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LARGE HIGH REDSHIFT *SPECTROSCOPIC* SURVEYS

Goals and principles
Historical perspective
Recent and on-going surveys
Some “hard facts”
Future surveys

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Why “Surveys” ?

1. “Continents mapping”: Map the distribution of galaxies in space
   - Large volumes
2. “Population surveys”: understand the properties of galaxies, in relation with their environment
   - Large numbers
3. “Discovery surveys”: pushing the observational frontier; higher redshifts, fainter galaxies, higher spectral/spatial resolution
   - Very faint
4. Provide robust sub-samples
   - More detailed follow-up studies: other wavelengths, IFU,…

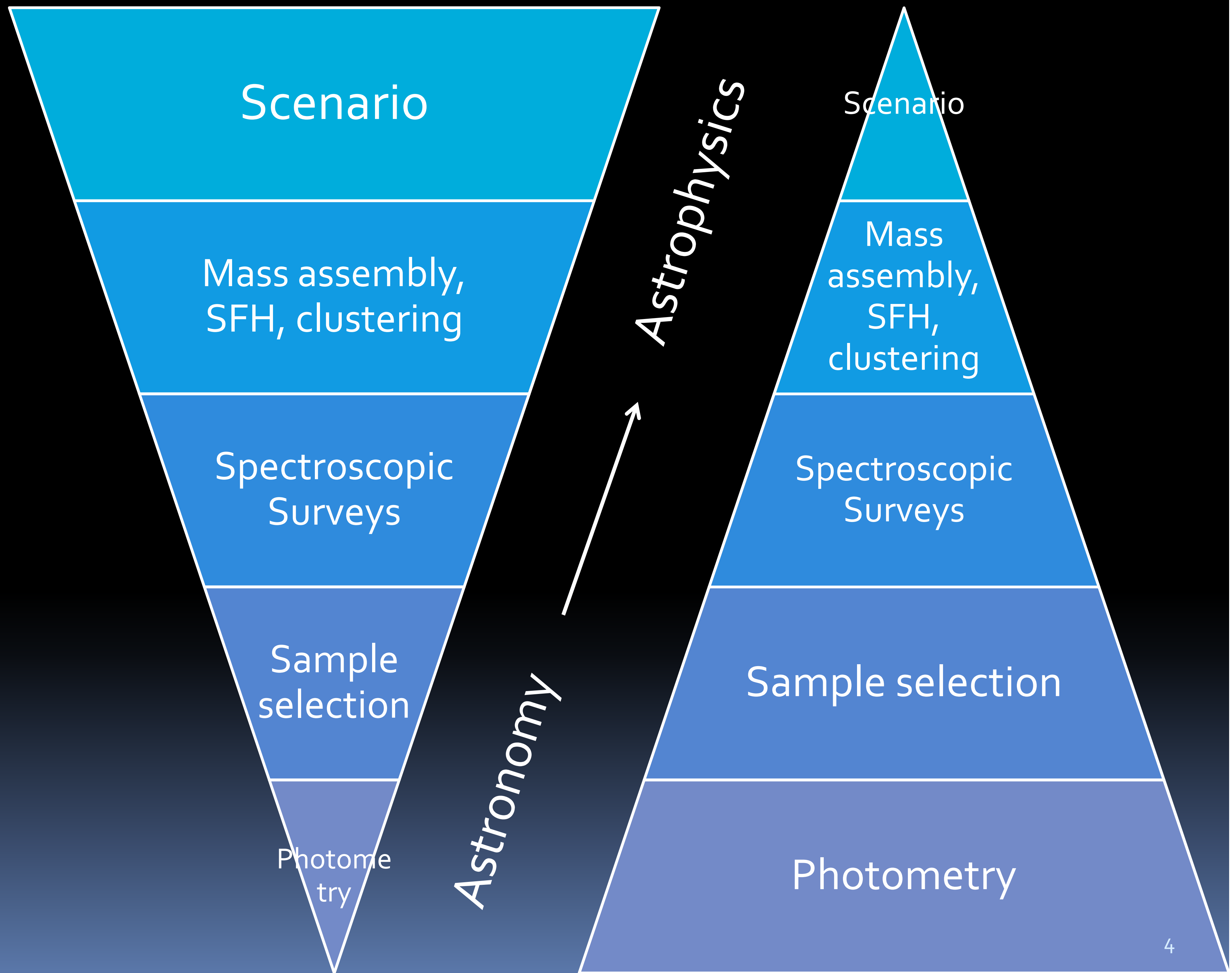
Establish a robust scenario for galaxy formation and evolution based on secure facts

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

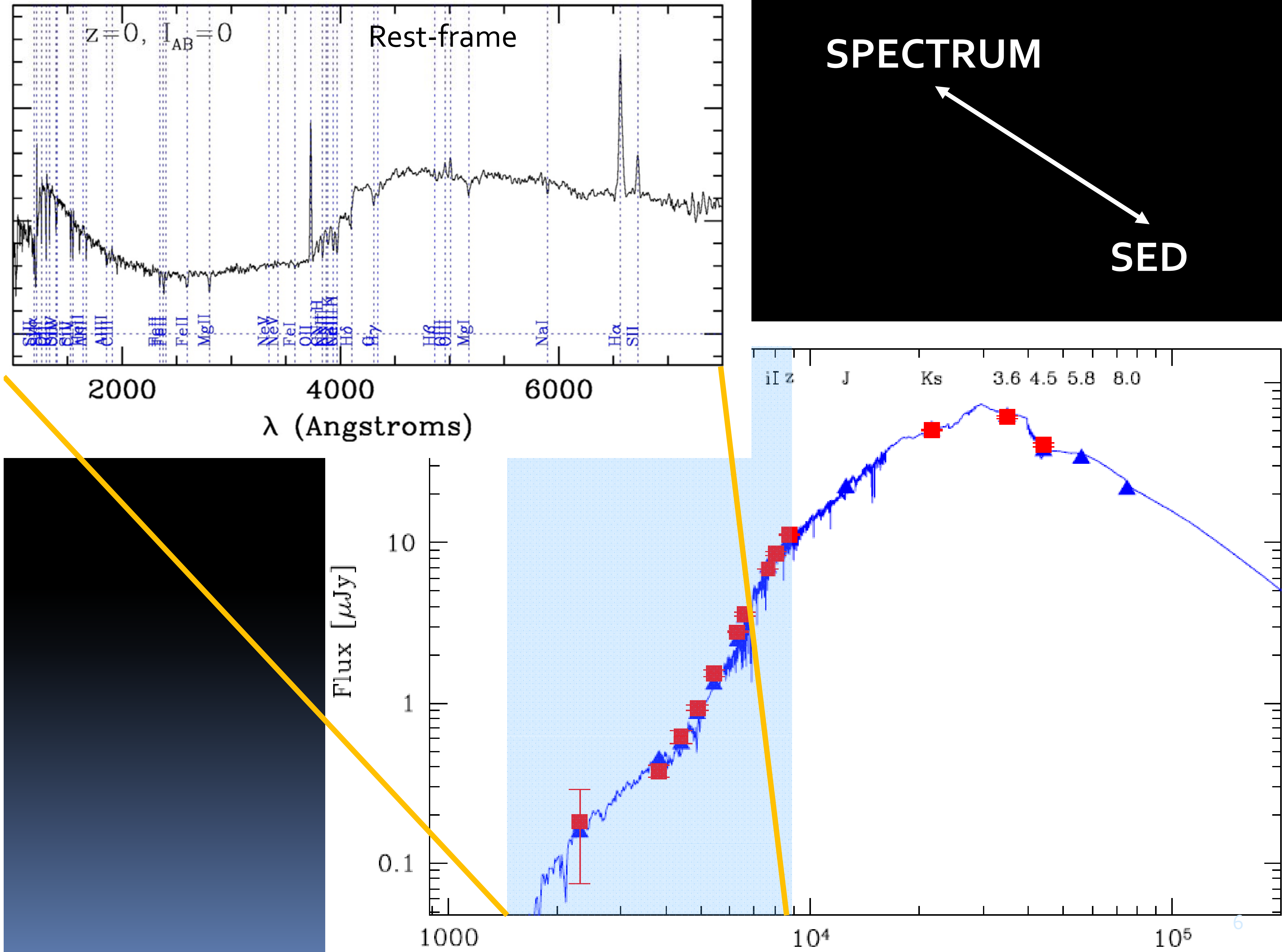

Scenario
Mass assembly, SFH, clustering
Spectroscopic Surveys
Sample selection
Photome try
Astronomy
Astrophysics
Scenario
Mass assembly, SFH, clustering
Spectroscopic Surveys
Sample selection
Photometry

Why *spectroscopic-z* surveys? (vs. *photo-z* surveys)

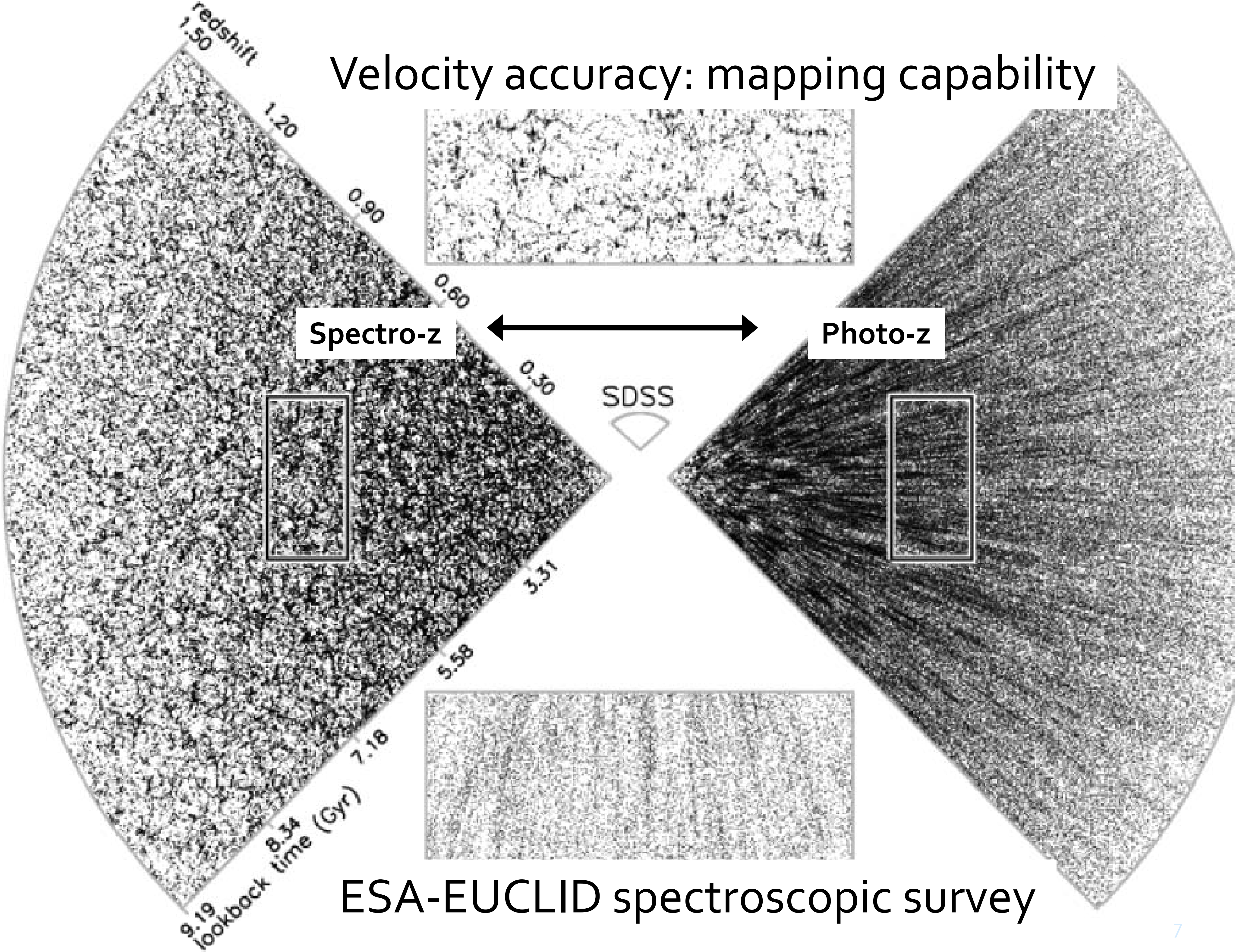
- Spectral features
  - Complementary to multi-λ Spectral Energy Distribution from photometry
- Redshift accuracy
  - A few tens to a few hundreds km/s
- Mapping ability
- High sample completness
  - Failure rate but limited catastrophic failures

