BAORadio/CRT
LSS P(k) measurement sensitivity and foreground subtraction

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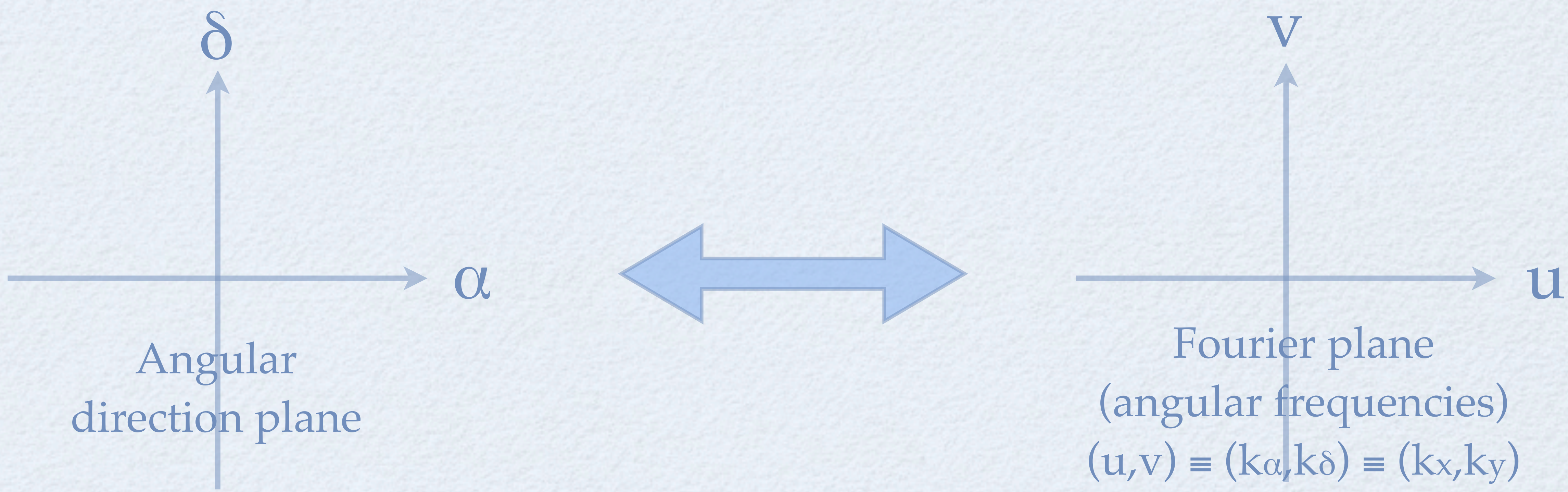
BAORadio/FAN meeting 3 Feb. 2011

based on CRT Workshop - Beijing / January 2011

UNIVERSITÉ PARIS-SUD 11

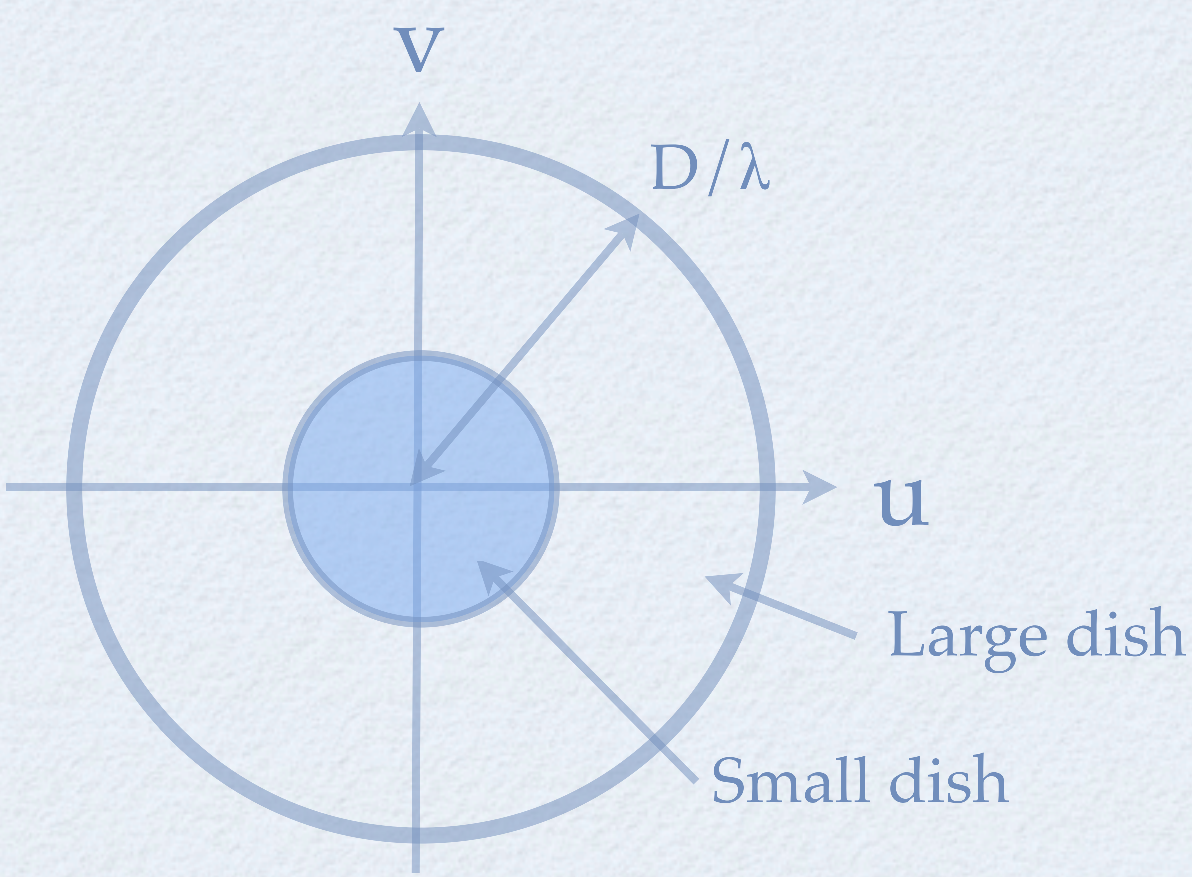
LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

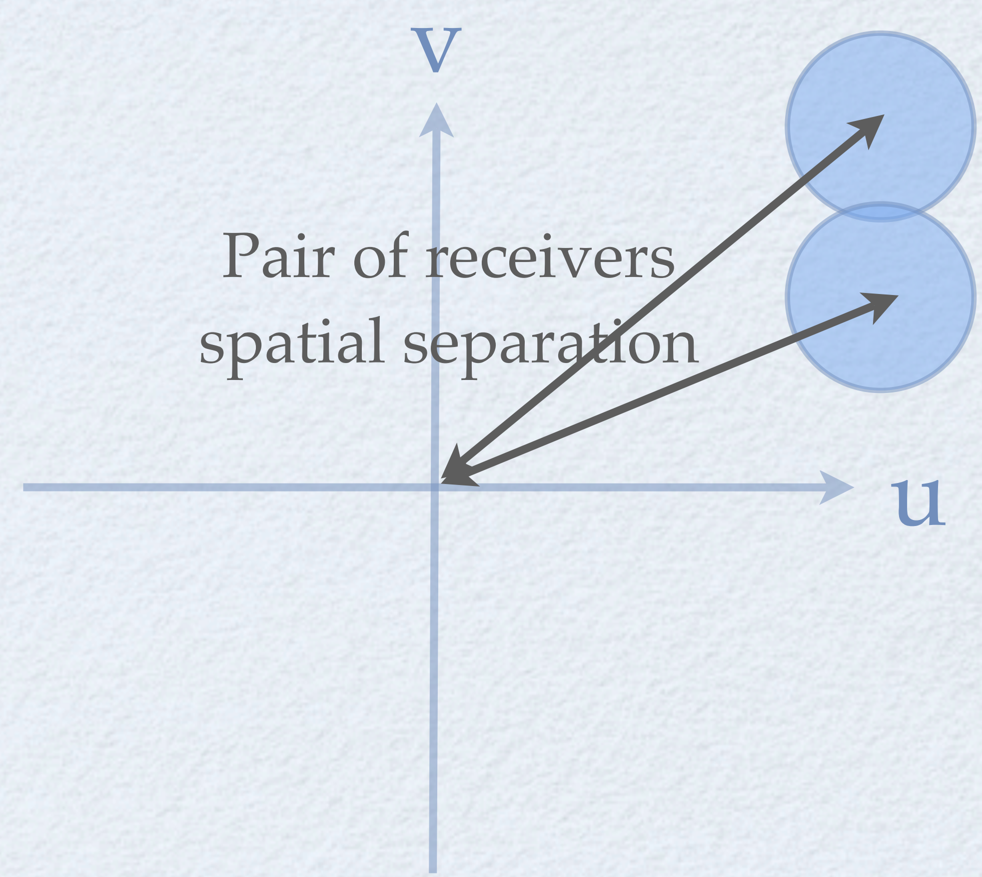
- A program to compute (u,v) plane coverage as a function of the interferometer configuration
- Pnoise(k) computed through a 3D power spectrum computation, weighted according to the (u,v) plane coverage
- CRT modeled as a set of rectangular receivers
- Filled array and semi-sparse array of dishes
- Different configurations, from 64 to 1280 receiver elements



PSF or beam (lobe)

