The Typical Massive Quiescent Galaxy at z∼3 is a Post-starburst

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ABSTRACT

We have obtained spectroscopic confirmation with *Hubble Space Telescope* WFC3/G141 of a first sizeable sample of nine quiescent galaxies at 2.4<z<3.3. Their average near-UV/optical rest-frame spectrum is characterized by low attenuation (Av∼0.6 mag) and a strong Balmer break, larger than the 4000 Å break, corresponding to a fairly young age of ∼300 Myr. This formally classifies a substantial fraction of classically selected quiescent galaxies at $z \sim 3$ as post-starbursts, marking their convergence to the quenching epoch. The rapid spectral evolution with respect to $z \sim 1.5$ quiescent galaxies is not matched by an increase of residual star-formation, as judged from the weak detection of [O II]λ3727 emission, pointing to a flattening of the steep increase in gas fractions previously seen from $z \sim 0$ to 1.8. However, radio 3GHz stacked emission implies either much stronger dust-obscured star formation or substantial further evolution in radio-mode AGN activity with respect to $z \sim 1.5$.

Table 1. Main properties of our sample derived from the stacked spectrum (see text). Solar metallicity and a Salpeter IMF were assumed throughout.

<z>	$< M_* >$ (10^{11} $M_\odot$)	t_{50} (Gyr)	Av (mag)	D_n4000	D_B	$EW_{[O\ II]}$ (Å)	$F_{[O\ II]}$ (erg s^{-1} cm^{-2})	SFR ($M_\odot$ yr^{-1})
2.808	1.8 ± 0.8	$0.30^{+0.20}_{-0.05}$	$0.9^{+0.4}_{-0.5}$	1.28 ± 0.05	1.88±0.07	2.1 ± 0.6	3.1± 0.7 ×10^{-18}	7 ± 3

Massive銀河のquenchingシナリオ

- Massive, passive銀河 (PEG) は進化の最終段階。
  - これらはいつ生まれてどのようにquenchしたのか？
- HST/WFC3分光 (R~130) サンプル at 2.4<z<3.3
  - pBzK sample → UVJ selection → z~2.8, Ms~1.8e11

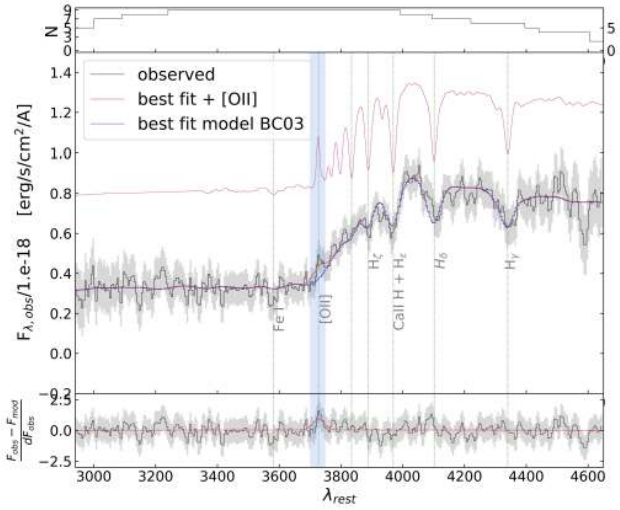

Figure 1. Top: Number of galaxies contributing to each spectral bin. Middle: Stack of 9 quiescent galaxies' spectra. Blue curve: best-fit model from the BC03 library. Red curve: Gaussian fit to the residual, added to the blue continuum. Pink curve: best-fit BC03 template smoothed for a σ_v ∼200 km s^{-1}, shifted in flux for clarity. Vertical dotted lines mark the identified absorption features. Bottom: Fit residuals normalized to the error spectrum.

