Spectroscopy from space - the synergy of Euclid with other spectroscopic facilities

Jarle Brinchmann (Leiden Sterrewacht, IA Porto)

with many thanks to the Euclid consortium.

1.2m telescope [Astrium Toulouse, satellite: Thalys Alenia Space]

VIS imager (0.79°x0.71° FoV)
(for weak lensing tomography)

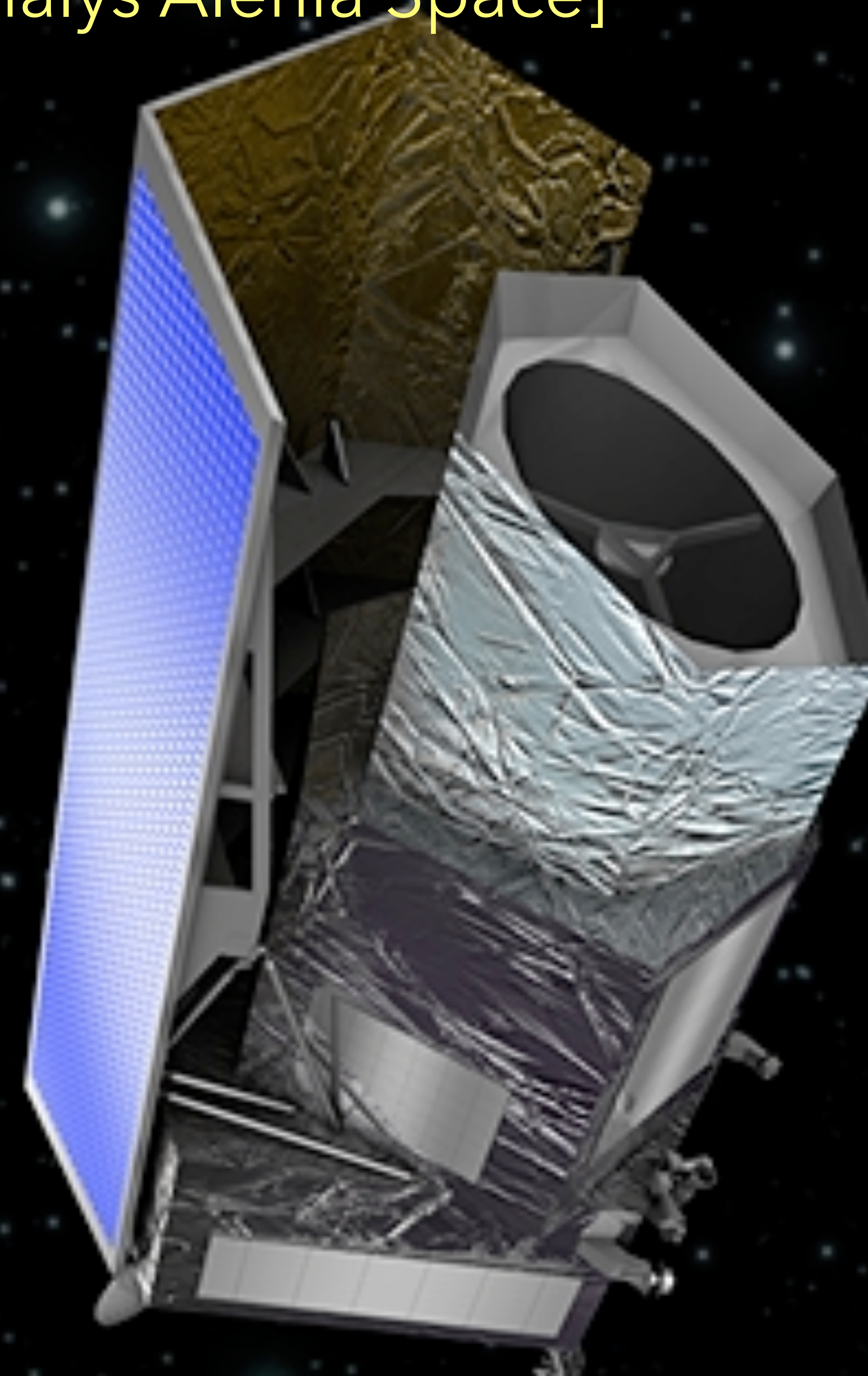
NISP imager & spectrograph (0.76°x0.72° FoV), for photo-zs and BAOs.

15000 deg^2 outside the Galaxy

Nominal survey duration: 6 years

Launch: mid 2021

Large consortium: >1100 members



Euclid science goals

Overarching goals: Dark energy & dark matter
Methods: Weak lensing and Baryon Acoustic Oscillation.

Cosmology needs *Gains for legacy science*

Very large samples → distribution functions

Exquisite imaging → morphological studies, mergers, strong galaxy-scale lenses, ..

Weak lensing → Galaxy evolution as a function of halo properties, galaxy alignment, ...

Very large volume → Rare sources, probing the extremes

Spectroscopy → Metals, star formation @ z>1

Useful numbers

Wide survey: 15,000 deg^2

Optical imaging:

AB 24.5 - 10σ extended source

Filter: 0.55-0.9μm

PSF: <0.18″ with 0.1″ pixels.

NIR imaging:

AB 24 - 5σ point source

Filters: Y, J, H

PSF: EE80 ~ 0.6″-0.7″, EE50 < 0.3″

NIR spectra:

$f_{line} > 2\times10^{-16}$ erg/s/cm^2 (3.5σ unresolved)

R = 250 with pixel sampling 0.3″

1.25μm < λ < 1.85μm

(SFR = 6 @ z=0.9
SFR = 36 @ z=1.8

Useful numbers

Deep survey: 40 deg^2

Optical imaging:

AB 26.5 - 10σ extended source

Filter: 0.55-0.9μm

PSF: <0.18″ with 0.1″ pixels.

NIR imaging:

AB 26 - 5σ point source

Filters: Y, J, H

PSF: EE80 ~ 0.6″-0.7″, EE50 < 0.3″

NIR spectra:

$f_{line} > 5\times10^{-17}$ erg/s/cm^2 (3.5σ unresolved)

R = 250 with pixel sampling 0.3″

0.92μm < λ < 1.85μm

(SFR = 0.3 @ z=0.4
SFR = 11 @ z=1.8

The Euclid deep fields

Three deep fields:

Euclid Deep Field North:

- close to the North Ecliptic Pole
- RA 17:55:00 , Dec 66:33:38.35
- 10 square degree, circular shape + 10 deg red spec

Euclid Deep Field South 1:

- close to the South Ecliptic Pole, avoiding LMC
- RA ?, Dec ?
- Shape TBD - stellar density presents challenges

Euclid Deep Field South 2:

- 10 deg^2 in Chandra Deep Field South
- Ra 03:32:28.0, Dec -27:48:30

Temporal synergy

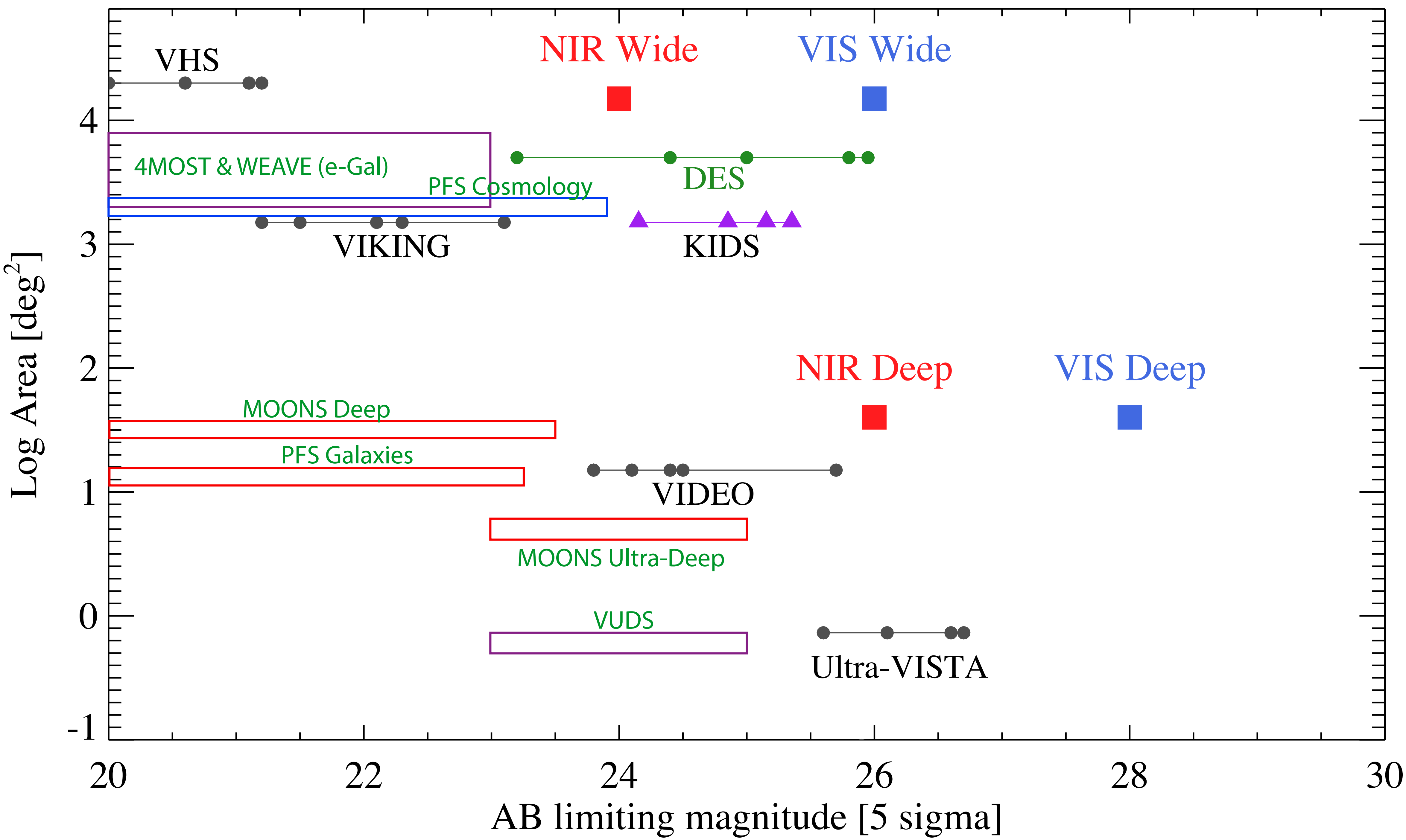
Euclid

launch: mid 2021
data: late 2021/early 2022

⇒ Euclid data becomes available when currently planned spectroscopic surveys are in full flow/nearing completeness.