SPECTRUM

SED



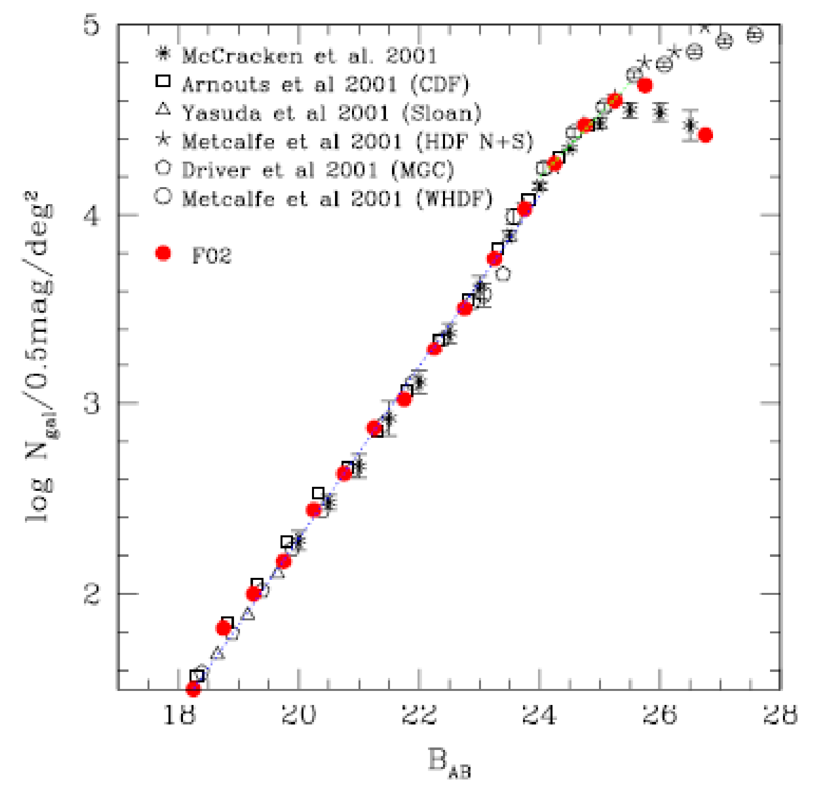
Velocity accuracy: mapping capability

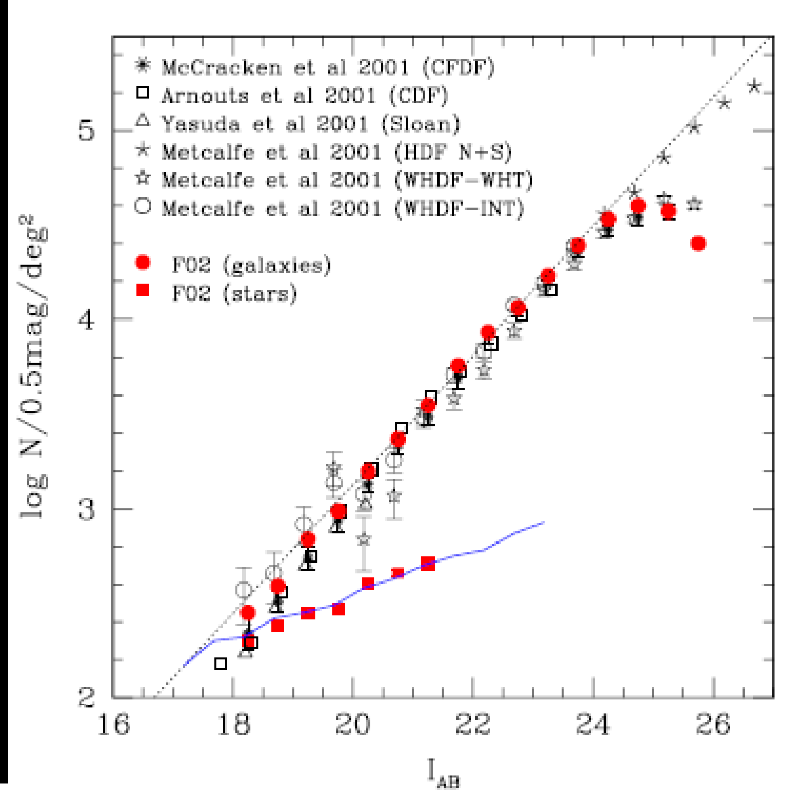


ESA-EUCLID spectroscopic survey

Spectroscopic surveys need deep(er) imaging surveys

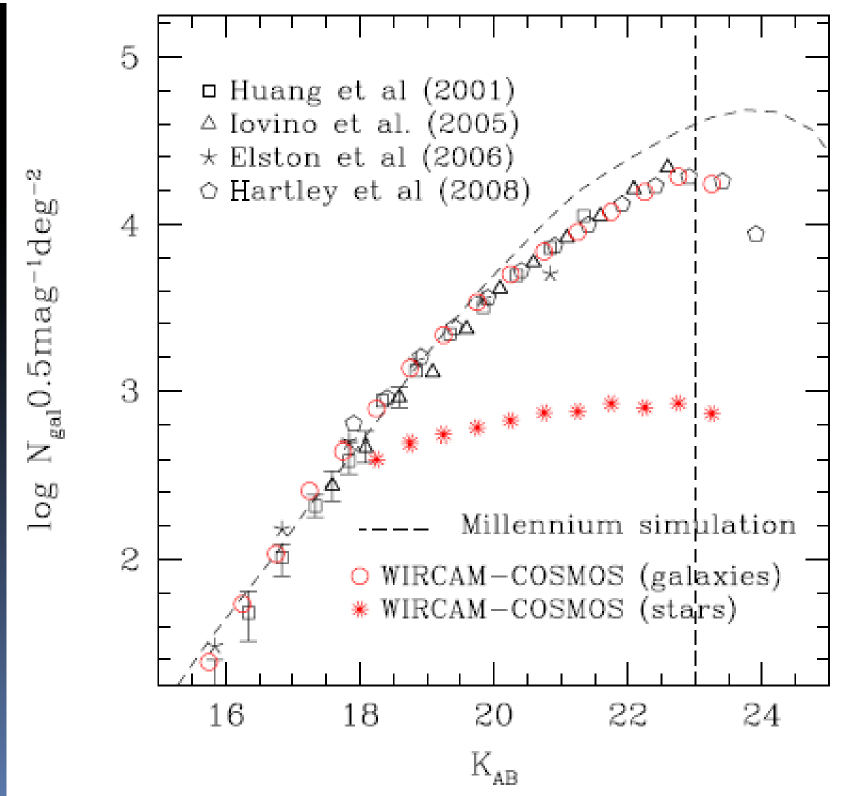
- Targets for spectroscopy are selected from imaging
  - Whatever the selection method (except "serendipitous" surveys)
- Imaging needs to be much deeper than spectroscopic limit
  - No bias from imaging
  - At least 1 mag. deeper (LSB, photometric errors…)
- Spectroscopic surveys progress follows imaging surveys progress
  - Field size
  - Depth
  - IR at higher redshifts
- Photometry+spectroscopy is needed to measure the SED, and get *mass, SFR, age, …





McCracken et al., 2003

McCracken et al., 2010



Measuring galaxy evolution with spectro-z 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
- ρ_{STARS}

