EUCLID Legacy with Spectroscopy

Gianni Zamorani

INAF - Bologna Astronomical Observatory

(on behalf of the E-NIS Team)

Observing the Dark Universe with Euclid
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EUCLID-NIS

Euclid-NIS is an extremely efficient redshift machine. It will produce 70-160 million redshifts in the redshift range at $0.5 < z < 1.2$ (slitless/DMD) over half of the sky

Such a number of spectroscopic redshifts, by itself, will have an enormous legacy potential, which will be greatly enhanced by the products of the imaging part of EUCLID (morphology, mass, colors etc.).

This combination of products will be a unique resource to the astronomical community and impact **all** areas of astronomy.

Comparison with some of the top existing spectroscopic surveys

	z range	area (sq.deg.)	# spectra	Papers	increase factor in # of redshifts
SDSS	< 0.3	~10,000	~ 1×10^6	> 2000	70 - 160
DEEP2	< 1.4	~ 3.5	50,000	~ 50	1400 - 3200
VVDS	0.2 - 5.0	~ 8.0	50,000	~ 50	1400 - 3200
zCOSMOS	0.2 - 3.0	~1.7	30,000	~ 25	2300 - 5000
Vipers	0.5 - 1.2	~ 24	100,000	---	700 - 1600

Increase by a factor more than 1,000 with respect to the top present spectroscopic surveys at z ~1, and a **factor > 70 with respect to the local SDSS**.

This, by itself, assures a very high legacy value

Other important features of the E-NIS Survey

Well defined selection criteria :
either emission line flux limit (Slitless) or magnitude limit (DMD)
→This will make “easy” the scientific analysis

Main differences between the baseline (slitless) and the DMD option:
Number of redshifts : a factor ~ 2.5
Targets : Slitless : emission line galaxies
DMD : all types of galaxies, including passive galaxies
Spectral features :
Slitless : only emission lines
DMD : also absorption lines

broader scientific output from the DMD survey
(evolution and physical properties of ALL galaxy types; physics of galaxies)

Some of the main scientific goals of the slitless survey

Galaxies :
The evolution of the **multivariate distribution functions** (e.g., luminosity, stellar mass, morphology, environment) of star-forming galaxies;

The cosmic evolution of the **star formation density** and activity at $0.5<z<2$, for different Hubble types;

Star forming galaxies in the LSS;

Evolution of the merger rate of different galaxy populations up to $z < 2$;

The identification of the rarest and most massive early-type galaxies at $z>1.5$, to constrain the evolution of the exponential ends of their luminosity and mass functions; a key test for galaxy formation models;

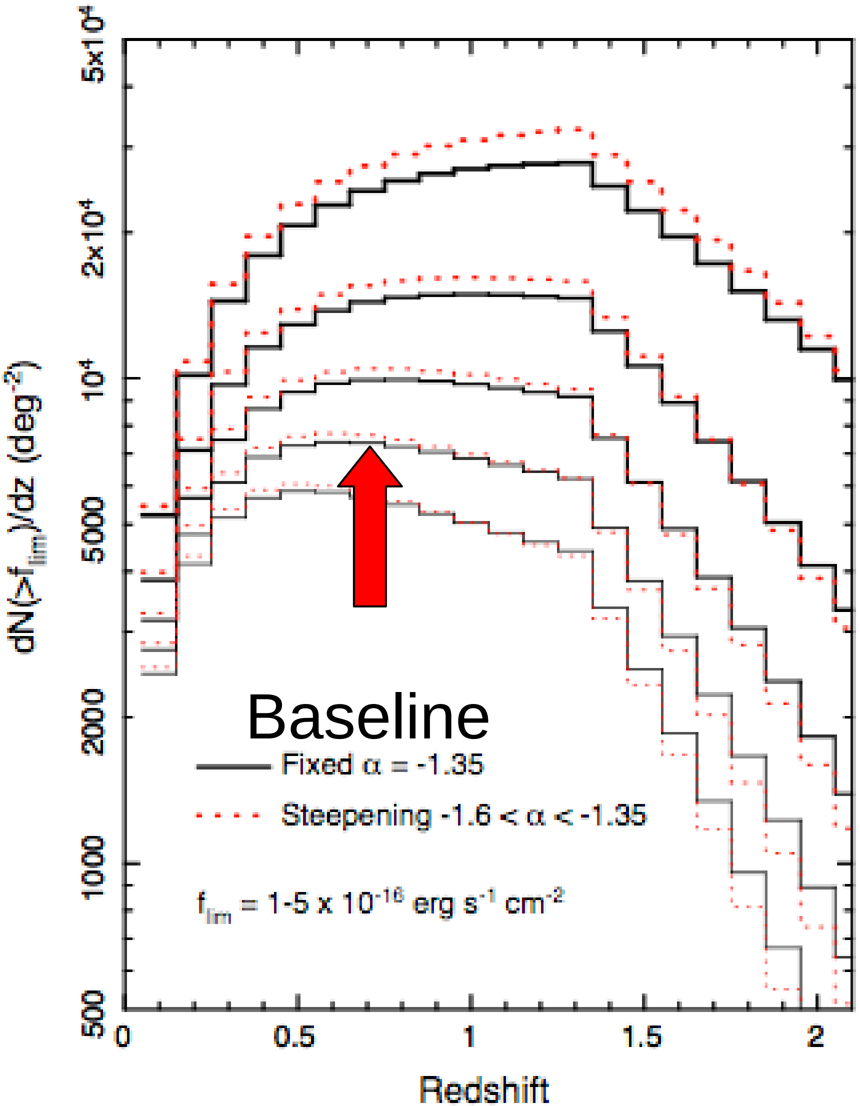
AGN : AGN – galaxy co-evolution
Large samples of Type 1 and type 2 AGN : **a unique sample of type 2 AGN at $z > 1$** and fraction of AGN as a function of properties of the host galaxy (mass, morphology, environment etc)

The High redshift Universe:
"blind" spectroscopic searches for **Lyα emitters and spatially extended Lyα nebulae (Lyα "blobs") + high redshift quasars**

Galactic Science : **ultra-cool dwarfs (L, T, Y);** IMF at very low mass etc.