- 9天体分のz~2.8 stacked spectrum
- BC03でfitし、$H_{\delta A}$, D_n(4000), D_Bを測定。
- MPFITで[OII]3727輝線をfit
  → residual SF ~ 7 Msun/yr → MSの1/60

f_{mol} = sSFR / SFE

- sSFR = SFR / Ms
- SFE = (SFR / M_{gas}) =5e-10

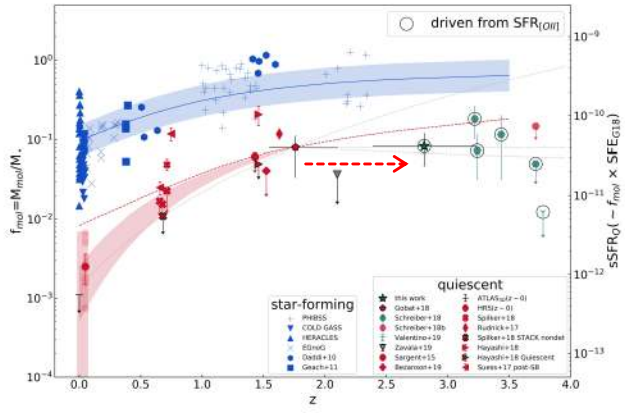

Figure 4. Evolution of f_{mol} or equivalently (see Sect. 5) the sSFR of quiescent galaxies (sSFR$_Q$) with redshift, adapted from Gobat et al. (2018). Red symbols mark quiescent galaxies, old and post-starbursts, with CO or dust-continuum measures, whereas circled green symbols mark estimates from $SFR_{[O\ II]}$ alone, converted to f_{mol} adopting G18 SFE. Black contours mark stacked samples, where horizontal error bars show the spread in redshift of individual targets. Blue symbols mark the gas fraction of low-, intermediate-, and high-z ($z > 1$) MS galaxies. The blue curve and shaded area mark the evolution of an average 5×10^{10} $M_\odot$ MS galaxy and its 0.2 dex scatter (Sargent et al. 2014). The red dotted curve shows the same relation, offset by a factor of 6 and for a stellar mass of $\log(M^*(z)+\Delta M)$, where ΔM is the offset between the median mass of G18 sample and the M^* of the passive stellar mass function at <z>∼1.8. The pink shaded area shows the trend derived in G18. Grey lines are extrapolations of the low redshift trend assuming a gas fraction rise as $(1+z)^\alpha$, with α ∼4-5, as fast as in G18; α=2.2 as for MS galaxies; α=0 for no evolution; and α=-0.5 representative of a negative evolution.

$H_{\delta A}$強, D_B強, D_n4000弱 → A型星が主のpost-SB

✓ これまで(測光で)quiescentと判定されていた銀河の多くはpost-SBとみられる。

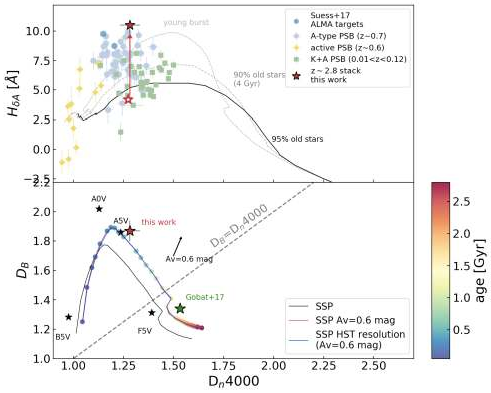

Figure 2. Top: comparison between our average D_n4000 and $H_{\delta A}$ and z∼0.7 A-type post-starburst galaxies (light blue dots) from Suess et al. (2017). Green squares and yellow diamonds: K+A local post-starbursts and z∼0.6 active post-starbursts, French et al. (2015); Sell et al. (2014) respectively. Open star: $H\delta_A$ computed on the stacked spectrum, as a lower limit due to resolution. Tracks with different amounts of old stars (age>4Gyr) from Suess et al. (2017) are shown, going from no old stars (dotted line) to 95% of old stars (solid line). Bottom: strength of the Balmer and 4000 Å break indices as a function of the SSP age. Red and green stars represent the indices measured on our stack spectrum and on Gobat et al. (2017) spectrum respectively. Black stars mark the indices computed on theoretical stellar spectra smoothed to HST resolution (Rodríguez-Merino et al. 2005).

- quiescent銀河のf_{mol}変化
  - z~0→1.5へ増加
  - 今回の結果 (z~2.8) はz~1.5と同等。
  - → f_{mol}はz~1.5以降はflatと考えられる。
  - SFはほぼ無いが、gasは失われていく。

✓ z~3 quiescent銀河の多くはf_{mol}を保ったまま quenching phaseに入りつつあるようだ。

- Cold flow, AGN feedback, dust grain growth, satellite accretion, dust destruction,,,