Cosmological observations with a wide field telescope in space

Pixel simulations of EUCLID spectrometer

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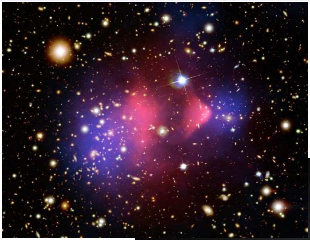
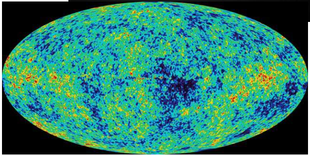
Cosmology today : A dark universe

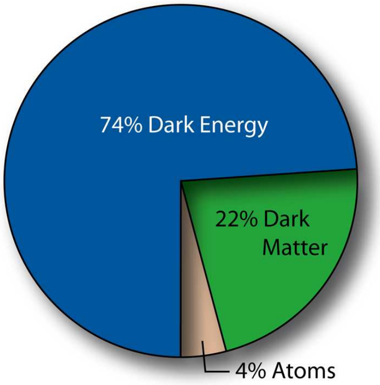
- Galaxy and cluster mass is dominated by a non-luminous component.
- On a large scale, the Universe is isotropic and homogeneous
- The expansion of the Universe is accelerated
- The simplest model which reproduce these observations is the ΛCMD model.



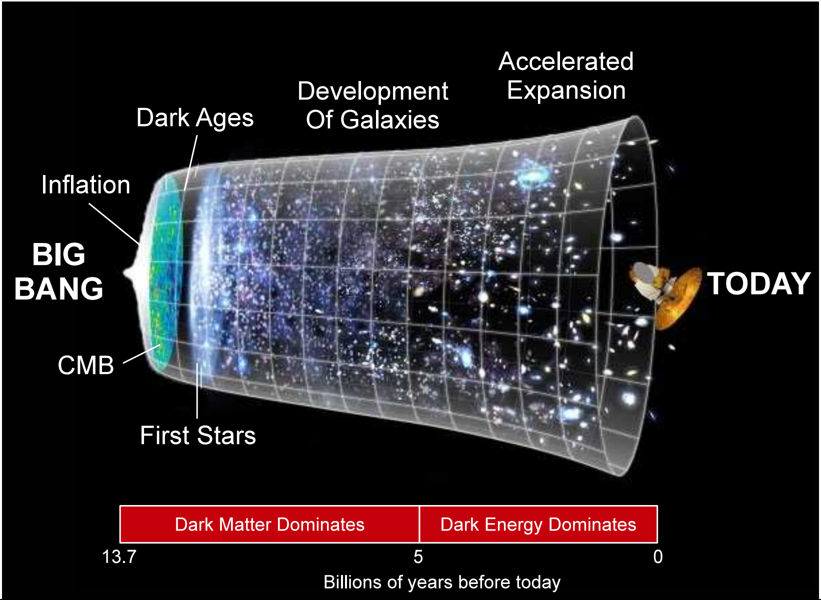


Cosmology today : The ΛCMD model

- Cosmological principle
- General Relativity
- Cosmological constant
- Cold dark matter
- Flat spatial geometry
- Big Bang



Cosmology today : History of the universe



Cosmology today : The key questions

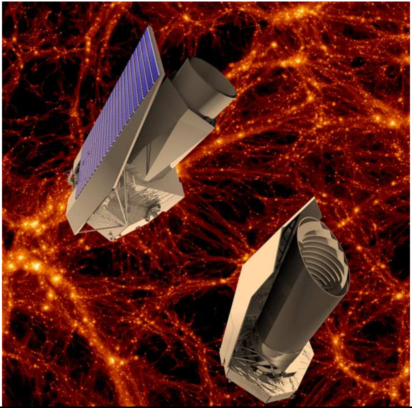
- Dynamical Dark Energy?
- Modification of Gravity?
- Nature of Dark Matter?
- Initial Conditions?

Outline

1. Explore the dark universe
   - Constrain the nature of the universe dark sides
   - Scientific requirements to EUCLID mission design
   - Purposes and needs of the instrument simulations
2. Simulation needs: model of the sky sources
3. Simulation purposes: tolerances on EUCLID/NIS

Constrain the nature of the universe dark sides

- Dynamical Dark Energy? $w(a) = w_p + w_a(a_p - a)$
- Modification of Gravity? $f(z) = \Omega_m(z)^\gamma$
- Nature of Dark Matter? Neutrino component? m_ν
- Initial Conditions? f_{NL}

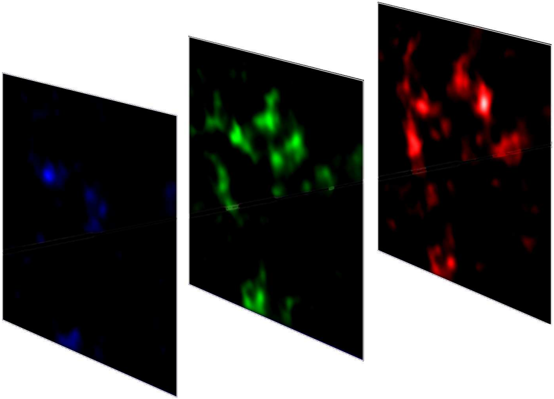


EUCLID

Definition Study Report

(Redbook)

Mapping the universe



Weak Lensing

The correlations in the galaxy shapes trace the matter distribution.

Galaxy Clustering

The correlations in the galaxy distance trace the matter distribution.

The Baryonic Acoustic Oscillations (BAO)

