

# Euclid Legacy Science

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Jarle Brinchmann (Leiden)

on the basis of the work of legacy coordinators and EC members.

# Euclid

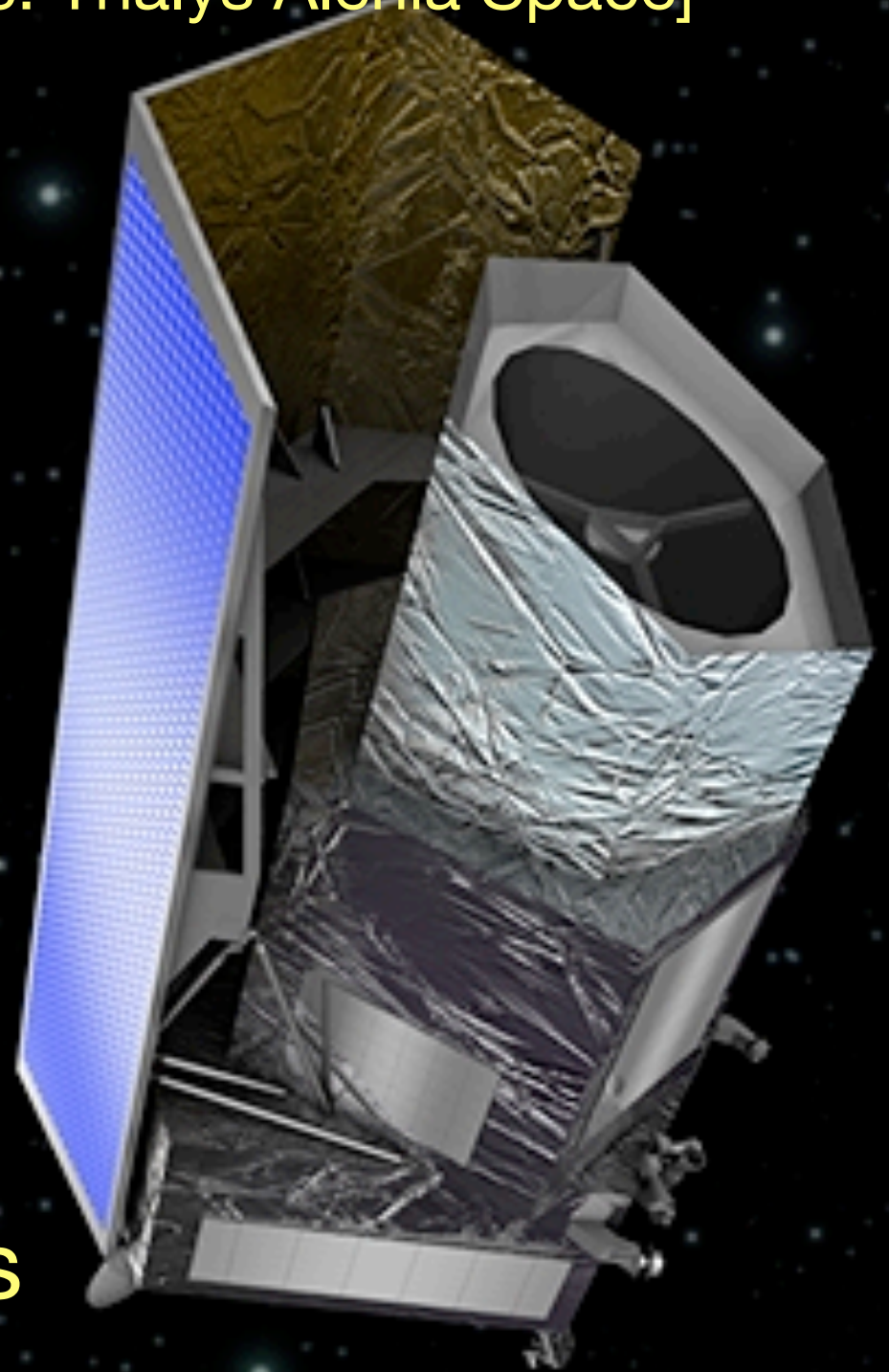
1.2m telescope [Astrium Toulouse, satellite: Thalys Alenia Space]

VIS imager ( $0.79^\circ \times 0.71^\circ$  FoV)

NISP imager & spectrograph  
( $0.76^\circ \times 0.72^\circ$  FoV)

Nominal survey duration: 6 years  
Launch: 2020

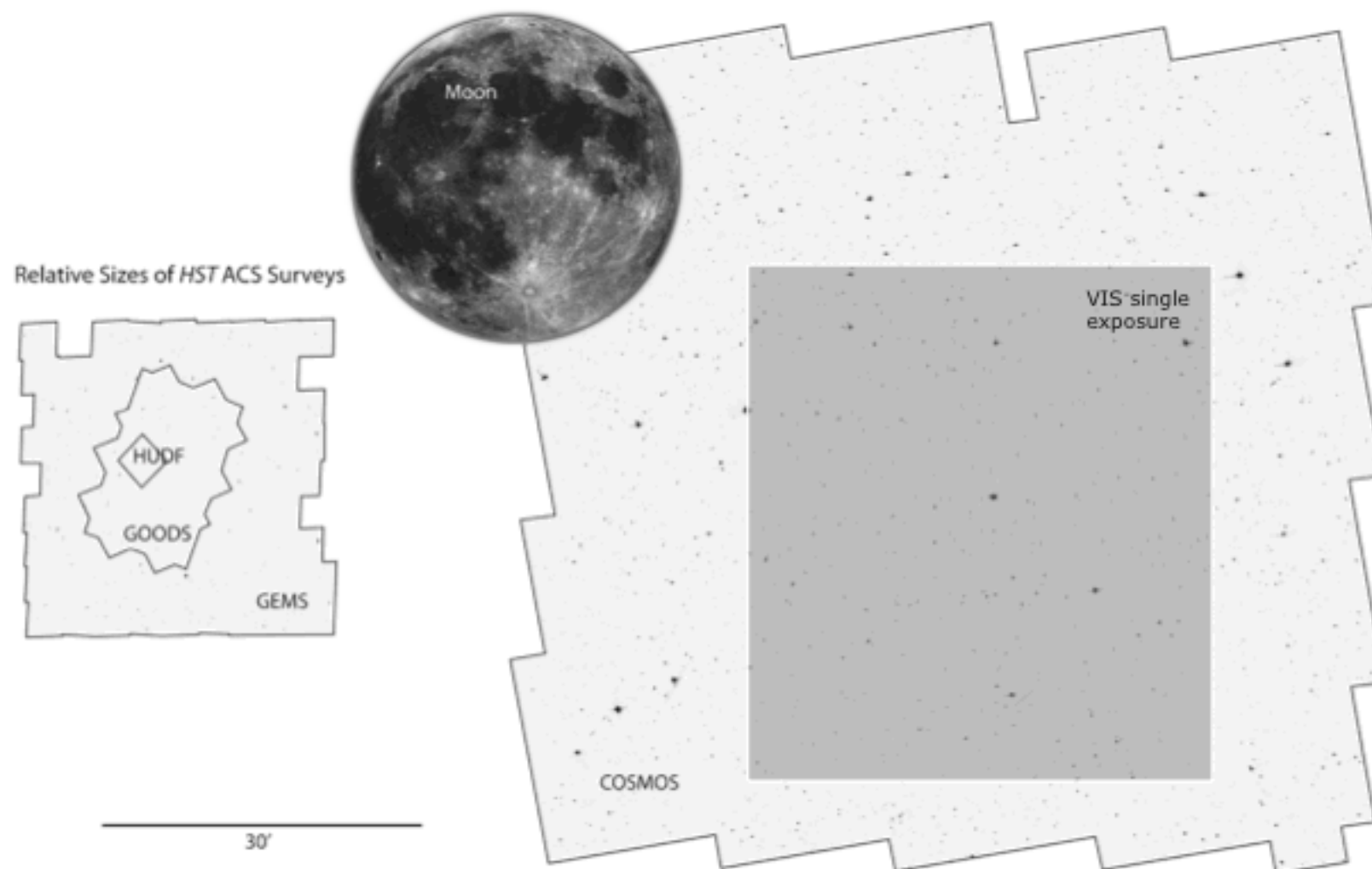
Large consortium: >1100 members



# The instruments

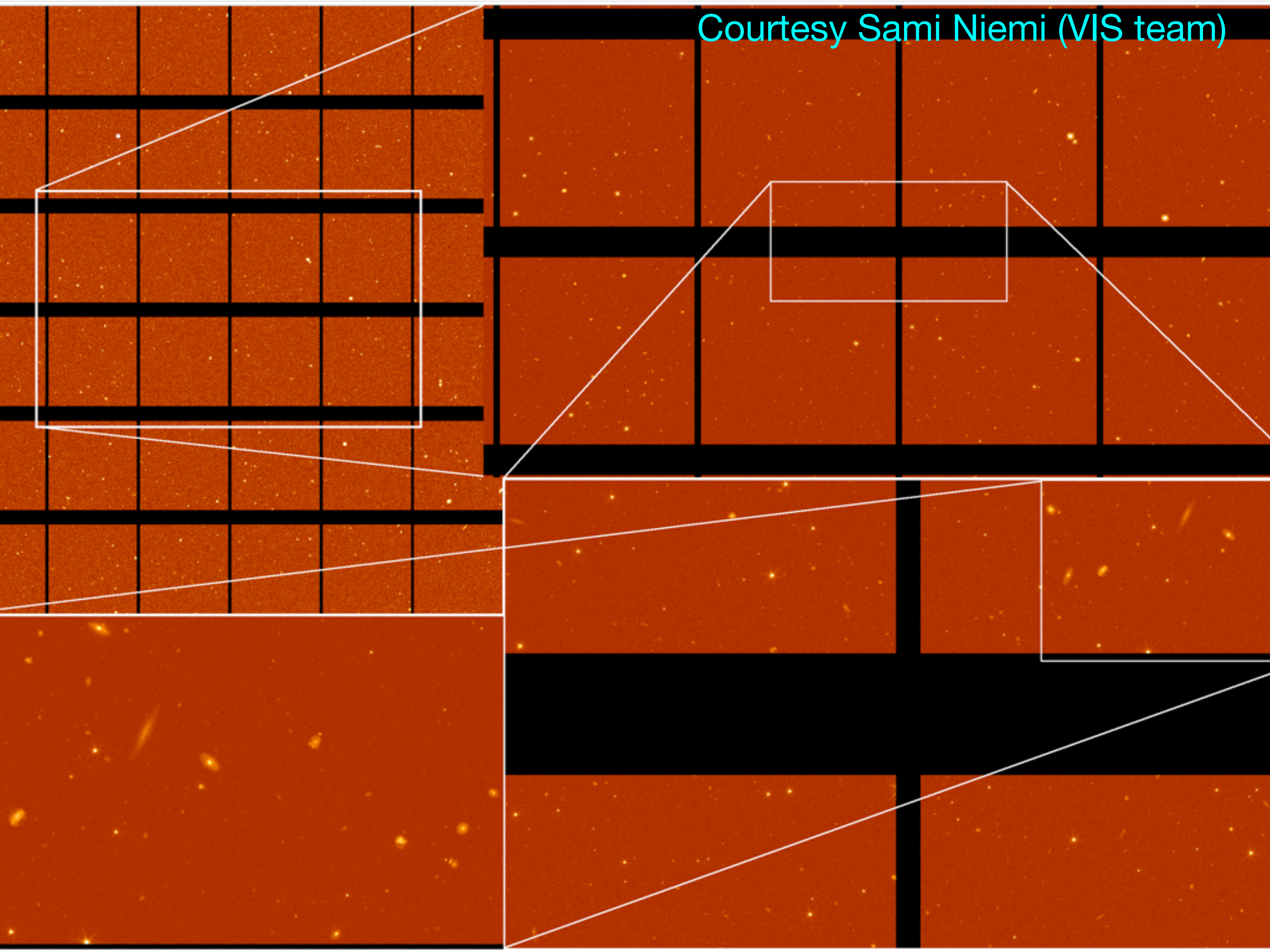
Weak lensing cosmology requires exquisite imaging - this will be delivered by the VIS instrument.

It also requires excellent photometric redshifts, this will be delivered by a combination of deep NIR images from Euclid and ground-based imaging.





Courtesy Sami Niemi (VIS team)





# The NISP instrument(s)

The other core cosmology goal is Baryon Acoustic Oscillations - for that you need redshifts



Courtesy OU-NIR/OU-MER

The full survey will be  $\sim 1.6 \times 10^6$  times larger



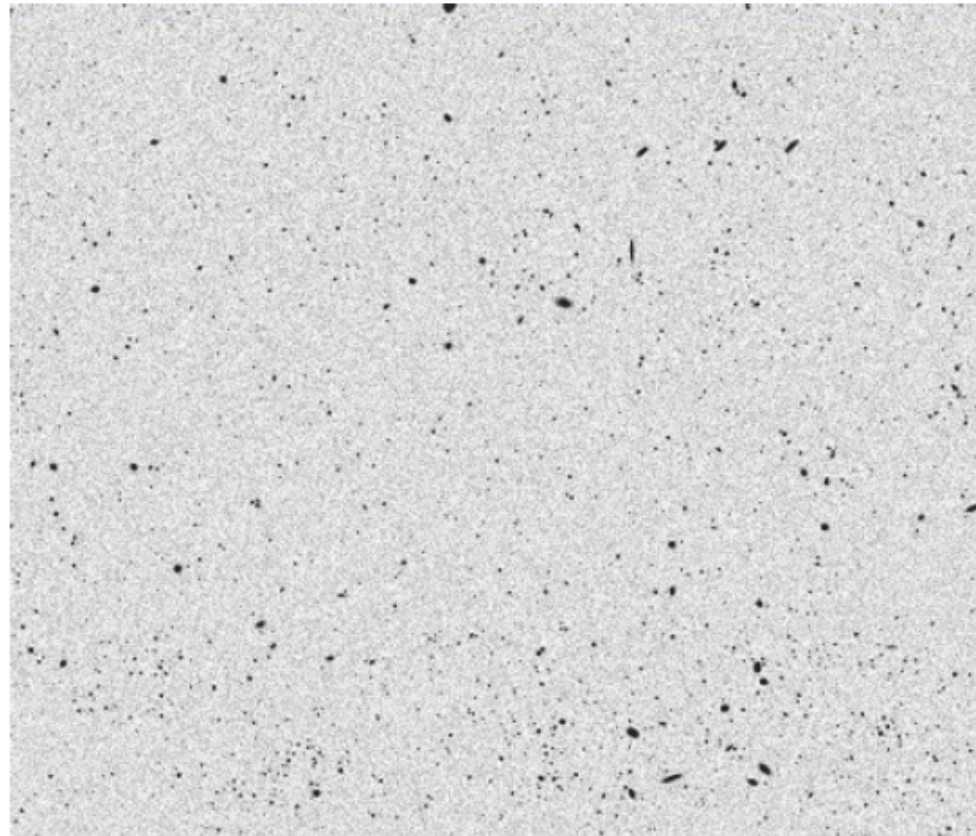
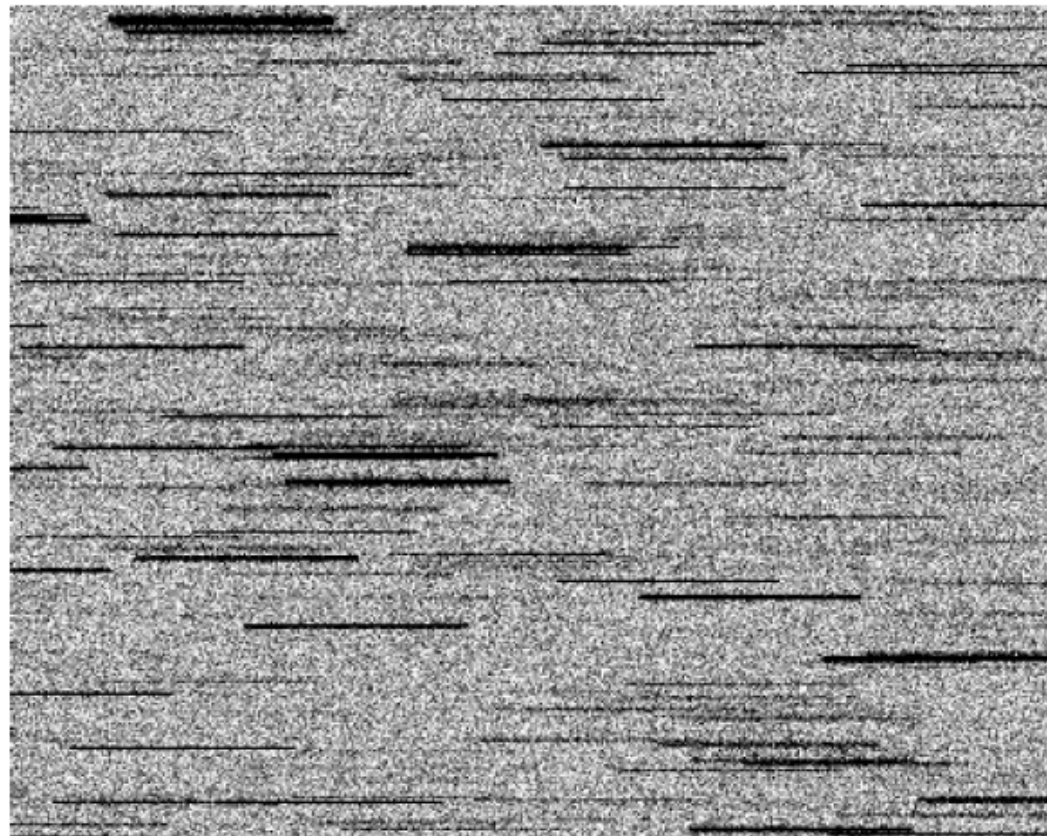
# The NISP instrument(s)

