# Spectroscopic observations of LBGs/Emitters in the GOODS-S field




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ITALY

Collaboration (INAF-OAT, ESO, ST-ECF, STScI, NOAO, INAF-AOPd, JPL, Geneva Obs., Rome Obs.):

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Paris 6 July 2009 - Lya Universe

# Basic information of the VLT/FORS2 survey (GOODS-S)

(Vanzella et al. 2005, 2006, 2008):
Available here: http://www.eso.org/science/goods/

## P.I. : C. Cesarsky

*Spectroscopy :*

- 180 hours (Oct. 2002 - Oct. 2006)
- 300I grism: ~ 6000 to 10000 Å (**R = 660**)
- 37 MXU masks: (4-8 hours each) ~ **1000 redshifts**

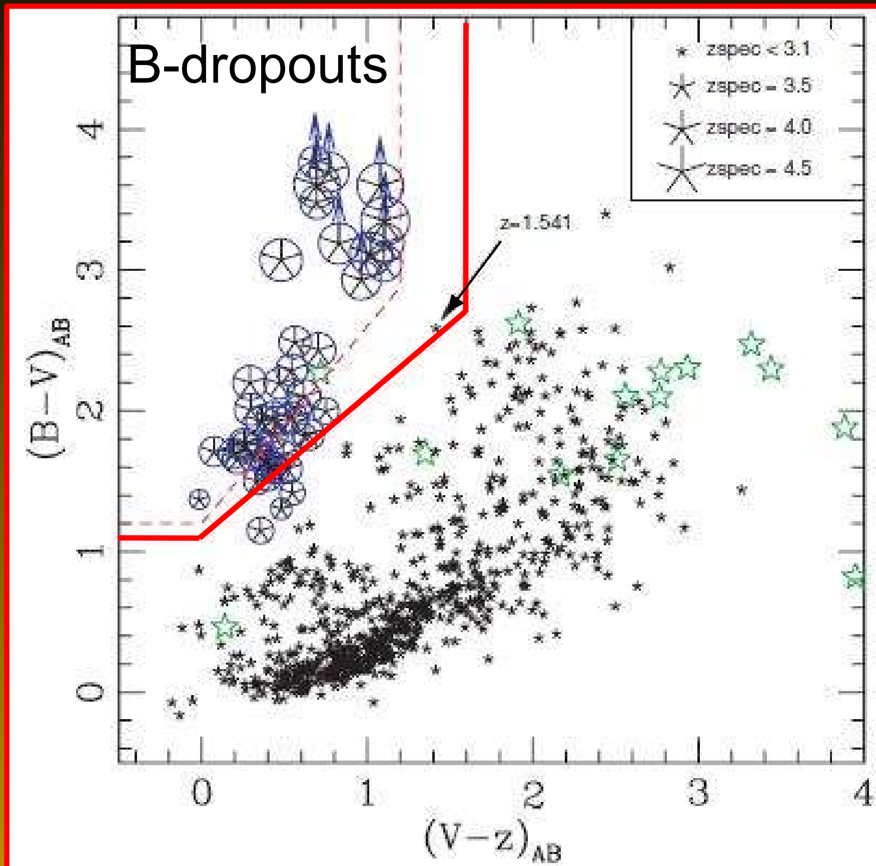
*Target selection:*

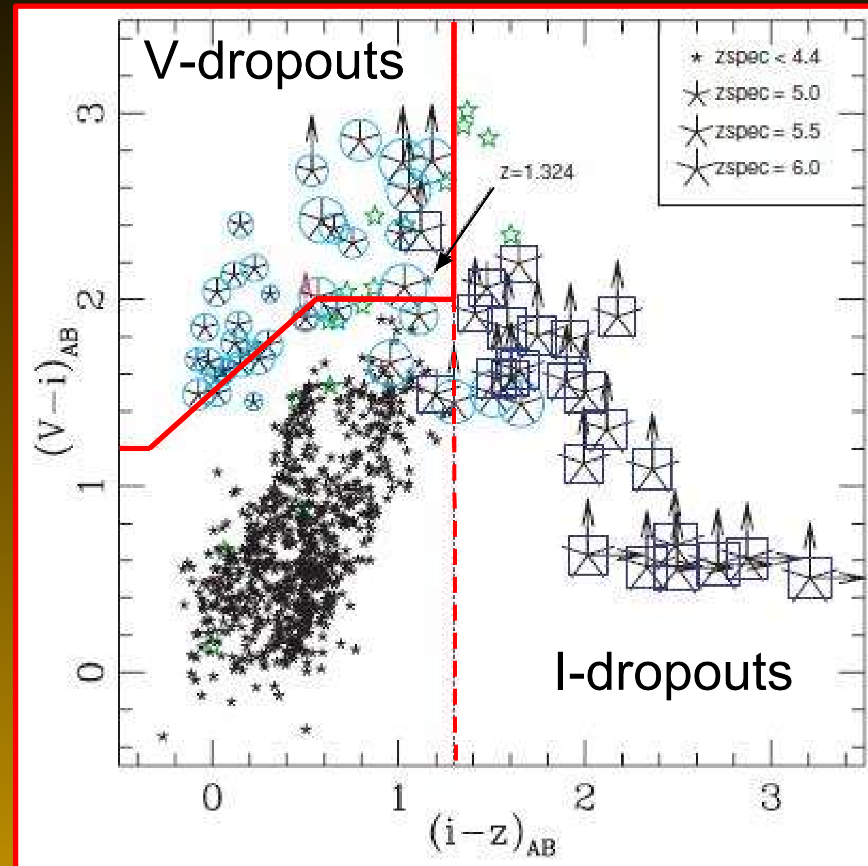
- mainly 1 < z < 2 and **3.3 < z < 6.5**
  (to exploit the high instrumental efficiency in the red, down to 10000 Å)

| Mask ID | Date | exp.time (s) |
|---|---|---|
| *RUN*1 (V05) | | |
| 990247 | Dec. 2002–Jan. 2003 | $12 \times 1200$ |
| 984829 | Dec. 2002–Jan. 2003 | $12 \times 1200$ |
| 985831 | Jan.–Feb. 2003 | $15 \times 1200 + 663$ |
| 973934 | Jan. 2003 | $12 \times 1200$ |
| 952426 | Jan. 2003 | $12 \times 1200$ |
| 981451 | Jan.–Dec. 2003 | $24 \times 1200$ |
| 995131 | Oct. 2002 | $8 \times 1800$ |
| 994852 | Oct. 2002 | $8 \times 1800$ |
| 990652 | Dec.–Nov. 2002 | $14 \times 1200 + 300 + 900$ |
| *RUN*2 (V06) | | |
| 914250 | Aug. 2003 | $17 \times 1200$ |
| 905513 | Sept. 2003 | $18 \times 1200$ |
| 943018 | Sept. 2003 | $12 \times 1200$ |
| 924345 | Sept. 2003 | $12 \times 1200$ |
| 945143 | Sept.–Oct. 2003 | $12 \times 1200 + 3 \times 1000$ |
| 992438 | Oct.–Dec. 2003 | $12 \times 1200$ |
| 985931 | Nov. 2003 | $12 \times 1200 + 2 \times 120$ |
| 990204 | Dec. 2003 | $12 \times 1200$ |
| 904509 | Dec. 2003 | $12 \times 1200$ |
| 991435 | Dec. 2003 | $12 \times 1200$ |
| 935030 | Dec. 2003 | $12 \times 1200$ |
| 951937 | Dec. 2003 | $12 \times 1200 + 1100 + 500$ |
| 960930 | Dec. 2003 | $12 \times 1200$ |
| 961839 | Jan. 2004 | $12 \times 1200$ |
| 932802 | Jan. 2004 | $12 \times 1200$ |
| 993304 | Jan. 2004 | $12 \times 1200$ |
| 951526 | Feb. 2004 | $3 \times 1200$ |
| *RUN*3 | | |
| 912940 | Dec. 2004 | $18 \times 1200$ |
| 925109 | Dec. 2004 | $16 \times 1200$ |
| 932249 | Dec. 2004 | $18 \times 1200$ |
| 940129 | Dec. 2004 | $17 \times 1200$ |
| 943544 | Dec. 2004 | $15 \times 1200$ |
| 965910 | Dec. 2004 | $18 \times 1200$ |
| *RUN*4 | | |
| 952801 | Nov.–Dec. 2005 | $15 \times 900 + 4 \times 870$ |
| 952942 | Oct.–Nov. 2005 | $15 \times 900 + 2 \times 870$ |
| 953015 | Nov. 2005 | $18 \times 900 + 2 \times 870$ |
| 953048 | Dec. 2005–Jan. 2006 | $33 \times 900 + 2 \times 870$ |
| 953132 | Feb.–Aug. 2006 | $17 \times 900 + 4 \times 870 + 370$ |
| 953159 | Jul.–Oct. 2006 | $18 \times 900 + 2 \times 870 + 436$ |