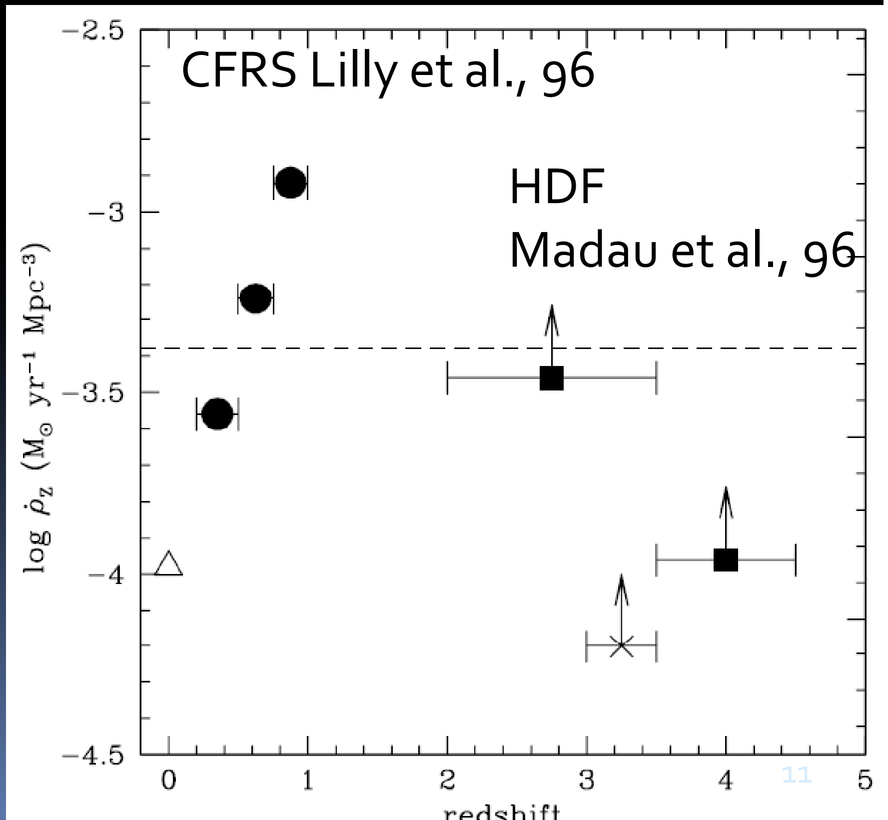
High redshift populations

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

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

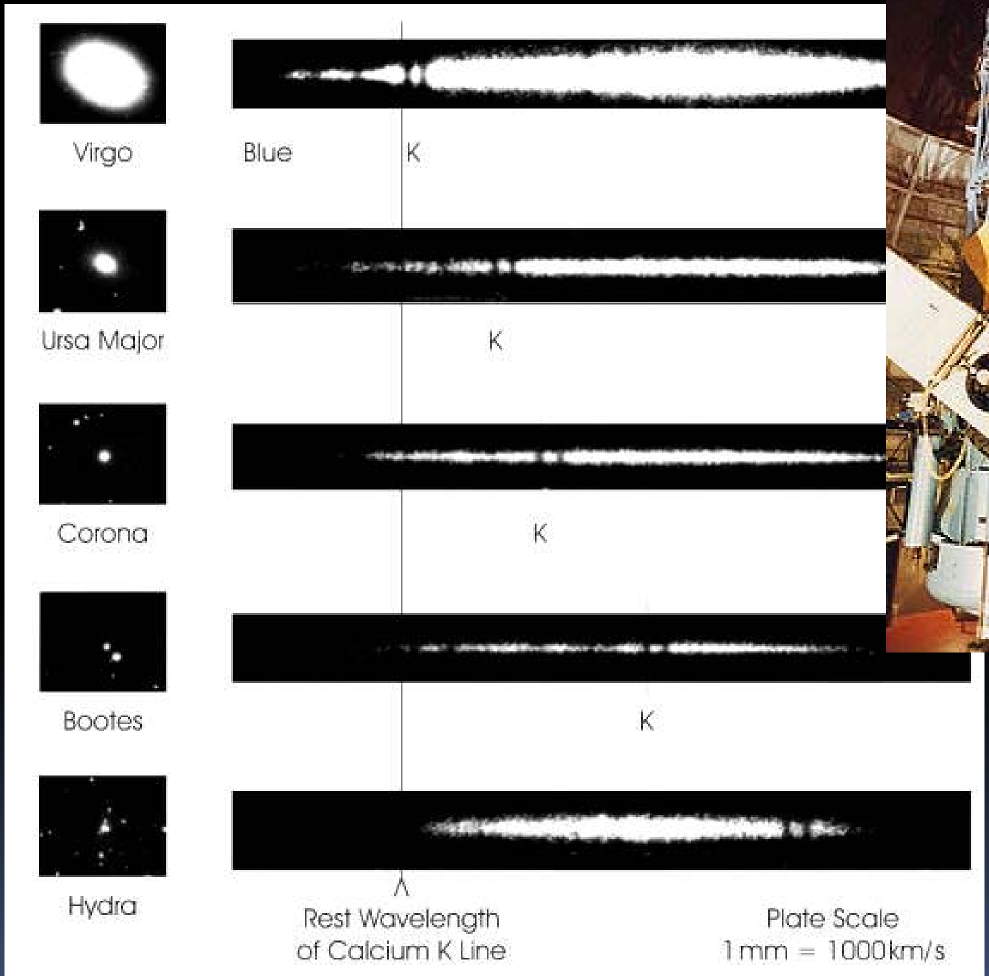
Historical perspective

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

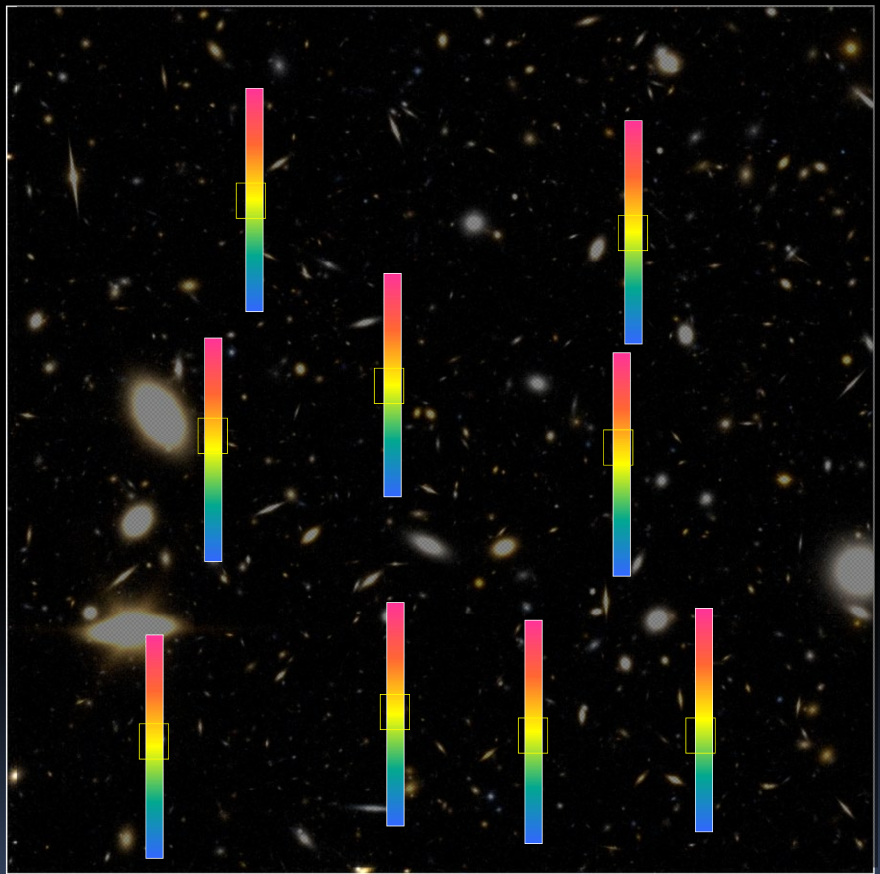


Spectra, one by one

E. Hubble



Today: multi-object spectroscopy



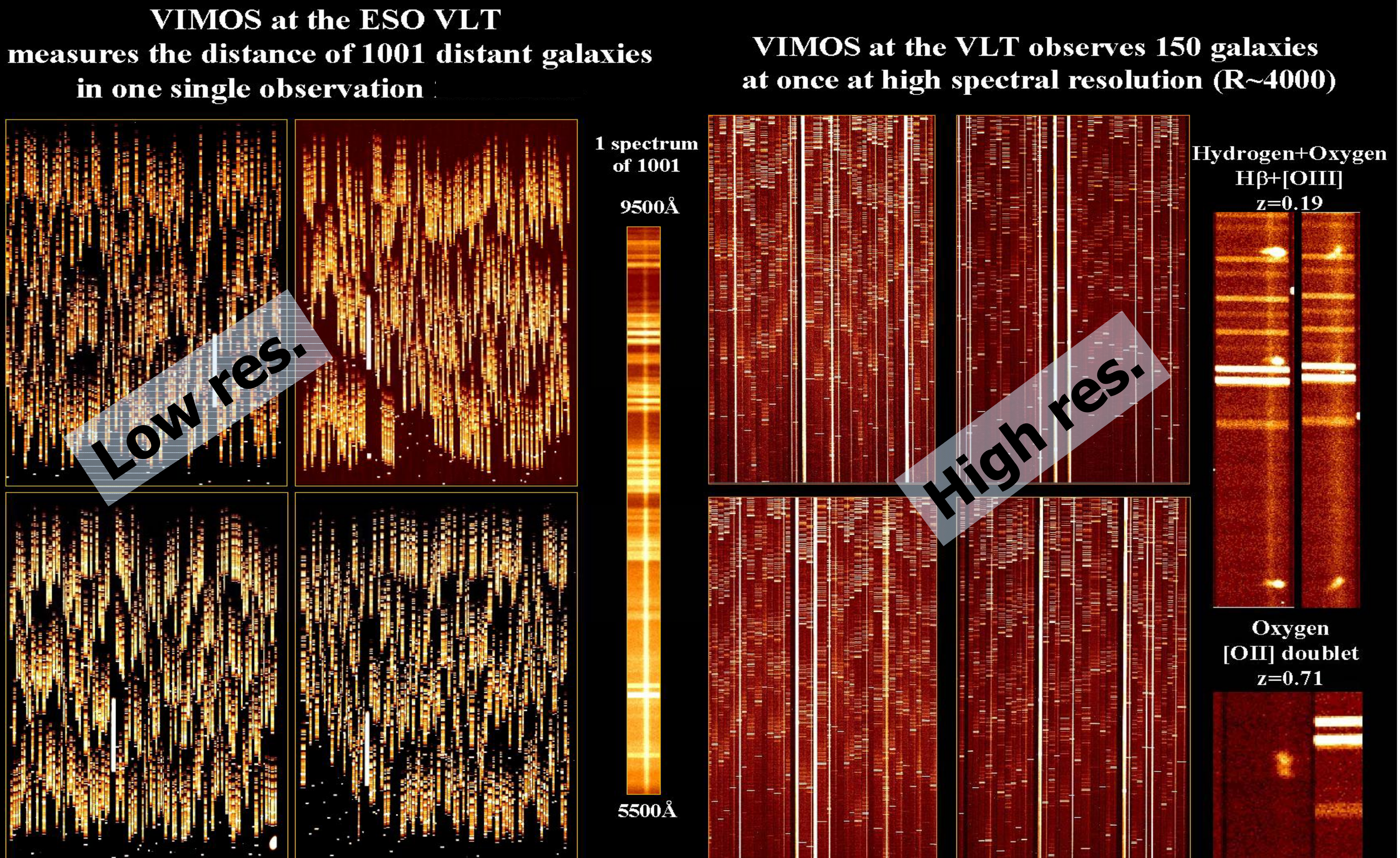
- Deep multi-color imaging
- Target selection
- Multi-object spectroscopy

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

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

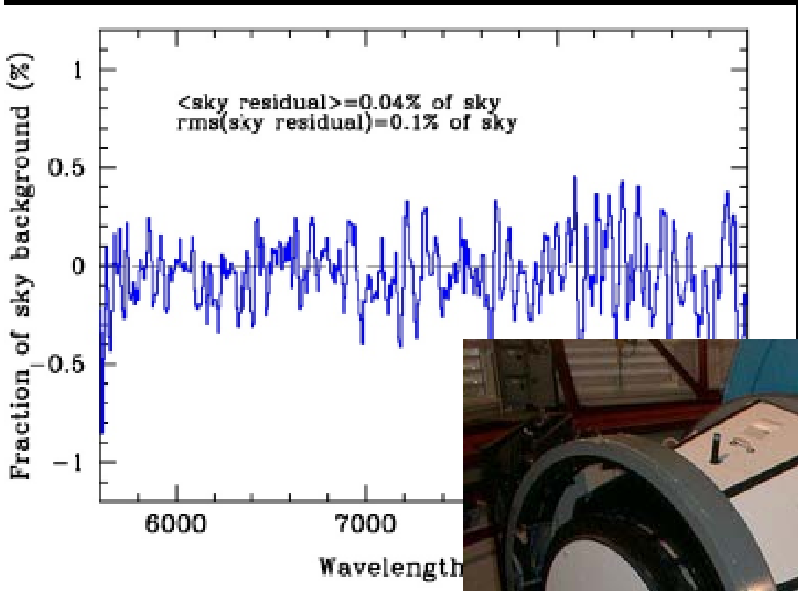
State of the art today: VIMOS example

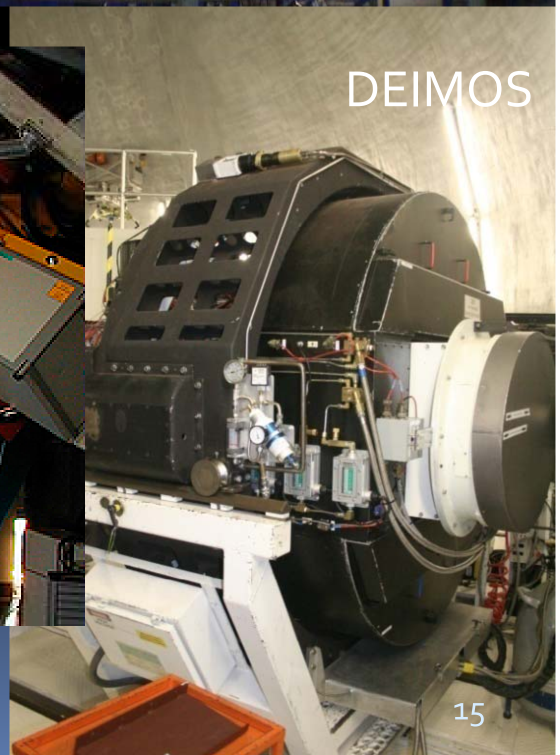
Strictly equivalent to 1000 8m telescopes doing single object spectro in parallel !



The power of multi-slit MOS at high-z

- The workhorse of major observatories: CFHT-MOS/SIS, Keck-LRIS, VLT-FORS, GMOS, Keck-DEIMOS, VLT-VIMOS, IMACS …
- Multi-slit: higher sky subtraction accuracy

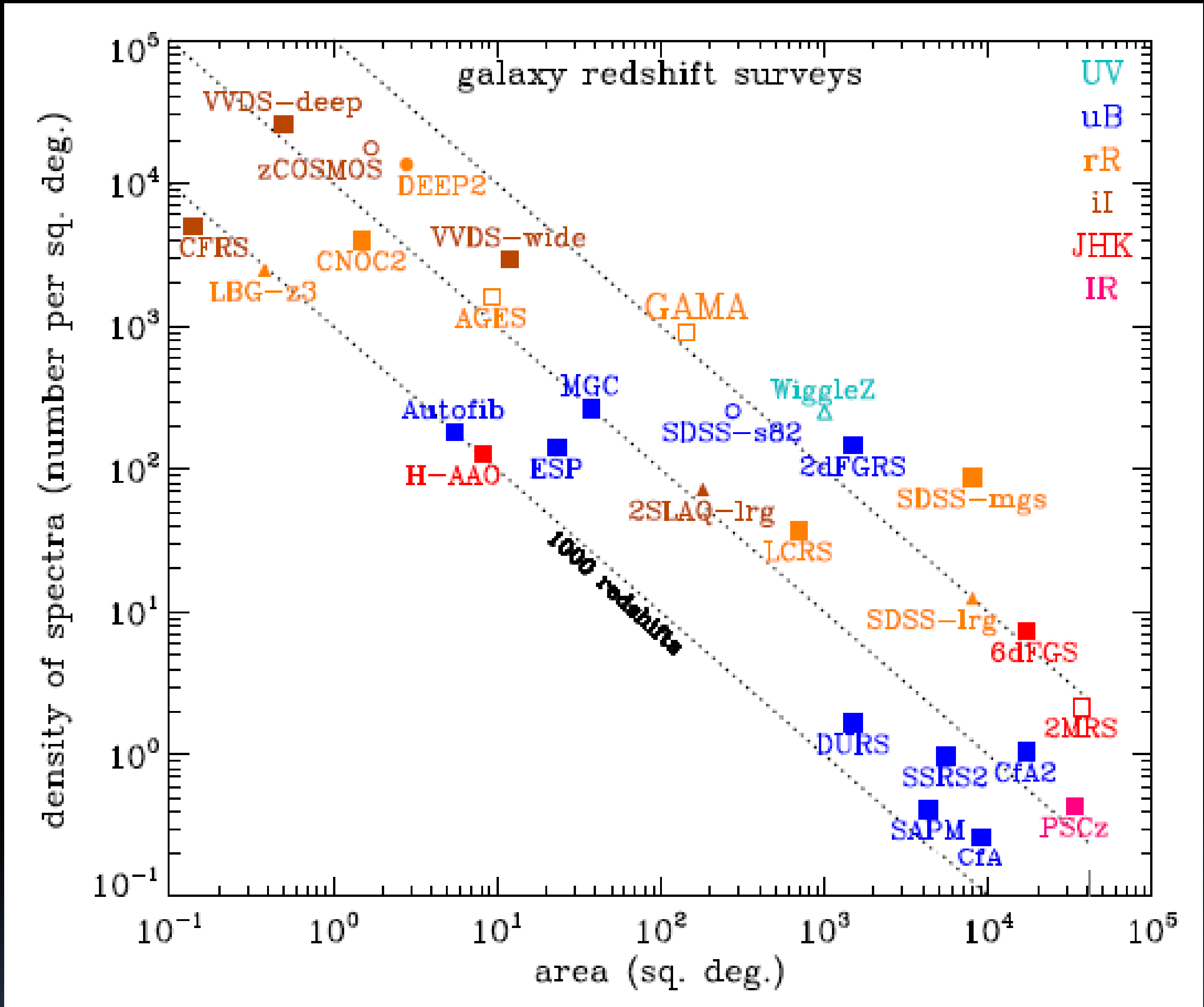




Past and present high-z spectroscopic surveys

Survey	Instrument	redshift	# galaxies	Exp. Time /gal eq. 8m	Total T survey
CFRS – 1995	CFHT-MOS	0<z<1.2	600	2h	21 nights
LBG – 1999	KECK-LRIS	2.5<z<4.5	1000	3h	40 nights
GOODS	VLT FORS2	0<z<7.1	1000	2h	40 nights
DEEP2, 2005+	KECK-DEIMOS	0.7<z<1.4	50000	1.5h	70 nights
VVDS, 2005+	VLT-VIMOS	0<z<5	50000	1h 4h	35 nights
zCOSMOS, 2007+	VLT-VIMOS	0<z<1.2 1.4<z<3	20000 10000	1h 4h	450h
VIPERS, 2009+	VLT-VIMOS	0.5<z<1.2	100000	1h	450h
VUDS , 2010+	VLT-VIMOS	2.5<z<7	10000	14h	640h

Not complete !



A lot of surveys

Another dimension: depth/redshift

From Baldry et al., 2010

Hard facts !

Which need to be reproduced by simulations…

- Redshift distribution N(z)
- LF/LD and Star formation history
- MF and stellar mass density history
- Merger rate history
- Build-up of the color-density relation
- Quenching at work ?

Redshift distributions
From magnitude selected surveys

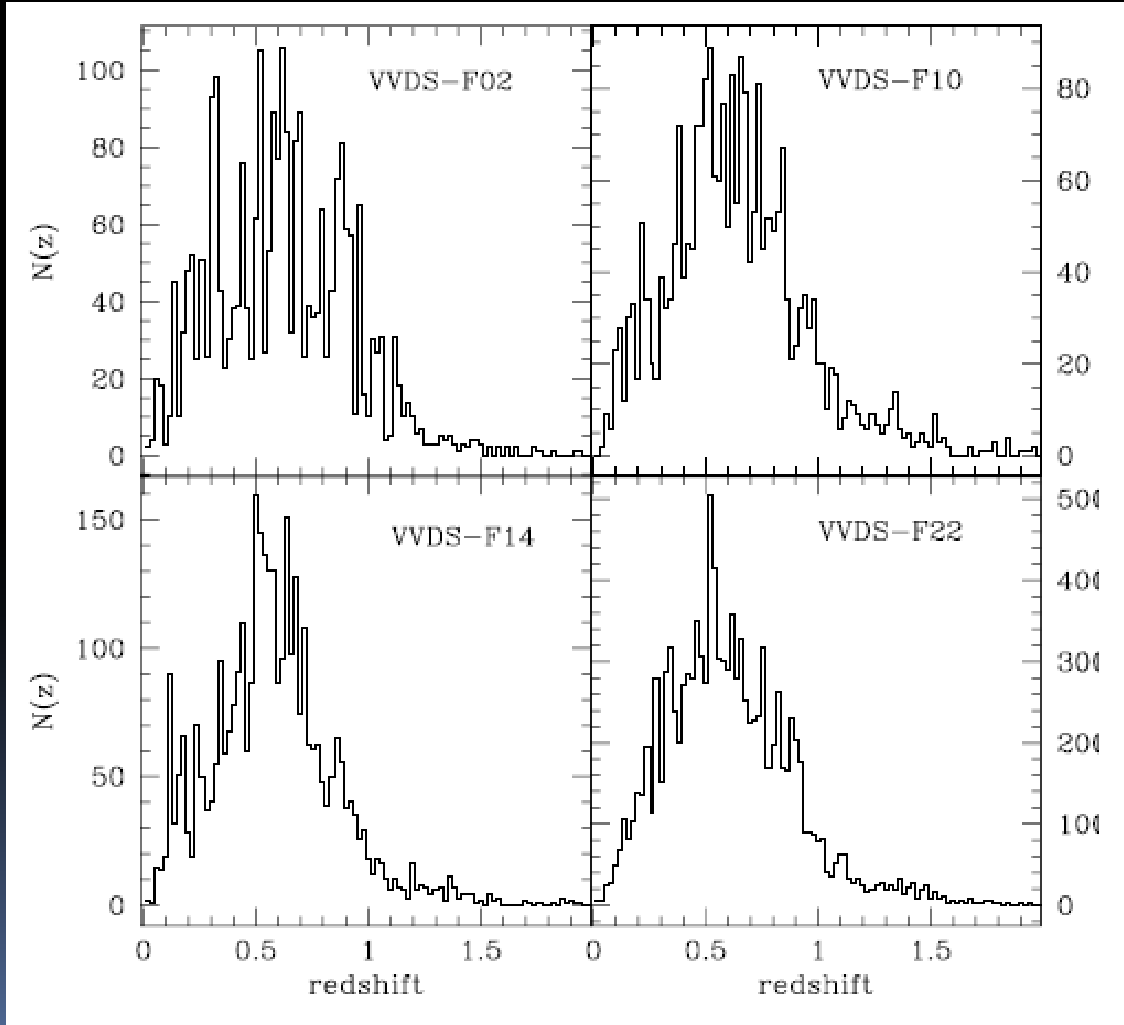
$i_{AB} \leq 22.5$

- CFRS
- VVDS-wide
- zCOSMOS-bright

$<z>=0.55$

Still strong variance on 1deg scales:

Cosmic variance is a serious problem for most current highz surveys



Garilli et al., 2008

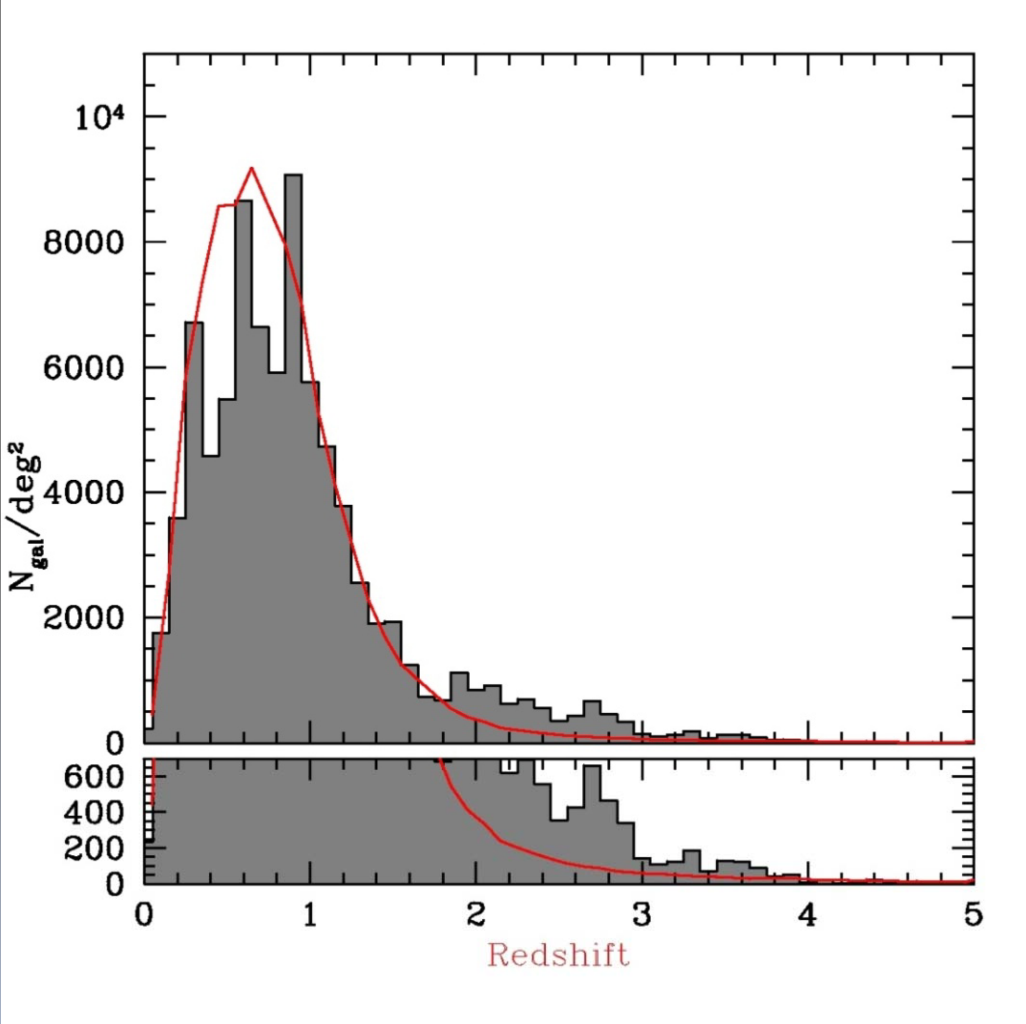
Redshift distributions

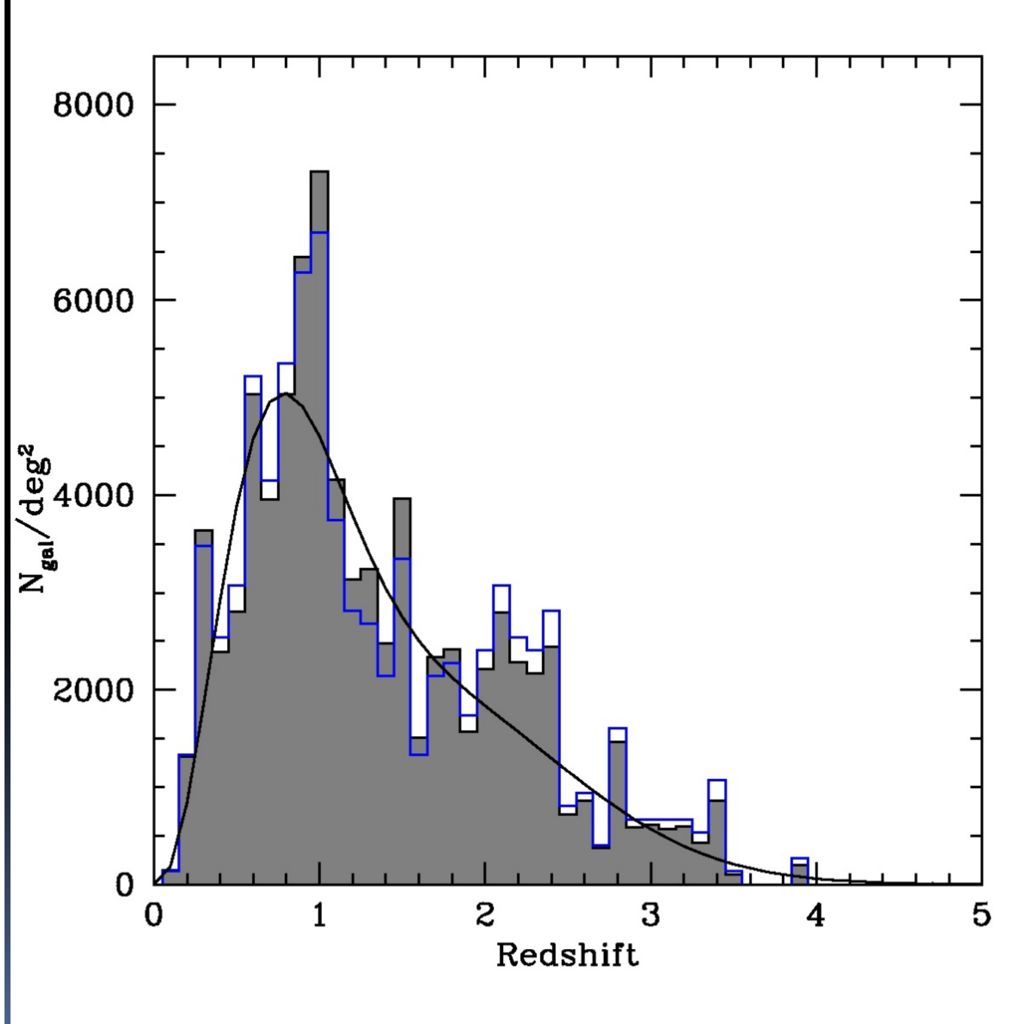
$i_{AB} \leq 24$

- $<z>=0.8$

$23 \leq i_{AB} \leq 24.75$

- $<z>=1.3$





Le Fèvre et al., in prep

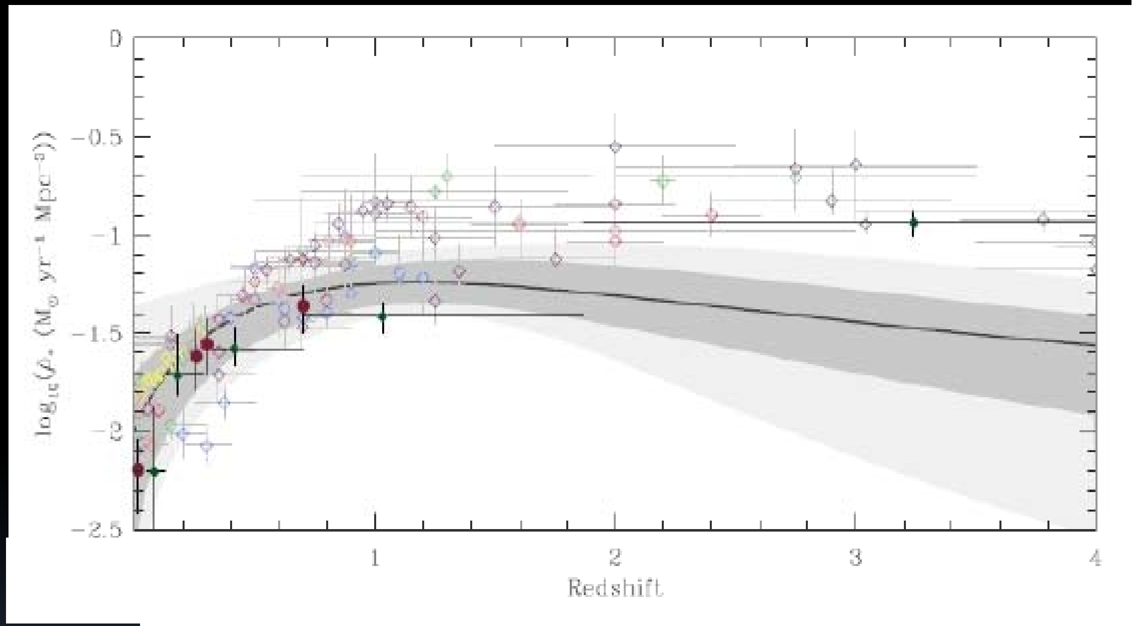
Star formation history

- Directly derived from Luminosity Function

Peak in SFRD at z~2

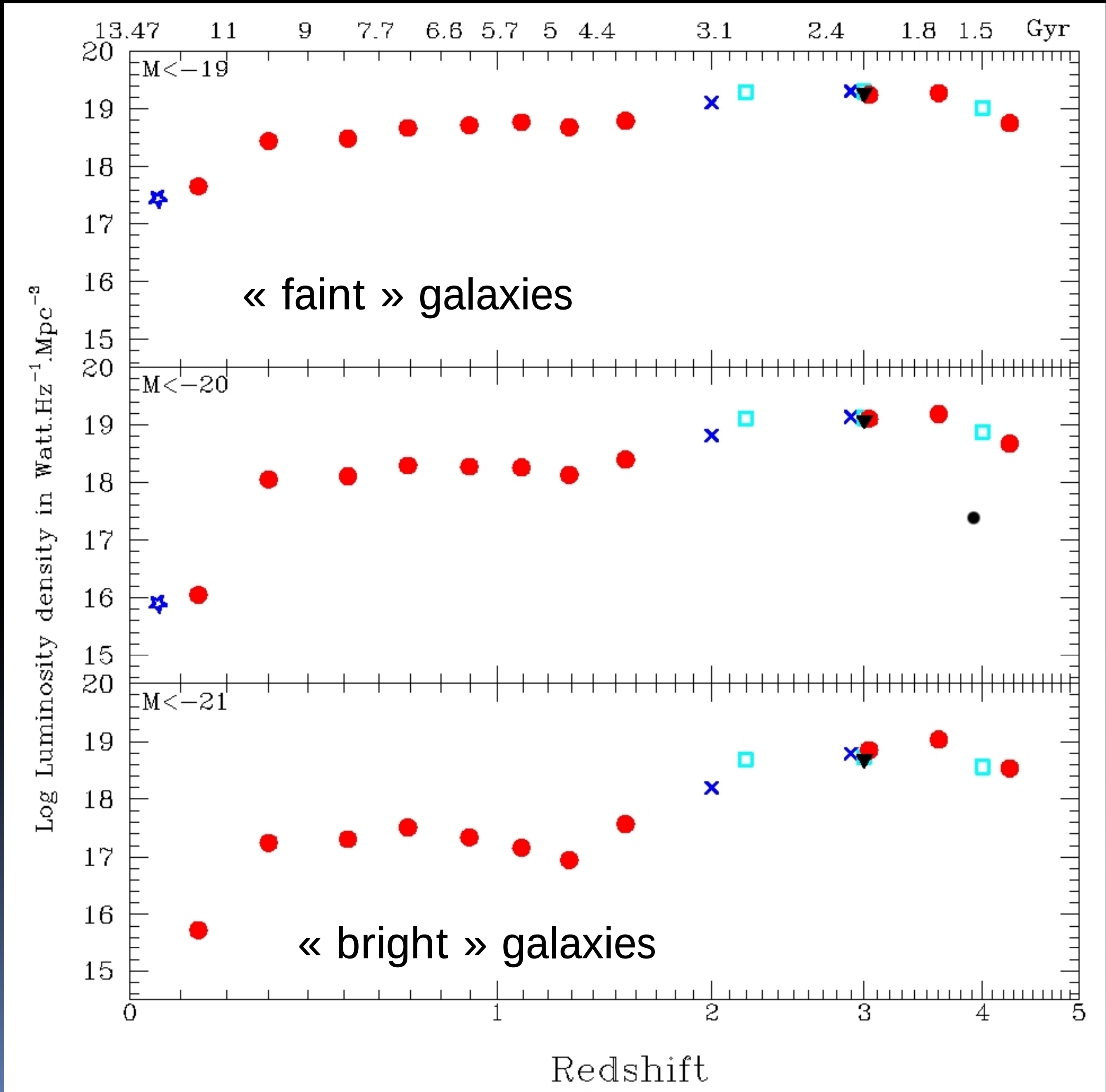
  - Strong rise from z=0 to z=1
  - Plateau to z~3
  - Decrease beyond z~3 ?

