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# DEEP GALAXY SURVEYS
## *AND NEXT GENERATION FACILITIES*

1. Why do we want to do deep surveys ?
2. Different types of surveys, survey design
3. What instruments are needed ?
4. Recent and on-going surveys
5. Next generation surveys and facilities

# Introduction

- Astrophysics progress is linked to progress in observational techniques
- Theories make predictions which can be verified or falsified by observations
- Observations open a discovery space which may challenge theories
- Observational Cosmology is the most challenging as extreme measurement precision at extreme depth over most of the Universe is ultimately needed !

# Why do we want to do deep galaxy surveys ?

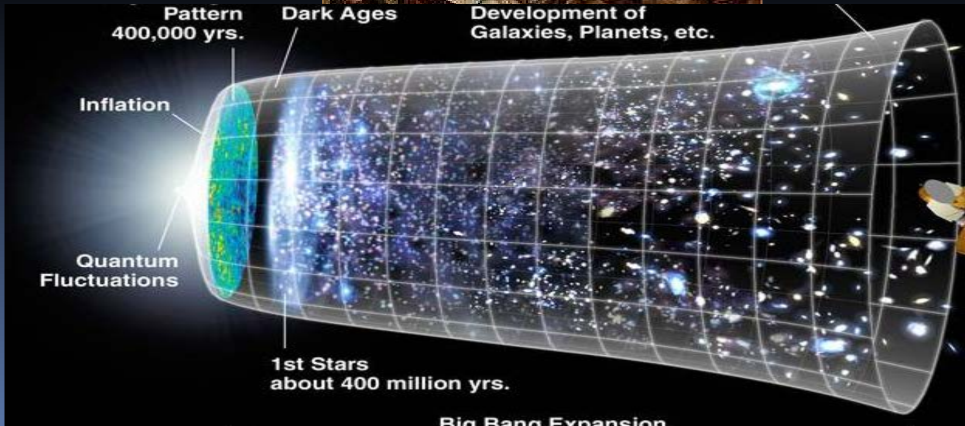
- To measure galaxy evolution
- To measure cosmological parameters
- To answer fundamental questions:
  - When did first galaxies appear ?
  - How did they assemble ?
  - What is responsible for the accelerated expansion of the Universe ?
    - Some form of energy / particle or modified Gravity ?

# The key role of surveys in Cosmology

- “Continents mapping”: Map the distribution of galaxies in space
- “Population surveys”: understand the properties of galaxies, in relation with their environment
- “Discovery surveys”: pushing the observational frontier
- Provide reference samples

**Establish a robust scenario for galaxy formation and evolution**

**Constrain the Cosmological model**



# Different galaxy survey types

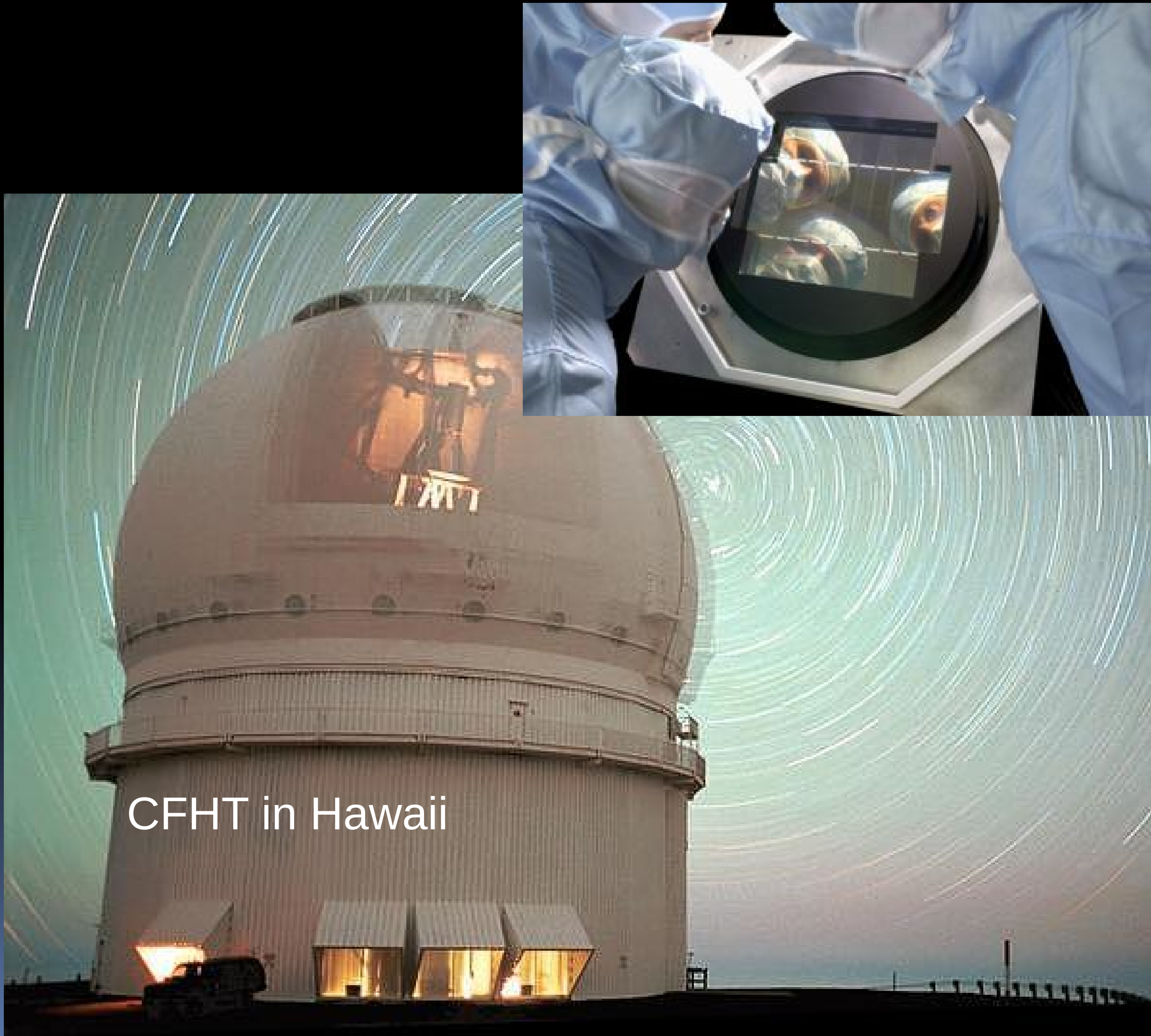
- Imaging – photometric surveys
- Spectroscopic surveys

Images are nice but how far are they ? Imaging + spectroscopy !

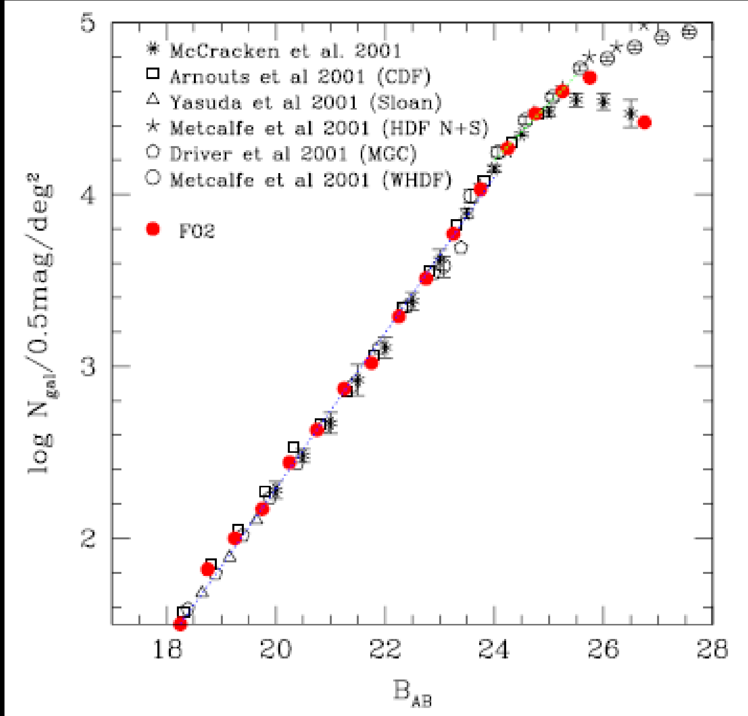
# Photometric surveys

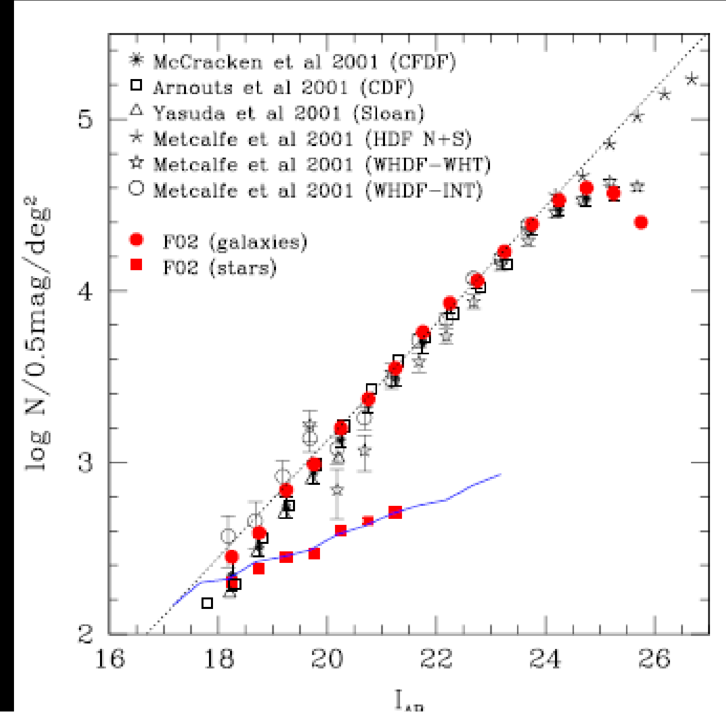
- Positions
- Luminosity (magnitudes)
- Colors
- Shapes
- Spectral energy distribution
  - Photometric redshifts
  - Mass, age…

MegaCam: 256 millions pixels

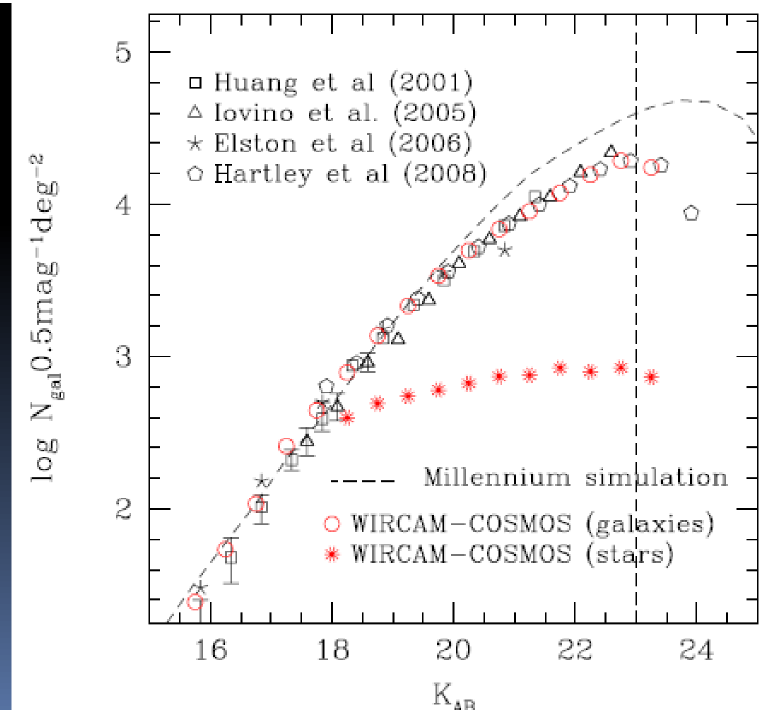


CFHT in Hawaii

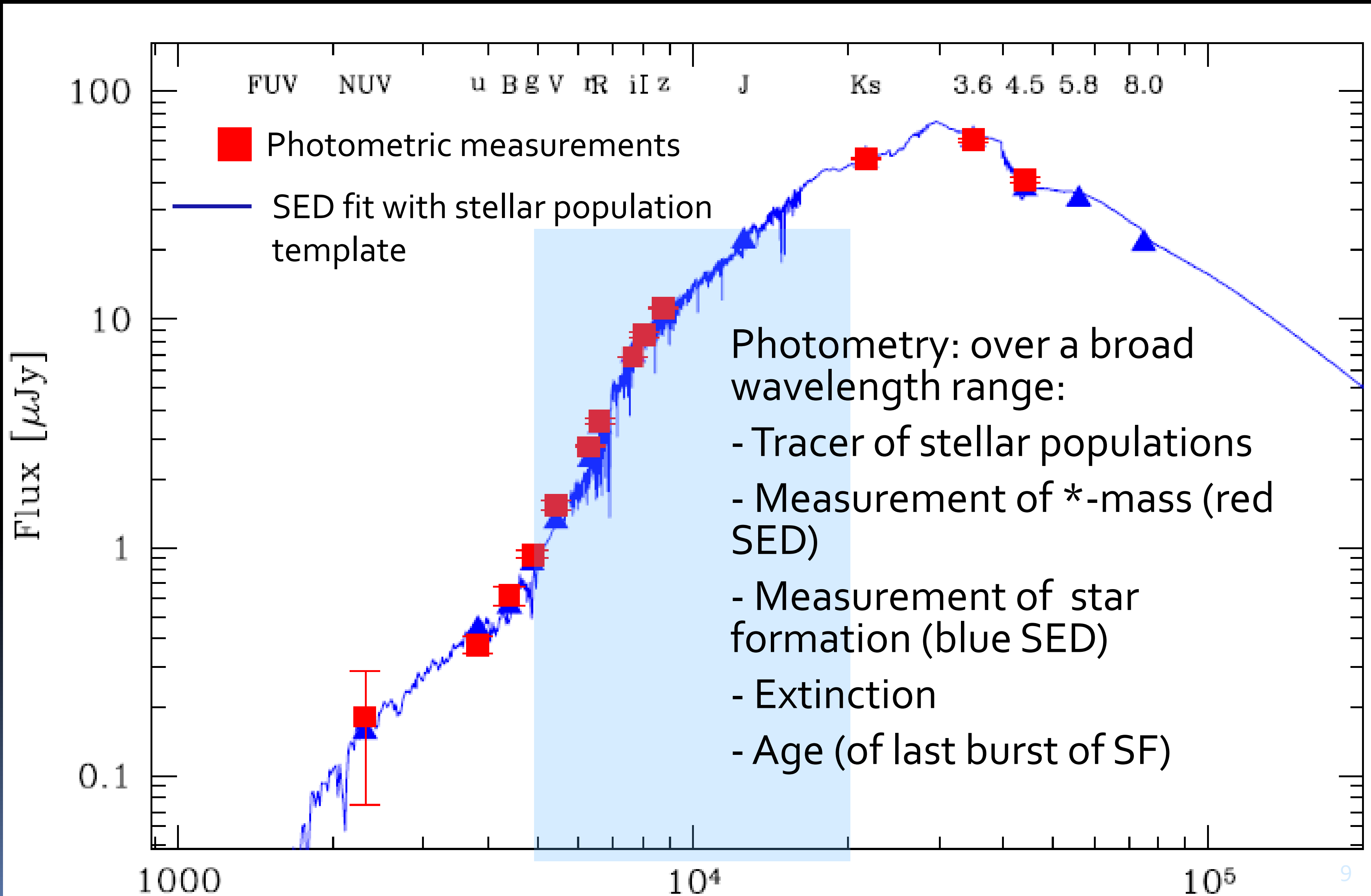



Comptages de galaxies:
N(m)