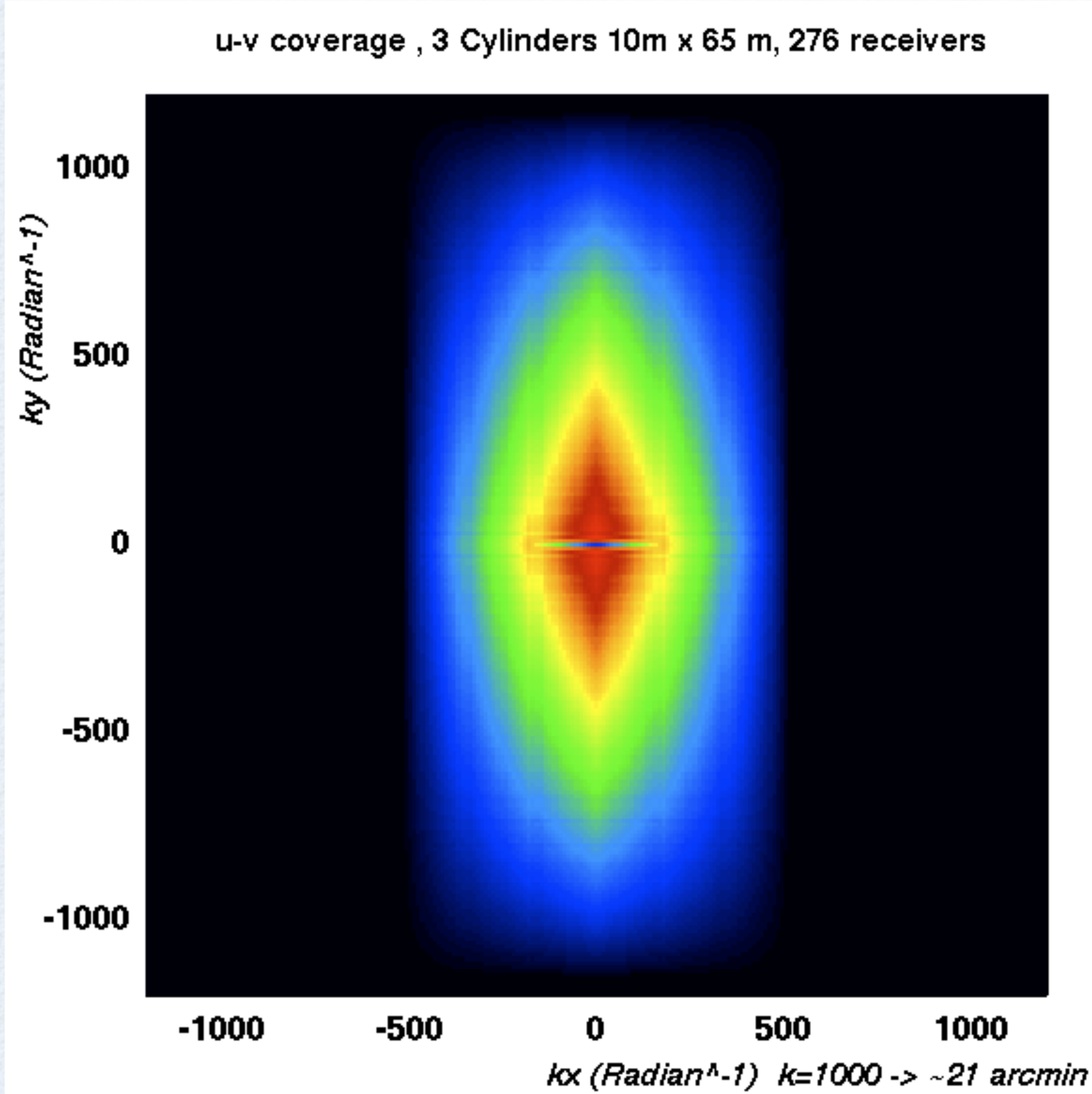
(u,v) plane response



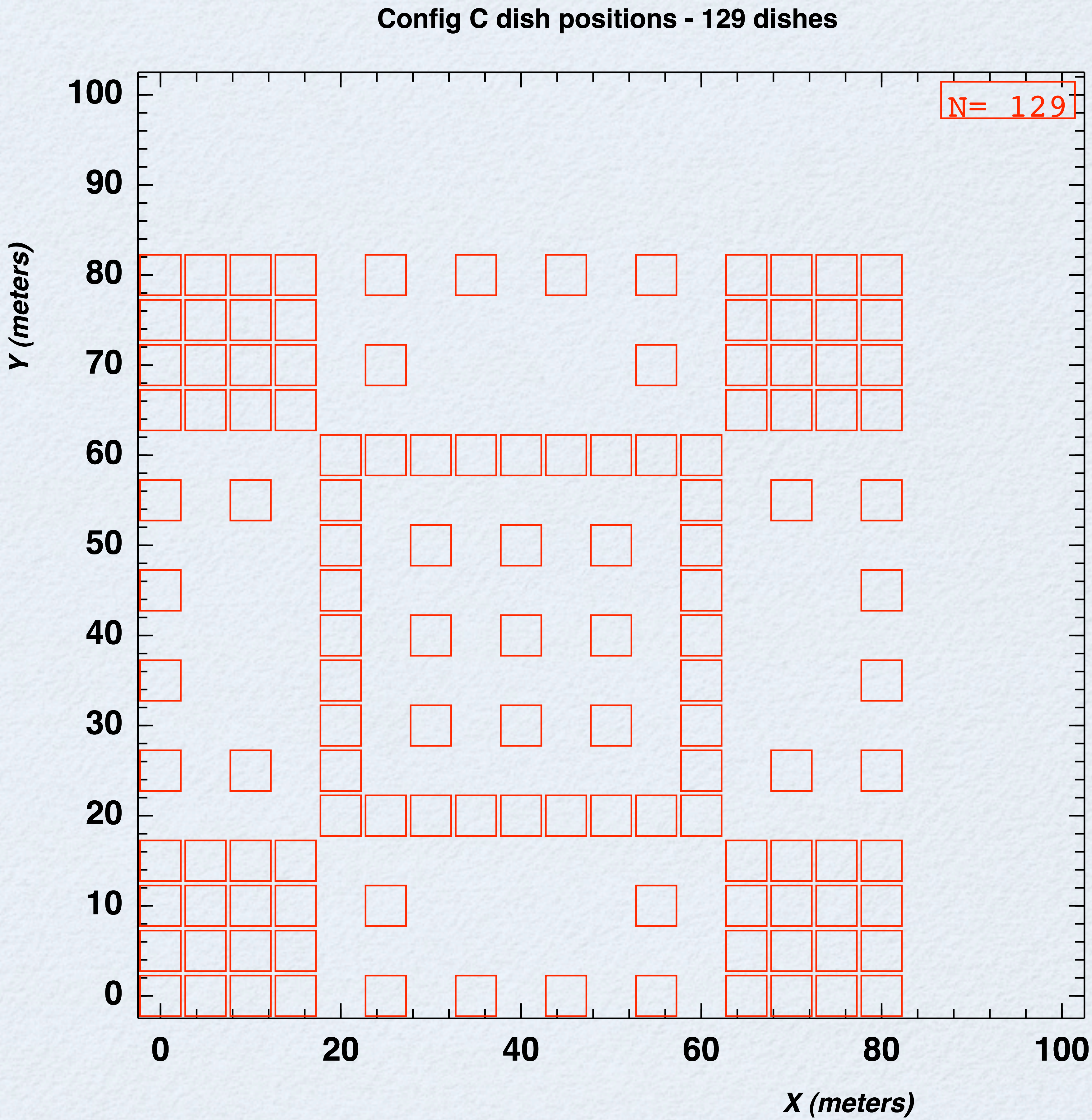


- Full (u,v) plane coverage gives better image quality and is necessary to reach the volume limited sample (cosmic) variance
- (u,v) plane coverage can be smoothed and enhanced at low (u,v) value with steerable dishes
- Examples of (u,v) plane coverage for 3-cylinder system (384 rec.), 20x20 filled array of D=5 m (400 rec.), and a semi sparse array of 129 D=5 dishes
- Noise power spectrum (Pnoise(k)) computed for several configurations with cylinders and dishes

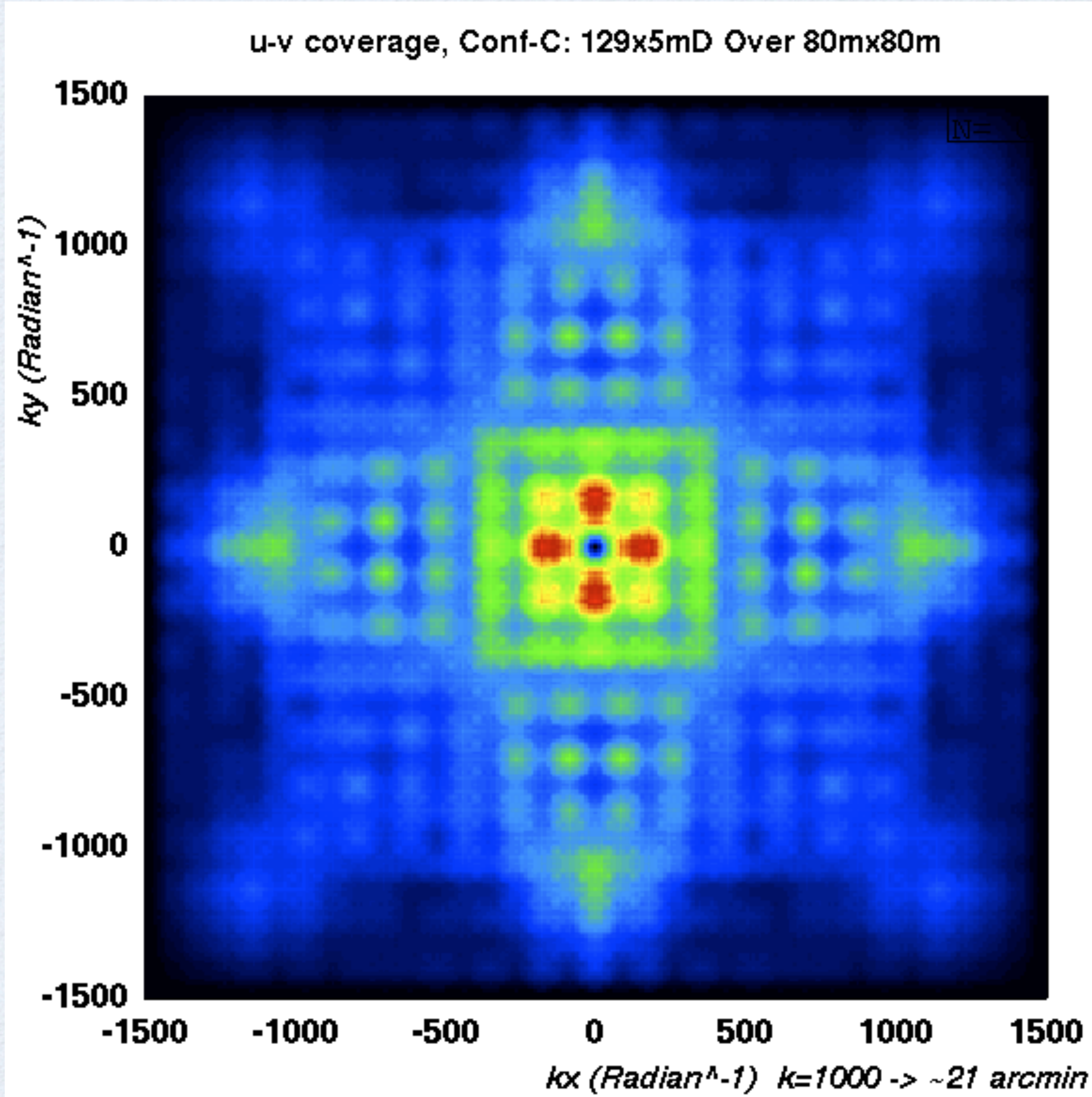
(u,v) plane coverage, packed three cylinders array of 10m × 65 m
3x92 = 276 rec. elements



