Imaging & Spectroscopy Complementarity

Optimising WL & z-surveys of DE space missions

Jean-Paul Kneib,

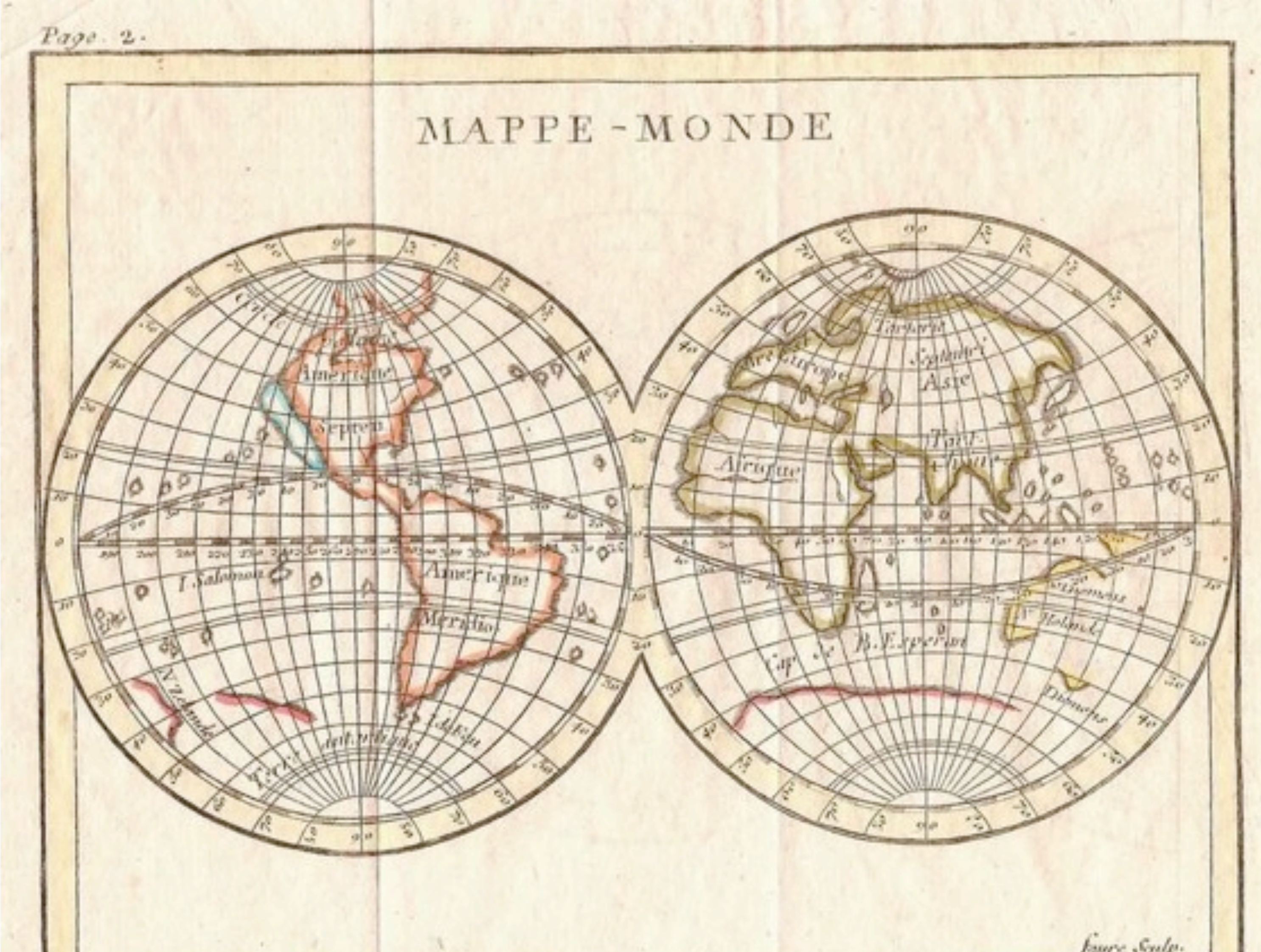
Stéphanie Jouvel, Julien Zoubian,

Anne Ealet, Olivier Ilbert, Carlo Schimd, B. Milliard (LAM)

Gary Bernstein (Upenn), ...

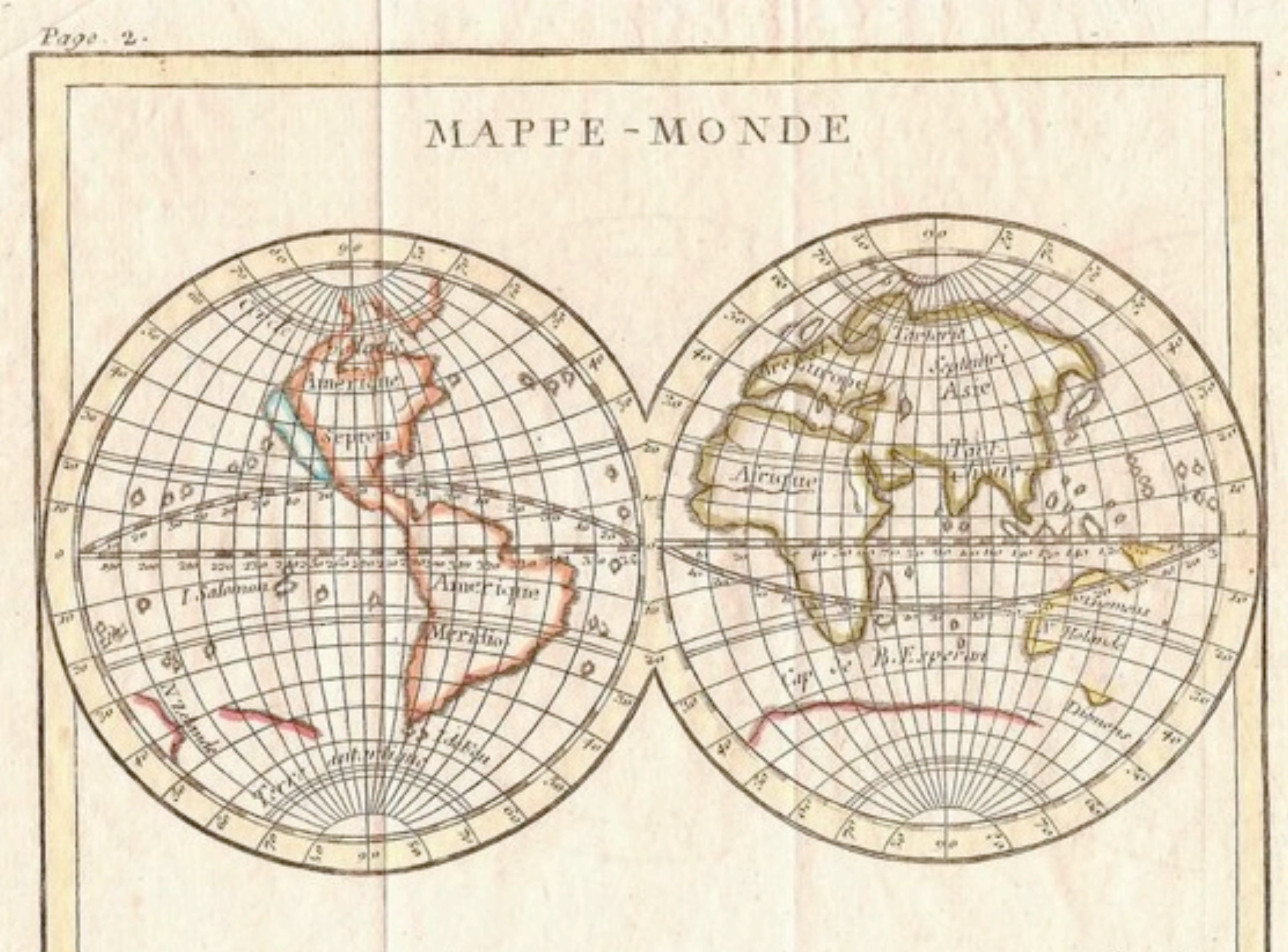
Outline

- Motivation
- Photometric redshift
- Need for spectroscopy
- **Optimizing Weak Lensing surveys**
- **Slitless, fixed-mask, or DMD-slit spectroscopy?**
- Conclusion



‘Geo-meter’

- First « good » world map in the XVIIIs century
- « Perfect » maps nowadays with space Earth observatories
- Deep understanding of our planet



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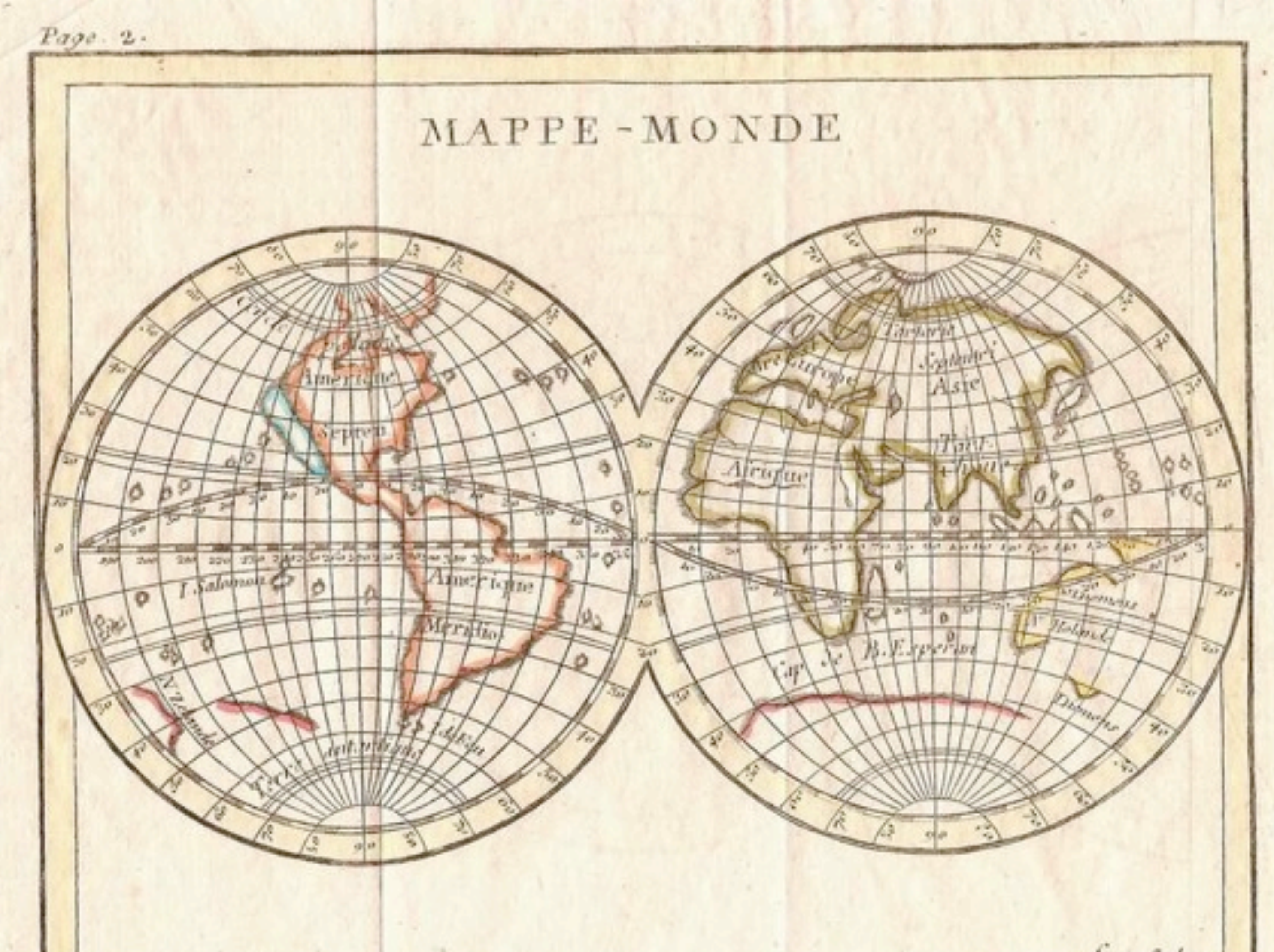

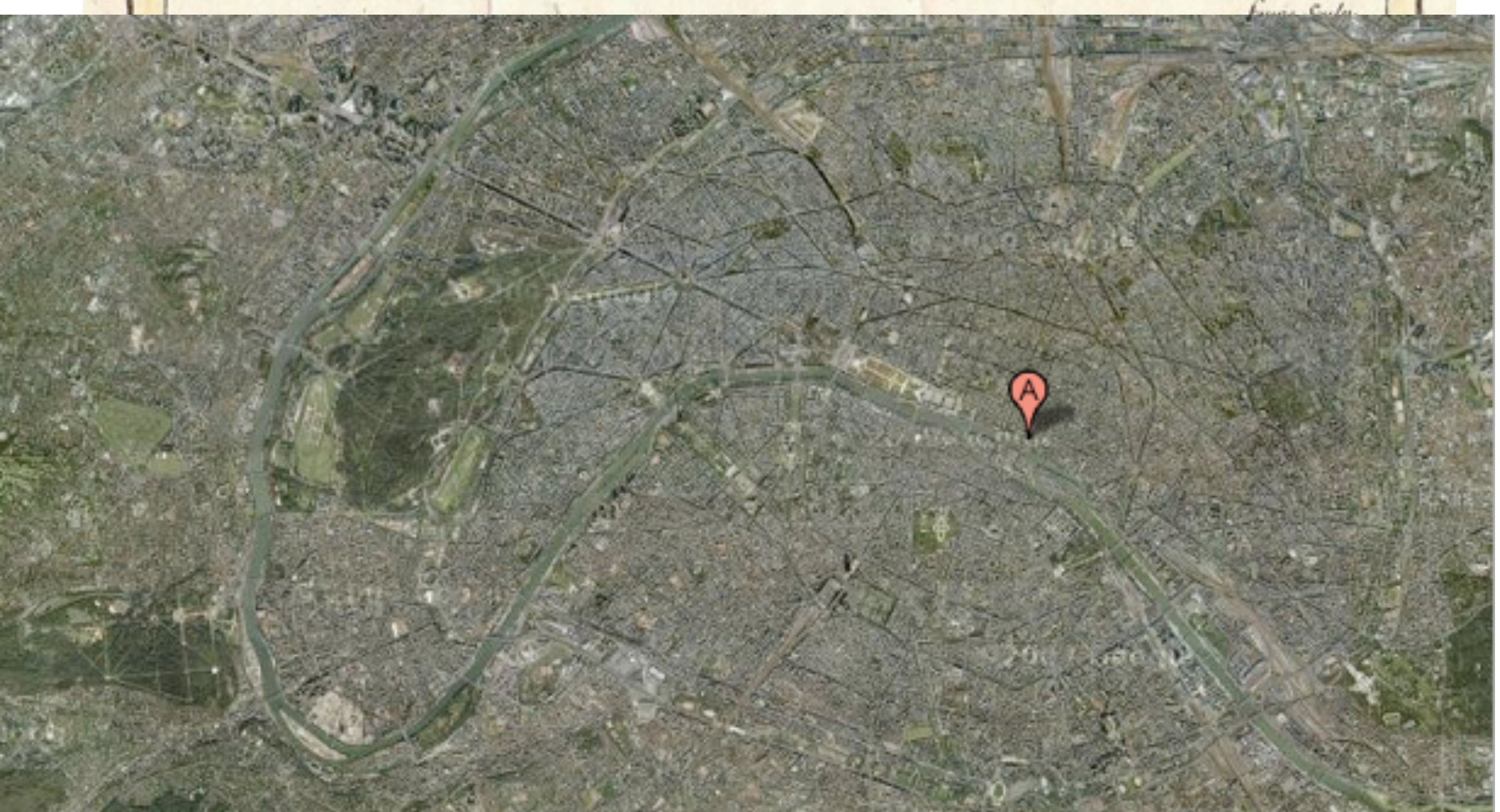

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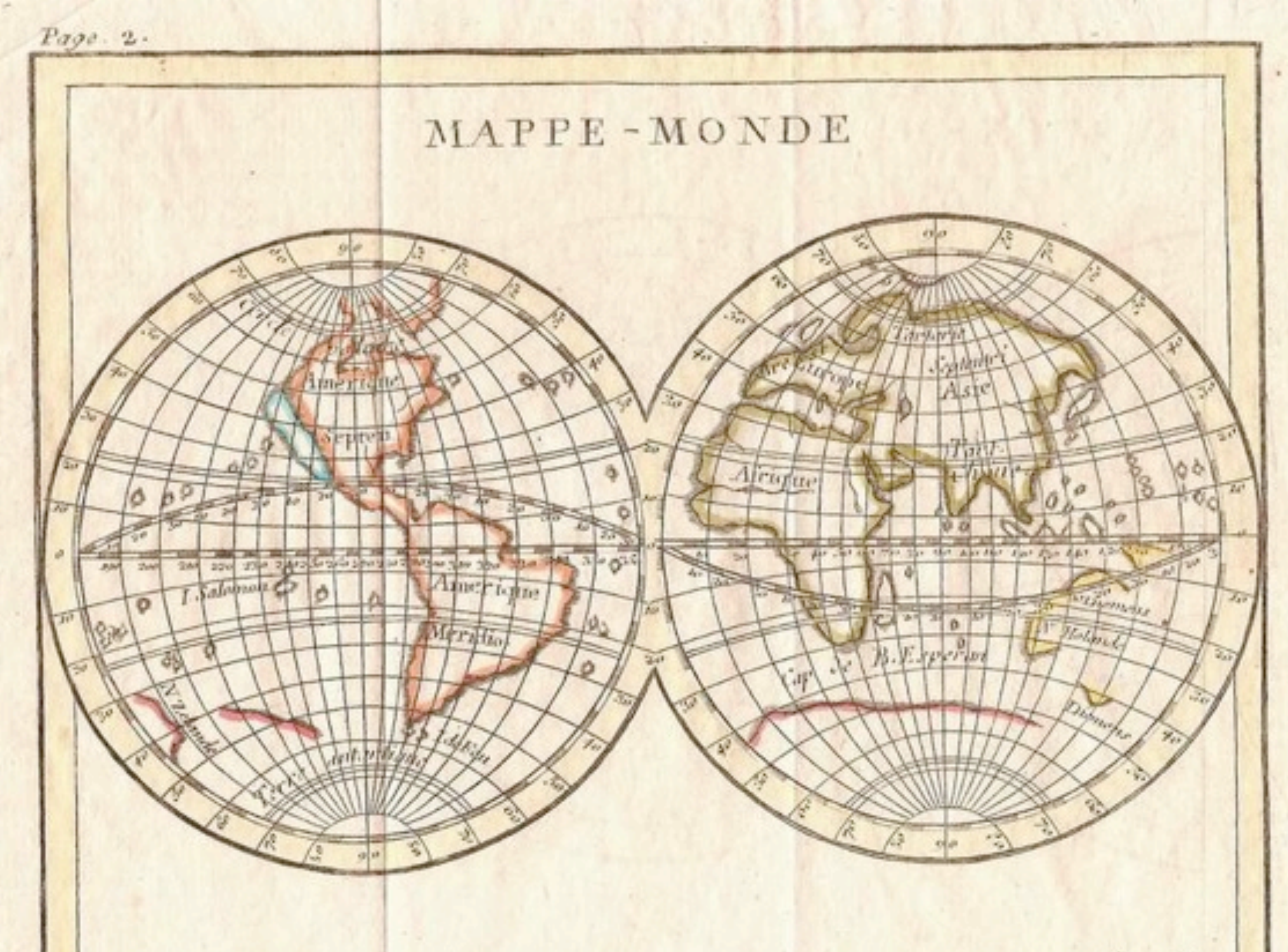

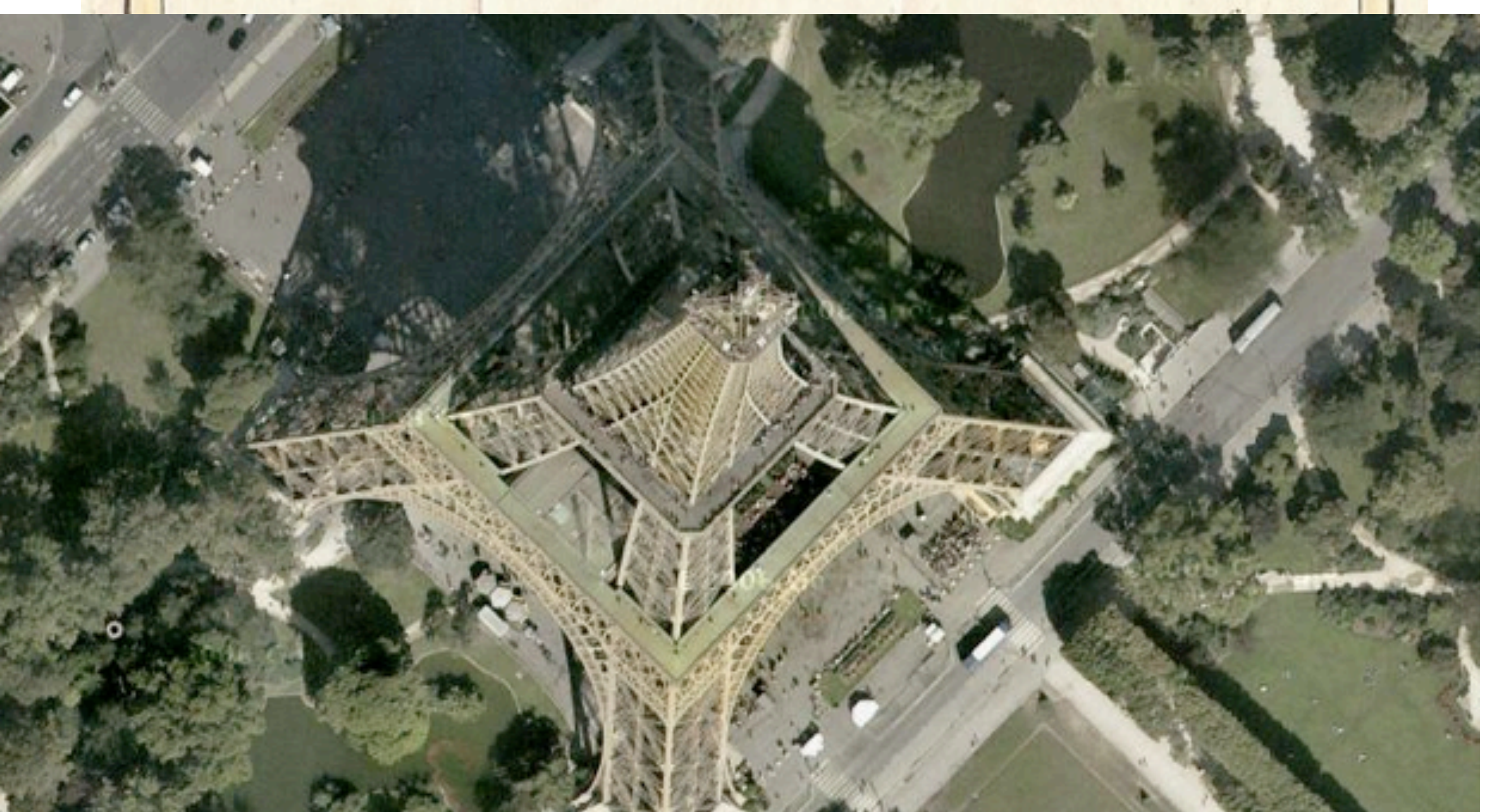

'Geo-meter'

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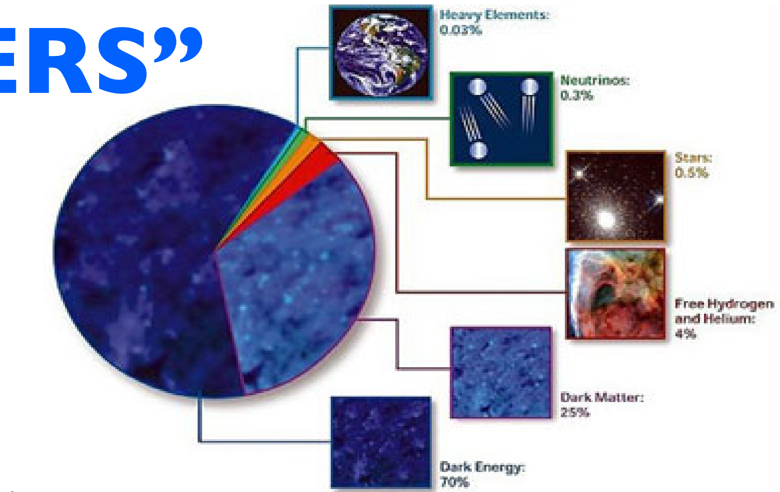
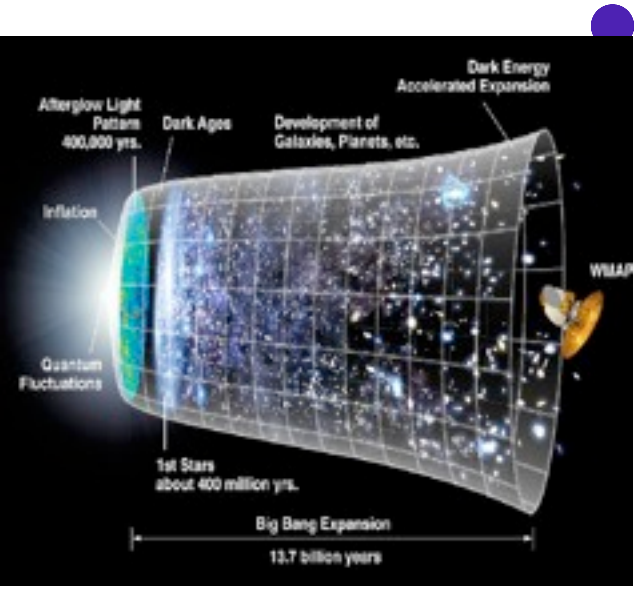
Understanding Our Universe

goals for "COSMOS-METERS"



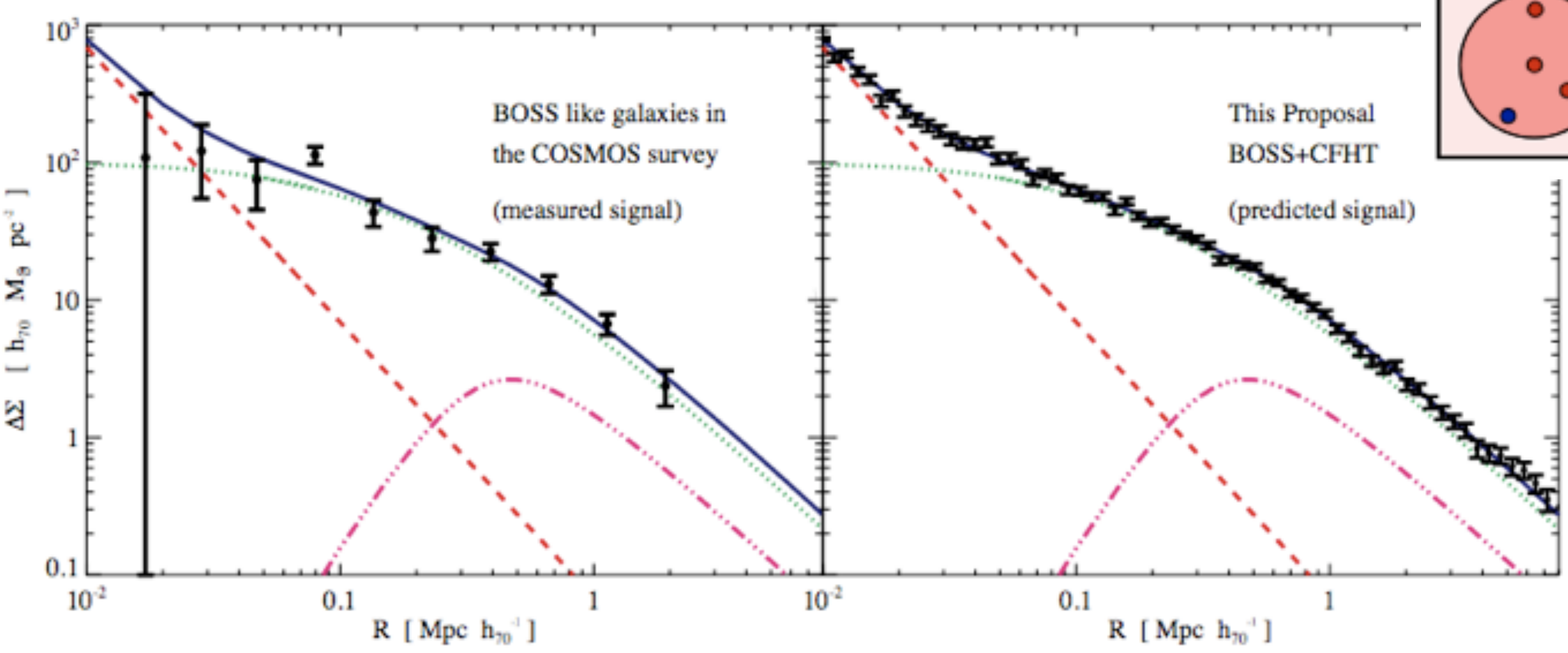
- What is its mass content (3D map)?
- What is the nature of Dark Matter?
- What is the geometry of the Universe?
- What drives the acceleration of the expansion?
- What is the nature of Dark Energy?
- **HOW?**
  - Masses through lensing (measuring shape & redshifts of <u>*faint galaxies*</u>) [Cosmic Shear, Clusters ...]
  - 3D mapping of galaxies (<u>*position, mass and redshift*</u>) [BAO, redshift distorsion, cluster dyanmics ...]
  - plus other techniques (SN, SL) not discussed here ...

