

21 cm cosmology : Tianlai and Paon4

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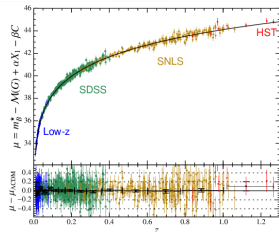
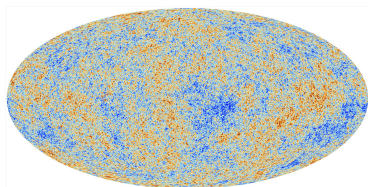
Université Paris-Saclay,
Orsay, France



11th FCPPL workshop
Marseille
may 25th, 2018

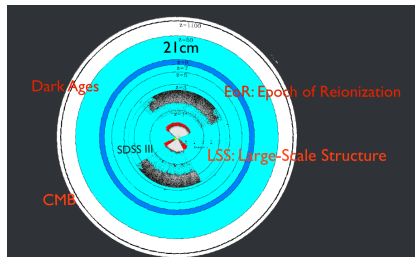
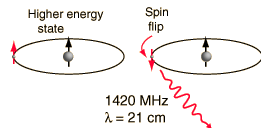
Cosmology

- Very successful concordance model (Λ CDM) based on GR
- Accounts for many observations : CMB (Planck), Type Ia SNe (SNLS), BAO (BOSS/eBOSS),...
- Minimal set of parameters precisely measured (combinations and/or cross-correlations of probes)
- Extensions (inflation, neutrinos, DE) sought for by next gen. projects (CMB-S4, LiteBird, DESI, LSST, Euclid, ...)
- Some “tensions” i.e. 2-3 σ offsets between measurements by different probes at different epochs/scales (e.g. H_0 , σ_8 /galaxy cluster count)



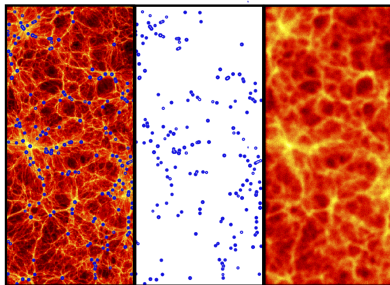
21 cm in cosmology

- Hyperfine transition of ($n=1$) neutral (HI) hydrogen atom : $\lambda \simeq 21\text{cm}$
- Narrow line : enables tomographic studies
- “dark ages” ($z \gtrsim 10$) : absorption of CMB photons
- EoR : tomographic study of reionisation (emission)
- “late” universe : HI 21 cm emission traces matter \Rightarrow LSS tomography for cosmological params, DE, non-gaussianities ...

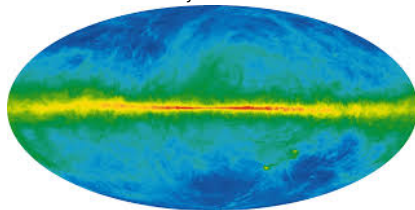


Intensity mapping

- retain **low angular resolution** - treat as a diffuse emission
- use frequency resolution (redshift) \Rightarrow tomography
- challenges :
 - ▶ **Foregrounds** : level $\sim 10^3$ above HI Signal
 - ▶ Radio Frequency Interferences (RFI), atmosphere (ionosphere)
 - ▶ ... and systematics !



The sky at 408 MHz

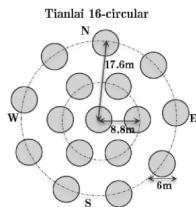
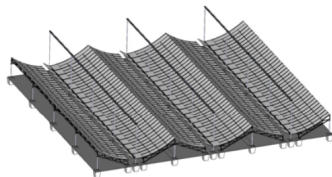


collaboration with NAOC on 21cm IM

- partners : NAOC (X. Chen) and LAL (R. Ansari) (+ Paris Obs. (J.-M. Martin), CEA/IRFU (C. Magneville))
- co-lead PhD students Jiao Zhang (defended 06/2017), Qizhi Huang
- visits from both teams e.g. Fengquan Wu (jan. & feb. 2018)
- work centered on observing strategies, data analysis & computing for Tianlai and PAON4 projects
- but also electronics development (IDROGEN board to be tested on PAON4)

