Fast Outflows identified in Early Star-Forming Galaxies at z=5–6

Sugahara et al., 2019, ApJ, 886, 29

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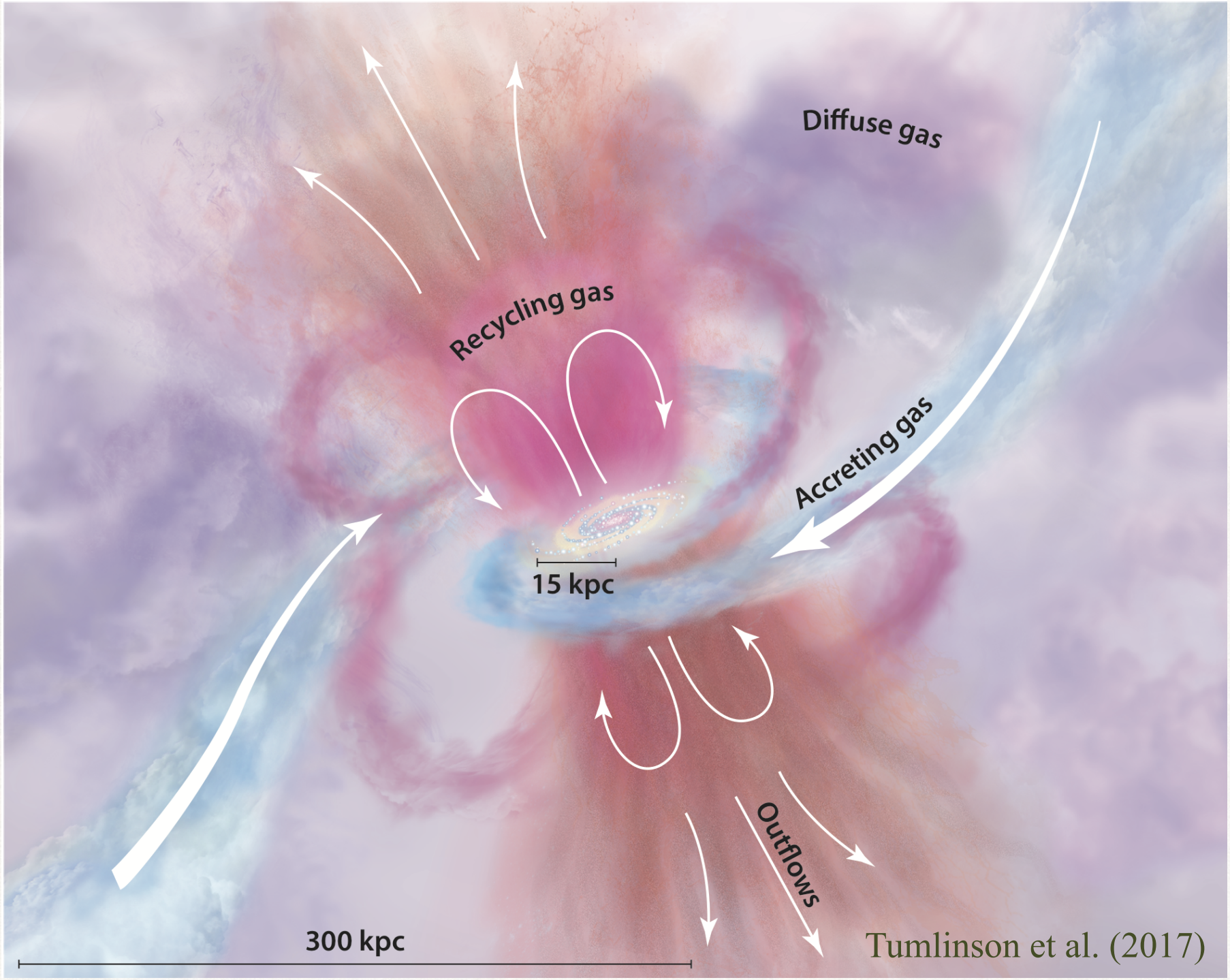
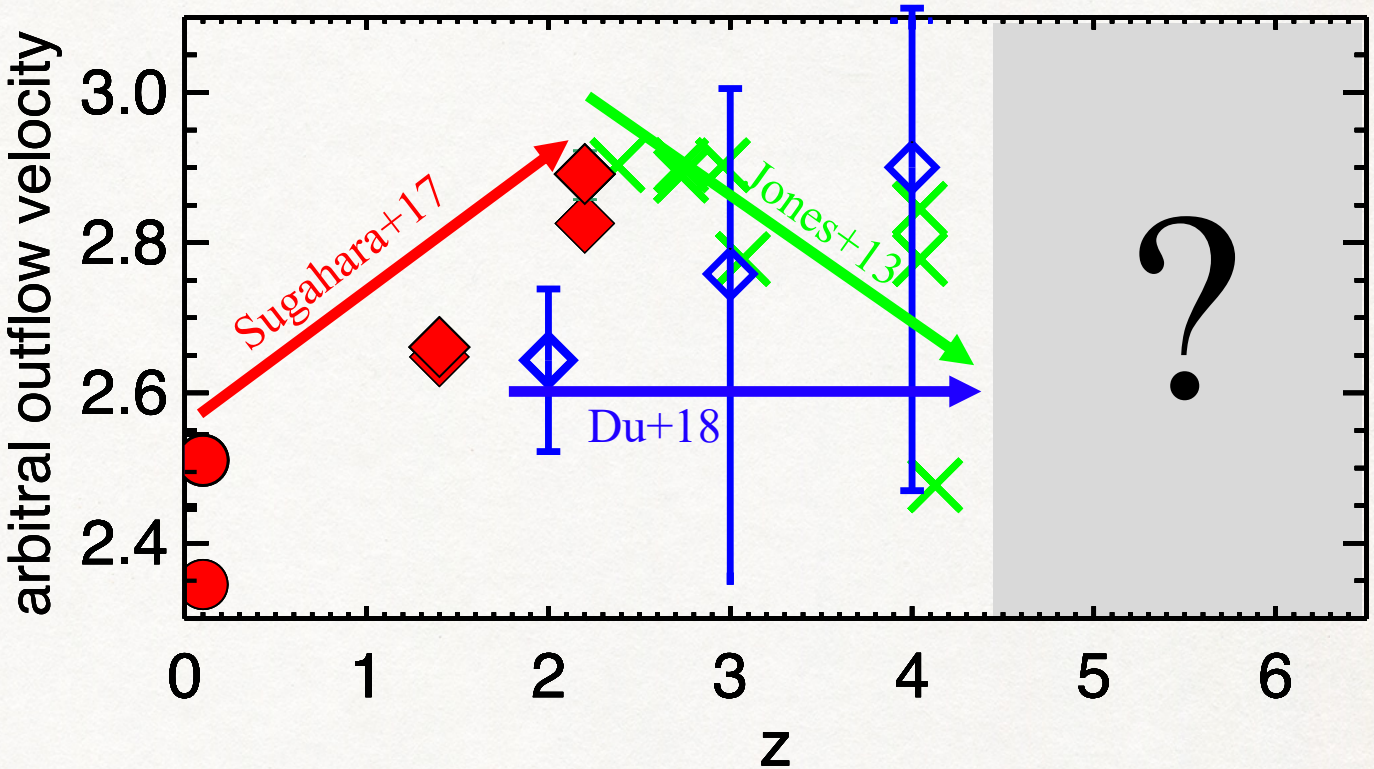


