Laboratoire de Physique Subatomique et de Cosmologie

Large Synoptic Survey Telescope

Baryon Accoustic Oscillation and photometric redshift with LSST

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Contents

Accelerating universe and Dark Energy

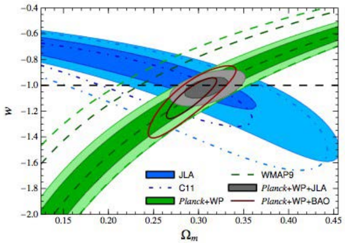
1998 : distant Type Ia supernovae have lower recession velocity than expected (Riess and Perlmutter, nobel prize 1991)

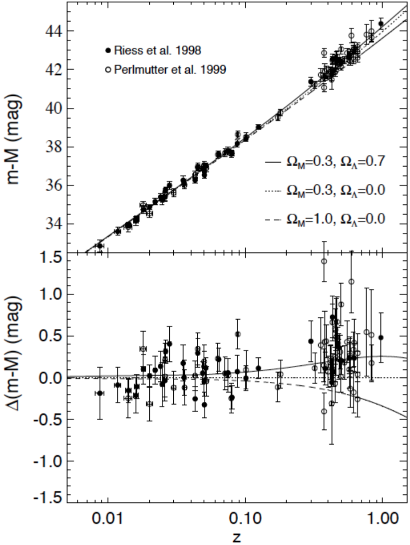
⇒ universe is accelerating

⇒ **Dark Energy** (p<0)

$$p = w\rho = [w_0 + w_a(1-a)]\rho$$

- observation is needed : CMB, SN, **BAO**, WL...

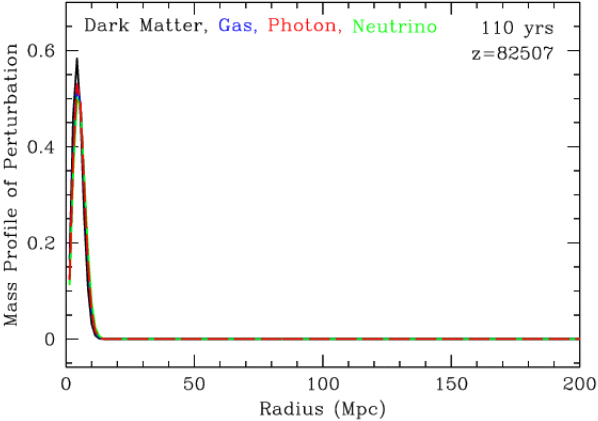




What is BAO ?

Structure formation in the universe relies on gravitational instability to aggregate the material.

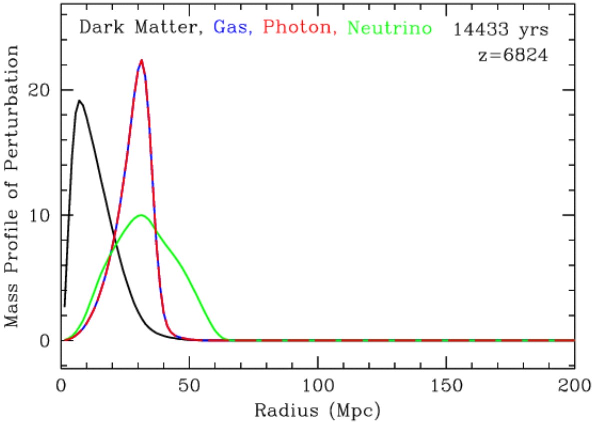
0) Initial perturbations : adiabatic → all of the species are perturbed the same fractional amount



What is BAO ?

Structure formation in the universe relies on gravitational instability to aggregate the material

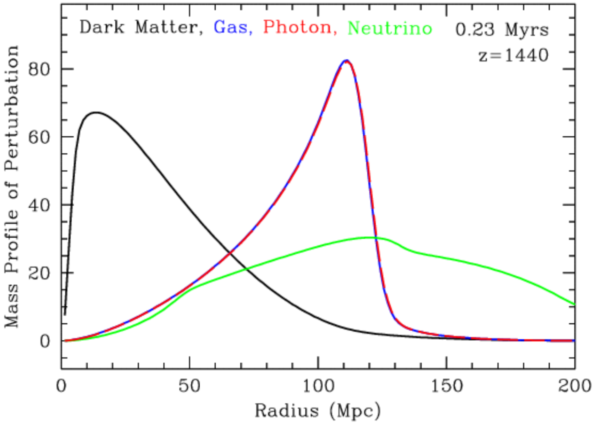
1) Spherical acoustic wave ; baryons coupled to photons ; **neutrinos escape**, dark matter moves only in response to gravity and has no intrinsic motion



What is BAO ?

