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THE VIMOS ULTRA-DEEP SURVEY

When did the massive galaxies at $2<z_{spec}<6$ start forming their stars ?

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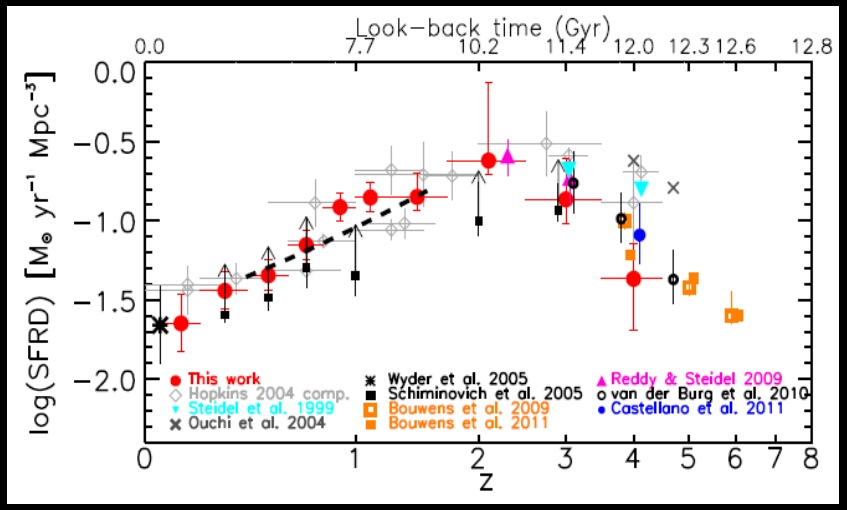
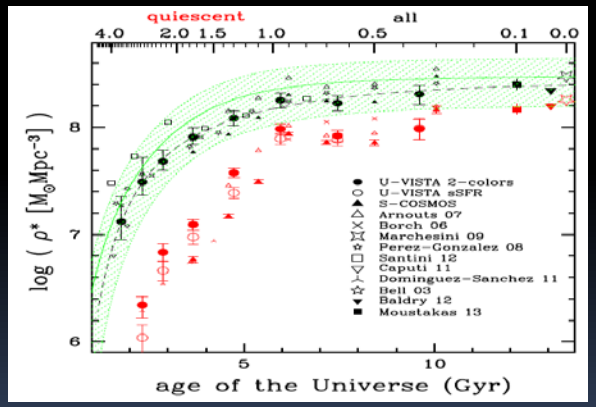
How and when did galaxies assemble ?

Two complementary perspectives:

- What fuels star formation ?
  - Processes related to transforming gas to stars
  - Modulated by accretion, feedback, environment (quenching ?)
- What contributes to the general mass increase ?
  - Evolution of the mass in stars
  - Merging
- When did galaxies form their stars ?



Star Formation Rate (e.g. Cucciati +12)



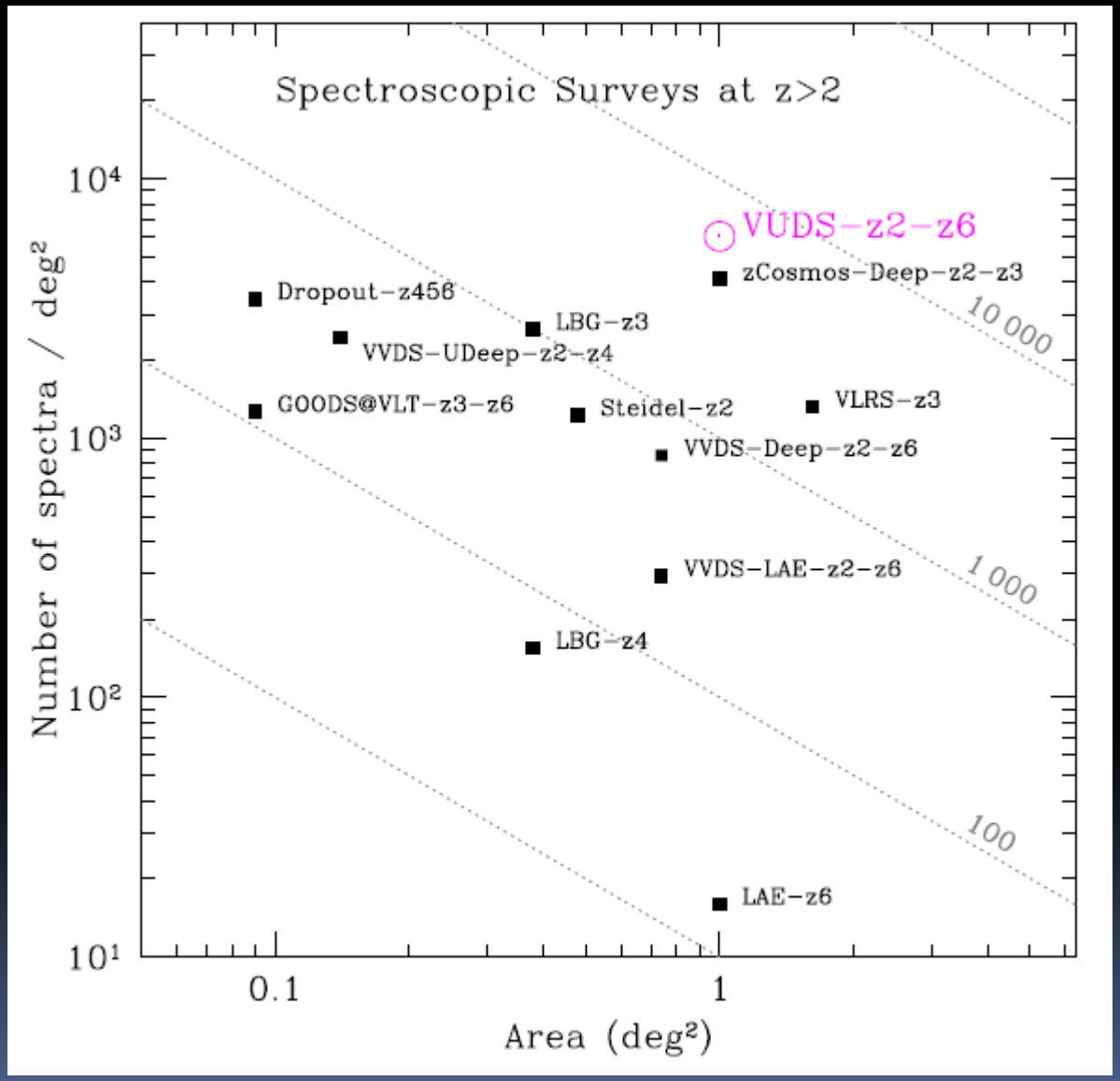
Stellar mass density (e.g. Ilbert+13)

Needed: large samples of galaxies with spectroscopic redshifts at z>2-3

- At z>2 most studies use photometric samples:
- The census of galaxies so far relies on small fields
  - Cosmic variance (Moster+11):
    - 50% on 100 arcmin^2 (GOODS, CANDELS)
    - 10% on 1deg^2 (COSMOS)

