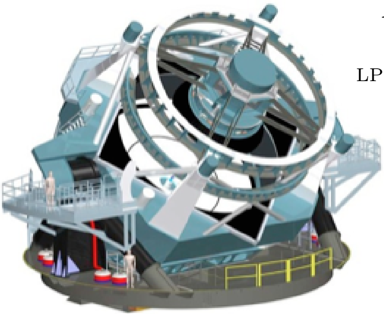
LSST :
camera calibration and photo-z study



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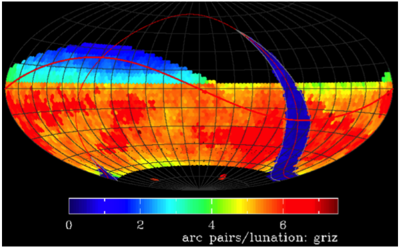
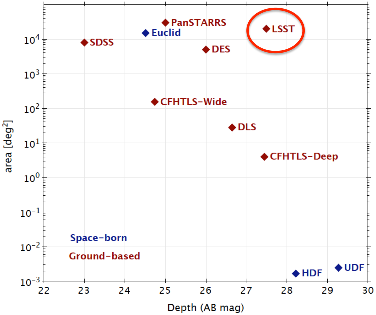
Contents

LSST project

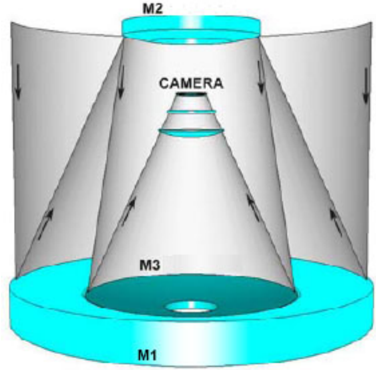
- **Site :** Cerro Pachón, Chili.
- **First light :** 2020.

- **Wide**
  - large apperture : 9.6 deg^2 (∼50 full moon)
  - visible sky : 20 000 deg^2
- **Fast**
  - rapidly scan the sky : 15 s pose + 2s read + 15 s pose + new pointing as reading
  - Revisit after 30-60 min ;
  - Complete scan every 4 night.
- **Deep**
  - Observe billions of galaxies
  - $m_r = 27.7$ (10 years)
    $m_x = -2.5 log(F_x)$
    $\Delta m = 3 \Leftrightarrow F/16$





Optics

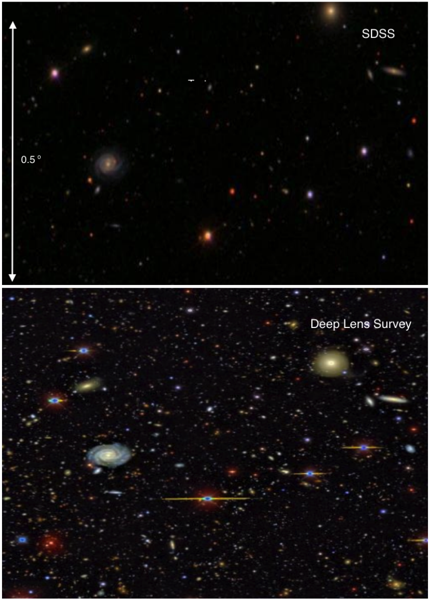


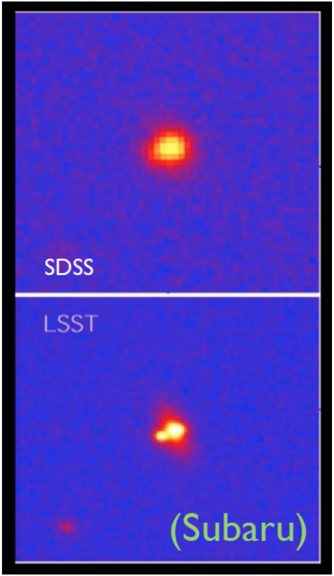
- Three mirror design (Paul-Baker system)
- primary mirror : 8.4m

⇒ large field of view with excellent image quality

  - quality is only limited by atmospheric seeing.