Structure formation in the universe relies on gravitational instability to aggregate the material

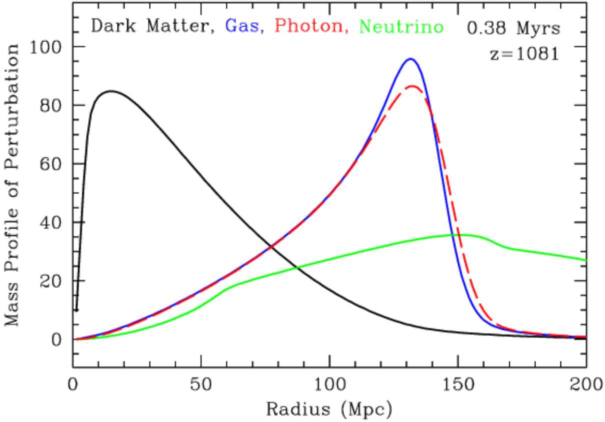
2) Spherical shell of gas and photons continues to expand. The **neutrinos spread out**. The dark matter collects in the overall density perturbation.



What is BAO ?

Structure formation in the universe relies on gravitational instability to aggregate the material

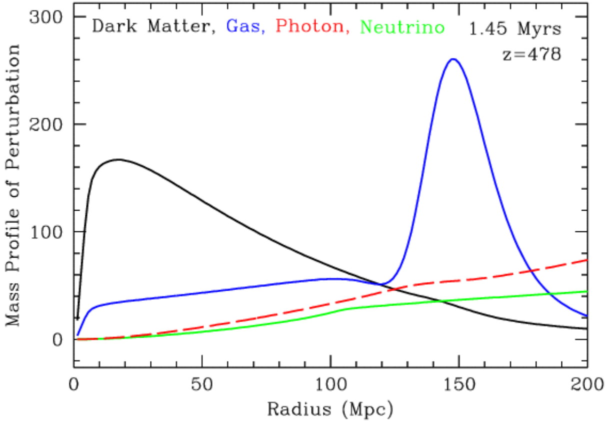
3) Electrons and nuclei begin to combine into neutral atoms. The expanding universe is cooling. **Photons and gas coupling is reduced.**



What is BAO ?

Structure formation in the universe relies on gravitational instability to aggregate the material

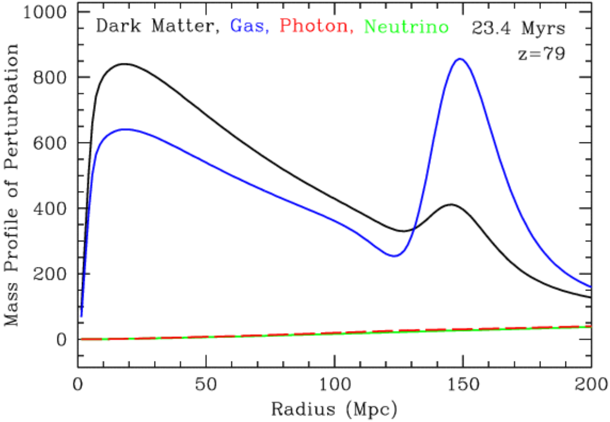
4) **Decoupling** : sound speed vanished ; baryon carry the footprint of fuctuations in a shell about 150 Mpc. Photon escape (CMB)



What is BAO ?

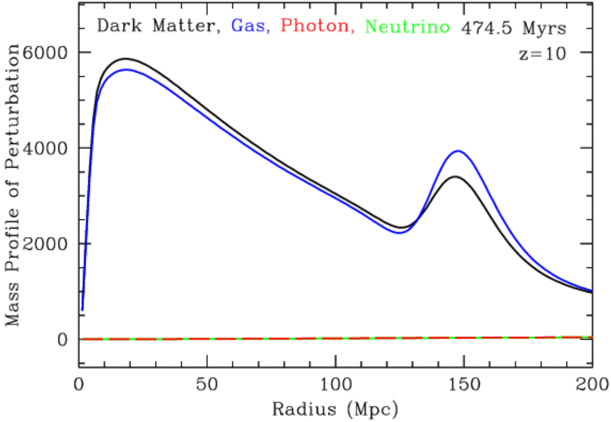
Structure formation in the universe relies on gravitational instability to aggregate the material

5) DM and baryons coupled by gravitation : the spherical shell of the gas perturbation has imprinted itself in the dark matter ⇒ **acoustic peak**.