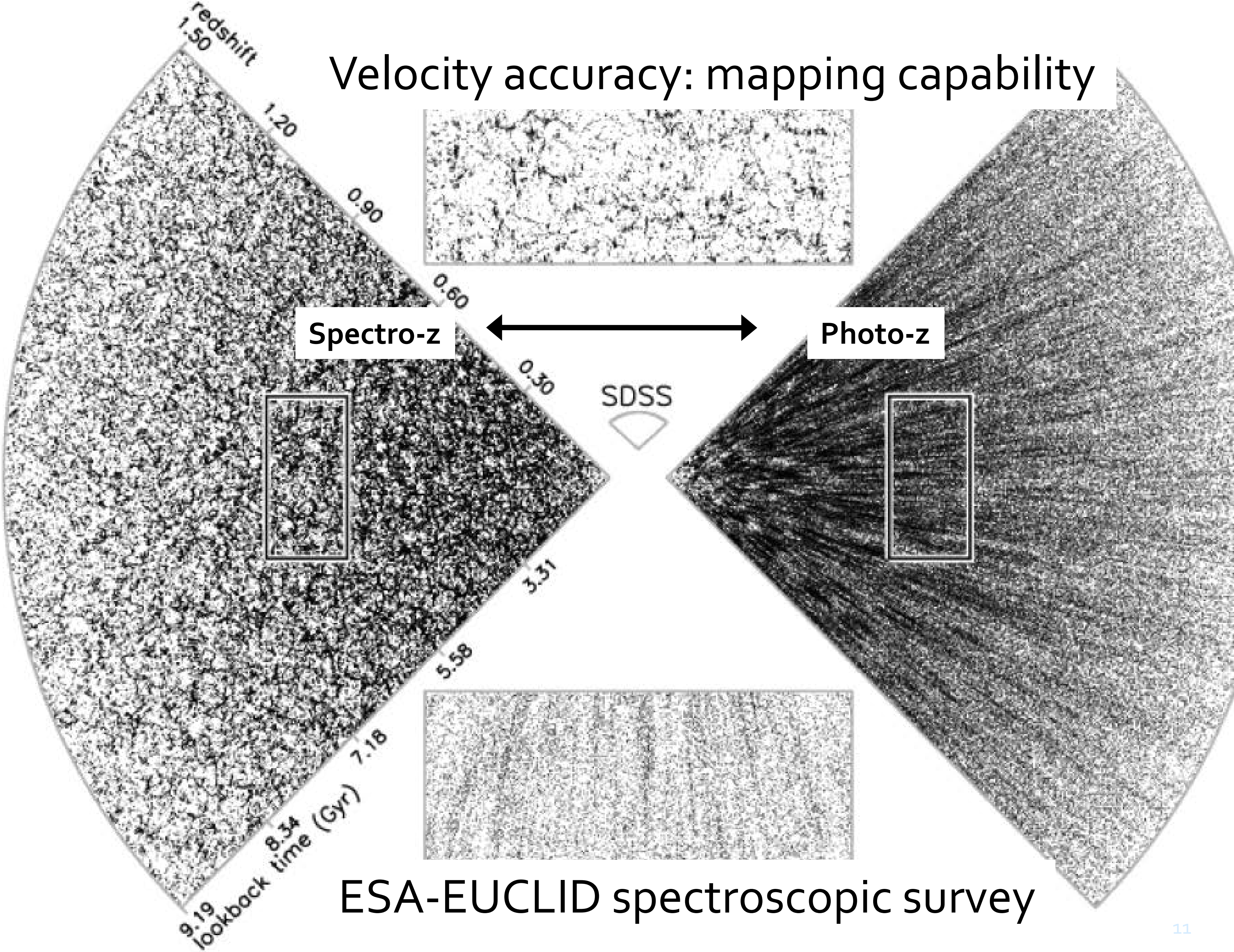
# Spectral energy distribution & derivatives



# Spectroscopic surveys

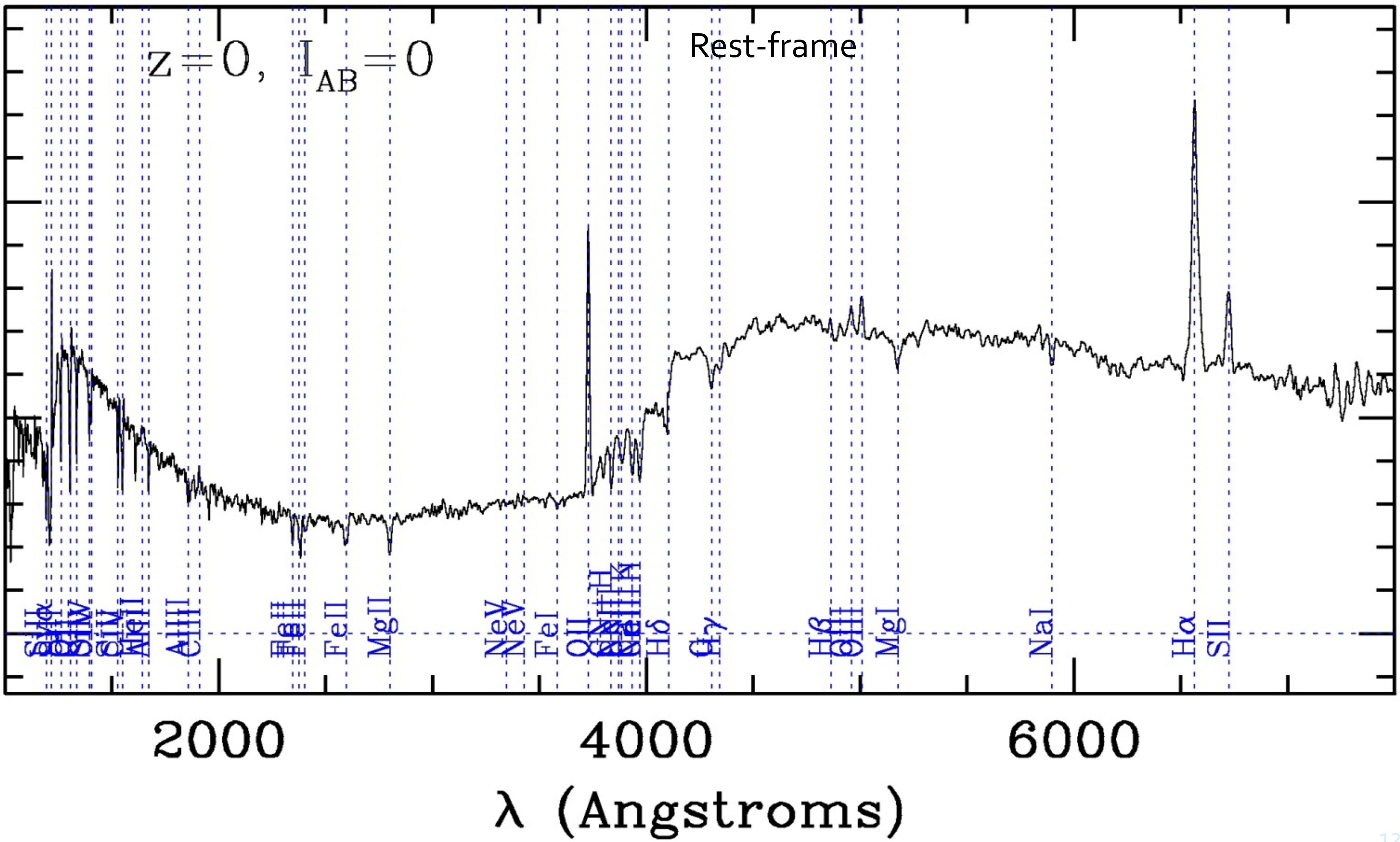
- Access to the 3rd dimension by measuring velocity - redshift
  - Accuracy 10-300km/s
- Counting galaxies N(z,m)
- Stars and gas content
- Dynamics from internal velocity field

# Velocity accuracy: mapping capability



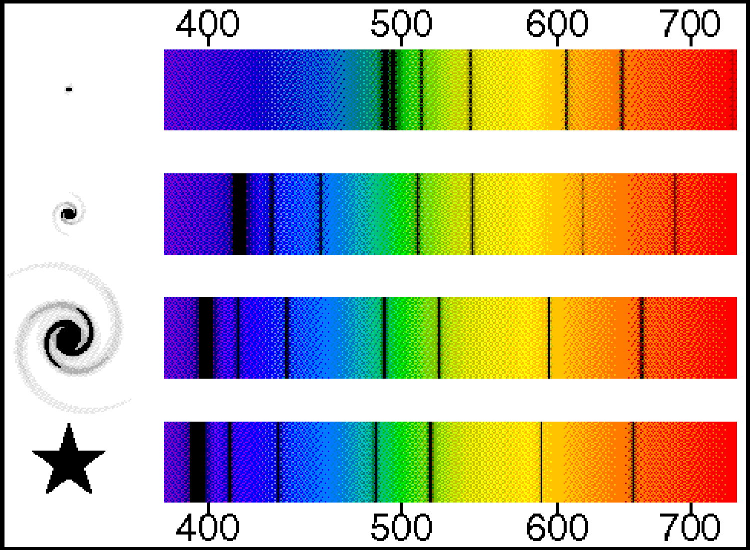

ESA-EUCLID spectroscopic survey

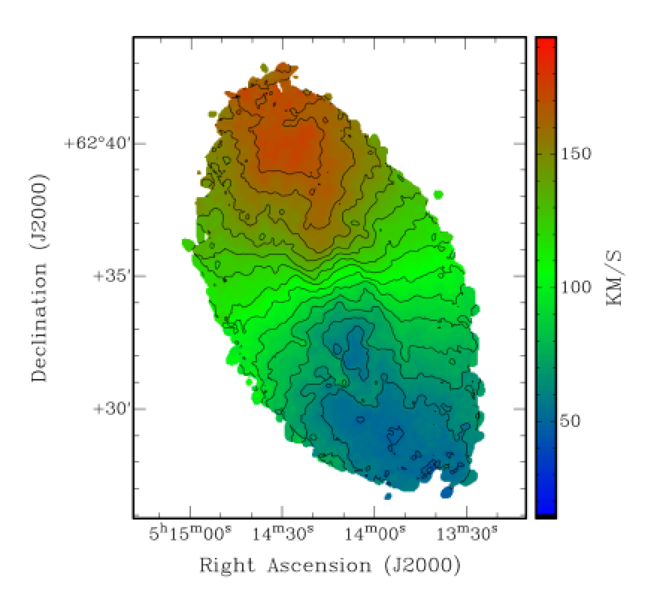
# Spectra


z = 0, $I_{AB}$ = 0
Rest-frame
FeII
MgII
NeV
FeI
OII
Hδ
Hγ
Hβ
OIII
MgI
NaI
Hα
SII
2000
4000
6000
λ (Angstroms)

# The Redshift $1 + z = \lambda_{obs}/\lambda_{em}$

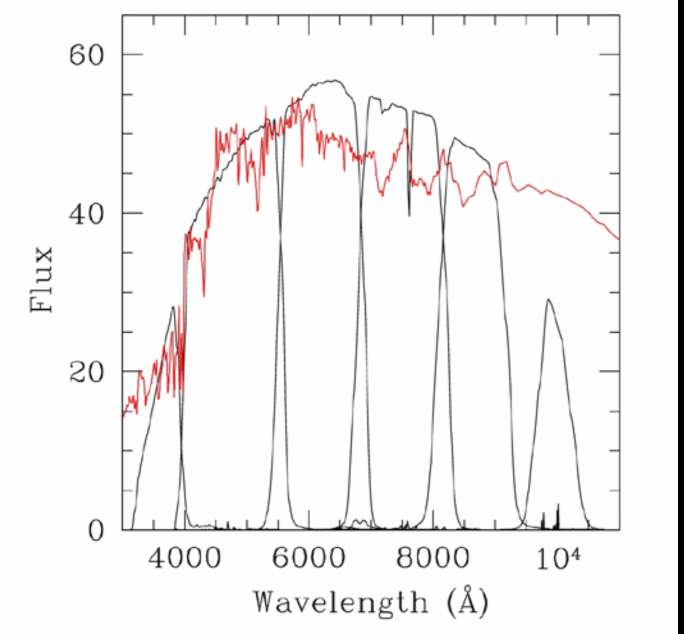
- The shift in observed vs. emitted wavelenght is a consequence of motion
  - Blueshift when moving towards the observer
  - Redshift when moving away from the observer
- In an expanding Universe objects are moving away from each other: Redshift
  - Redshift is distance: v=Hd
- Looking to a galaxy in rotation: velocity field with blue/red shift

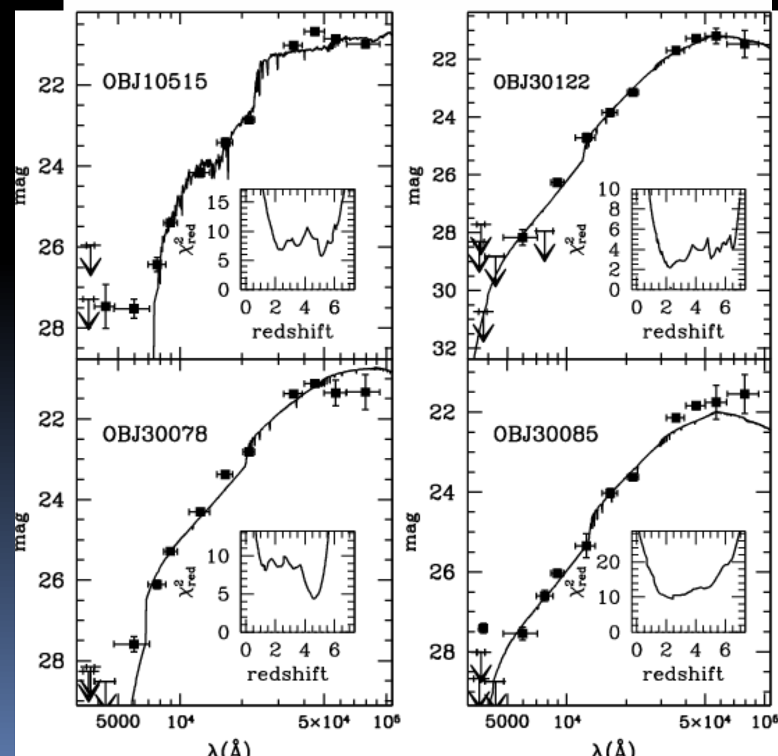


# Measuring photometric redshifts

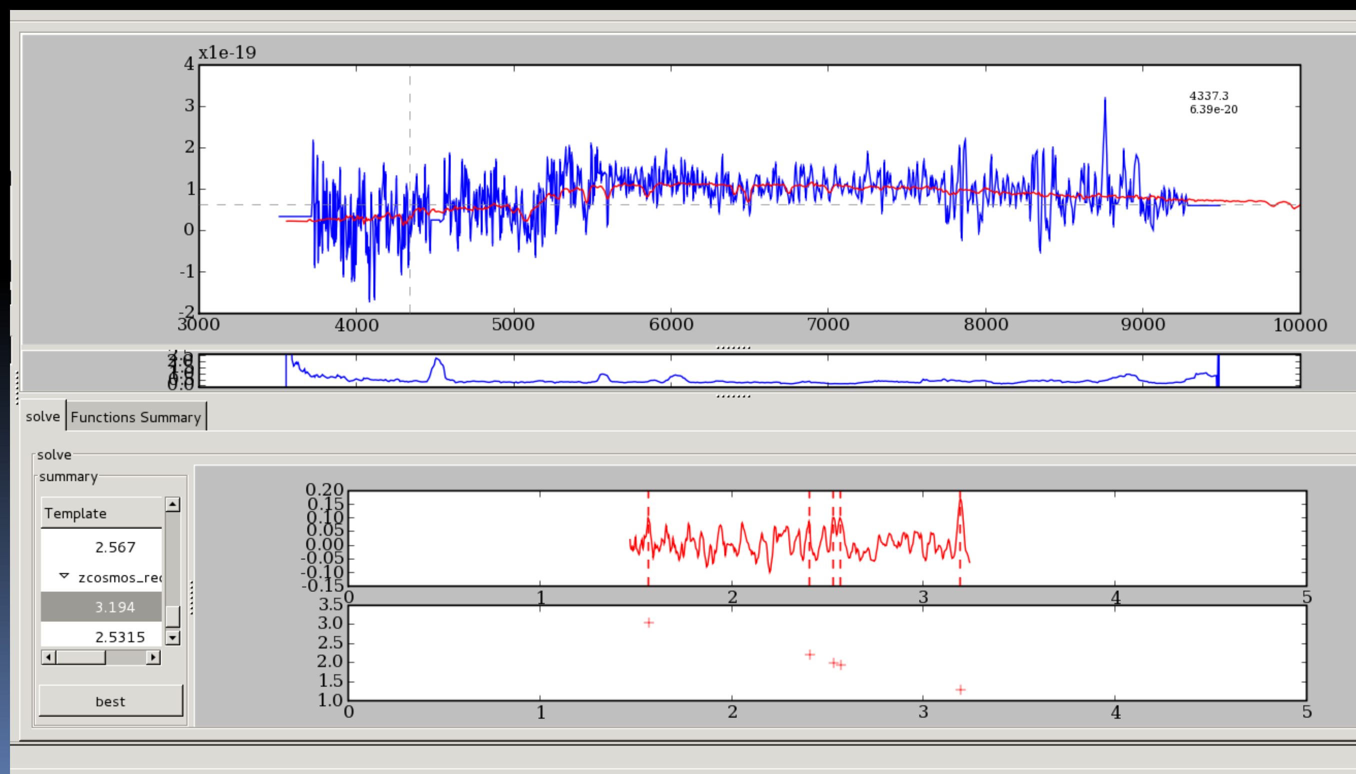
- Photo-z is a redshift derived from photometric data
- Use the SED
- Correlate against a set of templates
- Same process as for *-mass, SFR, age, etc.
- Accuracy $\delta z \sim 3\text{-}5\%$
  - Probability distribution function
- Pb of catastrophic redshifts



# Measuring spectroscopic redshifts

- Based on cross-correlation with templates
- Identify emission / absorption features
- Take continuum into account




EZ engine:
Garilli et al., 2010, PASP, 122, 827

# How are galaxy surveys designed ?

- Wide vs. Deep
- Wavelength
- Spatial and spectral resolution
- Total survey time

- Wedding cake approach

Deep / small field

Medium / large field

Shallow / all-sky

# Planning a survey: examples

- VLT 8m + VIMOS
- 500 objects per observation
- How much time to survey 10,000 objects ?

| Survey type | Limiting magnitude | Useful exposure time | Total exposure time | Total time with overheads |
|---|---|---|---|---|
| Wide | 22.5 | 0.75h | 15h | 19h |
| Deep | 24 | 4h | 80h | 100h |
| Ultra-Deep | 25 | 15h | 300h | 330h |

# Measuring galaxy evolution with galaxy surveys

**Distribution in LSS**

- N(z)
- Galaxy density field
- Correlation function
- Cosmology: BAO, fg(z)...