… and many others

EUCLID dn/dz at 0.5 < z < 2.0



Expected counts of Ha emitters for different flux limits and redshift bins (Geach et al. 2009):

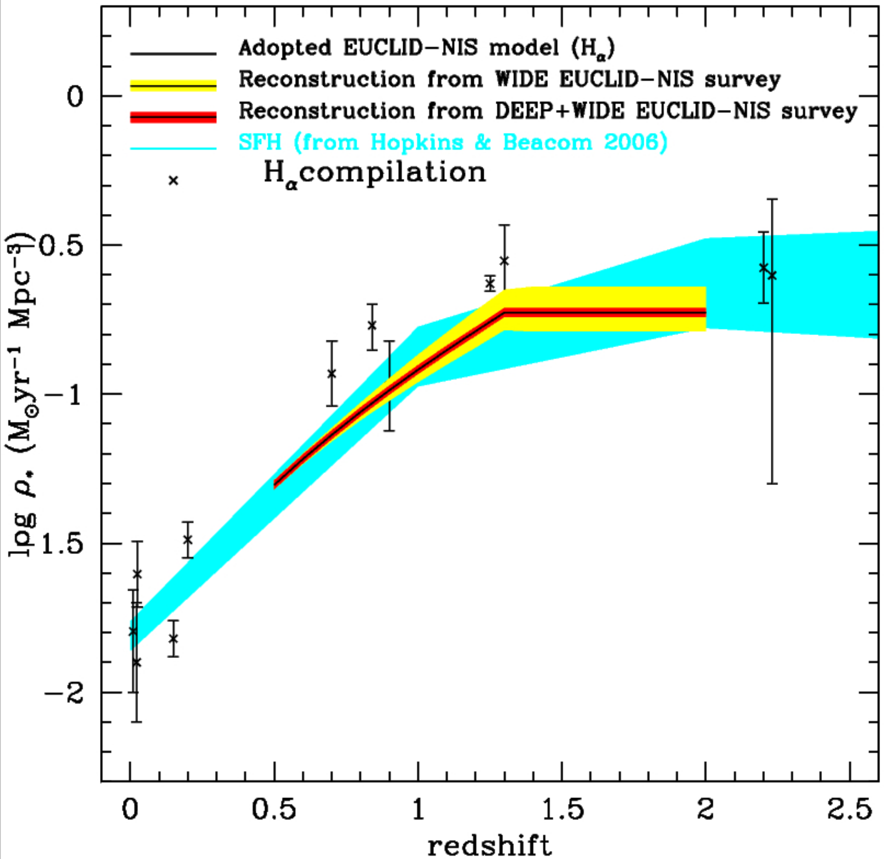
At S ~ 4 x 10^{-16} cgs we expect:

~ 7x10^6 galaxies in Δz bins = 0.1 at 0.5 < z < 1.4 and
~ 1 x10^6 galaxies in Δz bin = 0.1 at 1.8 < z < 2

The ENIS Wide spectroscopic survey will allow us to probe galaxy evolution in very narrow bins of mass, type, star-formation and environment; a necessary step forward to pin-down the main mechanisms of galaxy mass assembly. In addition, the Deep Euclid survey will provide ≈ 46,000 Hα emitters per deg^2 to a flux limit of F(Hα) ≈ 5 x10^{-17} erg s^{-1} cm^{-2}.

Star formation history at 0.5 < z < 2.0

Reconstructed SFR from the wide (yellow; close to zero Poissonian errors) and deep (red; excellent constraint on the faint end slope) surveys



L. Pozzetti

Limits in SF (in solar masses/year):

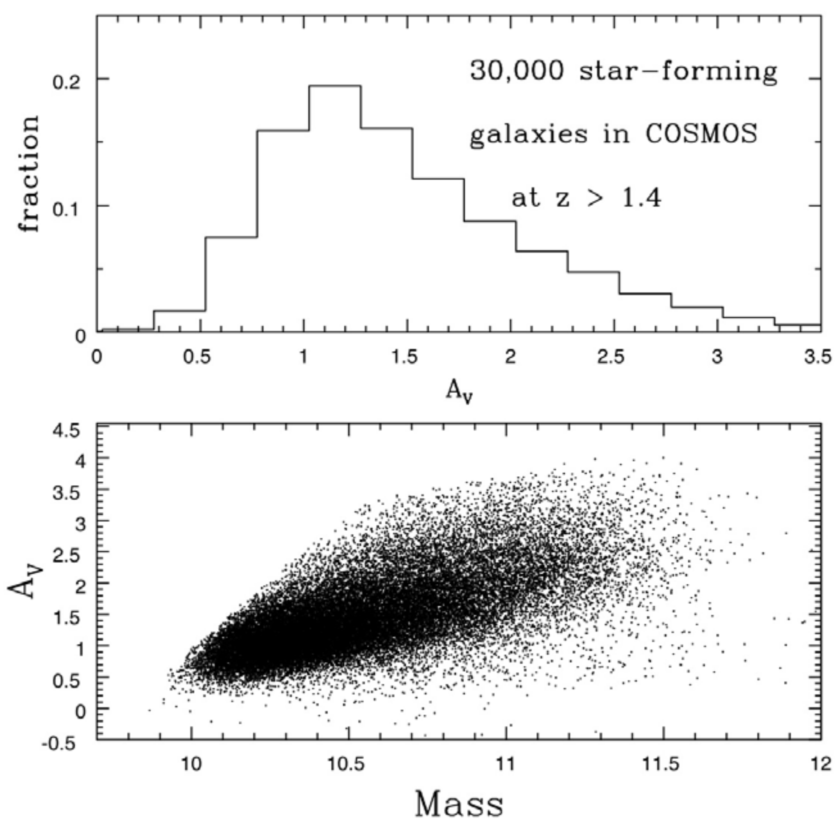
z	Wide	Deep
0.5	5	< 1
1.0	20	~ 2.5
2.0	120	~ 15

accuracy of a few % (modulo uncertainty on extinction correction) in the SFR Density in each dz = 0.1 bin with a **single** SFR indicator over a **wide** redshift range

Excellent example of sinergy between the Wide and Deep Surveys

How will we handle extinction?