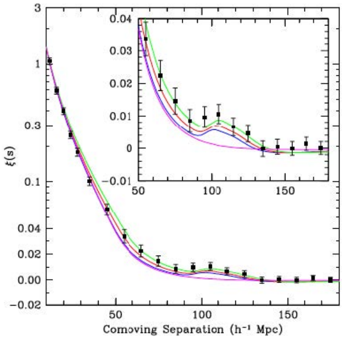
Structure formation in the universe relies on gravitational instability to aggregate the material

6) **The acoustic peak decreases** in contrast as the gas come into lock-step with the dark matter.



BAO as a cosmological probe

- Measure of the probability to find a galaxy from an other
  $\Rightarrow$ **correlation function** $\xi(r)$.
  $\rightarrow \chi = 100h^{-1}Mpc$
- First measurement :
  2005 (2dFGRS and SDSS)
- A 3D measurements :
  - Position of acoustic peak
    $\Rightarrow$ Size of the sound horizon $\mathbf{rs}(\Omega_m, \Omega_B)$
  - Transverse direction :
    $\Delta\theta = rs/(1+z)/DA(z)$
    $\Rightarrow$ Sensitive to angular distance $\mathbf{DA(z)}$
  - Radial direction :
    $\Delta z = rs * H(z)/c$
    $\Rightarrow$ Sensitive to Hubble parameter $\mathbf{H(z)}$:



$$H(z) = H0\sqrt{\Omega_m(1+z)^3 + \Omega_\lambda + (1-\Omega_m-\Omega_\lambda)^2}$$

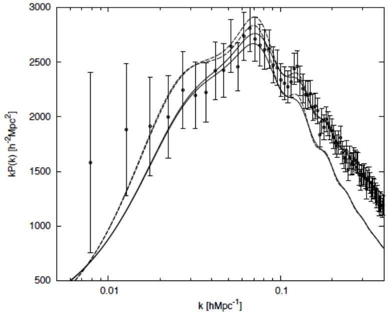
- Power spectrum :

$$P(k) = TF(\xi(r)) = \int \frac{d^3r}{(2\Pi)^3} exp(-ikr)$$

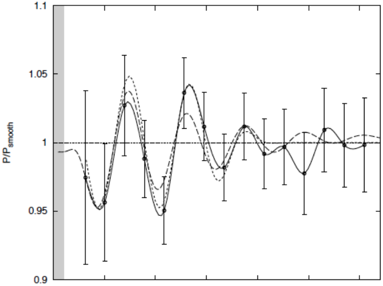
- Method "wiggle only"
  - P(k) is divided by a spectrum without wiggle

  → FKP method : $P_R(k)$ compute on a random catalogue with same selection function as the data catalogue.

  → fit with a parametrized function.



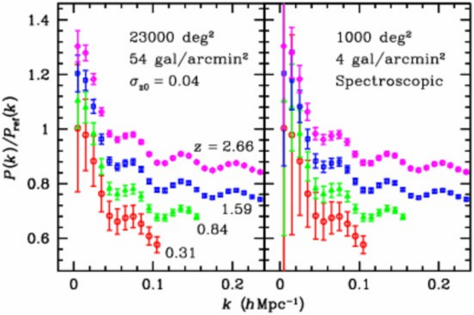
⇒



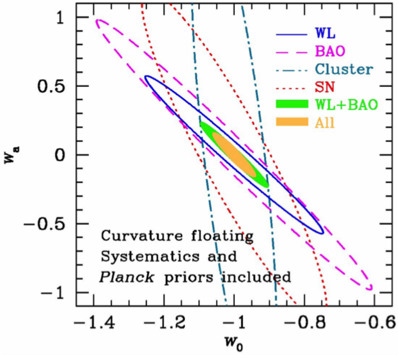
G. Hutsi (SDSS)

BAO with LSST

- Instument for BAO :
  - BOSS, eBOSS (2014-2020),
  - DASI (2019-2024)
  - Euclide (2020)
  - **LSST** (2021-2031) : 10 billions of galaxies, up to z = 3



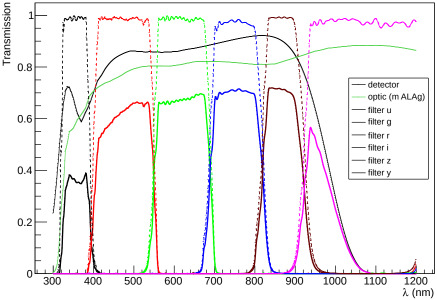
⇒



- power spectrum is measured at different redshif bins.