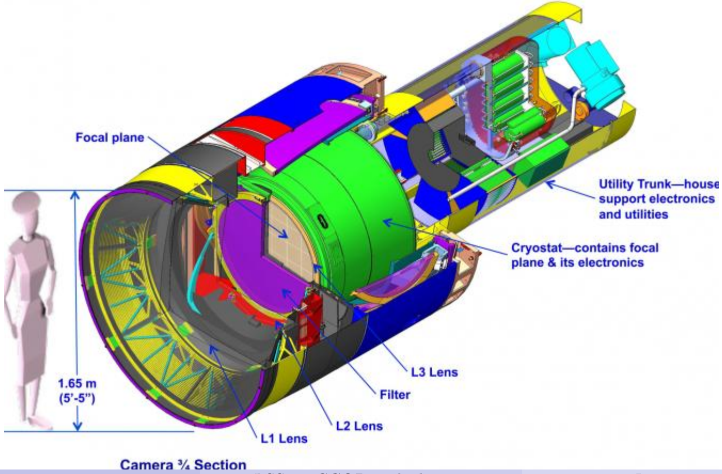
Image quality





Camera

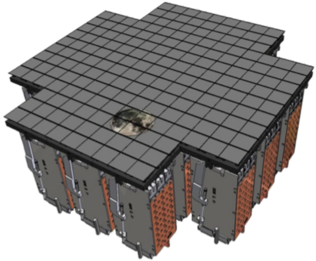
- 3 lenses + 6 filter (ugrizy)
- Mass 3000 kg,
- diameter : 1.65 m
- length : 3.73 m
- incident angle : 14.2° - 23.6°



Focal Plan

One of the most ambitious part of LSST :

- 64 cm diameter
- 189 CCD (21 raft of 3x3CCD)
- each raft has is own electronics
- 4096x4096 pixels per raft
  (3.2 billions of pixels),
- 1px = 10 μm size (0.2 arcsec)



⇒ the response of the CCD focal plane has to be well known :

- 0.5% level precision on the entire FP
- 0.2% level precision at a raft scale

⇒ **Camera Calibration Optical Bench (CCOB)**

Camera Calibration Optical Bench

CCOB specification

Large Beam

- beam diameter ∼ 20 mm
- scan entire FP
- deliver camera first light
  → bad and dead pixels
- measured the pixel to pixel relative response
- Should be deliver on 09/2016

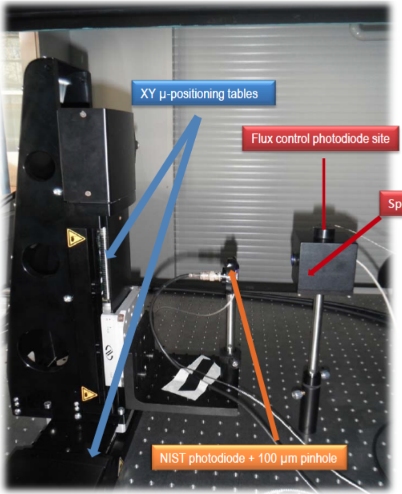
⇒ necessite flux control at 0.1 %

Thin Beam

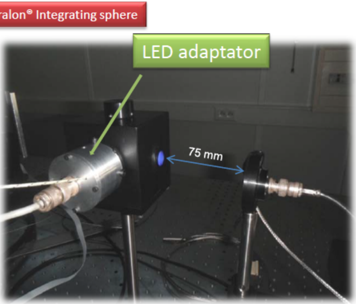
- beam diameter ∼ 1 mm
- optics study :
  - precision of 20μm on relative position
- ghost :
  - precision 1% on reflection coeficient
- Should be deliver on 09/2019

Test Bench

- We need to characterize the beam at LSST pixel scale.