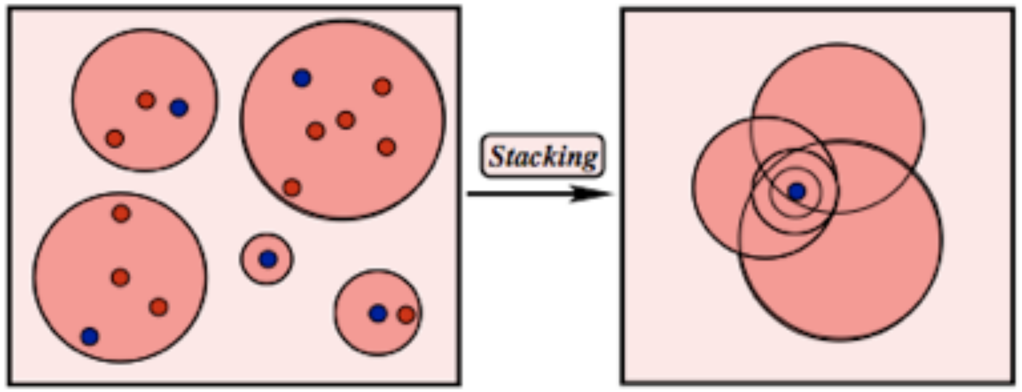


WL & Spectroscopy

- Combine WL & Spectroscopic information: investigate position of galaxies in large scale structures
- Frame-work: Halo Model
- Can put stringent constraints on the mass distribution but also Cosmology

Galaxy-galaxy lensing technique

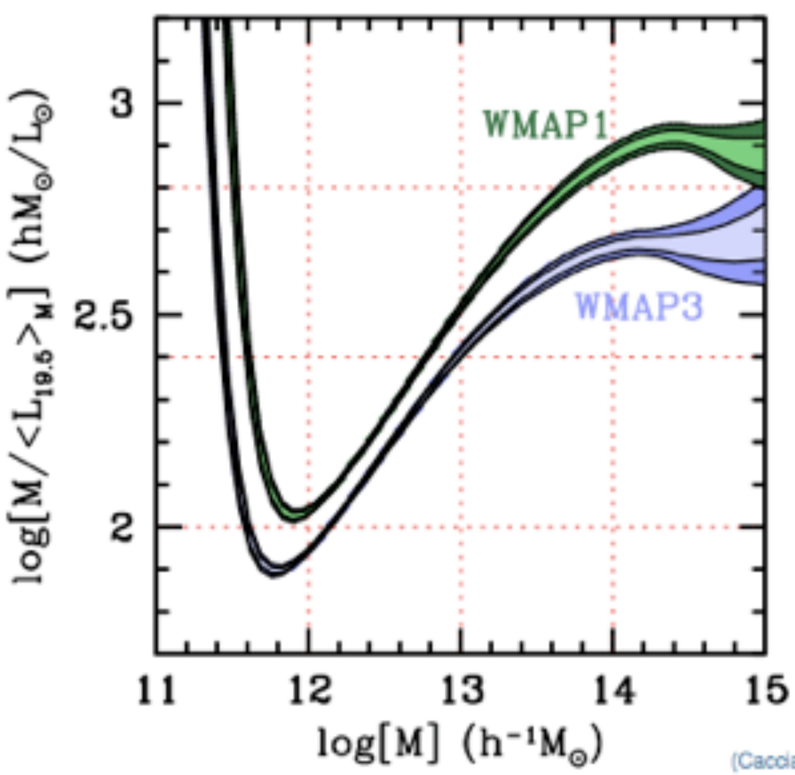




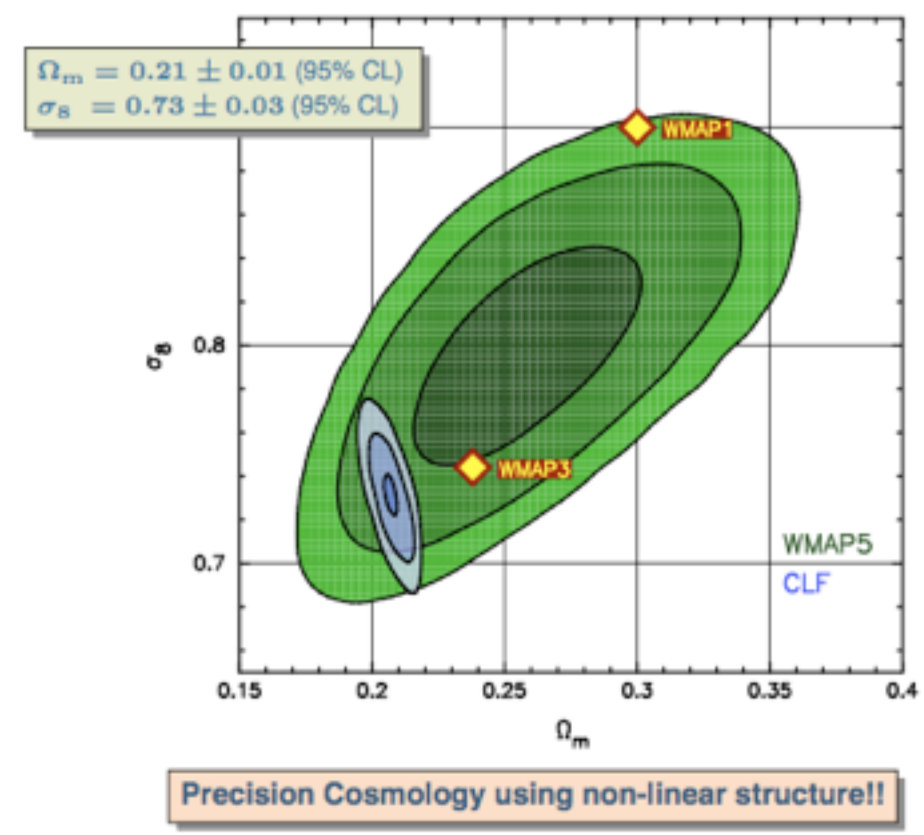
WL & Spectroscopy

- Combining information from galaxy distribution (Correlation function, Luminosity function, Galaxy-galaxy lensing)
- Probe Mass/Light (SDSS based)
- Probe Cosmology (with lensing)

Cacciato/Van den Bosch et al 2009



(Cacciato, vdB et al. 2008)



Our Universe Revealed by its Galaxies

- Star-light of galaxies allow to pinpoint their location and their "shape" with imaging technique (=> high resolution requirement)
- Galaxy distance comes from analysing the spectral information of the star-light:
    - Photometric redshift: a very low resolution spectroscopic information (R~3-5)
    - Spectroscopic redshift: detailed estimate with R~200 or better

Photo-z method

1. **Purely adaptative** (e.g. Neural network)

   > no need to deal with zero-points, filters, etc (although need uniform data)

   > need a large and representative spec-z sample

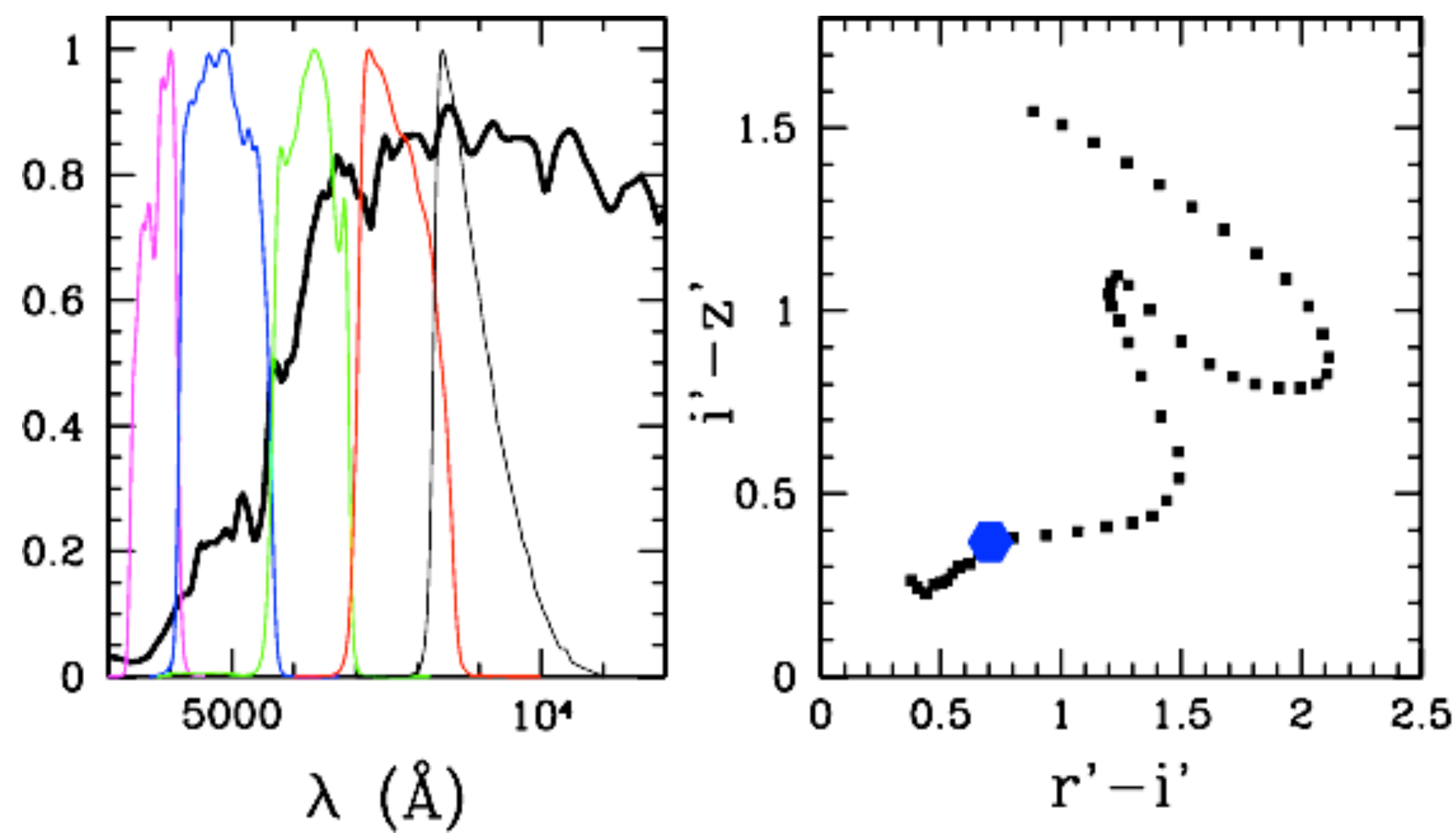
2. **Template fitting**

   > need a perfect knowledge of zero-points, filters, ... and the best template matching your data

   > need of a spec-z sample more limited: to check photometric calibration (shallow z-survey) - to define the templates (deep z-survey, matching the survey depth)

Photo-z method

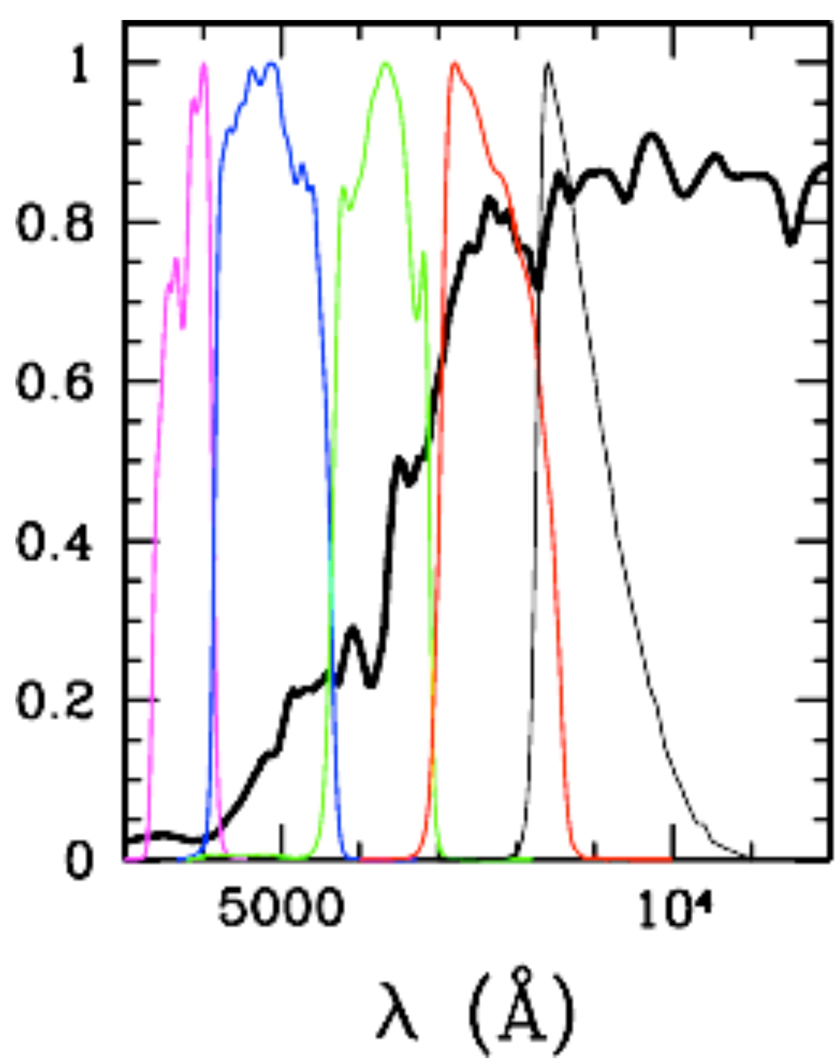
Template spectra redshifted every Δz, Integrated through filters => predicted colors

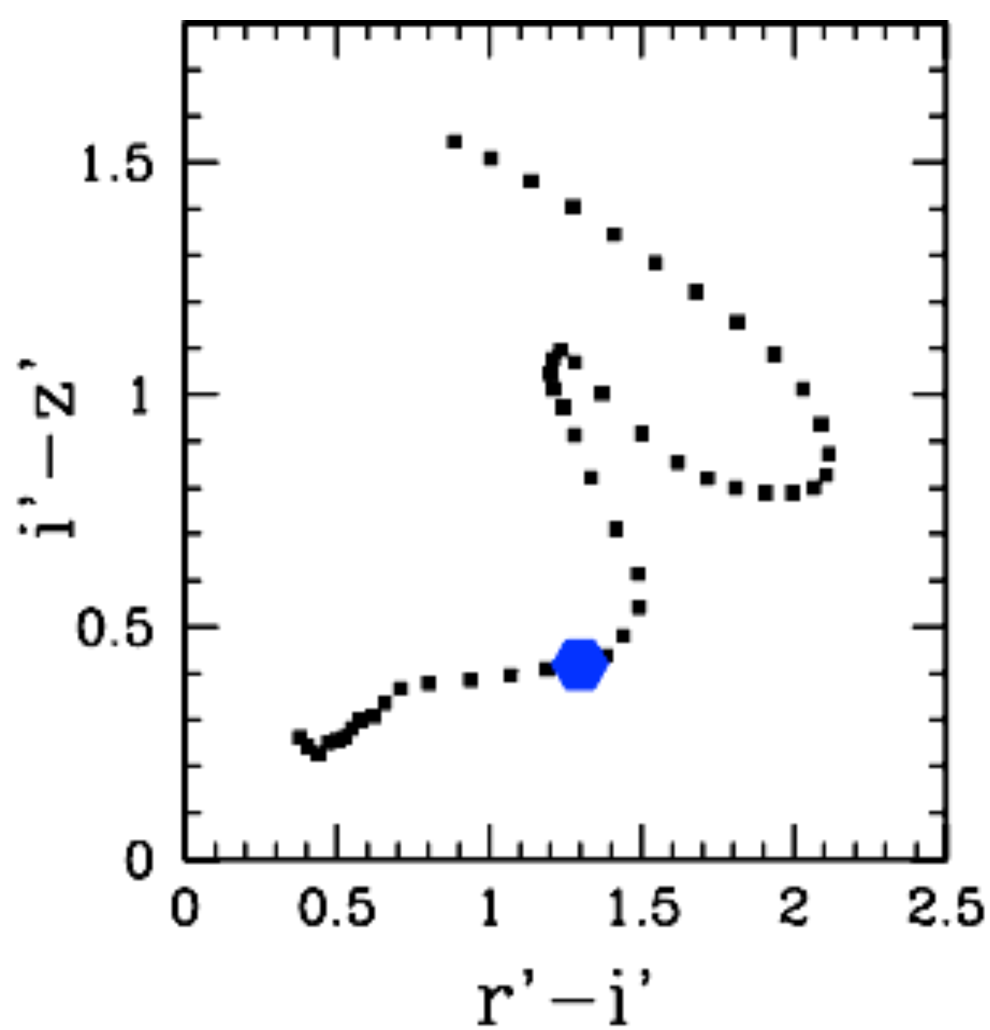


Z=0.4

Photo-z method

Template spectra redshifted every Δz, Integrated through filters => predicted colors

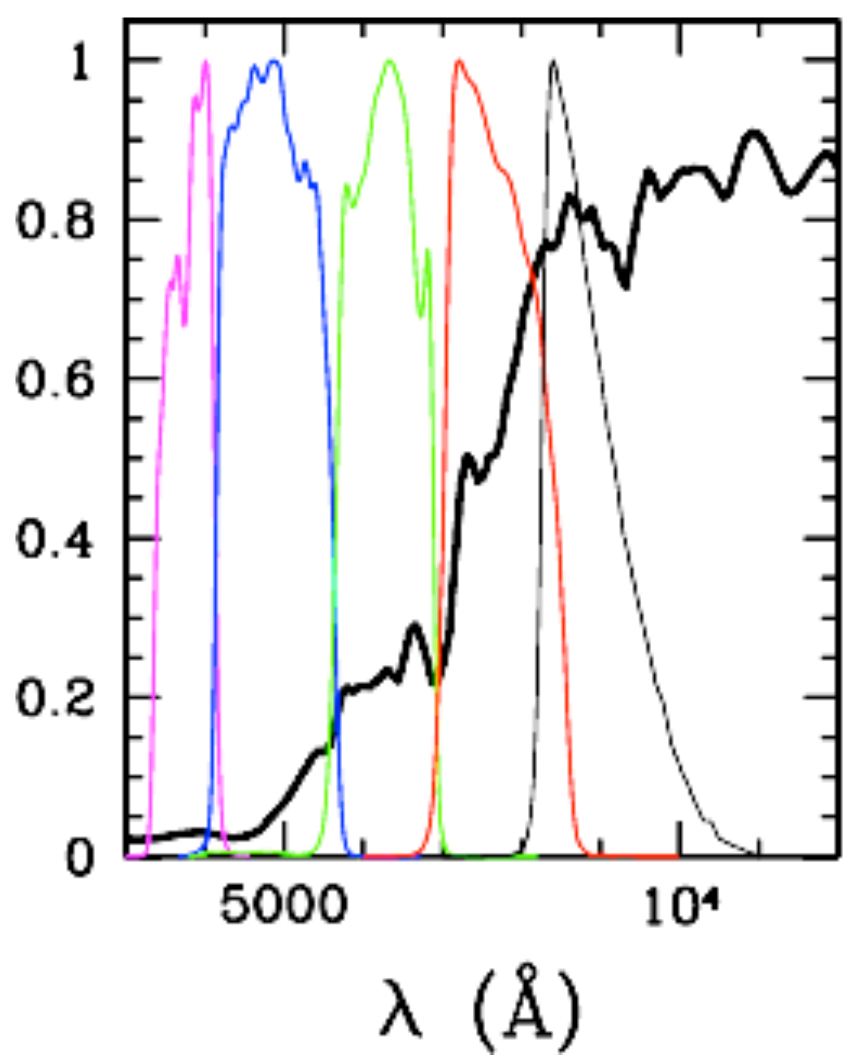


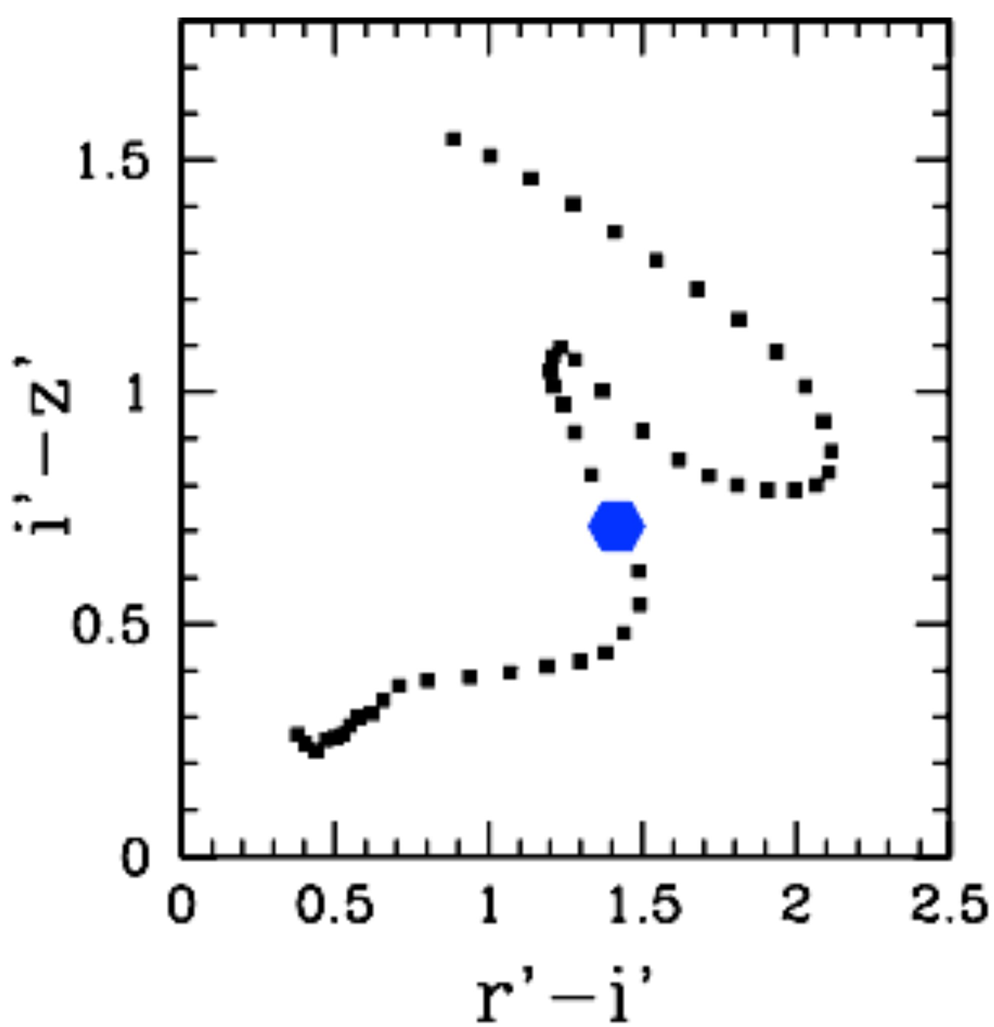


Z=0.6

Photo-z method

Template spectra redshifted every Δz, Integrated through filters => predicted colors

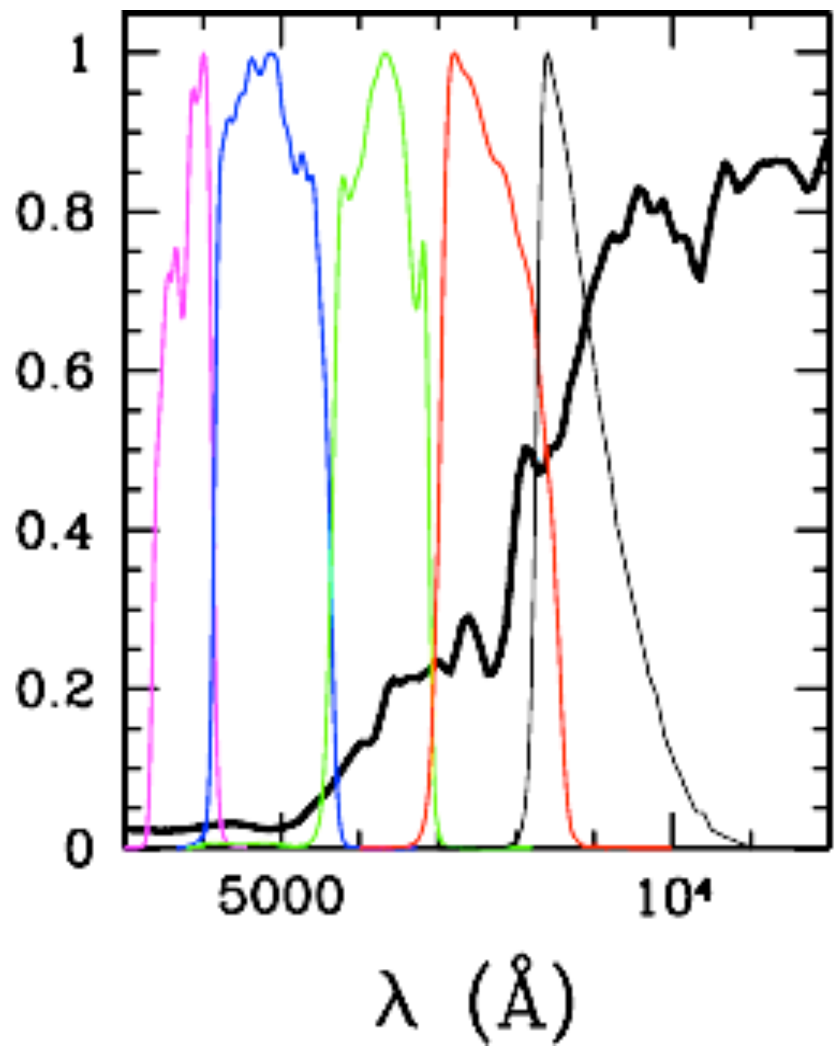


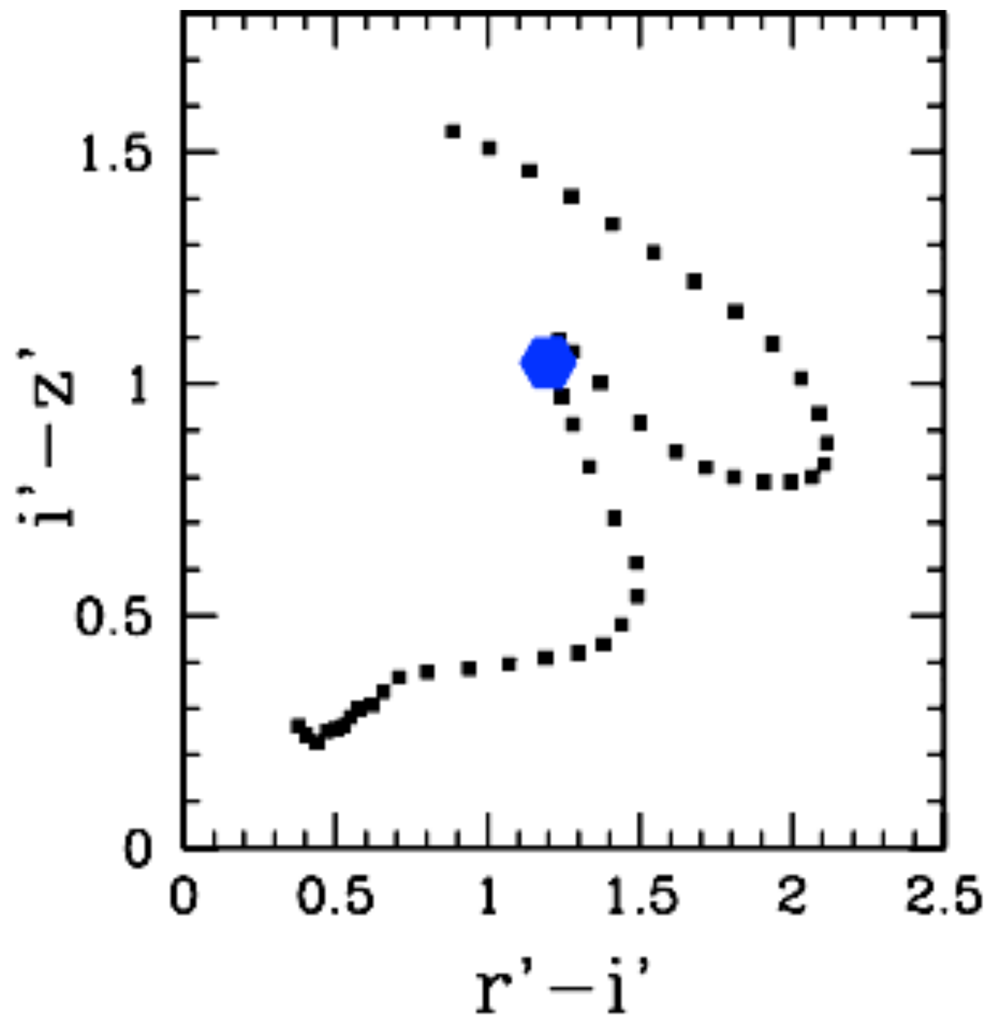


Z=0.8

Photo-z method

Template spectra redshifted every Δz, Integrated through filters => predicted colors

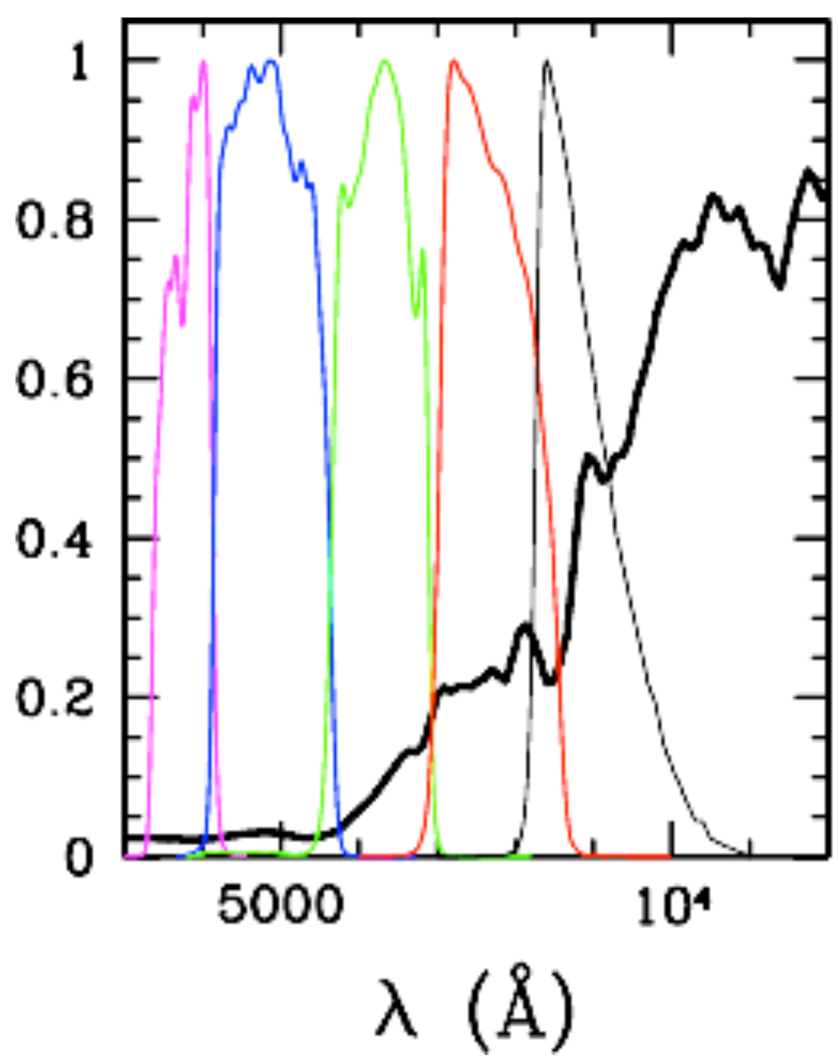


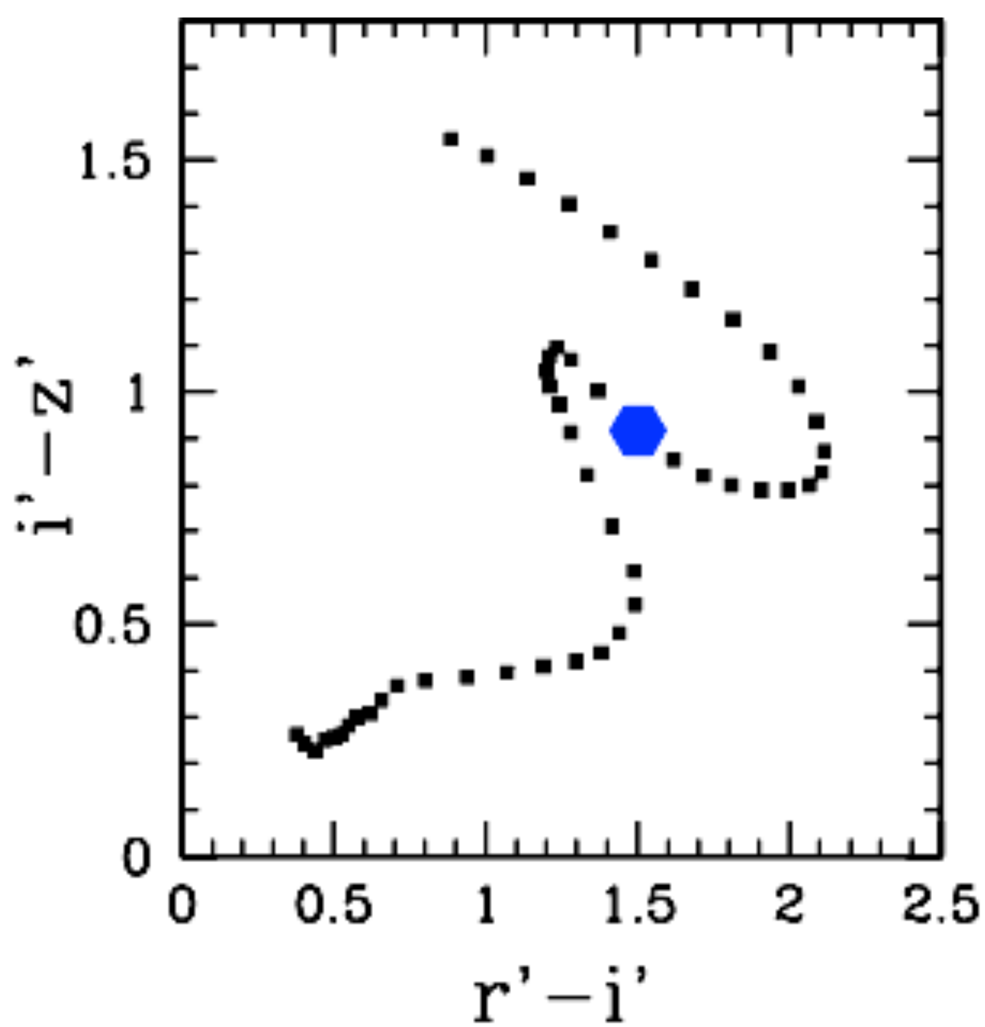


Z=1.0

Photo-z method

Template spectra redshifted every Δz, Integrated through filters => predicted colors