**Luminosity / SFR / Mass evolution**

- Luminosity Function
- Luminosity Density
- Mass function
- SFH
- $\rho_{STARS}$

**High redshift populations**

- Pre-selected: LBG, BzK, LAE, SMGs, EROs, DRGs
- The most distant LBGs, LAE
- Faint QSOs

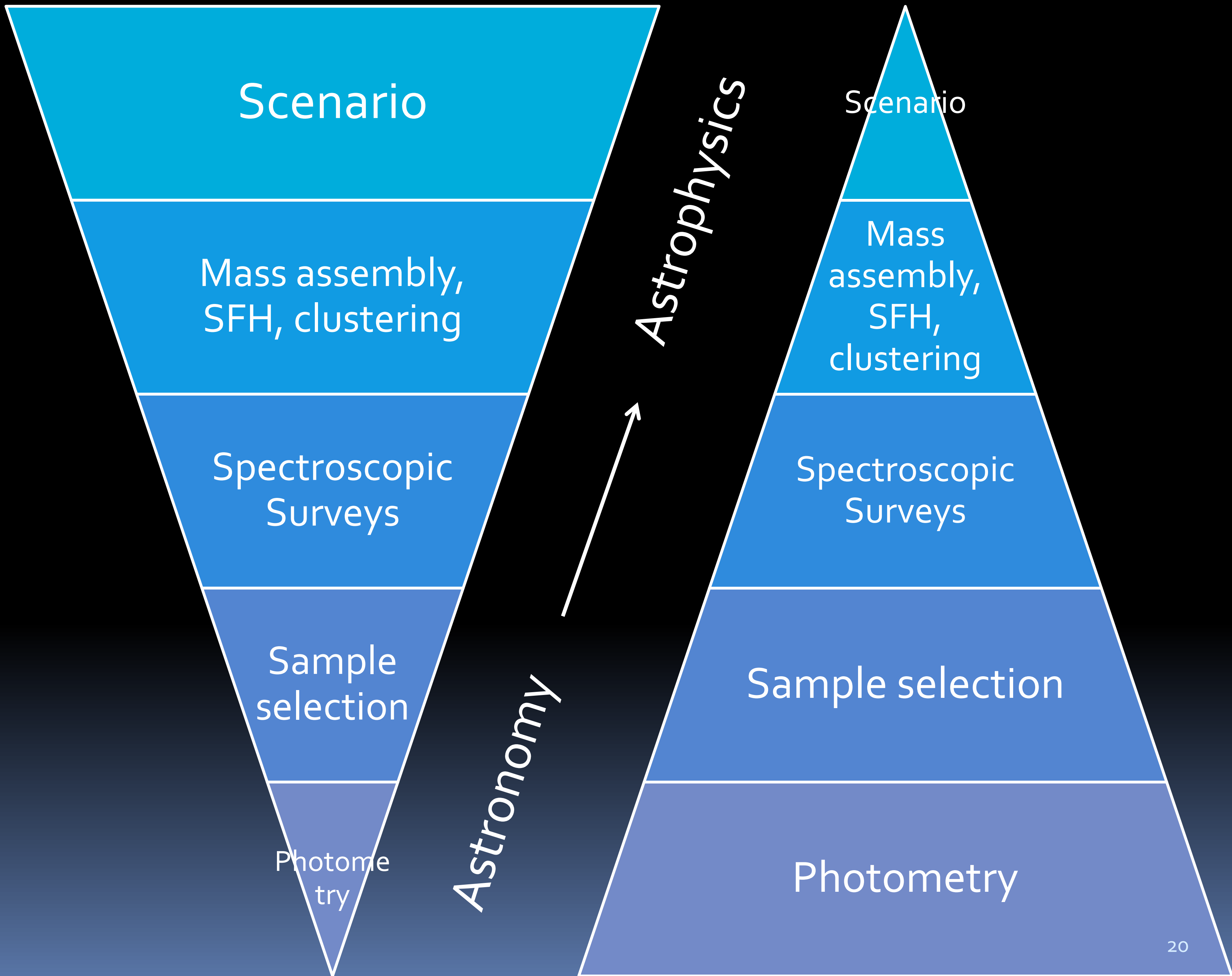
Track evolution versus Environment, Luminosity, galaxy type,...

# Some Principles

- Surveys need to be unbiased
  - Volume, luminosity/mass, type, environment…
  - Proper photometric catalogs
- Statistically robust
- Complete census

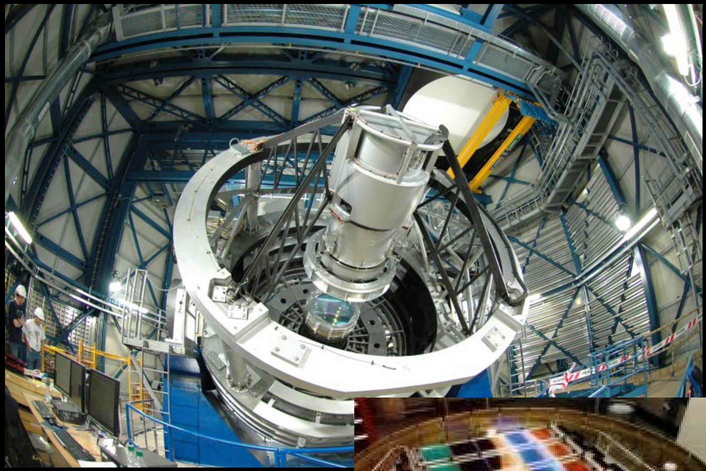
- Selection function control
  - Apriori hypotheses
  - Large deep imaging surveys
- Large samples
- Multi-wavelength

2 types of surveys: photometric and spectroscopic


Scenario
Mass assembly, SFH, clustering
Spectroscopic Surveys
Sample selection
Photometry
Astrophysics
Astronomy
Scenario
Mass assembly, SFH, clustering
Spectroscopic Surveys
Sample selection
Photometry

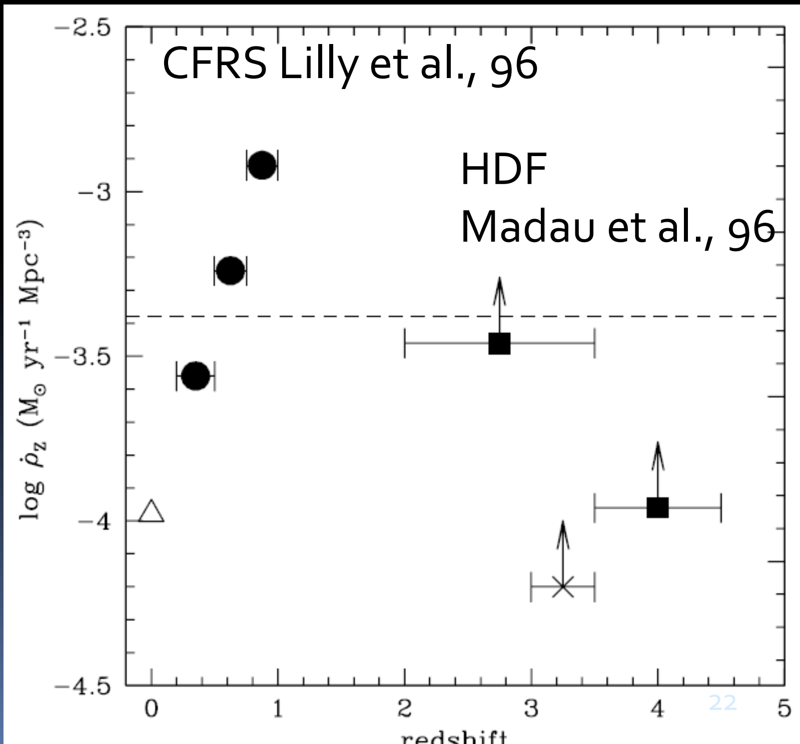
# What instruments are needed ?

- Wide field imaging cameras
  - Visible
  - Infrared
  - Space: UV, mid/far-IR
  - All wavelengths !!
- Wide field multi-object spectrographs
  - Multi-slit
  - Multi-fiber



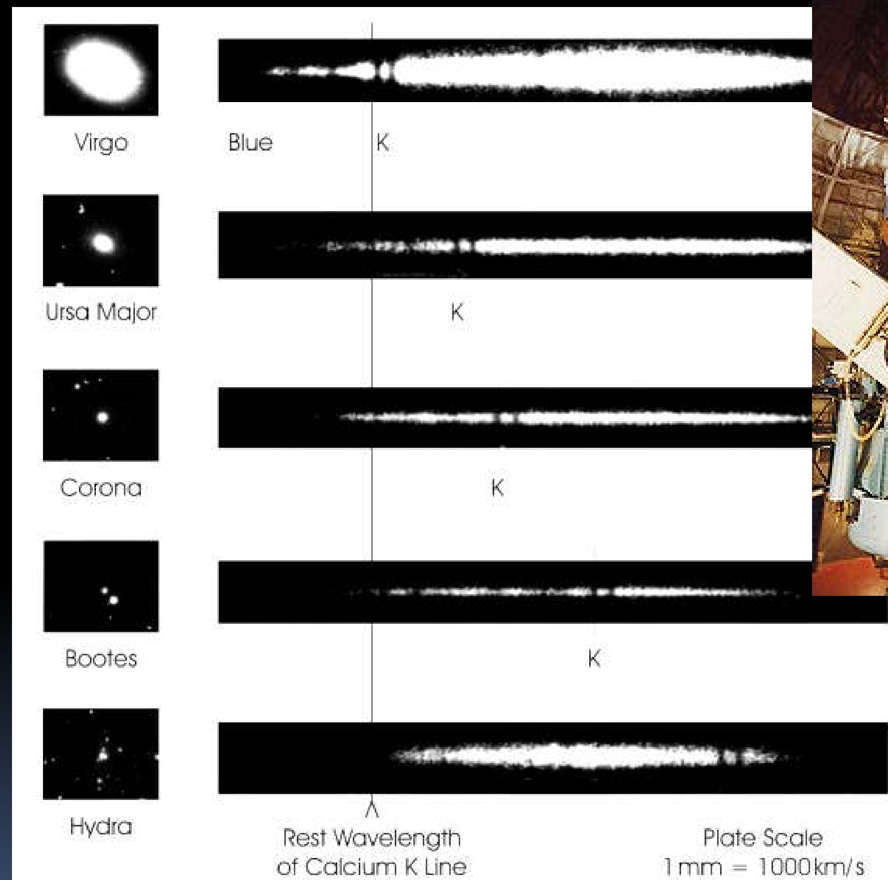
# Historical perspective

- Early times: galaxies one by one (Hubble…)
- The invention of multi-object spectroscopy
  - First efficient MOS in the '90s
- '90s: the golden age
  - 2dFGRS, SDSS in the local U.
  - CFRS, LDSS: z~1
  - LBG: z~3
- Today: the precision age

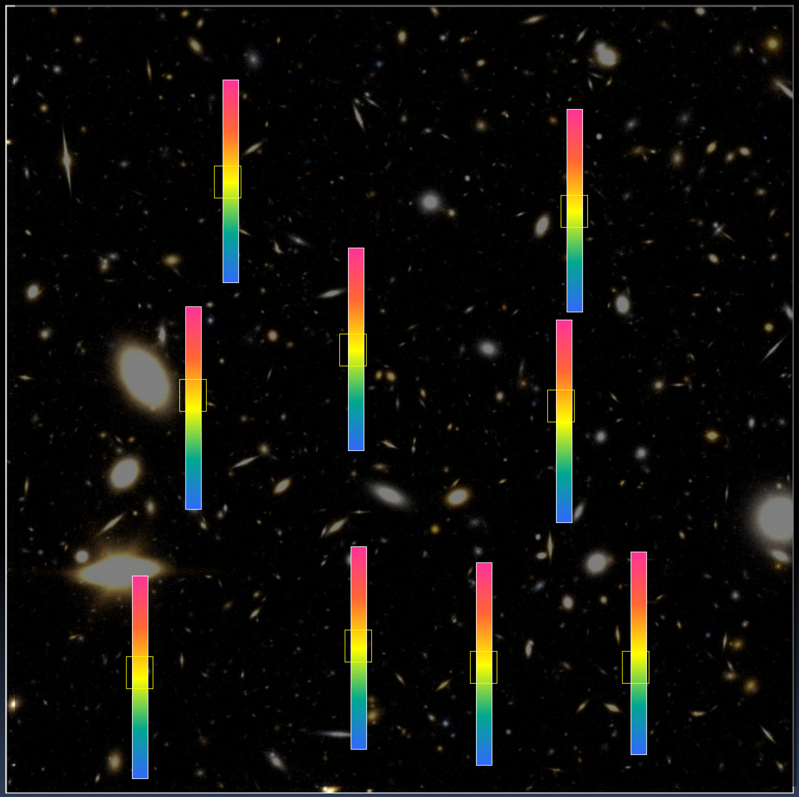


# Spectra, one by one

E. Hubble




# Multi-object spectroscopy



- Deep multi-color imaging
- Target selection
- Multi-object spectroscopy

Today MOS have $N_{obj}$ >> 100

Multiplies the efficiency of your telescope by $N_{obj}$ !

# Instrument design and development

- Instrument making is fundamental to astrophysics
- Relies on new & improved technology
  - Optics, detectors, mechanics, control (active)
  - Space technology
  - Software: data processing, databases
- Professional project development
  - Skilled instrument scientists and specialty engineers
  - Project management
- Expensive telescopes (~1B€) and instruments (~15M€ ground-based / ~150M€ space-based)

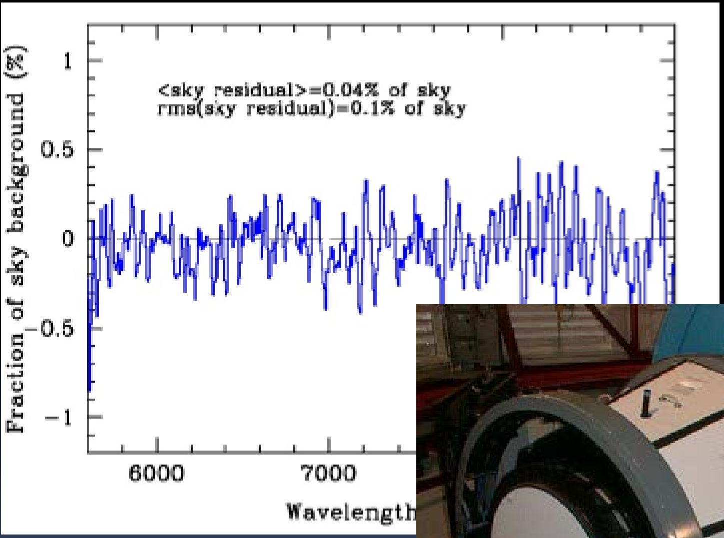
# Instrument development cycle

- Define science goals: science requirements — $T_0$
  - Survey volume, number of objects, redshift
- Derive technical requirements
  - Field of view, wavelength, resolution, throughput — $T_0$+1y
  - Global performances
- Produce strawman opto-mechanical design
- Identify new technology developments: grating, detectors,… — $T_0$+2y
  - Produce prototypes
- Manufacture all parts — $T_0$+4y
- Assembly, integration and tests — $T_0$+5y
  - Measure performances, calibrate
- First light — $T_0$+6-7y

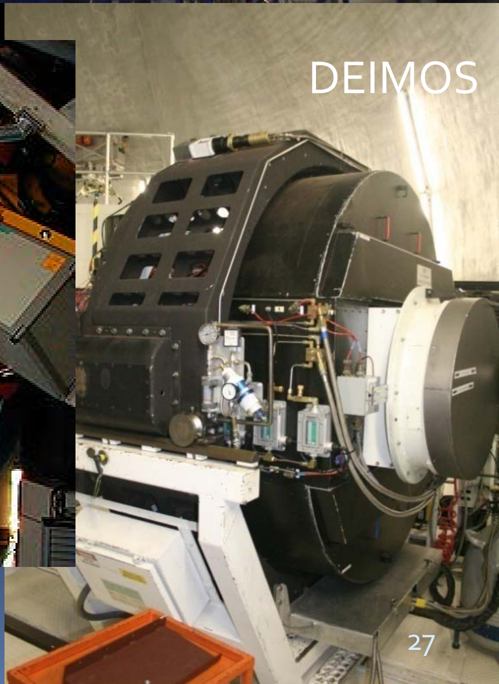
SPACE: 50-100% longer !