- ✦ Euclid will provide extra information for surveys
- ✦ Euclid can provide input for the next phase

Euclid compared to ground-based surveys

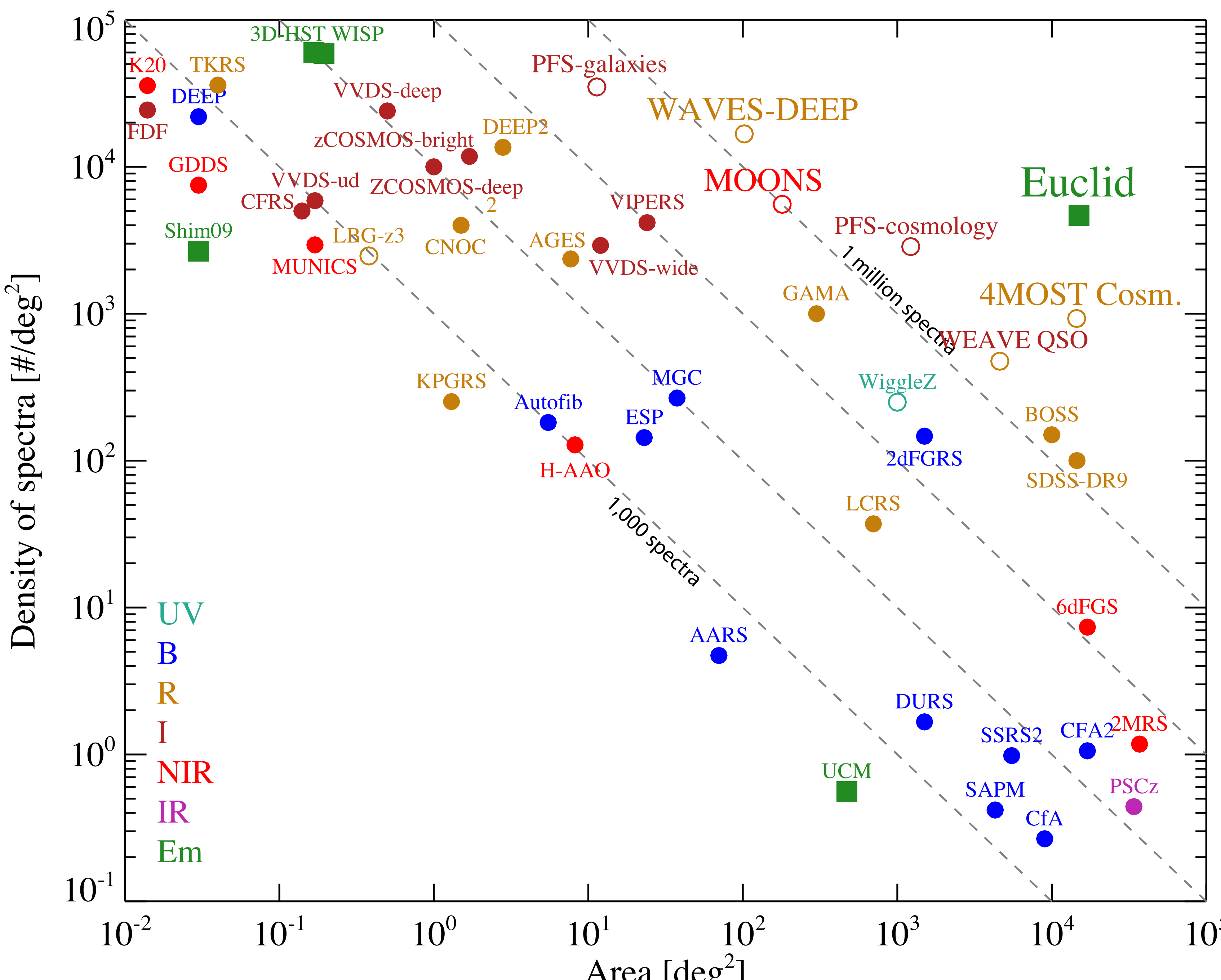


Note: All surveys except MOONS Ultra-Deep will have NIR+VIS from Euclid for all targets.

