MWA
MURCHISON
WIDEFIELD
ARRAY

Kumamoto University

SKA-JP
Square Kilometre Array
Japanese Consortium

MWA超低周波電波のデータ解析

SHINTARO YOSHIURA

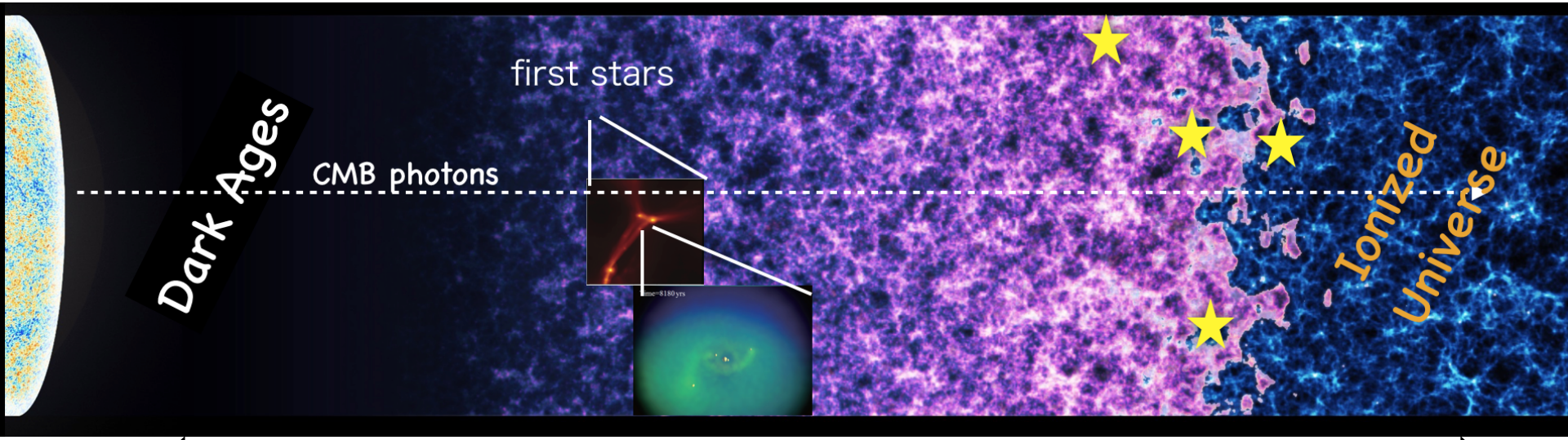
B. Pindor, C.M. Trott, K. Takahashi and MWA EoR team

All results are preliminary

Gurlgamarnu

Introduction

Credit : K Hasegawa



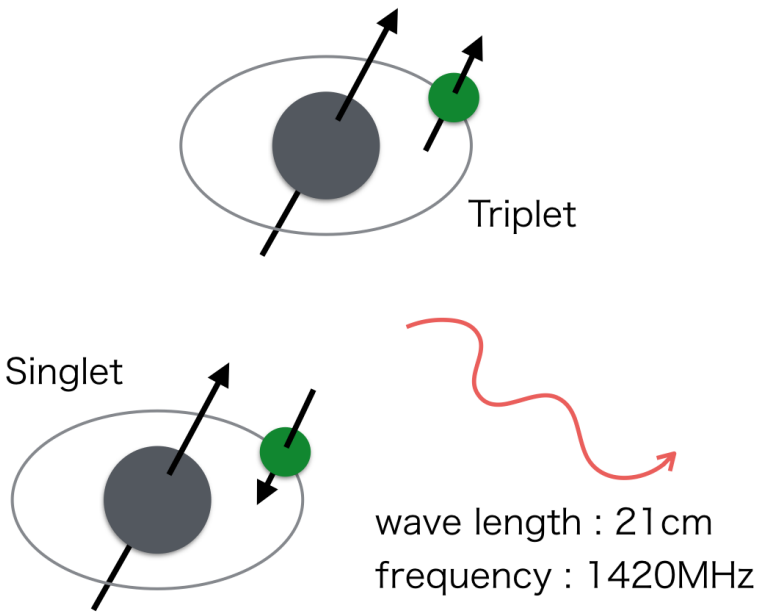
21cm line

21cm line

Hyperfine structure :
energy difference due to
the spins of proton and electron.

An atom emits a photon with
a wavelength of 21cm via
the spin-flip transition.

During the EoR and the CD,
the 21cm line is a good tracer of the IGM.



21cm brightness temperature

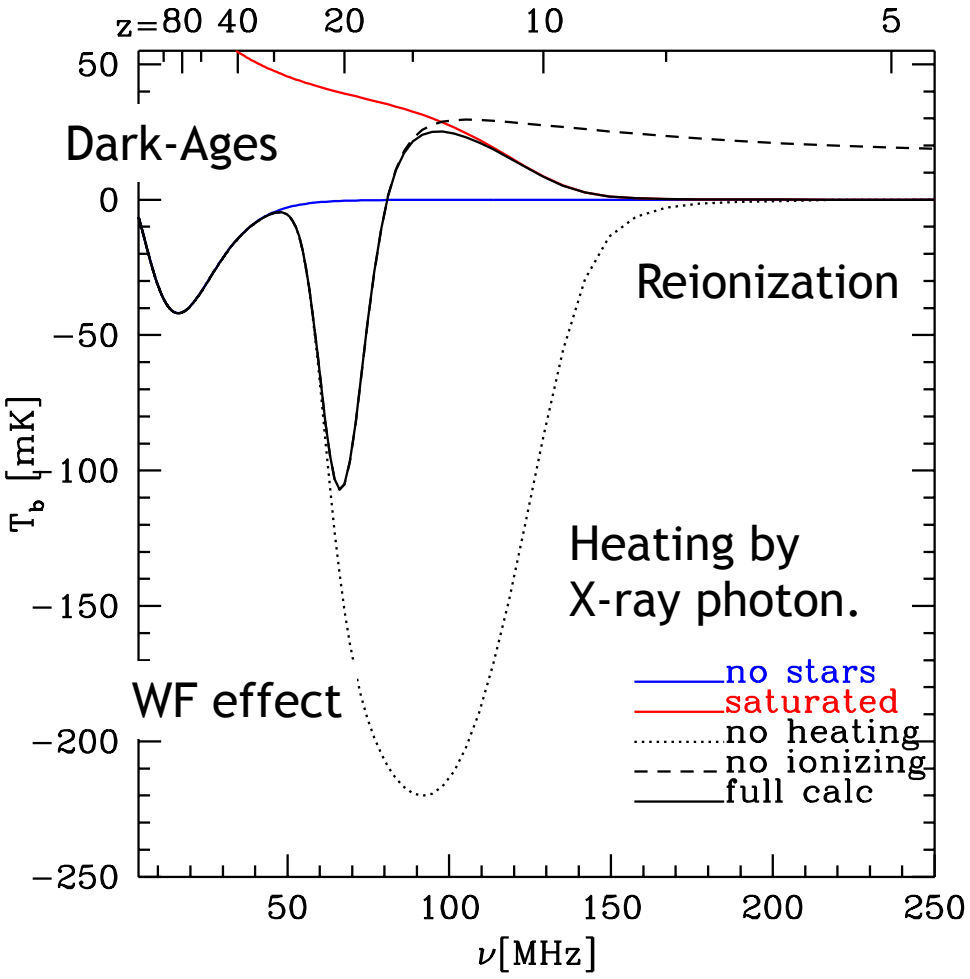
$$\delta T_b \propto x_{\rm HI}(1+\delta_{\rm m})(1-T_{\rm CMB}T_S^{-1})$$

Global signal

21cm Global signal :

$$T_{21} \propto x_{\rm HI}(1 - T_{\rm rad}T_{\rm S}^{-1})$$

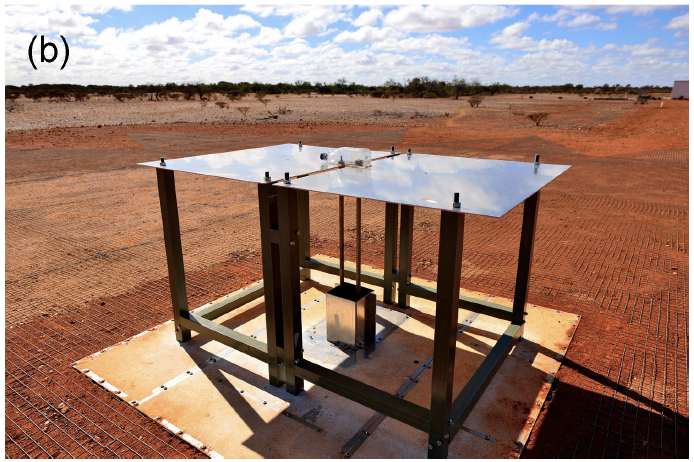
EDGES is designed for measuring the 21cm emission and absorption.



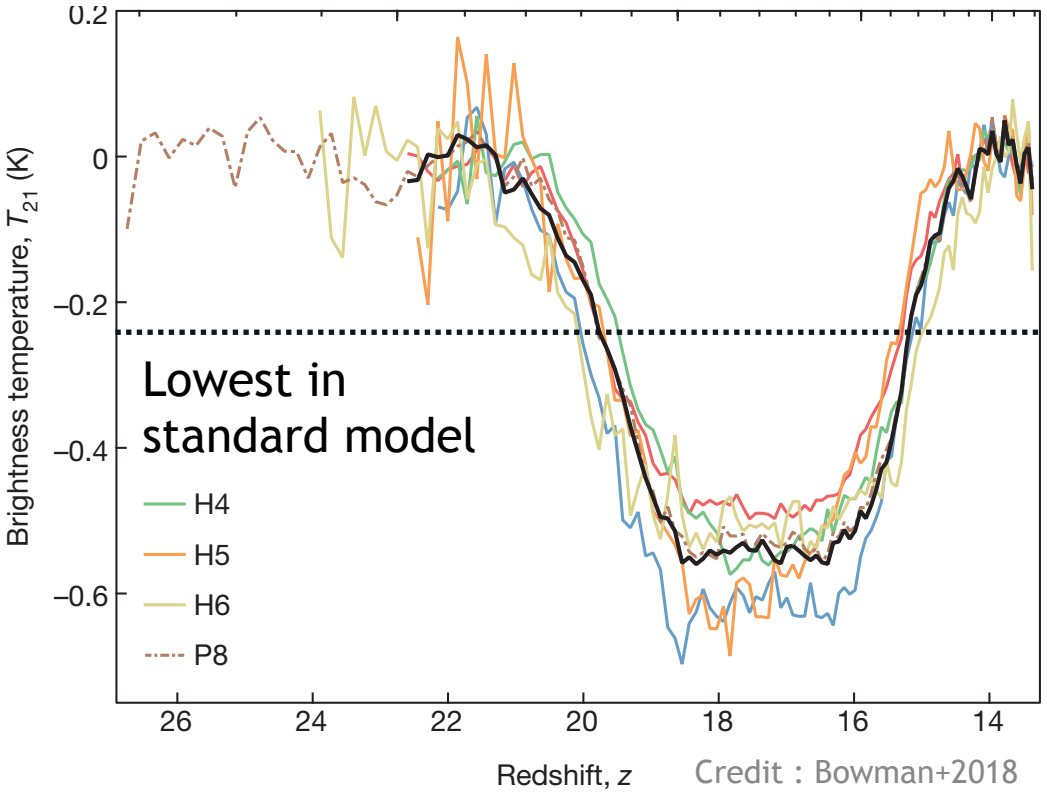
Pritchard & Loeb 2012

Too strong absorption

Measured δTb is -500 mK at z=17, and T_K need to be less than 3.2K.
However, the minimum T_K should be 6 K at z=17 in standard cosmology.



