Recent Star-formation in a Massive Slowly-Quenched Lensed Quiescent Galaxy at z=1.88

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ABSTRACT

In this letter, we reconstruct the formation pathway of MRG-S0851, a massive, $\log M_*/M_\odot = 11.02 \pm 0.04$, strongly lensed, red, galaxy at $z = 1.883 \pm 0.001$. While the global photometry and spatially-resolved outskirts of MRG-S0851 imply an early-formation scenario with a slowly decreasing or constant star-formation history, a joint fit of 2D grism spectroscopy and photometry reveals a more complex scenario: MRG-S0851 is likely to be experiencing a centrally-concentrated rejuvenation in the inner ~1 kpc in the last ~100 Myr of evolution. We estimate $0.5 \pm 0.1\%$ of the total stellar mass is formed in this phase. Rejuvenation episodes are suggested to be infrequent for massive galaxies at $z \sim 2$, but as our analyses indicate, more examples of complex star-formation histories may yet be hidden within existing data. By adding a FUV color criterion to the standard U-V/V-J diagnostic — thereby heightening our sensitivity to recent star formation — we show that we can select populations of galaxies with similar spectral energy distributions to that of MRG-S0851, but note that deep follow-up spectroscopic observations and/or spatially resolved analyses are necessary to robustly confirm the rejuvenation of these candidates. Using our criteria with MRG-S0851 as a prototype, we estimate that ~1% of massive quiescent galaxies at $1 < z < 2$ are potentially rejuvenating.

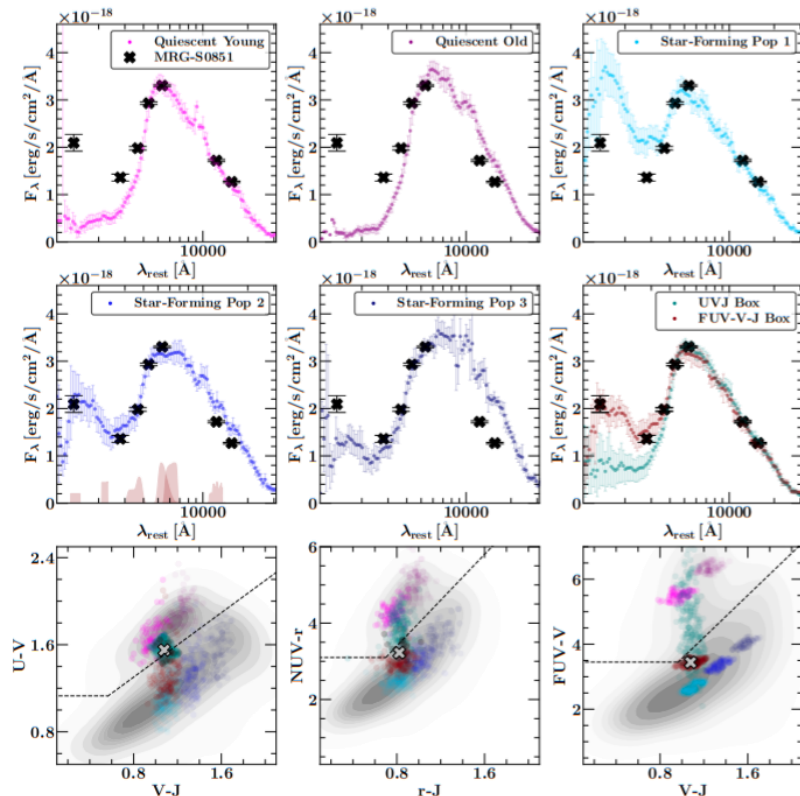## Quench後に星形成を起こした銀河の色選択

- z~2 (lensed) quiescent銀河 (MRG-S0851) のspatially-resolved SEDを見ると、中心部 (< 1 kpc) に星形成の兆候が見られた。
- UVJ色選択では見落としてしまうごく最近の星形成 (rejuvenation) をFUV (~1400A) で捉える新たな条件を提案。
  - → Quiescent銀河の1%が合致。