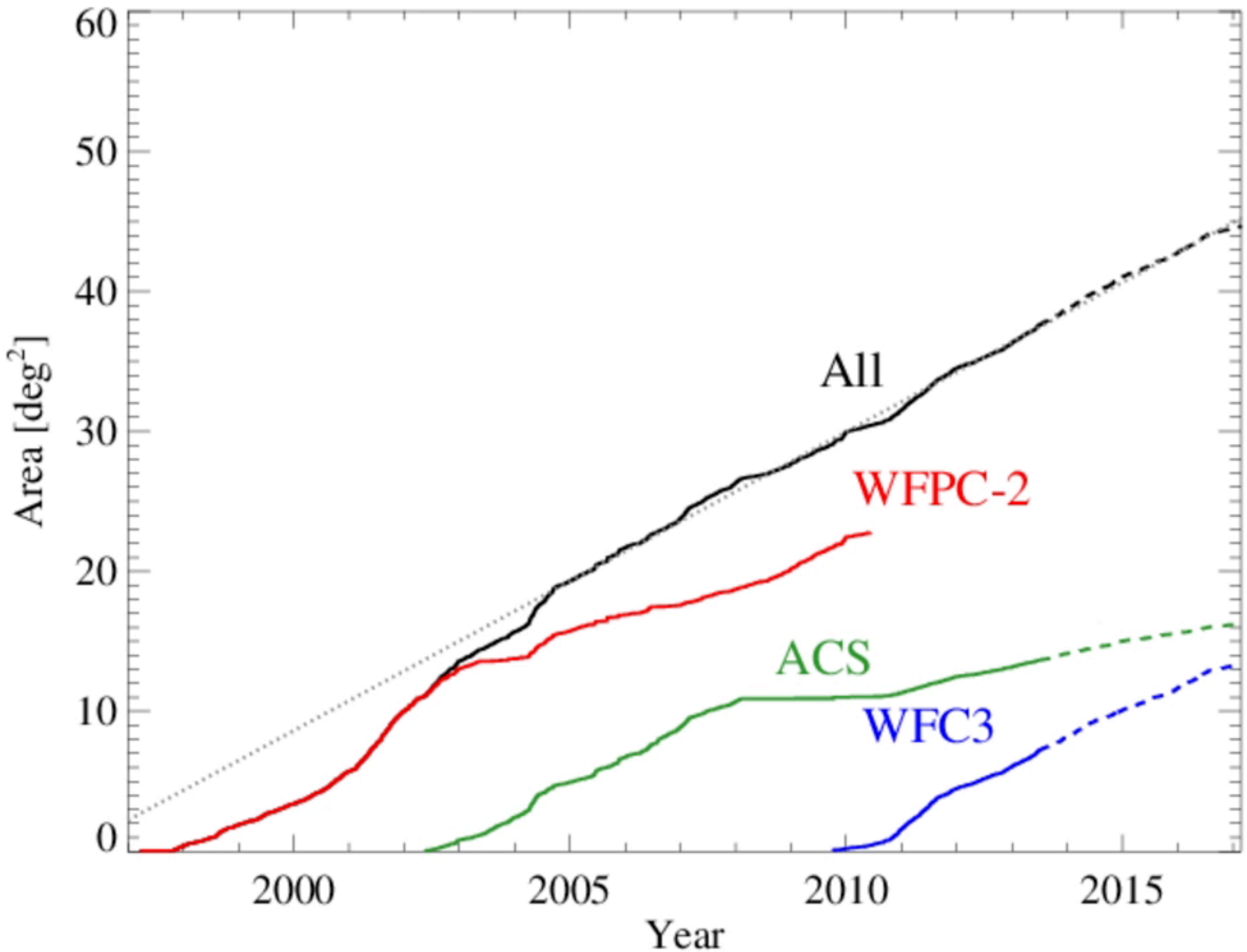
Euclid compared to ground-based surveys

MUSE GTO

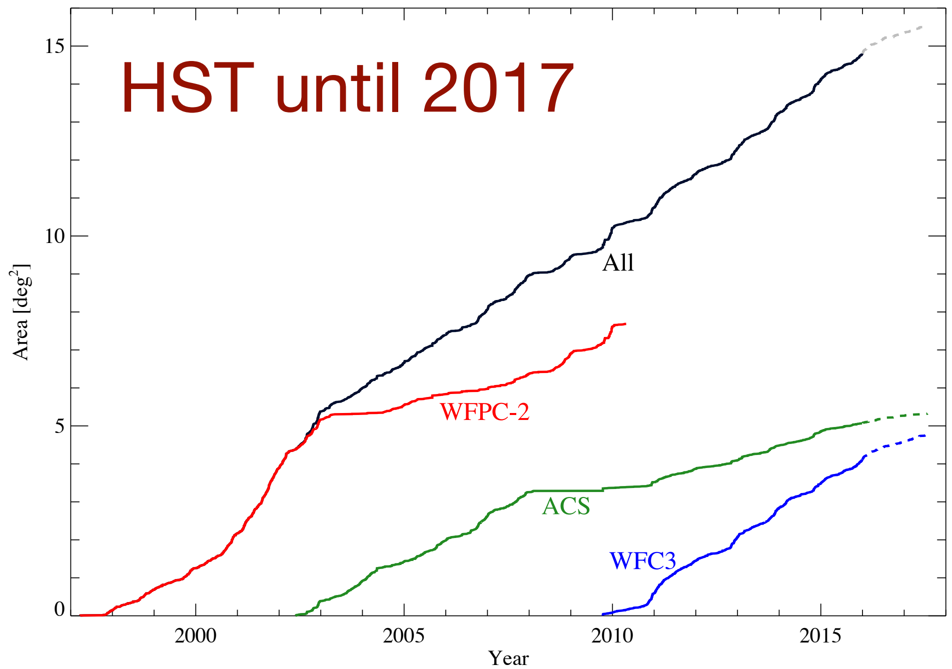
Based on a compilation by I. Baldry

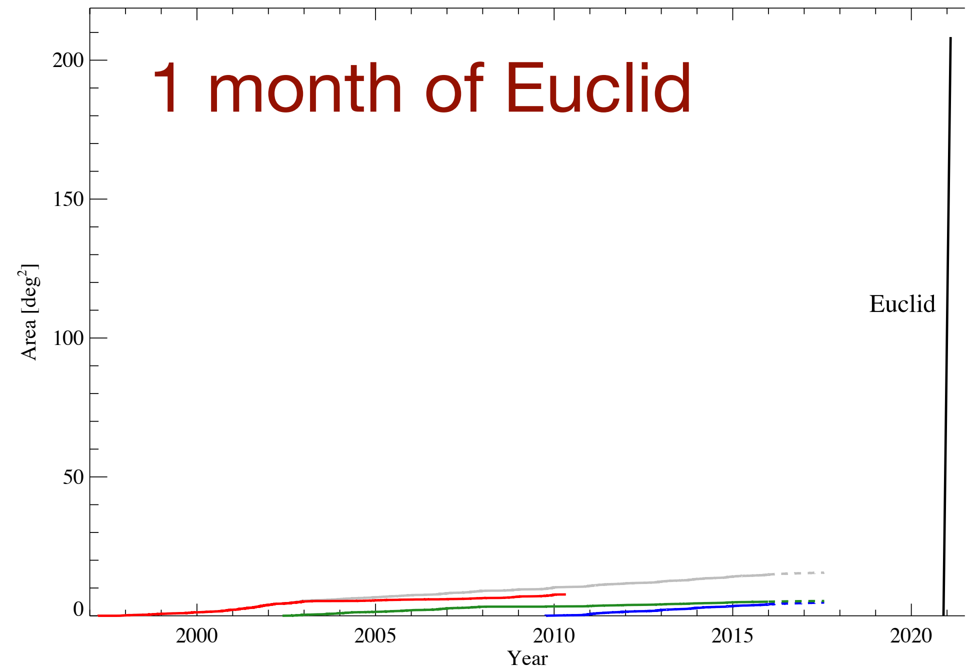


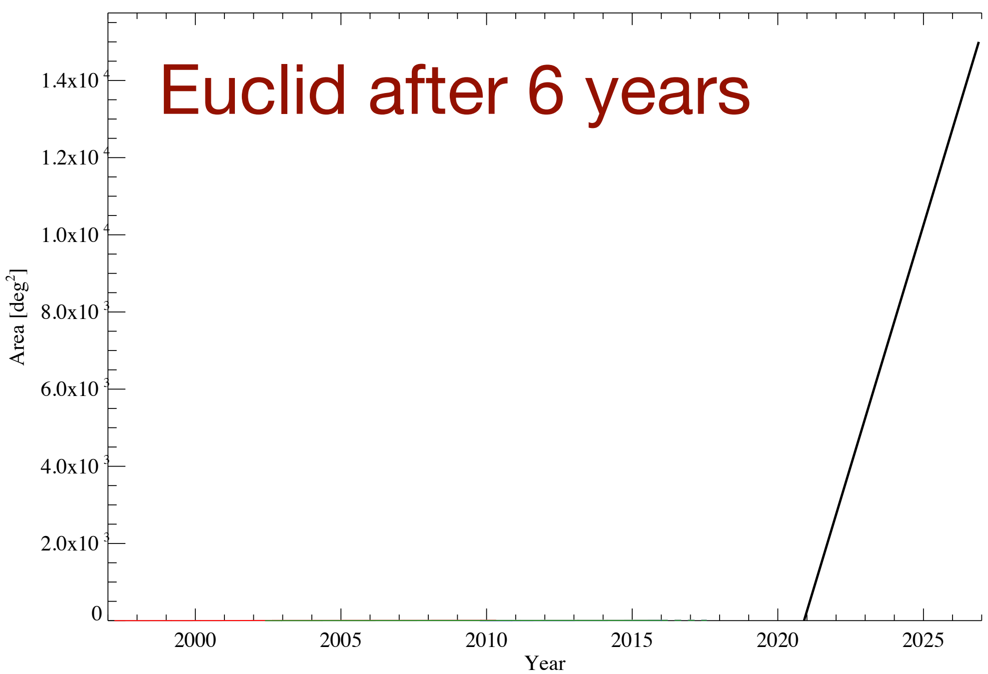
Lots of spectra ⇏ lots of science - hides spectral quality



Euclid will increase the area covered by high-res imaging by 3 orders of magnitude.







Bottom line:

Science that requires high resolution images will see ~3 orders of magnitude increase in sample sizes.

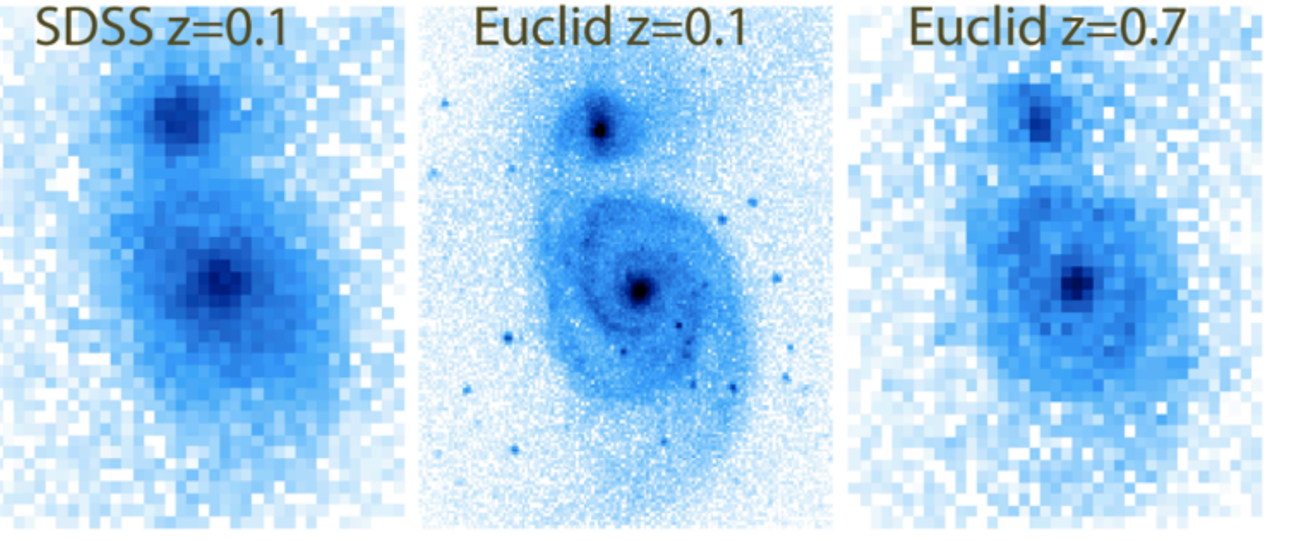
e.g.: High quality star-galaxy separation, strong lensing, galaxy mergers, galaxy morphology.

Slitless spectra: ~4 orders of magnitude…

The quick summary

Near-IR: Ultra-deep imaging in YJH, but not in Galactic/ Ecliptic planes, galaxy masses, cool stars, …

Visible: near-HST quality imaging of the same areas (think slightly blurry WFPC-2). Excellent star-galaxy split



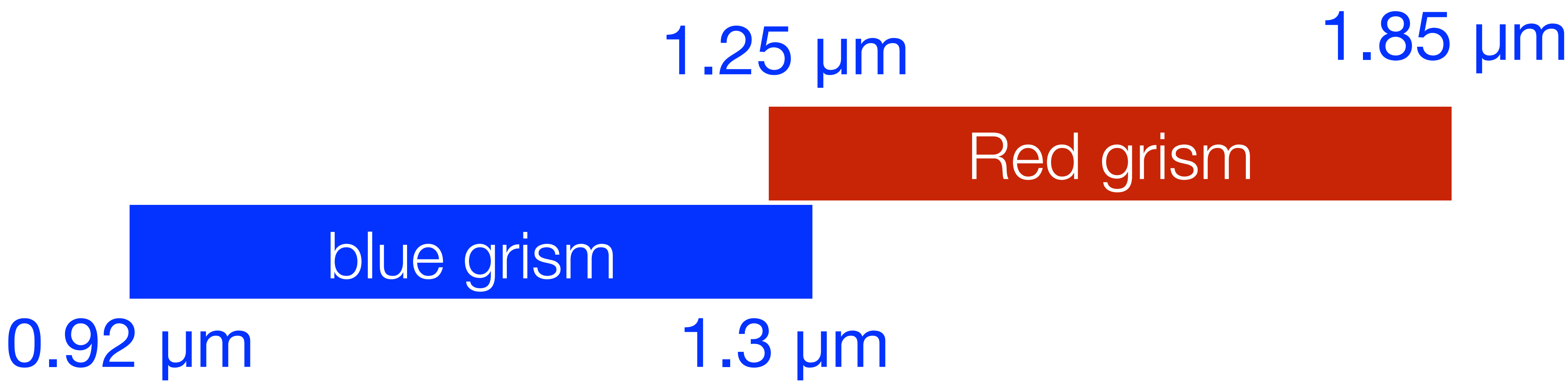
Spectra: >4000/deg (Hα typically) emitters. Good set of targets for follow-up.

Photo-zs: Homogeneous and precisely calibrated.

