What's regulating the escape of Lyα photons in high redshift star-forming galaxies? A view from the VANDELS survey

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and the VANDELS collaboration

VANDELS

Escape of Lyman radiation from galactic labyrinths - 11/14 September 2018 - Crete

INAF
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What's regulating the escape of Lya photons in high redshift star-forming galaxies?

Theoretical framework

The production of Lya photons depends on the on-going star-formation. However the Lya line is rather difficult to interpret since Lya photons can be **absorbed by dust** and can be **scattered by the neutral hydrogen** in the galaxy.

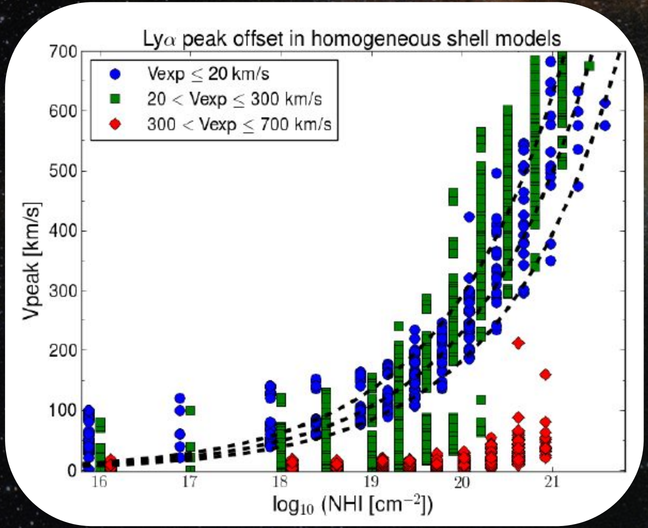
In particular **the velocity of the red-peak** of the Lya line profile is deeply affected by the neutral hydrogen column density (NHI) and the gas kinematics (in particular the velocity of the galactic outflows)
According to Verhamme et al. 2015, in the shell model scenario:

- small Lya velocity shifts can be due to:
  - **low NHI** (<10^{19} cm^{-2}) and **small outflow velocities** (<300 km/s)
  - **very large outflow velocities** (>300 km/s) regardless of NHI
- large Lya velocity shifts can be due to:
  - large NHI and v_{exp}<300 km/s

The **Lya spatial extent with respect to the UV continuum** can provide information about the HI column density (Verhamme et al. in prep.):

- Large values would be caused by **NHI>10^{19} cm^{-2}**, because the scattering is very efficient
- small values would imply either a small NHI or a large NHI but with very high outflow velocity

Verhamme et al. 2015



VANDELS

A deep VIMOS survey of the CANDELS UDS and CDFS fields

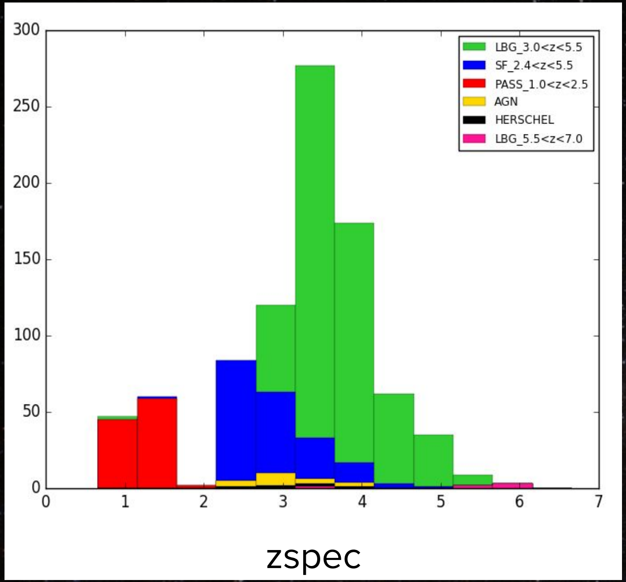
ESO public VIMOS spectroscopy survey of the UDS and CDFS fields

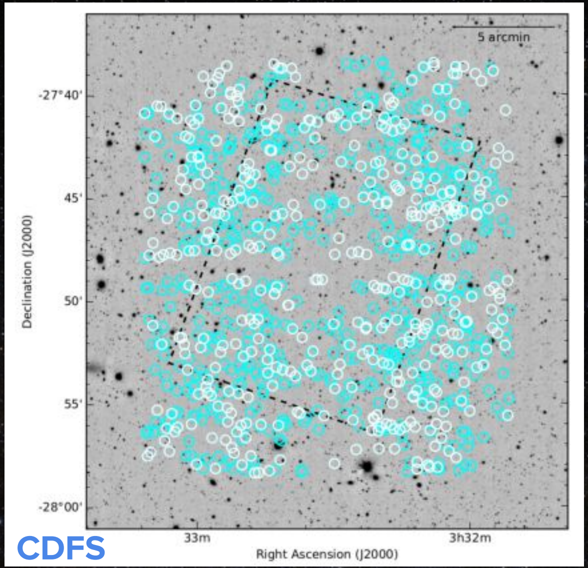
McLure et al. 2018
Pentericci et al. 2018

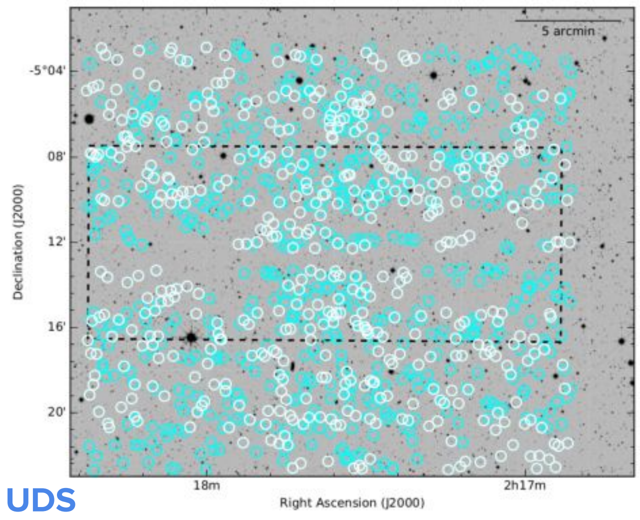
What is it?

- 912 hours of VIMOS visitor time: 2015-2018 → observation completed!
- spectra between ~4800-9800 Å
- 20-80 hours integration time, focused on z>3 star-forming galaxies
- Medium resolution ~600
- Science goals: ages, masses, stellar metallicities and outflows at high-z
- Raw data immediately public
- Regular releases of reduced data (DR1 available, DR2 available soon)
- Full details can be found at: **vandels.inaf.it**

VANDELS data release one (DR1): 5th Oct. 2017 (Pentericci et al. 2018)







(McLure et al. 2018)

The data release which is now available on the ESO webpages includes the spectra for all galaxies for which the scheduled integration time was completed during season one. In addition, it includes the spectra for those galaxies for which the scheduled integration time was 50% complete at the end of season one (i.e. 20/40 hours and 40/80 hours).

