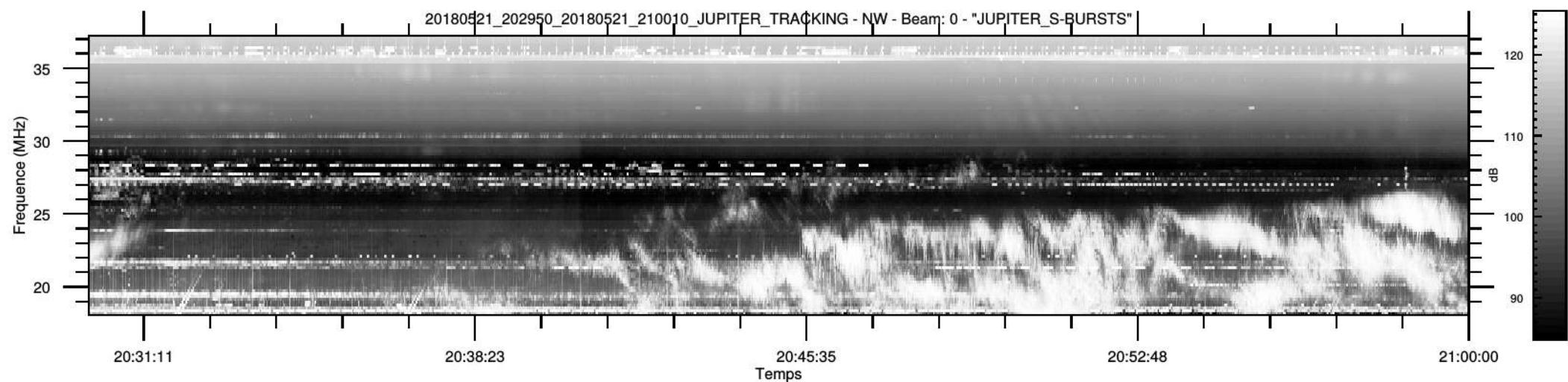




UnDySPuTeD

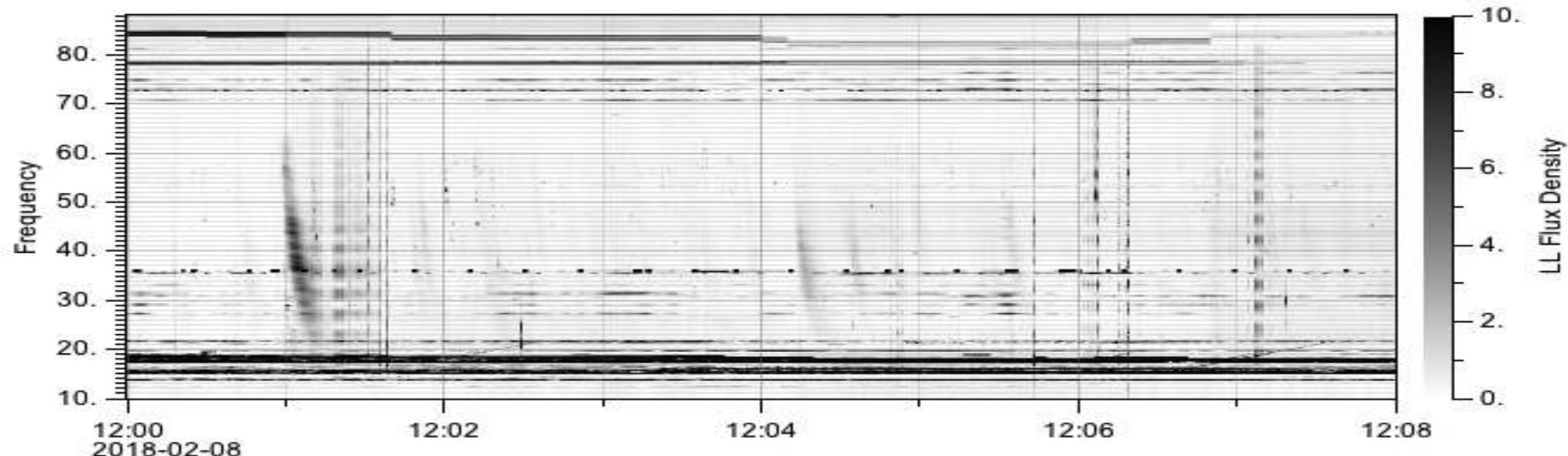
- Beamlets broadcasted to multiple listeners on VLANs
- 2x Serveurs :
 - 2x Intel Xeon E5-2620v4 8cores
 - 32GB DDR4
 - 2x GPU Nvidia GTX 1080
- Dynamic Spectra (under construction)
 - Traitera 1 à 2 flux de 4.8 Gb/s, $B=195$ kHz, $dt = 5.12 \mu\text{s}$
 - FFT + $\langle |x_i \cdot x_j|^2 \rangle$ pour produire les 4 Stokes, en continu, en temps réel
 - $B_{\min} = 762$ Hz, $dt_{\min} = 1$ ms
 - $B_{\max} = 195$ kHz, $dt_{\max} = 1$ s
 - Flux à traiter : 300-600 Mo/s (int8-int16) → 1.2 Go/s (float32)
 - Calcul FFT : ~ 2 GFLOPS