# Color selection of galaxies at redshift 4, 5 and 6

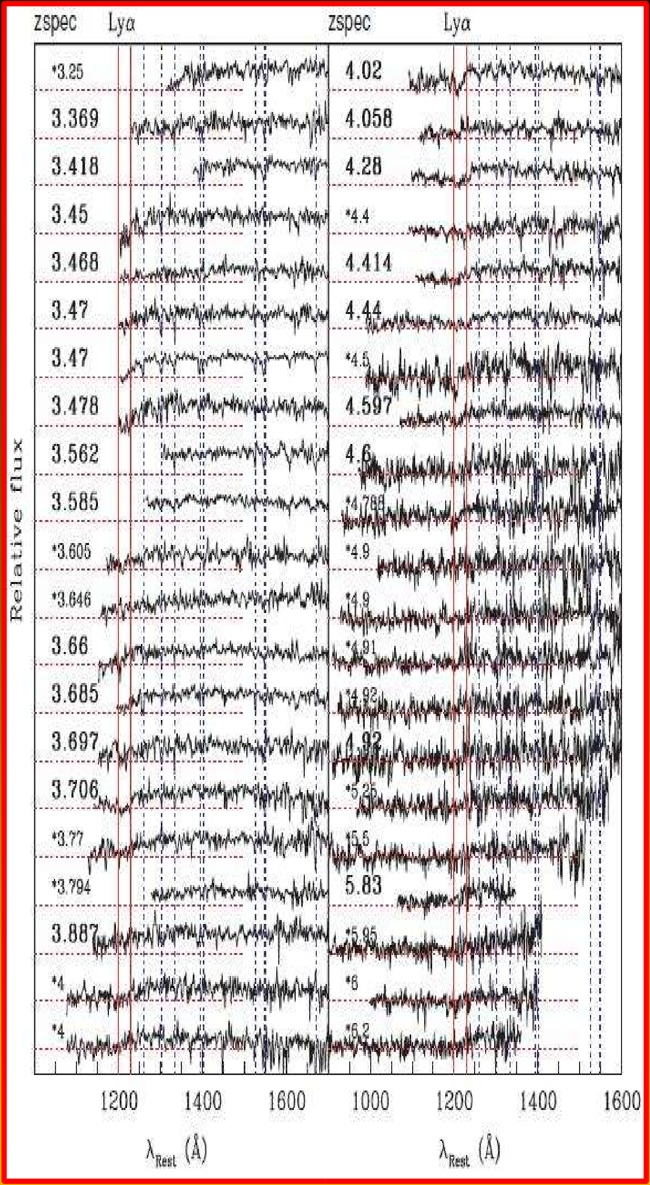
(Giavalisco et al. 2004, Dickinson et al. 2004, Vanzella et al. 2009, **V09**):

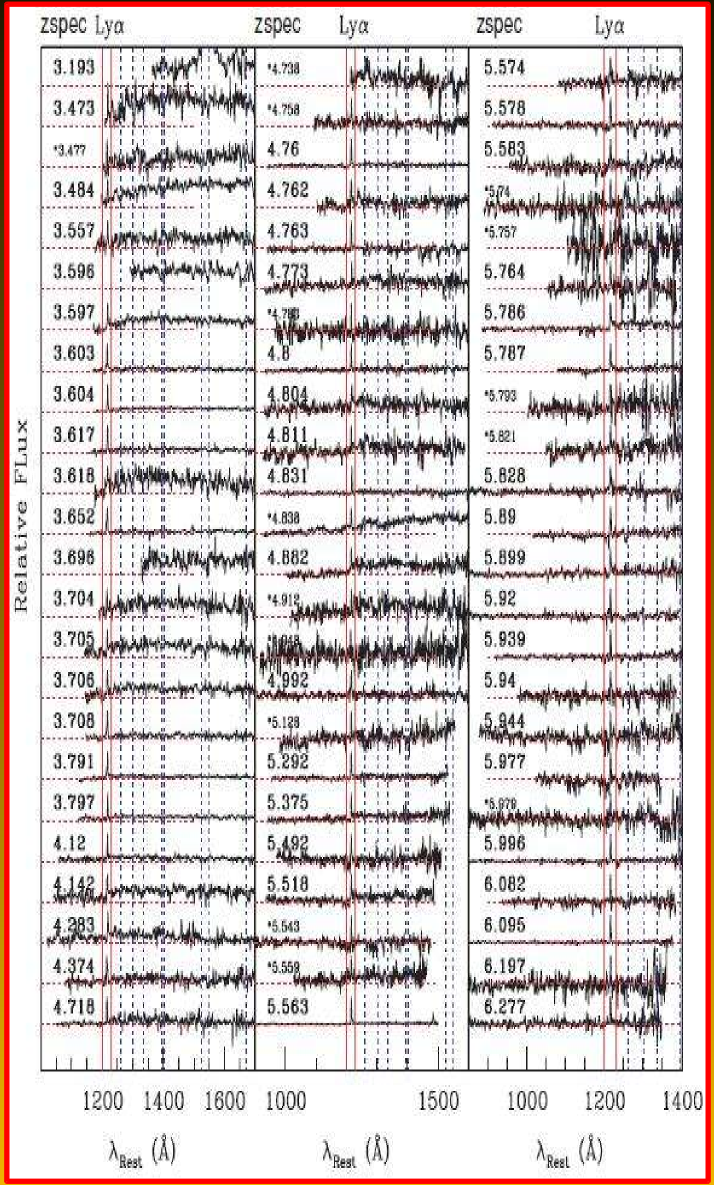


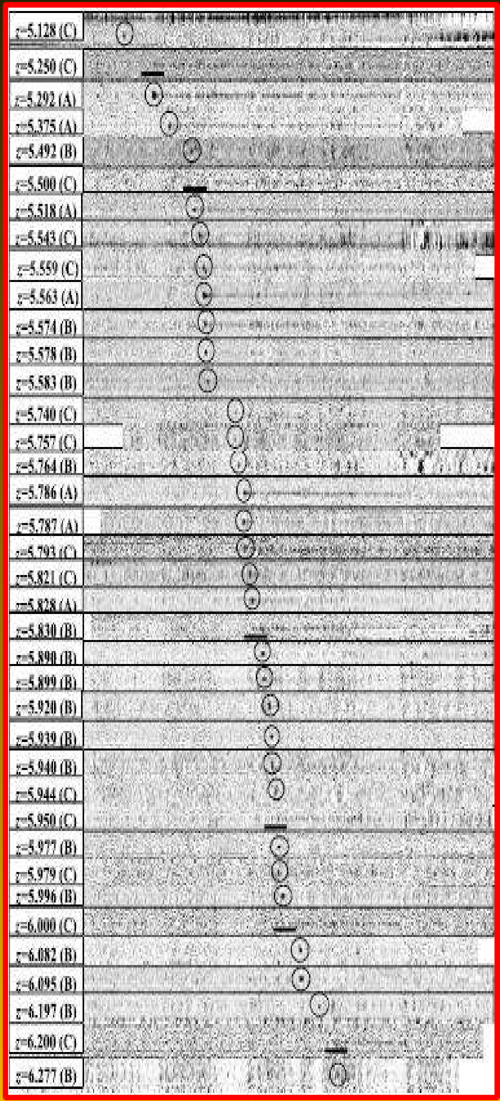

- 109 out of 202 selected targets have measured redshift (54% 65 $z_{850}>26$ - $z<3.6$ critical).
- **96%** , 89% and 82% of B,V and I-drops have redshift in the expected range.
- 12 low-z interlopers: 10 stars and two z<2 gal.
- 5 high-z serend. discovered.

