MOSEL: Strong [OIII]5007 Å Emitting Galaxies at ($3<z<4$) from the ZFOURGE Survey

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Structure:

- Abstract [1]
- Introduction [1]
- Data & Method [2]
- Results [4]
- Discussion [2]

Abstract

- Multi-Object Spectroscopic Emission Line (MOSEL) survey (ZFOURGE+MOSFIRE)
- 31 [OIII]5007Å ELGs (3 < Zspec < 3.8)
  - EW: 100 — 500 Å
  - Mass: $\log(M_*/M_\odot) \sim 8.2 - 9.6$
  - 0.9 dex above the SFMS
  - gas fraction $f_{gas} > 60\%$
- → These galaxies experience starburst
  - An early episode of intense stellar growth
  - Many galaxies at z > 3 go through this starburst phase

Strong emission line galaxies → SELGs

Introduction

- Strong [OIII]5007Å emission at z < 0.3 is detected because they increase the broadband flux
  - → so called “green pea" galaxies
- Strong Hβ+[OIII]5007Å emission are ubiquitous in Lyman-break galaxies at z ~ 7
- Dwarf galaxies ($\log(M_*/M_\odot)$< 9) at 0 < z < 2 with strong [OIII]5007Å emission is the bridge.

- The number density of SELGs increases with redshift
  - Evolution model: galaxies grow through multiple intense starbursts ← brief starburst phase (<100 Myr)
    - $EW_{rest} > 1000$Å are “first burst" systems
  - Important implications for cosmic reionization
    - SELGs have steep UV slopes (β < -2) and low metallicities ($Z/Z_\odot$ < 0.2)
    - Measure the Lyman-Continuum emission and escape fractions

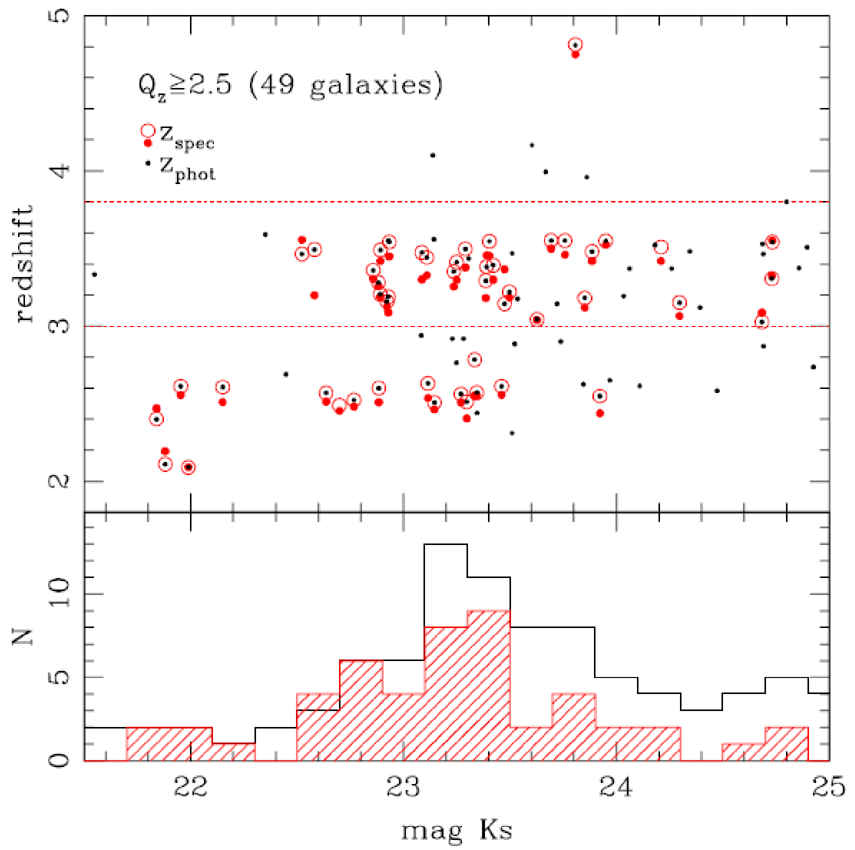
- ZFOURGE survey → SED fitting → ~ 80 galaxies with Hβ+[OIII] > 800Å at 2.5 < Zphot < 4.0 (14 at 0 < z < 1)
- MOSEL survey (spectroscopically confirm these ELGs)
- The spectroscopic measurements + physical properties obtained from deep multi-band imaging to infer gas fractions and virial masses, and test disk formation models.