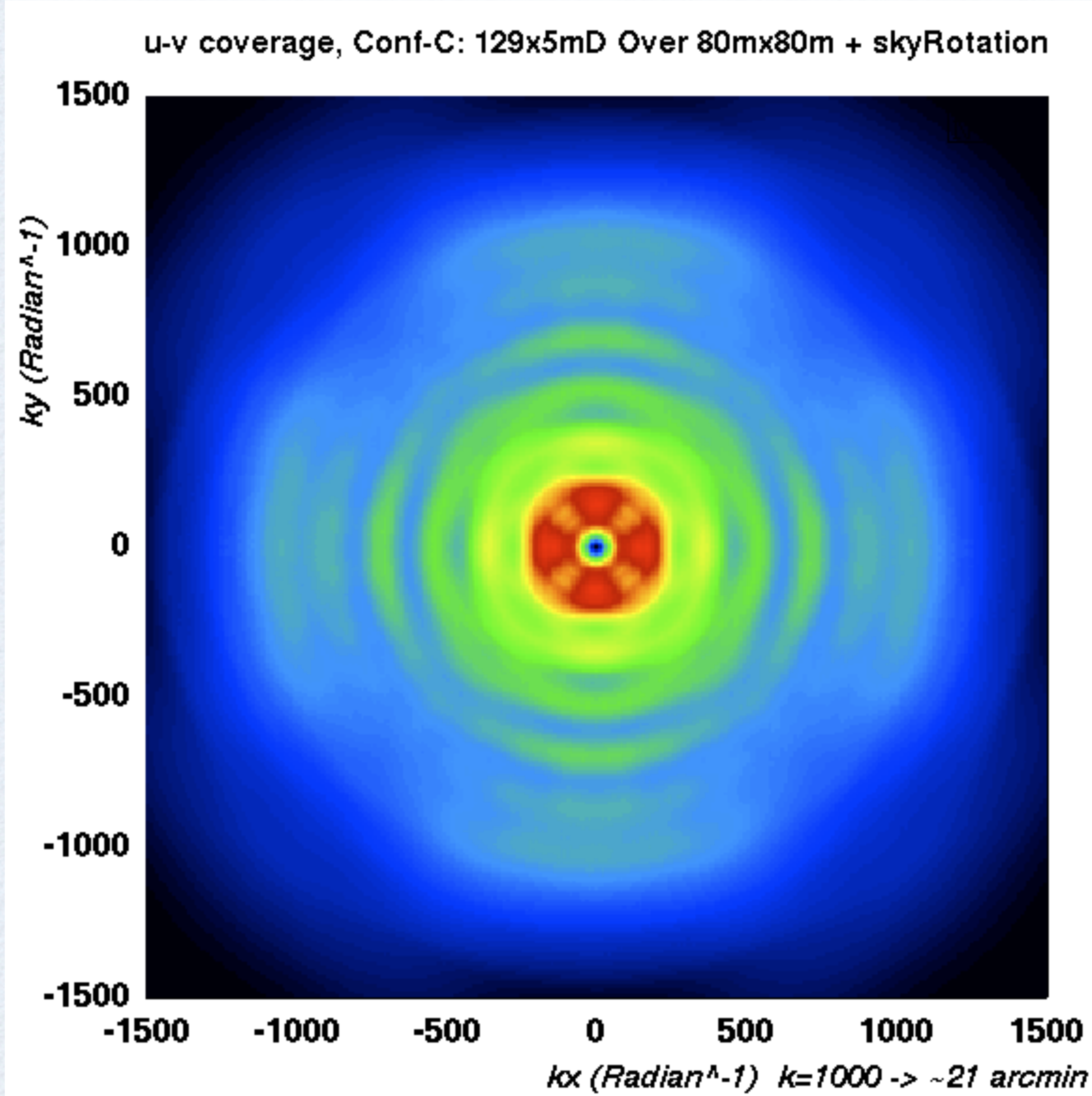
Semi filled array configuration of $129 \times D=5$ m dishes



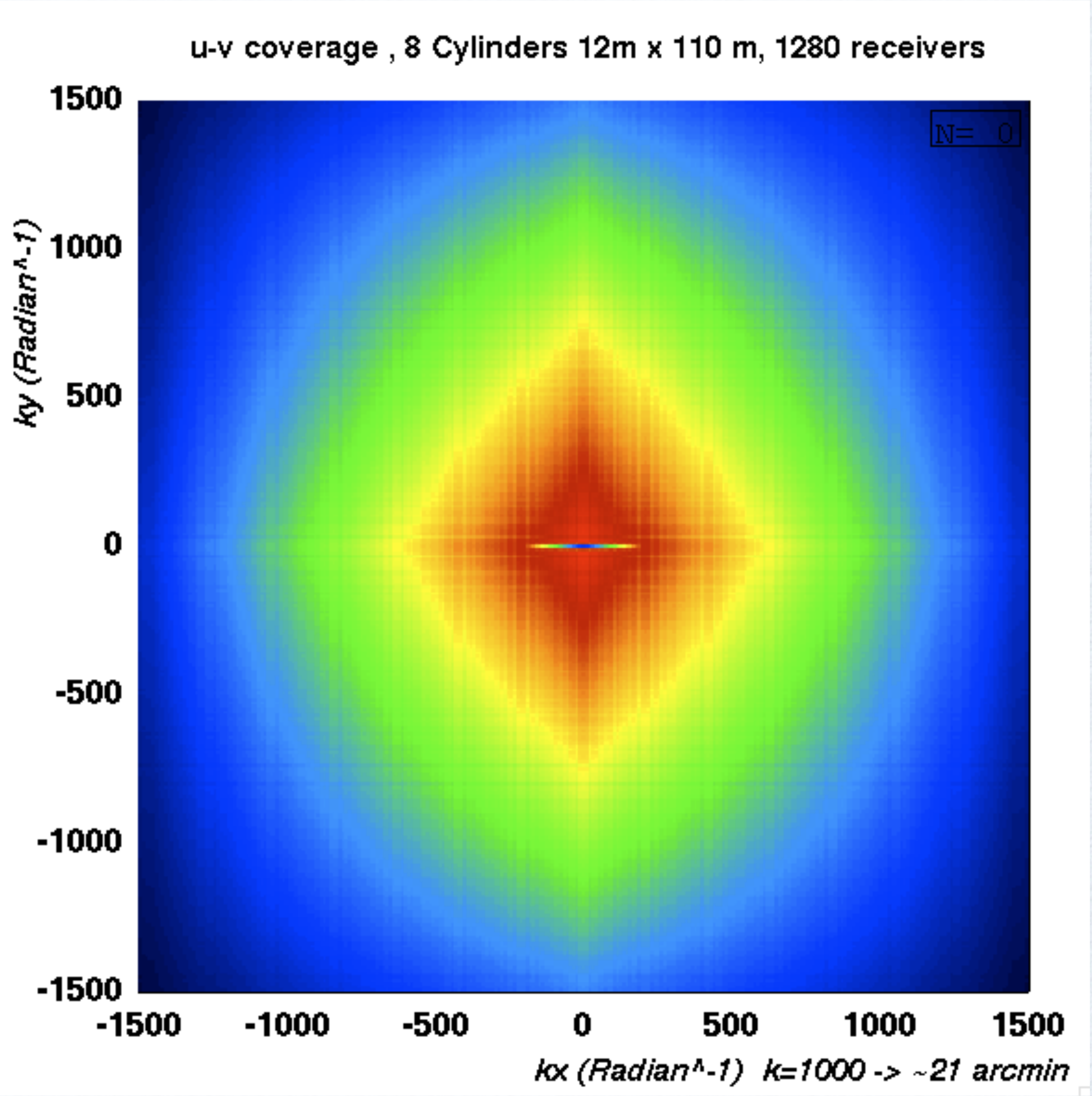
(u,v) plane coverage, semi-filled array
of 129 D=5 m dishes
No sky rotation



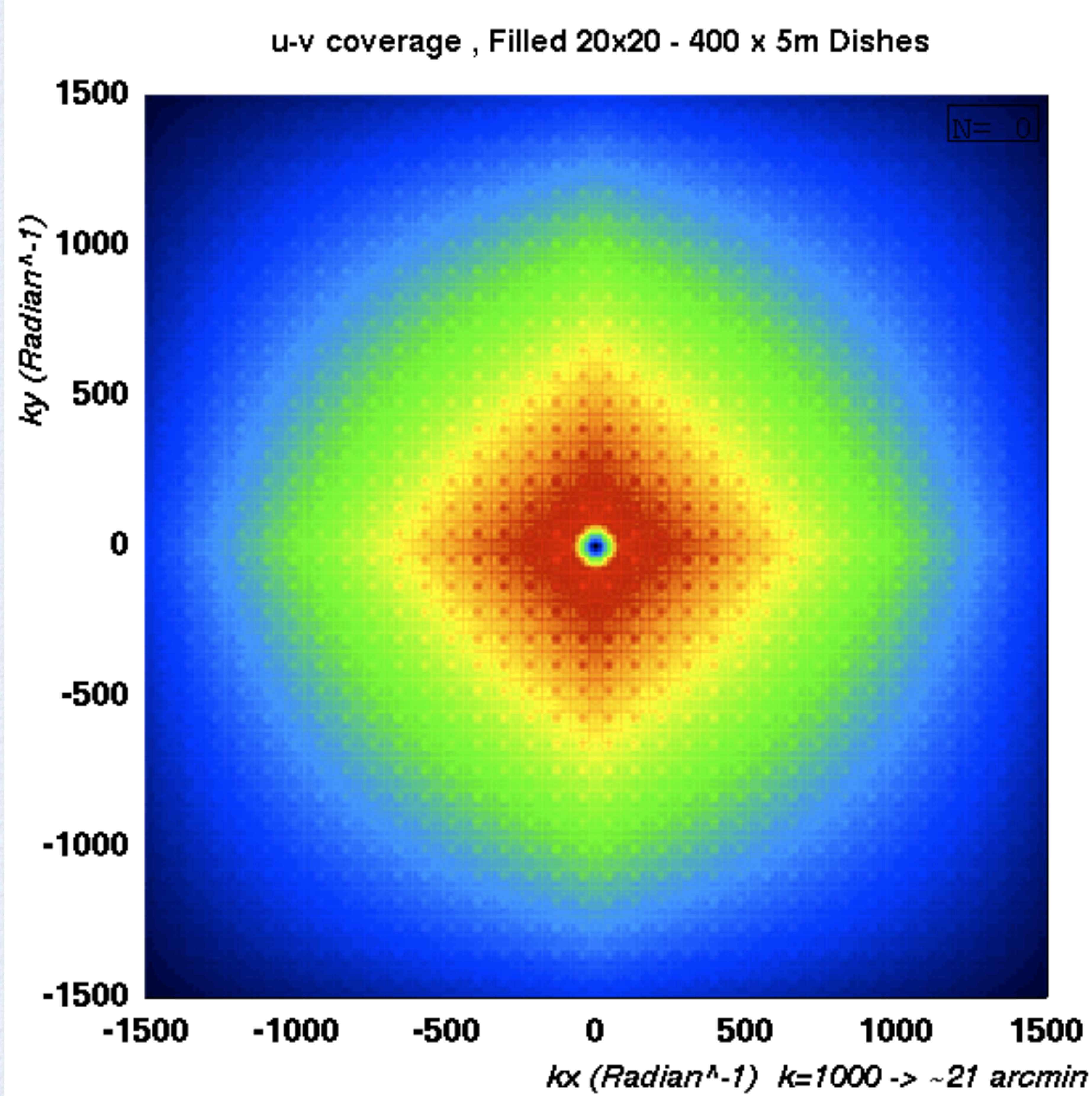
(u,v) plane coverage, semi-filled array
of 129 D=5 m dishes
sky rotation



(u,v) plane coverage, packed eight cylinders 12m × 110 m
8x160 = 1280 receiver elements
(2 λ spacing at z=0.7)



(u,v) plane coverage, filled array of 400 × D=5 m dishes, 100m × 100m ~ 10 000 m^2



- Noise power spectrum for an N×N filled array (white noise approximation up to $k_{max} = 2\pi D_{array}/\lambda$)

$$P_{\rm noise}(k) = \frac{T_{\rm sys}^2 \, \Omega_{tot}}{t_{tot} \, N^2} \times D_A^2 \, \frac{c}{H(z)} \, \frac{1}{\nu} \, (1+z)^3$$