Tumlinson et al. (2017)

Redshift Evolution of Outflow Velocity



- Outflow velocities increase at z > 2?
- How large velocities are at z > 4?

Goals of Our Work

This work study outflows in star-forming galaxies:

1. To measure outflow velocities in distant galaxies we can observe (at z~5–6).

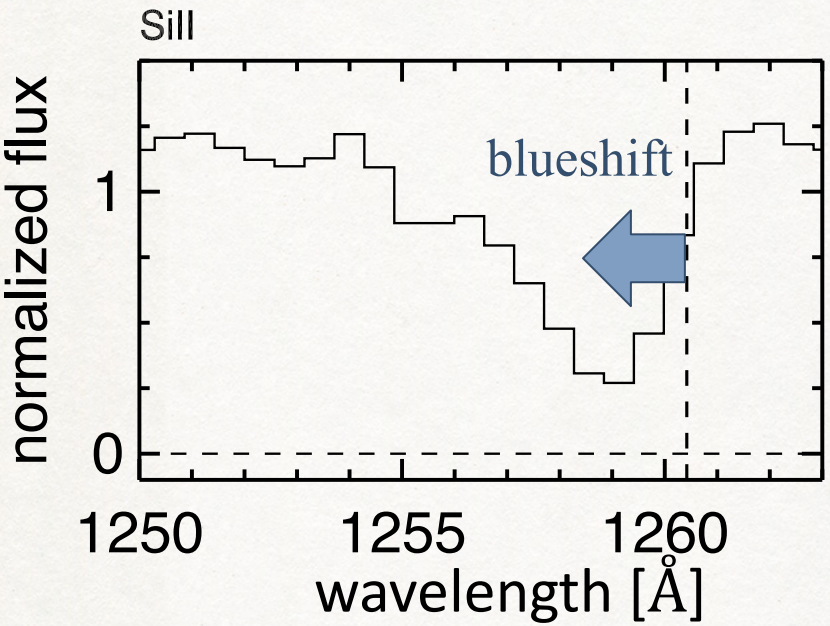
2. To investigate the redshift evolution of the outflow velocities.

