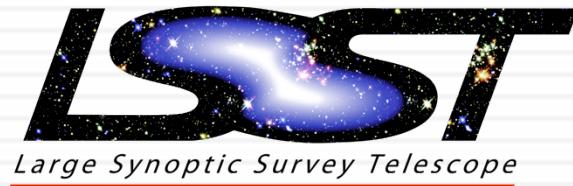


# Working with $C_\ell(z)$ matter power spectrum

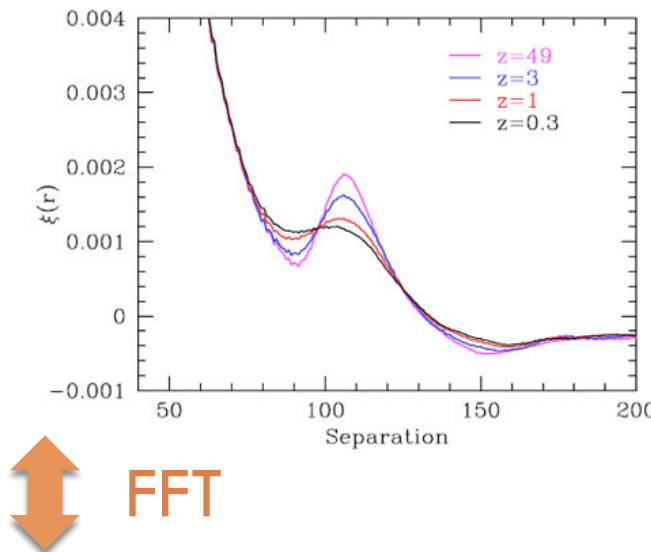
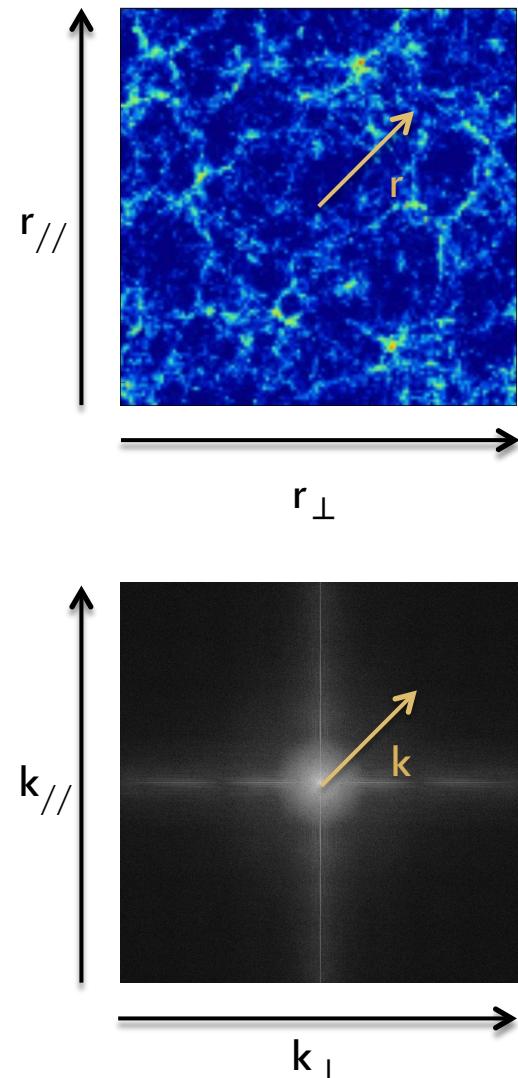
Jérémie Neveu – LAL