What do we need ?

- a huge statistics : not a problem for LSST
- a high precision on redshift measurement.



LSST : 6 photometric bands ugrizy
⇒ **photometric redshift**

- machine learning method
- **template fitting method**
  - → we compute the integrated flux in each bands,
  - → we compare expected flux to some known emission spectrum at a range of redshift.

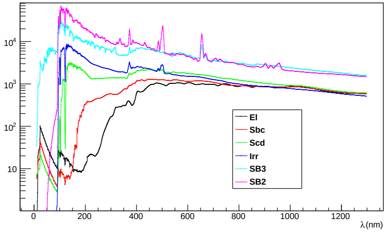
LSST specification on $|\Delta z| = |\frac{z_p - z_s}{1+z_s}|$:

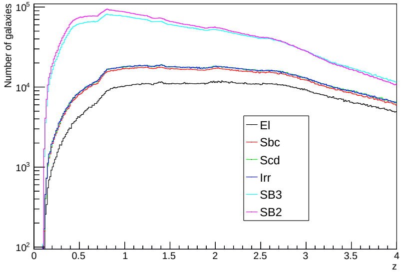
- 0.05 random error (RMS),
- bias $< 3.10^{-3}$,
- % outliers $< 10\%$.

The simulated catalogue

1) **Simulated Galaxies Catalogue**

- ΛCDM cosmology is assumed
  - computation of over density
  - luminosity function (Dalhen and al.)
- Absolute Magnitude, color escess E(B-V), z_{true},
- 51 galaxies spectral type interpolated between 6 main SED.
  - main spectral type : El, Sbc, Scd, Irr, SB3, SB2.





Method

2) Photometrique redshift reconstruction

- apparent magnitude : $m_X = MA + K_{BX} + MD \sim -2.5log(F_x)$ with :

flux: SED, reedening , Inter Galactic Medium

B band Of GOODs

$$K_{BX} = -2.5\log\left[\frac{1}{1+z}\frac{\int d\lambda\lambda T(\frac{\lambda}{1+z})X(\lambda)\int\frac{d\lambda}{\lambda}B(\lambda)}{\int\frac{d\lambda}{\lambda}X(\lambda)\int d\lambda\lambda T(\lambda)B(\lambda)}\right]$$

Filter

- error on apparent magnitude : atmosphere, systematics ...
- template fitting method :

Likelihood function

Prior

$$P(z,T,E(B-V)|\vec{m}) = \frac{\mathscr{L}(z,T,E(B-V)) * \Pi(z,T|\vec{m})}{P(\vec{m})}$$

$\Rightarrow$ photometric value z_p, T_p, ebv_p such as

$$\frac{dP(z,T,E(B-V)|\vec{m})}{d(z,T,E(B-V))} = 0.$$

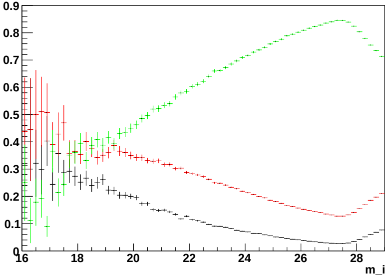
Prior computation

- $\mathbf{\Pi(z, T, E(B-V)|m_i)}$: probability for a galaxy with an m_i apparent magnitude in the i filter to be at a redshift z, with a spectral type T and color excess E(B-V) : (*Benitez method*)

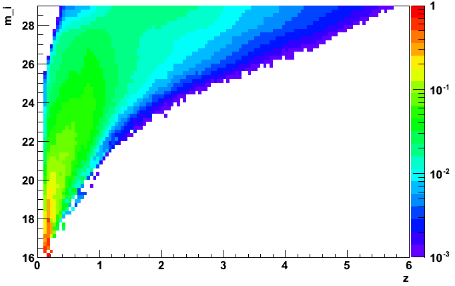
$$\Pi(z, T, E(B-V)|m_i) = P(T|m_i) * P(z|T, m_i)$$

- Computed for 3 spectral type : Elliptic, Spiral and Starburst.

