IM à 21 cm : un outil pour l'énergie noire ?

O. Perdereau

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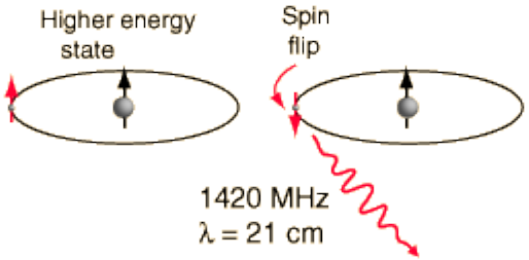
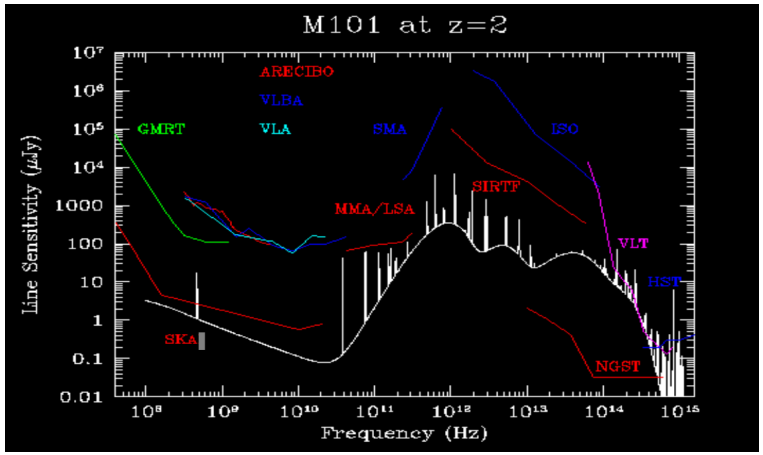
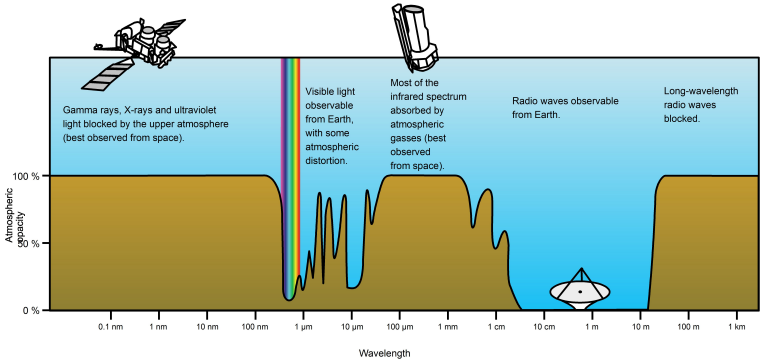
Action Dark Energy
IHP Paris
21 novembre 2019

The 21 cm H line

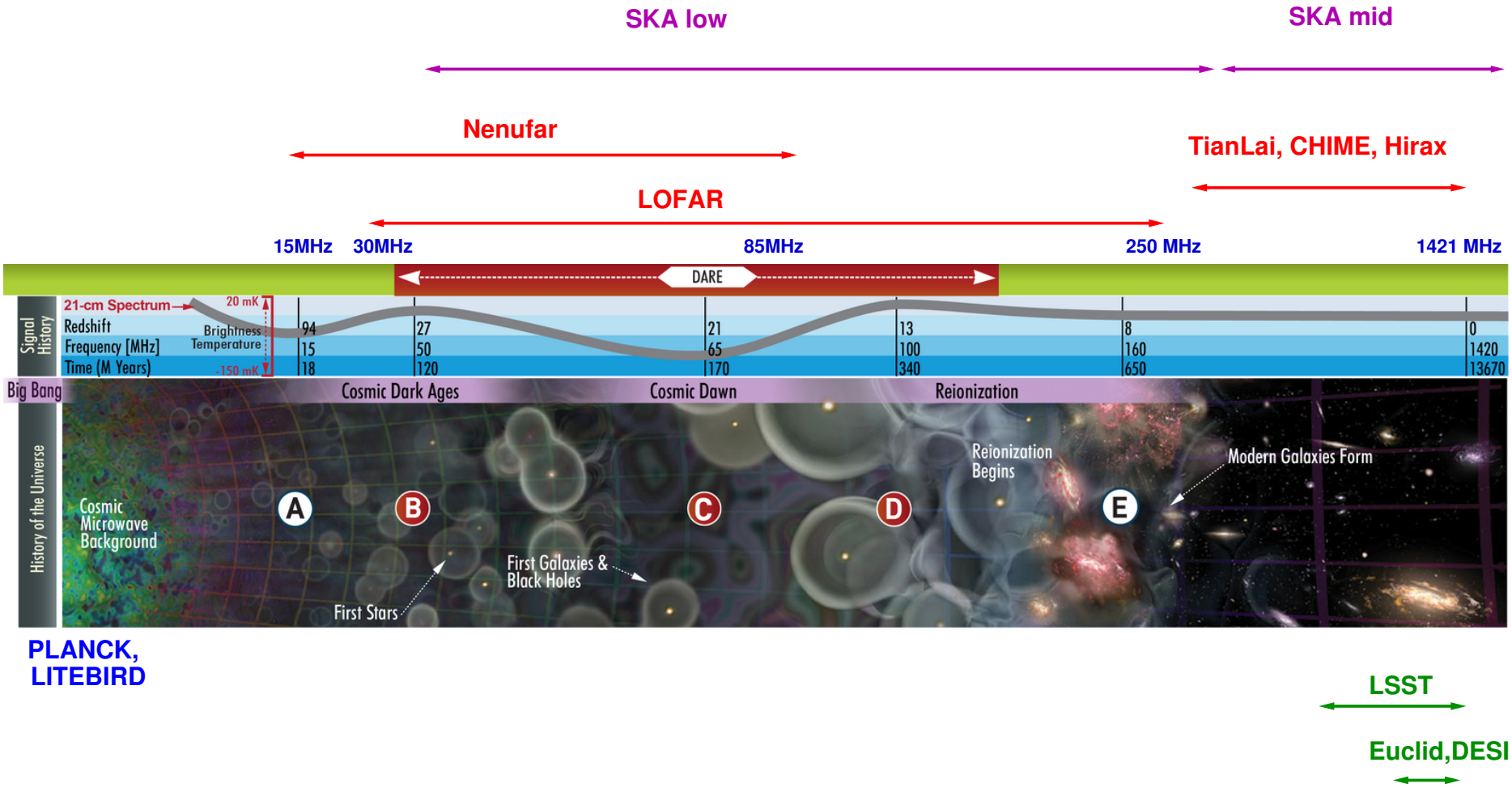
- introduced is astro (radio) in 1944
- ¨isolated¨ line ⇒ enables tomography : $z \Leftrightarrow \nu$
- ground observations possible down to ∼ 30 MHz (ionosphere) i.e. $z \sim 50$
  NB human-made perturbations (3/4/5G, TNT, FM, radars, ..)







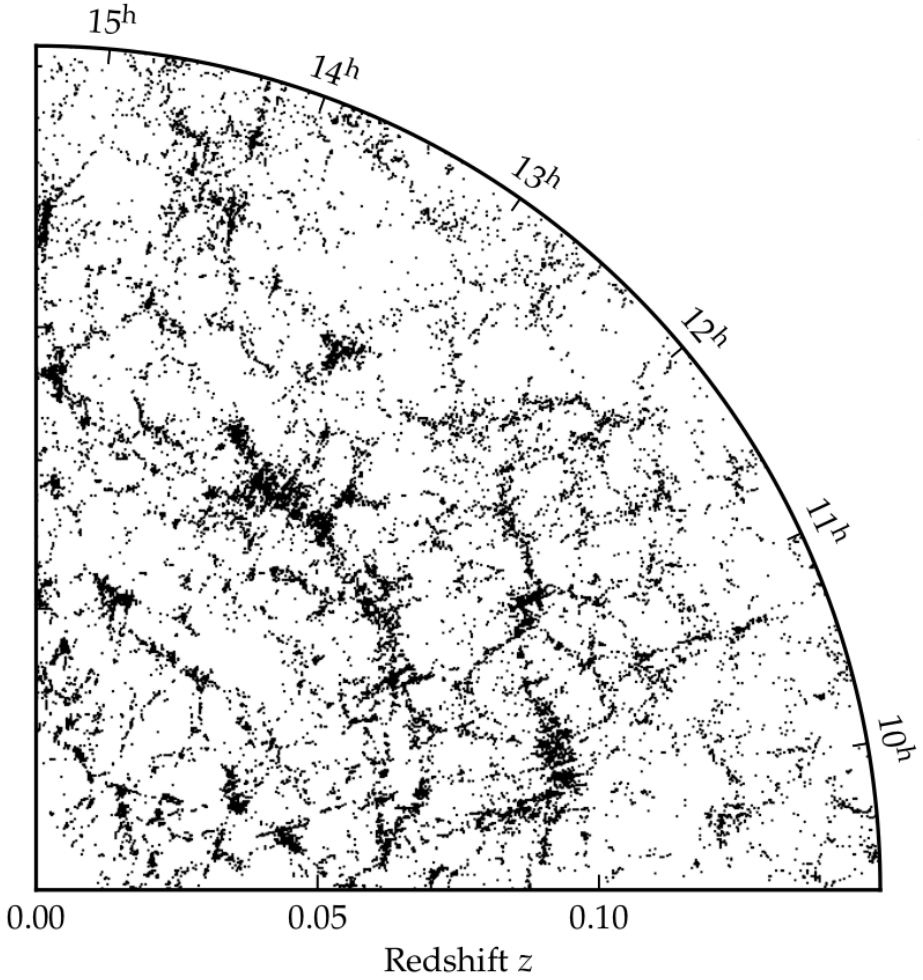
21 cm in cosmology



(In the following we focus on LSS at late epochs ($z \lesssim 6$))