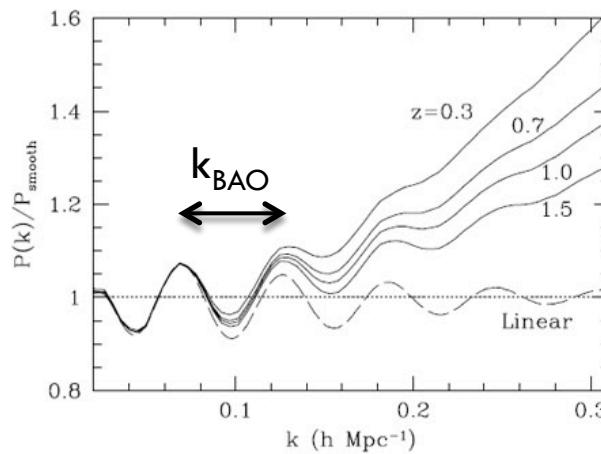
June 9th, 2016  
Grenoble



# Introduction

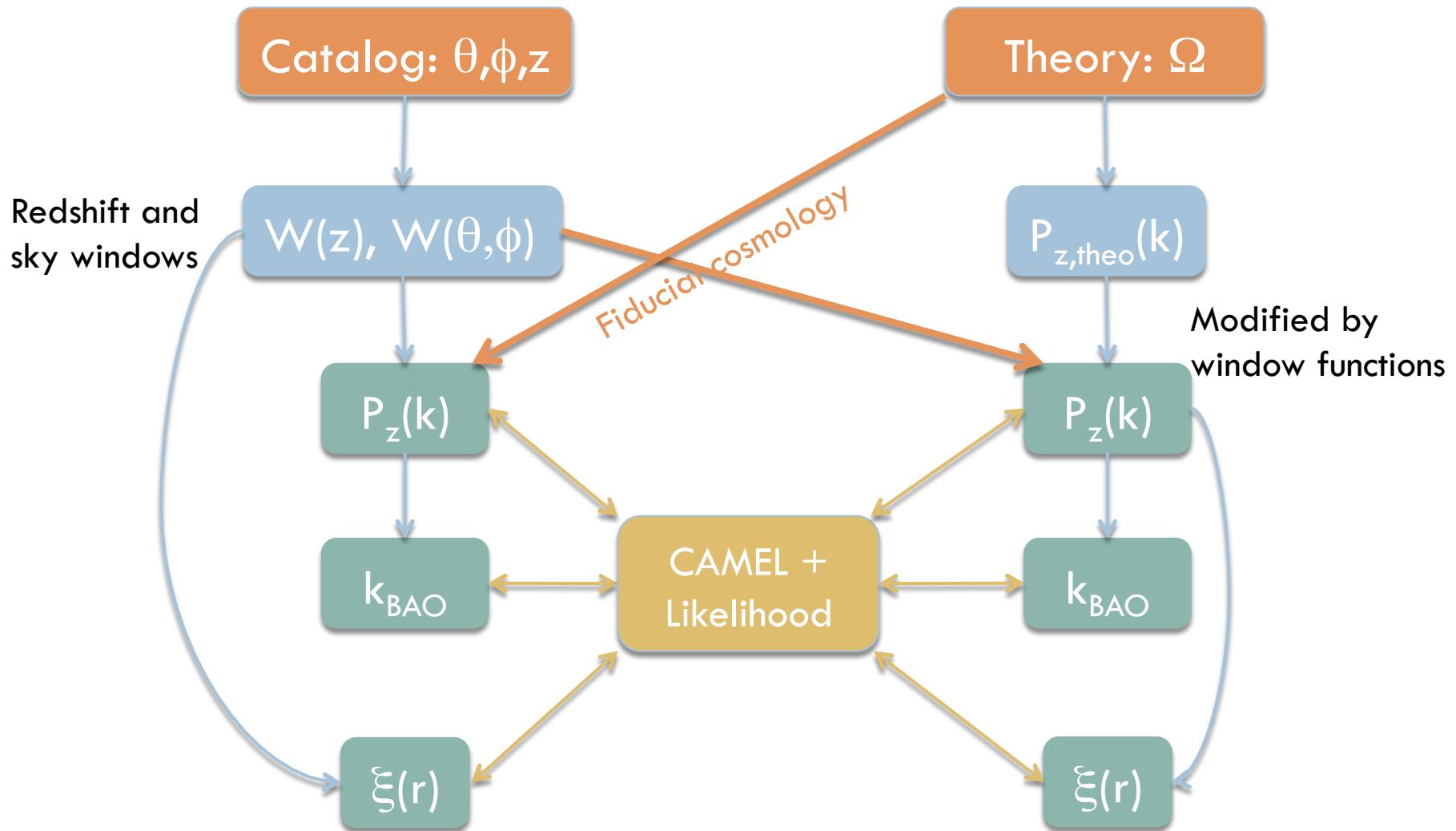
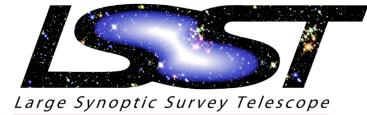


**FFT**

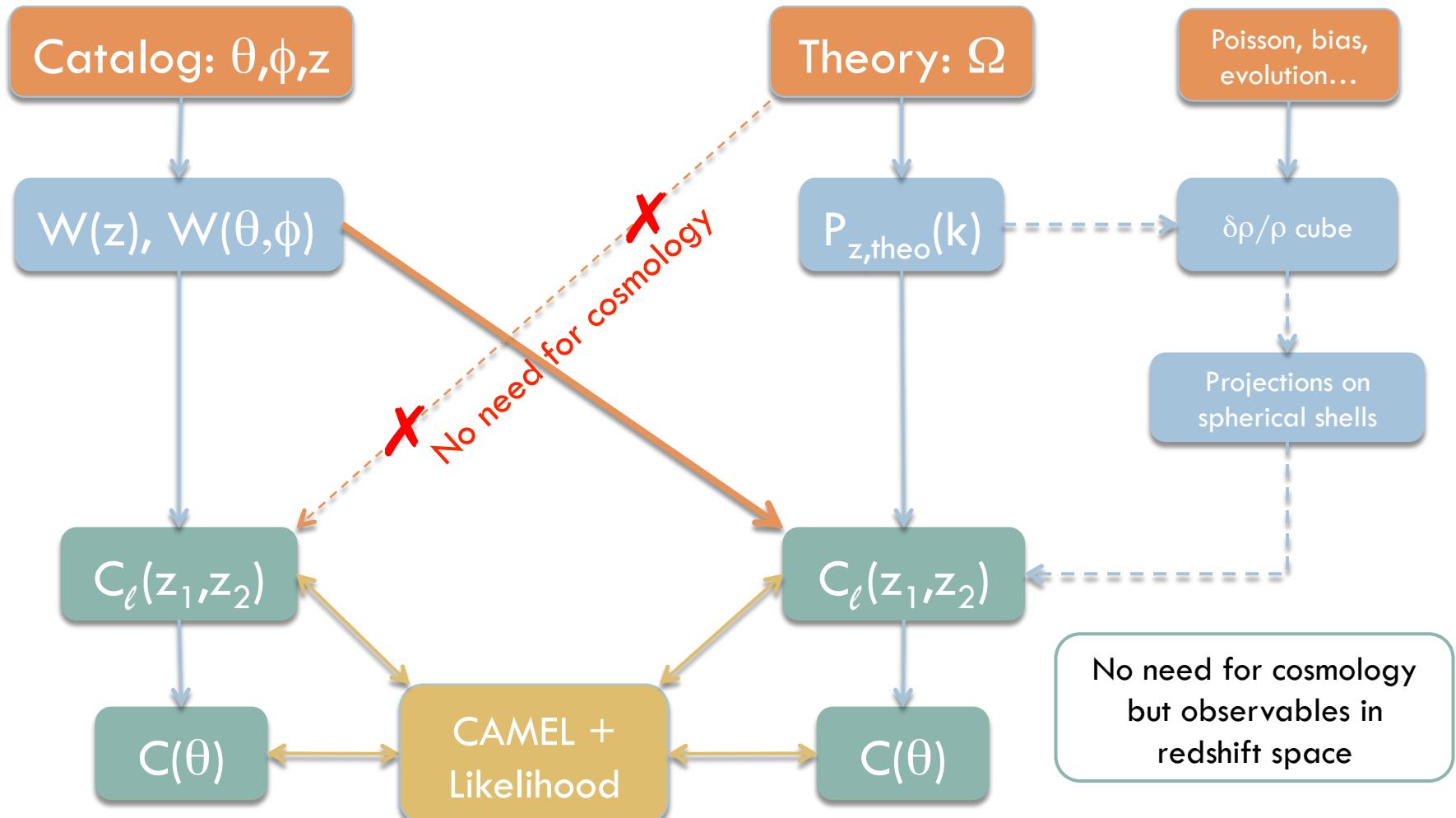
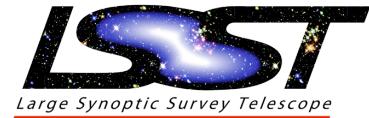


