

(TBD) Internal structure of galaxies at the violent epoch of galaxy evolution

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April

Internal structure of Kyoto

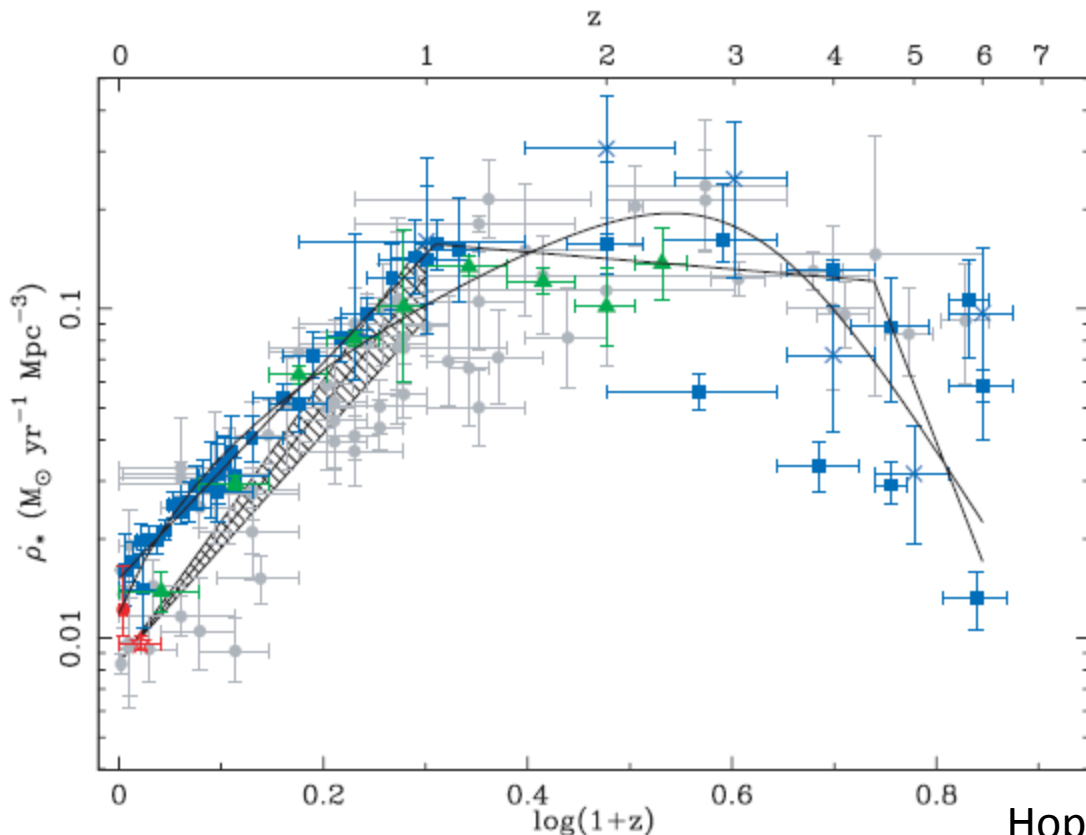
November



そうだ、京都、行こう 2011年 秋₁

Cosmic SF history

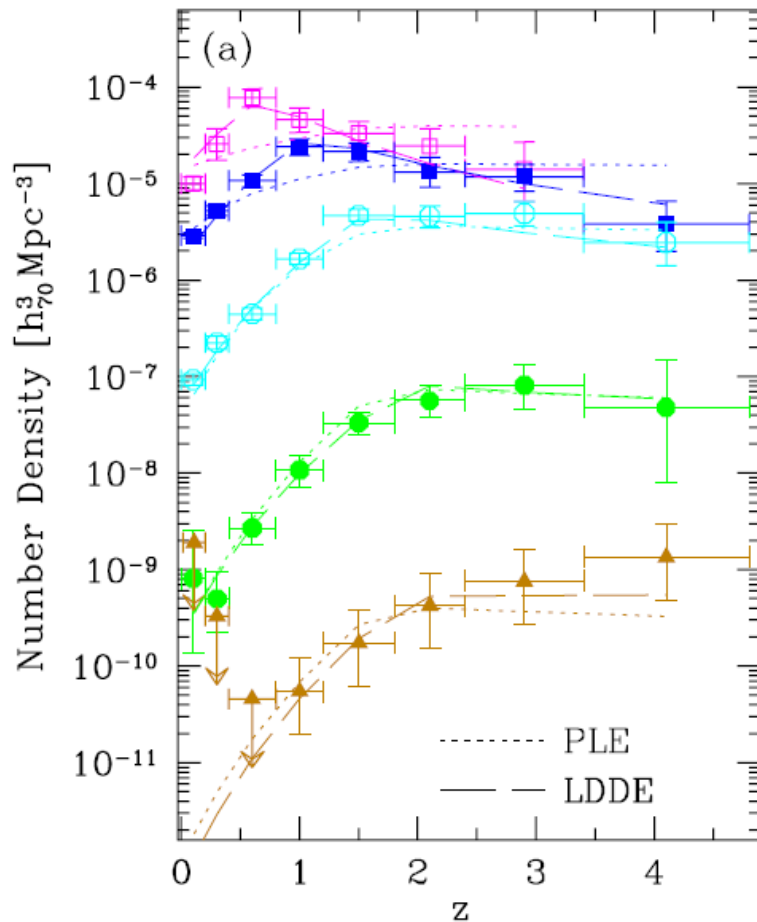
- SF activity peaks at $z \sim 2$
- i.e., highest prosperity in galaxy life (statistical sense)
- Formation of the Hubble sequence around this epoch