3. To discuss the fundamental galaxy property to determine the outflow velocities.

Challenges at High Redshift

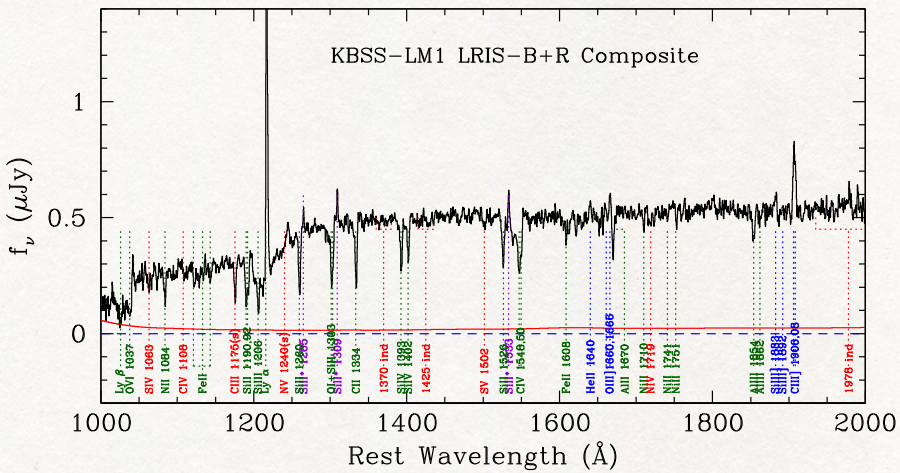
- Deep rest-UV spectra

  needed for absorption-line analysis



- No nebular emission lines

  to determine systemic redshift

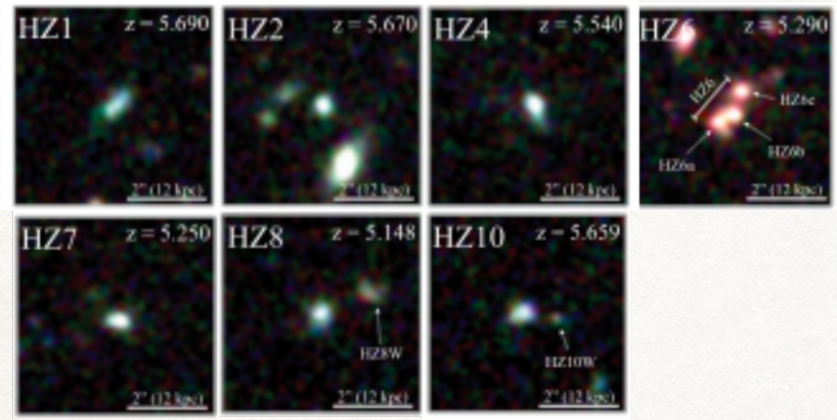


Steidel et al. (2016)

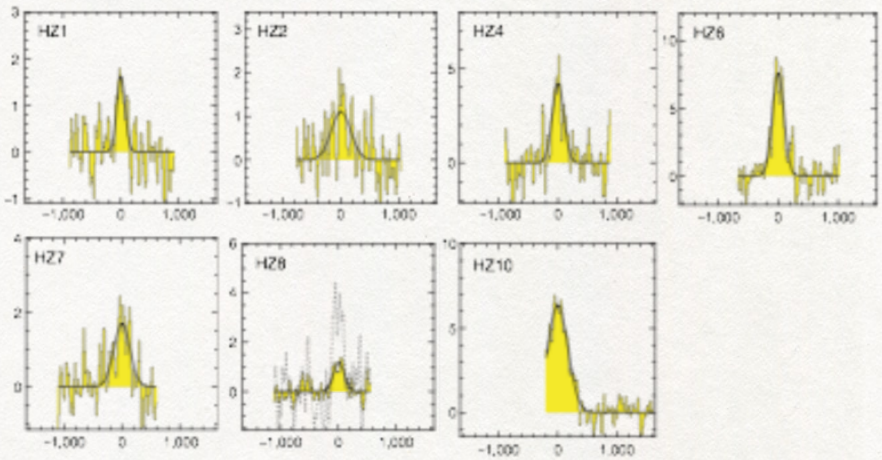
- Solution: deep UV spectrum & ALMA [CII]158μm

Sample

- Archival seven LBG spectra (PI: P. Capak)