Need larger and deeper spectroscopic samples

Spectroscopic surveys at z>2 are limited



Only ~3000 galaxies with z_{spec}>2, few hundred at z_{spec}>3.5

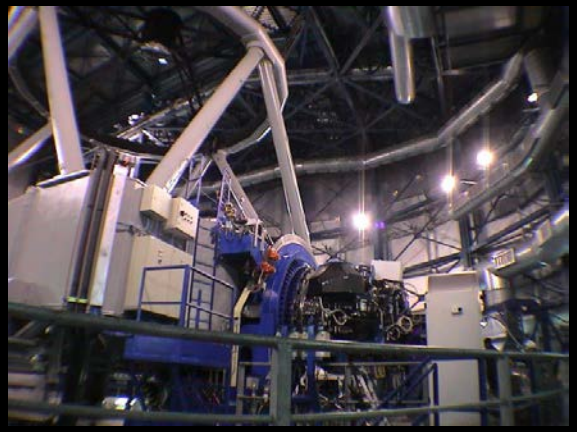
Heterogeneous samples

➡ **Adding VUDS**

Le Fèvre+15

VUDS: spectroscopic survey of the first phases of galaxy assembly

- ESO Large Program: 640h allocated (~80 nights, clear)
  - VIMOS on the VLT
- Focused on 2<z<6
- 1 deg²
- 10,000 targets
- 3 fields: mitigate cosmic variance

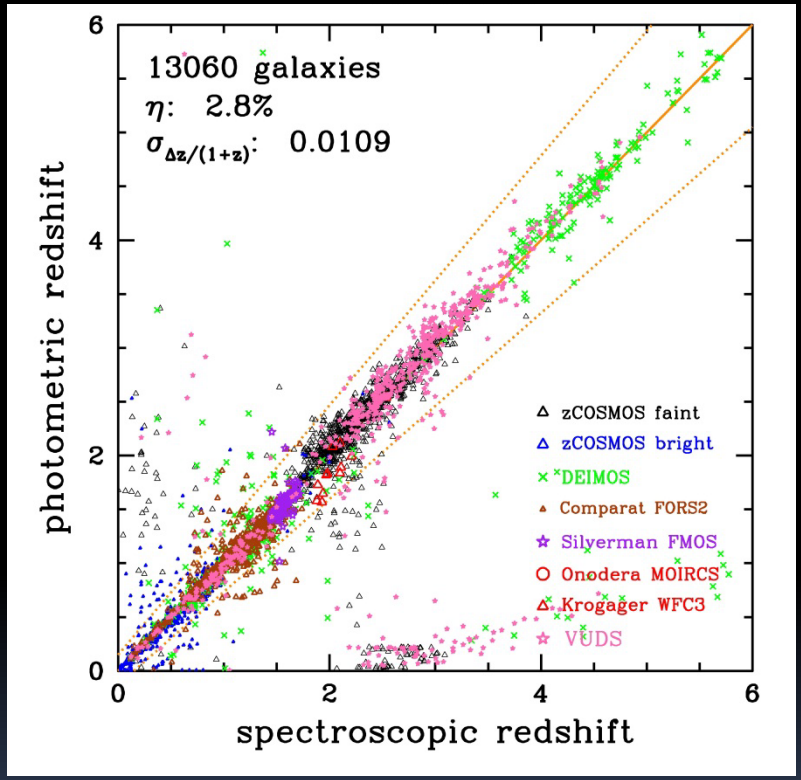


FIELD	VIMOS pointings	Area arcmin²
COSMOS	8	1800
ECDFS	2+1	675
VVDS-02	5	1125
TOTAL	*15+1*	*3600*

See Le Fèvre et al. arXiv:1403.3938 in press

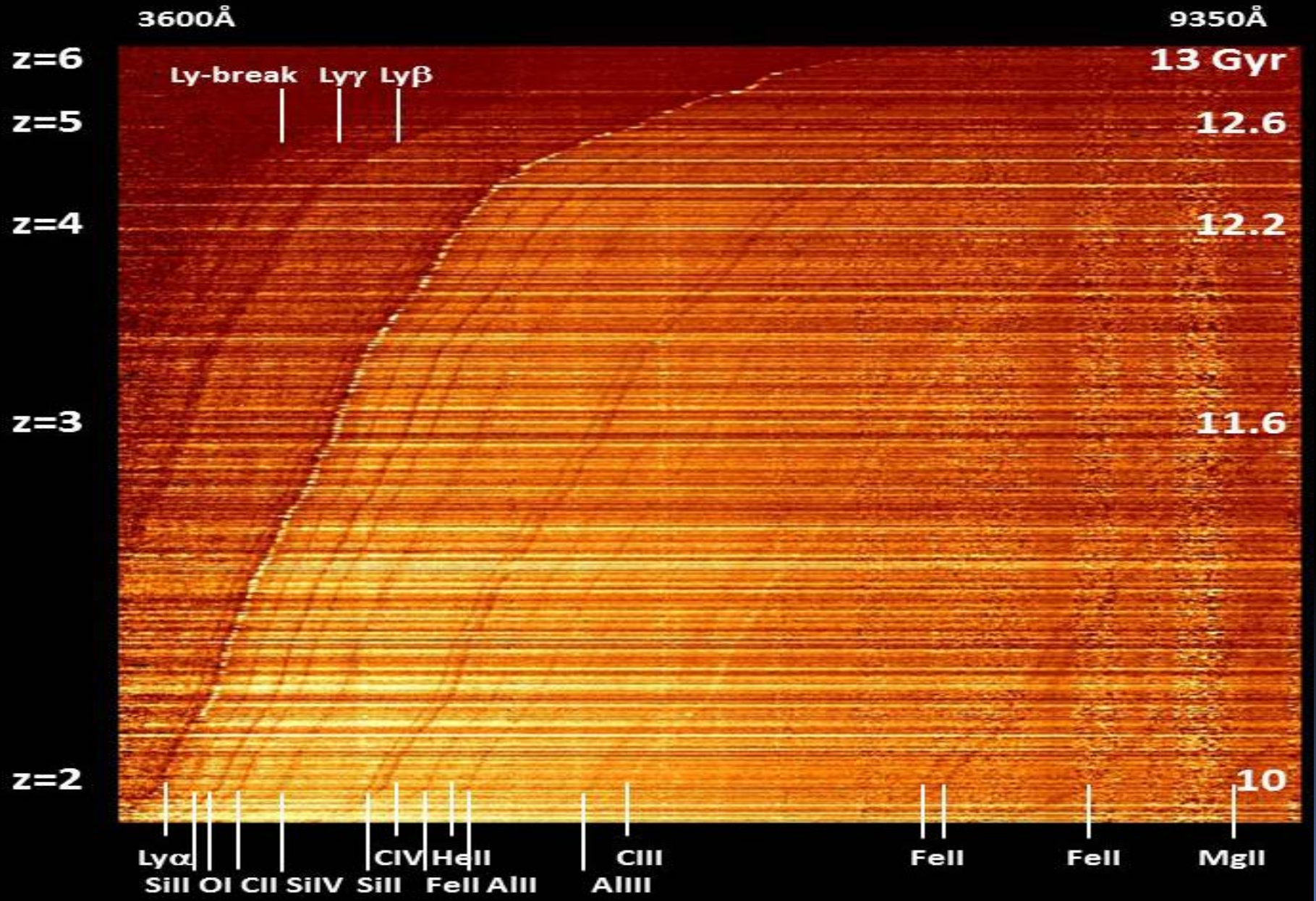
Target selection

- Additive selection:
  - **photometric redshift selected**
    $z_{phot}>2.4$ $22.5\leq i_{AB}\leq 25$
  - First and second peak in z_{phot} PDF
  - Color-color (LBG) AND $z_{phot}>4$ with $i_{AB}>25$
  - Add z+NIR detected, but not detected in optical
- Large wavelength range $3600<\lambda<9300$ Å
- 14h integration / target with VLT/VIMOS
  - 14h in LRBLUE, 14h in LRRED
- ~80% redshift success rate



Excellent photoz, Ilbert+ 13, 15

VUDS ~7500 spectra z>2:~3Gyr of evolution in one glance



When did these galaxies form their stars ?

