Lyman Alpha Emitters, Absorbers, and Typical Galaxies at High Redshift

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based on longslit spectrum: 92 hours w. ESO VLT FORS2

(and now also Keck LRIS data !) w. Sargent and Becker

MPIA Oct. 08

Motivation:

Two observational frontiers in the high redshift universe:
Redshift limits and intrinsic flux limits.

The higher the redshift, the less likely we are to see typically galaxies

→

Much of cosmic structure at high redshift has not been detected in emission.

Motivation:

QSO absorption studies demonstrate the existence of
dark baryonic structures, e.g.,
the intergalactic medium, or
damped Lyalpha systems

Hierarchical structure formation requires their existence:

Intergalactic medium ⟷ most baryons
Damped Lyalpha systems ⟷ most galaxies (?)

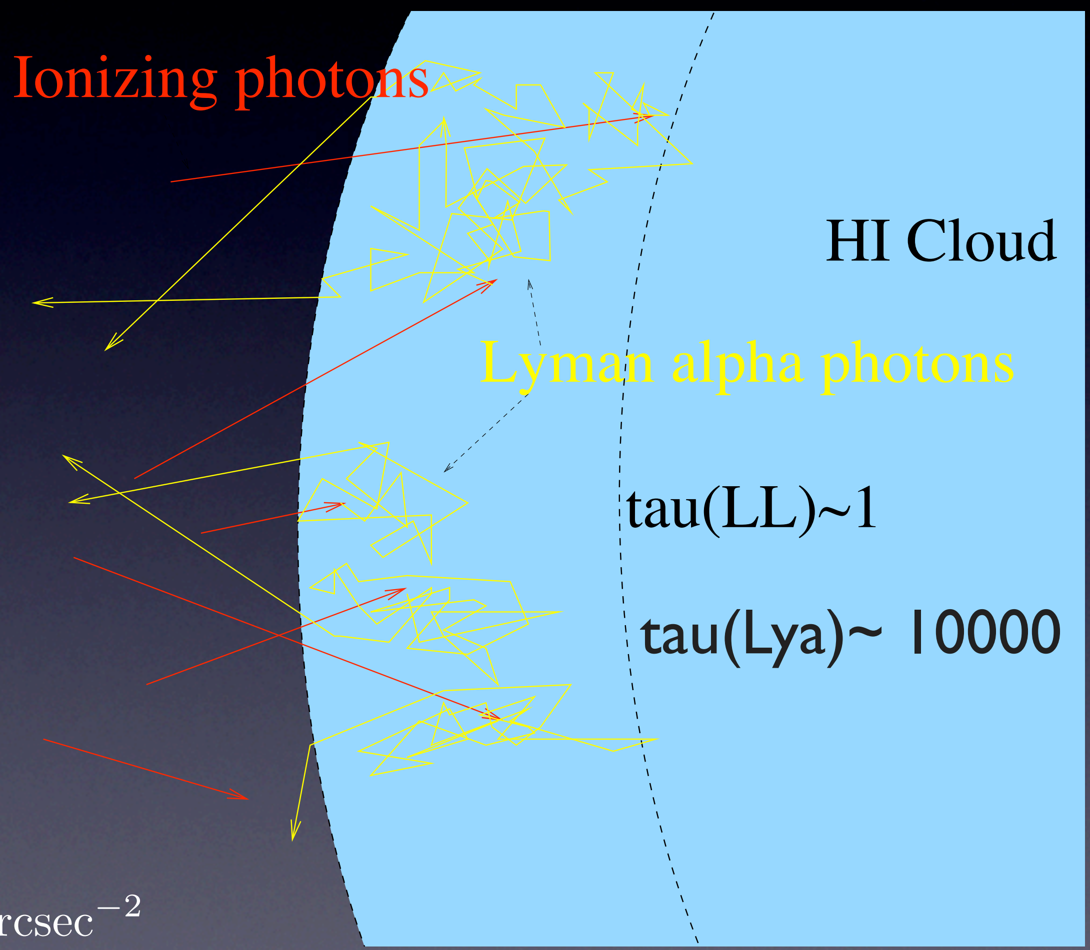
Can we hope to see these structures in emission ?

Map the Intergalactic Medium in Emission ?

Lyman alpha fluorescence induced by the ionizing background

"Image" cosmic web in Lya glow:

2-d image of optically thick cosmic web !



$$\mathrm{SFB} \sim 5 \times 10^{-20} \mathrm{erg\ s^{-1} cm^{-2} arcsec^{-2}}$$

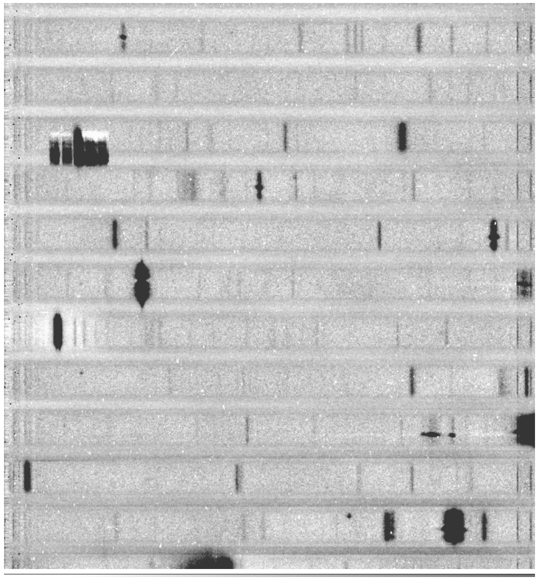
Hogan & Weymann 1987

Search for very low level light emission at high redshift

expect a uniform glow of line emission from all Lyman limit systems, damped Lyman alpha systems; virtually no continuum present.

need to strongly suppress sky background !

--> spectroscopy or extremely narrow filter

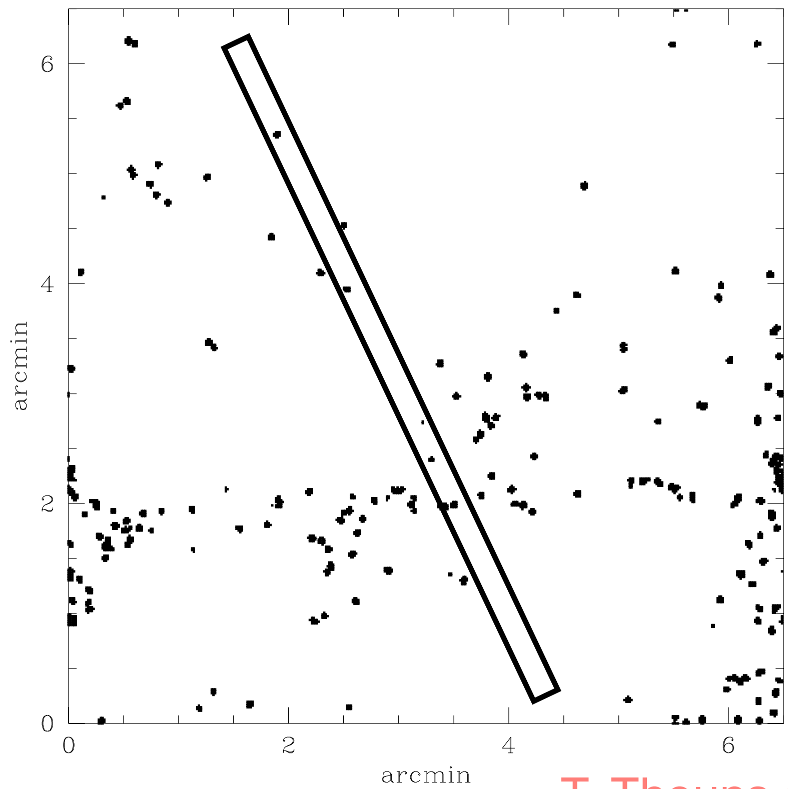


e.g., "Venetian Blind" spectroscopy : multi-longslit mask + filter + disperser

Put long slit on (judiciously chosen) blank piece of sky and expose for 100 hours !

LL emitters are much more numerous than, e.g., Lybreak galaxies

expect ~30 per unit redshift at z~3 on a typical long slit (Gould & Weinberg 1996)



T. Theuns simulation

Insert in service mode for bad seeing time.

ESO exposure resulted in 92 hours on source, median seeing 1.07", 1σ surface brightness limit $8 \times 10^{-20} \mathrm{erg\ s^{-1} cm^{-2} arcsec^{-2}}$ in $1\ \mathrm{arcsec}$ aperture. Field of z=3.2 QSO previously observed by Bunker et al.

Theoretical estimates of the signal kept falling.
Failed to reach required sensitivity...

but consolation prize:

sensitivity high enough to see dwarf galaxies in emission at redshift 3 !