Data & Method

- 1. Selecting Emission Line Galaxies
  - 1.1 ZFOURGE Imaging Catalogs
  - 1.2 Candidate Emission Line Galaxies at 2.5 < Zphot < 4.0
    - Hβ+[OIII] emission falls in the deep Ks imaging
    - rest-frame equivalent widths down to ~ 20Å can be recovered
    - SFG: Hβ+[OIII] EW < 230Å
    - SELG: Hβ+[OIII] EW > 230Å

      S_1ELG: 230Å < Hβ+[OIII] EW < 800Å (218)

      S_2ELG: Hβ+[OIII] EW > 800Å (60)
    - The majority of SELGs are in CDFS



- 2. Keck/MOSFIRE Spectroscopy
  - 2.1 Observation
    - 5 masks in COSMOS and 1 mask in CDFS → 38 SELGs candidates, 67 SFGs (targeted from SED)
  - 2.2 Spectroscopic Redshifts
    - 49 galaxies have Zspec (2.091 < Zspec < 4.751, 89 targeted, 53% success rate)
    - Zphot is ~ 0:054 higher than Zspec, $\sigma_z = [\Delta z/(1 + z)]$ = 0.0135
    - 8 S_1ELG, 13 S_2ELG, 10 SFGs at 3 < Zspec < 3.8 (ELGs is easier to be detected by Spectroscopy)

- 2.3 Measuring [OIII]5007Å Spectral Line Emission

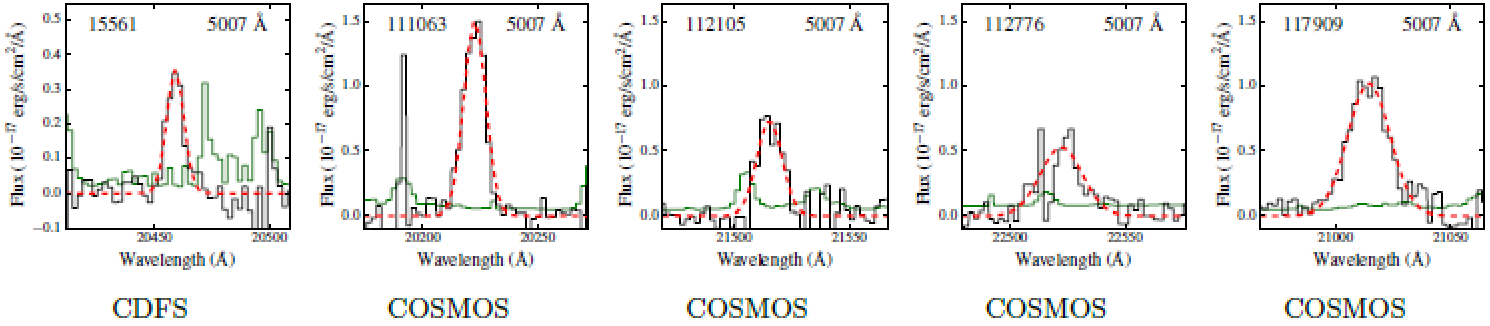


Figure 2. Example of fits to the MOSFIRE spectra (§2.2.3) showing the observed 1D spectrum (black), the 1D error spectrum (green), and the 1D Gaussian fit (red dashed curve).

