Lya emission from z=2-3 galaxies in SDSS/BOSS

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Talk plan:

(1) Intro: Lya emission in the high-z universe

-Lya emitting galaxies ("Lya emitters")
-Lya emission from IGM

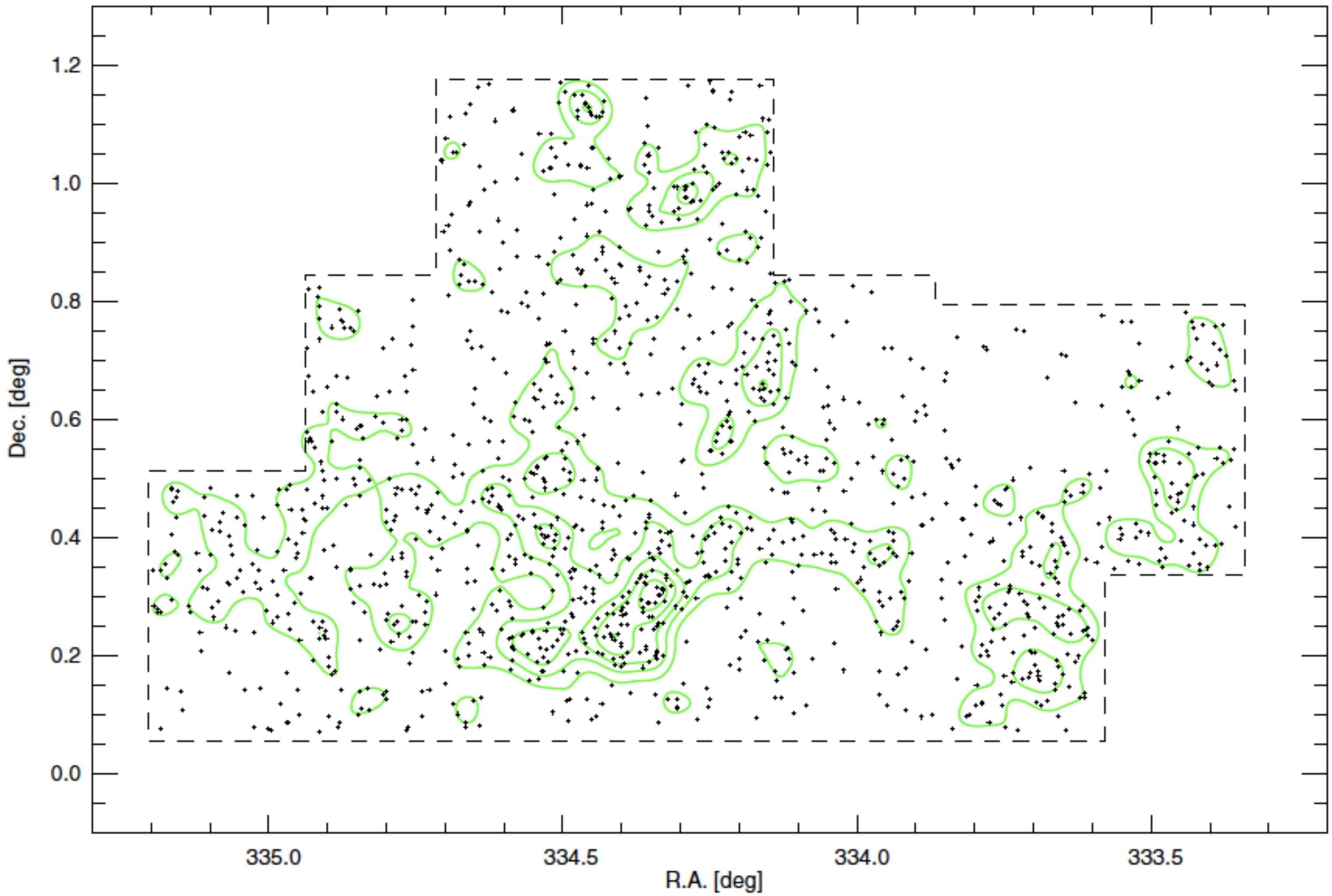
(2) How to use SDSS/BOSS spectra of z=0.5-1 galaxies
to measure Lya emission from z=2-3

(DR9 has 530,000 galaxy spectra+ 55,000 QSO spectra)

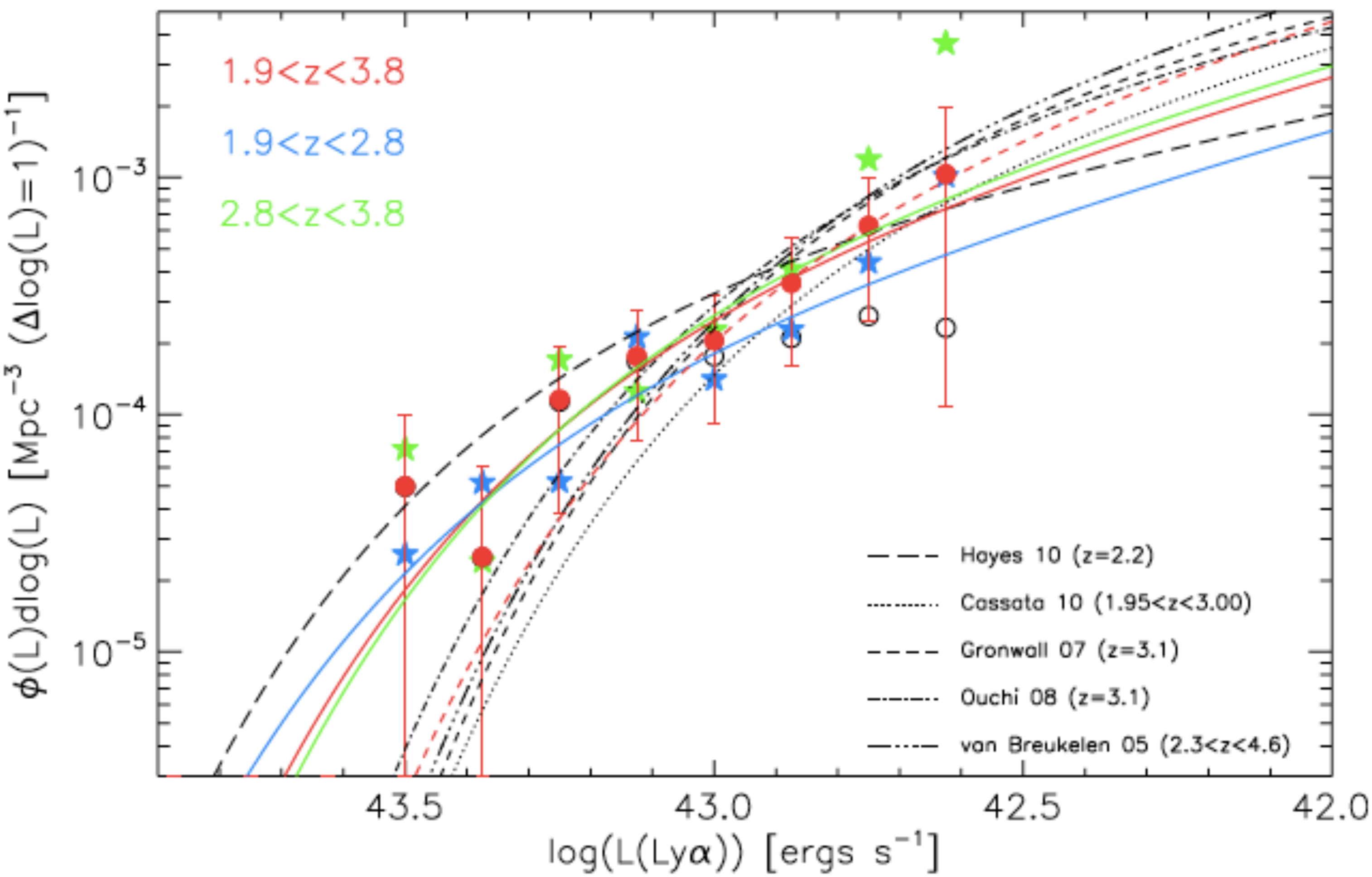
(3) Results and conclusions.

Traditionally, Lya emitters found using narrow band imaging, e.g.,

Yamada et al. 2012 (Subaru, z=3.1)