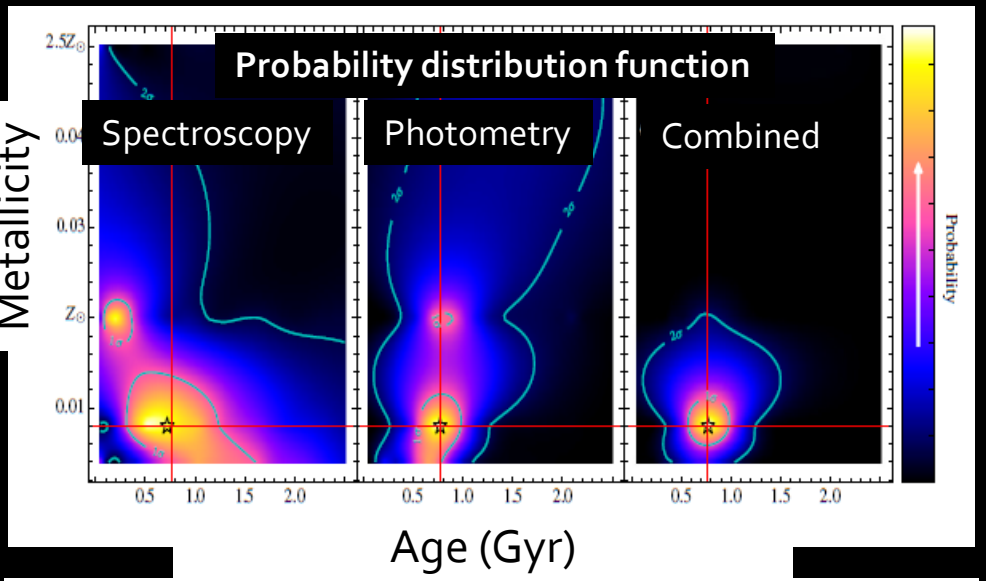
- Age: the forgotten physical parameter ?
- At low-z degeneracies age-metallicity-dust

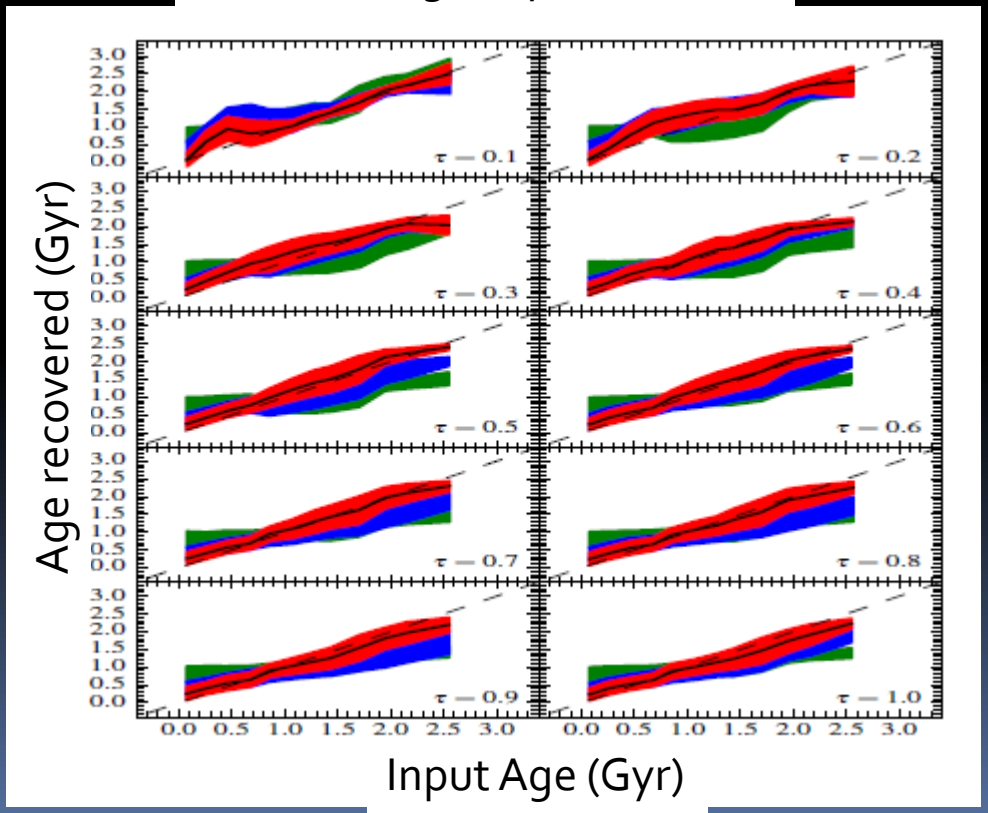
What about high-z ?

- New approach: combine photometry AND spectroscopy in SED fitting
  - GOSSIP+ SED fitting code (BC03, M05)
  - Includes IGM transmission variance
- Known redshift and age of U. limits age possibilities
- Large simulations: ~10000 galaxies
  - Vary Metallicity, E(B-V), SFH, Age
  - Noise to mimic observations