Credit : Bowman+2018



Credit : Bowman+2018

Figure 2 | Best-fitting 21-cm absorption profiles for each hardware case.

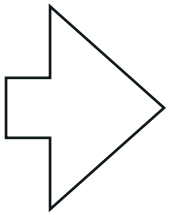
New physics? Need more data

EDGES low band : detection a powerful absorption

Inspired papers :
Barkana 2018, Fialkov+2018, Berlin+2018,
Fraser+2018, Hirano&Bromm 2018, SY +2018, Minoda+2019, etc

- early decouple of gas and radiation ?
- Hotter CMB ?
- High baryon density ?
- Radio background ?
- Did some exotic physics cool the HI gas ?

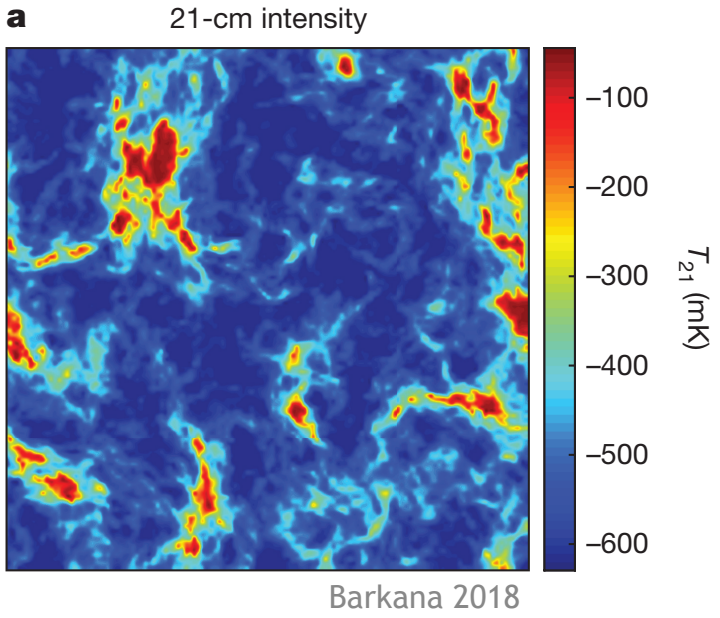
  > baryon and dark-matter interaction? Barkana 2018, Nature Letter.



We need to observe the frequency using other instruments !
e.g. Power spectrum with interferometers

Statistical approach

- Ideally, 21cm line will be imaged.
- Statistical analysis is required to increase sensitivity of ongoing telescopes.



Barkana 2018

Power spectrum

$$\langle \delta_{21}(\mathbf{k})\delta_{21}(\mathbf{k}')\rangle = (2\pi)^3\delta(\mathbf{k}+\mathbf{k}')P_{21}(\mathbf{k})$$

Bispectrum

$$\langle \delta_{21}(\mathbf{k}_1)\delta_{21}(\mathbf{k}_2)\delta_{21}(\mathbf{k}_3)\rangle = (2\pi)^3\delta(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_3)B(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3)$$

In this talk

Instrument : MWA phase I (128 tiles)
Bandpass : 74-100MHz (18 > z > 13)
Observation time : ~5hours

Showing foregrounds and systematics
Calculating power spectrum and bispectrum
Predict future detectability

Credit: Natasha Hurley-Walker

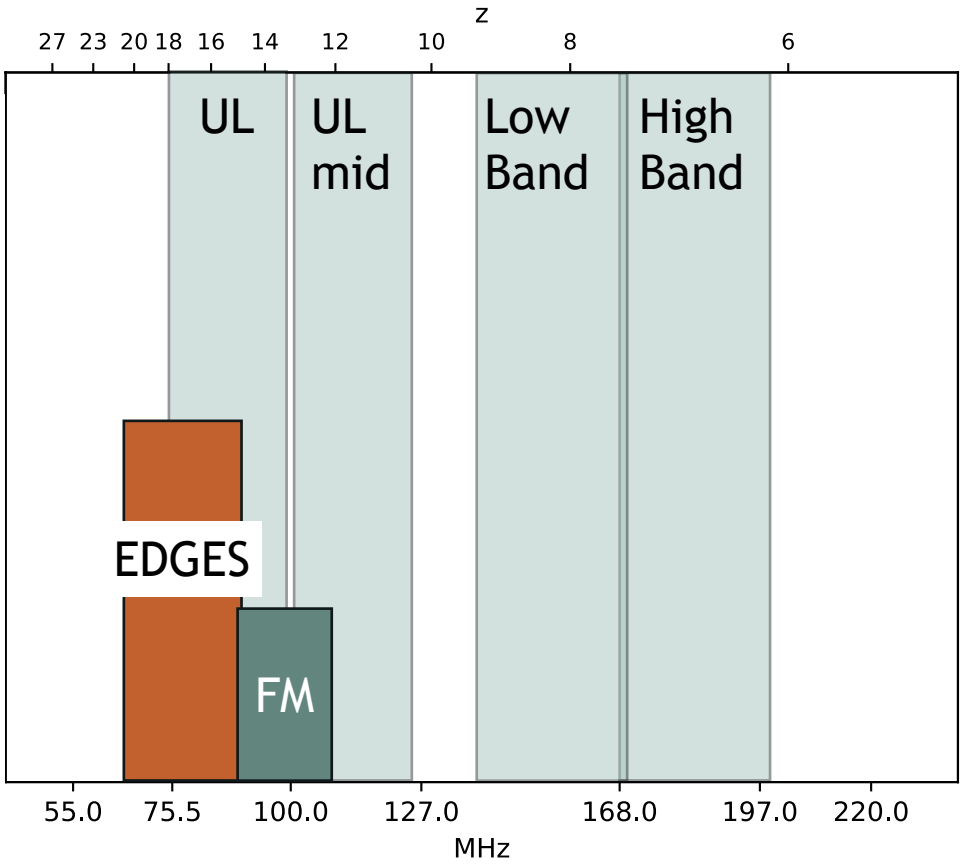
Software : RTS (calibration)
: CHIPS (power spectrum estimator)

Objectives ・detection of 21cm power spectrum at Cosmic Dawn
・the study MWA systematics and foreground at ultralow
・validation of EDGES result

Data property

Obstacles at ultralow frequency

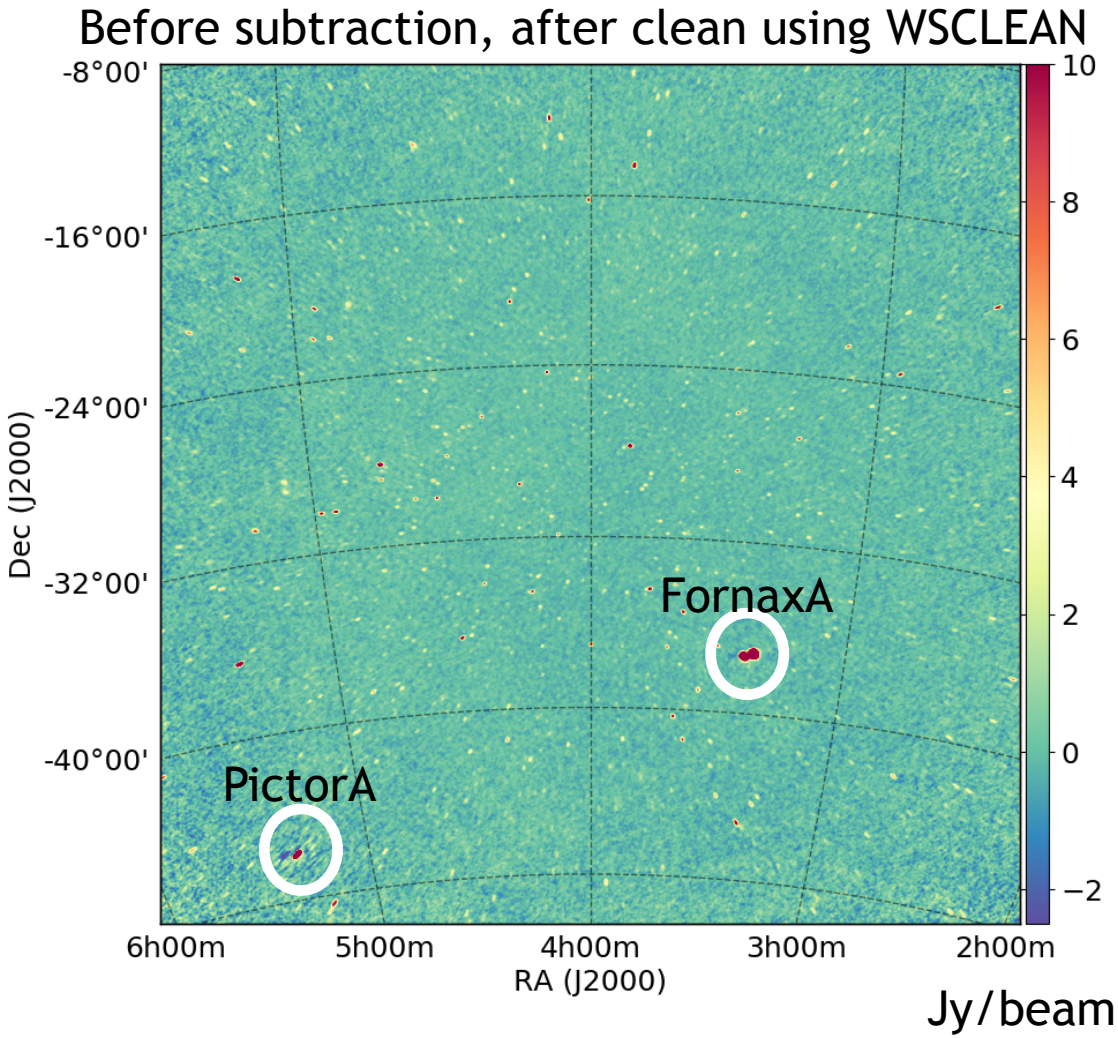
- powerful thermal noise
- high RFI contamination
- (too) bright foregrounds
- (too) wide field of view