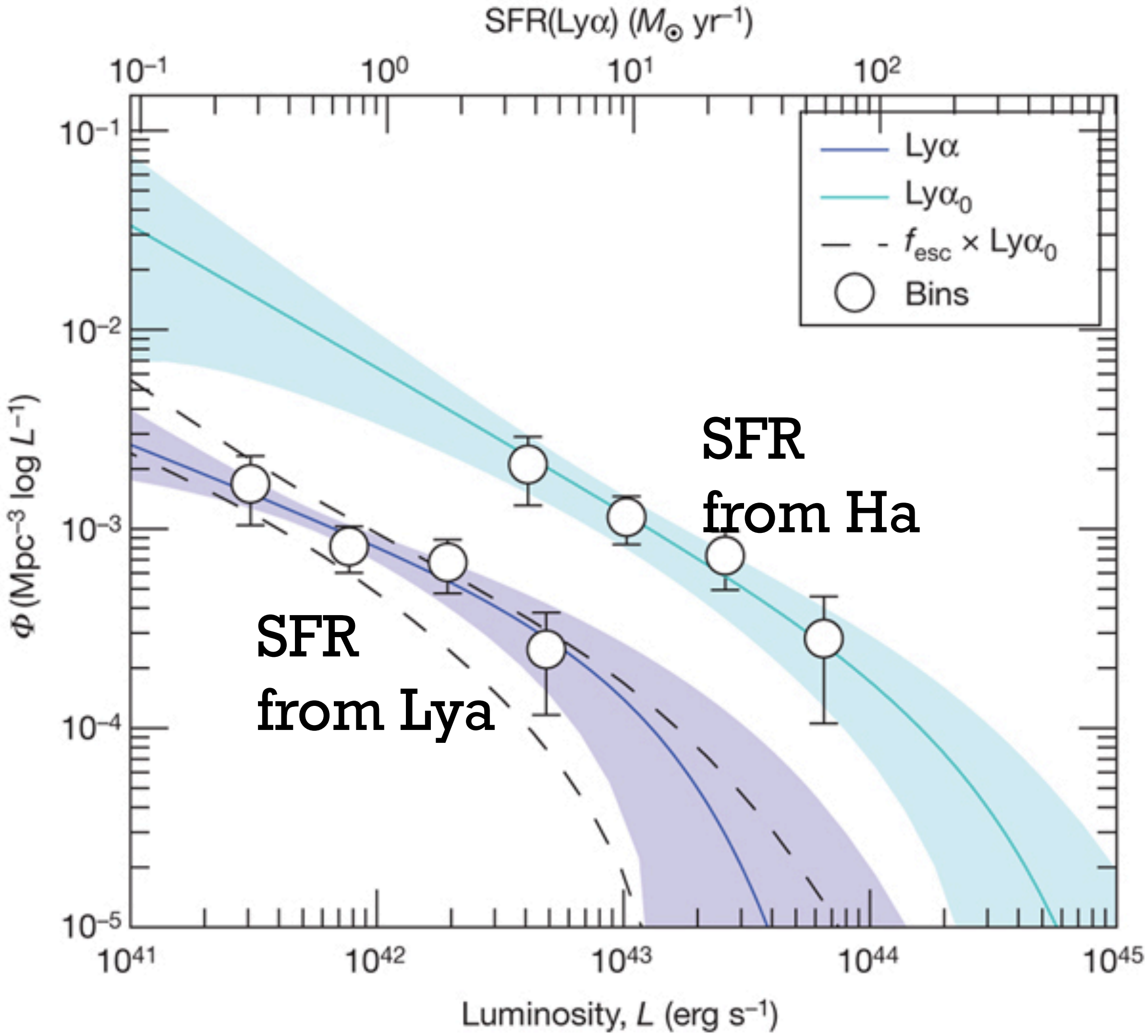


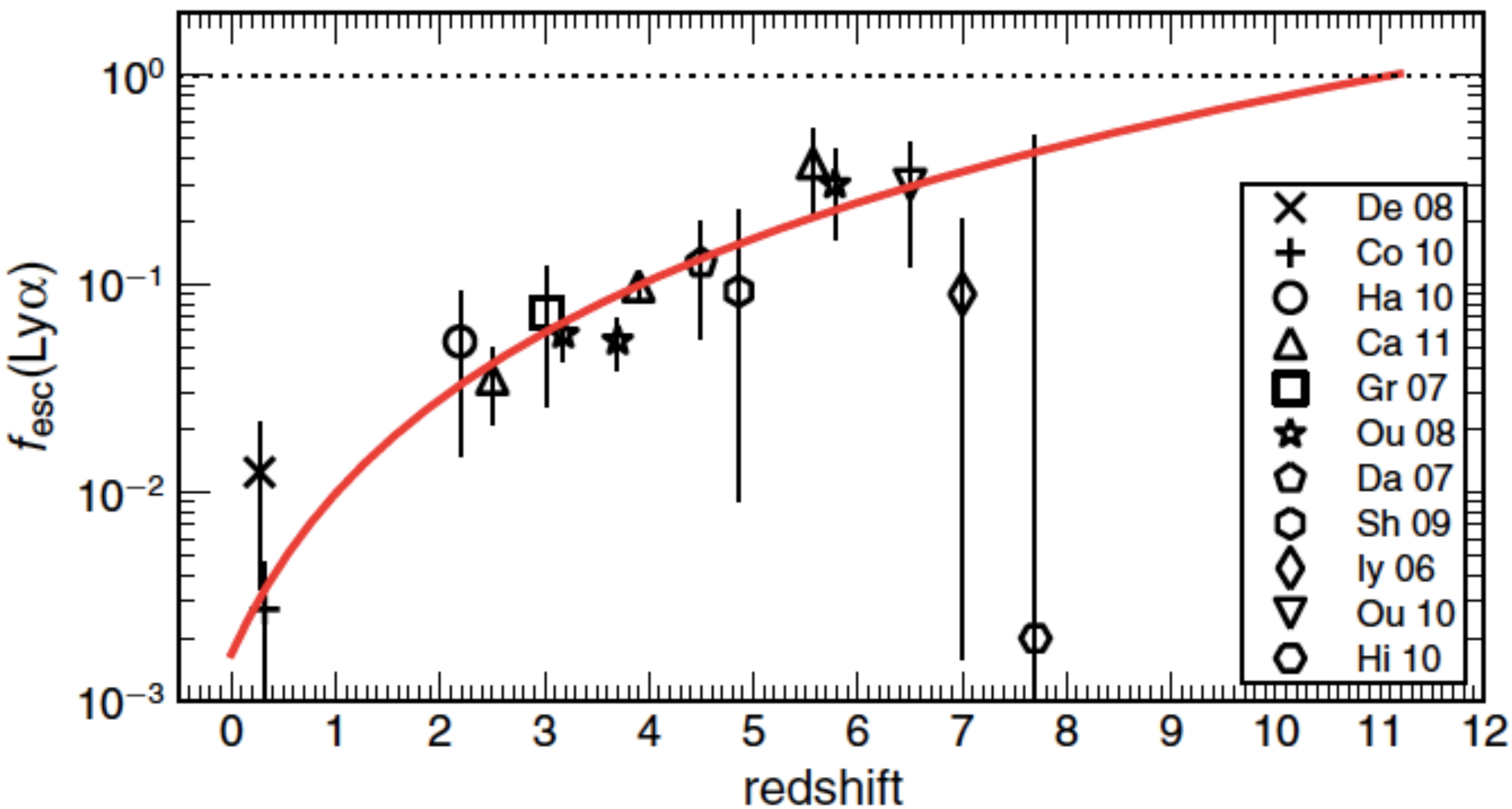
Blanc et al. 2011 (HETDEX pilot survey)
Integral field unit (VIRUS)



(line flux limit $5x10^{-17}$ erg/s/cm^{-2})

Hayes et al. 2010 (at $z=2.2$, $f_{esc}=5\%$)





Lya escape fraction declines at low-z : more dust

Fluorescent emission from IGM
e.g., Gould & Weinberg 1996

IMAGING THE FOREST OF LYMAN LIMIT SYSTEMS

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ABSTRACT

We show that it is now possible to image optically thick Lyα clouds in fluorescent Lyα emission with a relatively long (∼20 hr) integration on a large (∼10 m) telescope. For a broad range of column densities ($N \gtrsim 10^{18.5}$ cm^{-2}), the flux of Lyα photons from recombination cascades is equal to ∼0.6 times the flux of ionizing photons, independent of the geometry of the cloud. Additional Lyα photons are produced by collisional excitations when these are the cloud's primary cooling mechanism. For typical physical conditions expected in optically thick clouds, these mechanisms together lead to a Lyα emission flux that is $\sim \frac{2}{3}\langle\nu\rangle/\nu_0$ times the flux of ionizing photons, where $\langle\nu\rangle$ is the mean frequency of ionizing background photons and ν_0 is the Lyman limit frequency. Hence measurement of the surface brightness from an optically thick cloud (known to exist, e.g., from a quasar absorption line) yields a direct measure of the energy in the ionizing radiation background. Moreover, in the same long-slit spectrum, one could hope to detect emission from ∼200 other Lyα systems. Such detections would allow one to make a two-dimensional map of the distribution of Lyα clouds. By taking a series of such spectra, one could map the clouds in three dimensions, revealing the structure in the high-redshift universe.

Subject headings: cosmology: theory — intergalactic medium — large-scale structure of universe

Mean Lya surface brightness $\sim 10^{-22}$ erg/s/cm^2/A/arcsec^2

Questions we would like answered:

(1) What is mean Lya emissivity in the Universe, and how does it compare to integrating known Lya emitter LF?

(2) ~5% of Lya emission from galaxies can be seen directly at z~2.5. How much is absorbed by dust, and how much just scatters into IGM and can be detected?

(3) Can fluorescent emission from the IGM be detected?

History of ambitious observations…

The Deepest Spectrum in the Universe? Line Emission from Lyman-alpha Clouds at z 3

- Fulltext Article not available
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- Full record info

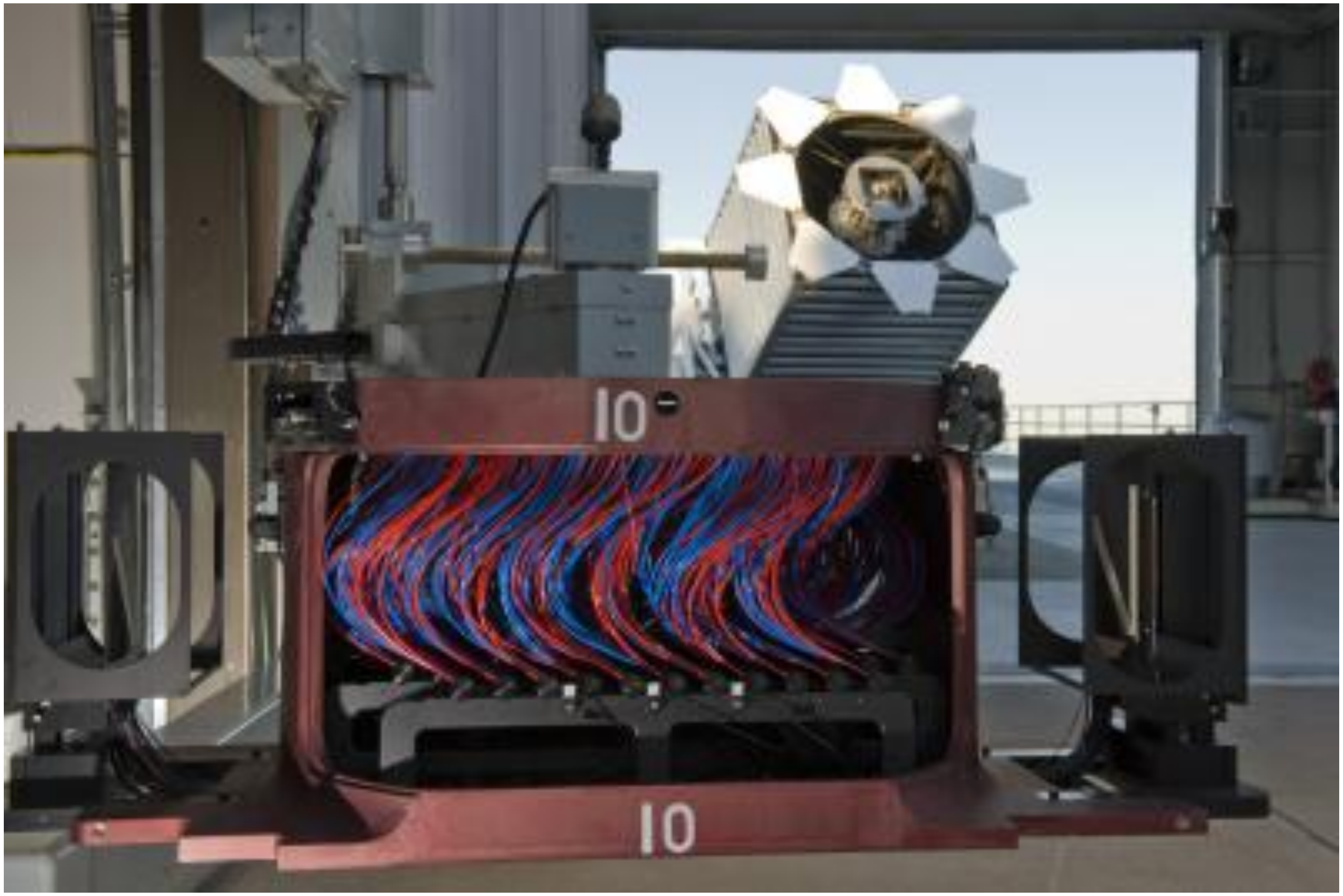
Bunker, Andrew J.; Rauch, M.; Haehnelt, M.; Becker, G.; Marleau, F.; Graham, J.; Research, European; Inter-Galactic Medium, Training Network on the