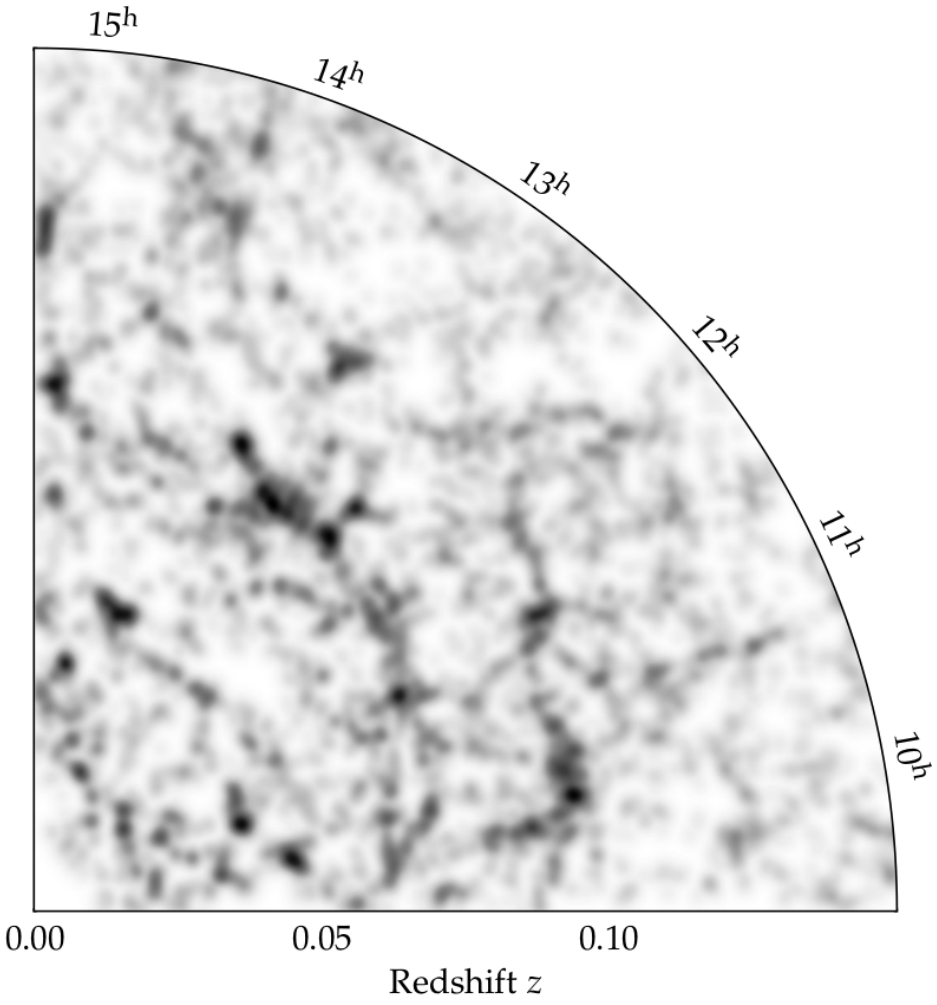
LSS with galaxies

- select galaxies
- measure z (spectrum or photo-z)
- extract P_k in few z bins
- for cosmology (in particular BAO features) focus on O(1 degree) scales ⇒ no need to measure individual galaxies

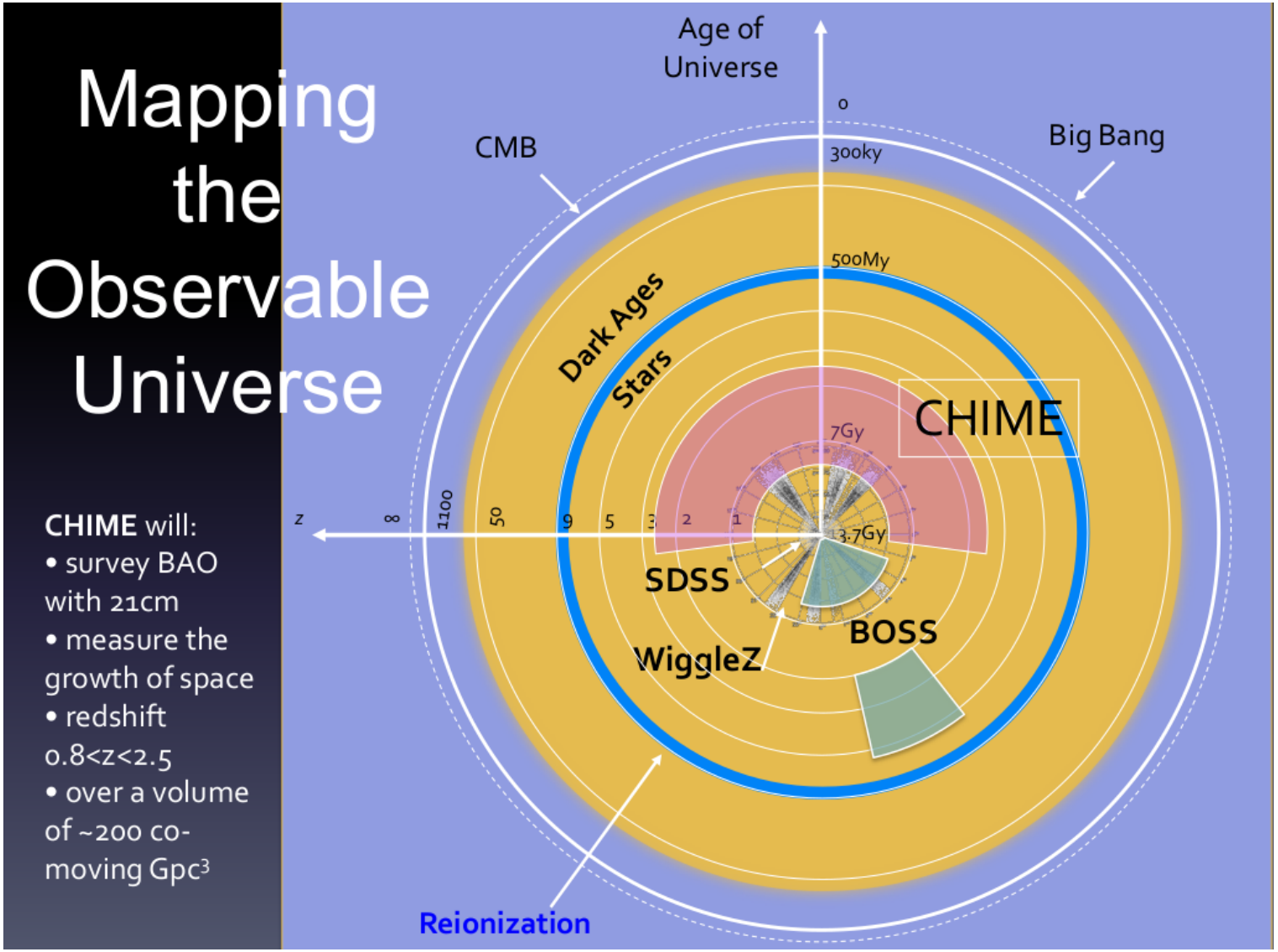


LSS from 21 cm line IM

- broad ν band, low angular resolution instrument
- measure intensity at "each" frequency $\Rightarrow z$: ¨easy¨ tomography
- but there are prices to pay :
  - low signal (only seen in Xcorr with surveys)
  - very high level of foregrounds
  - DAQ & calibration challenges
  - cosmological analysis : P_k^{HI} from parameters

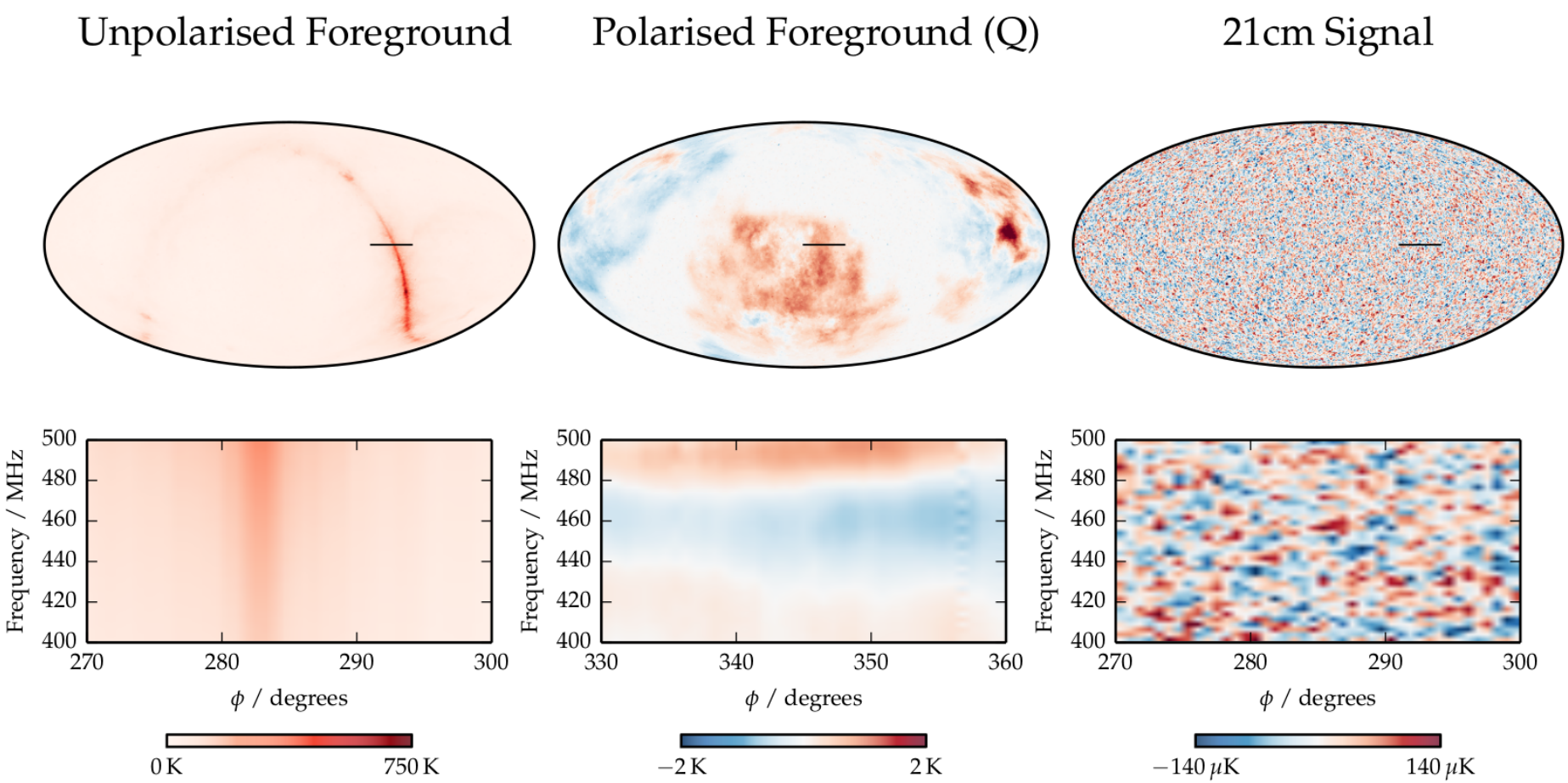


Observed volume



K. Bandura, 21cm cosmology workshop 2019

Signal & foreground ($\sim 400MHz$)



Removal needs calibration to ±0.3% (ampli), ±.0063 radians (phase), and beam to 0.1%