Halo masses: One of several products from Weak Lensing

Euclid spectroscopy - potential

Two grisms



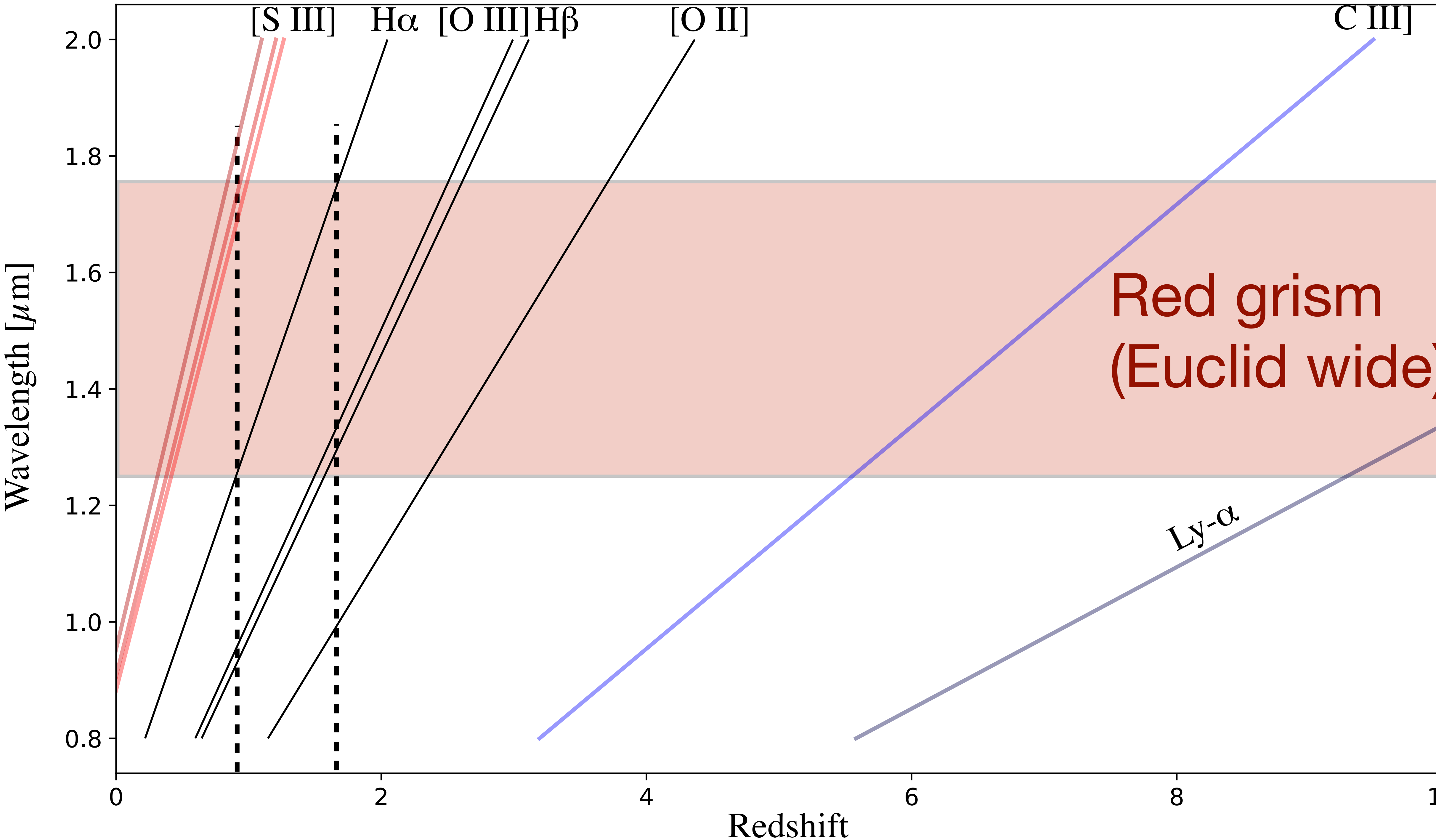
Red grism wide: 15,000 deg^2 @ f>2x10^{-16} (cgs)

cosmology - BAOs, but also discovery space

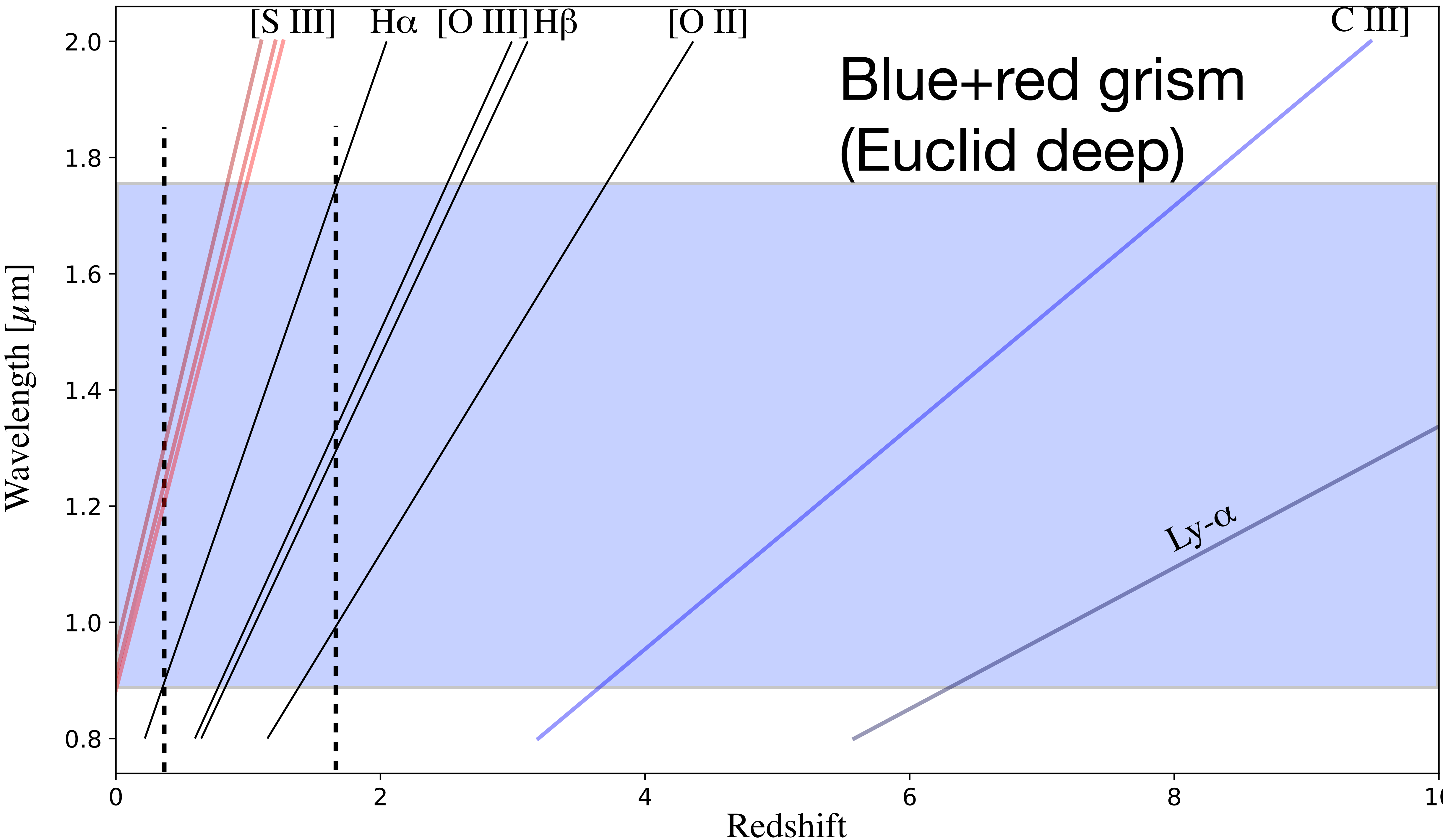
Red & blue grism: Deep survey.

40 deg^2 @ f<6x10^{-17} (cgs) [TBD]

Wavelength coverage - a challenge



Wavelength coverage - a challenge



Hα, Hβ, [O III]: 0.89<z<1.82

Hα-[O II]: 1.47<z<1.82

Hβ, [O III], [O II]: 1.47<z<2.69

Expected numbers in the deep survey

Galaxies with Hα: ~few x 10^6

Galaxies with Hα, [O III]5007, Hβ: ~few x 10^5

Galaxies with [O III]5007, Hβ, [O II]: ~9 x 10^4

Galaxies with Hα to [O II]: ~5 x 10^4

So small numbers relative to the total (~4x10^7), but still substantial!