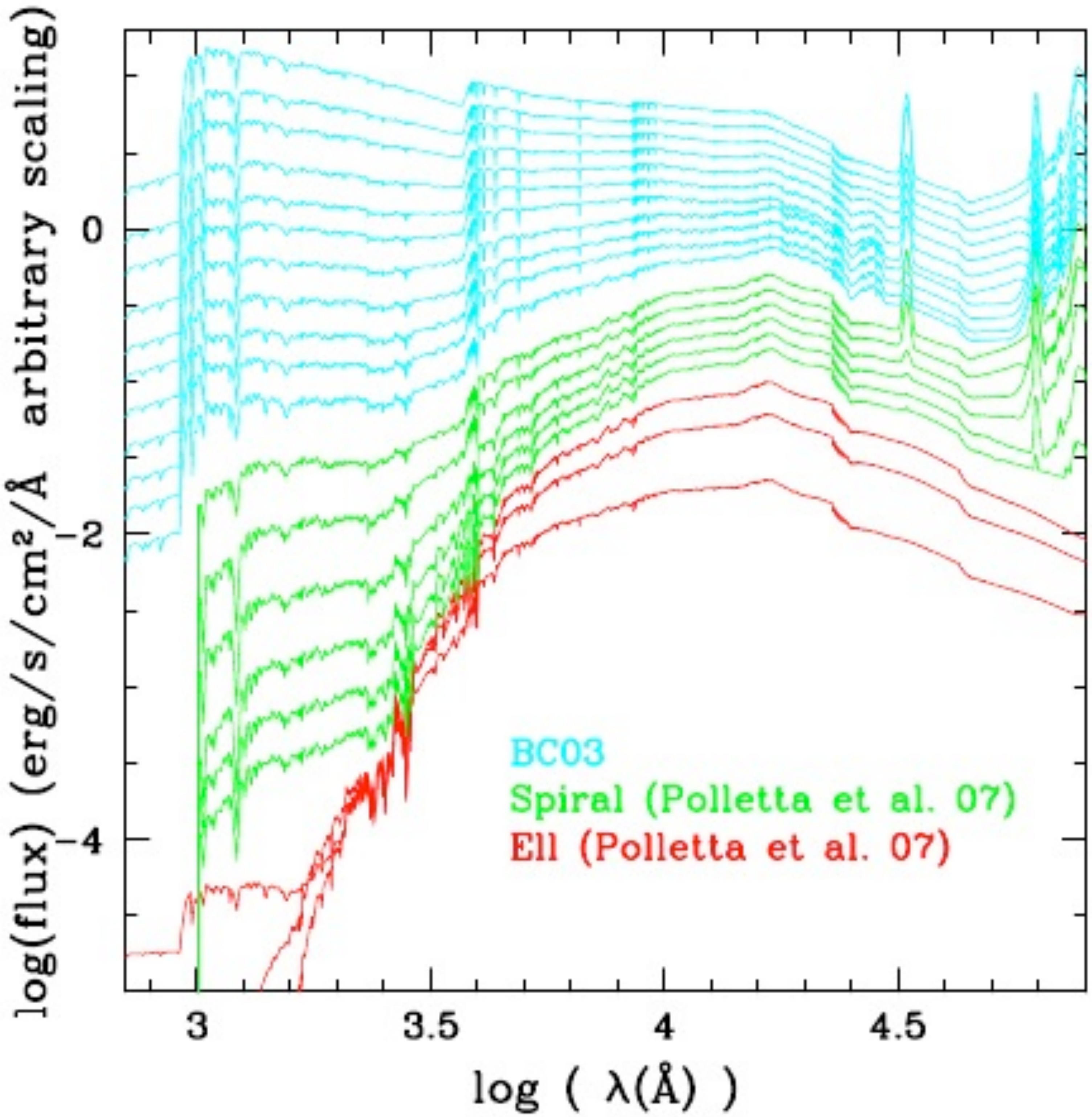
Z=1.2

Photo-z method

Different synthetic set of templates: Pegase, BC03, ...

Different empirical set of templates: CWW, Polletta et al., ...

There is a need of calibrating templates as a function of depth and redshift of the survey



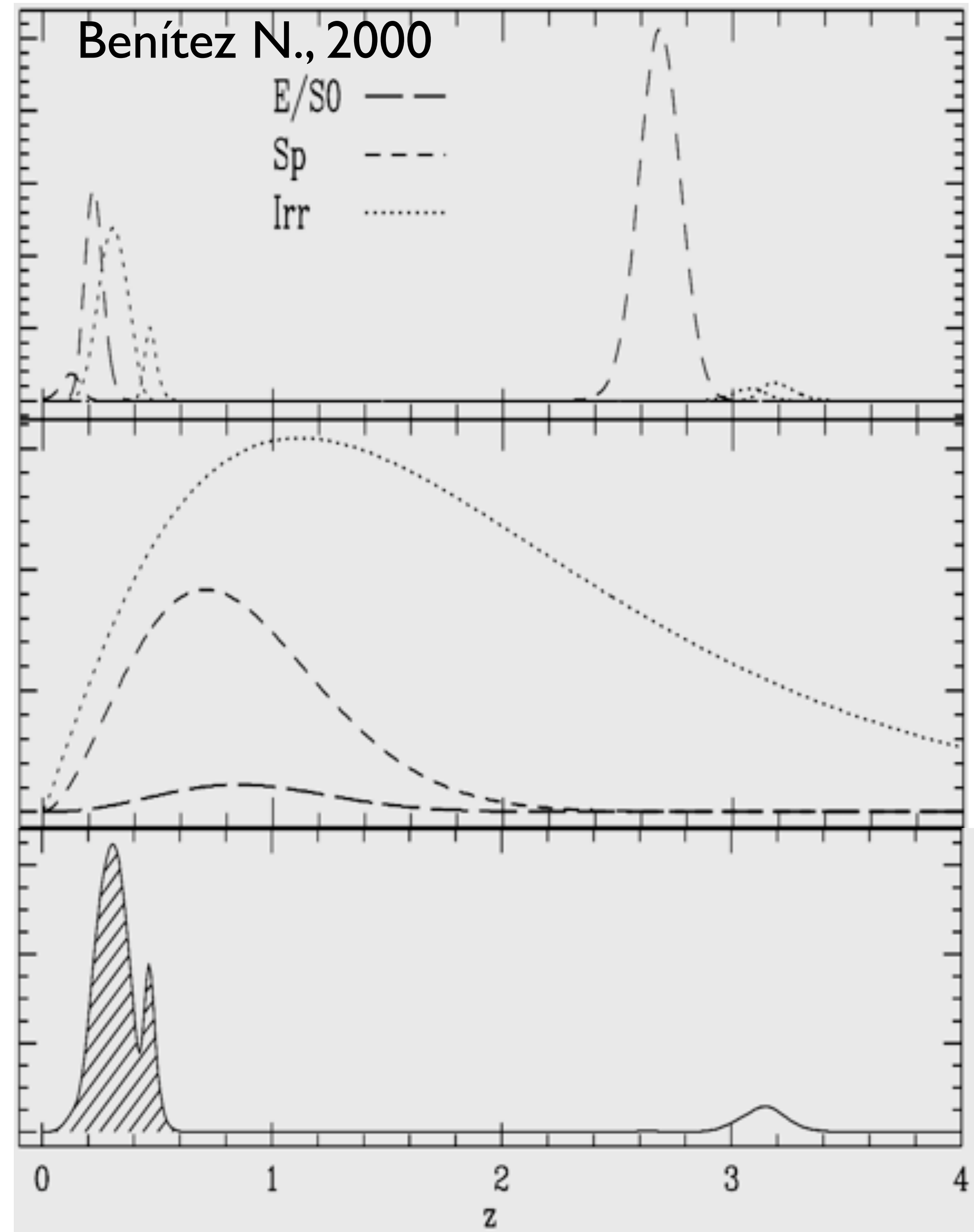
A lot of possible fine-tuning

- **set of templates**
- calibration of photometric zero-points

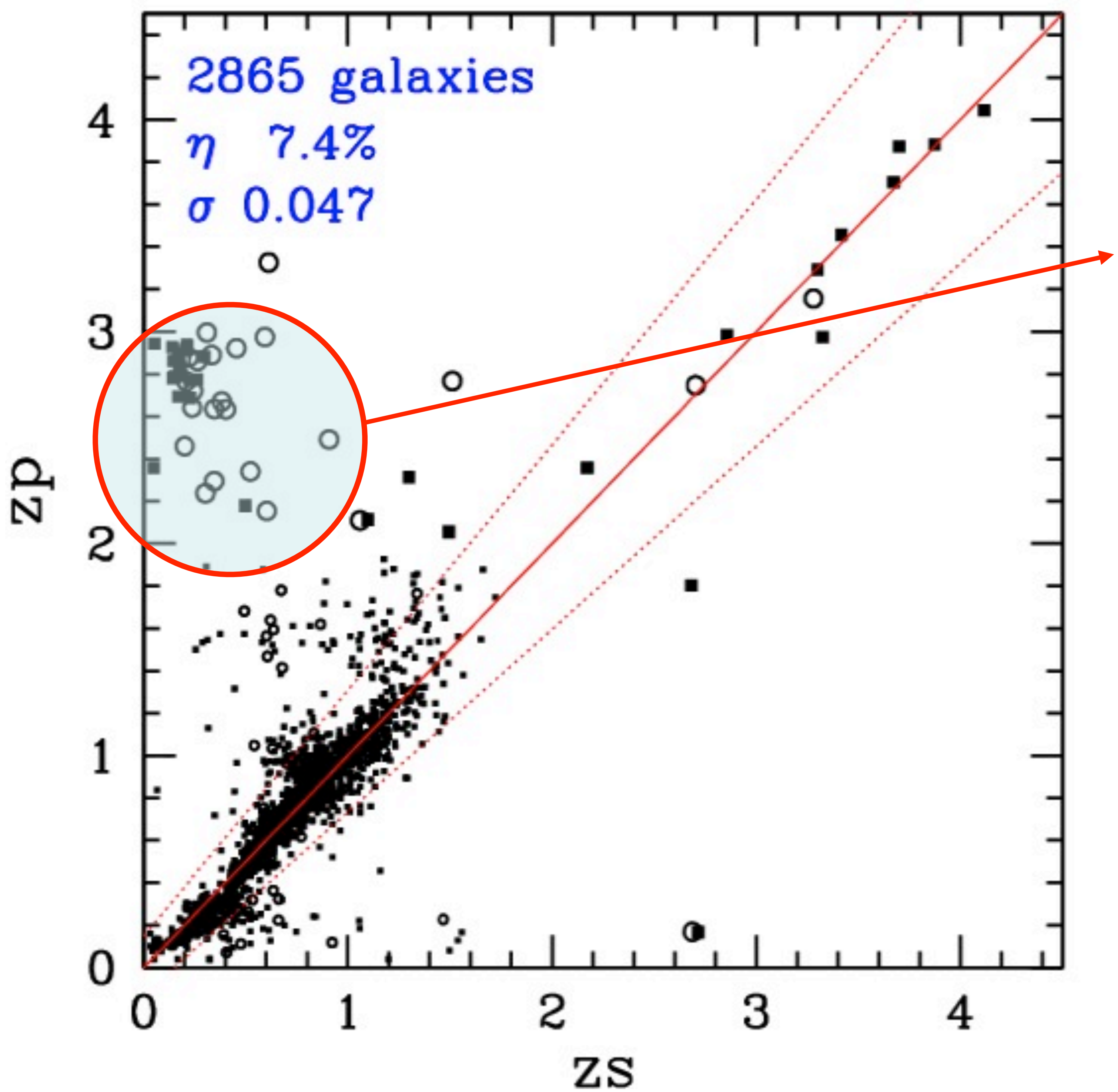
with spec-z

- emission line contribution
- combine attenuation curves
- possible prior on the z-distribution
- different way of analyzing the PDF

Physical output : stellar masses, LIR, SFR ...



The standard χ^2 method -Results

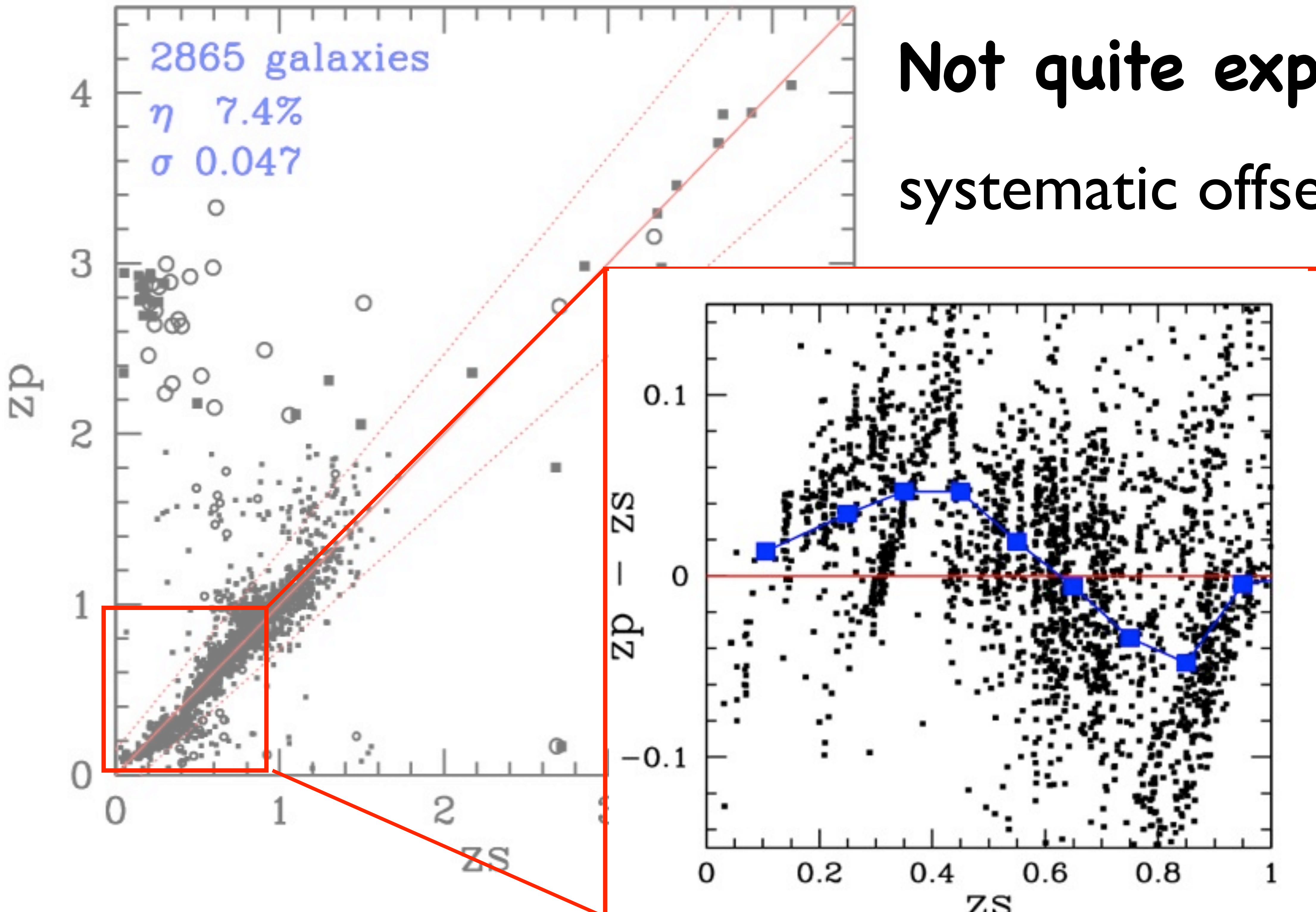


Expected

Degeneracy between the Balmer and Lyman breaks

CFHT-LS ugriz data

The standard χ^2 method -Results



Not quite expected

systematic offset

Need for spectroscopic calibration

Method successful to remove systematic trends

u* +0.019

g' -0.079

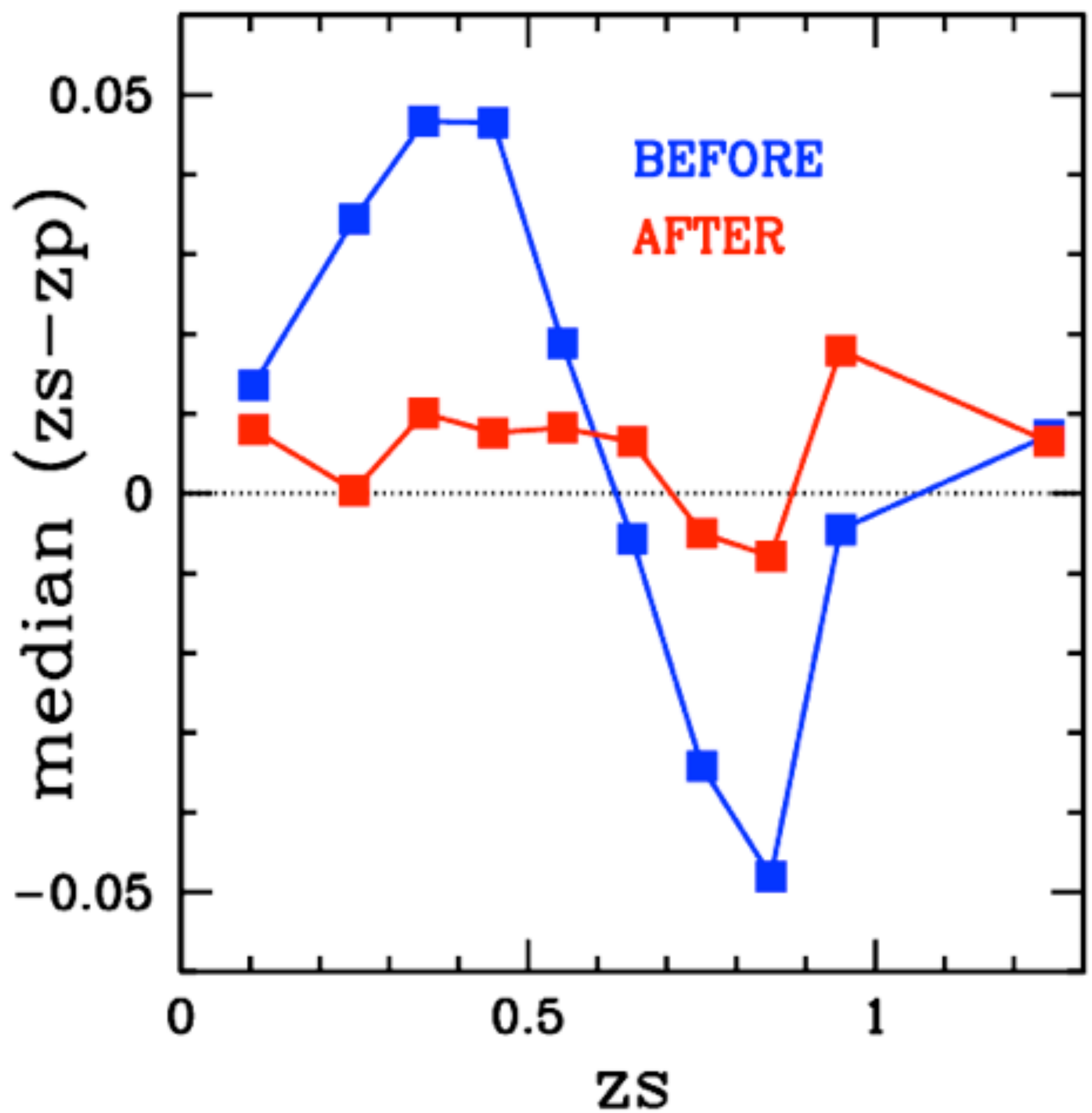
r' -0.002

i' 0

z' -0.008

Importance of the zero-point calibration

Further improvement of the templates



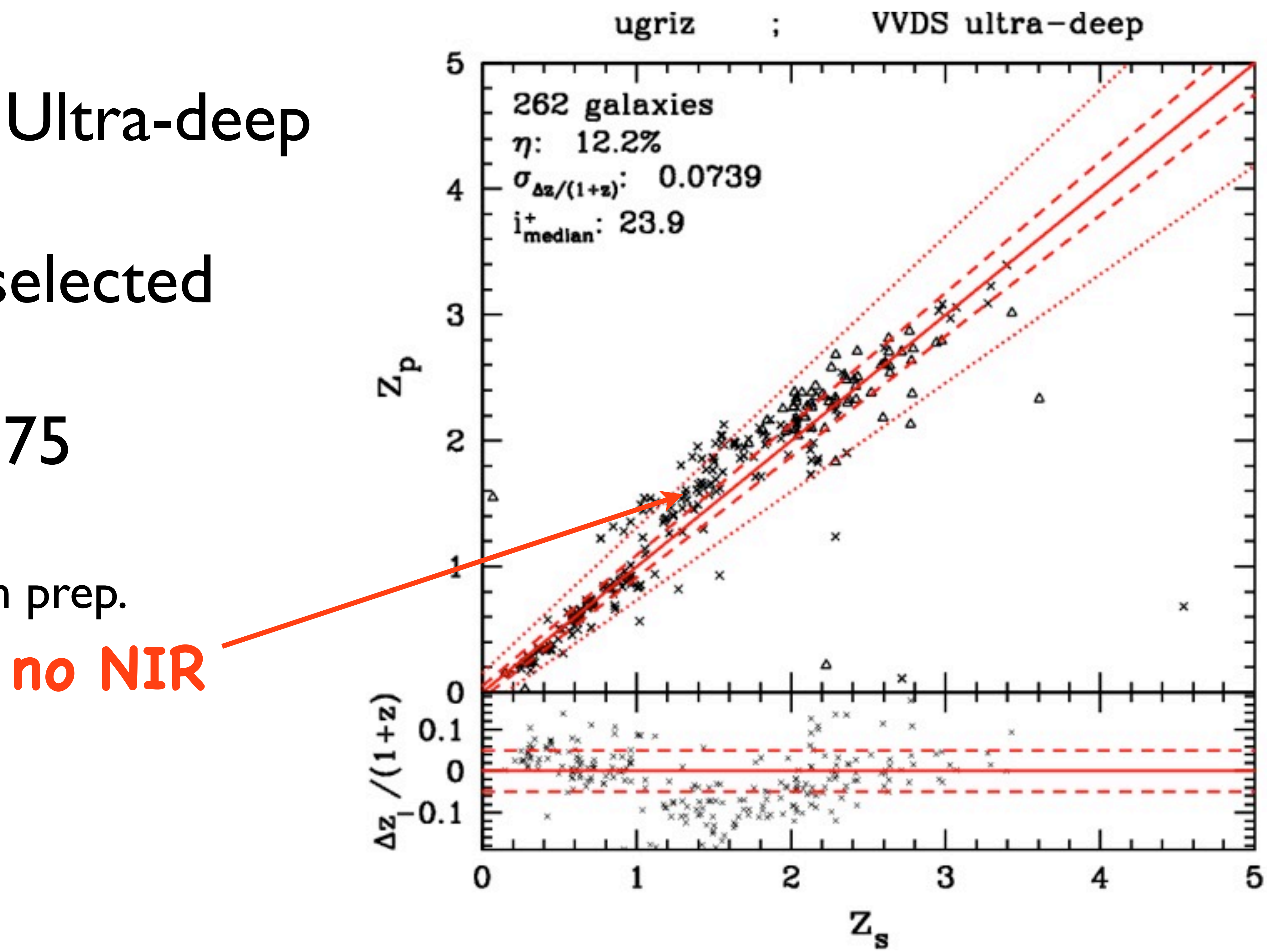
CFHT-LS vs. VVDS Ultra-deep

New VVDS Ultra-deep

Magnitude selected

23 < I < 24.75

Le Fèvre et al., in prep.



CFHT-LS vs. VVDS Ultra-deep

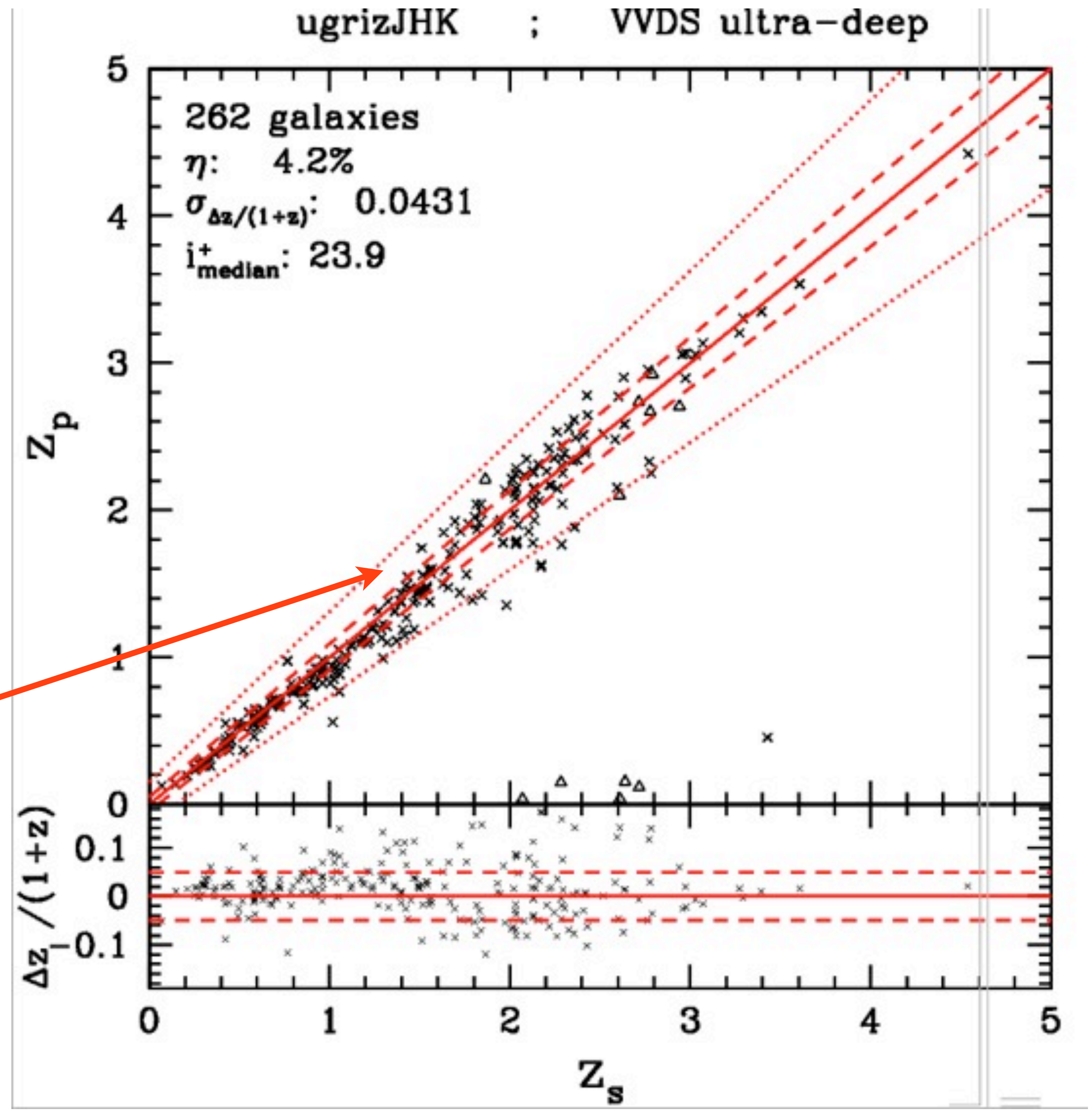
New VVDS Ultra-deep

Magnitude selected

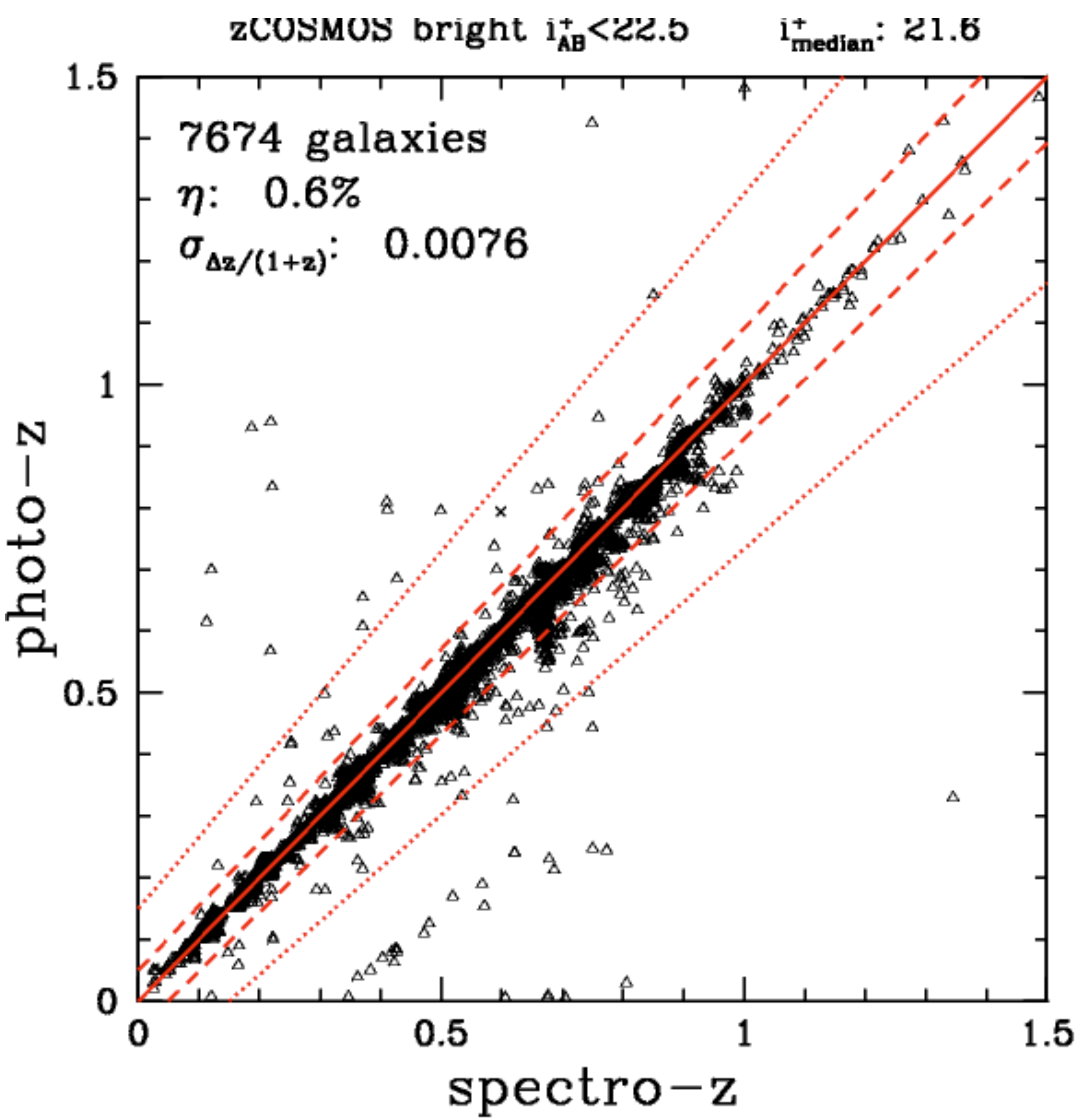
23 < I < 24.75

Le Fèvre et al., in prep.