# Multi-Object Spectrograph have become the work-horse of many observatories

- Dans tous les observatoires majeurs: CFHT-MOS/SIS, Keck-LRIS, VLT-FORS, GMOS, Keck-DEIMOS, VLT-VIMOS, IMACS …

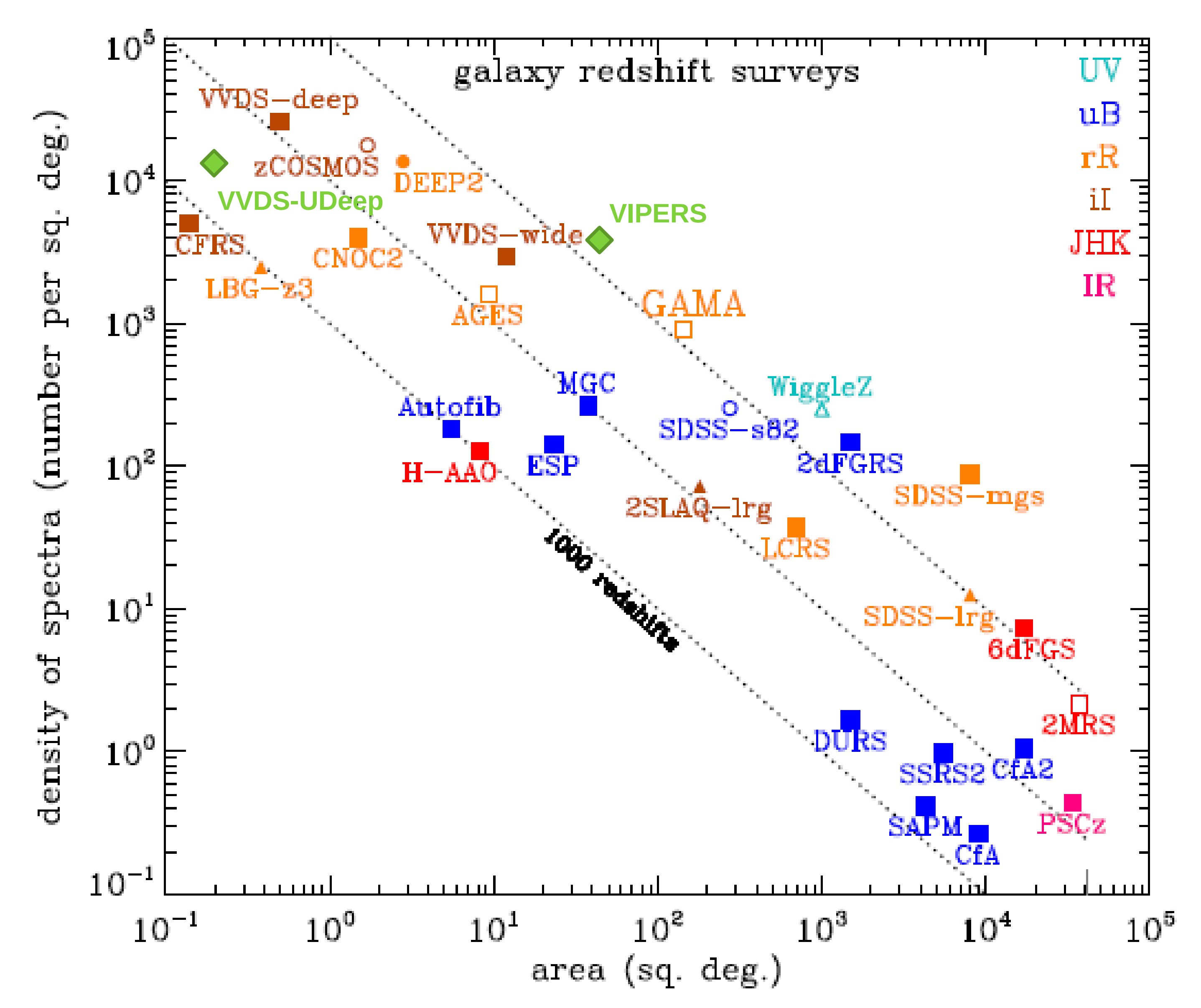


# Past and present deep spectroscopic surveys

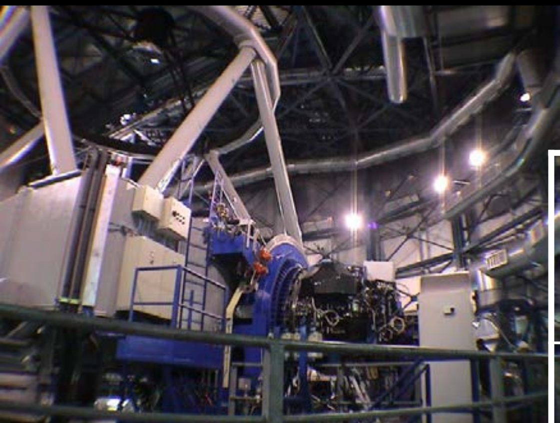
| Survey | Instrument | redshift | # galaxies |
|---|---|---|---|
| 2dFGRS | 2dF/AAT | $0<z<0.5$ | 220000 |
| SDSS | SDSS/Apache Point | $0<z<0.5$ | 930000 |
| CFRS – 1995 | CFHT-MOS | $0<z<1.2$ | 600 |
| LBG – 1999 | KECK-LRIS | $2.5<z<4.5$ | 1000 |
| DEEP2, 2005+ | KECK-DEIMOS | $0.7<z<1.4$ | 50000 |
| VVDS, 2005+ | VLT-VIMOS | $0<z<5$ | 50000 |
| zCOSMOS, 2007+ | VLT-VIMOS | $0<z<1.2$<br>$1.4<z<3$ | 20000<br>10000 |
| VIPERS, 2009+ | VLT-VIMOS | $0.5<z<1.2$ | 100000 |
| VUDS , 2010+ | VLT-VIMOS | $2.5<z<6.7$ | 10000 |
| GOODS | VLT FORS2 | $0<z<7.1$ | 1000 |

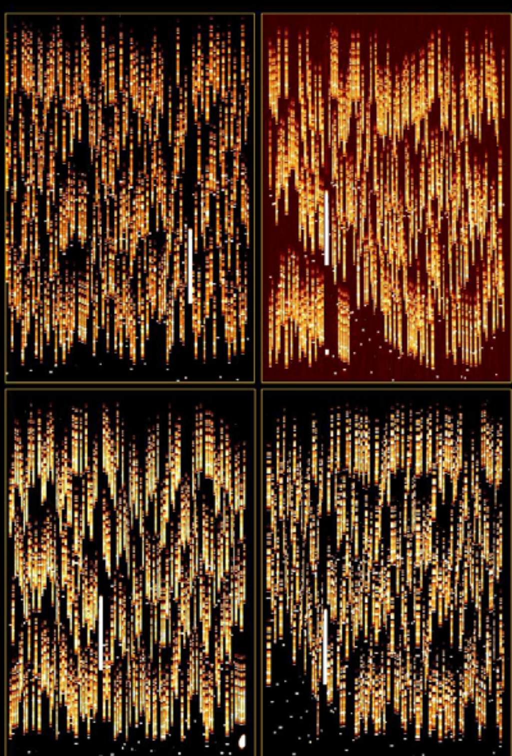
And more !




*From Baldry et al., 2010*

# VVDS: the final sample





## Magnitude selected samples

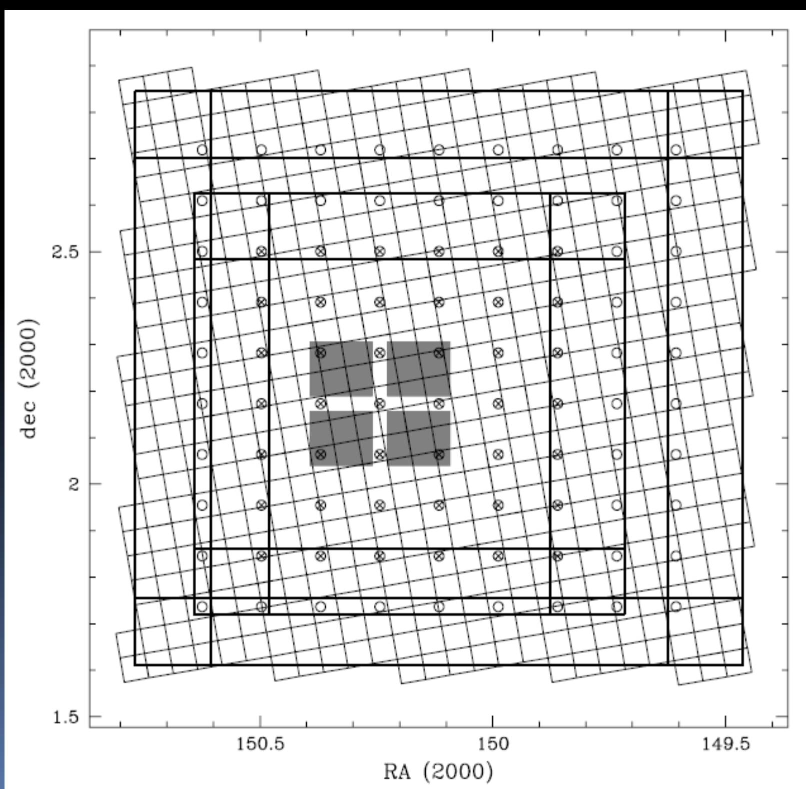
| Sample | Selection | redshift | galaxies Spectro-z | galaxies z>1.4 |
|---|---|---|---|---|
| Wide | $I_{AB} \leq 22.5$ | $0<z<1.5$ | 35000 | - |
| Deep | $I_{AB} \leq 24$ | $0<z<5$ | 15000 | 970 |
| UltraDeep | $I_{AB} \leq 24.75$ | $0<z<5$ | 863 | 220 |
| Ly$\alpha$ | Flux | $2<z<6.5$ | 204 | 204 |
| TOTAL | | | ~51000 | ~1400 |

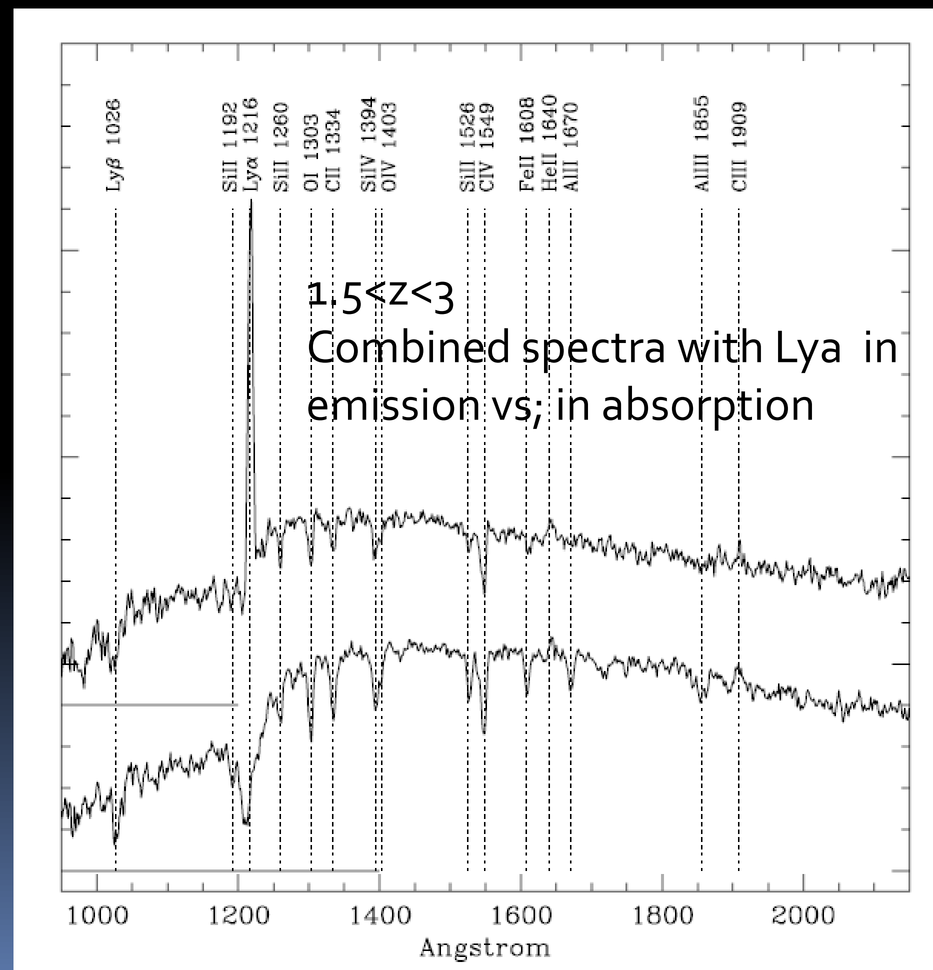
- >51000 galaxies with redshifts
- A total of ~1400 galaxies with $1.4<z<6.5$ and spectroscopic redshifts

# zCOSMOS

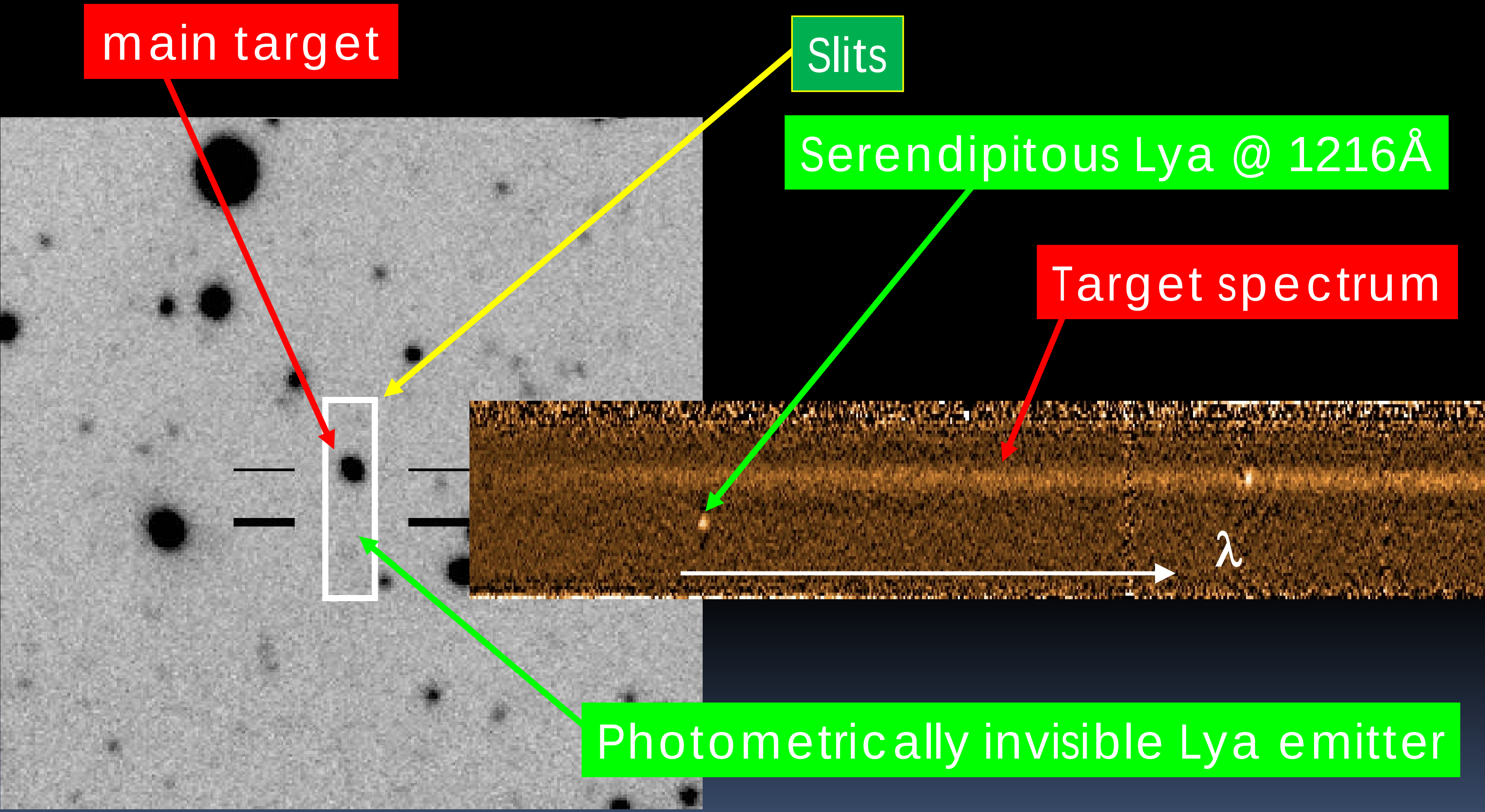
On HST-COSMOS 2 deg² field

- With VLT-VIMOS
  - Wide: 2 deg², 20000 spectra, $I_{AB}\leq 22.5$, $0<z<1.2$ (Public)
  - Deep: 1 deg², 5000 spectra, BzK+UGR selected $1.5<z<3$