- Large scale structures contain a lot of information about cosmic evolution:
  - BAO scale
  - Growth function
  - Non-linear features...
- In real and Fourier space:
  - $\xi(r) \leftrightarrow P(k)$
  - in 3D and 2D
- But part of the information can be altered by the survey

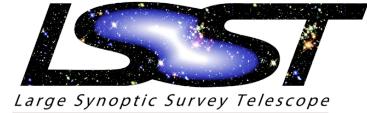
# $P_z(k)$ roadmap



# $C_\ell(z)$ roadmap

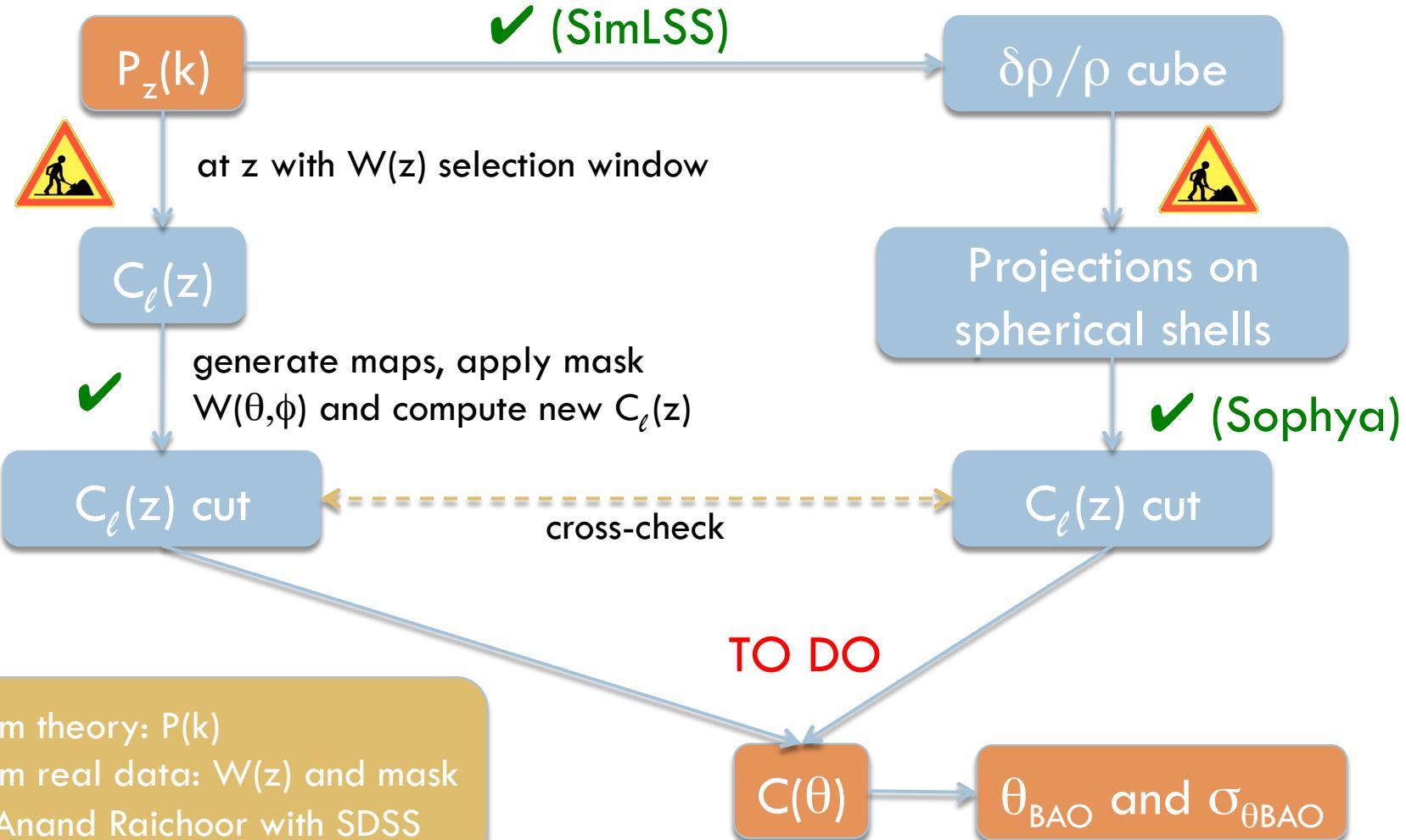
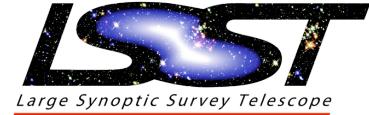


# Objectives



- Work with  $C_\ell(z)$  matter power spectrum
  - because LSST will map a very wide galaxy field
  - with no spectroscopic information
- Check impacts on BAO scale of:
  - photometric redshifts (selection window  $W(z)$ )
  - sky masks
  - geometric effects
    - Spherical projection, binning, etc...