R. Shaw et al 2017

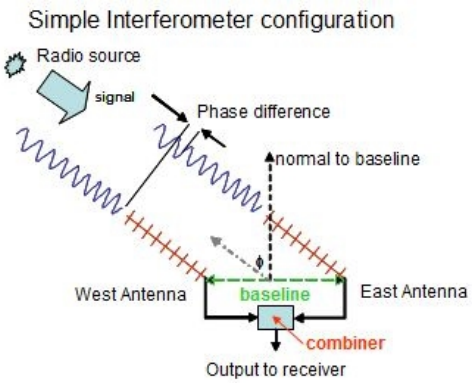
The idealized setup

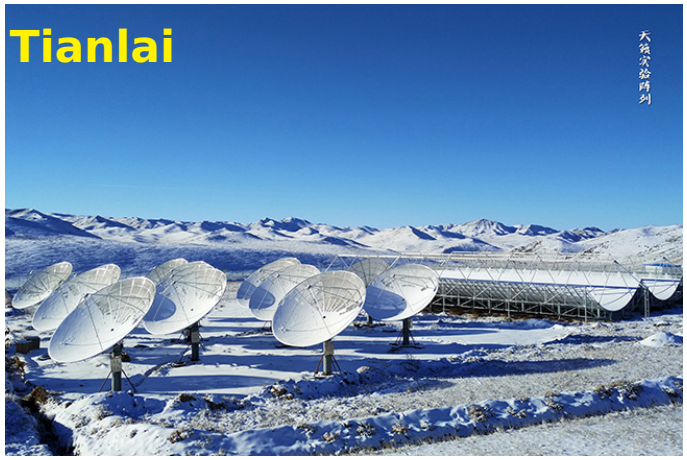
(some) Requirements :

- large collecting surface (S/N ratio)
- large sky area
- moderate (0.1 deg) angular resolution
- broad ν range (large volume)

⇒ tentative solution(s) :

- packed interferometric array (angular res., high S/N at BAO scale)
- (semi) fixed antenna(s) in transit mode (large sky coverage, cost)
- sampling of full signal waveform → FFT, digital correlation (GPU farm)





R&D Topics

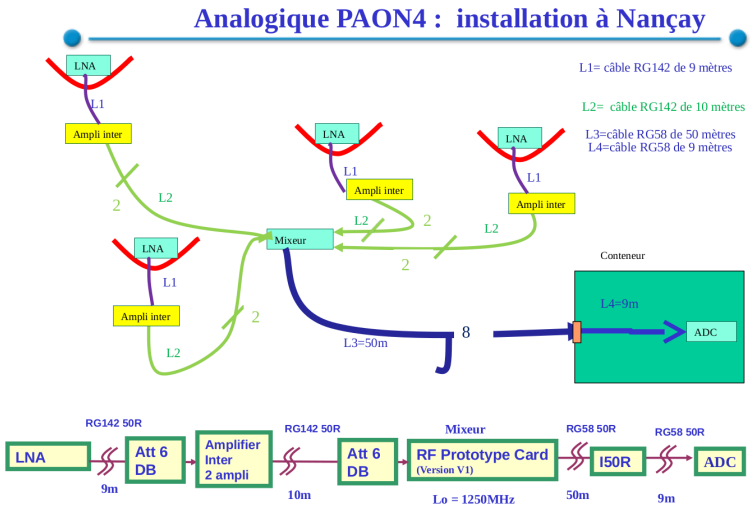
- observing strategy
- front-end electronics
- DAQ hard- and software (e.g. CHIME raw waveform stream $\sim 13 Tb/s$)
- calibration strategy & perfs
- environmental effects (TV, radars, phone, ...)
- analysis
- ...

.. some illustrations from PAON4 (2015-) and Tianlai dish pathfinder (2016-)

PAON4

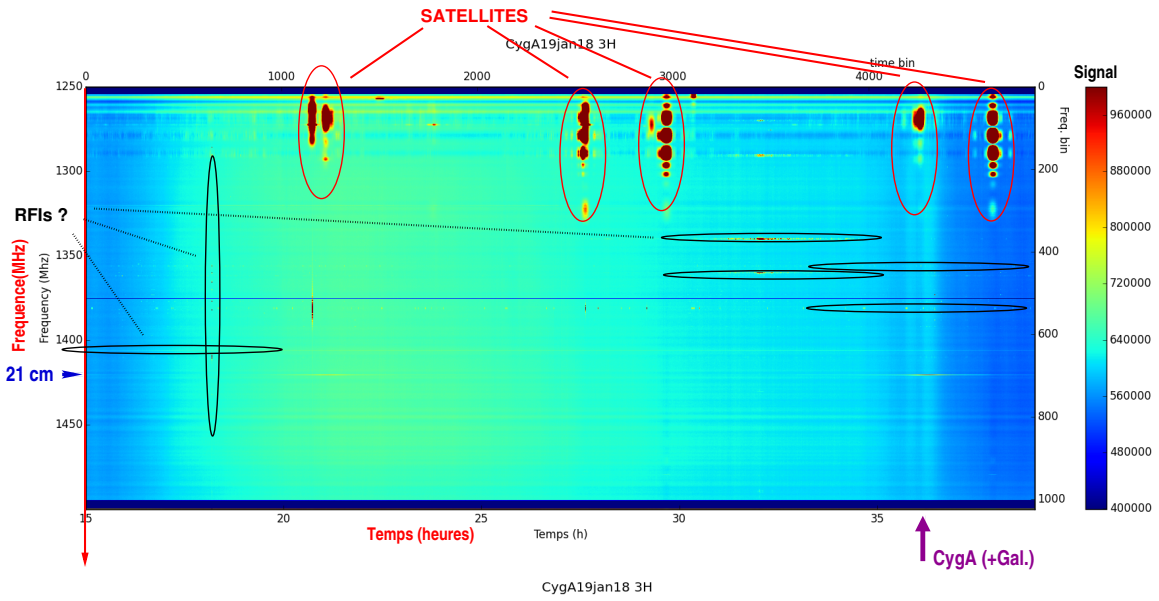
Collaboration between LAL, Obs. de Paris (Meudon, Nançay), IRFU
Characteristics :

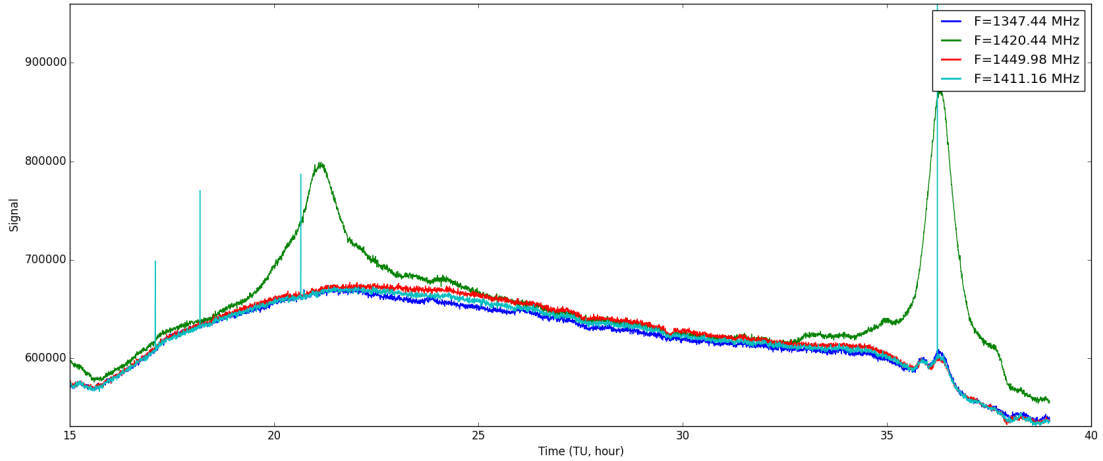
- 4 antennas (∼ 3 deg beams) in Nancay (∼ 200 km south of Paris)
- 2 polar./antenna
- Frequency band 1250 - 1500 MHz (∼ 1275 - 1480 MHz fiducial)
- ± 20 degrees from zenith
- transit observations ; ∼ 24h scans since 2015
- test bench for electronics, DAQ, on-line computing, analysis
- J.E. Campagne et al., MNRAS in press



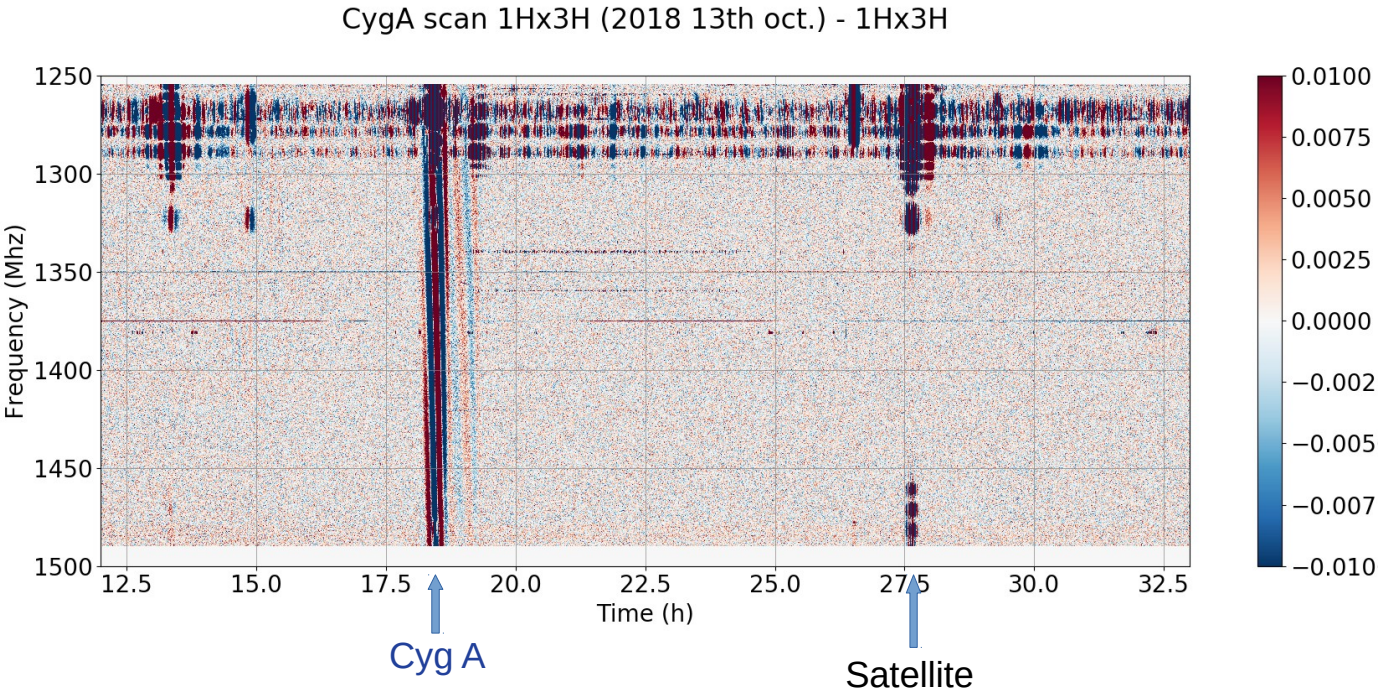
“Typical” time-frequency map (auto)

trend : gain variation with Temperature corrected for using dedicated (or blind) channel
⇒ long term stability down to $\sim \pm 3 - 5\%$





