Massive spectroscopic surveys in cosmology: the case of DESI, EUCLID and MOSAIC

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Aix*Marseille université Socialement engagée

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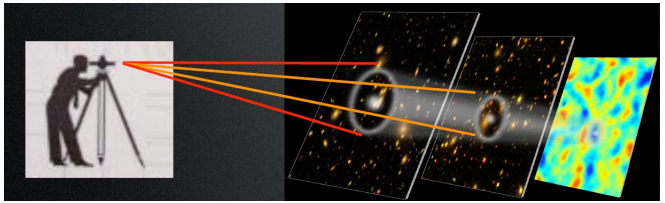
Spectroscopic Surveys: what for?

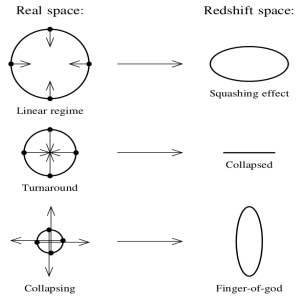
Galaxy and quasar surveys

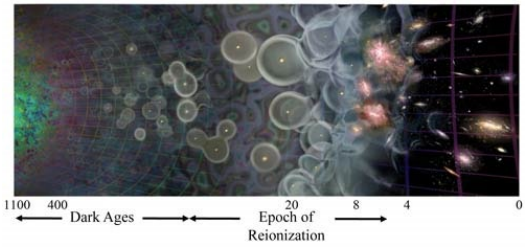
- Cosmology & Dark Energy
  - ➢ Standard rulers
  - ➢ Growth of fluctuations
- Galaxy formation and evolution
  - ➢ Initial conditions (structure formation, first stars and BHs, re-ionization, etc.)
  - ➢ Physical processes (star formation, stellar populations, cooling, feedback, mass assembly, chemo-dynamical evolution, etc.)

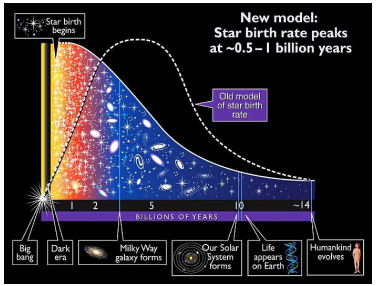
Star surveys

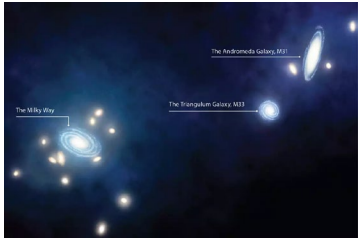
- Stellar populations in the nearby Universe
  - ➢ Evolution of stellar populations
  - ➢ Galactic structures and dark matter physics



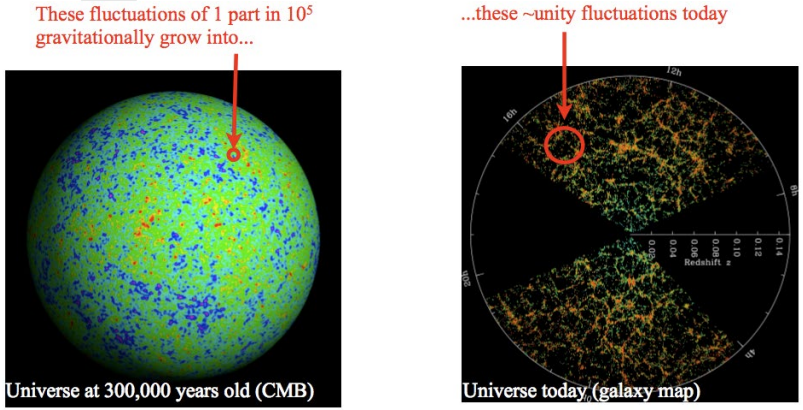




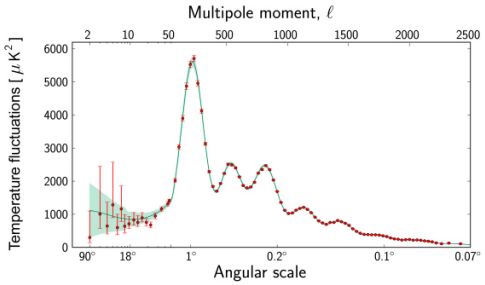




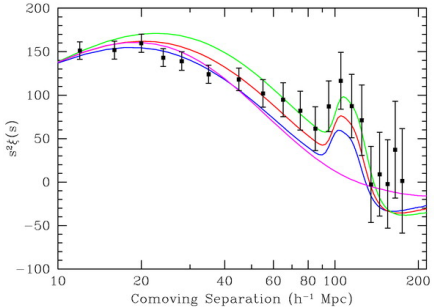
Spectroscopic Surveys: cosmology



Courtesy Picture: Schlegel, Ho

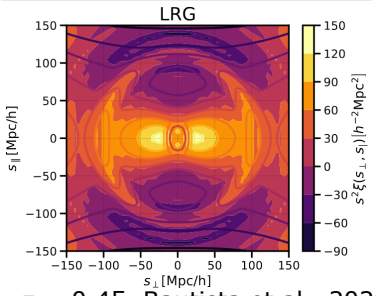


Planck

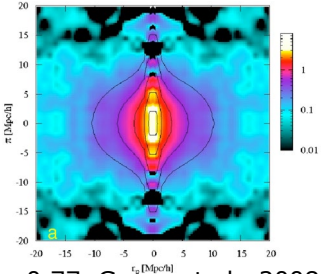


SDSS, Eisenstein 2005

Using the scale $\Delta\chi$ of the CMB peak as a standard ruler, the size of the Baryonic Acoustic Oscillations (BAO) as a function of z yields H(z) and $D_A(z)$