Commissioning, Calibration

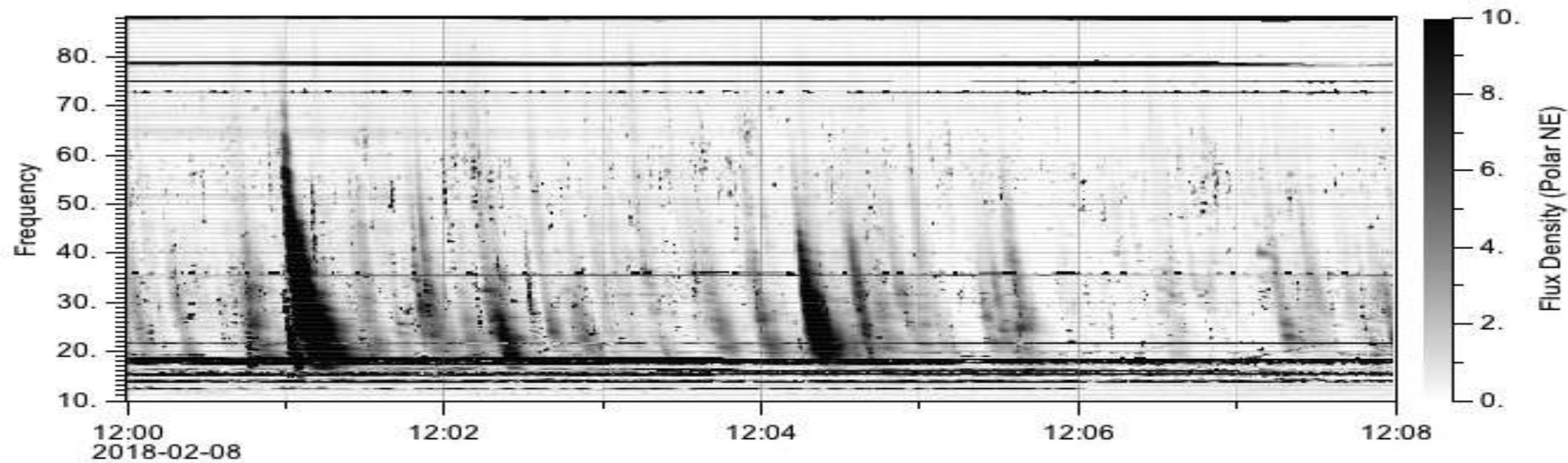


Commissioning, Calibration

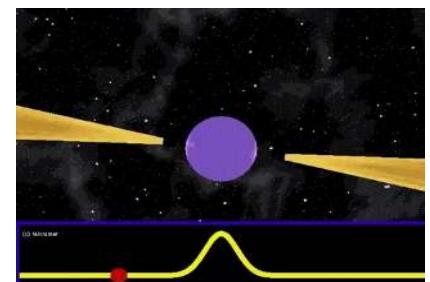
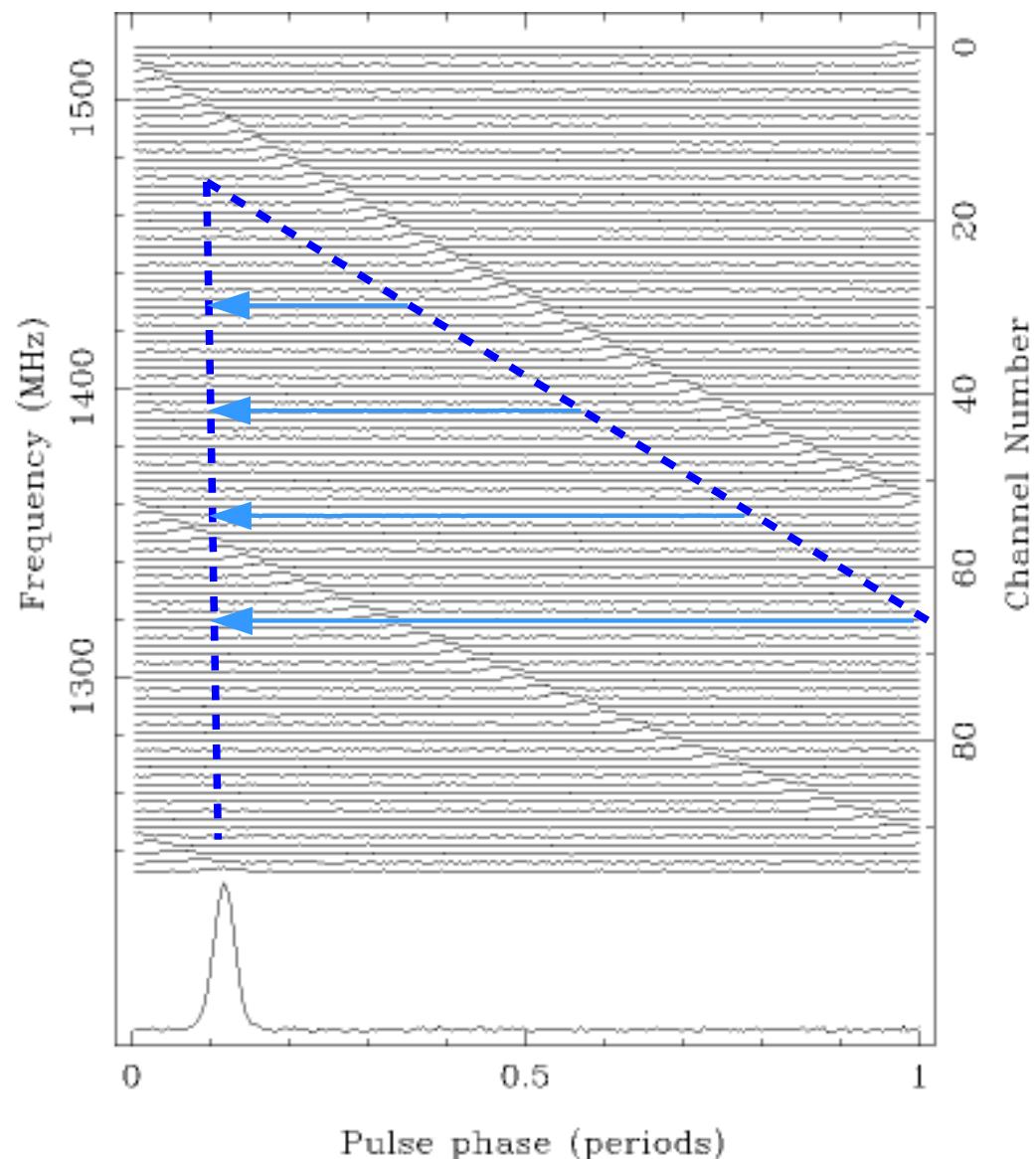
NDA/NewRoutine - LL



NenuFAR/BST - NE



L'observation des Pulsars



- Pulsar : résidu d'étoile massive, dense, en rotation ($T=1 \text{ ms} - 1\text{s}$) stable
- Signal impulsif déformé (dispersé) par le milieu interstellaire (e^-)
- Faible intensité
- Correction avant intégration fréquentielle => Dédispersion
- Intégration temporelle (folding)
- Chronométrie pulsar
 - Validation de modèles physiques
 - Détection d'ondes gravitationnelles
 - Étude du milieu interstellaire

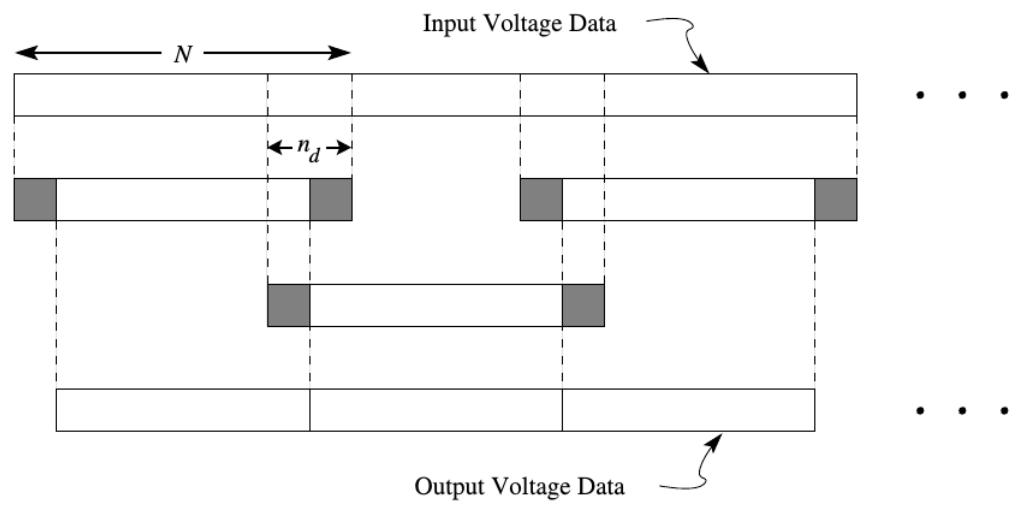
La dispersion et sa correction

- Retard chromatique à compenser :

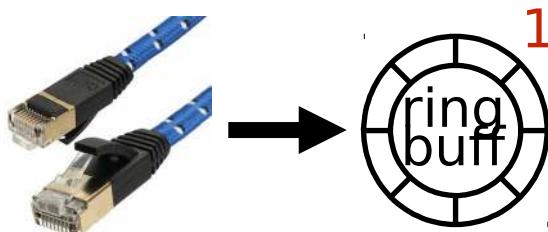
$$H(\nu + \nu_0) = \exp\left(i 2 \pi D \frac{\nu^2}{\nu_0^2 (\nu + \nu_0)}\right)$$

- Convolution plus facile à appliquer dans le domaine spectral

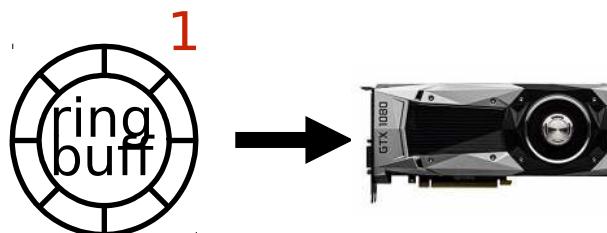
$$\begin{aligned}x[n] \\ X[k] &= \mathbf{TF}(x[n]) \\ X_{dedis}[k] &= X[k].H[k]^{-1} \\ x_{dedis}[n] &= \mathbf{TF}^{-1}(X_{dedis}[k])\end{aligned}$$



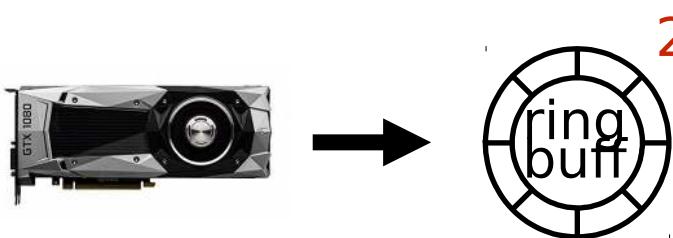
Implémentation de la déispersion : LUPPI



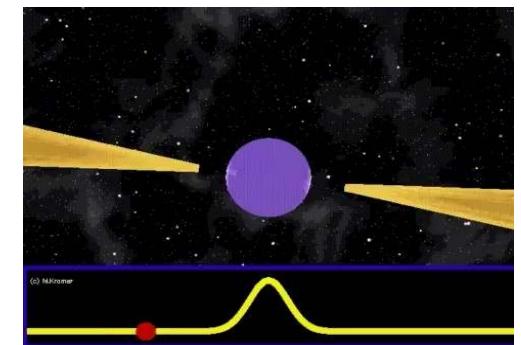
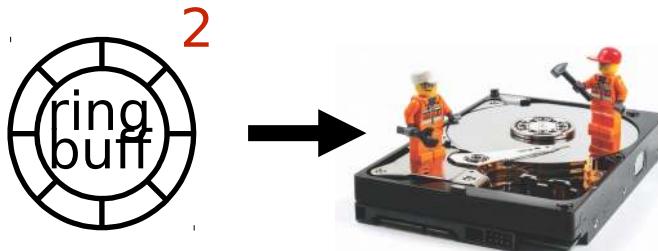
- net_thread
 - copies data from UDP ip on the first ring buffer



- GPU_thread
 - load data from the circular buffer to the GPU
 - coherent dedispersion for all channels
 - channelization (in construction)
 - Folding to the period of the pulsar (if required)
 - downsampling in time (if required)
 - copies output data on the second ring buffer