- T_{21} (Mass to 21 cm temperature conversion)

$$T_{21}(z) \simeq 0.057 \, {\rm mK} \times \frac{(1+z)^2}{\sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}} \left(\frac{h_{100}}{0.7} \right) \left(\frac{\Omega_{H_I}(z)}{4.\,10^{-4}} \right)$$

Noise power spectrum

- 21 cm LSS P(k) and noise power spectrum $P_{noise}(k)$
- **z = 0.7** (ν ≈ 820 MHz)
- Sky coverage : 10 000 sq.deg (π srad)
- Total observation time : 1 year
- Different instrument configurations
  - single dish, D=100 m
  - packed 3 / 4 / 8 cylinder arrays
  - filled array of 64=8x8 , 400=20x20 D=5m dishes
  - semi-filled array of 129 D=5m dishes (config C)

P(k)@21cm
PNoise(k)

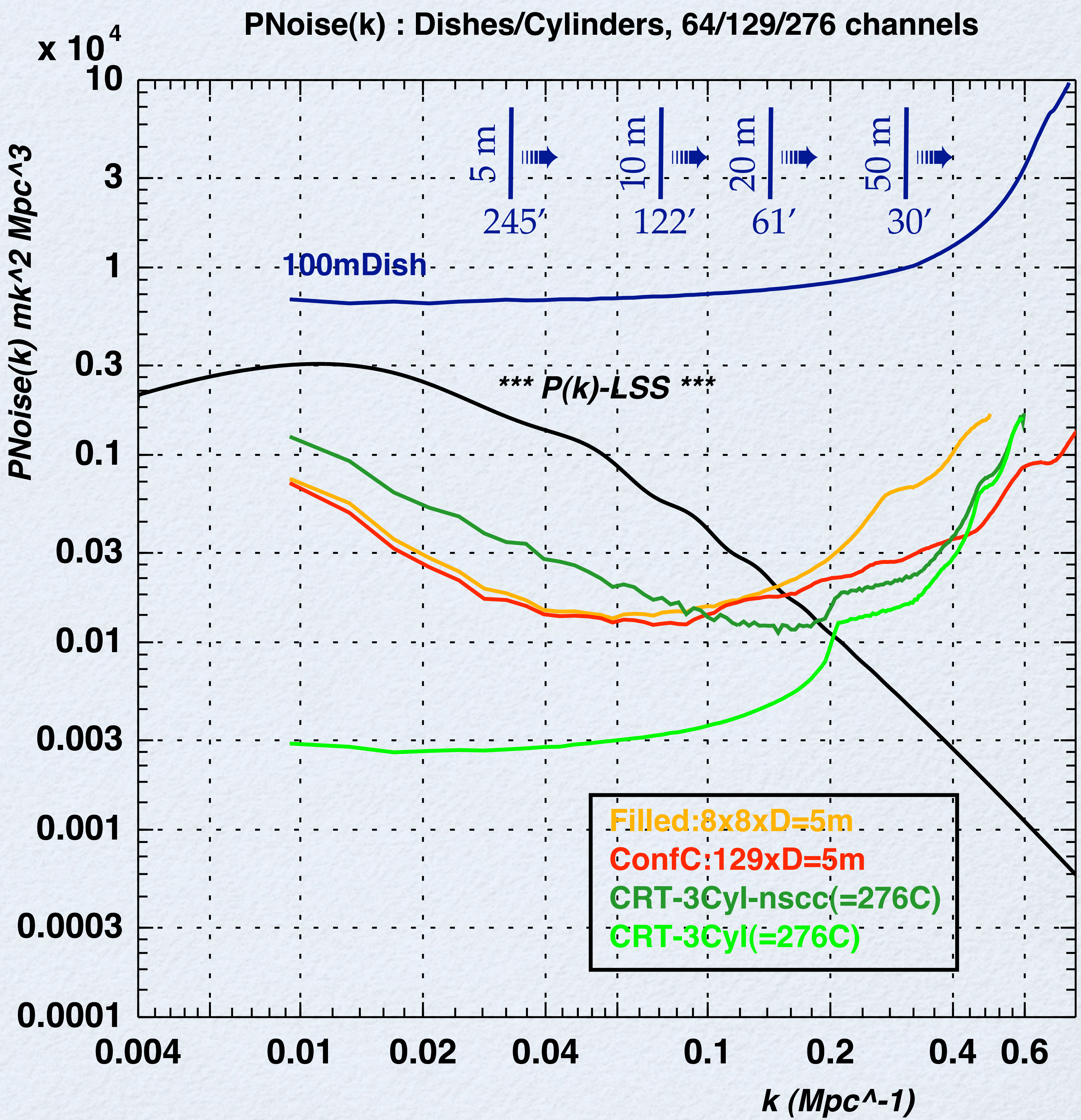
z = 0.7 (ν ≈ 820 MHz)

10 000 sq.deg

(π srad) - 1 year

- 100 m dish
- 64=8x8 D=5m
- CRT - 3 cylinders

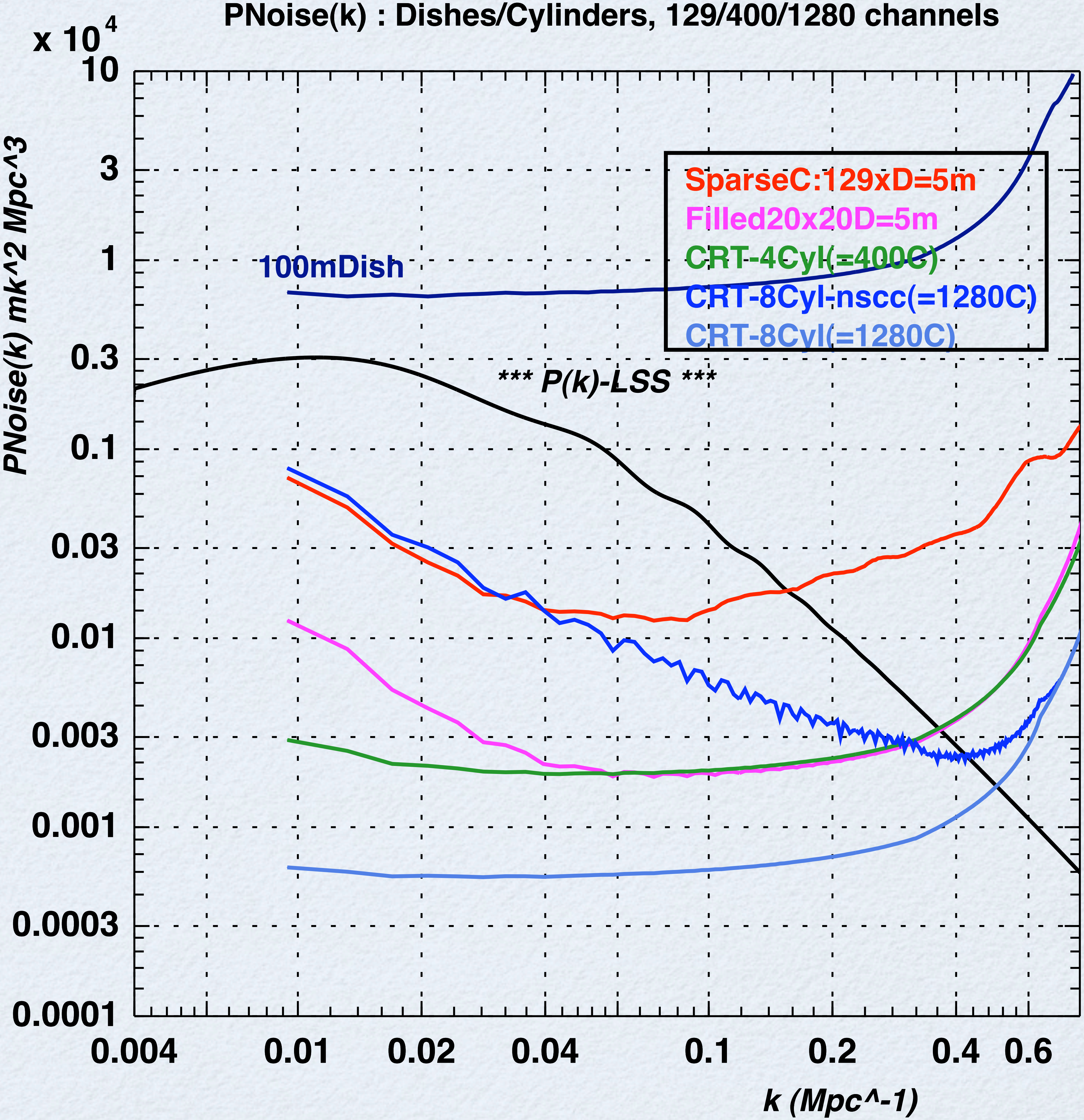
10x65 meters



P(k)@21cm PNoise(k)

z = 0.7 (ν ≈ 820 MHz)
10 000 sq.deg (π srad) - 1 year

- 100 m dish
- 400=20x20 D=5m
- CRT - 4 cylinders 25x110 meters
- CRT - 8 cylinders 12x100 meters



P(k)@21cm PNoise(k)