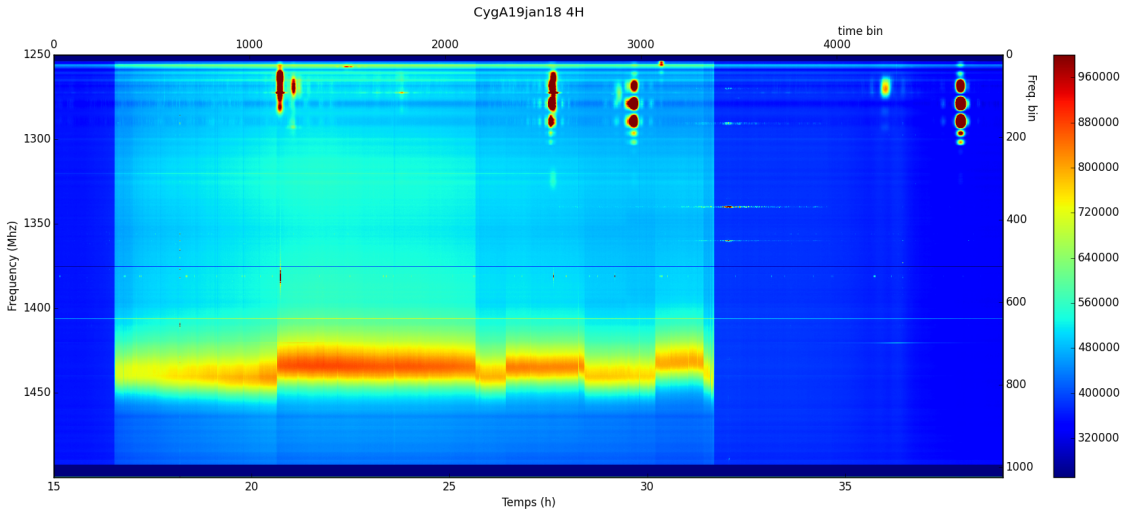
Cross-correlation time-frequency map (real part)

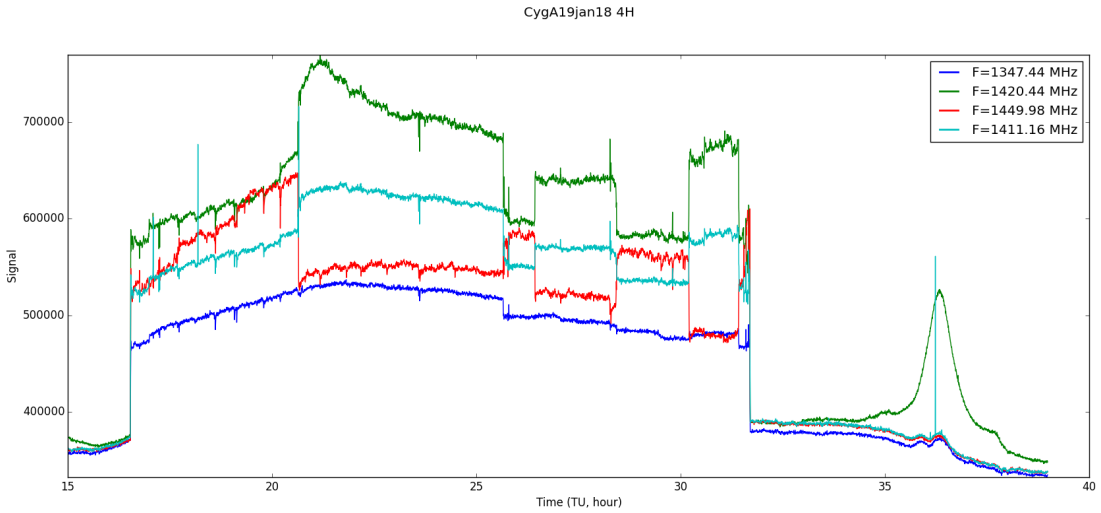


fringe rate ⟺ phase difference between the 2 channels

$\Delta\Phi$ result from instrument e.g. cable lengths, geometry & source position/motion

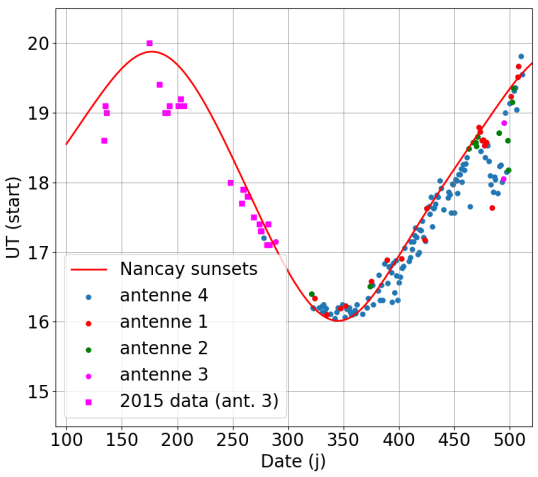
The 2017-2018 phenomenon

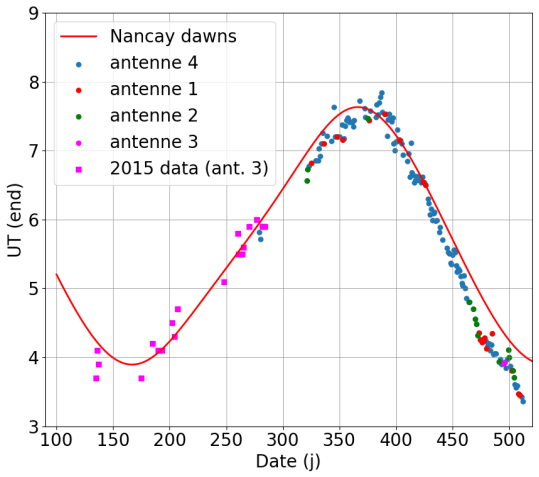




gain change(s) ? additional noise(s) ?

The strange case of the antenna no 4





- ~ 80% of integrations were perturbed
- only one antenna affected
- ~ 80% of perturbation on antenna no 4
- timing correlated with dawns and sunsets
- several direct ¨observations¨ failed

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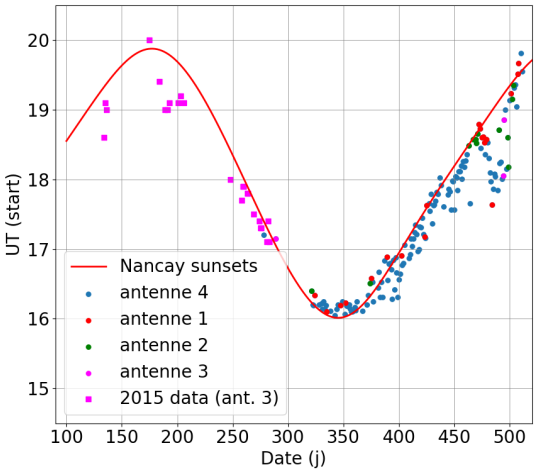

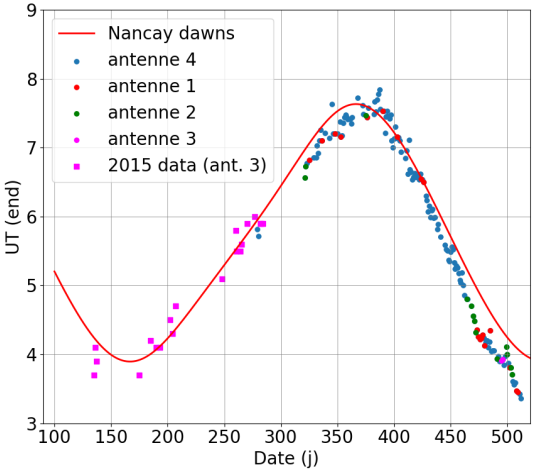

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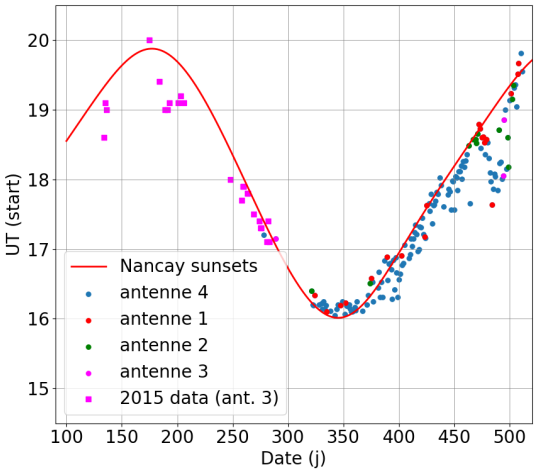