EoR1 field at ultralow band

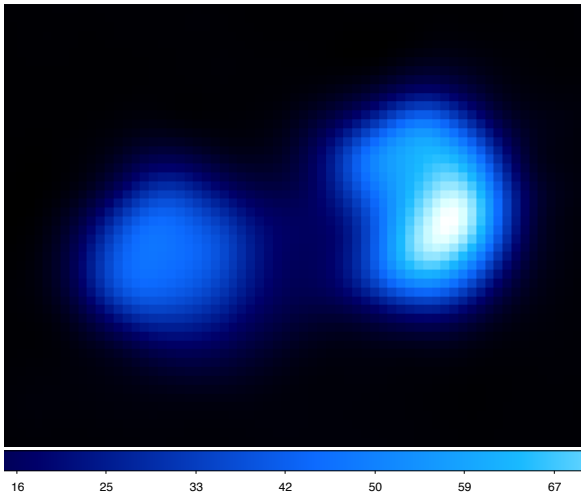
Phase center : EoR1
(RA,Dec) = (4h,-30deg)

Beam size : 40*40 deg^2



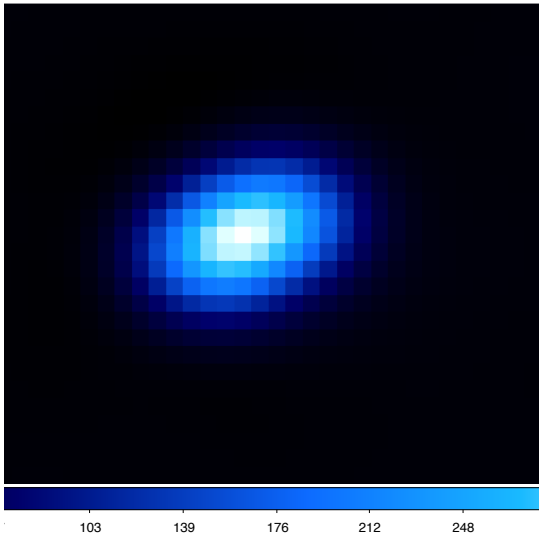
Extended sources

Fornax A
- extended source
- modeling with shape-let



Jy/beam

Pictor A
- extended source
- modeling with 2D gaussian

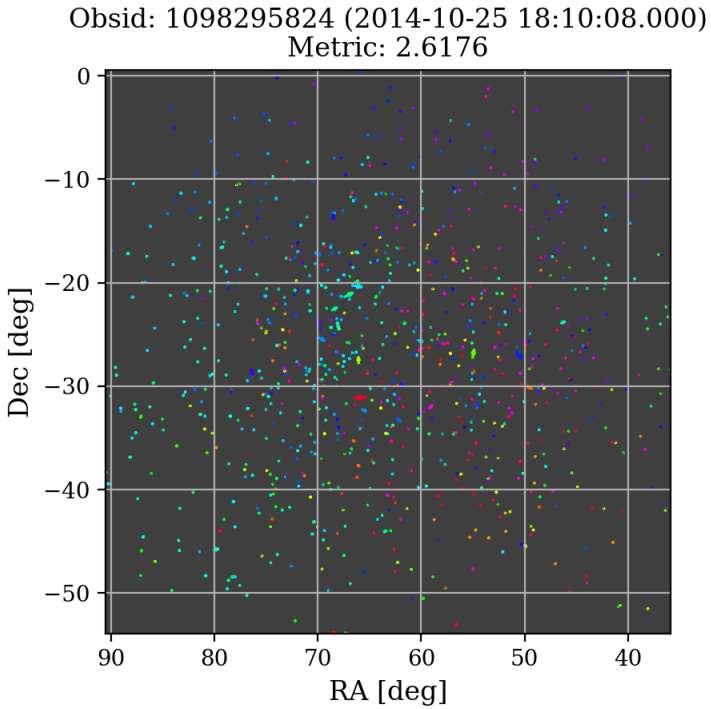


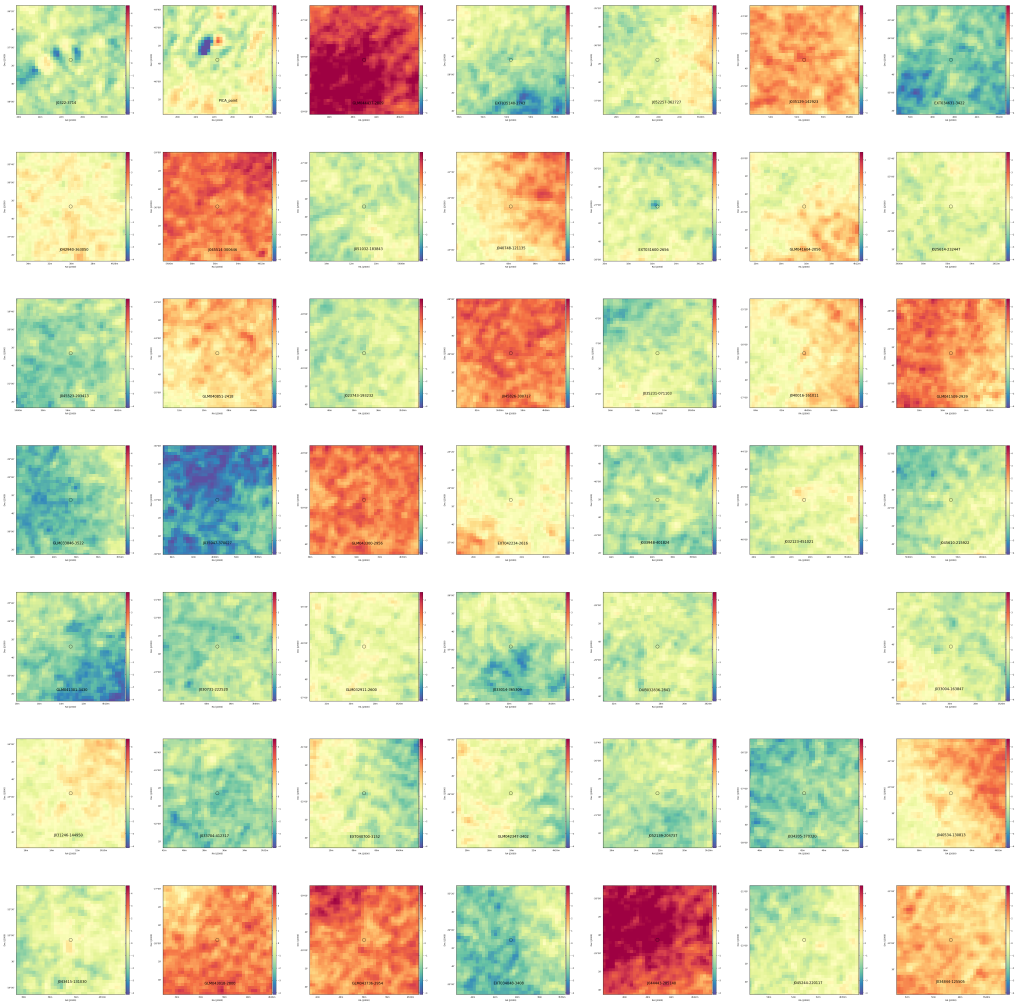
Jy/beam

Peeling

Results of point source subtraction
Quiet ionosphere data