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NIR images Y, J, H ( $\sim 1-1.7\mu\text{m}$ )

Slitless spectra  $1.1-2.0\mu\text{m}$  @  
 $R = 250$  & FWHM  $\sim 0.3''$





# The importance of legacy science

The Palomar Observatory Sky Survey:

**The** survey of the sky for many decades. It led to the discovery of so many new sources it would be hard to list.

The Sloan Digital Sky Survey:

A massive spectroscopic & imaging survey of the sky. The main goal was cosmology - but the vast majority of the SDSS papers have been **legacy** papers.

Many others:

IRAS

FIRST

etc. etc.

Rosat

NVSS

UKIDSS

HDF/UDF

Good surveys that are easy to use for the general astronomers always have big impact!

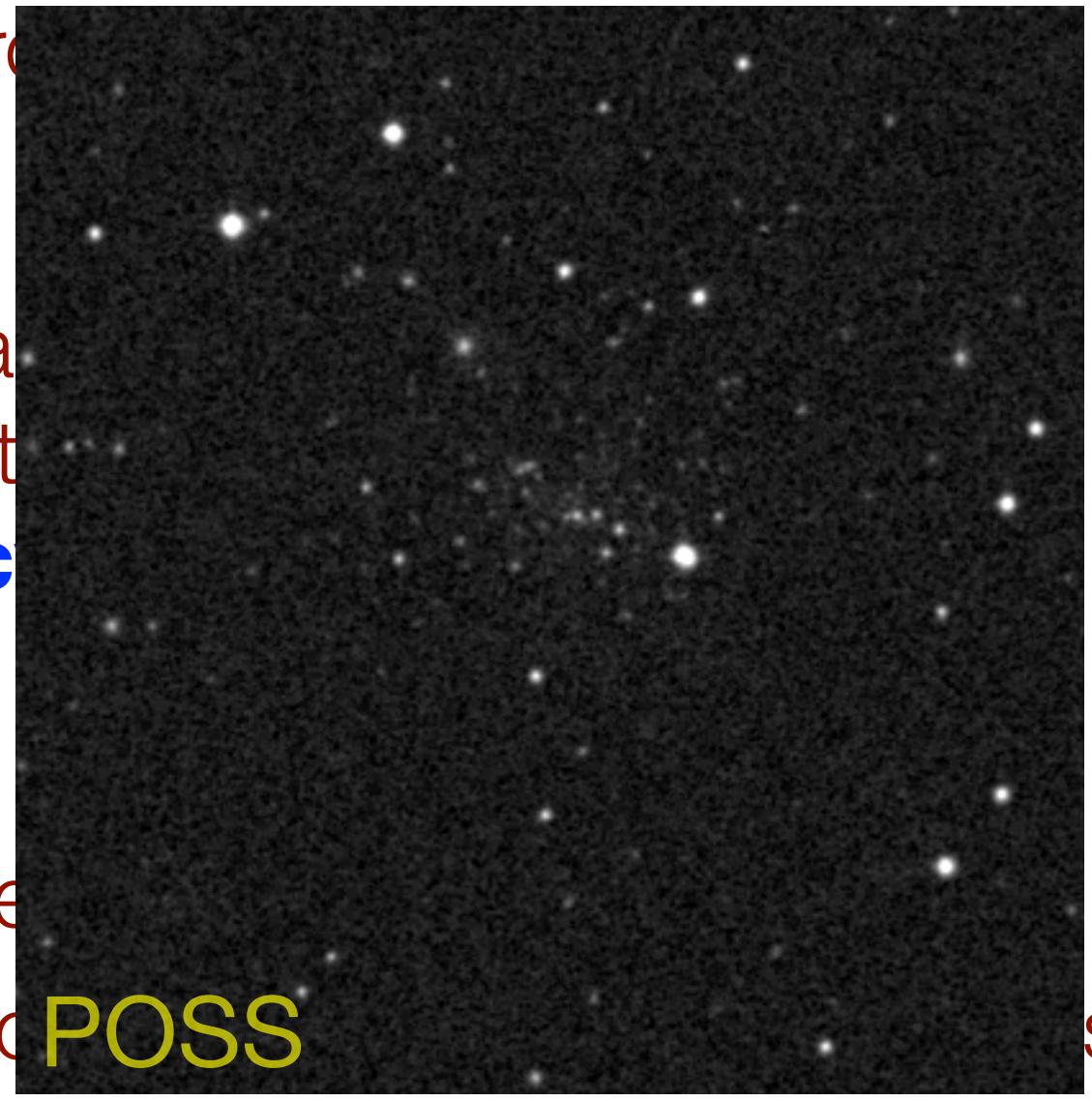
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SDSS



POSS

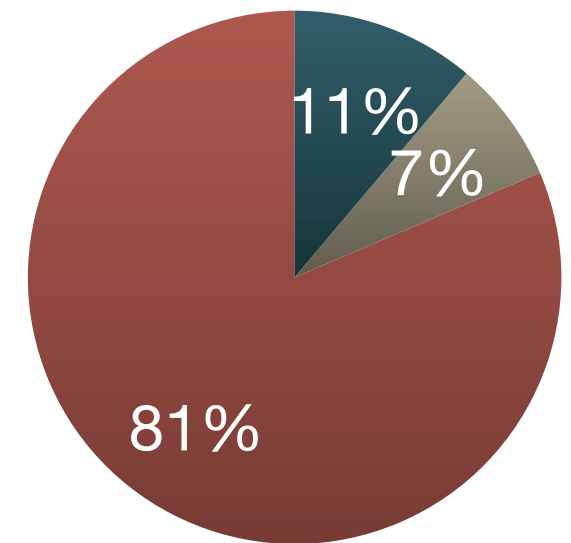
for the general astronomers always  
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# The SDSS lesson

Out of 834 “official” SDSS journal papers:

Area	# papers	Percentage
Cosmology	93	11.2%
Supernovae	62	7.4%
Legacy	679	81.4%



But many more (>4500) papers have been written using SDSS data by others: **It is crucial that the data can be used by the whole astronomical community.**

# Legacy Science Working Groups

Extra-solar planets

Milky Way and Resolved  
Stellar Pops

Local Universe

Galaxies and AGN  
evolution

Primeval Universe

Clusters of Galaxies

Supernovae and transients

Strong lensing

CMB Cross-correlations

Cosmological Theory

Cosmological simulations



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# Euclid legacy in numbers

What	Euclid	Before Euclid
Galaxies at $1 < z < 3$ with good mass estimates	$\sim 2 \times 10^8$	$\sim 5 \times 10^6$
Massive galaxies ( $1 < z < 3$ ) w/ spectra	$\sim \text{few} \times 10^3$	$\sim \text{few tens}$
H $\alpha$ emitters/metal abundance in $z \sim 2-3$	$\sim 4 \times 10^7 / 10^4$	$\sim 10^4 / \sim 10^2?$
Galaxies in massive clusters at $z > 1$	$\sim 2 \times 10^4$	$\sim 10^3?$
Type 2 AGN ( $0.7 < z < 2$ )	$\sim 10^4$	$< 10^3$
Dwarf galaxies	$\sim 10^5$	
$T_{\text{eff}} \sim 400\text{K}$ Y dwarfs	$\sim \text{few } 10^2$	$< 10$
Strongly lensed galaxy-scale lenses	$\sim 300,000$	$\sim 10-100$
$z > 8$ QSOs	$\sim 30$	None



# **Exo-planets**

- **a possible additional survey**



**ExELS**

Approx location of  
3 ExELS fields



### Survey design:

- 3 fields close to Gal Centre observed every 20 mins in NISP H and regularly in VIS for multiple 30 day periods over Euclid mission lifetime
- 1-2 days of observation during Euclid verification or early on in mission to establish proper motion baseline needed for planet mass measurements.
- Early Level-Q products in the form of ultra-deep VIS/NISP imaging close to Galactic Centre.



ExELS

Approx location of  
3 ExELS fields

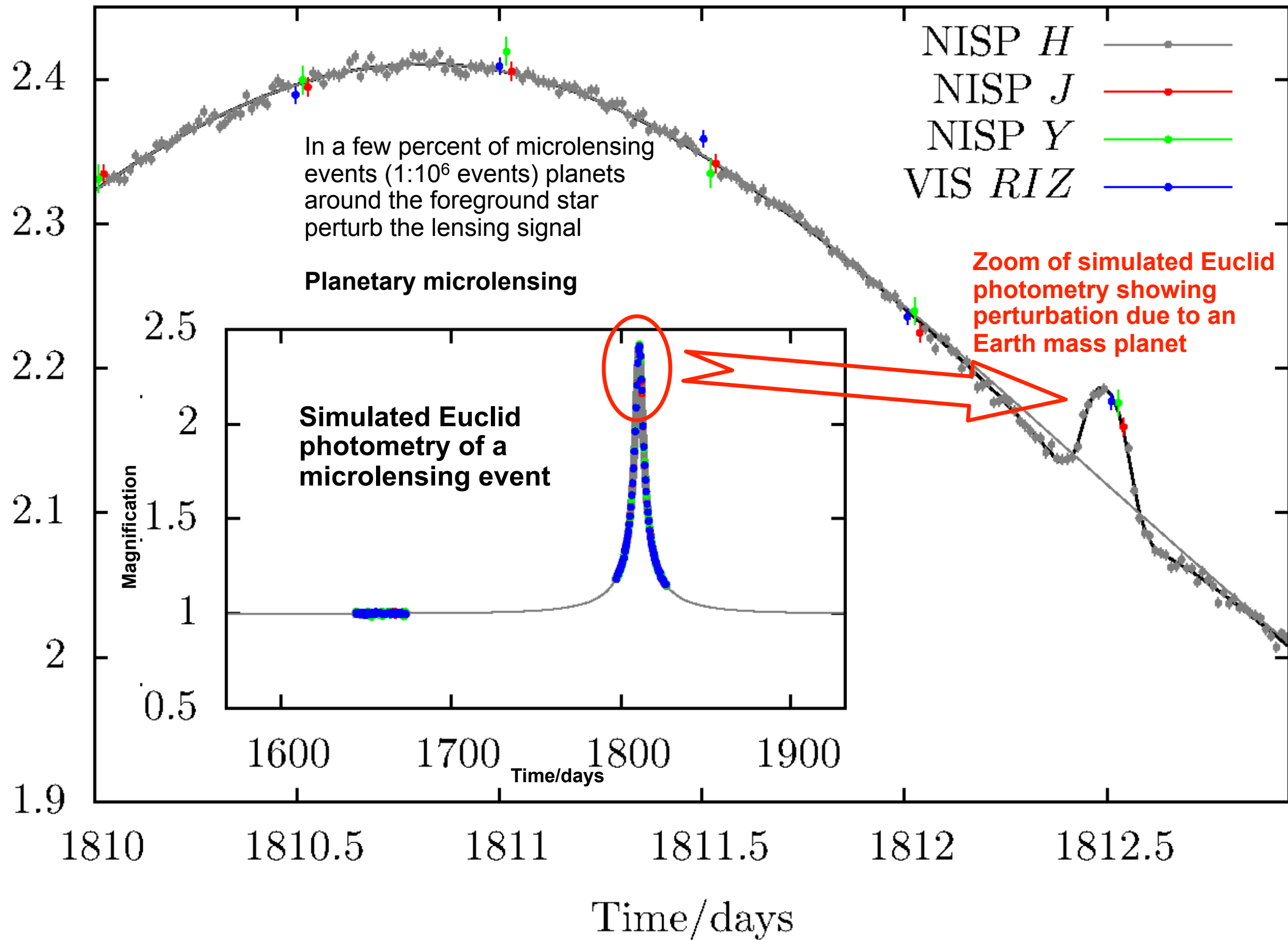
Simulated Euclid H band image  
from a single 2k x 2k NISP array

Detailed image-level simulation of ExELS  
photometry carried out by SWG (Penny et al 2013)



$$M_1 = 0.86 M_\odot \quad M_p = 1 M_\oplus \quad a = 2.4 \text{ AU} \quad \Delta\chi^2 = 1526.96$$

Normalized flux





# Microlensing & planets

The duration of an event depends on  $\sqrt{M_p/M_*}$   
hence the output of the survey depends on  
cadence possible.

Primary survey objectives	Yield	Science
Abundance of cool exoplanets down to Earth mass with host separation > 1 AU to at least 3-sigma precision	~ 35/month (incl. 4.5 Earths & 14 Neptunes)	Cool exoplanet regime is crucial for testing planet formation theories and constraining abundance of planets in outer Habitable zone.
Measure the abundance of free-floating planets	Around 15 free-floating Jupiters per month if there is one per Galactic star.	Unbound planets are predicted by planet formation theories. Young counterparts have been observed in clusters. Older population tentatively observed with ground-based microlensing

Full science study presented in  
Penny et al (2013): arXiv:1206.5296

# The role of additional surveys

## Two suggestions:

- ★The microlensing survey. (~4 months)
- ★A SN Type Ia survey to provide additional constraints on cosmology. (~6 months)

## In common:

Need a difference cadence to the standard survey - can not (easily) be incorporated in the main survey. Thus will take place towards the end if at all.