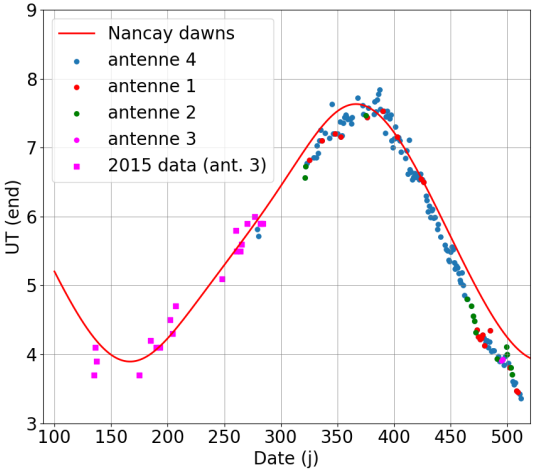

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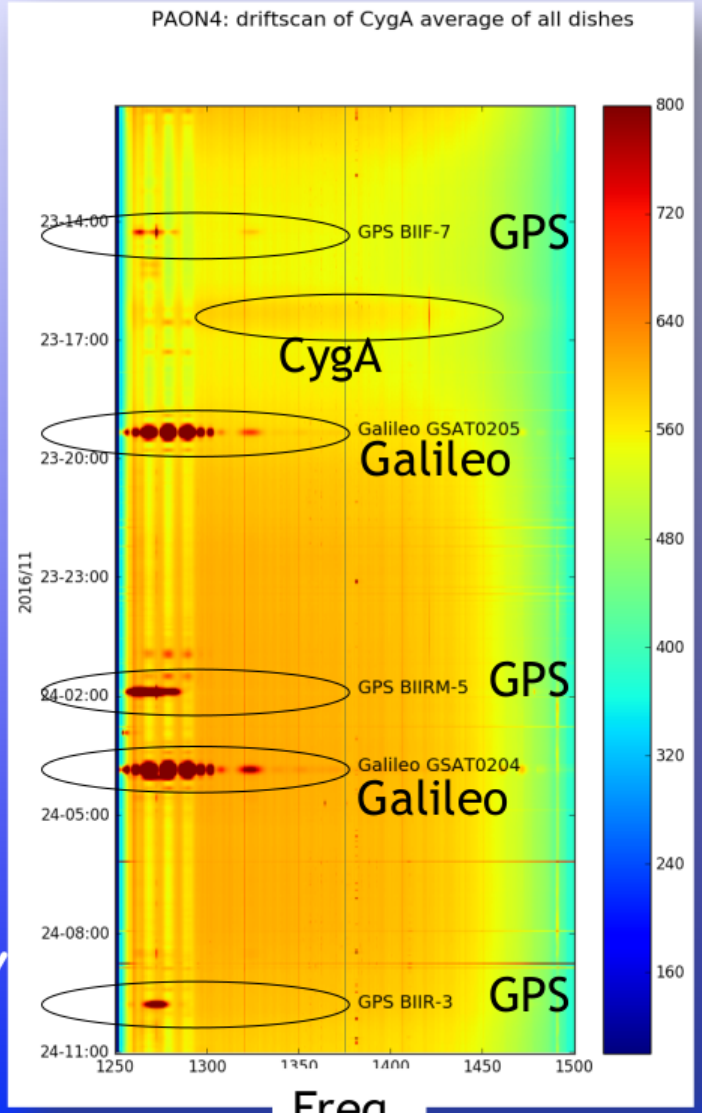
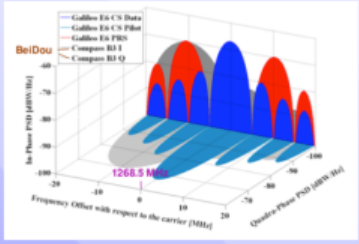
Satellites

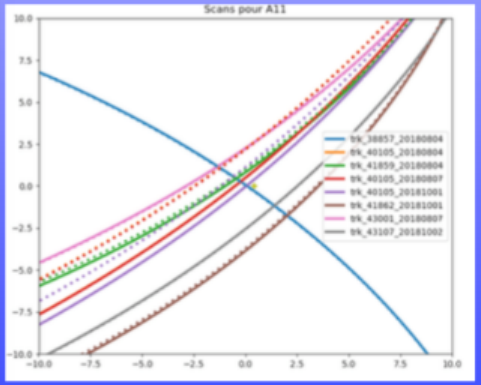


Strong signal < 1330MHz

Galileo & Beidou~ 1278 MHz
GPS L2 ~ 1227 MHz => 1273MHz



Use for geometry/phase calibration



Trajectories from SPG4

http://www.celestrak.com/NORAD/elements

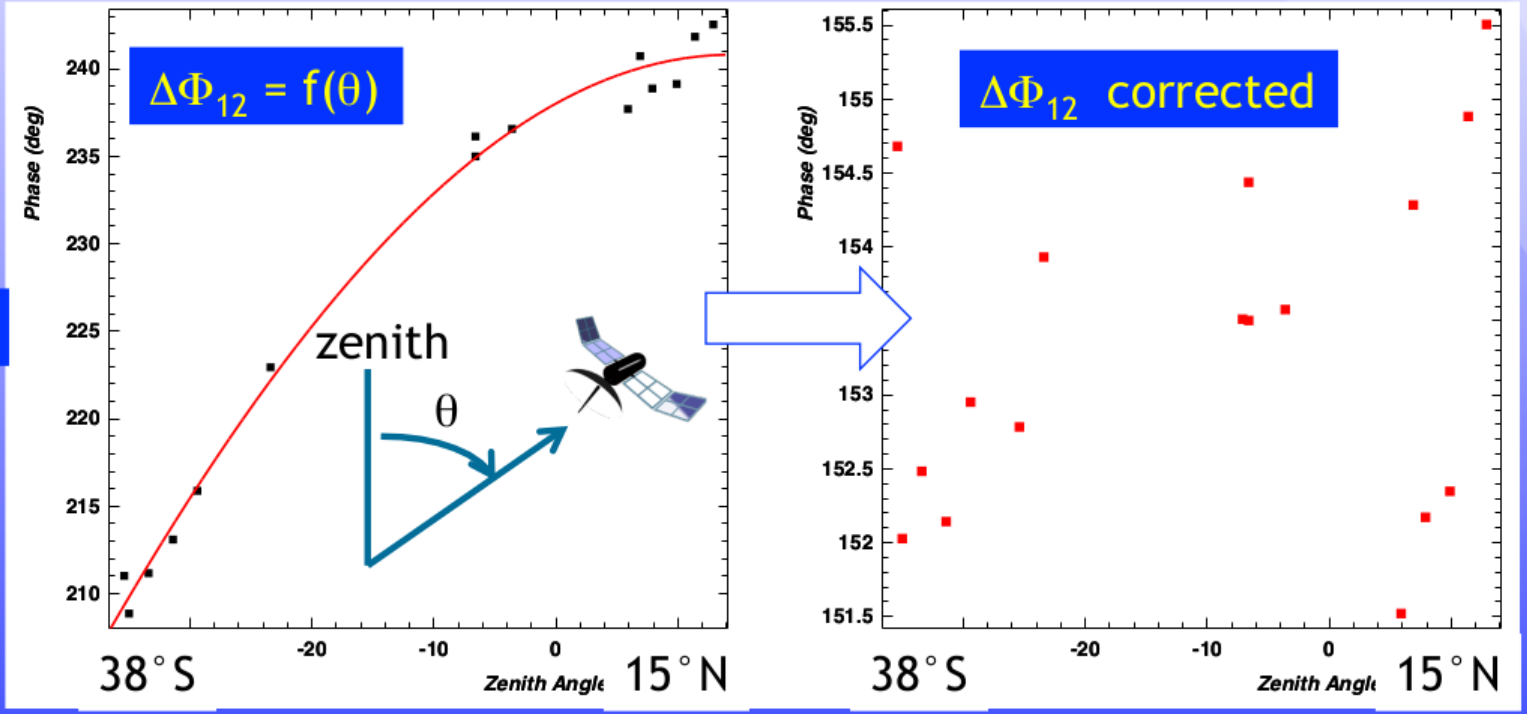
O(50%) 24h observations with 2 satellites

Phases

$$\varphi_{ij}(\mathbf{n_{b,ij}}, \Delta\Phi_{ij}; h) = -2\pi \left(\frac{\nu}{c}\right) \mathbf{n_s}.\mathbf{n_{b,ij}} + \Delta\Phi_{ij}$$

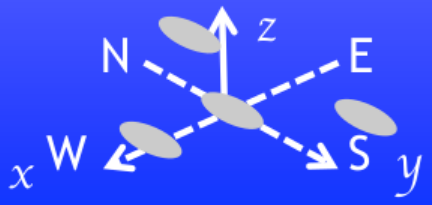
Geometry Instrumental

30°



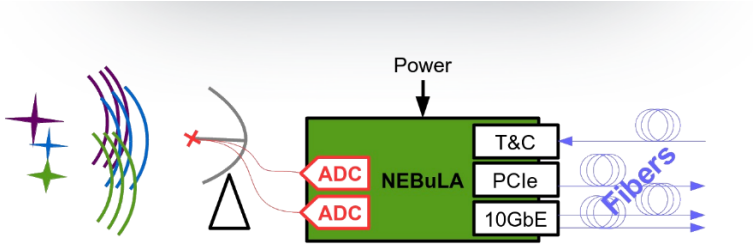
± 2°

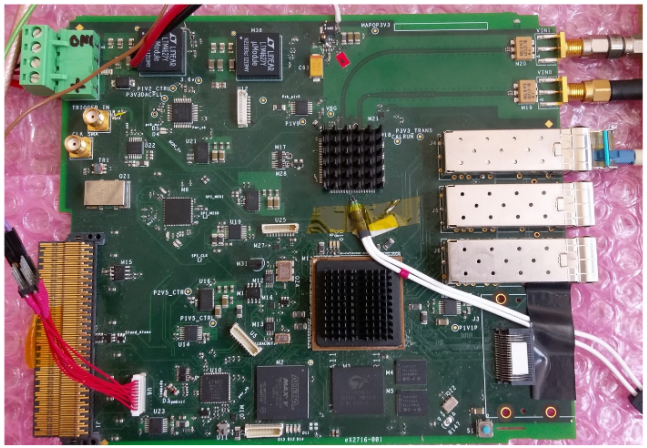
Δz_{12} = 5.5 cm
Δy_{12} = 1.4 cm

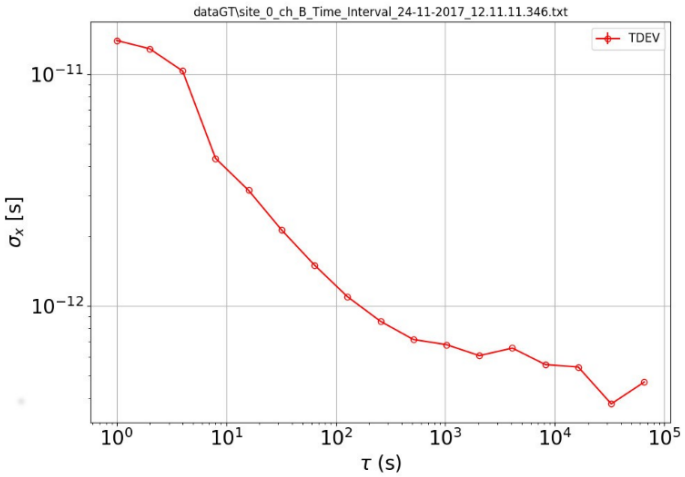


Idrogen

Bring numerisation close to the receiver
avoid analog signal transmission (long cables)
needs time distribution ⇒ White Rabbit
qualification on PAON4 in spring 2020







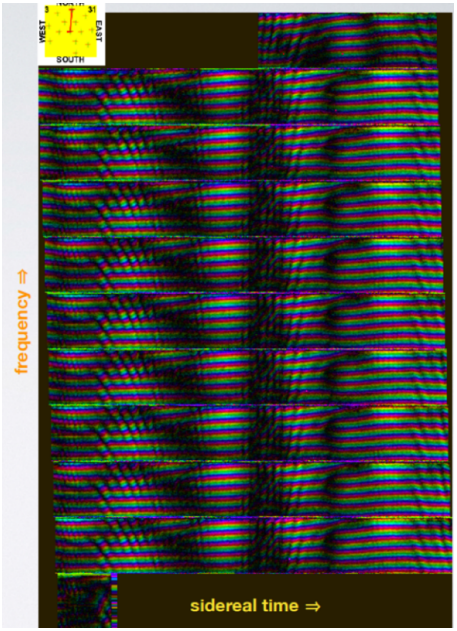
- Derived from Nebula board
  - White rabbit module
  - Power supply tree