American Astronomical Society, AAS Meeting #211, #54.04; Bulletin of the American Astronomical Society, Vol. 39, p.824

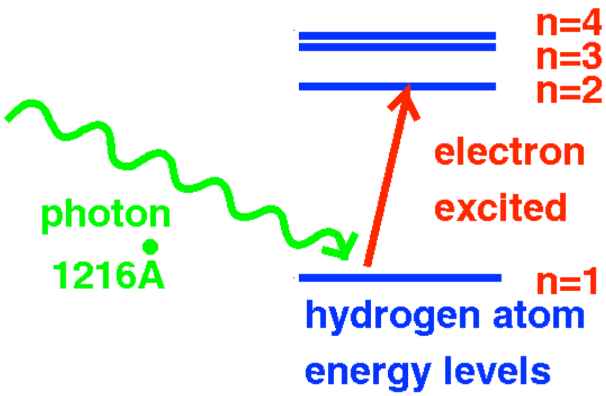
We present the results of an extremely deep long-slit optical spectroscopic search for low-luminosity Lyman-alpha emitters. Over several years we have accumulated 150-hours integration on a single field with 8-10m telescopes (VLT/FORS2, Gemini/GMOS and Keck/LRIS) at a spectral resolution of 300km/s. This is the deepest spectrum ever obtained - our 1 sigma sensitivity to line emission in a 1 $arcsec^2$ aperture is $10^{19} erg/cm^2/s$.

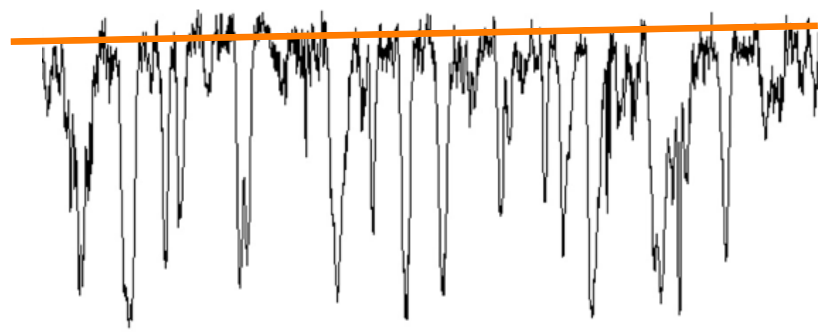
We have significant detections of 30 emission line objects, which are most likely Lyman-alpha emitters at $2.7<z<3.7$.

Published as Rauch et al. (2008)

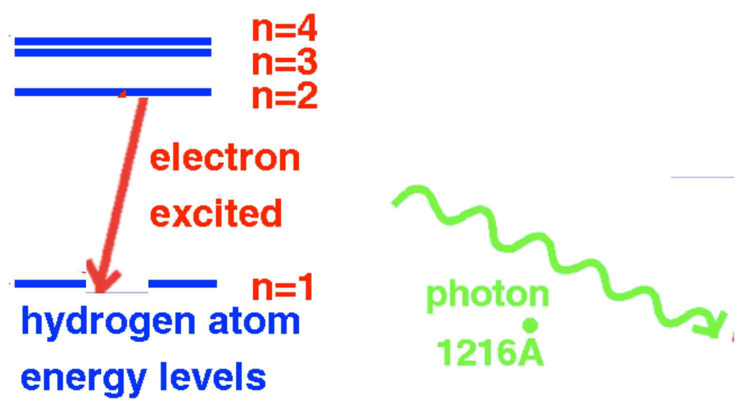


BOSS spectrograph



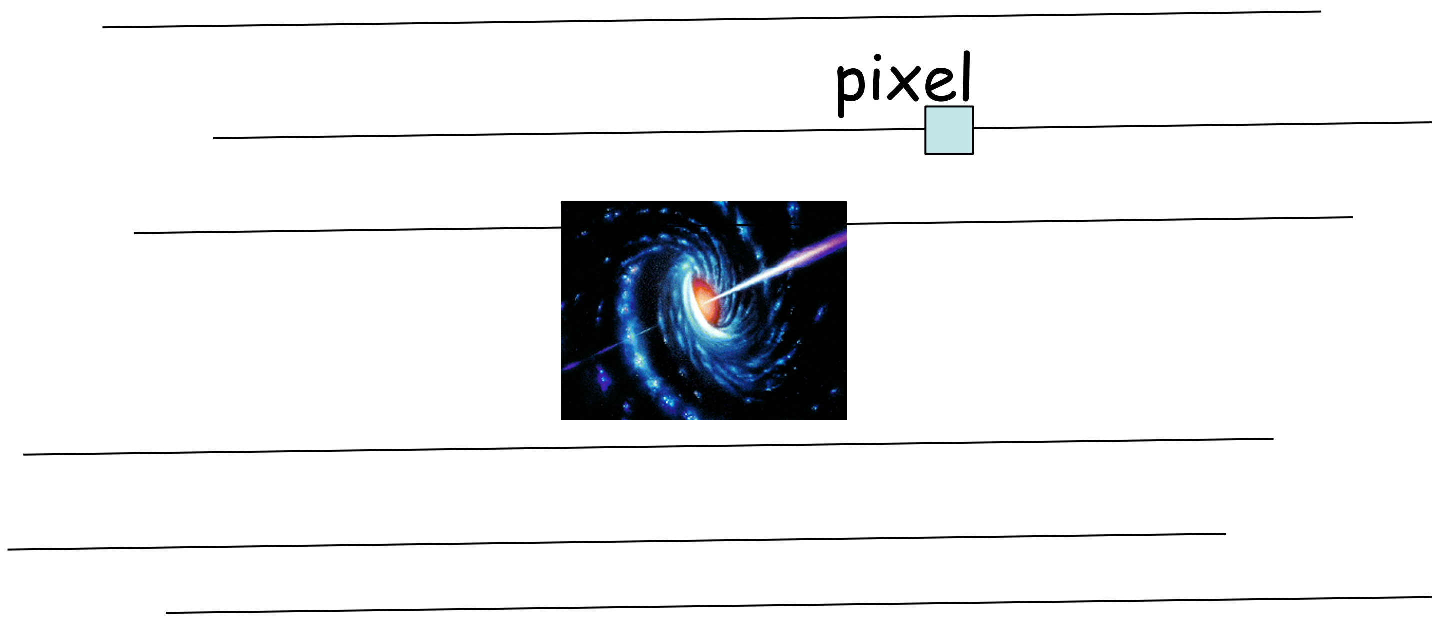


Looking for Lya emission



Around QSOs the most photons are being pumped into the IGM.

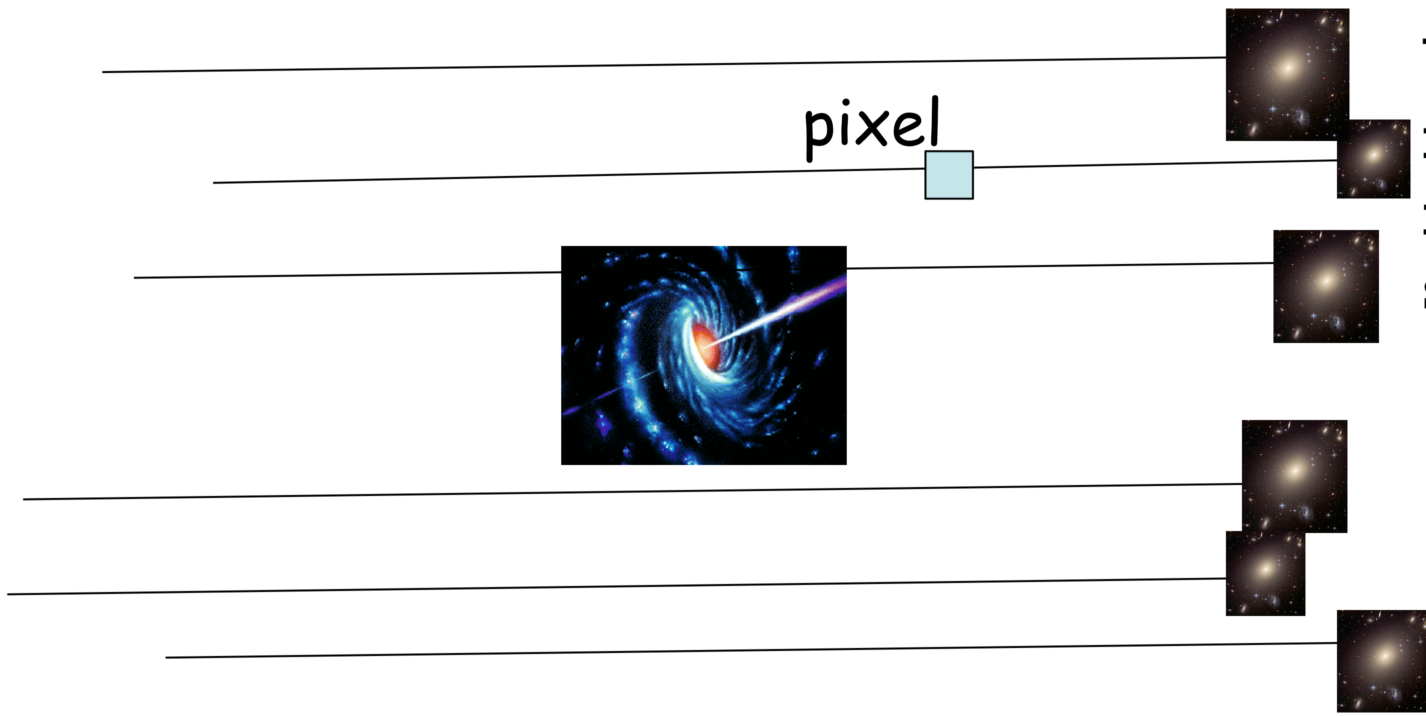
-look for Lya emission in fibers that pass close to QSOs



sky fibers?

Around QSOs the most photons are being pumped into the IGM.