## Additional benefits:

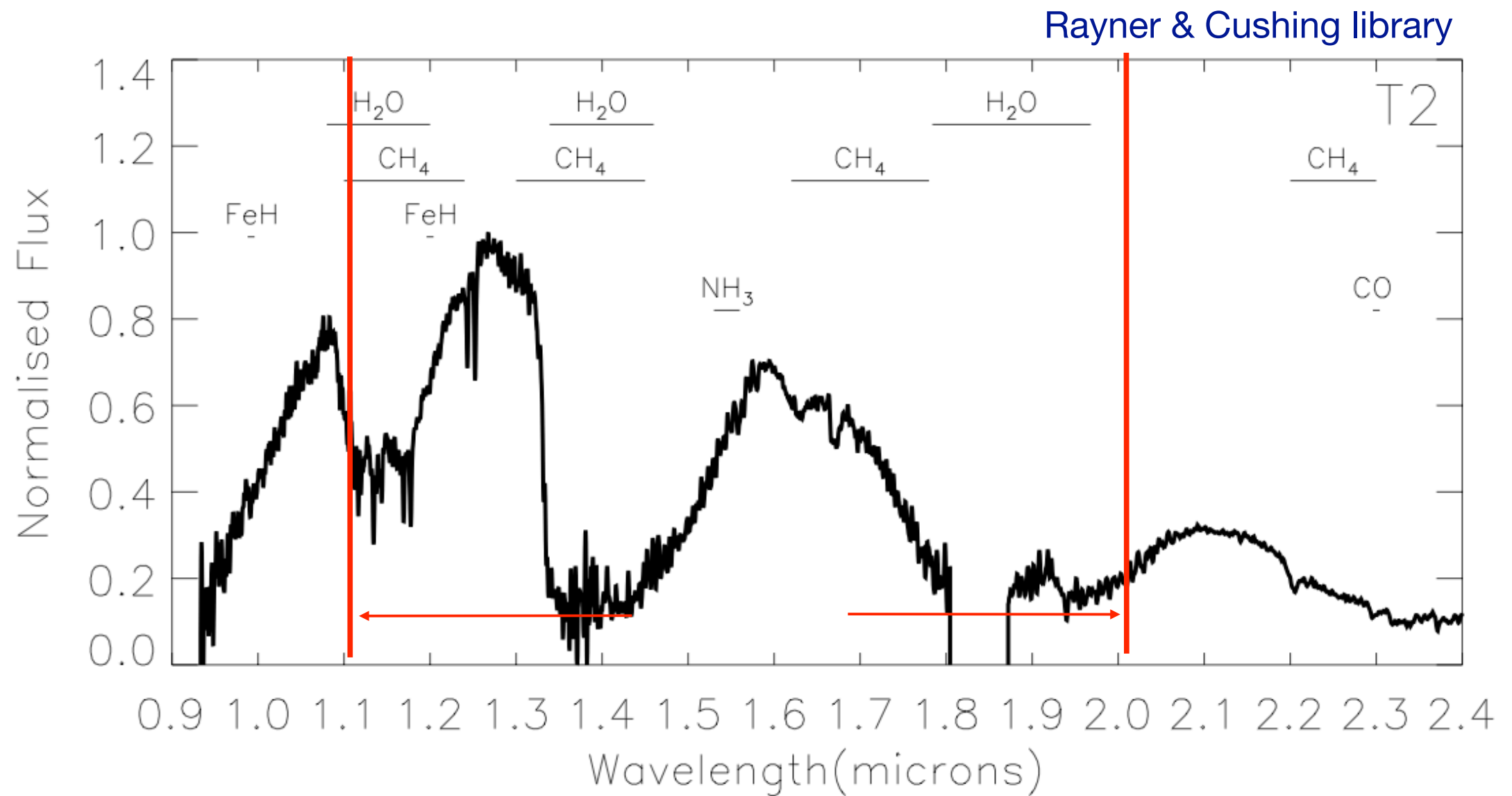
Co-adding data gives ultradeep final images ( $H_{AB} \sim 28$  for SNe survey over several  $\text{deg}^2$ ).



# **Stars & solar system**

# Stellar & Solar system science underexplored

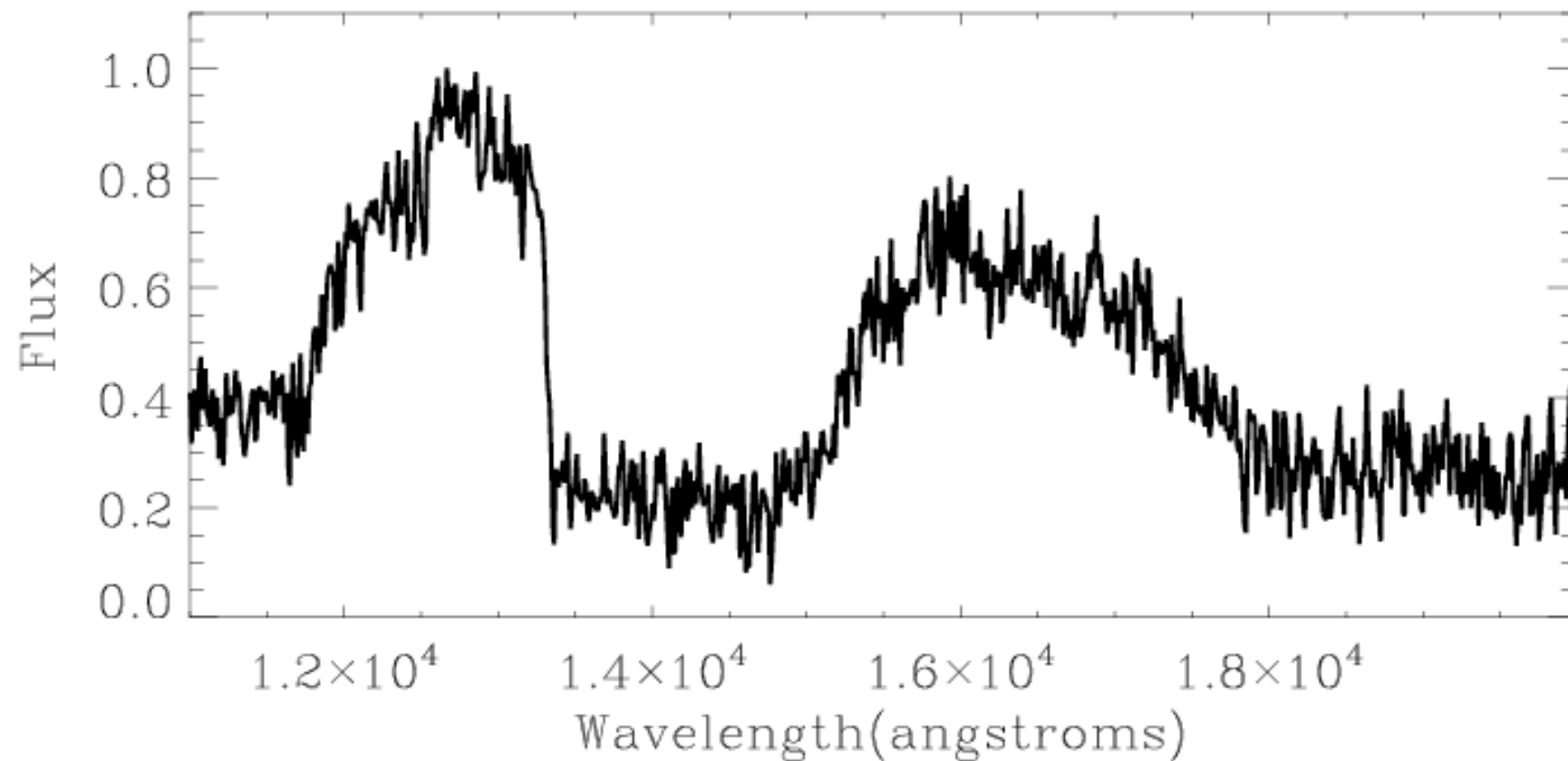
One exception: Cool brown dwarfs (also legacy scientist Eduardo Martin)



Niall Deacon, Bianca Garilli, Paolo Franzetti



# Brown Dwarfs with NISP

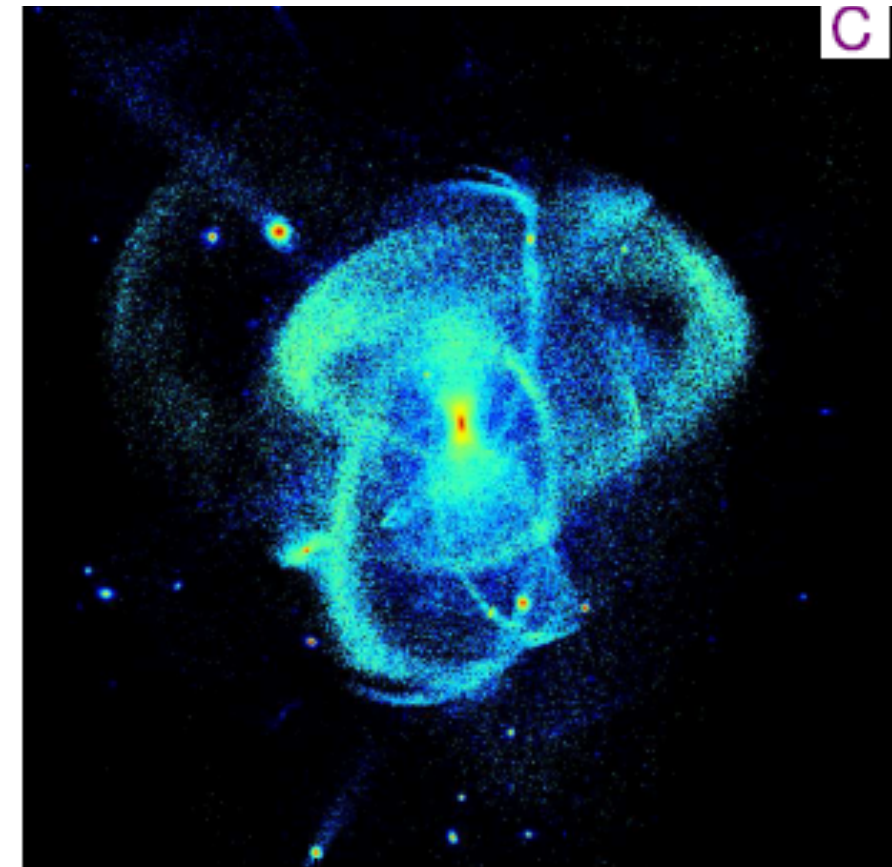


H=18.0

~900 brighter than this in Euclid wide.  
Can be used to assign spectroscopic type.

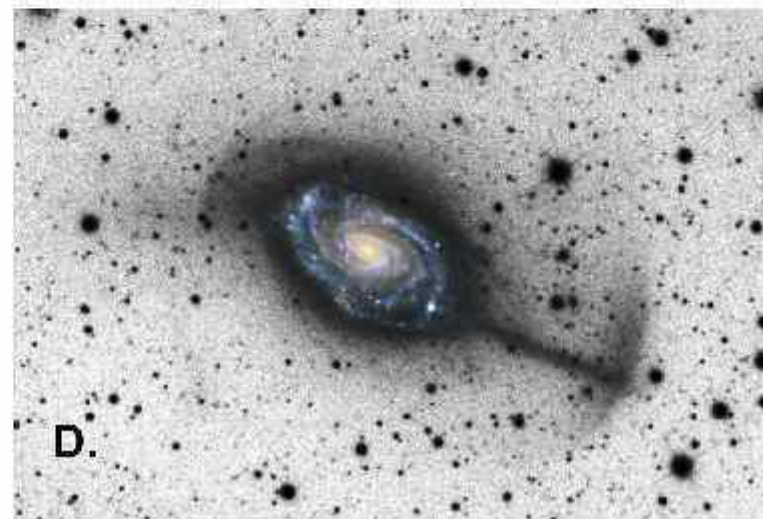
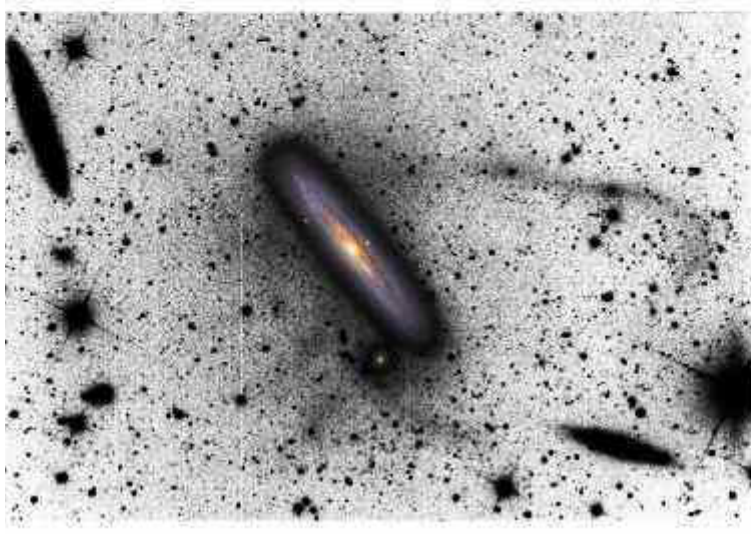
# Merger history and streams

Cosmological simulations predict significant substructure in the halos. Tracing this helps constrain the merger history.



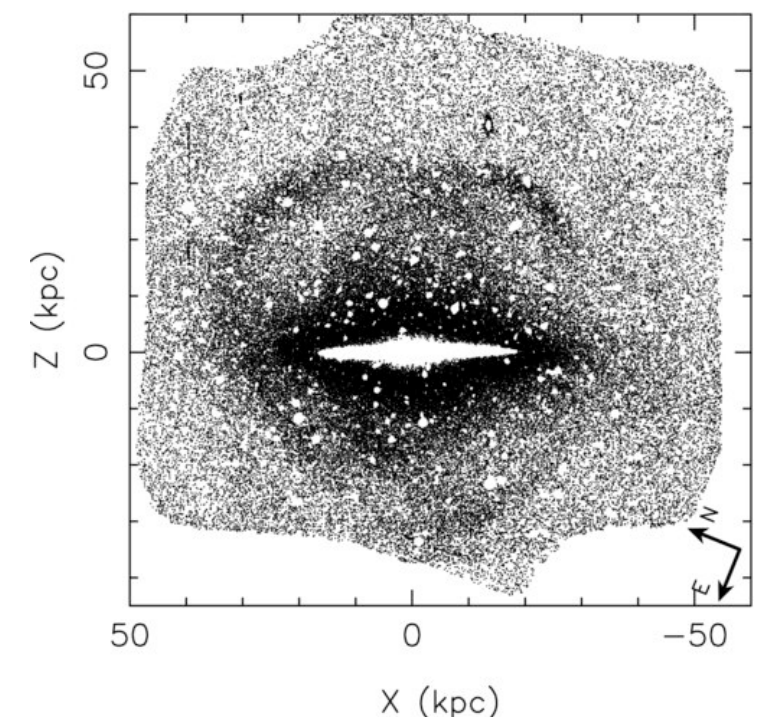
Cooper et al. 2010

And observations show these structures in deep images.



Martinez-Delgado et al. 2010

Mouhcine, Ibata & Rejkuba 2010





# Milky Way and Resolved Stellar Populations

The Euclid NIR imaging will allow detection of luminous giant branch stars in galaxies out to 5 Mpc.

This will allow studies of sub-structure in the galaxies and hence their formation process.

The NIR data together with optical data will also help place much better constraints on the properties of the stars in these galaxies.