with NIR



COSMOS photometric redshift



zCOSMOS bright
i’<22.5

VIMOS/VLT

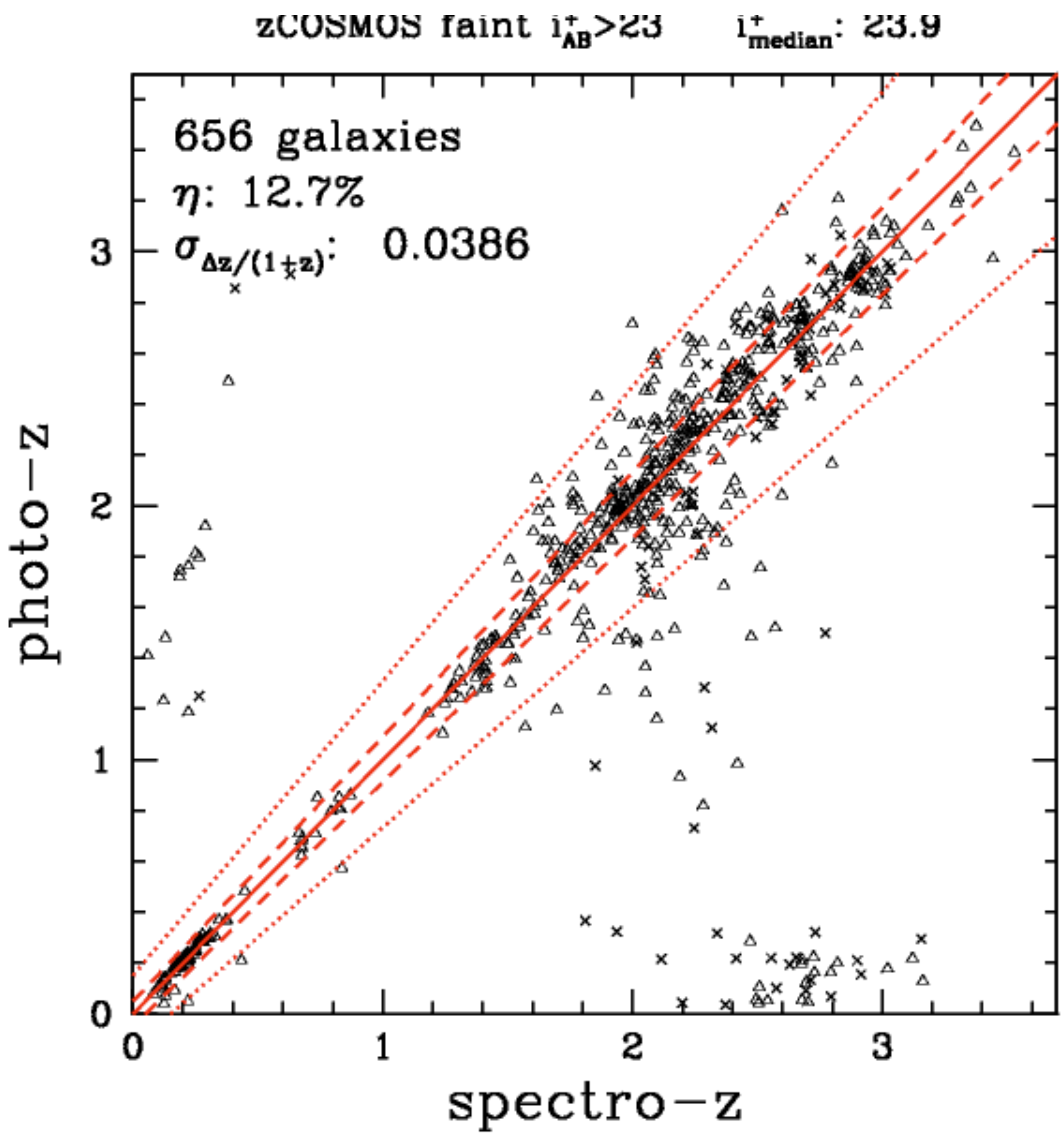
(Lilly et al. 2009)

1% redshift accuracy
at z<1.5

less than 1% failure

Ilbert, Capak, Salvato et al. 09

COSMOS photometric redshift



zCOSMOS faint

VIMOS/VLT

(Lilly et al. 2009)

up to i'<25

For 1.5<z<3

4% redshift accuracy

13% of failure

Need better IR to improve these numbers

Optimizing photometric redshift for WL surveys

Weak-Lensing Requirement

Shape measurement :

galaxies are small

HOW-TO: Measure PSF from stars and galaxy shape

Requires a PSF smaller than galaxies with good sampling :

large mirror diameter, large number of pixels.

Photometric redshift:

galaxies are faint

HOW-TO: Measure color gradient with maximal S/N

Requires wide wavelength coverage (visible+NIR) with high S/N:

Large mirror diameter, many filters.

BUT for a fixed amount of time and at minimal cost !
Need to optimize these surveys parameters for WL goals.

Known Galaxy Properties from Deep Surveys

Imaging:

the COSMOS survey

- $2deg^2$ (representative)
- 30 photometric bands from UV to IR with HST, Galex, Spitzer, Subaru, VLA, NOAO
- HST/ACS I band observation: galaxy sizes & shapes

Spectroscopy:

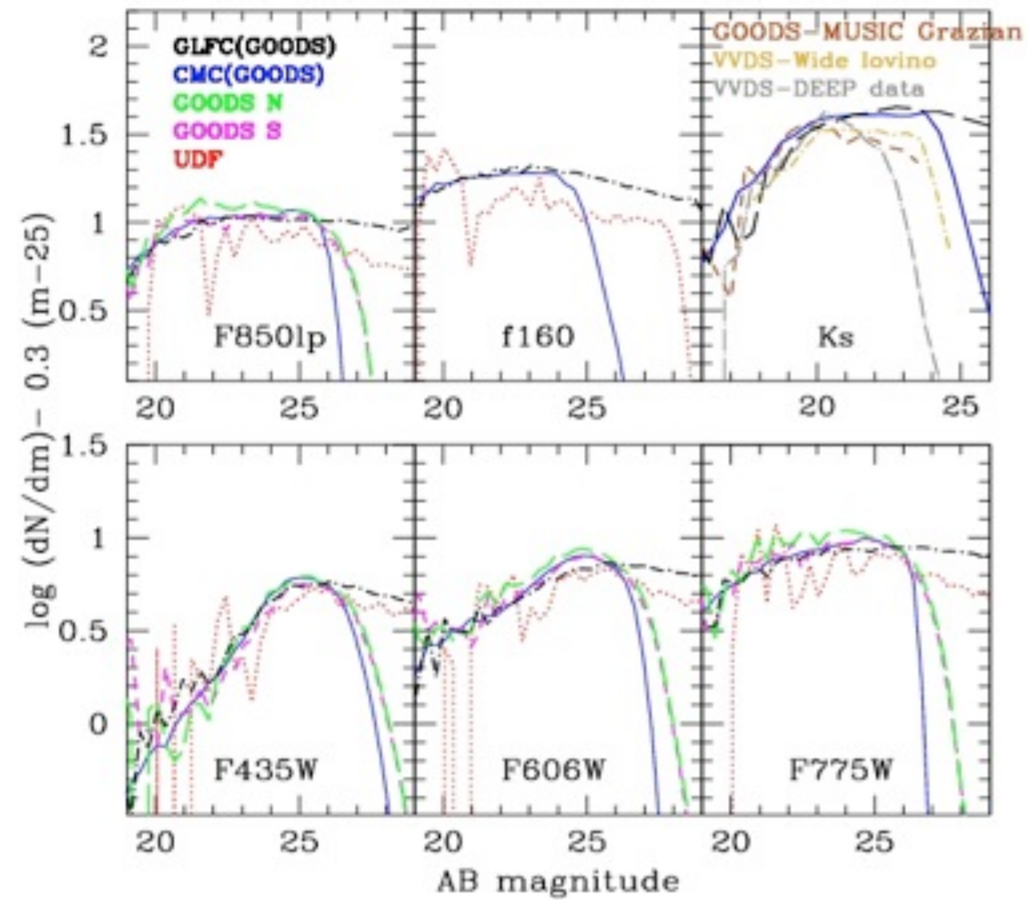
the VVDS "Deep" survey

- VIRMOS/VLT deep spectroscopic survey on ~0.5 sq.deg
- ~ 9000 spectra from $0<z<5$ to I(AB)~24

COSMOS Mock Catalog (CMC)

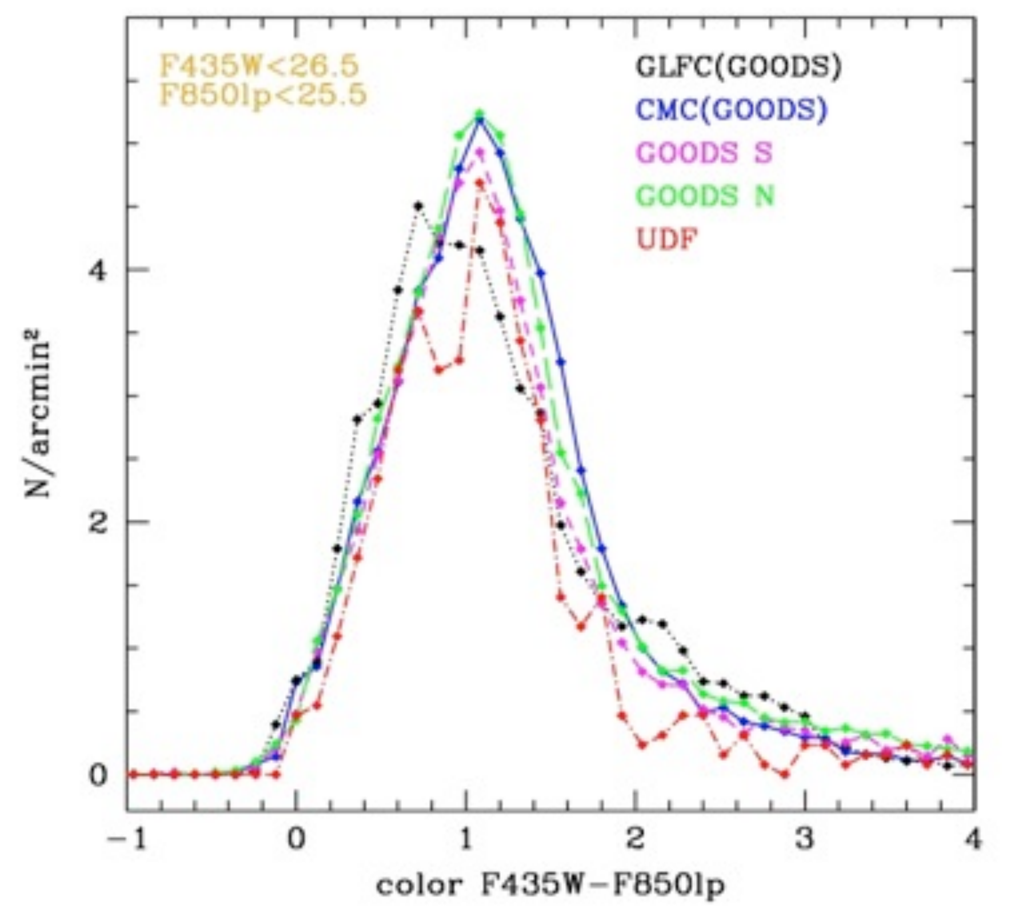
Construction using the properties of the COSMOS-ACS WL catalog using :

- *photometric redshift distribution*
30 photometric bands
calibrated with spectroscopic redshift :
  > zCOSMOS bright (I~22 AB)
  > zCOSMOS faint (I~25 AB)
  > MIPS-spectro-z sample
- *best-fit template* from this photoz distribution
- *galaxy size* measured by SExtractor from Leauthaud et al 2007



Validation of the CMC using :

- GOODS N&S *visible*
- UDF *visible + jh band*
- VVDS *Ks band + spectro-z*
- GOODS-MUSIC *Ks band*

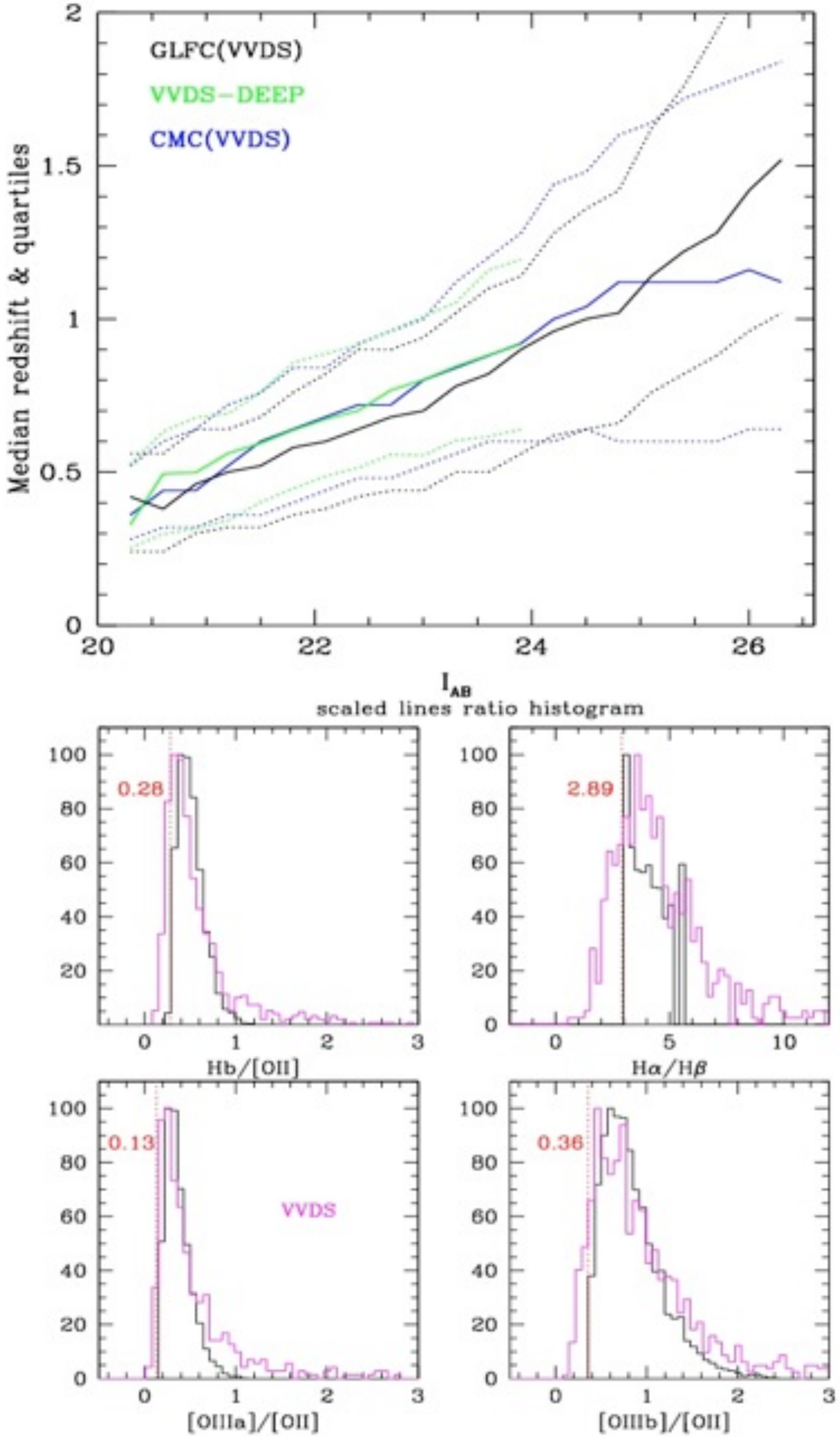


http://lamwws.oamp.fr/cosmowiki/RealisticSpectroPhotCat

COSMOS Mock Catalog (CMC)

Emission line prediction :

UV-OII relation, Kennicutt et al 1998



Validation of the redshift distribution and emission line fluxes using the VVDS-DEEP I~24 AB (Lamareille et al 2008)

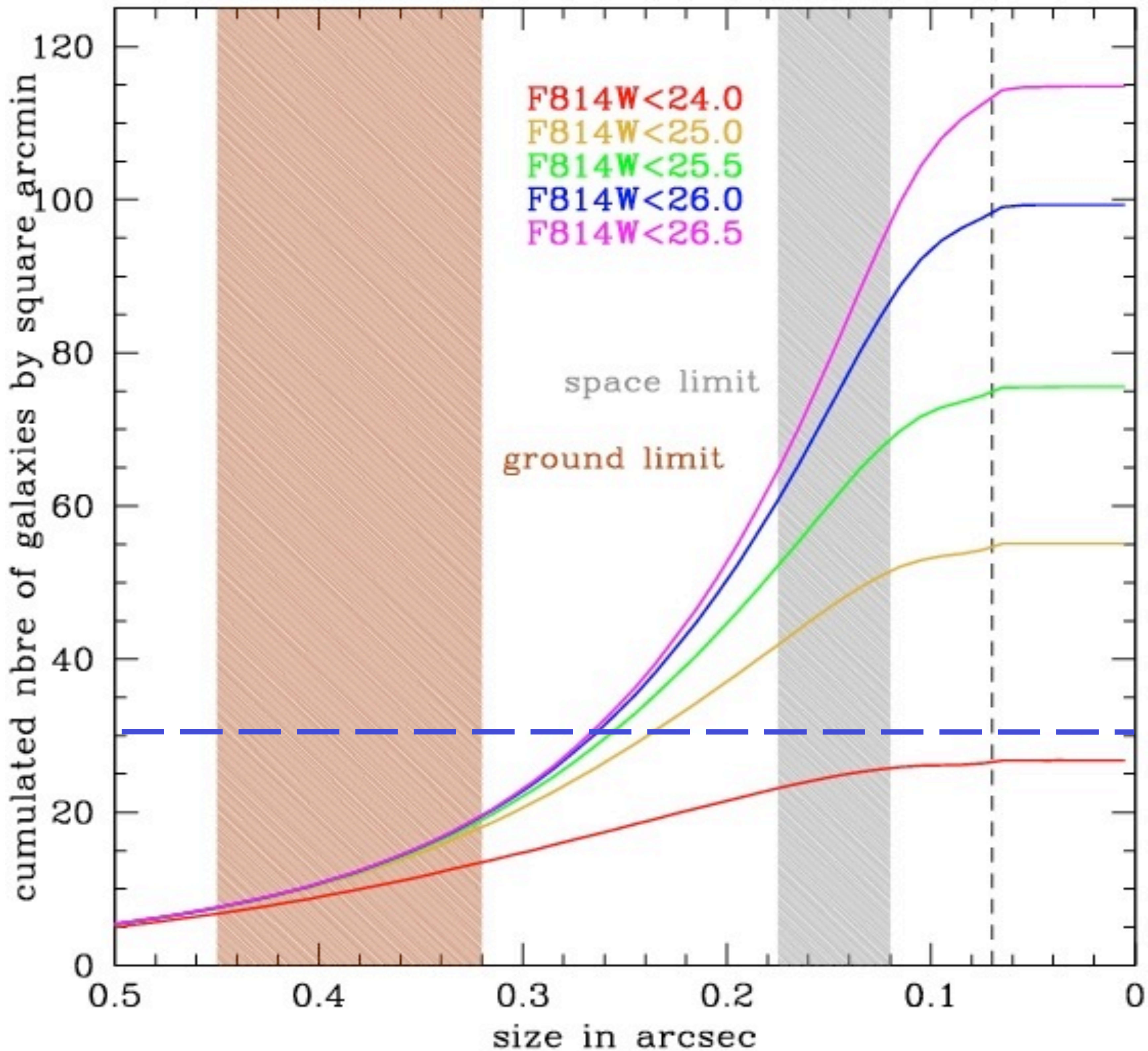
http://lamwws.oamp.fr/cosmowiki/RealisticSpectroPhotCat

Jouvel et al. 2009

Number of galaxies vs. Size & Magnitude

Ground: Going deeper than *I~25 AB* does not increase the number of « usable galaxies »
We are size limited

Space: Going deeper means more galaxies usable for WL. Smaller the PSF, larger is the number of galaxies.
We are S/N limited



Photoz and telescope design

We want to optimize photo-z for :

- Maximum galaxies
- Lowest errors
- Lowest catastrophic redshift rate

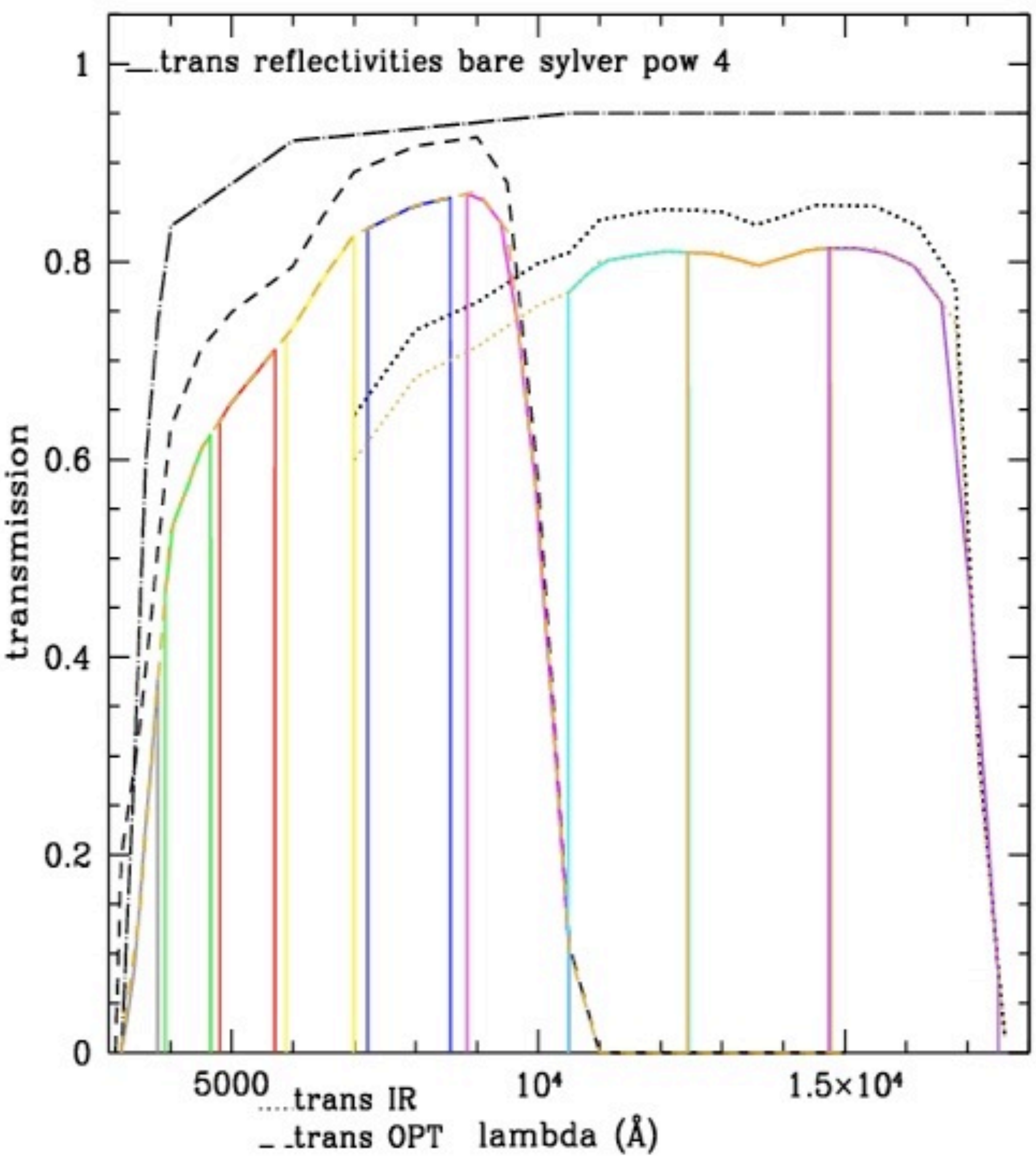
by choosing :

- Number of filters
- Resolution of filters (shape)
- Do we want Uband ?

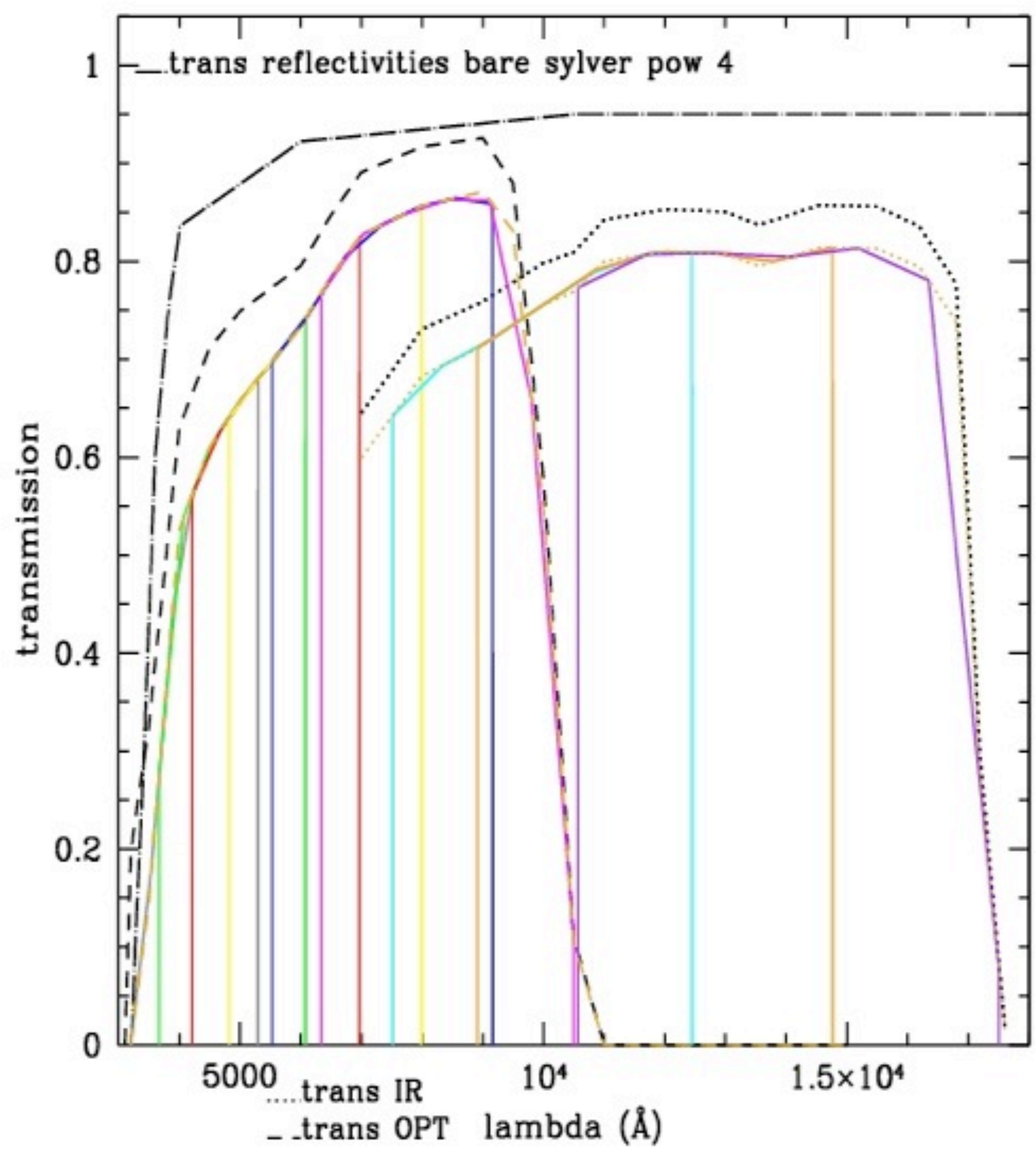
Answer using simulated surveys

We include all detector noises and instrument characteristics (exposure time, mirror size, efficiencies ...)