In CMB at z=1100

Correlations in the temperature fluctuations

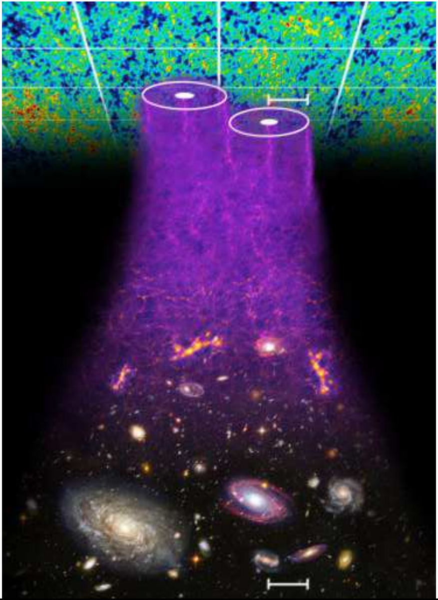
In Galaxy Distribution

Preferred comoving separation of galaxies of $\sim 100 Mpc/h$

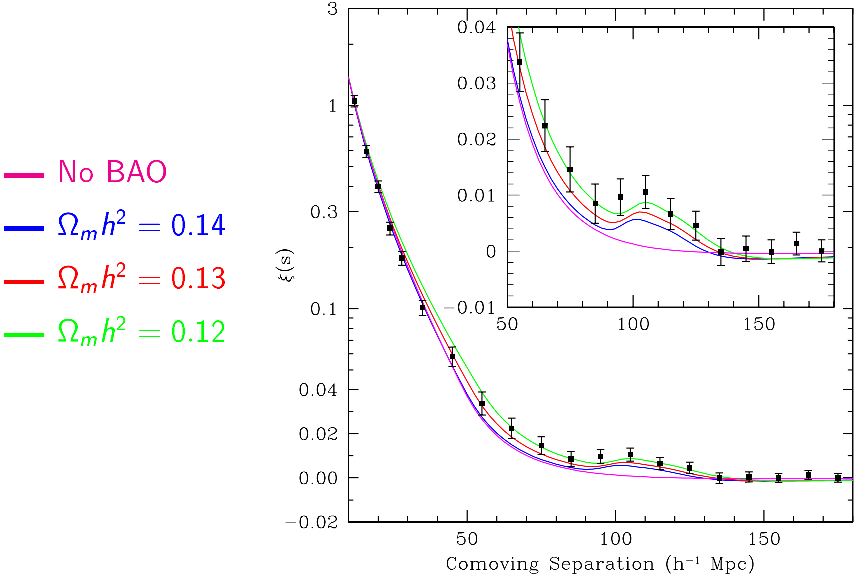
BAO

- Robust Standard Ruler

⇒ Probe the expansion history of the universe



BAO in the correlation function (Eisenstein et al. 2005)



EUCLID : Survey Requirements

Weak Lensing survey

- $> 15\ 000\ deg^2$
- $\geq 30\ gals/arcmin^2$
- $0 < z < 2\ \&\ z_{med} > 0.9$

Shape measurement

- down to $0.2\ arcsec$

Redshift measurement

- $\sigma(z)/(1+z) \leq 0.05$
- Catastrophic $\leq 10\%$

Galaxy Clustering

- $> 15\ 000\ deg^2$
- $\geq 3500\ gals/deg^2$
- $0.7 < z < 2\ \&\ z_{med} > 1$

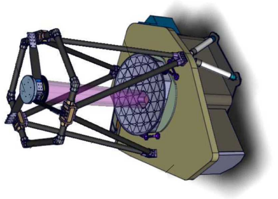
Redshift measurement

- $\sigma(z)/(1+z) \leq 0.001$
- Purity $> 80\%$
- Purity known to $> 1\%$
- Completeness $> 50\%$

EUCLID : Instrument Requirements

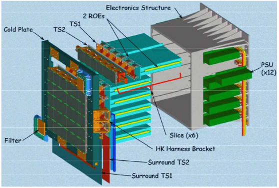
Space Telescope

- Collecting area $\sim 1.0\ m^2$
- FoV $\sim 0.5\ deg^2$



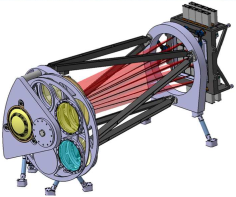
Visible instrument (VIS)

- 36 CCD $4k \times 4k$ & 0.1 $arcsec/pix$
- RIZ & Depth 24.5 @ SNR=10



Near IR Spectro – Photometer (NISP)

- 16 HgCdTe $2k \times 2k$ & 0.3 $arcsec/pix$
- 2 grims $(1100 - 2000\ nm)$
- Y, J, H & Depth 24 @ SNR=5



The instrument simulations

Check performances

- Instrument
- Survey
- Cosmology

Understand the instrument

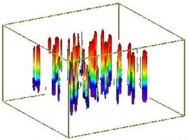
- Calibration
- Systematics
- Measurement

Needs for instrument performance studies

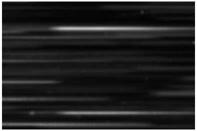
- Realistic distribution of sky sources
- Quantitative estimations of noise components
- Generic instrument model
- Unbiased and optimum estimators

Simulation Principle

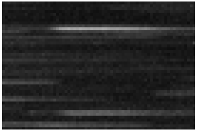
Sky :
- Input sources from CMC: position, spectrum, shape
- Sky background

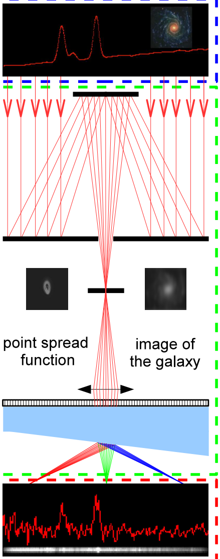


Optical effects :
- Telescope transmission
- Dispersion
- PSF



Detector Noise :
- Quantum Efficiency
- Dark Current
- Poisson Noise
- Read Noise





Simulation needs: model of the sky sources

1. Explore the dark universe
2. Simulation needs: model of the sky sources
   - Mock the sky
   - New calibration of emission line
   - The Cosmos Mock Catalog v2.0
3. Simulation purposes: tolerances on EUCLID/NIS

Mock the COSMOS field

Scoville et al., 2007

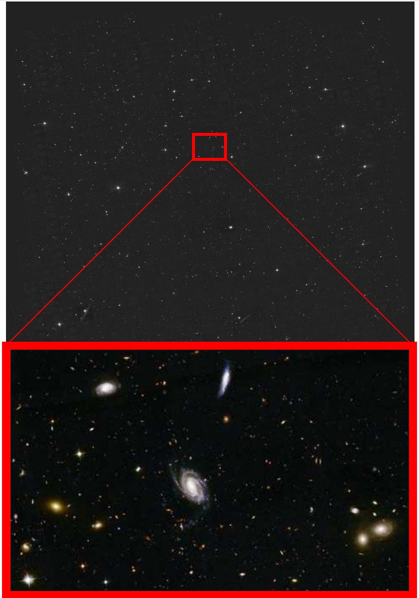
- 2 deg^2
- 31 photometric bands (Capak et al., 2008)
- zCOSMOS (Lilly 2010) and MIPS (Kartaltepe 09)