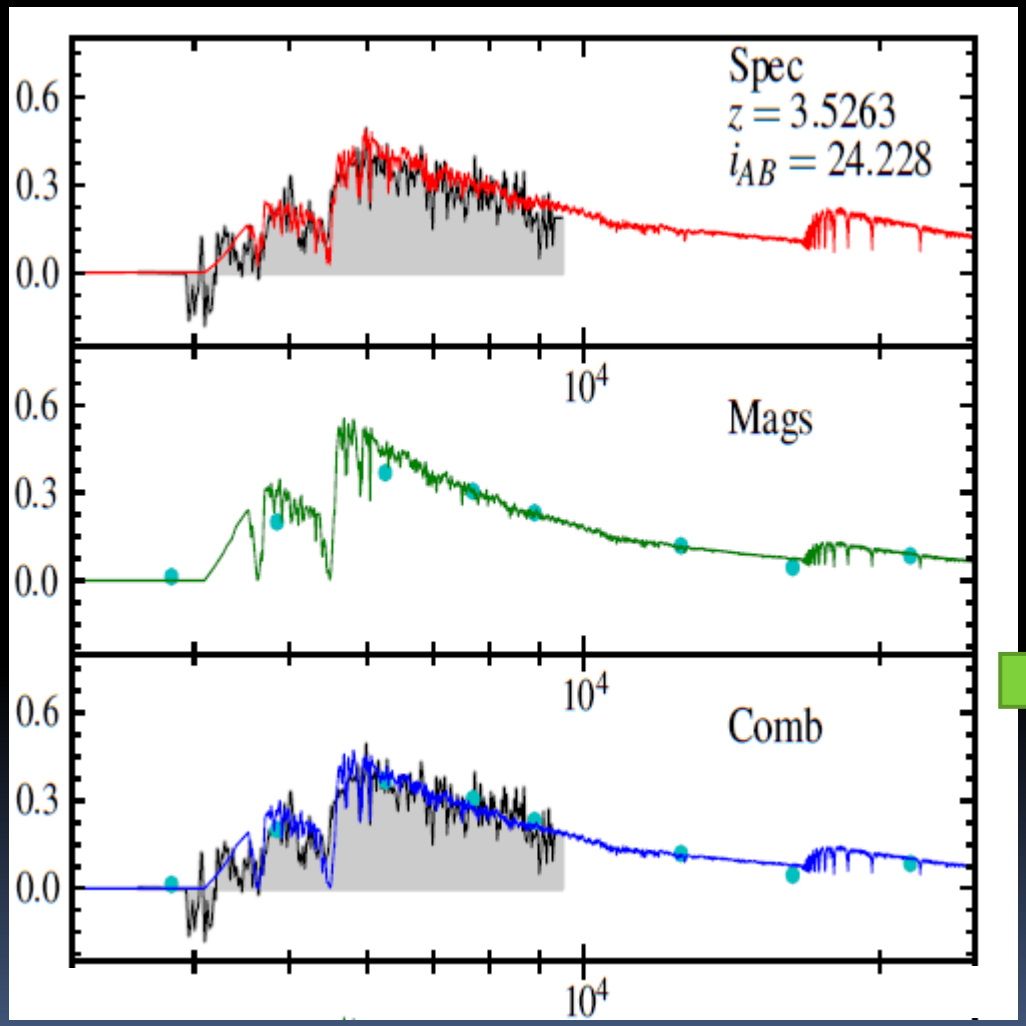
Results: at z>2, age is a robust parameter
- Typical errors 0.2-0.3 dex
- As robust as stellar mass

Romain Thomas et al. in prep

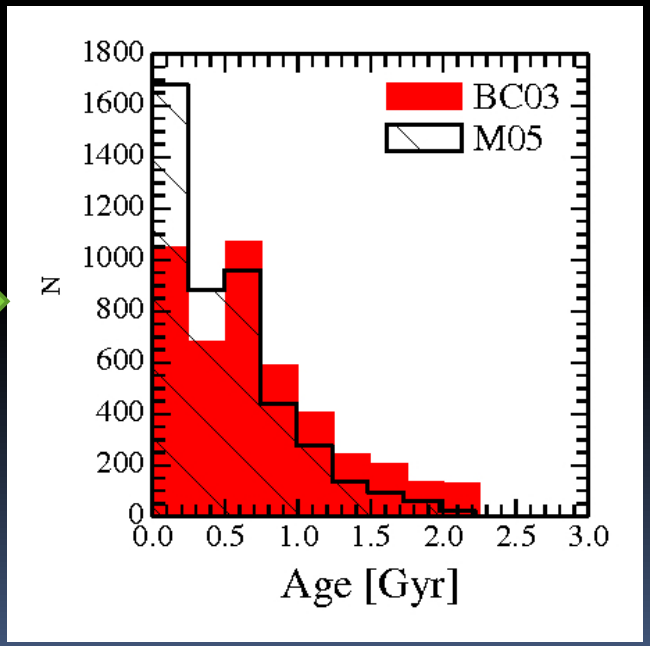




Age and redshift of formation



- Use the best ~4500 VUDS galaxies with spectro-z
- Compute ages combining spectroscopy and photometry



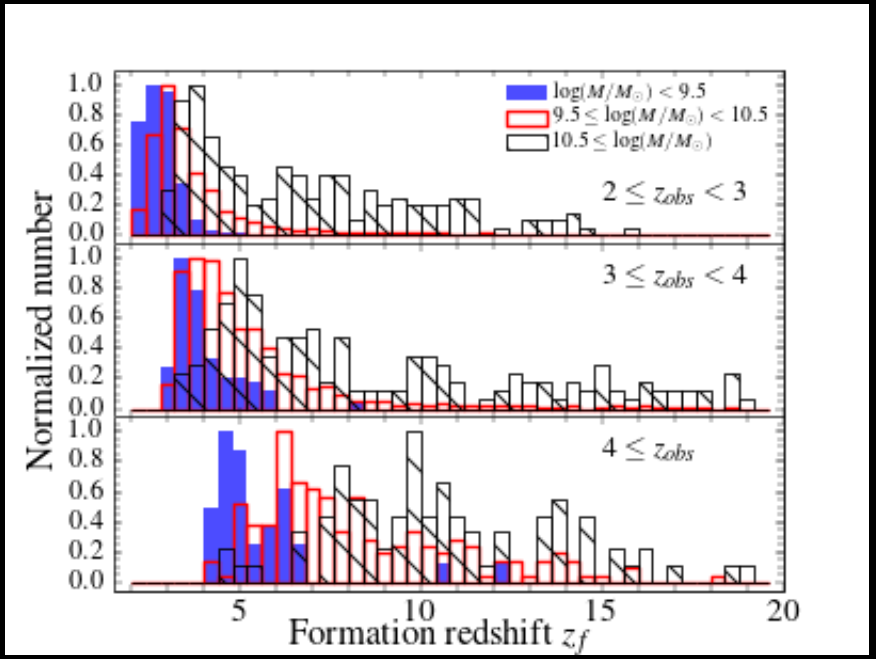
Downsizing in early galaxy formation

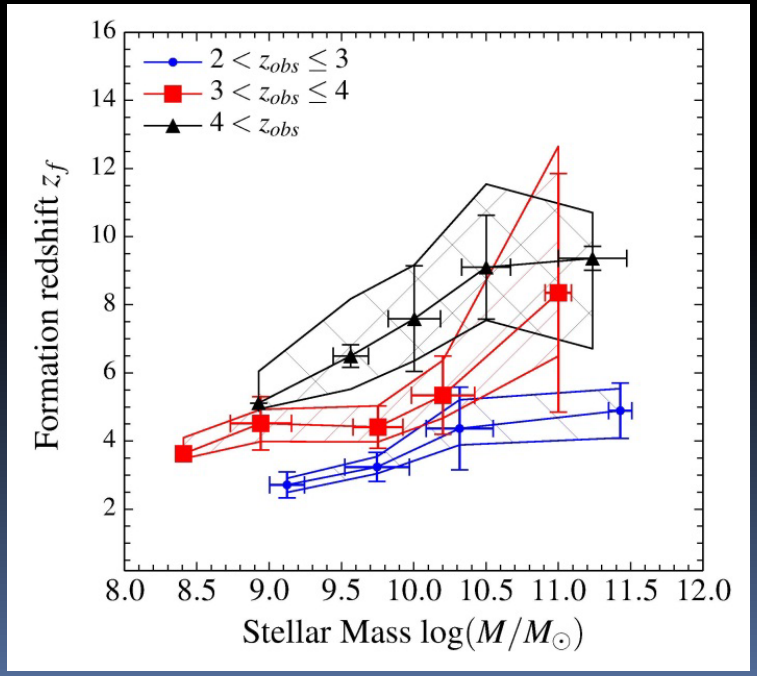
- Which galaxies formed their stars first ?
- Formation redshift vs. Stellar mass:

the most massive galaxies formed their stars first

- This downsizing started already at z~5
- In agreement with simulations (Cattaneo+08 +13)