Figure 1
- 測光のみ → SFRはz~9からslow quenchする傾向。
- 測光 + WFC3 Grism → z~2からSFRが (中心ほど) 増加する傾向が見えた。
  - 総星質量 (1e11M*)の~0.5%に寄与。
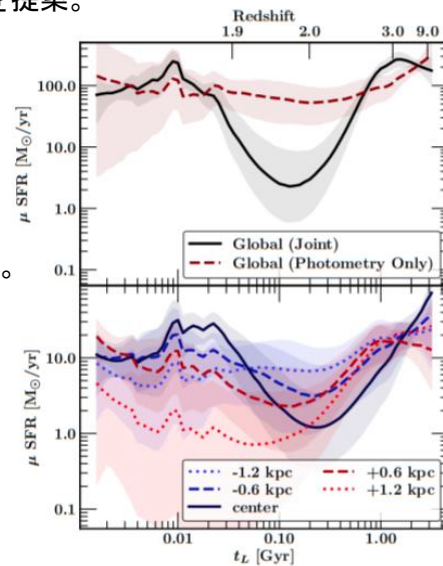- → Early formation + late (central) rejuvenation (Figure 5)

Figure 3
- MRG-S0851 は
  - UVJ図ではSFとQuiescentの中間。
  - UVJ選択銀河と比べて、FUV, NUVでexcess。
- FUV選択銀河は、UVJ図ではSF～Quiescentにまたがる。
  - SF: young (0.6 Gyr) & dusty
  - Q : old (2.4 Gyr) & less-dusty
- FUVもselectionに加えれば、MRG-S0851のような種族を選択できる。
  - Massive quiescent銀河の~1%が該当。
- JWST等による高感度分光による検証が必要。

Figure 1. Reconstructed SFHs of MRG-S0851 as a function of lookback time, t_L, demonstrating how photometry-only global fit misses the enhancement of SFH in the last ~100 Myr of evolution. The bottom panel shows the spatially-resolved model with global SSP prior, noting that the re-solved SSP prior yields a consistent result within 1σ for 5 central bins. The SFHs from the joint fit are generally de-creasing from $z \sim 9$ to $z \sim 2$, but the central bins' and the global stellar populations show an increase in the SFR in the last ~100 Myr of evolution. The SFRs are not corrected for gravitational lensing magnification μ.

Figure 3. The median and the median absolute deviation of the SEDs for seven populations of galaxies with $1.0 < z < 3.0$ and $\log M_*/M_\odot > 10.0$ selected from 3D-HST, based on their location in the FUVVJ and UVJ rest-frame color-color diagrams. The full distribution of 3D-HST galaxies with $1.0 < z < 3.0$ and $\log M_*/M_\odot > 10.0$ is shown with density maps in lower panels. The composite SEDs are shown with the same color of their corresponding population in the color-color diagrams. The photometric measurements of MRG-S0851 are shown with crosses. In the middle left panel, we show the throughput of different filters at the rest-frame, i.e. FUV ($\lambda_{pivot} \sim 1390\text{Å}$), NUV ($\lambda_{pivot} \sim 2199\text{Å}$), U ($\lambda_{pivot} \sim 3589\text{Å}$), V ($\lambda_{pivot} \sim 5479\text{Å}$), r ($\lambda_{pivot} \sim 6157\text{Å}$), and J ($\lambda_{pivot} \sim 12357\text{Å}$) from left to right (light red). The dashed lines separating star-forming and quiescent galaxies are drawn following Moutard et al. (2018); Leja et al. (2019b).
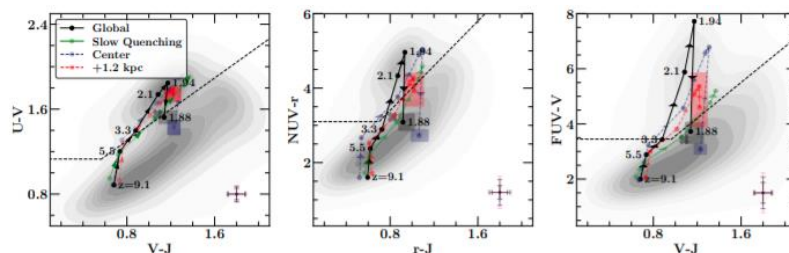

Figure 5. The reconstructed trajectories of MRG-S0851 for evolution in the rest-frame color-color diagrams, suggesting that the evolution of the global and spatially-resolved stellar populations at $z \gtrsim 2.0$ and the outskirt bins at all redshifts are consistent with a slow-quenching formation pathway. The circles are snapshots at 6 redshifts, and the black cross is the global color as measured by EAzY. The color scheme for the trajectories is the same as Figure 1, with black, dark blue and light red are used for global, central bin and the bin at +1.2kpc (adopting Global SSP prior). The boxes at the final redshift snapshot are 1σ uncertainty, and the median uncertainties of different tracks are shown on bottom right. The green trajectory demonstrates a slow-quenching trajectory, constructed following Belli et al. (2019).

Figure 5
- MRG-S0851はslow quenchingしながら、z~3辺りでquiescentに。
- しかし、その後中心付近はz~1.9から再度星形成。