Usually, an average extinction of about 1 mag at Hα is ASSUMED



Daddi et al., 2009

We will be able to do much better using, for example, the existing correlation between extinction and mass (mass from Euclid SED fitting)

In addition, for the higher fluxes, we will detect also Hβ at z > 1.05 → this will allow a direct spectral estimate of the extinction

This will help us in significantly reducing the uncertainty in the extinction correction on a galaxy-by-galaxy basis

AGN

About a few % of our spectra will be AGN (**~ 10^6 of them ! - an order of magnitude more than the SDSS quasars**)

1. These will cover an impressively large redshift range, fully sampled by at least two strong emission lines

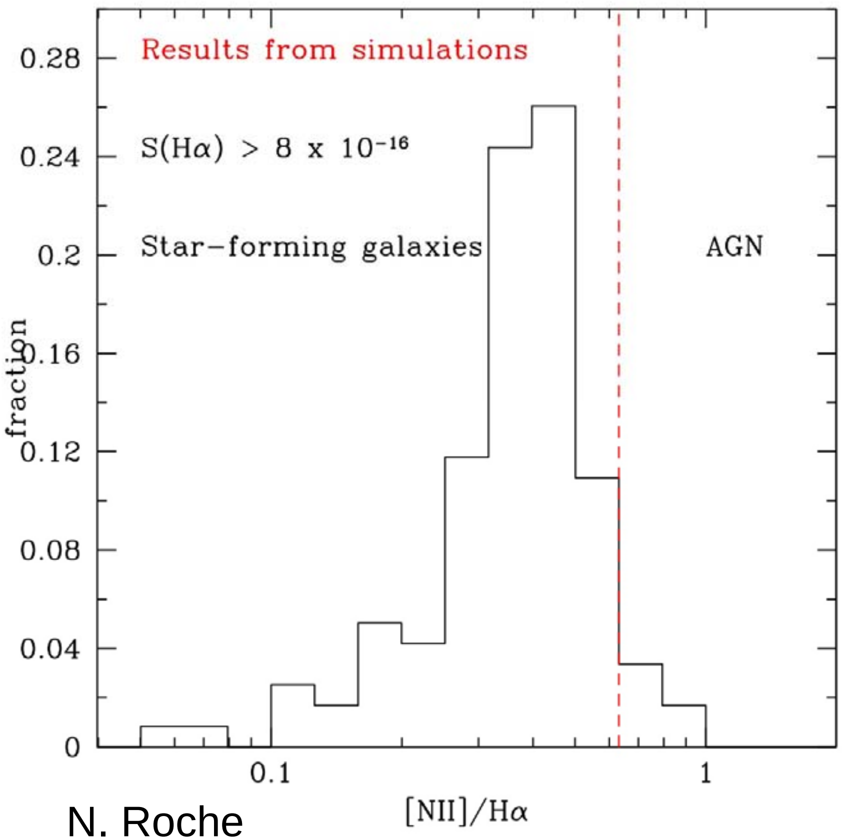
	z range
Ha	0.52 - 2.0
Hβ + [OIII]	1.05 - 3.0
MgII	2.60 - 7.1
CIV	5.45 - 11.9
Lya	7.10 - 16.4

Two strong lines (CIV and Lyα) at 7.1 < z <11.9 !

2. About equally splitted in type 1 (broad lines; easily recognizable from the spectra) and type 2 (narrow lines).

Note that because of the color-color selection, the type 2 AGN are severely under-represented in SDSS and as of today (much) less than 100 type 2 AGN are spectroscopically known in the redshift range 1 < z < 2.

TYPE 2 AGN



N. Roche

Most of our type 2 AGN will be in the same redshift range as our star-forming galaxies and, because of the adopted spectral resolution, we will be able to recognize most of them on the basis of the [NII]/Ha ratio.

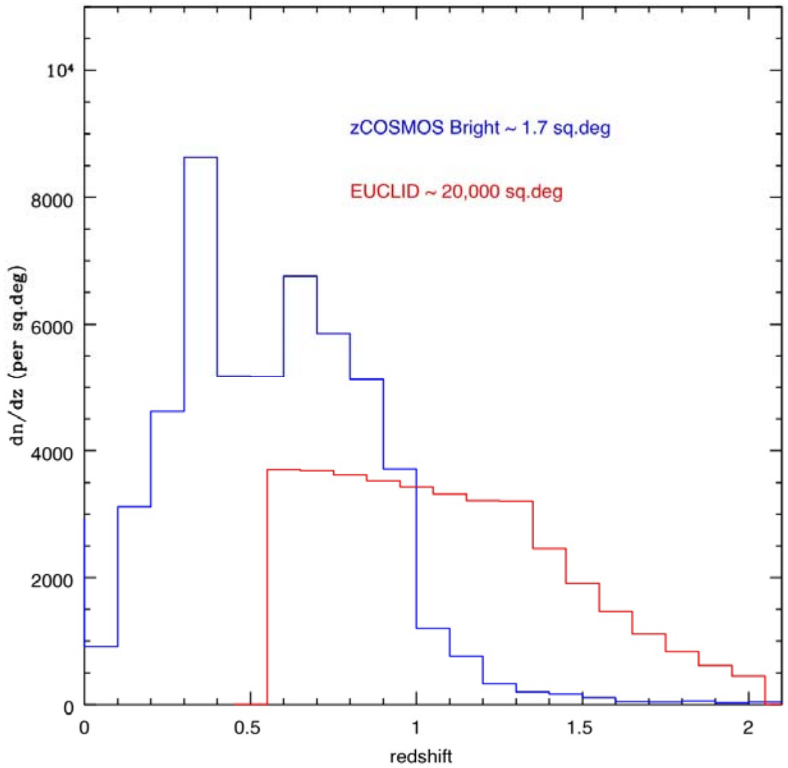
Very few emission line galaxies with S(Ha) > 8 x 10^{-16} cgs ([NII]/Hα ~ 0.3) have a measured ([NII]/Hα > 0.6). This will allow the selection of a clean and large sample of type 2 AGN **~200 x 10^3 at 1<z<2.**

A unique sample to study the f(AGN) as a function of mass, SF, environment and co-evolution of AGN and galaxies in a very interesting redshift range

A gain of a factor more than 10^3 with respect to the number of currently known type 2 AGN in this redshift range!

The LSS: How well will we recover it ?

This mainly depends on the density of the detected galaxies



Simulations described in the YB have predicted the number of groups/clusters expected to be detected with E-NIS.