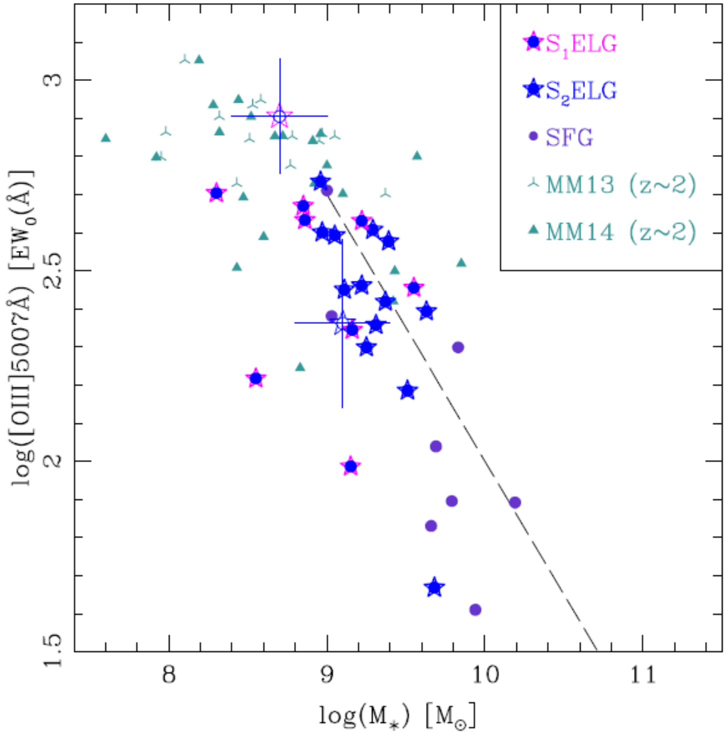
  - [OIII]5007Å Line flux: 3σ range of the best-fitting Gaussian

- 2.4 Determining [OIII]5007Å Equivalent Width
  - Combine spectro-photometrically calibrated [OIII]5007Å line fluxes with the deep continuum photometry from ZFOURGE (the galaxy sizes are comparable to or smaller than the slit-width)
  - SED fits: FAST with emission lines (Salmon et al. 2015), Metallicity subsolar (Z = 0.004)

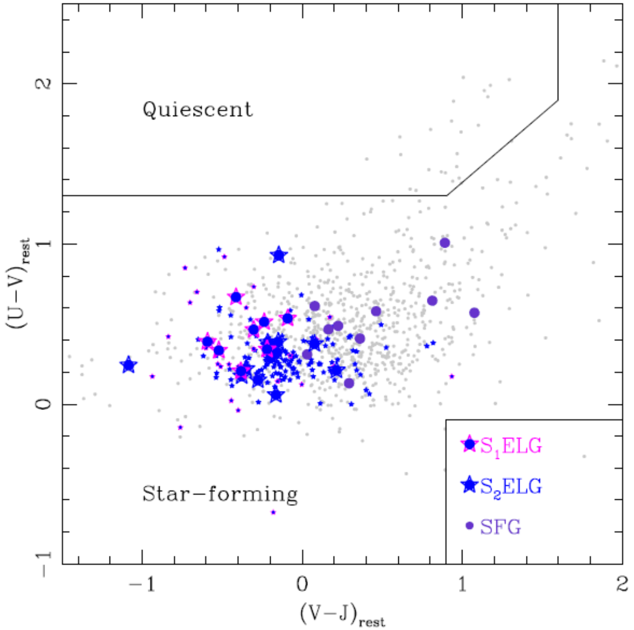
$$\mathrm{EW_{rest}}(5007) = \frac{f_{\mathrm{line}}(5007)}{[(f_{\mathrm{cont}}(4675) + f_{\mathrm{cont}}(5200)]/2} \left(\frac{1}{1+z}\right)$$

Results

- Research targets: 31 galaxies that are spectroscopically confirmed
- 1. Strong [OIII]5007Å Emission
  - Decreasing [OIII]5007Å equivalent width with increasing stellar mass
    Also observed in SELGs at z ~ 2 (cyan dots)
  - Overlap between $\mathrm{S_1ELG}$ and $\mathrm{S_2ELG}$
  - SFGs: larger stellar masses and lower EW
  - Selecting Strong ELGs from the ZFOURGE photometry is effective at identifying galaxies with the largest [OIII]5007Å EWs.



