Searching for Luminous Core-Collapsed Supernovae in a High-z Proto-Cluster

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It has been revealed that SSA22 region at z=3.1 is an extremely high density region of LAEs. In addition to this, star formation in this region is supposed to be biased to very large mass from the evidence such as a large number of large LyA EW objects. Therefore core- collapsed supernovae (SNe) of massive stars are expected to occur frequently in this region. While SNe has not been detected beyond z>2 to date, it is very important not only to detect core-collapsed SNe at z=3.1 but also to obtain any useful information to understand star formation in early universe. So we estimated the expectation of observing core-collapsed SNe in SSA22 region at z=3.1 based on our own sample of star-forming galaxies, and carried out preliminary observations and data analysis to search for variable objects to investigate the detectability of core-collapsed SNe at high-z by searching for variability of LAEs in this region.

Purpose

Approaching Galaxy formation & evolution in the early universe by studying star formation of LAEs & LBGs

⇨ Usual way (using UV, Hα etc...) have uncertainties.

⇨ Searching Core-Collapsed Supernovae(SNe)

Core-Collapsed Supernovae

Their progenitors are massive stars.

= Direct indicator of star formation because they are short-lived.

- Setting lower-limit on star formation rate of host galaxies
- Showing trend of IMF of host galaxies

(Whether to be biased large mass or not?)

Where? How?

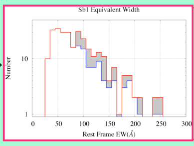
Target Field

The high density region of star-forming galaxies at z=3.1

= The SSA22 field (R.A. = $22^h 17^m$, Dec = + 00°15')

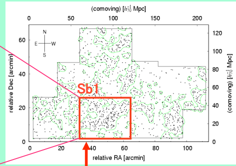
Subaru Telescope / Suprime-Cam 7 FoVs (4726 arcmin²)

= named Sb1〜Sb7



A Distribution of equivalent width(EW) of Lyman α emission line (Sb1). There are LAEs with large EW in the SSA22 field.

↓ Distribution of LAEs



Sb1, which has a highest density among 7 FoVs, is a target field this time.

Why in the SSA22-Sb1 field?

① High density region of LAEs & LBGs

→ We can get large samples of LAEs & LBGs. ⇨ Efficient survey

LAE : 614 obj.	LBG : 985 obj.
(1) NB497 < 26.0 (2) BV−NB497 > 0.8	(1)U−V−2×(V−i')≧1.0 (2)U−V ≧ 0.5 (3)V−i' ≦ 0.6 (4)24 ≦ R ≦ 25.5

② In the SSA22 field, there are LAEs with large Equivalent Width.

→ Probability of the star formation biased to very large mass.

The stars whose mass > 8 M_{sun} become core-collapsed SNe.

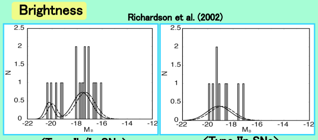
Frequent SNe explosions by massive star? = Frequent Core-collapsed SNe

But observed most distant core-collapse SN is at z<1 …

Probability of detecting SNe at z〜3

Brightness

Richardson et al. (2002)



<Type Ib/Ic SNe> <Type IIn SNe>

Expected brightness at Maximum light

M_{1700}〜 −17.9 ➡ m_{6500}〜27.7

But more luminous SNe could exist.

Expected number

- Consider constant, continuous star formation history.
- Initial mass function (IMF) :Salpeter IMF α=2.35 (0.1−130Msun)
- Star Formation Rate (SFR)
  - LAE:SFR=2 Msun/yr
  - LBG:SFR=40 Msun/yr

⇩ One SN could be observed for 2 weeks in the rest-frame

z〜3 LAE sample : 〜0.05 SN / 614objs.

z〜3 LBG sample : 〜0.2 SN / 985objs.

In case of star formation biased very large mass α=0.5

LAE:〜0.3 SN、LBG:〜3 SN

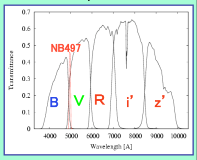
Method

- Observing data (Subaru Telescope / Suprime-Cam)

Band	date	PI	Exposure (hr)	5σ-limit (ABmag)
B	2002/9	Hayashino et al.	0.7	26.6
	2003/9	Capak et al. (archive)	1.1	27.1
V	2002/9	Hayashino et al.	0.7	26.6
	2003/9	Capak et al. (archive)	0.8	26.8
z'	2001/10	Capak et al. (archive)	1.2	26.0
	2002/9	Capak et al. (archive)	1.4	26.0

→ Using for detecting flux variances (V, z')

<Filters of Suprime-Cam>



<Flux variance>

① Star-forming galaxies in the SSA22 field

② The background objects in the same images

⇩

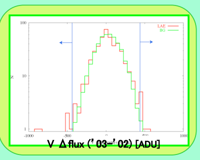
Aperture photometry (V / z'-band images, 2 epochs)

⇩

Flux variance between 2-epochs of the star-forming galaxies and the background objects ⇨ Comparing their flux variances

⇩

Selection of variable objects (Δflux ≧ 3σ of the background objects)



<Estimation of flux variance by noise>

Selecting objects those which might be non-variable objects as a control sample.