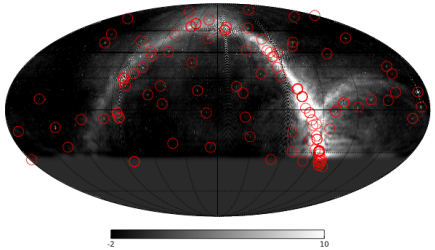
- In collaboration with SYRTE
  - Observatoire de Paris
  - Time-Frequency laboratory
- 400 fs after 1000 s and 1 km fibre

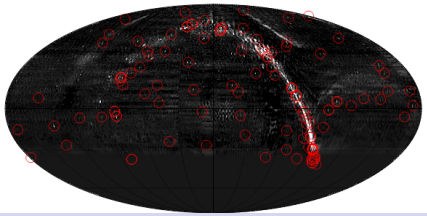
C. Viou/D. Charlet 21cm cosmology 2019

Outlook

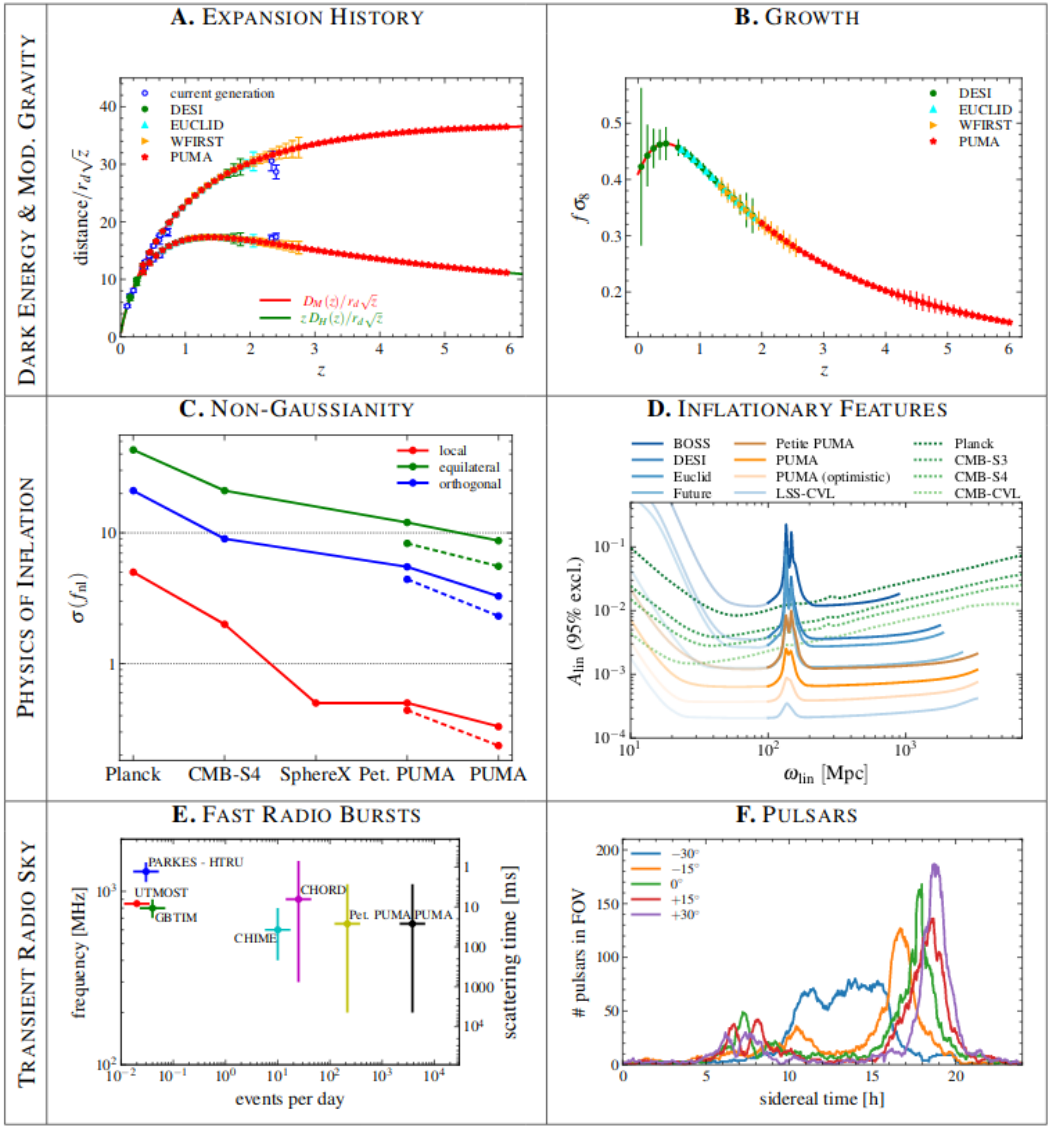
- “ New” domain
- cleaning & calibration are hard - we are learning, it’s fun !
- promising early data (Tianlai, CHIME)
- integration on NCP under way (Tianlai)
- ... still a long way to go
- new target (nuisance ? :-)) : FRBs
- larger scale projects e.g. PUMA - a large (O(10000)) dish array