z = 0.45, Bautista et al., 2020



z = 0.77, Guzzo et al., 2008

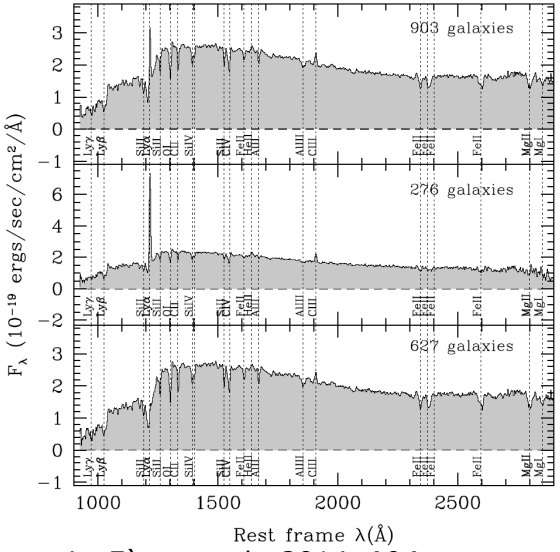
We can measure the growth of structure using Redshift Space Distortions (RSD)

Spectroscopic Surveys: galaxy evolution

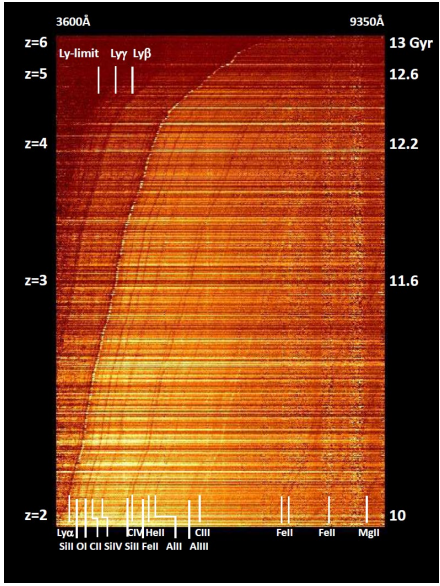
Galaxy formation and evolution up to the highest redshifts, now probing the re-ionization era.

Non exhaustive list of topics related to Galaxy formation and evolution in Euclid:

- Galaxy evolution in different environments
- Galaxy morphology
- Passive galaxies, Galaxy & AGN evolution, Type 1 and 2 AGNs
- High-z (z > 7) objects : QSOs, LBGs, LAEs
- Cosmic Infrared Background
- Galaxy clusters
- Strong lensing
- …



Le Fèvre et al., 2014, A&A



Le Fèvre et al., 2014, A&A

In memoriam

From galaxies to cosmology with deep spectroscopic surveys. A tribute to Olivier Le Fèvre

Marseille, 26-30 October 2021

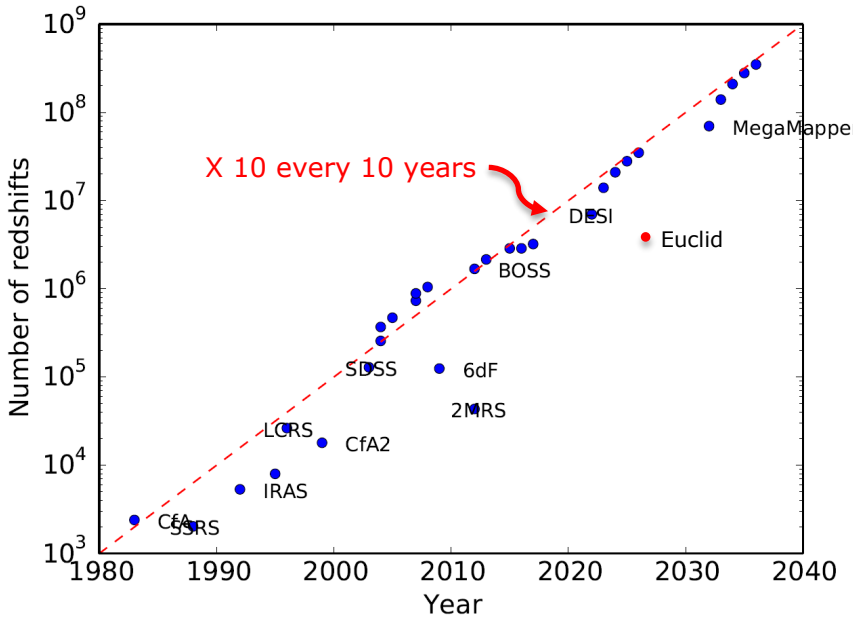
For four decades, wide and deep spectroscopic surveys have been a major tool for extragalactic studies. From precursor surveys with a few hundred galaxies (such as the CFRS in the 1990s) to current projects aimed at collecting several million z>1 redshifts (such as Euclid, PFS), several generations of increasingly deep and massive spectroscopic surveys have revolutionised our understanding of the universe. They have enabled detailed studies, on statistically significant samples, of galaxy evolution processes such as star formation, mass assembly, merging and interaction with the environment in a cosmological context. Advances in instrumentation have pushed observational limits, now allowing us to probe the epoch of reionization with unprecedented large samples of objects. With the current generation of large spectroscopic surveys about to begin, we are now entering the era of precision cosmology. These surveys will profoundly improve our understanding of dark matter, dark energy and of the detailed physics of galaxies in relation to their local (circumgalactic) and large-scale intergalactic environments.