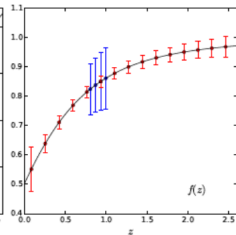
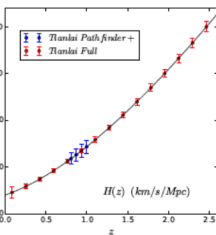
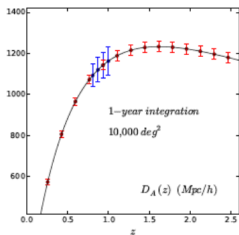
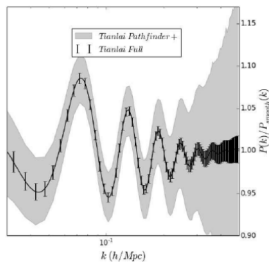
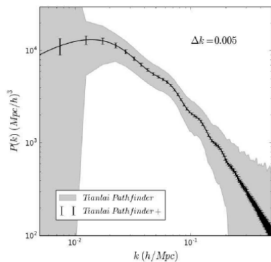
Tianlai

- A small pathfinder experiment to check the basic principles and designs, find out potential problems
- 3x15x40m cylinders, 96 dual polarization receiver units
- 16 x 6m dishes
- observe 700-800MHz, can be tuned in 600-1420MHz
- If successful: expand to full scale 120mx120m, 2500 units

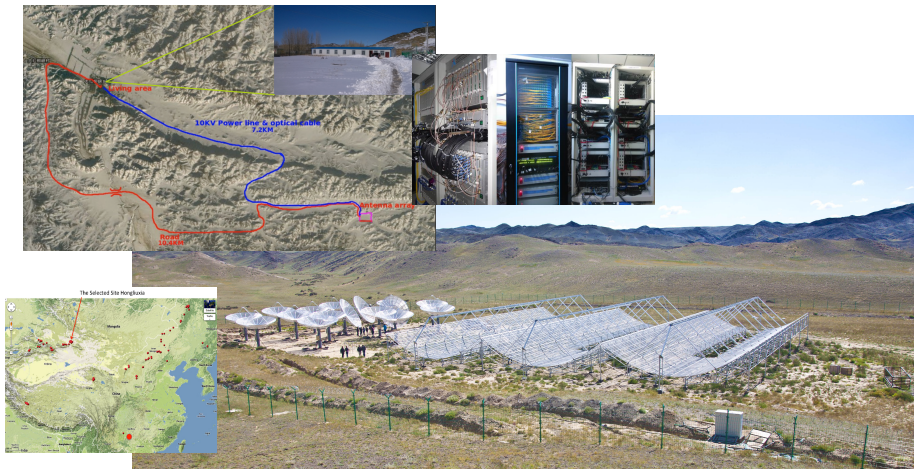


(X. Chen slides @Aspen 02/2018)

Forecasted sensitivity



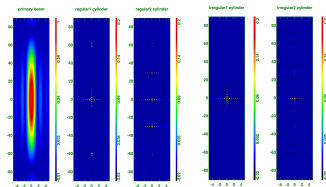
Tianlai on site



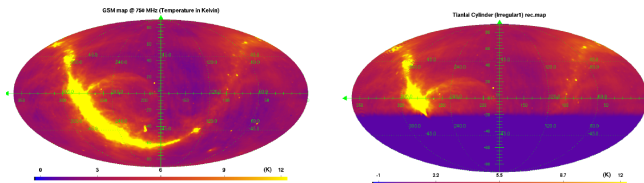
Observations started in fall 2016

Sky reconstruction (cylinder array)

- synthetic beam & array design (sensor positions)