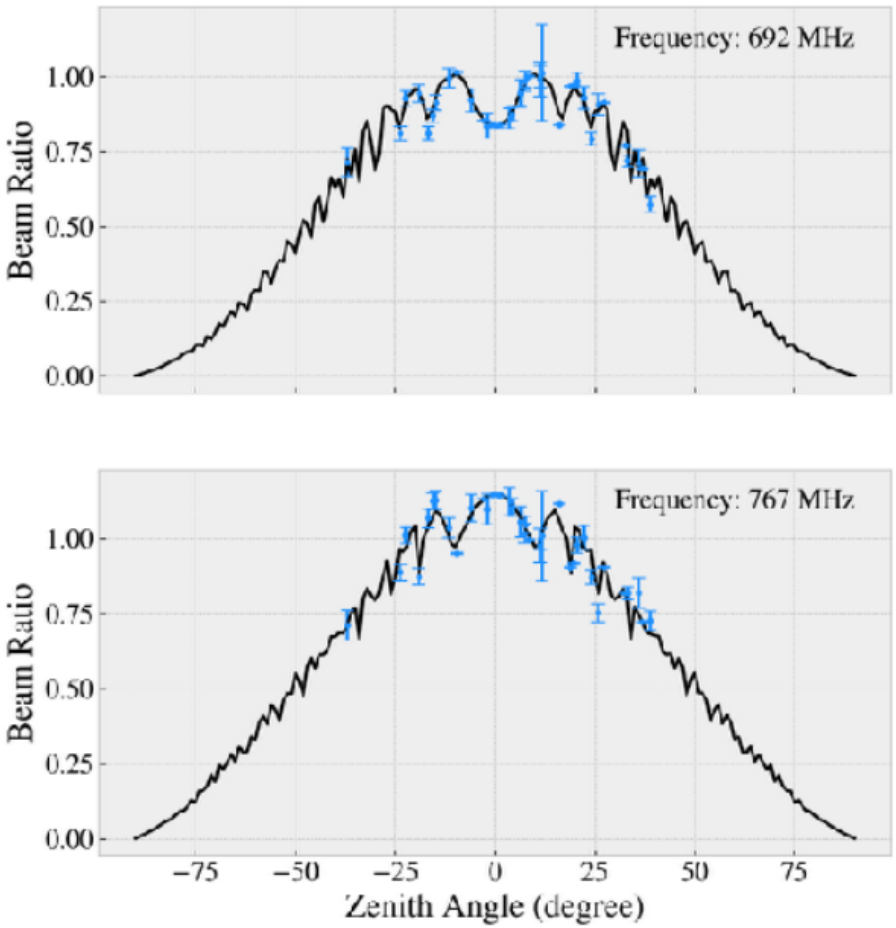
Advertisement for PUMA



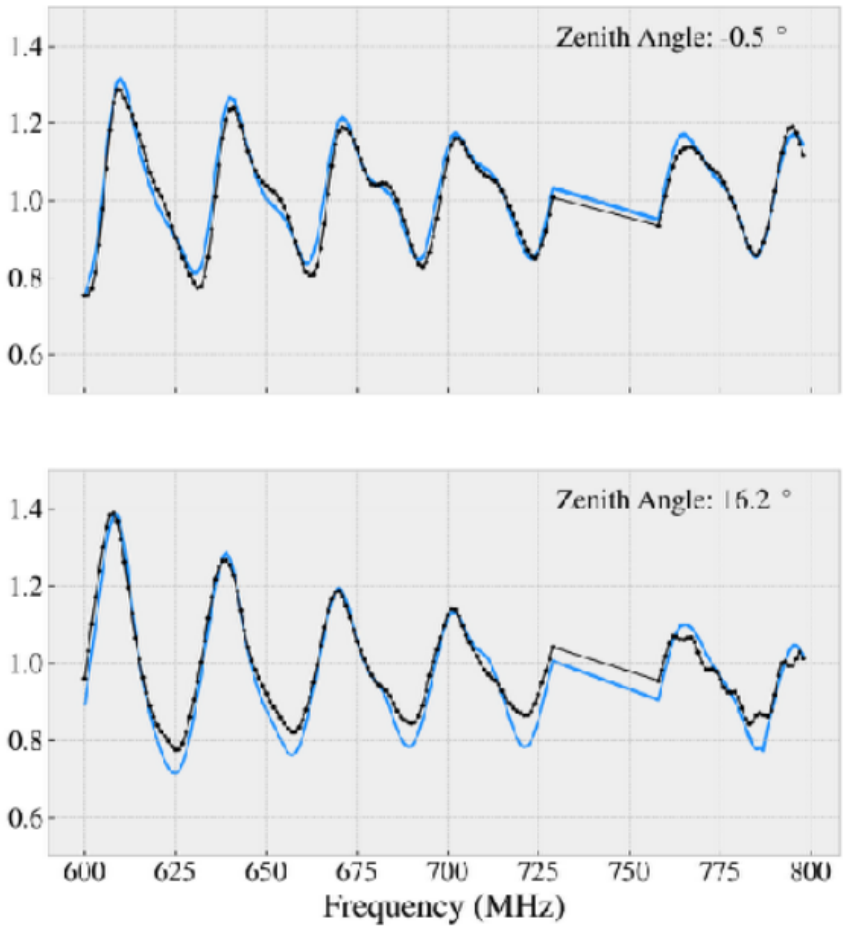
A. Slozar et al arXiv:1907.12559

Back-up

Beam for cylindric antenna



Beam as a function of angle

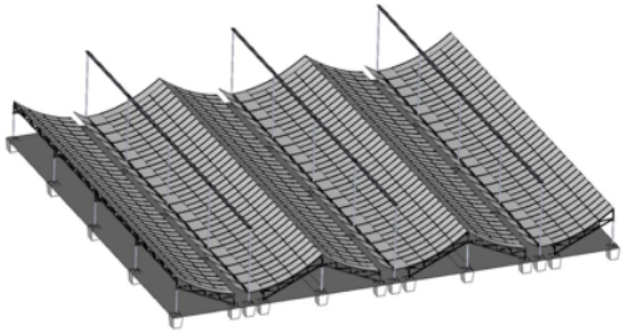


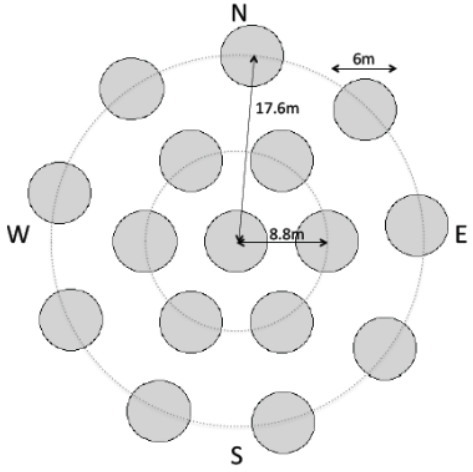
Beam as a function of frequency

K. Bandura, 21cm cosmology workshop 2019

Tianlai

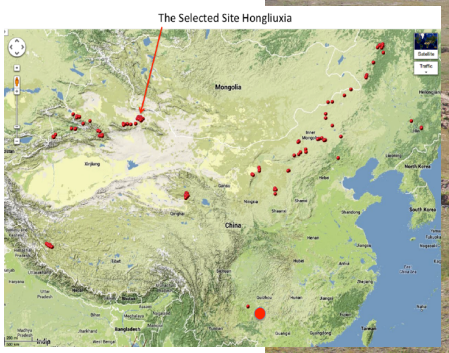
- **Band** 685-810MHz (0.77<z<1.3)
512 frequency channels
($\Delta\nu$=125MHz $\delta\nu$=244kHz δz=0.0002)
tunable in 600-1420MHz (0<z<1.5)
- **Cylinder Array** 3 x 15m x 40m cylinders
96 dual polarization feeds
4 sec sampling
- **Dish Array** 16 x 6m dishes
16 dual polarization feeds
1 sec sampling
- **Pathfinder+ Cylinder Array**
216 dual polarization feeds
4 sec sampling
- **Proposed Full Cylinder Array** 8 x 15m x 120m
2048 dual polarization feeds
400-1420MHz





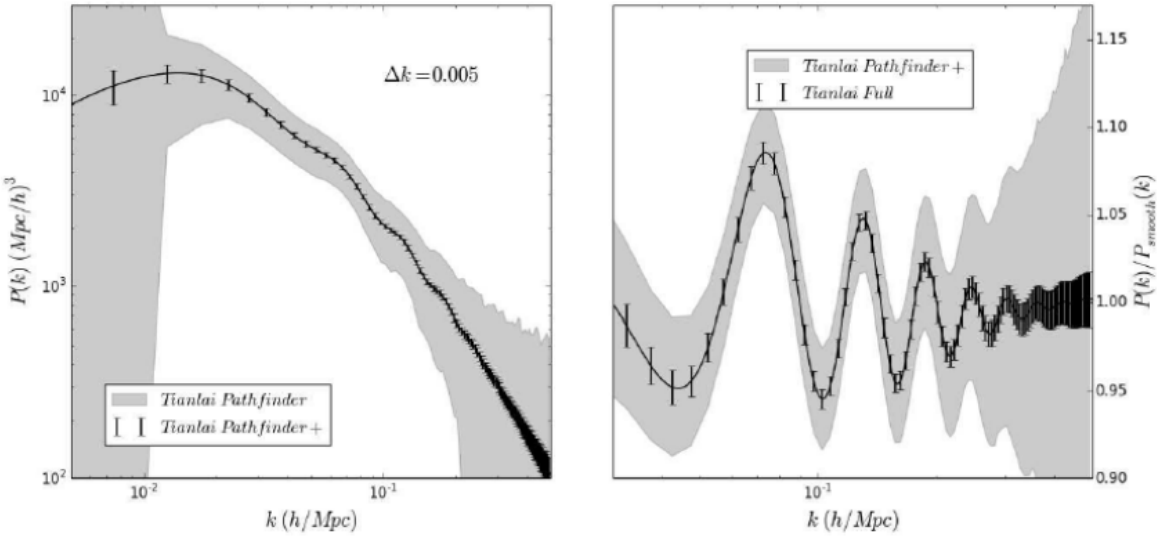
(X. Chen 21cm cosmology workshop 2019)

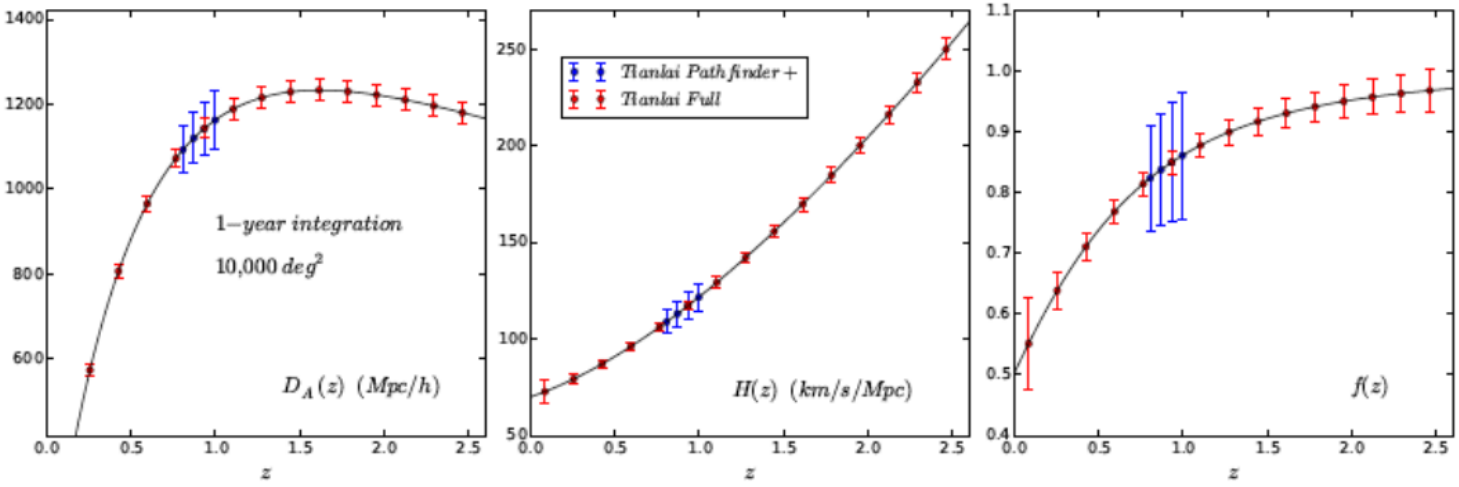
Tianlai site



Observations started in fall 2016

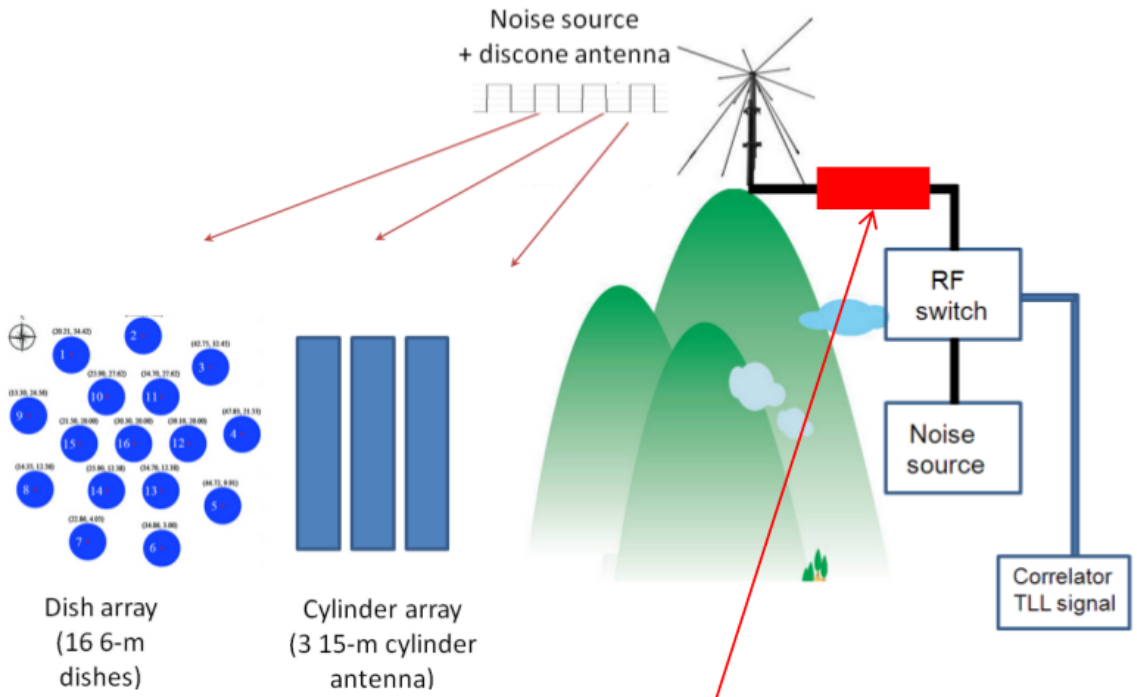
Forecasts (Tianlai)

