From galaxies to cosmology with deep spectroscopic surveys - Marseille 5 July 2022

Outflows and gas kinematics in VANDELS star-forming galaxies

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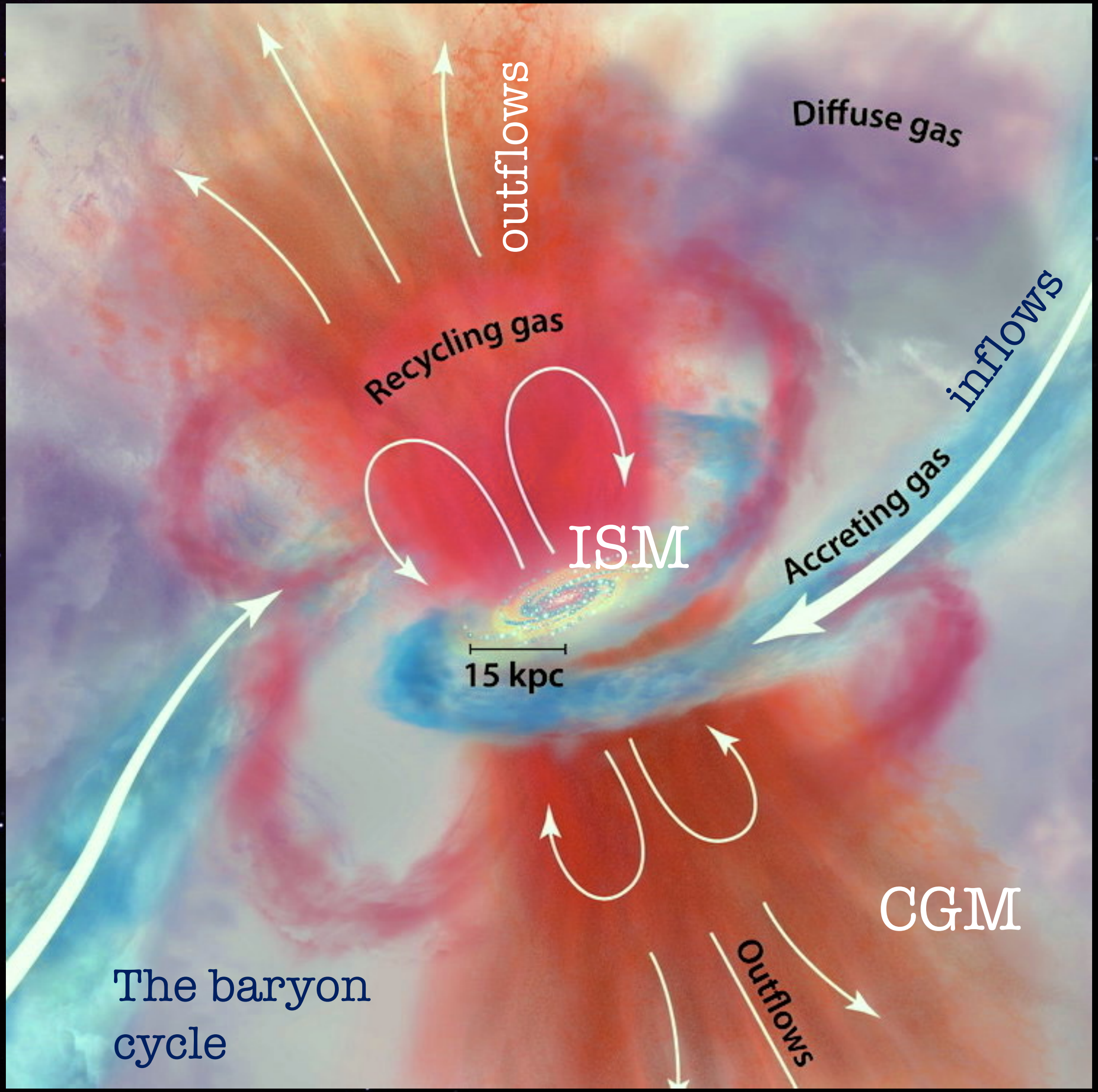
In collaboration with L.Pentericci, M.Castellano, M. Talia, G. Cresci, D. Belfiori, S. Mascia + VANDELS team

Motivations

- Gas flows **are** galaxy evolution (Tumlinson +17)
- they have a direct impact on chemical content and star-formation activity (Mannucci +09, Lilly +13, Somerville & Davé +15)
- AGN activity is also contributing to the regulation of gas flows (Harrison +18)



Tumlinson +17

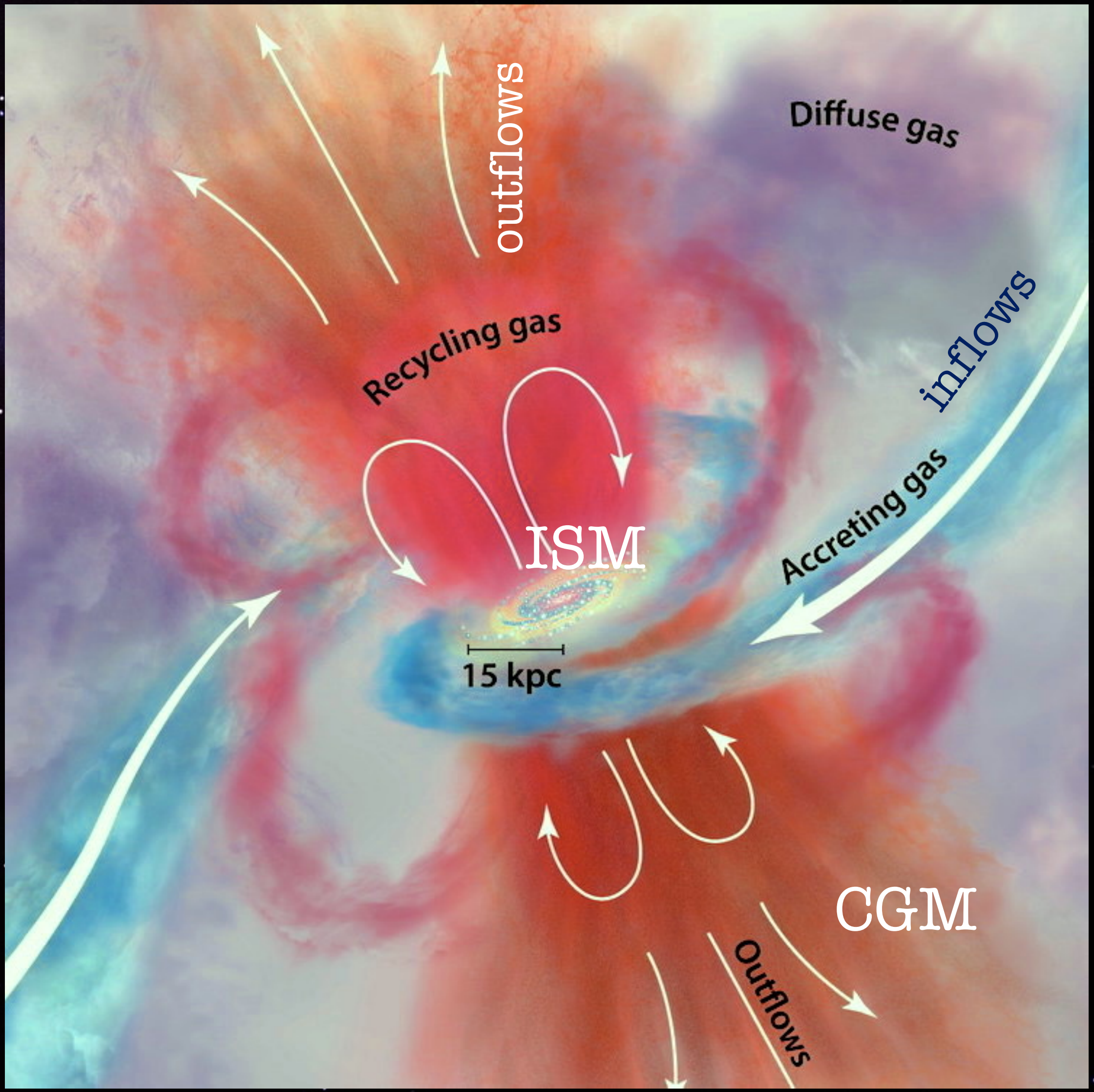
Motivations

What are the main physical drivers and the consequences of gas flows in star-forming galaxies ?
It is still debated ...

outflow velocities scale with Mass, SFR, Σ_{SFR} (Heckman +16, Davies +19)

no correlation with galaxy properties (Talia +12, Steidel +10)

VANDELS provides a great opportunity to study outflows in typical star-forming galaxies at 2 < z < 5