# $C_\ell(z)$ roadmap



# From $P_z(k)$ to $C_\ell(z)$

- A double integral with spherical Bessel functions :

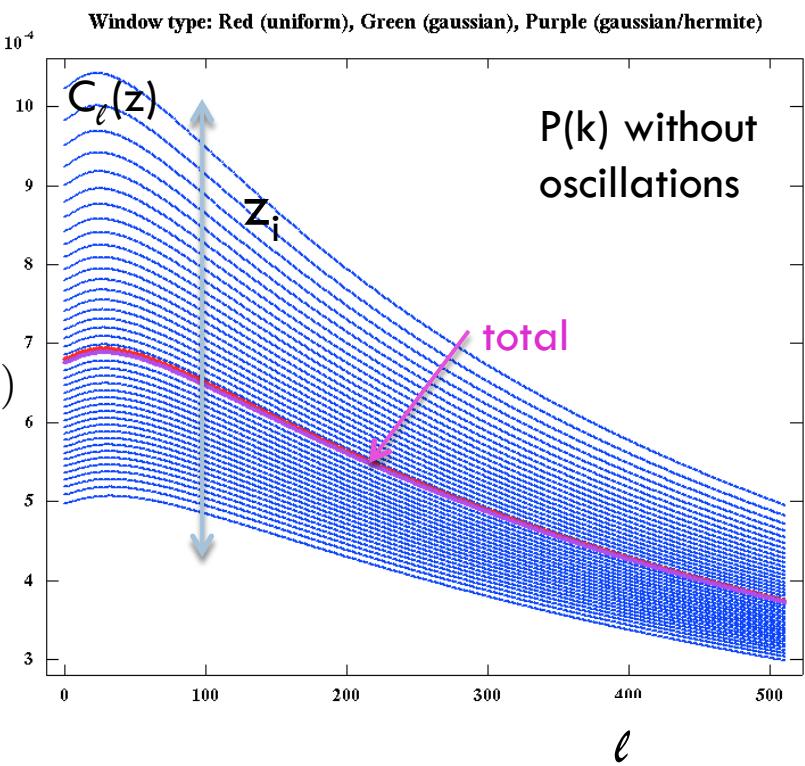
$$C_\ell(z) = \frac{2}{\pi} \int dz W(z) \left( \int dk P(k) k^2 j_\ell^2(kr_{\text{LOS}}(z)) \right)$$

- Optimised integral of Bessel functions coded by J.E. Campagne

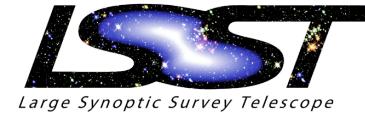
- Development on the spherical Bessel functions roots weighted by Chebychev/Clenshaw-Curtis coefficients

$$\int_{k_1}^{k_2} dk P(k) k^2 j_\ell^2(kr(z)) = \sum_{i=\text{roots}} w_i^{CC} P(k_i) k_i^2 j_\ell^2(k_i r(z))$$

- Very fast !
- $W(z)$  Gaussian, top hat or from data
- What is the optimal  $W(z)$  to detect the oscillations ?



# SDSS selection at $z \sim 0.75$

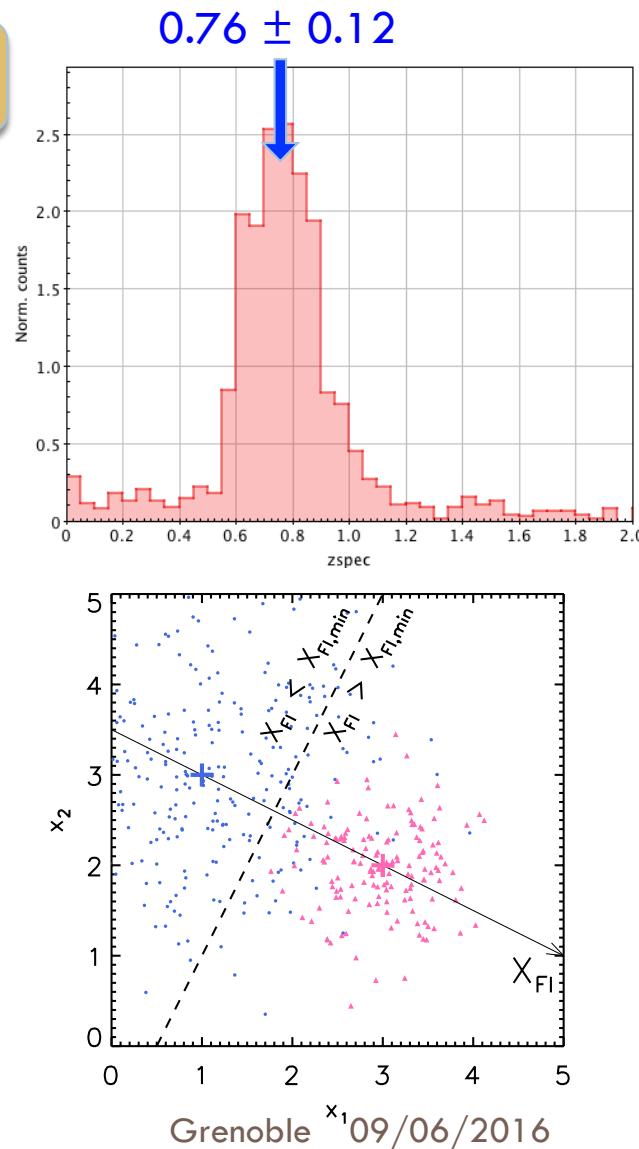


- Photometry: SDSS/gri + WISE/W1
- Selection done on colors
- No individual redshifts;  $W(z)$  characterized in some test regions
- SDSS full footprint:  $10,000 \text{ deg}^2 \rightarrow 2\text{e}6 \text{ objects}$