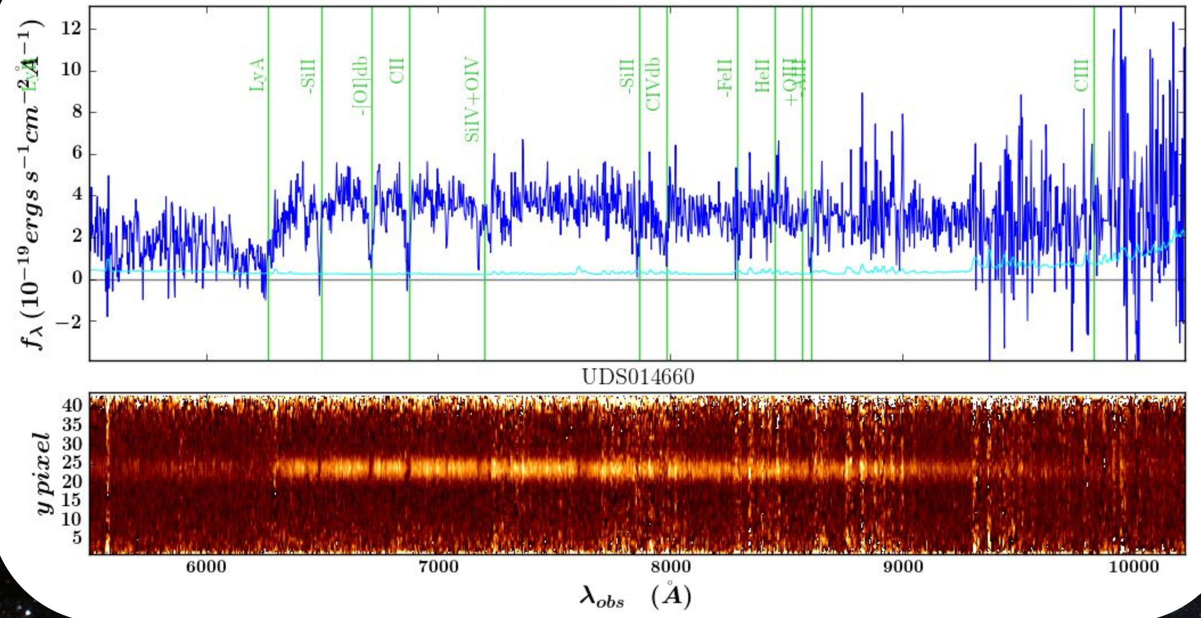
The total number of spectra released is 879 (415 in CDFS and 464 in UDS)

Francesca Marchi

VANDELS data release two (DR2): available soon

Total number of spectra that will be released: 1339 (557 in CDFS and 762 in UDS)
more than 200 spectra with ultradeep **80 hours exposures**!

Example of a **80 hours** spectrum: a star forming galaxy (UDS014660) at **z=4.15** with **f814w=24.26**



What's regulating the escape of Lya photons in high redshift star-forming galaxies?

Sample selection

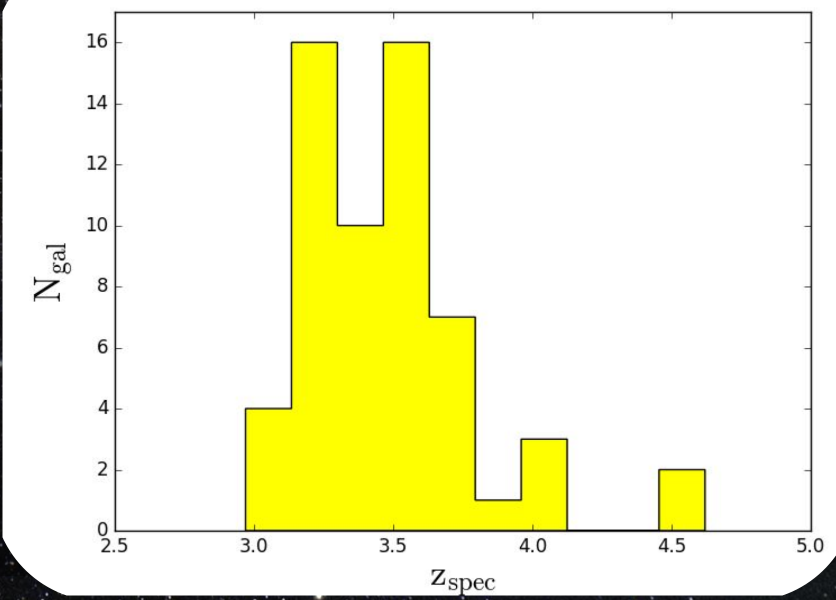
All the VANDELS galaxies in DR1 and DR2 with high quality spectroscopic redshift $3 \lesssim z \lesssim 4.5$ in UDS and CDFS.

Selection criteria:

- **Lya** emission
- **CIII[1909]** or **HeII[1640]** in emission to derive the systemic redshift
- **good SNR** in the continuum range 1420-1520 Å rest frame

→ ~60 galaxies

z_{median}=3.46
$zmag_{median}$=25.4



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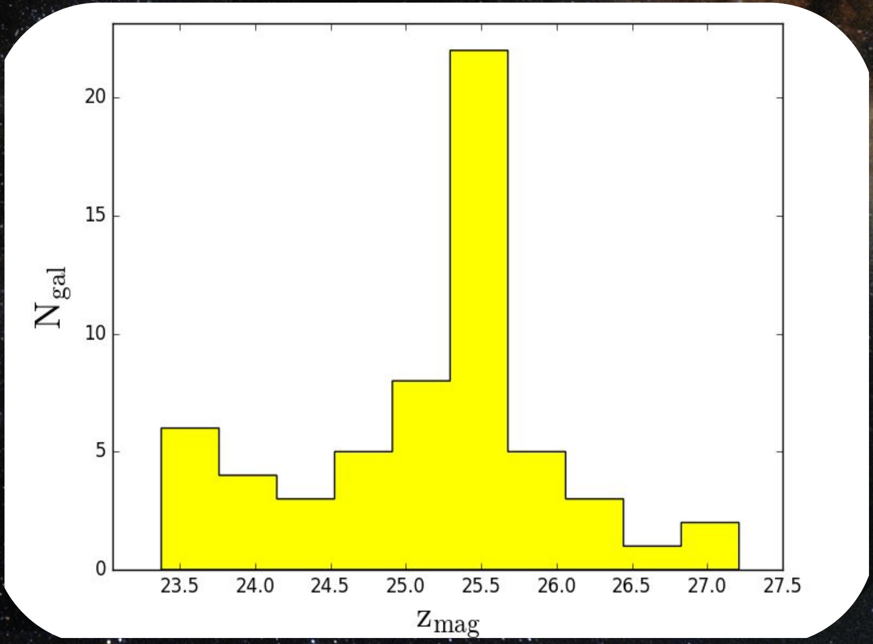


What's regulating the escape of Lyα photons in high redshift star-forming galaxies?

Method- from the **VANDELS spectra** we measure the following properties:

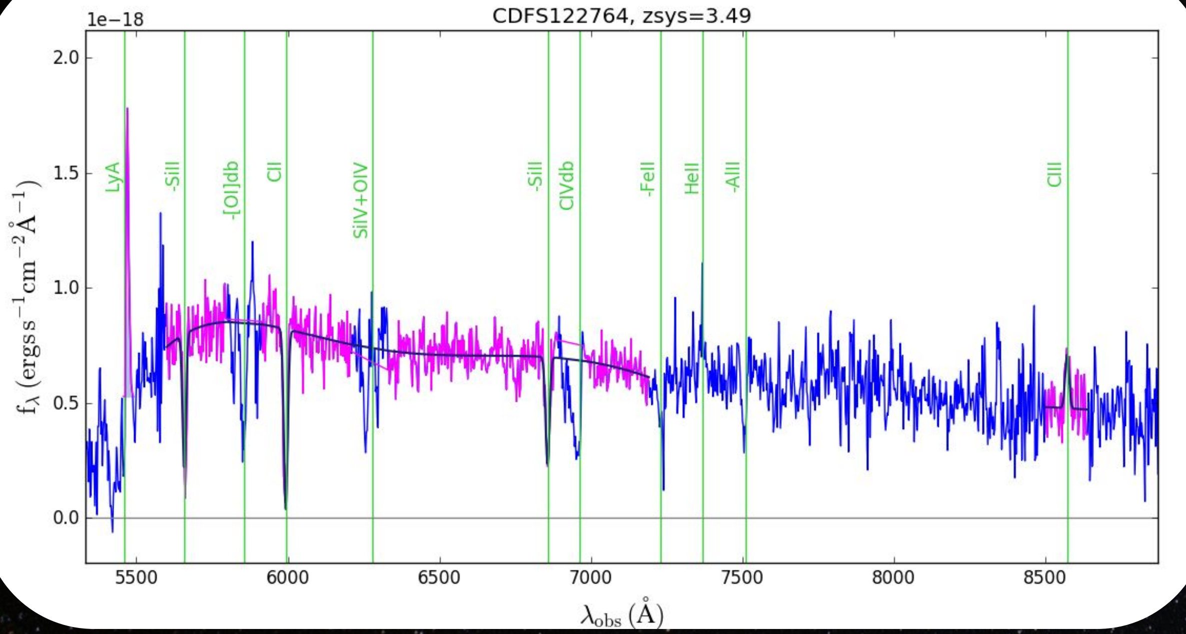
- **zsys** determined by fitting the nebular emission lines (CIII[1909 for the majority of galaxies or HeII[1640) with a gaussian fit plus a straight line
- **EW(Lyα)** from the 1d spectrum
- **Lyα velocity shift** with respect to the systemic redshift from the position of the peak of the line in the 1d spectrum
- **FWHM(Lyα)** from the 1d spectrum
- **EW(CIII)** where present
- **IS shift** with respect to the systemic redshift from a combined fit of SiII(1260), CII(1303) and SiII(1526.7). We fitted the UV spectrum with a 5th order polynomial + 3 gaussians
- **rUV** from the FWHM of the collapsed 2D spectrum in the range ~1400-1500 Å
- $\mathbf{Ly\alpha_{ext}}$ from the FWHM of the collapsed 2D spectrum in the Lyα range (~1210-1220 Å)

N.B. not all these quantities could be measured for all the galaxies in the sample

What's regulating the escape of Lyα photons in high redshift star-forming galaxies?

Method- from the **VANDELS spectra** we measure the following properties:

example: CDFS122764 at z=3.49



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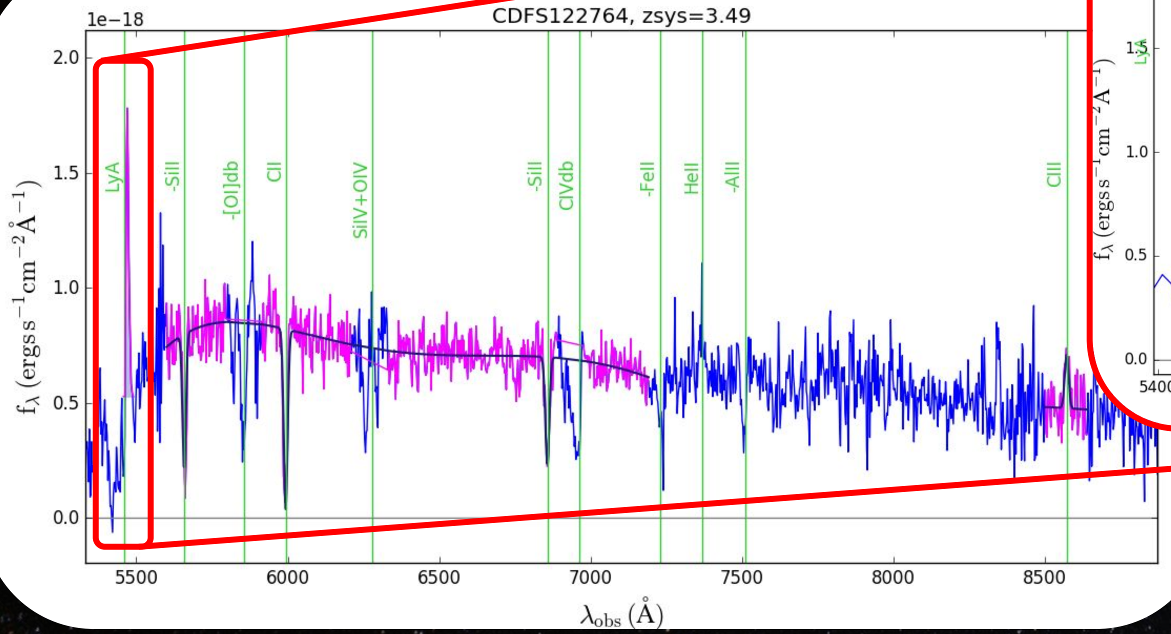

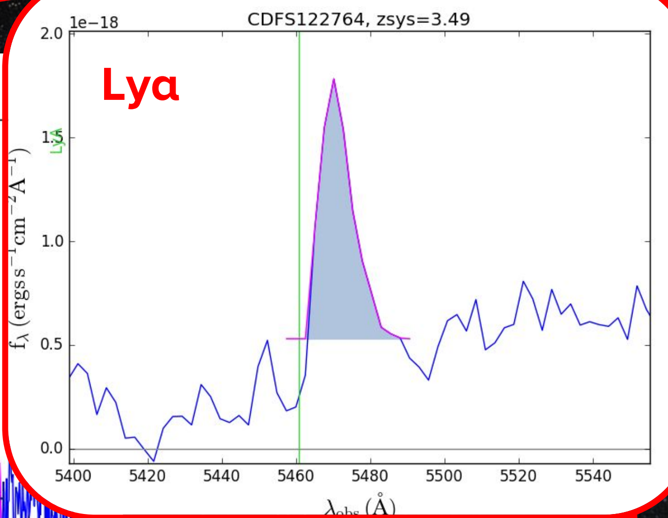

N.B. the shaded region represent the EW(Lyα)

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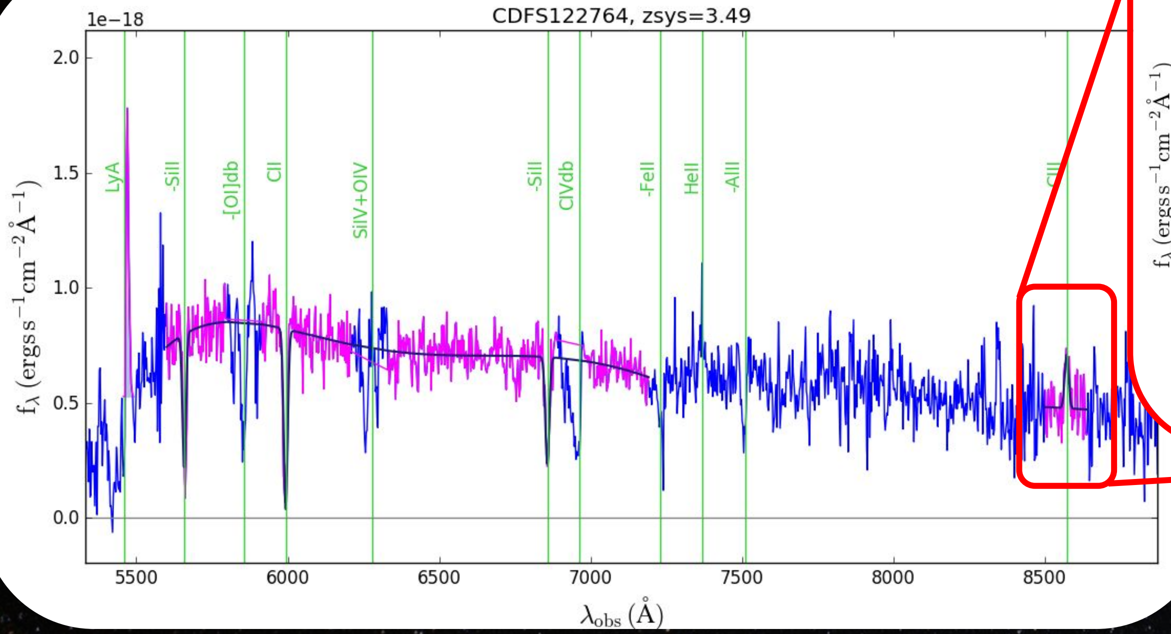