Romain Thomas, OLF, et al. in prep

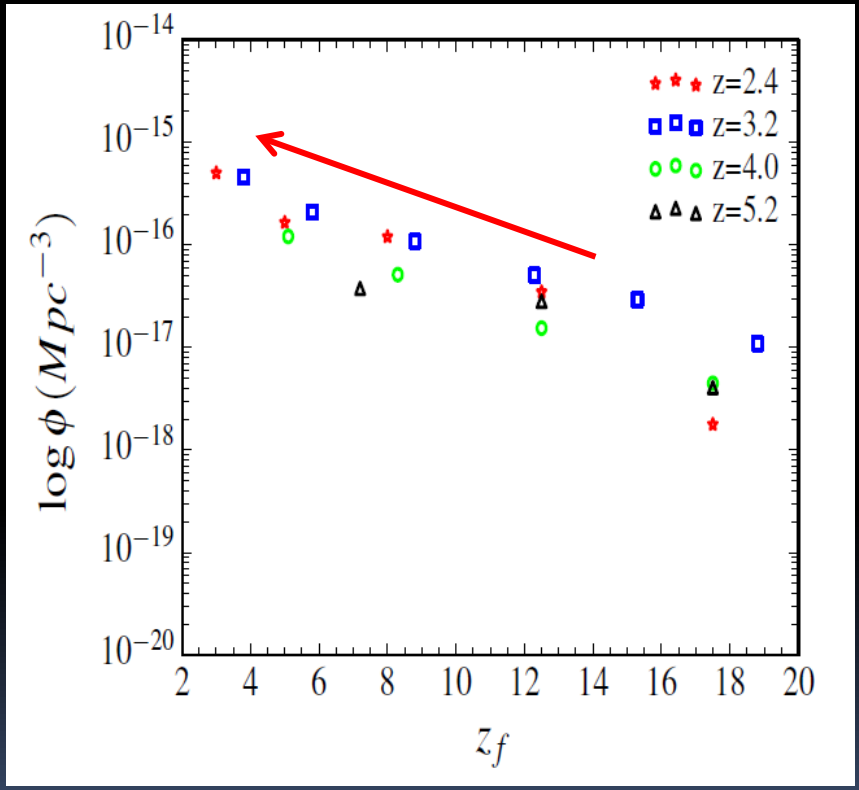




The formation redshift function FZF

- How many galaxies started forming their stars per unit volume per redshift bin ?
- Build using V_{max}
- FZF for galaxies observed at different redshifts is similar
- FZF is rising by 1 dex from z~10 to z~2
  - Following the rise in SFRD

Number of galaxies per Mpc³ per z_f bin



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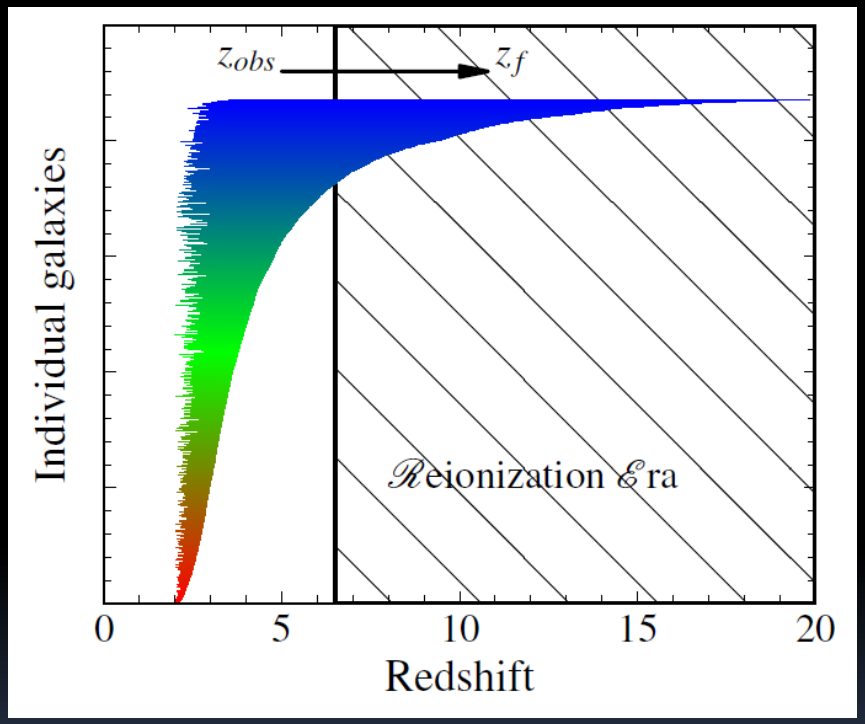
Archaeology: from z~4-6 to the reionization

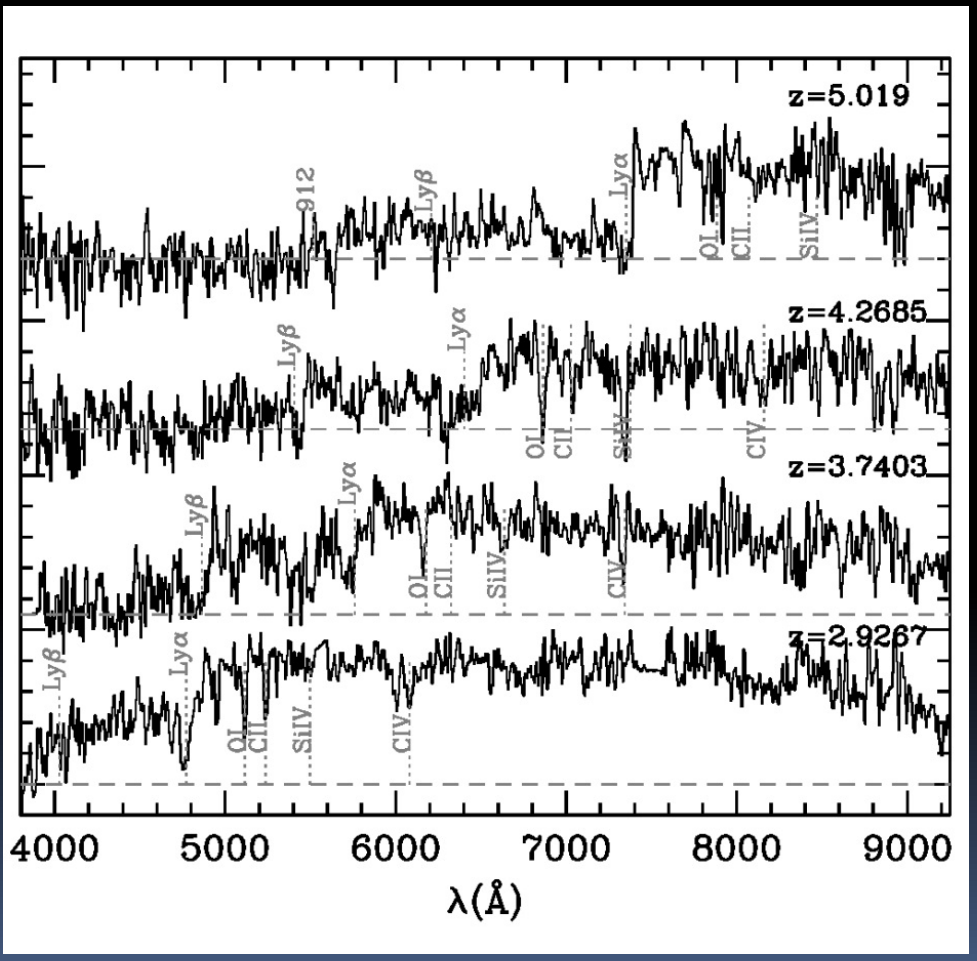
- Out of ~4500 galaxies, ~700 have started forming their stars before z=6.5
- z_f going to z>~15
- Main uncertainty: star formation history