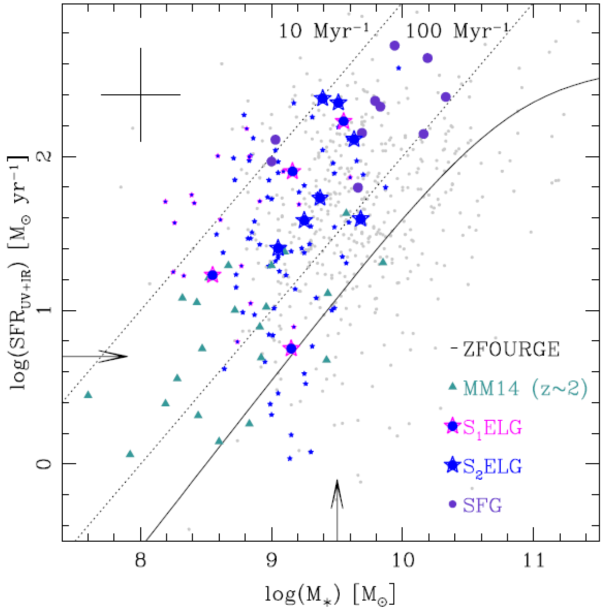
- 2. Rest-frame UV J Colors
  - None of the galaxies are dusty
    (V — J) > 1.2
  - Strong ELGs are offset towards bluer
  - A continuum of phases:
    age and dust content increases from SELGs to the more typical SFGs



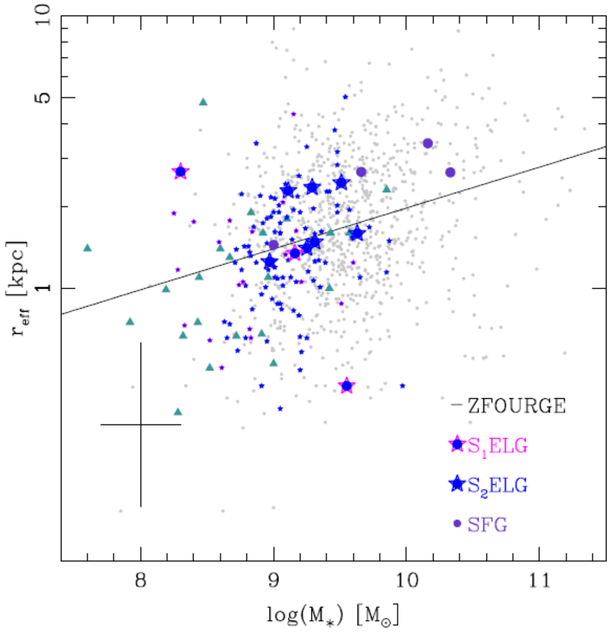
- 3. Star-Formation Rate vs. Stellar Mass
  - At z ~ 3, the log(M*) for the stellar luminosity function from ZFOURGE is ~ 10.7
  - For SELGs $\log(M_*/M_\odot) \sim 8.2 - 9.6$, (0.003—0.08 M*)