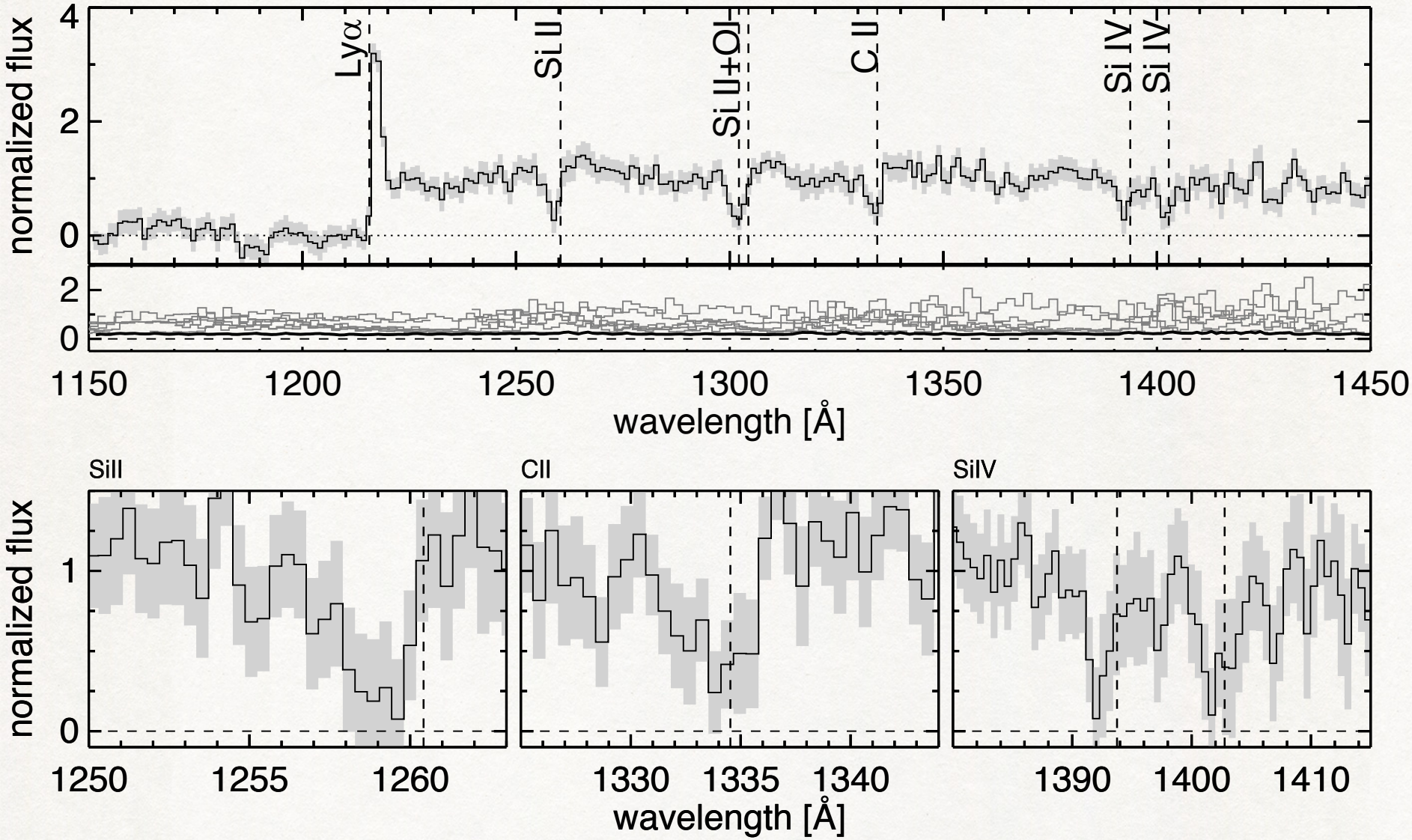
modifid from Barisic et al. (2017)