- Difficulties
  - Need complete samples
  - Transform luminosity into SF, dust correction
  - Large uncertainty on LF faint-end slope at high-z
  - SFRD from LF not consistent with SFRD from MF



Wilkins et al., 2009

FUV global luminosity density since z=5



Downsizing :

Luminous galaxies form most of their stars early

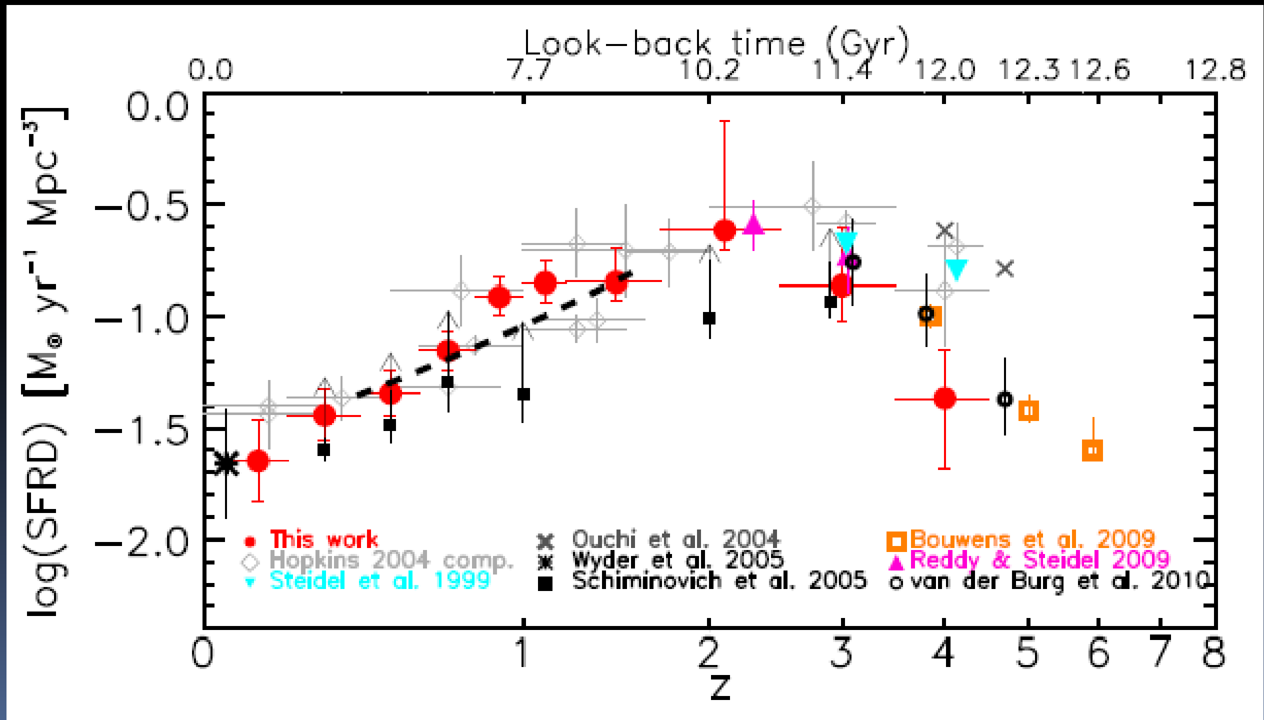
Faint galaxies contain more star formation at low z

Downsizing trends observed from various indicators

Tresse et al., 2007

VUDS: VIMOS Ultra-Deep Survey

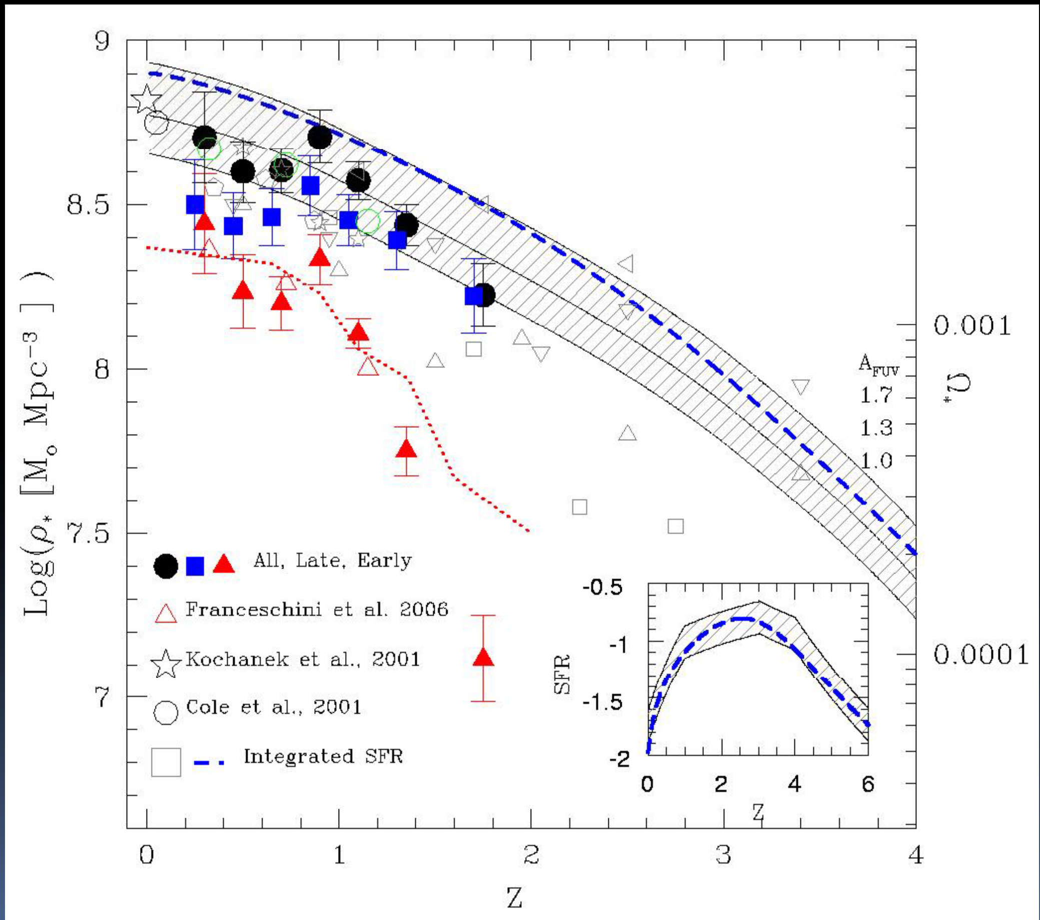
- Magnitude selected $23 \leq i_{AB} \leq 24.75$
- 15h blue + 15h red integrations
- First results from 1000 galaxies
- On-going: 10000 galaxies
- LF and SFRD derived from "spectroscopy-only" data
- Bright end well constrained
-Despite depth, still major uncertainty on LF slope @ z>1.5



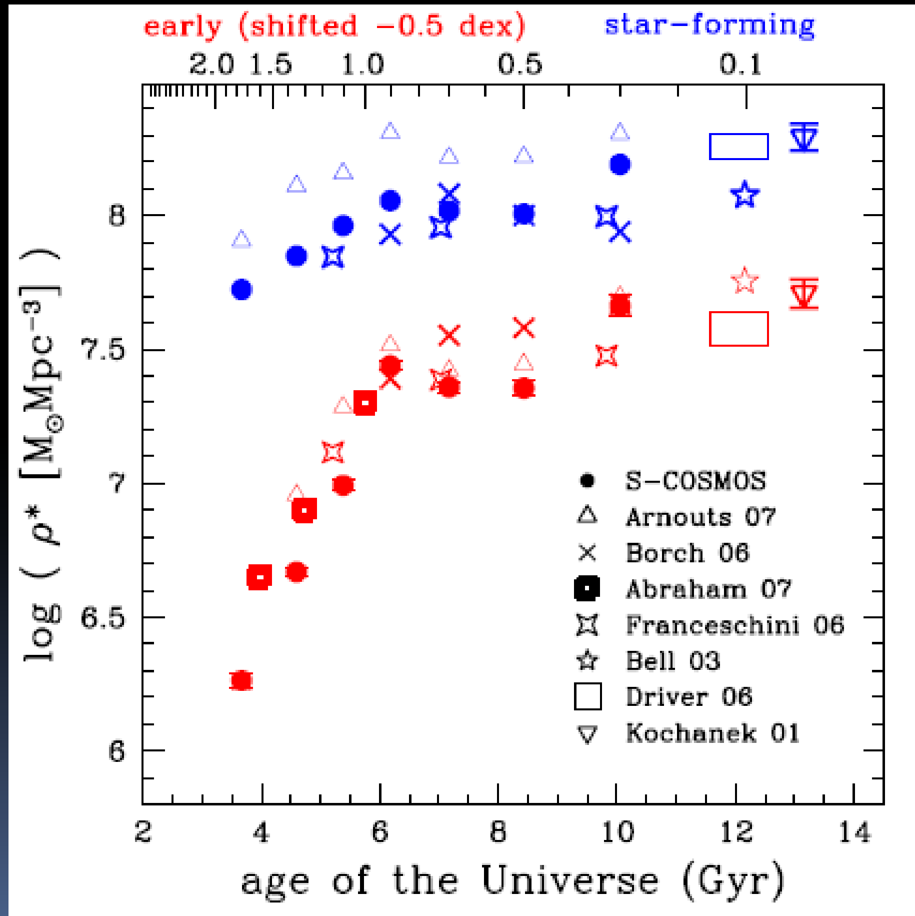
Cucciati et al., astroph

Assembly of stellar mass

- Very fast mass growth in early/red galaxies 1<z<2
- Steady mass growth in star-forming galaxies



VVDS, Arnouts et al., 2007

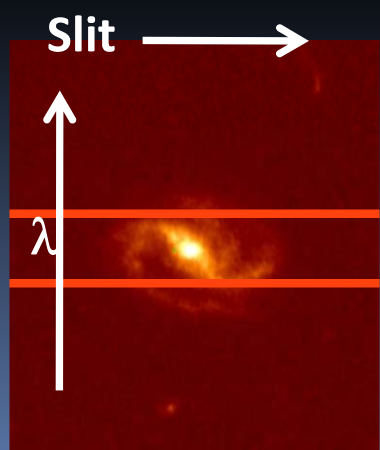


COSMOS, Ilbert et al. 2010

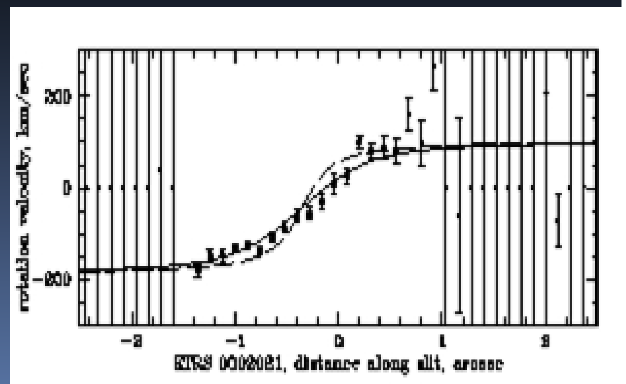
Mass assembly
*-mass vs. total mass

- Strong dependency of today's results on mass function on SED-derived "stellar mass"
- SED-derived *-masses differ by ~x2
- Need direct measurements of "total galaxy mass"
  - Use kinematics (2D/3D)
  - Use weak lensing

Tresse et al., VIMOS survey



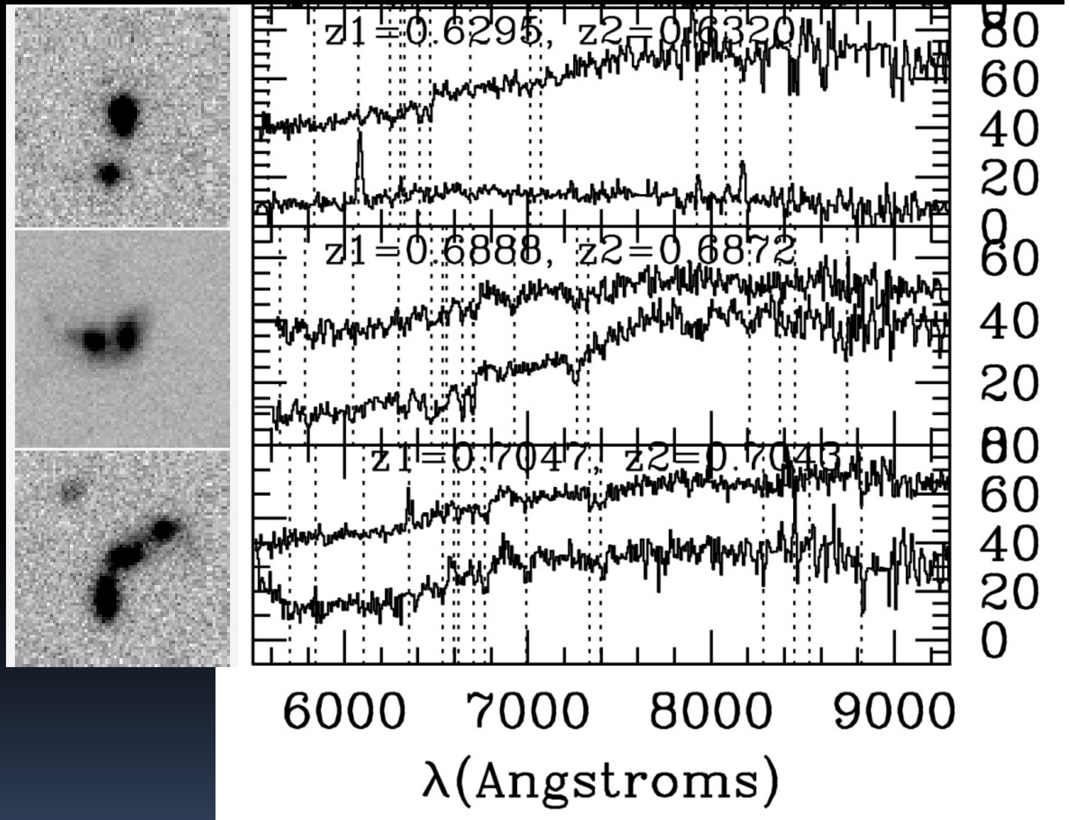
Rotation curve - mass



Merger rate history 1/3

What is the contribution of mergers to galaxy evolution ?