Ionosphere could have influence on subtraction of point sources

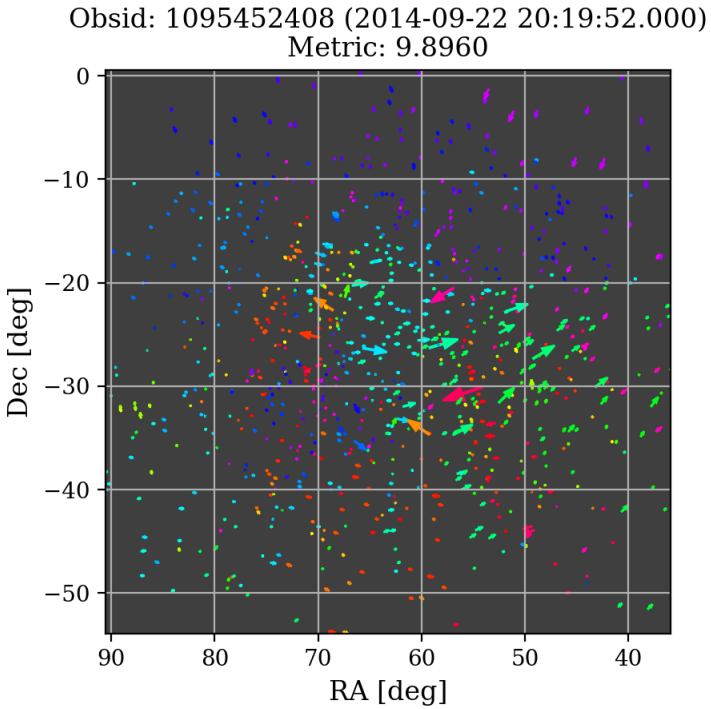


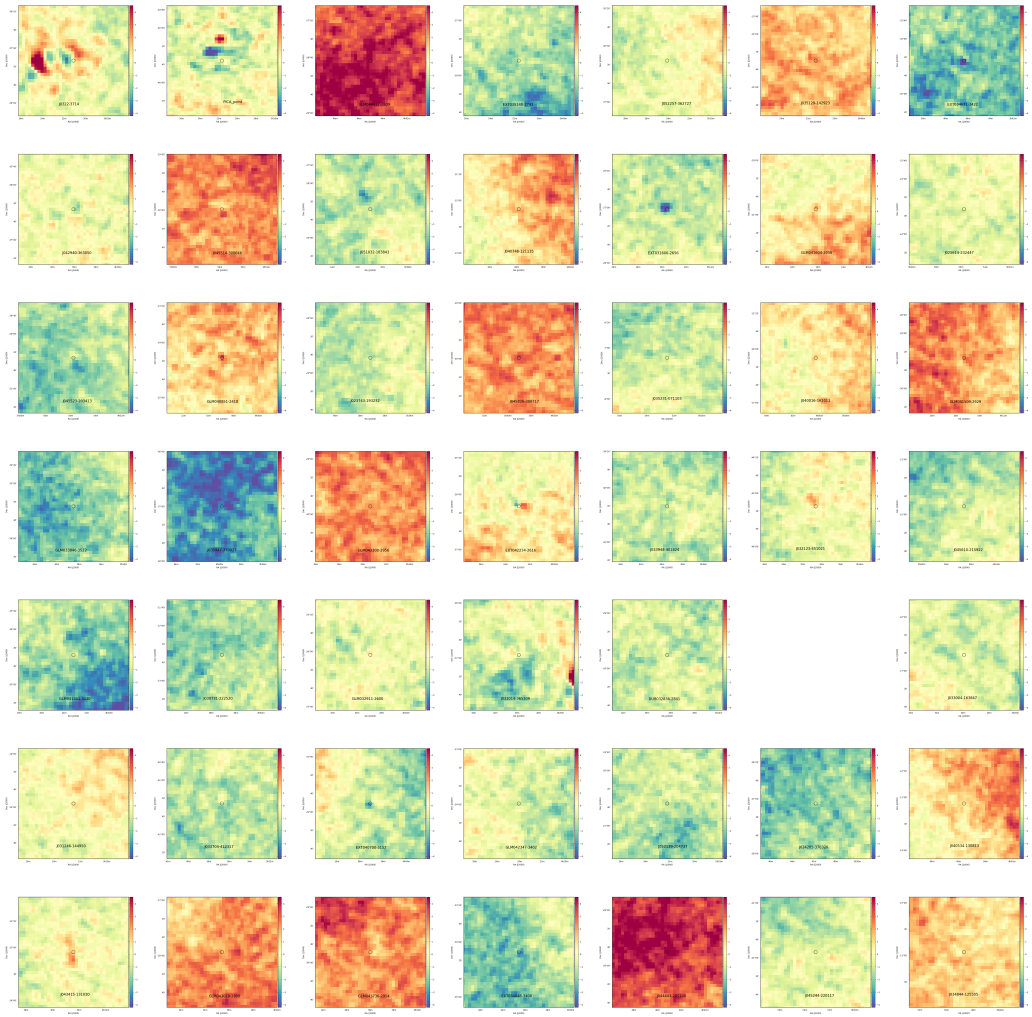


Peeling

Results of point source subtraction
Active ionosphere data

Ionosphere could have influence on subtraction of point sources



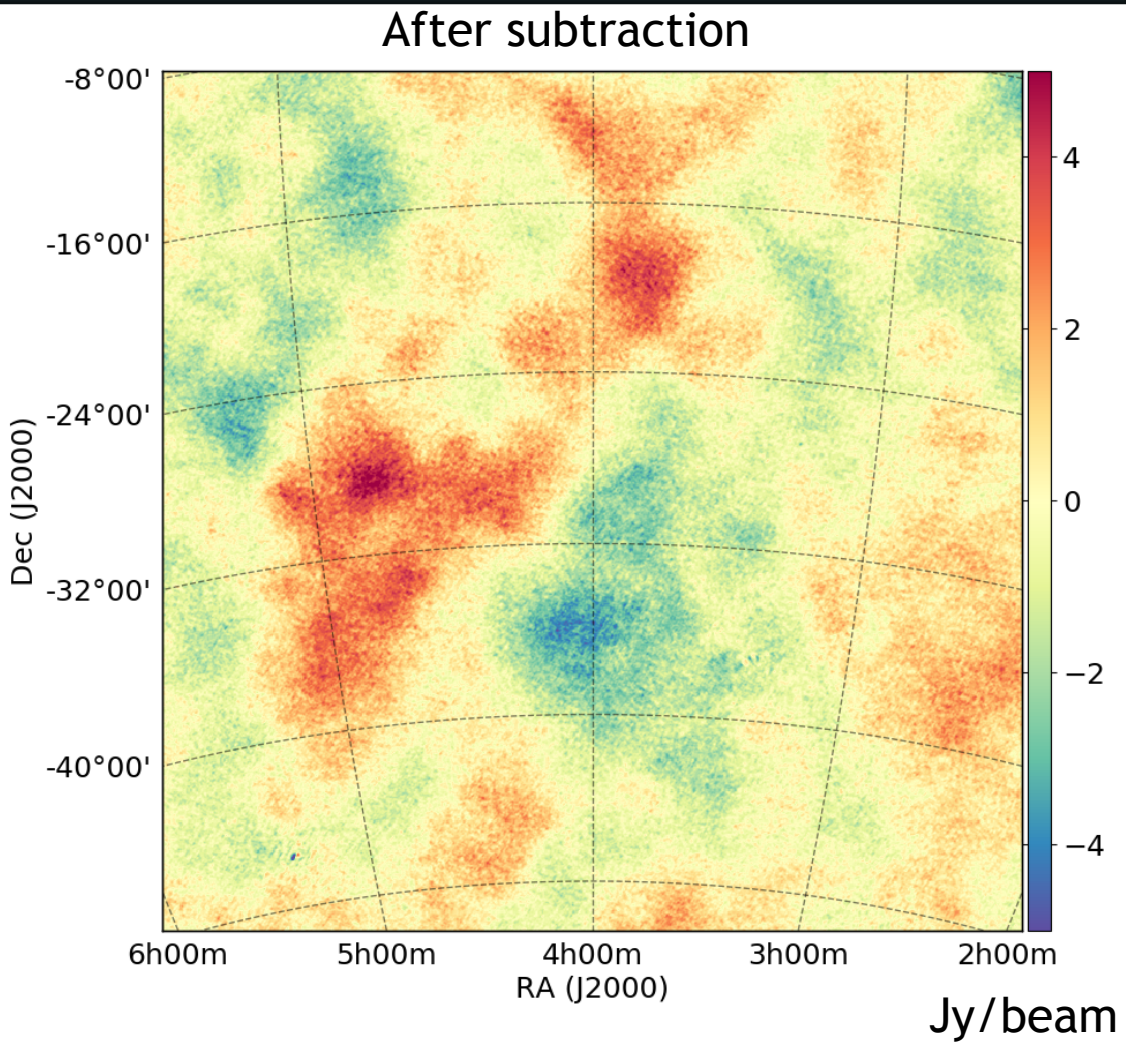


EoR1 field at ultralow band

Phase center : EoR1
(RA,Dec) = (4h,-30deg)

Beam size : 40*40 deg^2

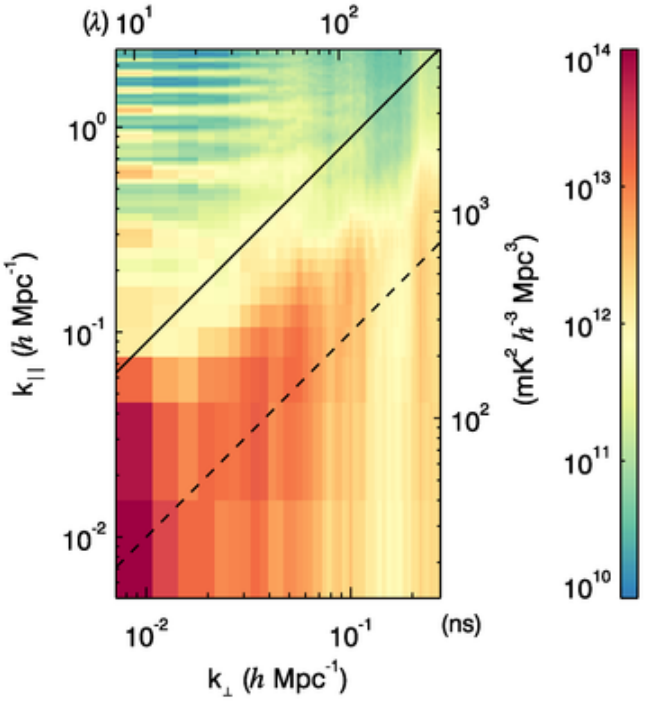
calculate power spectrum using the data after point source subtraction.