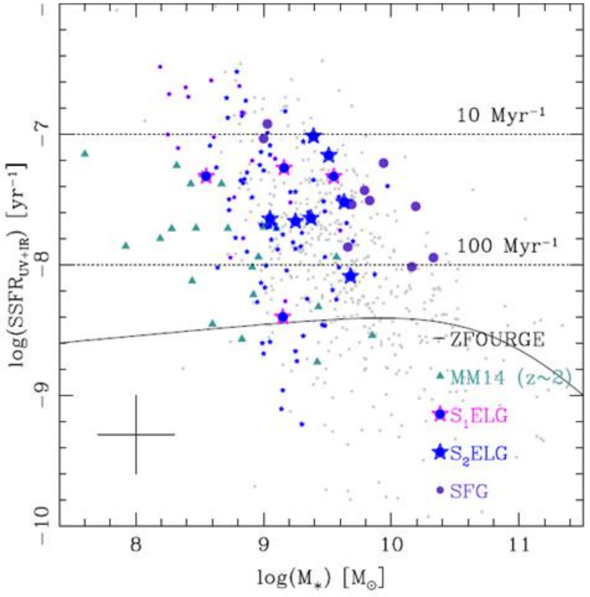
  - SELGs tend to lie ~0.9 dex above the SFMS at z = 3.5
  - Curve: (UV+IR) star formation rates from ZFOURGE
  - Dotted: mass-doubling timescales of 10 and 100 Myr
    - all of the Strong ELGs are starbursts
    - Increase their stellar masses by factors > 2 in less than 100 Myr

** The (UV+IR) based SFRs are near or below the IR detection limit of ZFOURGE (little dust however)



- 4. Galaxy Size vs. Stellar Mass
  - ELGs at 2.5 <Zphot< 4.0 follow the same $r_{eff} - M_*$ relation as the general population