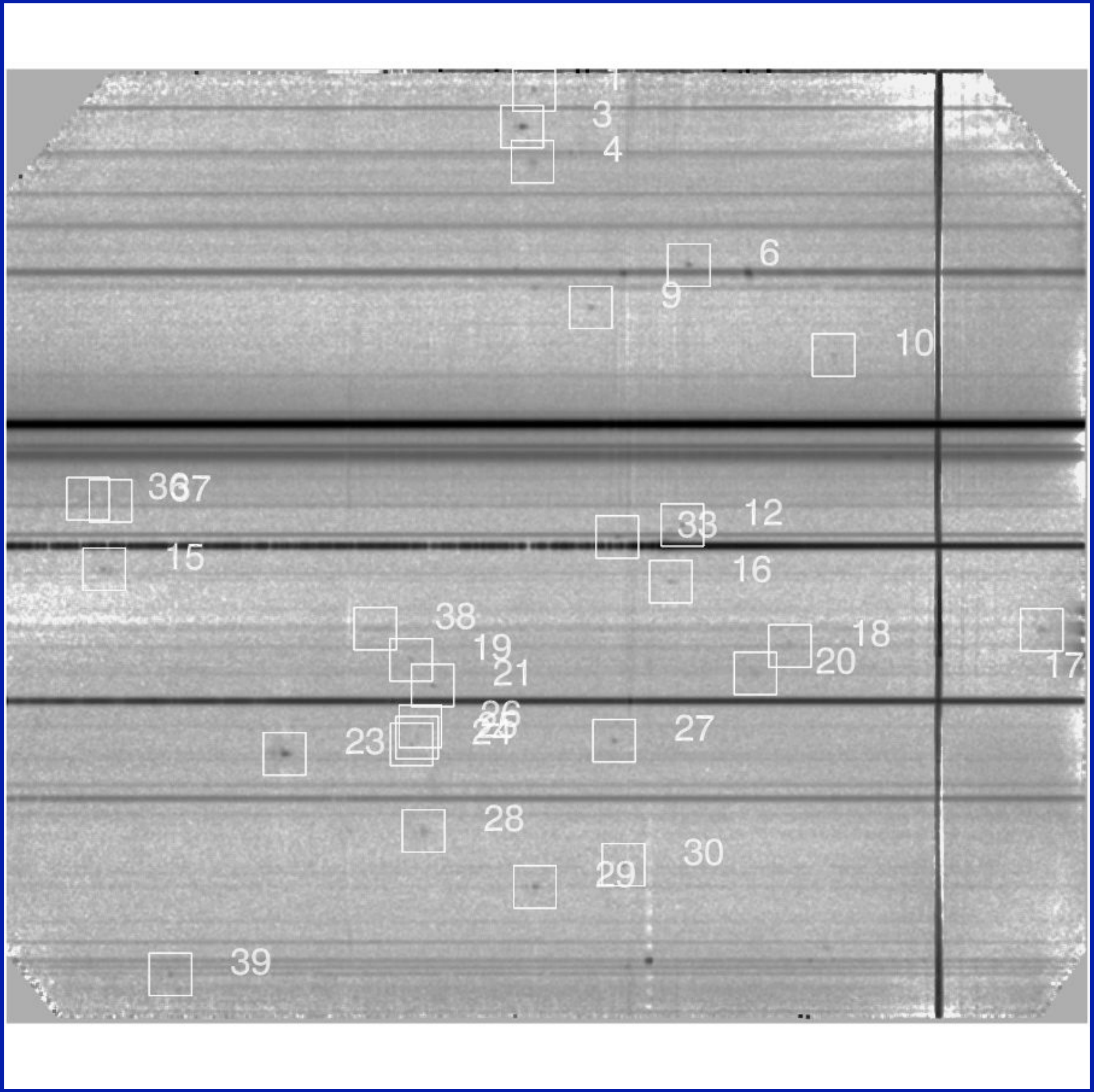
Questions we may be able to address:

What and where is majority of star forming galaxies ?
(so far undetected)

What are the host galaxies of damped Lya systems ?
(large, massive (Prochaska & Wolfe) or small, faint (Fynbo et al; Haehnelt et al))

Can we see all there is ?
(reach low mass limits where starformation is inhibited)

data reduction by
George Becker

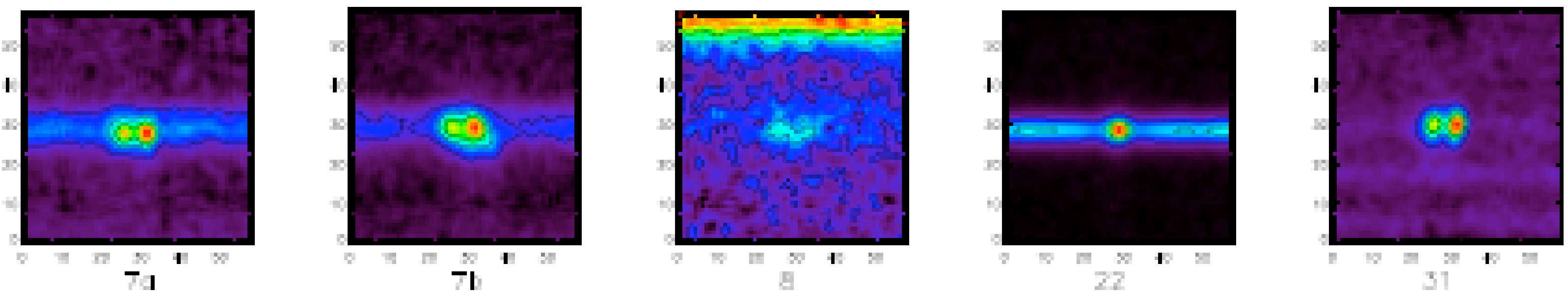


27 single line emitters, mostly without detectable continuum, over 4457 - 5776 A.
Fluxes a few $\times 10^{-18} erg\ cm^{-2} s^{-1}$; mean redshift 3.2

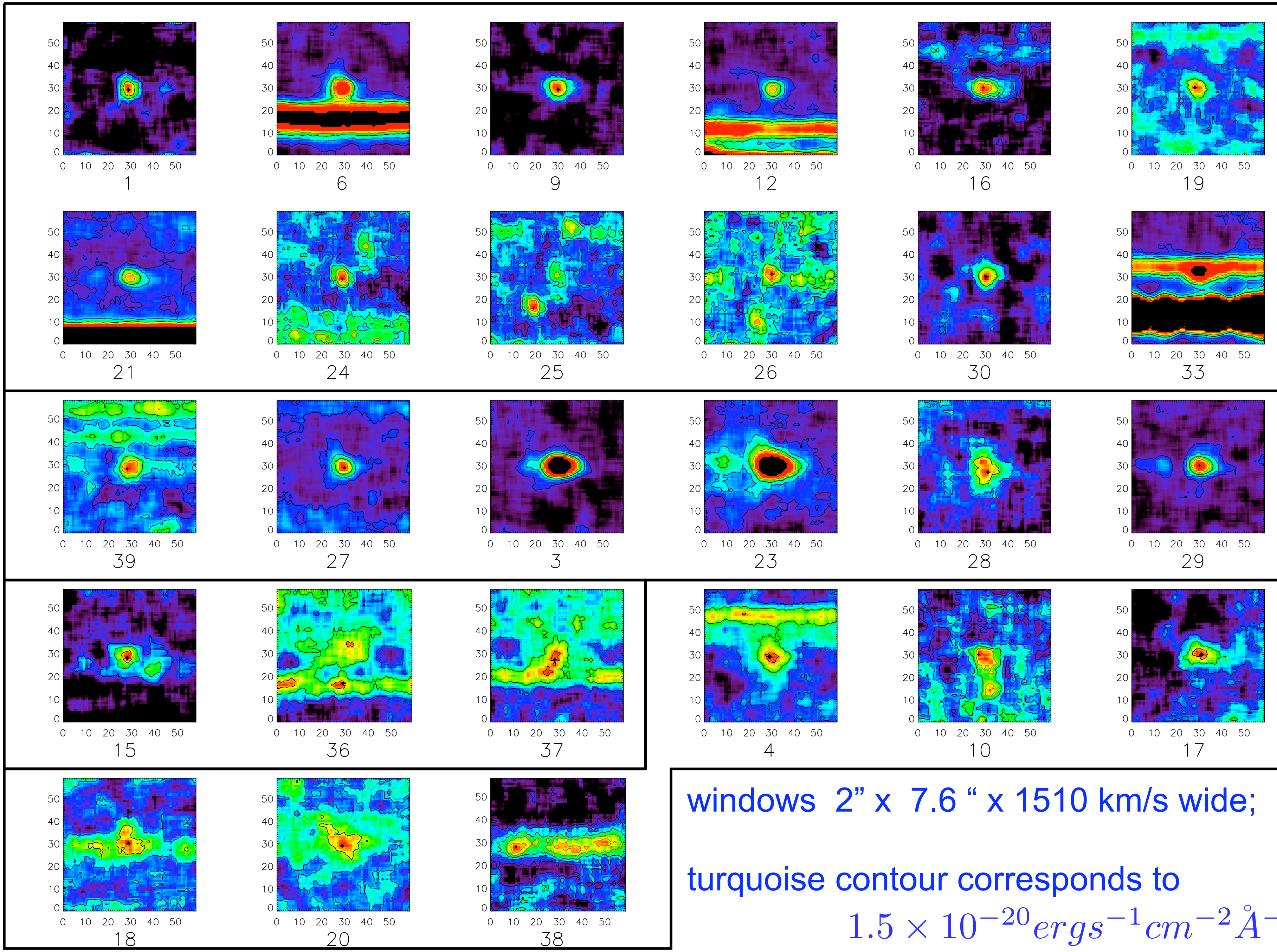
Identification of Lyman alpha emitters:

1) single emission line
2) none or point source continuum, discontinuity across emission line
3) co-incident with absorption redshift of background QSO in the field

Tricky, if faint.