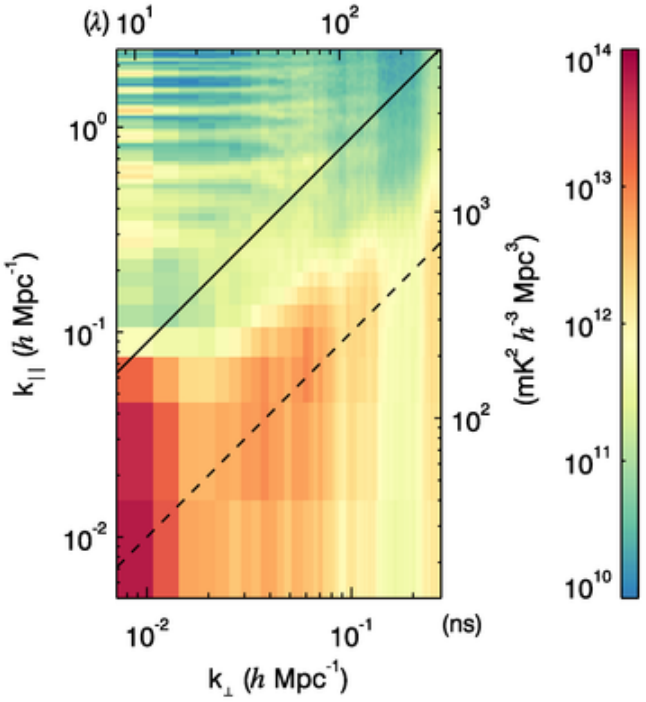
2D power spectrum

Using ultraCHIPS, good ionosphere, lower RMS

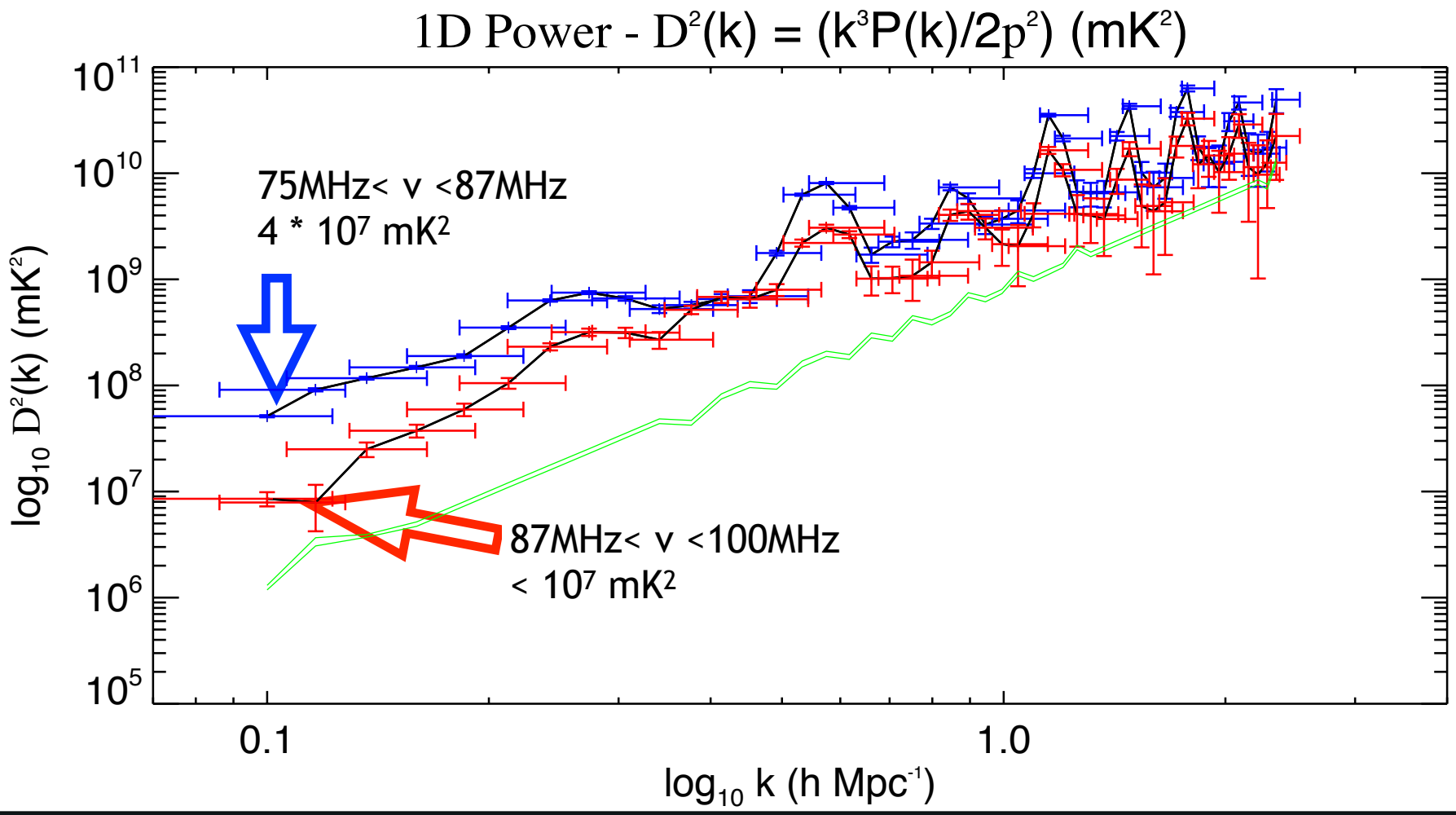
75MHz< ν <87MHz



87MHz< ν <100MHz

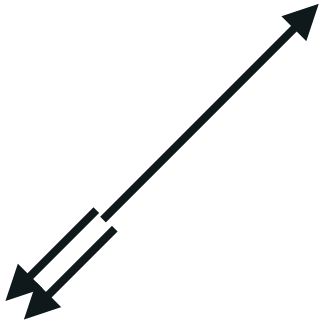


1D power spectrum

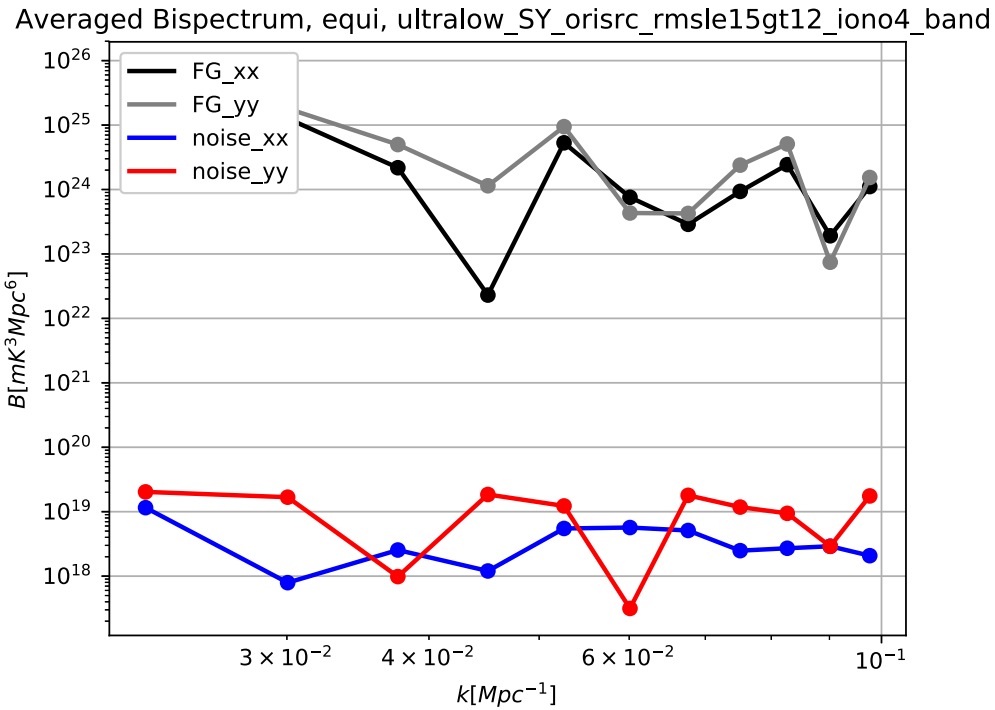


Folded Bispectrum

Choose three vector in Fourier space

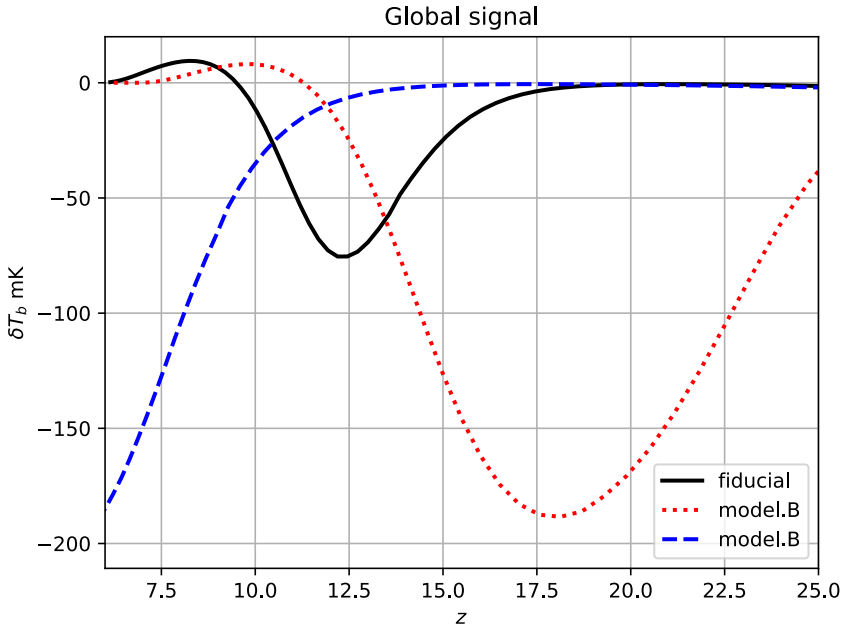


$$|k_1|/2 = |k_2| = |k_3|$$

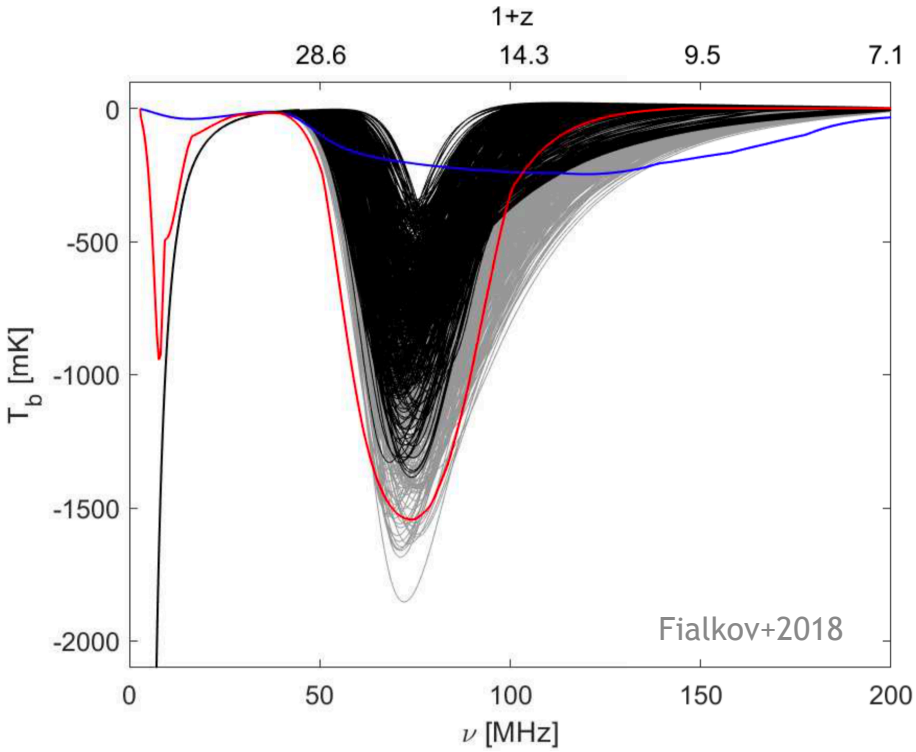


Signal prediction

To compare the data, we perform the 21cmFAST

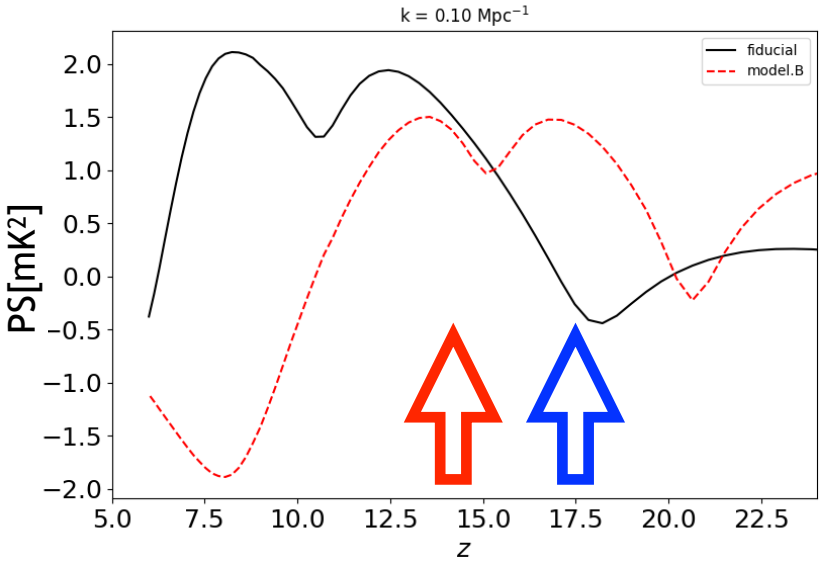


and refer Fialkov+2018

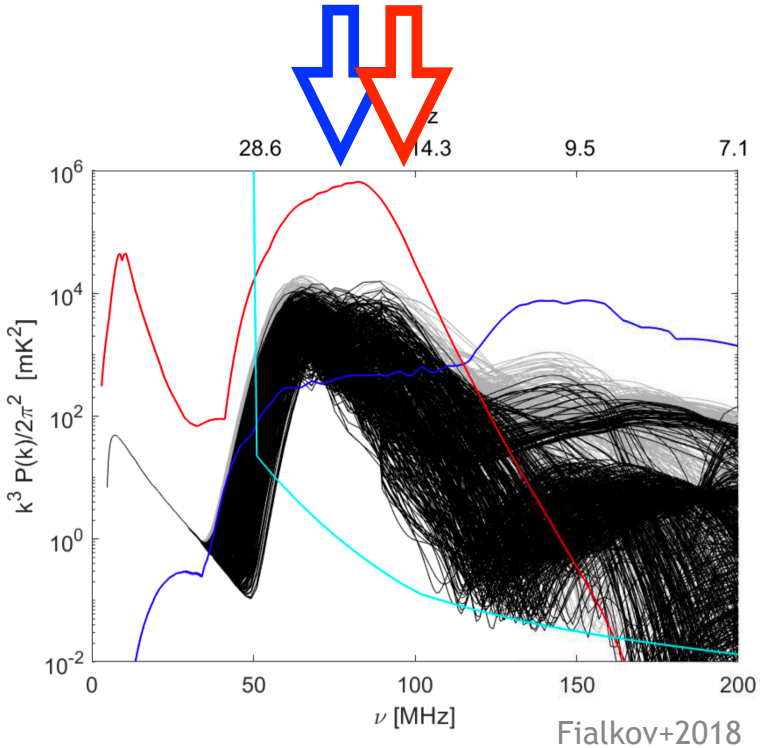


Power spectrum

Upper limits : 10^7 mK^2
Need to remove foreground (1~2 orders) and add more data



21cmFAST



