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Possible Identification Of Massive and Evolved Galaxies At $z \gtrsim 5$

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Abstract

We report the identification of the old stellar population galaxy candidates at $z \gtrsim 5$ in this paper. We developed a new infrared color selection scheme to isolate galaxies with the strong Balmer breaks at $z \gtrsim 5$, and applied it to the ultra deep and wide infrared survey data from the *Spitzer* Extended Deep Survey (SEDS) and the UKIRT Infrared Deep Sky Survey. The eight objects satisfying $K-[3.6]>1.3$ and $K-[3.6]>2.4([3.6]-[4.5])+0.6$ are selected in the 0.34 deg^2 SEDS UDS field. Rich multi-wavelength imaging data from optical to far-infrared are also used to reject blending sources and strong nebular line emitters, and we finally obtained the three most likely evolved galaxies at $z \gtrsim 5$. Their stacked SED is well fit by the old stellar population template with $M_* = (7.5 \pm 1.5) \times 10^{10}\,M_\odot$, SFR $= 0.9 \pm 0.2\,M_\odot\,yr^{-1}$, dust $A_V < 1$, and age $= 0.7 \pm 0.4$ Gyr at $z = 5.7 \pm 0.6$, where the dusty star-forming galaxies at $z \sim 2.8$ is disfavored because of the faintness in the 24 μm. The stellar mass density of these evolved galaxy candidates, $(6 \pm 4) \times 10^4\,M_\odot\,Mpc^{-3}$, is much lower than that of star-forming galaxies, but the non-zero fraction suggests that initial star-formation and quenching have been completed by $z \sim 6$.

Key words: galaxies: evolution — galaxies: formation — galaxies: high-redshift

Table 3. Observed properties of the most likely BBGs

NAME	R.A.	Dec.	K	[3.6]	[4.5]
SEDS_UDS_BBG-23	02:16:38.18	-05:13:52.1	25.24±0.43	23.75±0.13	23.73±0.13
SEDS_UDS_BBG-33	02:17:20.23	-05:09:07.5	25.45±0.52	23.98±0.14	23.66±0.13
SEDS_UDS_BBG-34	02:17:15.66	-04:57:59.8	>25.5 (2σ)	24.03±0.15	23.79±0.13

検出天体
- 8つのBBG候補天体
- コンタミの可能性
  - 強い[OIII]@z=4.5 or Ha@z=6
  - Foregroundのコンタミ
- より強い制限
  - BVRizで不検出
  - 24umで不検出
- 3天体が残る

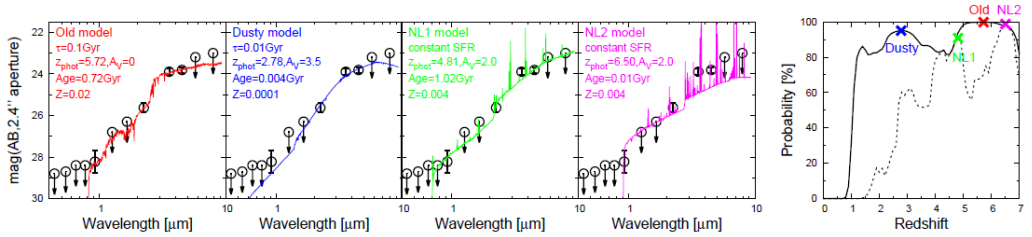


Fig. 7. The stacked SED of the three most likely BBGs (black circles) and the acceptable-fit templates from the BC03 or NL spectral templates. Black arrows mean that the flux points are the 2σ upper limit. In the far right-hand panel, we also show the probability distribution as a function of redshift. The probability distribution for only the NL templates are shown by the dashed line.