Optimizing Photo-z : Filter Resolution

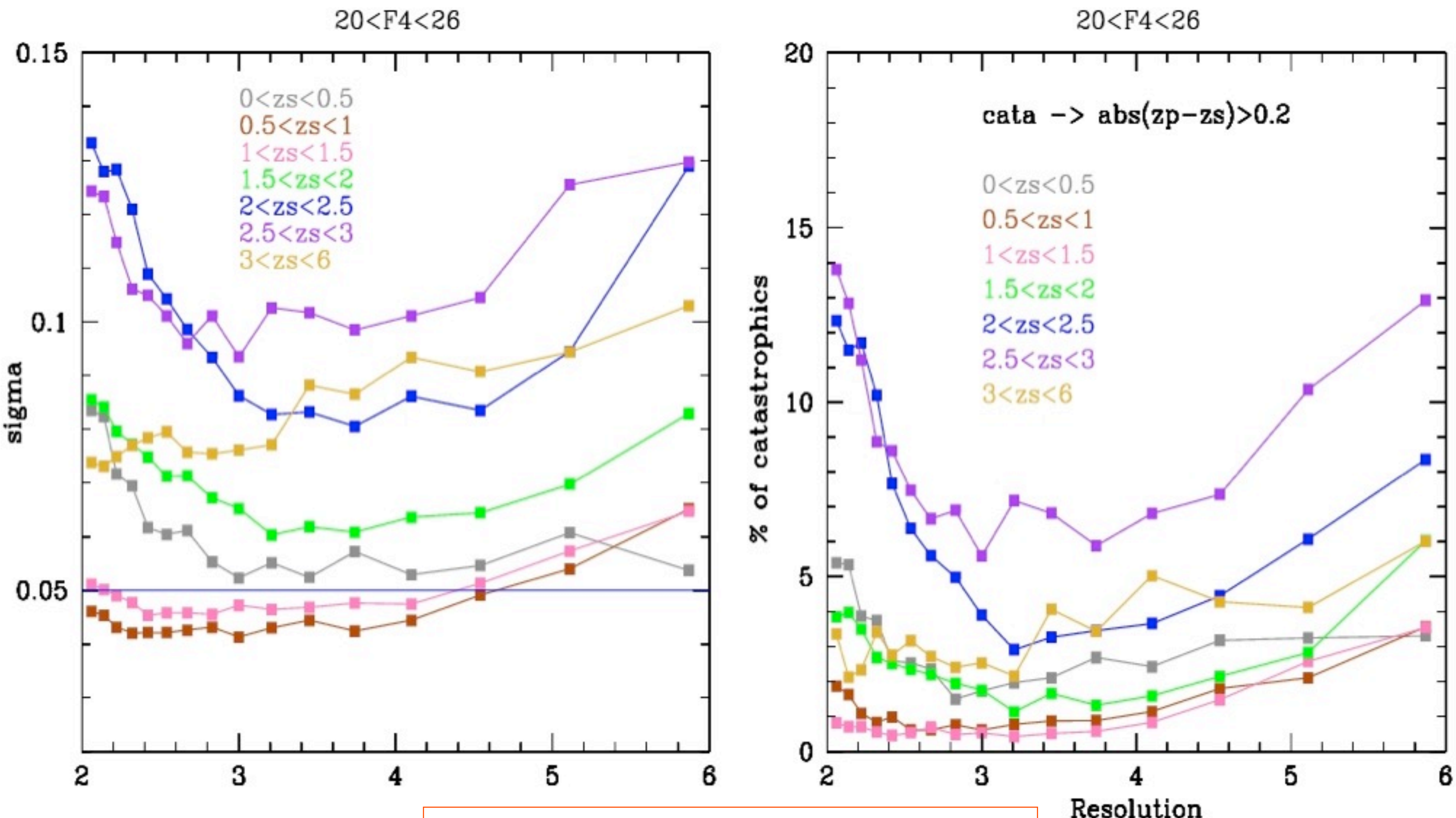


High Resolution= Narrow Filter



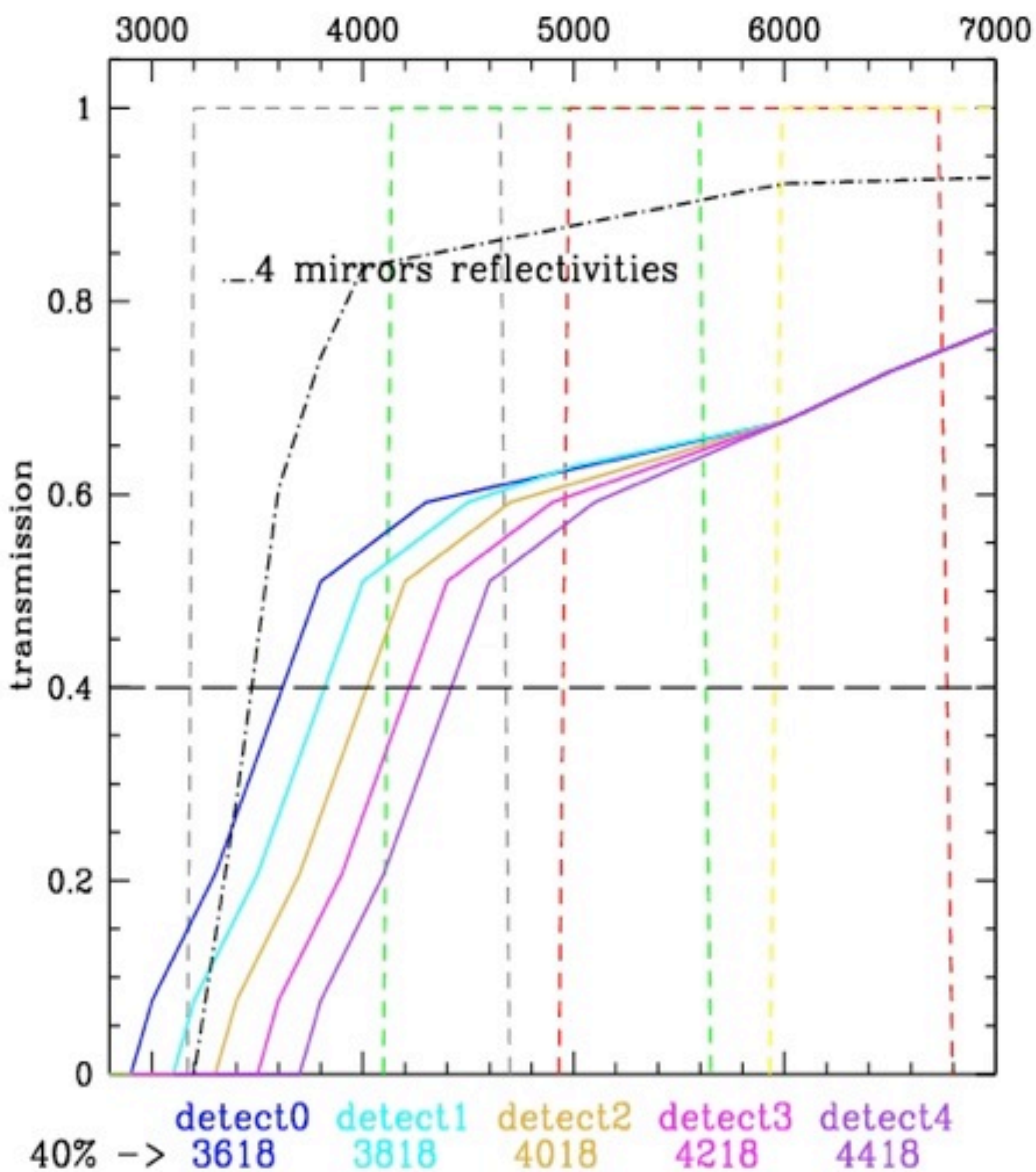
Low Resolution= Wide Filter

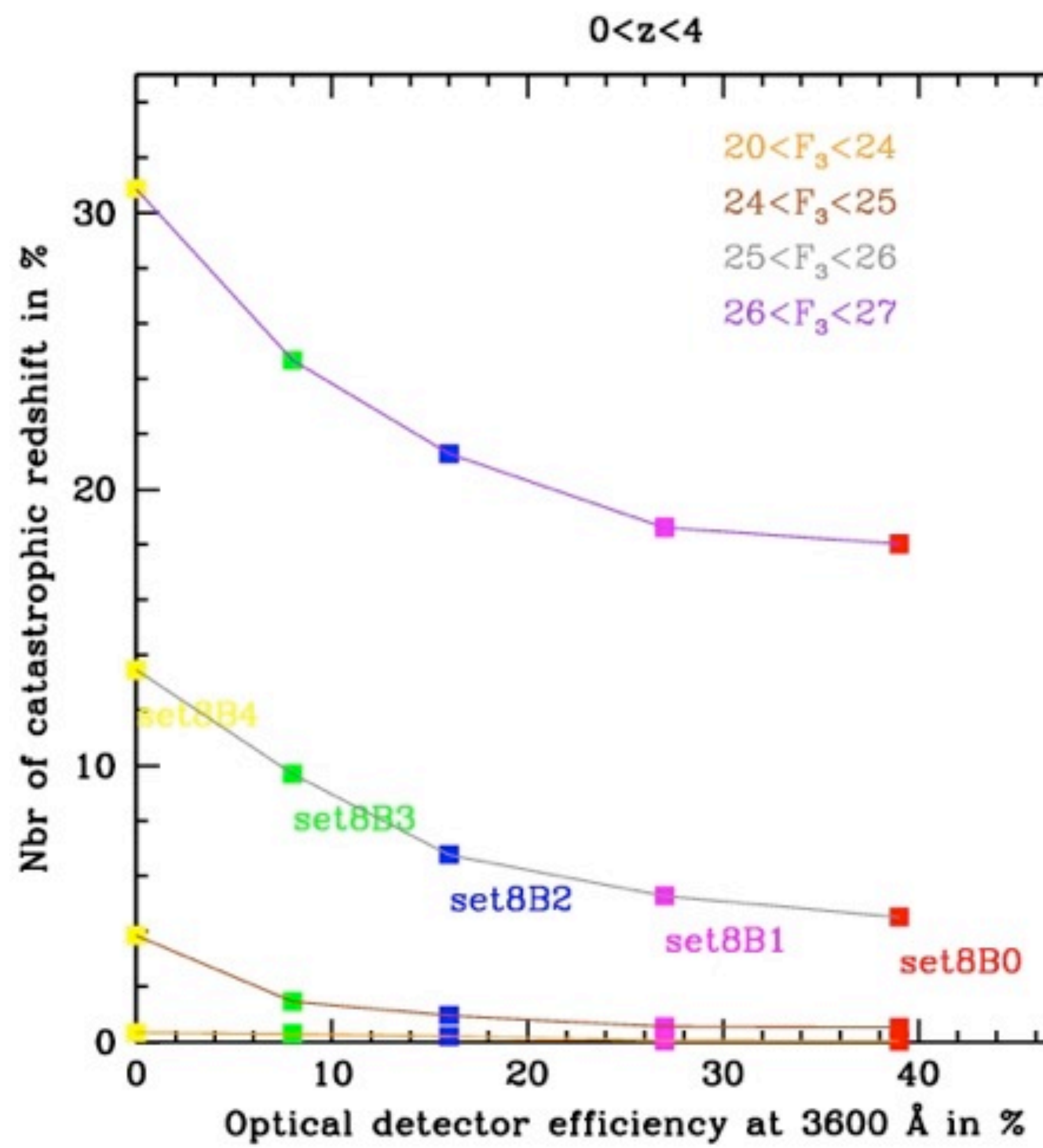
Optimizing: Minimizing Photo-z Dispersion and Catastrophic Redshifts



Optimal Resolution R~3

Optimizing Photo-z : U-band photometry removes catastrophic redshifts





Requires a total efficiency larger than 40% at 3600 AA

FoM : Most Important parameters for cosmological survey

Equations :

$$F_{\alpha\beta} = f_{\rm sky} \sum_l \frac{(2l+1)\Delta l}{2} \mathrm{Tr}\left[D_{l\alpha} \widetilde{C}_l^{-1} D_{l\beta} \widetilde{C}_l^{-1}\right]$$

Amara et al 2007

redshift distribution (e.g. Smail et al) :

$$P(z) = z^{\alpha} \exp\left[-\left(\frac{z}{z_0}\right)^{\beta}\right]$$

divided in tomographic bins

↓

FOM Calculation

Parameters :

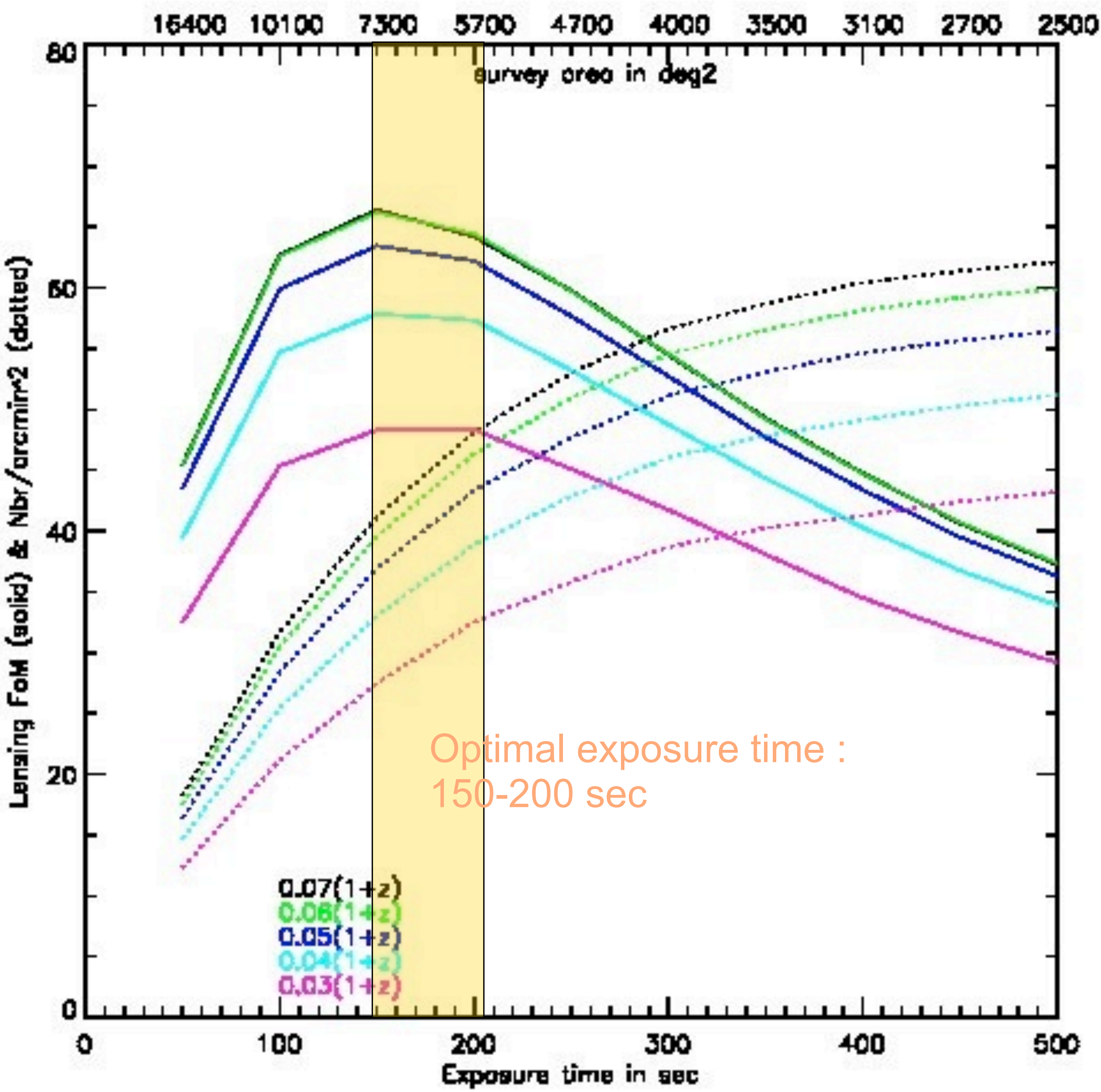
- Survey area:
  - Exposure time, FOV, Nbr of filters, survey efficiency
- Galaxy Number density (WL usable) :
  - Photo-z errors, 1.25xPSF size,
  - S/N>10
- Redshift distribution, Median redshift

FoM : Exposure time & photoz errors

Assumption: 1.5m diameter, fixed FOV (0.5 sq.deg), fixed survey time (1 yr).
Compute FOM (icosmo) vs. Texp.(assuming 4 exp.) for different number of filters

Conclusion:
Optimal Texp : 150-200sec
Above *δz~0.05(1+z)* the galaxy number density increase do not compensate the decrease of the photo-z quality.

Beware: catastrophic redshift not yet included in the FoM

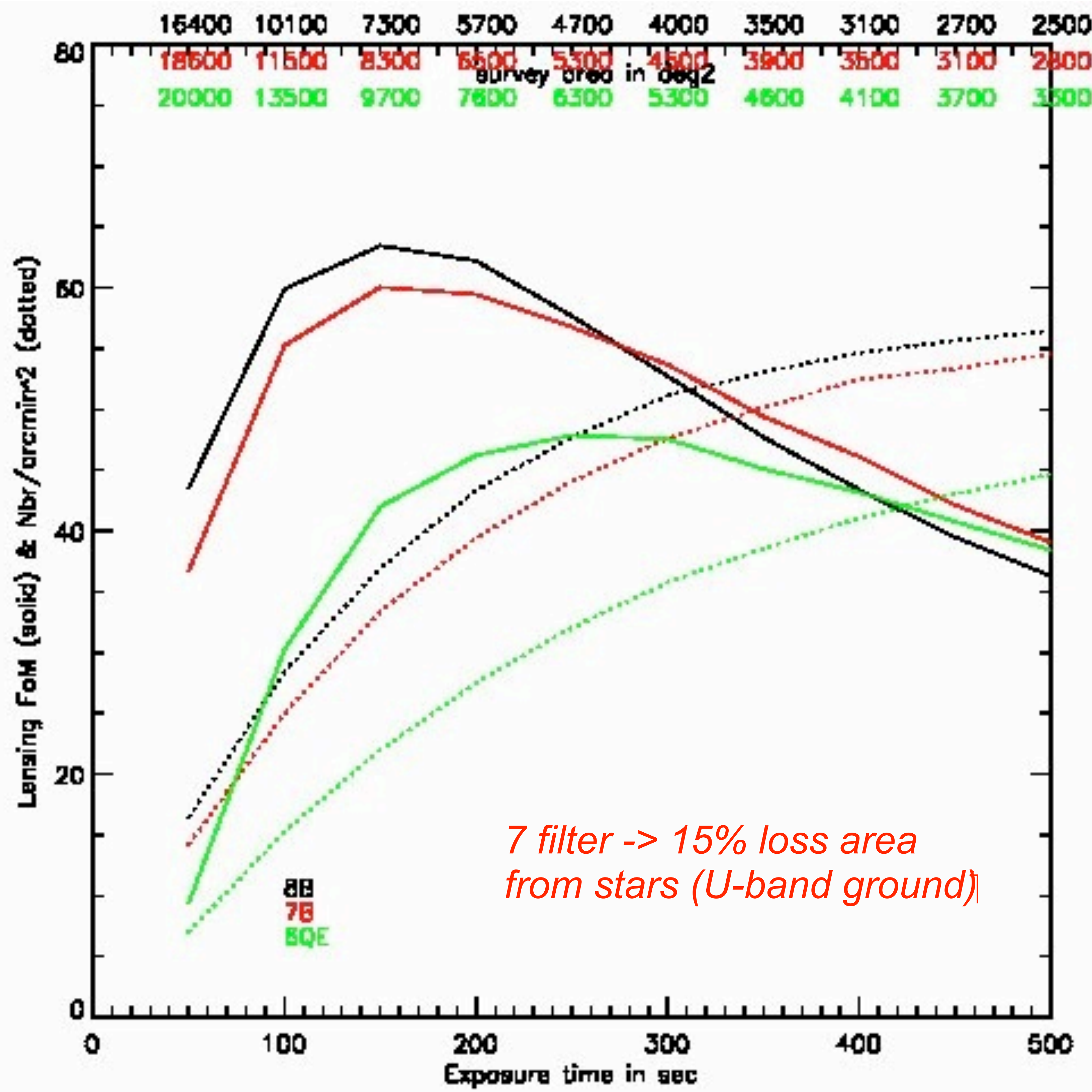


FoM : Optimizing the Number of

Assumption: 1.5m diameter, fixed FOV (0.5 sq.deg), fixed survey time (1 yr).
Compute FOM (icosmo) vs. Texp.(assuming 4 exp.) for different number of filters

Conclusion: 7 (ground U-band reaching the space-sensitivity) or 8 filters observing strategy are better than 6 filters observing strategy

Beware: catastrophic redshift not yet included in the FoM calculation



Need for Spectroscopic Redshift

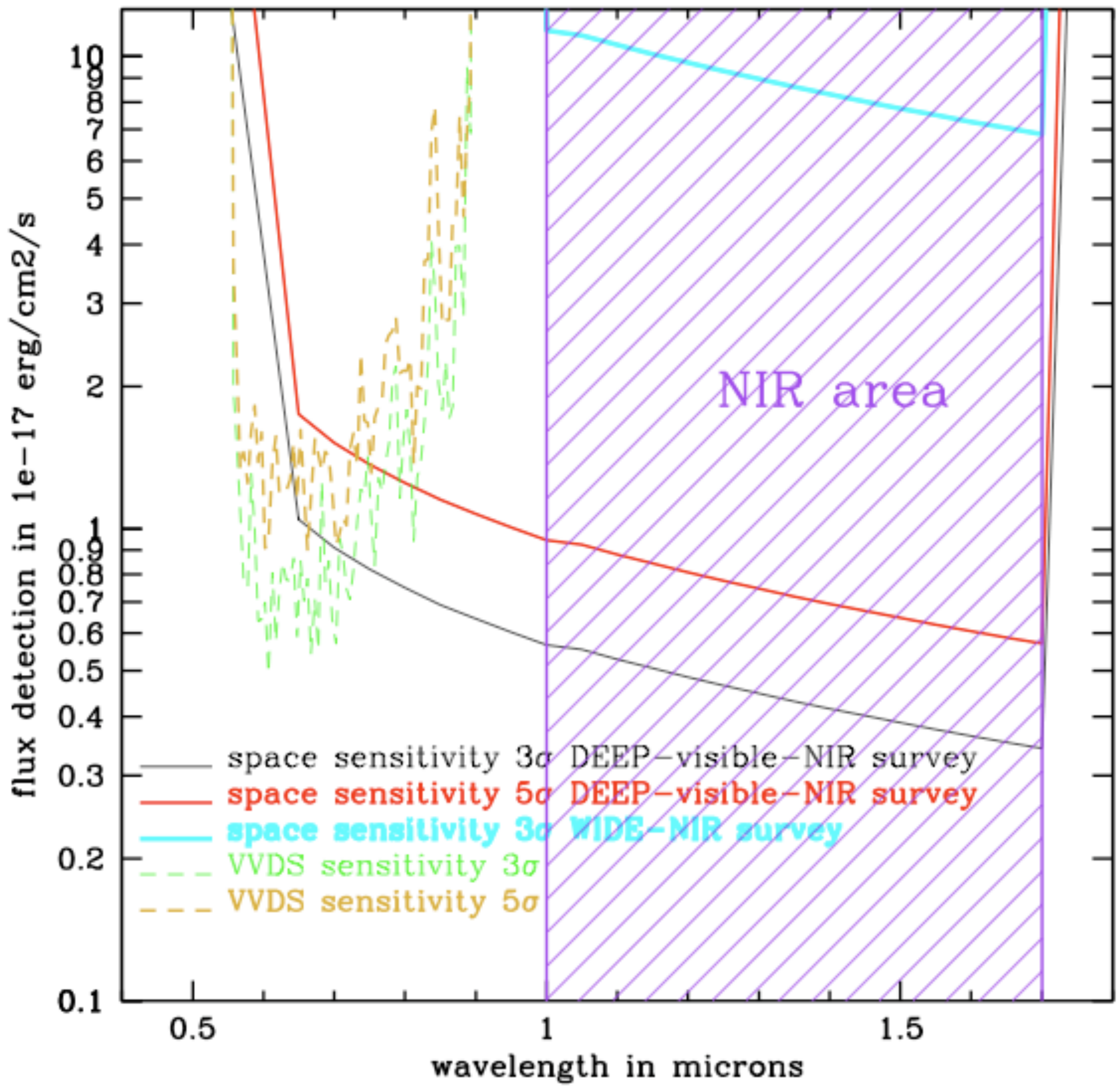
- Photometric redshift calibration (WL interest) [low-density over the full survey, very-deep for faintest galaxies]
- BAO [low-density]
- redshift distorsion [high-density]
- cluster redshift and velocities [high density]
- lensing of structures (galaxies, groups, clusters ...) [high-density]

Spectroscopic Success Rate : Validation and forecast

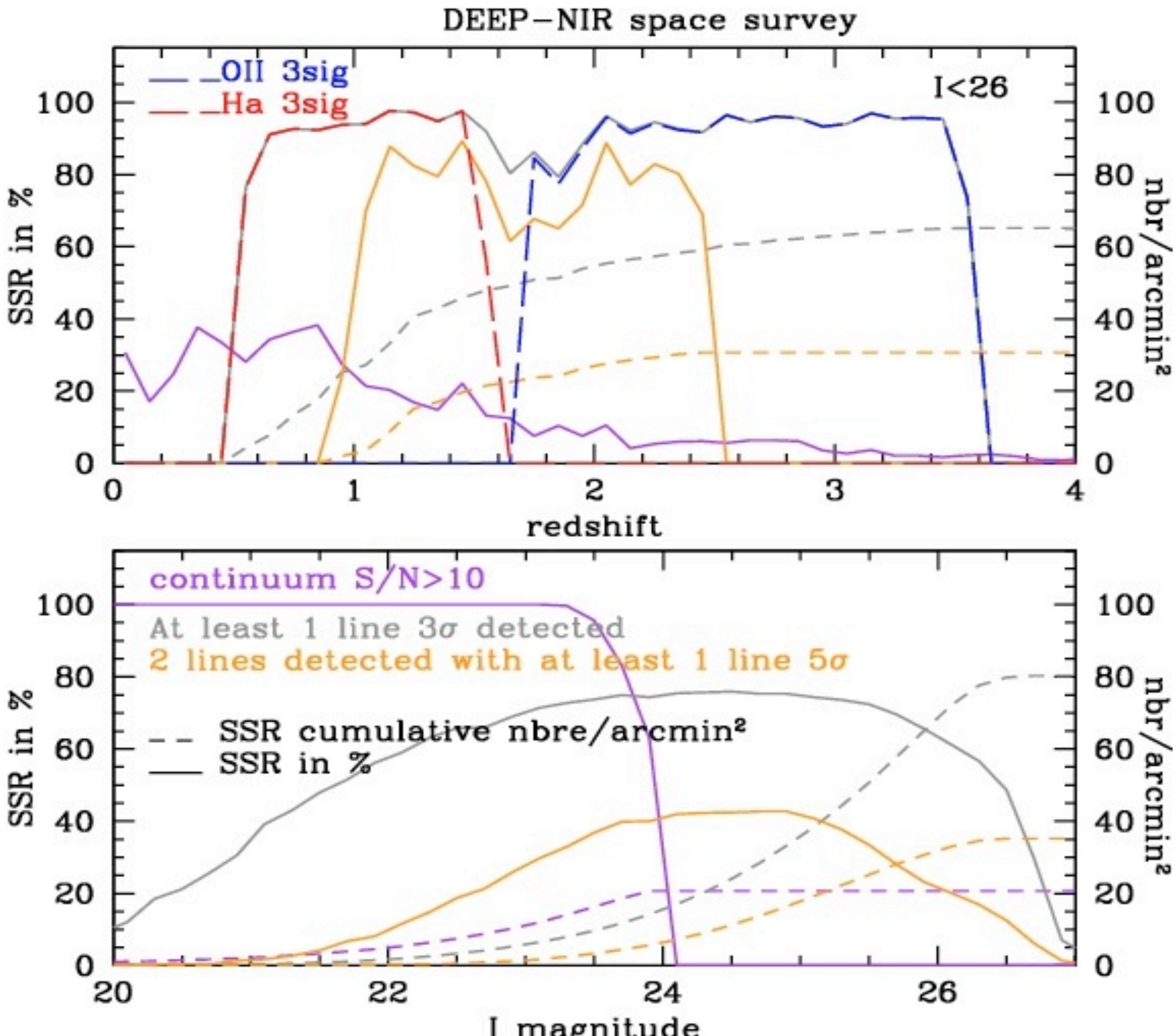
Flux detection limits: Space is very competitive in the infrared

Validation of estimates: reproducing the VVDS SSR

Forecast :
- DEEP visible/NIR space survey (Photo-z calibration)
- WIDE-NIR space survey (BAO like)
- Ground survey can be similarly forecasted.