z = 0.25, 0.7

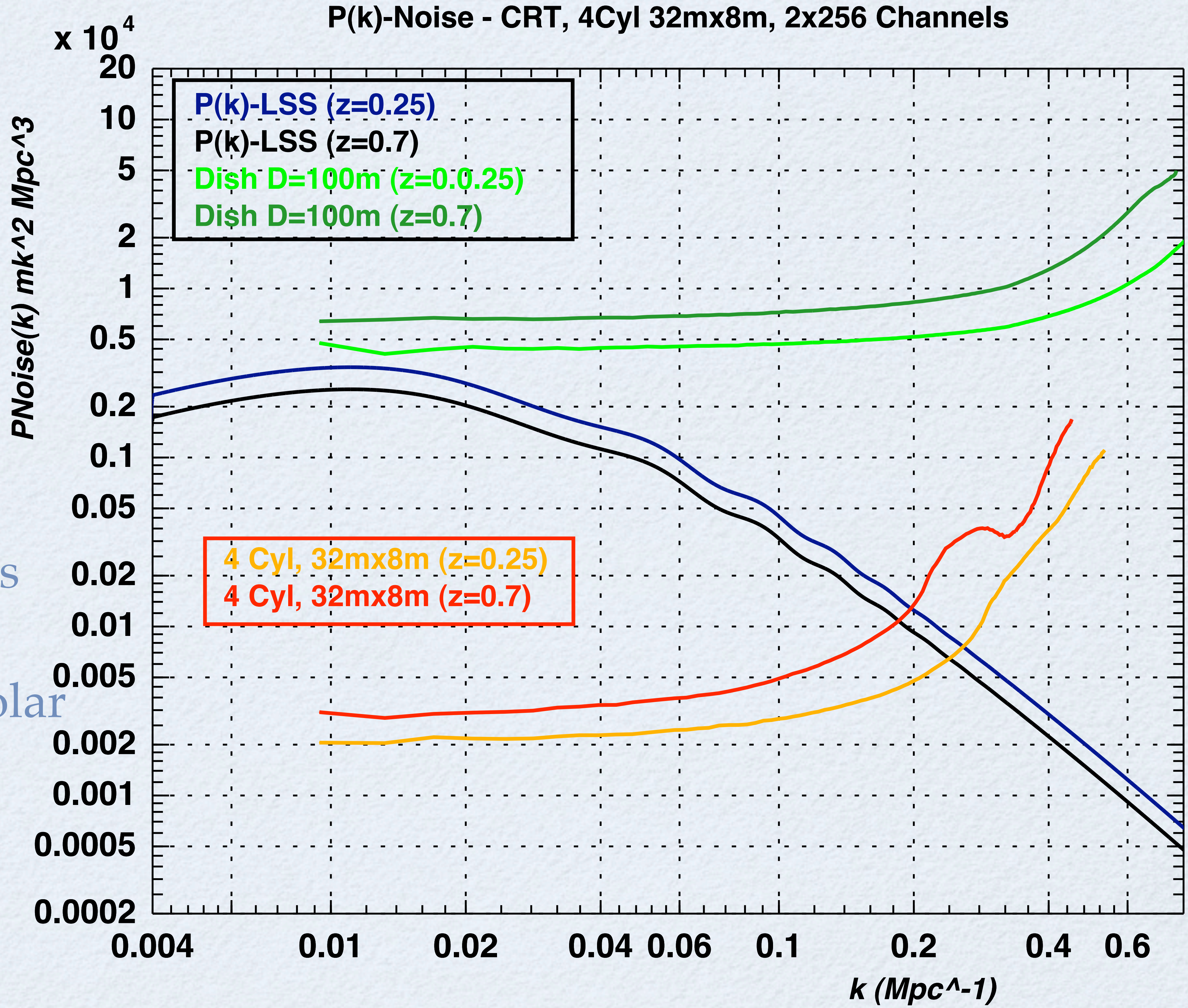
10 000 sq.deg

(π srad) - 1 year

- 100 m dish
- CRT - 4 cylinders

8x32 meters

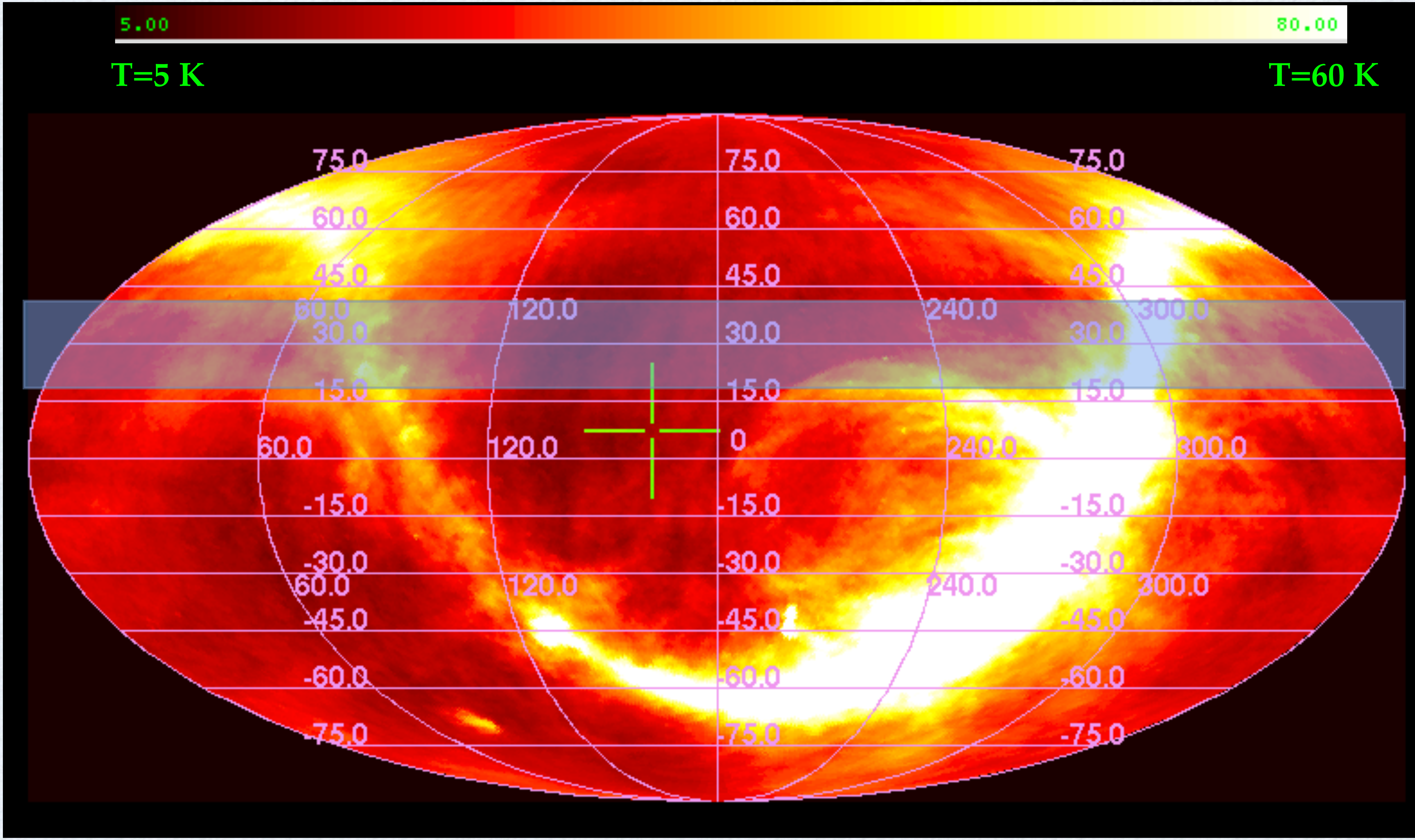
- 256 channels/polar



Foreground subtraction (synchrotron & radiosources

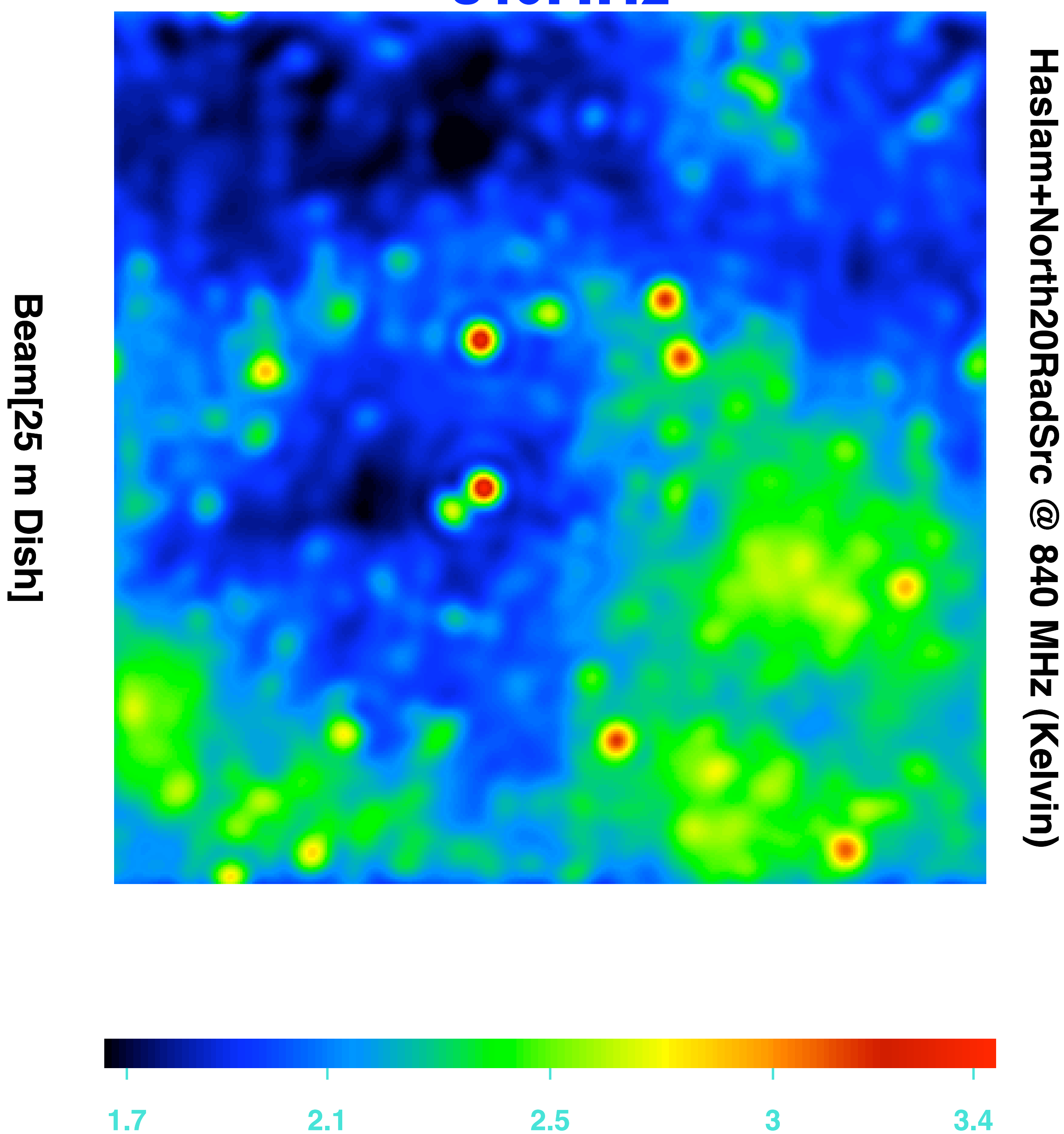
- Foreground : Haslam/Synchrotron (@ 400 MHz) + catalog NVSS catalog (Condom et al) or North20 (1.4 GHz)
- or GSM sky model
- Foreground cube: 30 x 30 deg^2 , 5 arcmin resolution, 820-948 MHz (z ~ 0.6) , ~ 500 kHz freq resolution
- Frequency dependent instrumental beam , D=50 m single dish
- Foreground + LSS + noise , or Foreground + noise
- Simple/basic foreground subtraction : beam correction + point-source removal + power law fitting along frequency

Synchrotron map @ 400 MHz - Eq. Coordinates (ra,dec)