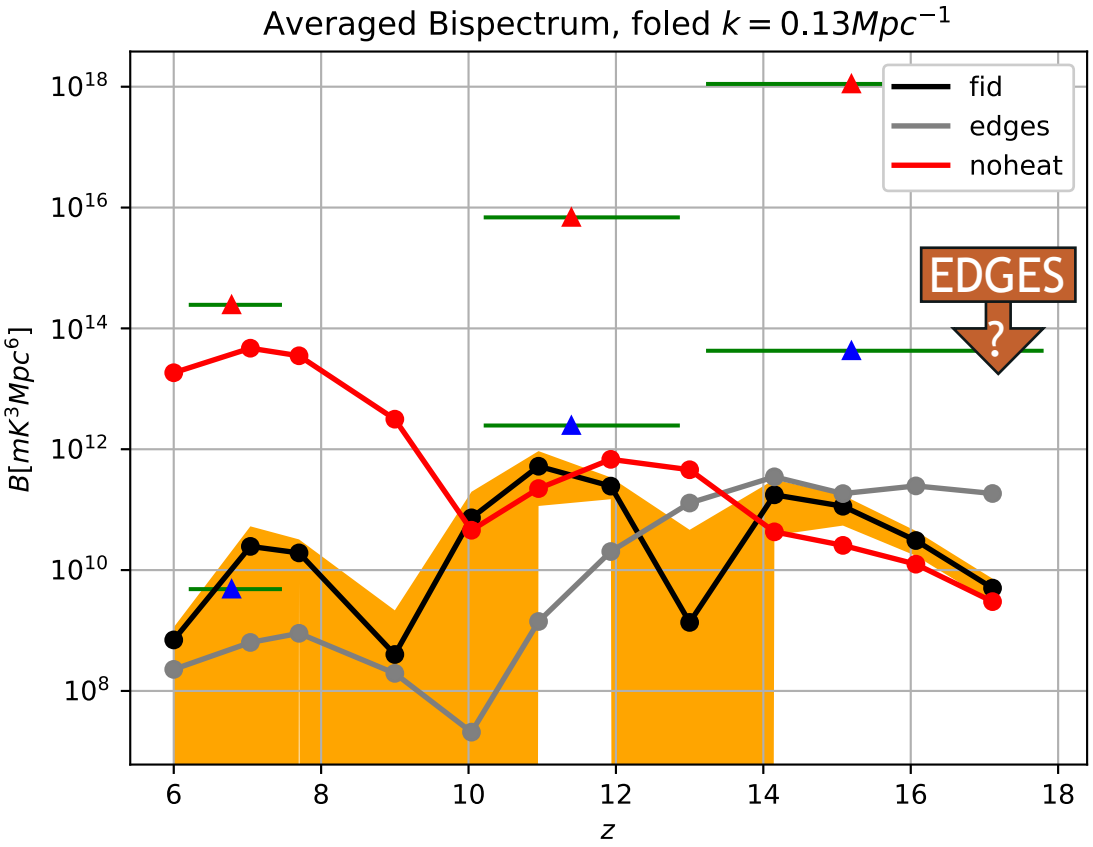
Fialkov+2018

Bispectrum forecast

Assumptions
- MWA PhaseII
- 1000hours observation
- FGRM 2 orders of magnitude

MWA can measure
the bispectrum at high band

MWA might validate
the EDGES results



Summary

Analyzing the MWA Ultralow data (75-100MHz)

Objectives

- Deep analysis on UL data
- validation of the EDGES strong absorption

Correct limits

- Power spectrum 10^{7} mK^{2} at 0.1 Mpc^{-1}
- Bispectrum 10^{24} $mK^{3}Mpc^{6}$ at 0.1 Mpc^{-1}
- MWA Phase II might validate the EDGES absorption

Requirements

- observation of 1000hours
- foreground removal more than 2 orders of magnitude in Kelvin

Next steps

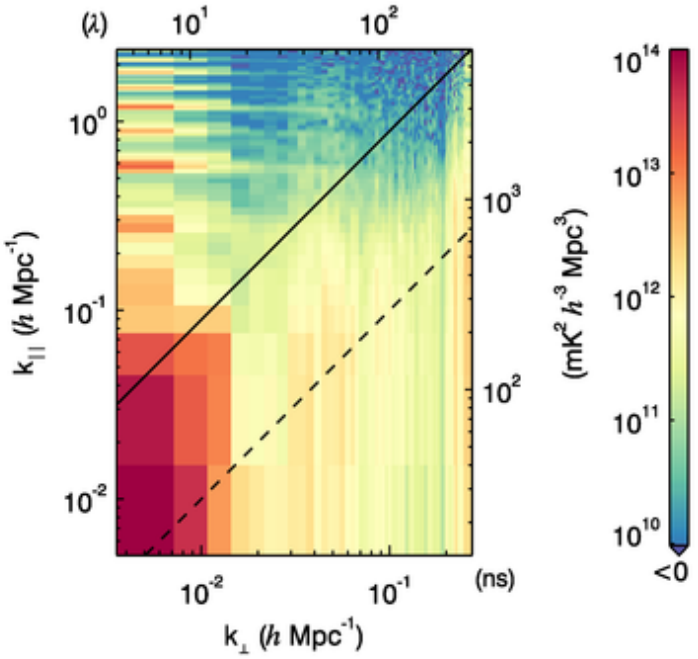
- Using more data,
- Attempting to foreground removal,
- Selecting clean data