- psrfits_thread
 - copies data on the raid

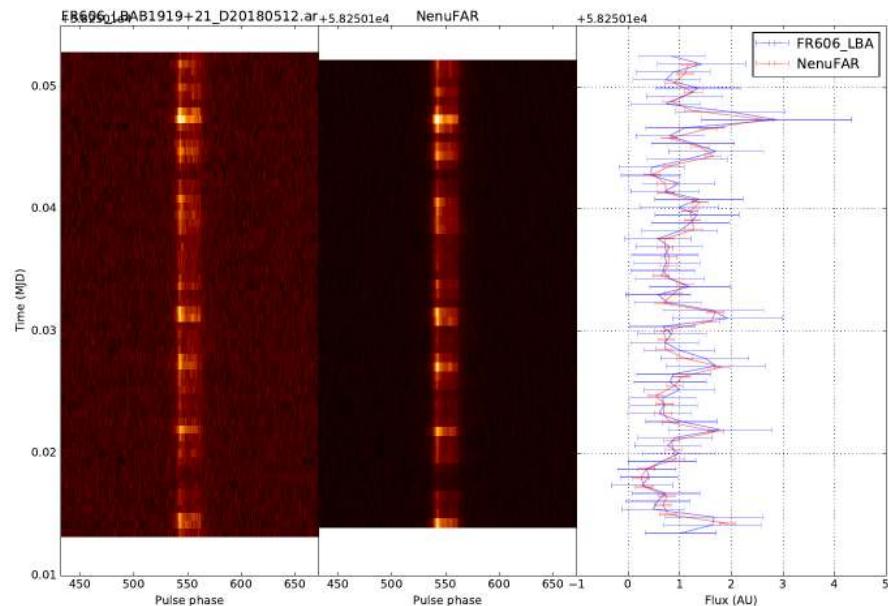
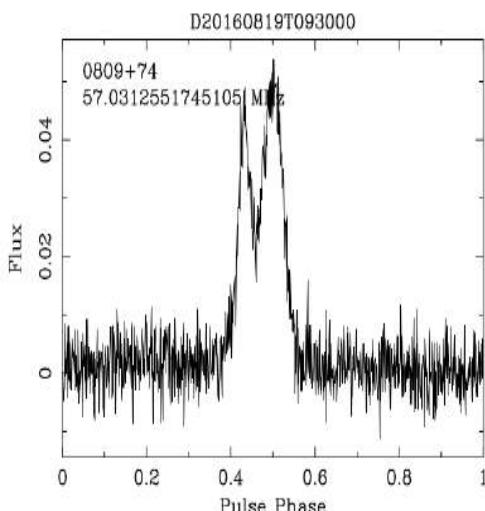


Contraintes

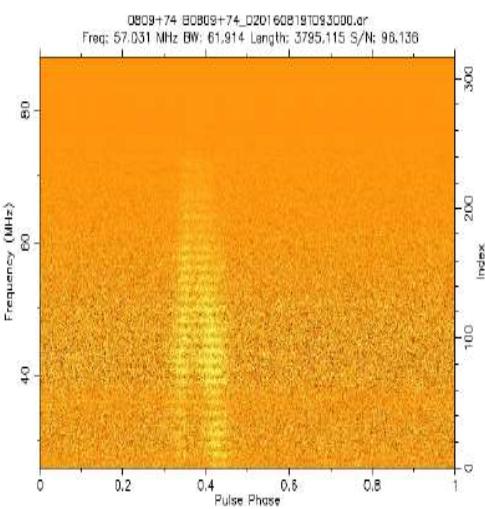
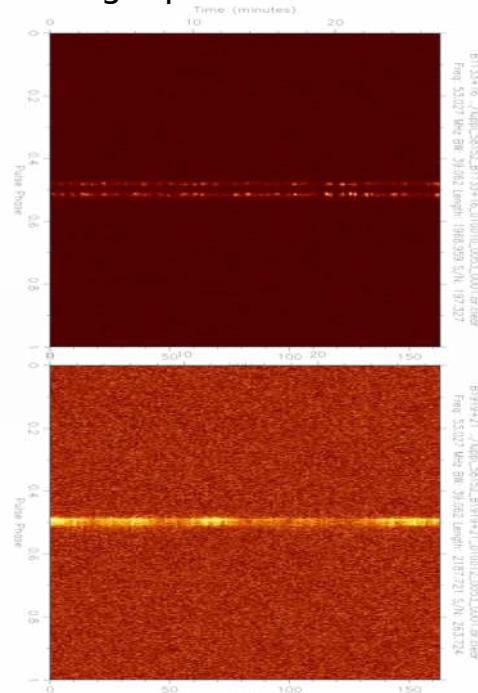
- Flux d'entrée continu (300-600 Mo/s) pendant plusieurs heures
 - Optimisation pour limiter les paquets réseaux perdus
- À basse fréquence, la dispersion est plus prononcée => besoin de traiter de long segments de données
 - Taille de FFT : 2M à 16M points
 - Besoin de stocker 256 H(k) de quelques 10^6 points
 - ~25 % d'occupation du GPU
- Fonctionnement en production
 - Temps de disponibilité du système

Commissioning, Calibration

FR606 + 15 MR

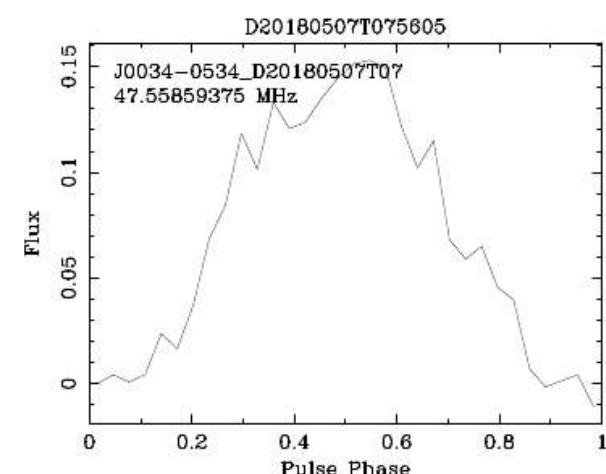


Single pulse detections

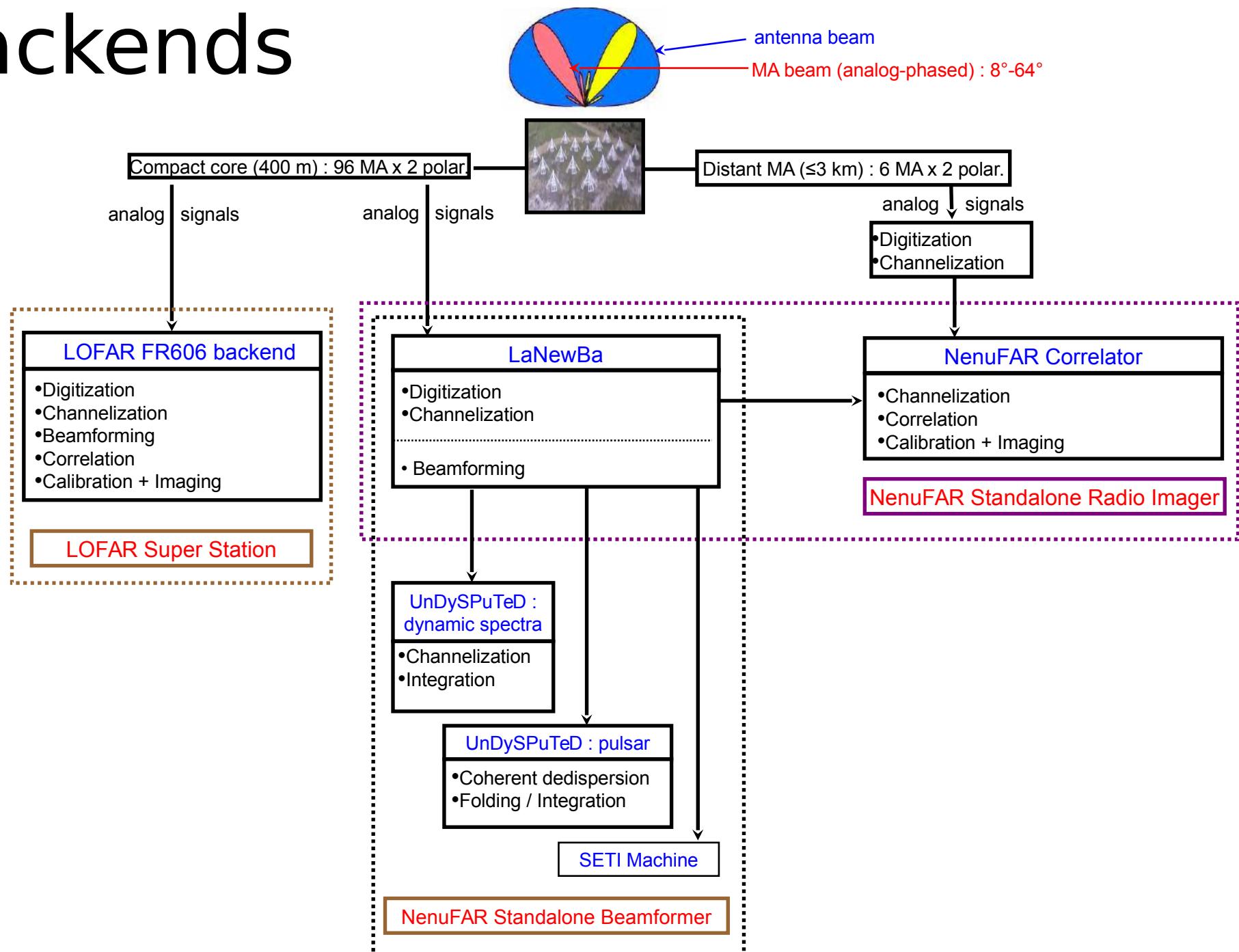


Milli-sec pulsar

observatory	nenufar
obs.id	J0034-0534_D20180507T075605_010072
PSRNAME	J0034-0534
JNAME	J0034-0534_bchl+94
P0	0.00187709210837433
DM	13.7662
length	7247.00540000001
nsubint	150
center freq.	47.55859375
BW	50
S/N	9.71
%RFI	2.42
quicklook created	May 7, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