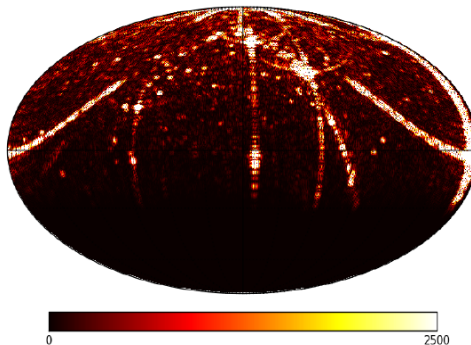
- sky reconstruction using spherical harmonics



Jiao Zhang et al arXiv :1606.03830

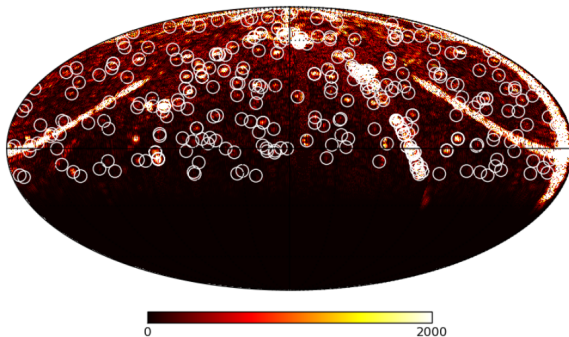
Preliminary sky maps

(data from sept. 2016)



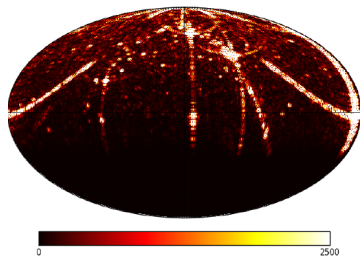
Preliminary sky maps

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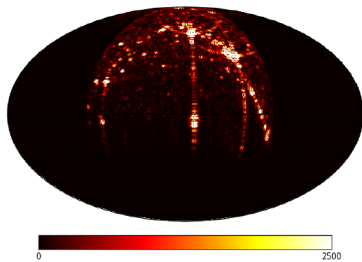


Preliminary sky maps

(data from sept. 2016)



All Day

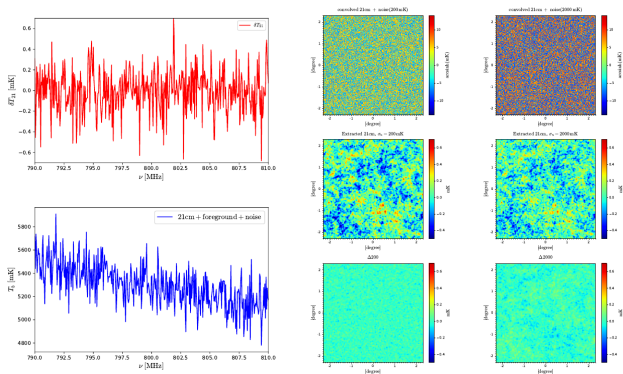


Night Only

Large effect from the Sun during daytime

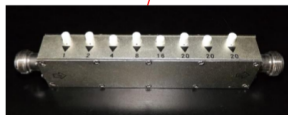
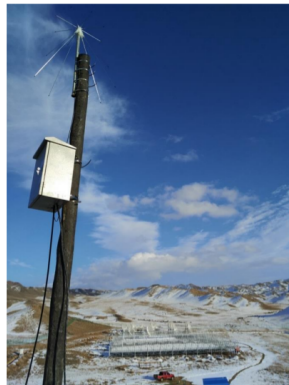
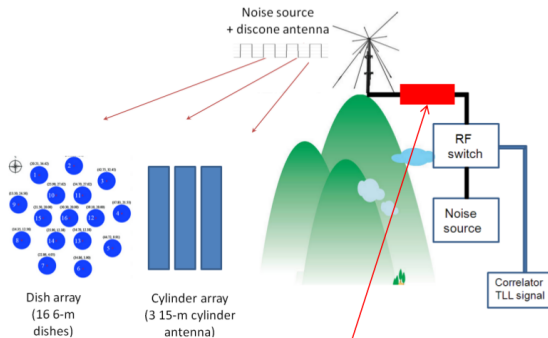
21 cm signal extraction

builds on the smoothness of foregrounds (in frequency space) and signal (in angular space, due to beam smoothing)