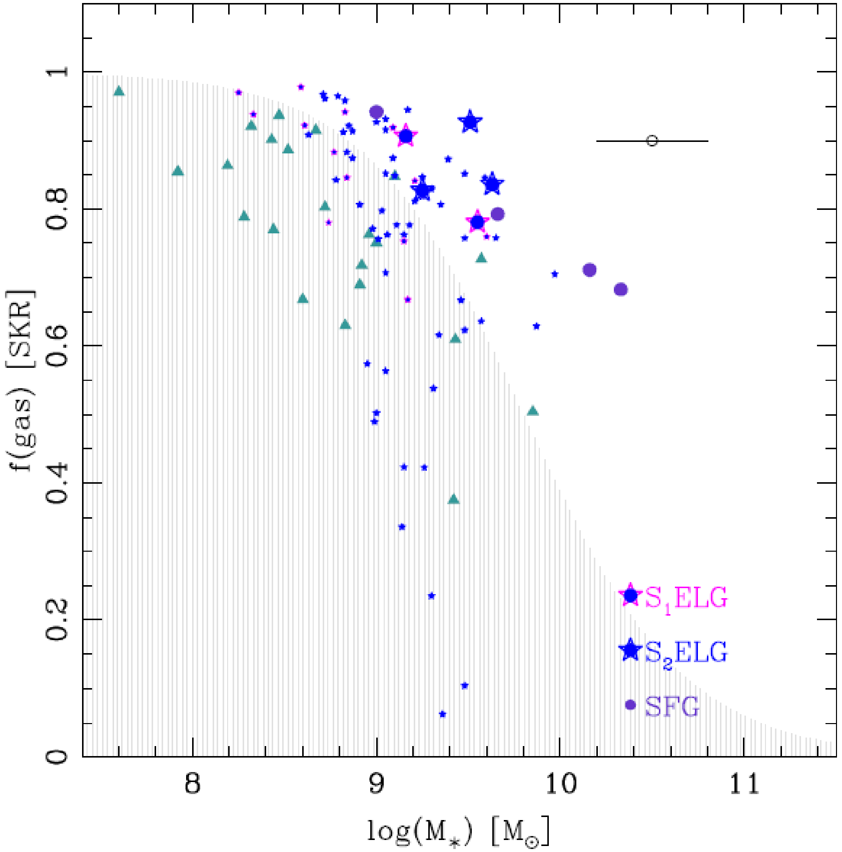




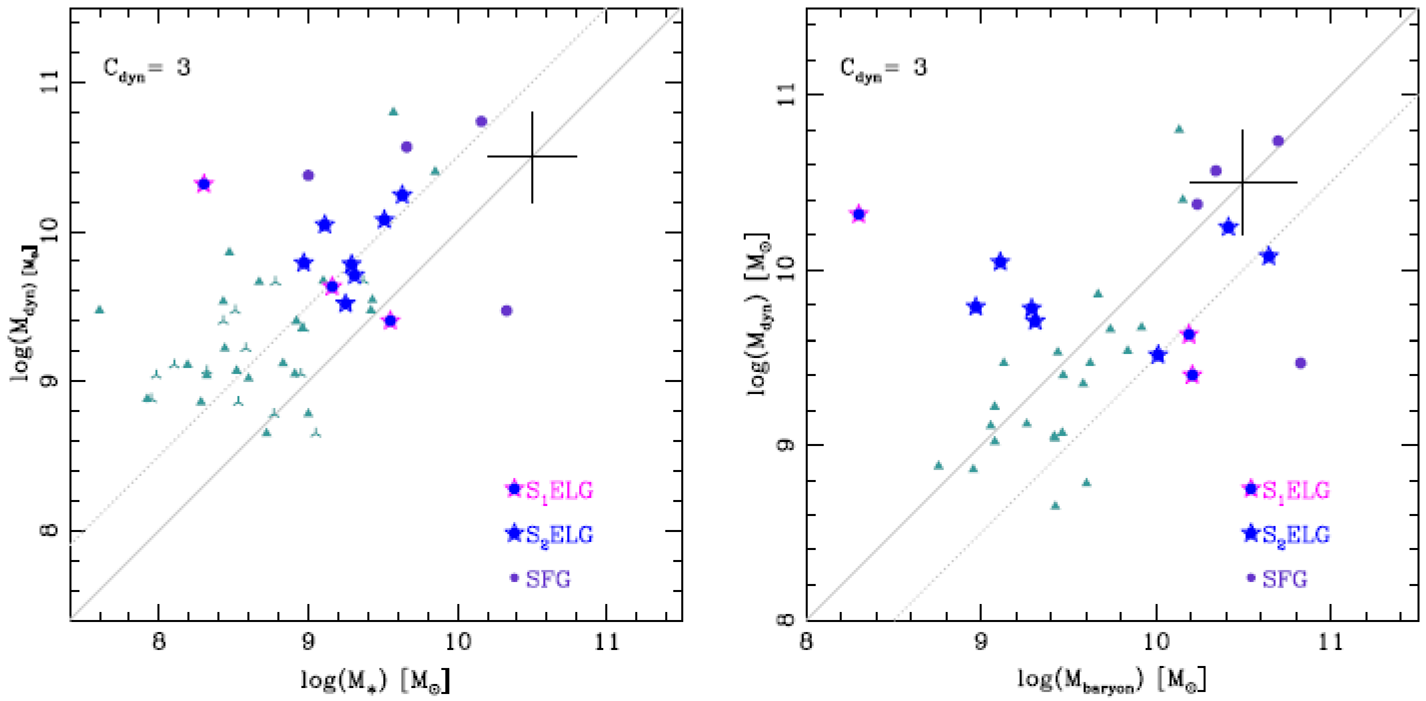
- 5. Inferred Gas Fractions
  - The Schmidt-Kennicutt Relation: relation between the gas density and SFR

$$\Sigma_{SFR} = (2.5 \pm 0.7) \times 10^{-4} \left(\frac{\Sigma_{gas}}{1M_\odot\ pc^{-2}}\right)^{1.4\pm0.15} M_\odot\ year^{-1}\ kpc^{-2} \qquad \log(M_{gas}) = \frac{5}{7}\log(L_{UV+IR}) + \frac{2}{7}\log[\pi(r_{eff})^2] + 1.52$$