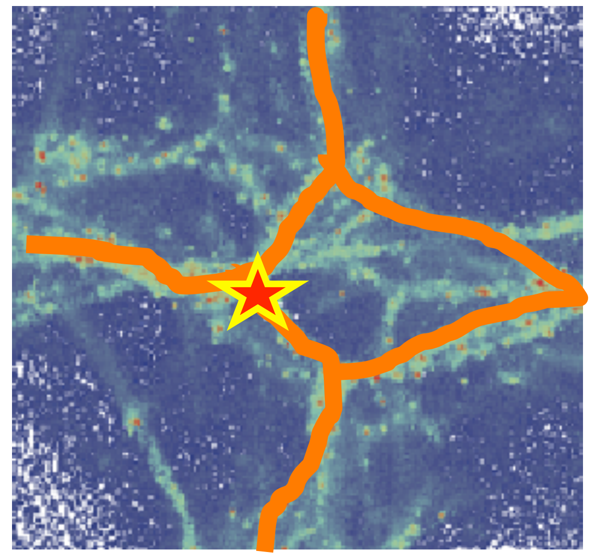
-look for Lya emission in fibers that pass close to QSOs



Use galaxy fibers with model galaxy subtracted

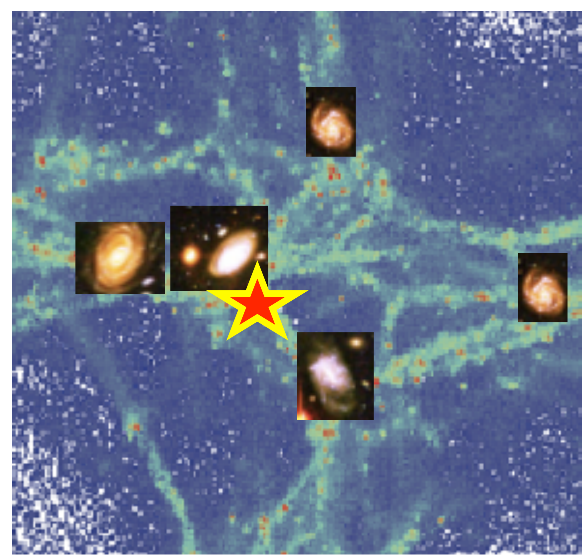
Use 530,000 galaxy fibers

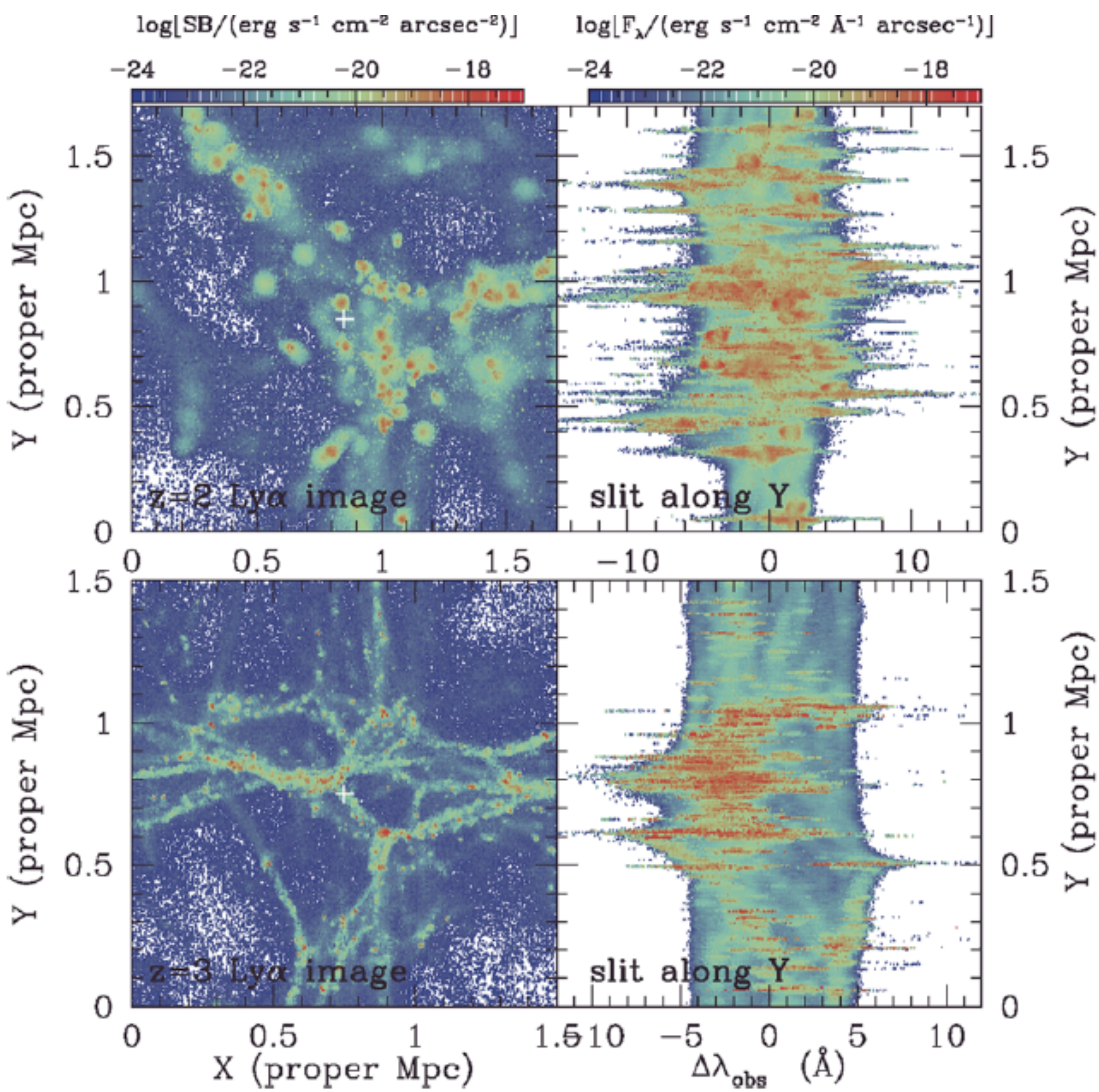
We expect 2 main contributions to Lya emission around QSOs:



(1) Fluorescent emission from IGM- mainly reprocessed quasar radiation.

(2) Emission from star forming galaxies clustered with QSOs.





Kollmeier et al. 2010

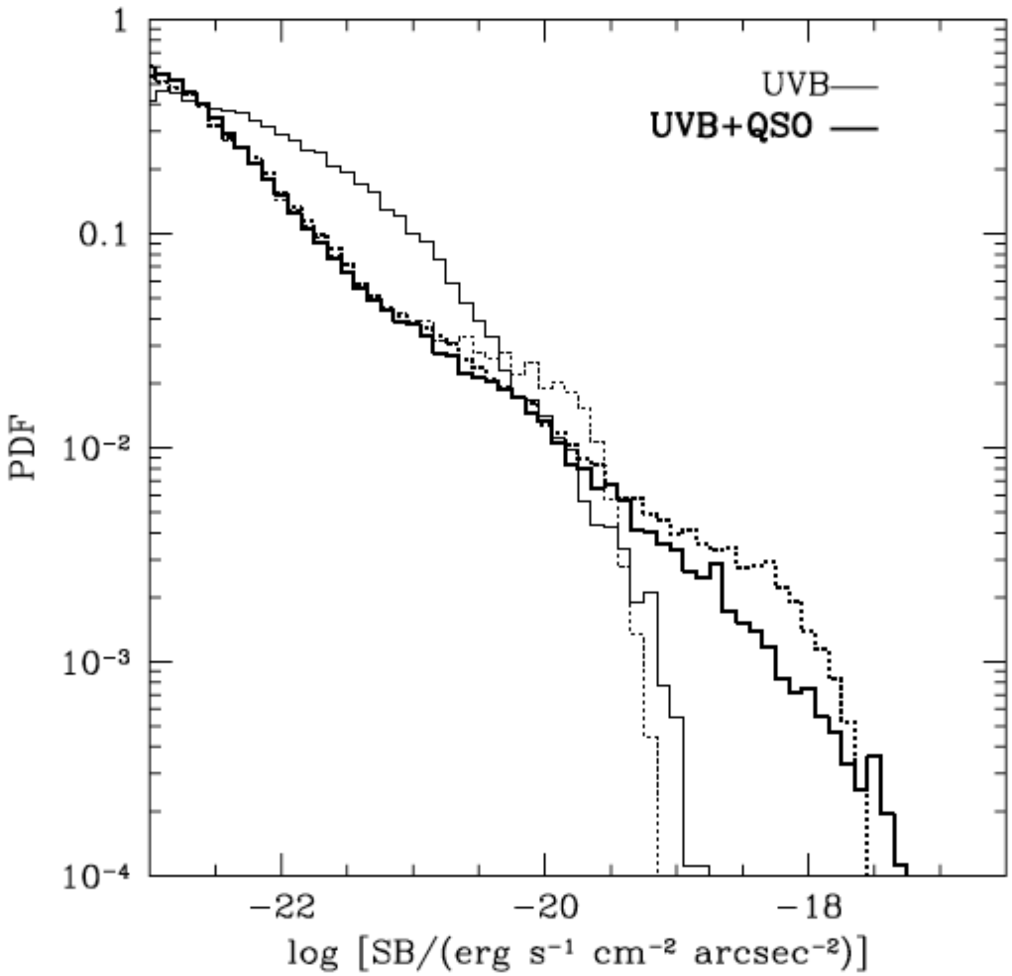


Figure 13. Distributions of resultant Lyα surface brightness of pixels for the UVB case and the UVB+QSO case. Solid (dotted) thin lines show the UVB-only case, and solid (dotted) thick lines show the UVB+QSO pixel distribution after (before) Lyα radiative transfer. The shift toward higher surface brightness pixels results directly from the quasar radiation impinging on the dense, optically thick clouds in the simulation.

Kollmeier et al 2010

Predictions? (1) Galaxies around QSOs.

$$\text{Profile of Lya emission= mean SB} \times \left(\frac{r}{r_0}\right)^{\gamma}$$

(a) RH piece: quasar-lyae cross-clustering:

From White et al. (2012) quasar bias=4
From Francke et al (2011) $b_{lyae}=1.8$

-> $b_{qso\text{-}lyae}=\mathrm{sqrt}(4^2+2^2)=2.8$

-> r0 in power law cross-correlation function at z=2.5 = 3.9 Mpc/h

(b) Second piece: integrate known Lye LF to (converges): Expect a mean SB of $\sim 1.2\times10^{-21}$ erg/cm^2/s/A/arcsec^2

Predictions?