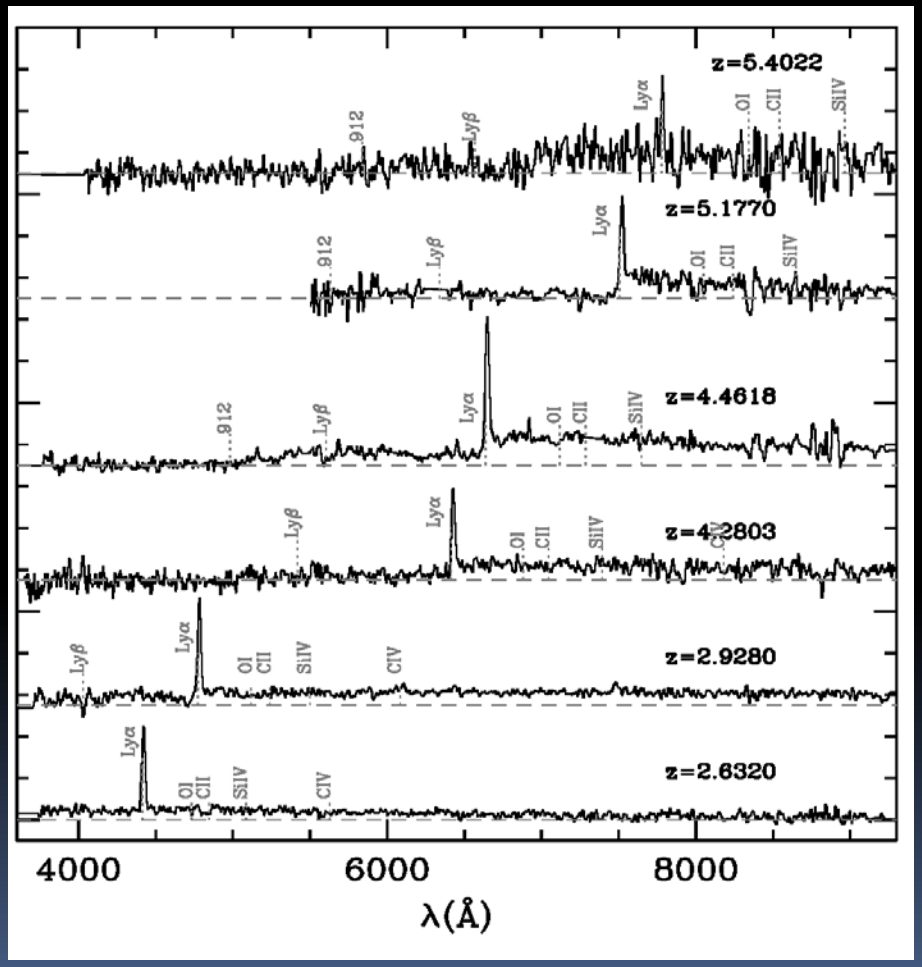
VUDS galaxies z_{obs} to z_f ordered by z_f



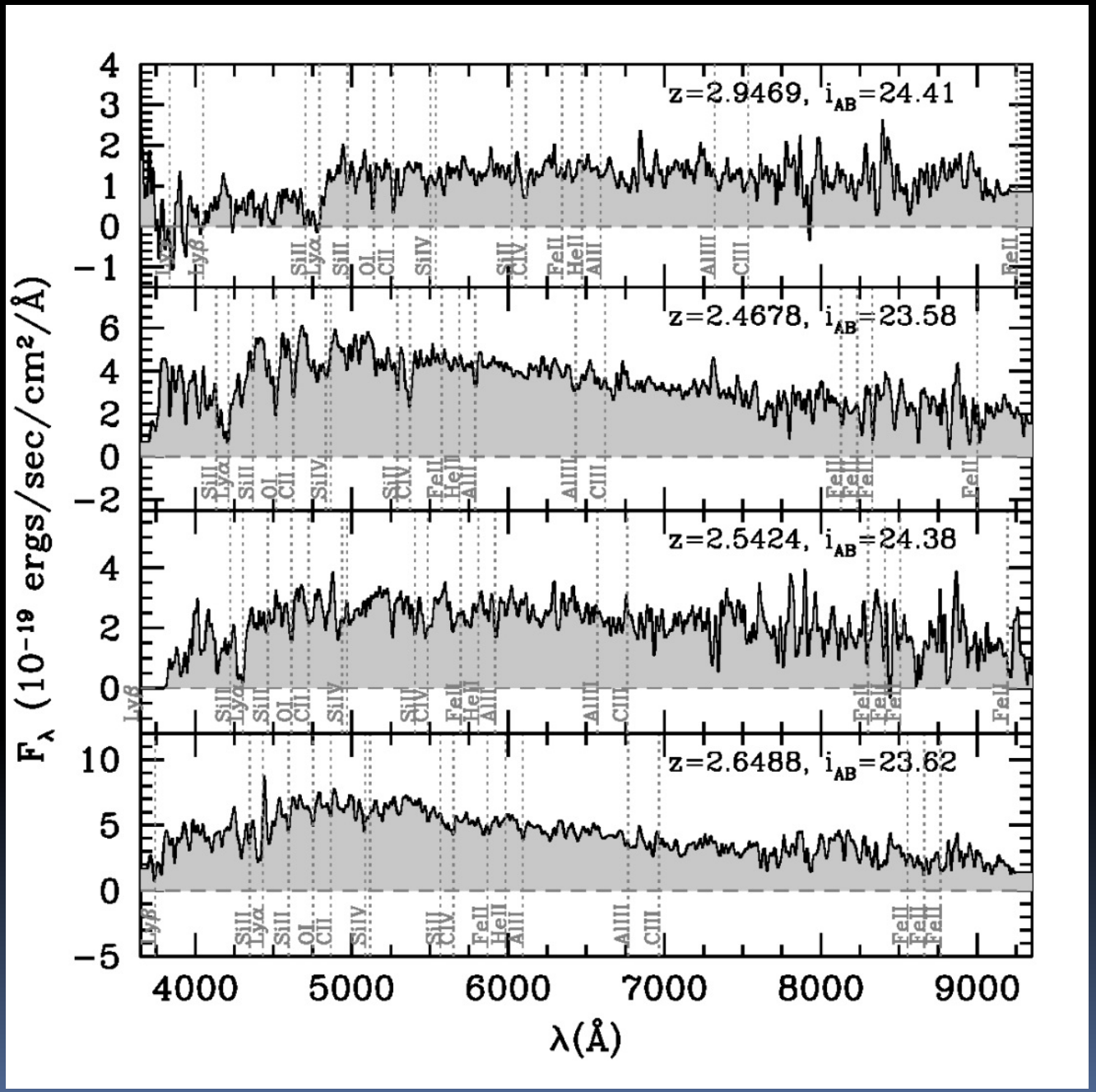
Summary

- VUDS is filling a window relatively un-probed with spectroscopy at 2<z<6
- ~7500 galaxies with z_{spec}>2
- Age dating galaxies at z>2 is more robust than thought
  - Combine spectroscopy and photometry
- Downsizing in galaxy formation observed up to z~5
  - More massive galaxies started to form their stars first
- Use the redshift of formation of galaxies just after reionisation to probe the reionisation epoch