DEEP-NIR :
I~27
0.5<z<3.5
35gal/arcmin2

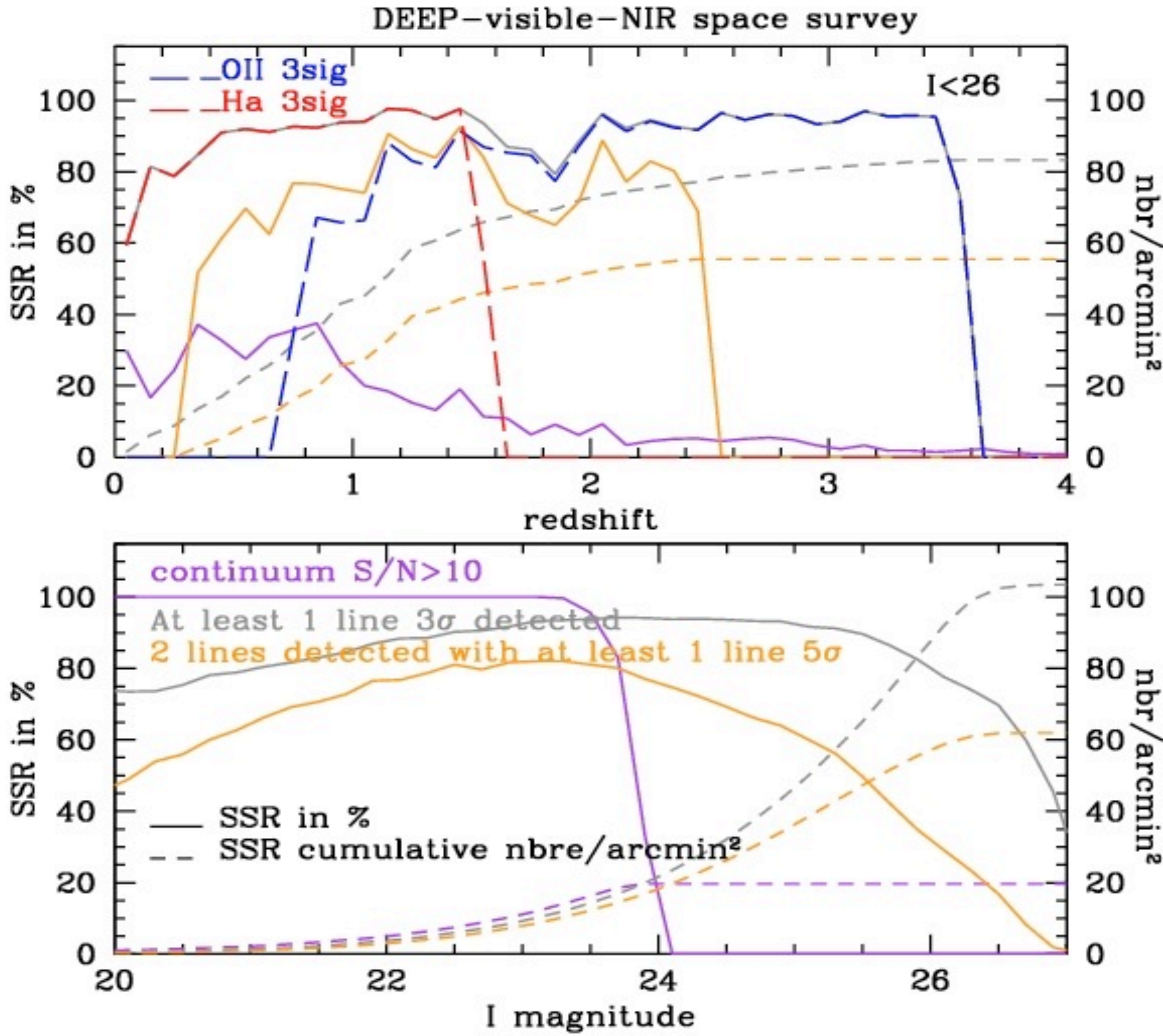


DEEP-vis-NIR :

I~27

0<z<3.5

60 gal/arcmin2

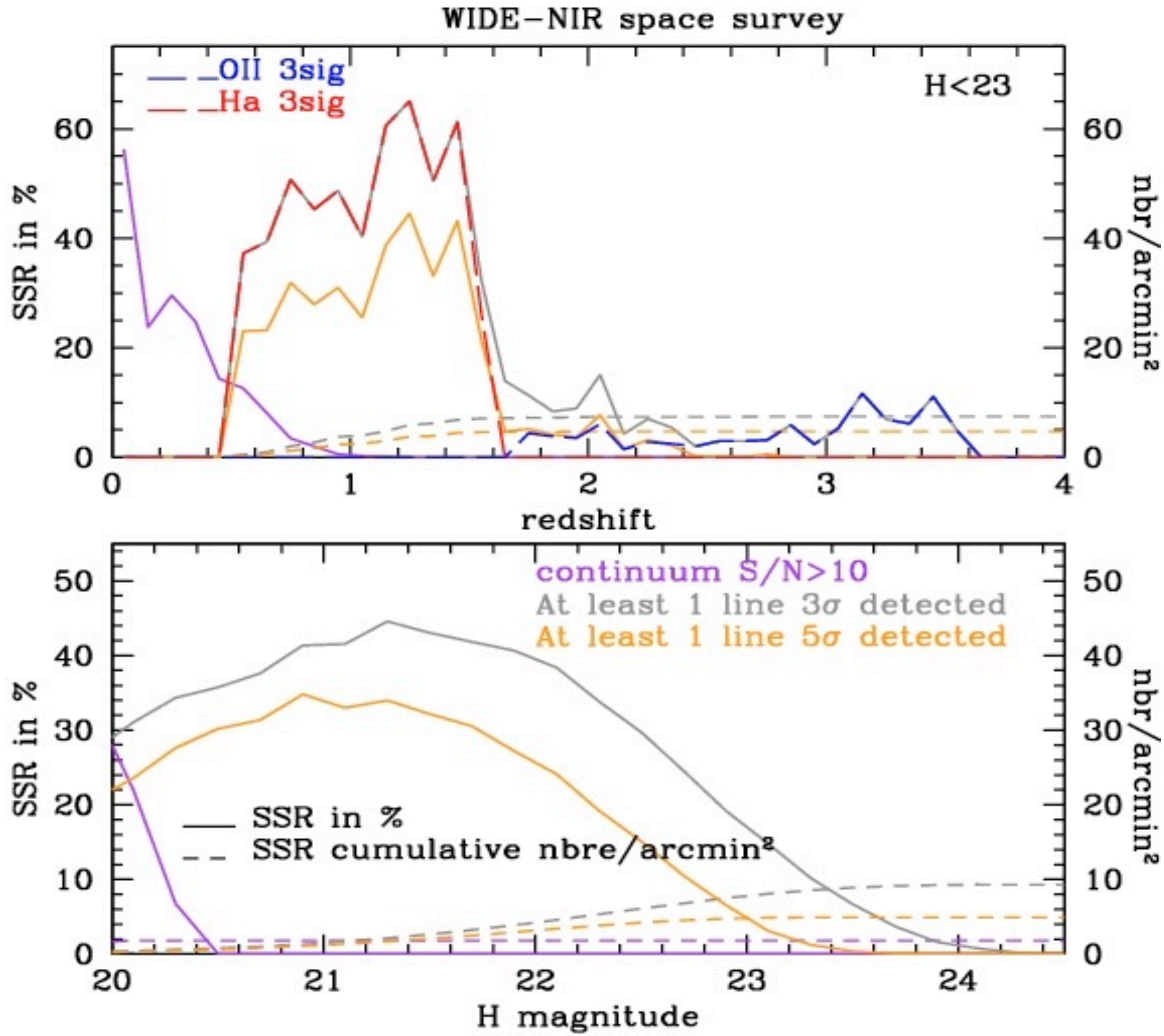


WIDE-NIR :

H ~22

0.5<z<1.5

5gal/arcmin2

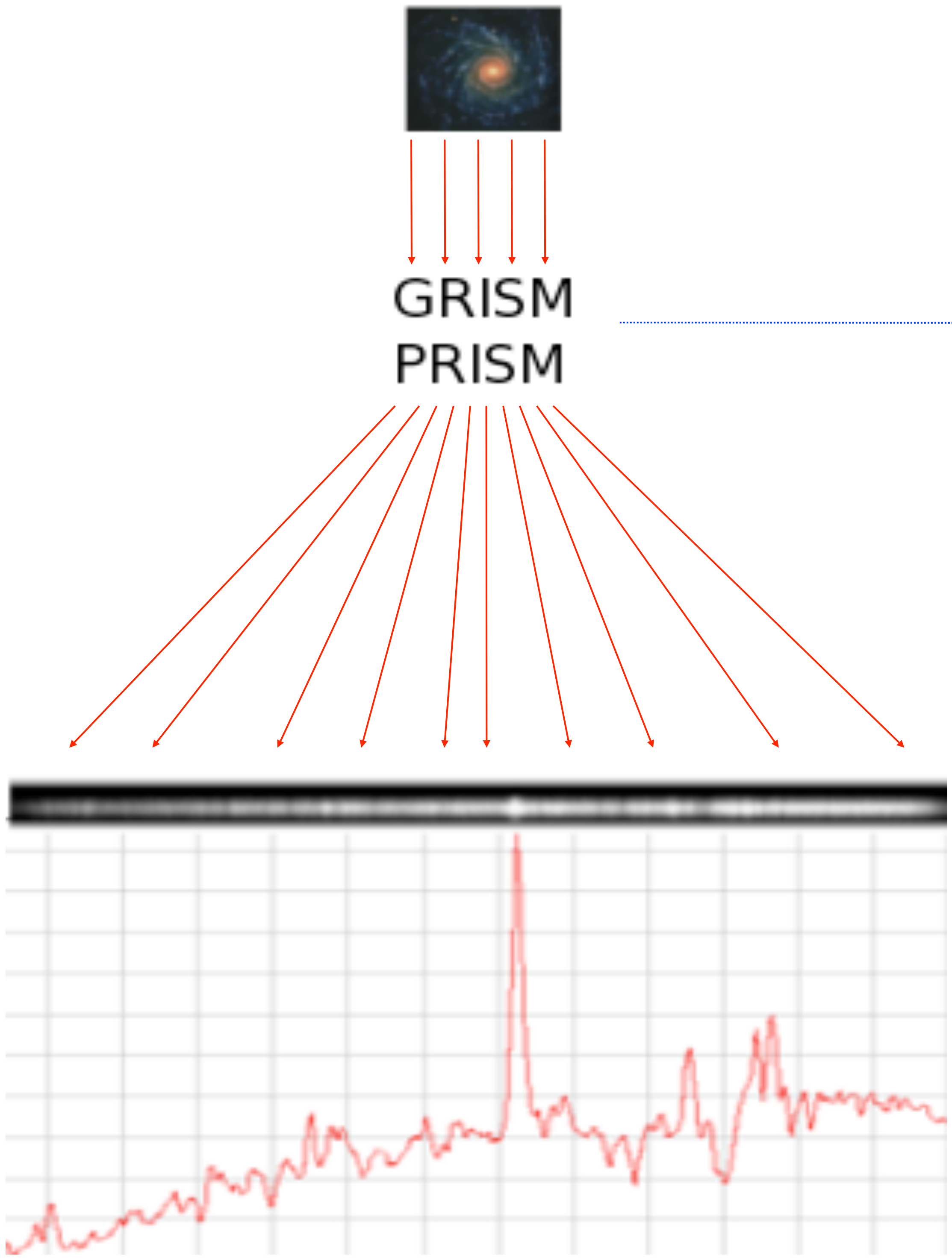


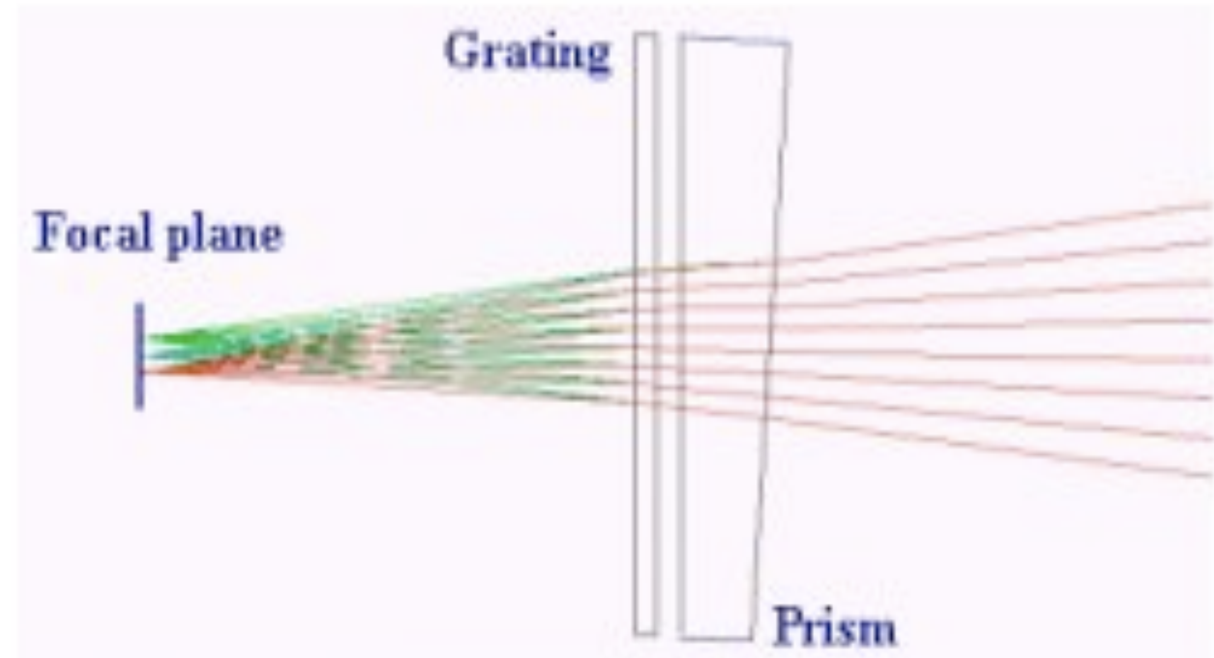
Optimizing Redshift Surveys for space Dark Energy missions

- Aim: Gets lots of redshift over all sky (BAO & redshift distorsion probe)

- Slitless (sky background limited => pixel size, telscope aperture)
- Fixed Mask (limit sky, but limit also number of galaxies)
- DMDs (ultimate technique, feasible?)

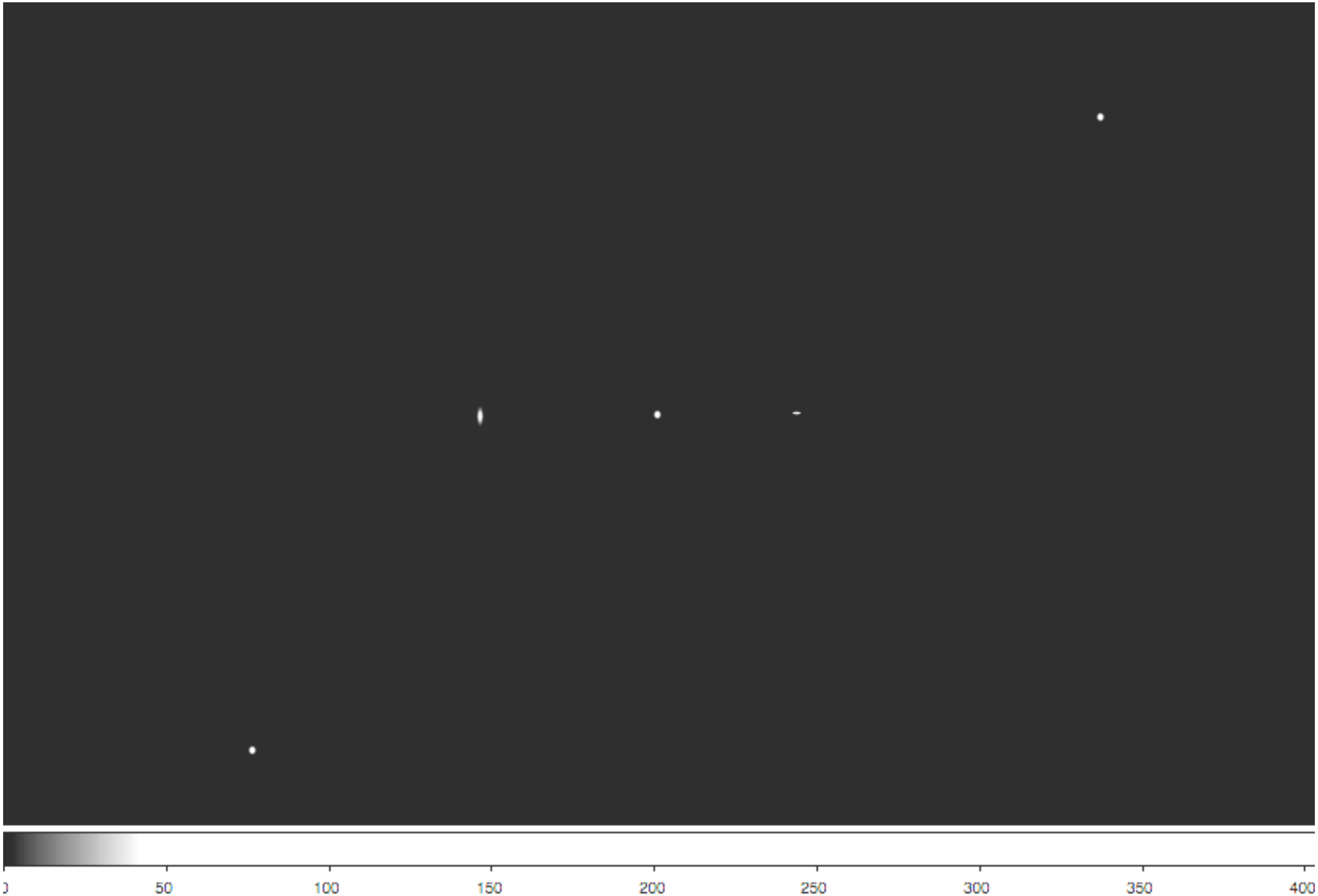
Slitless spectroscopy



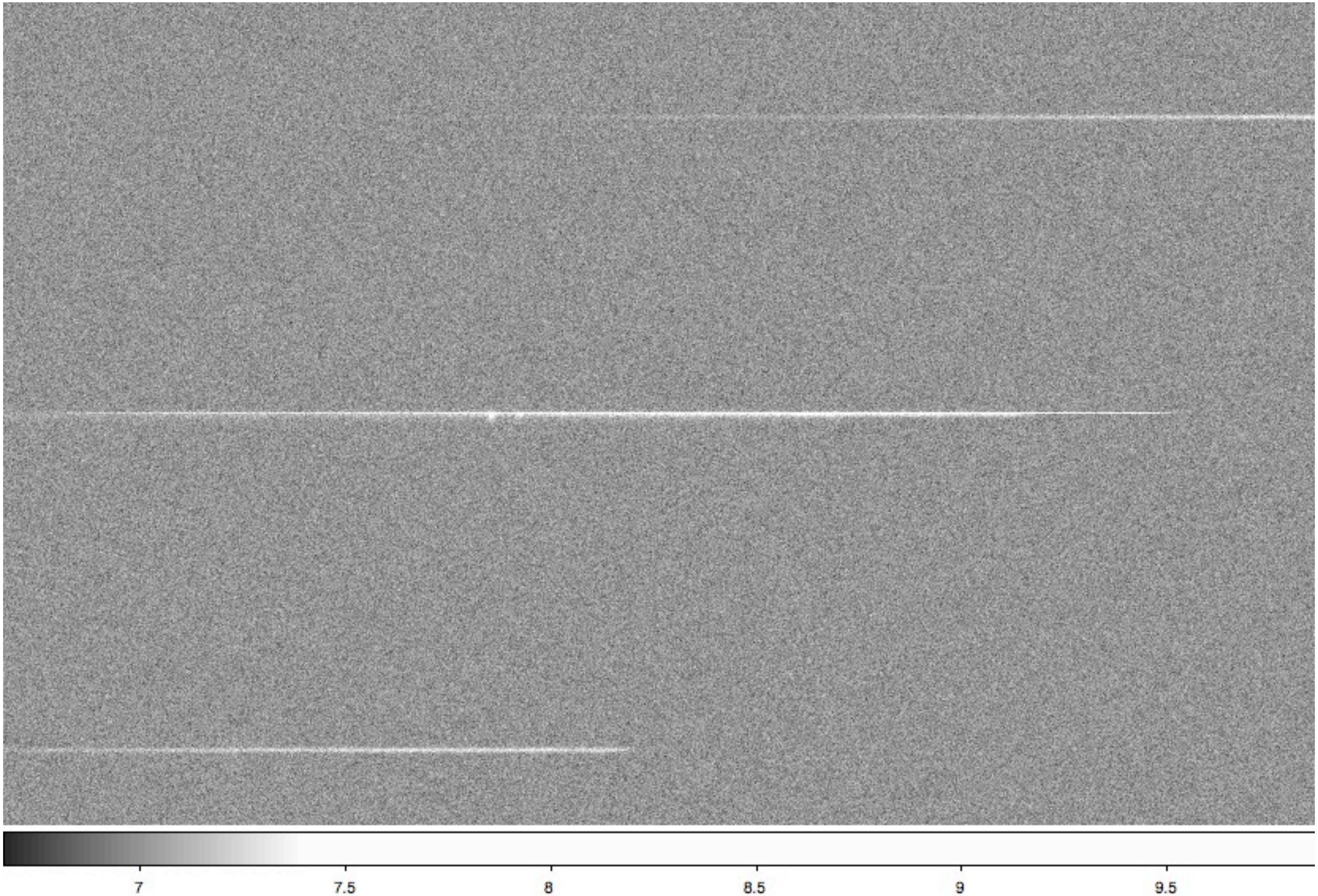


All spectra in the field are observed during the same time

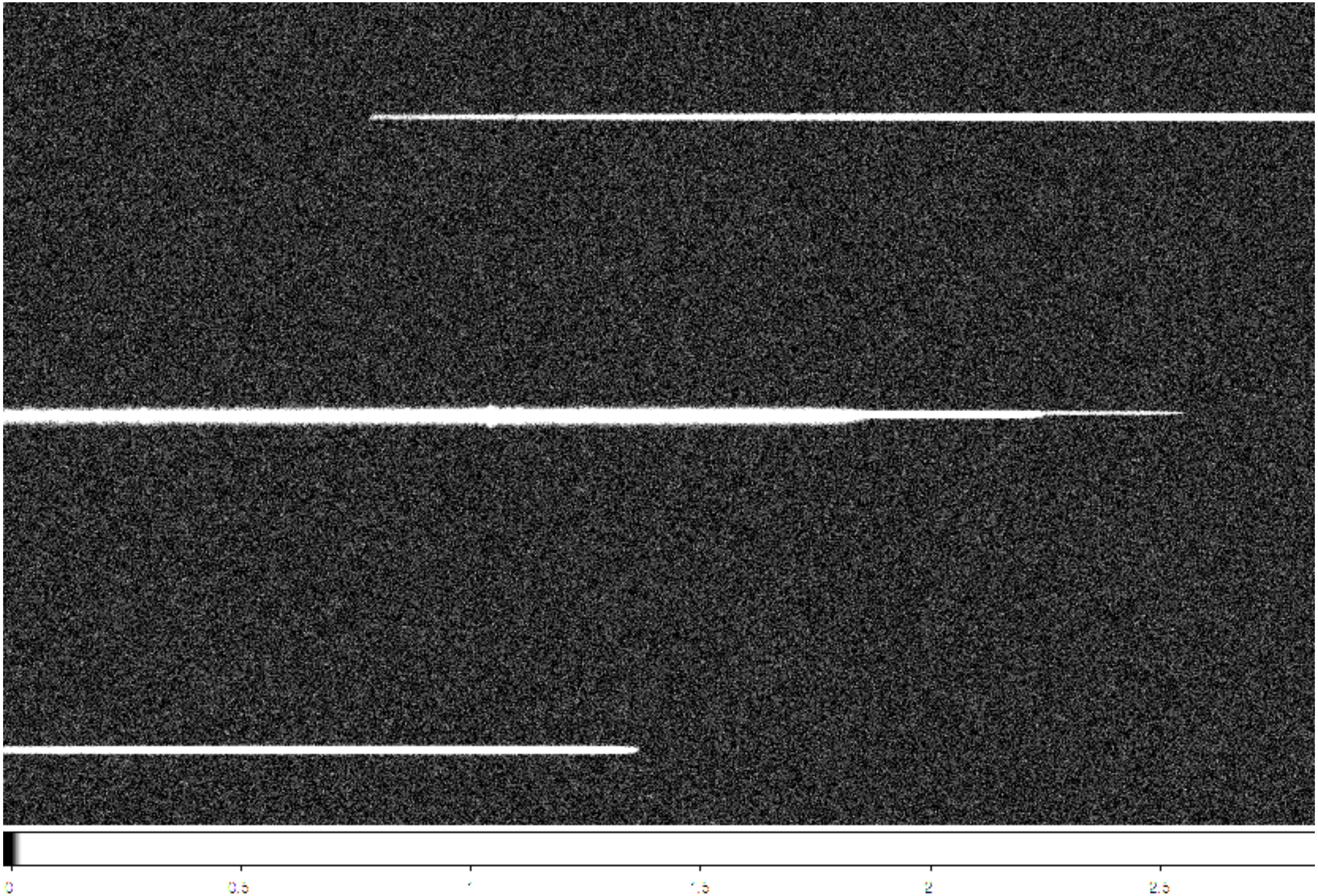
Direct image



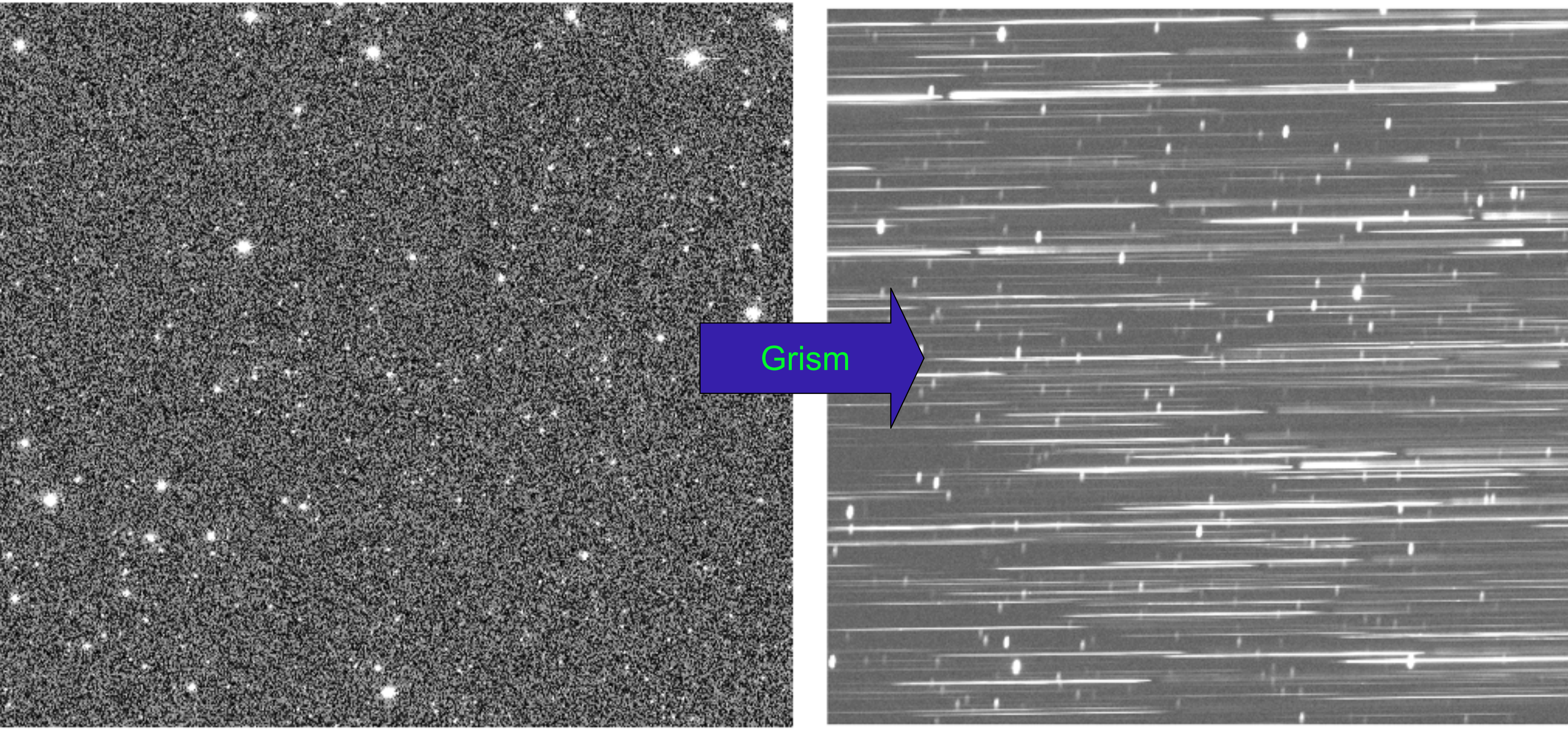
Slitless Image



Spectro image without sky background

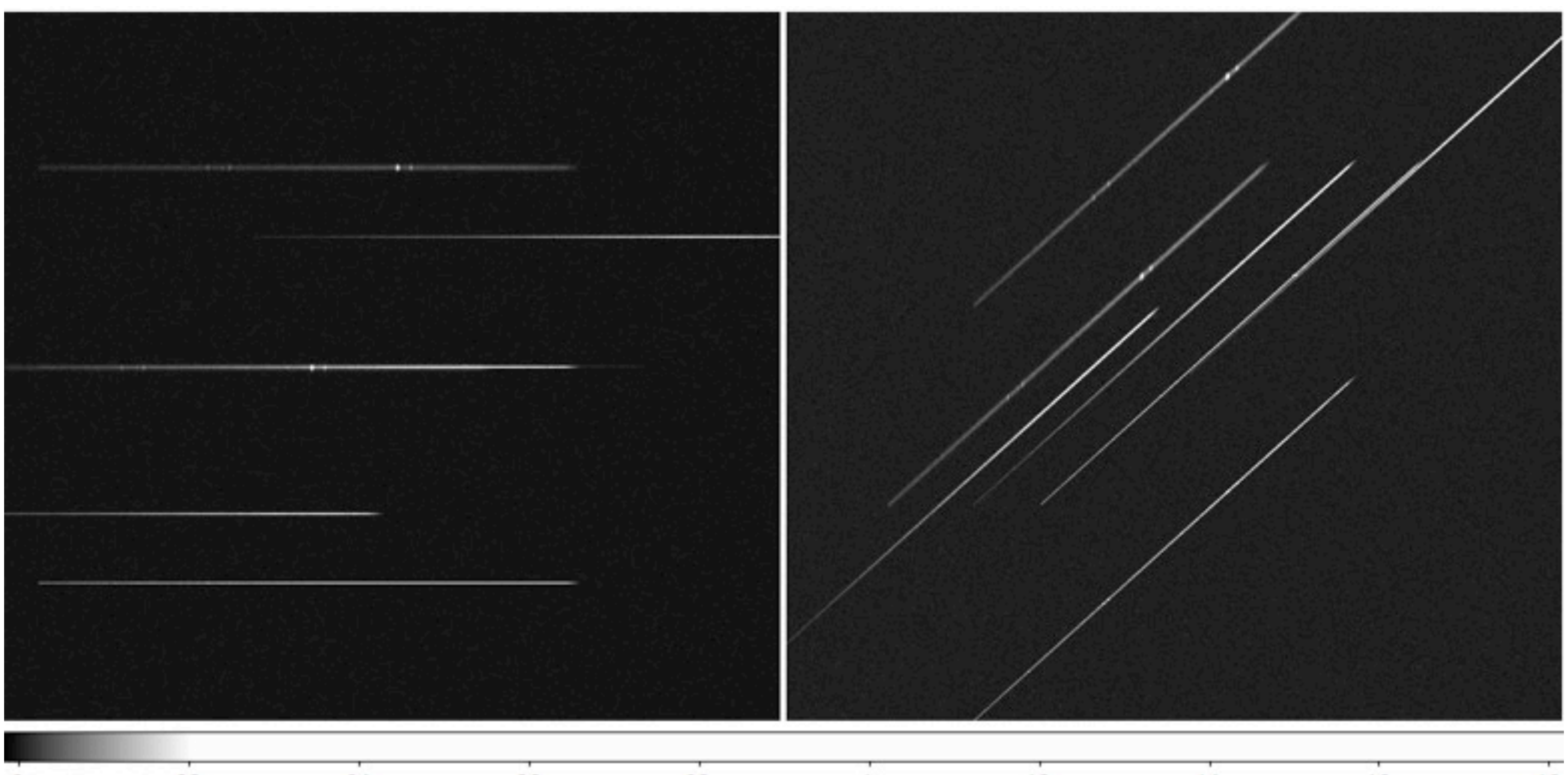


Realistic simulation (EUCLID parameters)



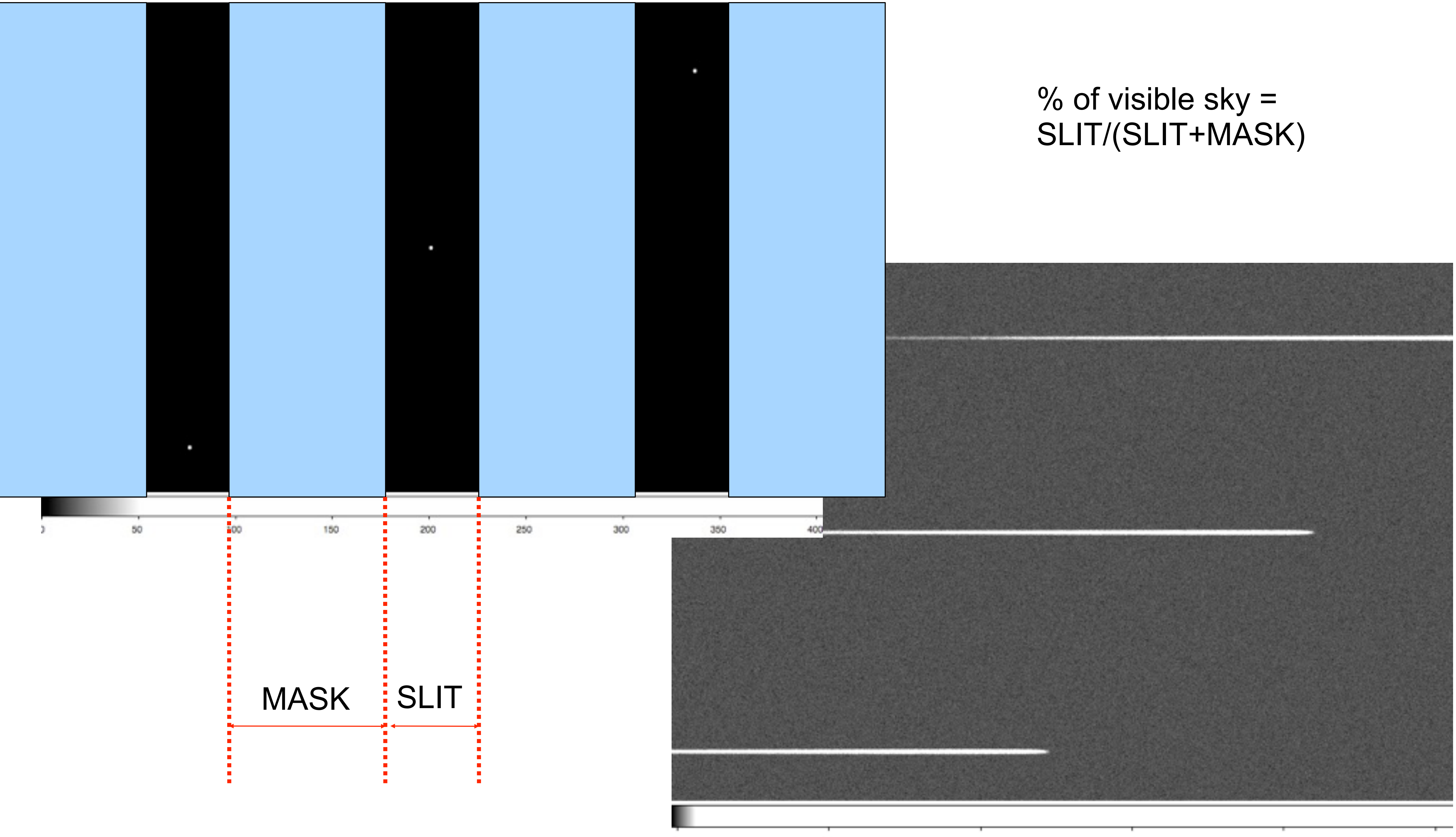
Dispersion direction

- Changing the dispersion direction, reduce spectra overlap [move the telescope - or rotating grism]
- Specially efficient for deep spectroscopy