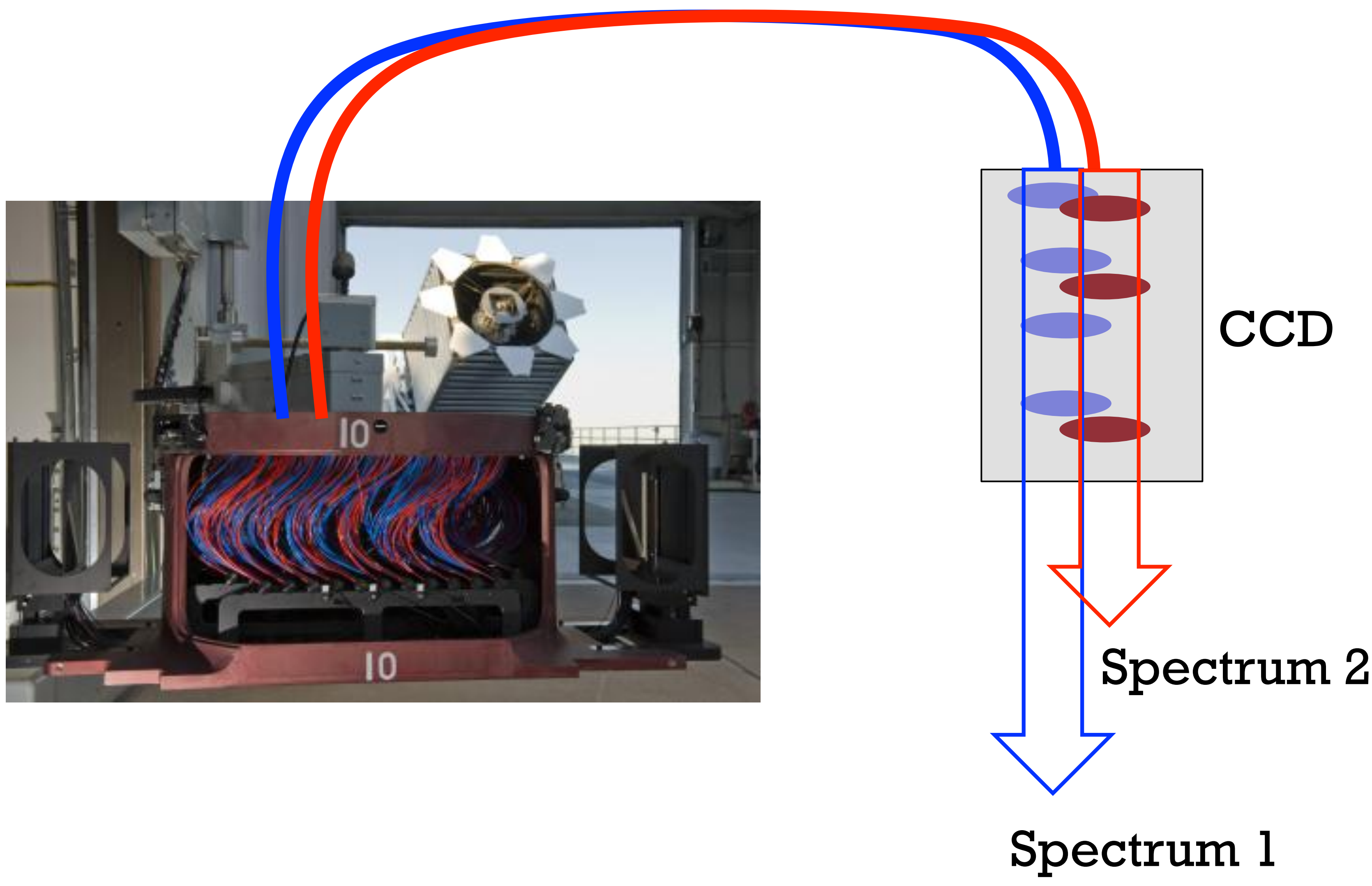
(2) QSO induced fluorescent AGN emission.

Very rough: For 1e44 erg/s luminosity in Lya line get equivalent emissivity epsilon_alpha at 4 Mpc/h
~ 5e39 erg/s/proper Mpc^3

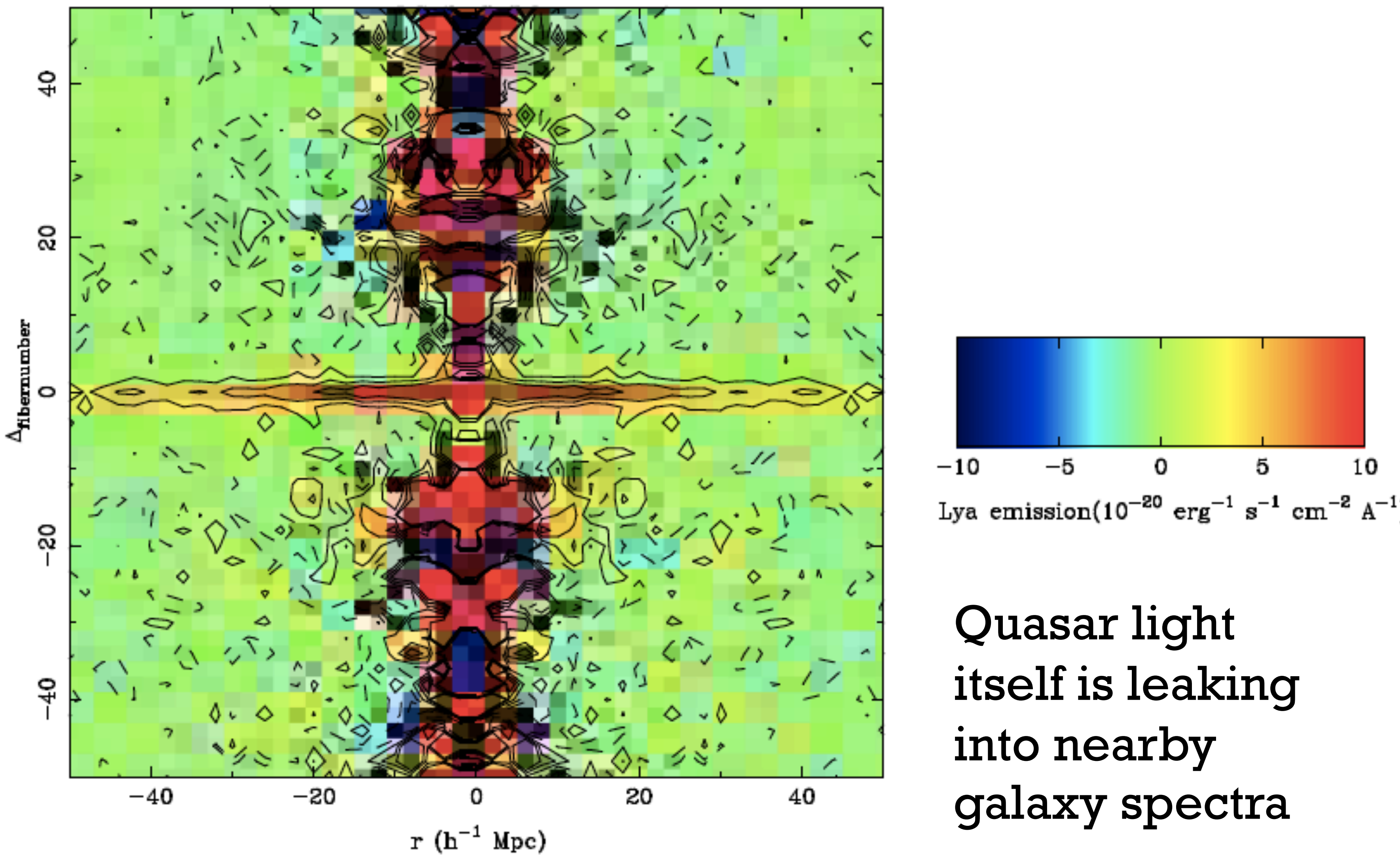
-> $\sim 10^{-21}$ erg/cm^2/s/A/arcsec^2
similar mean SB to Lya emitters.

(should use Lya RT sims around QSOs
e.g., Kollmeier et al. for real prediction)