[OII] [OII] Hbeta Hgamma [OII]



windows 2” x 7.6 “ x 1510 km/s wide;

turquoise contour corresponds to
$1.5 \times 10^{-20} ergs^{-1} cm^{-2} \mathring{A}^{-1}$

expect 30, find 27, BUT:

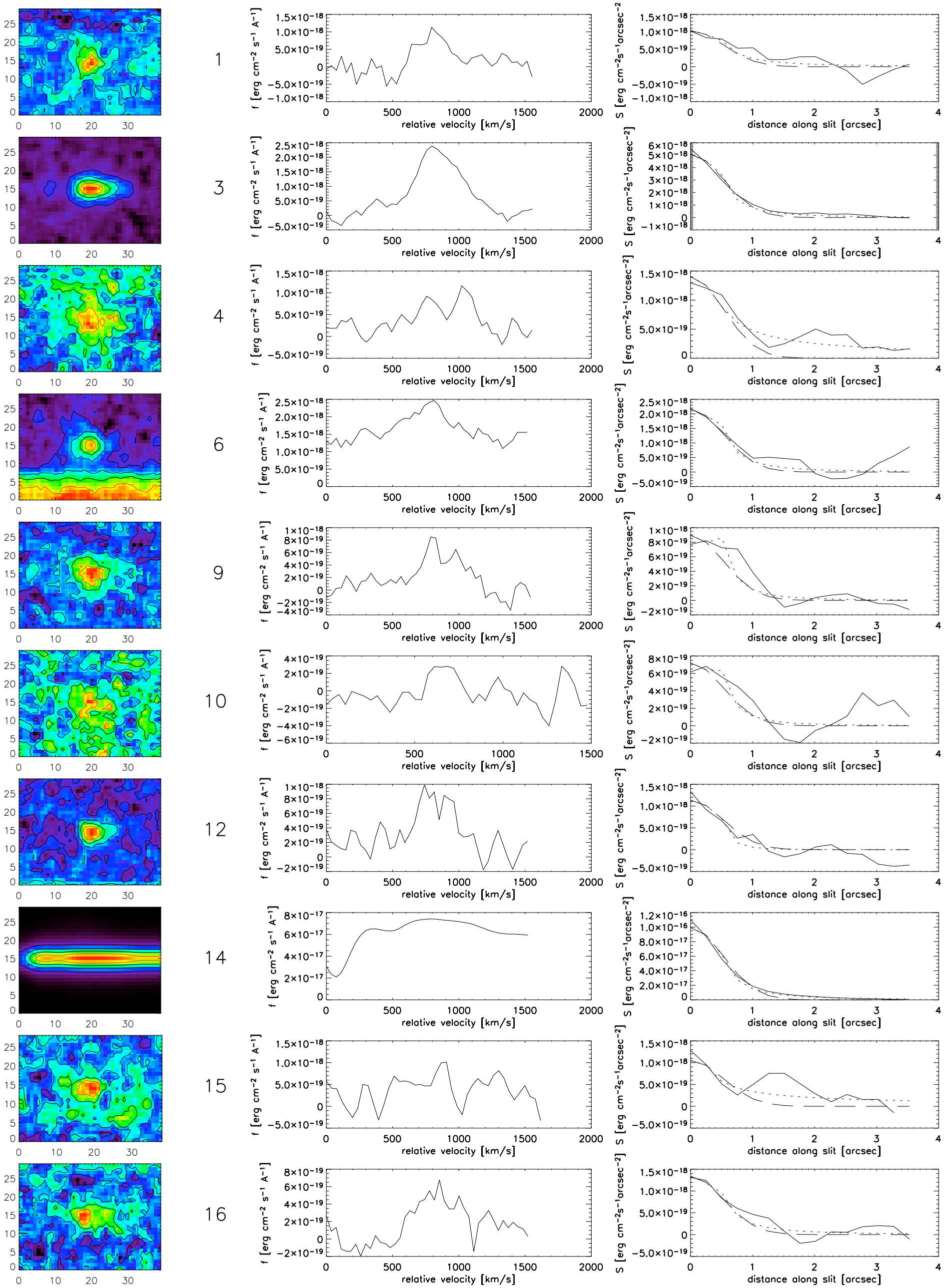
-SB higher by at least factors 2-4 and often much more than anticipated

-this is not the effect we were looking for

-evidence of outflows in some emission profiles

Optically thick HI regions already powered by star formation ?

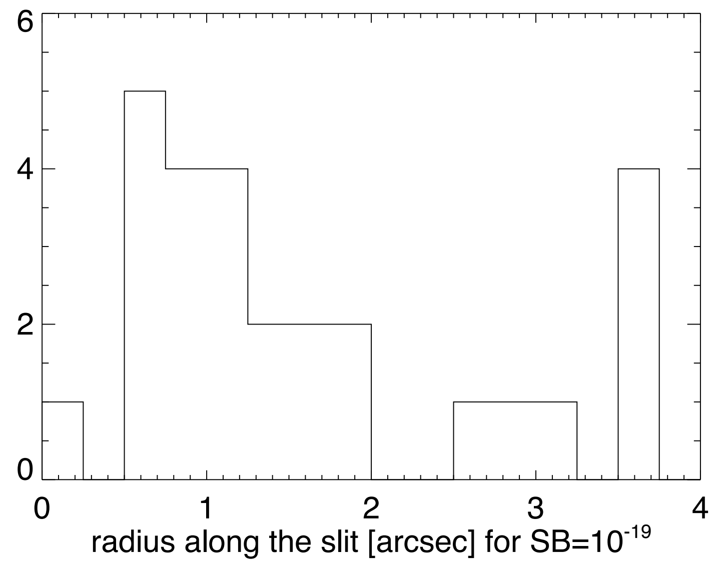
Foreground galaxies, misidentified as high z Lyalpha ?



Objects often extended in velocity and space.

fit surface brightness profile with Gaussian w. power law tails

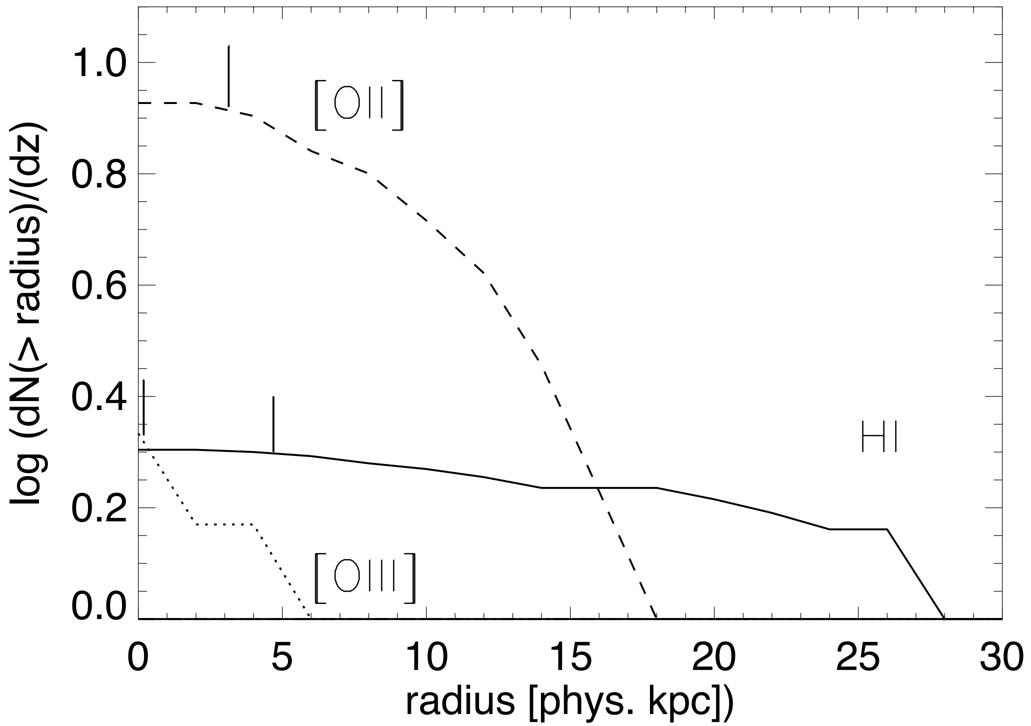
crude estimate of the radius := distance of the $1 \times 10^{-19} \mathrm{erg\ s^{-1} arcsec^{-2}}$ contour from the center.



Have comoving volume, number of objects, radius distribution, can compute

rate of incidence per unit redshift

$$\frac{dN}{dz} = \sum_i \frac{\sigma_i}{V_i} \frac{dl}{dz}$$



What are they ?

if [OII] 3726,3728 A ?: 0.2 < z < 0.55 $\frac{\partial^2 N}{\partial z \partial \Omega}$ = 302 arcmin^{-2}

$5 \times 10^{-3} \mathrm{M}_\odot \ \mathrm{yr}^{-1}$ < SF rate < $0.1 \ \mathrm{M}_\odot \ \mathrm{yr}^{-1}$

- based on Trentham et al (2005) local LF for field dwarves,
  expect about one remaining object in our emitter sample.

- dN/dz of our emitters if [OII]
  is about 14 times that of local DLAS (e.g., Rao, Turnshek & Nestor 2006).

Unlikely that our sample is dominated by [OII], unless clustered.

if [OIII] 5007 A ? 0 < z < 0.16 $\frac{\partial^2 N}{\partial z \partial \Omega}$ = 412 arcmin^{-2}

- space density would be 40 times higher than that of local dwarf galaxies.

- dN/dz would be 7 times that of local DLAS.

-observed density of emitters in wavelength where [OIII] can and cannot be detected is similar.

Unlikely that our sample is dominated by [OIII].