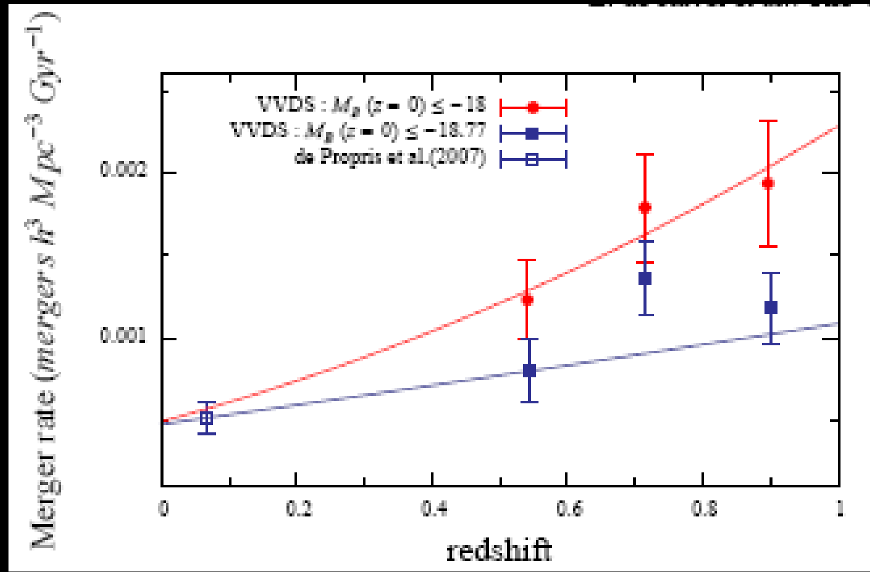
- Merger rate from spectroscopically measured pairs
  - Major (ratio>1/4), and minor (ratio <1/4) mergers
- Measurements
  - zCOSMOS
  - DEEP2
  - VVDS



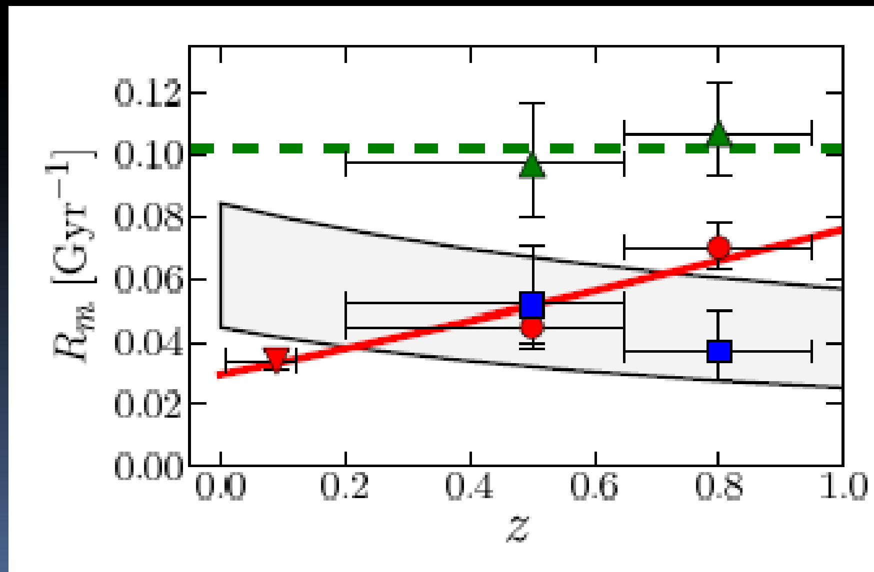
Merger rate history 2/3

- Merger rate is depending on luminosity/mass
- $L_B \geq L_B^*$ galaxies have grown 25% of their mass from mergers since z~1 (1/4 minor, ¾ major)
- Major mergers more important for the mass growth of ETGs (40%) than LTGs (20%)

Mergers contribute significantly to mass growth since z~1



Major mergers, de Ravel et al. 2009

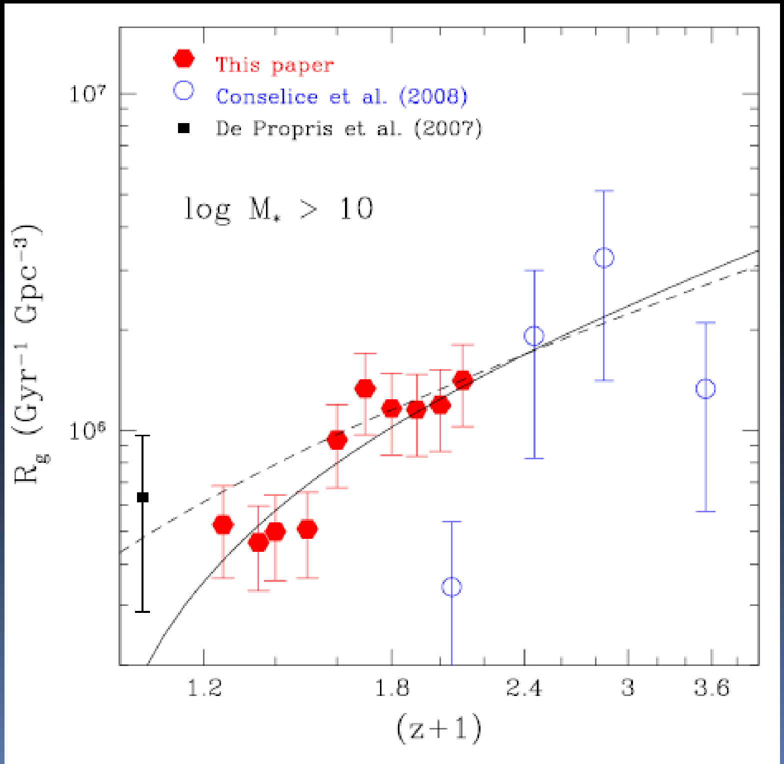


Minor mergers, Lopez-sanJuan et al. 2009

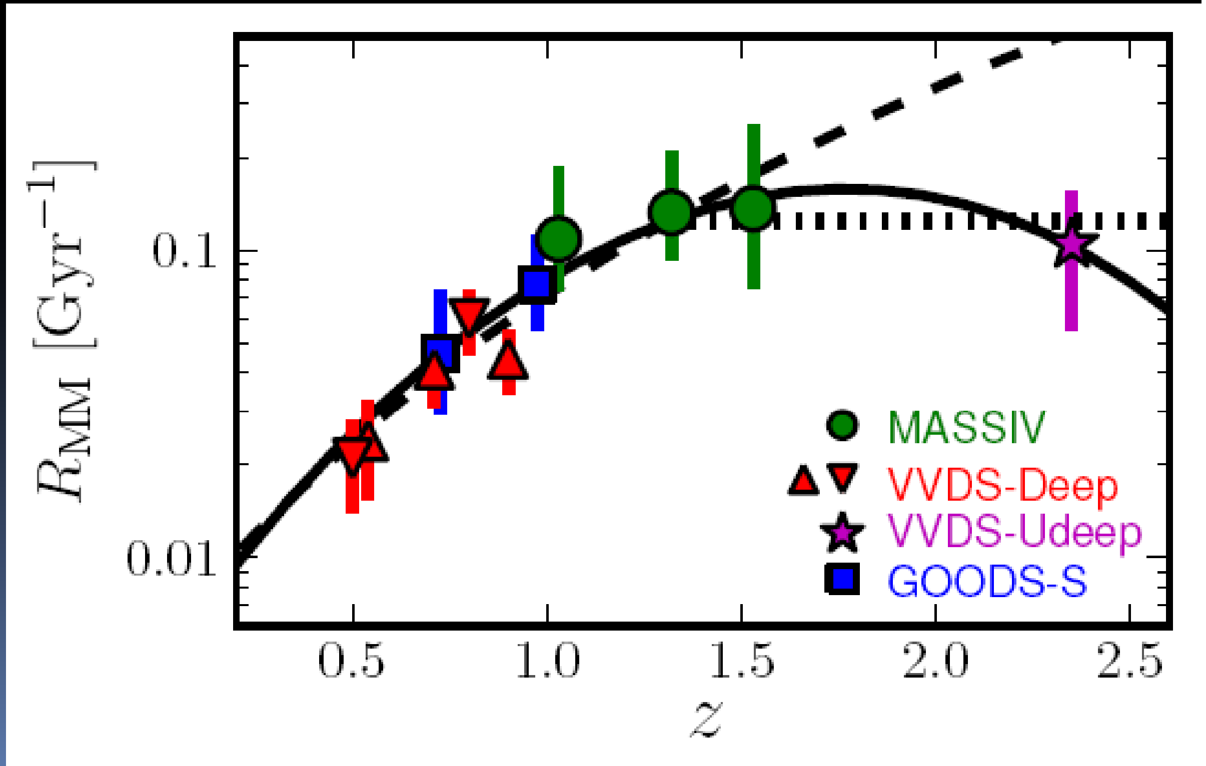
Merger rate history 3/3

- Evolution of merger rate beyond z~1 is not yet securely established
- Peak in major merger rate at z~1.5 ?
  - On-going from VVDS and MASSIV