Leauthaud et al. 2007

Measure of galaxy size

Ilbert et al. 2009 and 2010

Measure of z, SFR, Mstar



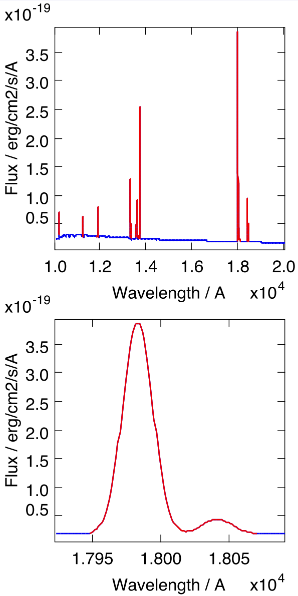
Mock sky : The COSMOS Mock Catalog v1.0

The mock catalog

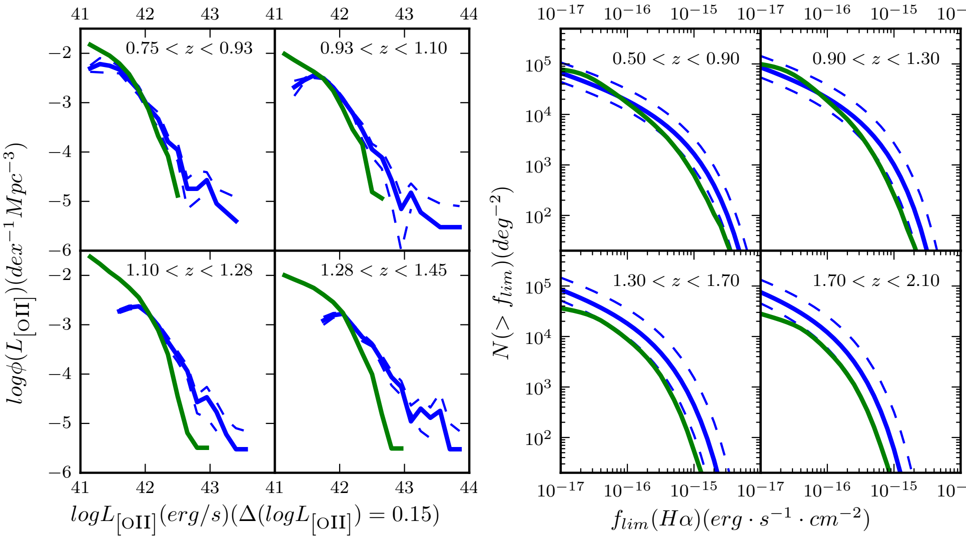
- Photo-z best fit
- ⇒ SED and extinction law
- Emission Lines: Kennicutt at al. (1998)
- Simulated spectra: (SED + EL) * extinction

Validation in Jouvel (2009)

- Color distribution
- Redshift distribution



Mock the sky for spectroscopic survey simulation



Zhu et al. (2009) CMCv1.0 Geach et al. (2010)

Calibration of emission lines

Argence et al. 2009 shown with SDSS data

- Used dust from SED fitting to correct emission lines

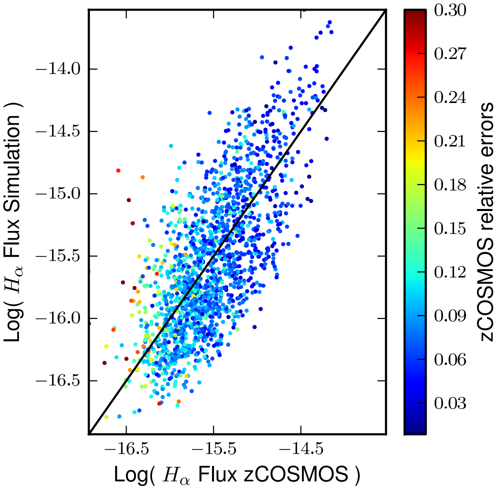
$\Rightarrow$ Huge uncertainty in the stellar to gas attenuation ratio

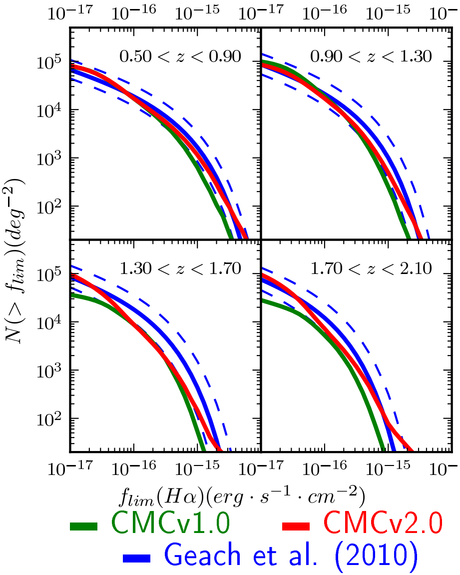
- Direct calibration still quite poor in terms of dispersion but they show a significant better residual slope

Constrain

- from the real galaxy with zCOSMOS data (Lamareille et al., 2006)
- from luminosity function for [OII] (Zhu et al., 2009) and H_α (Geach et al., 2010)
- from emission line ratio with zCOSMOS and VVDS (Le Fèvre et al., 2005)

Calibration result for H_α lines





The Cosmos Mock Catalog v2.0

Magnitude Limits

- $I < 26.0$
- $H < 23.5$
- $K < 23.0$

Size Limits

- 1.73 deg^2
- 1.4M galaxies
- 15 000 stars and 2000 AGN

CMC galaxies

- RA and DEC from real COSMOS sources
- redshift and SED from photo-z
- SFR, Mstar from SED fitting
- Emission lines: Balmer lines, [OII], [OIII], [NII], [SII]
- Shape measurement from ACS (1.38 deg^2, 500k galaxies)

CMCv2.0 : Applications

- Input sky sources of pixel simulations
- Investigating Emission Line Galaxy Surveys with the Sloan Telescope (Comparat et al. 2012)
- The WFIRST Galaxy Survey Exposure Time Calculator (Hirata et al. 2012)
- ETC-42
  Fast simulator of slitless spectroscopy and overlap noise
- Investigating wide survey strategy for BAO measurement with space slitless spectroscopy.

CMCv2.0 : Analytic simulations of EUCLID BAO survey

Strategy 1

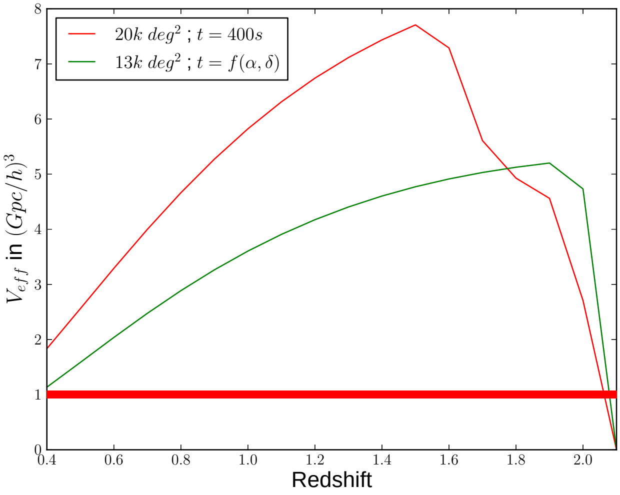
- $20000\ deg^2$
- $t_{exp} = 400s$

Strategy 2

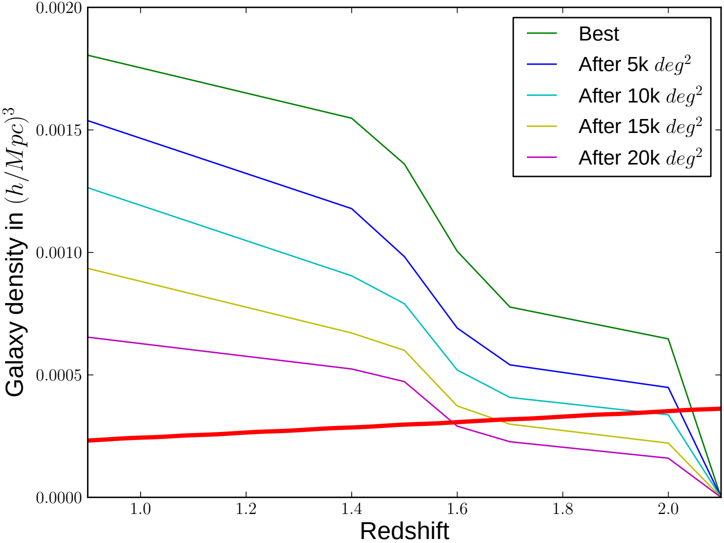
- $13000\ deg^2$
- $t_{exp} = f(\alpha, \delta)$
- $t_{exp} \geq 400s$

Sky evolution

- Leinert 2002
- Schlegel 1998



CMCv2.0 : Analytic simulations of EUCLID BAO survey



Discussion : CMCv2.0 Issue for Wide Survey Studies

Is it correct to extrapolate results for a $\sim 15000\ deg^2$ survey from a mock catalog of less than $2\ deg^2$?