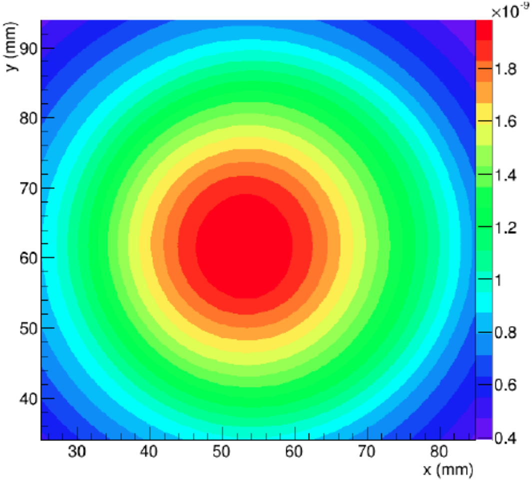


Scan in the plane orthogonal to the beam emission



Beam map - 100μm pinhole

- we shown that beam fluctuation > 100μm,
- using bilinear interpolation methode : scaning step of 0.5 mm,
- 1 scan take a lot of time : temperature variation.

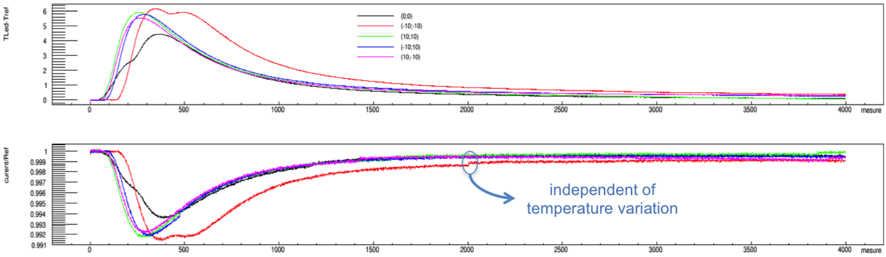


⇒ Interpolated map

- **pinhole 100 μm**
- 60x60 mm
- **step : 0.5 mm**
- time ~ 8h

Beam stability as a function of temperature (1)

- No scanning, 1000 mesures $\Rightarrow \sim$ 1h
- temperature measurement using thermocouple (precision $\sim 0.1°C$) ,
- heating cable is around the LED adaptator.



Results :

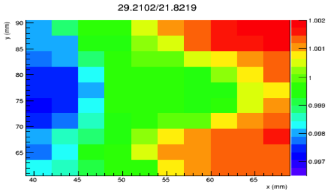
- Good correlation between T_{LED} and measured flux
- $\Delta Flux \sim 0.14\%$ per deg

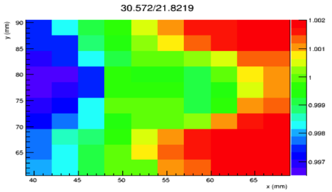
$\Rightarrow$ Could we correct temperature effect ?

Beam stability as a function of temperature (2)

- Scanning, 30x30 mm, step = 3mm ⇒ ∼ 3min,
- 12 + 1 measure (reference $<T> = 21.8$)
- $Flux(px) = \frac{flux(px)}{fluxRef(px)} * \frac{<FluxRef>}{<Flux>}$

$<T>$	δT	ΔT	$\Delta F = \delta F_{max} - \delta F_{min}$
21.8	0.032	/	/
26.6	0.20	4.80	$1.0\ 10^{-3}$
26.5	0.15	4.65	$1.3\ 10^{-3}$
27.9	0.30	6.07	$1.3\ 10^{-3}$
27.7	0.34	5.89	$1.9\ 10^{-3}$
27.7	0.34	5.86	$1.9\ 10^{-3}$
28.12	0.10	6.30	$1.5\ 10^{-3}$
29.21	0.29	7.39	$4.5\ 10^{-3}$
29.22	0.18	7.39	$4.3\ 10^{-3}$
29.21	0.11	7.39	$4.4\ 10^{-3}$
30.62	0.24	8.80	$3.8\ 10^{-3}$
30.57	0.25	8.75	$5.4\ 10^{-3}$