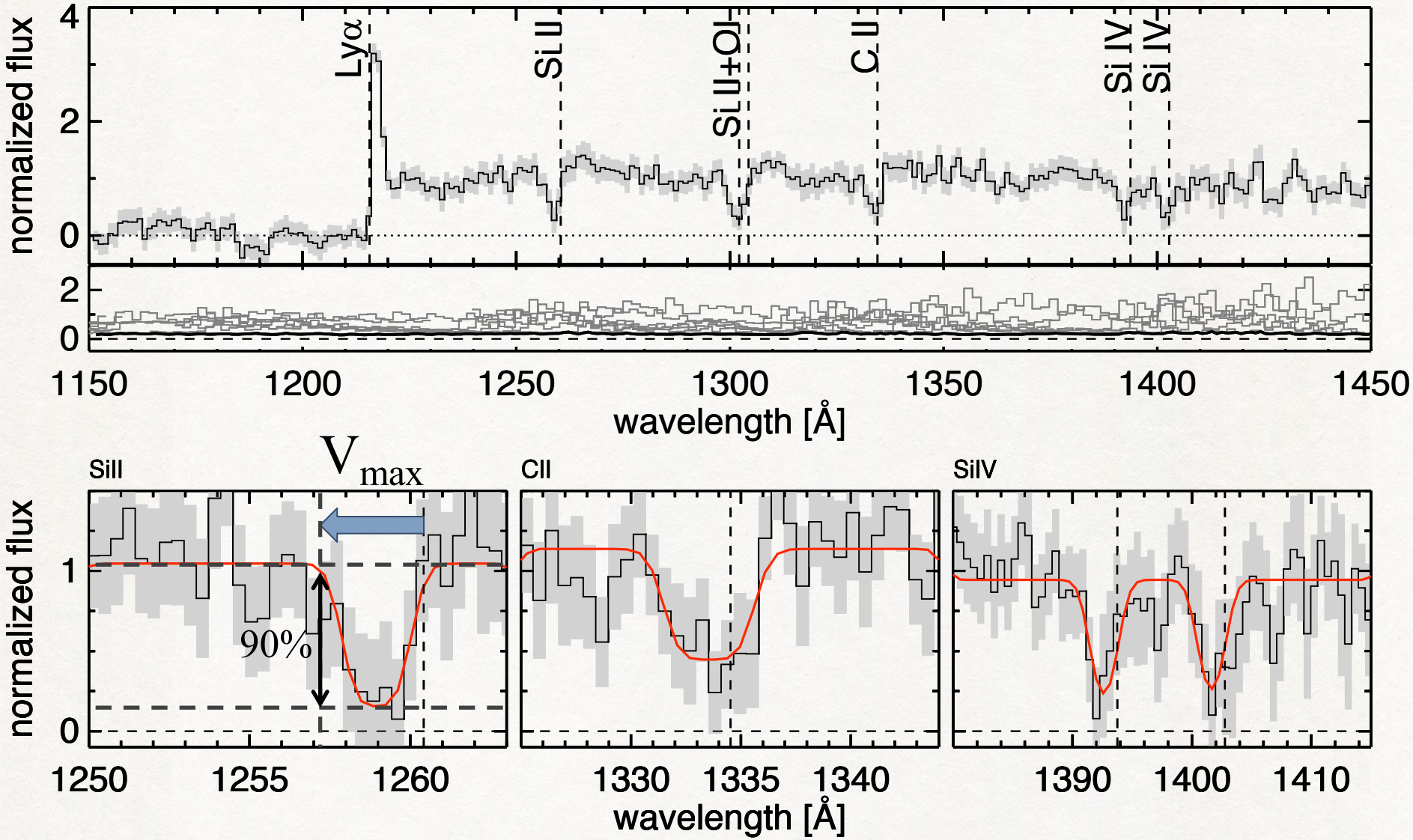
modified from Capak et al. (2015)

- DEIMOS rest-UV spectra (Texp ~ 3.5h)
- ALMA [CII] emission line (z_{err} ~ 10 km/s)
- z = 5–6 | log M* = 9.6–10.5