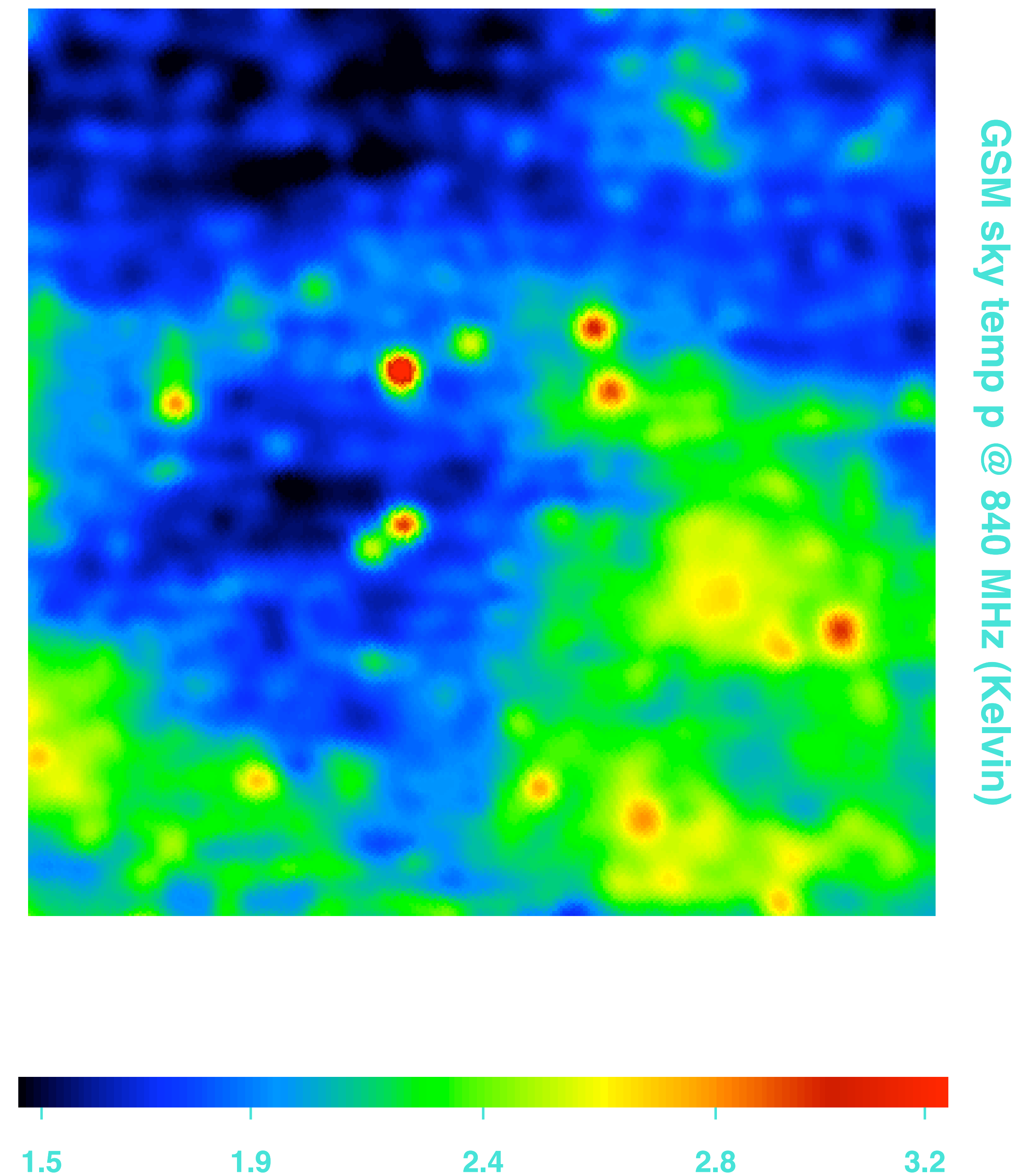
GSM / HASLAM+Sources comparison

HASLAM +North20SrcCat @ 840MHz



1.7 K 3.4 K

GSM @ 840 MHz

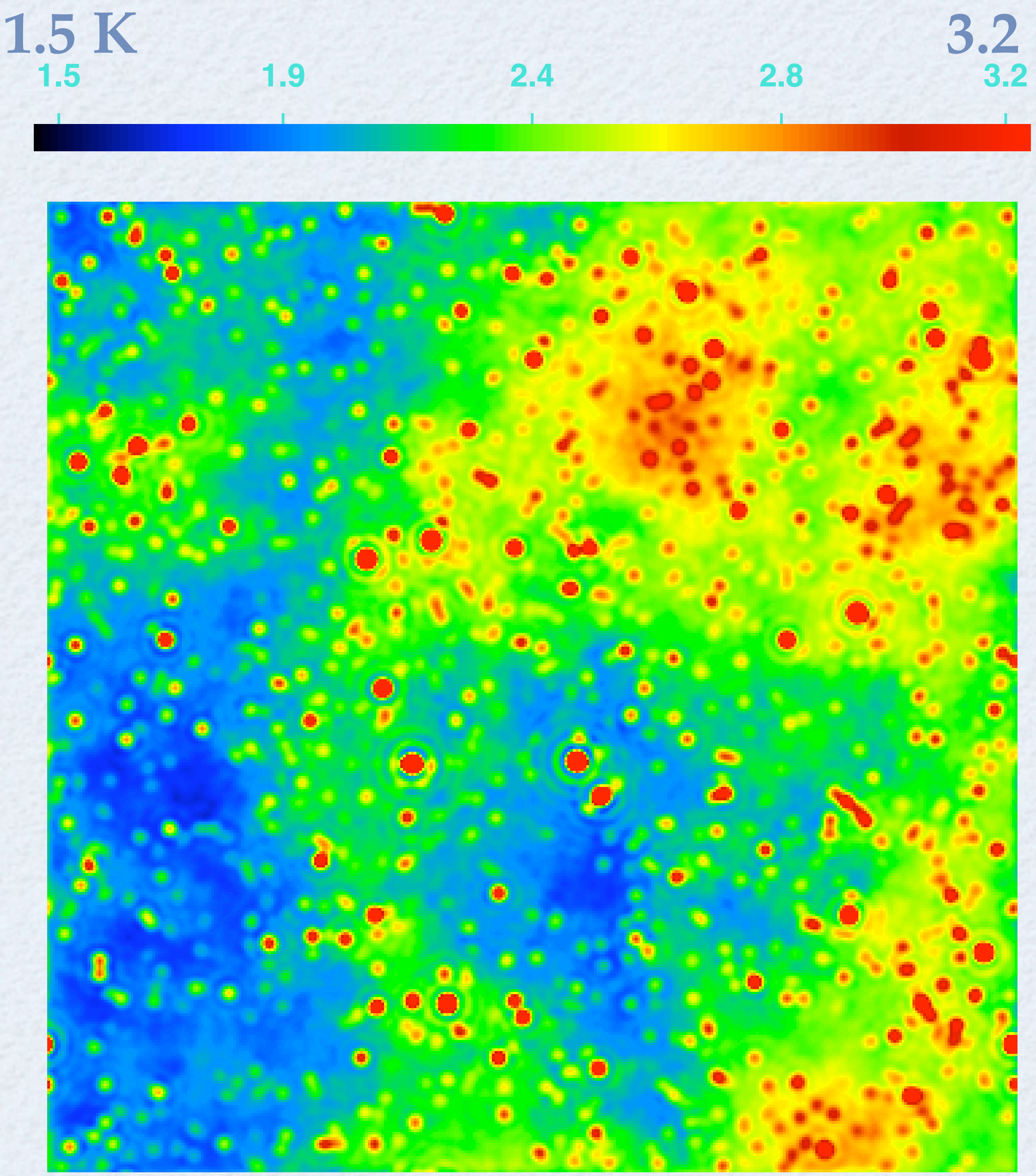


1.5 K 3.2 K

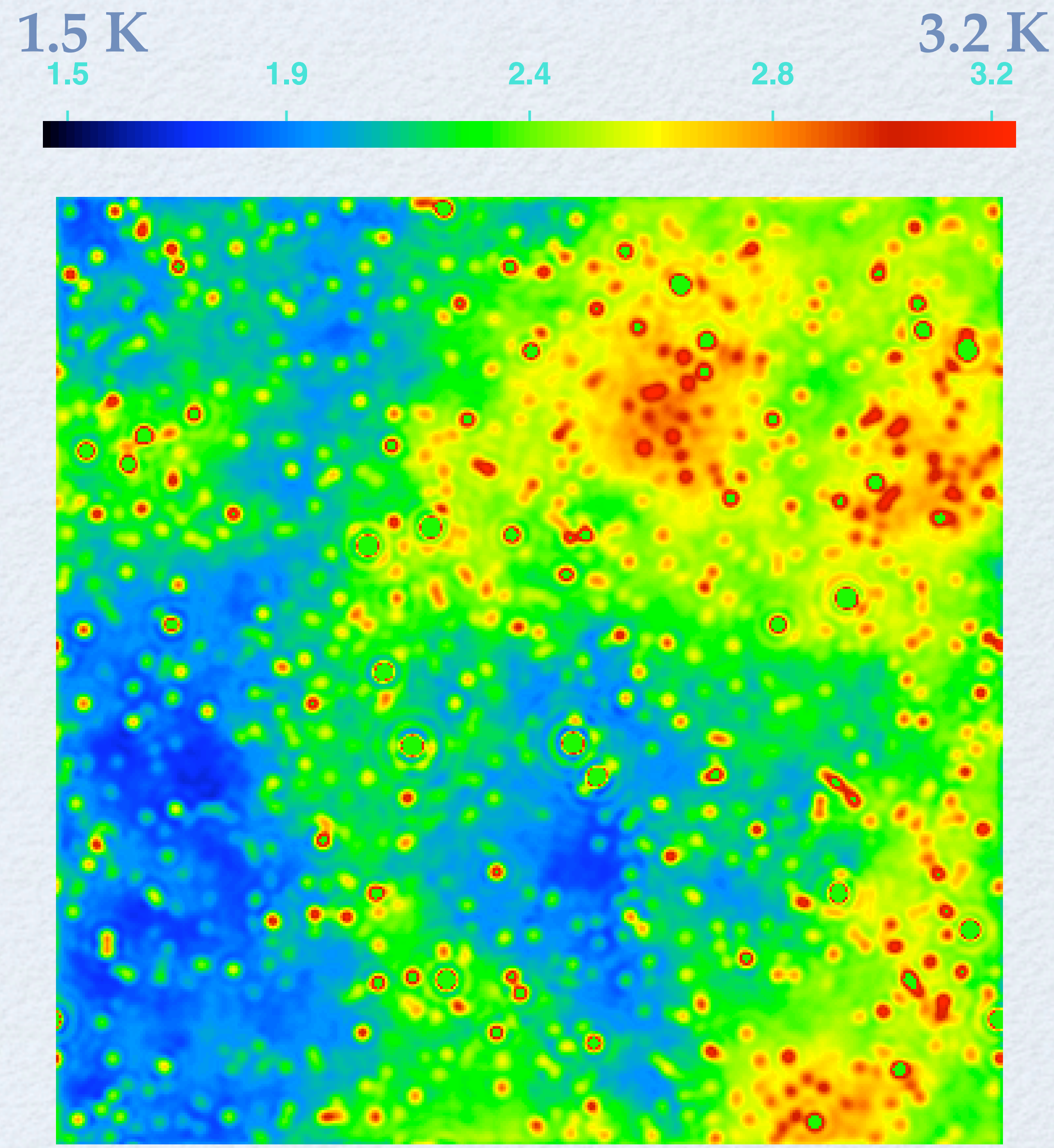
- TrueSky = LSSCube + foregroundCube
- Apply Instrument beam (u,v)(ν) to each frequency plane of the cube (in Fourier space) and back to (ra,dec, ν) space
- Add white noise in direct space (?)
- ObservedCube clean-up

1. Correct for beam to the lowest angular resolution (lowest frequency)
2. Clean (remove) negative temperature pixels
3. Clean (remove) point sources on the stacked 2D map
4. Fit and subtract a power law in frequency for each (ra,dec) pixel → extracted LSS cube
5. Compute P(k)