Potential contamination: light from other fibers

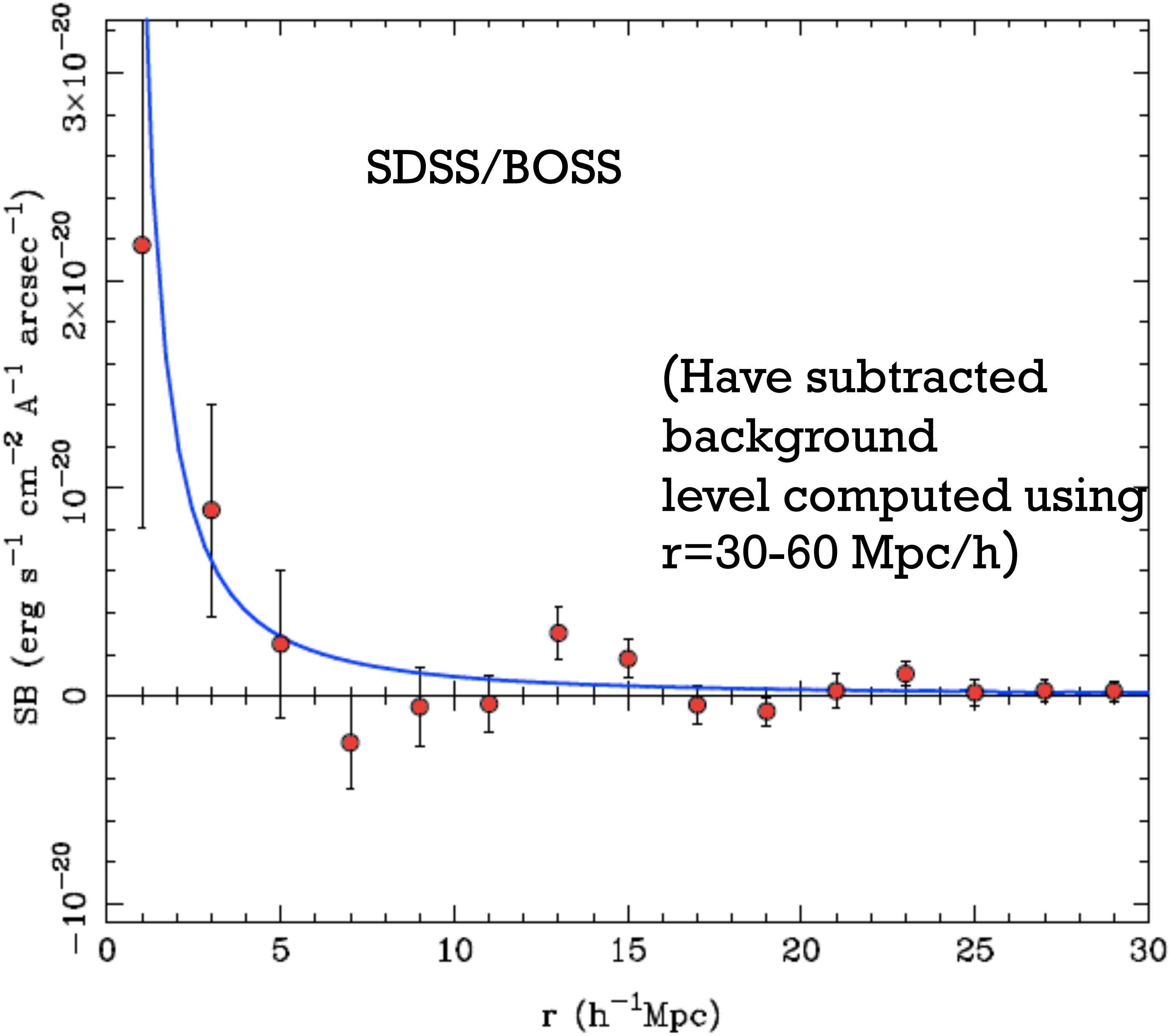


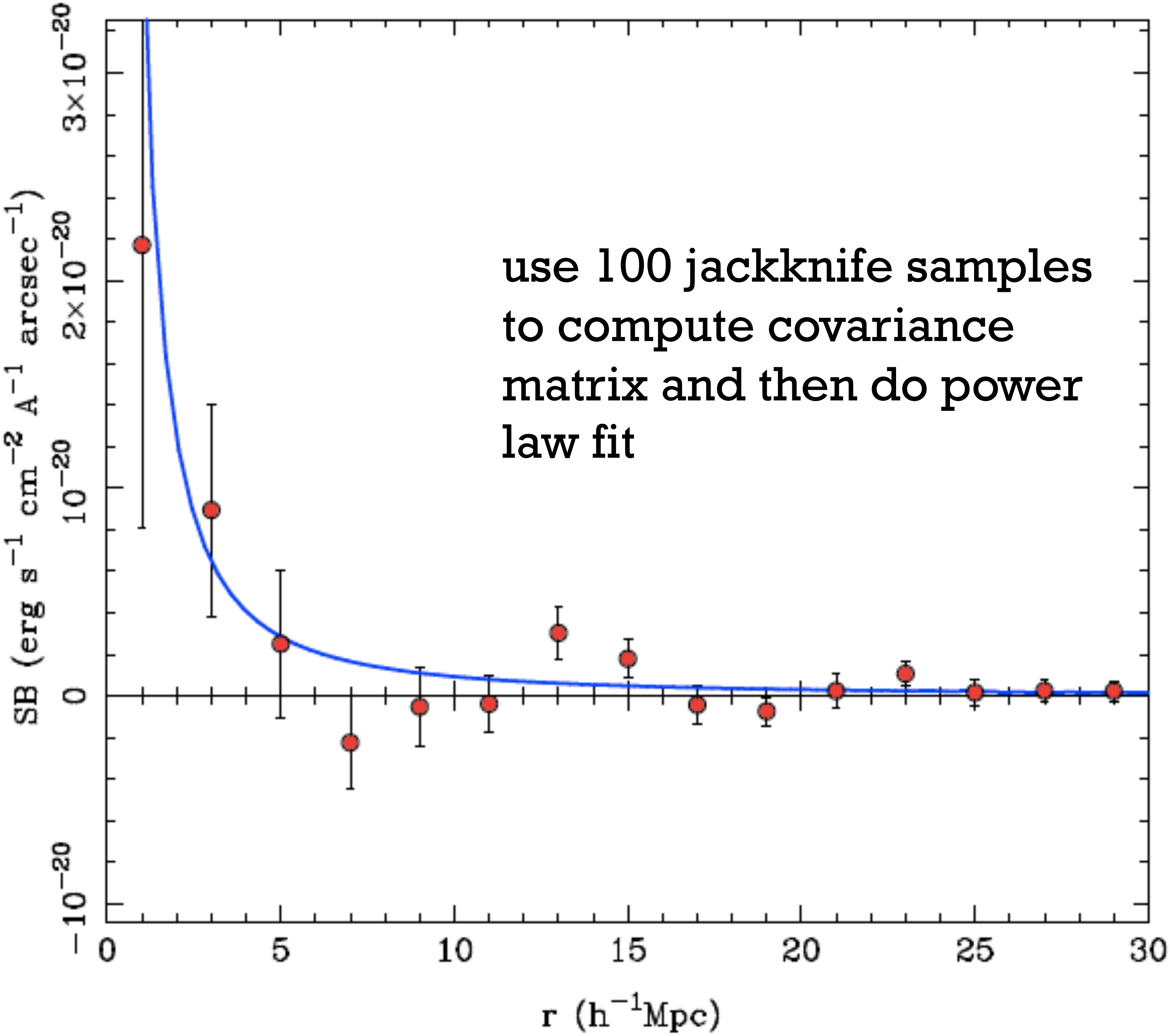
Signal vs difference between fiber numbers and r



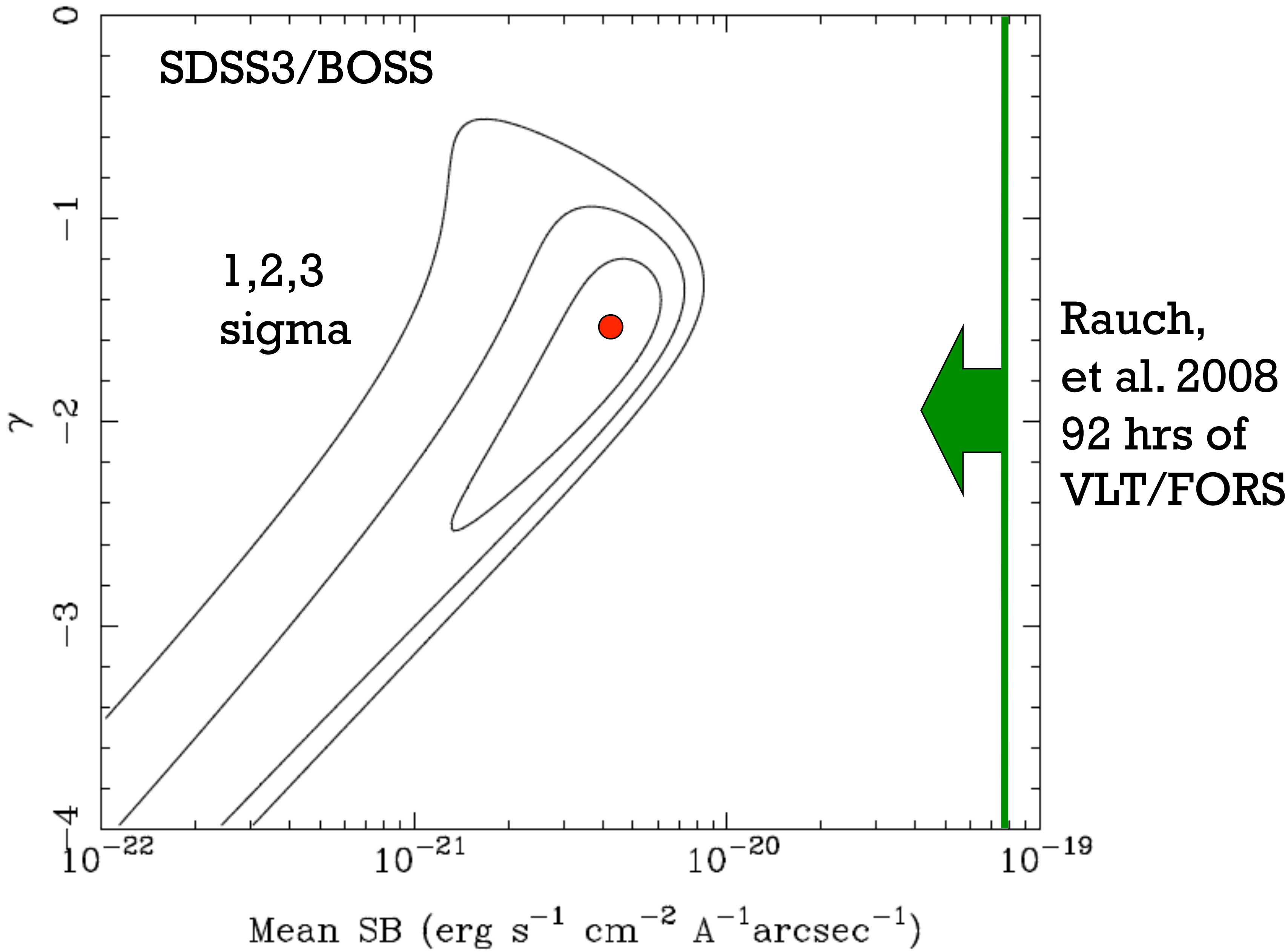
Quasar light itself is leaking into nearby galaxy spectra