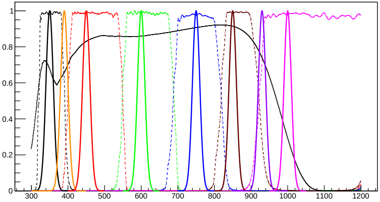


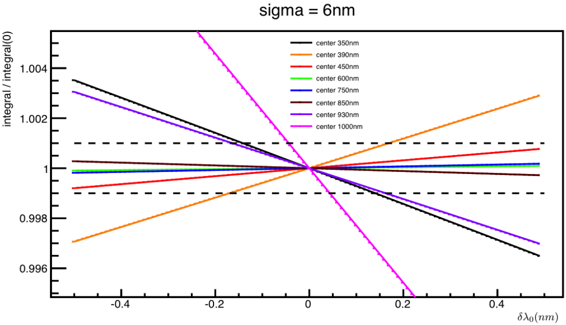


- spatial inhomogeneities : $\Delta T < 7° \Leftrightarrow \Delta F < 2.10^{-3}$,
- **spatial dependence ⇒ difficulties for temperature correction**

Wavelenght shift as a function of temperature

- LED spectra = gaussienne (λ_0, σ),
- λ_0 vary from 0.05 nm to 0.5 nm for $\Delta T \sim$ a fiew degrees.





- λ_0 350nm, 390nm and 930nm : $\Delta F > 10^{-3}$ if $|\delta\lambda_0| > 0.1nm$,
- λ_0 1000nm should not be used.

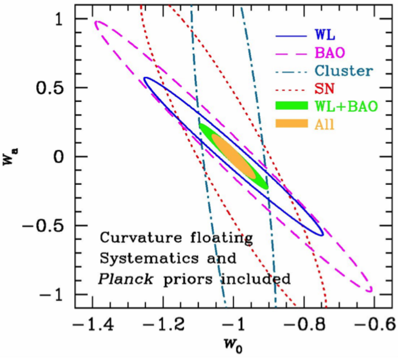
Cosmologie with LSST

Photometric redshift reconstruction

LSST science goal

4D univers mapping : (α, δ), z (redshift), time variation.

- Inventory of Solar system :
  - hazardous asteroids,
  - Long Period Comets ...
- Mapping the Milky Way :
  - stellar population (observation of billions of stars)
  - → star formation, evolution ...
- Transient object :
  - gamma ray burst, AGN ...



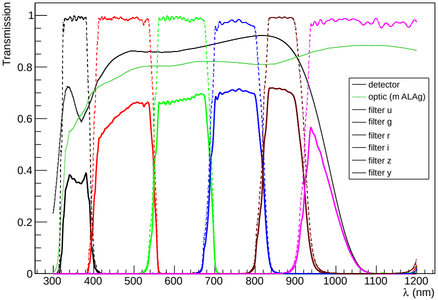
- Probe Dark mater,
- **Probe Dark Energy** (p<0)

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

  - **BAO**, supernovae, weak lensing ...

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.

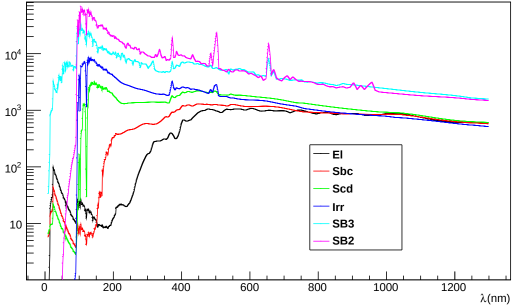
LSST specification on $|\Delta z| = |\frac{z_p - z_s}{1+z_s}|$:

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

The simulated catalog

1) **Simulation Catalog**

- ΛCDM cosmology is assumed
  - computation of over density
  - luminosity function (Dalhen and al.)
- Absolute Magnitude, color excess 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 : $m_X = MA + K_{BX} + MD$ 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 : Fobs(m); Fexp(z,T,ebv)

Prior

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

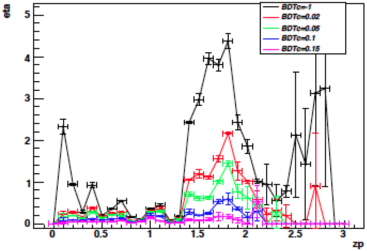
$\Rightarrow$ photometric value z_p, T_p, ebv_p :
maximisation over on a 3D grid.