Olivier Le Fèvre has pioneered, led and tirelessly promoted several of the largest spectroscopic surveys to date. He has been at the forefront of these scientific topics for decades. This conference is a tribute to his legacy.

Spectroscopic Surveys

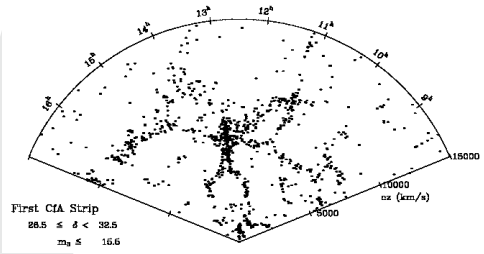
- Roman (2026+)
- Euclid (2023+): $N_{H\alpha}$ ~ 25,000,000 ; 14,000 sq. degrees
- DESI (2021+): N_{spec} = 30,000,000 ; 14,000 sq. degrees
- eBOSS (2020): N_{spec} = 200,000 ; 800 sq. degrees ; NUV,r ≤ 22.5
- 2MRS (2003): N_{spec} = 45,000 ; 37,000 sq. degrees ; K ≤ 11.8
- WiggleZ (2011) : N_{spec} = 200,000 ; 800 sq. degrees ; NUV,r ≤ 22.5
- 6dFGS (2006): N_{spec} = 110,000 ; 17,000 sq. degrees ; B ≤ 15.7
- VVDS-WIDE (2013): N_{spec} = 26,000 ; 8.7 sq. degrees ; i_{AB} ≤ 22.5
- 2dfGRS (2003): N_{spec} = 230,000 ; 1,500 sq. degrees ; B < 19.5
- CfA (1982): N_{spec} = 1,100 ; 780 sq. degrees ; B < 15.5

Schlegel et al., 2019, arXiv:1907.11171v1



Adapted from Vincent Le Brun and Martin Crocce, Advanced Euclid School 2020, Le Fèvre et al. 2013, A&A

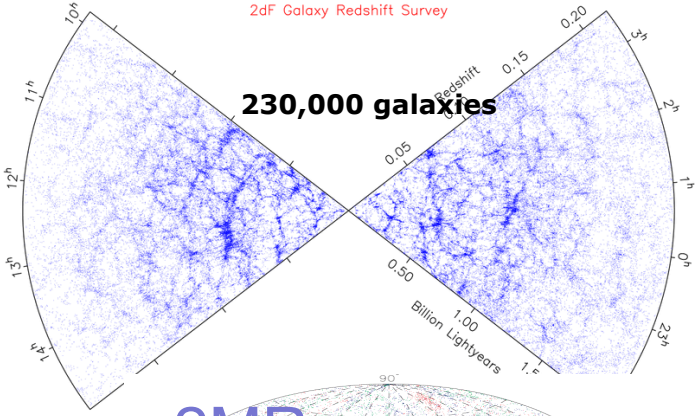
Spectroscopic surveys



De Lapparent et al. 1985

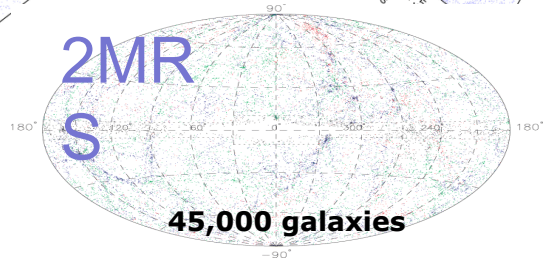
1,000 galaxies

2dFGRS



230,000 galaxies

2MRS



45,000 galaxies

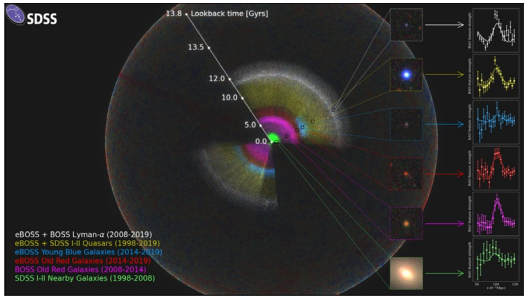
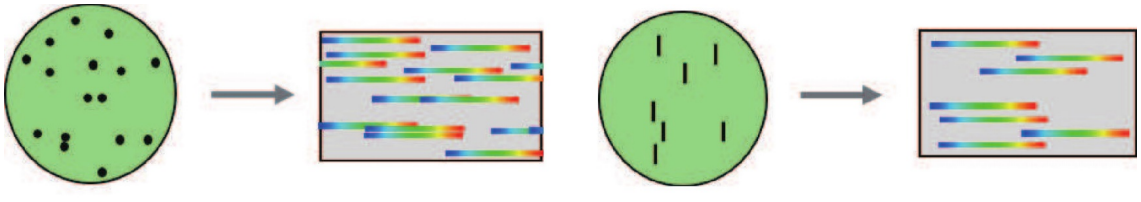