- **NO in absolute**
  The properties of the COSMOS field is not representative of the whole universe.
- **Still very interesting in relative**

Solution 1

- Mock bigger surveys
- CFHTLS, Stripe 82

Solution 2

- Numerical simulations
- Derivate the sky sources

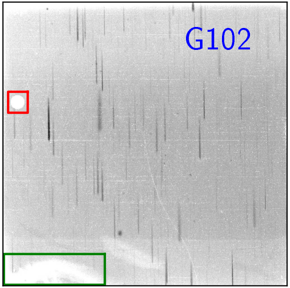
Tolerances on EUCLID/NIS

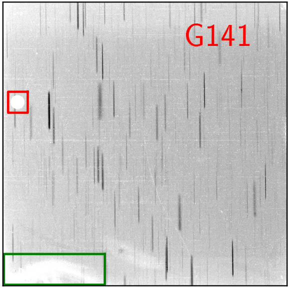
1. Explore the dark universe
2. Simulation needs: model of the sky sources
3. Simulation purposes: tolerances on EUCLID/NIS
   - Simulate the sky for performance studies
   - Simulate the EUCLID/NIS PSF
   - Results

CMCv2.0 as sky model for performance studies

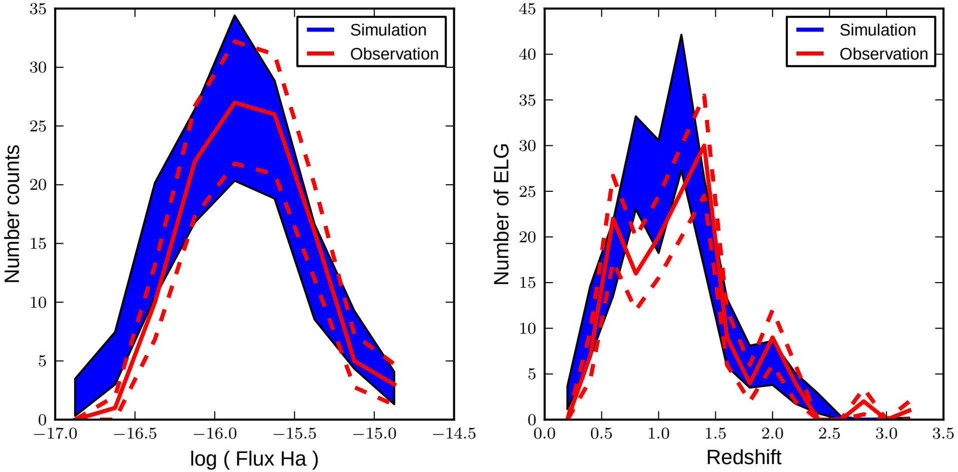
The WISP Survey

- Atek et al. (2010)
- 19 fields, 63 $arcmin^2$
- Photo: F110W, F140W
- Spectro: G_{102}
  $0.8 - 1.17\ \mu m$, $R \sim 210$
- Spectro: G_{141}
  $0.8 - 1.11\ \mu m$, $R \sim 130$
- Median depths:
  $5 \times 10^{-17}\ erg \cdot s^{-1} \cdot cm^{-2}$





WISP Simulation Results



CMCv2.0 as sky model for performance studies

Summary

- H_α lines of simulation is in good agreement with H_α lines observed in WISP.
- The errors are dominated by the galaxy distribution variance.
- Over line counts are in the 1σ statistic errors.
- Reshift distribution is in good agreement but it is more sensitive to the variance.

Conclusion

The CMCv2.0 is good tools to simulate the sky, at least for performance studies of slitless spectrometer.

Simulation Parameters

Sky

- Sky Sources: CMCv2.0
- Sky Background: Ecliptic pole zodiacal level

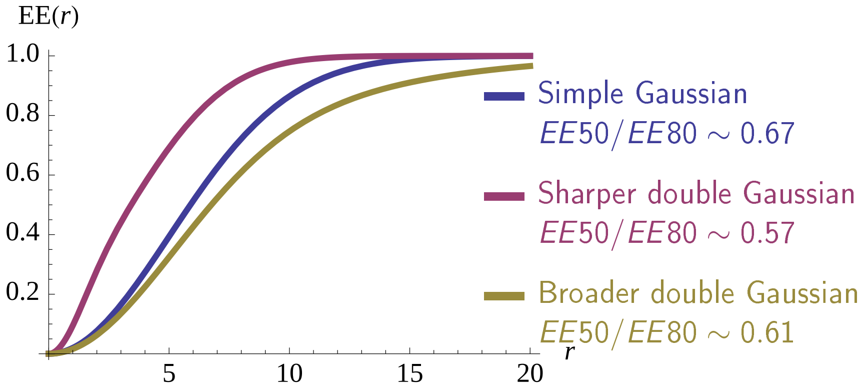
Optics

- Collecting area: 1.0 m^2
- Gblue: $1100 - 1457$ nm ; Gred: $1455 - 2000$ nm ; resolution: 9.8 nm
- Scattered Light: 10% of zodiacal background
- Instrument Noise: 10% of zodiacal background

Detector

- Array: $2k \times 2k$ pixels ; 18 μm ; 0.3 $arcsec$
- Quantum Efficiency: 0.75
- Dark Current: 0.1 $e^- / s / pixel$
- Readout Noise: 6 $e^- / pixel$