Selection criteria for the background objects

(1) same magnitude range as LAEs / LBGs

LAE : 25 < V < 27.3 , LBG : 24 < V < 25.5

(2) eliminate blue objects (AGN) : 0.2 < R−i' < 0.4

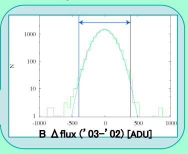
⇩

Aperture photometry in the B-band images (2-epoch)

⇩

Δflux ≦ 3σ → Aperture photometry in the V/z'-band images

→ control sample



Result

Variable objects candidates: LAE : 13 objs. / LBG : 14 objs.

⇨ what are the origins of variances showed by these variable object candidates?

<LAE>

ID	V Δmag	V year₊	z' Δmag	z' year₊	Spectrum
35	0.65 (3.6σ)	03	−	−	−
102	−	−	1.1 (3.0σ)	02	−
120	1.86 (3.8σ)	03	−	−	−
135	0.58 (3.3σ)	03	−	−	−
157	0.41 (3.4σ)	03	−	−	−
216	0.77 (3.4σ)	03	−	−	LAE?
335	0.67 (3.0σ)	02			−
384	−	−	0.29 (3.6σ)	02	AGN
392	0.25 (6.2σ)	02	−	−	AGN
457	0.37 (43.6σ)	03	−	−	AGN
489	−	−	0.07 (3.8σ)	02	−
645	0.22 (3.0σ)	03	−	−	LAE
686	0.17 (3.5σ)	02	0.48 (7.8σ)	01	−

<LBG>

ID	V Δmag	V year₊	z' Δmag	z' year₊	Spectrum
32	0.29 (11.4σ)	03	−	−	−
72	0.3 (3.1σ)	03	−	−	LBG
168	−	−	0.18 (3.4σ)	01	−
491	−	−	0.29 (3.6σ)	02	AGN
500	0.25 (6.2σ)	02	−	−	AGN
614	0.33 (3.1σ)	03	−	−	−
691	0.3 (3.4σ)	03	−	−	AGN?
699	0.35 (3.4σ)	02	−	−	−
701	0.3 (3.4σ)	03	−	−	−
818	−	−	0.37 (3.2σ)	01	−
869	0.15 (5.2σ)	02	−	−	−
927	−	−	0.5 (3.0σ)	02	−
984	0.16 (3.6σ)	02	−	−	−

(year₊ ; The year when luminosity of galaxies increase)

Consideration

Candidate1 ・・・Supernova

unidentifiable now (Because only 2-epoch images exist.)

⇨ Need more photometric and spectroscopic data !!

Candidate2 ・・・Active Galactic Nuclei (AGN)

<Spectrum Features>

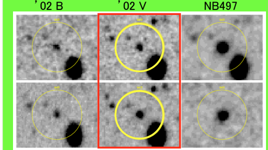
- Width of Lyman α emission line
  Type I : 50〜100Å, Type II : >10Å ⇔ LAE : <10Å (Observing frame)
- NV emission line (Observing wave length〜5080Å)

⇨ Some of the candidates those have spectrum-data have been confirmed as AGNs.

Images

<Identified>

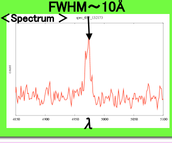
LAE 645



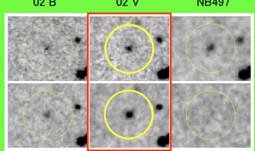
V Δflux : 3.0σ (year₊=03)

➡ Δmag=27.21

Lyman α emission FWHM〜10Å



LBG 72

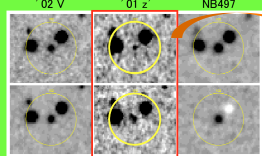


V Δflux : 3.1σ (year₊=03)

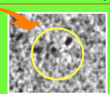
➡ Δmag=27.13

<Unidentified>

LAE 102



z' Δflux : 3.0σ (year₊=02)



〜3pixels difference

‖

SN-like variance

z'-band subtracted image ('02−'01)

➡ Δmag=26.32

Summery

✦ 2 variable objects remain as candidates of star-forming galaxies without evidence of AGN contributions, which are potential candidates of SNe at z=3.1.

(And there was an unidentified variable object candidate showing SN-like variance.)

➡ There is possibility of detecting high-z SNe.

✦ Multi-epoch photometric data and spectra can prove the origins of the variability.