Image credit: Anand Raichoor (EPFL), Ashley Ross (OSU) and the SDSS Collaboration, 2020

2,000,000 galaxies

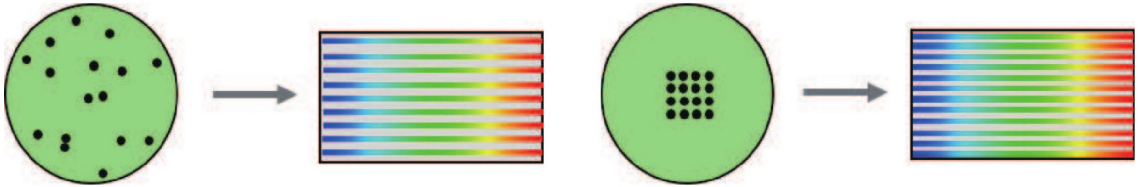
1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025

Multi-Object Spectrographs (MOS)



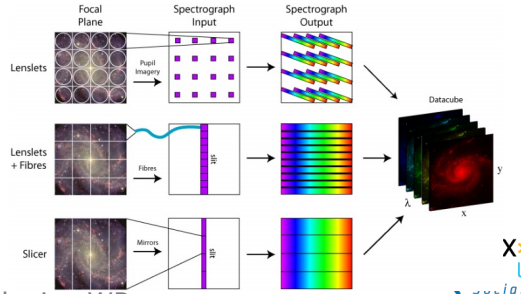
(a) Objective prism spectrographs

(b) Multi-slit spectrographs



(c) Multi-fiber spectrographs

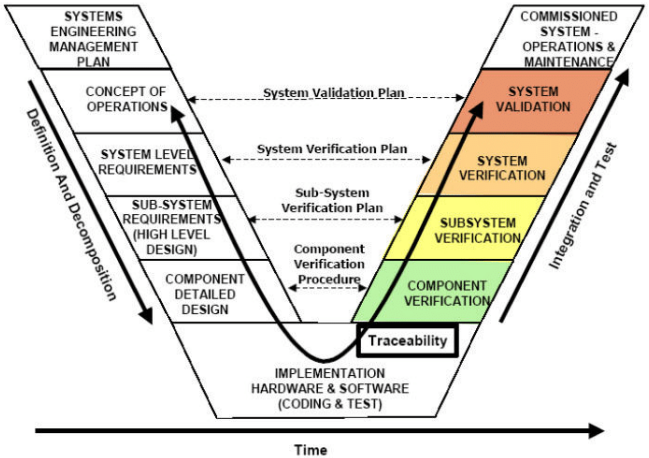
(d) Integral field spectrographs



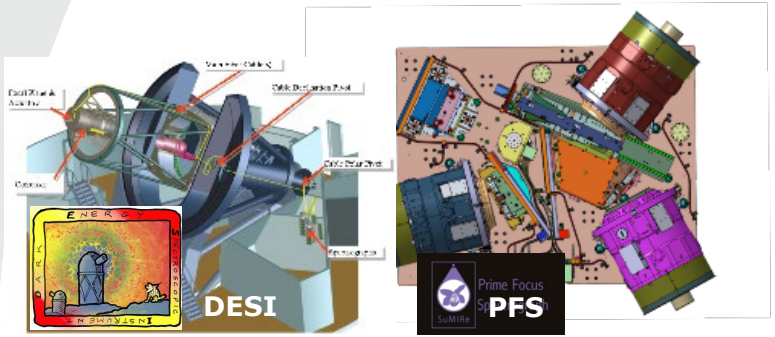
Locks (personal view)

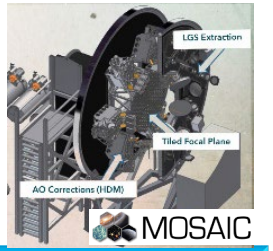
From IPhU Cosmology & Galaxies WP seminar series organizers: Ideally, these seminars are intended to give the researchers of the Cosmology and Galaxies WP the opportunity to present themselves "extra-muros", to discuss at the pedagogical level one or more of their projects/ideas with an emphasis on **the locks to be lifted**, be they technical, experimental or theoretical

- In project speak this is addressed as risks in the risk register where you identify what the risks are and how you propose to mitigate them
- Another way to look at it is through SWOT analyses (strengths, weaknesses, opportunities, threats)
- **Technical** weaknesses and threats (W&Ts) are progressively retired as the project evolves. In principle, no more technical risks or W&Ts after commissioning
- **Scientific** W&Ts may remain or appear until the end of the project/mission

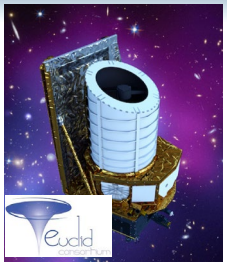


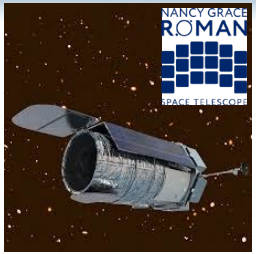
Spectroscopic Survey Instruments @ LAM





2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030





DESI Concept

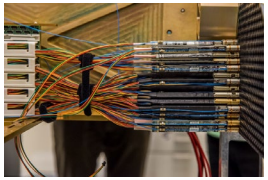
Scale up of BOSS with a massively parallel fiber-fed spectrometer with 5x more fibers (**5,000**), larger telescope aperture (Mayall, **4-m**), robotic fiber positioners