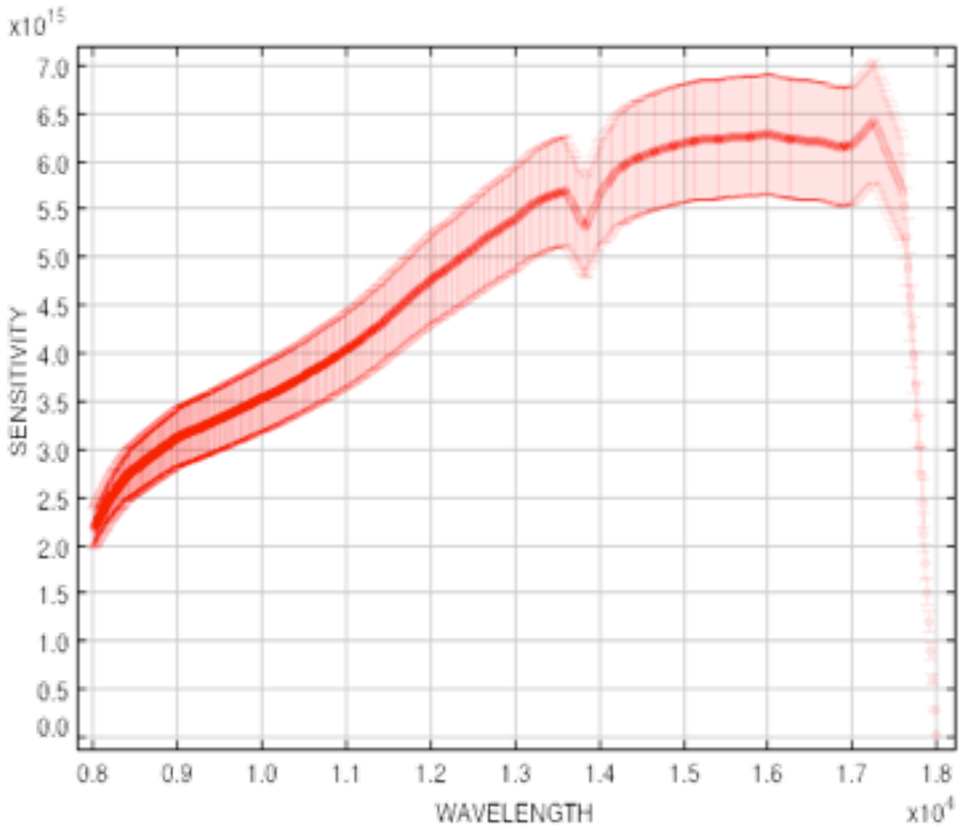


Fixed Mask

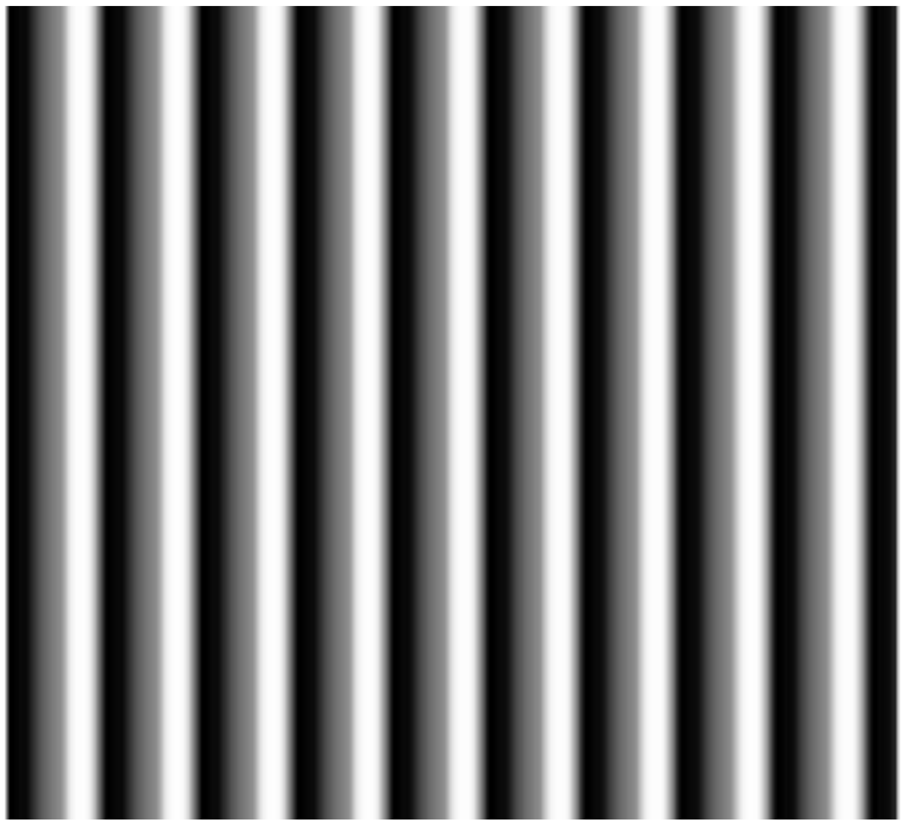
% of visible sky =
SLIT/(SLIT+MASK)



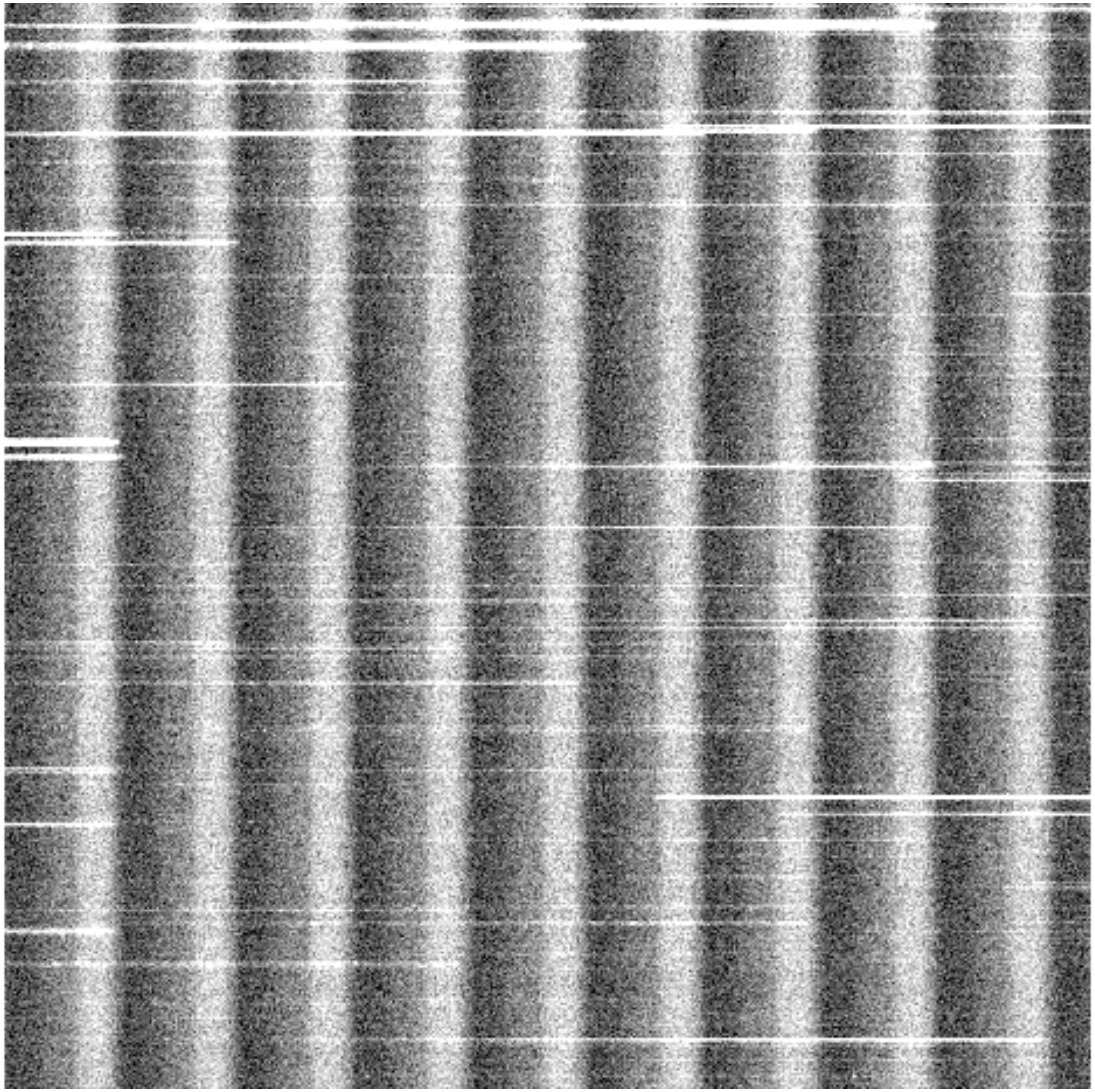
Simulation input



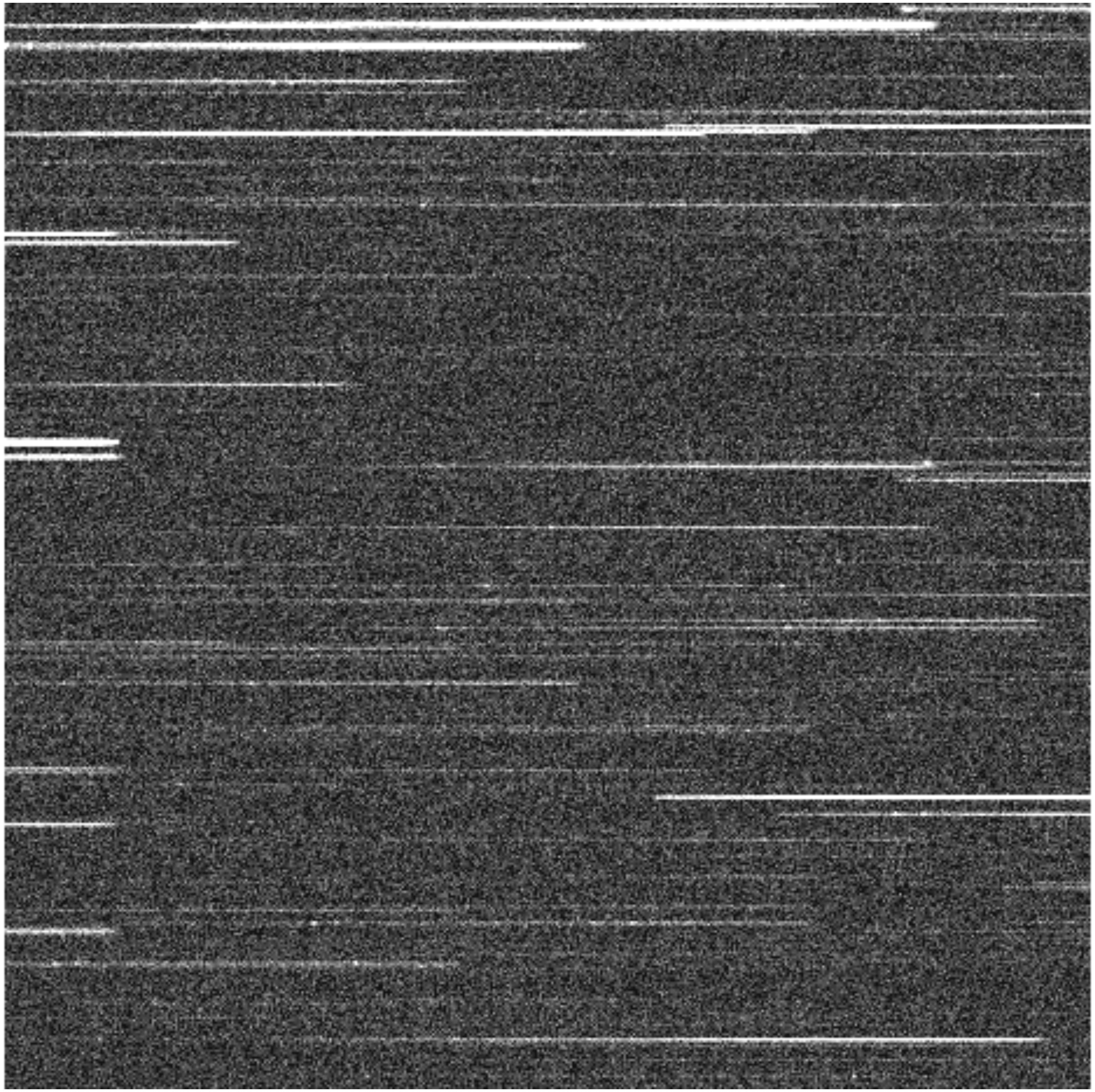
- Instrument parameters (EUCLID like): RN=5e, DC: 0.01e/s, pixel: 0.47”, ExpTime=1500sec, ...
- Zodiacal light
- Cosmos Mock Catalogue with modeled emission lines



Simulation output - with sky background



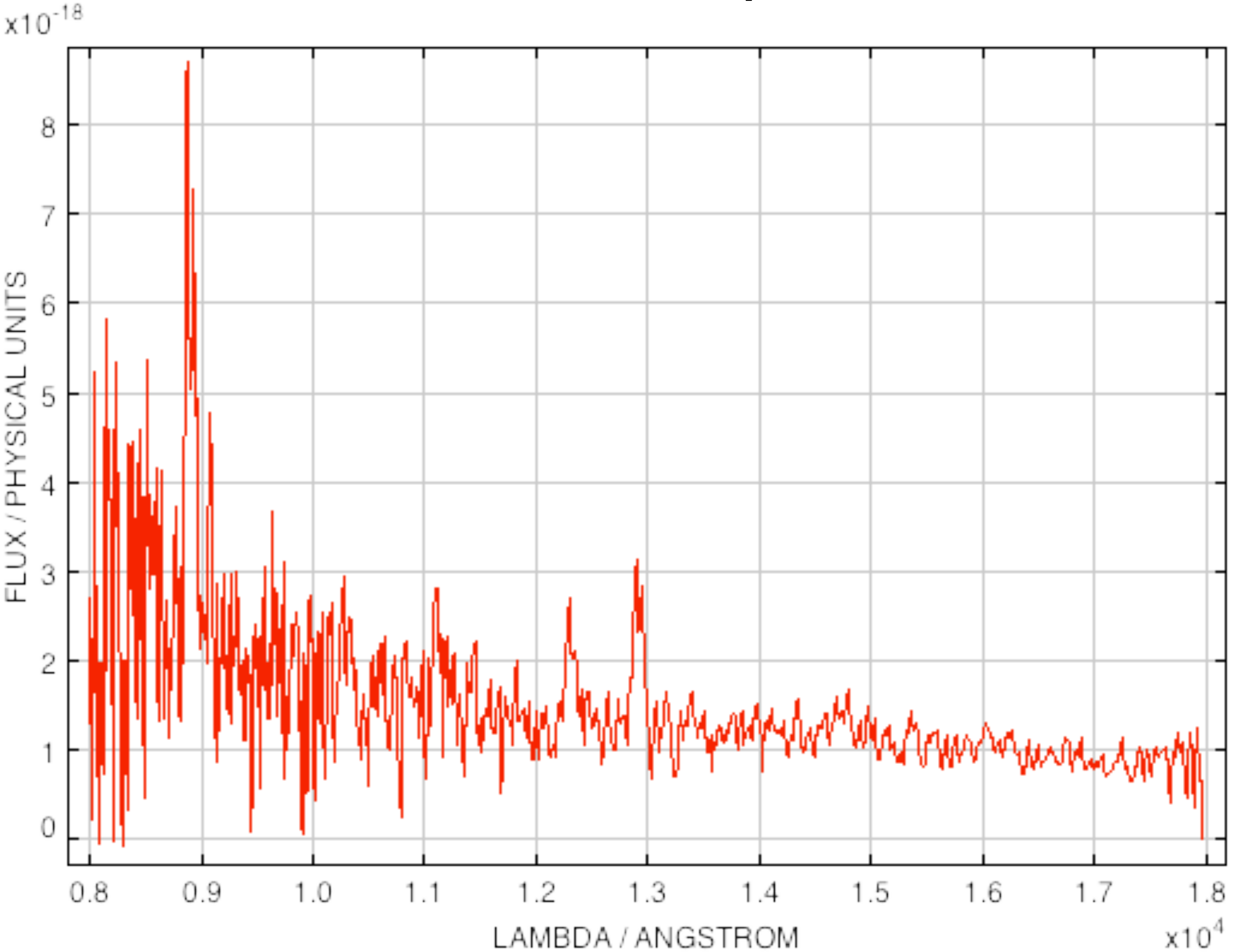
Simulation output - background removed



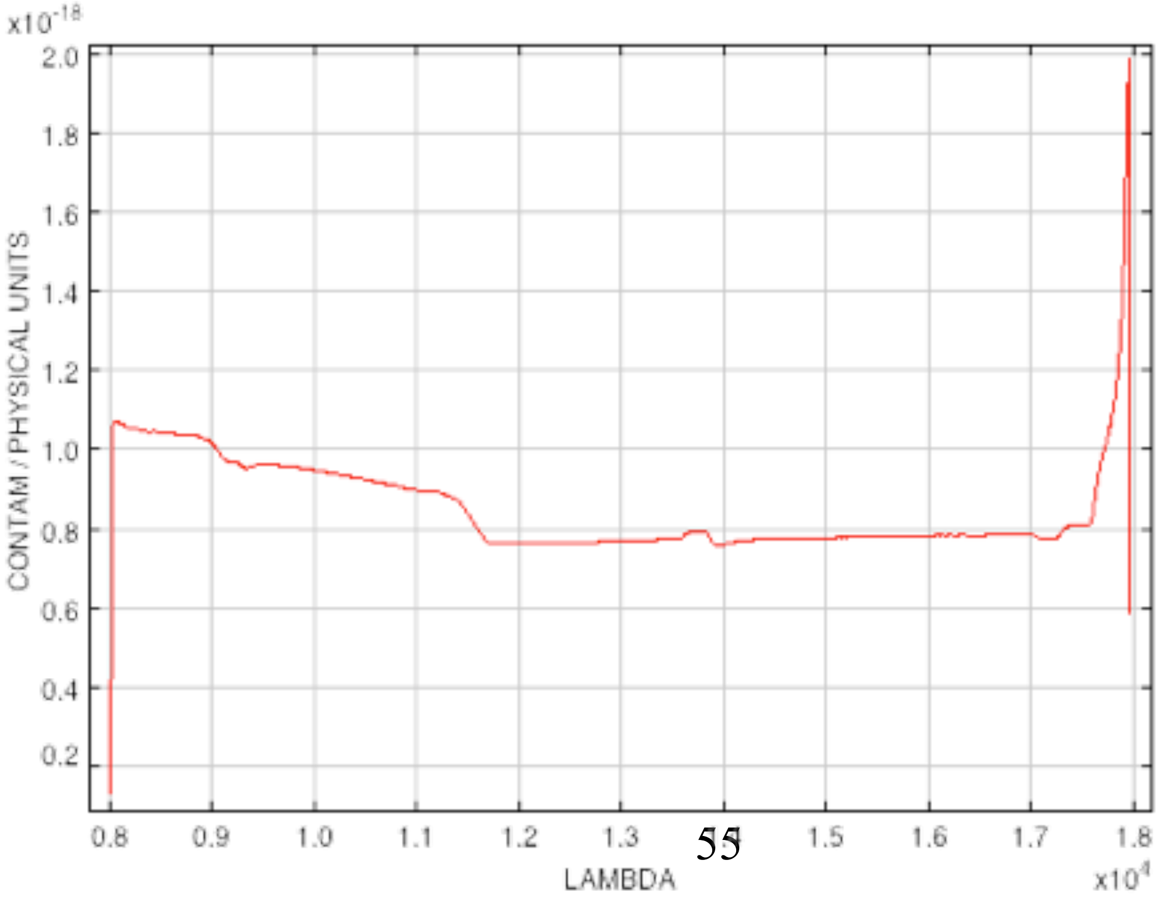
Data Reduction

2D extracted spectra

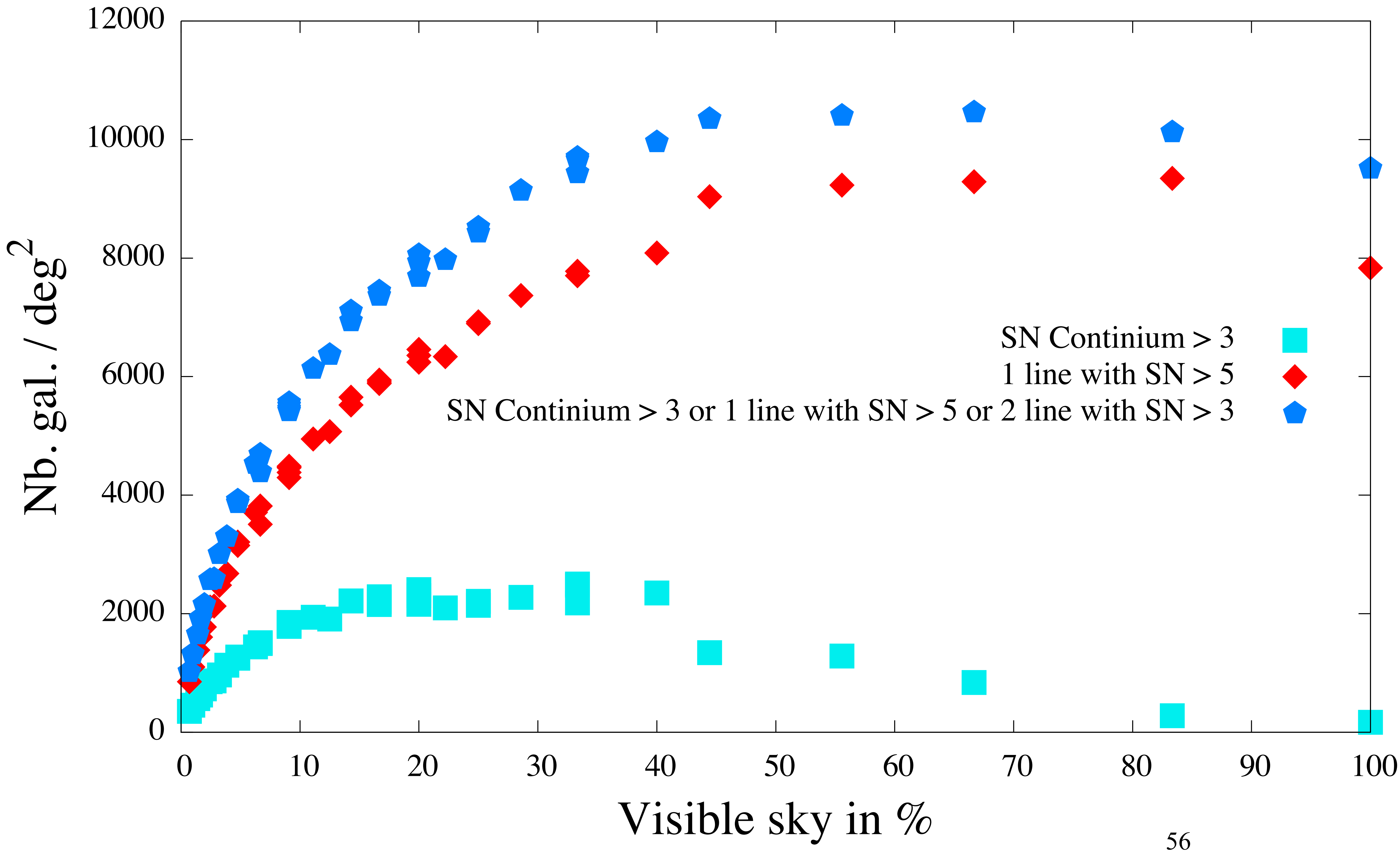
1D extracted spectra



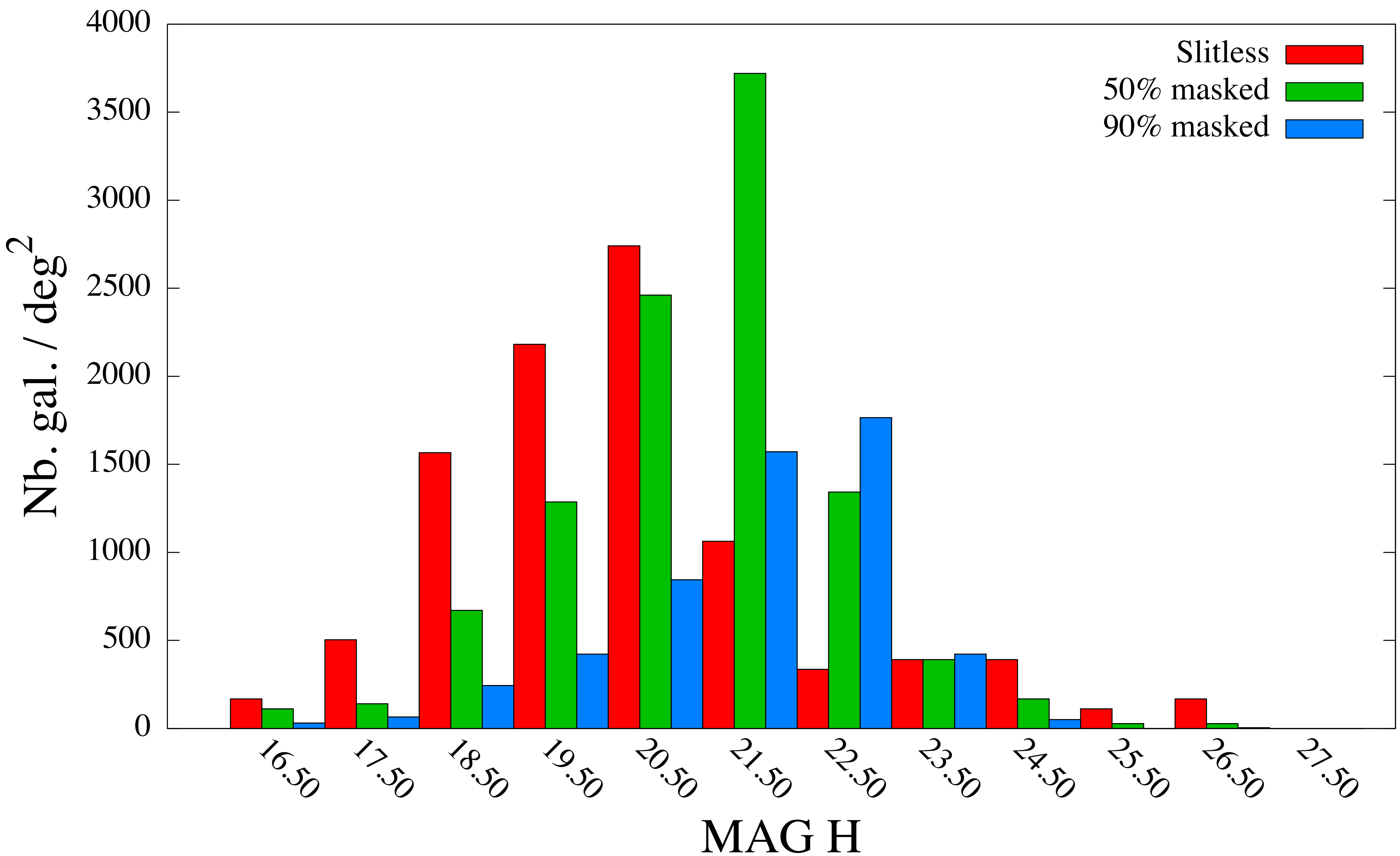
Contamination estimation



Spectroscopic efficiency

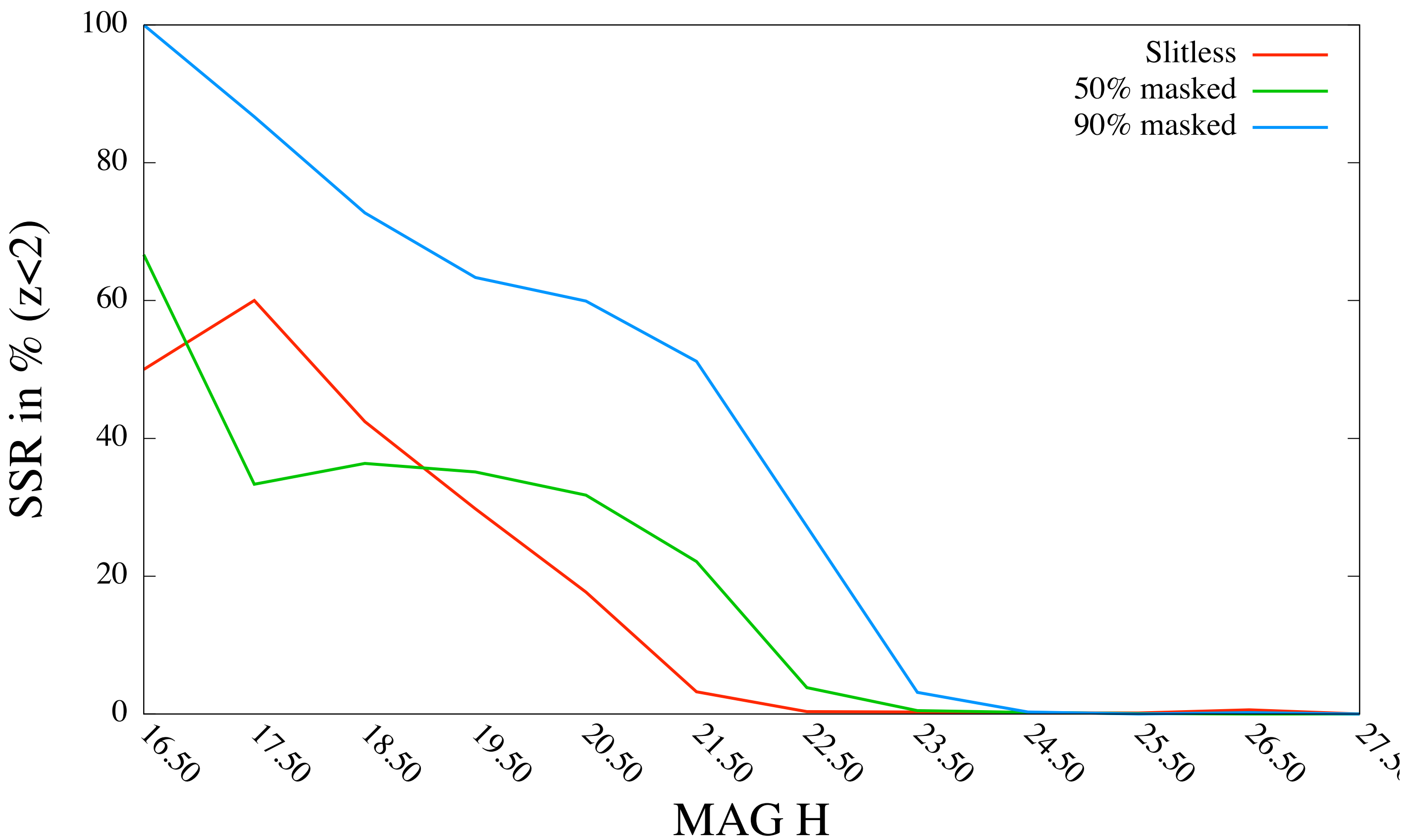


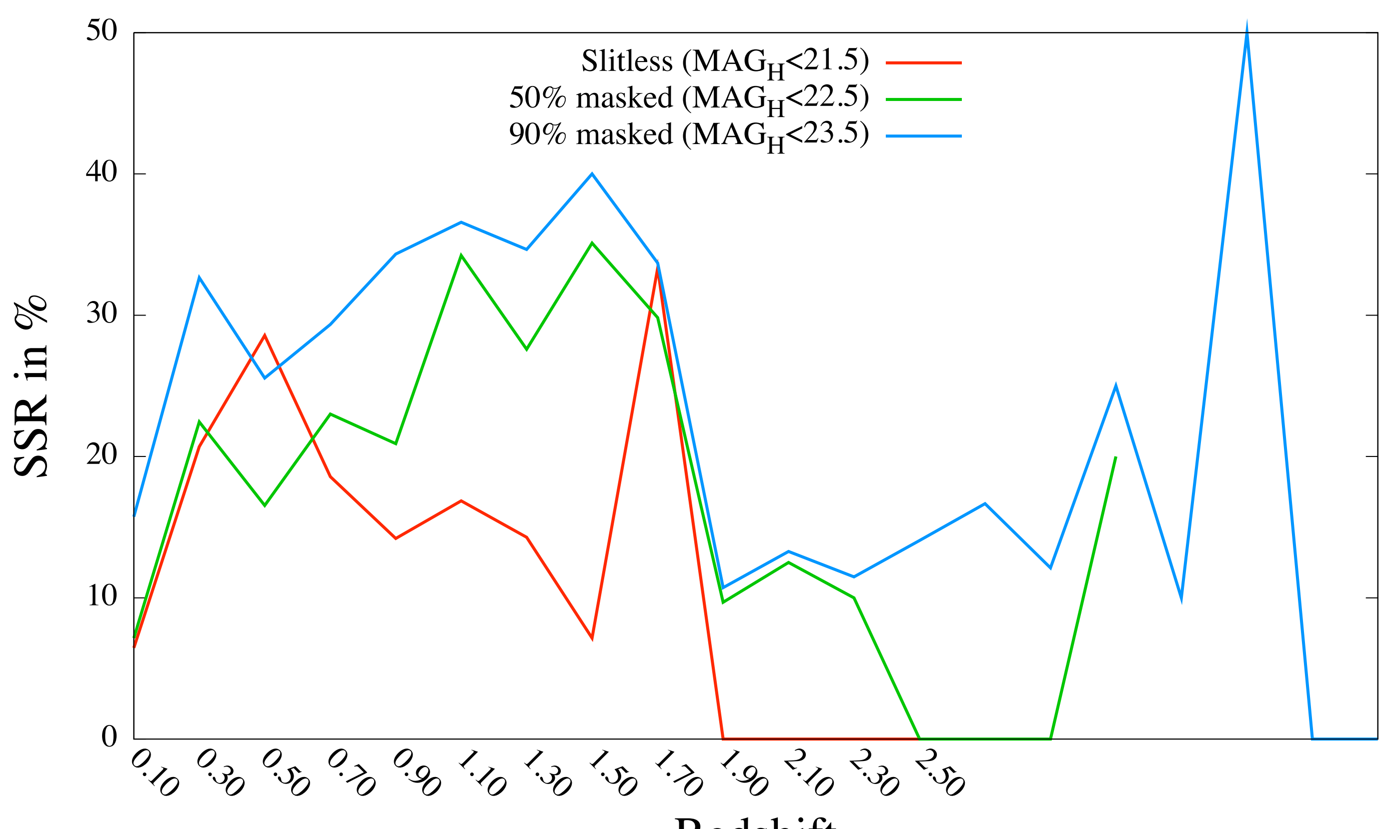
Magnitude distribution as a function of f(sky)