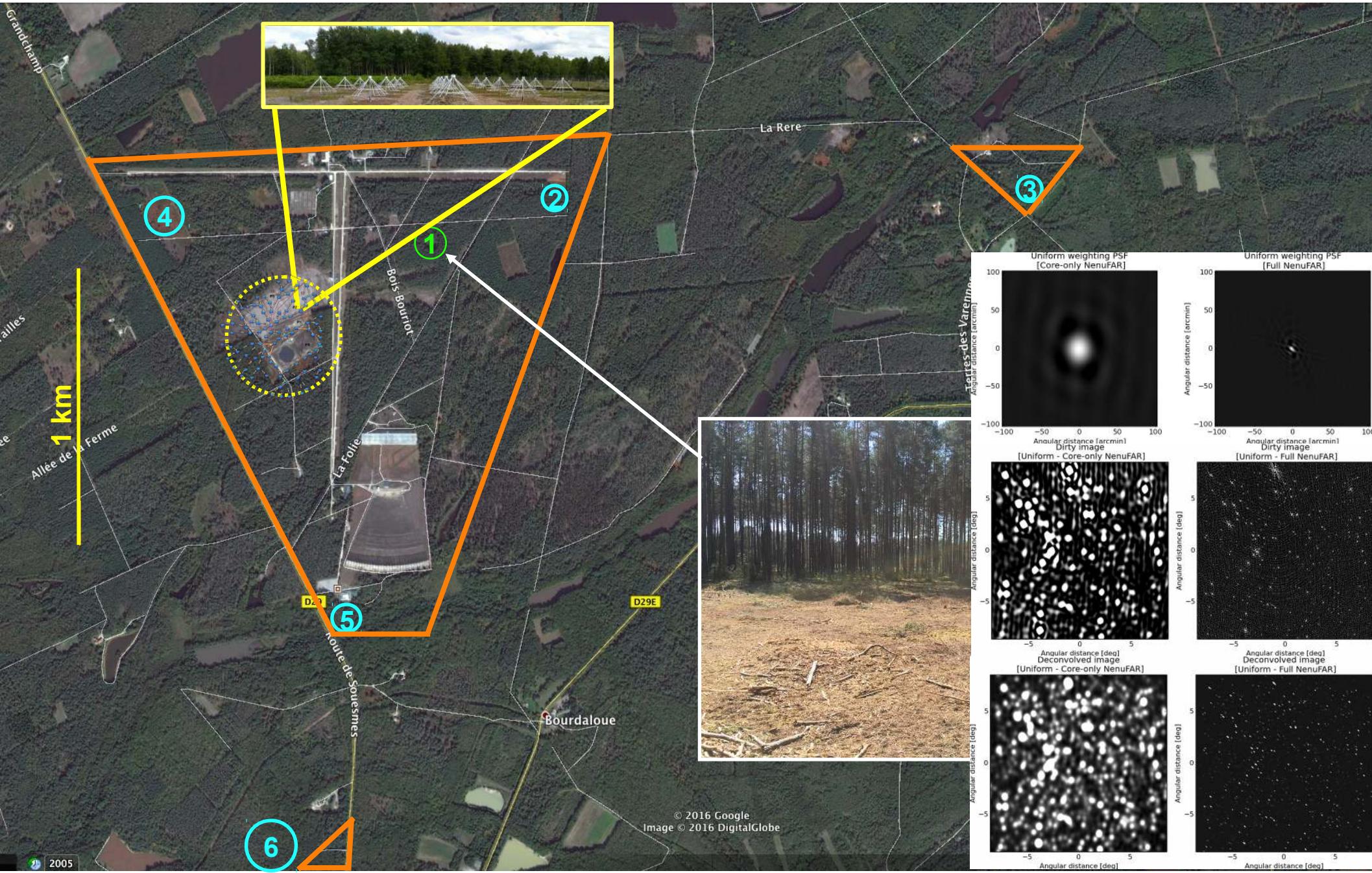


Backends

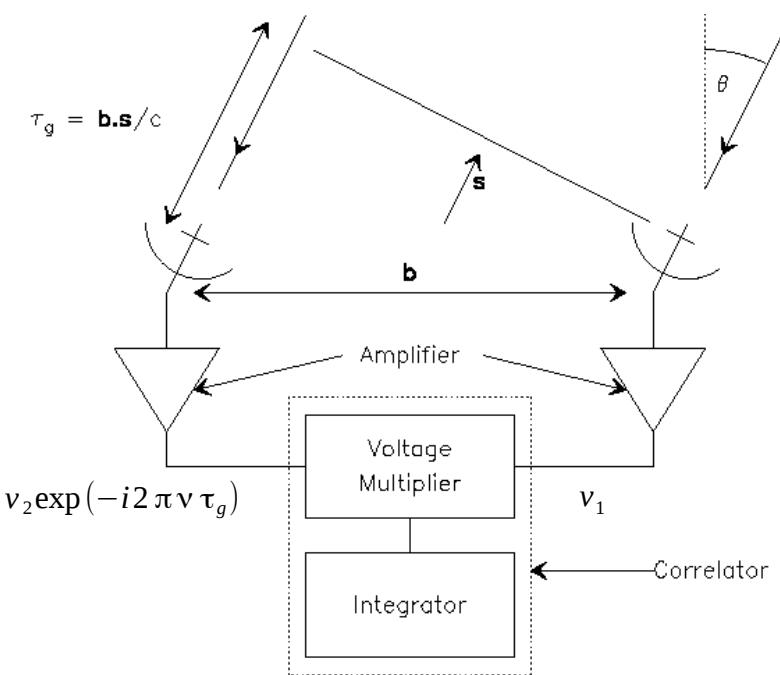
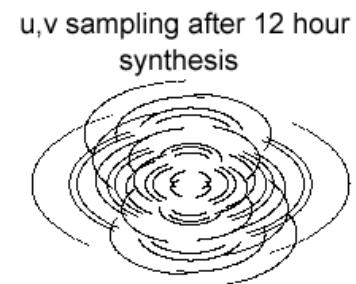
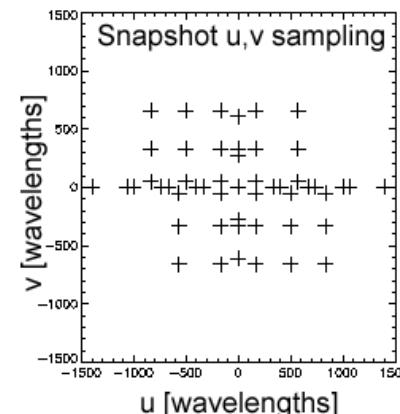
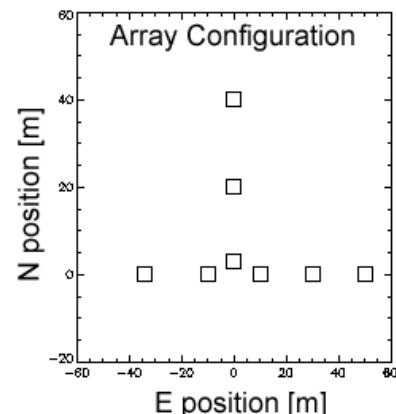
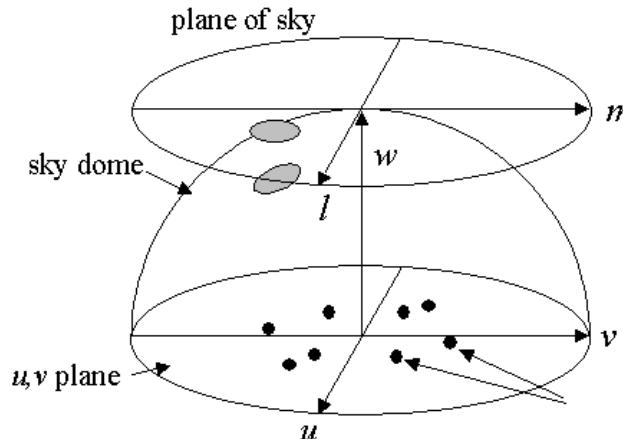