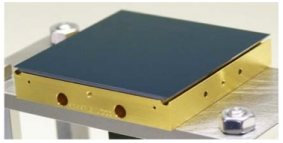
BAO over a broad redshift range: $0.5 < z < 1.6$, $2.2 < z < 3.5$

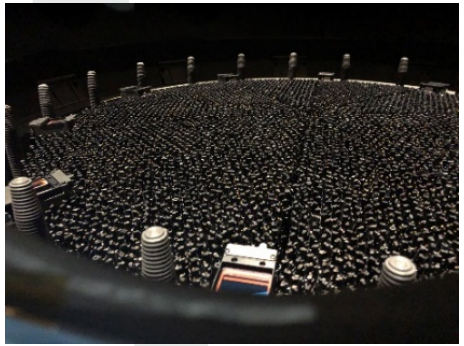
Sky area: 14,000 square degrees

Number of galaxy redshifts: 30 million

Medium resolution spectroscopy, R ~ up to 5500



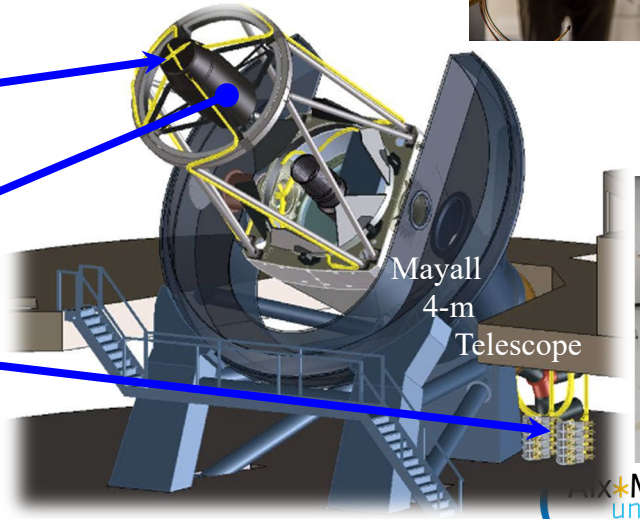




5000 fiber actuators

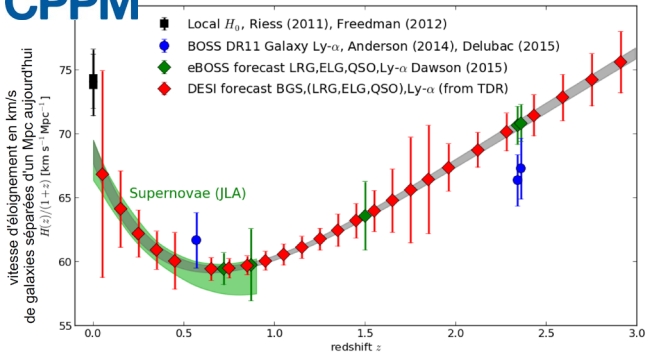
New 8 deg^2 field-of-view corrector
DES heritage