# Panoramic view of all spectra with and without Lyα in emission (V09)

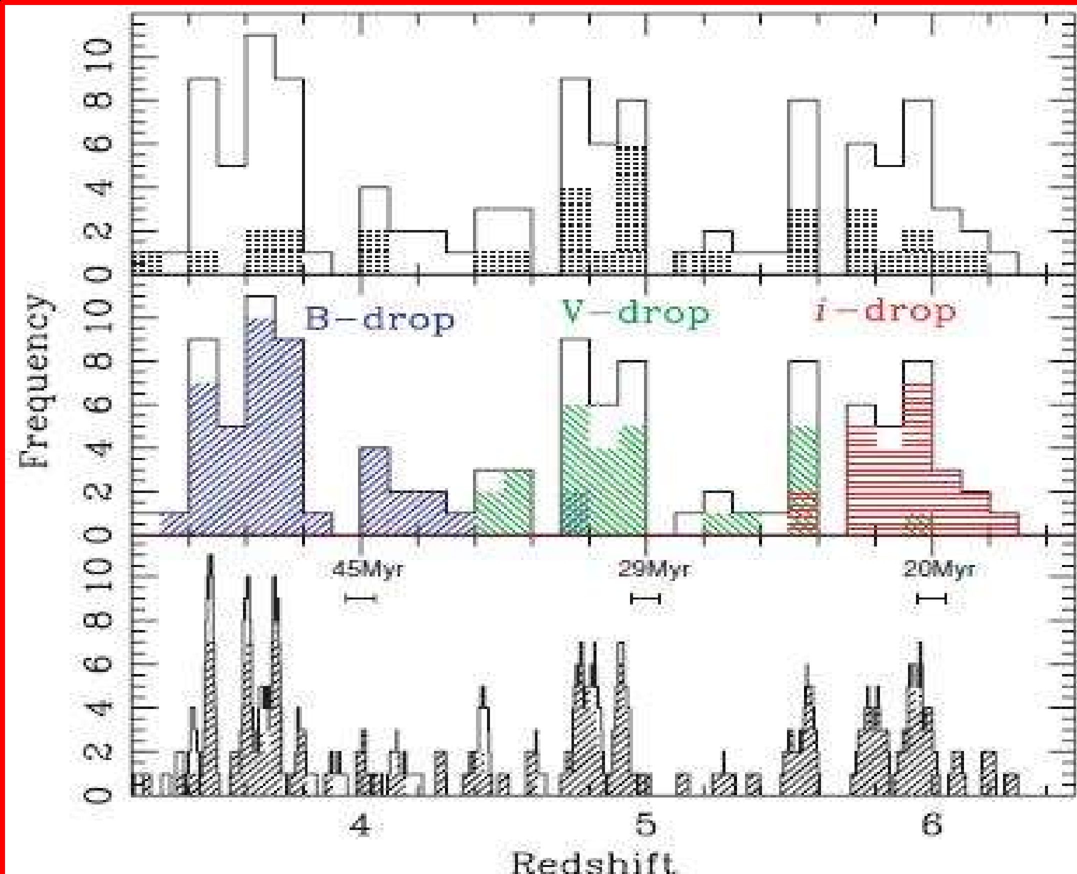



38 @ z>5



# Redshift distribution 3.3<z<6.5 (V09):




Fraction of Confirmed Dropout Candidates, "Nobs." Indicates the Number of Candidates Observed

| Classes | Nobs. | High-z $N^{(em,abs,comp)}_{(A,B,C)}$ | Low-z $N^{(em,abs,comp)}_{(A,B,C)}$ | Measured[a] $\langle z\rangle\pm\sigma$ | Expected[a,b] $\langle z\rangle\pm\sigma$ | Compl.[a] $z_{AB}<26.5$ |
|---|---|---|---|---|---|---|
| $B_{435}$-drop | 85 | $46^{(15,21,10)}_{(27,11,8)}$ | $2^{(1,1,0)}_{(0,2,0)}$ | $3.76\pm0.33$ | $3.78\pm0.34$ | 5% |
| $V_{606}$-drop | 52 | $32^{(19,13,0)}_{(9,12,11)}$ | $4^{(0,4,0)}_{(2,2,0)}$ | $4.96\pm0.38$ | $4.92\pm0.33$ | 14% |
| $i_{775}$-drop | 65 | $28^{(24,4,0)}_{(3,13,12)}$ | $6^{(0,6,0)}_{(0,2,4)}$ | $5.90\pm0.18$ | $5.74\pm0.36$ | 29% |
| Fillers | ... | $3^{(1,2,0)}_{(1,1,1)}$ | ... | $3.4<z<5.5$ | ... | ... |
| Serend. | ... | $5^{(4,1,0)}_{(0,1,4)}$ | ... | $3.2<z<5.8$ | ... | ... |
| Sum | 202 | 114 | 12 | | | |

**Malhotra et al. 2005, z~5.9±0.2**

Bdrop:

$<z_{850}>=24.7$ +/- 0.4

Overdensity @ z=3.7, Kang & Im (2009)

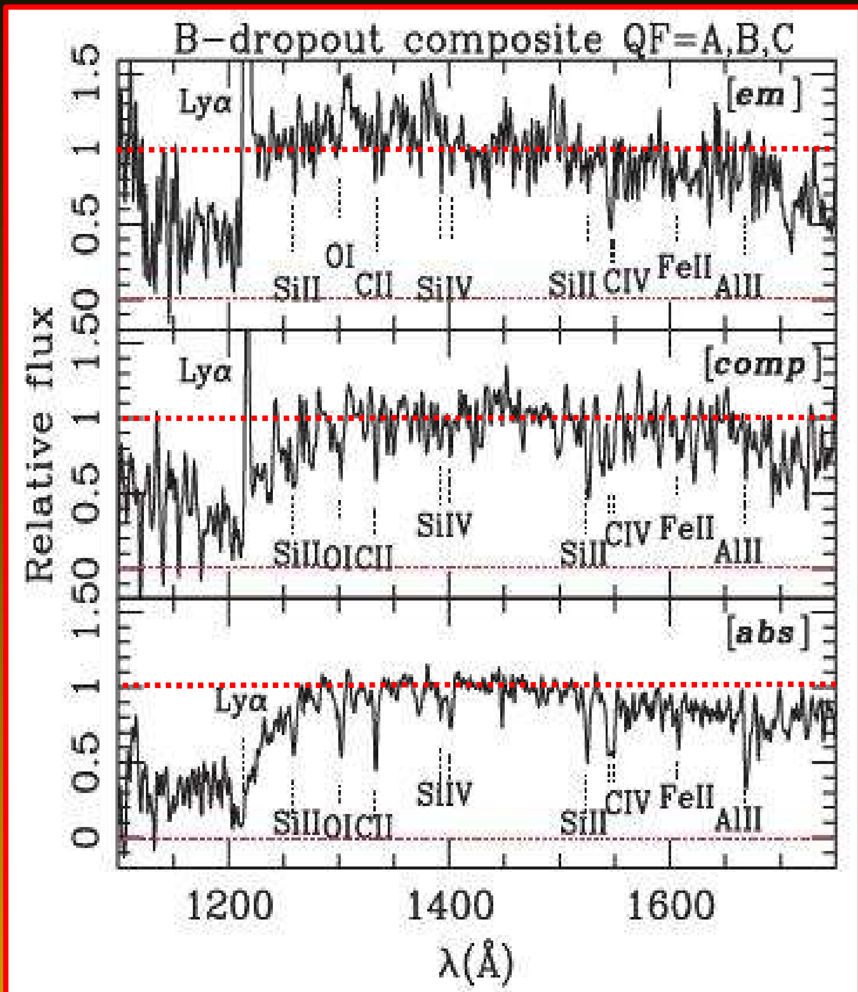
Vdrop:

$<z_{850}>=25.5$ +/- 0.5

Idrop :

$<z_{850}>=26.2$ +/- 0.6

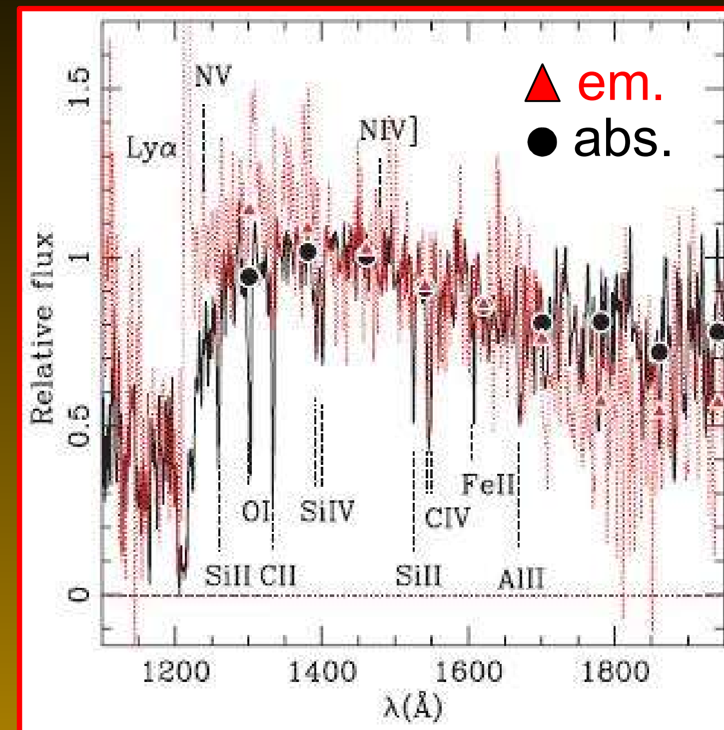
# Bdrop stacked spectra <z> = 3.76 +/- 0.33 - 54% show Lyα em.




EW(Lyα) ~ 30Å

EW(Lyα) ~10Å

No Lyα em.




| | EM. | ABS. |
|---|---|---|
| β | -2.0±0.1 | -1.7±0.1 |
| Age | 200±50 Myr | 410±70 Myr |
| E(B-V) | 0.07±0.01 | 0.10±0.02 |
| Mass (stellar) | $5\pm1 \times 10^{9}$ $M_{\odot}$ | $2.3\pm0.8 \times 10^{10}$ $M_{\odot}$ |

Pentericci (2007)

Interstellar abs. lines increase at faint Lyα emission
Similar to redshift 3 LBGs, e.g. Shapley et al. '03

Vdrop stacked spectra

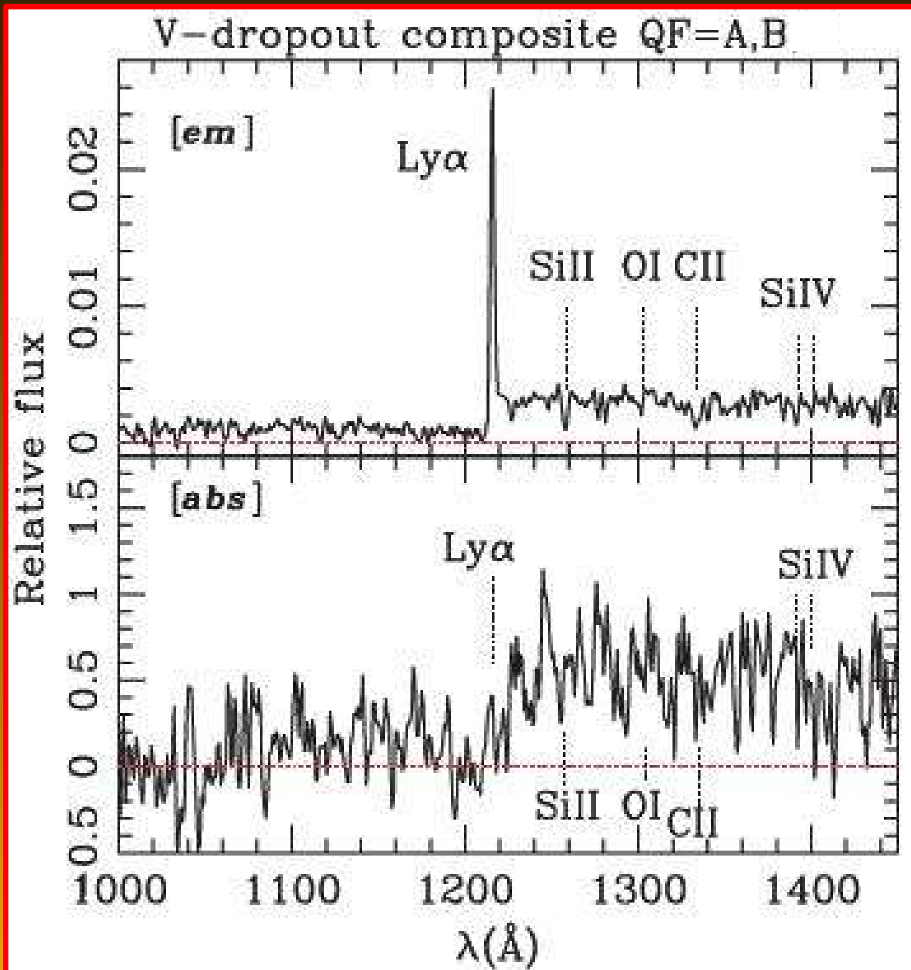
<z> = 4.96 ± 0.38

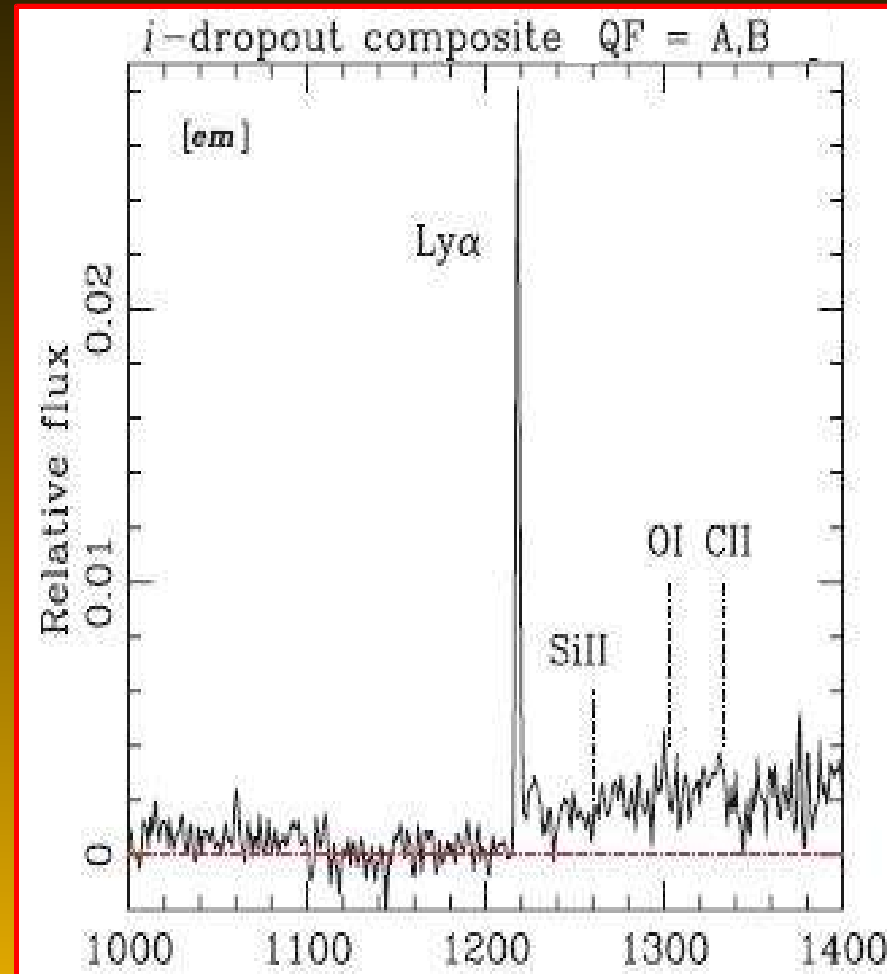
59% show Lyα em.