Quiescent galaxyがいつ出現したか？
- これまでのサーベイは星形成銀河をメインターゲットとしている
- Passive galaxyは数が少ない
- 4000A / Balmer breakくらいしか指標がない
- Z<3くらいまでだと、最近はrest-frame UVJ planeでの選出
- Z>3ではまだよくわかっていないが
  - IRAC,MIPS24umも含めた選出がいろいろある

この論文では
- Spitzer Extended Deep Survey(SEDS) : 0.34 deg^2
  - IRAC 4.6, 4.5, 5.8, 8um : 22~25AB
  - MIPS 24um : 19.2AB
- + UKIDSS-UDS JHK : 24~25AB
- + Suprime-cam BVRiz : 26~27AB
- + Hershel/SPIRE 250, 350, 500um : 13.5AB
- K-[3.6]カラーでz=5-6のbalmer-breakを選出

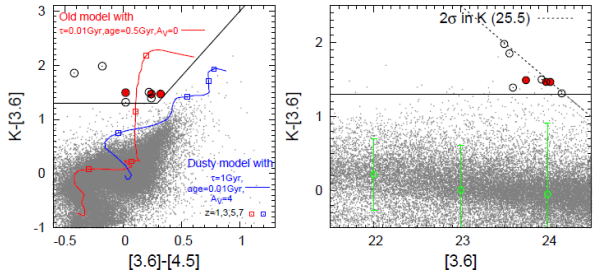
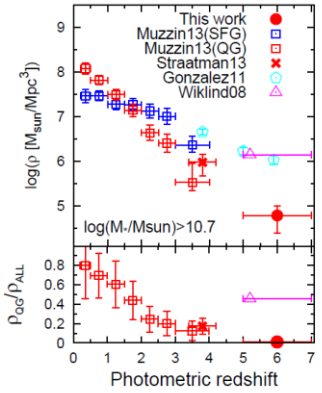


Fig. 5. (Left panel) All objects detected in the SEDS image (grey points) in the $K-[3.6]$ vs. $[3.6]-[4.5]$ two color diagram. Black open circles are the BBG candidates selected by our color criteria (black horizontal and diagonal lines). Red filled circles are the most likely BBGs at $z \gtrsim 5$. Solid red and blue curves are the BC03 model tracks with different star-formation timescale, age, and A_V, where metallicity is fixed to $Z = 0.02$. (Right panel) All objects (grey points), color-selected BBG candidates (black open circles), and most likely BBGs at $z \gtrsim 5$ (red filled circles) in the [3.6] versus $K-[3.6]$ color magnitude diagram. The green circles show the peaks of $K-[3.6]$ color distribution as a function of 3.6μm magnitude, and error bars correspond to the 4σ color errors estimated from the photometric uncertainties in the K and 3.6μm images.

Hyper-zによるStacked-SEDフィット
- BC03 templates
- Strong Nebular template

結果:
- Best-fitはz=5.7 0.7Gyr / 7.5e10 Msol / 0.9 Msol/yr / Av=0
- Z=2.8 Av=3.5 もacceptableだが、24umで検出できるはずなので×
- Z=4.8 or 6.5 strong nebular emitterもacceptableだが、3個ともそうである確率は非常に低い

Discussion
- Stellar mass densityの赤方偏移進化はこれまでの観測とconsistent
- このようなmassive quiescent 銀河はmassive DM-haloにいるはず。周囲の環境を見てみると面白いかもしれない
- Progenitorは？ HFLS3(@z=6.3, 3000Msol/yr)のような天体か？
- HFLS3のDuty Cycleは？
  - Starformation timescale=1-10Myr
  - ~1%くらいになる
  - Progenitorであっても不思議ではない



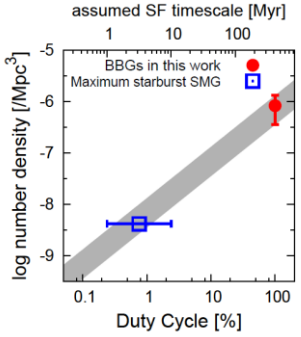


Fig. 9. The number densities of the evolved galaxy candidates (red filled cir-