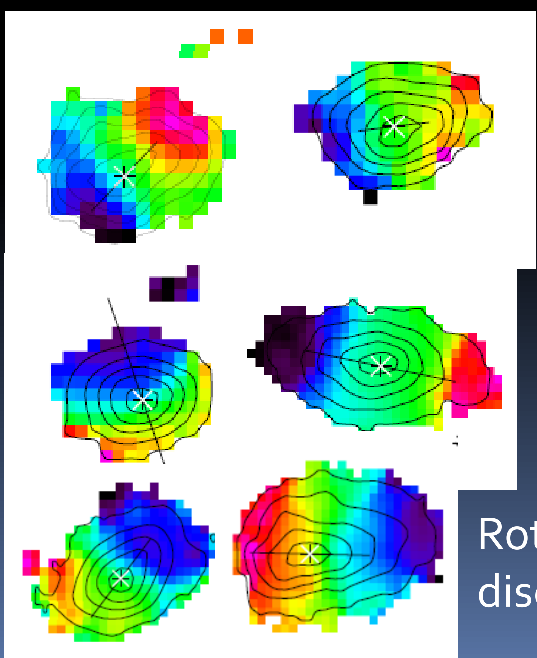



# Serendipitous power of MOS

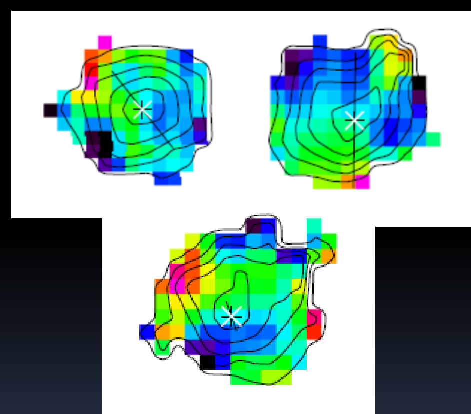


# Follow-up surveys

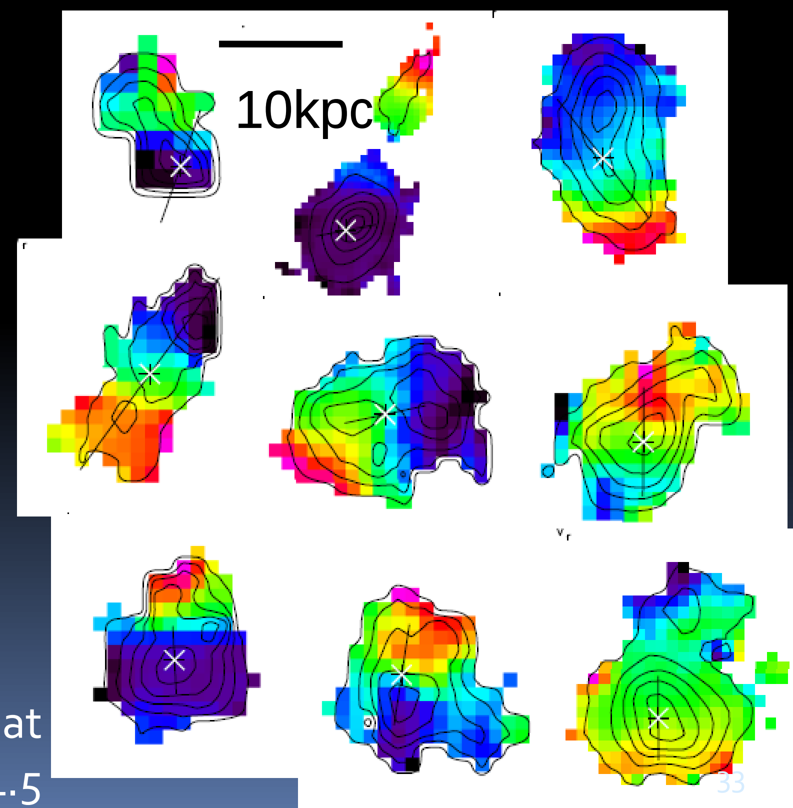
- Select clean samples from deep spectroscopic surveys
- Example of 3D integral field spectroscopy surveys
  - MASSIV: a complete sample, 80 galaxies from VVDS at $1<z<1.8$ with IFU-3D (At the peak of star formation), kinematics/dynamical studies
  - SINS: ~100 galaxies z~2



Rotating discs at z~1.5



Perturbed at z~1.5




Mergers at z~1.5

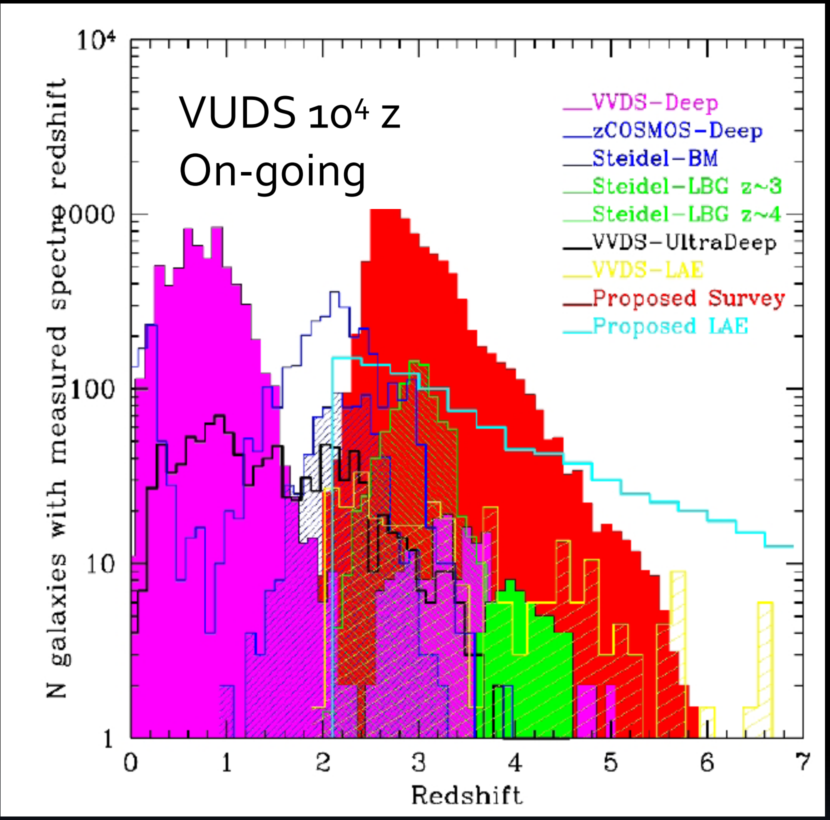
# Next generation surveys and facilities

- Need to go fainter/deeper
  - Faint end of the luminosity function
  - Early objects – reionisation
- Need to observe in the near infrared
  - SED redshifted out of the visible/CCD domain for z>7
- Need to observe large volumes
  - Get rid of cosmic variance effects
  - Access to very large scales for cosmology
- Continue to build-up the wedding cake !

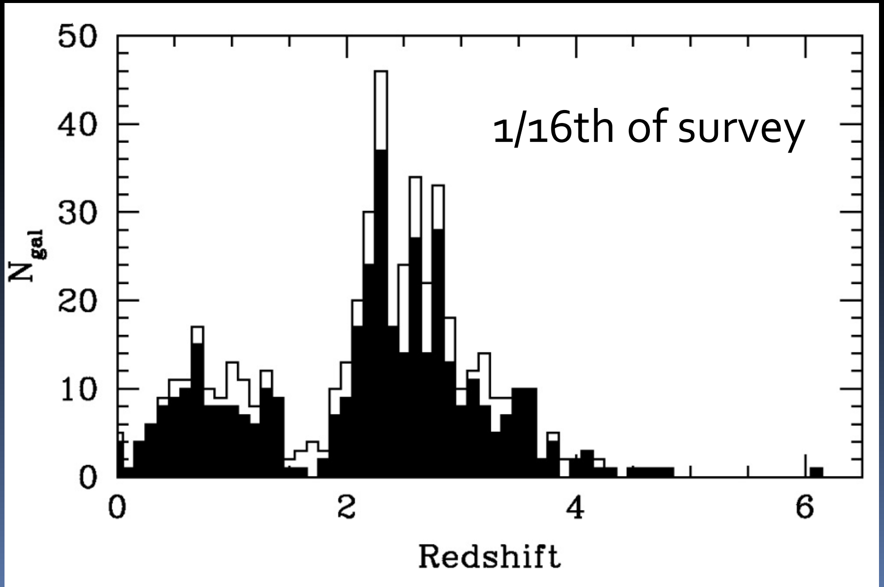
# Future surveys and facilities

- Very wide field, all-sky to z~2
  - Cosmology and galaxy evolution
  - VIMOS-VIPERS, on-going: $10^5$ redshifts, z~1
  - Big-Boss, SUMIRE-PFS…: $3\times10^7$ redshifts, z~1-1.5
  - ESA-EUCLID: $5\times10^7$ redshifts, z~2
- Large surveys, z~2-5
  - UltraVista: on-going
  - VUDS at VLT: $10^4$ redshifts, on-going
- Reionisation, SFH, z>5
  - JWST: NIRSPEC, MIRI
  - EELT: DIORAMAS, EAGLE

# VUDS: VIMOS Ultra-Deep Survey

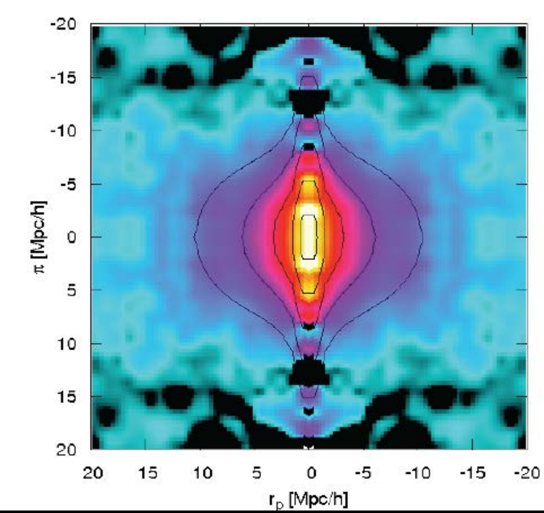



- Large program on VLT (640h)
- Magnitude selected $23 \leq i_{AB} \leq 25$
- VIMOS: 14h blue + 14h red integrations
- On-going: 10,000 galaxies