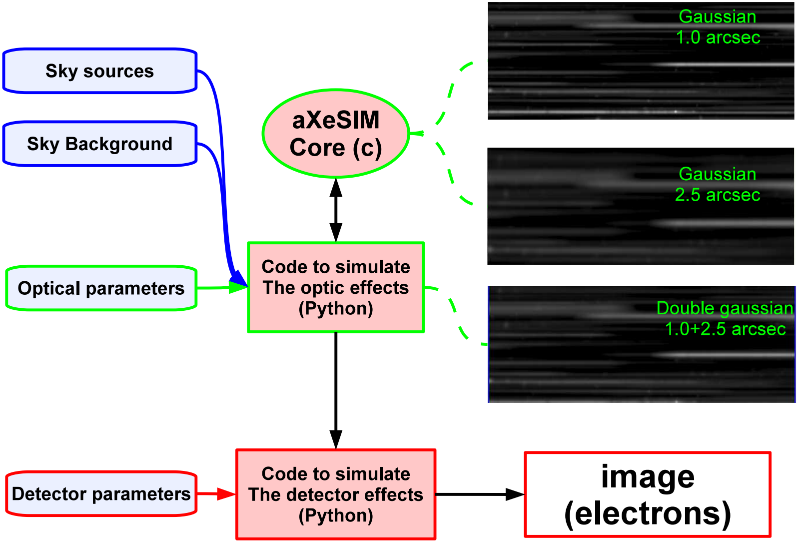
Model of PSF



Encircled Energy

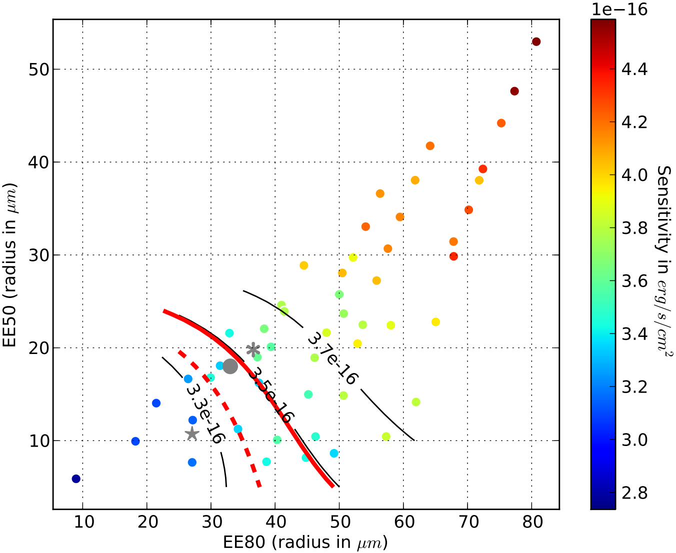
$$EE(\rho) = c\left(1 - e^{-\frac{\rho^2}{2\sigma_1^2}}\right) + (1-c)\left(1 - e^{-\frac{\rho^2}{2\sigma_2^2}}\right)$$

PSF simulation code



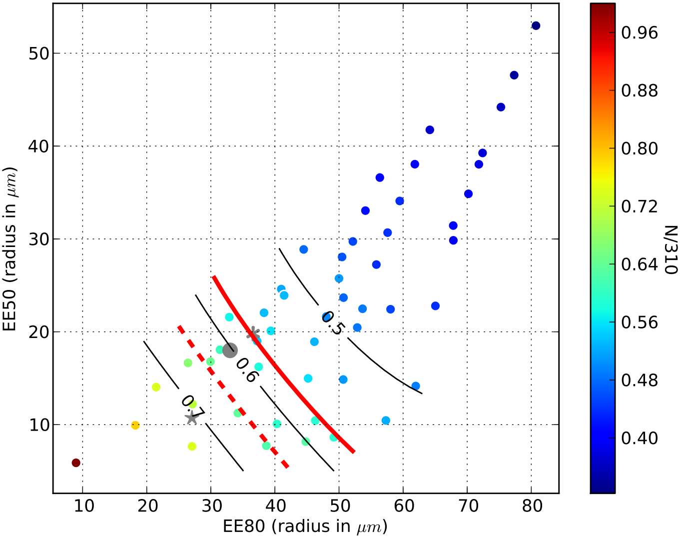
Sensitivity as function of the PSF parameters for Gblue

- ⋆ $PSF_{Average}$
- ● PSF_{Worst}
- ∗ $PSF_{Worst+10\%}$
- Iso sensibility contours
- $PSF_{Average}$ sens +5% contours
- $PSF_{Average}$ sens +10% contours



H_α counts as function of the PSF parameters for Gblue

- ⋆ $PSF_{Average}$
- ● PSF_{Worst}
- ∗ $PSF_{Worst+10\%}$
- Iso fraction contours
- $PSF_{Average}$ frac +10% contours
- $PSF_{Average}$ frac +20% contours



Discussion : Tolerances on EUCLID/NIS PSF (preliminary)

Tolerance criteria

10% of galaxy lost comparing to the mean PSF

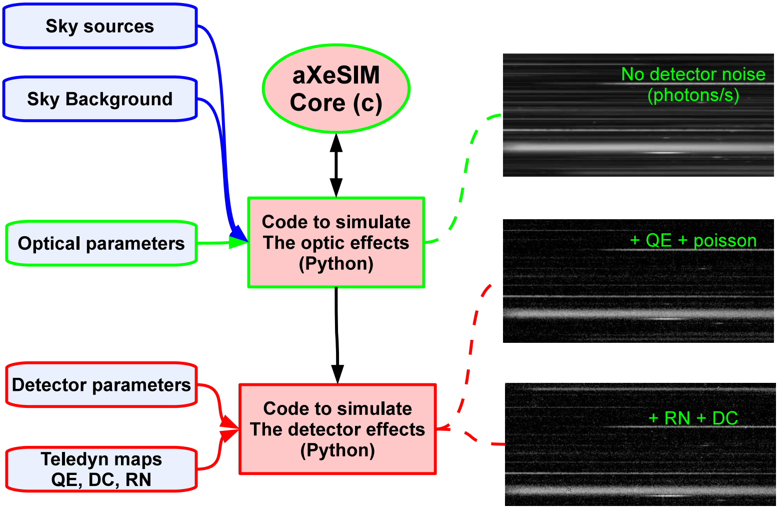
Gblue

- $(EE50)_{blue} < 20\ \mu m$
- $(EE80)_{blue} < 40\ \mu m$
- $(EE80)_{blue} < -1.15\,(EE50)_{blue} + 48.08$

Gred

- $(EE50)_{red} < 25\ \mu m$
- $(EE80)_{red} < 50\ \mu m$
- $(EE80)_{red} < -1.39\,(EE50)_{red} + 59.72$

Other Results: Simulation of Detector Noises



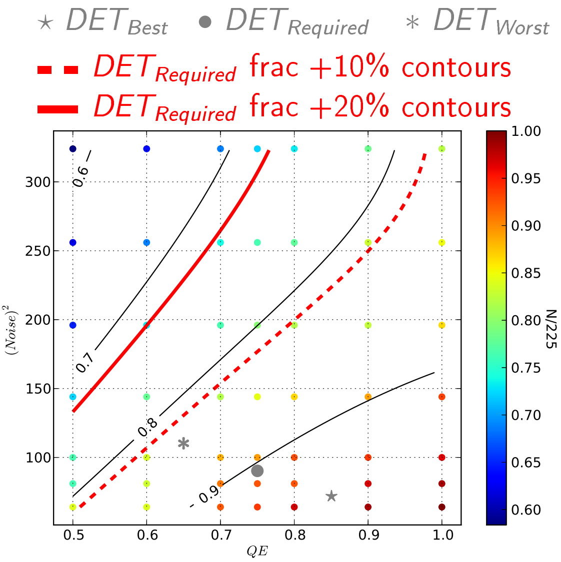
Other Results: Tolerances on Detector Noises (preliminary)