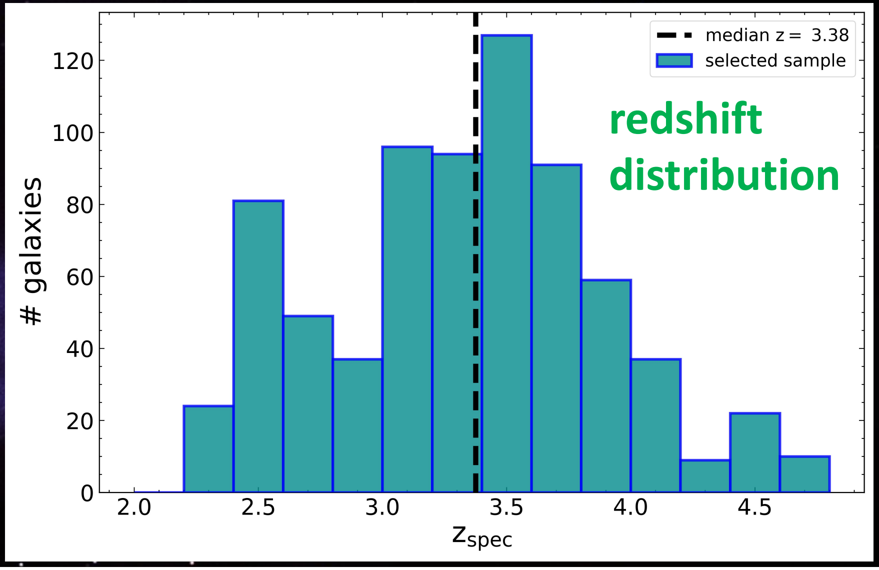
Tumlinson +17

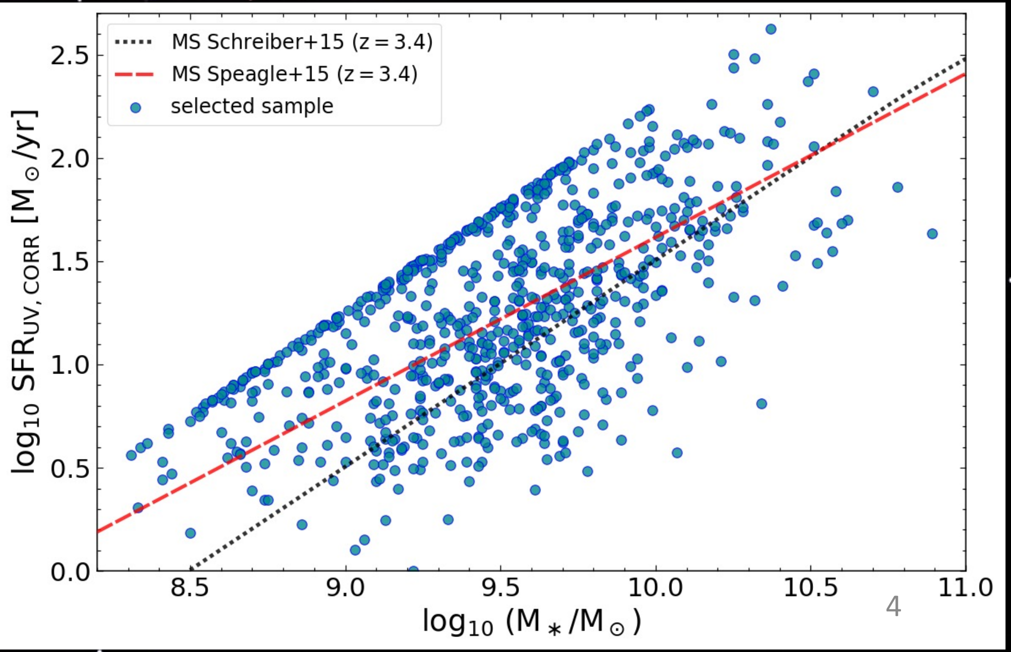
VANDELS : the deepest spectroscopic large survey at z > 2

- ultradeep **optical spectroscopic survey** of ~ 2000 galaxies with the VIMOS spectrograph at the ESO-VLT
- P.I. : L.Pentericci and R.Mc Lure

- covering an area of 0.2 deg^2 , centered on the CANDELS- CDFS and UDS fields
- the main targets are Main Sequence **star-forming galaxies at redshift 2 < *z* < *5*** (i_{mag} < 27.5 or 26 in wide fields)
- 20-80 hours of integration per source → high S/N spectra (above 7 for 80% of the sources)

- spectral coverage: 4900 Å < λ < 9800 Å,
- with resolving power R = 580 ($\Delta\lambda_{res} \simeq$ 2.7 Å in rest-frame at 1600 Å)



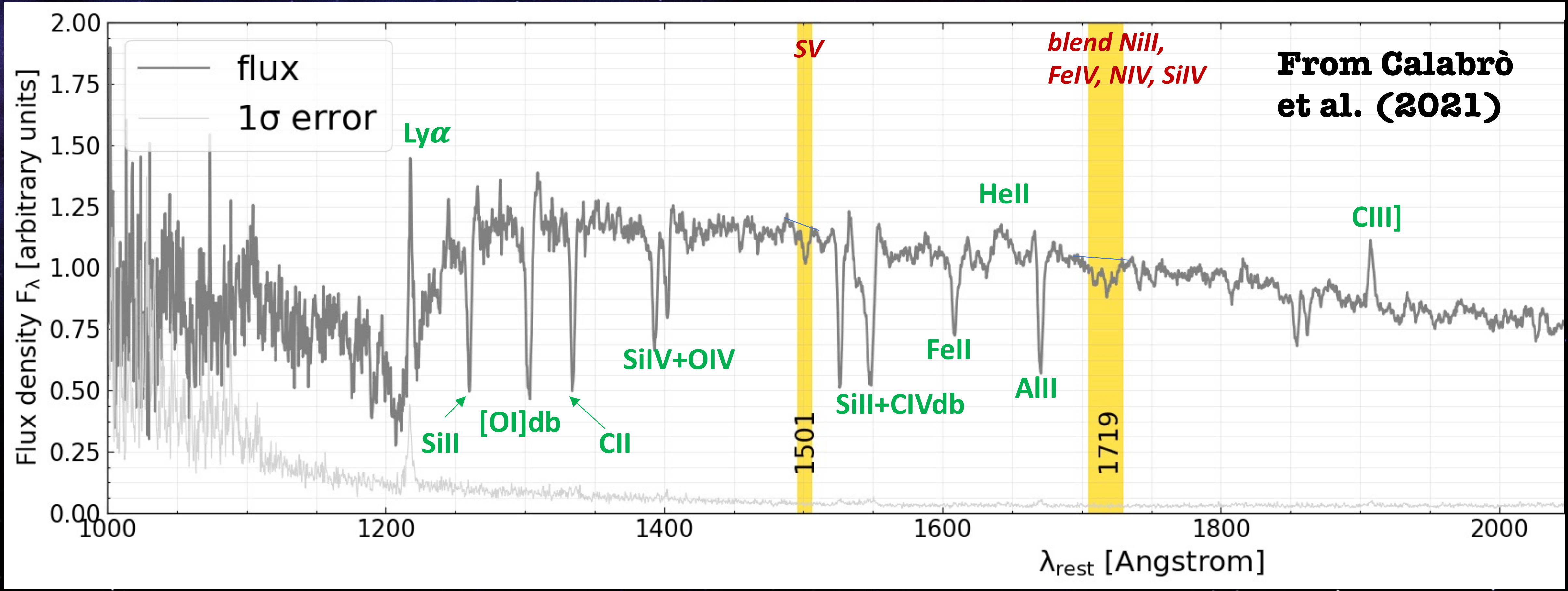


The VANDELS ESO public spectroscopic survey:

final Data Release of 2087 spectra and spectroscopic measurements

B. Garilli and VANDELS team , 2021

VANDELS representative stacked spectrum

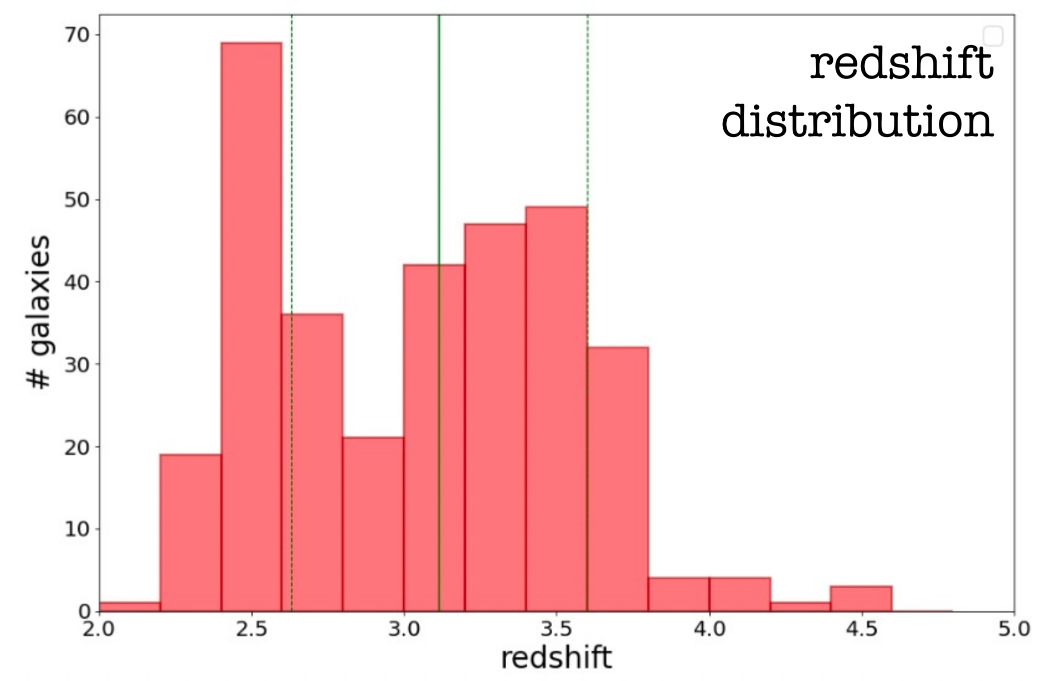


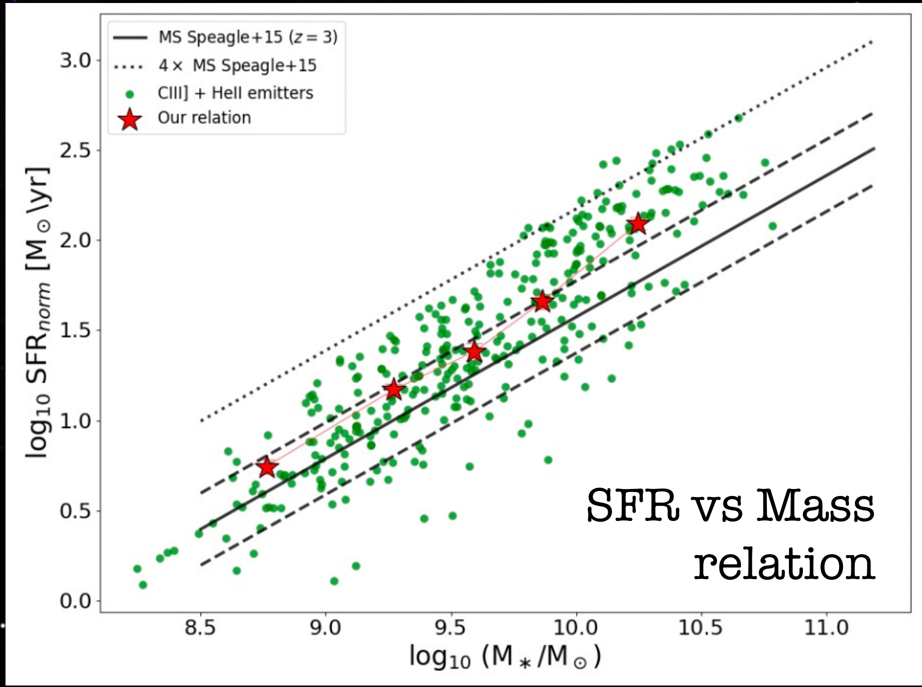
- probing galaxy properties with UV absorption lines (e.g., Fanelli+92, Rix+04, Leitherer+11)
- **1501** and **1719** Å photospheric features trace the stellar metallicity
- He II and CIII] trace the systemic redshift of the galaxies

Sample selection from the final VANDELS catalog :

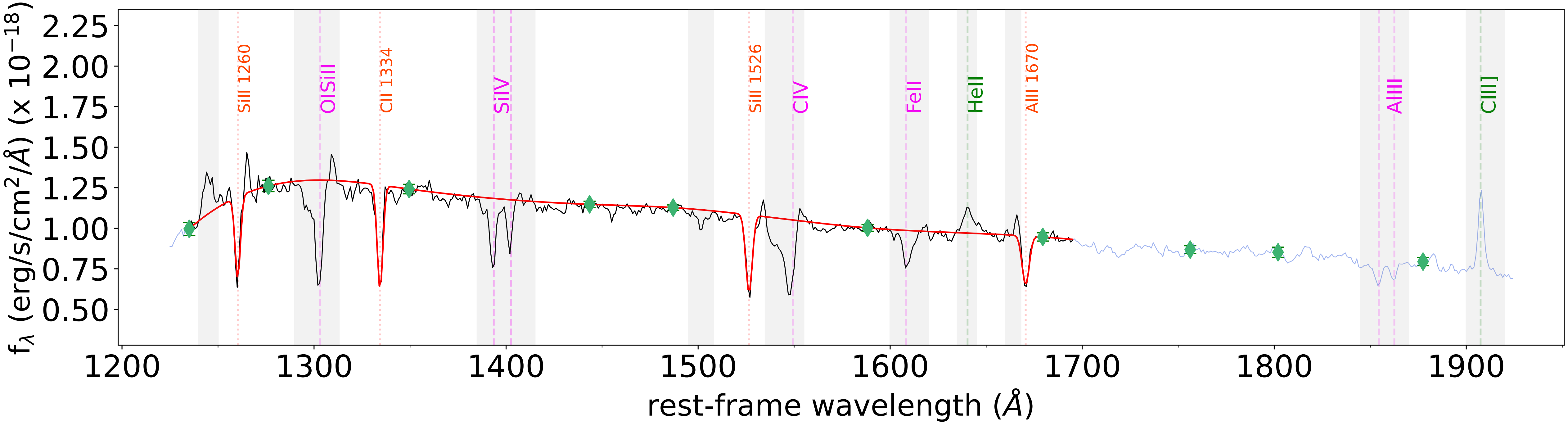
- spectroscopic flag = 3, 4, or 9
- 3σ detection of the CIII] or HeII line
- X-ray and UV-selected AGNs removed (see catalog by Bongiorno et al., in prep.)

➔ 330 purely star-forming galaxies with a systemic redshift estimation





Probing different conditions of the ISM from absorption lines



Types of absorption lines :

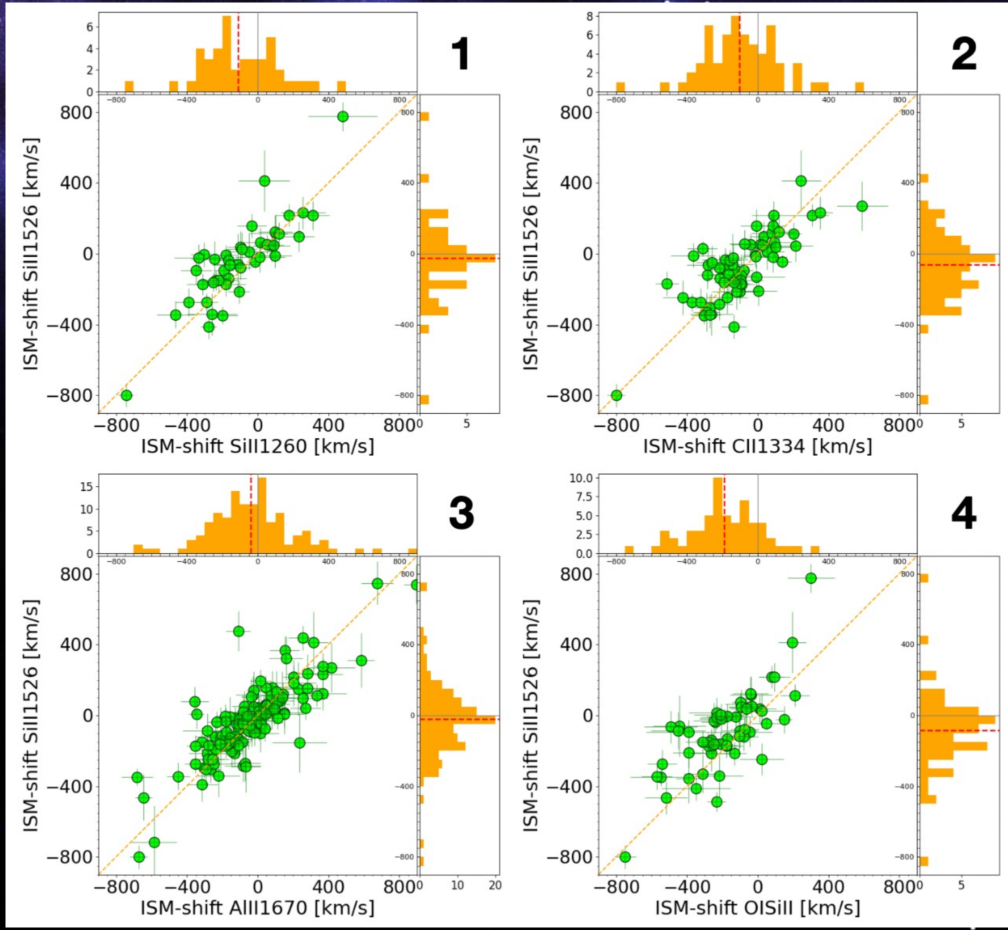
- **SiII 1260 Å, CII 1334 Å, SiII 1526 Å, AlII 1670 Å : ISM origin** → low-ionization absorption lines (LIS) tracing the neutral gas (Shapley +03)
- **AlIII 1855-1863 Å , SiIV 1394-1403 Å : ISM+stellar** → trace gas in higher ionization state and temperature