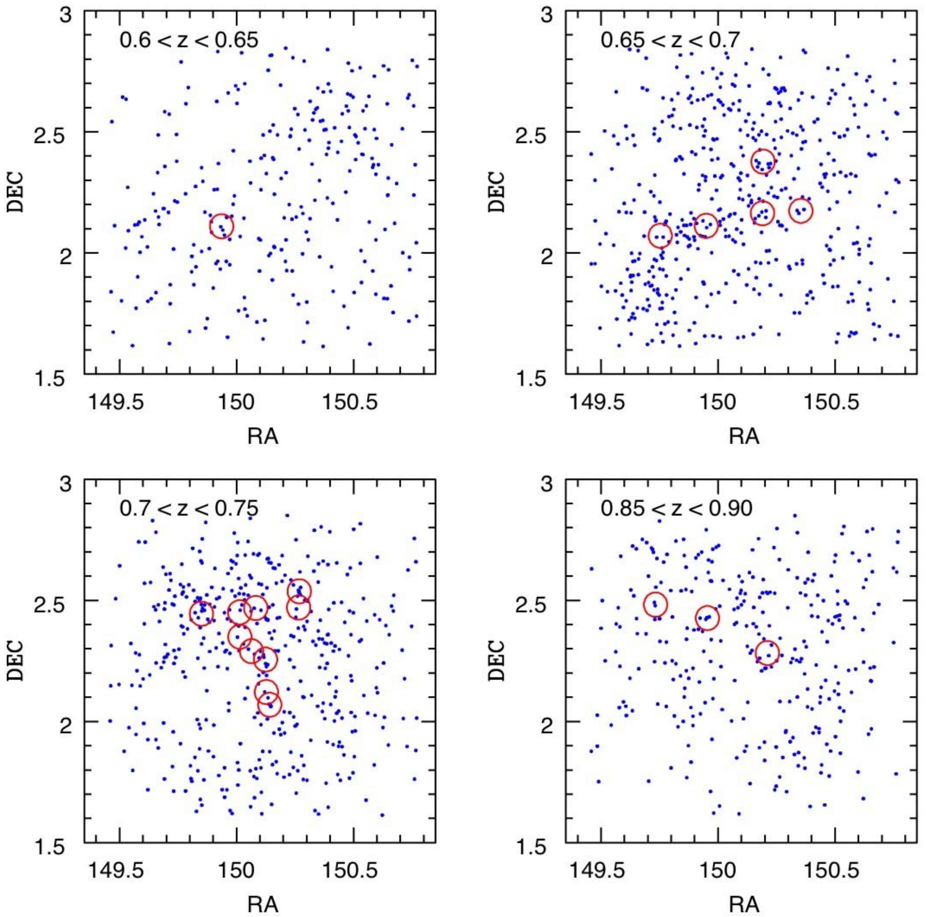
These predictions have been verified using some recent “real” data at $0.6 < z < 1.0$

In the redshift range **0.6 - 1.0**, our expected density (dn/dz) is only ~30% smaller than that in the 10K zCOSMOS sample, from which a well defined group catalog has been derived (Knobel et al. 2009)

Then the EUCLID-NIS dn/dz will stay ~ constant up to at least $z \sim 1.35$

The LSS : what will we see?

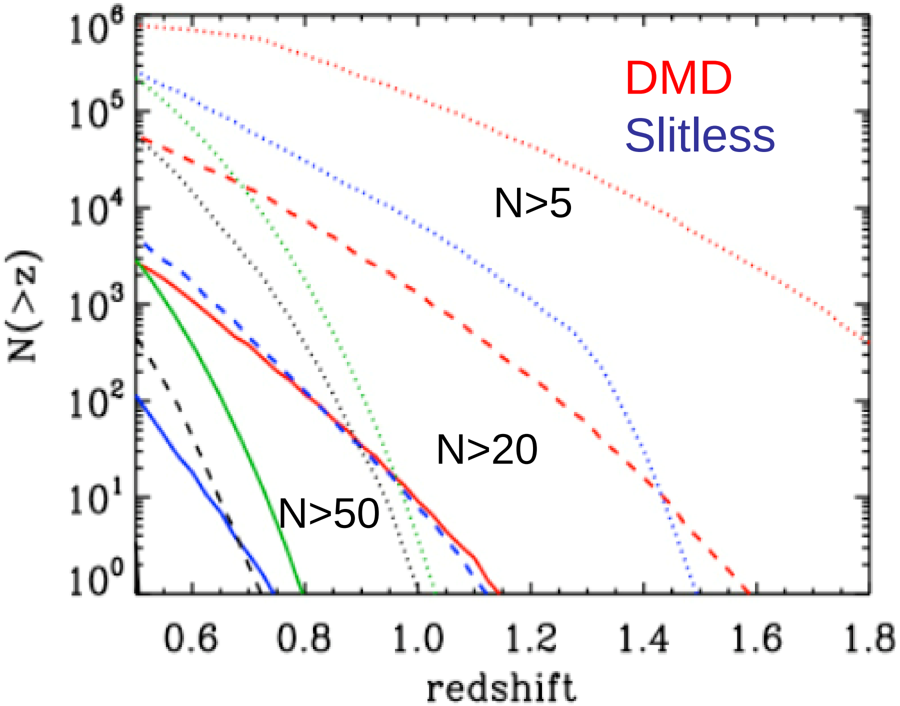
zCOSMOS 10 k data in redshift slices,
with groups (red circles) overimposed



This is approximately what we expect to see (filamentary web + groups) over 20,000 sq.deg.

In z COSMOS there are 24 groups with N>5 members and 0.55<z<0.95. Reducing this number by a factor of two (because of the worse EUCLID redshift accuracy), it implies **~ 140,000 Euclid groups** with N_{memb} > 5 in the same redshift range, in rather good agreement with the theoretically expected number (see Biviano's talk)

The LSS : which questions can we answer ?