NenuFAR-Radio-Imageur

ANR «NRI» 2017-2019



Interférométrie radio pour l'imagerie



$$V = \langle v_1 v_2 \exp(-i2\pi\nu\tau_g) \rangle = |v_1 v_2| \exp(i2\pi\nu\tau_g)$$

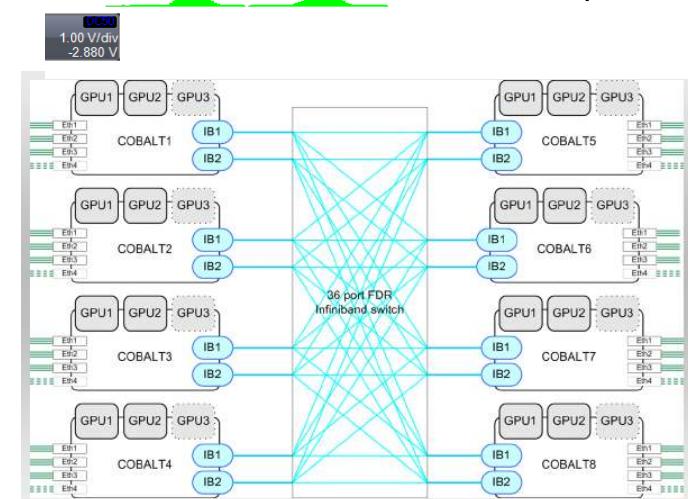
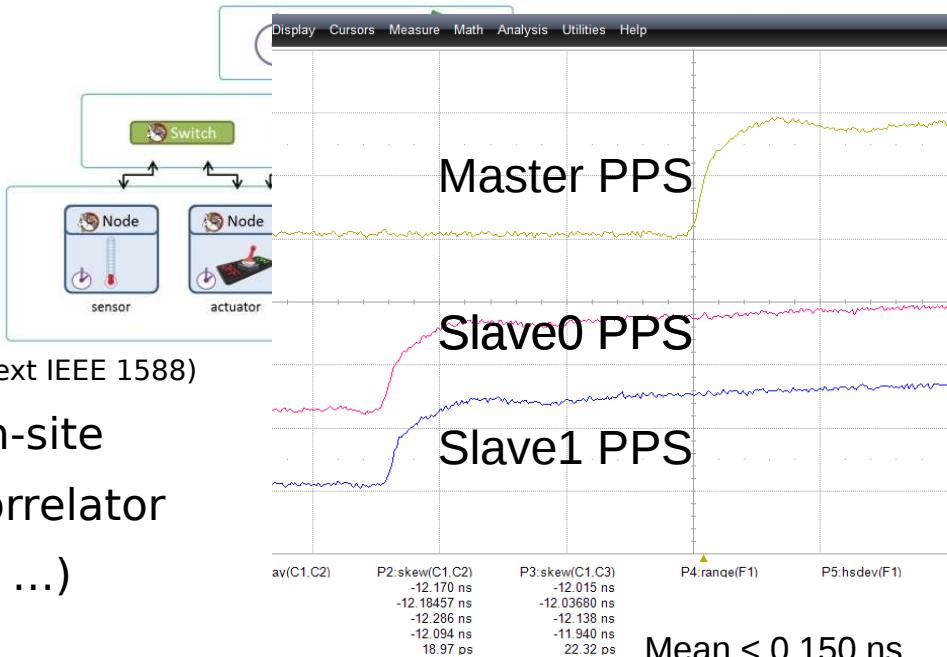
$$I(l, m) = \iint V(u, v) e^{i2\pi(u l + v m)} du dv$$

Transformée de Fourier-2D inverse

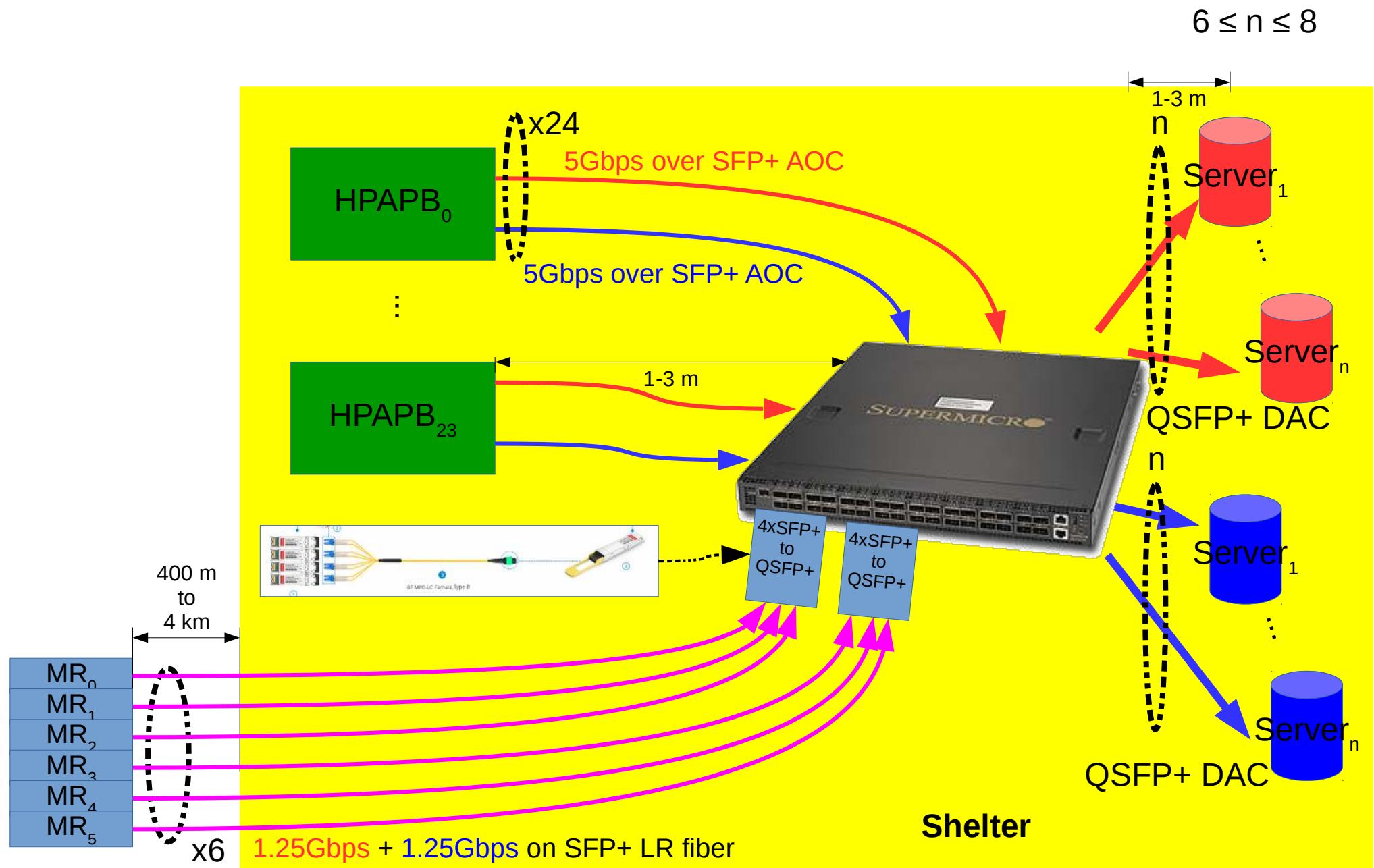
- N antennes → $N(N+1)/2$ visibilités
 - Ex : 96 MRs polarisés → 18528 visibilités
- Chaque visibilité coûte $4 B_{Hz}$ MAC/s (ou FLOPS)
- 96 MRs dans 75 MHz → 5 TFLOPS
- Stabilité instrumentale
- Transposition Antennes VS Bande coûteuse

NRI

- Remote Digitization
 - WhiteRabbit network
 - 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, ...)
- Correlator
 - LOFAR-COBALT(1-2) based
 - 96 (+6) antenna fields, 384 subbands (75 MHz)
 - 240-480 Gb/s
 - 64 sub-channellization
 - 0.25 s - 1 s dump time
 - Requires some computing power (5 TFLOPS)
 - But:
 - easier data distribution (latency controlled local network)
 - FPGAs could hold transposing [antenna, ssb] with a switch (32x 40-100GbE)