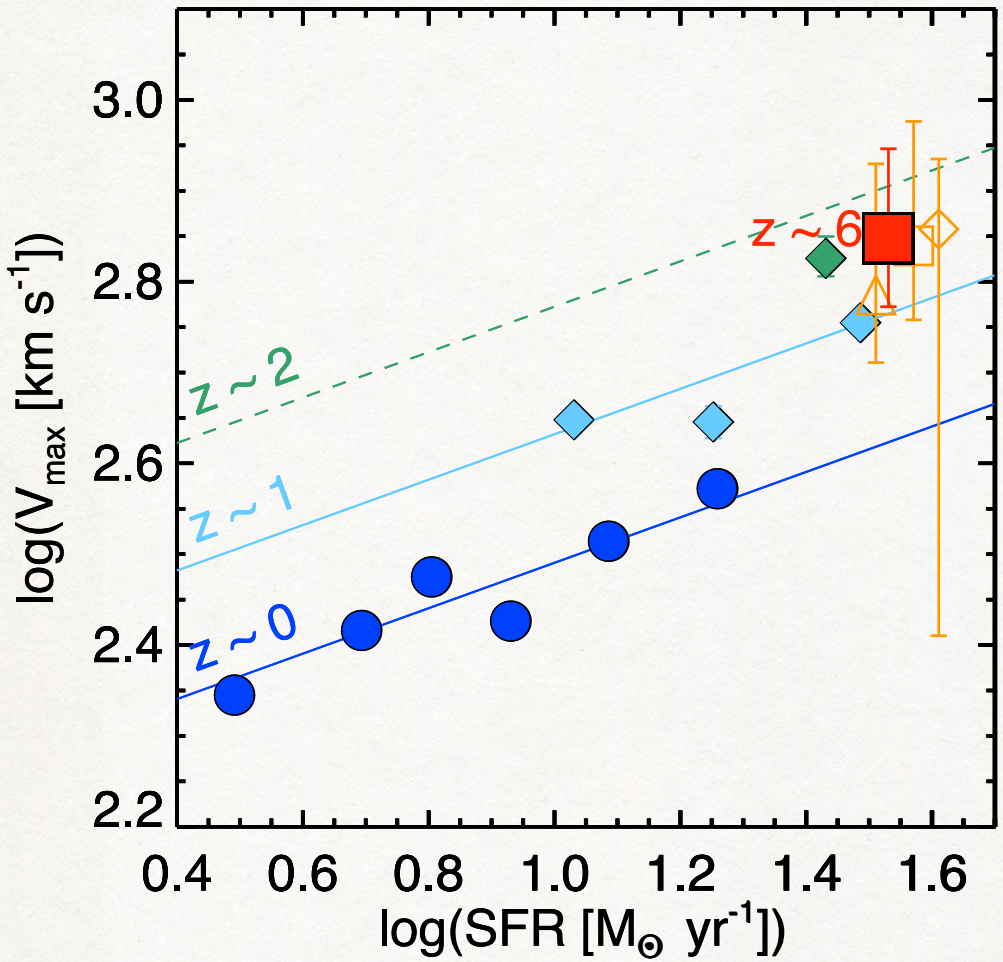
Analysis — Rest-UV Spectra Stacking



Analysis — Fitting



Result 1: Vmax vs. SFR



Red: SiII+CII

$V_{max} = 700^{+180}_{-110}$ km s^{-1}

Orange: SiII,CII,SiIV

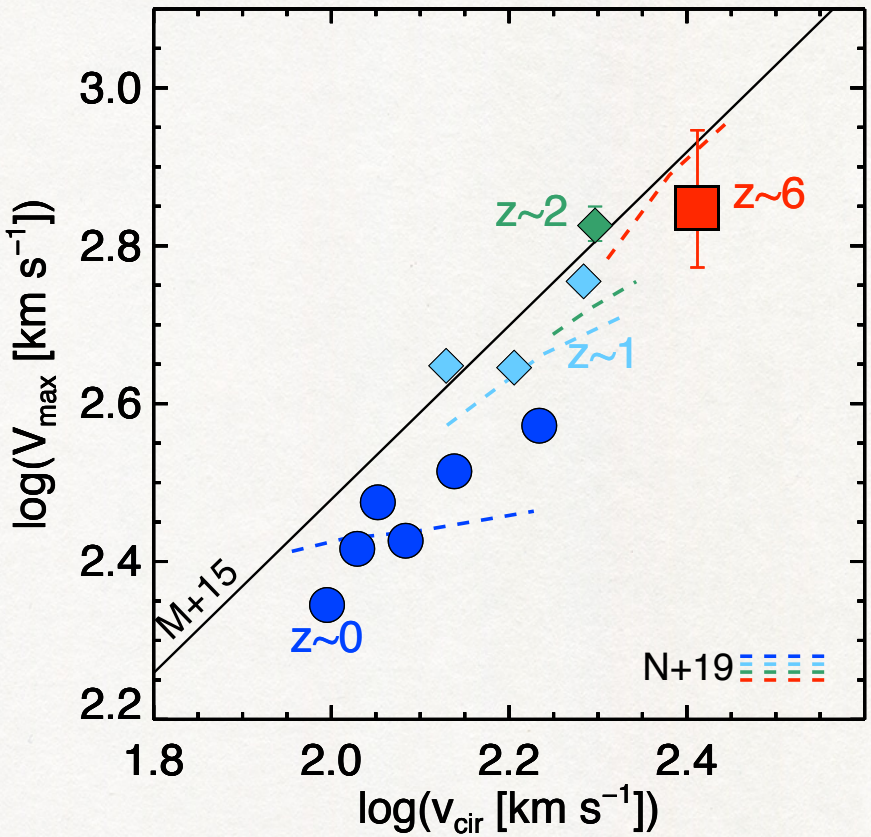
→ consistent

z~0,1,2 (Sugahara+17)