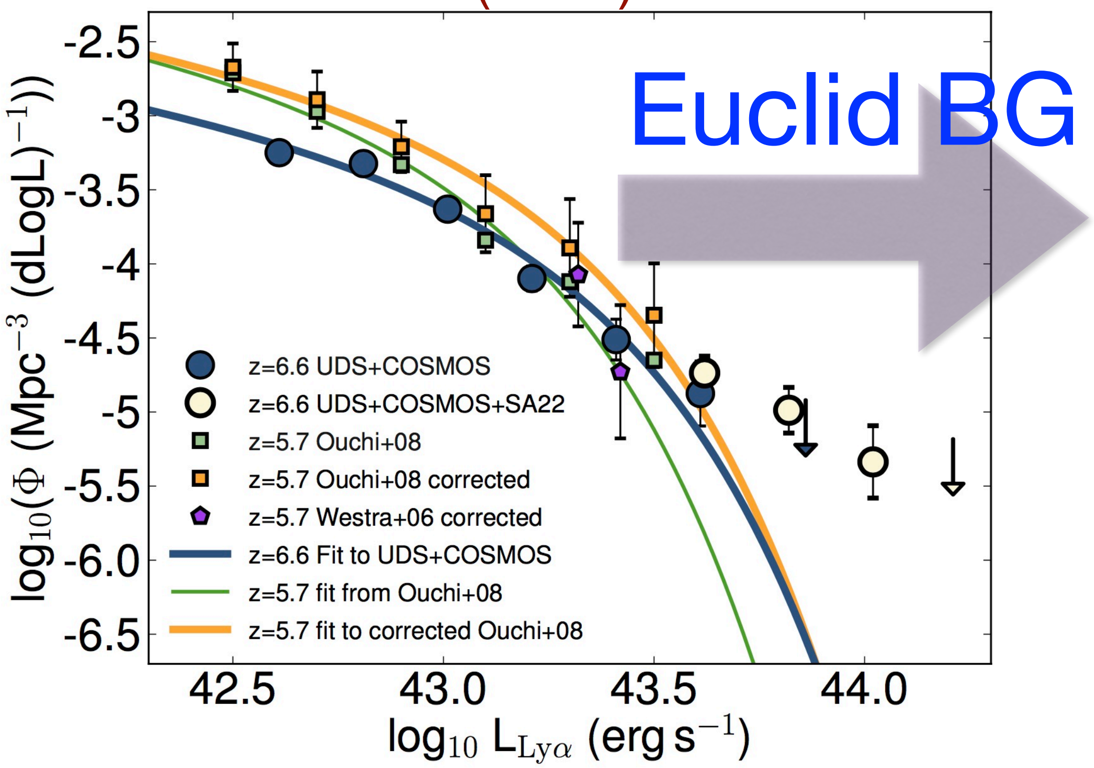
Hα, Hβ, [O III]: $0.89<z<1.82$

Hβ, [O III], [O II]: $1.47<z<2.69$

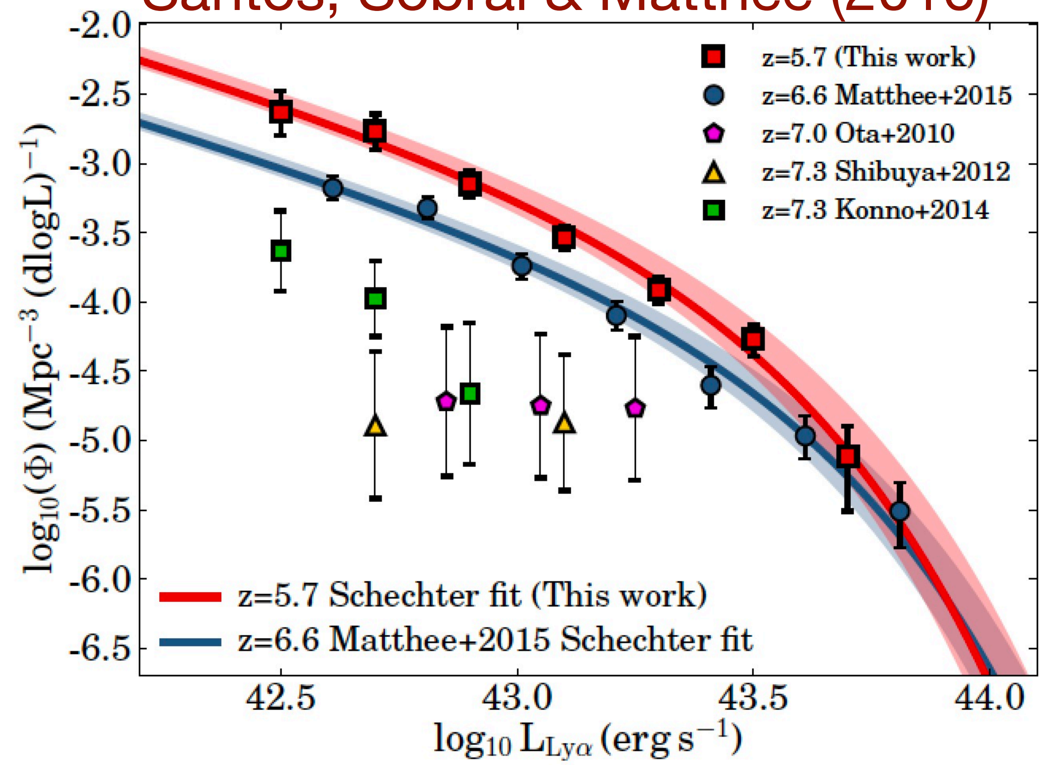
Hα-[O II]: $1.47<z<1.82$

Bright Ly-α emitters - a case for the blue grism

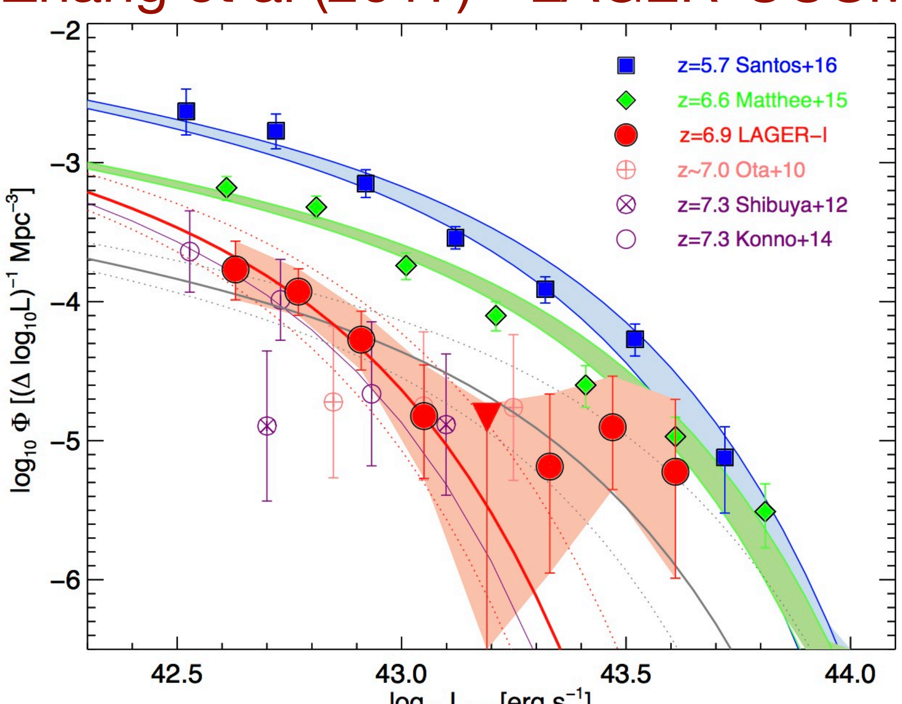
Matthee et al (2015)



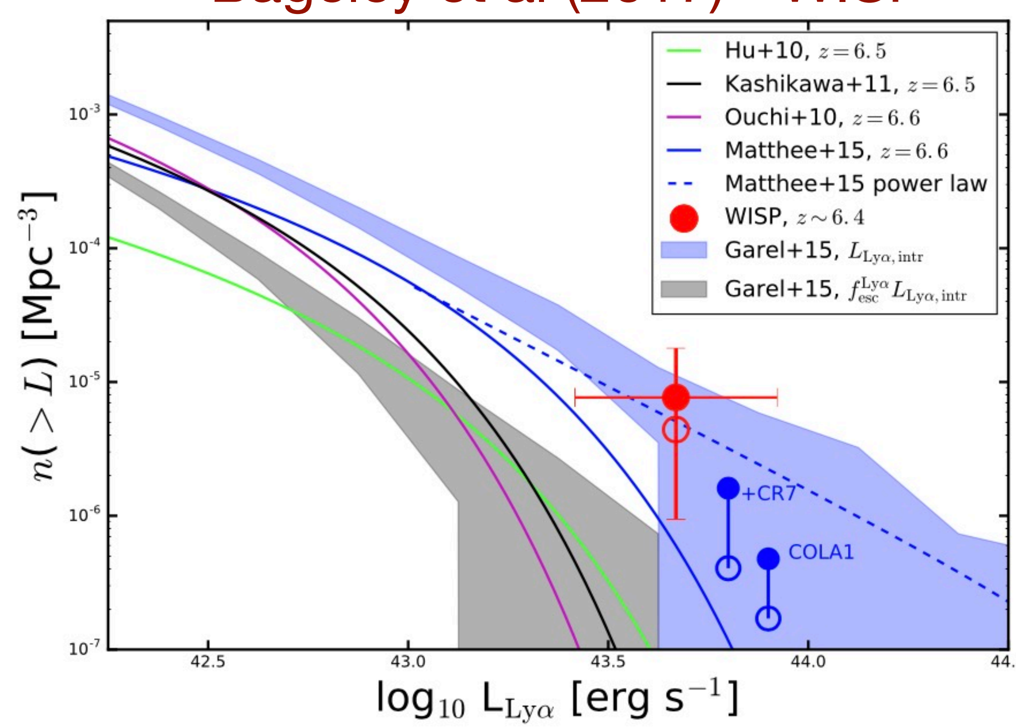
Santos, Sobral & Matthee (2016)