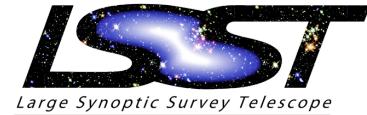
By Anand Raichoor

## Selection method details

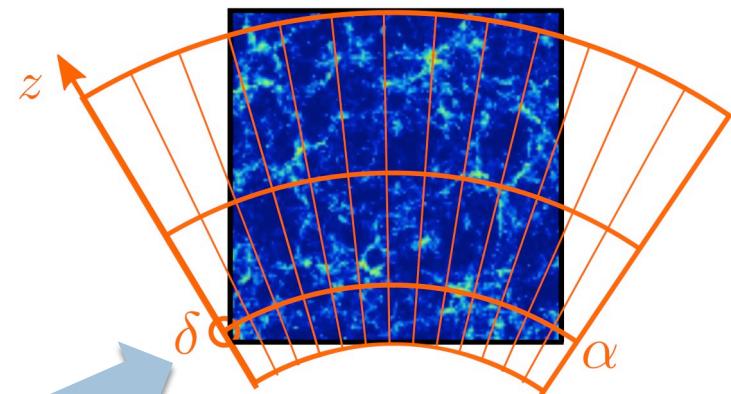
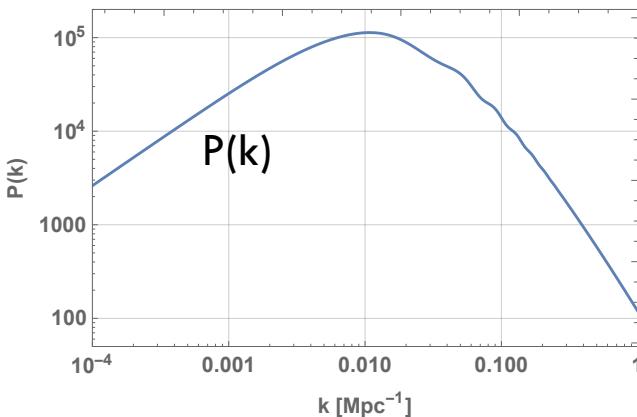
- $X_{FI}$  = Fisher discriminant
  - = linear combination of colors ( $g-r$ ), ( $r-i$ ), ( $r-W1$ )
  - = correlates with redshift by construction on a training sample
- Selecting with  $X_{FI} > X_{FI, \text{cut}}$  provides a sample at  $180/\text{deg}^2$
- We can adapt the density &  $W(z)$  by changing  $X_{FI, \text{cut}}$
- Details in Raichoor et al. 2016.



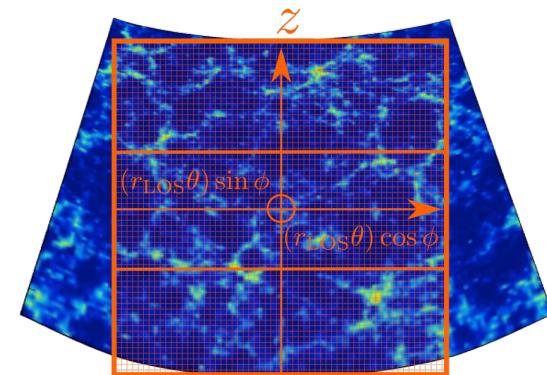
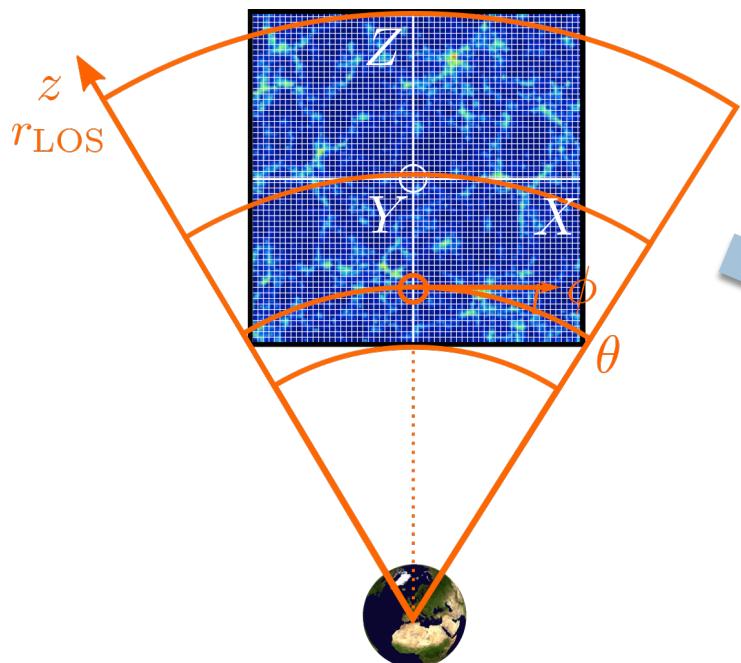
# Projection on spherical shells