# **Extra-galactic astronomy**



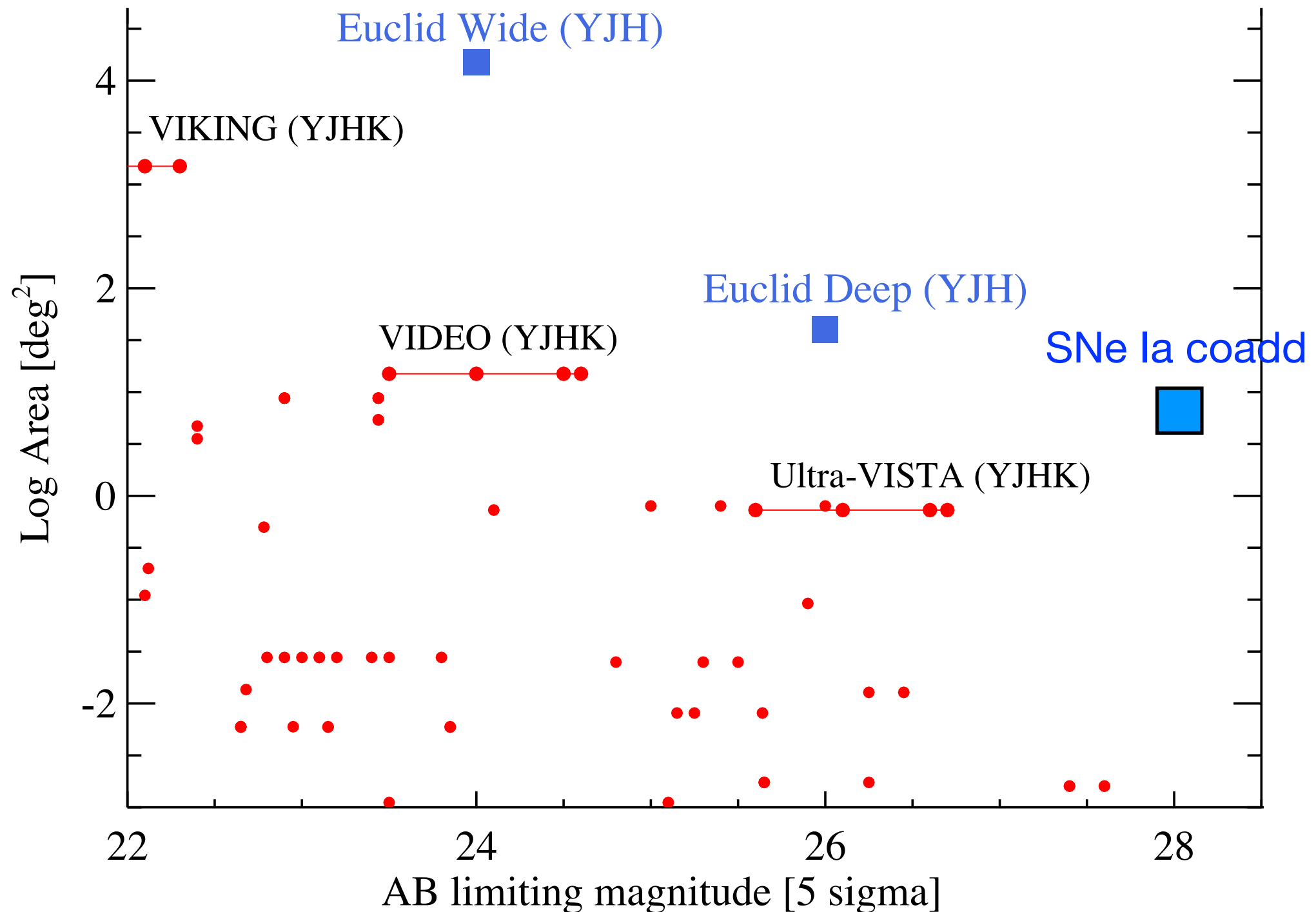
# Extra-galactic astronomy - what are the gains?

- What Euclid will provide us with.
- Galaxy formation science with Euclid
  - 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 @  $z > 1$



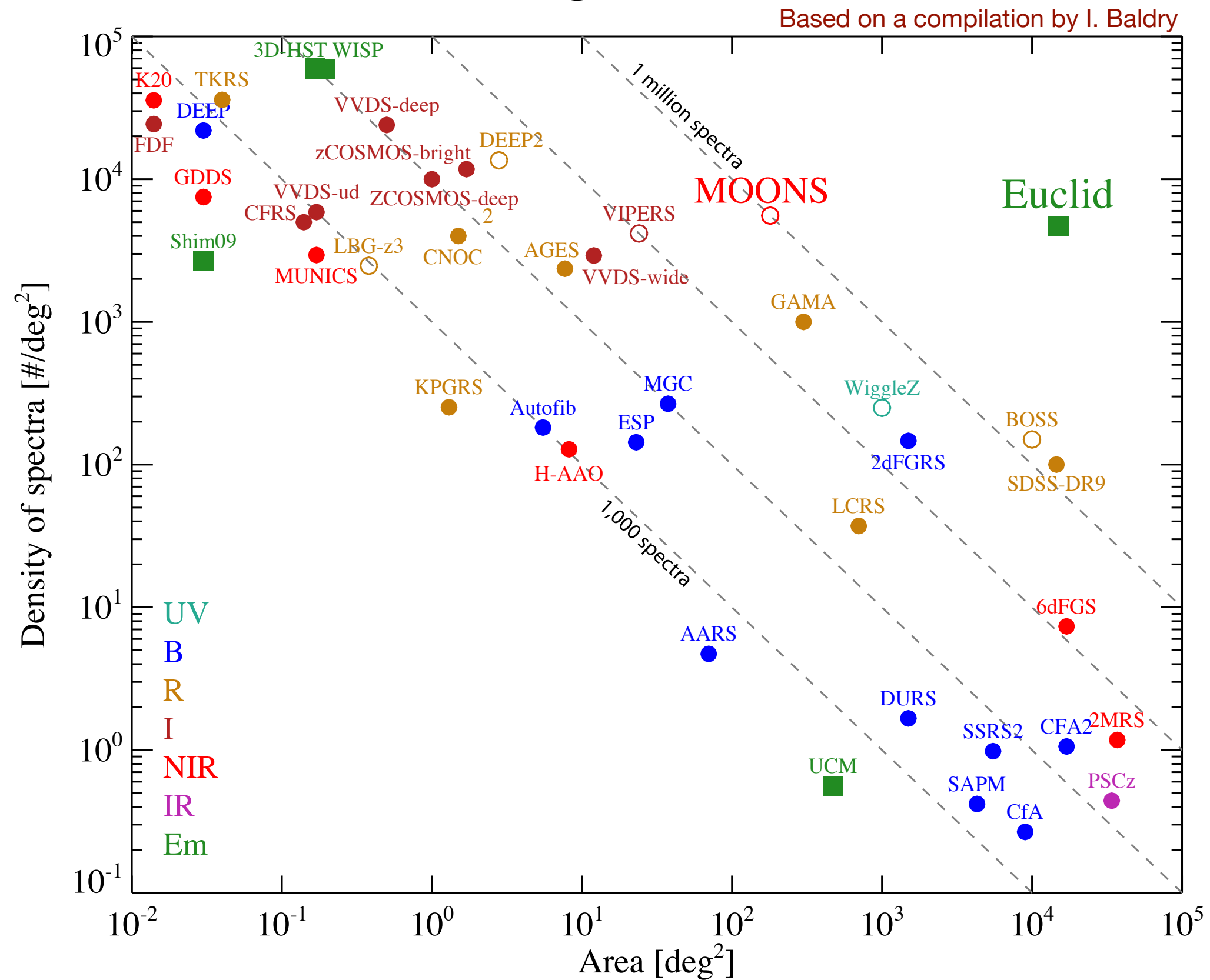
# Euclid compared to ground-based surveys

NIR imaging depth is similar to the deepest images from the ground.



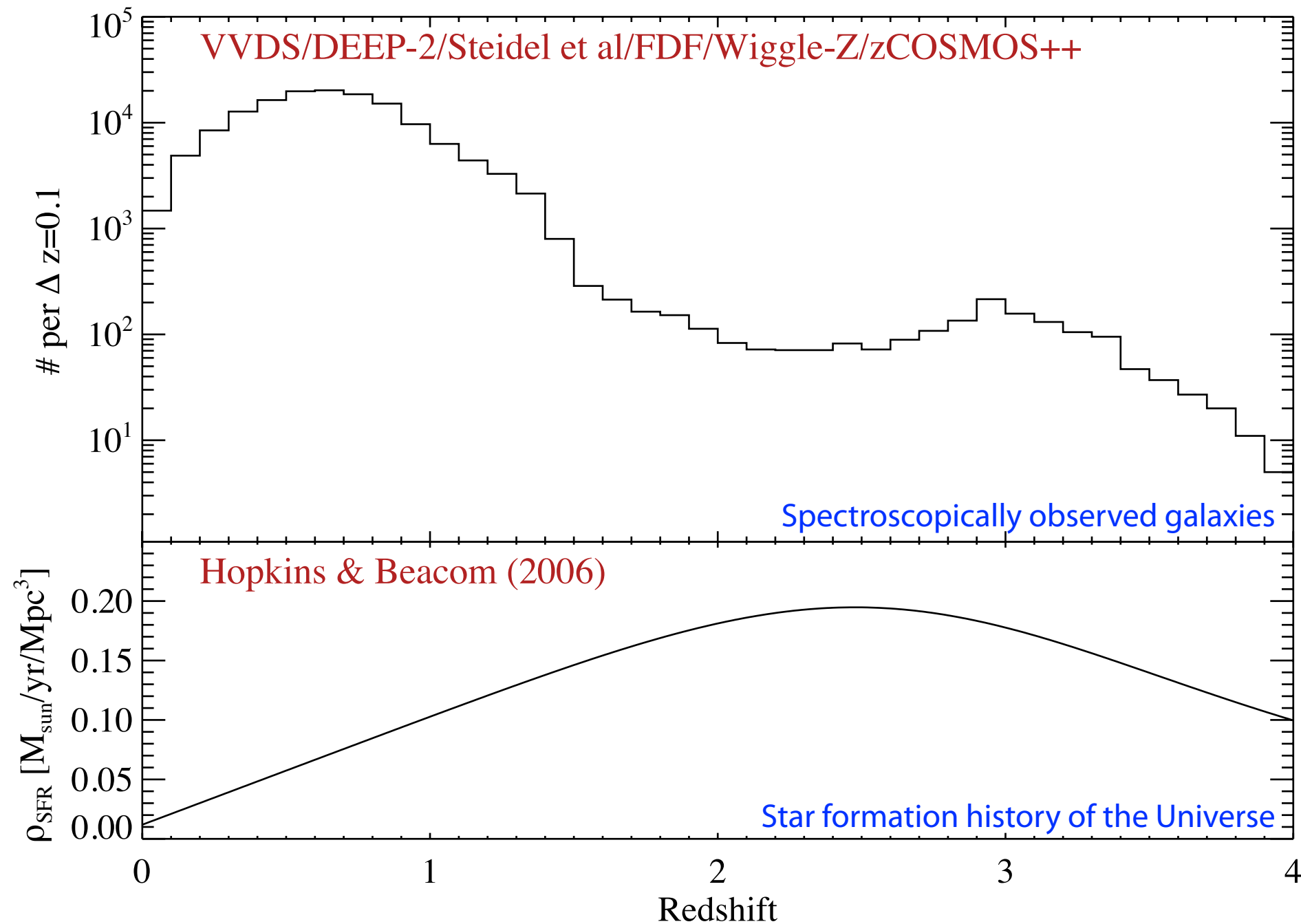


# Euclid compared to ground-based surveys





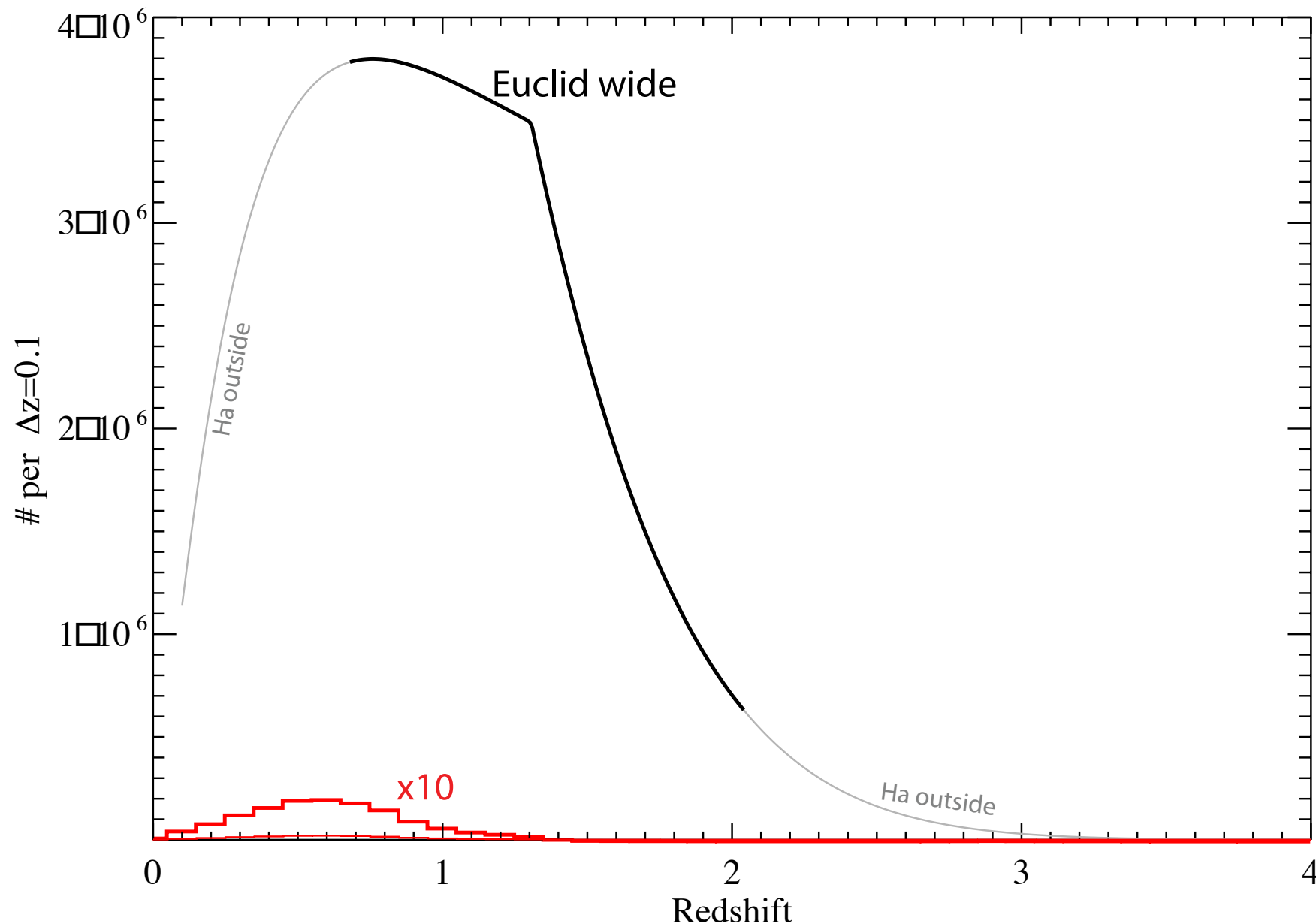
# Galaxy & AGN Evolution



Today we lack spectroscopic studies of galaxies at a crucial time of the Universe