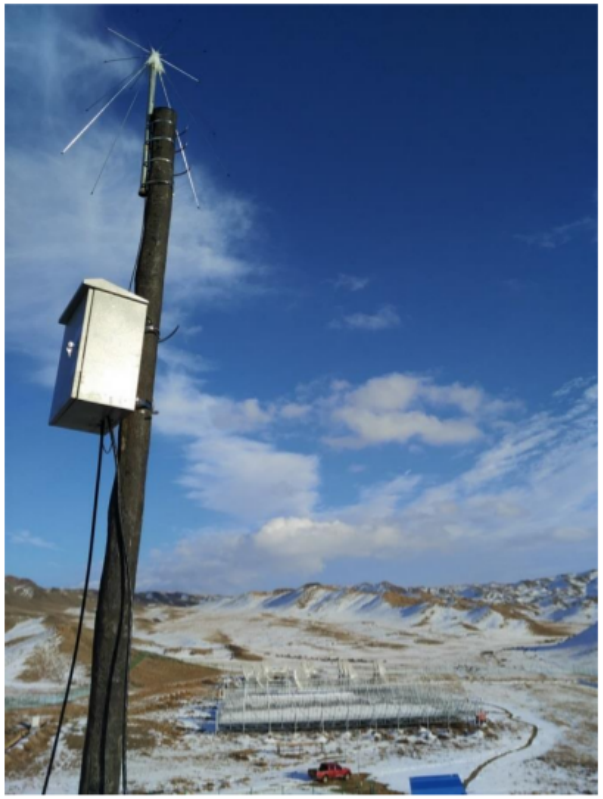


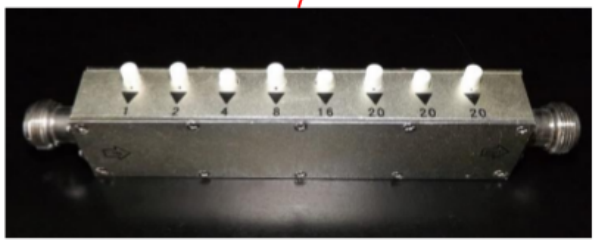


Xu et al arXiv:1410.7794

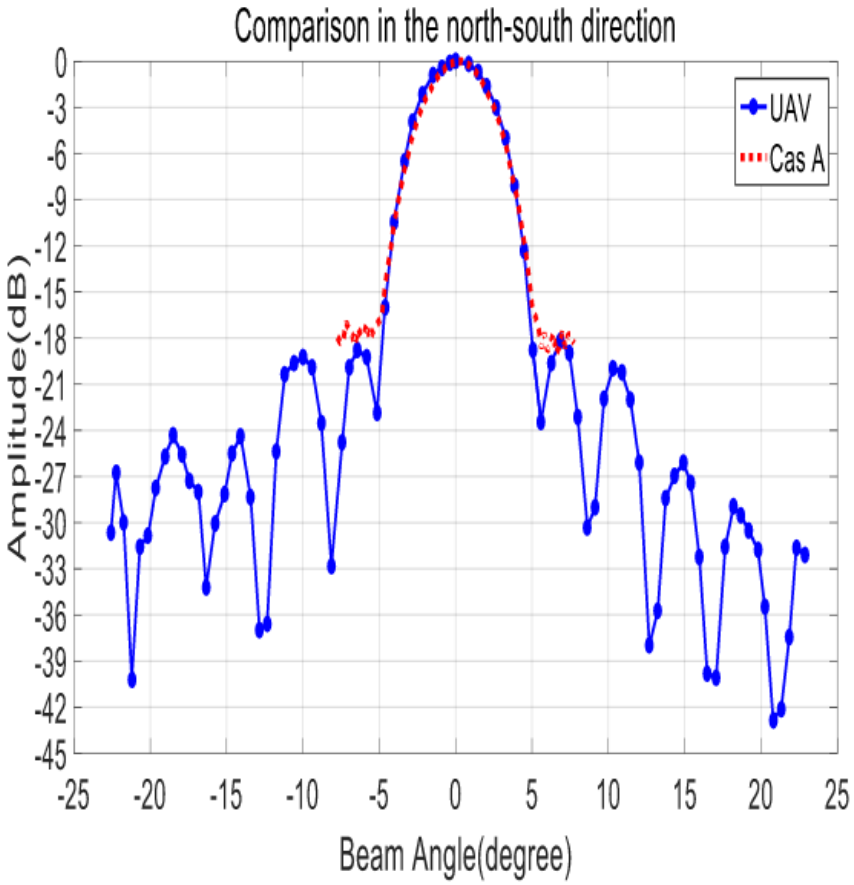
Calibration source

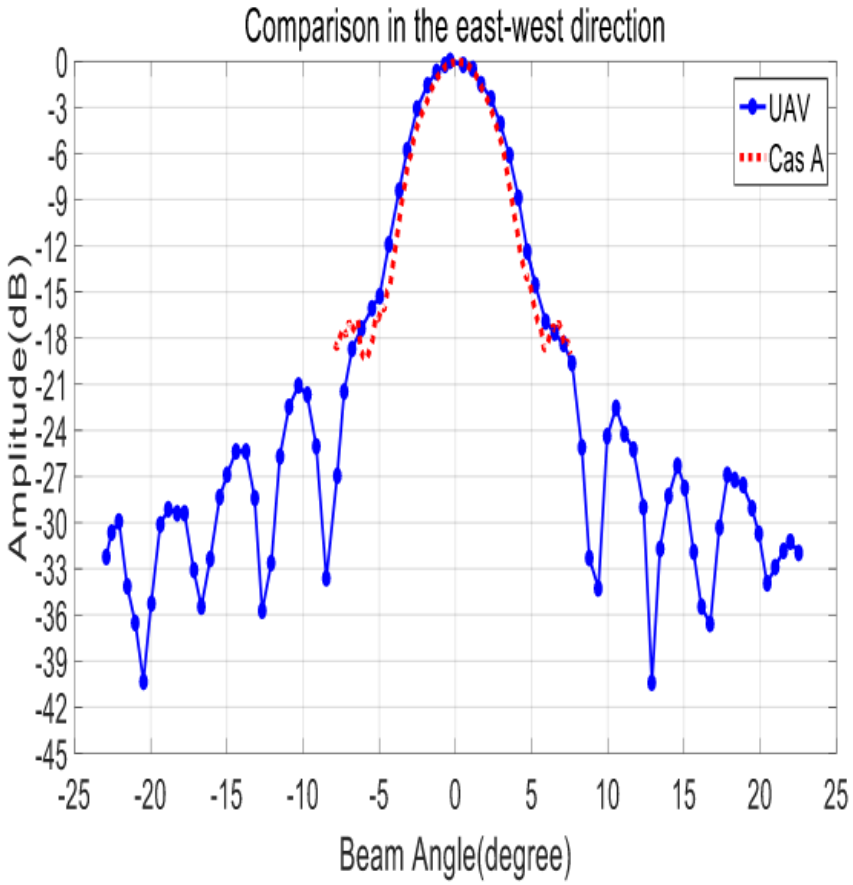




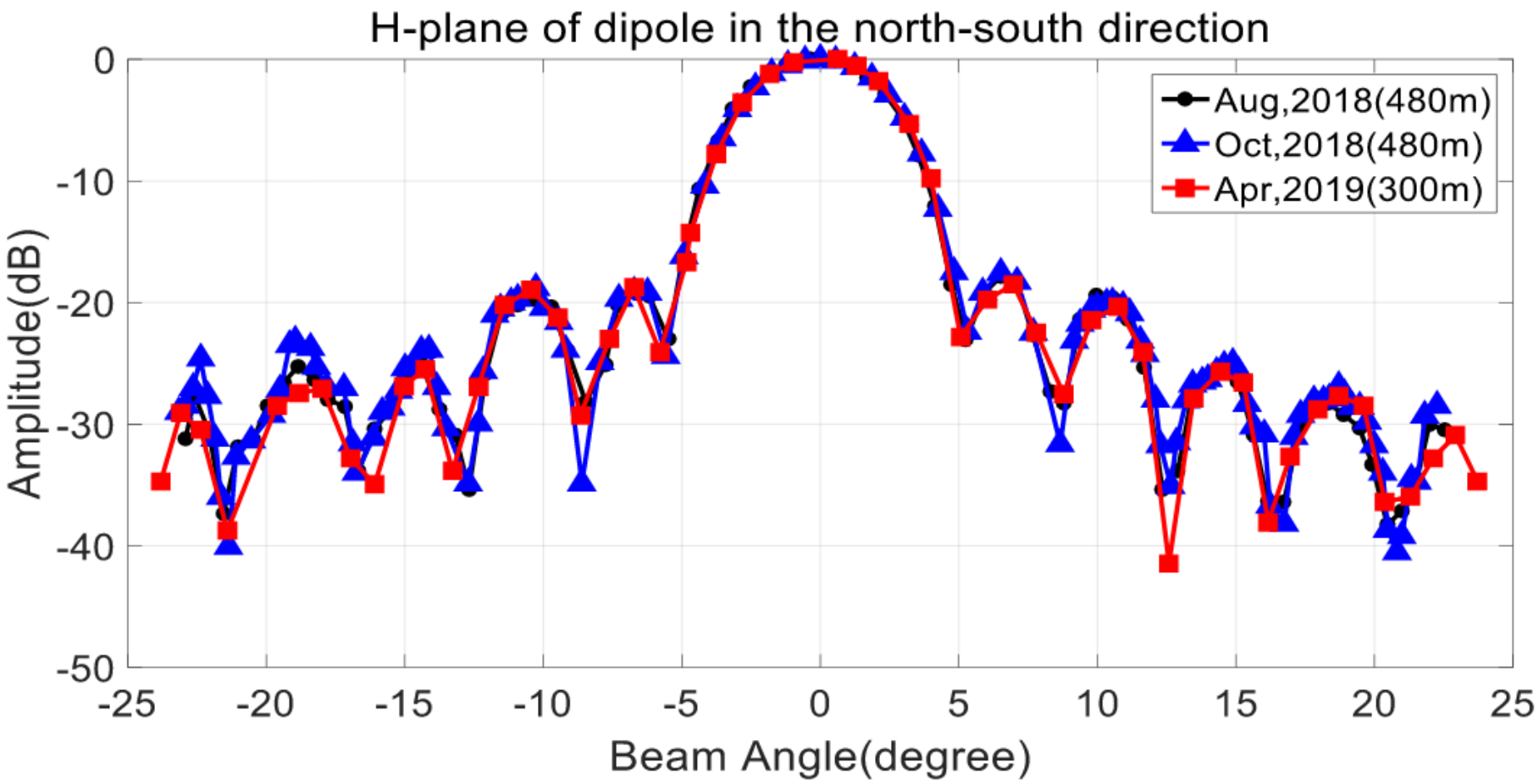


Adjustable Attenuator


Comparison in the north-south direction
UAV
Cas A
Amplitude(dB)
Beam Angle(degree)
0
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30
-33
-36
-39
-42
-45
-25
-20
-15
-10
-5
0
5
10
15
20
25


Comparison in the east-west direction
UAV
Cas A
Amplitude(dB)
Beam Angle(degree)
0
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30
-33
-36
-39
-42
-45
-25
-20
-15
-10
-5
0
5
10
15
20
25

Juyong Zhang et al., in preparation


H-plane of dipole in the north-south direction
Aug,2018(480m)
Oct,2018(480m)
Apr,2019(300m)
Amplitude(dB)
Beam Angle(degree)
0
-10
-20
-30
-40
-50
-25
-20
-15
-10
-5
0
5
10
15
20
25