Input  $P(k)$

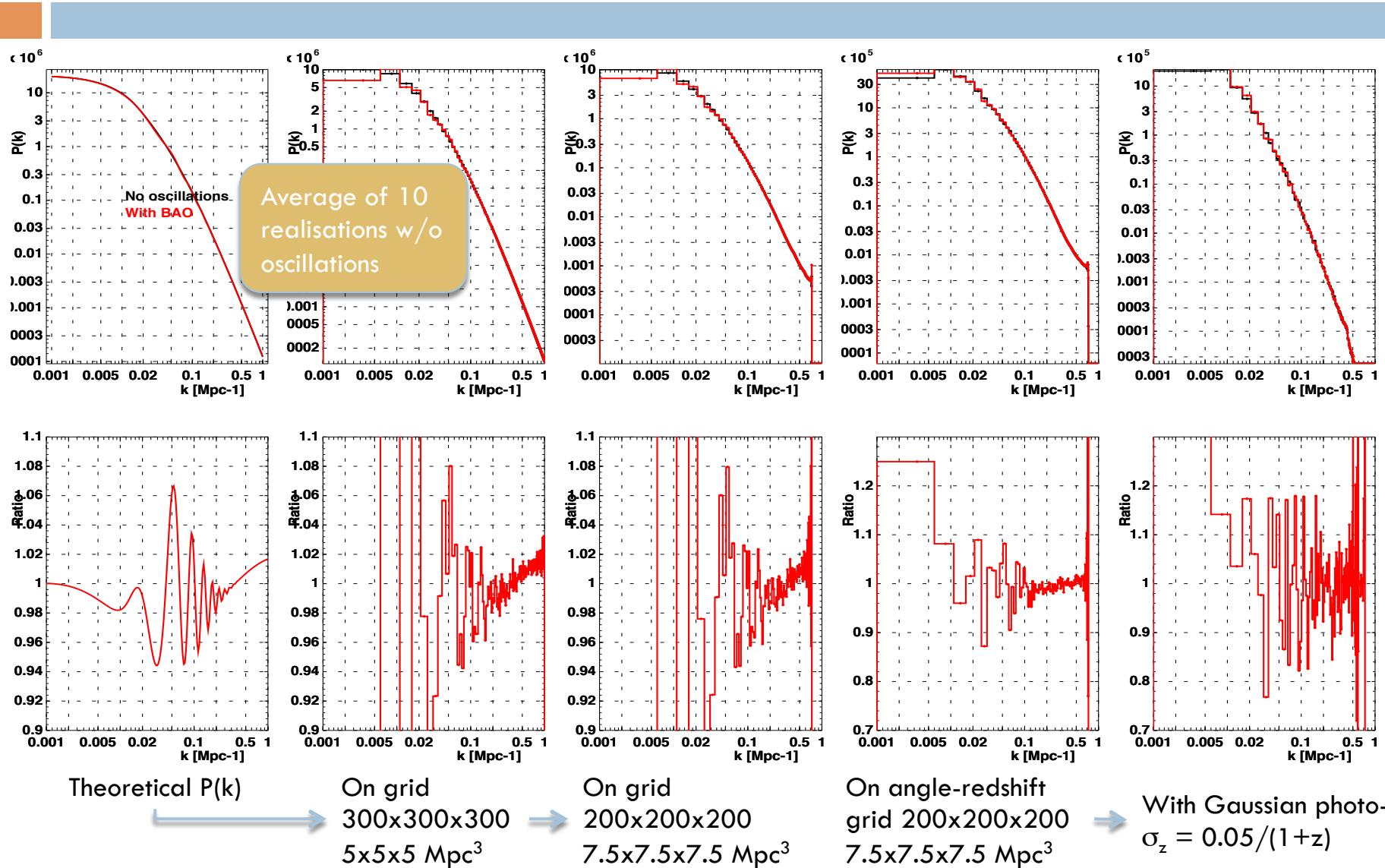
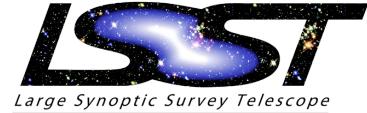