→ A spectroscopic sample is needed.



$P(T|m_i)$



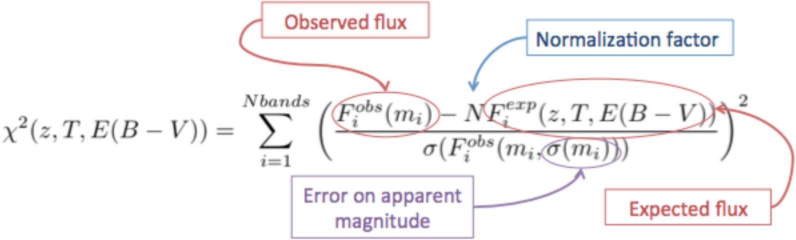
$P(z|T, m_i)$ (Starburst galaxies)

Likelihood computation

$$\mathscr{L}(z, T, E(B-V)) = exp[\frac{-1}{2}\chi^2(z, T, E(B-V))]$$

1) Observation $\Rightarrow F_i^{obs}(m_i)$

2) 3D gride over z, spectral type T and colore excess E(B-V)
$\Rightarrow F_i^{exp}(z, T, E(B-V))$



$$\chi^2(z, T, E(B-V)) = \sum_{i=1}^{Nbands} \left(\frac{F_i^{obs}(m_i) - N F_i^{exp}(z, T, E(B-V))}{\sigma(F_i^{obs}(m_i, \sigma(m_i)))} \right)^2$$

3) χ^2 minimisation ($\Leftrightarrow \mathscr{L}$ maximisation)

$\Rightarrow$ photometric value z_p, T_p, ebv_p

Quality cut

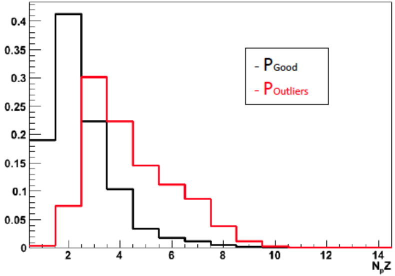
Outliers : $|\Delta z| = |\frac{z_p - z_{true}}{1+z_{true}}| > 0.15$

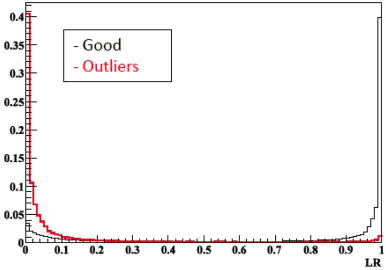
LikelihoodRatio

- training set $\sim$ 450 000 galaxies
- 16 discriminant variables
  - form variable : Npeak in the z marginalised pdf ...
  - color terme (ex : r-i)
- $LR = \frac{\Pi_{i=1}^{N} P(\mu_i|G)}{\Pi_{i=1}^{N} P(\mu_i|G) + \Pi_{i=1}^{N} P(\mu_i|O)}$

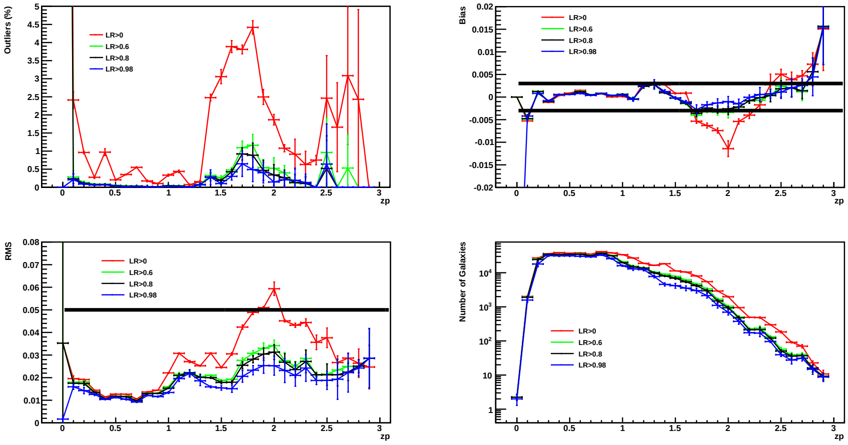
$\Rightarrow$ $LR \in [0,1]$

- Limitation of the method :
  - $P(\mu_i|G) = 0 \rightarrow LR = 0$
    Goods $\Rightarrow$ Otliers
  - $P(\mu_i|O) = 0 \rightarrow LR = 1$
    Outliers $\Rightarrow$ Goods