Foreground subtraction performance

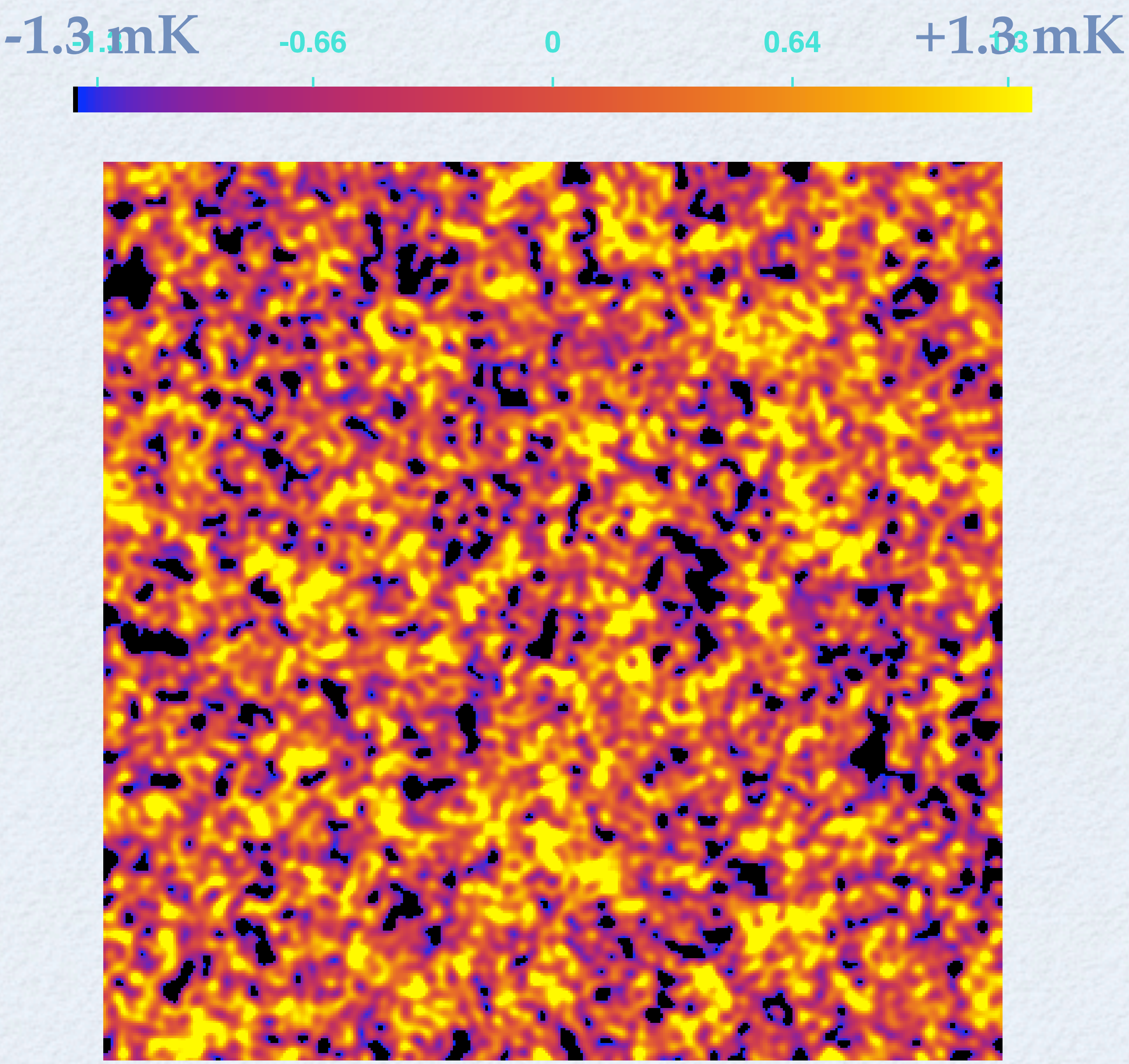


Original foreground map (frequency slice)

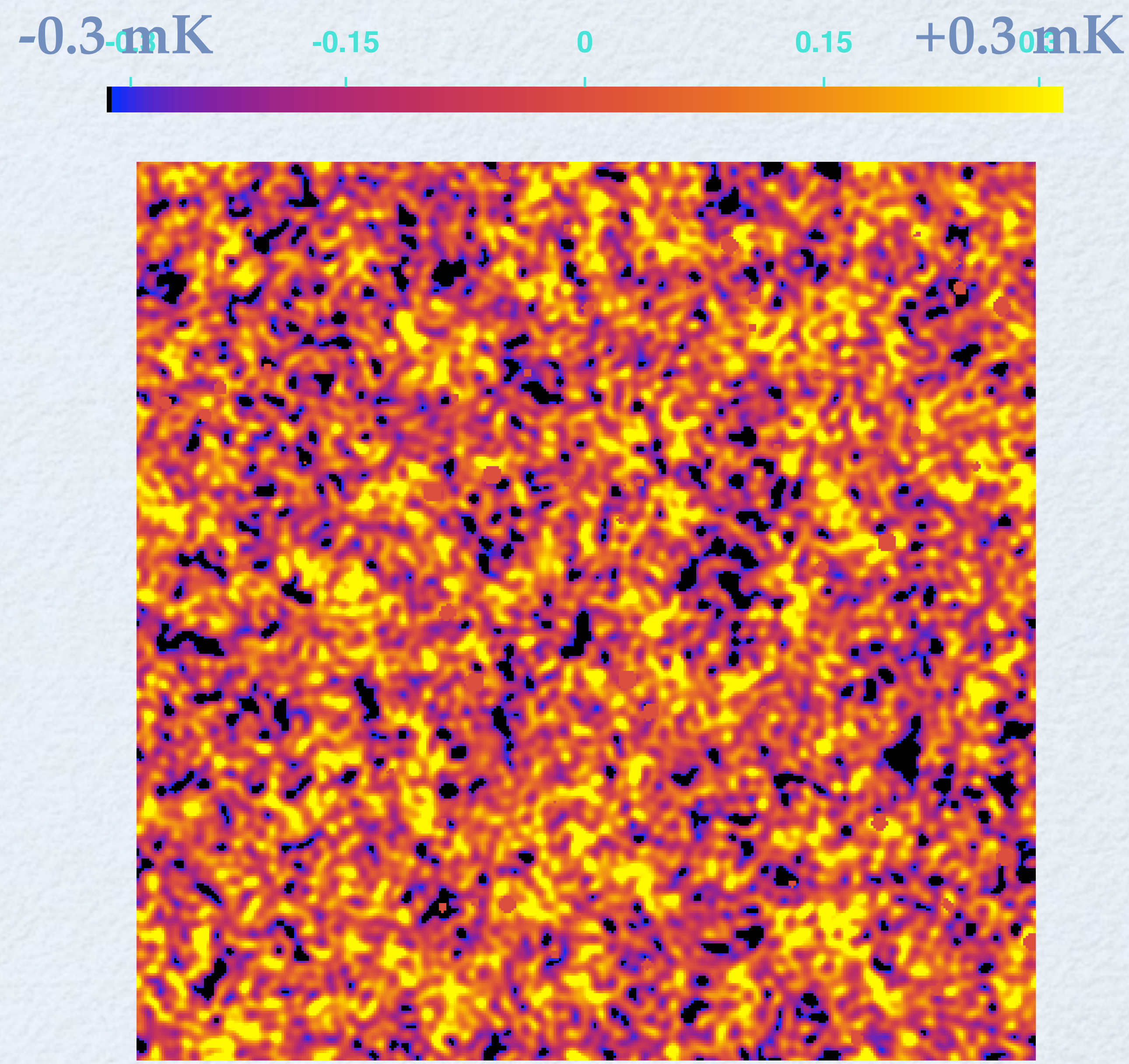


Recovered foreground map (frequency slice)