IF HI Lyalpha: (2.67 < z < 3.75) $\frac{\partial^2 N}{\partial z \partial \Omega}$ =98 arcmin^{-2}

- comoving density $3 \times 10^{-2} \mathrm{Mpc}^{-3}$

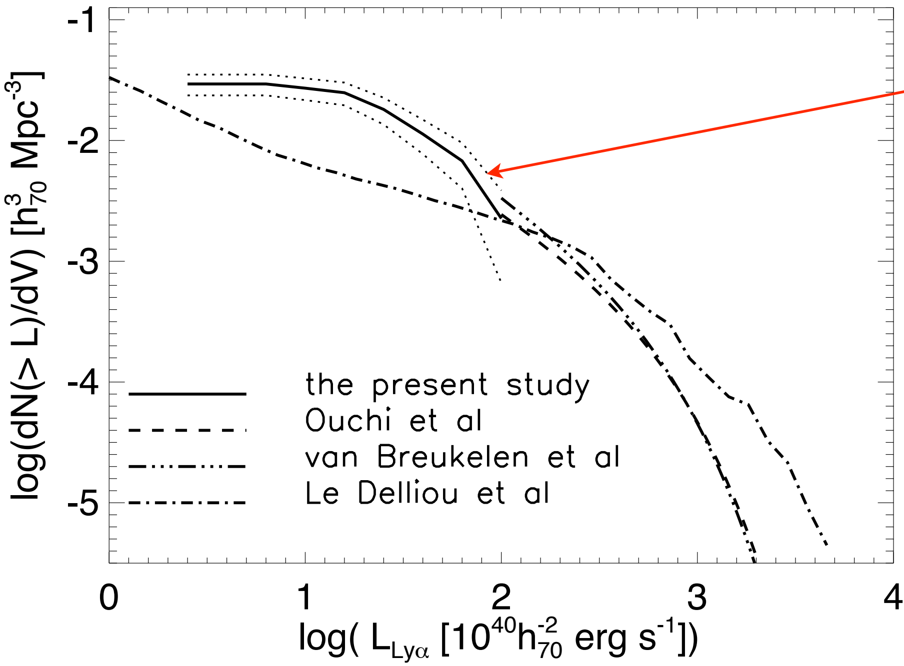
- $7 \times 10^{-2} \mathrm{M}_\odot\ \mathrm{yr}^{-1}$ < SF rate < $1.5\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$

-SF rate density $1.2 \times 10^{-2}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}\ \mathrm{Mpc}^{-3}$

- stellar mass within a Gyr $7 \times 10^7\ \mathrm{M}_\odot - 1.5 \times 10^9\ \mathrm{M}_\odot$

- total masses $> 3 \times 10^{10}\ \mathrm{M}_\odot$

virial velocities $v_c > 50\ \mathrm{km\ s}^{-1}$ (Mo & White 2002, Wang et al 2007)



Steepening of the luminosity function
wrt. shallower surveys
and modelling with constant Lya
escape fraction :

escape fraction (extinction) simply
may not be constant:

is dust diminishing towards fainter
objects?

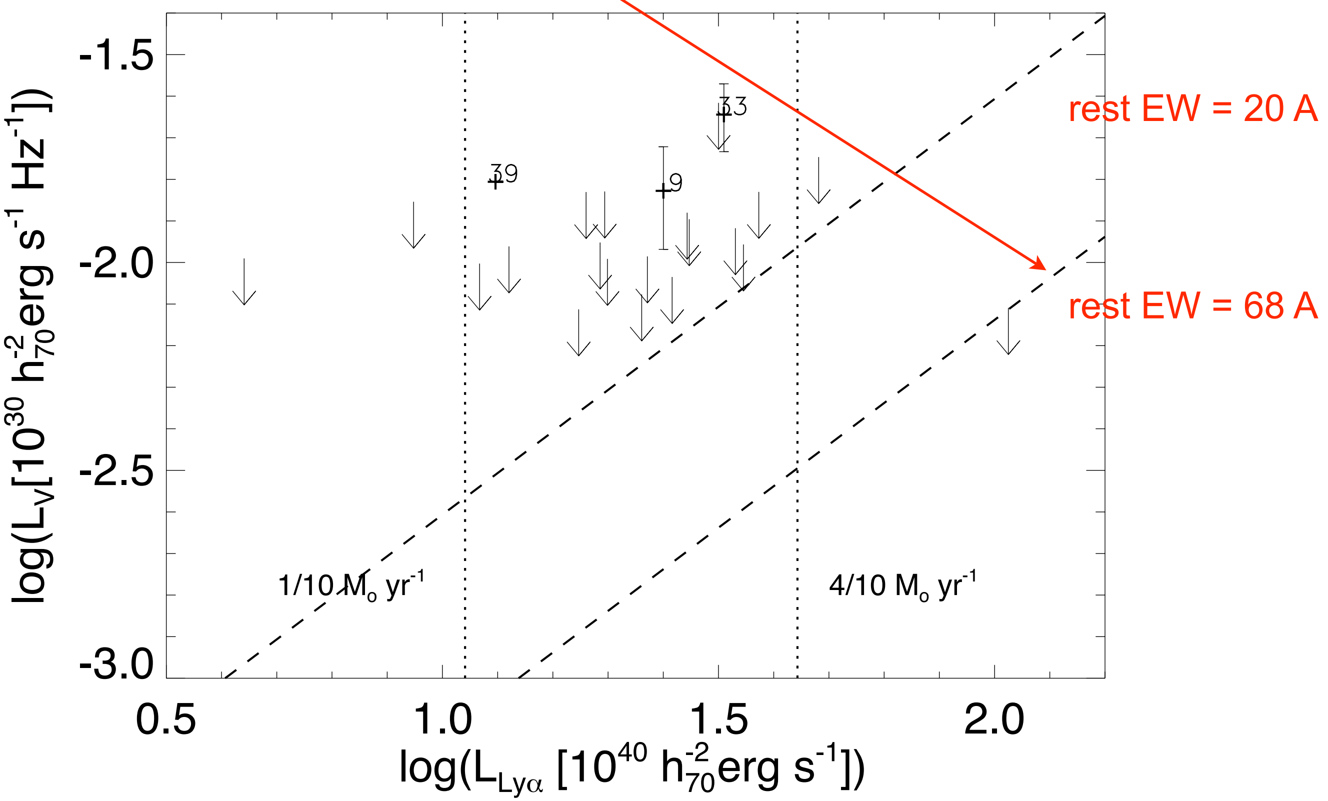
Have mostly only upper limits on continuum detections

Crude estimate of continuum based on conversion between SF rates and Lya, Luv fluxes:

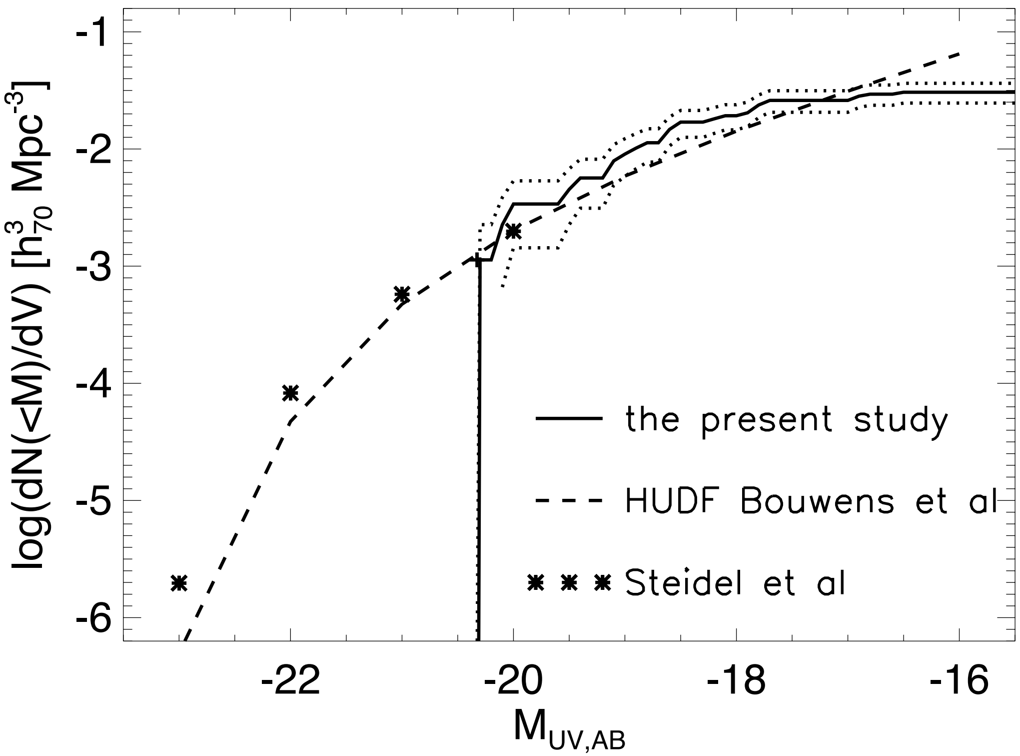
$$L_{UV}(\mathrm{erg\ s^{-1}Hz^{-1}}) = 8 \times 10^{27}\ \mathrm{SFR}(\mathrm{M_\odot yr^{-1}})$$ Madau et al 2000

$$\mathrm{SFR}(\mathrm{M_\odot yr^{-1}}) = 9.1 \times 10^{-43} L_{Ly\alpha}(\mathrm{erg\ s^{-1}})$$ Kennicutt 1998, Brocklehurst 1971

$$\log(L_{UV}) = -14.14 + \log(L_{Ly\alpha})$$



Convert Lya into "continuum magnitudes" and place objects into context of Hubble Ultra Deep Field (HUDF) (B band dropouts)