Conselice et al., 2009

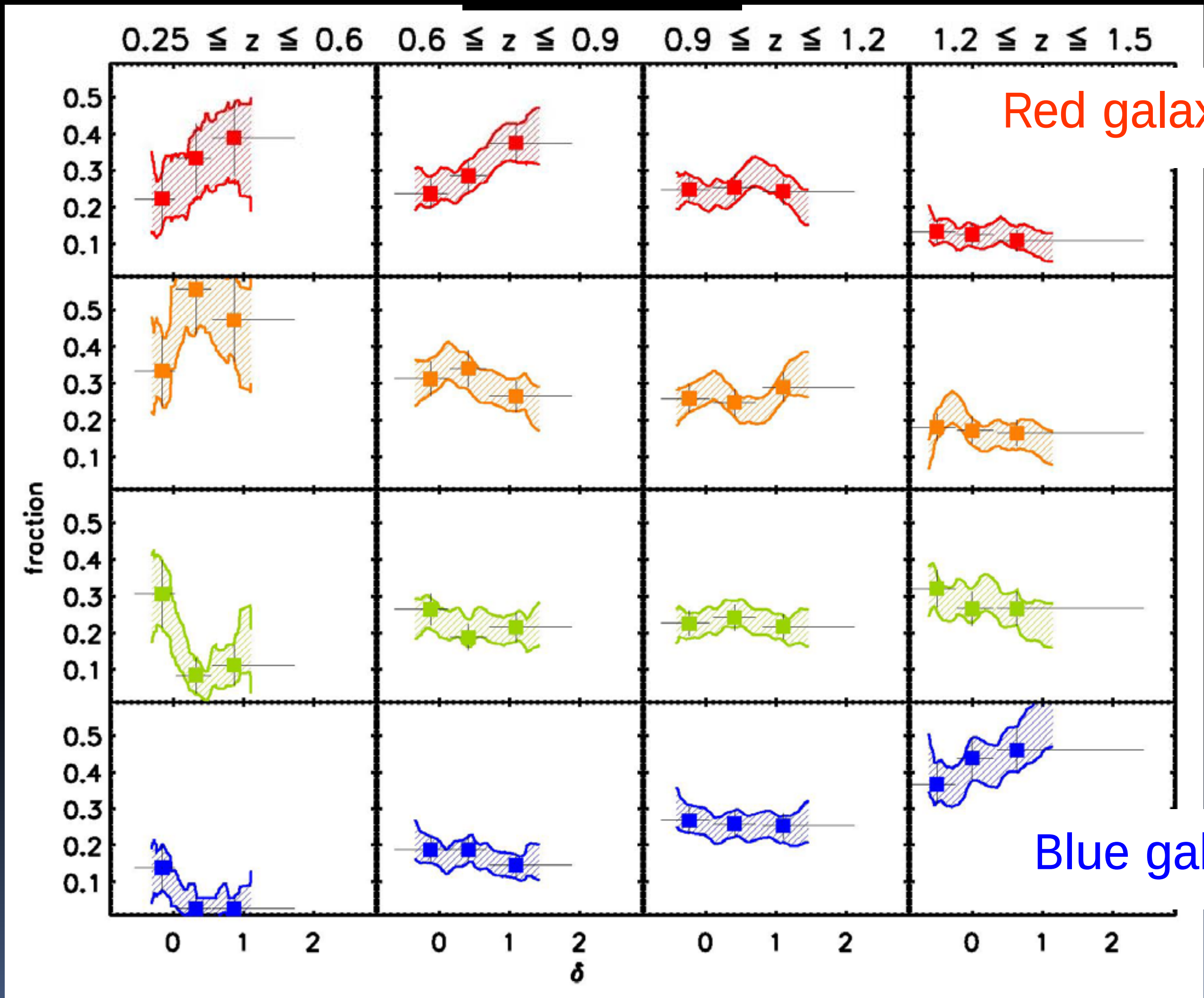


Lopez-SanJuan, Le Fèvre et al., in prep



the build-up of the Colour-density relation

Redshift



Red galaxies

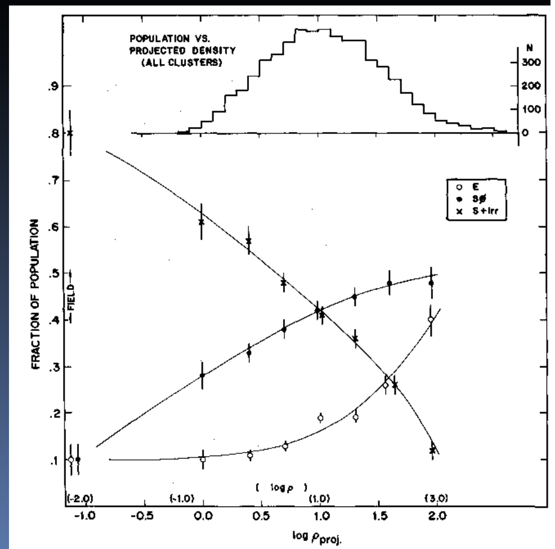
Blue galaxies

Density contrast

VVDS: Cucciati et al., 2006

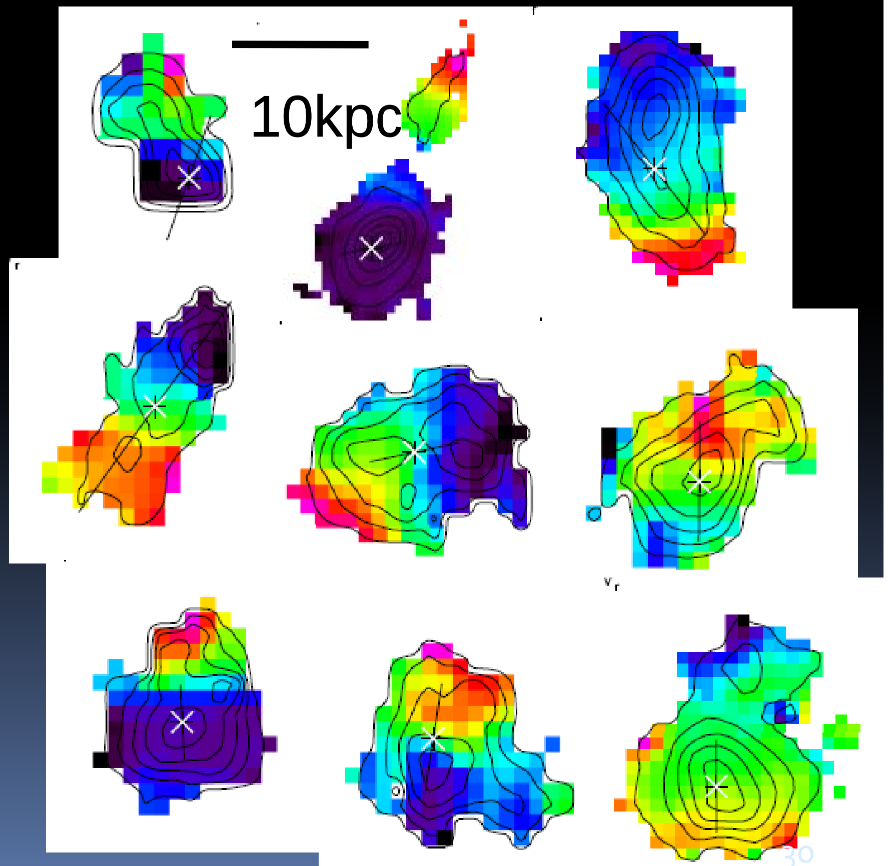
DEEP2: Cooper et al., 2006

Dressler, 1980



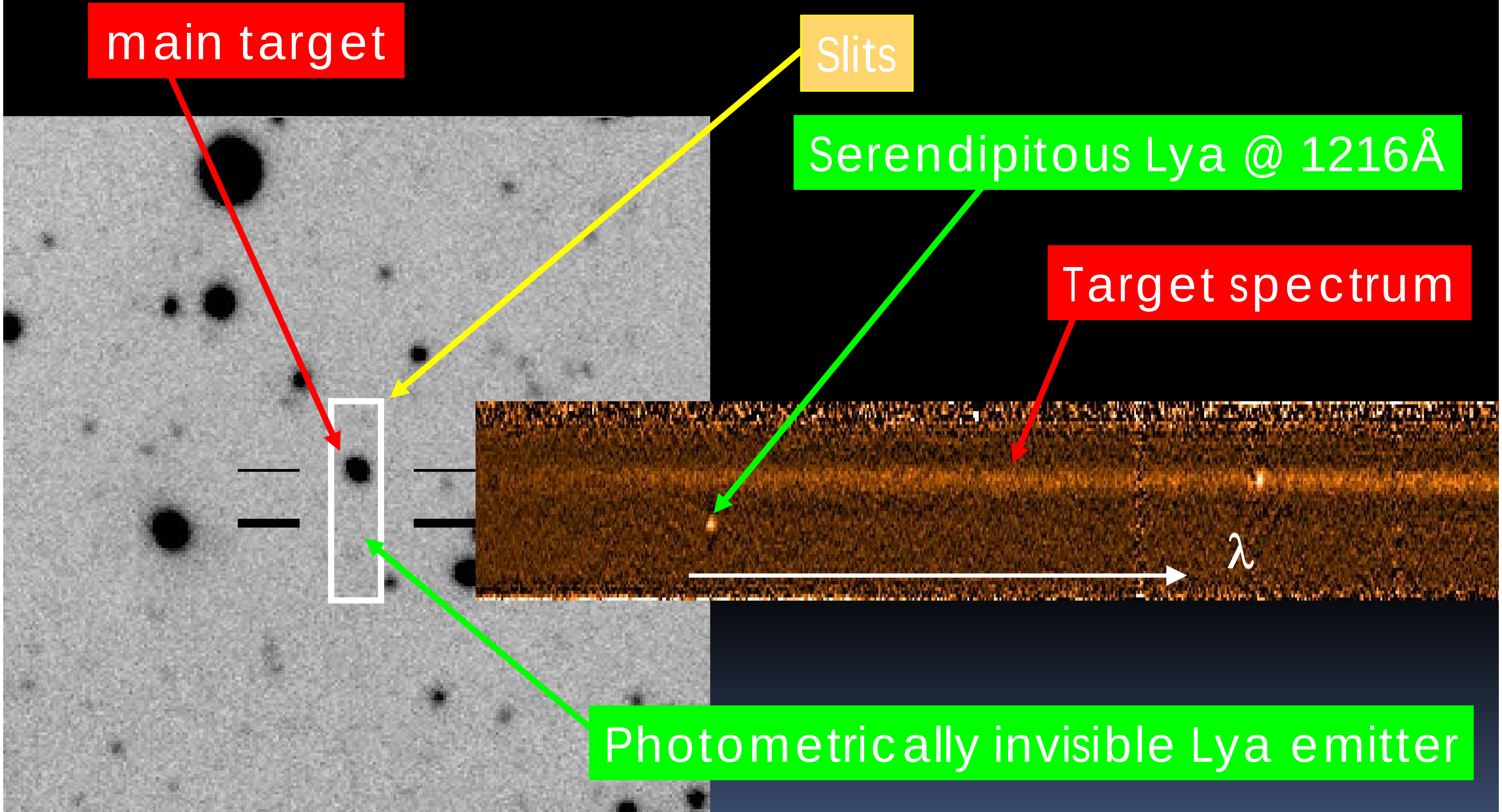
Follow-up surveys

- Use bias-free MOS surveys to select unbiased populations
- Complete IFU-3D surveys
  - MASSIV @z~1.5
  - SINS @z~2
  - …
  - MUSE



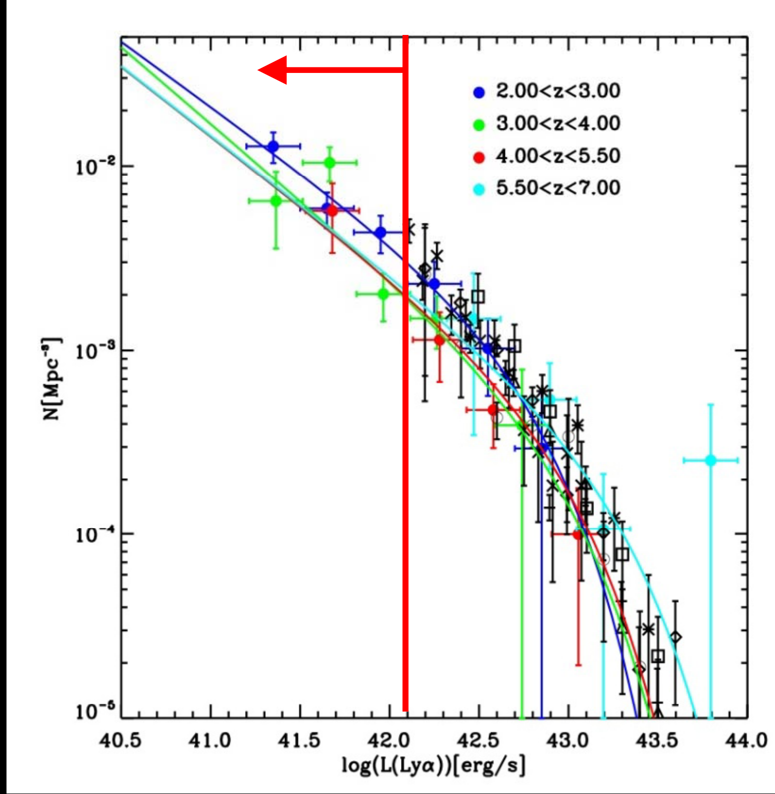
MASSIV:
Mergers at z~1.5

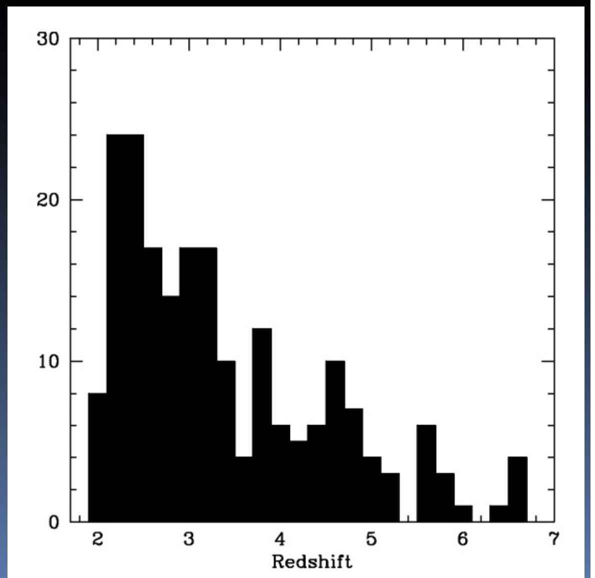
Serendipitous power of multi-slit MOS

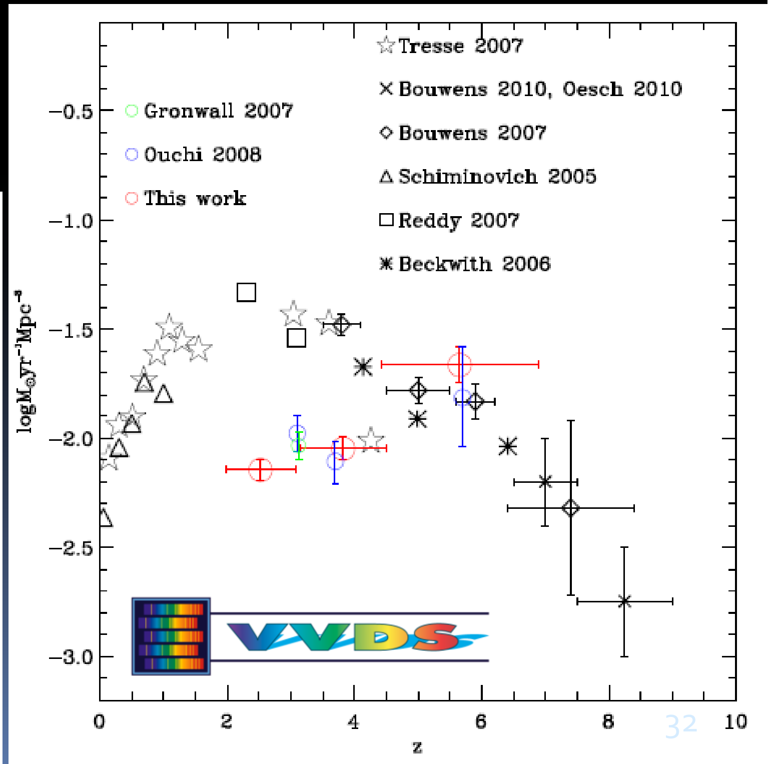


Serendipitous redshift surveys

- Rauch et al. 2008, 92h VLT, 27 LAE
  - 10^{-18} erg.cm^{-2}.s^{-1} !
- VVDS: Cassata et al., 2011
  - 15-30h VLT, 1.5×10^{-18} erg.cm^{-2}.s^{-1}
  - 10,000 slits, 25 arcmin² of "blank sky" covered
  - 217 serendipitous LAE $2<z<6.5$!
- Steep slope of the LF: α=1.7
- LAE: dominant contribution to SFRD beyond z~5
- MUSE will contribute to the faint end



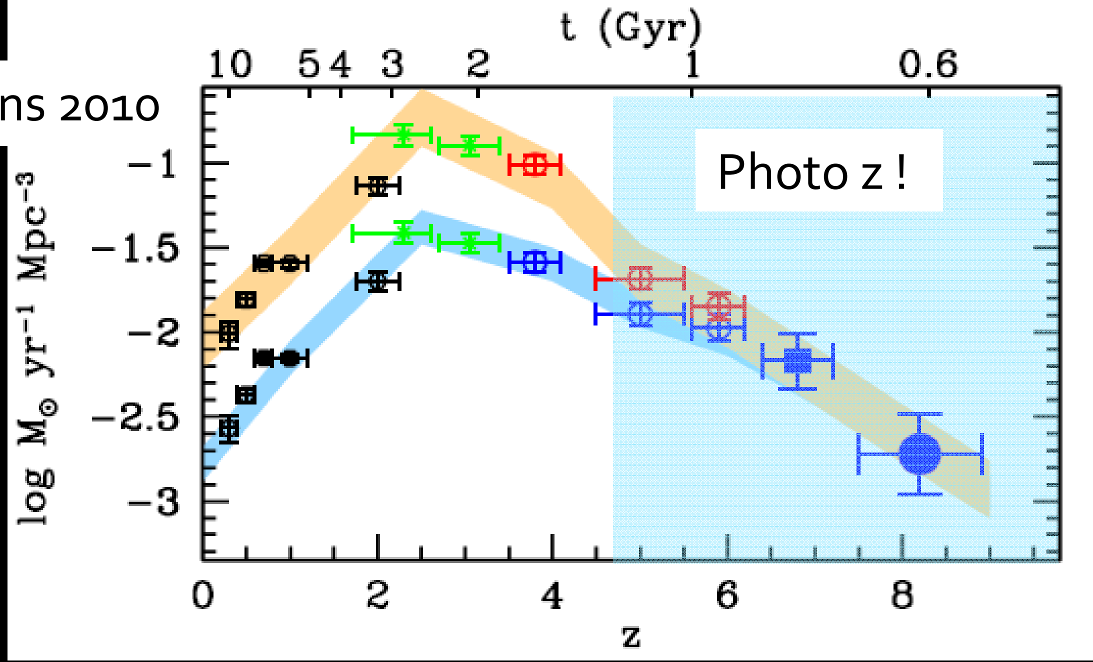


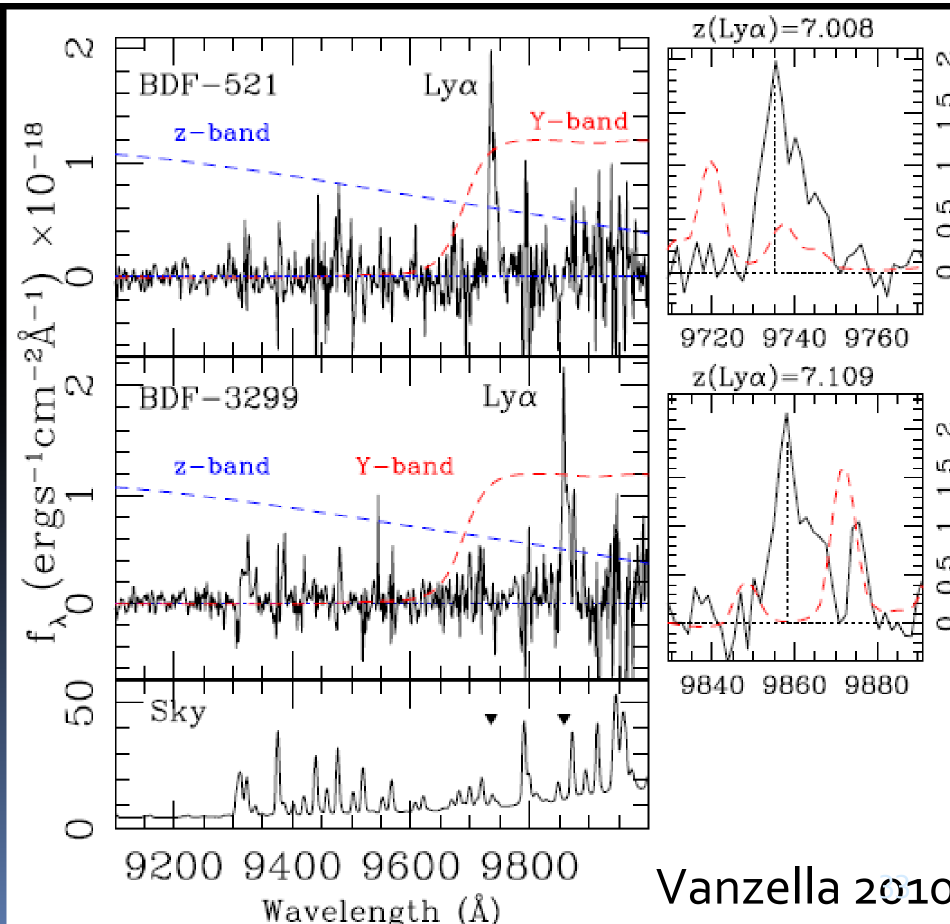


Discovery space: z>6

- Spectroscopy needed !
  - SFH beyond z=4 is mostly photometry-selected
- Photo-z or color selection is increasingly uncertain at higher z
  - LAE selection promising (Ouchi et al., 2009)
  - Serendipitous power (Cassata et al., 2011)
- Very deep NIR imaging needed
  - Ultra-Vista at ESO
- Very deep NIR spectroscopy needed