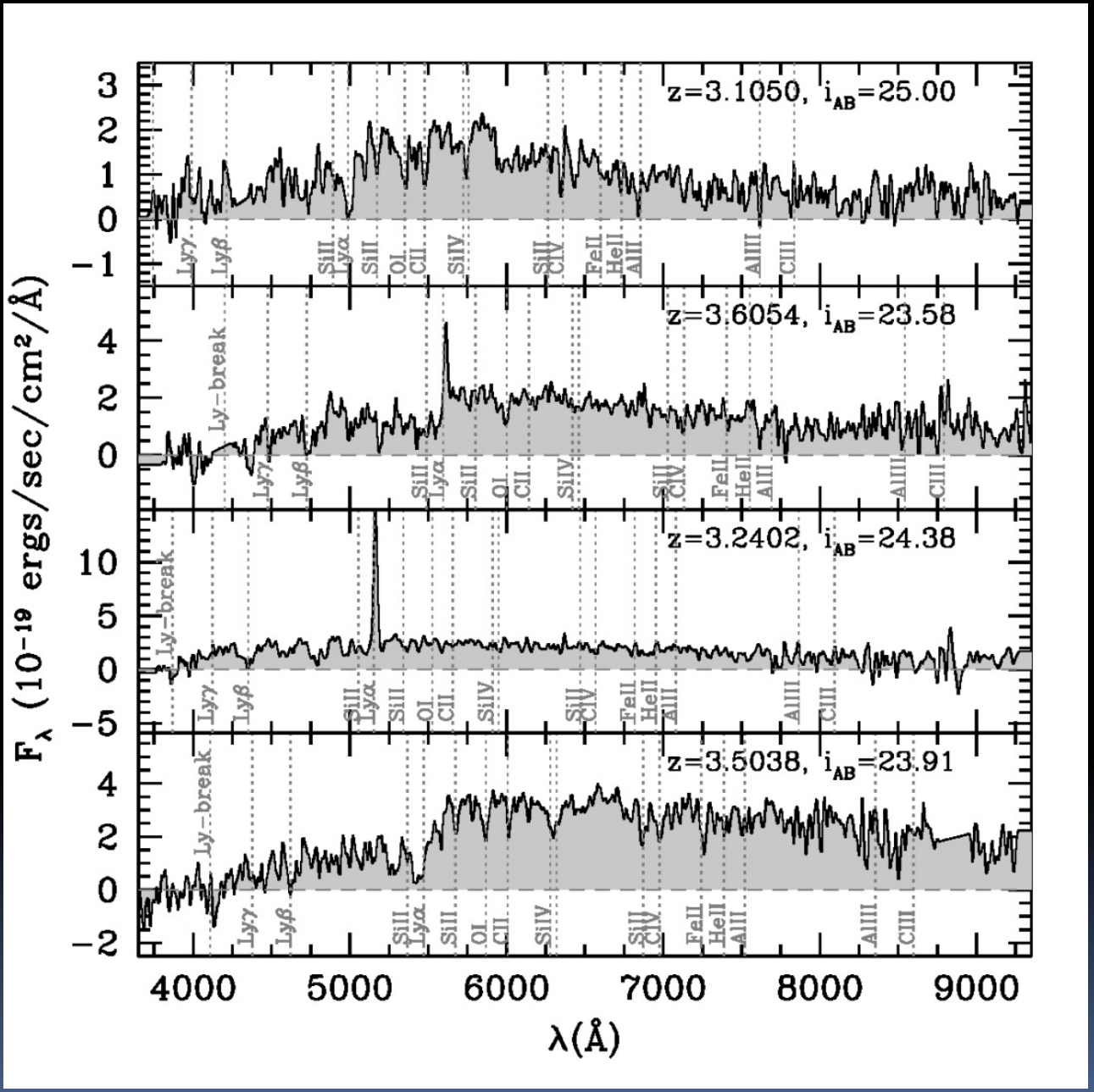

z=5.019
z=4.2685
z=3.7403
z=2.9267
912
Lyβ
Lyα
OI
CII
SiIV
CIV
4000
5000
6000
7000
8000
9000
λ(Å)


z=5.4022
z=5.1770
z=4.4618
z=4.2803
z=2.9280
z=2.6320
912
Lyβ
Lyα
OI
CII
SiIV
CIV
4000
6000
8000
λ(Å)