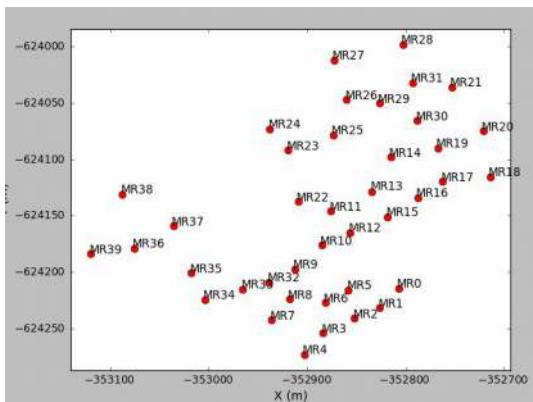


Réseau Haut débit

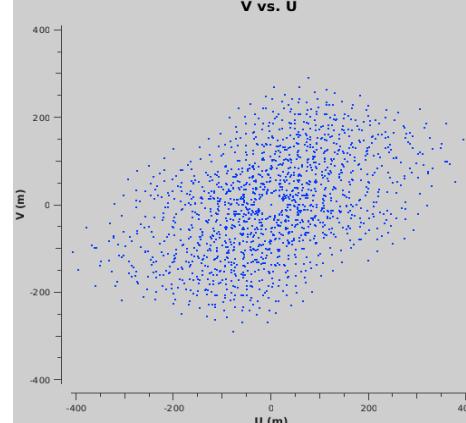


29/03/2018 9h10 TU

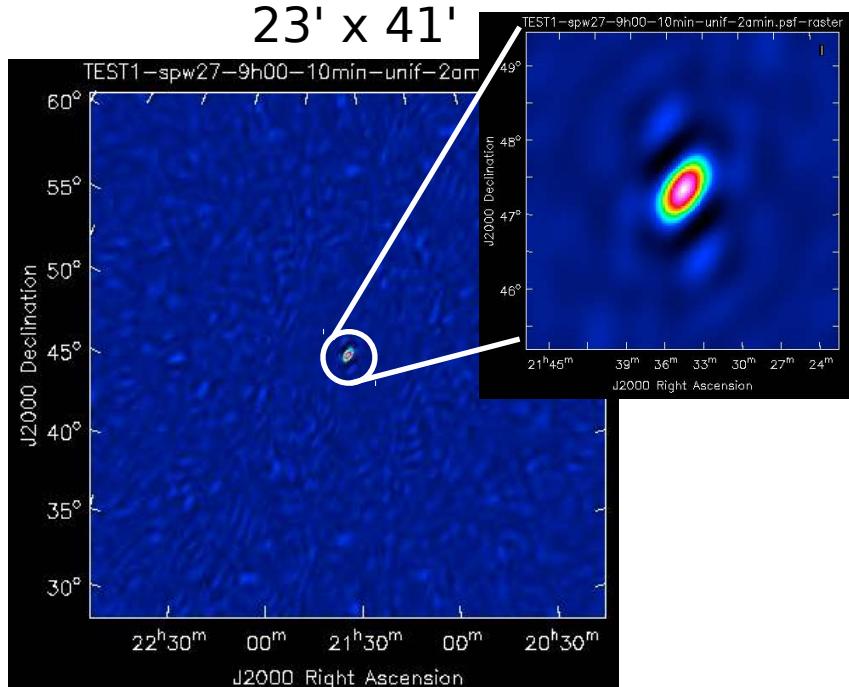
Interferometer
NenuFAR-40MR



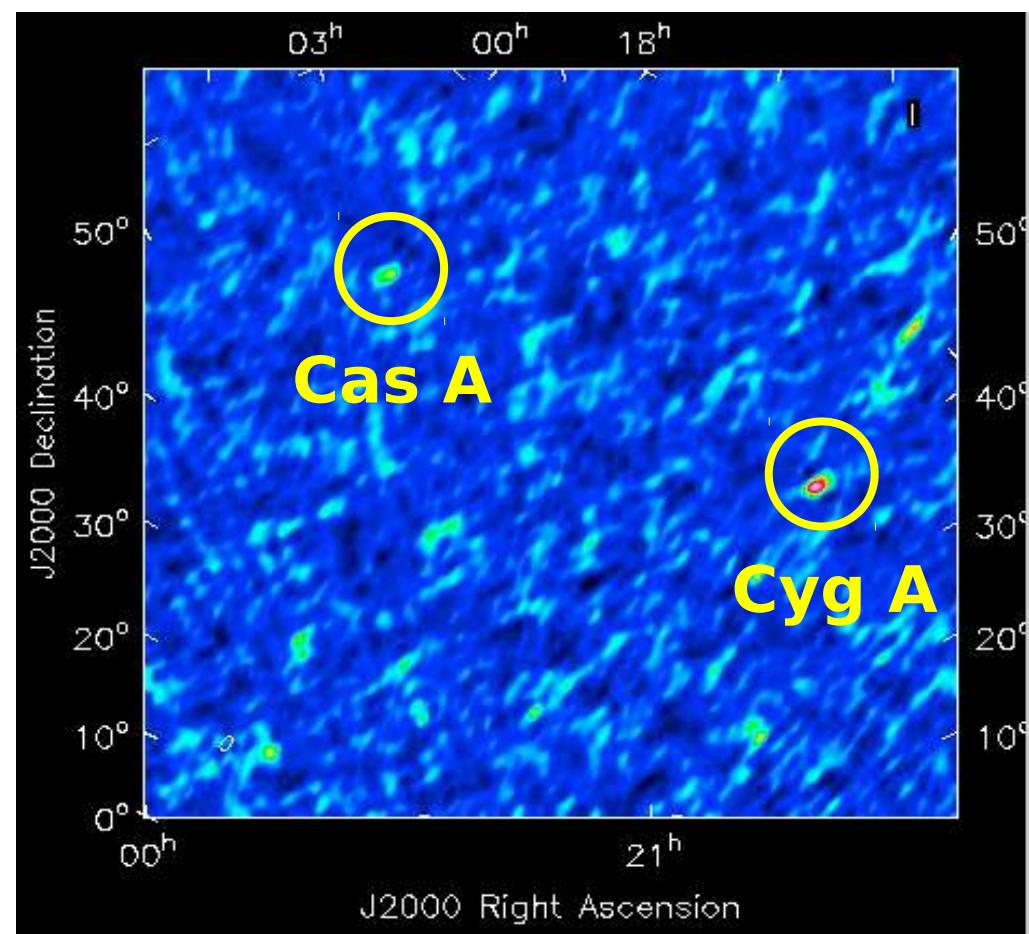
Instantaneous
UV coverage



PSF @ 85 MHz
23' x 41'



First Sky-map (uncalibrated)



Calibration on-going ...

- Gui:
 - Monitoring
 - Observation settings and submission
 - Fault detection
 - Maintenance
- Real-time command, monitoring and recording

gui-nenufar.obs-nancay.fr

NenuFAR JUPITER_TRACKING 2 days

Dashboard ParseFiles Planning Google map Tracking Survey Real time Reports Maintenance Tools Documentation

WELCOME TO NenuFAR

Welcome to the largest low-frequency radiotelescope in the world Nançay

Just come in and have a look at this wonderful world

Continue

The screenshot shows the NenuFAR web-based control interface. At the top, there's a header with the station's name and a lock icon followed by the URL 'gui-nenufar.obs-nancay.fr'. Below the header is a navigation bar with the title 'JUPITER_TRACKING' and a '2 days' tracking duration indicator. To the right of the title are several icons: a stack of three dots, a small antenna, a bell with a '0-1' notification, an envelope, and a refresh arrow. On the left side, a vertical sidebar lists various operational tools with corresponding icons: Dashboard, ParseFiles, Planning, Google map, Tracking, Survey, Real time, Reports, Maintenance, Tools, and Documentation. The main content area features a large image of the NenuFAR radio telescope array in a field under a clear sky. Overlaid on this image is a white rectangular box containing a 'WELCOME TO NenuFAR' message, a description of the telescope being the largest low-frequency radiotelescope in the world, and a call to action to 'Just come in and have a look at this wonderful world'. At the bottom of this overlay are social media sharing buttons for Facebook, Twitter, and Email, along with a 'Continue' button.

Map

Today at 13:44:37 UTC

Select a mini-array to show more details.