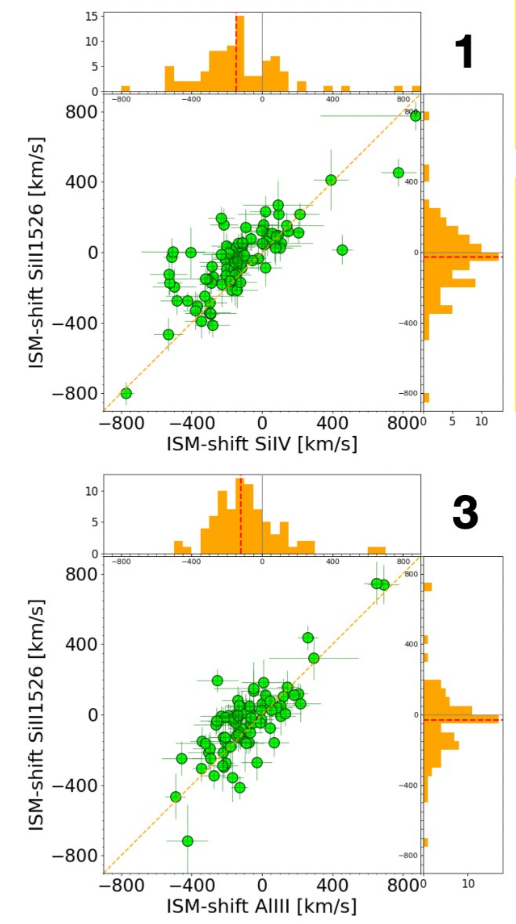
Quantitative analysis of the gas kinematics in VANDELS

ISM-shift : velocity shift between the ISM absorption line centroids and the CIII] or HeII lines (which trace the bulk of the stars, i.e., the systemic redshift) :

GAUSSIAN FIT

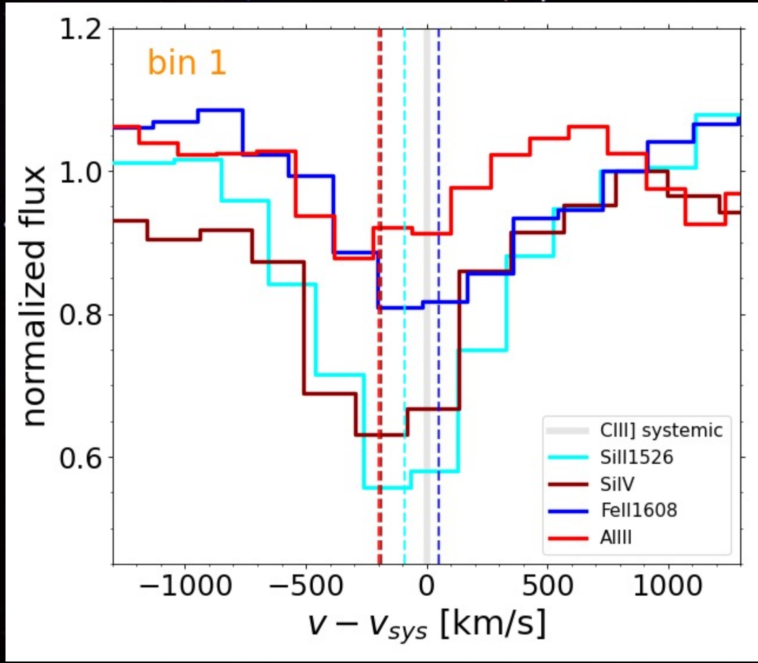
$$v_{IS,\,line} = \frac{z_{line} - z_{sys}}{(1 + z_{sys})} \times c$$





ISM-shift combined (representative of low-ionization lines) : $v_{ISM,avg}$ = -60 ± 10 km/s

ISM-shift of AlIII and SiIV (higher ionization lines) : $v_{ISM,avg}$ = -160 ± 30 and -170 ± 30 km/s

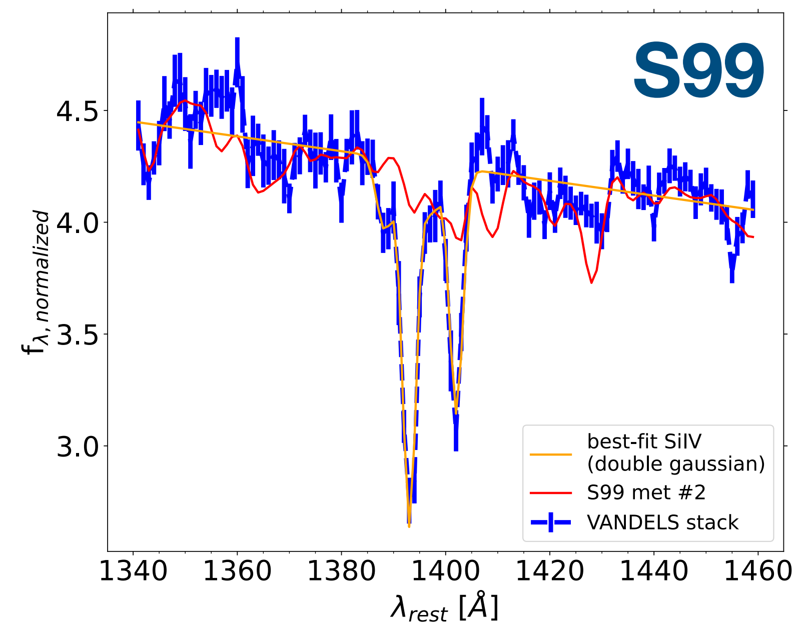


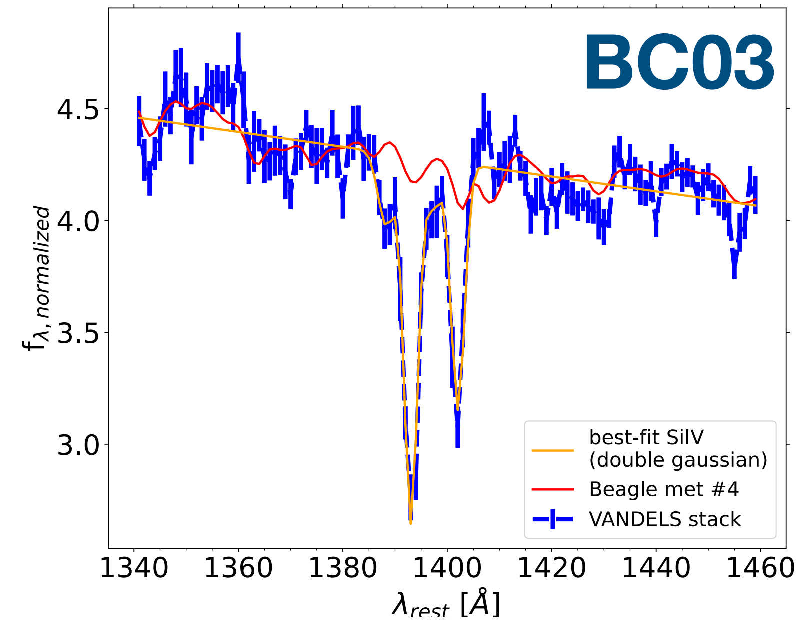
SiII 1260 + CII 1334 + SiII 1526 + AlII 1670 → combined fit

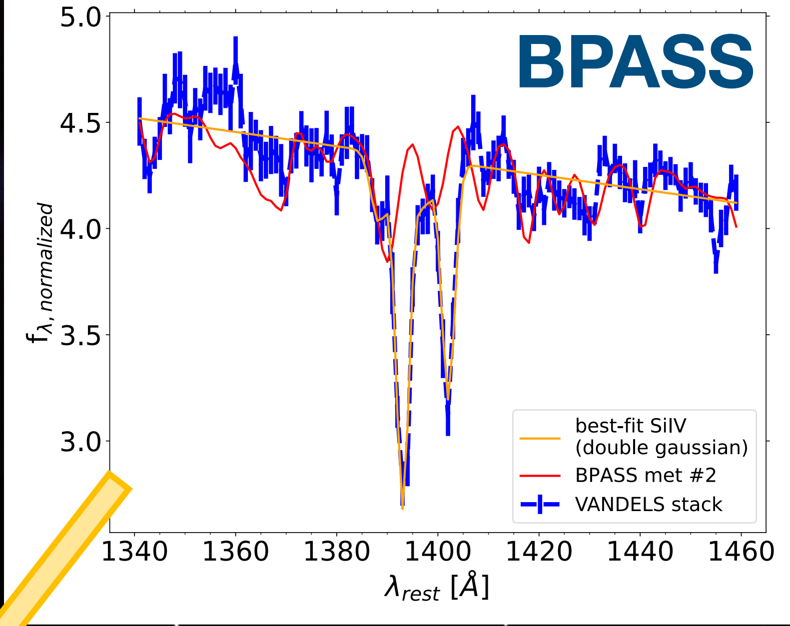
Fitting the SiIV line profile

- large blue-shift residual from a single gaussian fit to the SiIV profile (by ~ 1000 km/s)

extreme (additional) ISM outflow **or** stellar wind ?