Note : all results are preliminary

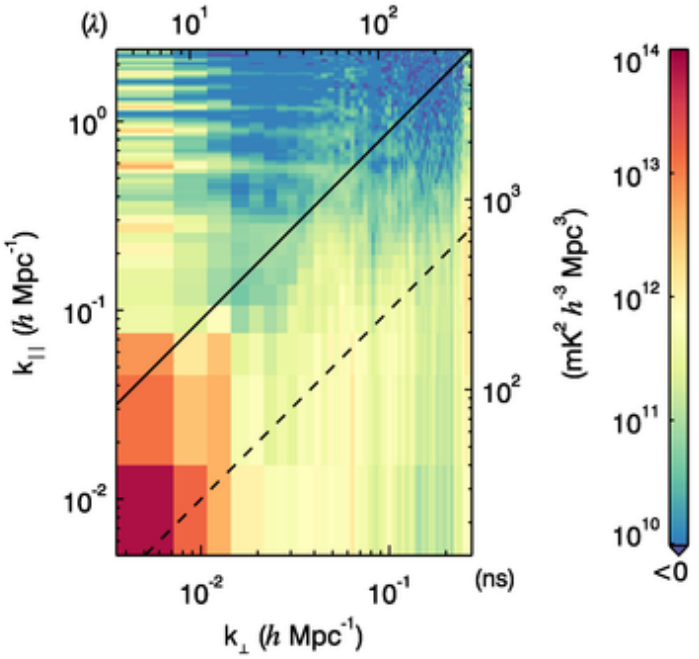
2D power spectrum

Using ultraCHIPS, good ionosphere, lower RMS

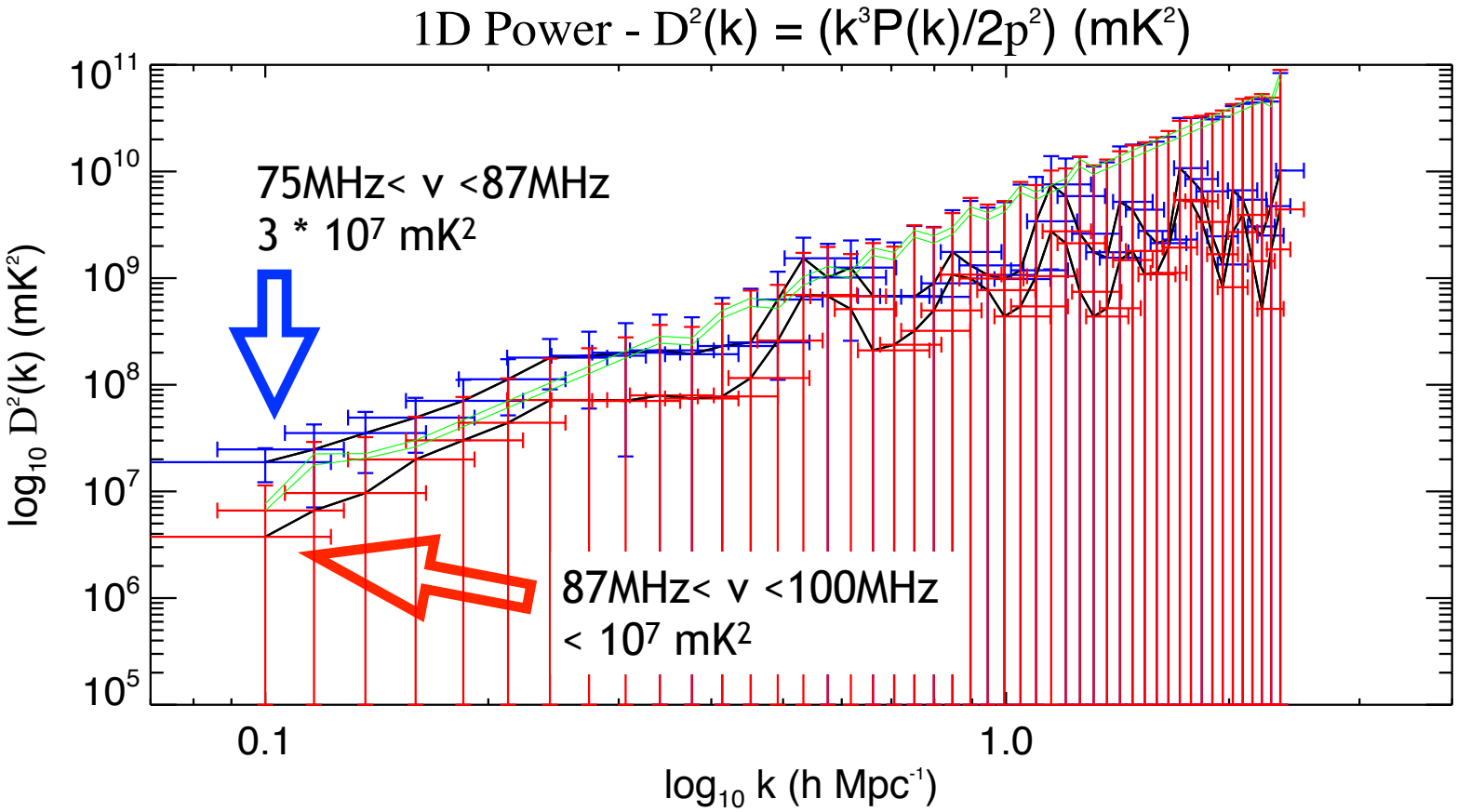
75MHz< ν <87MHz



87MHz< ν <100MHz

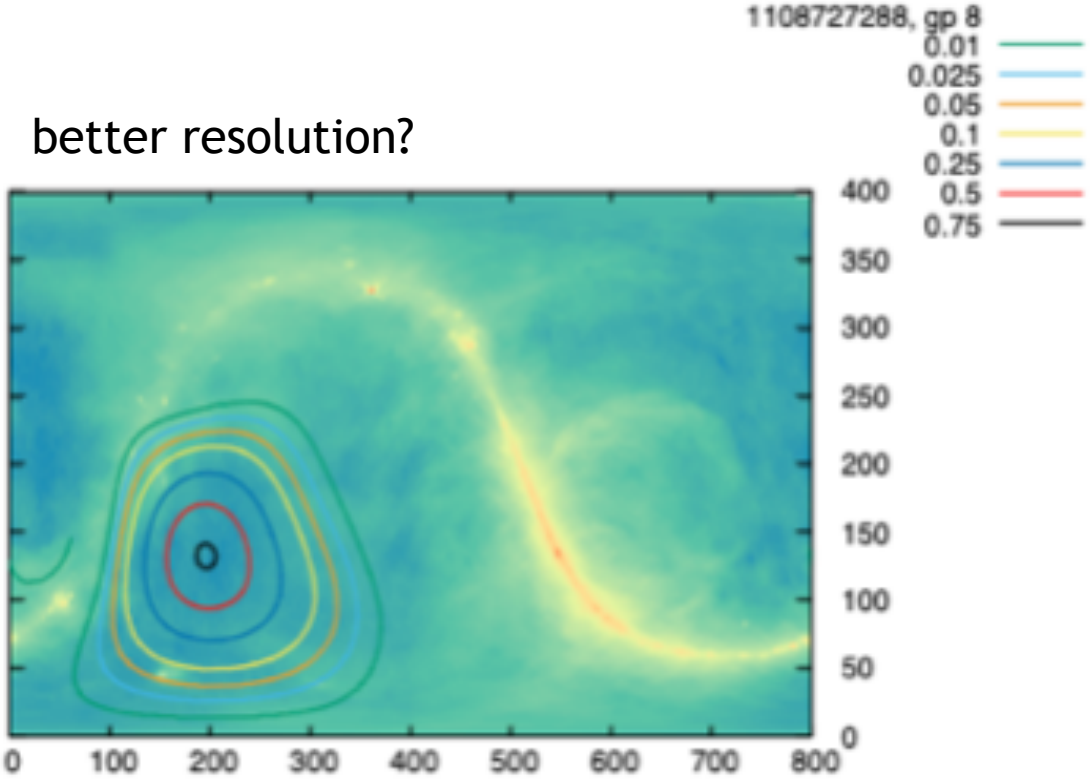


1D power spectrum



Beam

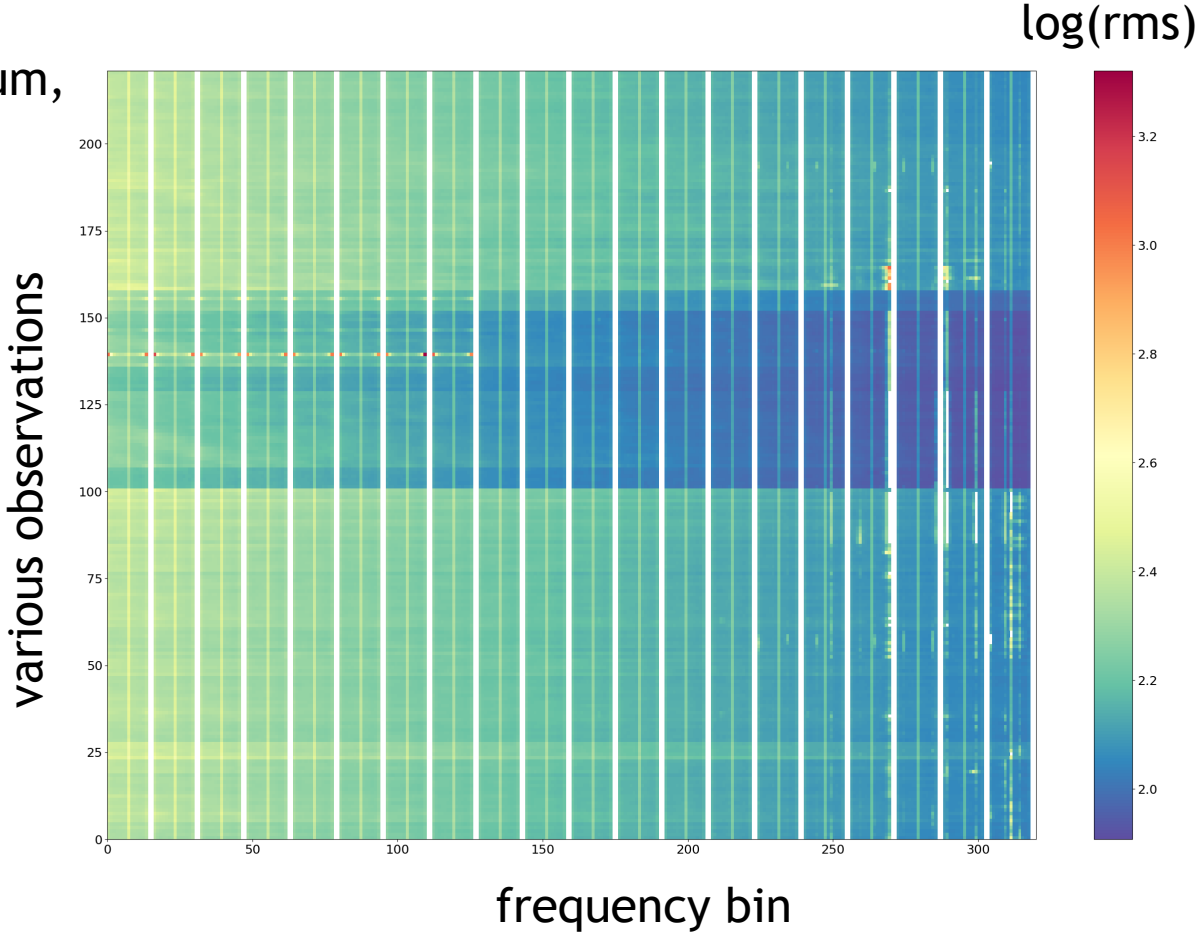
better resolution?