Number of groups/clusters

N(z)	slitless	DMD	Gain(DMD)
> 5	~220,000	~800,000	~ 4
>20	~ 5,000	~50,000	~10
>50	~ 100	~3,000	~30

With more than **10^6** galaxies in groups (or >**10^5** in clusters with N_{memb}>20) + photo-z for passive galaxies we will study in detail:

a) mass function of galaxies in groups vs.field and its evolution with redshift;

b) SF as a function of z and environment up to at least z ~ 1.4 in groups;

c) evolution of the morphology-density relation, an essential step to understanding structure formation;

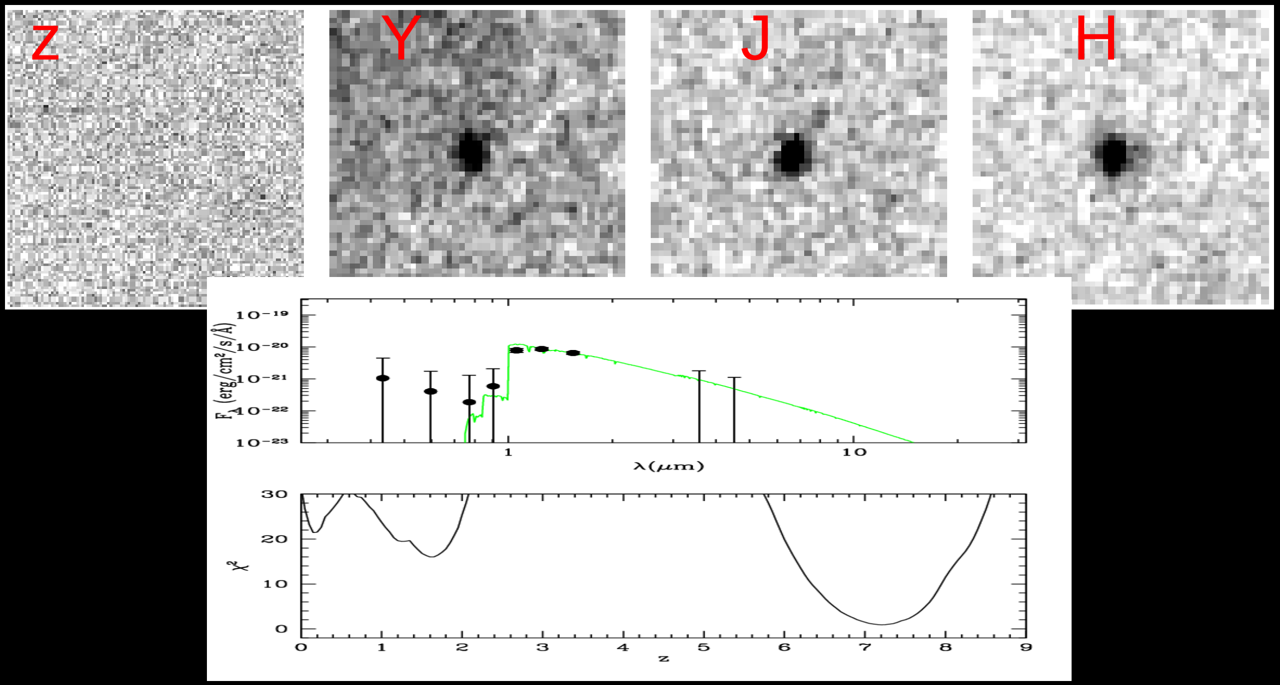
d) physical processes which produce **differential evolution** in fields and clusters

e) ….

With DMD, this science (field vs. environment) would be more powerful by about one order of magnitude : number of clusters + spectra of passive galaxies

Selecting galaxies into the epoch of reionization
(M. Cirasuolo)

Two basic techniques:
1. Lyman-break selection (LBGs)
2. Lyman alpha emitters via narrow-band or spectroscopy (LAEs)



McLure, Dunlop, Cirasuolo et al. 2009, arXiv: 0909.2437

Short wavelength light (λ<1215 Å) is absorbed by neutral hydrogen

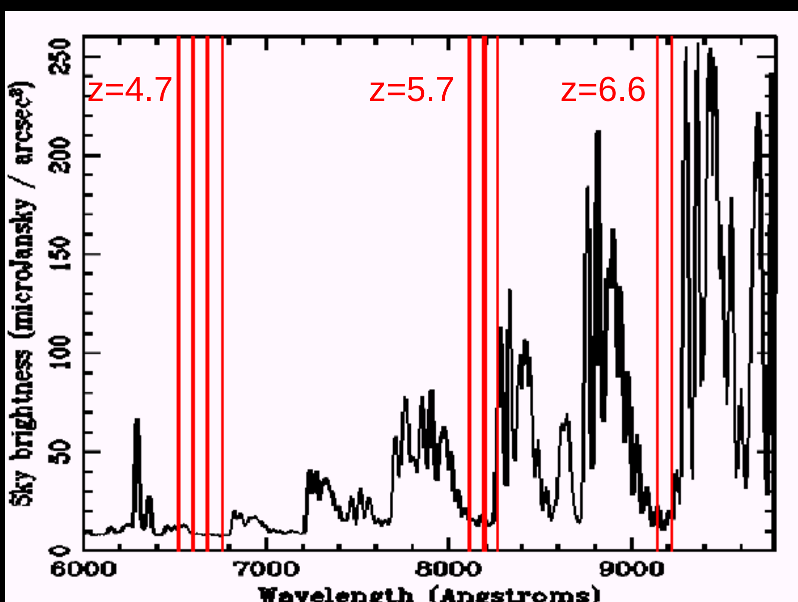
To find the first galaxies at z>7, near-IR observations are crucial

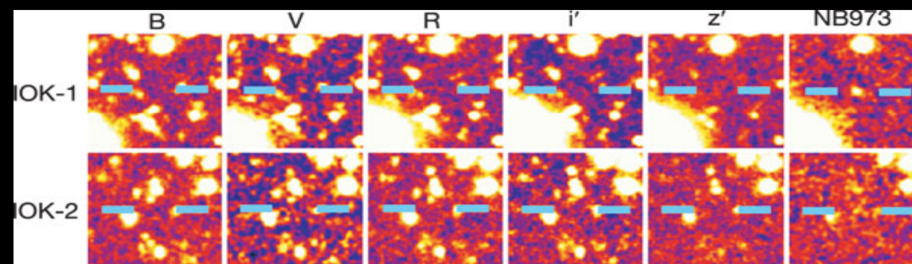
Selecting galaxies into the epoch of reionization