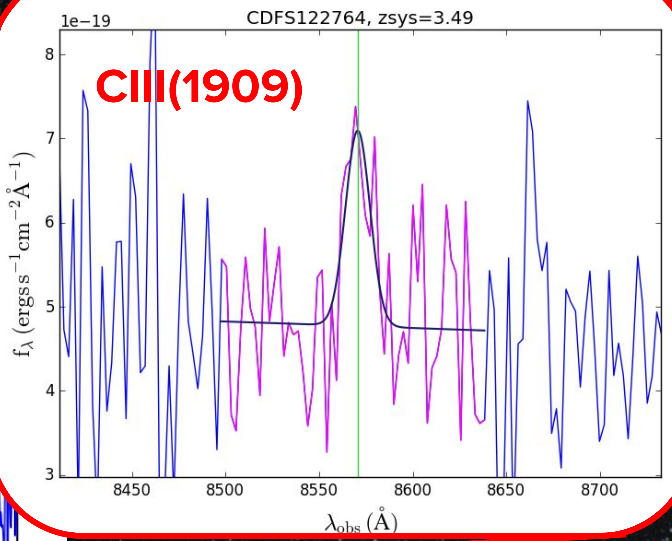

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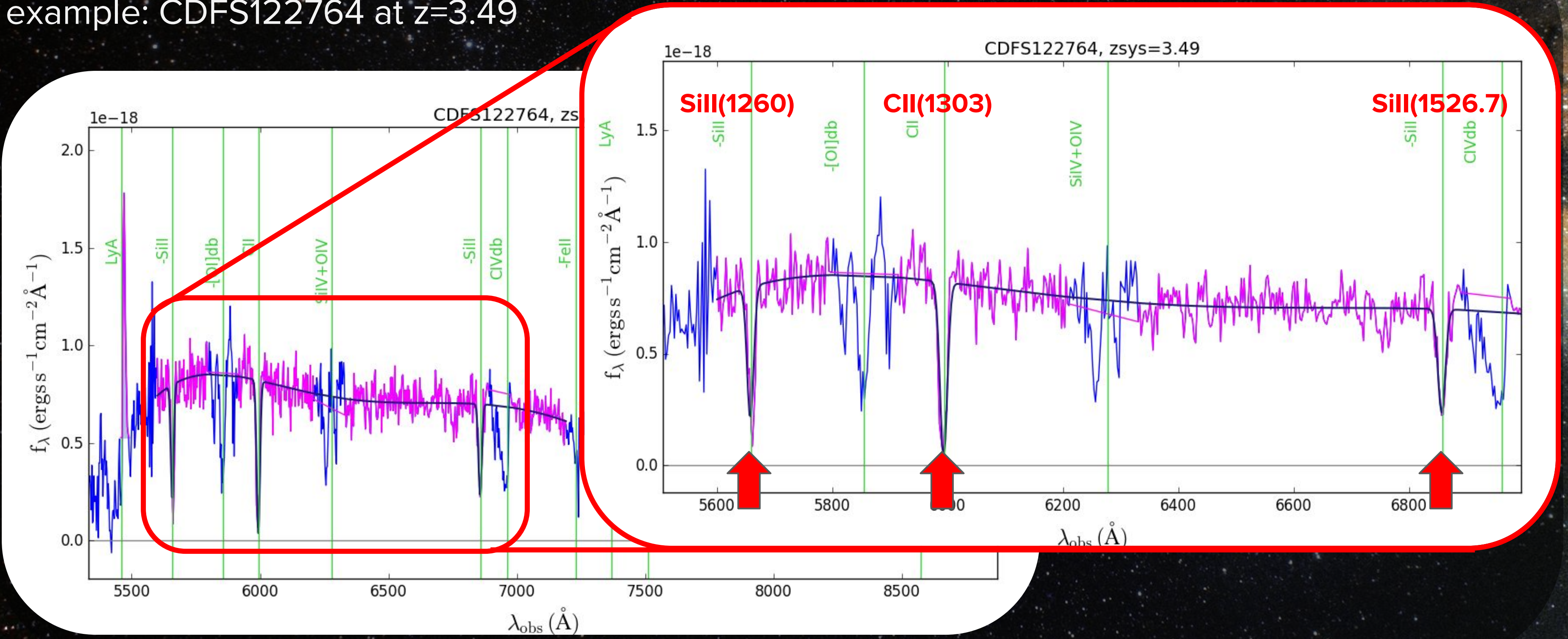


What's regulating the escape of Lyα photons in high redshift star-forming galaxies?

Method: using the **BEAGLE tool** (Chevallard et al. 2016) we derive the physical properties

The BEAGLE tool incorporates the consistent modelling of stellar radiation and its transfer through the interstellar and intergalactic media, allowing one to interpret, in a *Bayesian framework*, any combination of photometric and spectroscopic galaxy observations.

We use:

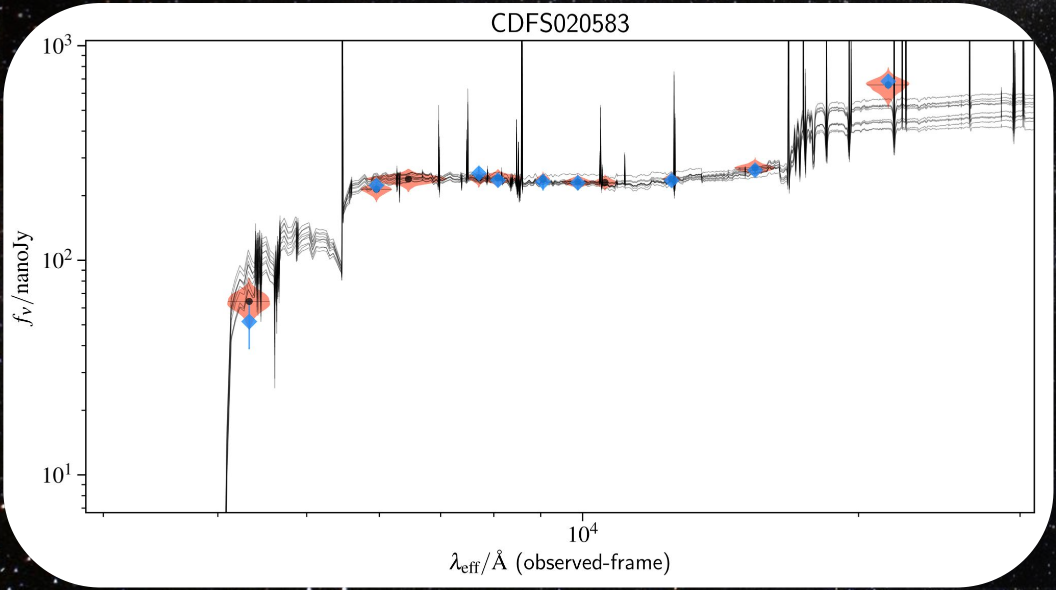
- z fixed at the VANDELS redshift
- Stellar emission from the latest model of Bruzual & Charlot
- Nebular emission (Gutkin, Charlot & Bruzual 2016)
- Fixed IMF (Chabrier 2003)
- Constant SFH
- Fixed metallicity $Z=0.1\,Z_\odot$
- Calzetti attenuation law for the dust
- the CANDELS photometric catalogue for the sources in the CANDELS footprint and the *new photometric catalogue* generated for the sources in the wide-field areas of the CDFS and UDS fields (McLure et al. 2018)