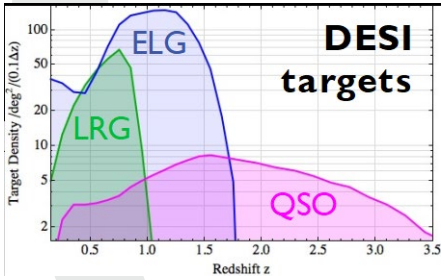
10 New spectrographs
BOSS heritage

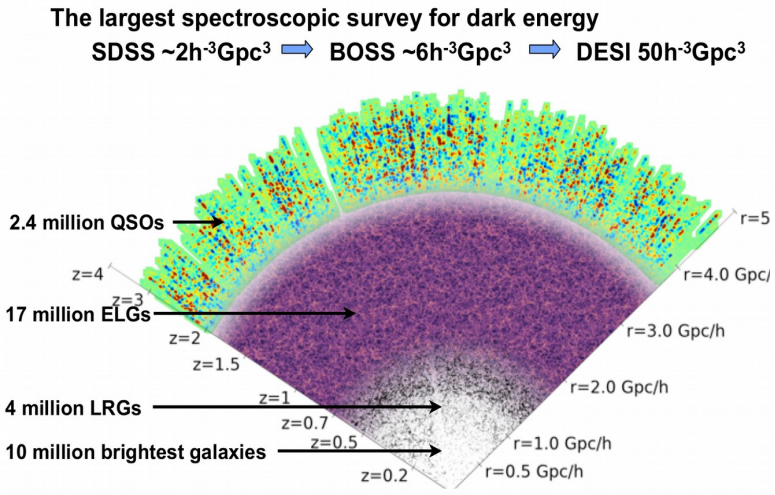


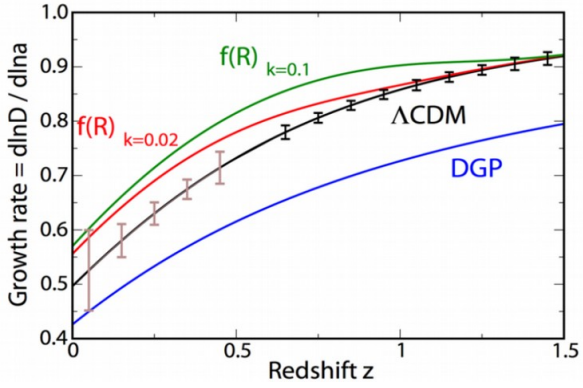
DESI Survey

- Will produce the best measurement of BAO by performing a spectroscopic survey over 14,000 sq. degrees out to redshifts of 3.5
- 4 million Luminous Red Galaxies (LRGs)
- 23 million Emission Line Galaxies (ELGs)
- 1.4 million quasars (QSO)
- 0.6 million quasars at z>2.2 for Lyman-alpha-forest



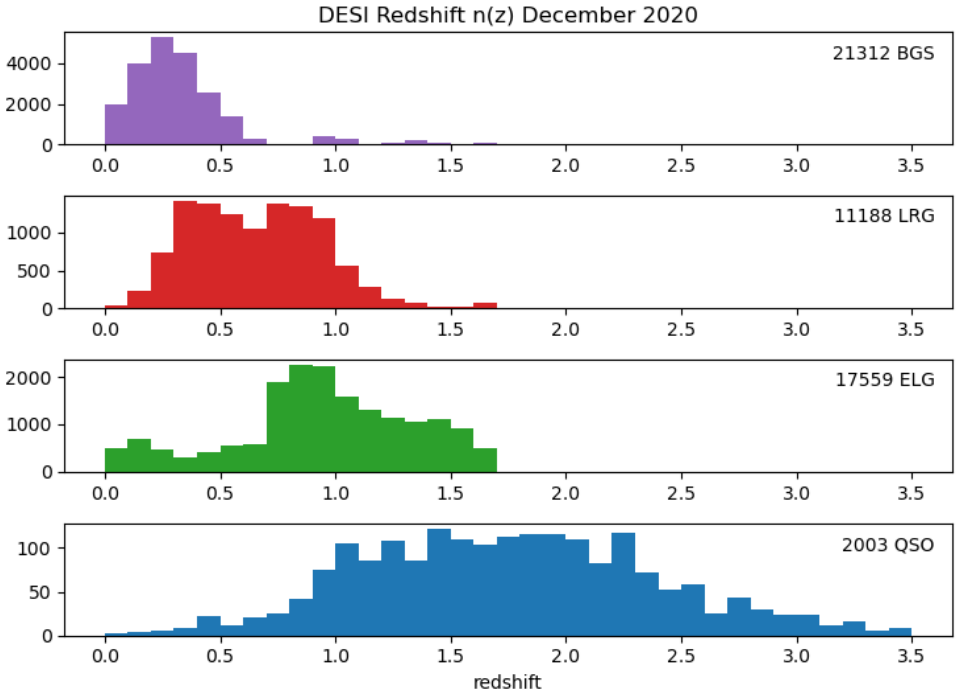






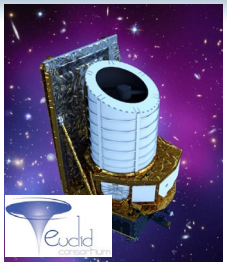
DESI locks, risks, weaknesses & threats

- Except Covid and major technical or environmental issues, almost no risks !
  - ➢ Technical risks have been retired now that the instrument is in science verification (6+ months of delay due to Covid). Almost everything is in spec
  - ➢ No immediate science competitor (Euclid is next)
- From the very beginning, DESI was a low-risk project, building on considerable heritage (SDSS, BOSS, eBOSS)



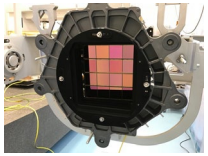
Spectroscopic Survey Instruments @ LAM

2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030

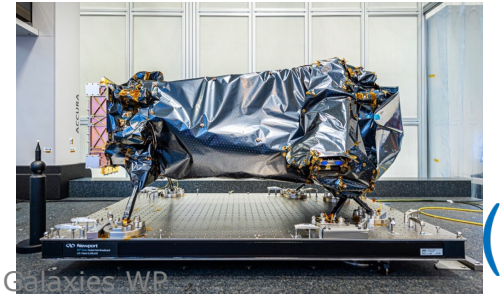


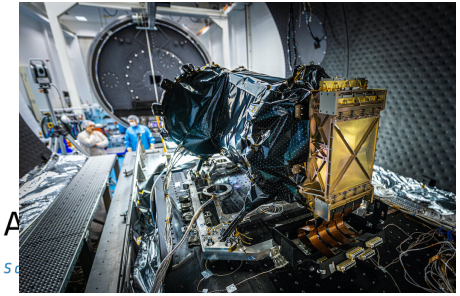
Euclid

- M-class ESA Cosmic Vision Mission with a contribution from NASA
- Orbit : L2 ; Launch date : 09/2022 ; 6-yrs survey only mission
- Telescope diameter = 1.2 m
- 1 optical band, 3 NIR bands
- 0.10’’ optical pixels for weak lensing measurement
- 0.30’’ IR pixels for photometry
- Low-res NIR Spectroscopy (13.4 Angstrom/pixel)
- Wide Survey : 15,000 sq. deg.
- Deep Survey : 40 sq. deg.