MA0
MA1
MA2
MA3
MA4
MA5
MA6
MA7
MA8
MA9
MA10
MA11
MA12
MA13
MA14
MA15
MA16
MA17
MA18
MA19
MA20
MA21
MA22
MA23
MA24
MA25
MA26
MA27
MA28
MA29
MA30
MA31
MA32
MA33
MA34
MA35
MA36
MA37
MA38
MA39
MA40
MAT17
MAT20
MAT21
MAT22

Satellite

MAO

Enabled

Date Today at 13:44:01 UTC

Status OK

Power ON

Temperature 27°C

NE Relay 15.80V

NW Relay & adder 16.80V

NE Electronic 10.20V

NW Electronic & adder & ctrl 9.30V

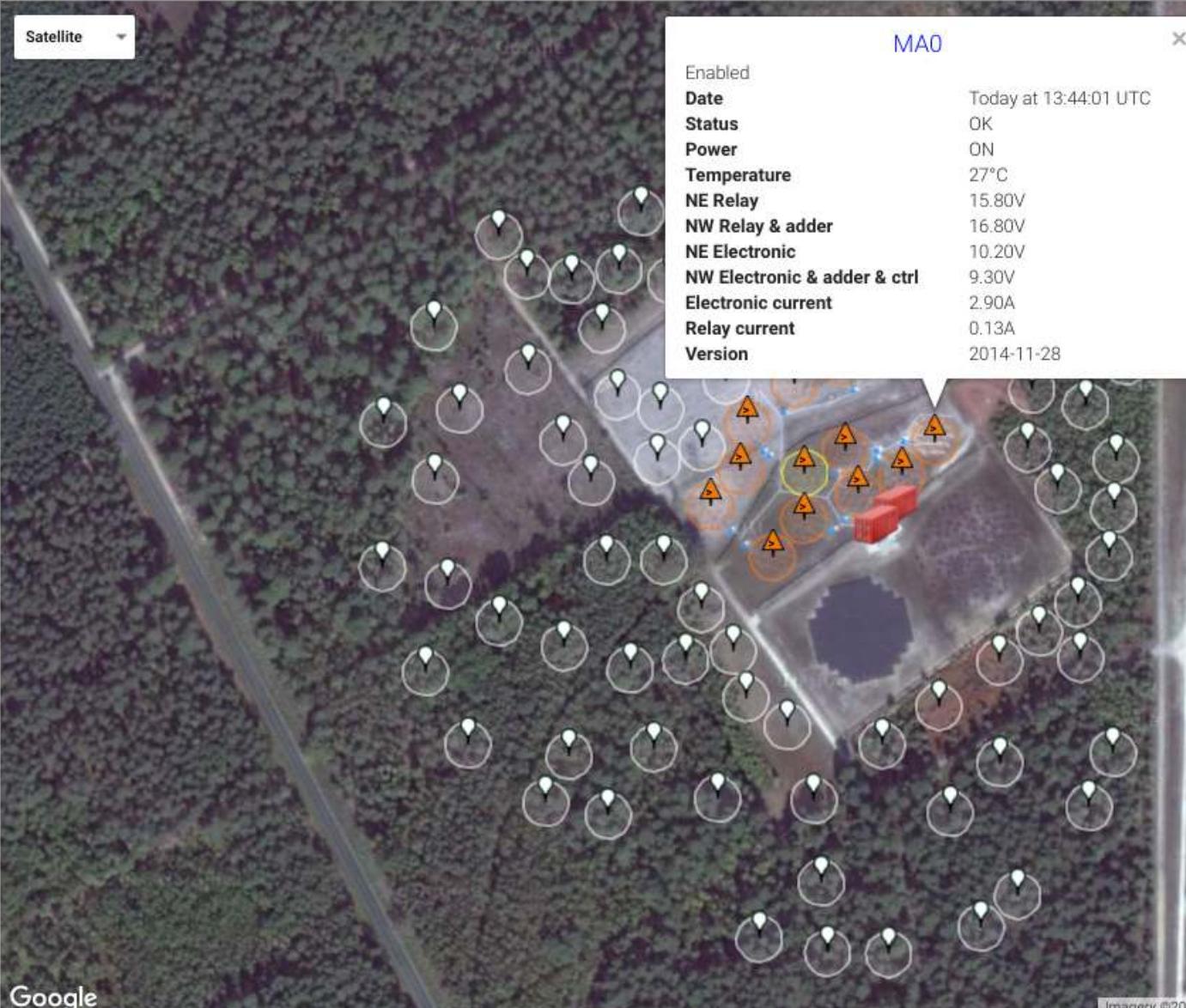
Electronic current 2.90A

Relay current 0.13A

Version 2014-11-28

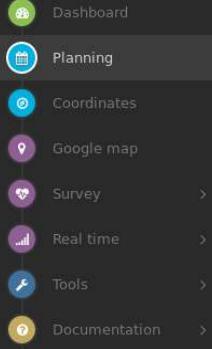
Google

Imagery ©2016, DigitalGlobe | 50 m | Terms of Use | Report a map error



NenuFAR v2.4.11 SUN_TRACKING_5_BEAMS 10 min left

08:07:56 UTC 





May 21 - 27, 2018

Mon 5/21	Tue 5/22	Wed 5/23	Thu 5/24	Fri 5/25	Sat 5/26	Sun 5/27
20:29 - 21:00 JUPITER_TRACKING	15:29 - 15:55 ZENITH_AC	02:08 - 02:39 SATURN TRACKING 06:53 - 06:54 TESTAMPLI 06:54 - 06:55 TESTRELAY_CELL 07:00 - 07:07 TESTANT	10:03 - 10:04 TESTAMPLI 10:04 - 10:05 TESTRELAY_CELL 10:05 - 10:12 TESTANT	01:00 - 05:18 TESTRELAY 06:55 - 06:56 TESTRELAY_CELL 06:56 - 06:57 TESTAMPLI 07:48 - 08:18 SUN_TRACKING_5_BEAMS	01:56 - 02:26 SATURN_TRACKING	



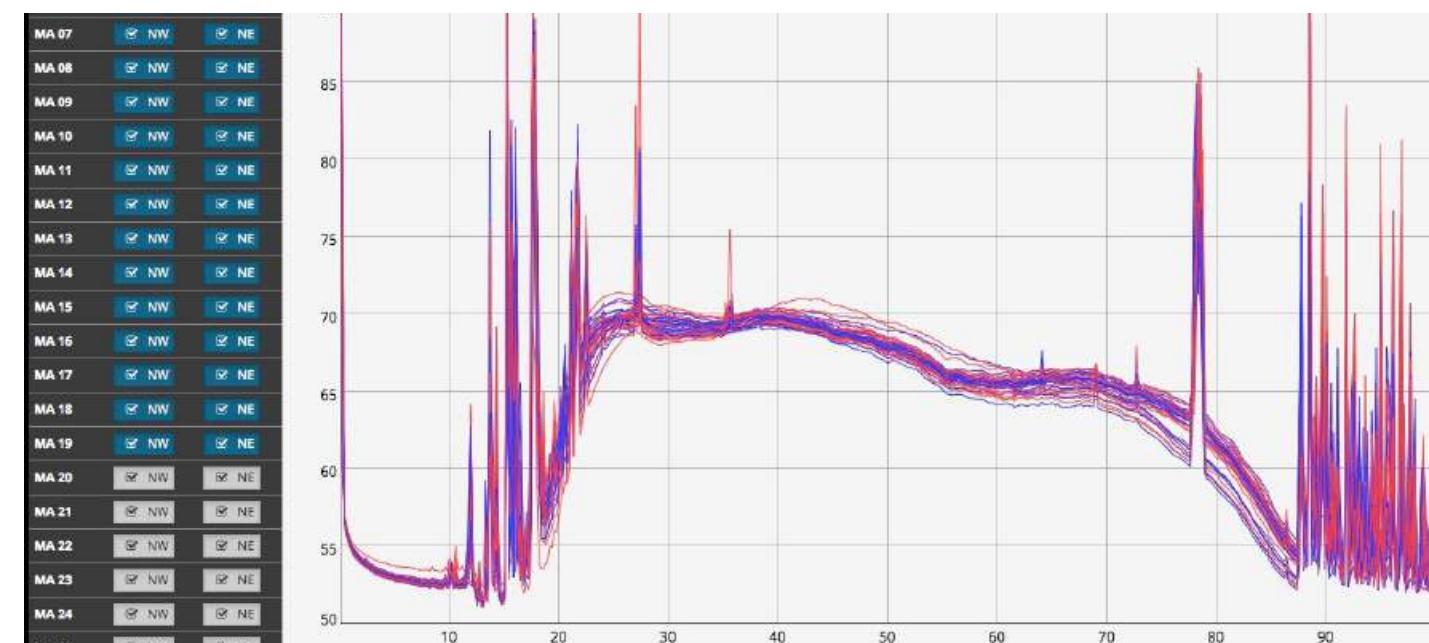
+ Submission time 2018-05-25 07:34:17 ✓ by Laurent Denis • duration 0h30