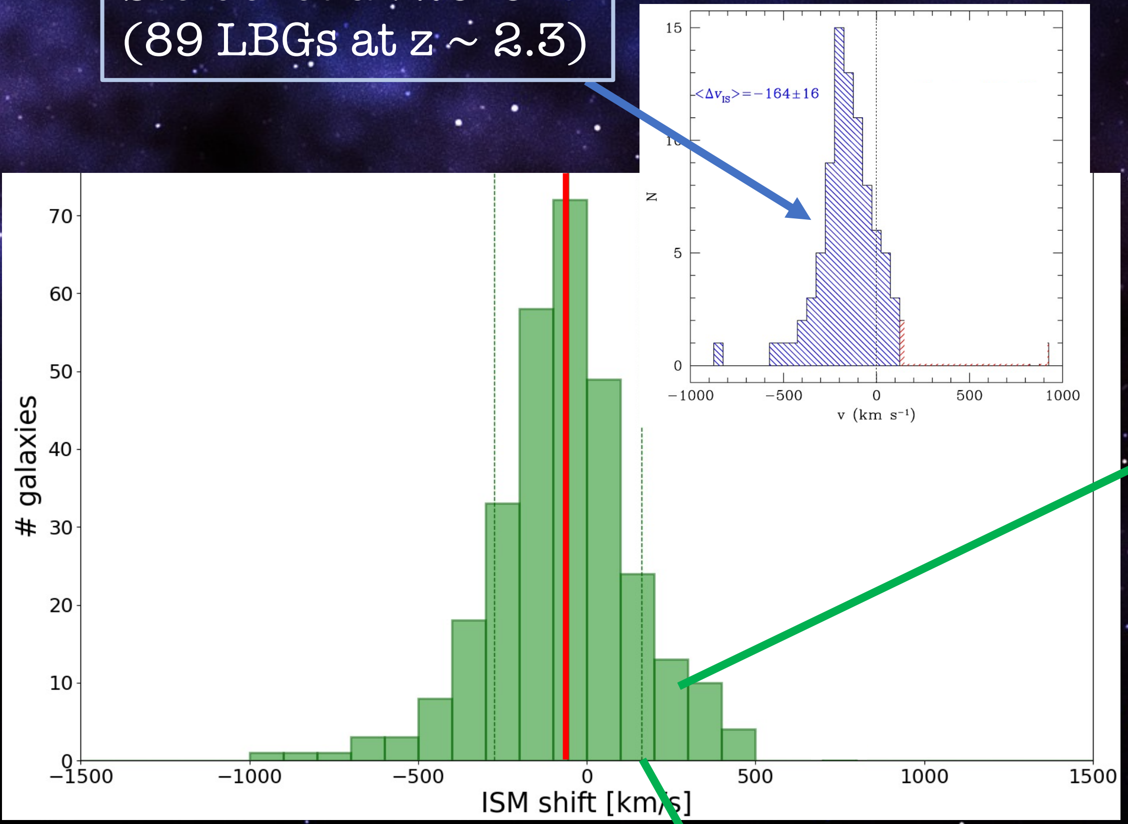


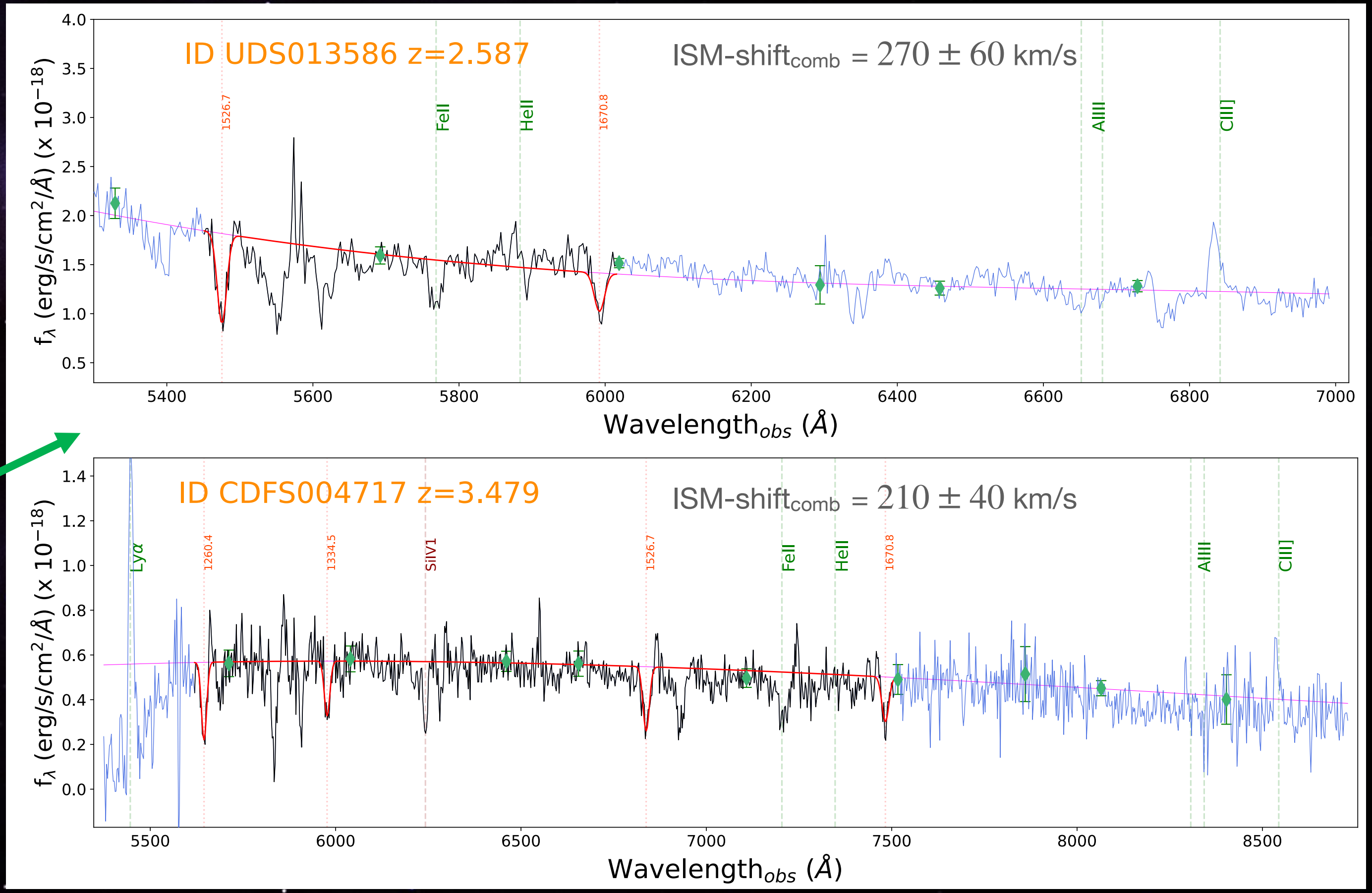
- For all the models we assumed a stellar metallicity of ~ 0.15 solar, consistent with Z_* of star-forming galaxies at z ~ 3 (Calabrò et al. 2021)

- In BPASS, the absorption strength of the SiIV stellar wind feature increases with metallicity. New possible stellar metallicity indicator, even though requires S/N > 10

Galaxies with inflow signatures

Steidel et al. 2010
(89 LBGs at z ~ 2.3)