# Galaxy & AGN Evolution

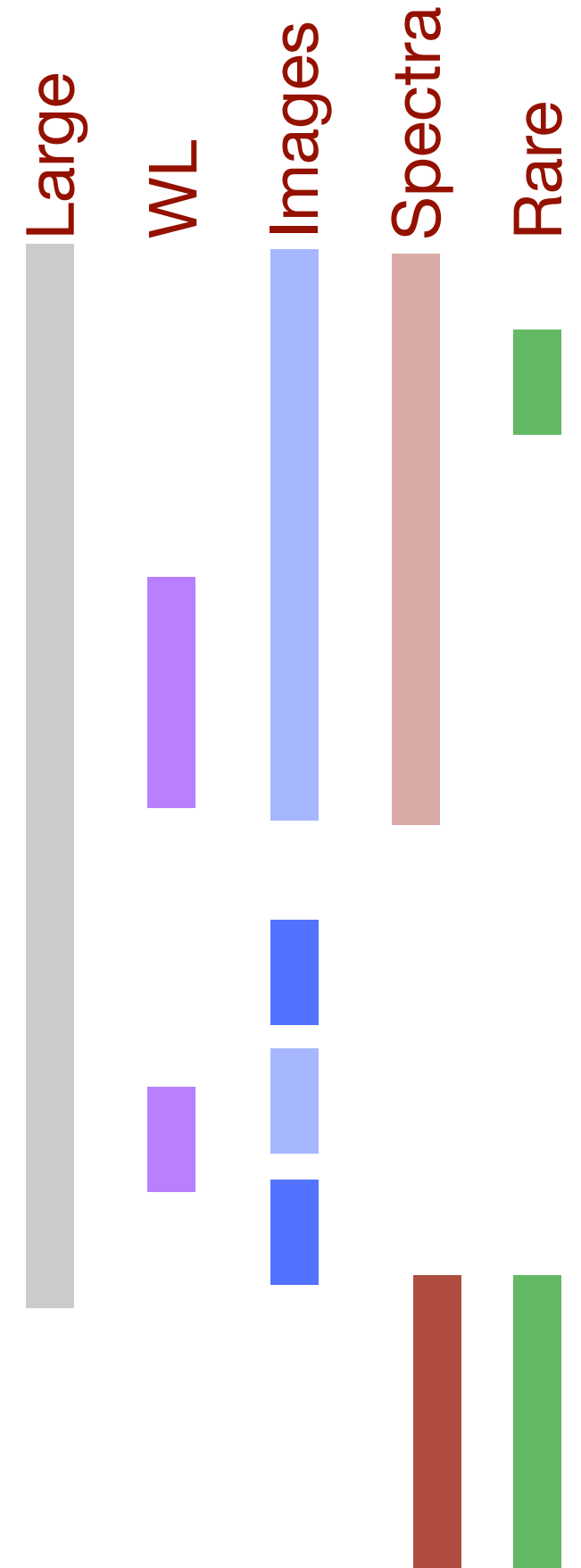


This will change dramatically with Euclid but much progress will happen before then also with e.g. MOSFIRE and MOONS

Should think of Euclid and MOONS/MOSFIRE etc as *complementary* facilities.

# (Some) Science cases for galaxy evolution with Euclid

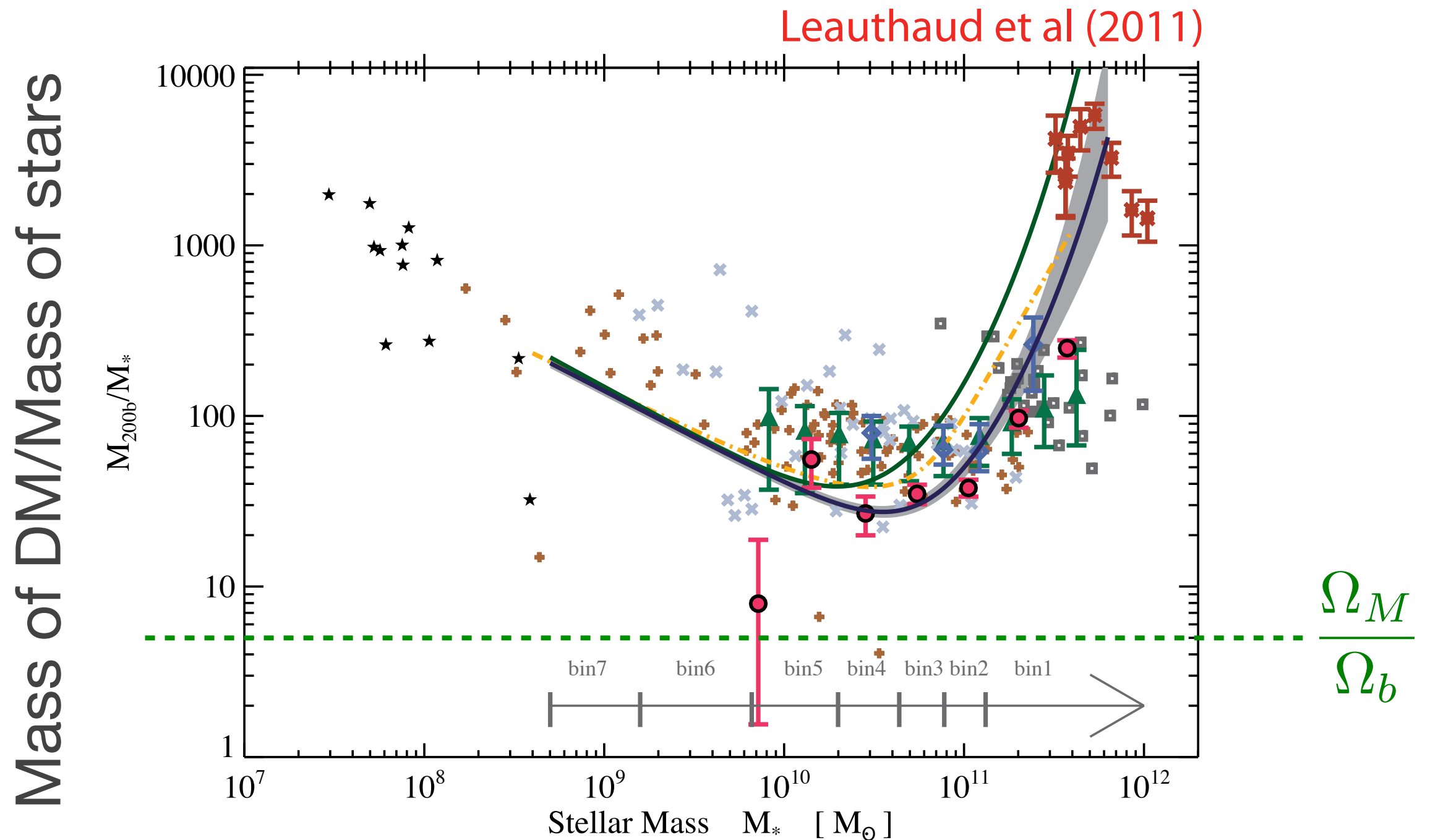
- Multi-dimensional distributions of physical parameters.
- The growth and evolution of quiescent high- $z$  galaxies.
- Galaxy evolution as a function of environment.
- Galaxy evolution at fixed halo mass.
- Baryon to star conversion efficiency as a function of physical properties of halos and galaxies.
- Detailed properties of galaxy halos from large samples of strongly lensed galaxies.
- Intrinsic alignments and galaxy properties.
- Galaxy merger evolution.
- QSOs at  $z > 8$ .
- Type II AGN, their evolution and relationship to dark matter halos and galaxy properties





# Galaxy formation in halos is inefficient

The use of weak lensing in galaxy evolution studies has a lot of potential but has not been fully explored yet.

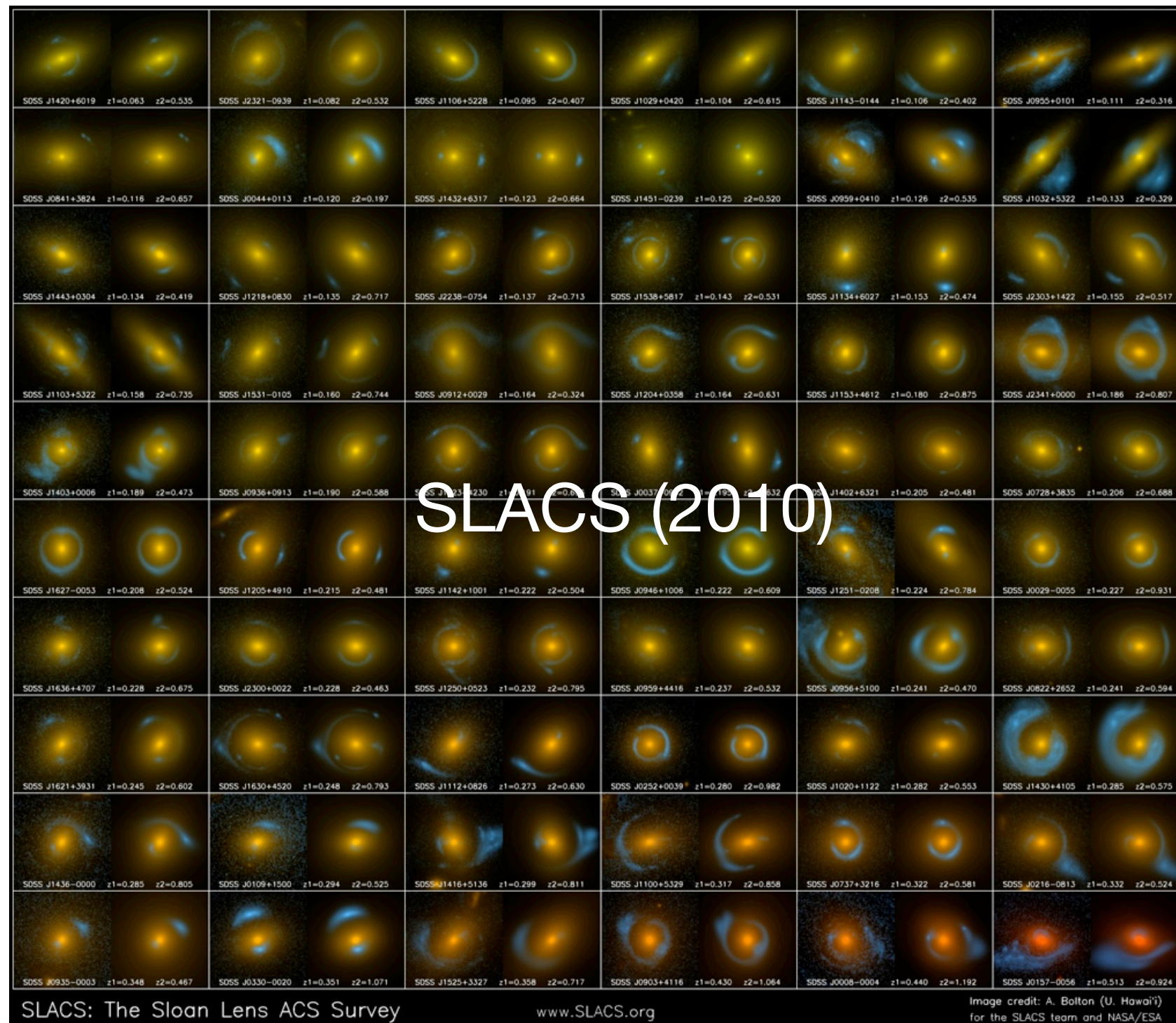


**Strong lensing**



# Strong lensing with Euclid

From curiosity to a multi-purpose tool for unique galaxy structure & formation studies