Little overlap with other ground based surveys

exactly one Lyman break selected galaxy in the field

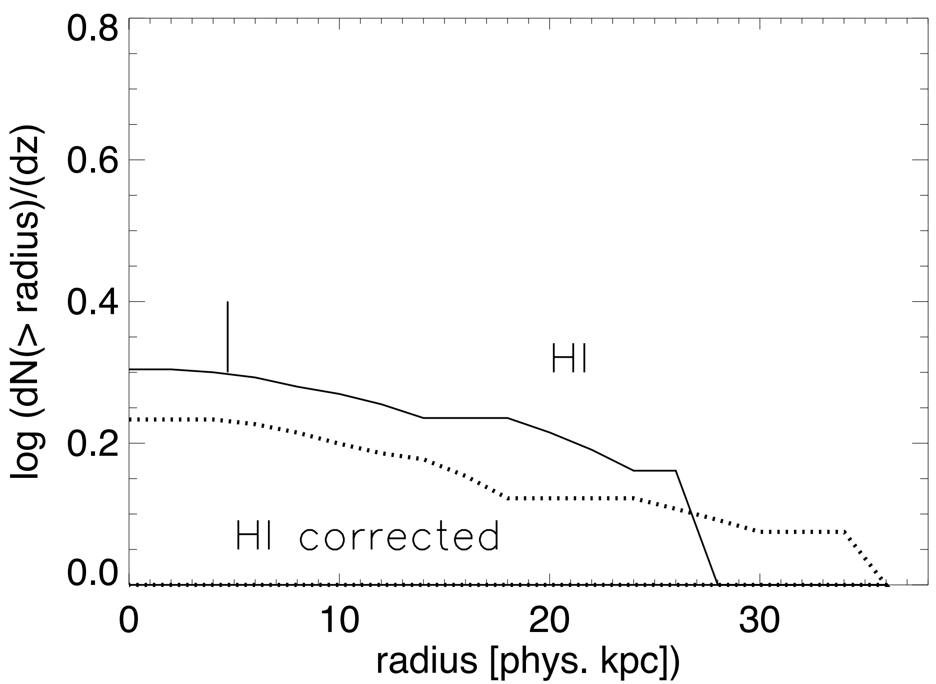
account for 36 percent of B-dropout SF rate density.

Are we seeing the faint end of the HUDF high z population from the ground in Lya emission ?

Caution: Plot only illustrative; precise magnitude range of our LF depends on EW width (logarithmically). Bouwens et al HUDF LF is for B-band dropouts, at somewhat higher redshift.

Rate of incidence dN/dz:

geometric cross section
and number density →



$$\frac{dN}{dz} = \sum_i \frac{\sigma_i}{V_i} \frac{dl}{dz}$$

(correct for finite sizes, slit losses)

Find:

total dN/dZ = 0.23;

cf. dN/dz(DLAS)= 0.26 (e.g., Peroux et al 2005)

Are these the long-sought host galaxies of DLAS ?

Close correspondence between emitters and DLAS:

both must be extended, optically thick gas

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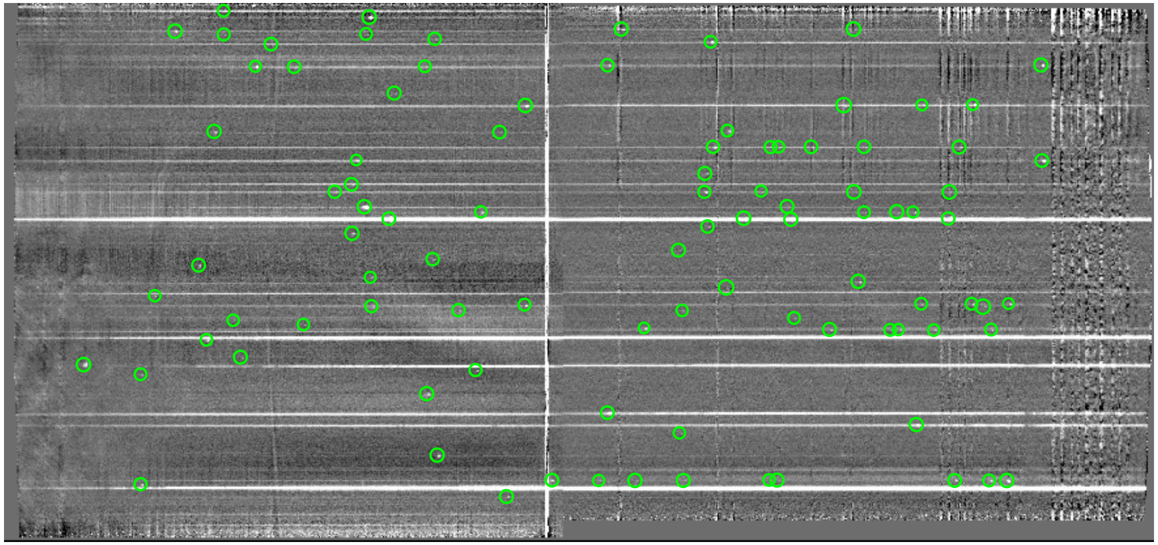
Confirms protogalactic clump model for high z QSO absorbers (MR, Haehnelt, & Steinmetz 1998, HSR 1998,2000), which are low mass, multiple objects later to merge into typical present day L* galaxies. (see also Barnes & Haehnelt).

Where to go from here ?

- Link Lya to stellar populations (perform LS spectroscopy in fields with very deep broad band imaging (HDFN, HUDF)

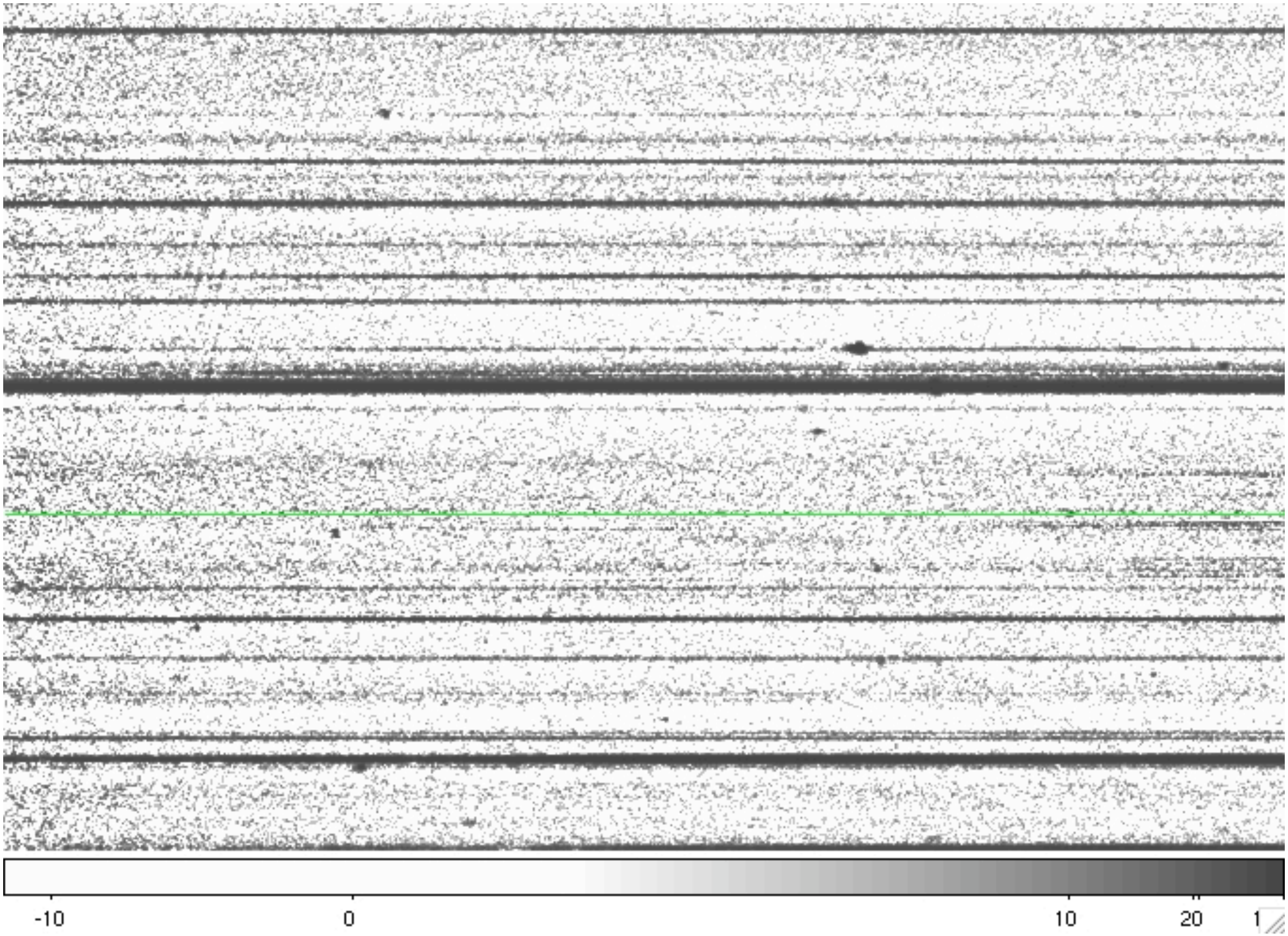
- eliminate interlopers with broad band imaging, greater spectral coverage

- model 2D Lyman alpha emission line: study infall, outflows ?