Idrop stacked spectrum

<z> = 5.90 ± 0.18

86% show Lyα em. (coution sel. eff.)

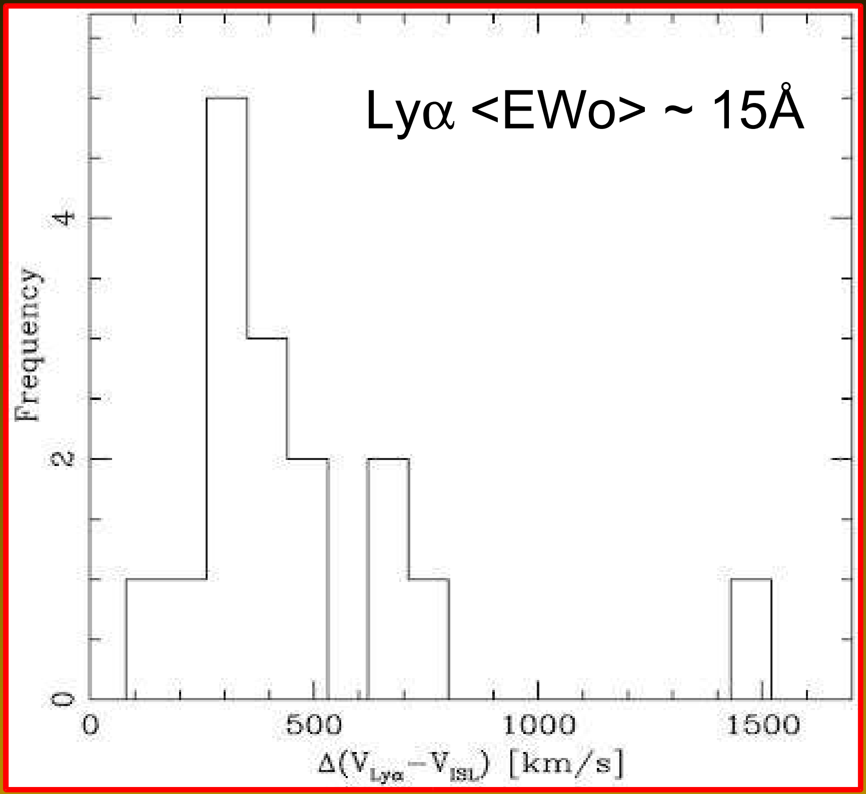



Low quality spectra (QF="C") have not been considered

# Outflows at redshift 4 and 5 (V09)

Bdropout sample (z~3.8)




$\langle V_{Ly\alpha}-V_{ISL}\rangle_{median} = \mathbf{370}^{+270}_{-116}$ km/s (16 gal.)

mean is **450±180** km/s (16 gal.), from stacked **480** km/s

Vdropout sample (z~4.9)

$\langle V_{Ly\alpha}-V_{ISL}\rangle \sim$ **450** km/s from stacked spectrum

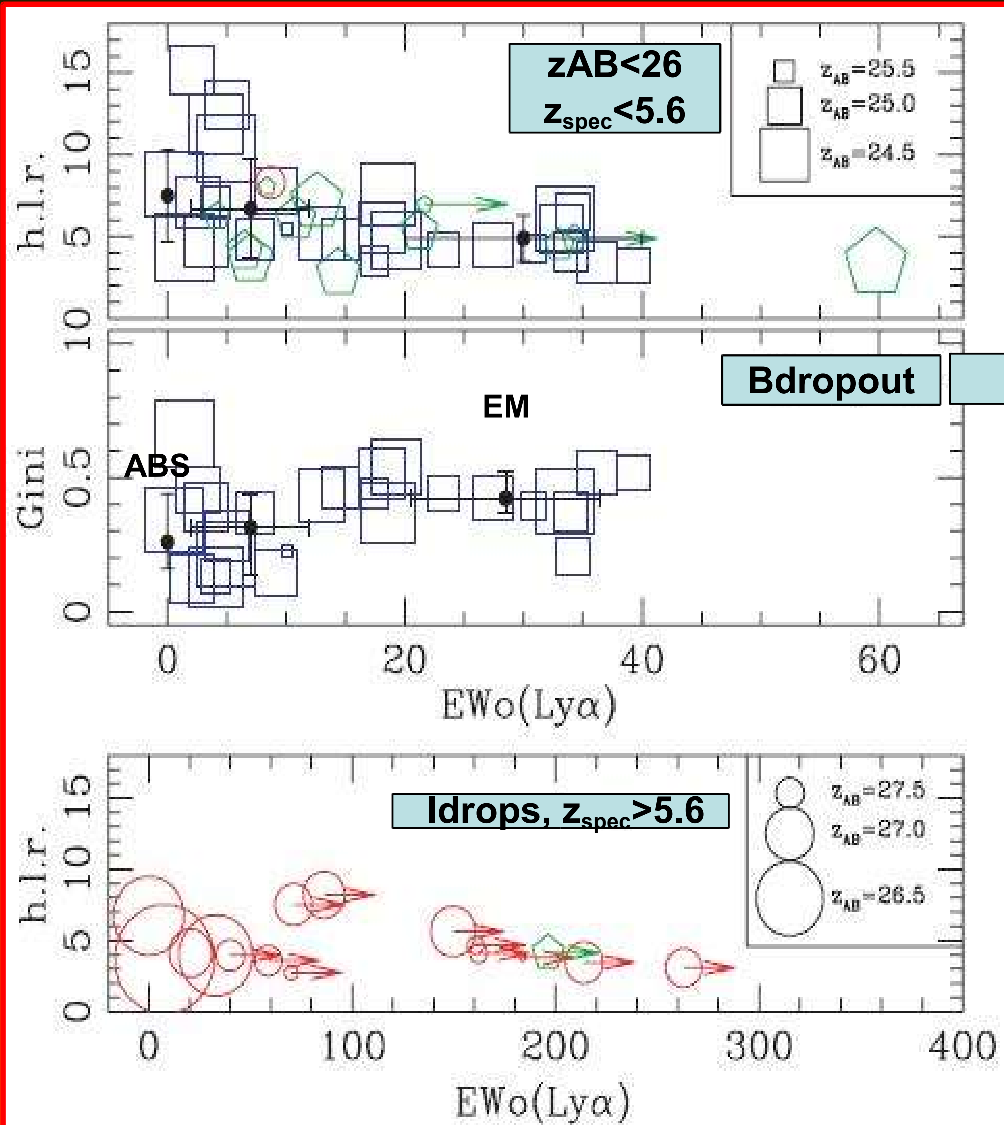
8 gal. with z>5 and continuum detected (z ~ 5.6)

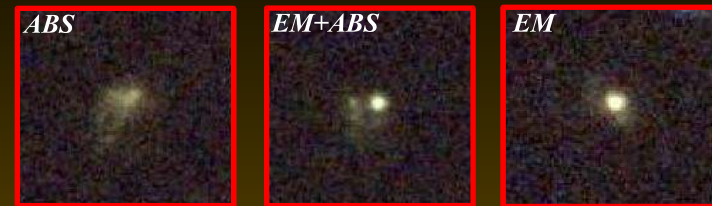
$\langle V_{Ly\alpha}-V_{ISL}\rangle \sim$ **500** km/s from stacked spectrum (6 Vdrops and 2 Idrops)

$\langle V_{ISL} - V_{neb}\rangle \sim$ **-165** +/- 170 km/s (10 gal.) (comparable to Adelberger et al. 04)