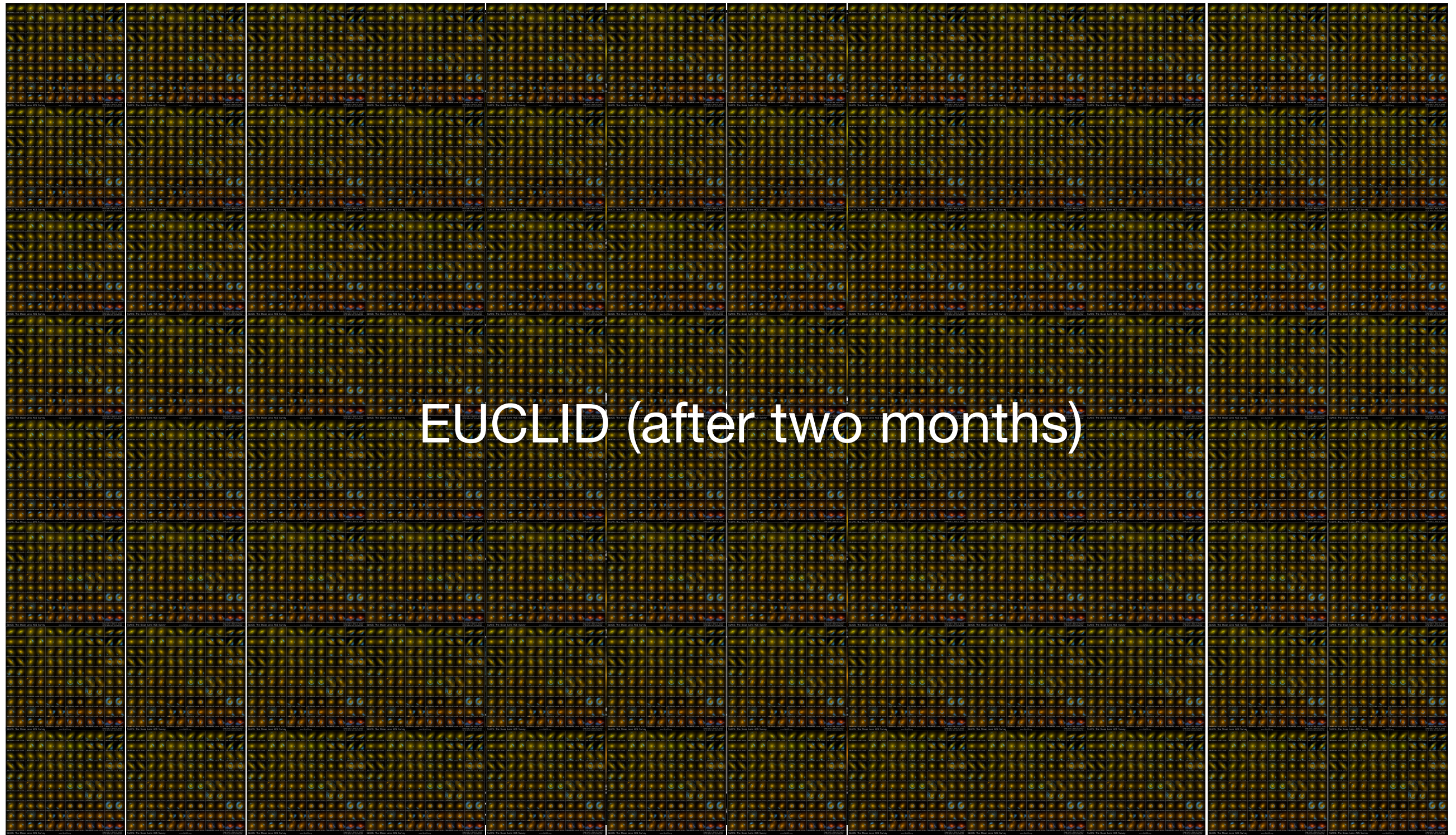


Based on slides from L. Koopmans



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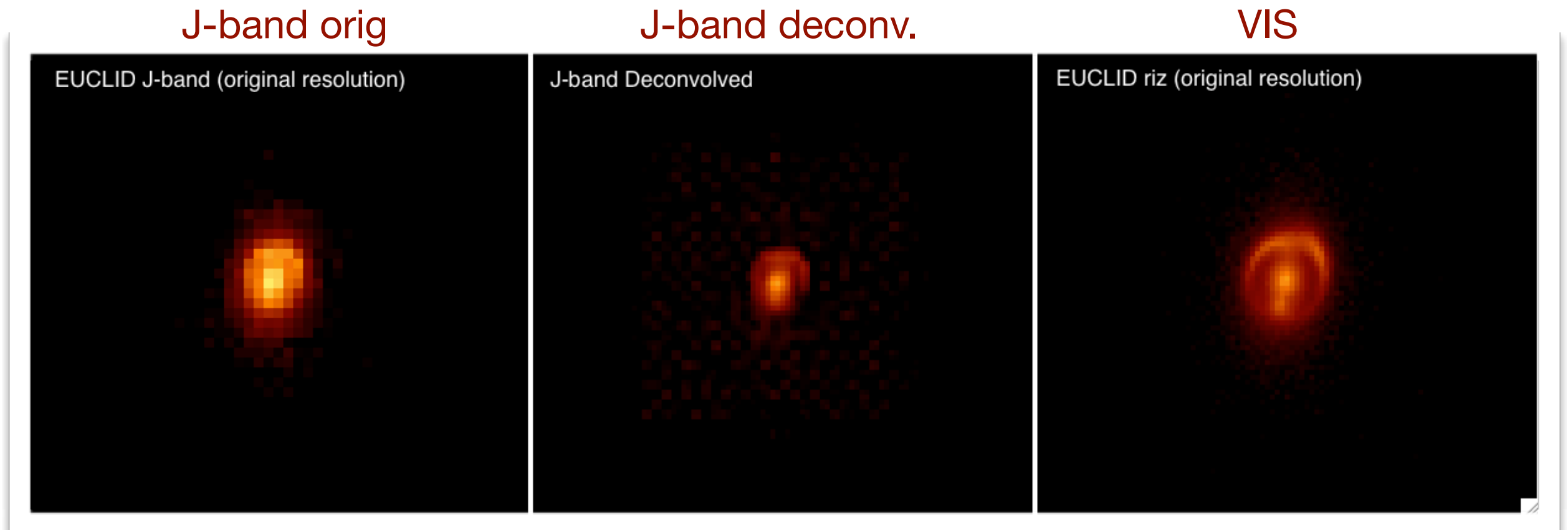


Based on slides from L. Koopmans



# SL Expectations from EUCLID

## Simulation tools for Galaxy-Scale Lenses



Simulated observations of a strong lensing galaxy. The left and the right panels show the IR (J band) and the VIS (RIZ) images of the same object. A prominent arc is visible in the RIZ band. The feature is clearly detectable also in the J band by applying state-of-the-art deconvolution [Courtesy: F. Courbin].

# Strong lensing with Euclid

## Some Science Goals:

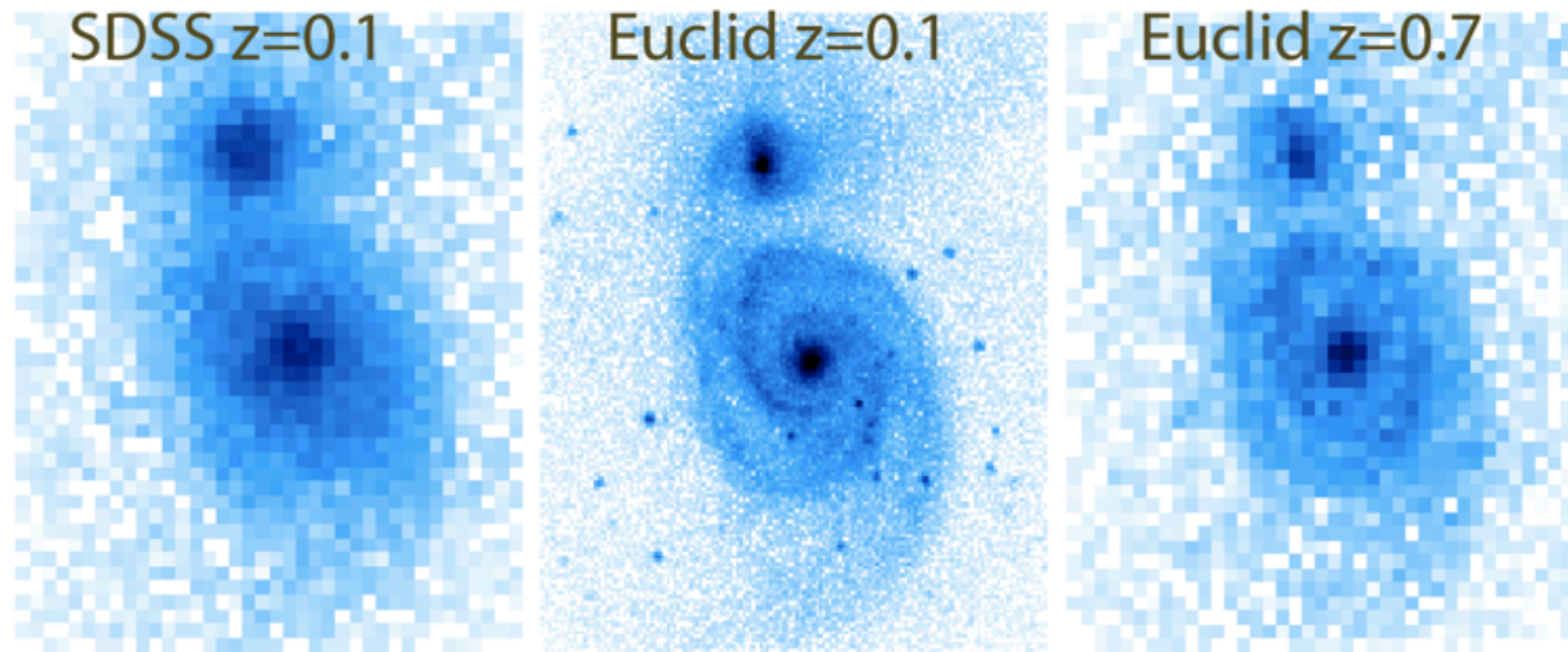
- Total-mass density profiles of galaxies in the inner several effective radii
- WL of strong-lenses on larger scales.
- The stellar and dark matter mass fraction in the inner regions of galaxies.
- The inner dark matter density distribution
- Scaling relations: e.g. Fundamental plane/TF
- The stellar IMF from combined lensing, dynamics & stellar pop. analysis.

*All as a function of redshift, galaxy mass, type, etc.*



# **Galaxy morphology** - with mergers as an example

# Morphologies & associated science



Euclid @  $z \sim 1$  will give similar images to SDSS @  $z \sim 0.1$

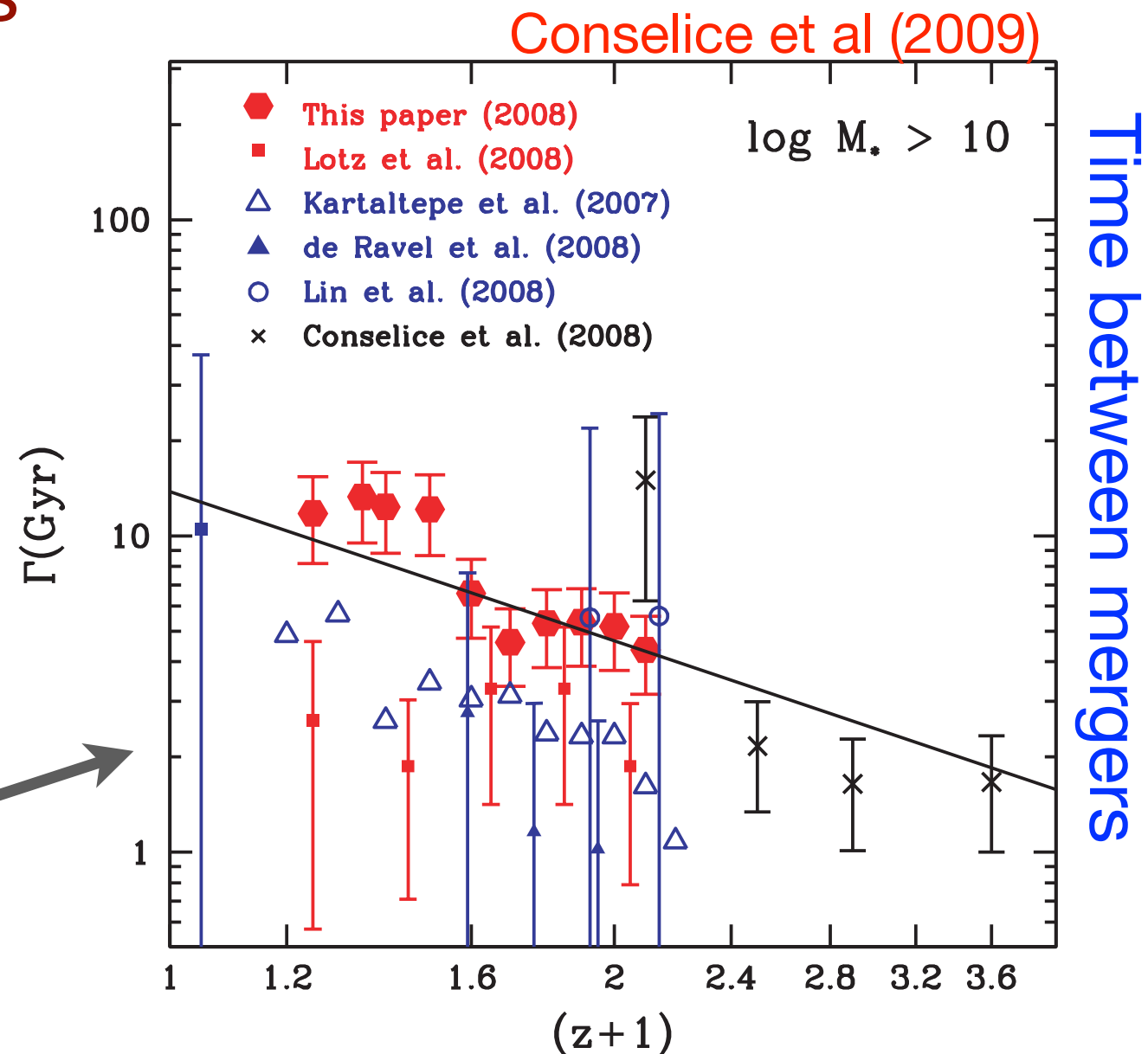
Provides great opportunities for a large range of studies. Example: Galaxy mergers.



# Galaxy mergers

But getting merger **rates** right is proving very challenging:  
Theoretical models **differ** by an **order of magnitude** in their predictions - the main obstacle:  
Baryon physics (Hopkins et al 2010)

Current surveys (zCOSMOS, VVDS, etc) are too small to help constrain the physics.



# Galaxy mergers

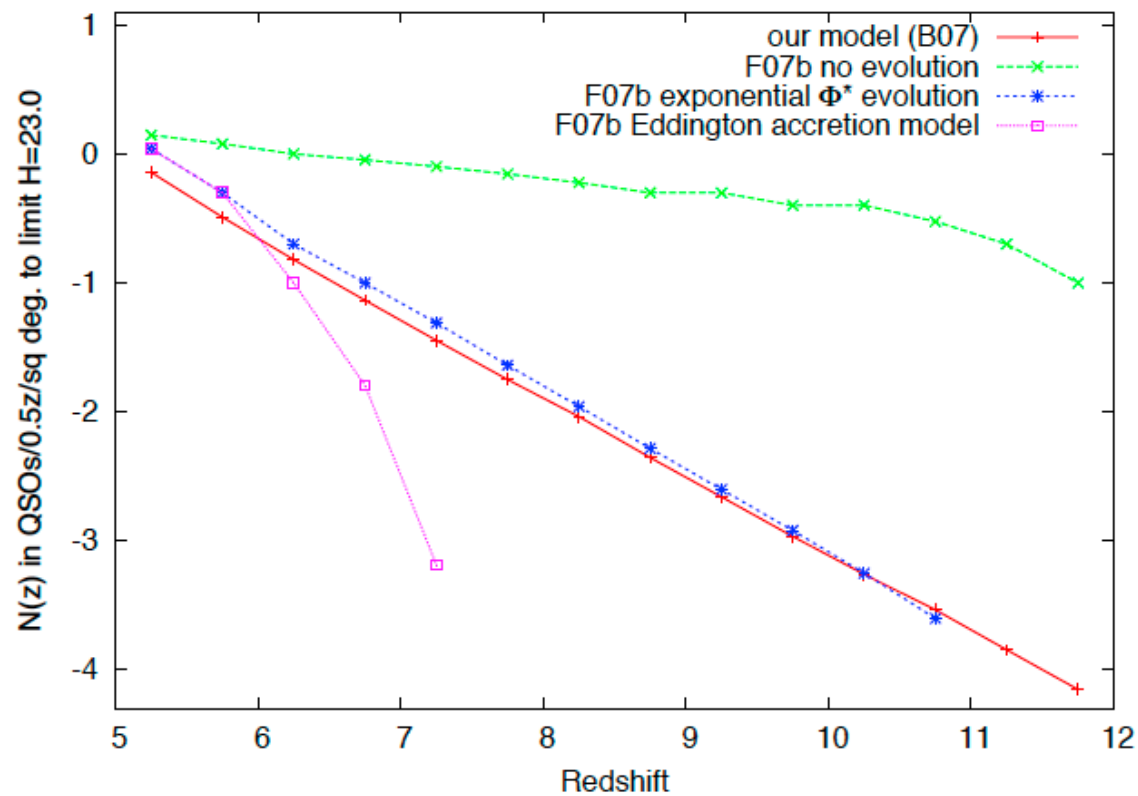
Euclid will:

- Increase the sample size of  $z > 1$  spectroscopically known mergers by  $\sim 3$  orders of magnitude (much more when combined with photo-zs)
- Provide high-resolution imaging and allow non-parametric merger classifications (e.g. CAS, Gini, M20)
- Provide physical properties for the systems by combining spectroscopic and photometric information.
- Allow us to study mergers as a function of environment, mass, nuclear activity, ...