► Start time 2018-05-25 07:48:00

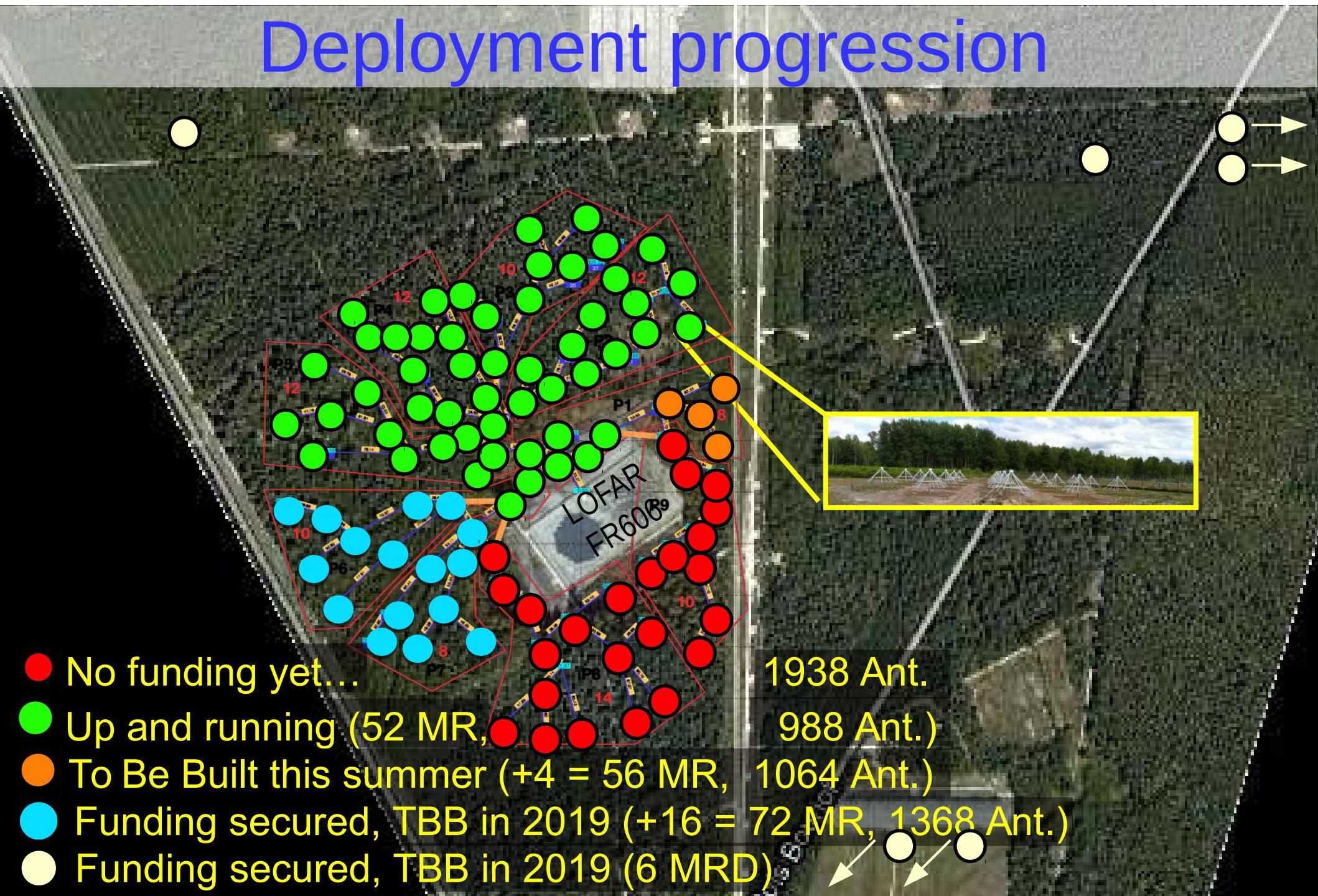
■ Stop time 2018-05-25 08:18:20

type Science Standard observation for science.

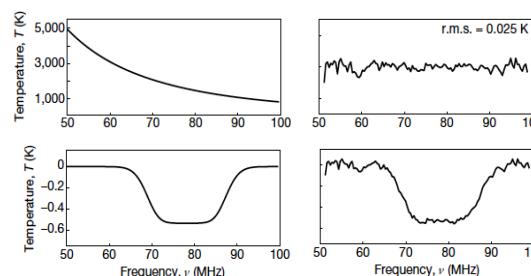
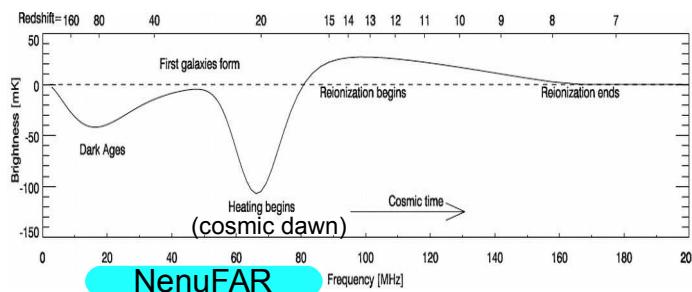
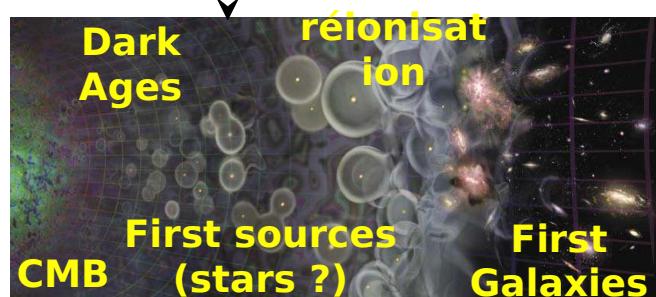




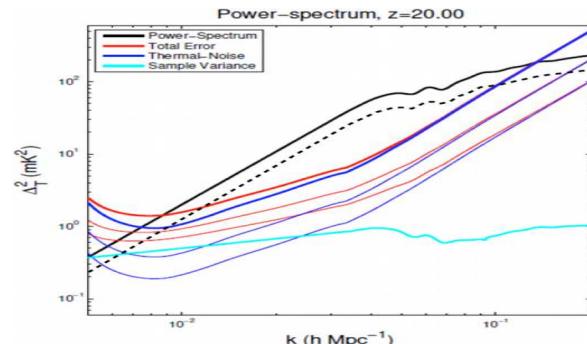
Deployment progression



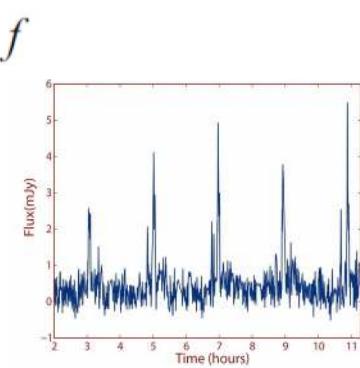
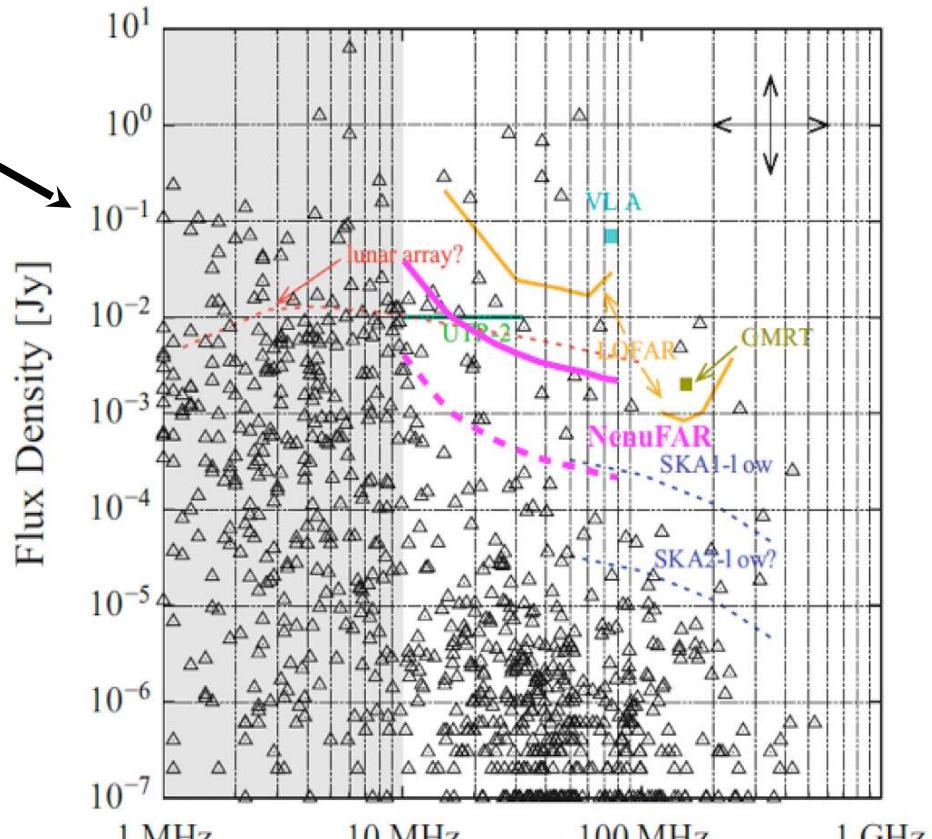
Cosmic Dawn, exoplanets/stars, pulsars, transients (GW, FRB...), galaxies, ISM, Heliosphere, ...



[Bowman et al.,
Nature 2018]



[Koopmans et al. 2015 ;
Semelin et al., 2015]



[Zarka et al. 2015 ; Greißmeier 2018 ; Hallinan et al. 2007]

Questions ?