- Status: AIT @ Airbus

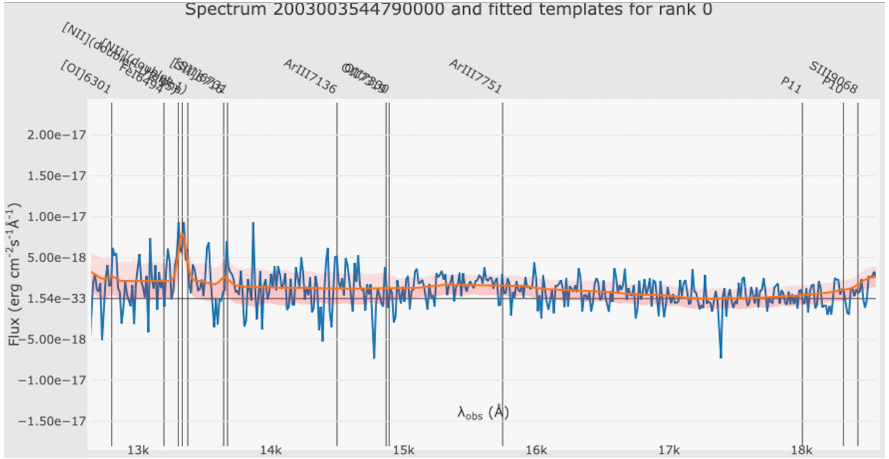




Euclid spectroscopy

- BAO & RSD science with ~ 25 million spectroscopic redshifts with 0.001 (1+z) accuracy over 15,000 deg^2
- $0.9 < z < 1.8$
- Hα > 2. 10-16 erg/s/cm^2
- Automatic pipeline detection with 45% completeness and 80% purity

Hα ~ 2. 10^{-16} erg/s/cm^2

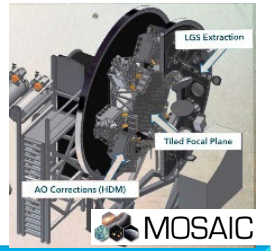


Developments on-going @ LAM (Surace, Le Brun and Amazed team)

Euclid locks, risks, weaknesses & threats

- Still 2 yrs or slightly less to launch, so technical risks are not all retired
  - ➢ Pbs with one NISP grism and VIS readout electronics were found in 2020
- A recent internal analysis of the Galaxy Clustering SWG identified some managerial weaknesses and … no threats (“no obvious ones”) !!!
  - ➢ Major technical issues still possible (and till the end of the mission !)
  - ➢ Meeting pipeline requirements is hard
  - ➢ Scientific threat: DESI (will give results earlier)
- Euclid S&Os remain overwhelming: BAO and RSD science highly complementary to DESI (e.g. in redshift, selection, etc.), combination of cosmological probes (weak lensing and galaxy clustering), legacy science from solar system to re-ionization, etc.

Spectroscopic Survey Instruments @ LAM



2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030

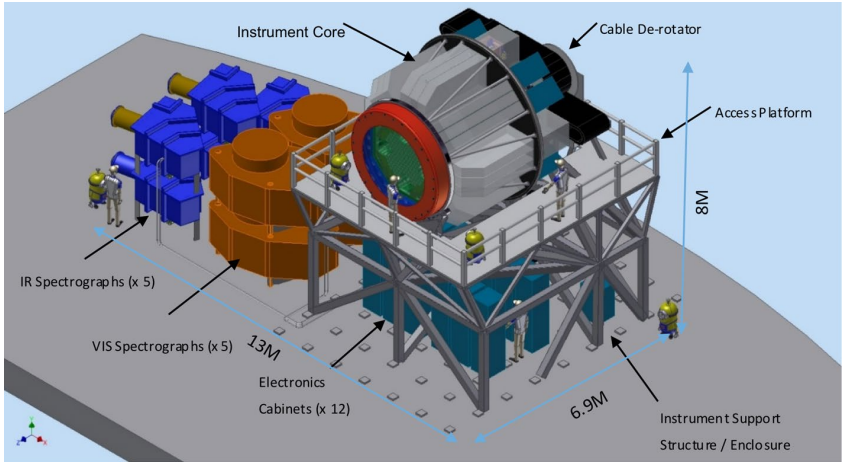
ELT Status

- ELT
  - The ELT is in construction. First light is expected in 2026
  - 39-m diameter

MOSAIC

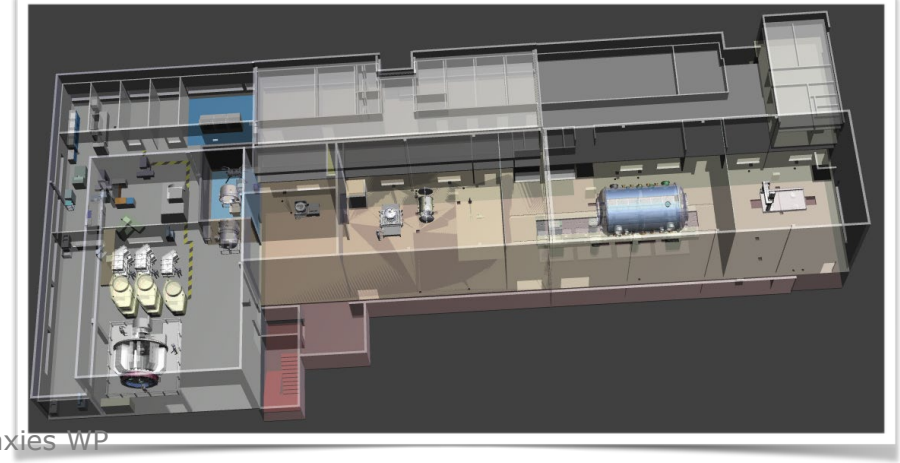
- Status
  - PI (Lidia Tasca), as of 12/2020 !
  - LAM: Project Office, AIT, one or more product and SW WP
  - Phase B contract to be signed in 2021