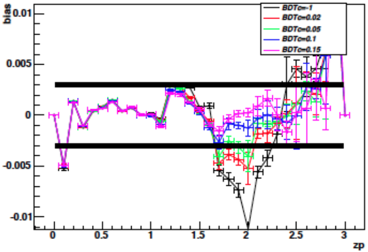
Quality cut

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

Boosted Decision Tree (BDT)

- Learning machine methode :
  - $\rightarrow$ training set $\sim$ 450 000 galaxies
- $|\Delta z| = |\frac{z_p - z_{true}}{1+z_{true}}| < 0.15 \Rightarrow$ "signal"
- 17 discriminant variables
  - form variable : Npeak in the z marginalised pdf ...
  - color terme (ex : r-i),
  - z_p.





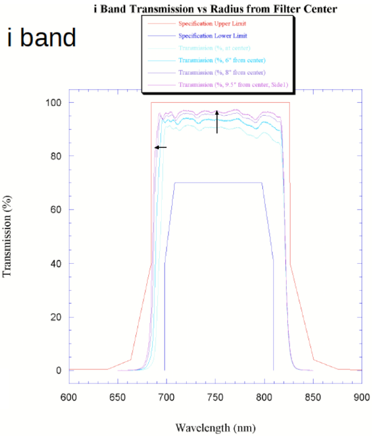
Impact of spatial variation

- The photo-z quality could be affected by differents uncertainties on parameters which enter in the likelihood computation :
  - reddening or intergalactic medium law,
  - the SED library,
  - **filters**

- 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
  - slope design modification,
  - impact of spacial variation ?



Impact of filters transmission shape

- Due to spatial variation filter could be shifted up to $\pm 2.5\%$ (*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).
  1) computation of a medium effective filter for 10 years of observation,
  2) reconstruction of the photometric redshift using differents filters for each galaxies.

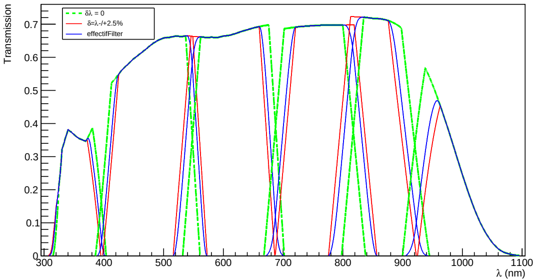
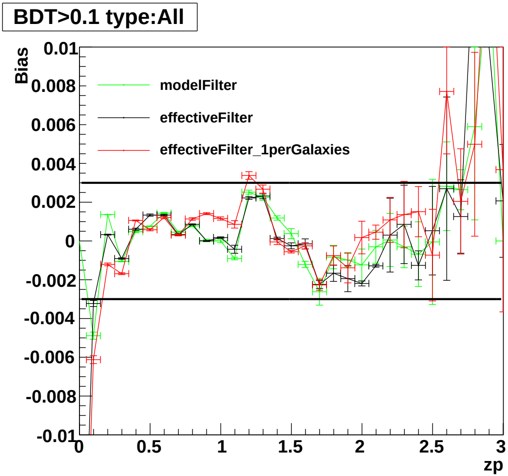


Photo-z quality



- One filter per galaxies ⇔ uncertainties on filters measurement :
  - F_{exp} is computed using effective filters ,
  - F_{obs} is computed using different fiters for each galaxie