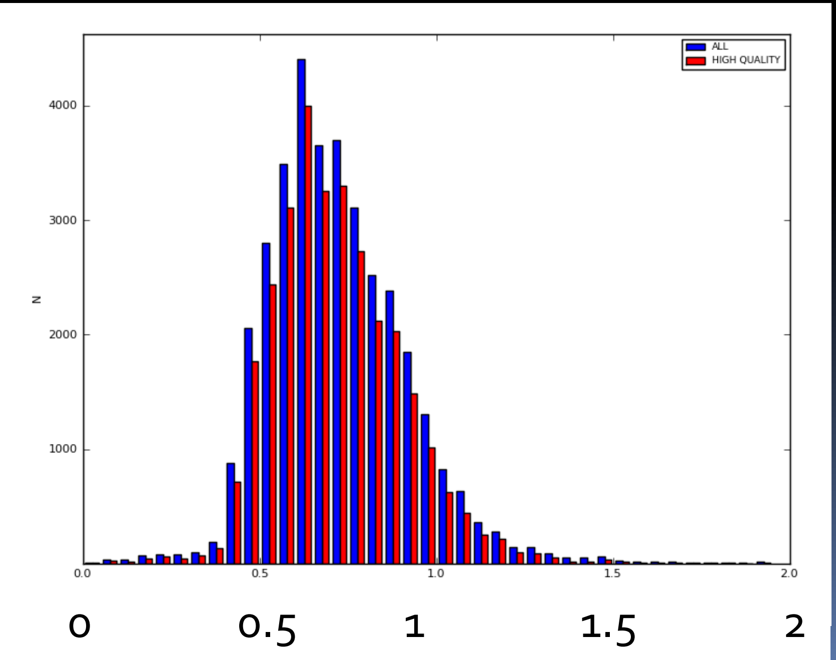


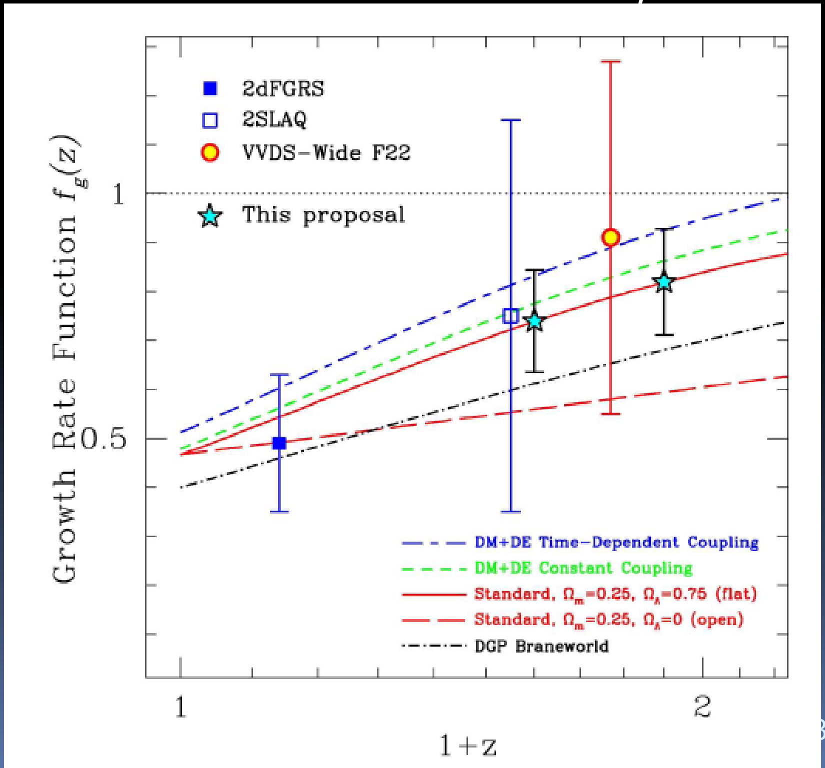
# VIPERS: 100000z at z~1

- VLT-VIMOS
- Measure growth rate



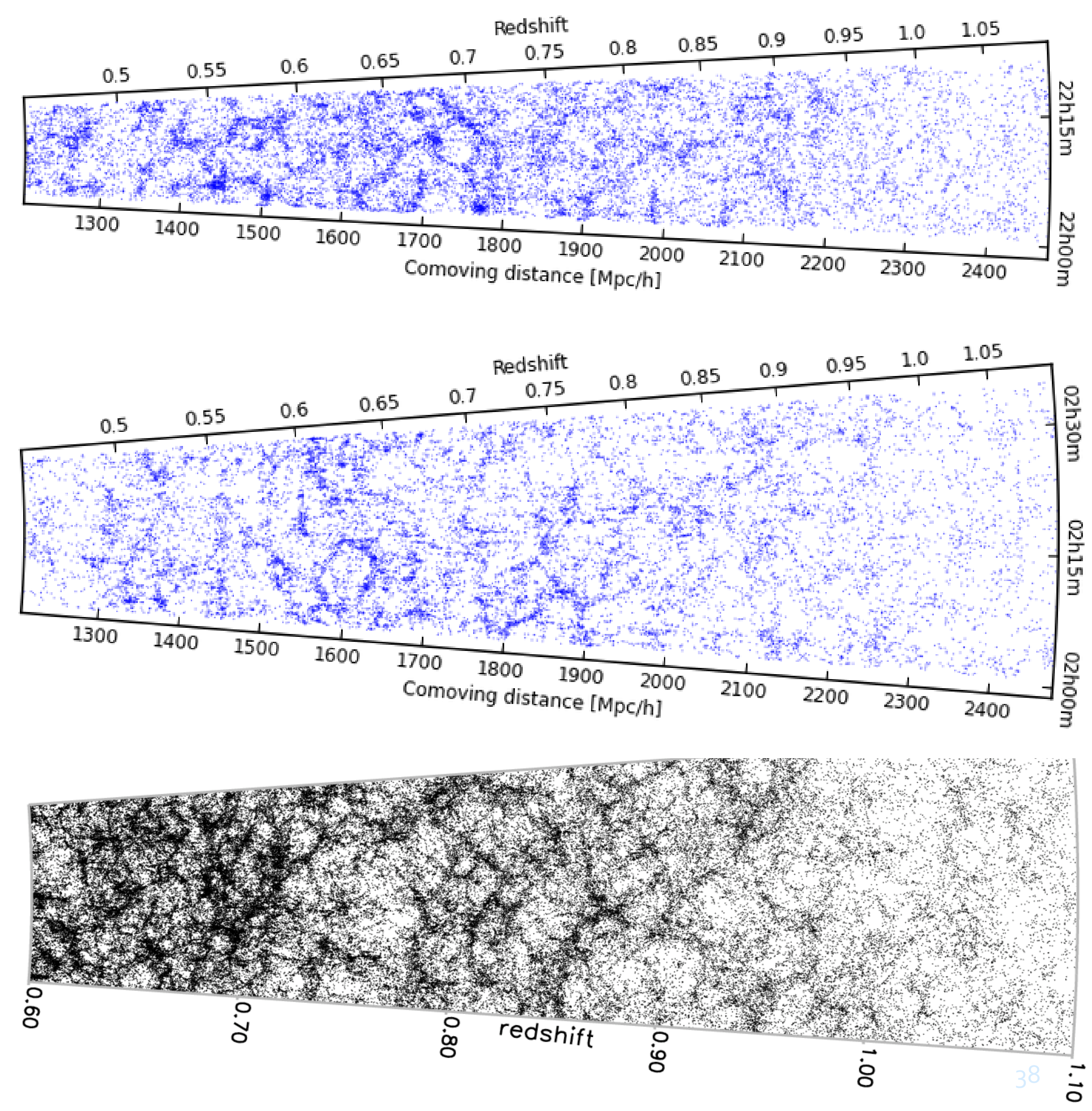

VVDS: Guzzo et al., Nature, 2008



# VIPERS

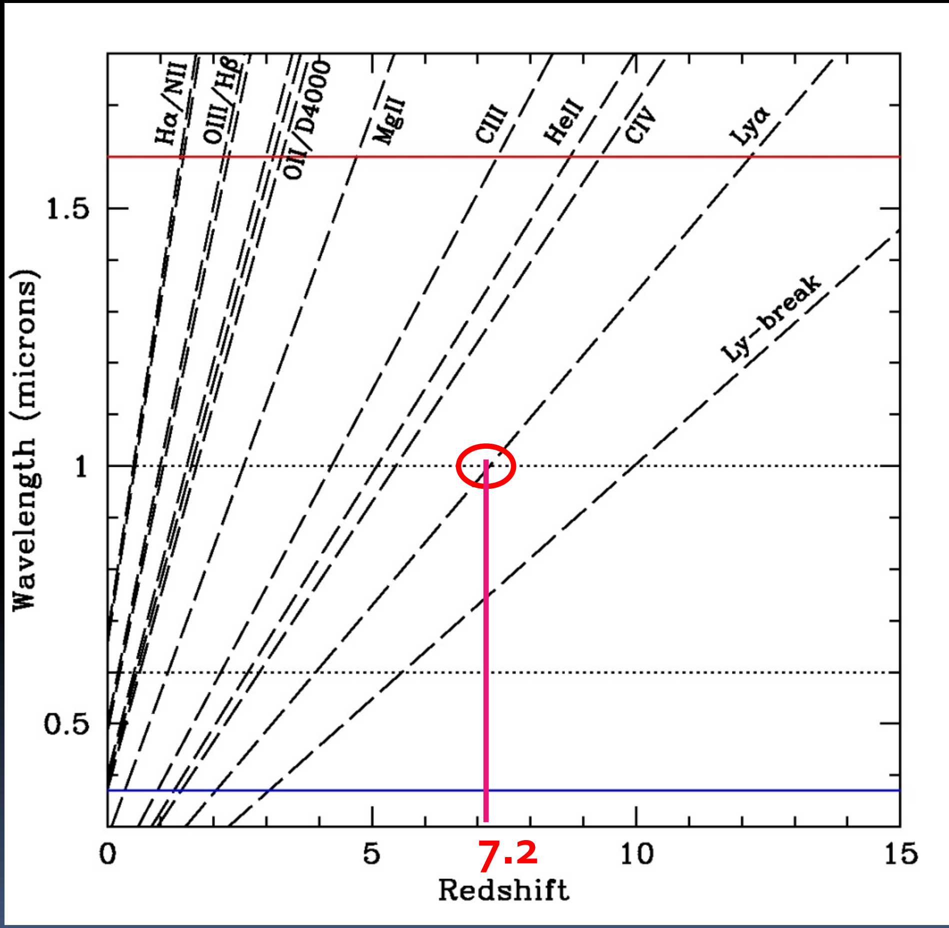
- What is real ?
- What is simulated ?




- 40000 redshifts so far

# Breaking the z-frontier: need for efficient NIR multi-object spectrographs

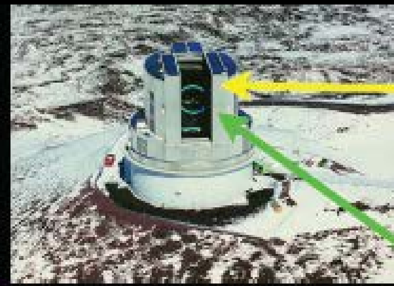
- ~NOW
  - MOSFIRE on Keck: 2011
    - YJHK, 6x6 arcmin²
    - 45 slits
  - KMOS on VLT, 2012 ?
    - YJHK, 7 arcmin diameter
    - 24 IFUs, 2.8x2.8 arcsec²
  - LUCIFER on LBT
  - EMIR on GTC
- NEXT
  - PFS: 2016
  - NIRSPEC-JWST: 2018
  - EUCLID: 2019

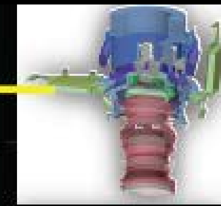


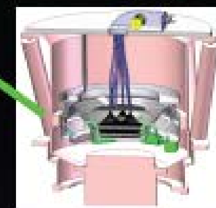
# Some new facilities for surveys

- SUMIRE – PFS
- JWST
- EELT
- EUCLID

# SuMIRe


Subaru

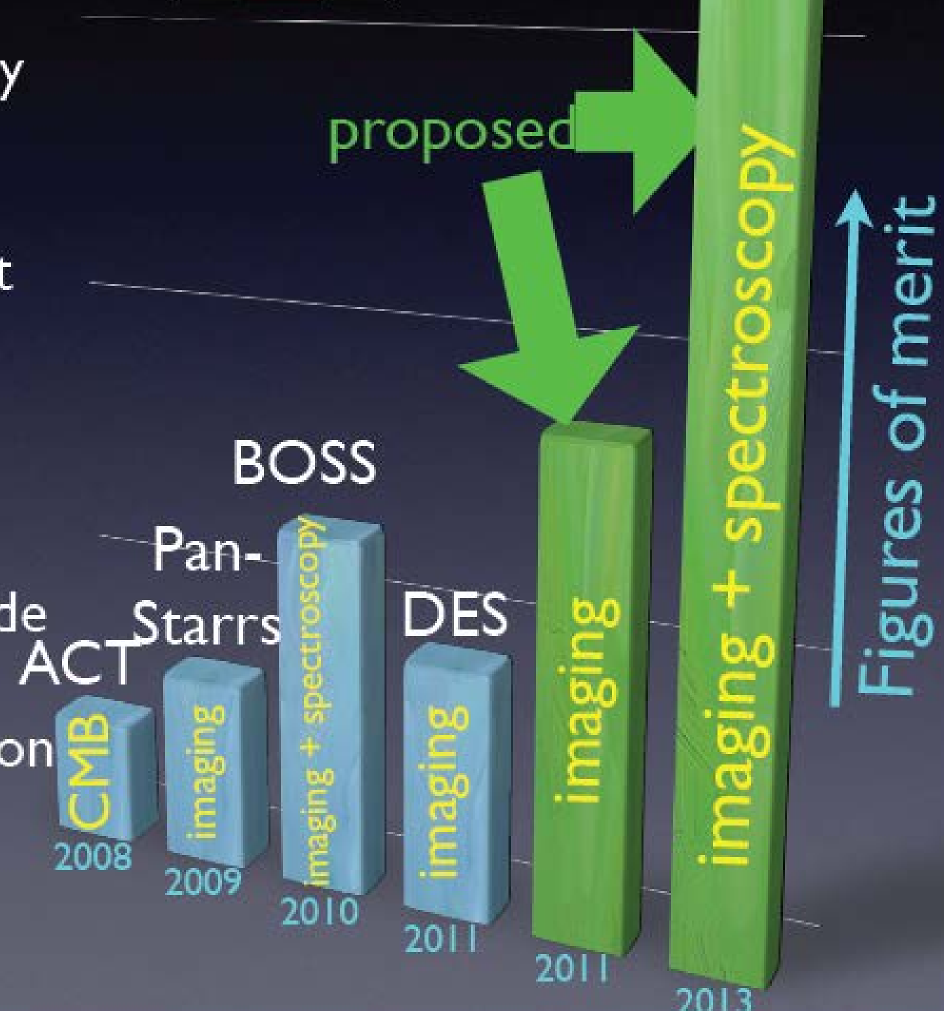



- Major study of dark energy
- Subaru Measurement of Images and Redshifts

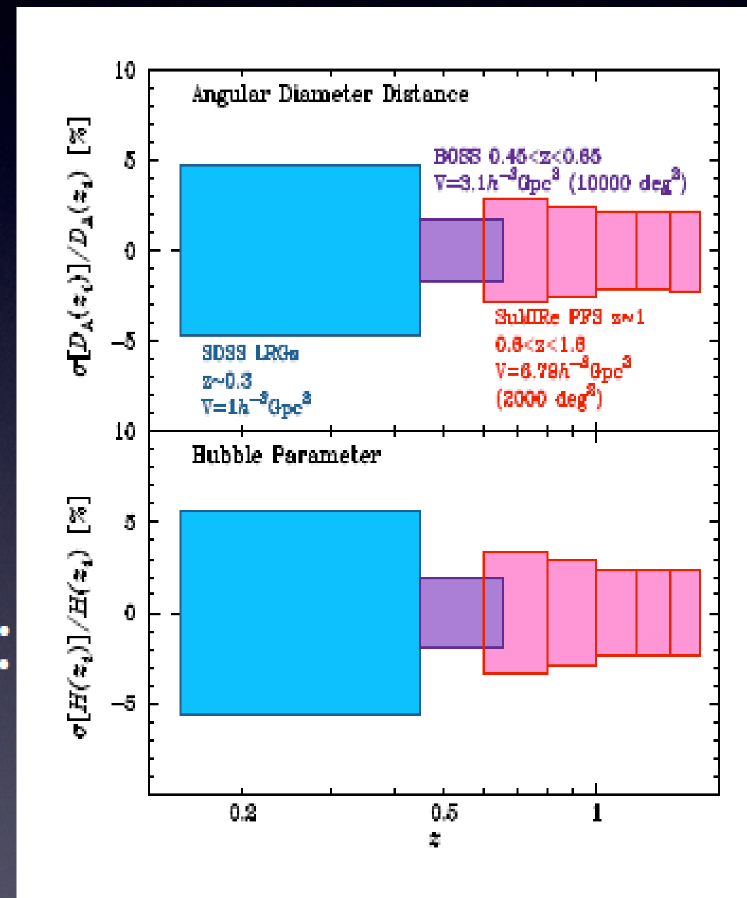
1. imaging with 0.9B-pixels 3t CCD camera from 2011
2. spectroscopy with ≈2000 objects >2015

- *best measurements of dark energy params* in this decade
- 3D map of dark matter to observe structure formation
- same telescope for both imaging and spectroscopy *like SDSS but 8.2m!*



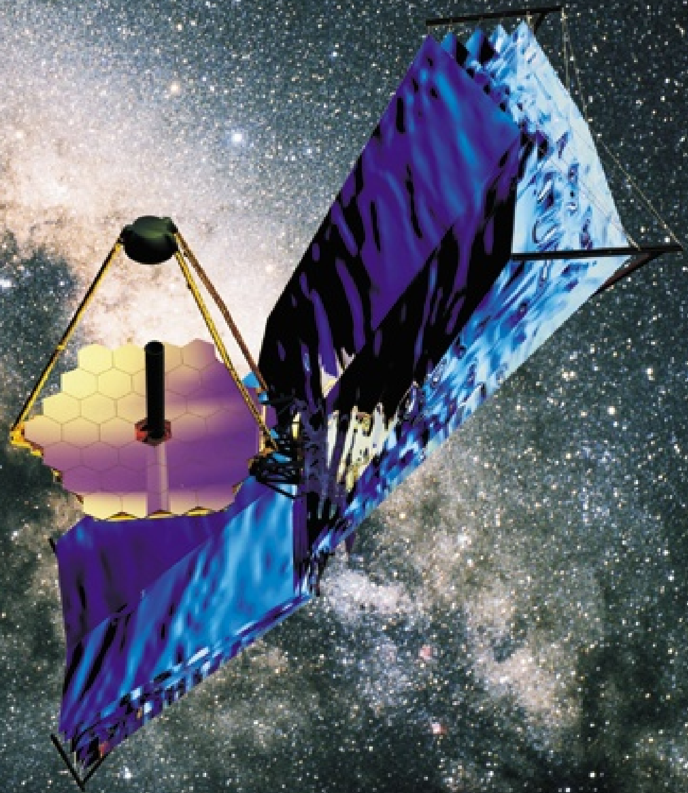
# technical specs

- BAO
  - correlate distance from BAO to redshift → dark energy
  - targets selected with HSC
  - go beyond BOSS: z≈0.6–1.6
  - most efficient (least exposure): OII emission 372.7, 373.0 nm
  - need 600-1000nm, R≈3000
  - measure w down to 3%



# JWST

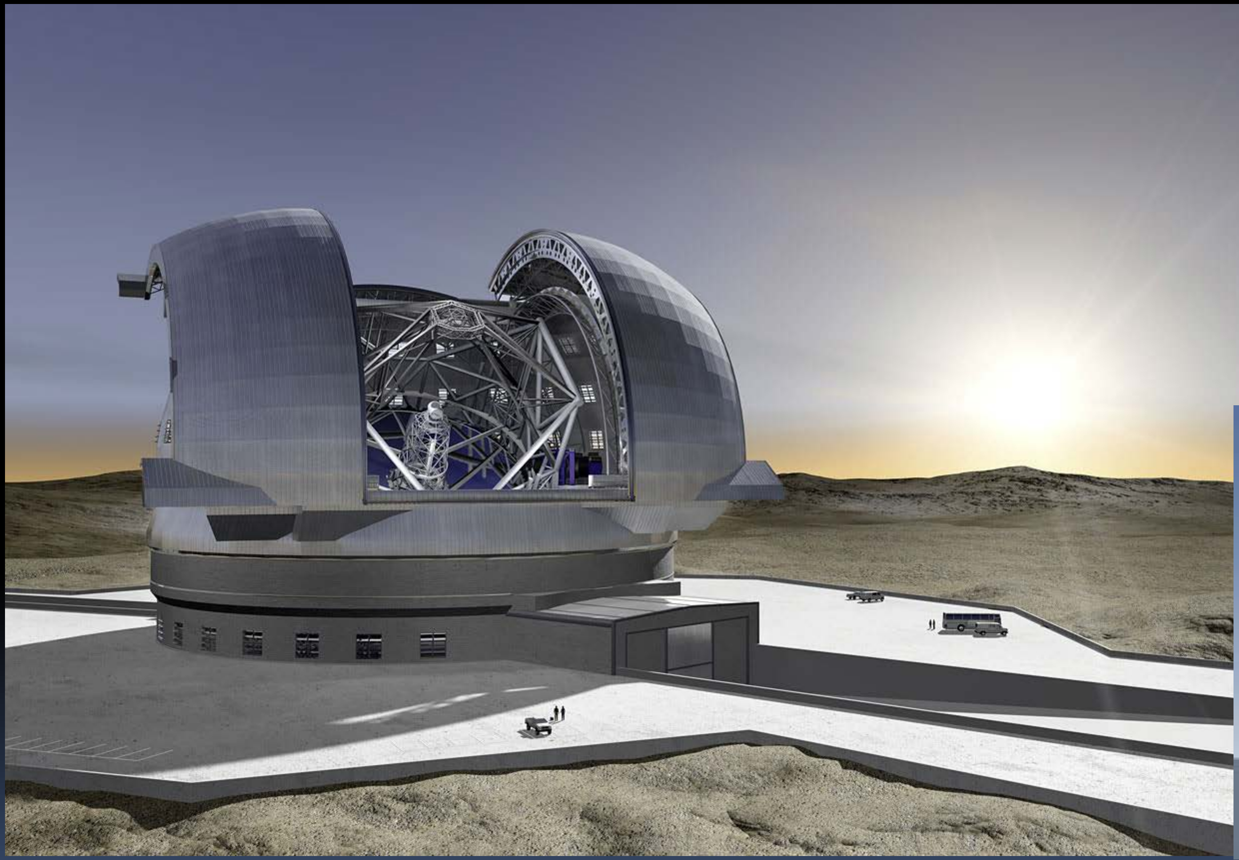
- Space telescope
- *Diameter: 6.5m*
- 0.6-25 microns
- Observe first light
- Launch 2018