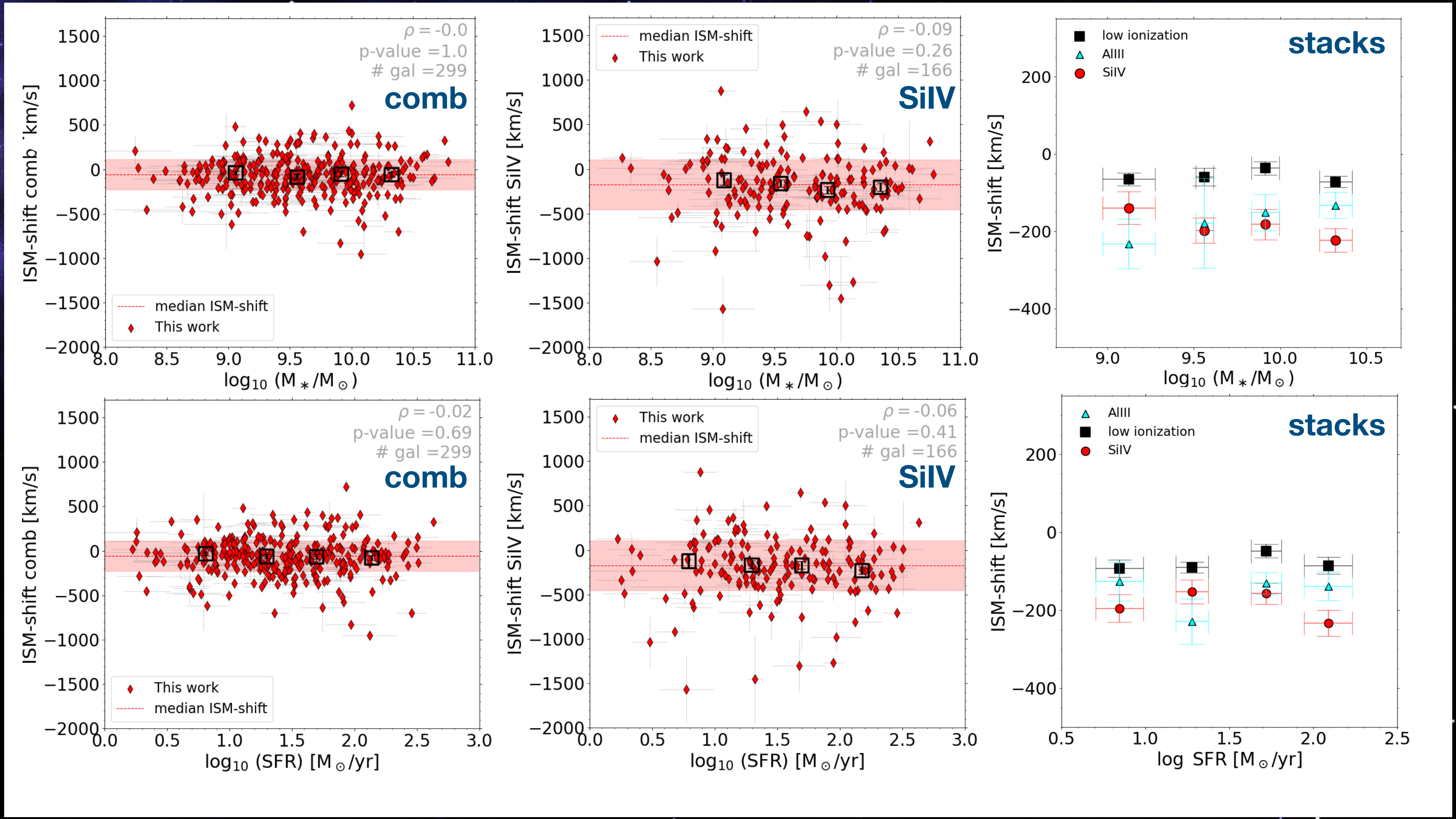


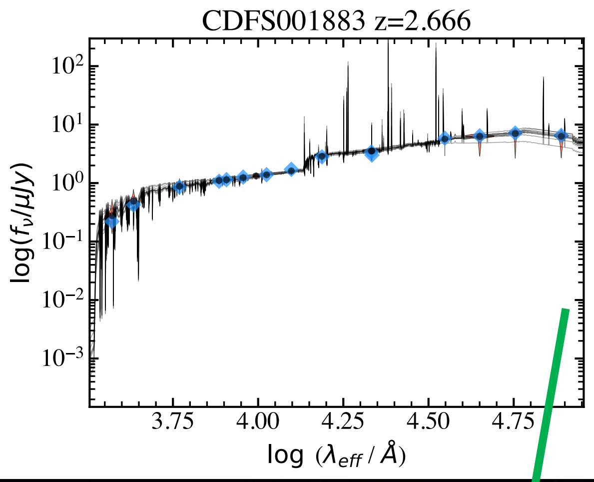
- we reach higher ISM velocities
- we find a higher fraction of galaxies (34%) with ISM in inflow (i.e., $v_{ISM} > 0$)

Physical explanation :

- mergers, collisions
- Important role of inflows at high-z

No correlations of v_{ISM} with stellar mass and SFR



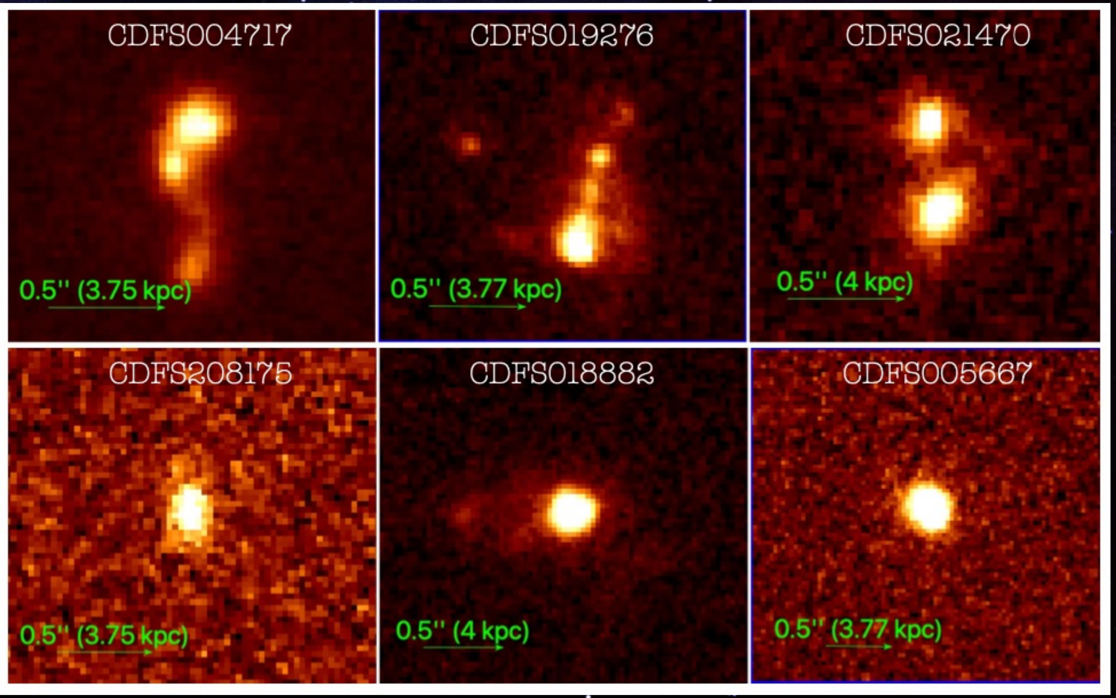


- Stellar masses and SFRs from SED fitting with Beagle
- No correlations with Stellar Mass and SFR for both low and high ionization lines
- Galaxies with higher SFR and stellar mass reach higher outflow velocities

Calabrò et al. 2022 (submitted A&A) arXiv:2206.14918

Morphology related properties :

- **merger vs isolated galaxies** by visual inspection in F814W band (criteria of Kartaltepe et al. 2015)
- 27 % of the sample have merger-clumpy(i.e., multi-component) morphology

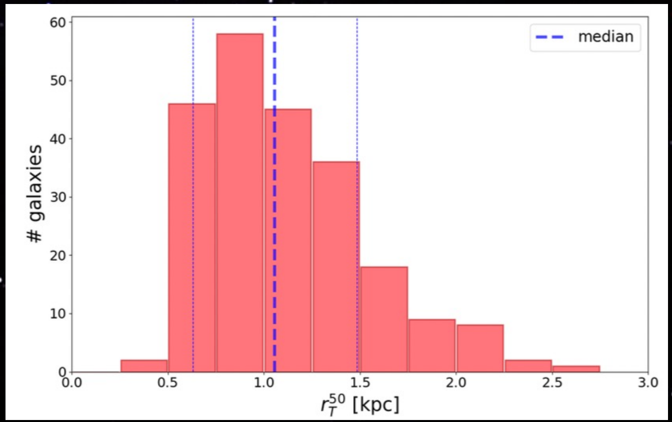


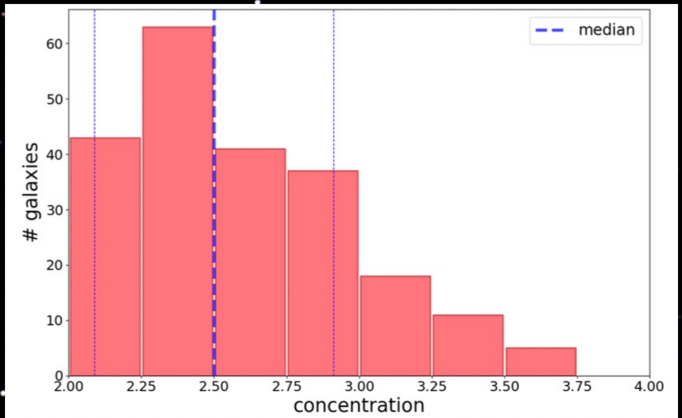
- equivalent radius r_e and concentration parameter as in Ribeiro +2016 (VUDS) :

$$r_T^{50}[kpc] = \frac{\sqrt{N_{50}\, L^2 \times 2 \times 10^{-11} D_A^2}}{\sqrt{\pi}}$$