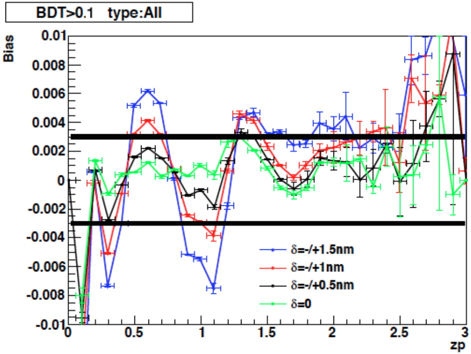
  ⇒ impact on photo-z quality for $0.8 < z_p < 1.3$

  ⇒ if $z_p > 1.9$: higher errors barres.

- Effective filters :
  - no significant impact, except at $z_p \sim 2$
  - still under LSST specification up to $z_p \sim 2.6$

Evolution of filter transmission

- Variations on central weavelenth (filter shift), -+ case :



- translation different for each filter,
- important effect from $\delta_\lambda = \pm 1nm$,
- $\delta_\lambda = \pm 0.5nm$ could be a maximal uncertainty to keep the photo-z quality

⇒ How important will be those effect ? → Cosmology

Conclusion

- LSST will observed billions of galaxies which allowed the measurement of BAO scale at many z bins,
  - → the redshift of all of those galaxies is needed with a excellent precision.

⇒ Franzona method for photometric redshift reconstruction :

- template fitting method form 51 interpolated SED
- we can reconstructed the redshift in LSST specification up to $z \sim 2.7$

- impact of filters shape is negligible if filters are well known
- filters has to be well known, with a precision better the 0.5nm in order to keep a good quality on photometric reconstruction.

Perspectives

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

- **BAO analysis** using Franzona tools :
  - computation of power spectra,
  - exctraction of BAO scale,
  - constraintes on dark enery parameters.

$\Rightarrow$ with which precision can we get the BAO scale using our photometric redshift ?

$\Rightarrow$ how important are photometric quality variations due to filters transmission shape ?

Back up

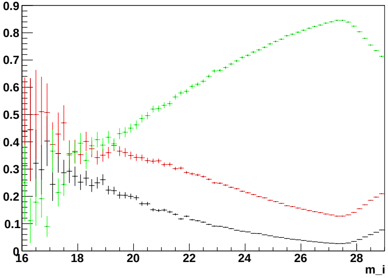
Prior computation

- $\mathbf{\Pi(z, T, E(B-V)|m_i)}$: 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*)

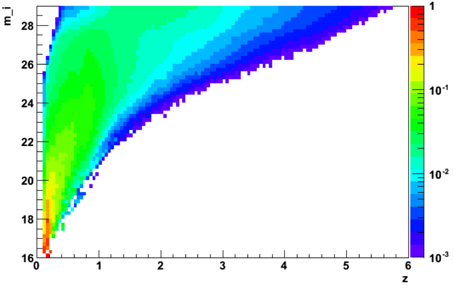
$$\Pi(z, T, E(B-V)|m_i) = P(T|m_i) * P(z|T, m_i)$$

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

→ A spectroscopic sample is needed.



$P(T|m_i)$



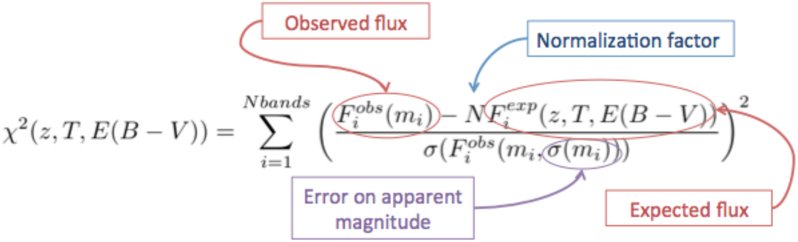
$P(z|T, m_i)$ (Starburst galaxies)

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)
$\Rightarrow F_i^{exp}(z,T,E(B-V))$



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

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

$\Rightarrow$ photometric value z_p, T_p, ebv_p

BAO as a cosmological probe

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

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