[OII], [OIII] lines from AMAZE Maiolino et al. (2008)

# Ultraviolet morphology ($z_{850}$ band) (V09)




## Bdropout sample (z~3.8)

| | | EM. ($\langle z \rangle = 3.757$) | | ABS. ($\langle z \rangle = 3.735$) |
|---|---|---|---|---|
| $a$ | | $4.54 \pm 1.03$ | | $6.51 \pm 2.18$ |
| h.l.r. | **(1.1 kpc)** | $5.38 \pm 1.65$ | **(1.6 kpc)** | $7.49 \pm 2.85$ |
| Area | | $305 \pm 117$ | | $438 \pm 172$ |
| FWHM | | $10.38 \pm 4.06$ | | $20.01 \pm 11.97$ |
| Gini | | $0.41^{+0.11}_{-0.06}$ | | $0.26^{+0.18}_{-0.10}$ |

Similarly to lower-z gal. (z~2-3)

Law et al. (2007)

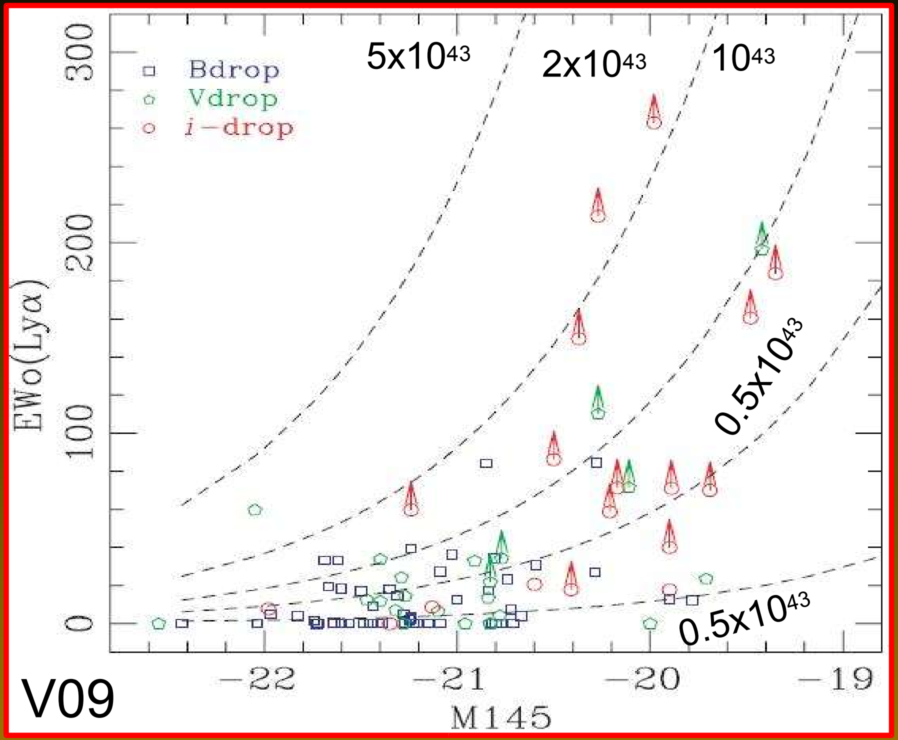
z~5.95

$\langle h.l.r.\rangle_{med} = \mathbf{0.12}^{+0.05}_{-0.02}$ arcsec (**0.7** kpc)

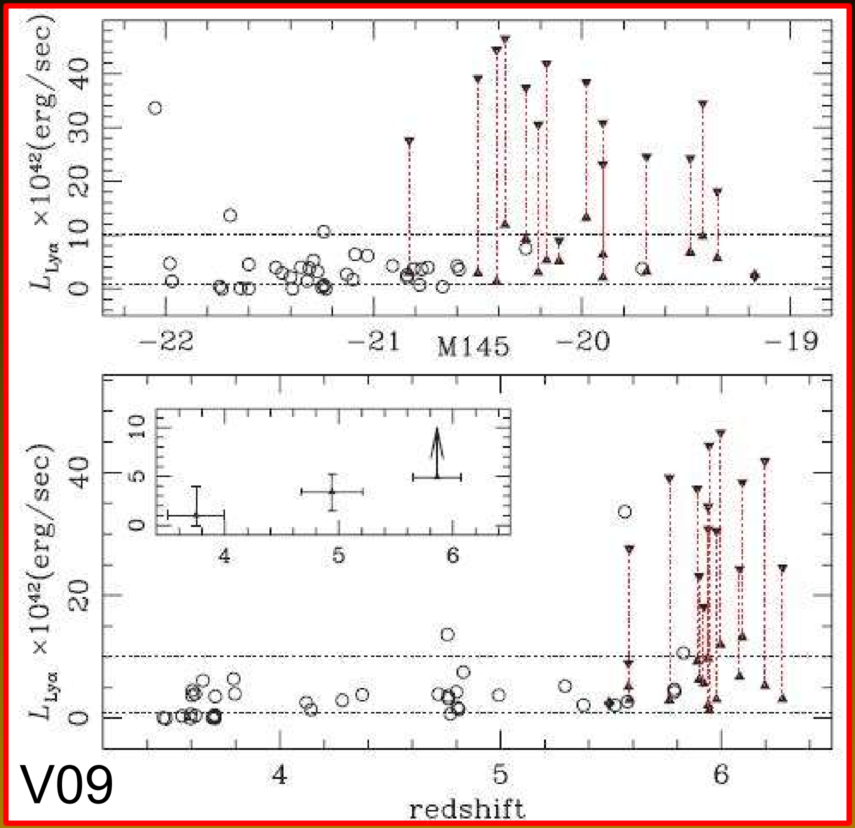
$\langle h.l.r.\rangle_{stars} = 0.08^{+0.04}_{-0.04}$ arcsec

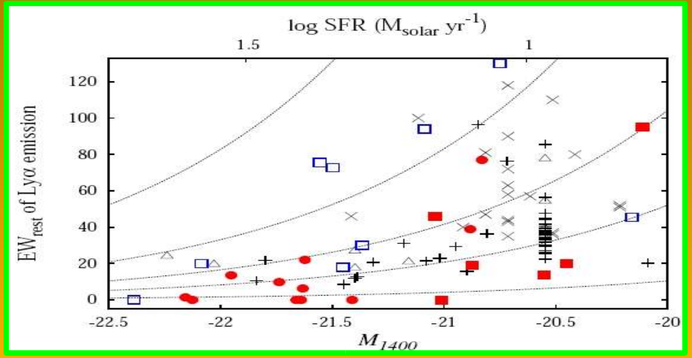
Similar to LAEs (e.g **Taniguchi et al. 2009, Dow-Hygelund et al. 07**)

# Deficiency of large Lyα EW em. in UV luminous sources (V09)




More luminous, more massive
(e.g. Stark et al. 09, Pentericci et al. 09)




Increasing Lyα luminosity with redshift ?
(e.g. Dow-Hygelund '07, Frye '02,
but caution to the selection effects…)

Ando et al. 06, 07

# Conclusions

## ● B drops (z~4).

- Spec. features: "em." have weaker interstellar abs lines than "abs", different $\beta$ (similar to z~3, e.g. *Shapley et al. 2003, Law et al. 2007*).
- UV Morph: apparent correlation between Lyα EW and size (h.l.r./nucleation), more nucleated than abs (Gini) (similar to z~2,3 *Law et al. '07*). Dust effect ?
- Outflows: velocity offset is detected in individual spectra, $<V_{Lya}-V_{ISL}>_{median} = \mathbf{370}^{+270}_{-116}$ km/s Lya, ISL, nebular emission (comparable to lower-z gal, *Shapley 03, Adelberger 04*).

## ● V drops (z~5).

- Outflows: outflow estimation from composite spectrum $<V_{Lya}-V_{ISL}>$ ~ 450 km/s, and 500 km/s at z~5.6.
- UV Morph: Also in this case it appears to be a correlation between h.l.r. and Lyα EW.