Tolerance criteria

10% of galaxy lost comparing to the required detector

Constrains on median value of detector noises

- $QE > 0.6$
- $Noise < 15.8$
- $(Noise)^2 < 500QE + 250$



Conclusion : Performance Studies

Needs for instrument performance studies

- Realistic distribution of sky sources
- Quantitative estimations of noise components
- Generic instrument model
- Unbiased and optimum estimators

Conclusion : Performance Studies

Needs for instrument performance studies

- ✓ Realistic distribution of sky sources
- Quantitative estimations of noise components
- Generic instrument model
- Unbiased and optimum estimators

The COSMOS Mock Catalog v2.0

- Revisited version of the CMC (Jouvel et al. 2009)
- Estimation of the emission line fluxes based on new calibrations using COSMOS, zCOSMOS and luminosity function (Zhu et al. 2009 and Geach et al. 2010)
- Simulation of the WISP survey (Atek et al. 2010)
- **Validation of the CMCv2.0 realism as input for pixel simulation of slitless spectroscopy**

⇒ Zoubian et al. (in prep)

Conclusion : Performance Studies

Needs for instrument performance studies

- ✓ Realistic distribution of sky sources
- ✓ Quantitative estimations of noise components
- ✓ Generic instrument model
- Unbiased and optimum estimators (on going work)

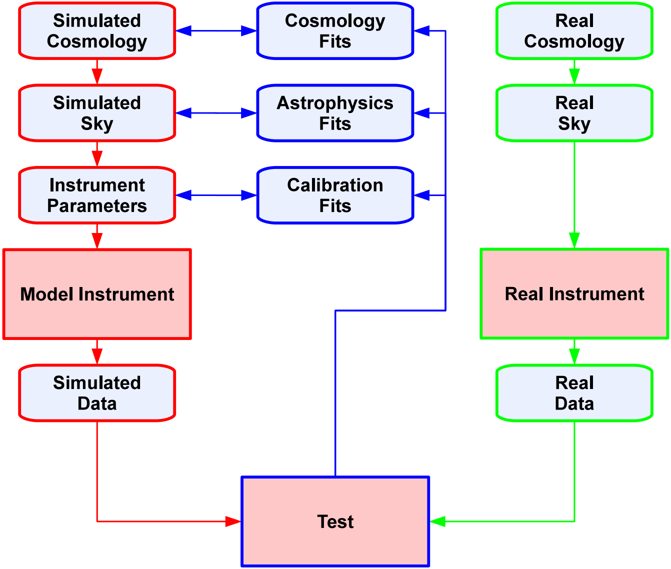
Pixel Simulations

- Modular simulation code with 3 independent blocks: sky, optics and detector
- New PSF model based on double gaussian
- New detector model with different pixels
- **Constrain on PSF distribution of EUCLID/NIS**

⇒ EUCL-CPP-NPS-TN-00208 "NISP spectro PSF studies" E. Jullo, A. Ealet and J. Zoubian.

- **Constrain on properties of EUCLID/NISP detectors**

Future and Prospect of the instrument simulations



Future and Prospect

Needs: science measurement

Instrument Calibration

- Simulation of calibration sources
- High realism of the simulation
- Optimum set of parameters
- Reconstruction method: fit? inversion? bayesian?

Astrophysics Measurement

- On going studies at LAM
- Sky cube tomography and emission detection
- Parametric spectra reconstruction and redshift extraction

Cosmology Measurement

- Feasibility?

Thank You

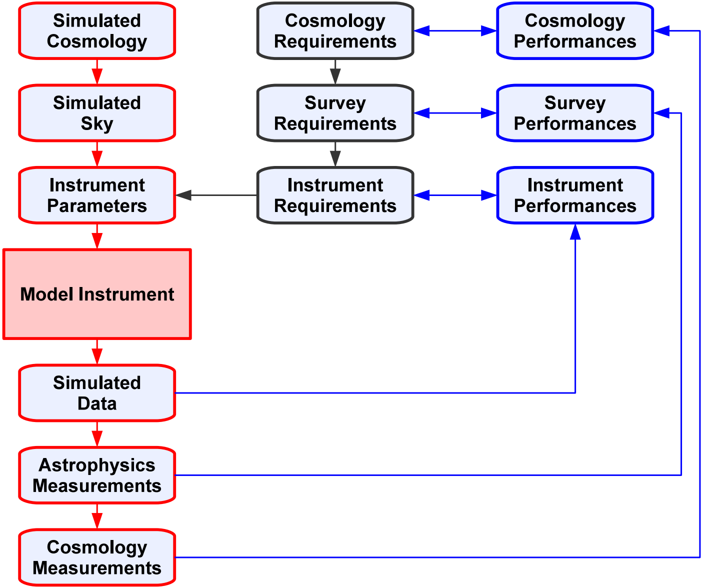
EUCLID : Cosmology Requirements

- Dynamical Dark Energy? $w(a) = w_p + w_a(a_p - a)$
- Modification of Gravity? $f(z) = \Omega_m(z)^\gamma$
- Nature of Dark Matter? Neutrino component? m_ν
- Initial Conditions? f_{NL}

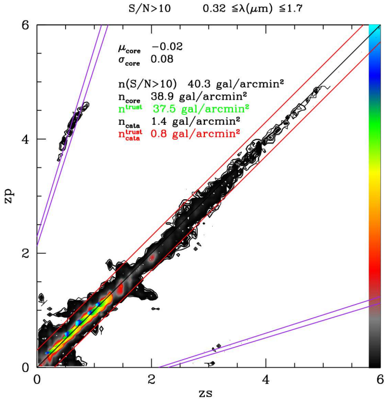
EUCLID Science Objectives (Redbook)

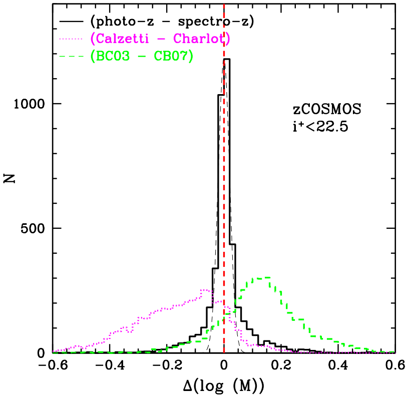
Parameter	γ	m_ν	f_{NL}	w_p	w_a
Current accuracy	0.200	0.580	100	0.100	1.500
Euclid accuracy	0.009	0.020	2.0	0.013	0.048
Euclid+Planck	0.007	0.019	2.0	0.007	0.035
Improvement Factor	30	30	50	>10	>50

Instrument simulations for performance study



The COSMOS survey





Build spectra

Continuum:

- SED (Polleta et al. 2007 and Bruzual et al. 2003)
- Extinction law (Prevot 1984 and Calzetti 2000)

Emission Lines in CMCv2.0

- Kennicutt law $SFR \propto L(UV)$ and $SFR \propto L(Ha)$

$\Rightarrow$ $flux(Ha) = -0.4 * (MUV + DM(z)) + 10.81$

- Other lines ([OII], [OIII] and Hb) are computed assuming constant emission lines ratio (Ilbert et al. 2009)