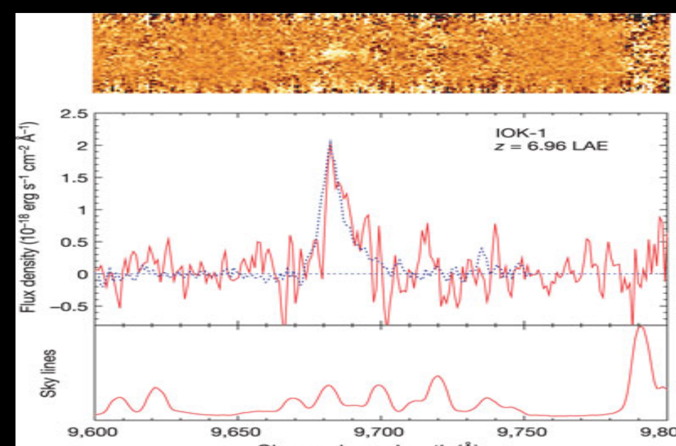
Two basic techniques:

1. Lyman-break selection (LBGs)
2. Lyman alpha emitters via narrow-band or spectroscopy (LAEs)

Narrow-band filters sample dark regions between sky lines
Clean selection method if combined with deep multi-wavelength imaging data
Currently only one object with spectroscopic confirmation at z ~ 7

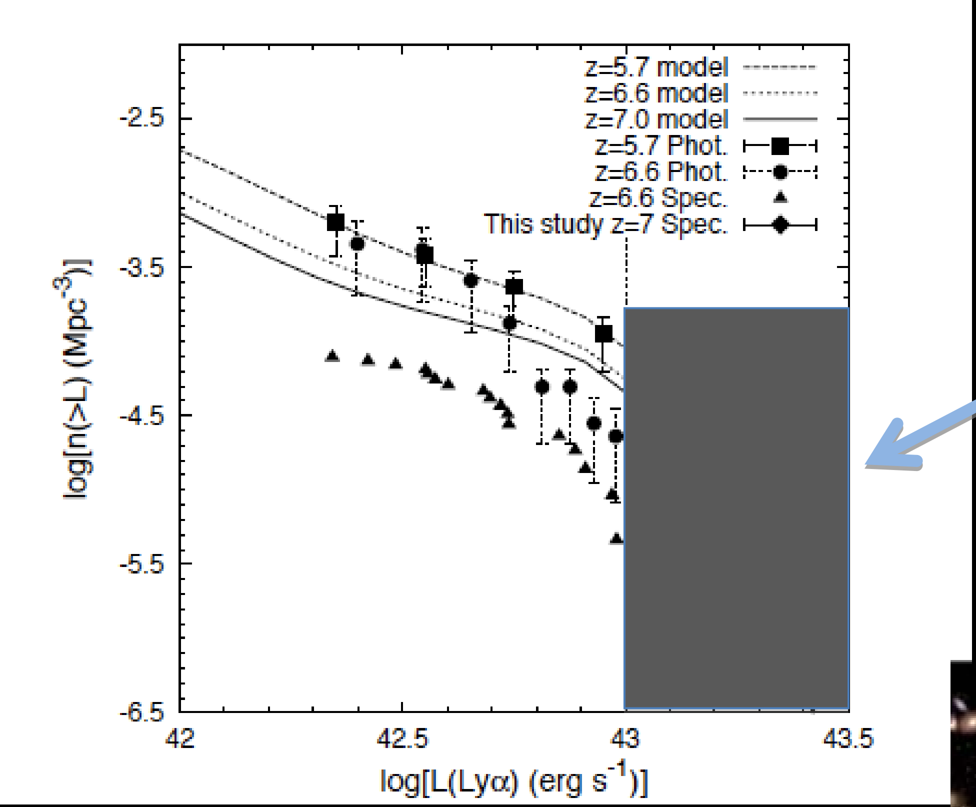






Iye et al. 2006

Evolution of Lyman-alpha emitters



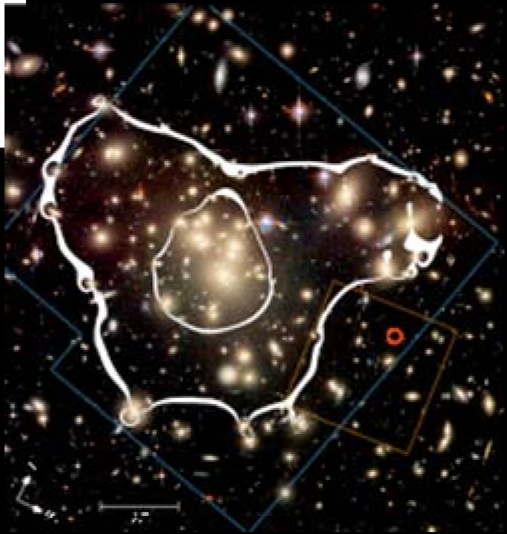
Kashikawa 2006; Ouchi 2008; Ota 2008

The bright end very poorly constrained

Euclid NIS down a flux limit of 5×10^{-17} erg s^{-1} cm^{-2}

will detect (in 1 square degree)