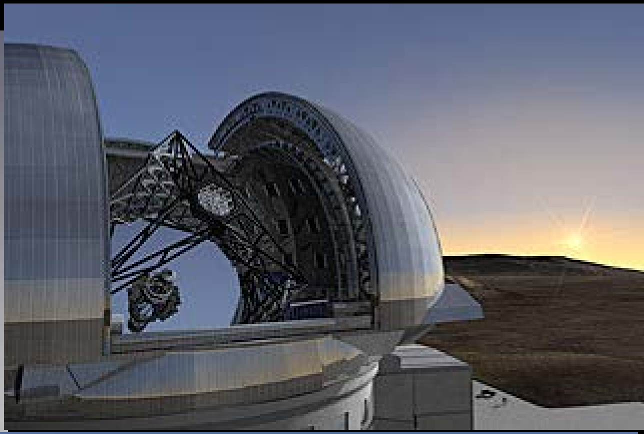


# JWST instruments

- NIRCAM: 0.6-5 microns
  - 2.2′x4.4′
- NIRSPEC:  1-5 microns
  - 3′x3′
  - Multi-slit
- MIRI: 5 to 27 microns
  - Imaging and spectroscopy
  - 1.3′x1.7′

# EELT: Europea, « Extremely Large Telescope »





Construction to be decided in 2012

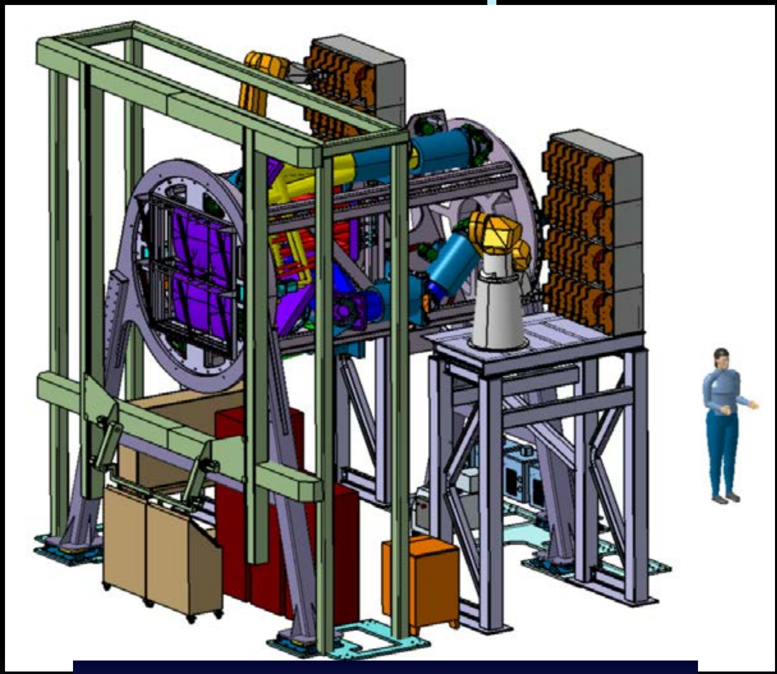
# DIORAMAS (OPTIMOS)
## A wide field imaging & multi-slit spectrograph for the EELT

- One single instrument for the deepest images and the deepest spectra possible with an ELT
- Multi-slit for the most accurate sky subtraction for faint objects
- Capability to work with GLAO-corrected images
- Optional capability: Integral field unit

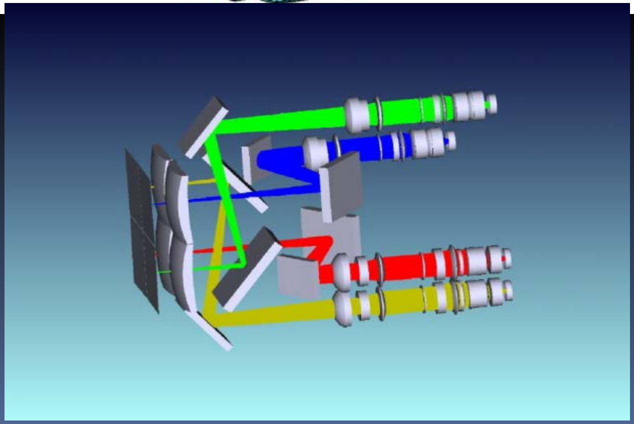
DIORAMAS @ EELT = FORS+VIMOS+HAWKI+KMOS @ VLT

*A powerful imaging-MOS which can do surveys !*

# DIORAMAS
# Innovative and robust concept

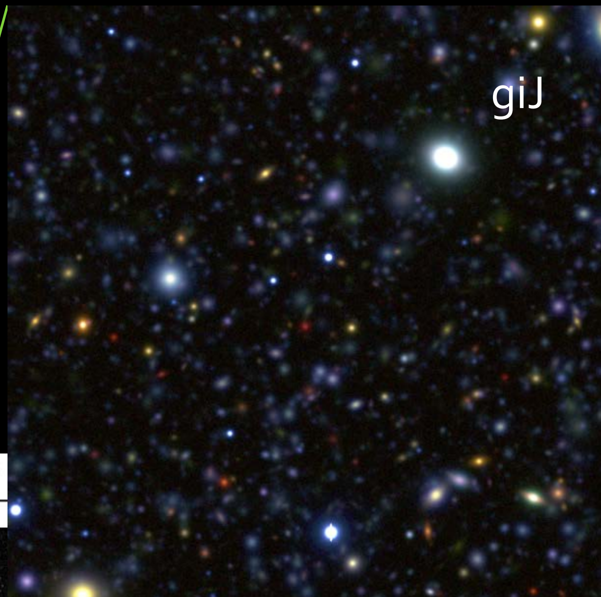


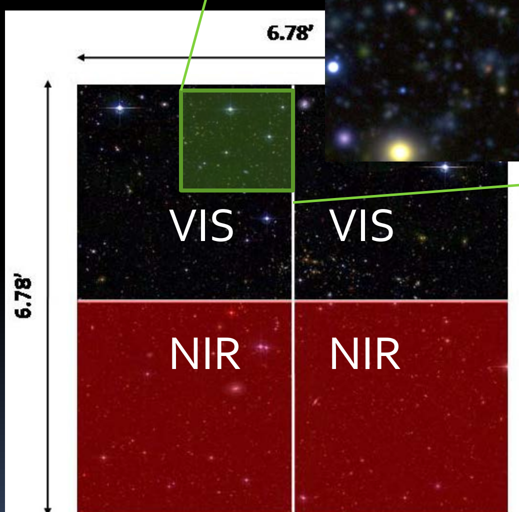
- Wide field up to 44 arcmin², use seeing limited or GLAO-corrected images, 0.05 arcsec/pix
  - 2 Visible and 2 NIR quadrants, with 0.6-1µm overlap
- Imaging and MOS (slits) from 0.37 to 1.6 µm
  - IFU possible
- Superb optical design and compact mechanical layout
- Opto-mechanical systems using industry standards, no R&D required
- Low risk



# Wide field, multi-mode

Imaging

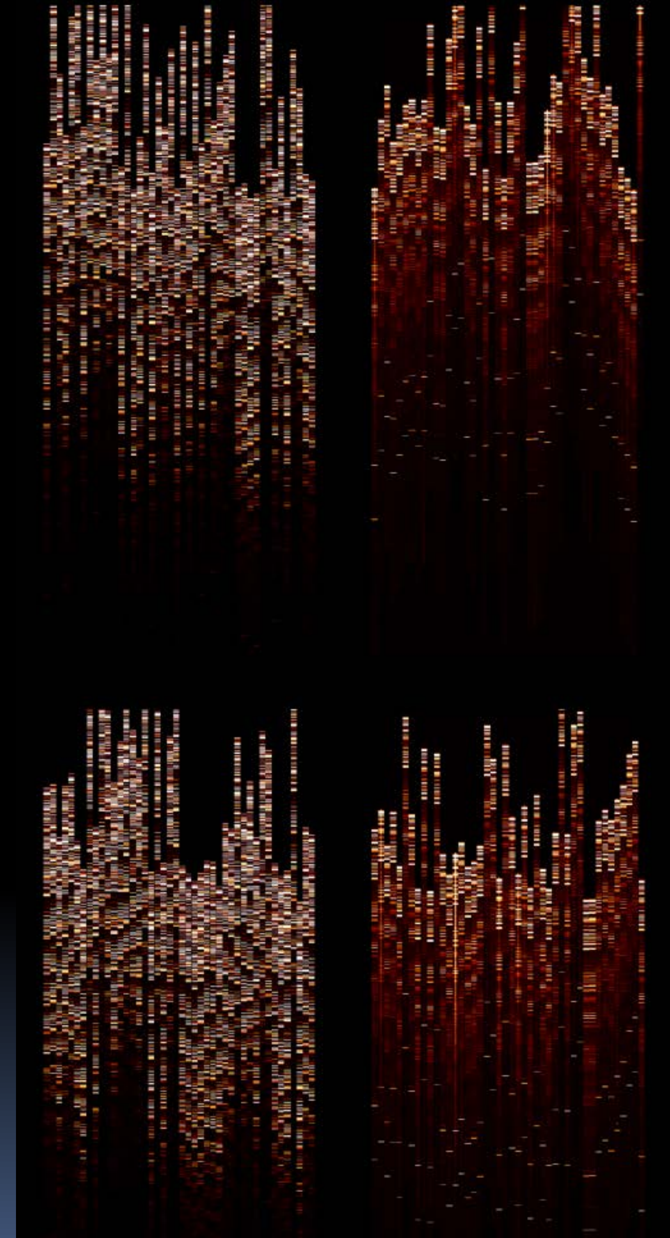



>30,000 sources in 7'x7' to $r_{AB}$=29.8

JWST-NIRCAM

JWST-NIRSPEC



Multi-slit R~300, 480 slits

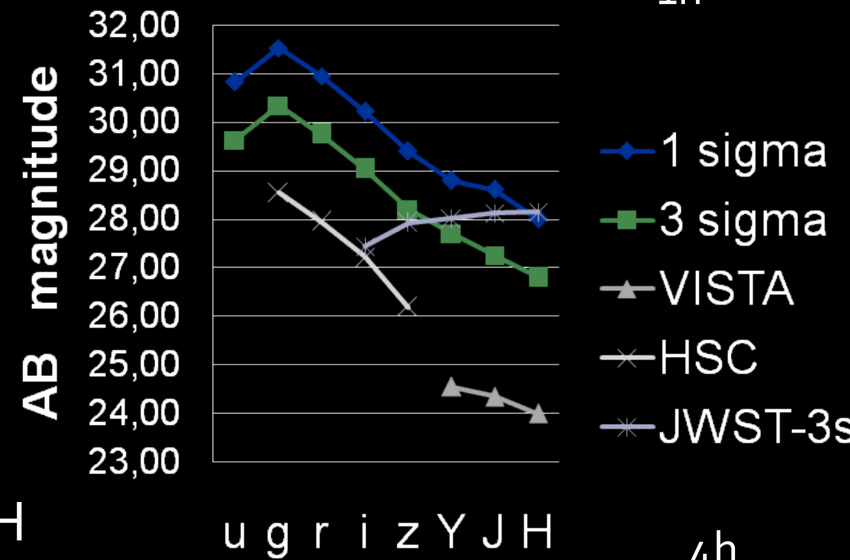
Multi-slit R~3000, 160 slits

# DIORAMAS

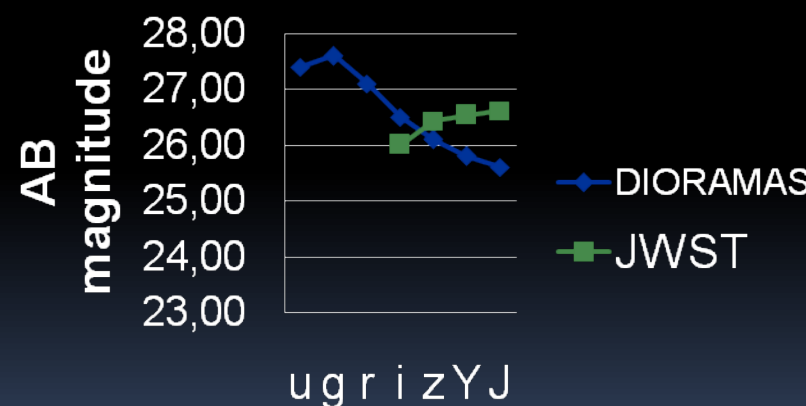
## High level of performances

- Excellent image quality and high throughput (~70%)
- Extremely deep imaging from u' to H
- High multiplex: 160 slits in HR, 480 slit in LR, 0.37 to 1.6µm
- Limiting magnitude (4h): AB~29 in imaging, AB~26.5 in MOS
- GLAO: from 0.7 to 0.4 arcsec over FOV

1h




4h

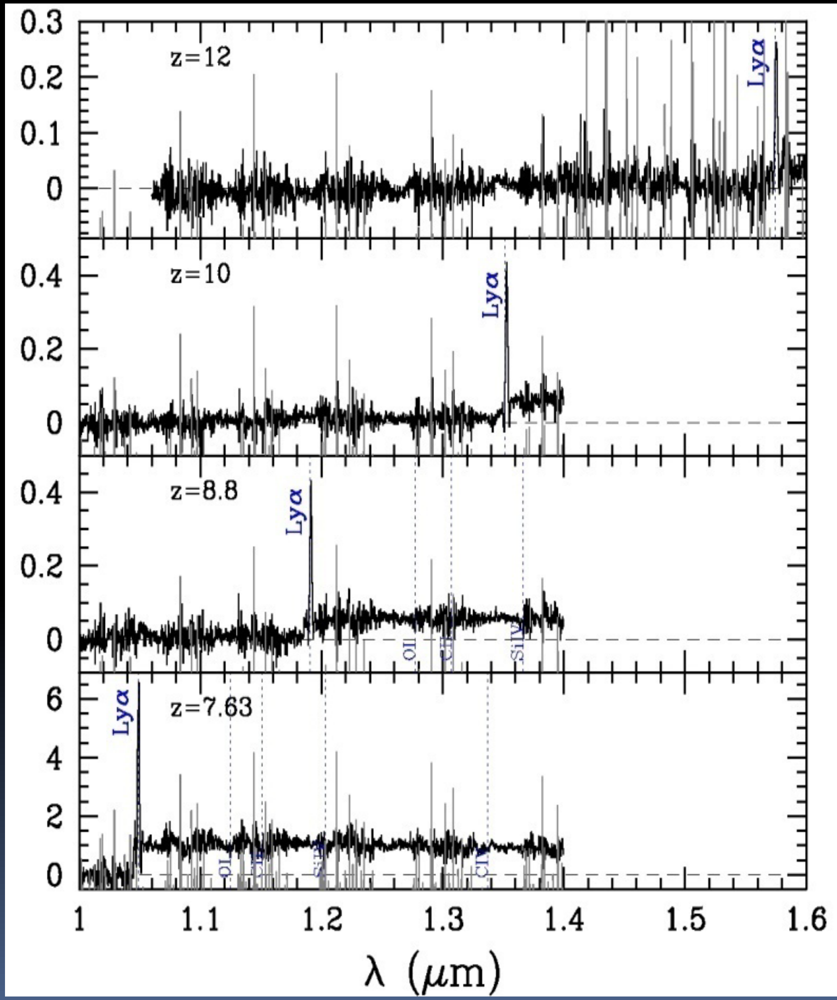



Gain @1µm compared to JWST-NIRSPEC: x5 multiplex, x2.5-5 the FOV, at equivalent depth/unit time