Qizhi Huang et al arXiv :1805.08265

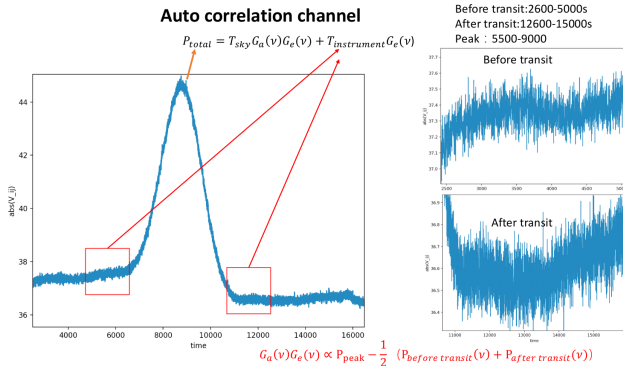
Calibration source



Adjustable Attenuator

Calibration of dish array data

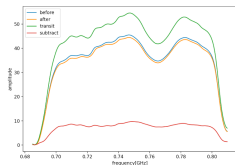
disentangling various components of the frequency response of each channel using transits



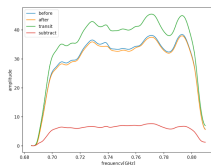
Fengquan Wu

Calibration of dish array data(2)

disentangling various components of the frequency response of each channel

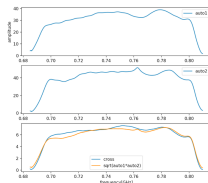


Auto23-23

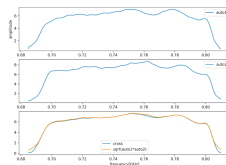


Auto29-29

Cross-correlation channel 2-22



No subtraction on auto channels

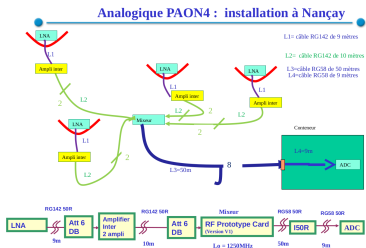


Do subtraction on auto channels

PAON4

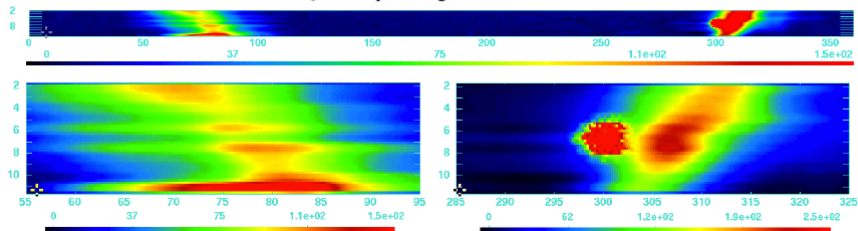
Characteristics :

- 4 antennas (~ 3 deg beams) in Nancay (~ 200 km south of Paris)
- 2 polar./antenna
- Frequency band 1250 - 1500 MHz ($\sim 1275 - 1480$ MHz)
- ± 20 degrees from zeith
- transit observations ;
 ~ 24 h scans since 2015
- test bench for electronics, daq and on-line computing analysis



early maps with PAON4

Quick map making in 1420MHz



Jiao Zhang PhD

several improvements in hardware since then ...

Outlook

- 21 cm intensity mapping = a new probe for precision cosmology
- instrumental and analysis challenges !
- several projects on-going or starting e.g. CHIME, HIRAX, [Tianlai](#), BINGO...
- ... and SKA !
- **thank you !**