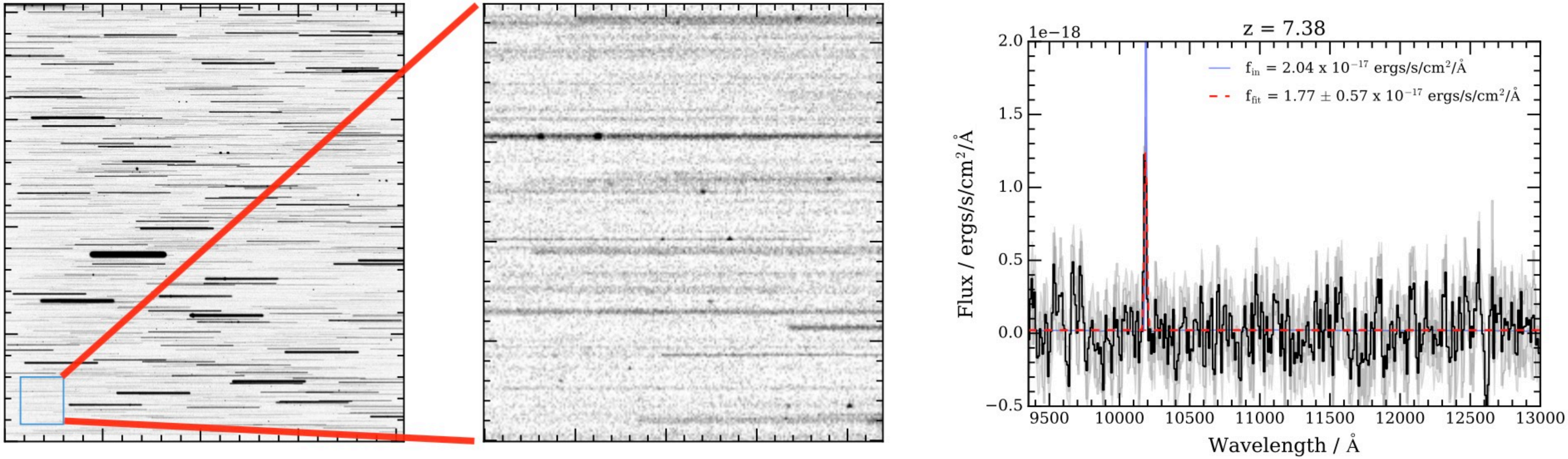
Zhang et al (2017) - LAGER-COSMOS



Bageley et al (2017) - WISP



Euclid deep - simulated observations



Work by **Cullen**, Dunlop et al

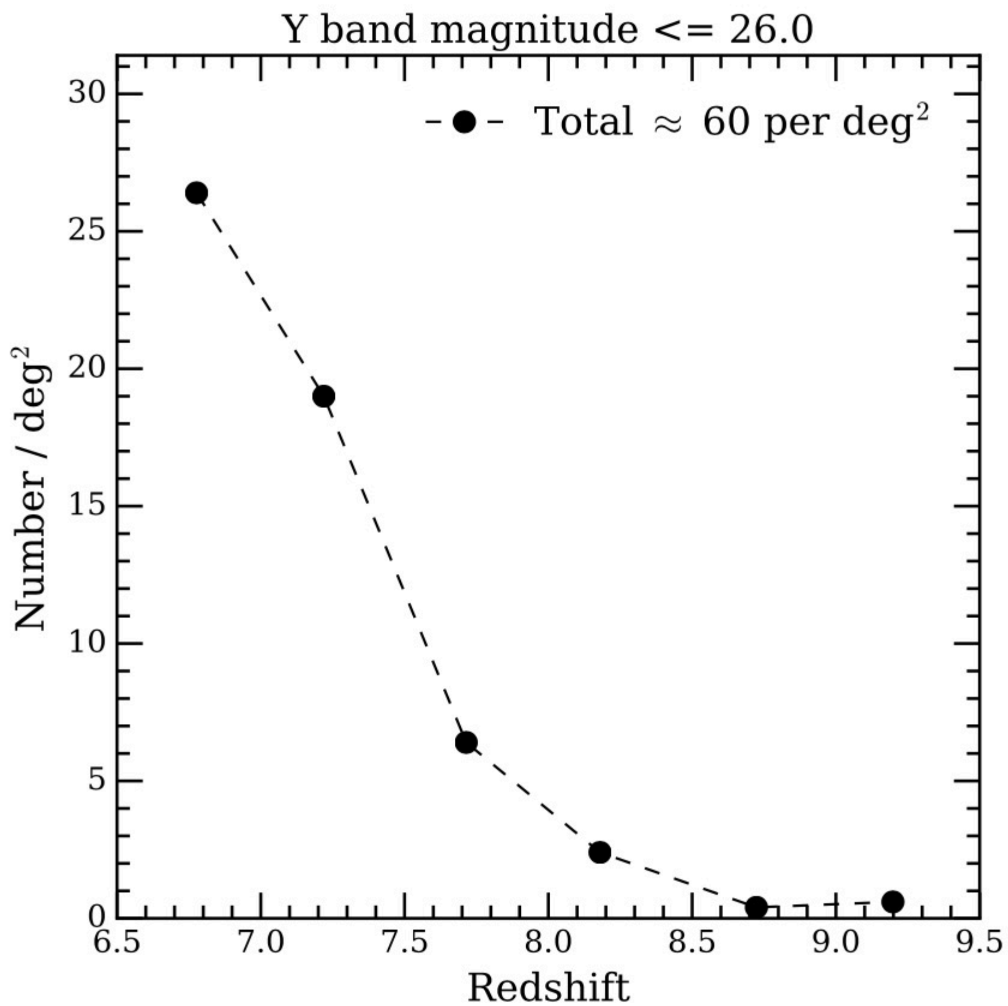
Simulation + EGG + aXeSIM ⇒ Simulated Euclid spectra

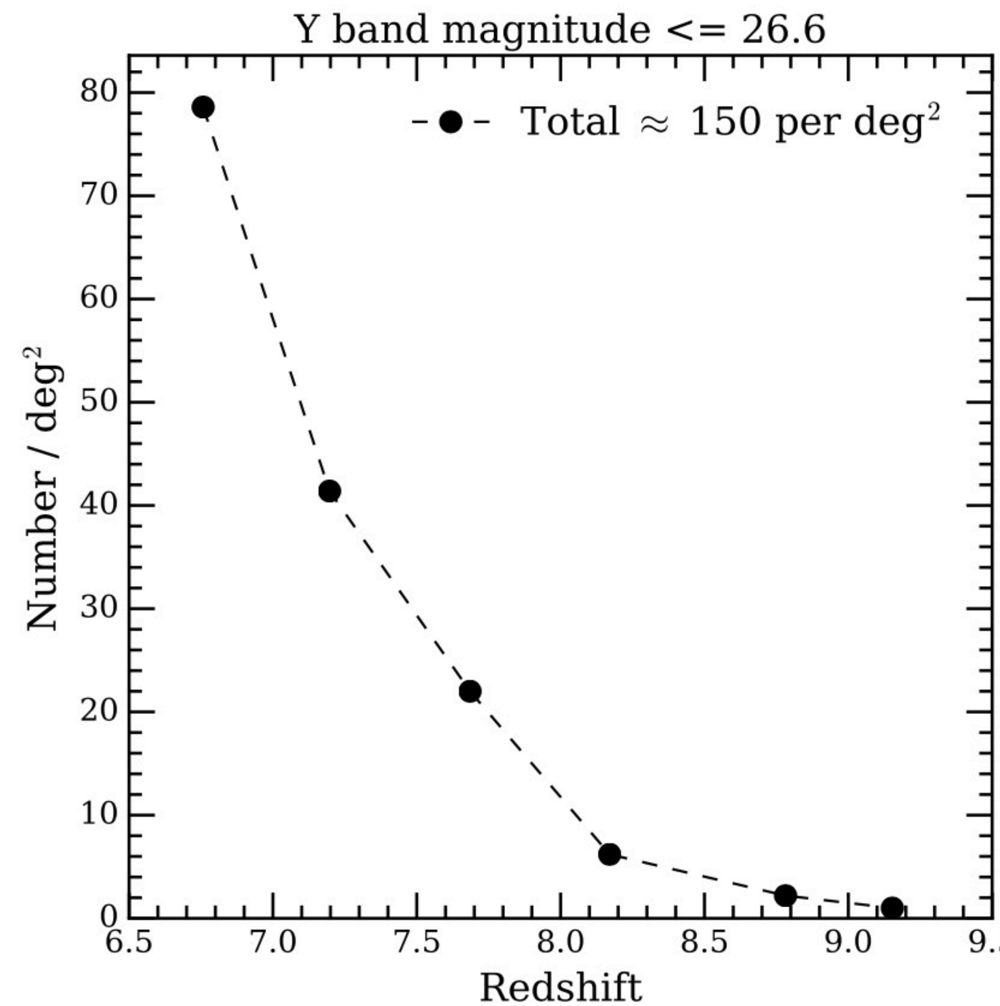
Schreiber et al (2016)

Reproduces the Matthee et al (2015) Ly-α luminosity function

Predicted Ly-a numbers

Courtesy Fergus Cullen





With 40 deg^2, we expect to have:

2400 emitters to Y=26.0

6000 emitters to Y=26.6

$$f > 6 \times 10^{-17} \mathrm{erg s^{-1} cm^{-2}}$$

$$L > 3 - 6 \times 10^{43} \mathrm{erg\,s^{-1}}$$

the longer summary

Image from josephwashere.com

Visible imaging - rare objects

Caution: Not down to a particular detection limit!

What	Euclid	Per MOONS FoV	Per 4MOST FoV	Per WEAVE FoV
Galaxy mergers	$\sim 10^5$-few x 10^6	1-30	~30-800	~10-400
Strongly lensed galaxy-scale lenses	~300,000	1-5	~30-150	~10-70

Neither of these will (probably) truly dominate fibre/slit allocations, but inclusion among the target will be very valuable:

Redshifts/metallicities (4MOST, WEAVE at low-z, MOONS, MOSFIRE at higher)

Velocity dispersions for the more massive strong lenses (4MOST, WEAVE at low-z, MOONS, MOSFIRE at higher)

NIR & slitless spectra

What	Euclid	Per MOONS FoV	Per 4MOST FoV	Per WEAVE FoV
Galaxies at $1<z<3$ with good mass estimates and morph.	$\sim 2\times10^8$	$\sim 10^3$	$\sim 5\times10^4$	$\sim 2\times10^4$
Massive galaxies ($1<z<3$) w/spectra	~few x 10^3	<<1	~1	~1
Hα emitters/metal abundance in z~2-3	$\sim 4\times10^7/10^4$	few x 10^2/<1	$\sim 10^4$/~1	5×10^3/~1
Galaxies in massive clusters at z>1	$\sim(2\text{-}4)\times10^4$	~40 (per cluster, $H_{AB}<22.5$)	~40?	~40?
Type 2 AGN ($0.7<z<2$)	$\sim 10^4$	<1	~1	~1

NIR & slitless spectra - synergies

What	Euclid	Per MOONS FoV	Per 4MOST FoV	Per WEAVE FoV
Galaxies at 1<z<3 with good mass estimates and morph.	~2×10^{8}	~10^{3}	~5×10^{4}	~2×10^{4}
Massive galaxies (1<z<3) w/spectra	~few x 10^{3}	<<1	~1	~1
Hα emitters/metal abundance in z~2-3	~$4\times10^{7}/10^{4}$	few x 10^{2}/<1	~10^{4}/~1	5×10^{3}/~1
Galaxies in massive clusters at z>1	~$(2\text{-}4)\times10^{4}$	~40 (per cluster, $H_{AB}<22.5$)	~40?	~40?
Type 2 AGN (0.7<z<2)	~10^{4}	<1	~1	~1

Euclid to 4MOST/WEAVE/MOONS/MOSFIRE:

: Galaxy stellar masses more uniform.