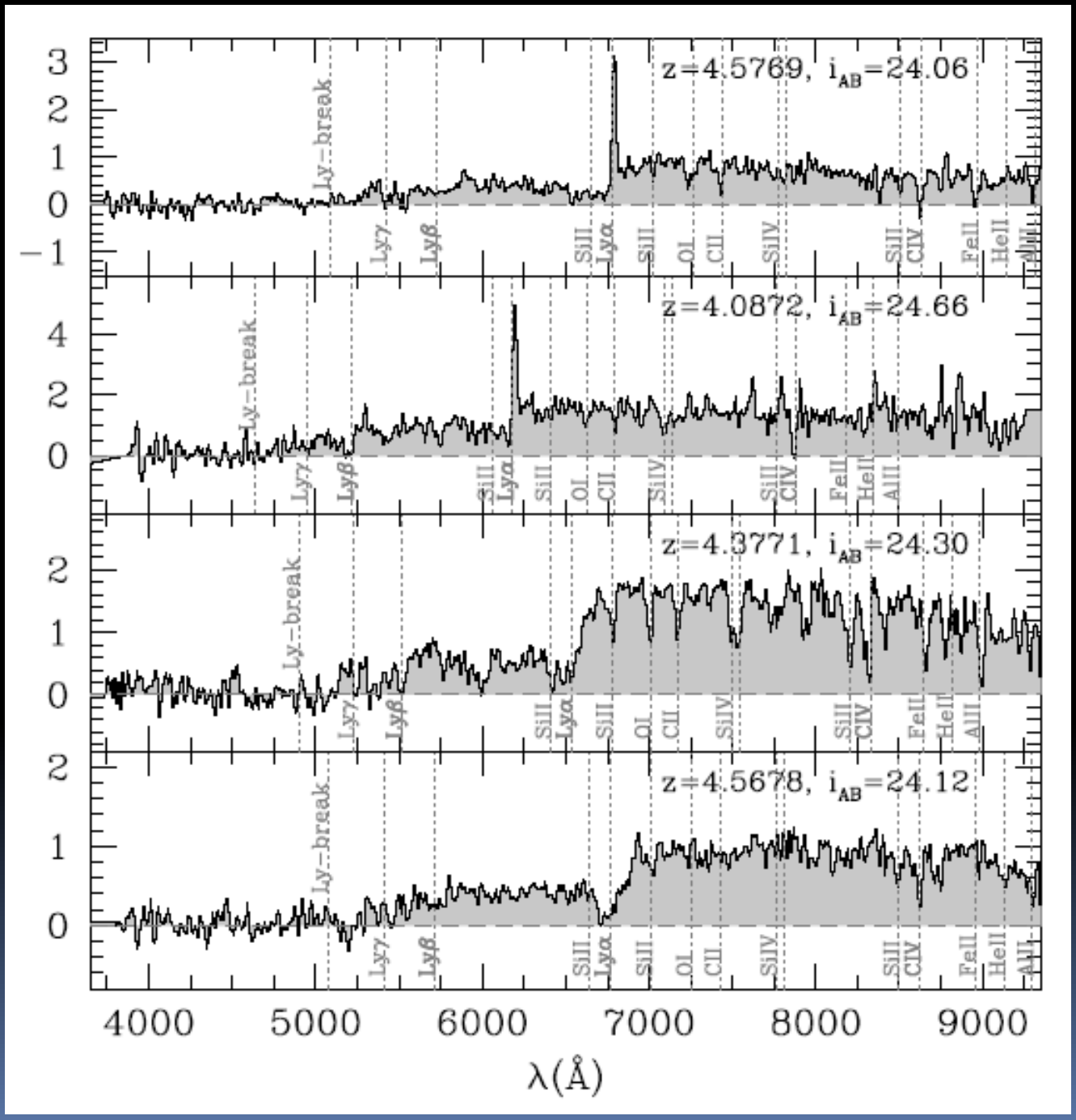
2<z<3


z=2.9469, i_AB=24.41
z=2.4678, i_AB=23.58
z=2.5424, i_AB=24.38
z=2.6488, i_AB=23.62
F_λ (10^-19 ergs/sec/cm²/Å)
λ(Å)
4000
5000
6000
7000
8000
9000
Lyβ
SiII
Lyα
SiII
OI
CII
SiIV
CIV
FeII
HeII
AlII
AlIII
CIII
FeII

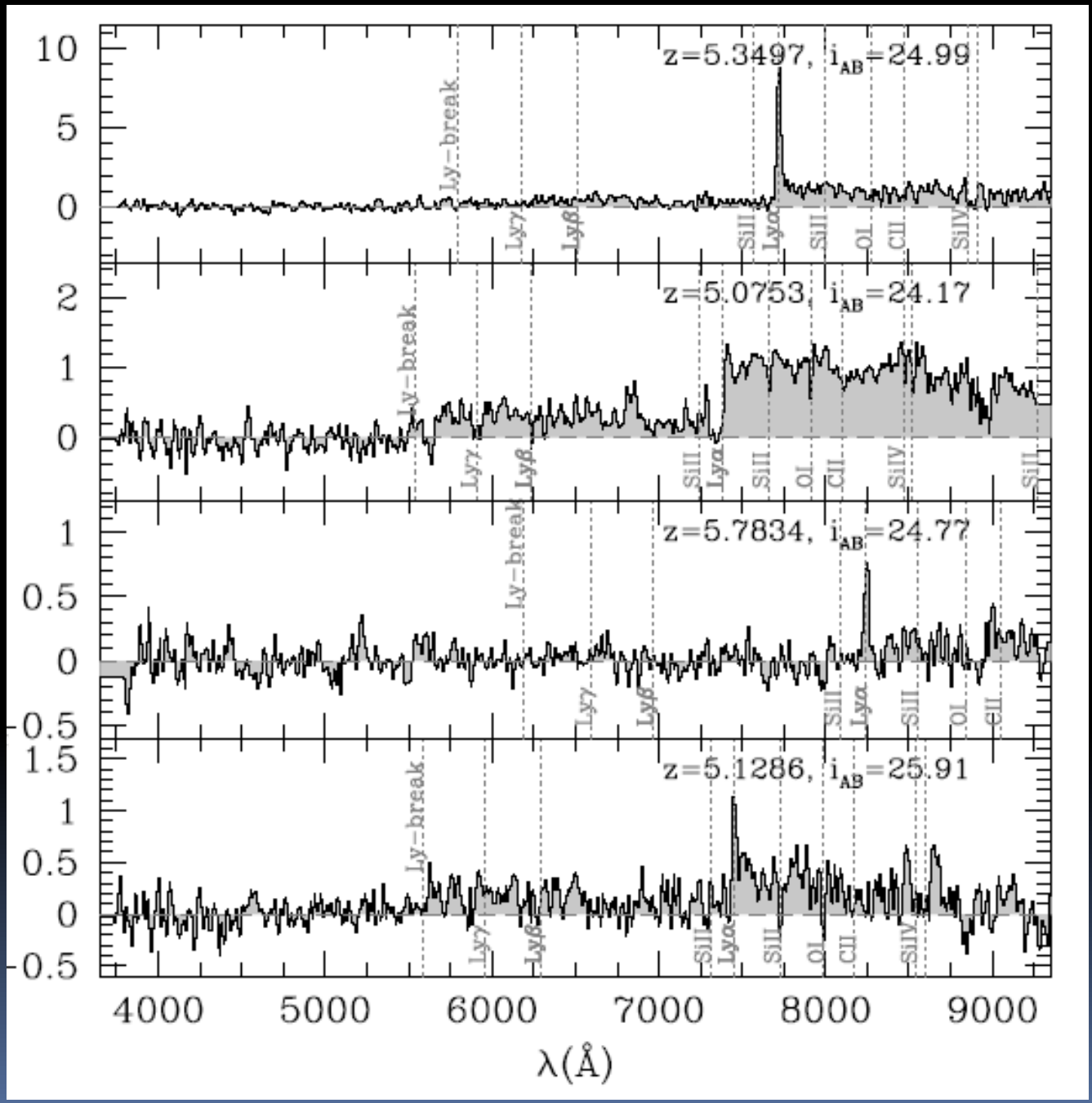
3<z<4


z=3.1050, i_AB=25.00
z=3.6054, i_AB=23.58
z=3.2402, i_AB=24.38
z=3.5038, i_AB=23.91
Ly-break
Lyγ
Lyβ
SiII
Lyα
SiII
OI
CII
SiIV
CIV
FeII
HeII
AlII
AlIII
CIII
F_λ (10^-19 ergs/sec/cm²/Å)
λ(Å)
4000
5000
6000
7000
8000
9000

4<z<5


z=4.5769, i_AB=24.06
z=4.0872, i_AB=24.66
z=4.3771, i_AB=24.30
z=4.5678, i_AB=24.12
Ly-break
Lyγ
Lyβ
SiII
Lyα
SiII
OI
CII
SiIV
SiII
CIV
FeII
HeII
AlII
4000
5000
6000
7000
8000
9000
λ(Å)

5<z<6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z=5.0753, i_AB=24.17
z=5.7834, i_AB=24.77
z=5.1286, i_AB=25.91
Ly-break
Lyγ
Lyβ
SiII
Lyα
SiII
OI
CII
SiIV
CII
λ(Å)
4000
5000
6000
7000
8000
9000