R.M.S of visibility

Before calculate power spectrum, check the visibility r.m.s

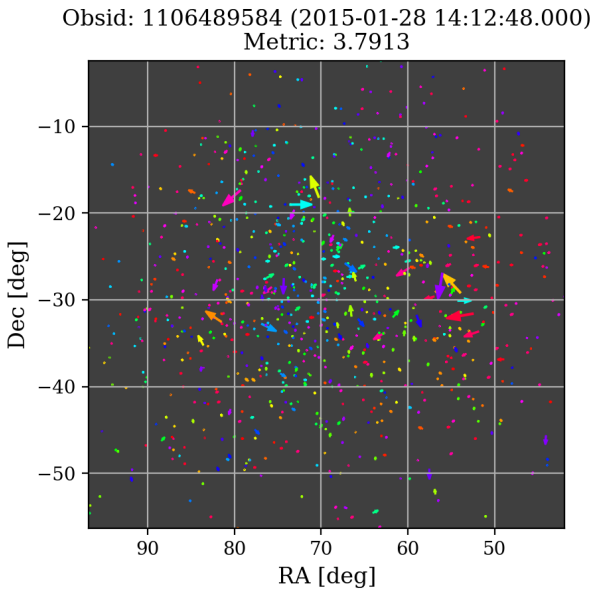
Weird data should be removed

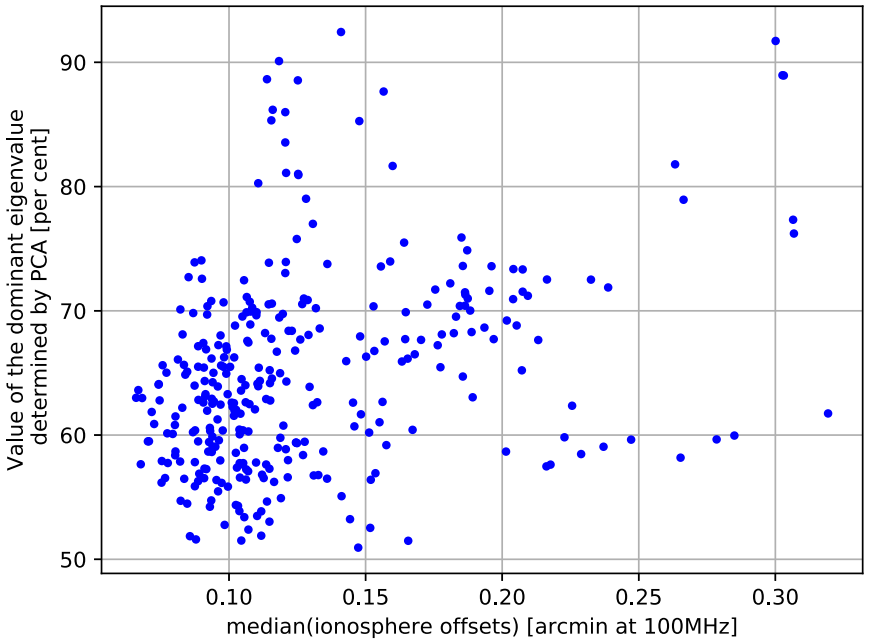


Ionosphere

“cthulhu” (C.Jordan+2017)
: python software for ionosphere analysis

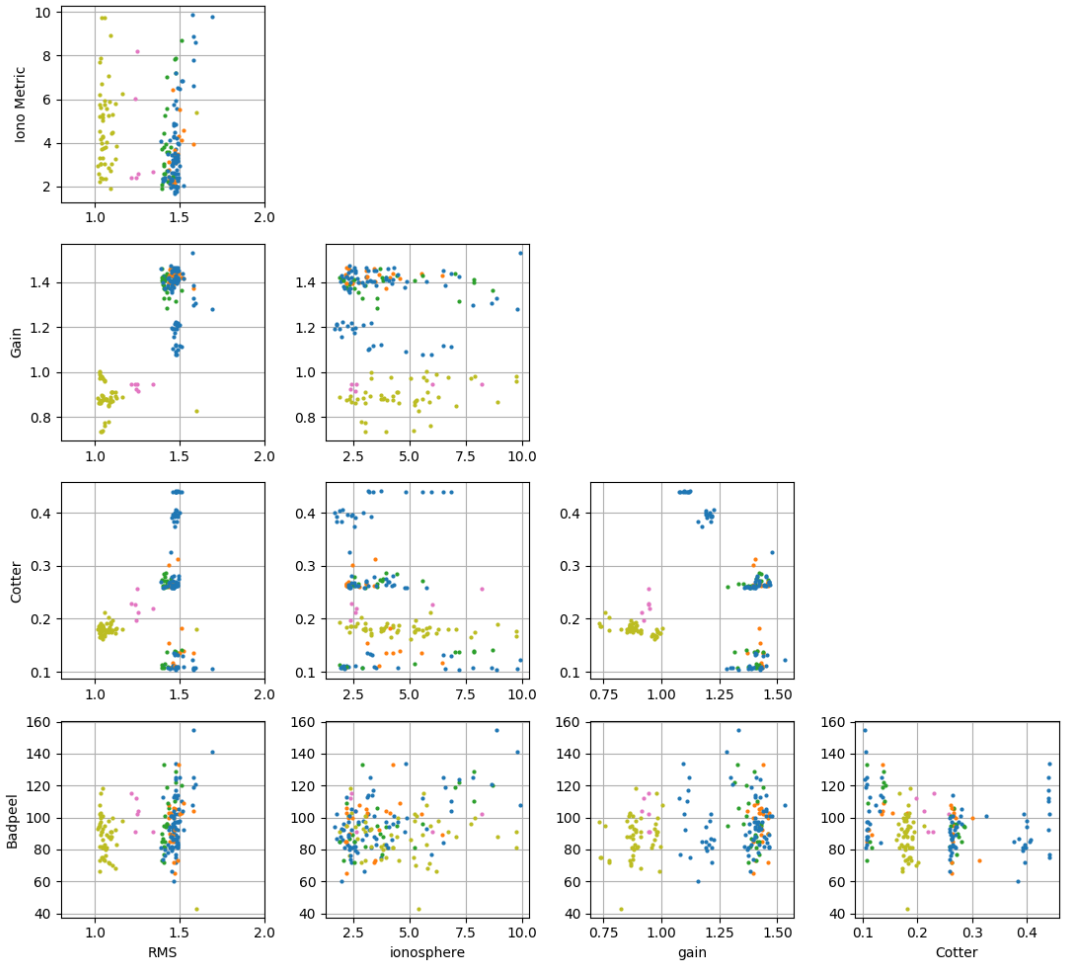
Ionosphere offset is measured by comparison the observed position of point sources and the position listed in radio catalogue





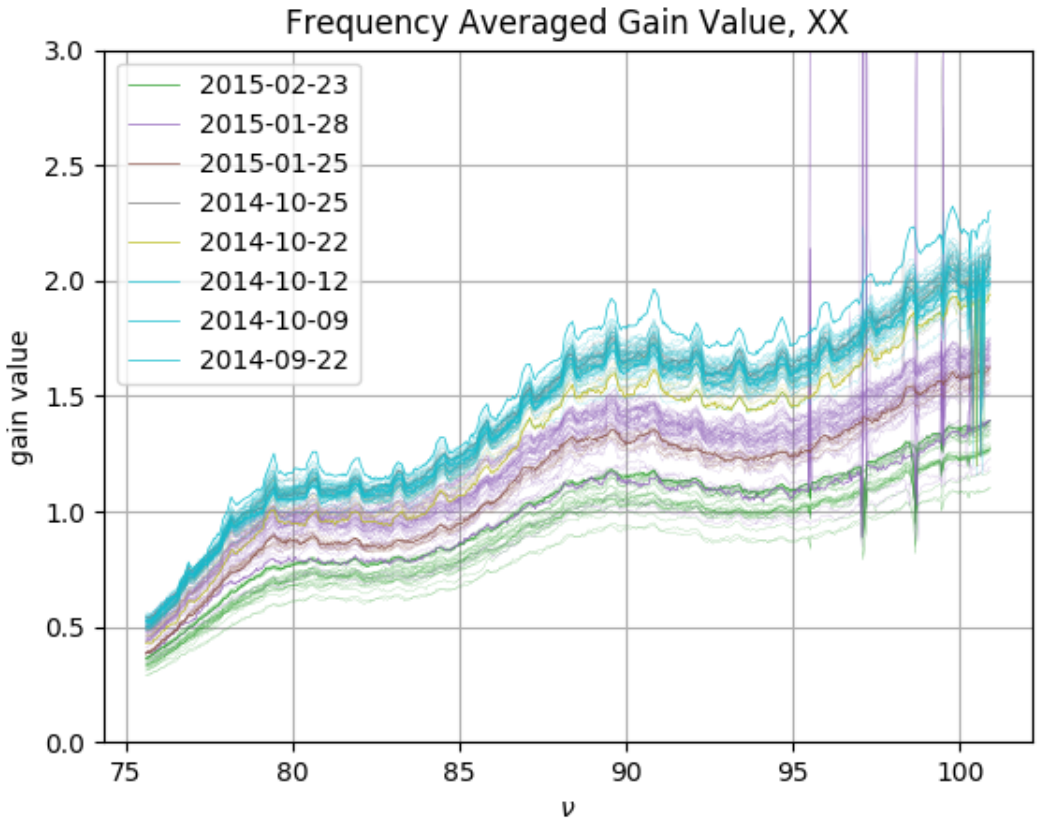
Data quality

For now,
choose data with
- quiet ionosphere
- lower r.m.s

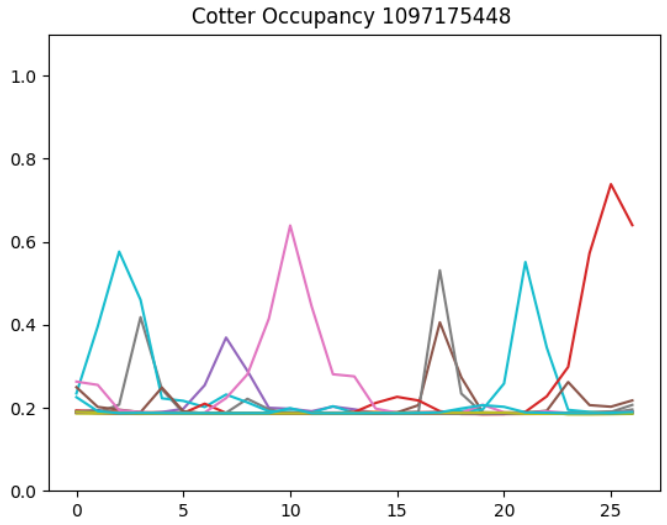


Gain

gain
water roof?



Plot before after



Click to add title

- Click to add text
  - Text
    - Bullet 1
      - Bullet 2
        - Bullet 3

Image credit: John Goldsmith, 2012

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