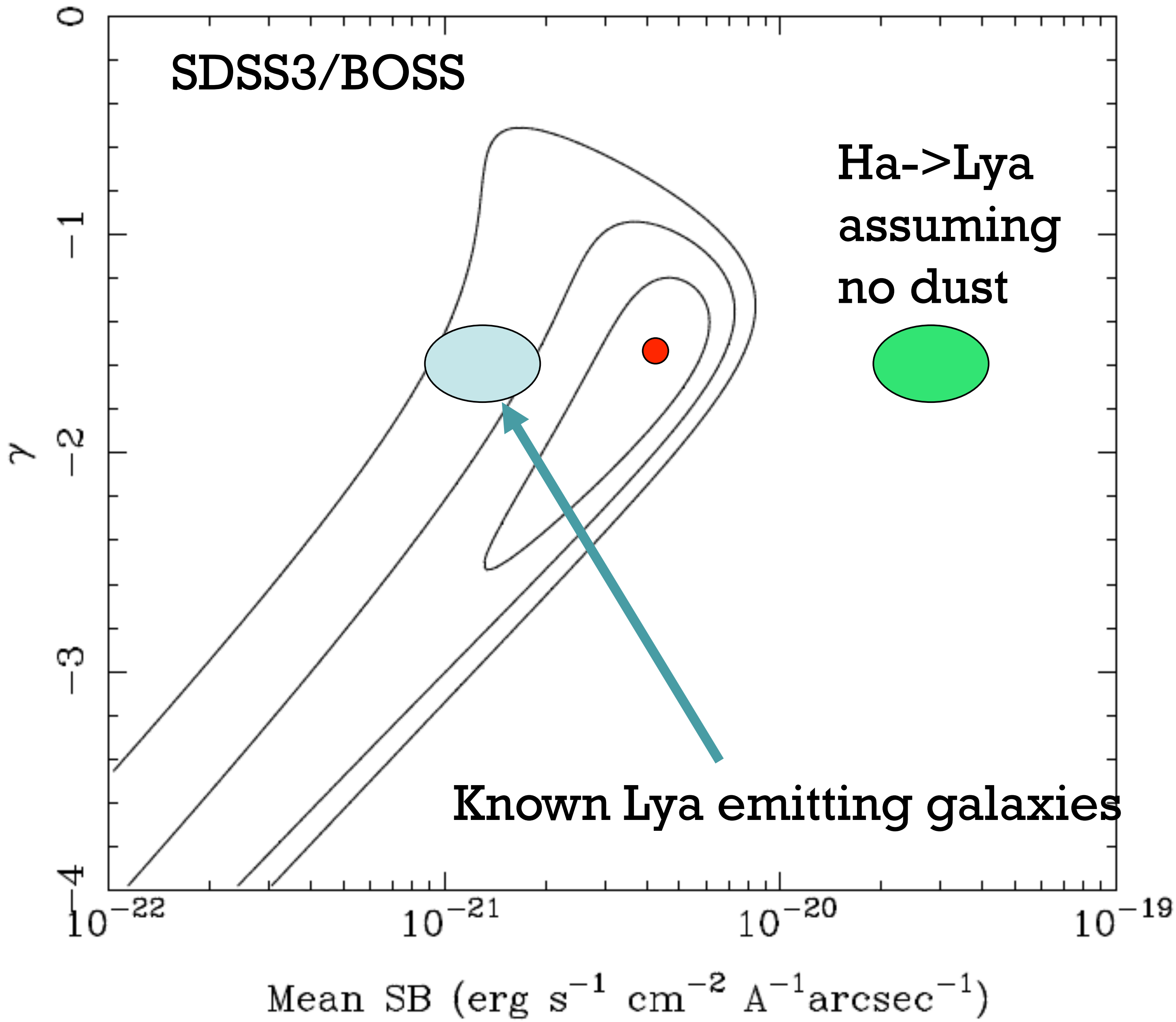
Solution: do not use quasar and galaxy spectra within 5 fibers


SDSS/BOSS
(Have subtracted
background
level computed using
r=30-60 Mpc/h)
SB (erg s^{-1} cm^{-2} A^{-1} arcsec^{-1})
3×10^{-20}
2×10^{-20}
10^{-20}
0
-10^{-20}
0
5
10
15
20
25
30
r (h^{-1}Mpc)

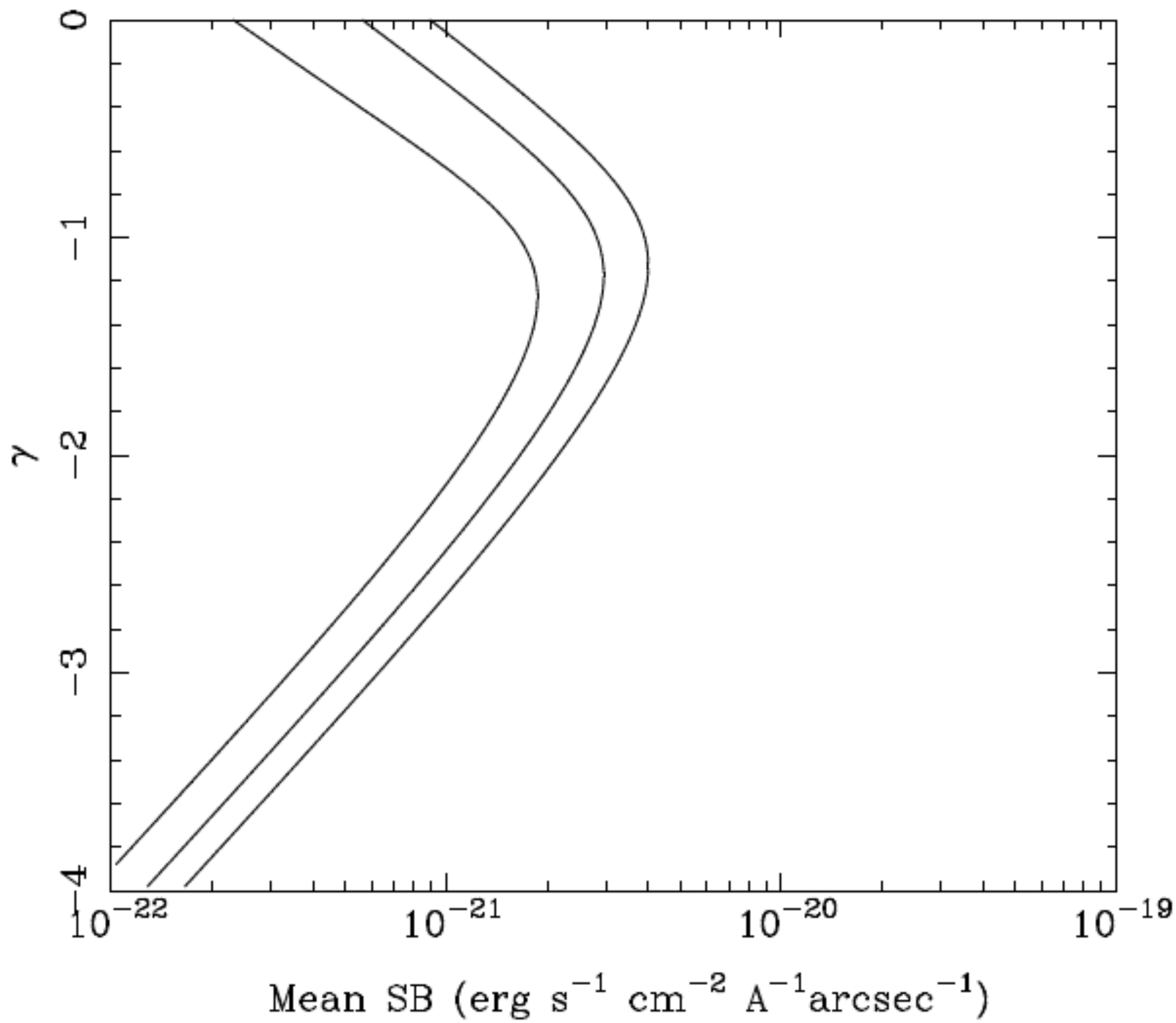


use 100 jackknife samples to compute covariance matrix and then do power law fit

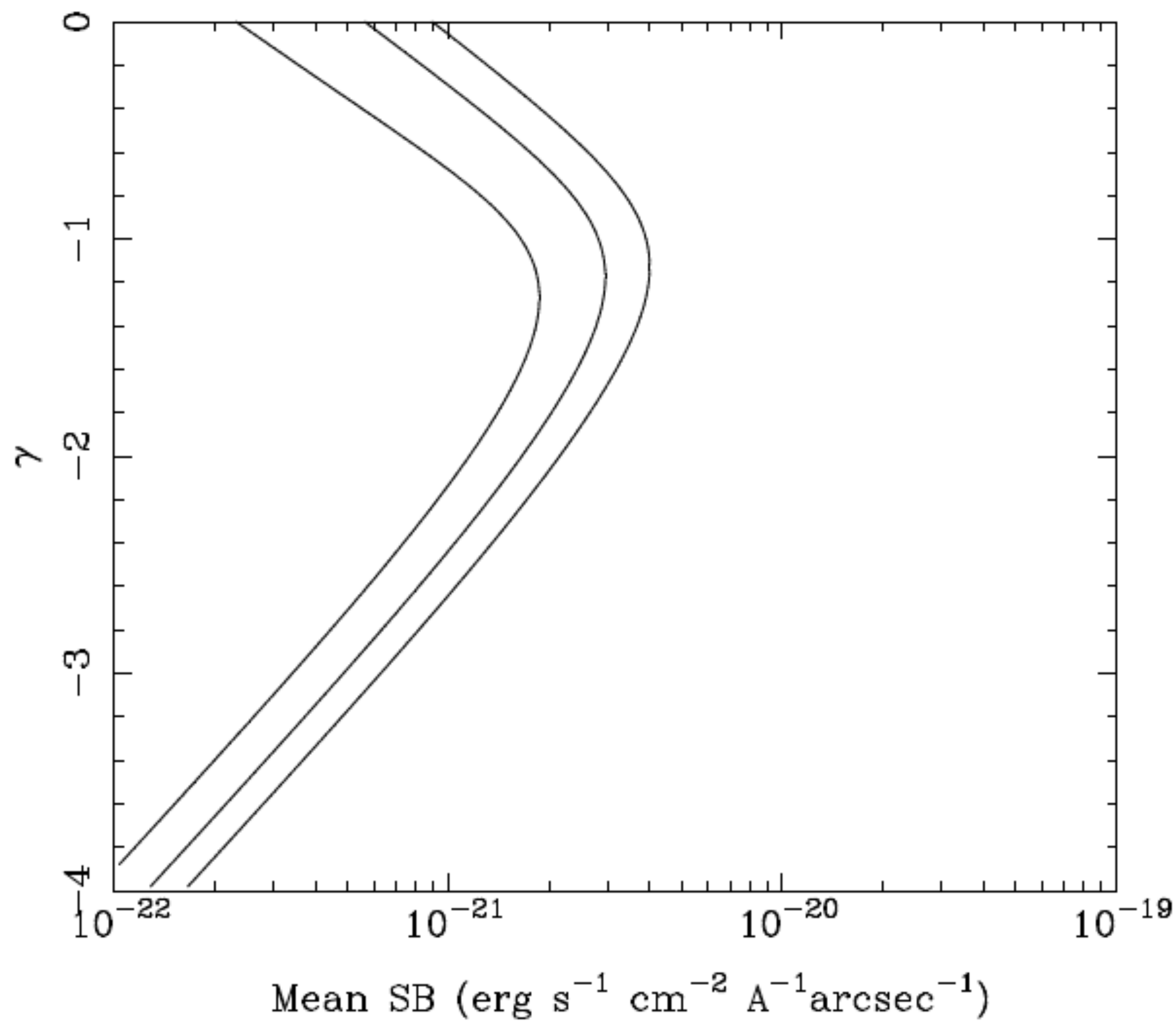

SDSS3/BOSS
1,2,3
sigma
Rauch,
et al. 2008
92 hrs of
VLT/FORS
γ
0
−1
−2
−3
−4
10^{-22}
10^{-21}
10^{-20}
10^{-19}
Mean SB (erg s^{-1} cm^{-2} A^{-1}arcsec^{-1})