## ● I drops (z~6).

- Sel. effect: Large spread in Lyα EWs => selection effects: spec. & phot → broad band single color selection tend to identify emitters at fainter limits ($z_{AB}$>26).
- UV morph: $<R_{h.l.r.}>$ ~ 0.7 kpc , comparable with LAEs @ z~5.7 (e.g. *Taniguchi et al. 09*).

~1.6Gyr

Age of the Universe

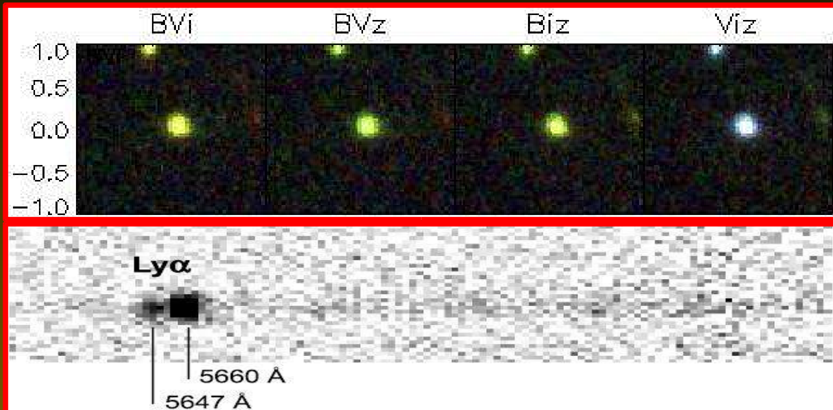
~0.9Gyr

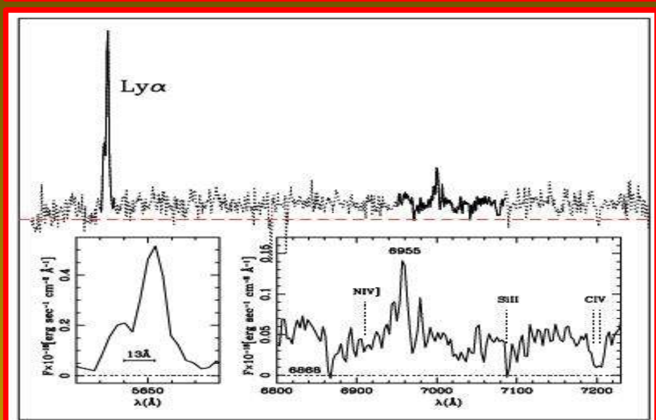
## In general (from 4 to 6):

- **Deficiency of large Lyα EW at bright UV magnitudes** (***Shapley 03, Ando 06,07, Tapken 07***).
  **Increasing** Lyα luminosity with redshift (?) (noted also by Frye et al. 2002).
- Emitters appear to be younger, less massive and less extincted than "absorbers" (agree with simul. and Lyα modelling, e.g. Mori & Umenura 2006, Dayal et al. 2009, Tilvi et al. '09, Verhamme et al. 2008), even though there are cases of "evolved" emitters (Pentericci '09).
- Emitters appear more nucleated. Several cases show multiple cores, signature of ongoing merger ?

# Individual note (I): double Lyα profile at redshift ~ 3.7

GDS J033217.22-274754.4 z=3.65

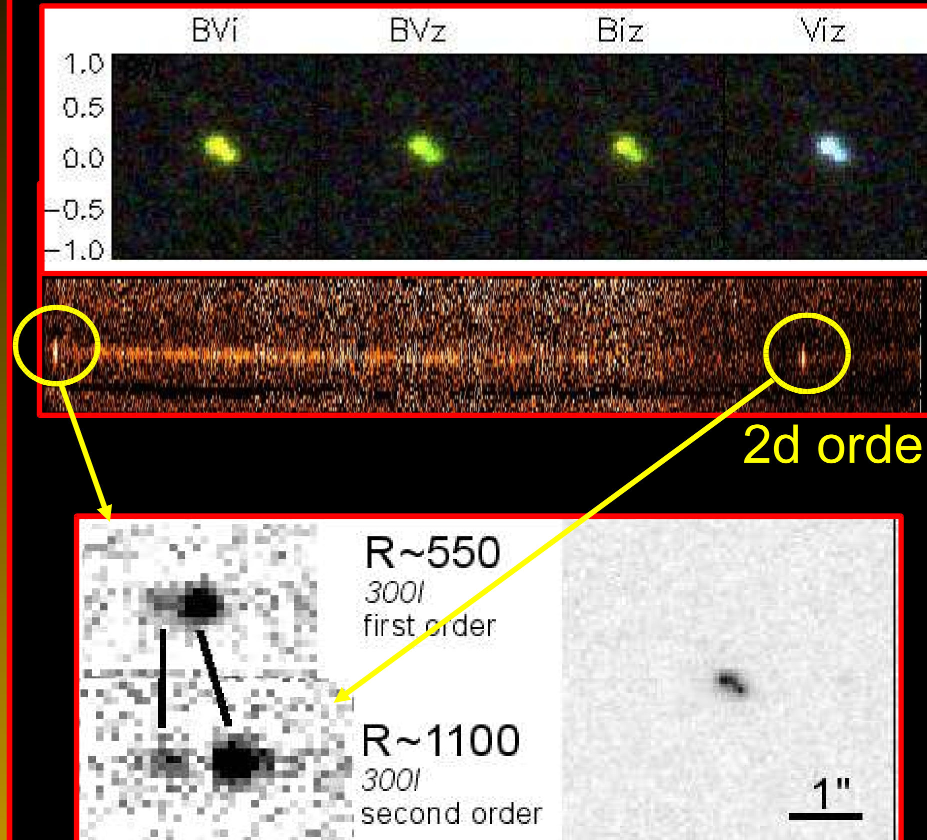



| Line | λ(Å) | Redshift |
|---|---|---|
| | emission | |
| Lyα(1215.8) (blue) | 5647 | 3.645 |
| Lyα(1215.8) (red) | 5660 | 3.655 |
| ?? | 6955 | |
| | absorption | |
| ?? | 6868 | |
| SiII(1526.7) | 7089 | 3.643 |
| CIV(1548.2-1550.8) | 7200 | 3.647 |

Vanzella et al. 2008

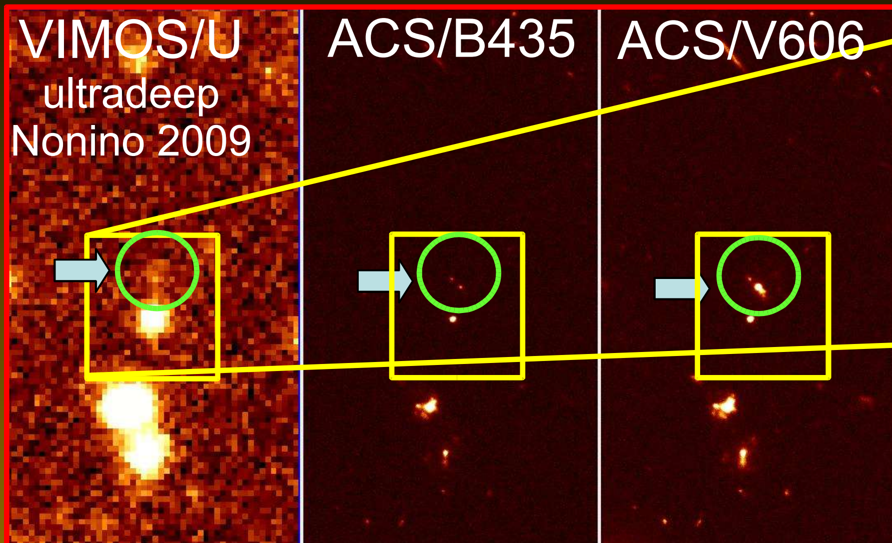
GDS J033233.33-275007.4 z=3.80

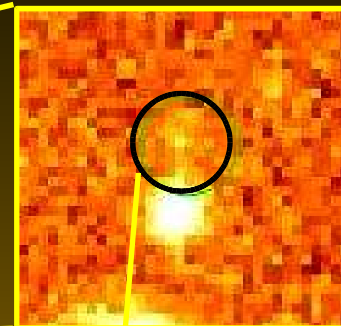



dv ~ 650 km/s - **Lyα from each blob (merger)** ?