Bouwens 2010

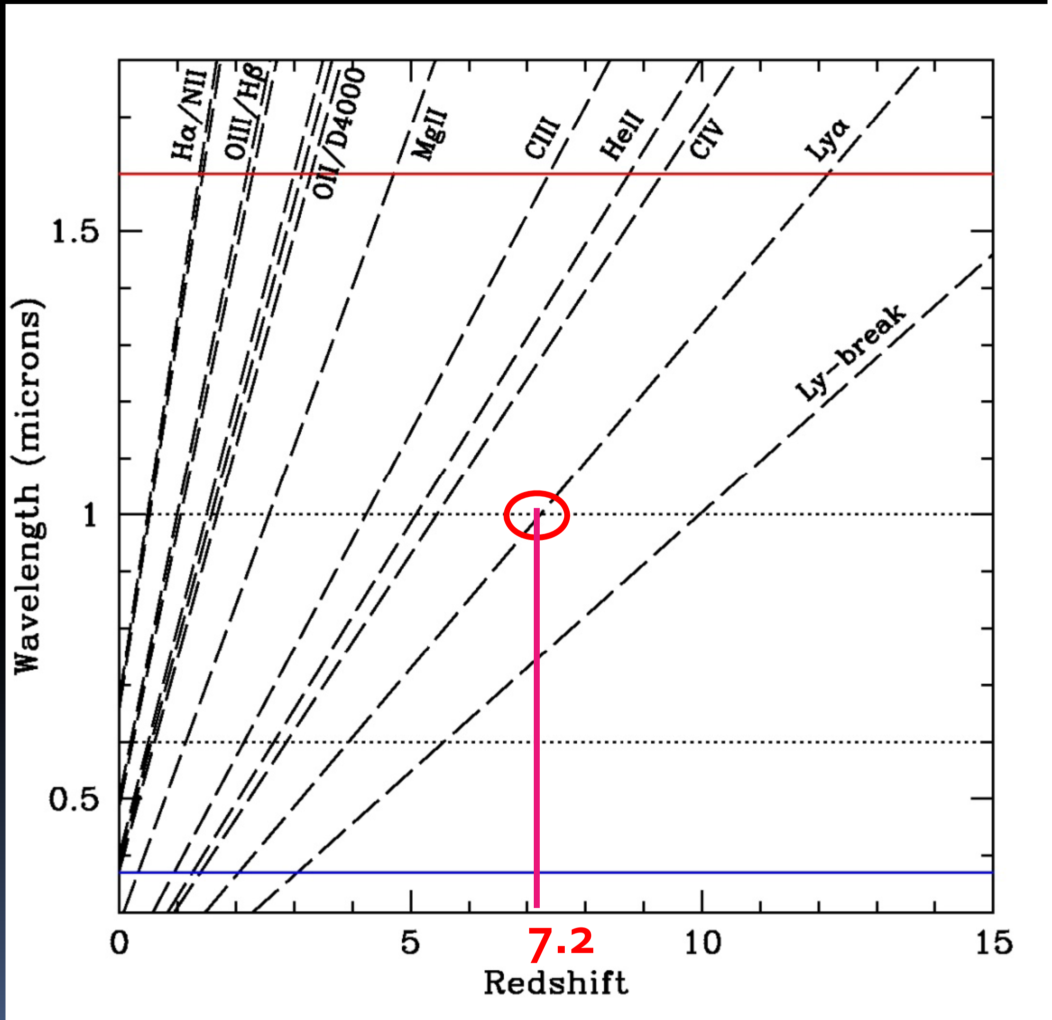




Vanzella 2010

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

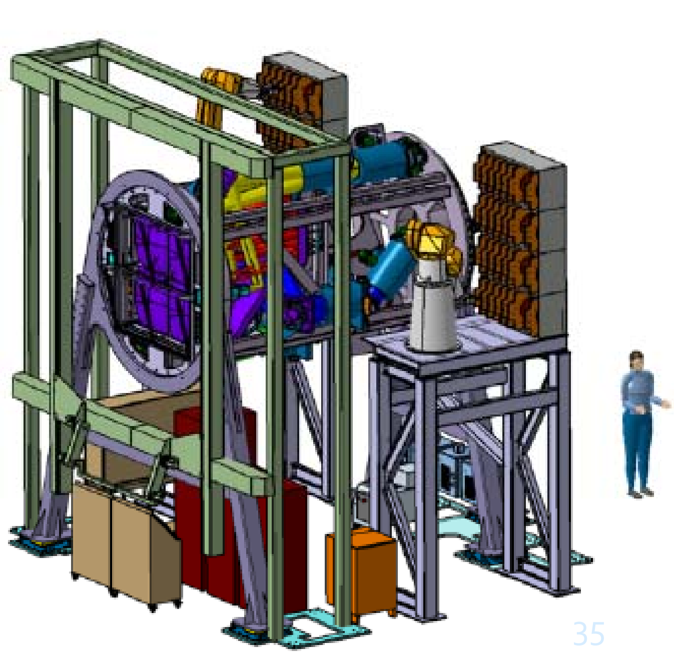
- MOSFIRE on Keck: 2012
  - YJHK, 6x6 arcmin²
  - 45 slits
- KMOS on VLT, 2012 ?
  - YJHK, 7 arcmin diameter
  - 24 IFUs, 2.8x2.8 arcsec²
- LUCIFER on LBT
- EMIR on GTC
- NIRSPEC-JWST: 2018…

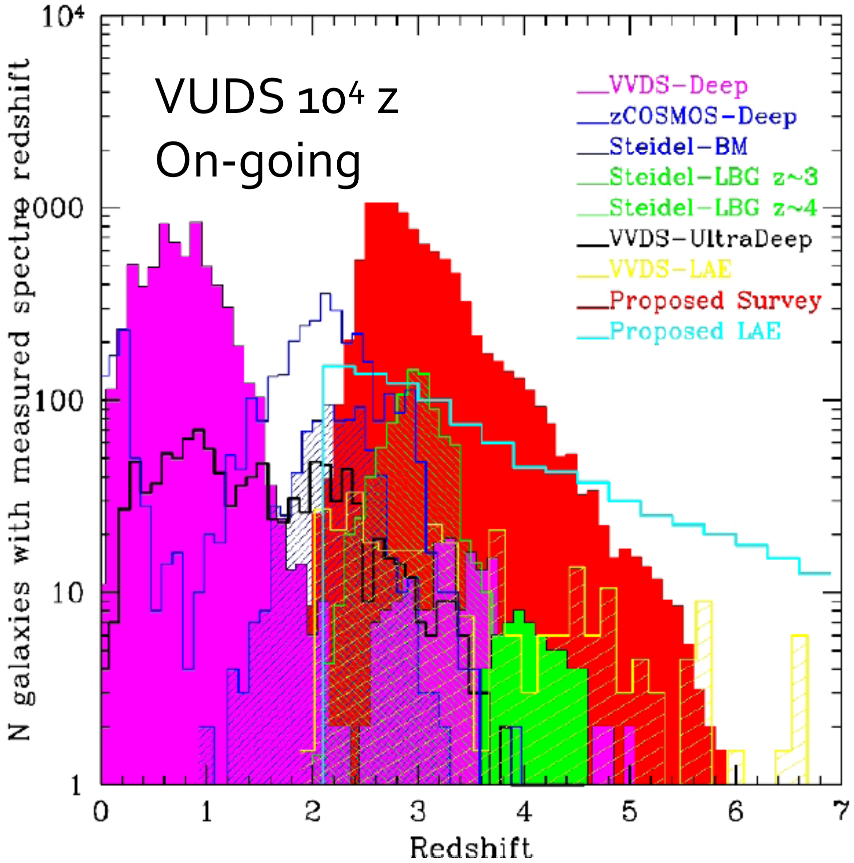


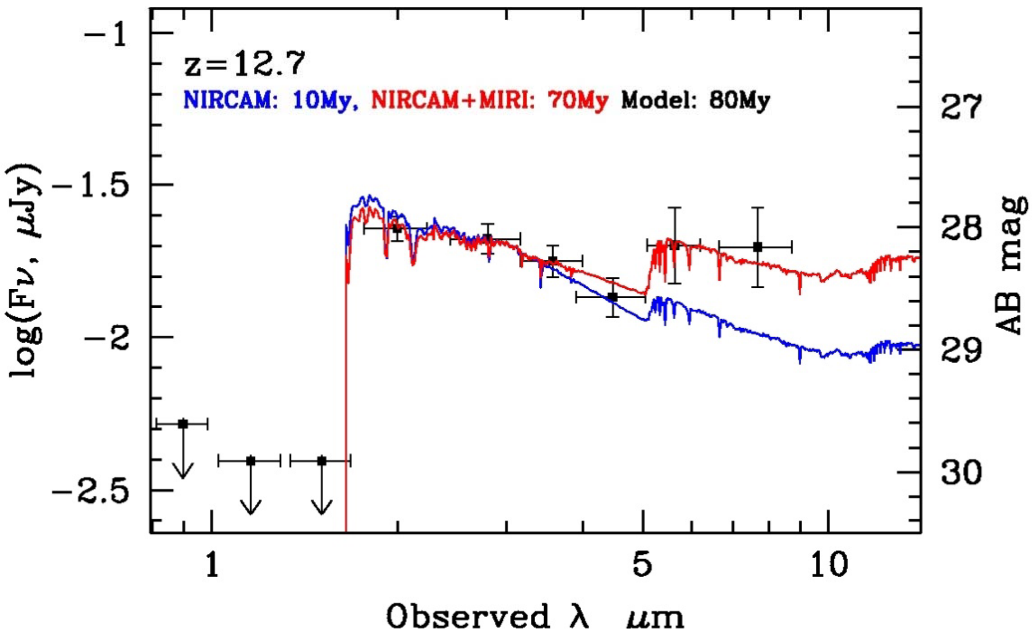
Future surveys

- Very wide field: toward all sky to z~2
  - VIMOS-VIPERS, on-going: 10^5 redshifts, z~1
  - Big-Boss, PFS-SUMIRE…: 3×10^7 redshifts, z~1-1.5
  - ESA-EUCLID: 5×10^7 redshifts, z~2
- Large surveys, mass assembly, z~2-6
  - VUDS: on-going at the VLT: 10^4 redshifts
  - Proposed for the VLT-VIMOS: 10^5 redshifts
- Large galaxy kinematics surveys
  - VIMOS: Tresse et al., 1000-z, on going
  - VLT-KMOS, 24 IFU, near-IR
  - MUSE surveys
- Reionisation, early SFH, z>6
  - VUDS: VIMOS Extreme Spectroscopic Survey
    - On-going at the VLT-VIMOS: 10^4 redshifts, z~4-7.2
  - JWST: NIRSPEC, MIRI
  - EELT: DIORAMAS, EAGLE

EELT-DIORAMAS





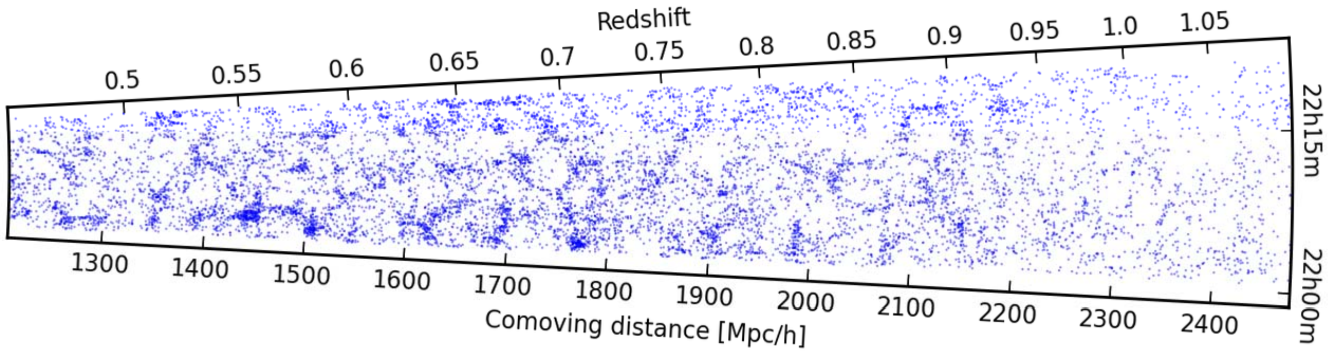


JWST: finding first light ?

EELT: survey reionisation epoch

VIPERS 10^5 z (25,000 z so far

On-going



DIORAMAS-EELT

Simulation