: Ha redshifts from Euclid useful for NIR targeting.

4MOST/WEAVE/MOONS/MOSIFRE to Euclid:

: Metallicities (MOONS, MOSFIRE), UV properties (4MOST, WEAVE) of Euclid Ha emitters.

: Higher quality spectra for galaxy clusters.

: Sanity checks - photo-zs, emission line redshifts

Euclid and massive spectroscopic facilities

The simple picture

Imaging: Great for any spectroscopic survey:

High-resolution visible images

Deep NIR photometry

Spectroscopy: **Great for some science, good starting point.**

Large amount of Ha SFRs
Excellent for finding extreme & luminous sources

Euclid will get (lots of) spectra - but we need more:

Euclid spectroscopy: (in the wide)

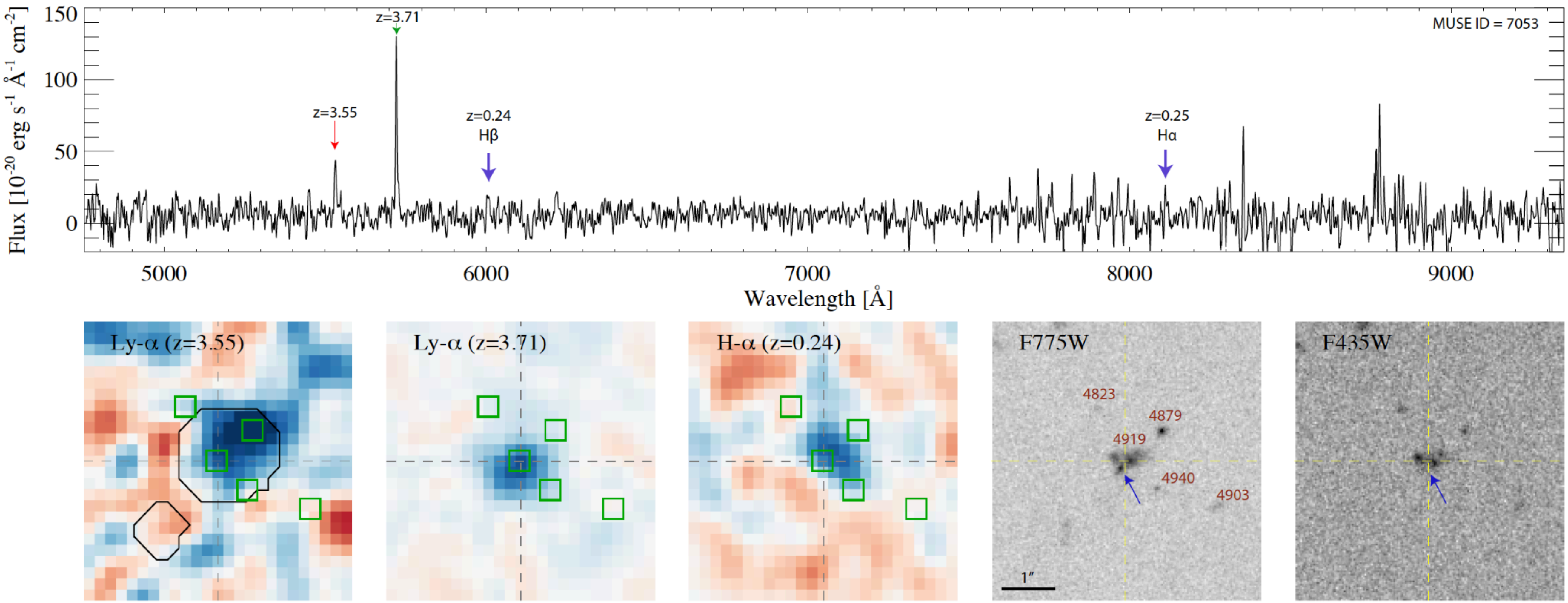
$$R \sim 250 \quad \& \quad 1.25\mu\mathrm{m} < \lambda < 1.85\mu\mathrm{m}$$

$f_{line} > 2\times10^{-16}$ erg/s/cm^2 (3.5σ unresolved)

- Not sensitive enough to detect much besides Hα and [O III]5007.
- The spectral resolution is insufficient to separate the [O II] and [S II] doublets reliably.
- A blue cut-off at 1.25 μm reduces the number of galaxies with metallicity determinations to ~zero in wide (better in deep).
- A spectral resolution of 250 is insufficient for dynamical studies - e.g. finding high dispersion systems, complex kinematics systems etc.
- Slit-less spectra not ideal in dense environments, e.g. clusters.
- Spectra are unlikely to be useful for the bulk of the passive galaxy population.

Multi-object optical/NIR spectrographs are a must.

Spatial resolution is important for spectra!

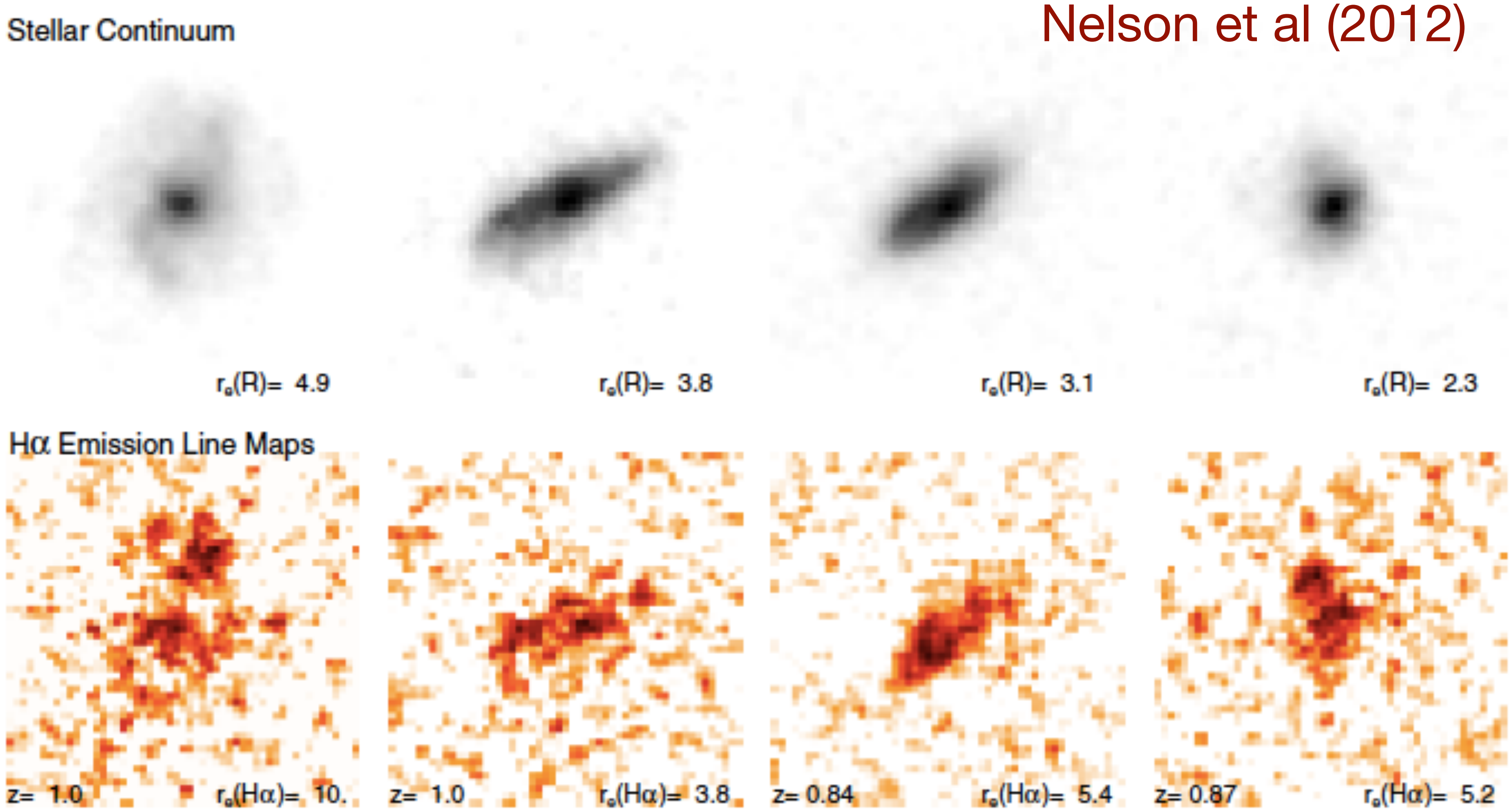


Brinchmann et al (2017, subm)

In MUSE UDF GTO observations: ~5% of sources would have wrong redshift associated without spatial information & photo-z's are not enough to resolve this problem.

Resolved spectroscopy with Euclid

Nelson et al (2012)



The slit-less spectra are actually imaging the galaxies, thus we will be able to reconstruct emission line maps for some fraction of galaxies.