    With UV+IR luminosities from ZFOURGE and r_{eff} from the HST/F160W imaging
  - Gas fraction: $f_{gas} = M_{gas}/(M_{gas} + M_*)$ gas mass limit is $\log(M_{gas}/M_\odot) = 9.8$
  - ELGS have inferred gas fractions of $f_{gas} > 60\%$
    ** 1. High sSFR 2. Detection limits



- 6. Kinematics
  - Integrated velocity dispersions σ_{int} (based on line-widths)
    $\sigma_{int} \sim 40 - 150\ km/s$
  - Virial mass (Dynamical mass): $M_{dyn}(< R_e) = K_e \frac{\sigma_{int}^2 R_e}{G}$
  - The dynamical masses for ELGs are ~ 0.4 dex larger than their stellar masses
  - Baryonic mass ($M_{gas} + M_*$): parity but lack of confidence

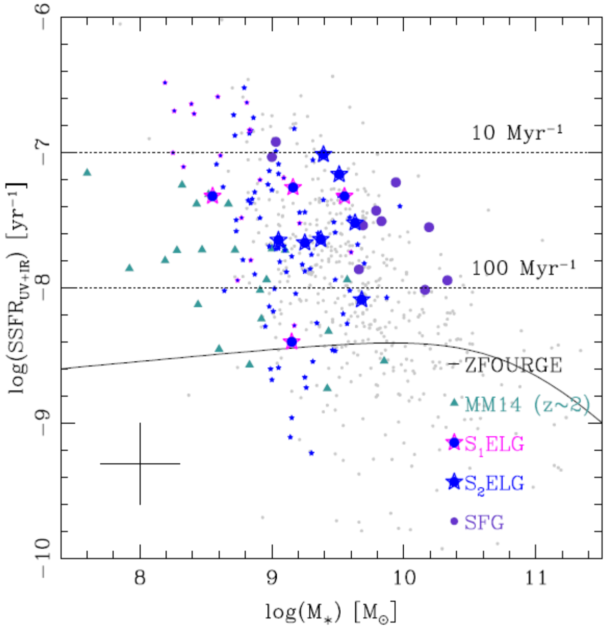


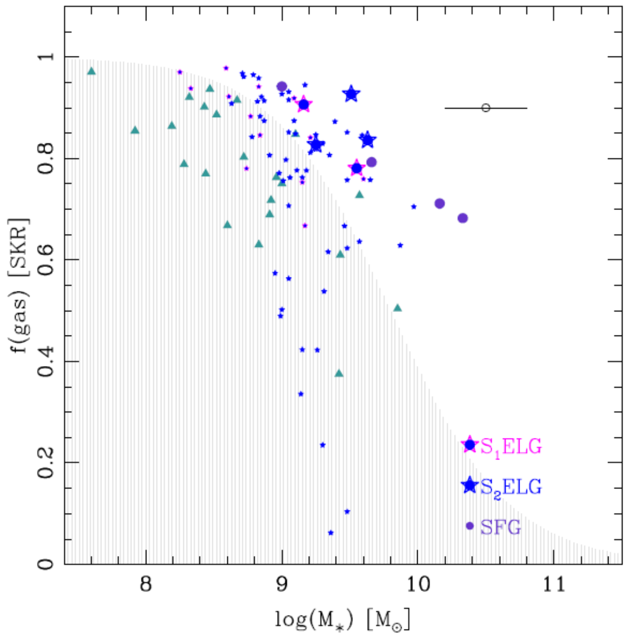
Field	ZFOURGE[a] ID	$f(5007\text{Å})$[b] 10^{-17} erg s^{-1} cm^{-2}	σ_{1D}[b] Å	σ_{int}[b] km s^{-1}	EW$_{rest}$[c] Å
COSMOS	1877	2.2 ±0.6	10.5	151	23.3
COSMOS	4214	1.4 ±1.1	3.0	39	23.0
COSMOS	7239	10.1 ±0.3	4.3	62	542
COSMOS	9884	10.5 ±0.6	9.0	124	392
COSMOS	11063	17.3 ±0.4	4.1	60	468
COSMOS	11284	16.8 ±0.9	4.9	68	262
COSMOS	11544	12.3 ±0.6	6.0	83	153
COSMOS	12000	8.3 ±0.4	8.5	119	78.0
COSMOS	12105	9.6 ±0.7	4.9	67	221
COSMOS	12273	8.0 ±0.5	7.7	110	78.6
COSMOS	12776	11.5 ±1.6	8.7	116	199
COSMOS	12922	4.9 ±1.1	10.0	141	67.6
COSMOS	14984	8.1 ±0.2	5.1	70	228
COSMOS	15625	8.7 ±0.3	4.1	58	199
COSMOS	15636	4.8 ±0.5	11.4	154	514
COSMOS	16067	24.8 ±0.4	6.3	90	428
COSMOS	16325	6.7 ±1.3	7.8	105	109
COSMOS	16513	13.0 ±0.6	4.3	58	289
COSMOS	16518	4.3 ±1.0	8.3	113	40.8
COSMOS	16984	14.7 ±0.3	4.4	60	405
COSMOS	17008	10.6 ±0.8	6.3	84	399
COSMOS	17423	12.3 ±1.1	6.9	90	285
COSMOS	17909	22.5 ±0.7	8.8	125	248
COSMOS	18022	6.5 ±0.4	6.2	83	282
COSMOS	20001	22.0 ±0.5	7.3	97	378
CDFS	22136	2.8 ±0.7	14.3	208	97.0
CDFS	15782	2.6 ±0.5	6.6	96	240
CDFS	18053	1.0 ±0.6	3.6	49	165
CDFS	17189	2.3 ±0.4	8.0	105	506