- Requirements
  - Optical & Near-IR
  - Low & High (18,000) spectral resolution
  - Multiplex visible: 200
  - Multiplex near-IR: 140
  - Multi-IFU (near-IR) > 8



Near IR

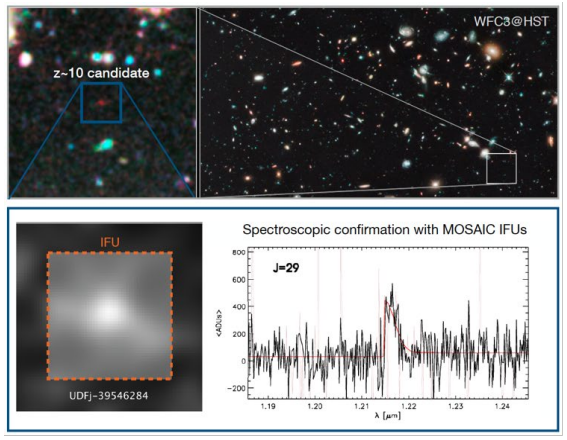
10
44.2 arcmin^2
0.8 - 1.8 µm
1.9 arcsec (hexagonal)
80 mas
5000 & 20,000

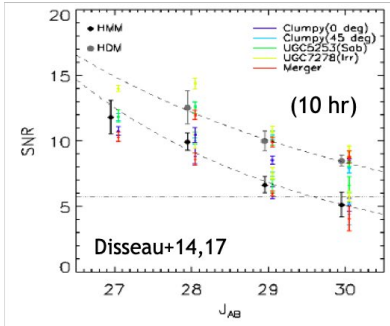


Science Cases

From the nearby Universe stellar populations to the high-redshift Universe

- SC1. First light galaxies & reionisation
- SC2. Inventory of matter
- SC3. Mass assembly of galaxies through cosmic time
- SC4. Resolved stellar population beyond the local group
- SC5. Galaxy archeology



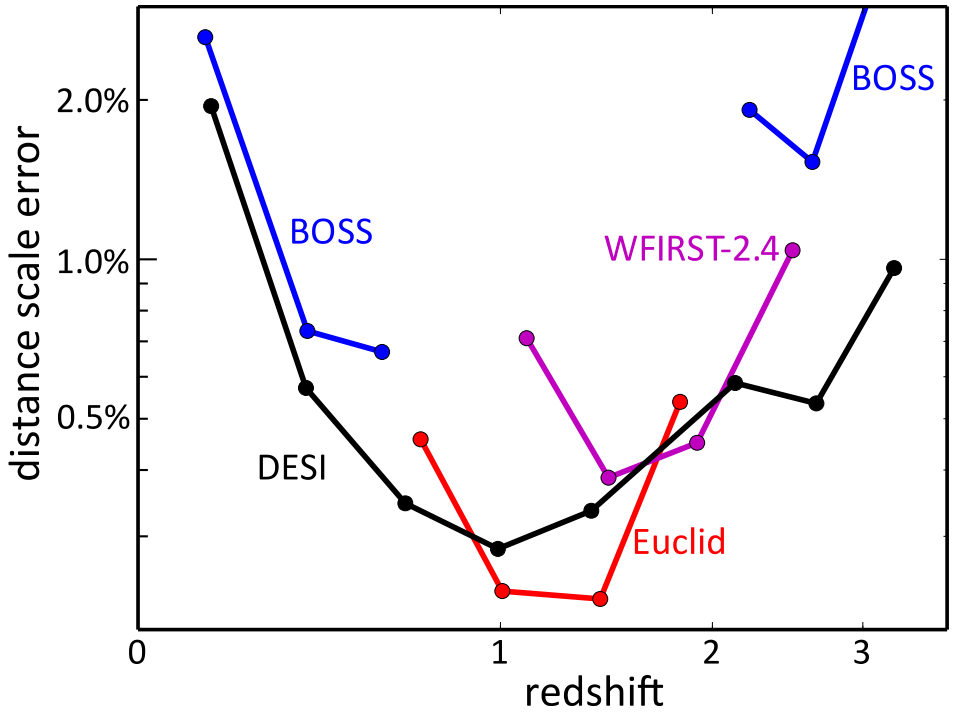


MOSAIC locks, risks, weaknesses & threats

- At the moment, risks are essentially managerial
- Technical and scientific risks to be evaluated during Phase B

- A major opportunity: MOSAIC will be the only MOS instrument on the only ELT built for quite some time

END


distance scale error
2.0%
1.0%
0.5%
0
1
2
3
redshift
BOSS
BOSS
WFIRST-2.4
DESI
Euclid