- Decreasing the visible sky fraction, reduced the sky background, but the total number of targeted sources
- From slitless to 50%, typical gain of 1 magnitude, to 90%, typical gain of 2 magnitude

Spectroscopic Success Rate





- at 50% of visible sky, the main increase is the depth, and redshift distribution
- at 10% of visible sky, the main gain is the greater SSR and wider redshift distribution

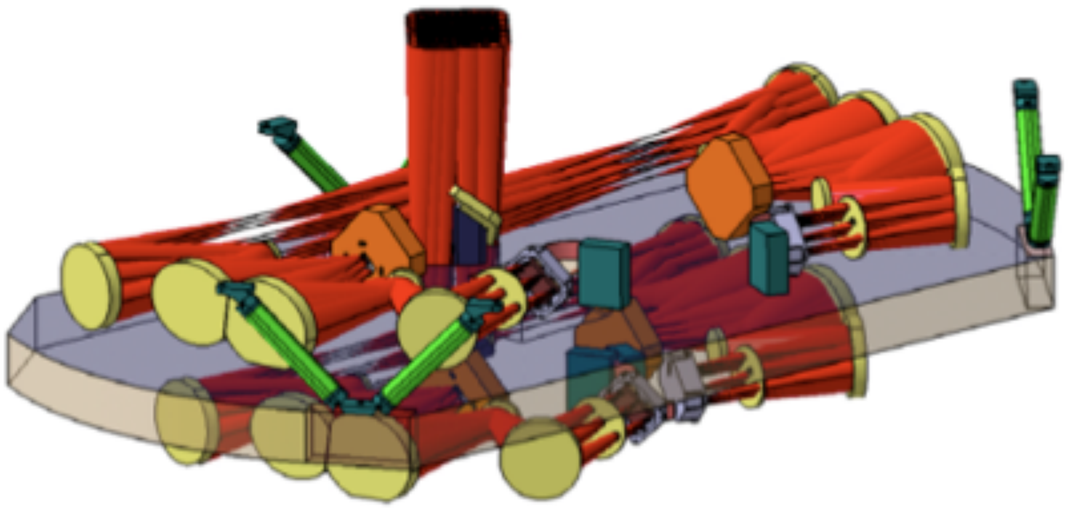
Fixed Mask vs. Slitless

- Fixed Mask are easy to implement (but need some special optical design of the instrument)
- They provide an easy route to go deeper
- at 50% of visible sky, the number of measured redshift is similar to slitless spectroscopy but at fainter magnitude limits, and higher-z
- smaller % of visible sky, means less redshift
- TBD: explore the gain for deeper exposure time
- TBD: go over DMD performances

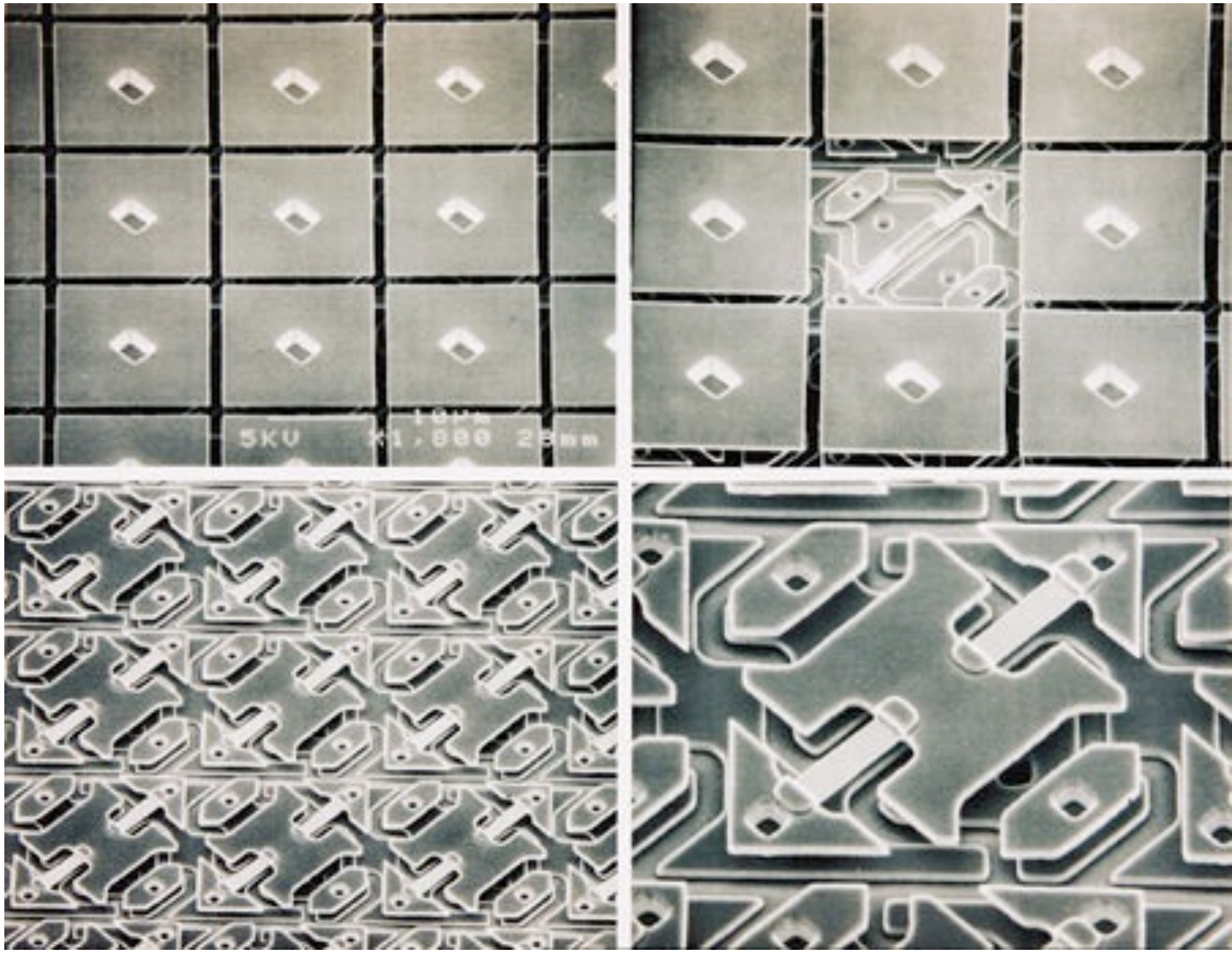
Conclusion

- We have developed a realistic mock galaxy catalogue based on our knowledge of galaxy surveys (Jouvel et al 2009)
- We used this catalogue:
  - To define the best filter system for photo-z (R~3, U-band critical)
  - To forecast the FOM of WL cosmological surveys (7-8 filters seems better than 6-filter survey - 1.5m telescope, ~200 sec exposure) - but need to properly account for catastrophic errors, explore ground+space strategies.
  - To explore efficiency of slitless, fixed mask, (and soon DMDs) spectroscopic surveys
- **Lot more (new) science if both imaging and spectroscopy are matching up**

Digital Micromirror Devices (DMDs)

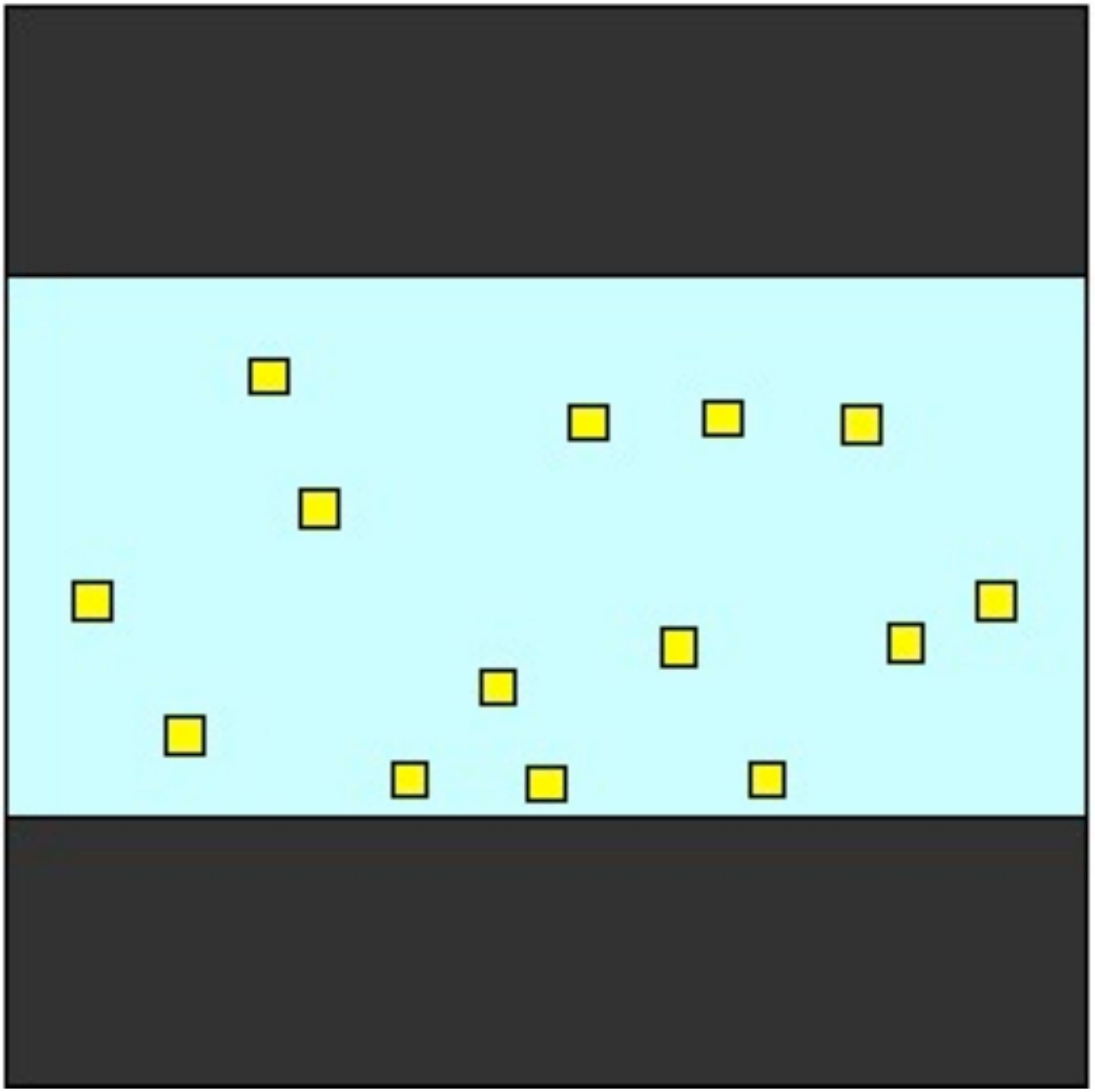


- Square mirrors, 14 x 14 µm
- Up to 2048×1080 elements
- Tilt angle ±12°

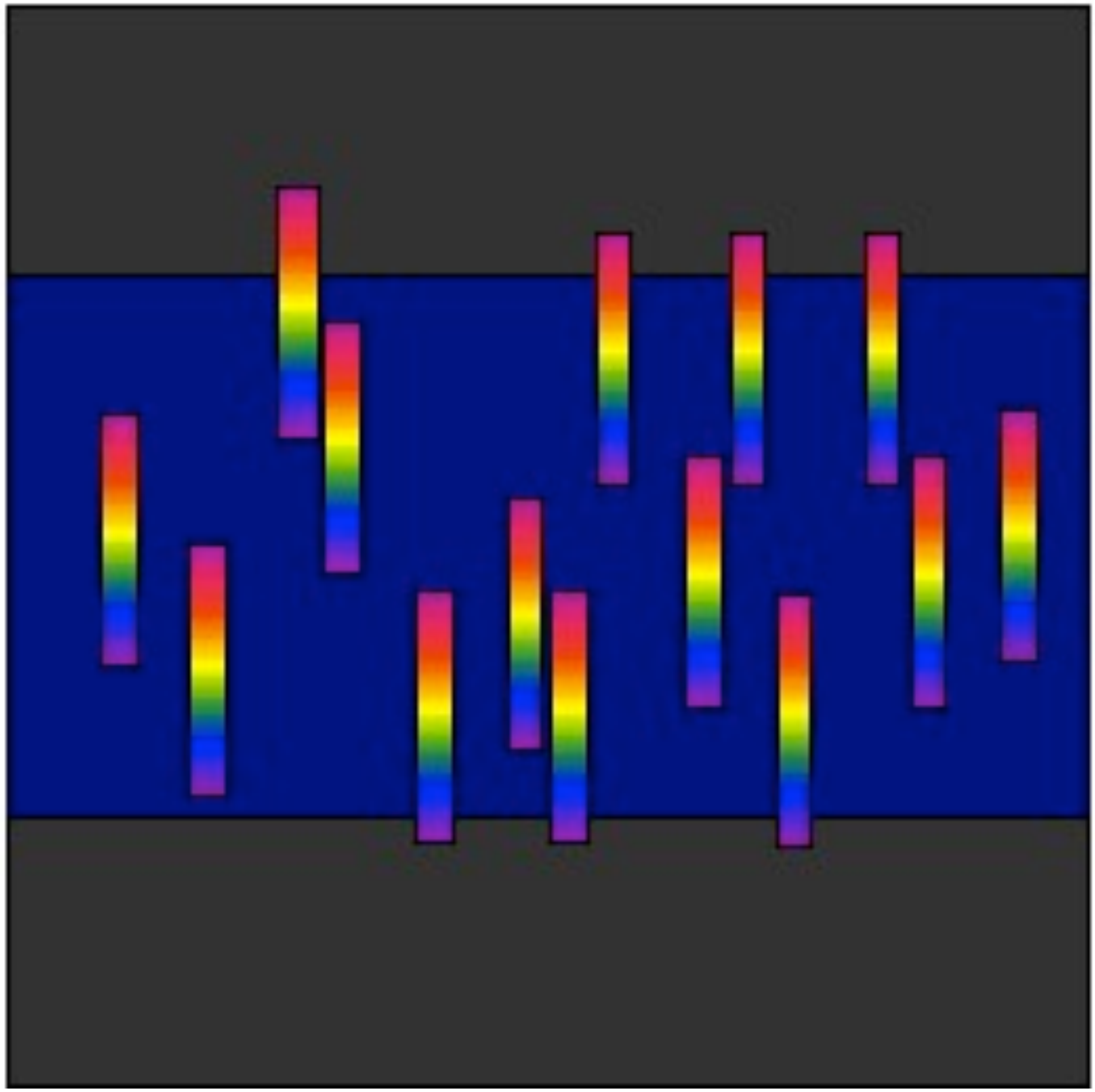


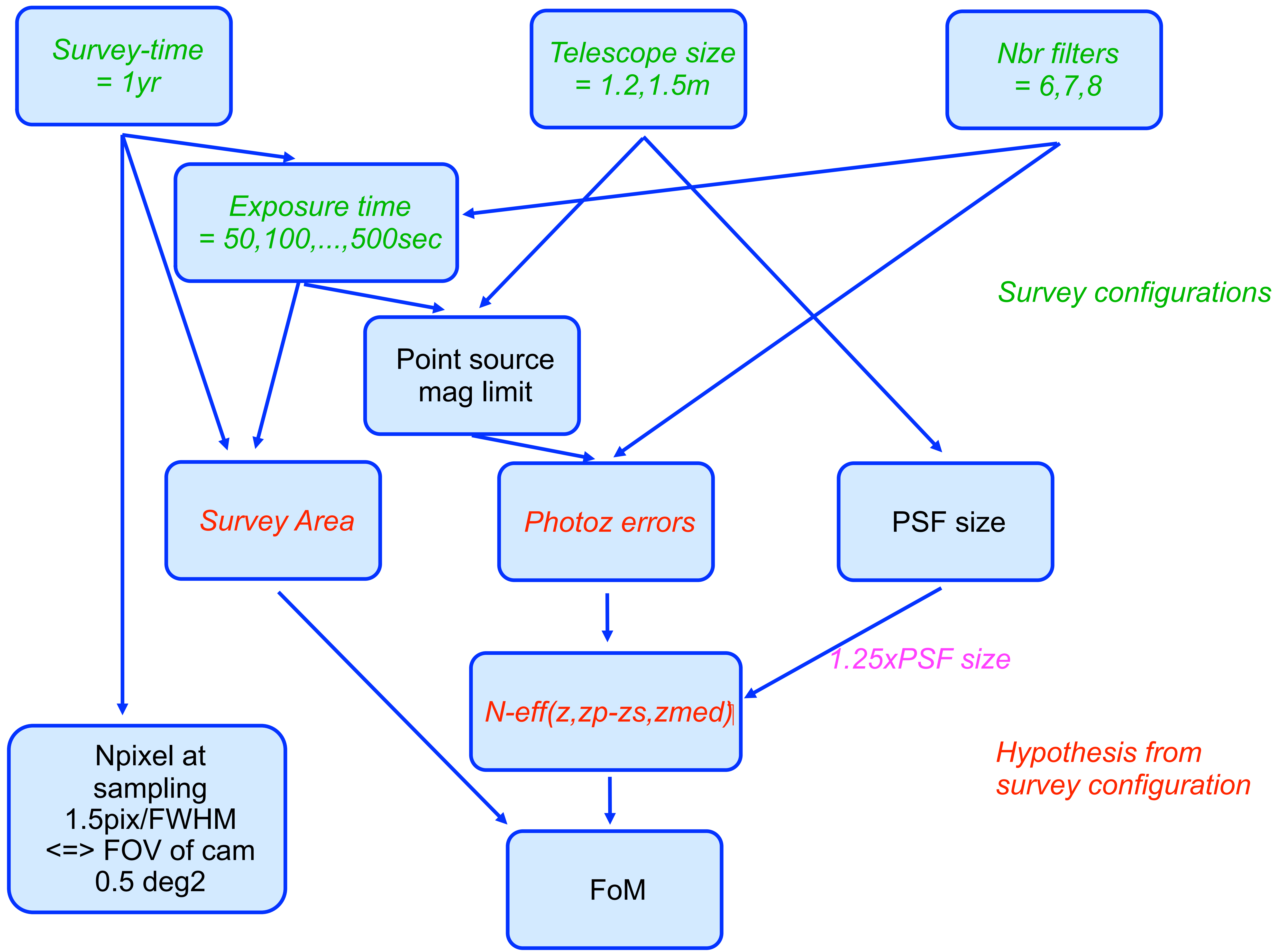
EUCLID proposed design (conducted at LAM):
4 spectrograph
0.77”/DMD pixel
~0.5 sq.degree
sample 30% of galaxies with 90% SSR (H<22)

DMD field projected onto the detector (dark backgroud). All DMDs turned off except those of targets

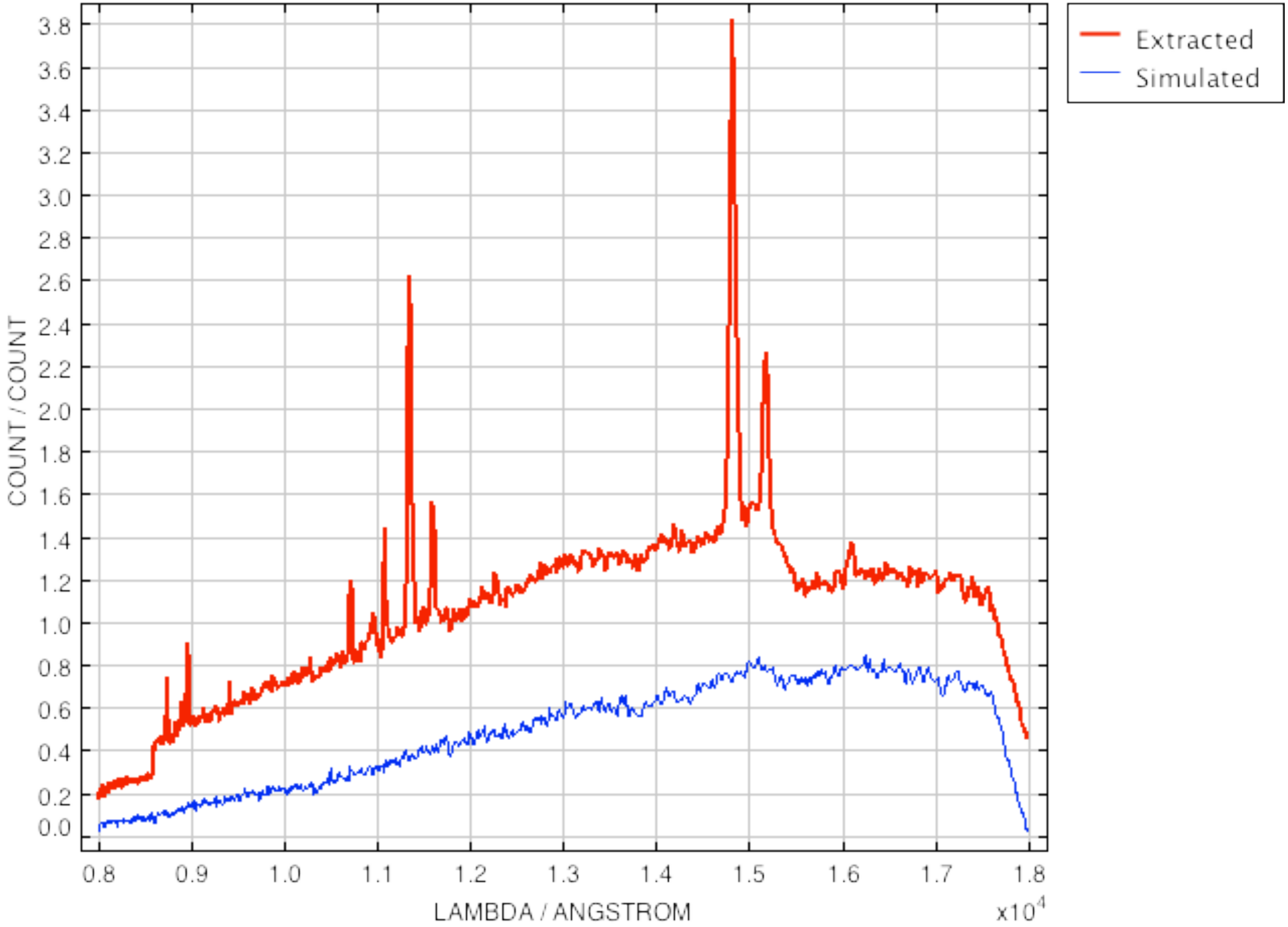


Spectra of the selected targets



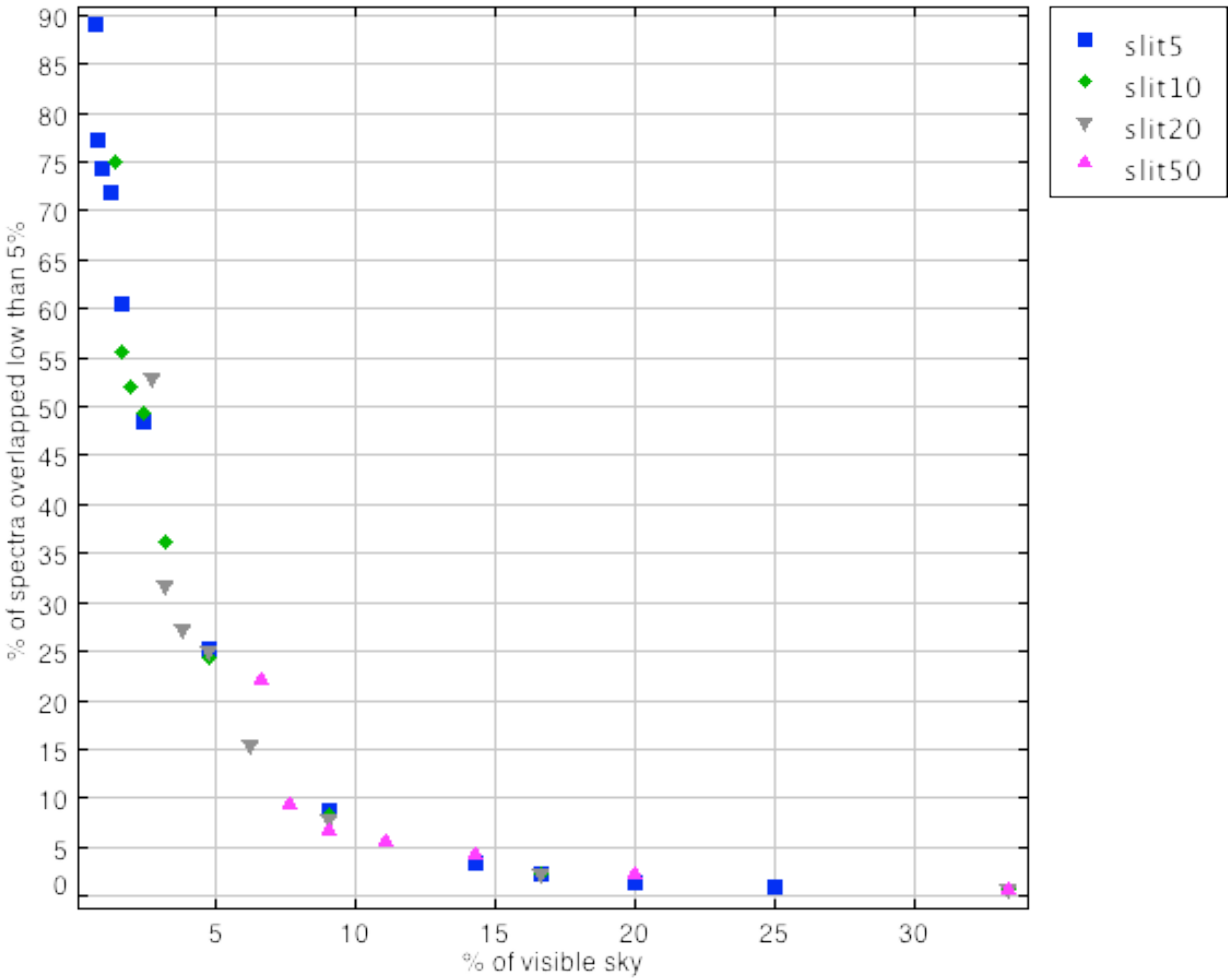

Survey-time
= 1yr
Telescope size
= 1.2,1.5m
Nbr filters
= 6,7,8
Exposure time
= 50,100,...,500sec
Survey configurations
Point source
mag limit
Survey Area
Photoz errors
PSF size
1.25xPSF size
N-eff(z,zp-zs,zmed)
Hypothesis from
survey configuration
Npixel at
sampling
1.5pix/FWHM
<=> FOV of cam
0.5 deg2
FoM

Overlap



Extracted
Simulated
COUNT / COUNT
LAMBDA / ANGSTROM
x10^4
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8

Overlap



90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
% of spectra overlapped low than 5%
5
10
15
20
25
30
% of visible sky
slit5
slit10
slit20
slit50