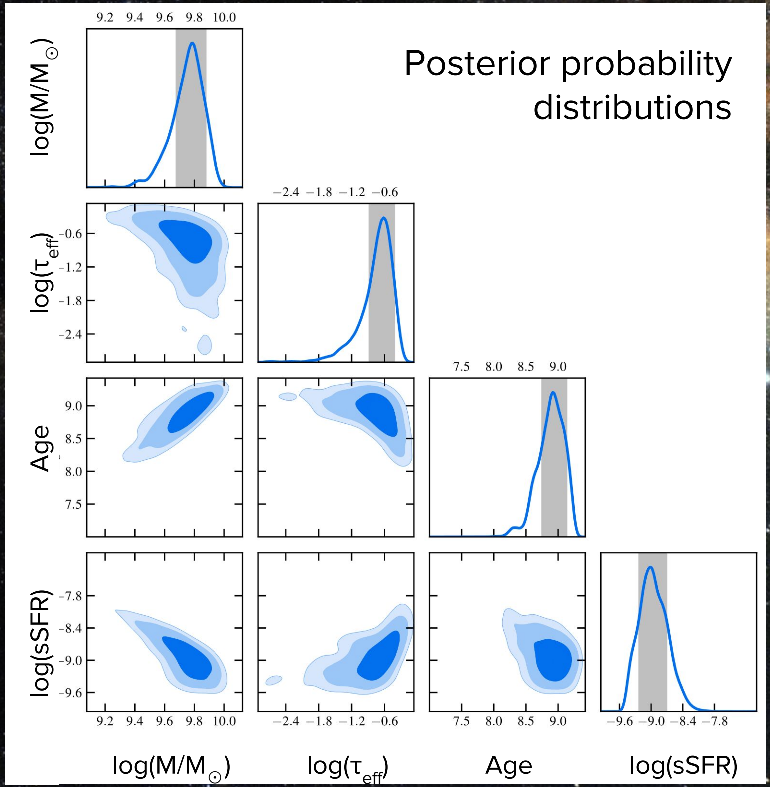
Field	Filter	Depth(5σ)	Telescope
UDS	*U*	27.0	CFHT
	B	27.8	Subaru
	V	27.4	Subaru
	R	27.2	Subaru
	i′	27.0	Subaru
	z'_1	26.0	Subaru
	z'_2	26.4	Subaru
	NB921	25.8	Subaru
	Y	25.1	VISTA
	J	25.5	UKIRT
	H	24.9	UKIRT
	K	25.1	UKIRT
CDFS	*U*	27.8	VLT
	B	27.1	ESO 2.2-m
	IA484	26.4	Subaru
	IA527	26.4	Subaru
	IA598	26.2	Subaru
	V_{606}†	26.6	*HST*
	IA624	26.0	Subaru
	IA651	26.3	Subaru
	R	27.2	VLT
	IA679	26.2	Subaru
	IA738	26.1	Subaru
	IA767	25.1	Subaru
	z_{850}†	25.6	*HST*
	Y	24.5	VISTA
	J	24.7	CFHT
	H	23.8	VISTA
	K	24.1	CFHT

What's regulating the escape of Lyα photons in high redshift star-forming galaxies?

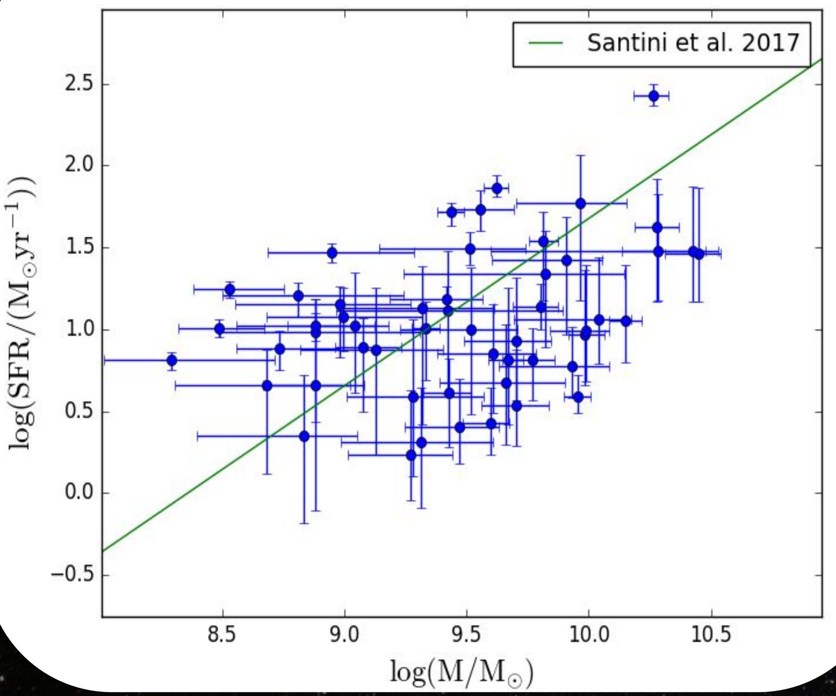
Method: using the **BEAGLE tool** to derive the physical properties

Example of a SED and a triangle plot:
CDFS020583 at z=3.5





What's regulating the escape of Lyα photons in high redshift star-forming galaxies?



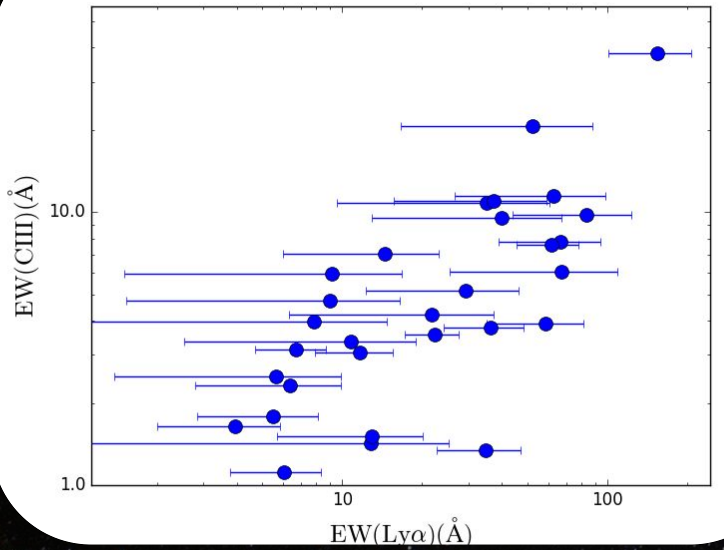
Our galaxies lie on the main sequence in the SFR-M plane (Santini et al 2017)

<u>log(M/M$_\odot$) range</u>: 8.3 - 10.6
<u>SFR range</u>: 2 - 200 $M_\odot yr^{-1}$

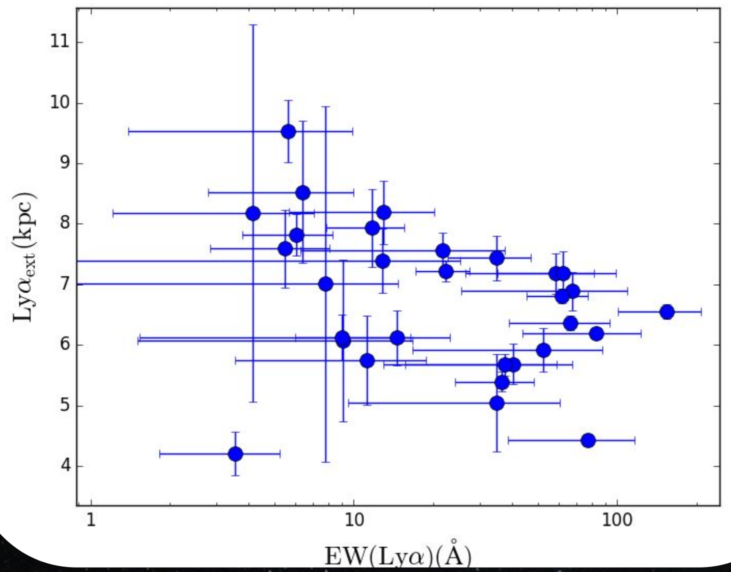
What's regulating the escape of Lyα photons in high redshift star-forming galaxies?