Future exploitation of Euclid:

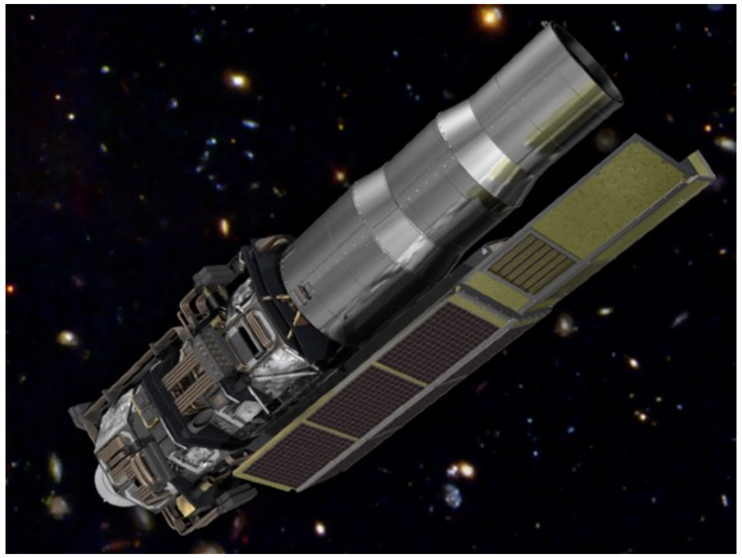
two proposed possibilities

Better spectroscopy from space - ATLAS

DMDs to get ~5,000-10,000 spectra simultaneously

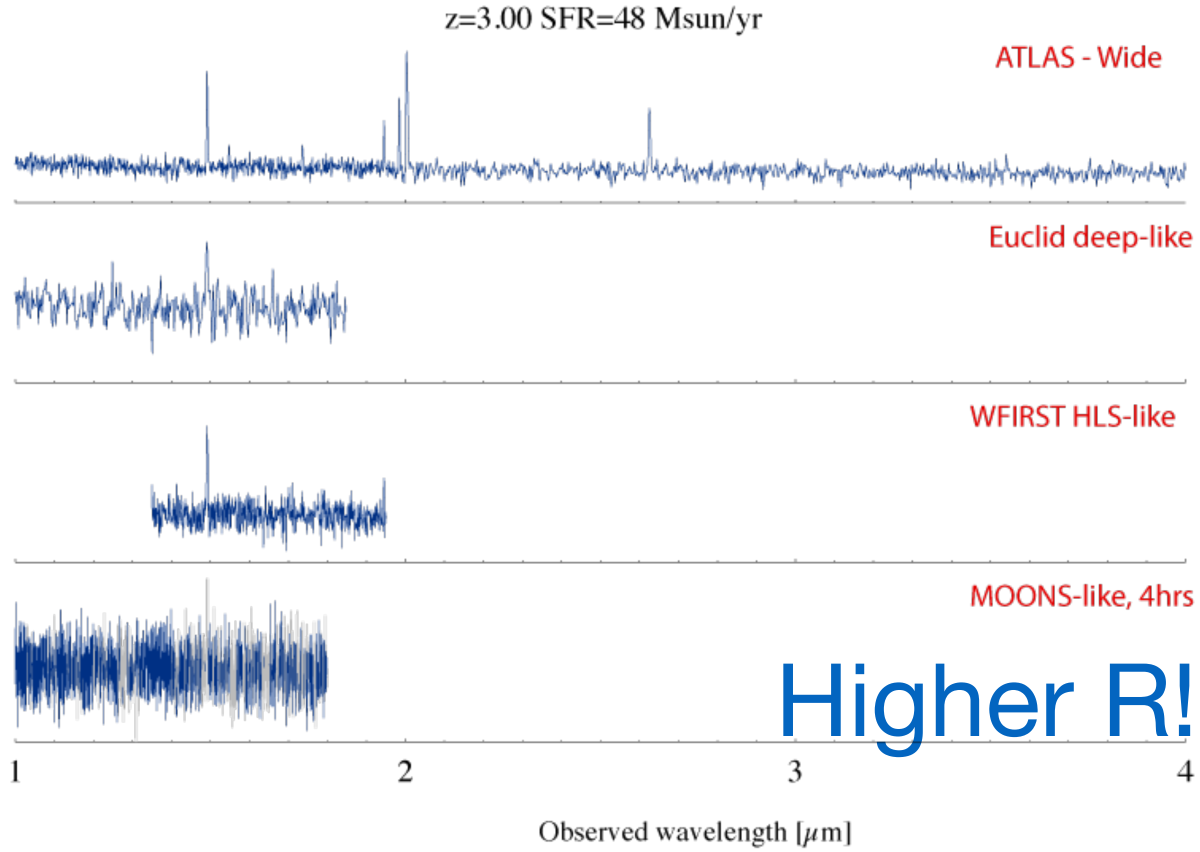
Aperture ~1.5m, FoV: 0.4 deg^2

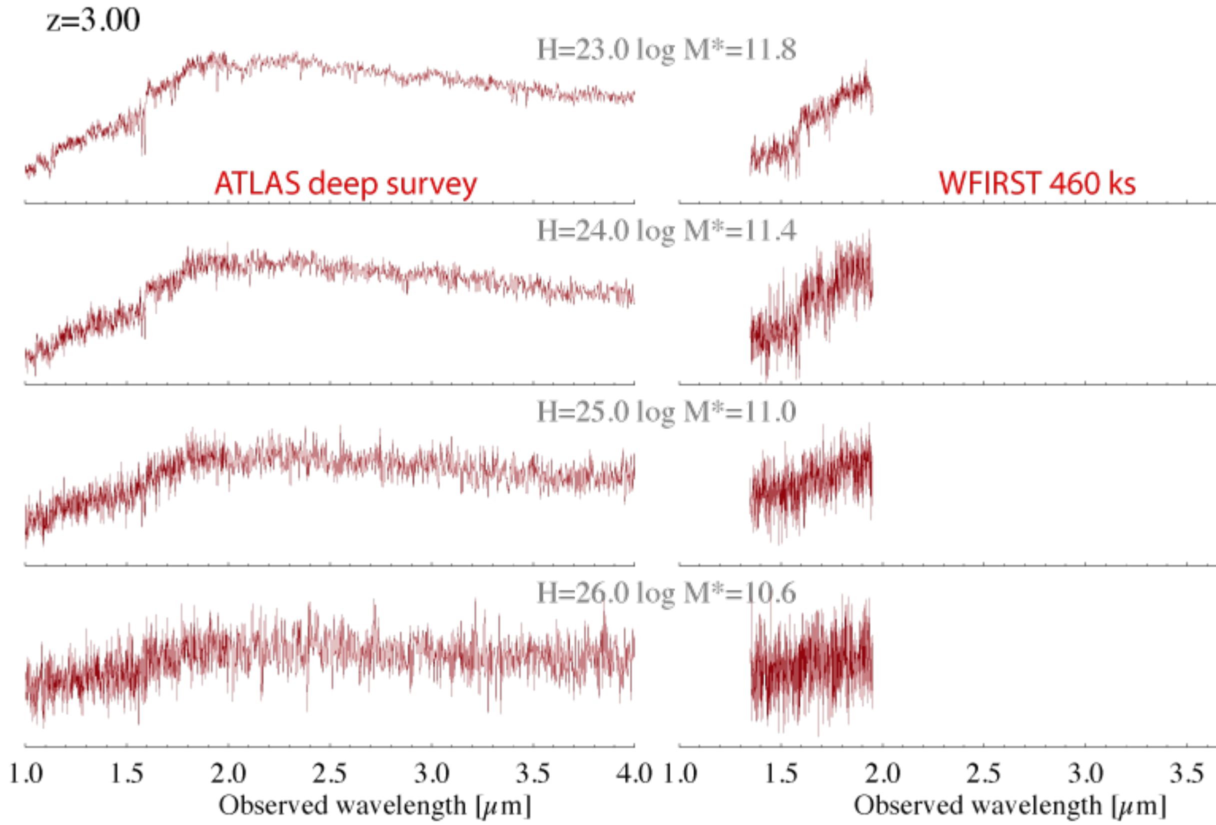
R = 600, λ=1-4μm



PI: Yun Wang (Caltech/IPAC)

Instrument PI: Massimo Roberto (STScI)





The ground - ESO Spectroscopic Survey Telescope:

Slide from Richard Ellis (chair of working group):

Summary of Science Requirements

Report collates telescope & spectroscopic requirements for 3 science areas recognising they may present technical challenges (see later)

- **Telescope aperture**: 10-12m driven by R~40,000 spectra of V~17 stars & R~3000 spectra of AB~24 galaxies. Competitive with PFS/MSE.
- **Field of view**: 5 deg^2 driven by surface density of V~17 stars, LBGs and rarity of transients
- **Multiplex gain**: N~5000 driven by need to fully utilise FOV and complete science programmes on <5 year timescales
- **Spectral resolutions**: R~1000-3000 (galaxies, transients)
  R~20,000-40,000+ (stars)
- **Wavelength Range**: 360-1000nm: blue important for stars and Lya forest; IR extension optional (c.f. MOONS)
- **Super-MUSE?** exciting extragalactic applications, perhaps implemented as later upgrade with additional focal station

22

arXiv:1701.01976

Summary

- The addition of high quality imaging will make strong and weak lensing an integral part of galaxy evolution studies in general.
- The exquisite imaging will greatly help star/galaxy separation
- The uniformity of the data will be unprecedented (e.g. photo-zs)
- Euclid spectroscopy will be spectacular for finding rare objects and provide fairly accurate spectroscopic redshifts & large samples in the deep.
- BUT. Euclid spectroscopy is not particularly deep in the wide, not efficient in crowded regions, and low resolution.
- Combining Euclid with a ground-based MOS such as MOONS, MOSFIRE, 4MOST, or WEAVE, is crucial for a large fraction of the galaxy evolution science one might want to do - e.g. metallicities, dynamics, etc.
- Likewise Euclid will provide input lists for these MOS-es and allow very efficient spectroscopic surveys at z>1 by allowing targeting of sources with a maximum number of lines between sky lines.
- To fully exploit the data we will need new facilities, however. A space-based spectroscopic facility, or a 10-12m ground-based spectroscopic survey telescope, or both, is strongly desired.