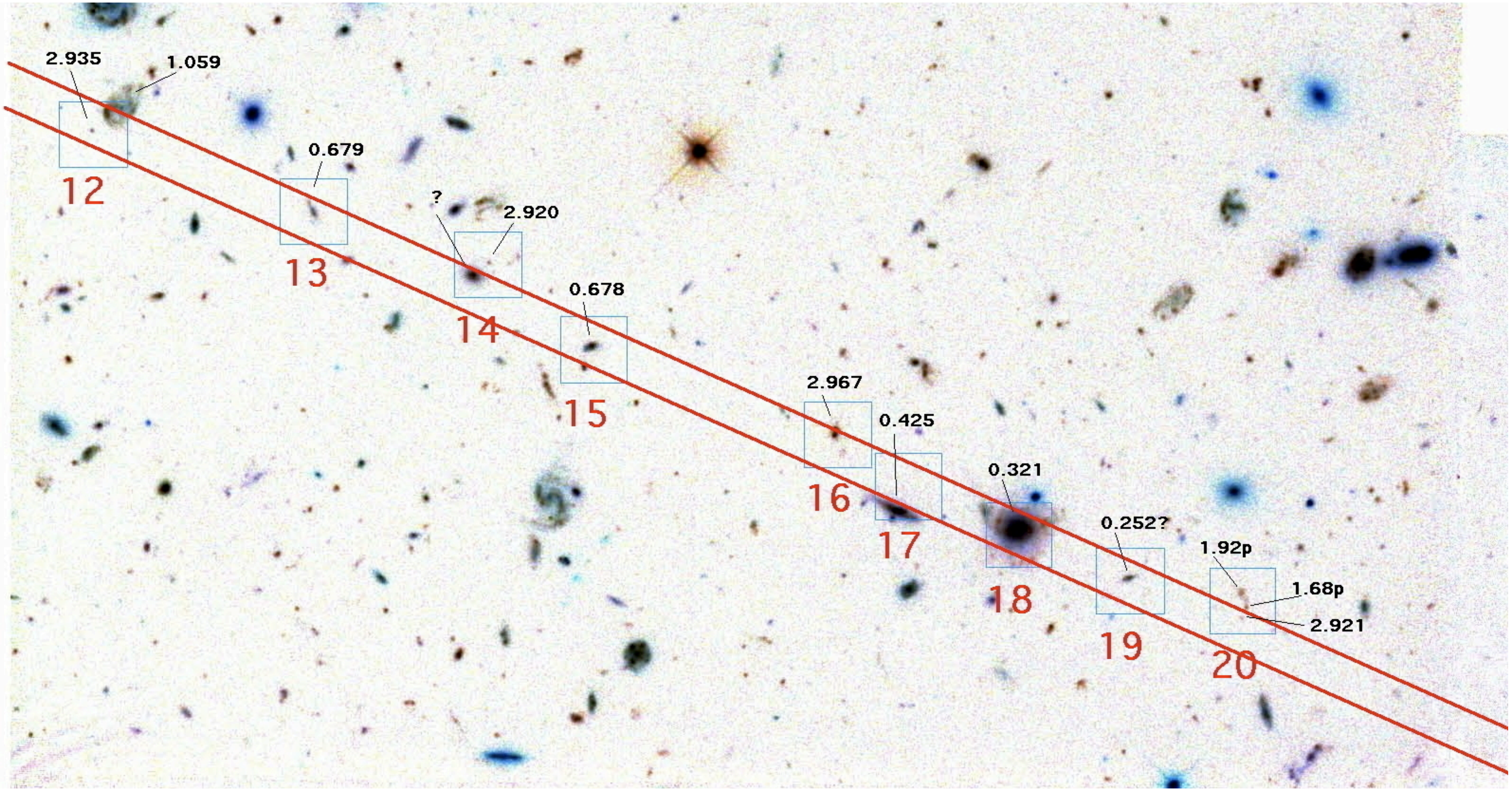


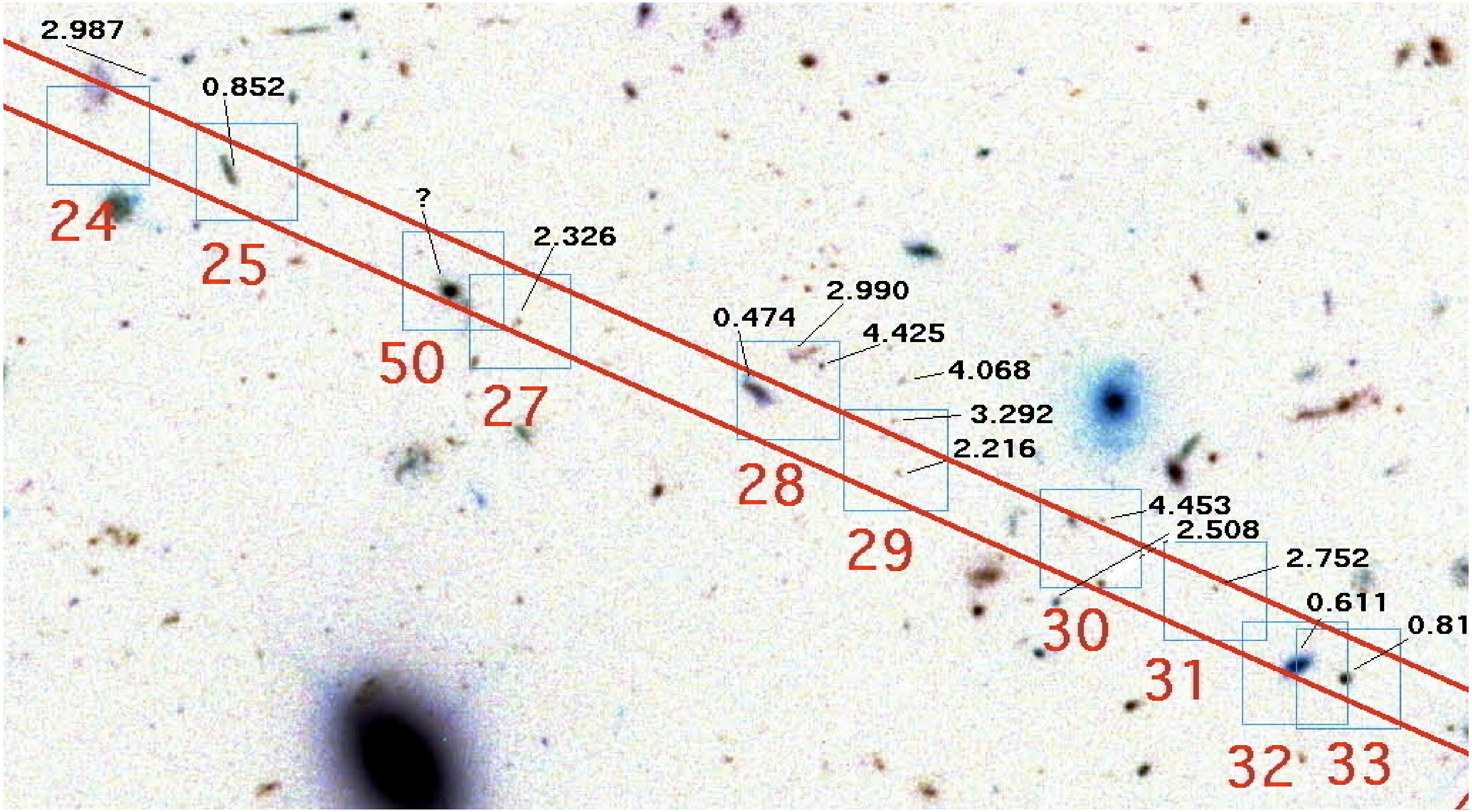
HDFN longslit with LRIS

- Keck LRIS LS spectroscopy of the Hubble Deep Field North
- so far 20 hours on sky (w. Sargent & Becker)



What are these objects ?





13 confirmed Lya emitters in 2 < z < 3.7 on 162” long slit.

Space density $2.9 \times 10^{-2} h_{70}^{3} Mpc^{-3}$!

None of them detected in U band, but all of them identified with compact faint broad band images. (F606 etc, plus three b-band dropouts).

Conclusions

Population of faint Ly alpha emitters with high space density (25x as common as all other galaxy types detected from the ground); low star formation rates, and probable low masses, and stellar counterparts;
are we finally seeing typical high z starforming gals ?

Will we soon be able to see “all” starforming galaxies ?

likely counterpart of DLAS and optically thick QSO absorption systems (cross-section, low metallicity, SF rate, heating rate)
map the bulk of the neutral hydrogen in the universe in emission!

progenitors of present day Milky Ways likely to be drawn from these objects.

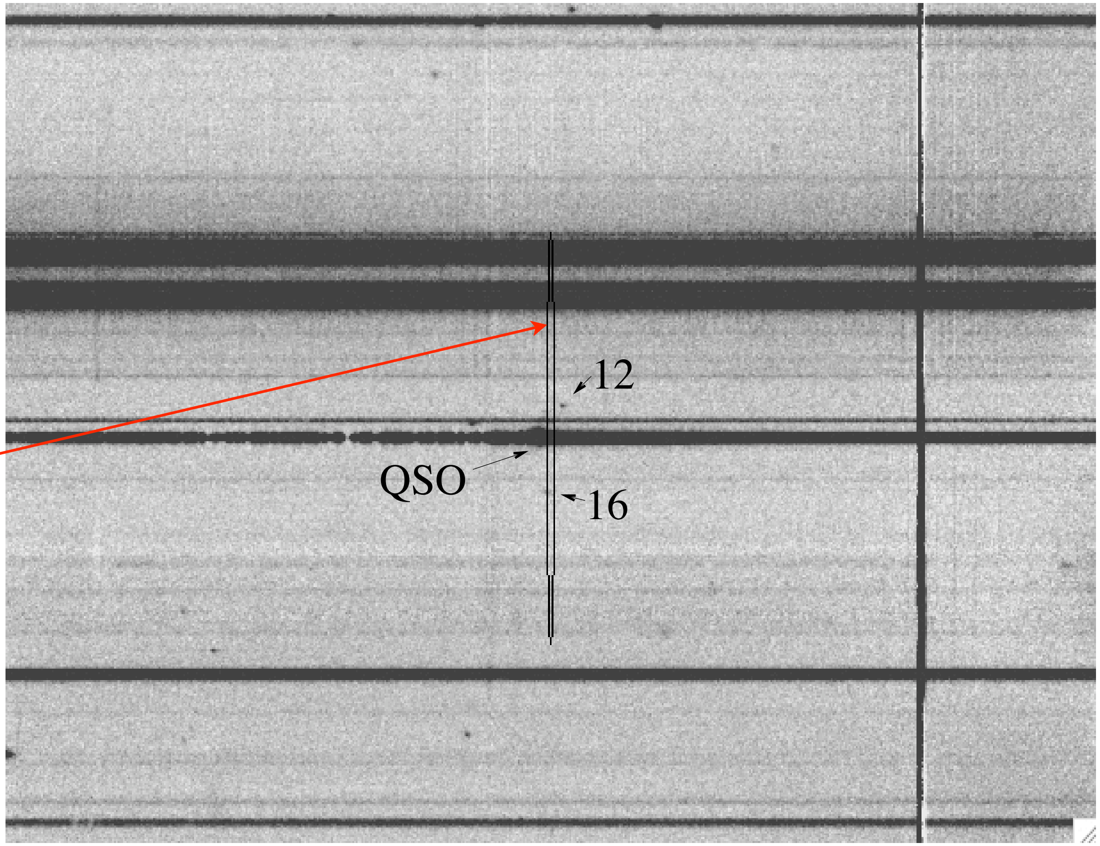
Ground-based spectroscopy can (in principle) go deeper than space-based imaging (high sky-suppression, long exposure times are key)

If HI Lyalpha, what drives the emission ?