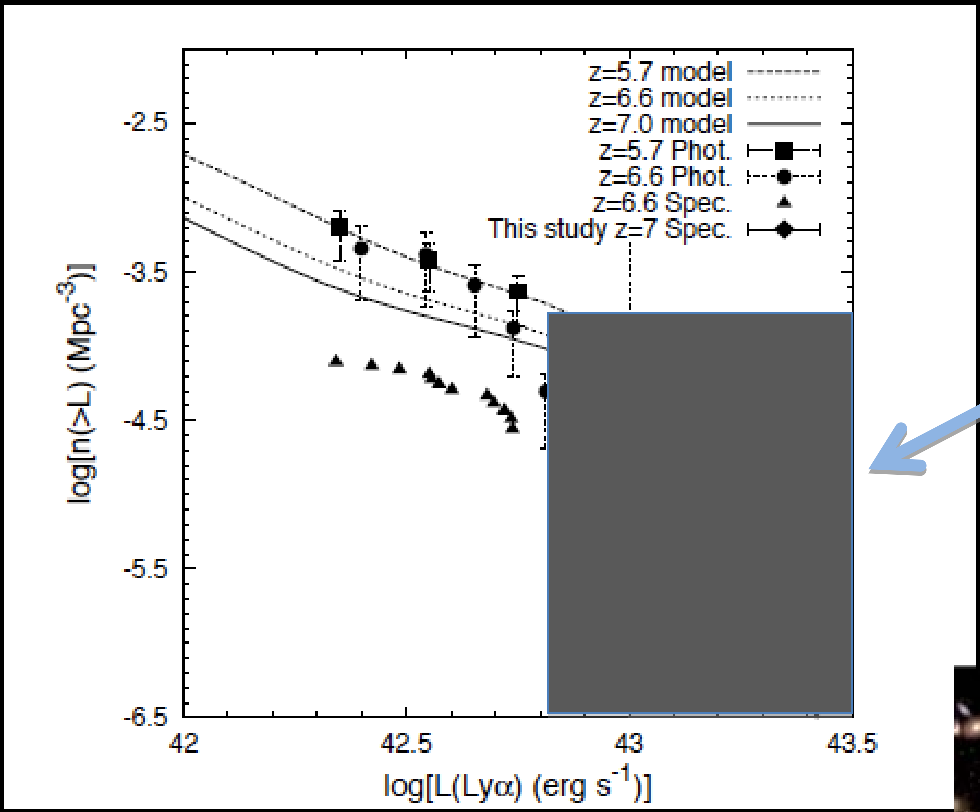
≈ 10-100 galaxies at z>6
≈ 1 - 20 galaxies at z>7
≈ 0-5 galaxies at z>8



Even higher redshift by targeting the critical gravitational lensing lines in clusters (e.g. Bradley 2008)

Similar numbers of quasars per sq.deg (Lyα and CIV) are expected at the same redshifts (A. Martinez Sansigre)

Evolution of Lyman-alpha emitters



Kashikawa 2006; Ouchi 2008; Ota 2008

With DMDs we can sample below the knee of the LF (pre-selection with optical/near-IR colours), better constraining the shape of the LF

The bright end very poorly constrained -> need for large FoV

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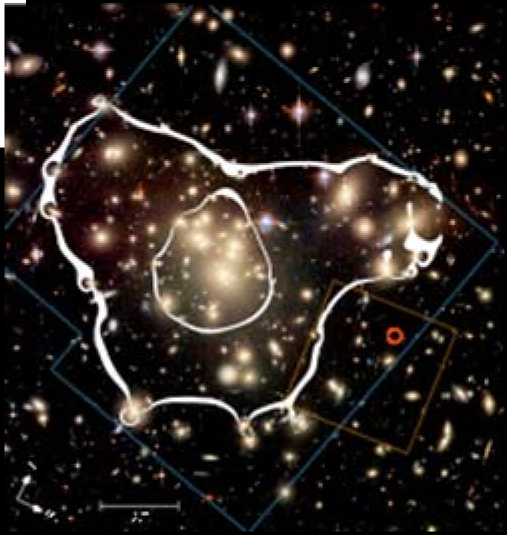
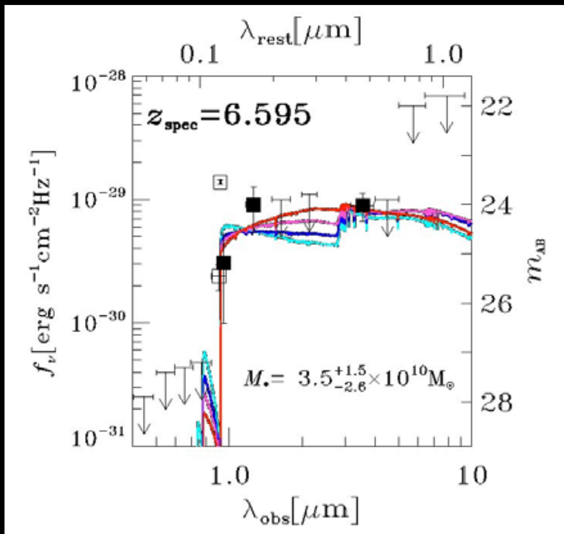
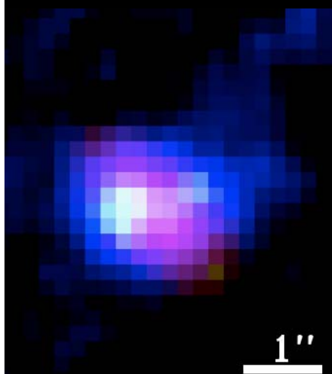
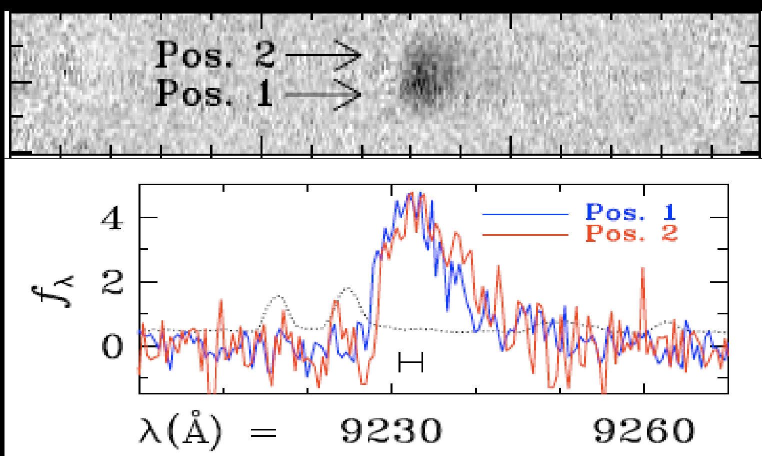


Even higher redshift by targeting the critical gravitational lensing lines in clusters (e.g. Bradley 2008)

Giant Lyman-α nebulae







Ouchi et al. 2009

Extended Lyman-alpha nebulae are rare sources and mostly found at z≈2-3, but recently Ouchi et al. (2009) discovered one at z=6.5

The nature of these nebulae is still unknown:

1. Proto-galaxies in their very early stages (<<10^7yr) with large outflows contributing to the metal enrichment and cosmic re-ionization.