Results:

We confirm that **Lyα EW** is correlated with the **EW(CIII)** and anti-correlated with the **Lyα extent**.
See e.g. Le Fèvre et al. 2017 and Stark et al. 2014 for the former and Guaita et al. 2017 (from stacks) for the latter.



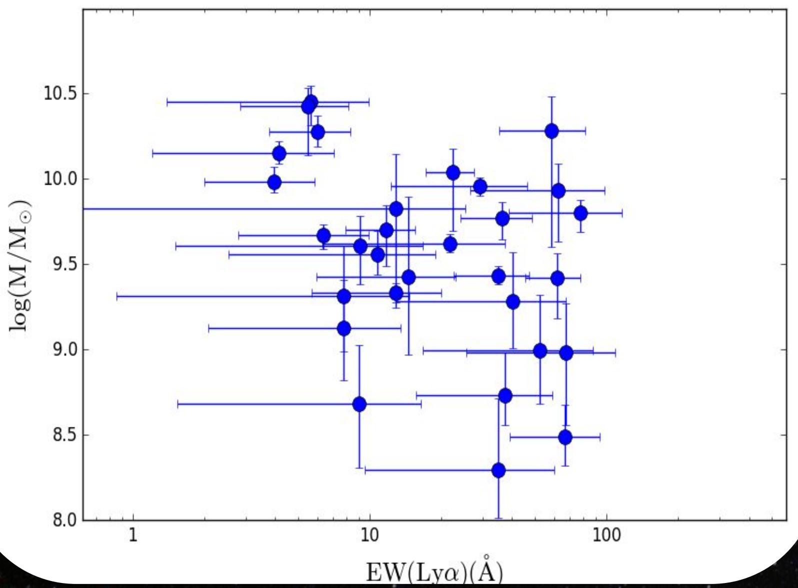
Spearman rank correlation coefficient: 0.73



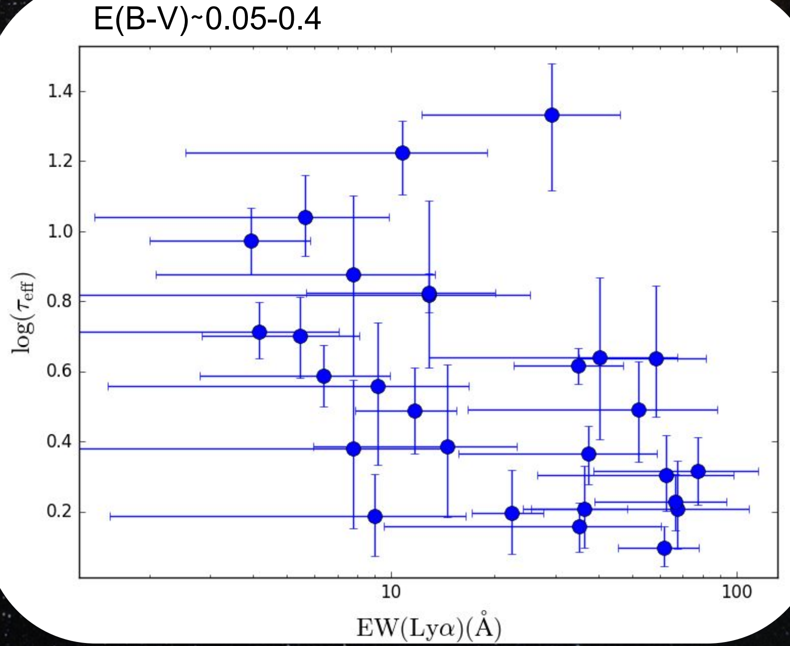
Spearman rank correlation coefficient: 0.38

What's regulating the escape of Lyα photons in high redshift star-forming galaxies?

We also observe a correlation between **EW(Lyα)** and **Stellar Mass** which was observed by some works (e.g. Finkelstein et al. 2007; Bouwens et al. 2007; Pentericci et al. 2010) but not by others (e.g. Shapley et al. 2003, Kornei et al. 2010) and the known correlation between **EW(Lyα)** and **dust content.**



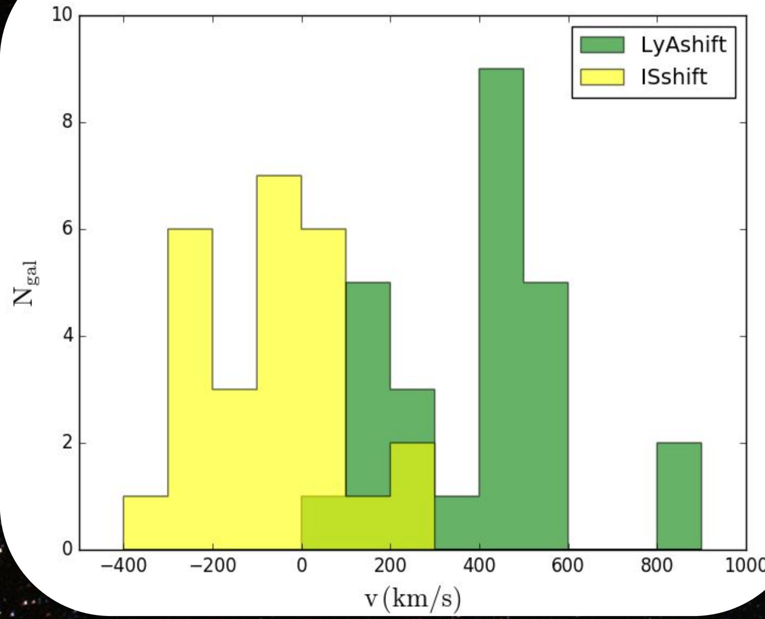
Spearman rank correlation coefficient: 0.39

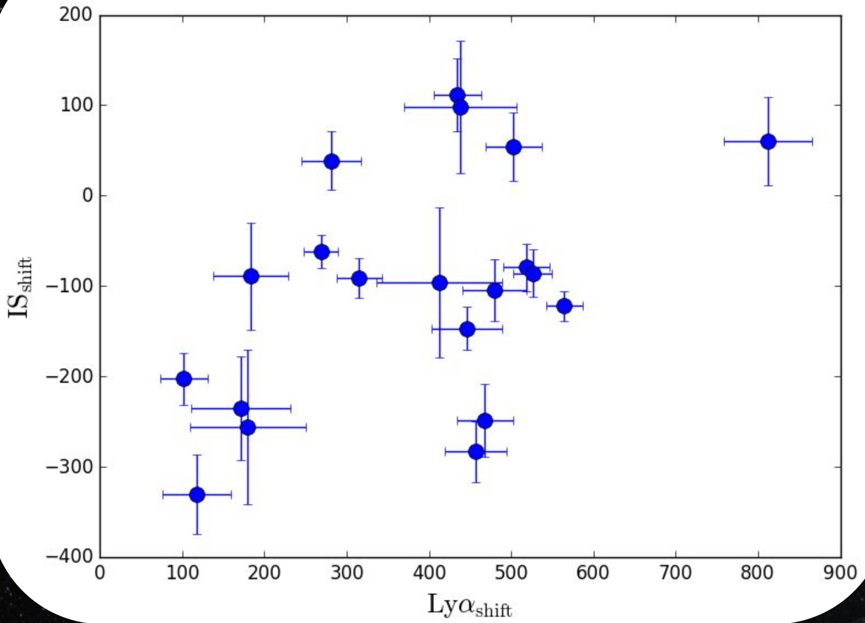


Spearman rank correlation coefficient: -0.54

What's regulating the escape of Lyα photons in high redshift star-forming galaxies?