Global Lya fluorescence induced by UV background (Hogan & Weymann 1987) factor ten weaker (Gould & Weinberg 1996).

Fluorescence locally enhanced by the QSO in the field (e.g., Cantalupo 2005) explains at most 1-2 objects (QSO too faint).

“Zone of influence”



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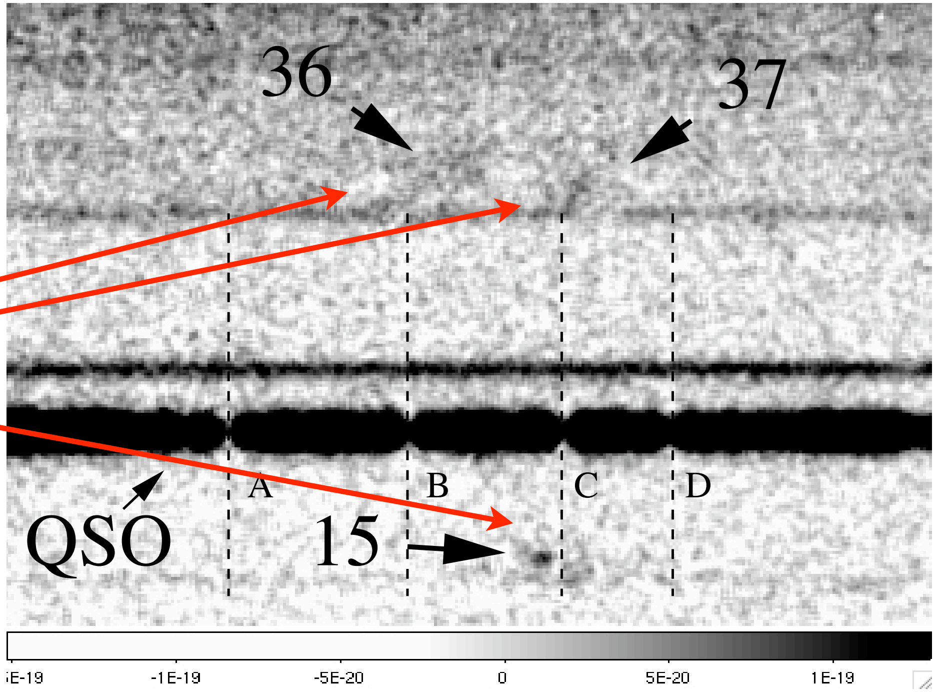
Cooling radiation (e.g., Dijkstra et al 2005) may explain a few objects, but most objects cannot be massive enough to be dominated by cooling radiation.

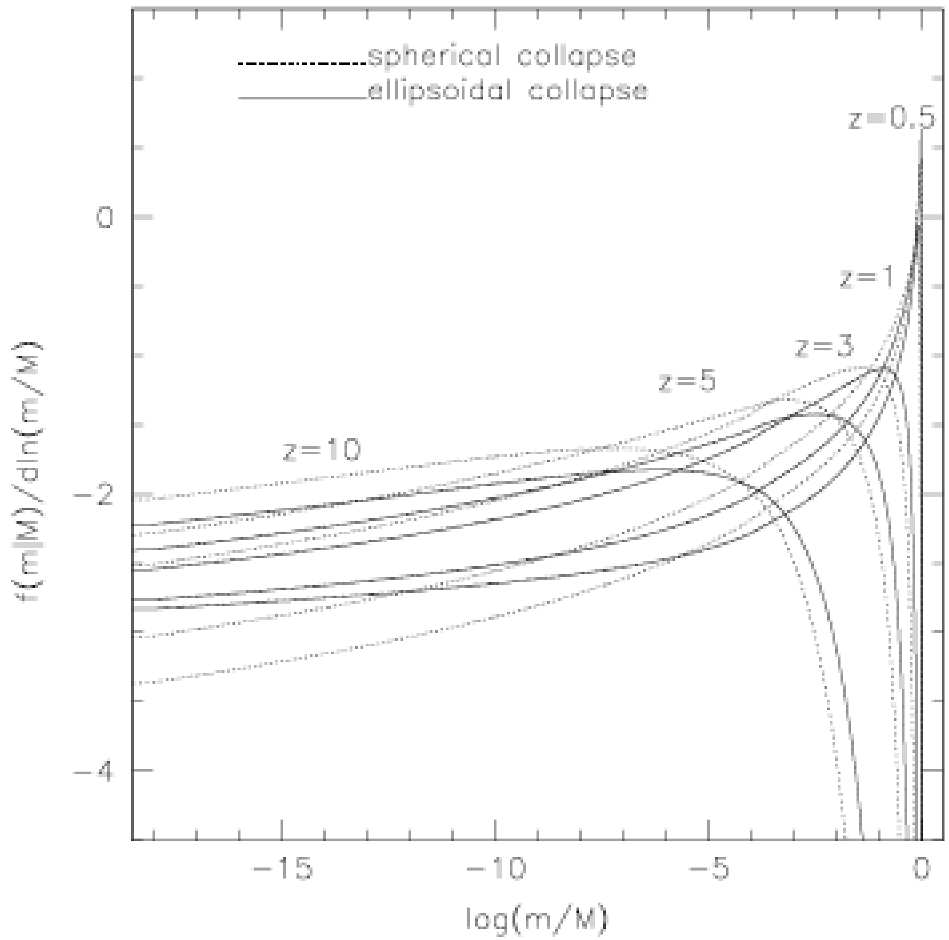
Star formation ok

Weird structures in emission and absorption

Cooling flows ? Outflows ?