$C_\ell$  in  $z$  shells

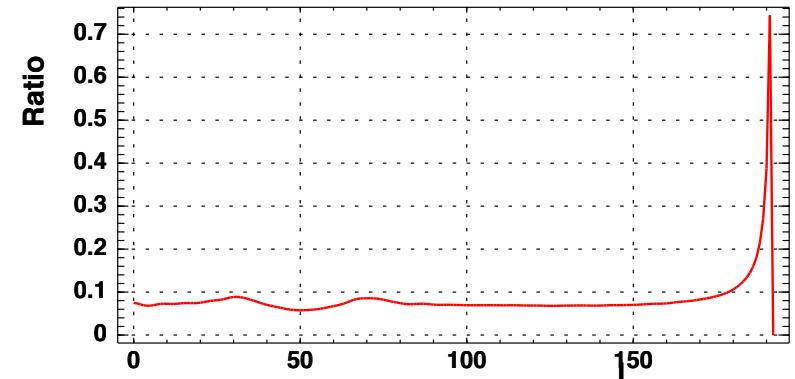
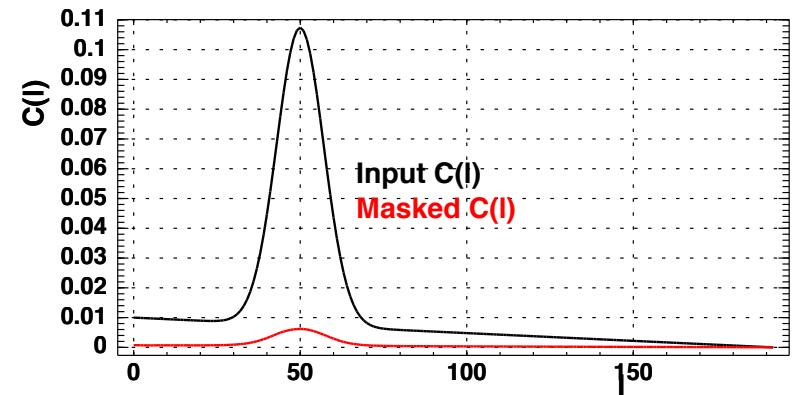
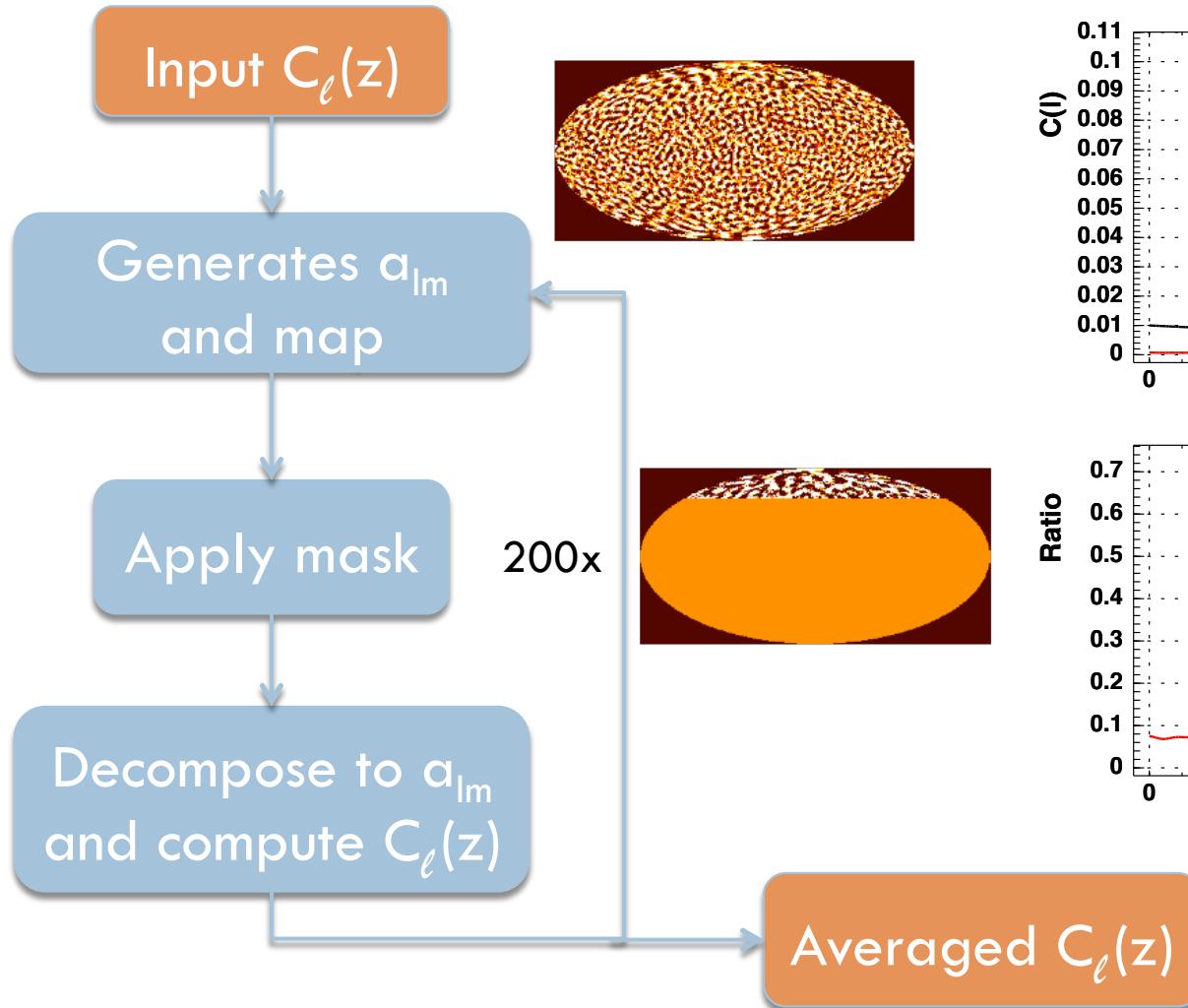


Distorted  $P(k)$

# Distorted $P_z(k)$ at $z=0.2$



# Masking $C_\ell(z)$



# Features

- LagSHT performs Laguerre Spherical Harmonic transform over different set of 2D-sphere mappings with user choice of generalized Laguerre parameter  $\alpha$  and spin (eg. 0 for scalar, 2 for polarization).
- Code available at  
<https://gitlab.in2p3.fr/campagne/LagSHT>
- Delivable accepted for DESC 3DDC
- Original work by J. McEwen & B. Leistedt (IEEE VOL. 60, NO. 12 (2012))

# Basics

$$K_{lmn}(r, \Omega; \tau) \equiv Y_{l,m}(\Omega) \times \mathcal{K}_n(r, \tau) \quad \text{3D ortho-basis}$$

$$\mathcal{K}_n(r, \tau) = \tau^{-3/2} \sqrt{\frac{n!}{(n + \alpha)!}} e^{-r/2\tau} \left(\frac{r}{\tau}\right)^{\frac{\alpha}{2}-1} L_n^{(\alpha)}(r/\tau) : \text{Gen. Lag. Func}$$

$$f(r, \Omega) = \sum_{n=0}^{\infty} \sum_{l=0}^{\infty} \sum_{m=-l}^l f_{lmn} K_{lmn}(r, \Omega; \tau) \quad \text{Synthesis}$$

$$f_{lmn} = \int_{B^3} dr d\Omega r^2 f(r, \Omega) K_{lmn}^*(r, \Omega; \tau) \quad \text{Analysis}$$

# Basics (cont'ed)

3D-Discretization ( $f_{ijk}$ ) and also in Spherical-Laguerre space ( $f_{lmn}$ )

**Analysis :**  $f_{ijk} \xrightarrow{SHT} a_{lmk} = a_{lm}(r_k) \xrightarrow{\text{Lag.Trans}} f_{lmn}$

**Synthesis :**  $f_{lmn} \xrightarrow{\text{Inv.Lag.Trans}} a_{lmk} = a_{lm}(r_k) \xrightarrow{\text{Inv.SHT}} f_{ijk}$

## Exact Gauss-Laguerre quadrature

$$f_{lmn} \propto \sum_{k=0}^{N-1} w_k a_{lmk} e^{-r_k/2} L_n^{(\alpha)}(r_k) r_k^{1-\frac{\alpha}{2}} \quad n \in \{0, \dots, N-1\}$$



By product

Alm on each sub-shells



Tomography

New coefficients to be used for analysis

# Basic

- SHT on each sub-shells performed via libsharps ((ECP/Fejer1 sum rule, Gauss, Healpix, user-defined). Tomographic analysis for free
- Radial part: Laguerre Transform quadrature: new own-made fast & accurate implementation with Martin Reinecke expertise.