Outflow velocity at z∼6 is comparable to one at z∼2

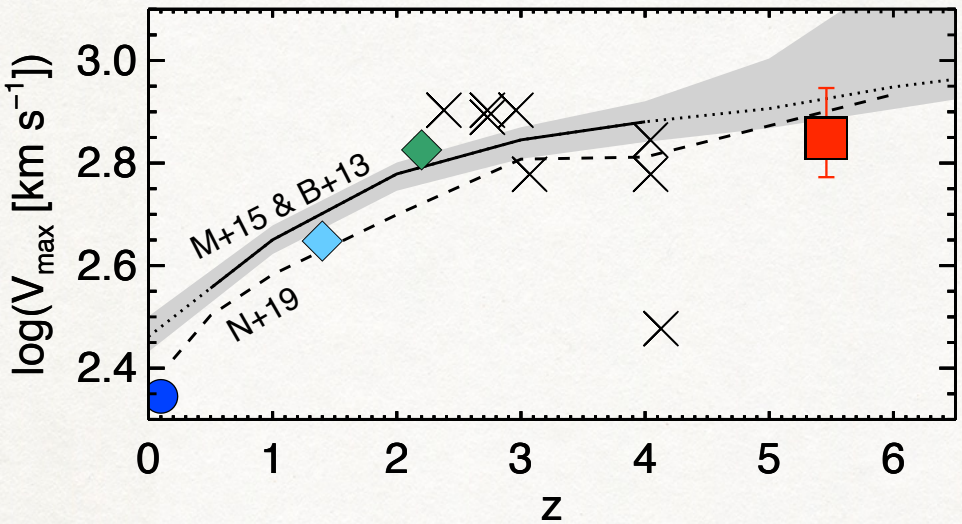
Result 2: Vmax vs. Vcir

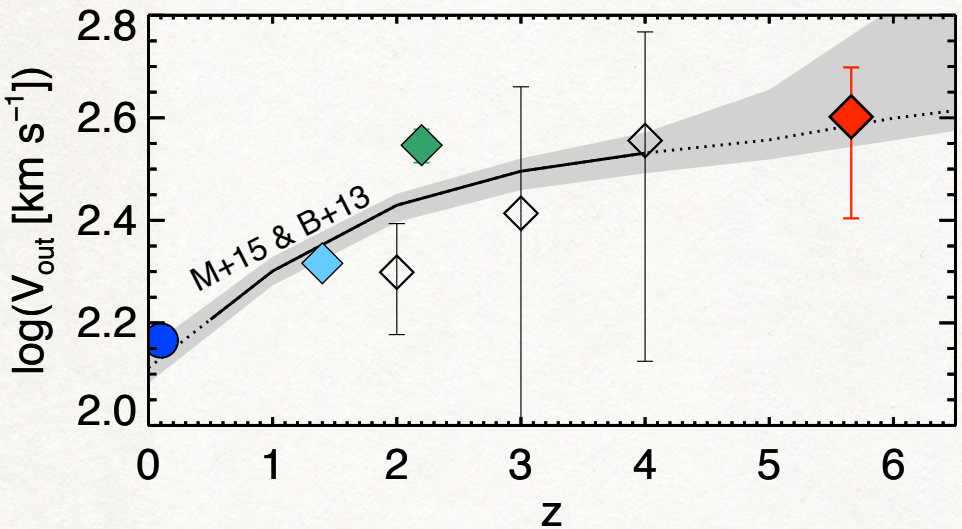
- Halo circular velocity
  - $M_* \rightarrow M_h$ Behroozi+13
  - $M_h \rightarrow V_{cir}$ Mo&White 02
- Data points over z~0-6 on the same relation
- agree with predictions
  - FIRE simulations: Muratov+15
  - IllustrisTNG: Nelson+19