Simulated Galaxy

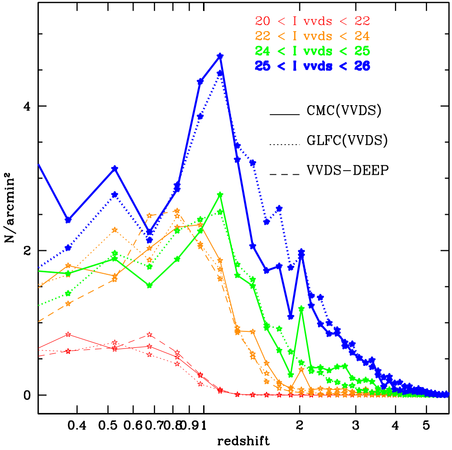
Spectra = (SED + Emission lines) * Extinction law

The Cosmos Mock Catalog v1.0

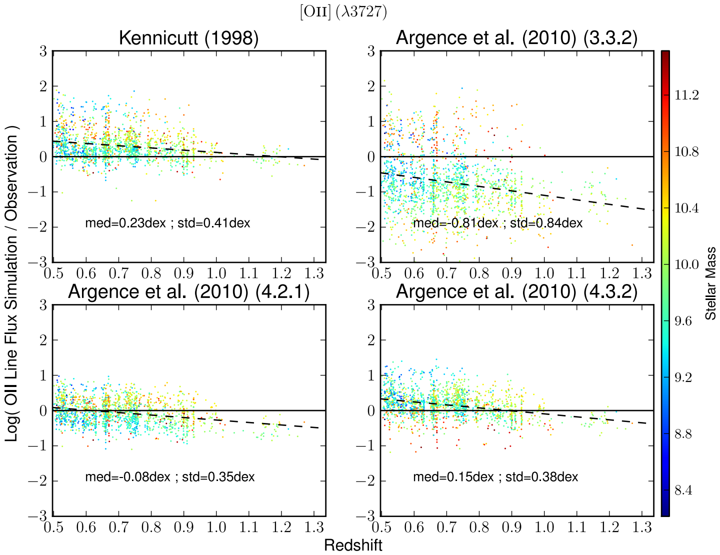
Jouvel et al. 2009

CMC validation:

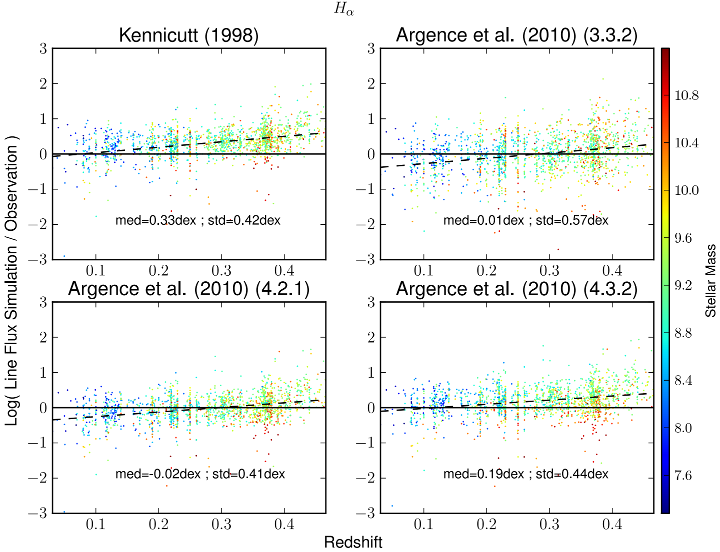
- Color distribution comparing CMC to UDF and GOODS surveys
- Redshift distribution comparing CMC to VVDS



Apply SDSS calibration: [OII]



Apply SDSS calibration: H_α



Line model bases

Emitted luminosity models

$$(L_{line})_{cor} = \left(L_{NUV}^{zphot}\right)_{cor} + b_{line}^{NUV}$$

$$(L_{line})_{cor} = SFR_{SED}^{zphot} + b_{line}^{SFR}$$

Observed luminosity models

$$L_{line}^{NUV} = a_{line}^{NUV} \cdot \left(L_{NUV}^{zphot}\right)_{cor} + b_{line}^{NUV}$$

$$L_{line} = a_{line}^{SFR} \cdot SFR_{SED}^{zphot} + b_{line}^{SFR}$$

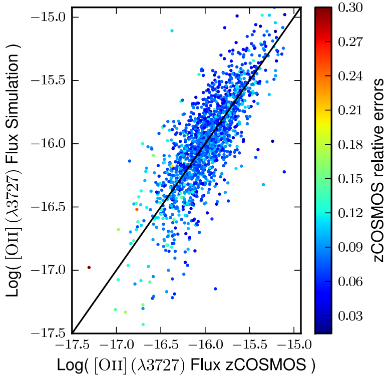
Line model bases

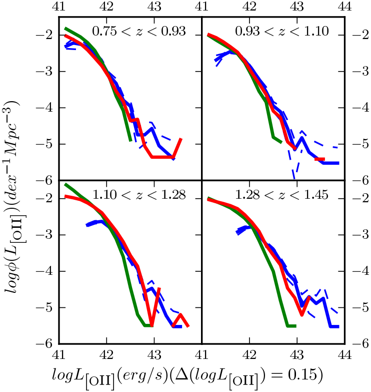
Additional corrections

$$cor_{line}^{par} = \sum_{par} a_{line}^{par} \cdot par + b_{line}^{par}$$

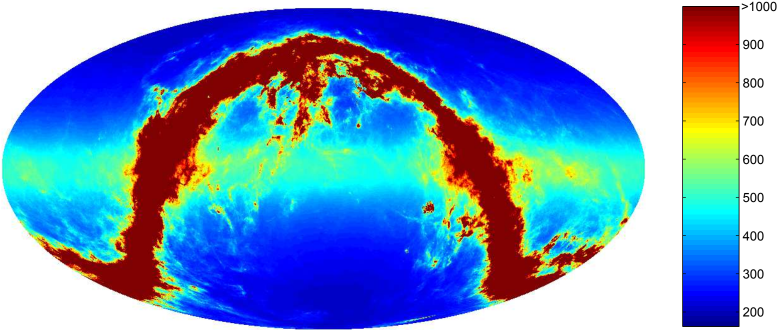
- Photo-z best fit SED
- Photo-z best fit continuum extinction
- Absolute B magnitude computed from photo-z best fit SED and extinction law
- Redshift
- Stellar mass from Ilbert 2010
- Star Formation Rate from Ilbert 2010

Calibration : Result for [OII]