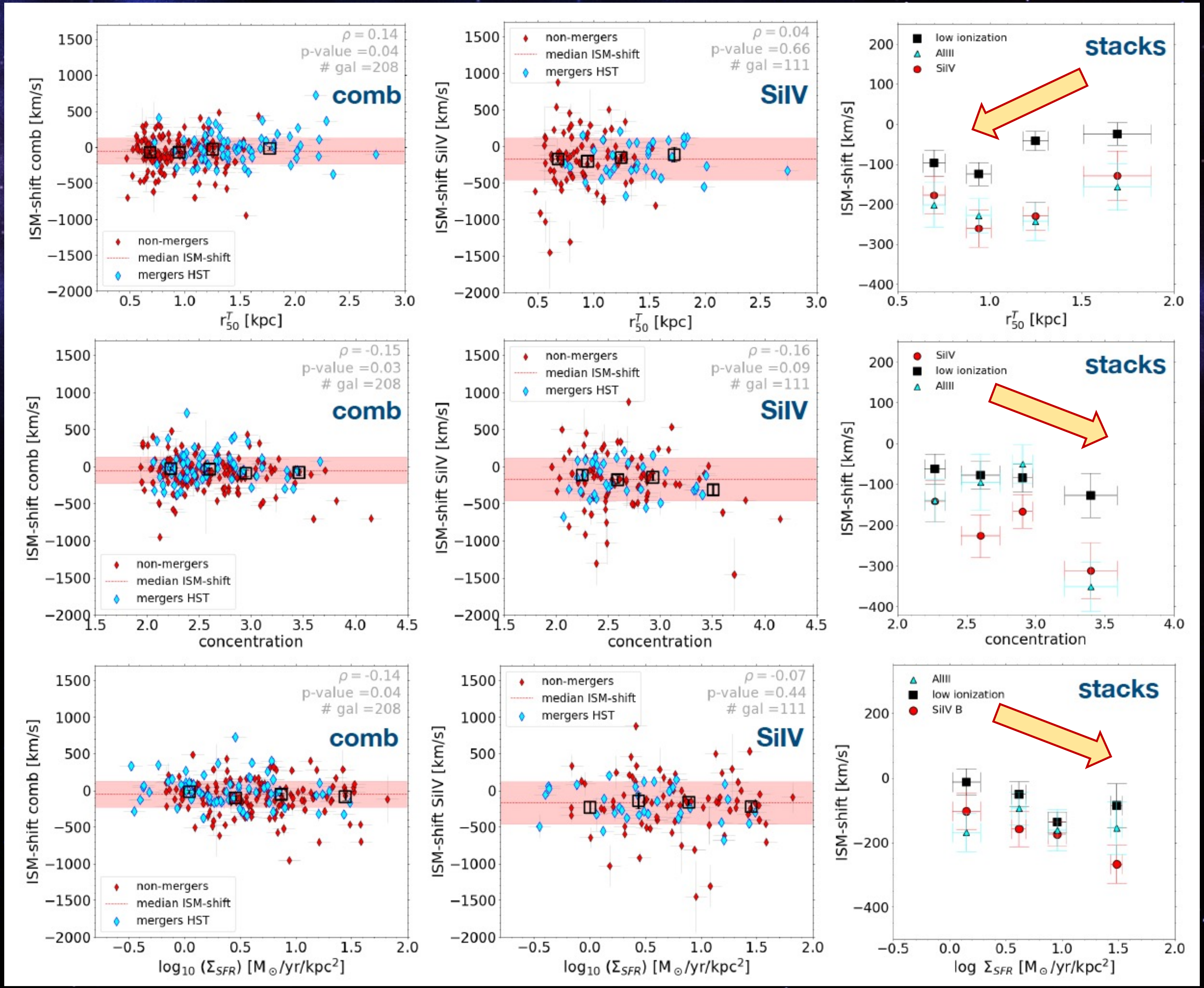
$$C_T = 5\, log_{10} \frac{r_T^{80}}{r_T^{20}}$$

$$\Sigma_{SFR} = \frac{SFR}{2\pi r_T^2}$$





Weak correlations with size, concentration, and SFR surface density

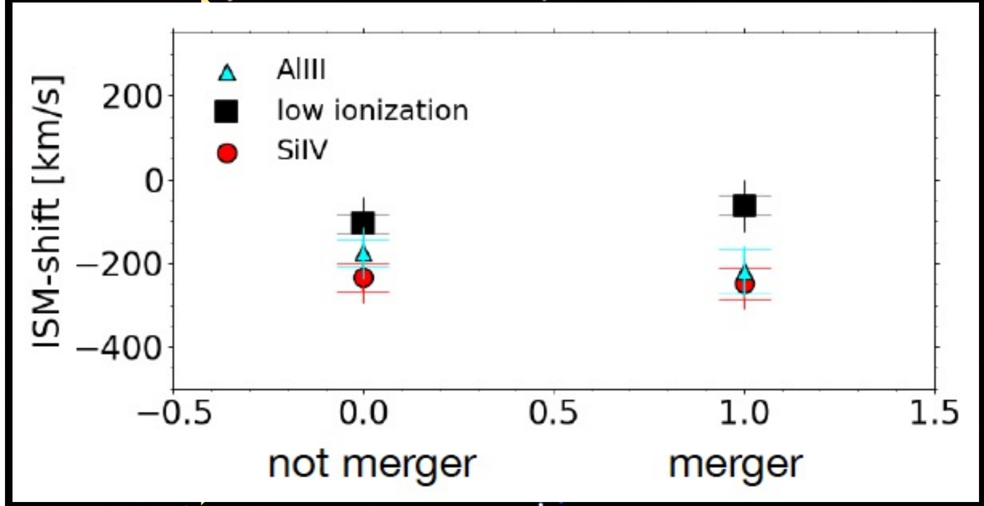


SIZE

larger outflow velocity for smaller galaxies

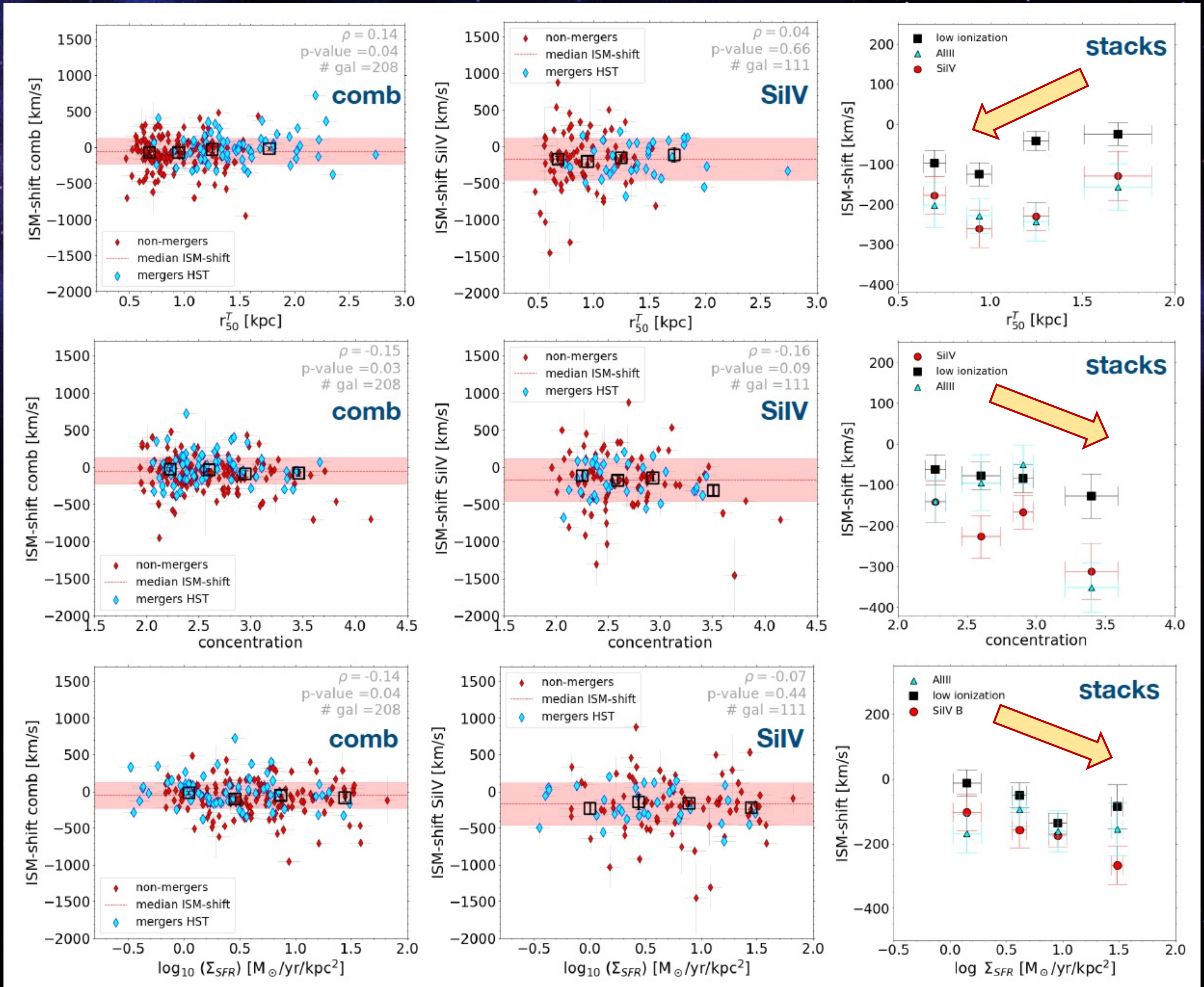
However, the significance is between 2 and 3 σ

concentration



- Mergers and isolated galaxies have similar ISM velocities

Weak correlations with size, concentration, and SFR surface density



SIZE →

larger outflow velocity for smaller galaxies

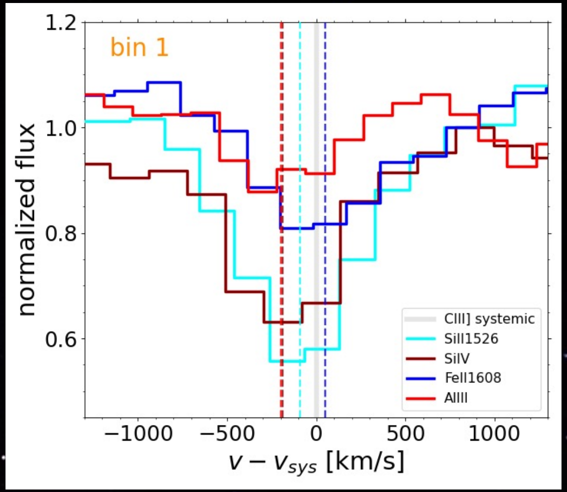
However, the significance is between 2 and 3 σ