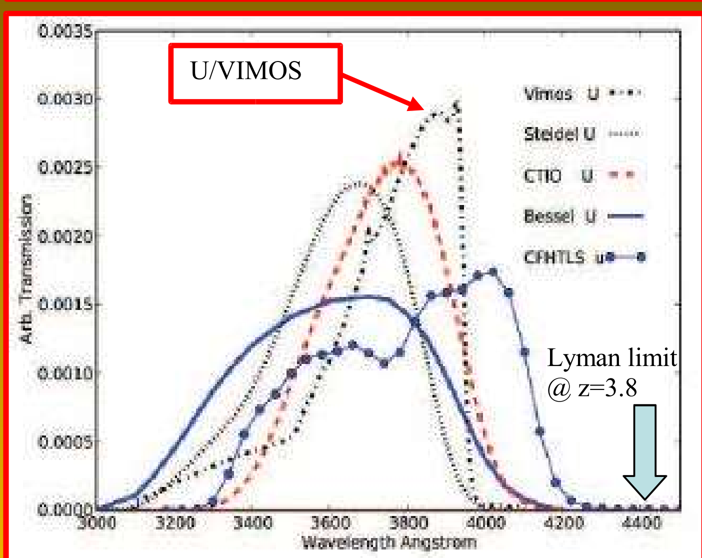
# Individual note (II) : Lyman continuum emission at z ~ 3.8

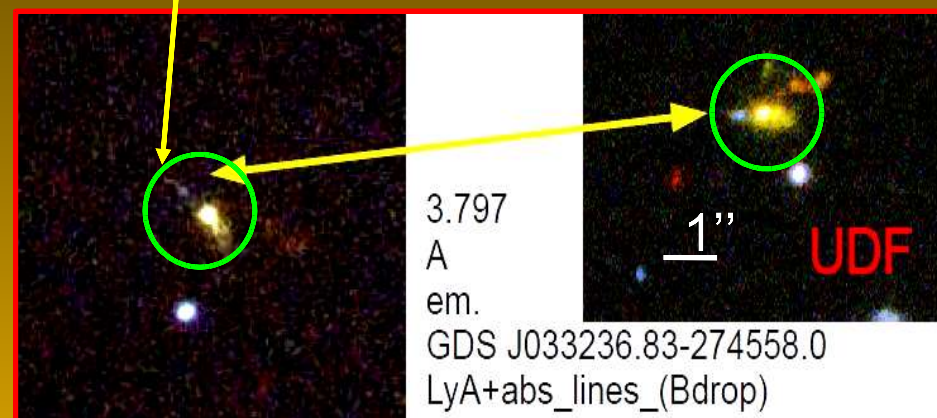
GDS J033236.83-274558.0 (z = 3.797, quality A), probing $\lambda$<900 A



Mag U(AB)=**28.63** +/-0.2
clear detection …

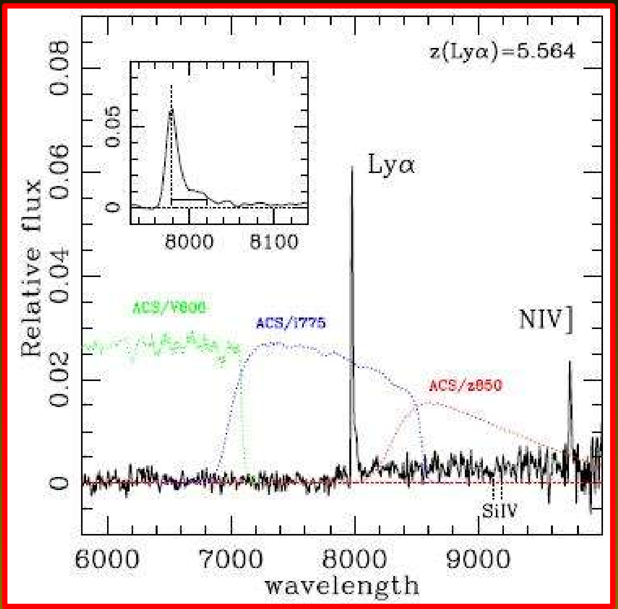


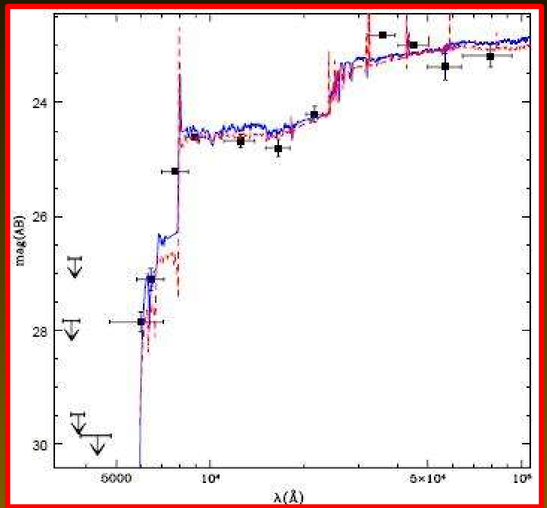




***… but, contamination by a foreground blue compact galaxy ?***

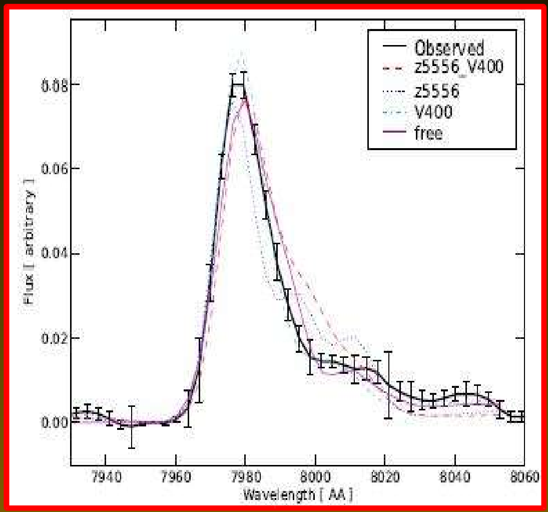
# Individual note (III) : Peculiar source @ z=5.56:

(Vanzella et al. in prep., see Raiter and Fosburycontributions)

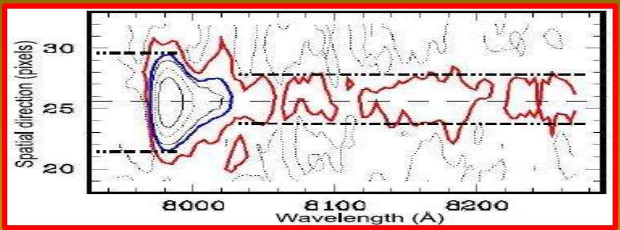


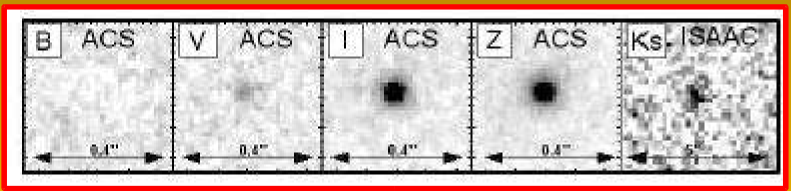




SED fitting (Vanzella 2009b)




Lyα fitting (MCLyα, Verhamme 06)




From SED and Lyα fitting:

- Column density is high (**NH≥10²¹**)
- Outflow velocity from Lyα model and measured are consistent: **460** km/s
- Stellar mass (**M*~5x10¹⁰M☼**) young and evolved stellar populations (0.01 Gyr, 0.4 Gyr).
- **E(B-V) ≤ 0.1** (small).

See also Wiklind 2008, (ID 5197) and Stark et al. (2007), (ID 32_8020)