CDFS	14864	2.7 ±0.3	10.8	142	46.6
CDFS	15561	3.2 ±0.2	2.8	41	430

Discussion

- Strong emission line phase is the exception or the norm at high redshifts
- 1. Strong [OIII]5007Å Emission May Be Common in Early Galaxy Formation
  - UVJ diagram: SELGs (V-J < 0) → SFGs (0 < V-J < 1)
  - Amorin et al. 2017: Strong [OIII]5007Å emission is the earliest episodes of intense star formation
    - grow in stellar mass → grow in amount of continuum light → decrease in EW → typical SFGs
    - Great gas fraction (>60%)
  - Cohn et al. 2018: (Prospector SED) SELGs has $Z < 0.02Z_{\odot}$, sSFR 4.6 Gyr^{-1} (SFGs 1.1 Gyr^{-1})
  - SELGs are “first burst" systems continue to form stars and chemically enrich to evolve into more typical SFGs

  - For these two figures:
    - SELGs will move from upper-left to bottom-right





- 2. A Potential Source of Ionizing UV Photons
  - Galaxies rather than AGN generated the UV photons needed to ionize the universe
  - No enough massive galaxies at z ~ 6 to generate the required UV photons
  - Nakajima et al. 2016: low-mass system at z > 3, with [OIII]5007Å > 300Å and escape fraction $f_{esc} > 10\%$
  - At z > 8, these low-mass, star-bursting galaxies should be in large numbers to generate the required UV photons.

  - Izotov et al. 2016 …:

    [OIII]/[OII] is track of Lyman-Continuum photons (O32 > 5, more leaked photons)
  - Bassett et al. (2019):

    the correlation between large [OIII]5007/[OII]3727 ratios and more Ly-C photons is weak

  - Future plan: Measure [OII]3727Å emission for the ELGs to characterize their ionization conditions and constrain their production of Lyman-Continuum photons (H-band Spectroscopy)

SWIMS detection

- K_1, K_2, K_3-band, medium-bandwidth
- Directly detect the emission flux from SED fits with a large samples