We observe a well defined correlation between IS and LyA velocity shifts (both for outflows and inflows)





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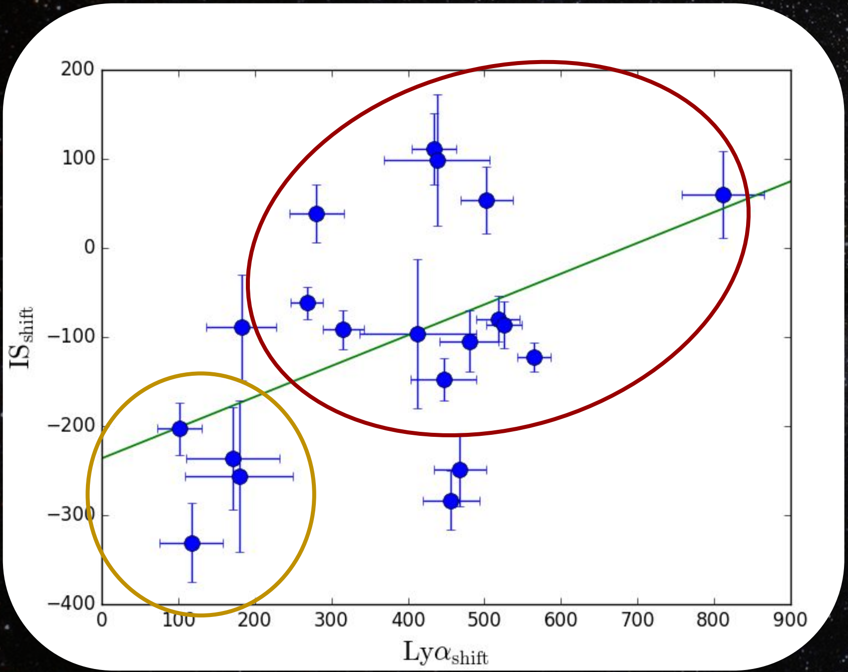


Spearman rank correlation coefficient: 0.35

We can interpret this relation in the context of the **shell model** (e.g., Verhamme et al 2015):

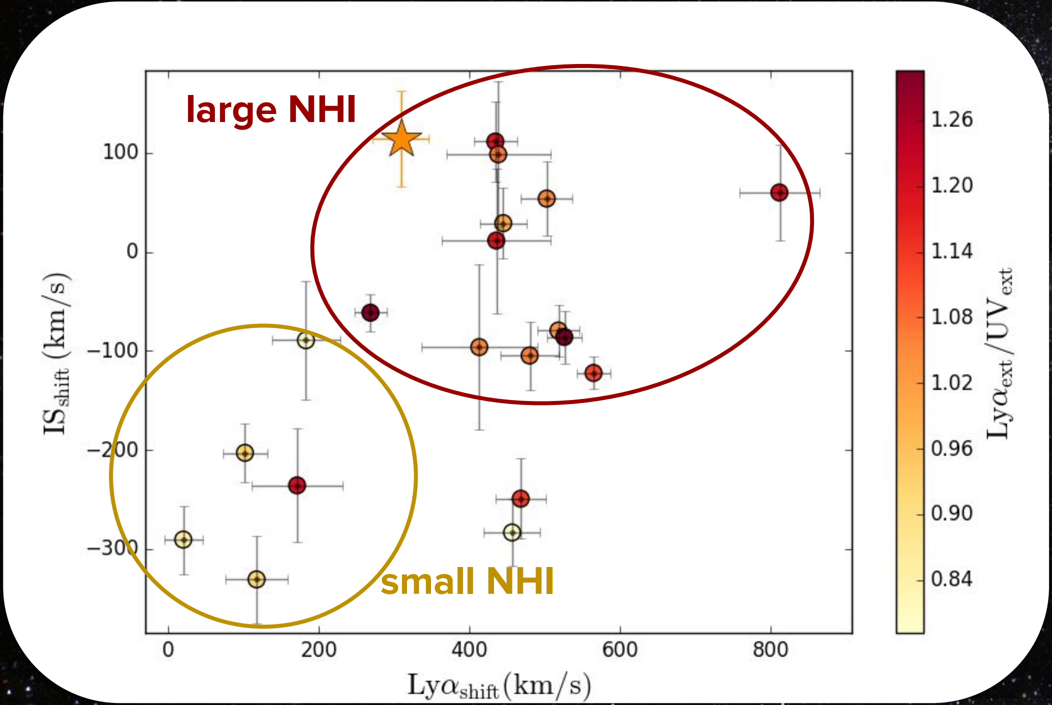
- Small Lyα shifts and large outflow velocities are predicted only for **small HI column densities** (~10^{19} cm^{-2})
- large Lyα shifts but with small or null outflow velocities can be observed in case of **large HI column density** (~10^{20} -10^{21} cm^{-2}) because the Lyα photons must have undergone many scatters before escaping the galaxy

Is this in agreement with the physical properties of the galaxies?

We investigate the relation between NHI and Mass, SFR, sSFR, Σ_{SFR}, dust, EW(Lyα) and $Ly\alpha_{ext}/UV_{ext}$

Is this in agreement with the physical properties of the galaxies?

We investigate the relation between NHI and Mass, SFR, sSFR, Σ_{SFR}, dust, EW(Lyα) and **Lyα$_{ext}$/UV$_{ext}$**



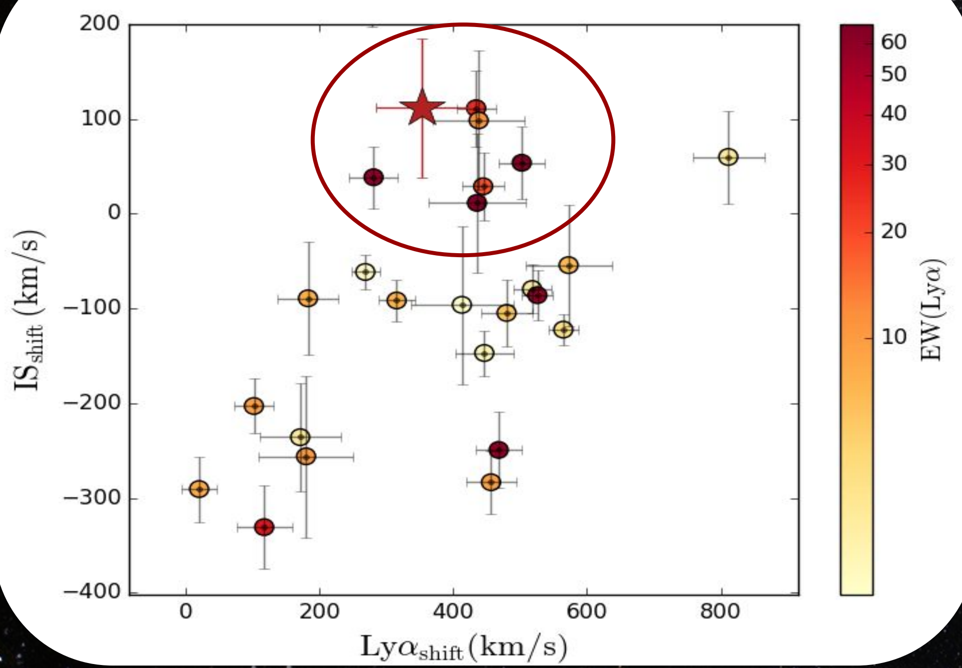
- galaxies with larger outflow velocities and smaller Lyα velocity shifts, show smaller Lyα$_{ext}$/UV$_{ext}$ ➔ small NHI
- galaxies with no outflows and larger Lyα shifts show larger Lyα$_{ext}$/UV$_{ext}$ ➔ large NHI

✔ In agreement with the expectations

N.B. the **star** on the plot is the **stack** of the sources with no individual IS shift measure. Its colour is given by the median of the measured Lyα$_{ext}$/UV$_{ext}$ of the IS undetected

Is this in agreement with the physical properties of the galaxies?