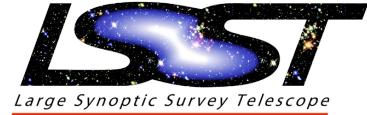
# Installation

- Mac OSX/Linux with gcc OpenMP compliant
- Use OpenBLASS on Linux if installed, on Mac use native framework accelerator
- Libsharp
- FFTW for the Laguerre to Bessel transform passage (experimental)

# Exemple

- $L_{max} = 1024$ ,  $N_{shells} = 128$  (Gauss mapping)  $N_{phi} = 2048$ :
  - Analysis or Synthesis in 13-15sec on Mac OSX i7
  - Max abs. err.  $2 \cdot 10^{-11}$

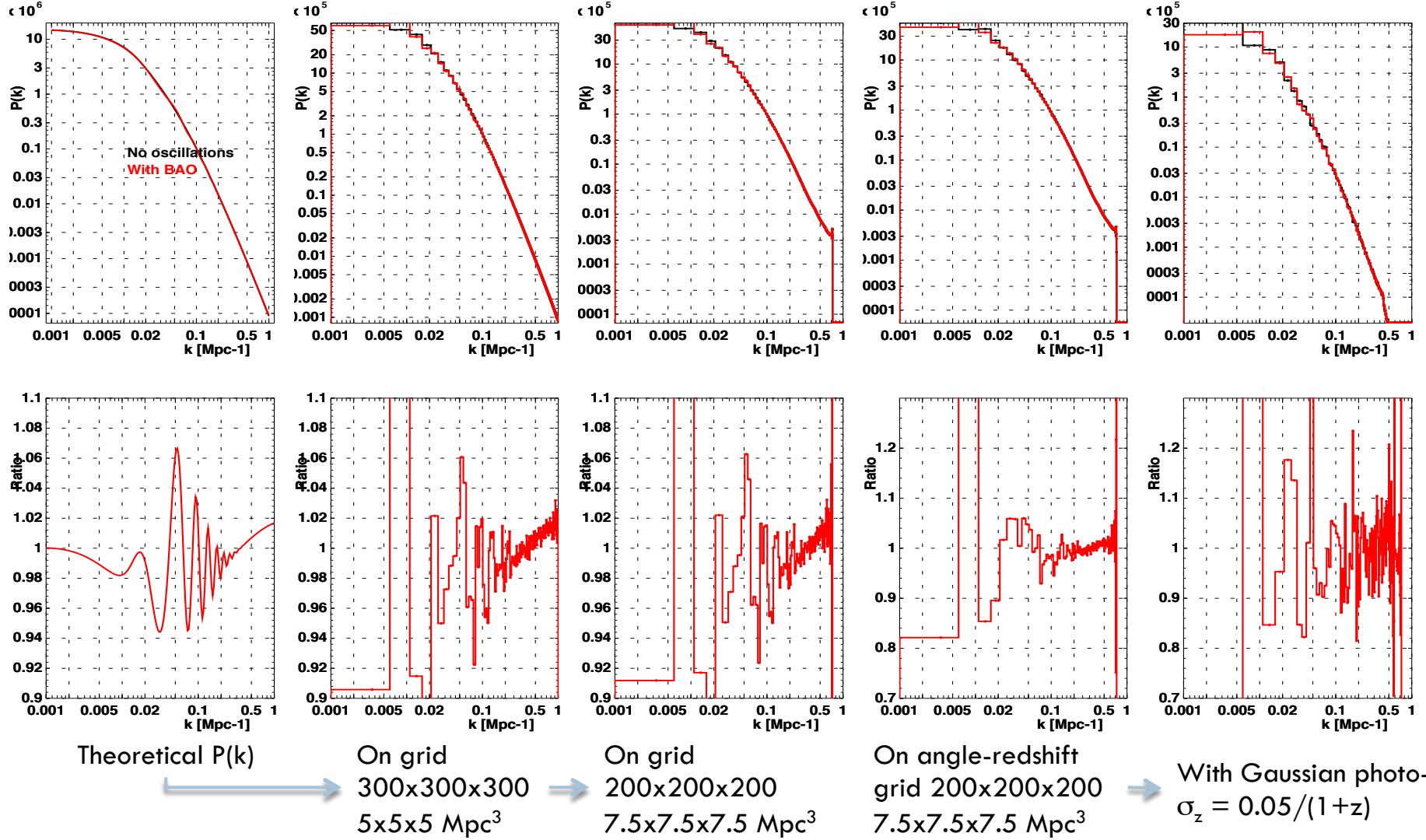
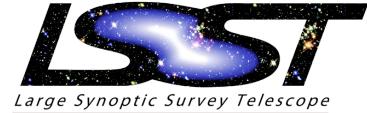
# Summary and future



- Development of tools to derive  $C_\ell(z)$  from theory, real galaxy catalogues and LSST previsions
  - Apply sky mask and selection windows
  - Geometric distortions
- Future applications to SDSS data → BAO at  $z \sim 0.75$  ?
- $\Lambda$ CDM but also modified gravity theories ?
- Going beyond  $C_\ell(z)$  ? 3D spherical correlations

<https://gitlab.in2p3.fr/campagne/LagSHT>

# Distorted $P_z(k)$ at $z=0.5$



# Distorted $P_z(k)$ at $z=1.0$