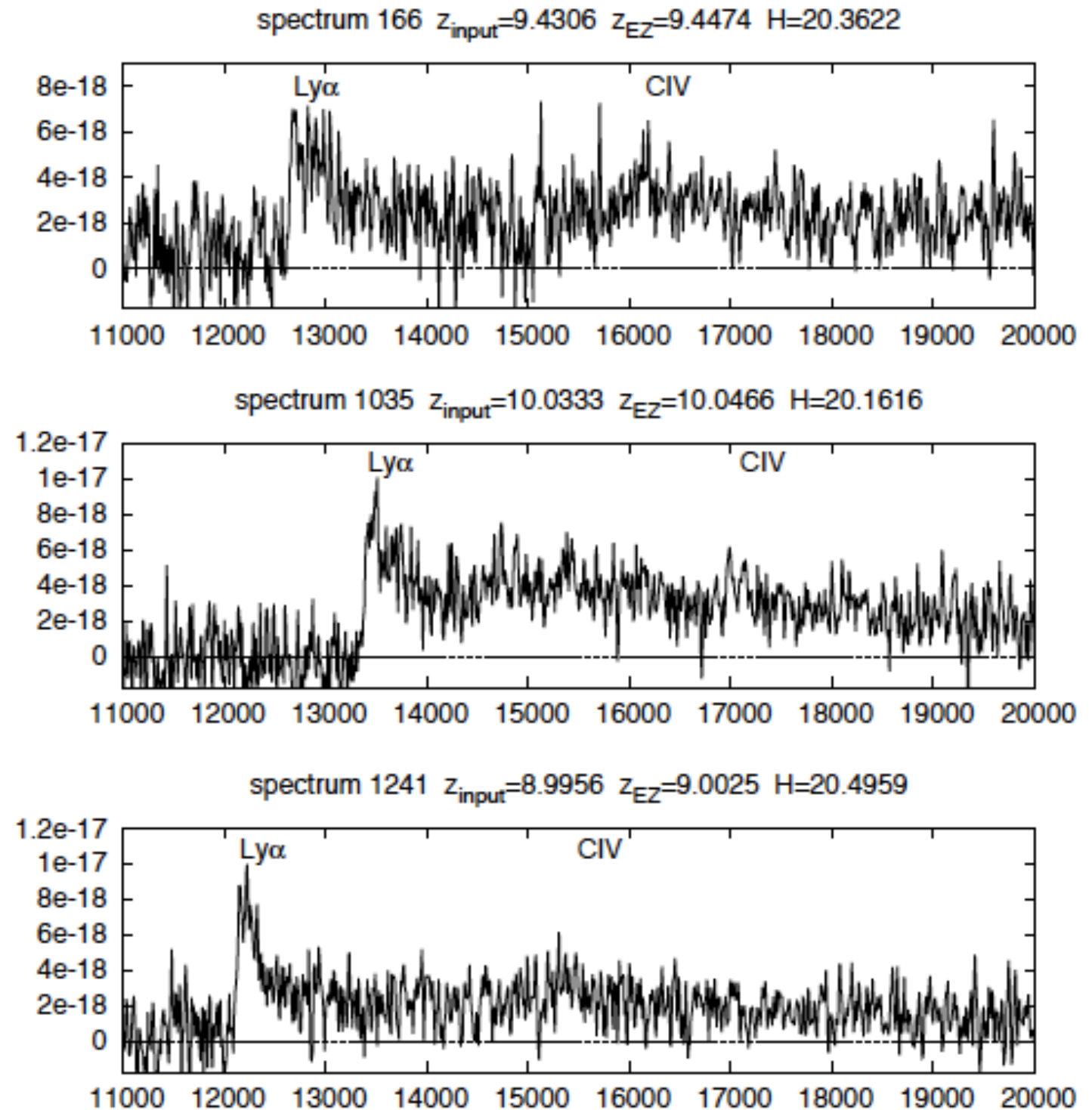


**High-redshift**

# $z > 8$ AGNs with Euclid



Are there QSOs at  $z > 8-9$ ?  
Euclid should be able to get spectra of the brightest. But follow-up, and to find fainter QSOs, requires ground-based NIR spectrographs on large telescopes.

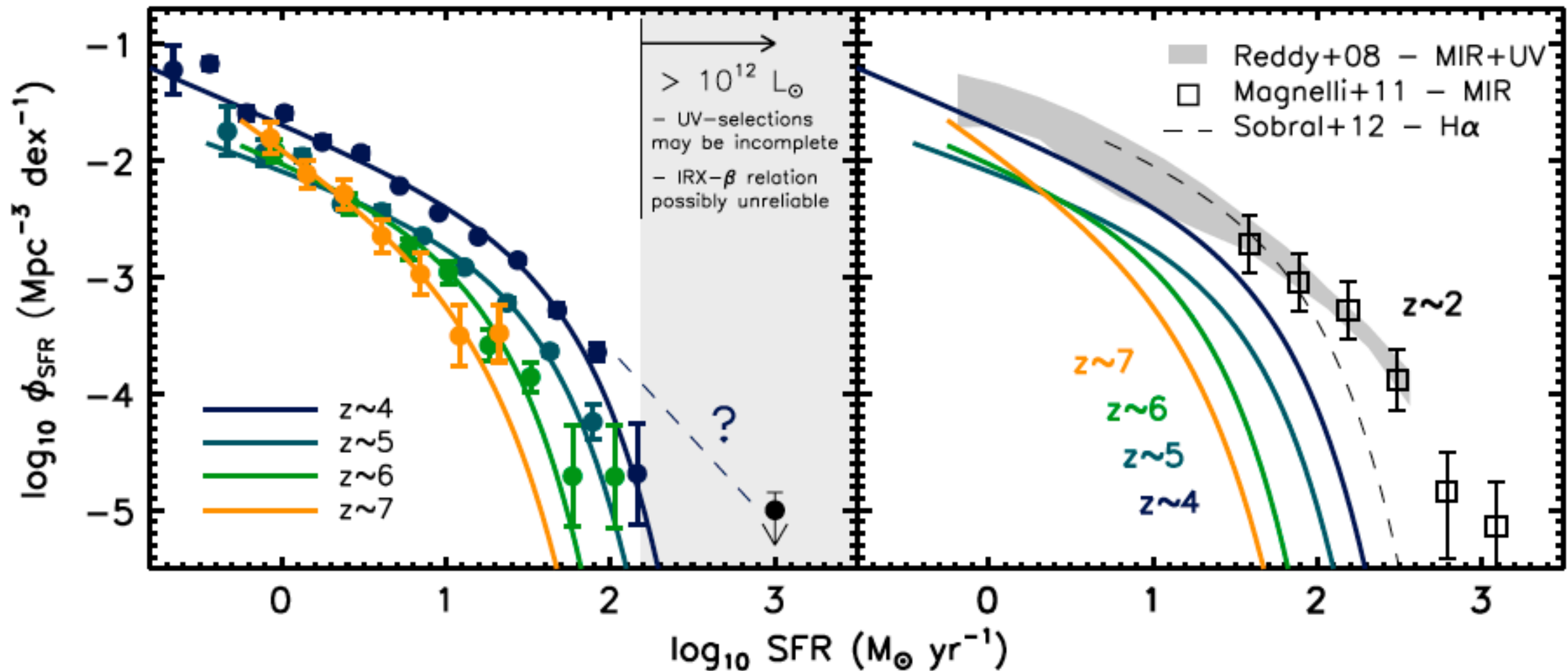


Roche et al (2011)



# The high- $z$ star-formation history of the Universe

Smit et al (2012)



The highest SFR galaxies at any redshift are rare. Euclid will be very good for finding these (at least candidates), and out to  $z \sim 4.3$  detect them in [O II]3727.

These are excellent targets to follow-up from the ground with  $>8\text{m}$ -class telescopes or with JWST.

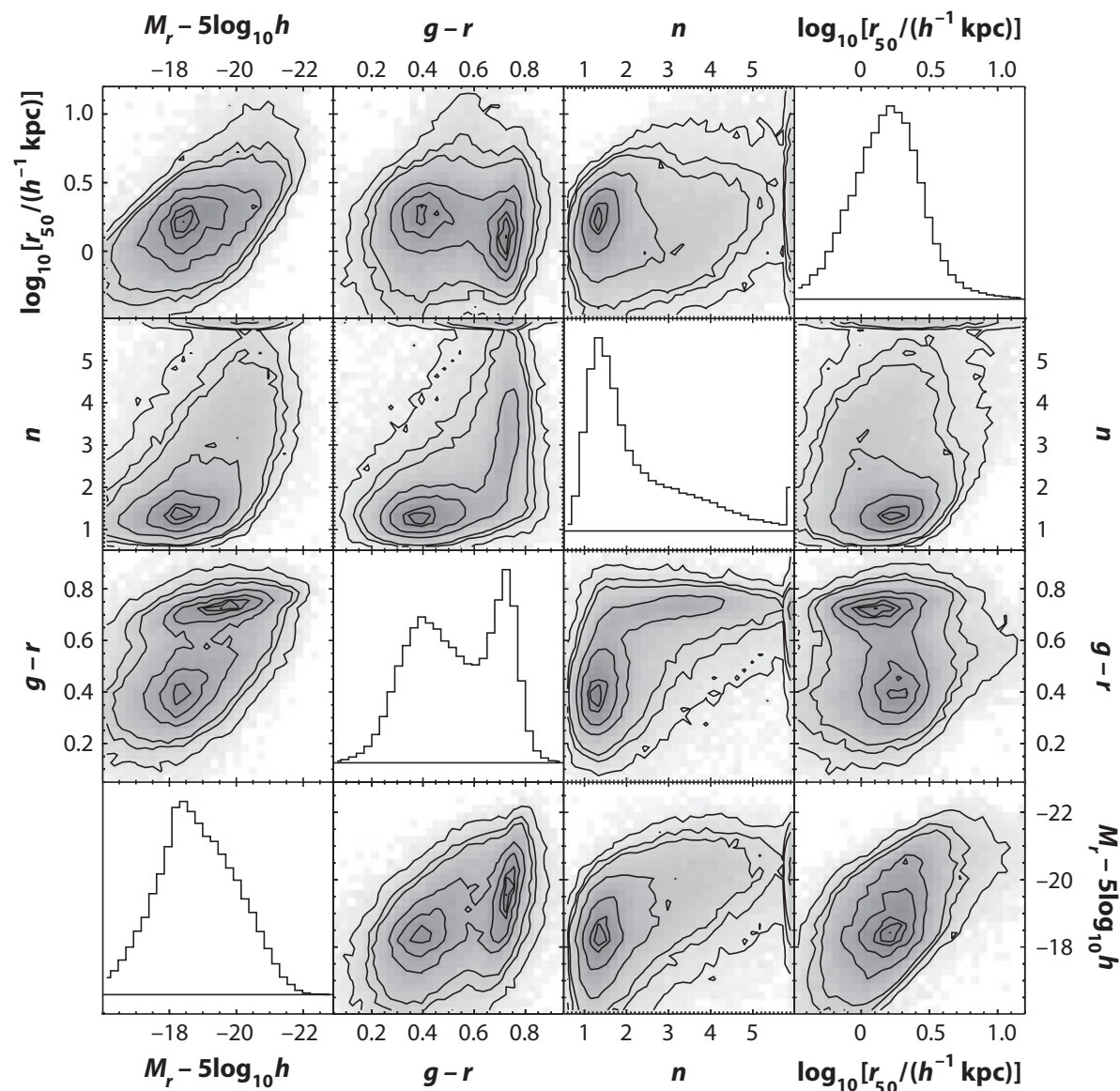
# Distributions



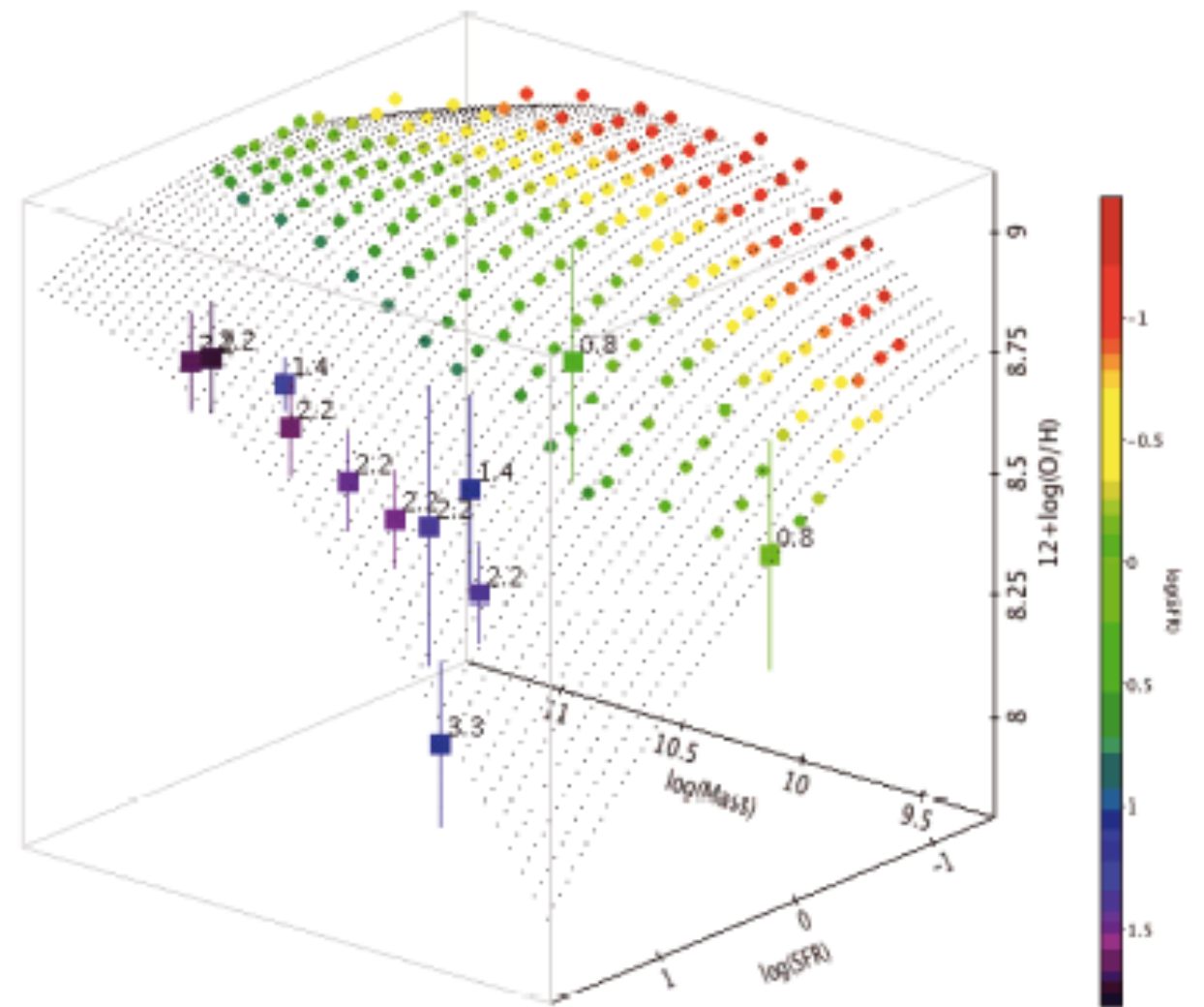
# Distribution functions

$$\mathcal{G}(Z, \text{SFR}, M_*, M_{\text{gas}}, \sigma, V_c, \dots)$$

We have found a large number of scaling relations, and at low redshift we can see that some of these are projections of higher dimensional distributions.