Foreground subtraction performance

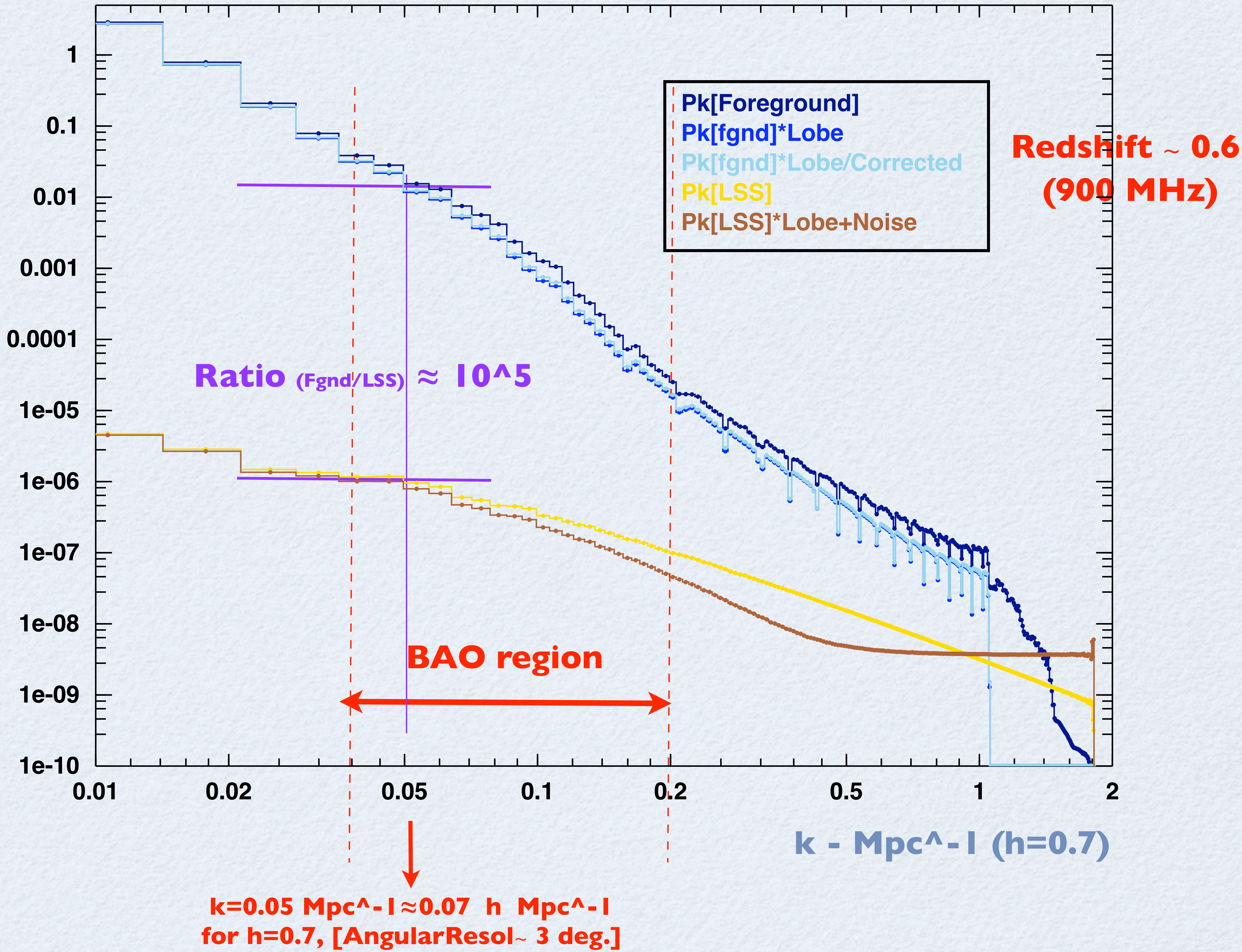


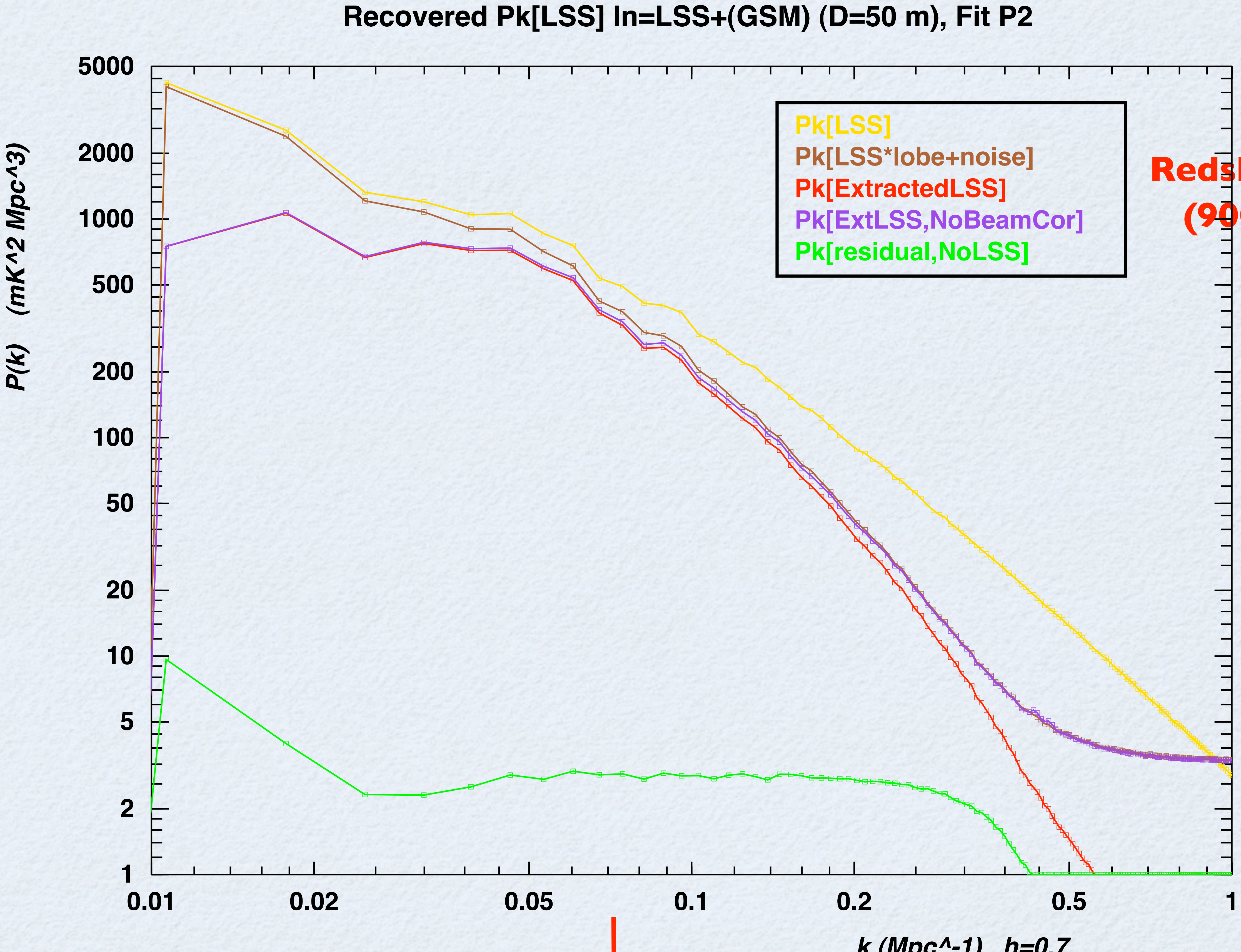
Original LSS map (frequency slice)



Recovered LSS map (frequency slice)

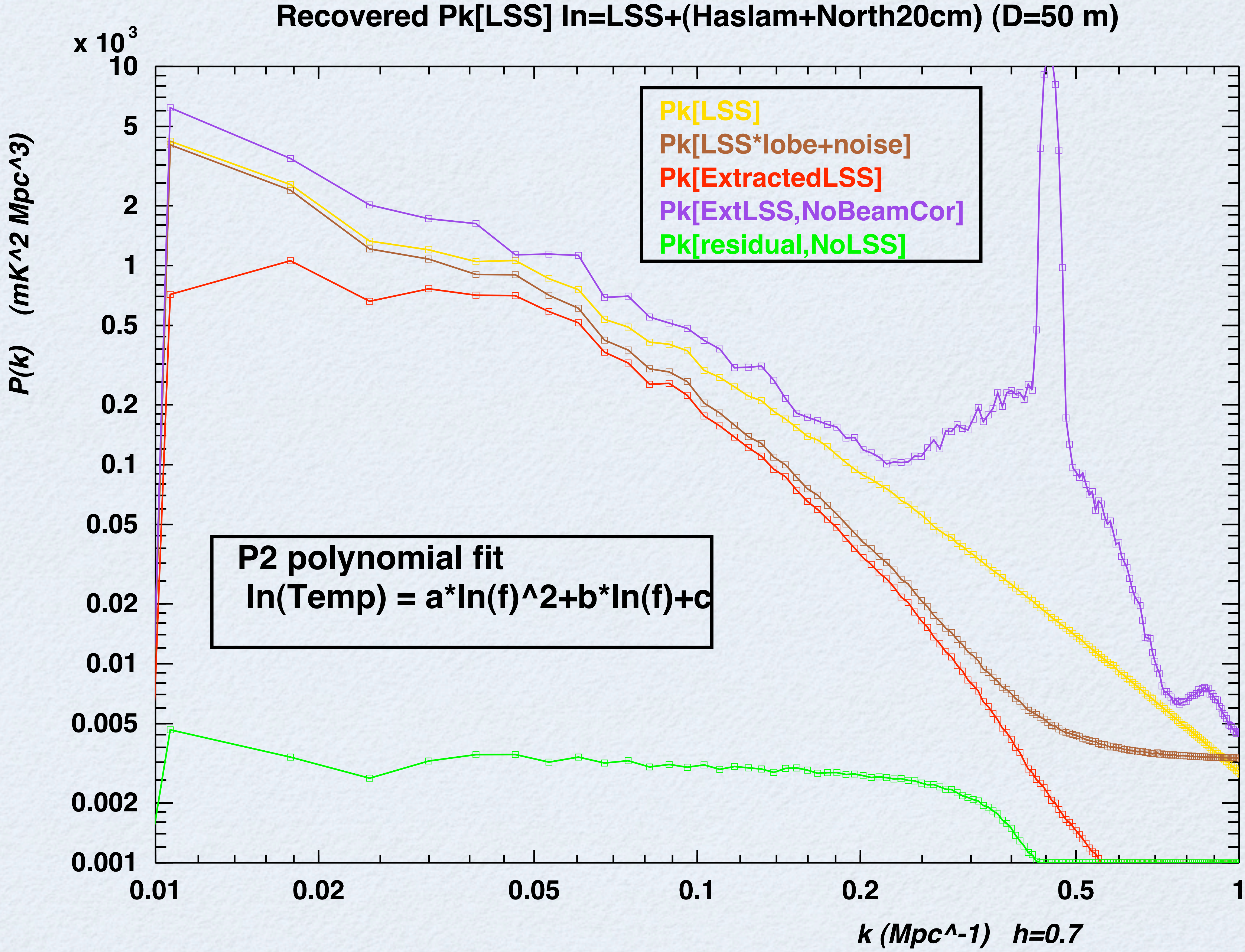
Pk[LSS] , Pk[Foreground=GSM] and lobe effect (Dish D=50 m)





Redshift ~ 0.6 (900 MHz)

k=0.05 Mpc^-1 ≈ 0.07 h Mpc^-1 for h=0.7


Recovered Pk[LSS] In=LSS+(Haslam+North20cm) (D=50 m)
x 10^3
P(k) (mK^2 Mpc^3)
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
Pk[LSS]
Pk[LSS*lobe+noise]
Pk[ExtractedLSS]
Pk[ExtLSS,NoBeamCor]
Pk[residual,NoLSS]
P2 polynomial fit
ln(Temp) = a*ln(f)^2+b*ln(f)+c
0.01
0.02
0.05
0.1
0.2
0.5
1
k (Mpc^-1) h=0.7

21 cm observation of LSS at z ∼ 1

Instrument sensitivity and foreground subtraction

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Received December 15, 2010; accepted xxxx, 2011

ABSTRACT

Context. Large Scale Structures (LSS) in the universe can be traced using the neutral atomic hydrogen H_I through its 21 cm emission. Such a 3D matter distribution map can be used to test the Cosmological model and to constrain the Dark Energy properties or its equation of state. A novel approach, called intensity mapping can be used to map the H_I distribution, using radio interferometers with large instanteneous field of view and waveband

Aims. In this paper, we study the sensitivity of different radio interferometer configuration for the observation of large scale structures and BAO oscillations in 21 cm and we discuss the problem of foreground removal.

Methods. For each configuration, we determine instrument response by computing the (u,v) plane (Fourier angular frequency plane) coverage using visibilities. The (u,v) plane response is then used to compute the three dimensional noise power spectrum, hence the instrument sensitivity for LSS P(k) measurement. We describe also a simple foreground subtraction method to separate LSS 21 cm signal from the foreground due to the galactic synchrotron and radio sources emission.

Results. We have computed the noise power spectrum for different instrument configuration as well as the extracted LSS power spectrum, after separation of 21cm-LSS signal from the foregrounds.

Conclusions. We show that an interferometer with few hundred elements and a surface coverage of ¡ 10000 sq.m will be able to detect BAO signal at redshift z ∼ 1

Key words. Cosmology:LSS – Cosmology:Dark energy

1. Introduction

The study of the statistical properties of Large Scale Structure (LSS) in the Universe and their evolution with redshift is one the major tools in observational cosmology. Theses structures are usually mapped through optical observation of galaxies which are used as tracers of the underlying matter distribution. An alternative and elegant approach for mapping the matter distribution, using neutral atomic hydrogen (H_I) as tracer with Total Intensity Mapping, has been proposed in recent years (Peterson et al. (2006)) (Chang et al. (2008)) . Mapping the matter distribution using HI 21 cm emission as a tracer has been extensively discussed in literature (Furlanetto et al. (2006)) (Tegmark & Zaldarriaga (2008)) and is being used in

strain the properties of this new cosmic fluid, more precisely its equation of state: The Hubble Diagram, or luminosity distance as a function of redshift of supernovae as standard candles, galaxy clusters, weak shear observations and Baryon Acoustic Oscillations (BAO).

BAO are features imprinted in the distribution of galaxies, due to the frozen sound waves which were present in the photons baryons plasma prior to recombination at z ∼ 1100. This scale, which can be considered as a standard ruler with a comoving length of $\sim 150 Mpc$. Theses features have been first observed in the CMB anisotropies and are usually referred to as *acoustic pics* (Mauskopf et al. (2000)) (Hinshaw et al. (2008)) . The

PAPER PLAN

1. Introduction
2. Intensity mapping and HI power spectrum
3. Interferometric observations and P(k) sensitivity
4. Foreground and component separation
5. Dark Energy constraints (DETF FOM)
6. Conclusion and outlook