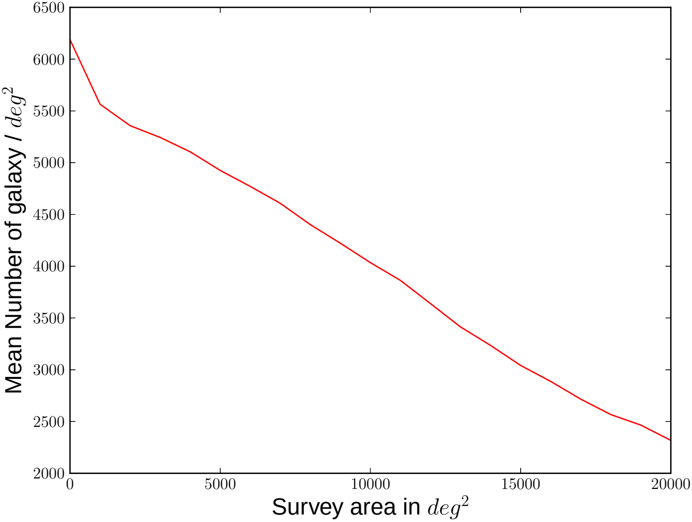




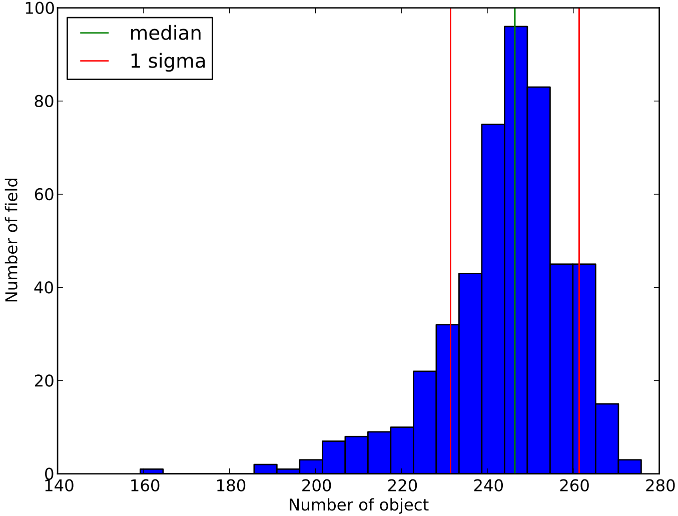
Analytic simulation of EUCLID Wide Survey



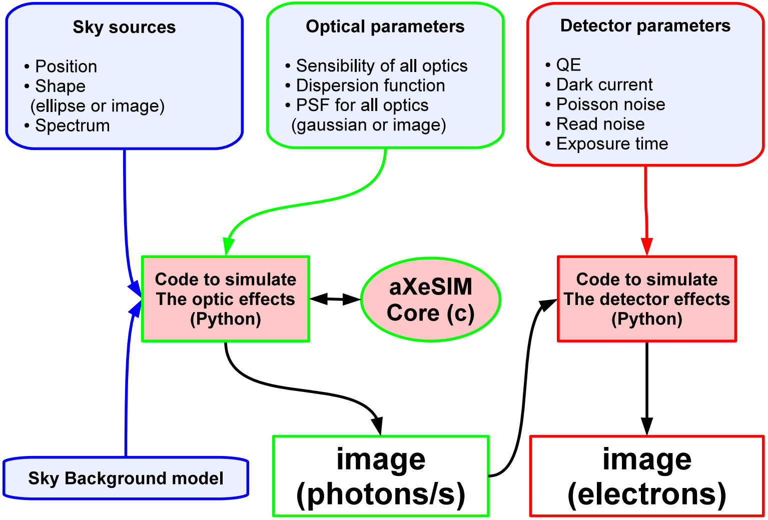
Analytic simulation of EUCLID Wide Survey



Chose of CMC field



Simulation Code



Model of PSF

Double gaussian model

$$PSF(\rho) = c\frac{e^{-\frac{\rho^2}{2\sigma_1^2}}}{2\pi\sigma_1^2} + (1-c)\frac{e^{-\frac{\rho^2}{2\sigma_2^2}}}{2\pi\sigma_2^2}$$

Encircled Energy

$$EE(\rho) = c\left(1 - e^{-\frac{\rho^2}{2\sigma_1^2}}\right) + (1-c)\left(1 - e^{-\frac{\rho^2}{2\sigma_2^2}}\right)$$

Analysis of the simulations

Spectra extraction

- Extraction with aXe
- Extraction with the same parameters those used in WISP survey analysis
- **Optimal extraction in a gaussian profile**

Spectra analysis

- Line positions known
- Fit of the lines and measure of the SNR
- Detection simulation:

$$p = \frac{1}{\sqrt{2\pi}} \int_{\alpha - SNR}^{\infty} e^{\left(\frac{-x^2}{2}\right)} dx$$

Discussion : Suboptimal Extraction Bias

Comparison double gaussian and simple gaussian profile

Until now, no quantitative estimation of the SNR bias

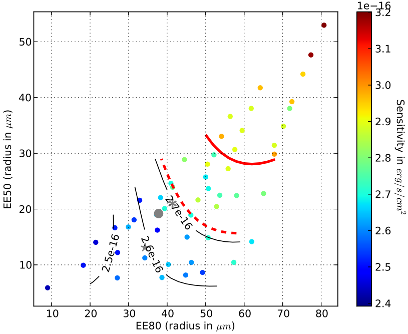
Energy distribution

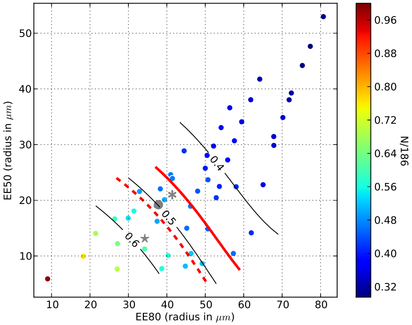
- Cases $c \to 0, 1$, simple gaussian is a good approximation
- The gap is maximum for $c = 0.5$ (σ_1/σ_2 fixed)
- Bigger is σ_1/σ_2, smaller is the gap (c fixed)

Signal to noise ratio

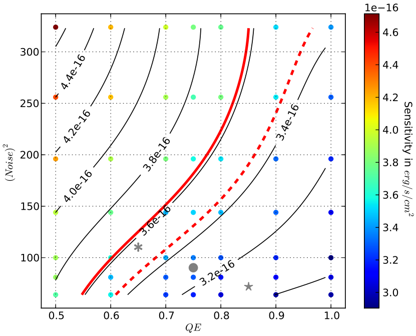
- SNR profile of double gaussian depends on noise value
- Low noise regime: the component $\sigma_2 (> \sigma_1)$ is dominant
- High noise regime: the component $\sigma_1 (< \sigma_2)$ is dominant

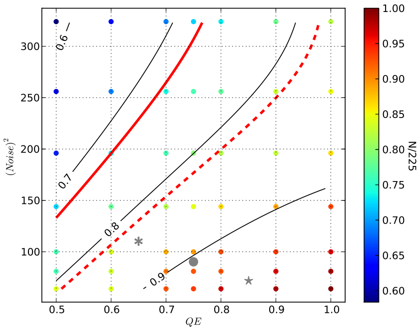
Performances as function of the PSF parameters for Gred





Performances as function of the detector parameters for Gblue





Performances as function of the detector parameters for Gred