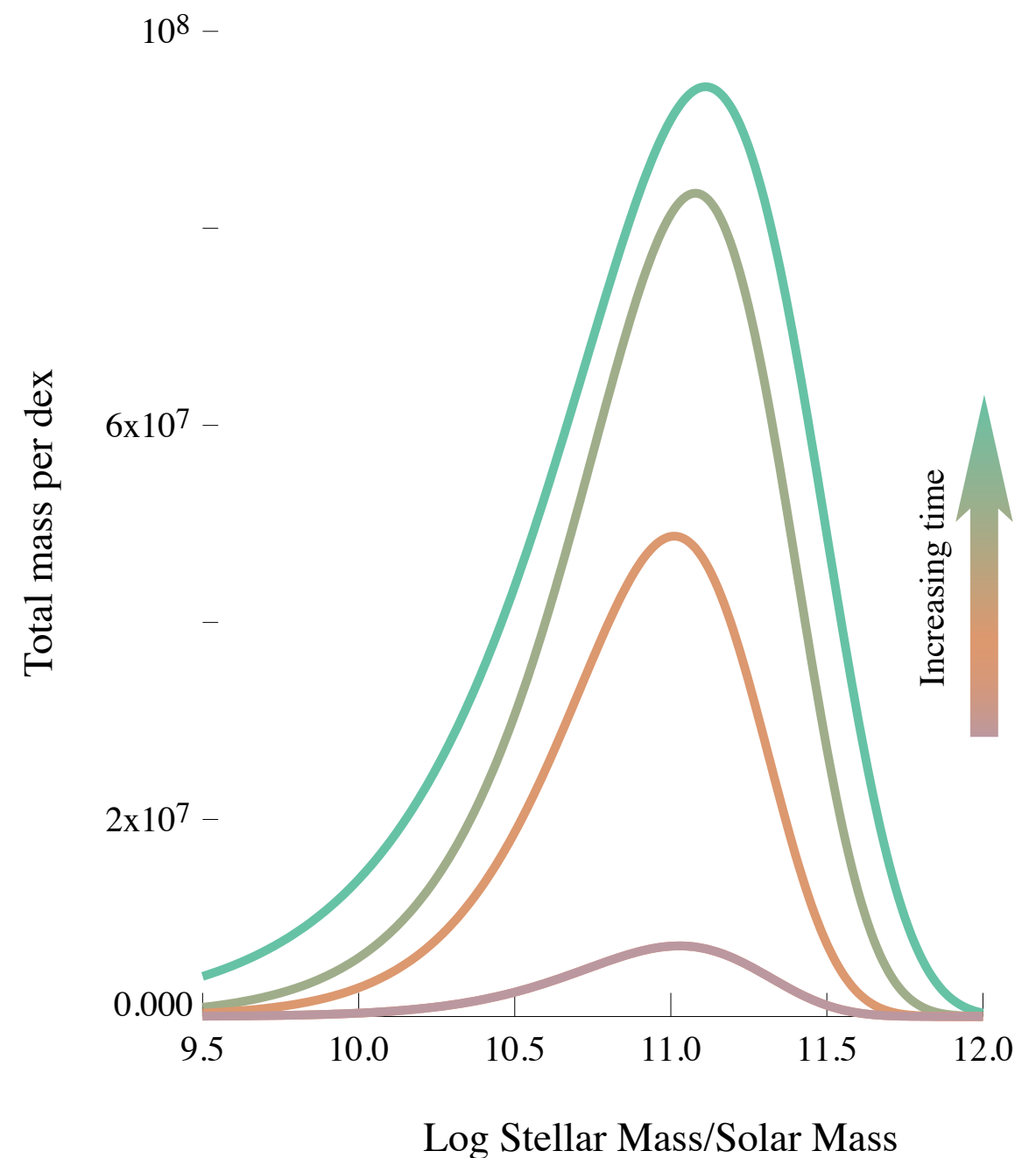
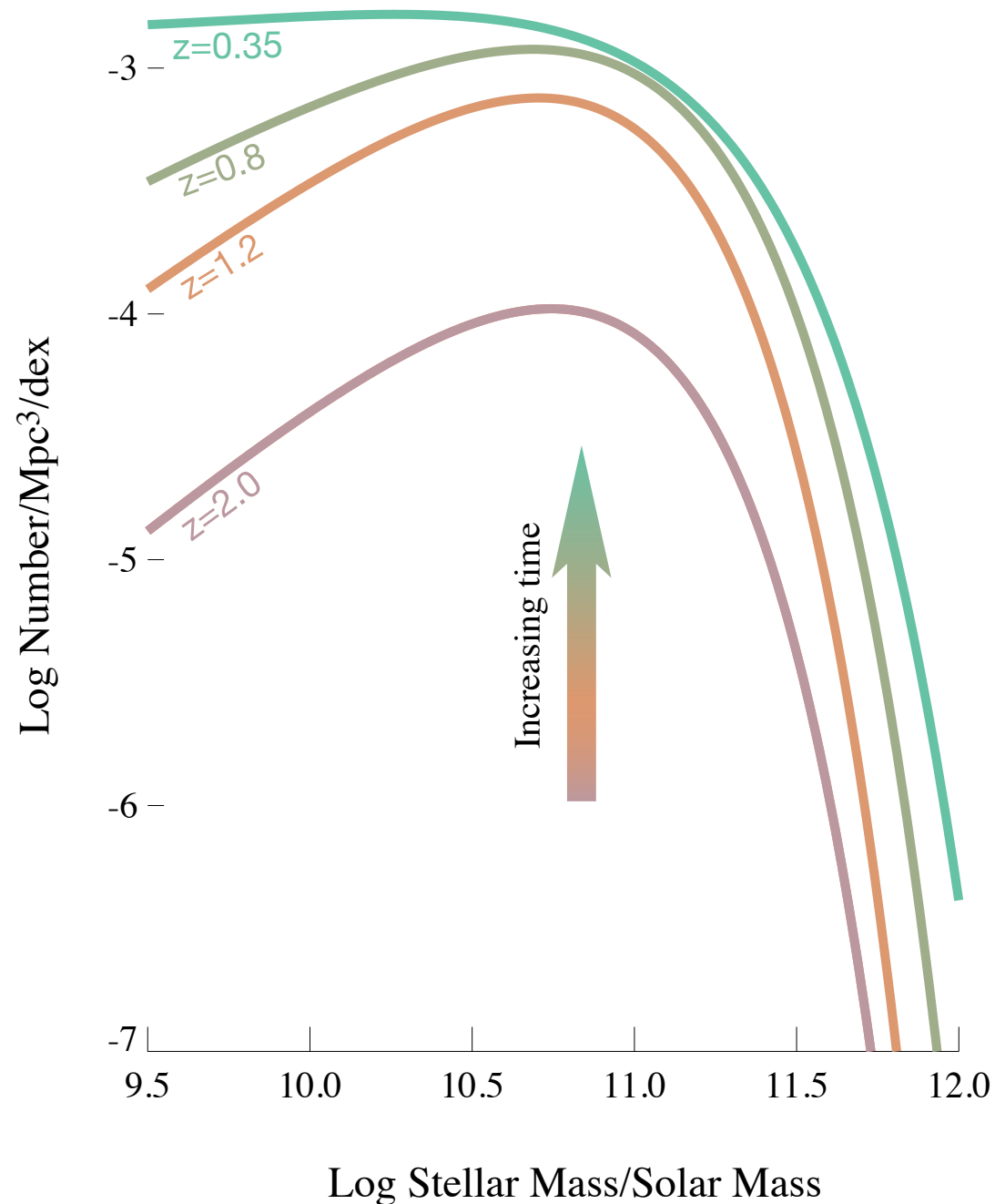
Blanton & Moustakas (2009)



Mannucci et al (2010)

# The mass in stars builds up with time

UltraVISTA (Muzzin et al 2013; Ilbert et al 2013)

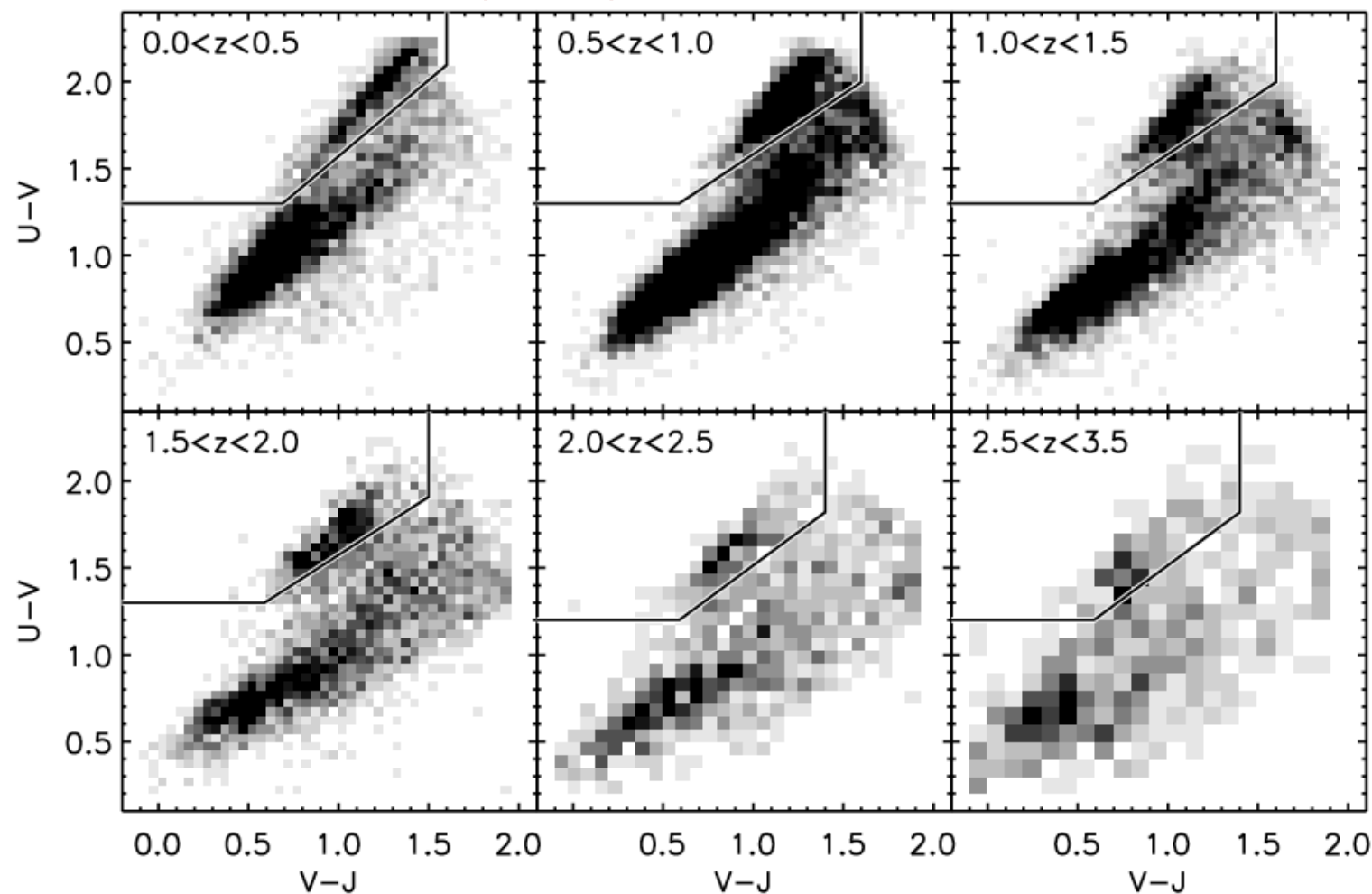


Significant evolution at low masses - need deep NIR data to probe better and understand environmental effects.

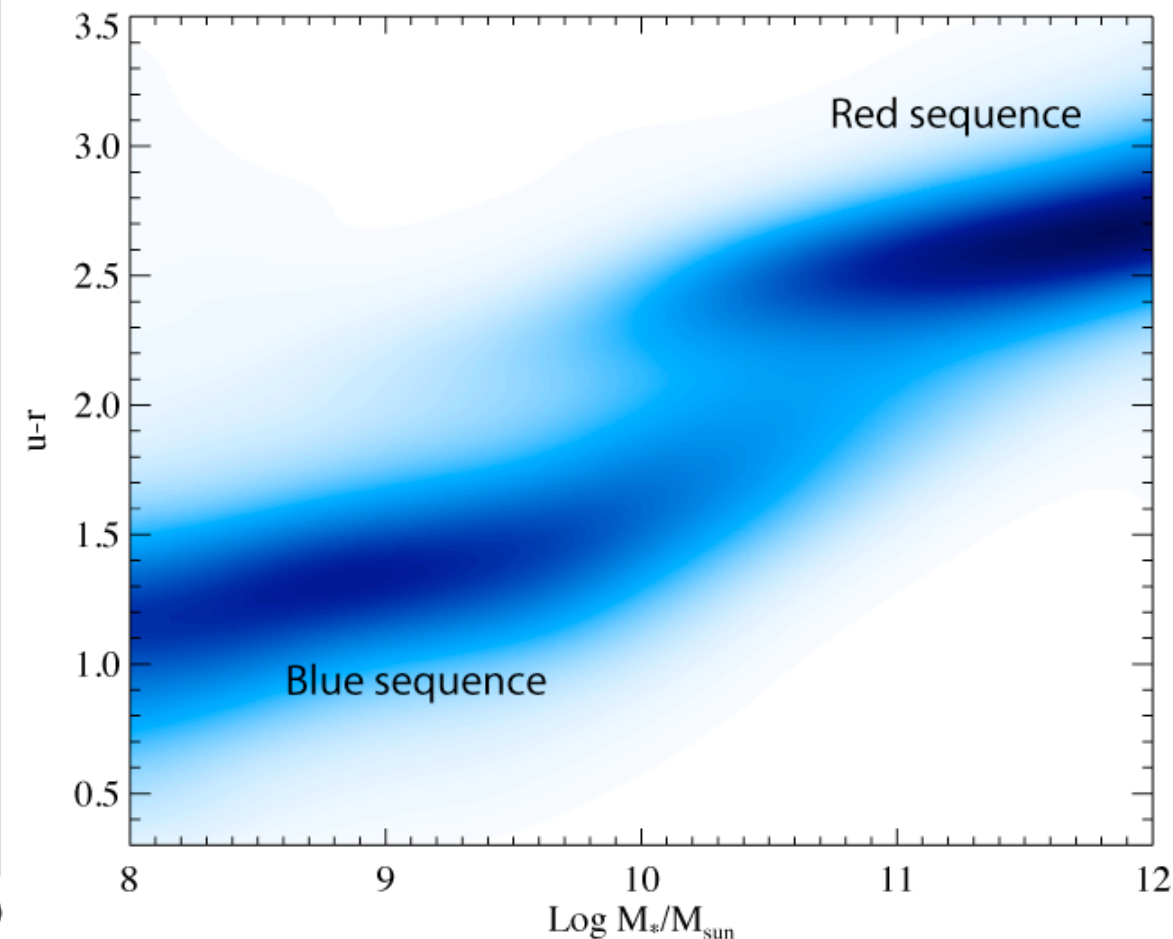


# E.g.: Bi-modality with redshift

Whitaker et al (2011)



SDSS DR7:



Euclid will provide a major improvement - and for many objects provide spectra. The number of galaxies required goes up exponentially with the number of dimensions of your distribution: Particularly important for the extremes of distributions.

# Euclid & distribution functions

## Particular strengths:

Morphological information.

Lensing information.

Environment & clustering.

Very large numbers of sources

## But:

Slit-less spectroscopy not optimal for dense regions

Low resolution spectroscopy

Optical imaging is not very deep.



# How can I get involved?



Issue 3, April 2013

see: <http://www.euclid-ec.org/>

Has a list of names and contacts for the SWG coordinators.

Think about what you can contribute/are interested in and discuss with the SWG leads to clarify this.

If you want to start something completely new, contact the legacy coordinators: **Steve Warren** and **Jarle Brinchmann**

# Summary

- Euclid's NIR imaging and spectroscopy will open up a large number of scientific questions from the solar system to the most distant galaxies.
- The addition of high quality imaging will make strong and weak lensing an integral part of galaxy evolution studies in general - the implications of this have probably not yet been worked out in full.
- Euclid spectroscopy will be spectacular for finding rare objects
- BUT. Euclid spectroscopy is not particularly deep, not efficient in crowded regions, and low resolution.
- Combining Euclid with a NIR MOS/JWST is crucial to make optimal use of the data.
- In the long term the aim is to make Euclid the reference survey of the sky outside the Galactic plane for years to come.



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# Operations