We investigate the relation between NHI and Mass, SFR, sSFR, Σ_{SFR}, dust, **EW(Lyα)** and Lyα$_{ext}$/UV$_{ext}$



We do not observe any particular trend with EW(Lyα)

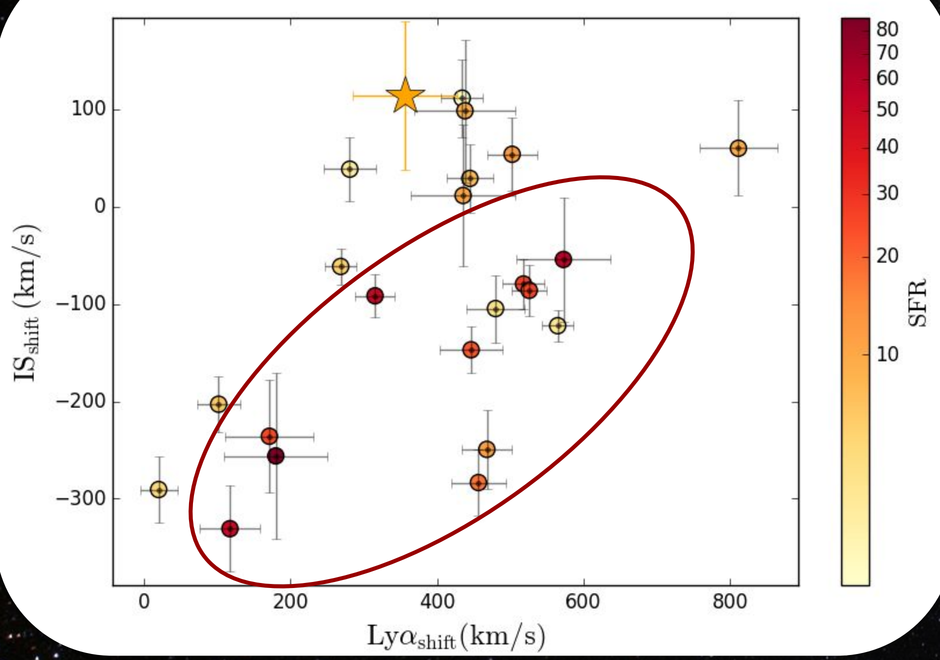
✖ we would expect large LyaEW for small NHI (e.g. Pardy et al. 2014, Yang et al. 2017)

The galaxies with brighter Lyα show on average **no outflows** and **Lyα peak shifts around 400 km/s**

N.B. the **star** on the plot is the **stack** of the sources with no individual IS shift measure. Its colour is given by the median of the measured EW(Lyα) of the IS undetected sample

Is this in agreement with the physical properties of the galaxies?

We investigate the relation between NHI and Mass, **SFR**, sSFR, Σ_{SFR}, dust, EW(Lyα) and Lyα$_{ext}$/UV$_{ext}$



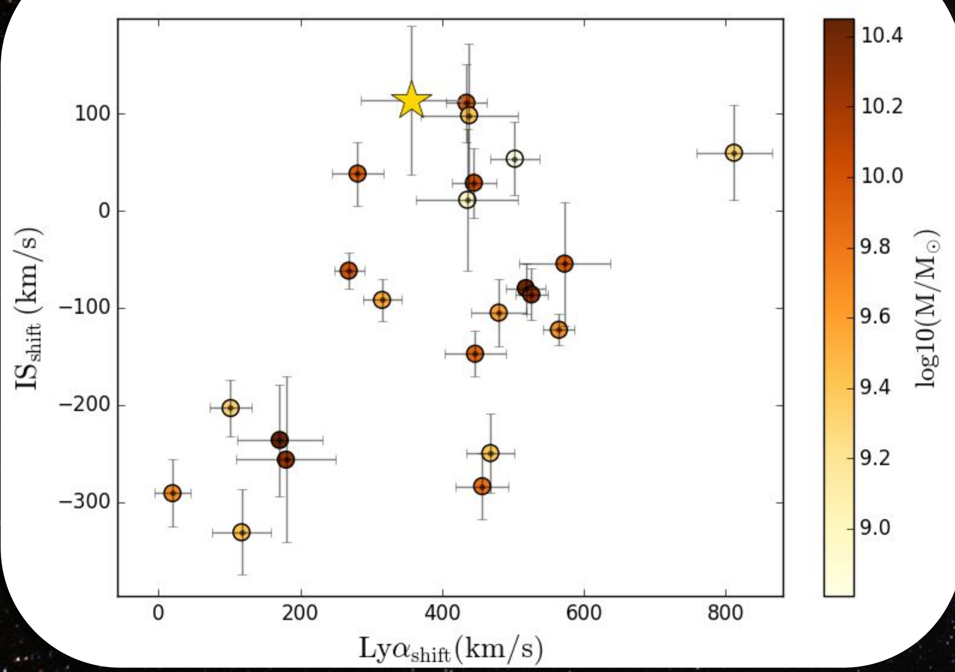
We do not observe any correlation between NHI and SFR

At fixed Lyashift, galaxies with **higher outflow velocities**, seems to shown on average **higher SFR** (same correlation observed between IS_{shift} vs SFR)

N.B. the **star** on the plot is the **stack** of the sources with no individual IS shift measure. Its colour is given by the median of the measured SFR of the IS undetected sample

Is this in agreement with the physical properties of the galaxies?

We investigate the relation between NHI and **Mass**, SFR, sSFR, Σ_{SFR}, dust, EW(Lyα) and Lyα_{ext}/UV_{ext}



We do not either observe any correlation between NHI and Mass

N.B. the **star** on the plot is the **stack** of the sources with no individual IS shift measure. Its colour is given by the median of the measured Mass of the IS undetected sample

In summary

- We confirm the correlation between **EW(Lyα) and CIII,** the anticorrelation between **LyaEW and Lyα spatial extent**, and the anti-correlation between **EW(Lyα) and Mass.**
- We observe only a weak correlation between **ISshift and SFR.**
- We observe a correlation between **Lya velocity shift and IS shift**
    - Galaxies with **large outflow velocities** also show **small Lyα velocity shifts**. According to the shell model, this would be explained if these galaxies have **low HI column densities** (~10^{19} cm^{-2}). They also show **compact Lyα$_{ext}$/UV$_{ext}$**, in agreement with the expectations.
    - Galaxies with **no outflows** show **large Lyα shifts (~ 500 km/s)**. In the context of the shell model this would be predicted for galaxies with **high HI column densities** (~10^{20}-10^{21} cm^{-2}). These galaxies also show **large Lyα$_{ext}$/UV$_{ext}$**, in agreement with the expectations.
- We do not observe any correlation between the trend observed for the IS and Lyα shifts (and therefore NHI) and EW(Lyα), SFR, Mass, sSFR, Σ_{SFR} and dust