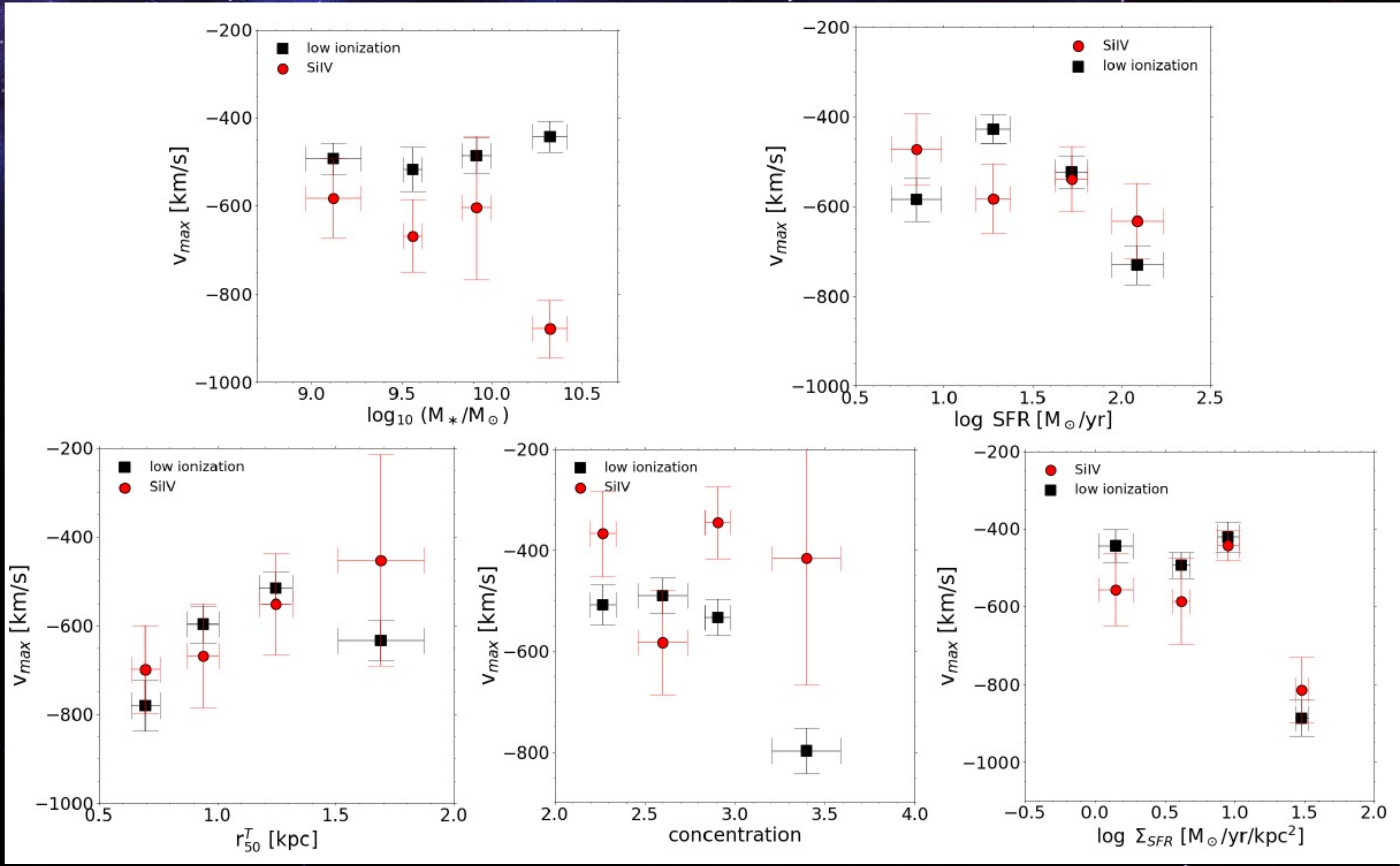
concentration →

Σ_{SFR} →

Larger outflow velocity in galaxies with higher concentration and higher SFR surface density Σ_{SFR}

Slightly more significant correlations with v_{MAX}





Definition of v_{MAX}:

$$v_{max}[km/s] = 0.872 \times FWHM_{line} + v_{ISM,line},$$

- Slightly more significant correlations with SFR, size, concentration, and Σ_{SFR}
- Smallest galaxies with $C_T > 3$ and $\Sigma_{SFR} > 1$ have $v_{MAX} < -600$ km/s

Outflow velocities are typically lower than the escape velocity

MOSFIRE follow-up :
[OII]3727 line available for 12 VANDELS galaxies (similar mass distribution of CIII] emitters)

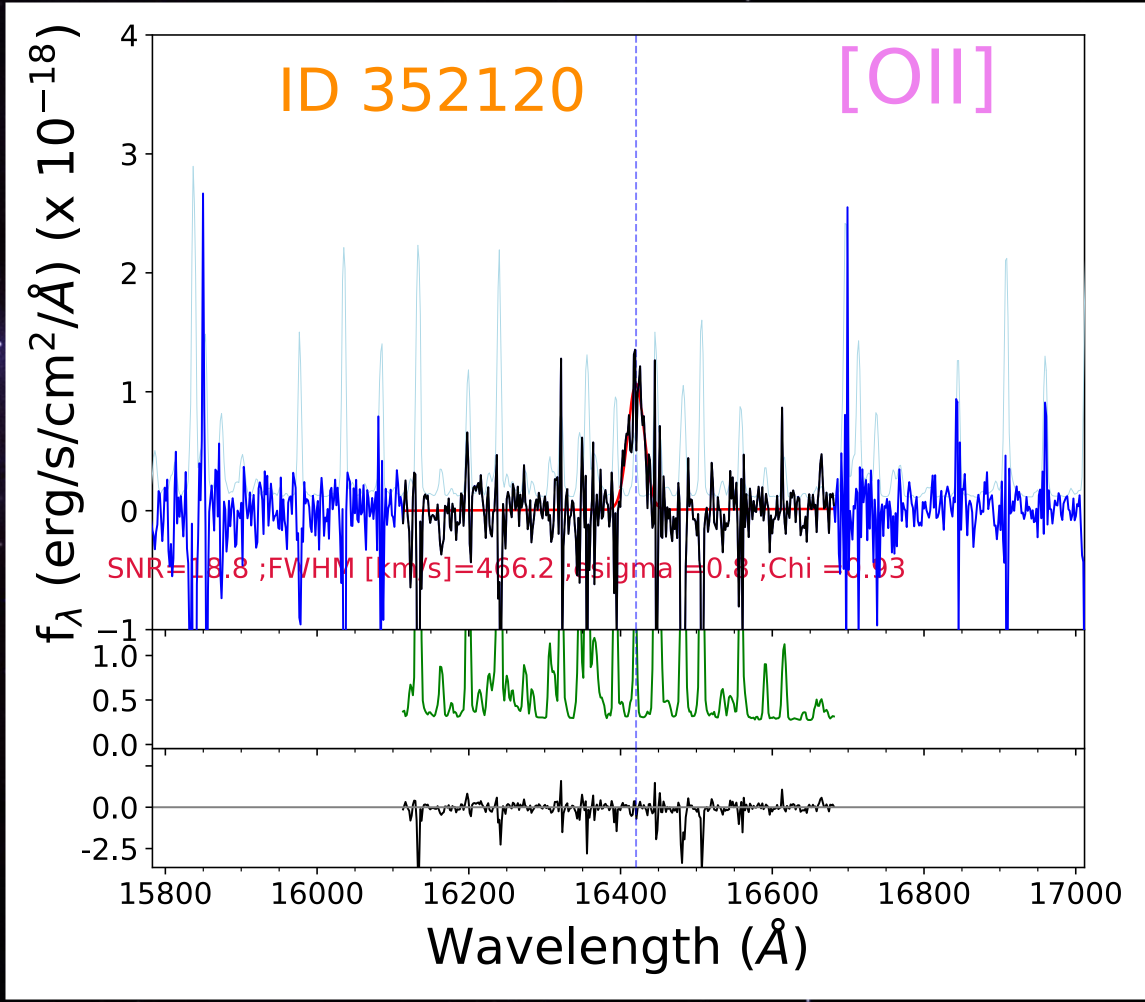
Assumptions :

rotation

$\sigma_{vel} \sim 0.6 \times v_c$ (Rix et al. 1997)

$v_{esc} = 3 \times v_c$ (Binney & Tremaine 1987)

$\Rightarrow$ v_{esc} = 625 km/s >> $|v_{ISM}|$



Most of the ISM will remain bound the host galaxy halo

SUMMARY AND CONCLUSIONS

1. average ISM velocity: $-60 \pm 10\ km/s$ for low-ionization gas , $-160 \pm 30\ km/s$ and $-170 \pm 30\ km/s$ for AlIII and SiIV → they likely trace different regions of the outflows

2. BPASS models reproduce better the stellar winds around SiIV compared to other stellar models

3. no significant correlations between ISM velocity, stellar mass, and SFR

4. weak, marginally significant (2 σ) correlations with morphology related parameters, namely equivalent radius, concentration, and Σ_{SFR}

5. slightly more significant correlations between v_{MAX} and galaxy physical properties

6. Mass outflow rates are comparable to the SFR of the galaxies (mass loading factor ~ 1.3)

THANKS FOR THE ATTENTION !