2. Cooling clouds accreting onto a massive dark halo.

Based on the results from Ouchi et al. (2009) Euclid-NIS will detect ≈ 50 spatially extended Lyman-alpha nebulae at z>7 in the Deep Survey

Galactic Science (Rebolo et al.)

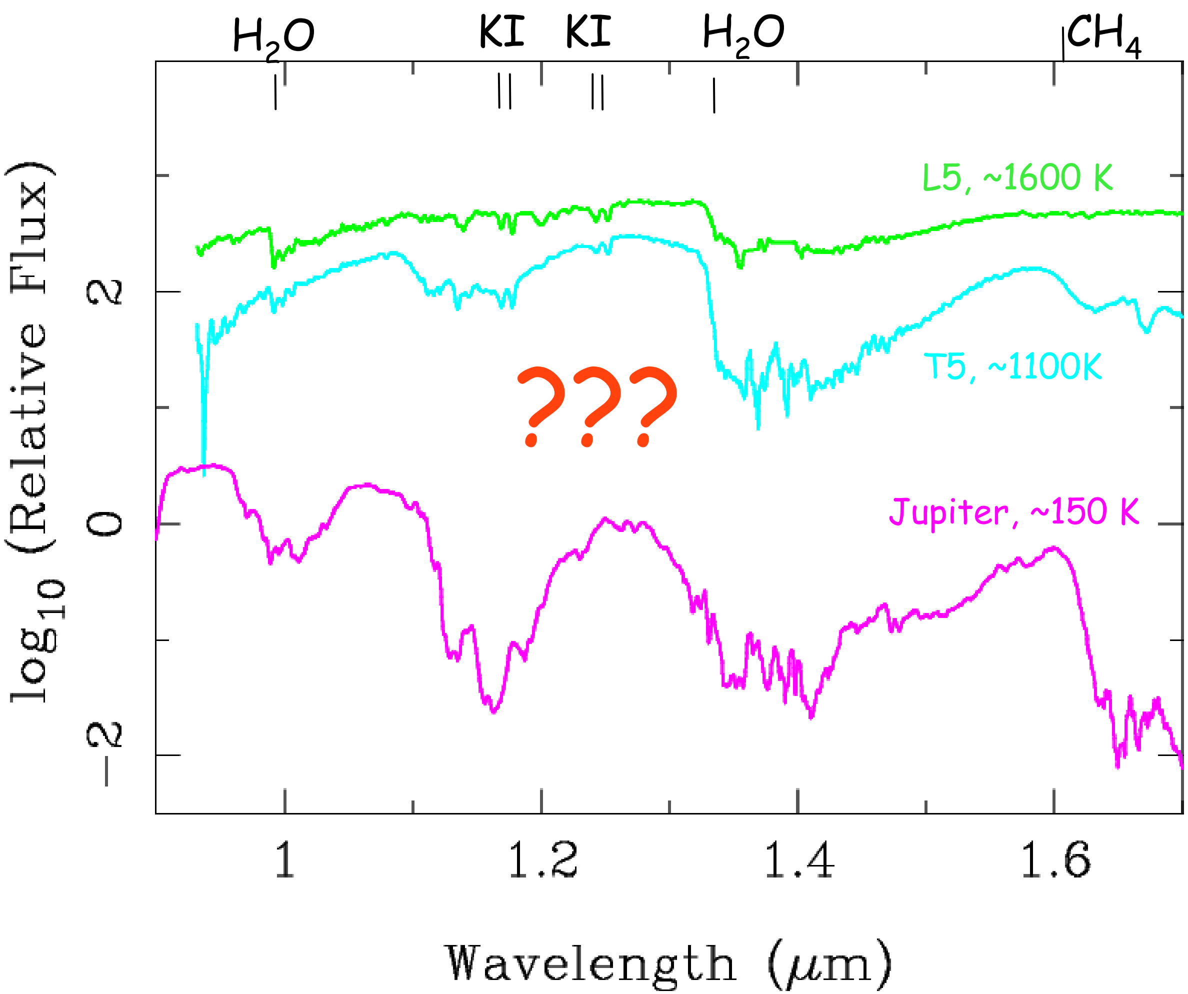
- Ultra-cool dwarfs in the solar neighborhood (T_{eff} < 2000 K):
- Characterization of atmospheres and complete mass function of free-floating very low-mass stars, brown dwarfs, and giant planets.
- Includes spectral types L (1300-2200 K), T (1300-700 K), **and Y (< 700 K).**
- Slitless EUCLID allows to explore the presence of free-floating giant planets as old as the Sun up to r = 8 pc.
- DMD slit EUCLID increases the explored volume by factors of 25 (Y-type) and 125 (L- and T-types).

- Ultra-cool dwarfs in star-forming regions:
- Is there a minimum mass cut-off in the initial mass function (IMF)? Where is it?
- Slitless EUCLID allows to determine the complete brown dwarf IMF of most nearby star-forming regions.
- Slit EUCLID allows to study the "universality" of the IMF including the planetary-mass regime, and its dependence on various environments.
- Dependence of ultra-cool atmospheres on age (gravity) and metallicity.

- Binaries containing compact objects (black holes, neutron stars).
- Cool white dwarfs to explore the age of the Galactic disk and halo.
- Trans-Neptunian objects in the Kuiper Belt (pristine chemical composition of solar nebula).
- EUCLID will complement (and significantly enhance) GAIA.

Galactic Science : An example

Extremely low-temperature brown dwarfs: a bridge to terrestrial planet characterization



Observed spectra from Rayner et al. (2009, ApJS) degraded to the resolution of Euclid.

Between the coolest known dwarfs (T-type) and "Jupiter" there is an interval of temperatures typical of planet atmospheres **(including Earth-like temperature of 300 K)** where EUCLID can make relevant contribution to the identification and characterization of the smallest population beyond the Solar System. EUCLID wavelength interval covers important features due to water vapor, methane, oxygen, and ammonia.

Conclusion

In addition to the main cosmological products, E-NIS will produce **exciting science**, with a large legacy value, **in all areas of astronomy**, from galactic studies to the evolution of galaxies, AGN, and LSS and the high redshift Universe, close to the re-ionization epoch.

This is true for the current baseline configuration (slitless). However, there is no doubt that the E-NIS legacy value would be even (significantly) larger if the “DMD option” becomes the baseline.