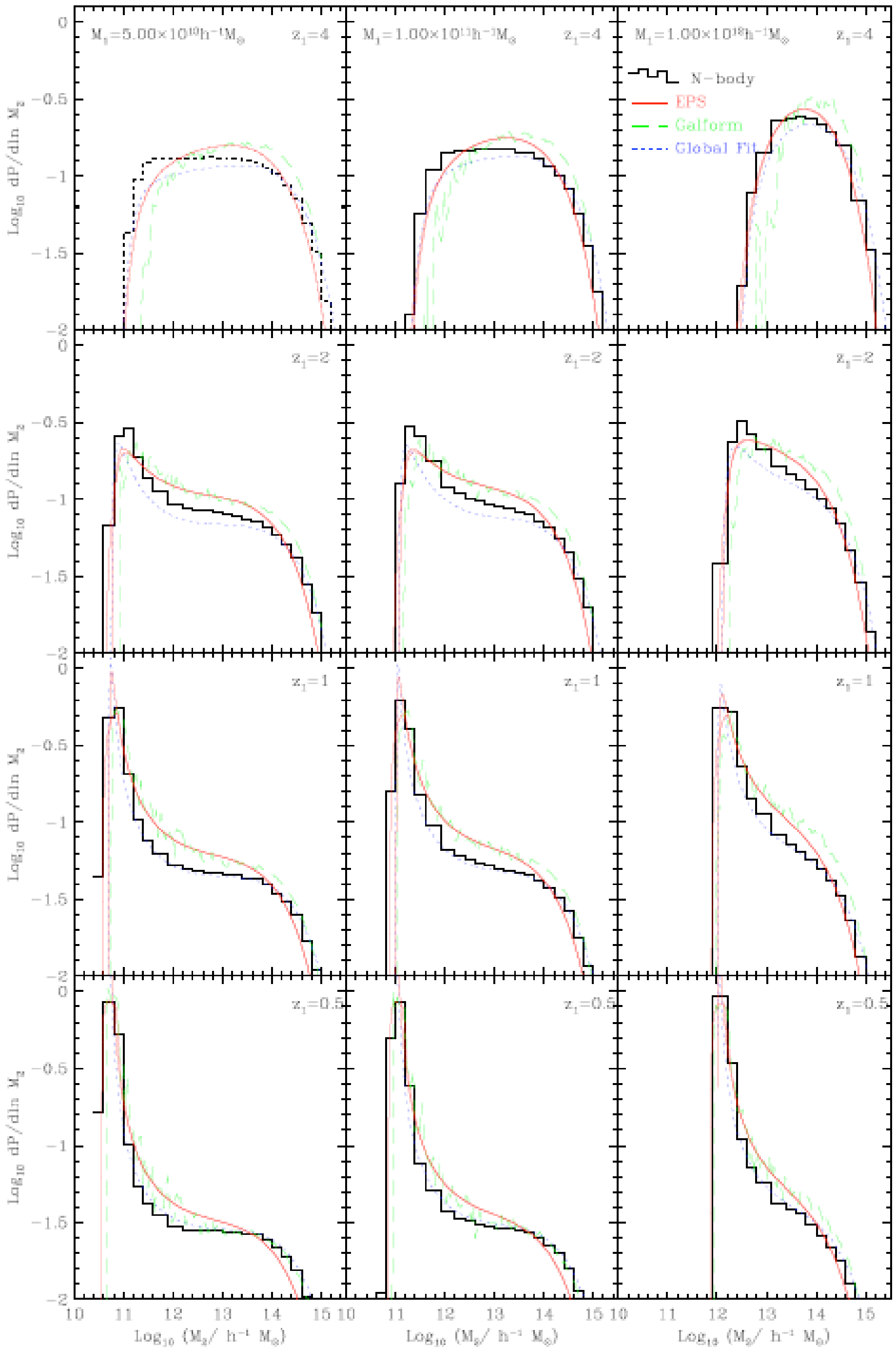
Giocoli et al 2007



conditional mass function for $10^{12} M_\odot$ halo

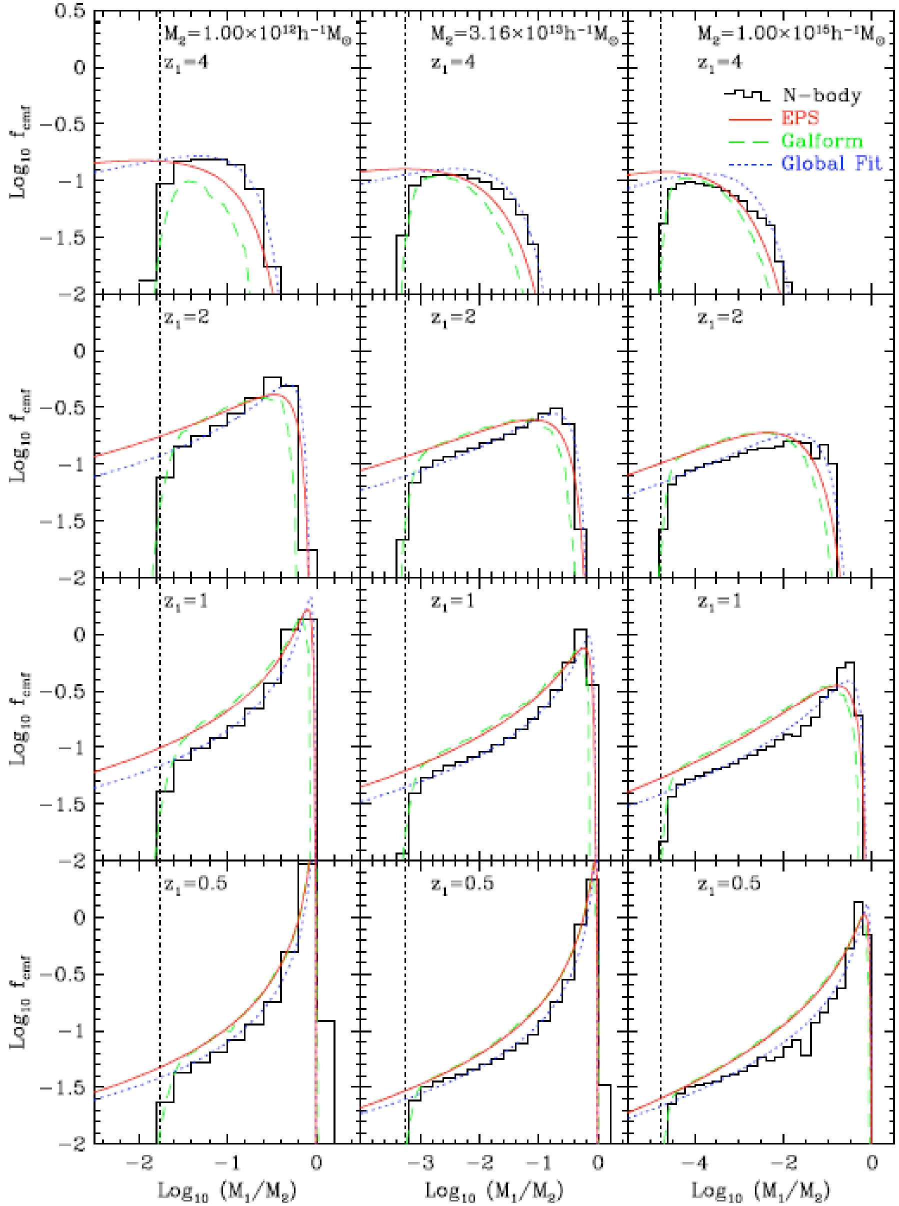
Distribution of final halo masses

Cole et al 2007



halos end up predominantly in present day halos less than 10-100 times more massive conditional mass function for halo

Cole et al 2007

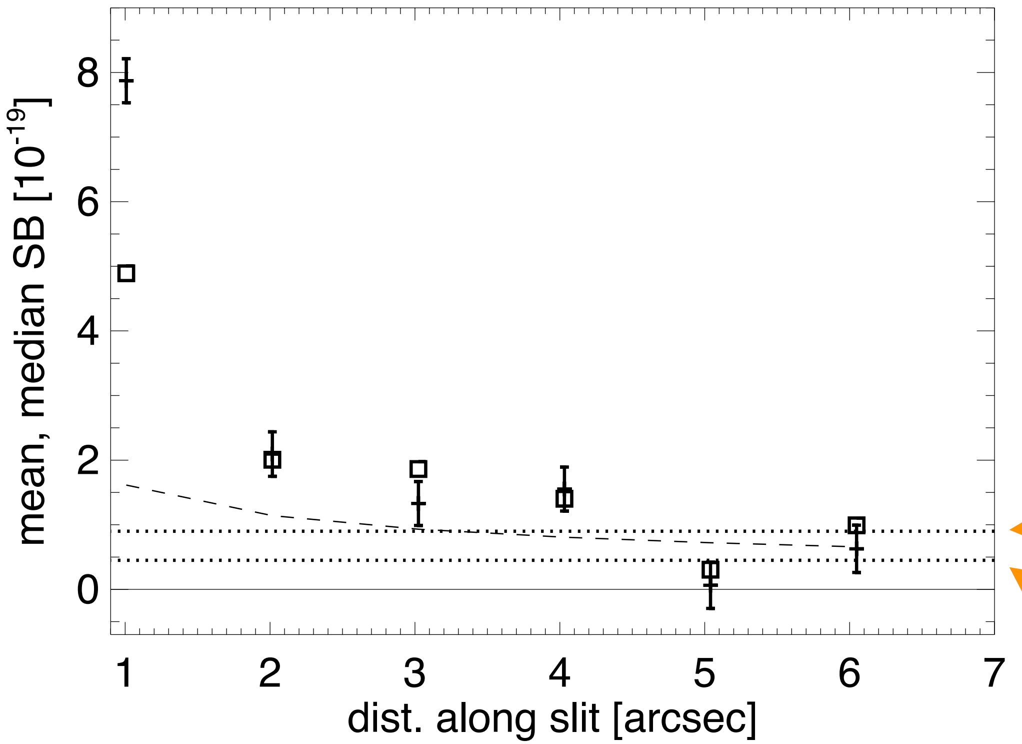


What about Lya fluorescence ?

found already ~30 objects but all factor > 2-4 brighter than expected

most Lyman limit patches have some star formation !?

mean (error bars) and median surface brightness for stacked objects



4.3×10^{-22}erg $s^{-1}cm^{-2}sr^{-1}$

(Bolton et al 1995)

pure QSO

50% QSO, 50% gals

extended emission out to r = 4" at $2 \times 10^{-19} erg\ cm^{-2}s^{-1}arcsec^{-2}$

Results

- 27 objects with fluxes $7 \times 10^{-19} - 1.5 \times 10^{-17} \mathrm{erg\ s^{-1} cm^{-2}}$

- discovered in 92 hour exposure w. FORS2/VLT

- extended (r < 4”) faint line emission at $2 \times 10^{-19} \mathrm{erg\ s^{-1} cm^{-2} arcsec^{-2}}$

number density and dN/dz enormous no matter if [OII], [OIII], or HI Lya.

Most emitters likely to be Lya; moderate contamination by [OII], [OIII] and HI Balmer series possible.

Continuum mostly undetected.

Interpretation →

If emitters are mainly Lya at 2.67 < z < 3.75:

- space density > 20 times that of starforming galaxies previously found in ground-based surveys (continuum selected; strong Lya emitters).

- Lya line luminosity function steepens from previous surveys; disappearance of dust with decreasing luminosity / SF rate ?

- UV luminosity function naively derived from line emission + standard assumptions similar to faint end of HUDF

- luminosity functions appear to flatten at the faint end before detection limit is reached. Have we found already all star forming galaxies ? (possibly yes, if they correspond to DLAS, which contain already most of the neutral gas available for SF).

- identification with DLAS strongly suggested. Accounts for and reconciles many DLA results from the past.

If emitters are mainly Lya at 2.67 < z < 3.75:

- CDM paradigm and number density confirms DLAS are low mass ($3 \times 10^{10} \mathrm{M}_\odot$), low v_virial (50km/s) objects (Haehnelt et al 1998, 2000).

- emission dominated by star formation, as opposed to cooling, fluorescence.

- total stellar masses $10^8 - 10^9 M_\odot$

- emission regions likely extended in space and frequency by radiative transfer

- some objects may show structure reminiscent of cooling radiation

- stacked objects show optically thick gas radiating above expected Hogan - Weymann level.

If emitters are not Lya, but, e.g., [OII] or [OIII]:

- huge comoving densities → very low-mass low z galaxies