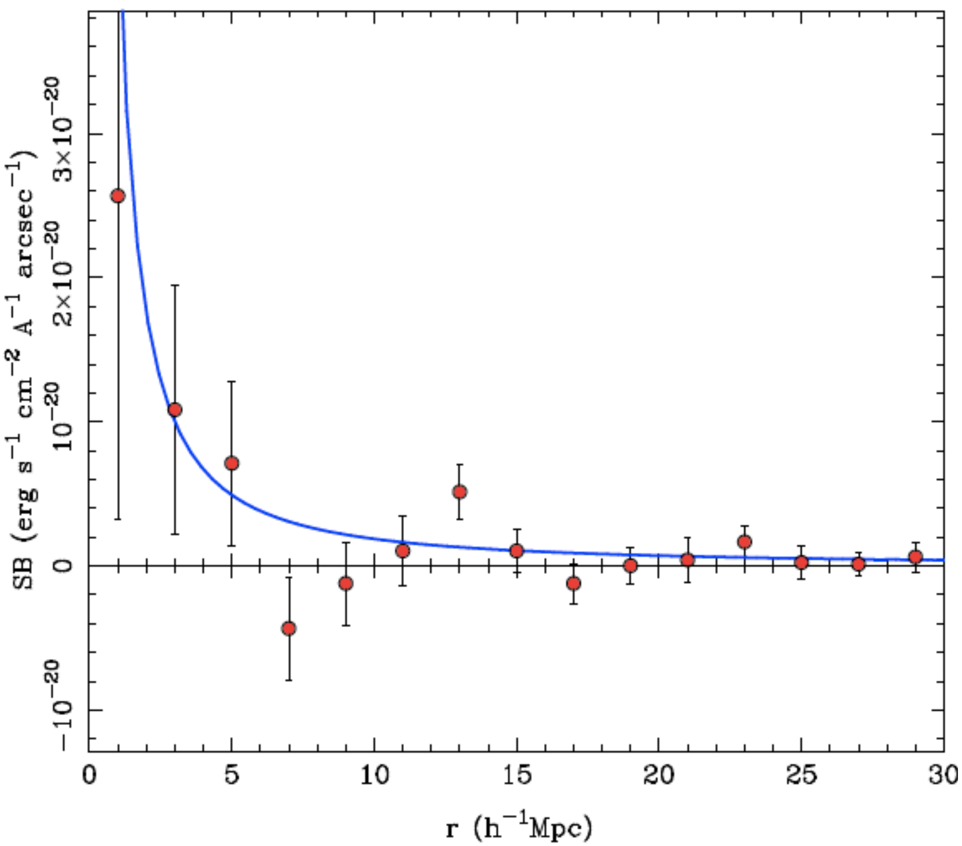

SDSS3/BOSS
Ha->Lya
assuming
no dust
Known Lya emitting galaxies
0
−1
−2
−3
−4
γ
10^{-22}
10^{-21}
10^{-20}
10^{-19}
Mean SB (erg s^{-1} cm^{-2} A^{-1}arcsec^{-1})

Check: randomize galaxy fiber angular positions



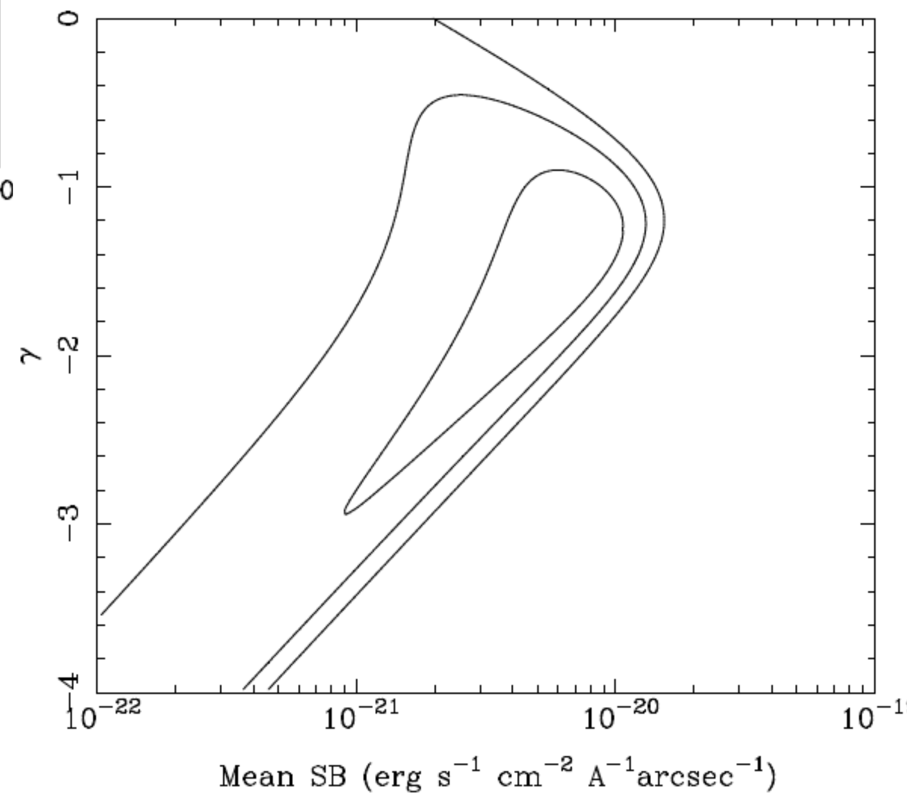
Check: center on wavelength other than Lya

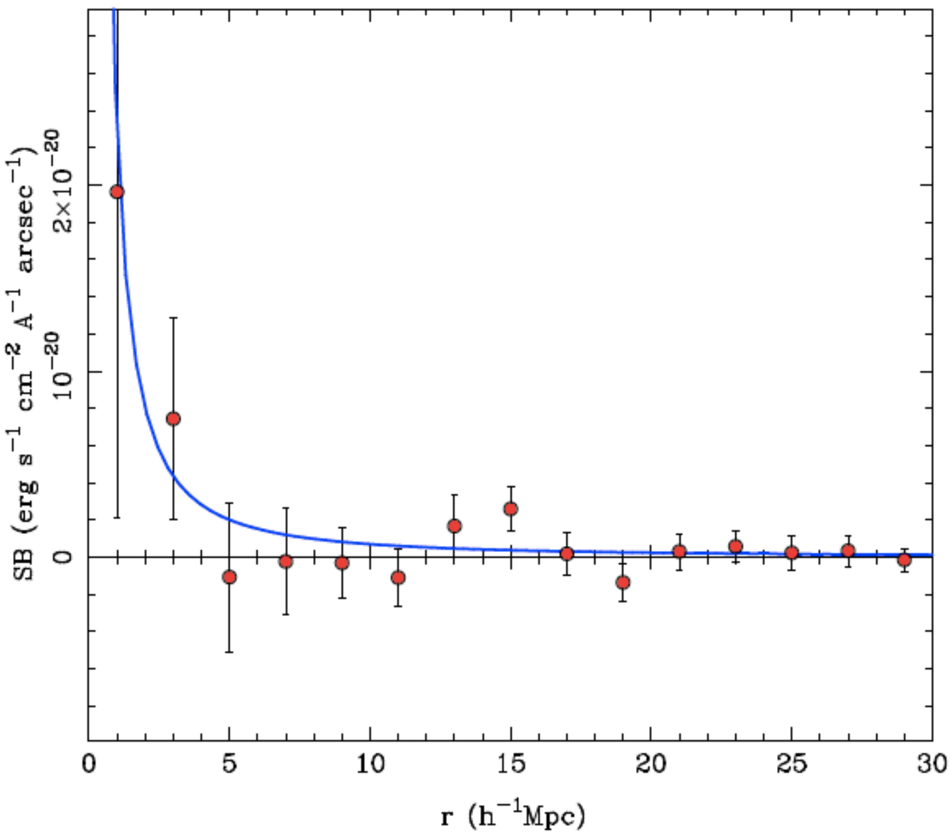




Low z half

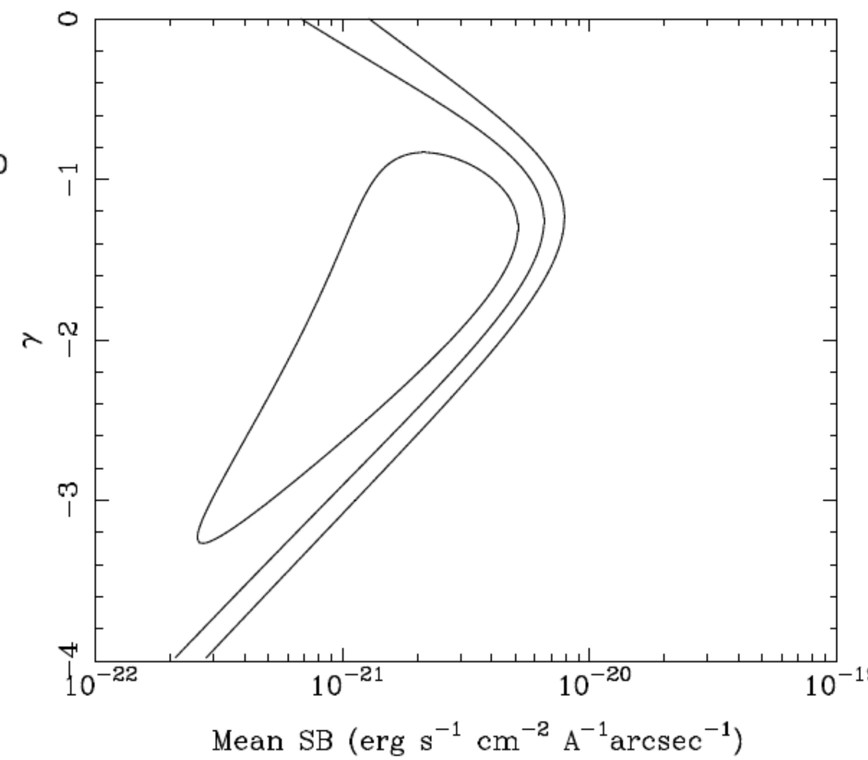
<z>=2.2





High z half

<z>=3.1



Conclusions

(1) What is mean Lya emissivity in the Universe, and how does it compare to integrating known Lya emitter LF?

3 sigma detection of mean Lya emissivity, value is 3x sum of known Lya emitters

(2) ~5% of Lya emission from galaxies can be seen directly at z~2.5. How much is absorbed by dust, and how much just scatters into IGM and can be detected?

The "true" escape fraction is between 5% and 20% (i.e. up to 15% scatters and can be detected)

(3) Can fluorescent emission from the IGM be detected?

Excess surface brightness over known lya galaxies is limited to be < 5e-21 erg/s/cm^2/arcsec^2 at 1 sigma (>10 times better than previous limits from 92hrs of VLT)

How many galaxies are expected to contribute to each bin?