# DIORAMAS:‘first light’ science

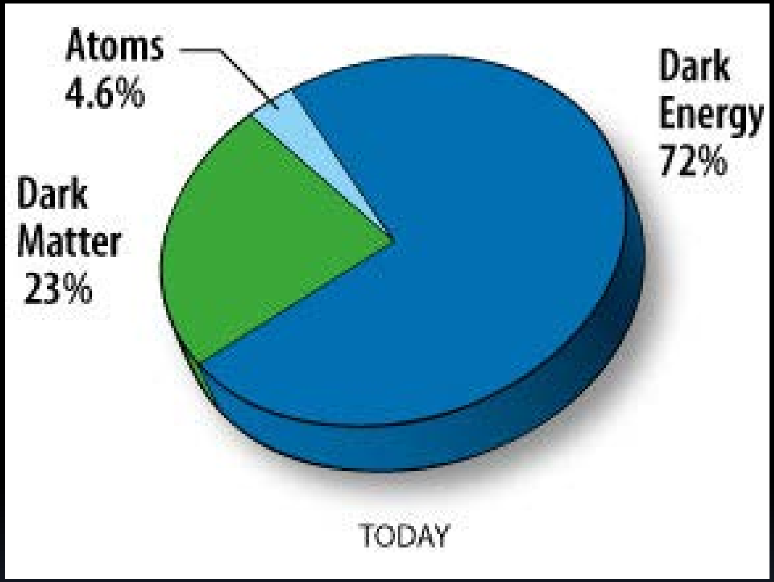
Combine first light study of ~100 galaxies z>7 with galaxy assembly 1<z<6 on 10000 galaxies

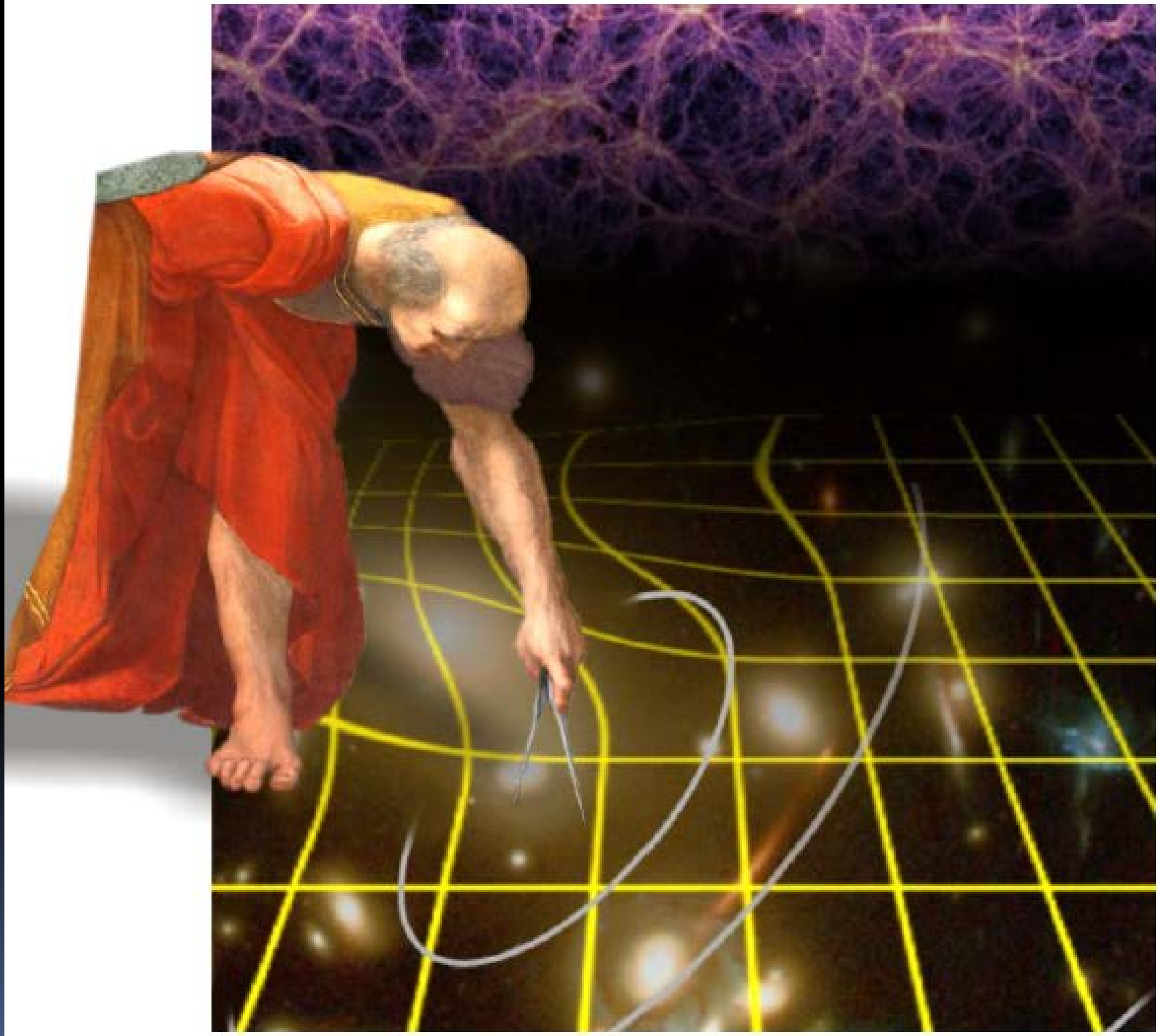
- 88 arcmin², 2 DIORAMAS pointings
- ugrizYJH GLAO imaging, AB~30, 20h per pointing: 40h
- NB imaging z~8.8: 2x5h
- R~300 GLAO MOS, AB~27.5, 10x2h masks per pointing: 40h
- IFU (optional), 4 gal per pointing, 25 pointings, 100h



# The ESA-Euclid space mission

- The major space cosmology mission for the next decade
- Selected by ESA in Oct.2011
- Launch 2019
- Goals: understand the nature of dark matter and dark energy





# Euclid

## Mapping the Geometry of the Dark Universe

http://www.euclid-ec.org

# Science drivers of the Euclid Mission



**Understand the origin of the Universe's accelerating expansion**

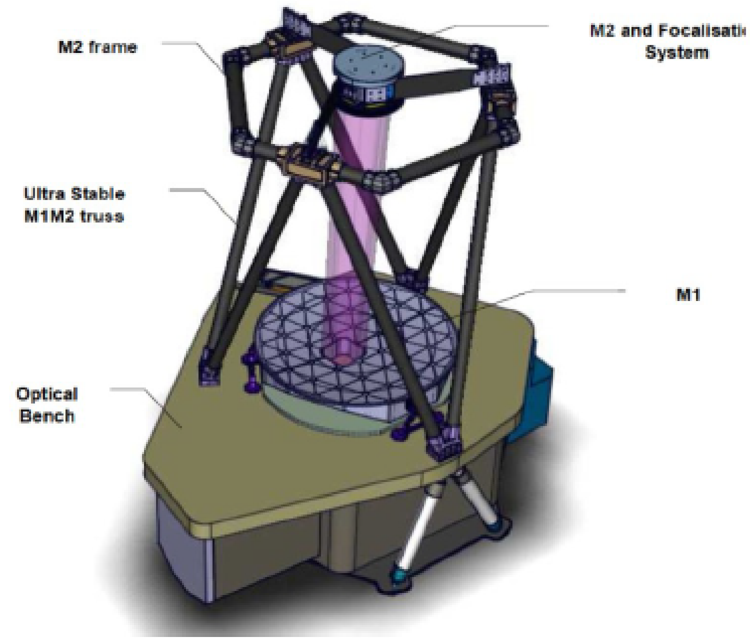
→ probe the properties and nature of

*dark energy, dark matter, gravity*

and distinguish their effects decisively

→ by tracking their observational signatures on the

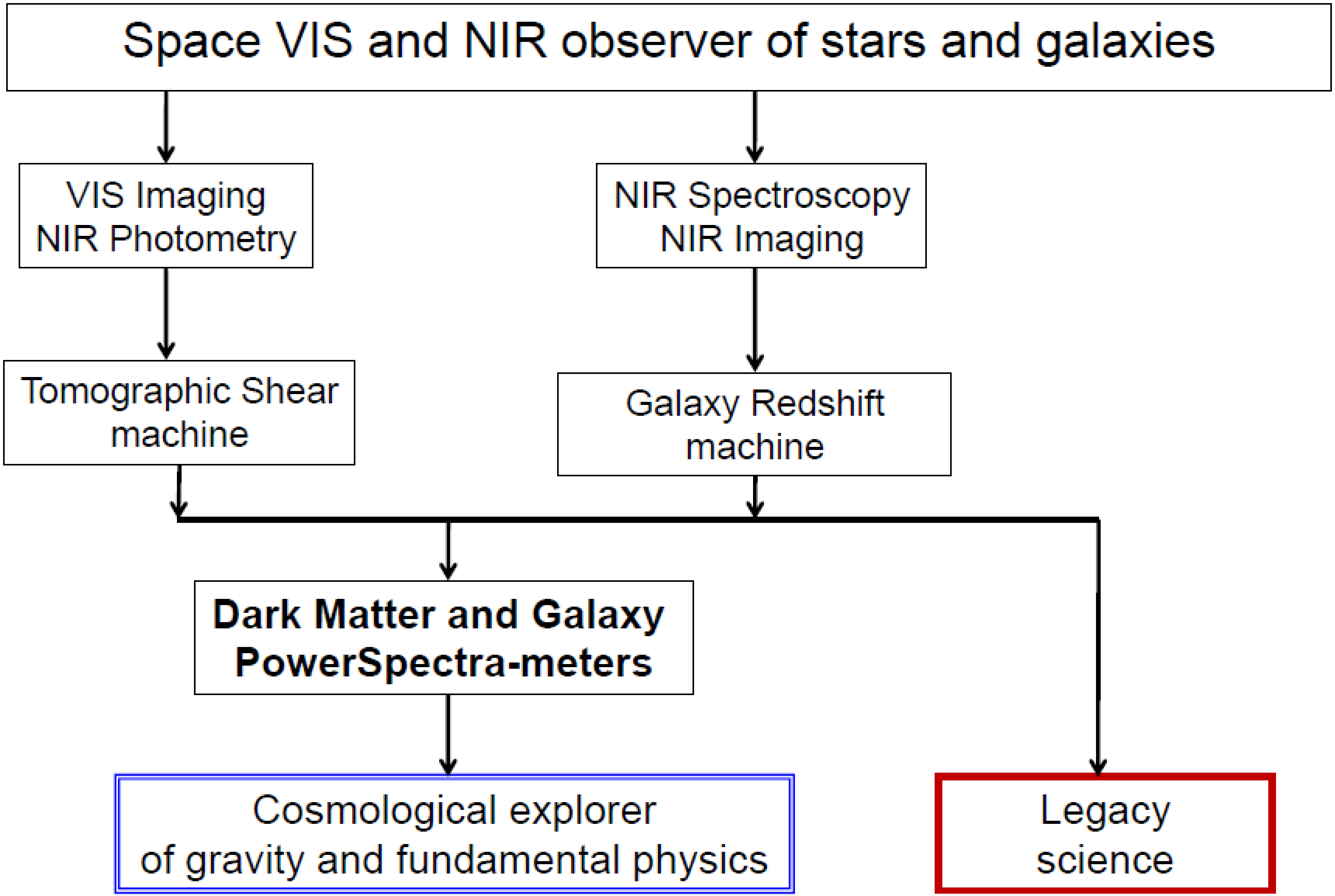
- geometry of the universe: Weak Lensing + Galaxy Clustering
- cosmic history of structure formation: WL, z-space distortion, clusters of galaxies




→ **controling systematic residuals to an unprecedented level of accuracy, that cannot be reached by any other competing missions/telescopes**

# The Euclid high-precision machine

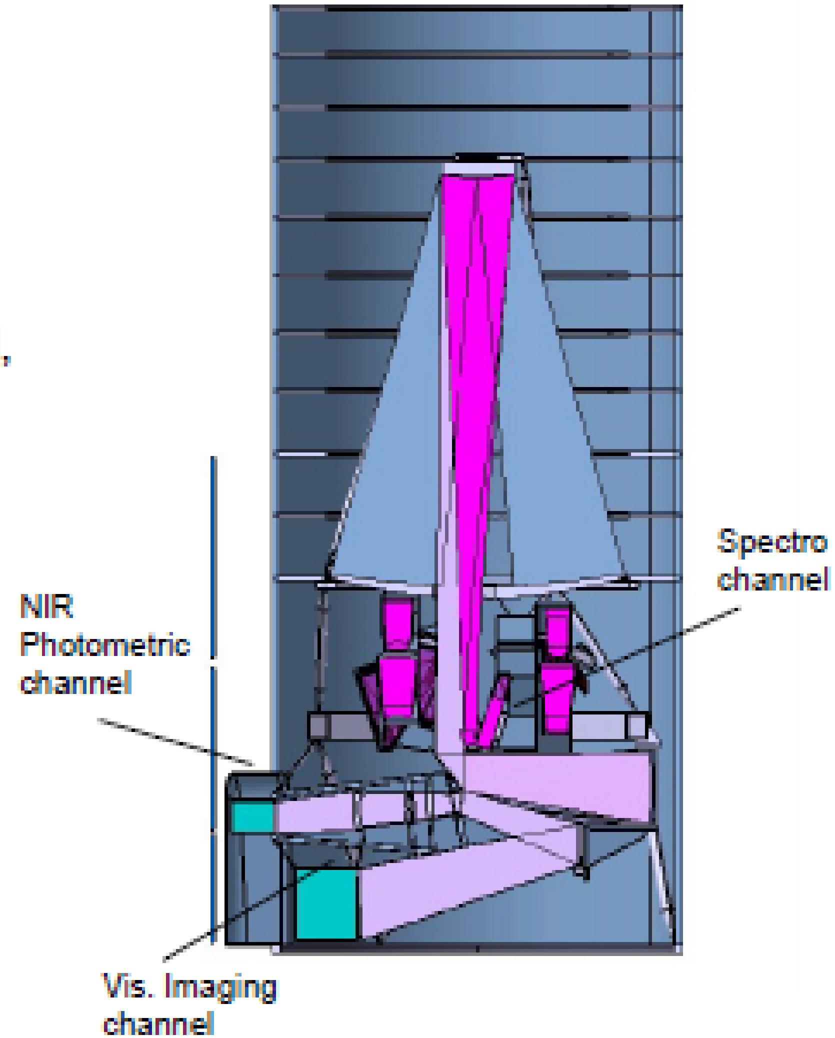




# Euclid mission element



- Launch Soyuz, end 2019 L2 Orbit
- 6 years mission
- Telescope: 1.2 m
- Instruments:
- **VIS**: Visible imaging channel:
  - 0.54 deg$^2$, 0.10'' pixels, 0.16'' PSF FWHM,
  - 1 broad band R+I+Z (0.55-0.92mu),
  - 36 CCD detectors, galaxy shapes
- **NISP**: NIR photometry channel:
  - 0.54 deg$^2$, 0.3'' pixels,
  - 3 bands Y,J,H (1.0-1.7mu),
  - 16 HgCdTe detectors, photo-z's
- **NISP**: NIR Spectroscopic channel:
  - 0.54 deg$^2$,
  - R(mean)=250,
  - 0.9-1.7mu, slitless, spectro redshifts



# Euclid mission baseline: surveys



## I. Wide Survey: 15,000 deg$^2$: Extragalactic sky - 5.2 years

- **Visible:**
  - Diffraction limited images (0.16 " FWHM PSF)
  - Galaxy shapes for 1.5.10$^9$ galaxies to $RIZ_{AB} \leq 24.5$ (AB, 10σ Extended source)
  - 30-40 gal/amin$^2$, <z>~ 0.9
- **NIR photometry**:
  - $Y$, $J$, $H \leq$ 24 (AB, 5σ Point source), 0.33"/pixel
  - photo-z's errors <0.05(1+z) with ground based PS, DES, LSST, HSC, etc…
- **NIR slitless Spectro:**
  - R=250 at 1.2 micron:
  - Redshifts for 50.10$^6$ gal with em. line fluxes >4.10$^{-16}$ ergs/cm$^2$/s at 0<z<2 and
  - spectro-z errors < 0.001

## II. Deep Survey: 40 deg$^2$ (at ecliptic poles?) 1 visit/month - 6 months

- Science: +2 magnitudes in depth for both visible and NIR imaging data.
- Spectroscopy of ~10,000 galaxies
- Calibrations: monitoring of PSF (>40 visits over 6 years), calib. of NIR data

# Summary

- Deep galaxy surveys have become a central tool for cosmology
- Existing instrumentation produces a lot of great surveys, lot of data, mostly public
- Next generation surveys require complex hence expensive facilities
  - Whole sky survey to z~2 now planned (Euclid)
  - First light survey planned (JWST)
  - ELTs to start soon
- Bright future for galaxy surveys !