Vcir strongly correlates with Vmax

Result 3: Redshift Evolution of Vmax



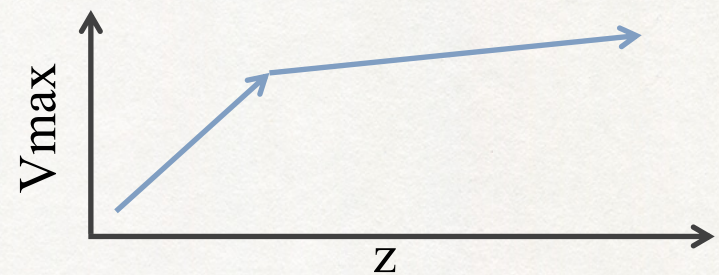


monotonic increase with z

$$V_{\rm cir} = \sqrt{\frac{GM_{\rm h}}{R}} \propto (1+z)^{\frac{1}{2}}$$

at fixed halo mass

If V_{max} linearly correlates w V_{cir}

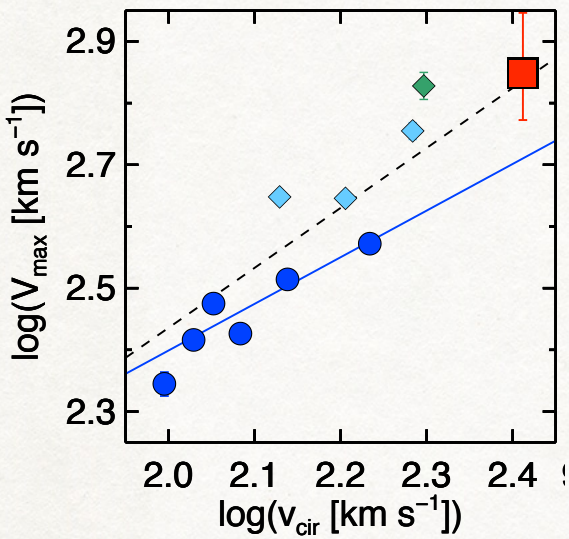


Evolution at $M^* \sim 10^{10.1} M_\odot$

Comparing to:

Jones+13 (×), Du+18 (◇)

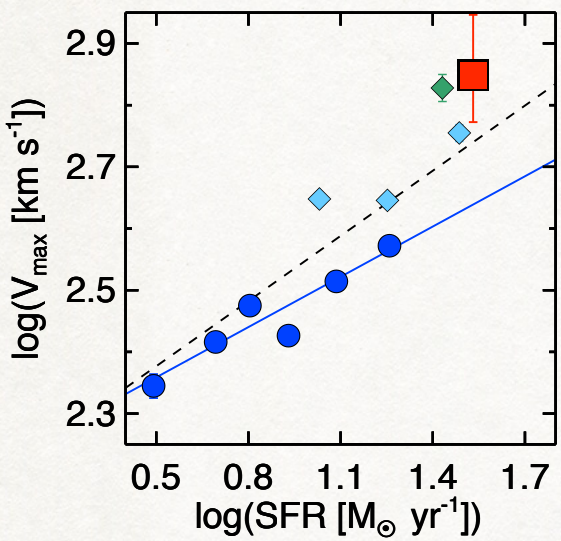
Vmax correlation with gal. properties



Vcir & SFR

Similar Relations

at z~0 & at z=0–6 (dash)

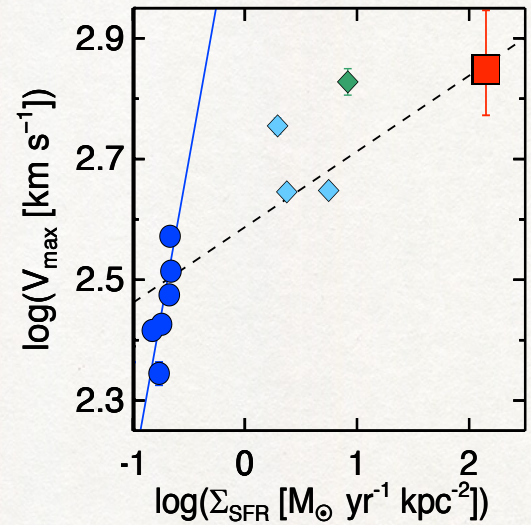


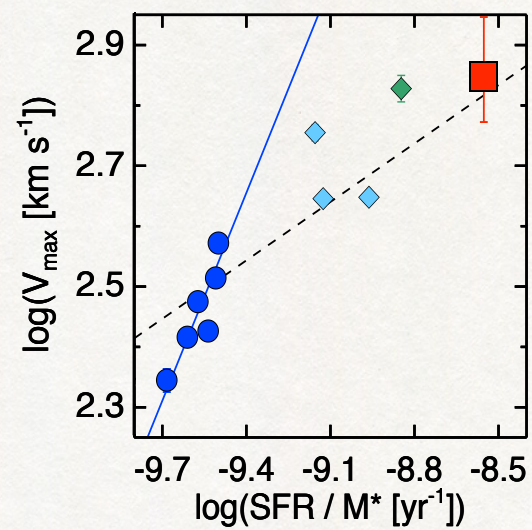
Fundamental

Vcir or SFR

Different slope of the relations

Σ_{SFR} & SFR/M*





Fast Outflows in Early SFGs at z=5–6

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- Sample & Analysis
  - LBGs observed with DEIMOS & ALMA (PI. P. Capak)
  - V_{max} by fitting to abs. lines of composite spectrum
- Results
  - $V_{max} = 700^{+180}_{-110}$ km s^{-1}
  - Outflow velocity increases at z ~ 0→6 at a fixed M*
  - V_{cir} or SFR would be fundamental to determine V_{max}