Result

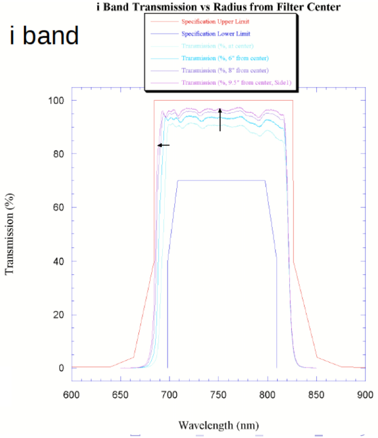


⇒ photo-z is in LSST requirement up to $z \sim 2.6$ if $LR > 0.98$

Gorecki & al : *arxiv :1301.3010*

Impact of spatial variation

- We can get the photometric redshift with a good precision,
- The photo-z quality could be affected by differents uncertainties on parameters which enter in the likelihood computation :
  - reddening or intergalactic medium law,
  - **filters** ,
  - the SED library ...



- LSST filters are quite big (78 cm diameter)

⇒ coating could'nt be perfect

⇒ What happen on photo-z if filters vary ?

  - impact of the incidence angle : → effective filter
  - what happen if constraints on filters can't be reach ?
  - **impact of spacial variation ?**

Impact of filters spatial variations

- Filter diameters : 78 cm
- Due to spatial variation filter could be shifted up to ±2.5% (*LSST spec.*)

u	g	r	i	z	y
±9 nm	±12 nm	±16 nm	±19 nm	±22 nm	±25 nm

- the worst case should be : $\delta\lambda = \{-9, 12, -16, 19, -22, 25\}$ (+- configuration) or the opposite (-+) configuration.
  1) computation of a medium effective filter for 10 years of observation (for -+ configuration),
  2) reconstruction of the photometric redshift using differents filters for each galaxies.

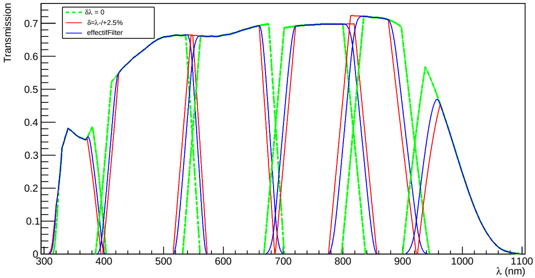
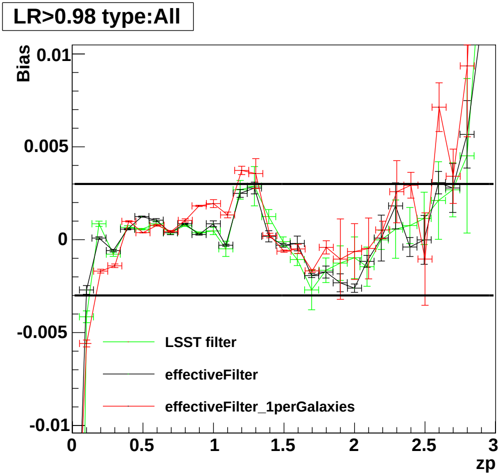


Photo-z quality



- Effective filters :
  - no sinificant impact
  - still within LSST specification up to $z_p \sim 2.6$
- One filter per galaxies $\Leftrightarrow$ uncertainties on filters measurement :
  - F_{exp} is computed using effective filters ,
  - F_{obs} is computed using different fiters for each galaxie
  - $\Rightarrow$ impact on photo-z quality for $0.8 < z_p < 1.3$
  - $\Rightarrow$ if $z_p > 1.9$: higher error barres.

How important will be those effect ? $\rightarrow$ Cosmology

Conclusion and perspectives

Conclusion

- LSST will observed billion of galaxies which alowed the measurment of BAO scale at many z bins,
  - → the redshift of all of those galasies is nedded with a excelent precision.

⇒ Franzona method for photometric redshift reconstruction :

- template fitting method form 51 intepolated SED
- we can reconstucted the redshift in LSST specification up to $z \sim 2.7$
- we need spectroscopic data to train the method → euclide, DASI ...

⇒ synergies with Euclide, BOSS ... will led to unprecedent quality on dark energy constrainte.

Perspective

- Test the method using an other SED library
- A real catalogue data is in developpement to test the method
- BAO analysis using Franzona tools