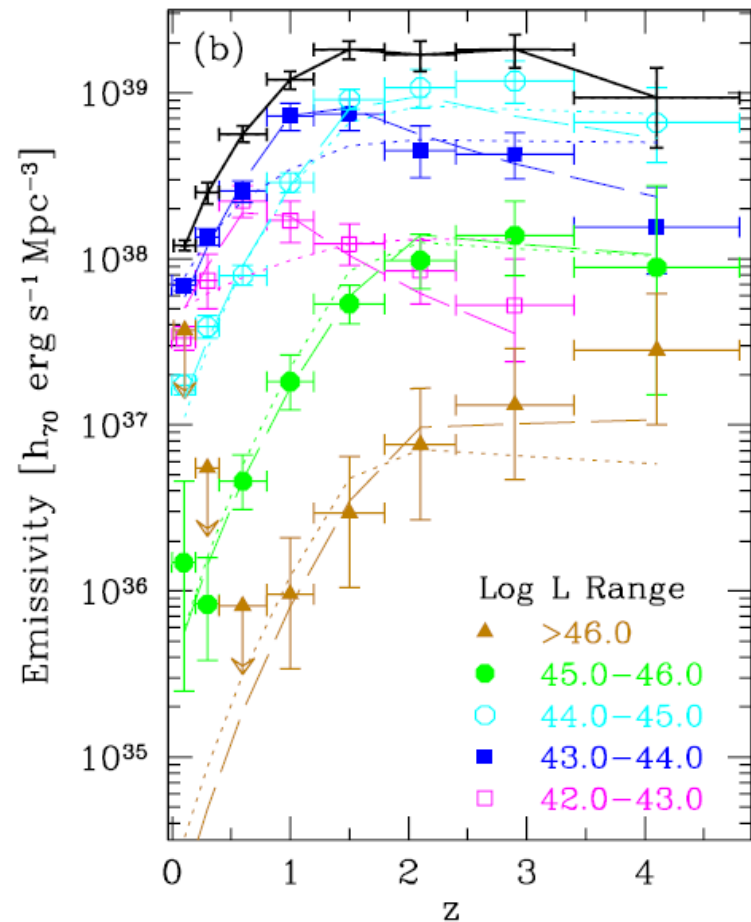
Important epoch to unveil galaxy formation/evolution

AGN activity also peaks at the epoch

Number density



Volume emissivity



, though downsizing nature is seen

Next step: evolution of internal structure of galaxies around the epoch

- Previous many studies: Evolution of galaxy as one zone object (w/o structure)



- How does a galaxy evolve into a disk or elliptical galaxy?
- What is the transformation of gases to stars in a galaxy?
- How did it proceed in it?
(these two subjects are very important in ALMA era)
- What is the evolutionary connection between AGN and galaxy? (feedback/co-evolution)
- etc

Example of actual observing plans

- Based on our recent results (Q5)
- With (multi-)IFU spectrograph with GLAO (Q1,Q4)

1) An elliptical under (late?) formation?

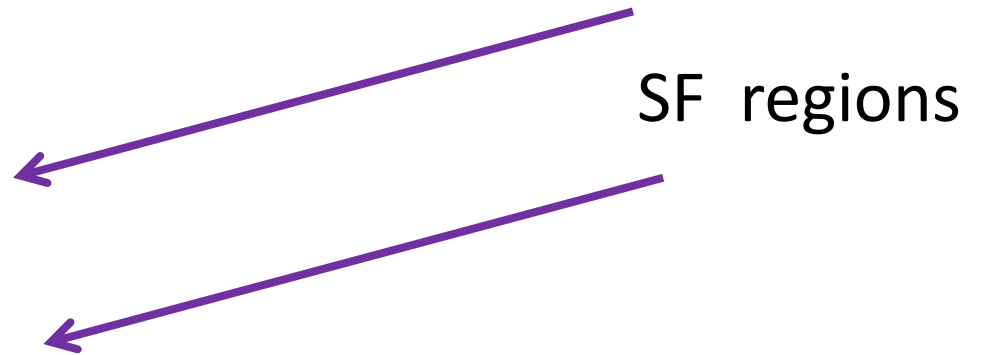
One of our FMOS targets at $z_{\text{sp}} = 1.5$ in SXDS (CANDELS)
5" x 5"

SED fitting \Rightarrow $M_{\text{star}} = 2 \times 10^{11} M_{\text{sun}}$,
SFR = 150-300 M_{sun}/yr

HST WFC/H-band
Sersic index = 6.7
 $R_e \sim 1''$

Rest UV image (w/ HST ACS) + rest optical image (w/HST HST WFC3)
(gray scale) (black contours)

2"x2"



CO (5-4) channel maps with ALMA

Channel map 5''x5'' $\Delta v = 50$ km/s, 1,2,3,4,5,6 σ contours

km/s
component

km/s
component

km/s
component

km/s
component

Multi-molecular components? $M(\text{H}_2) \sim$ a few $\times 10^{10}$? M_{sun}

HST WFC3 (rest optical) image + CO contours

2.5"x2.5"

SF region?

Molecular gas components

図2: 楕円銀河形成後期と考えられる銀河の内部構造. 水色/白コントア: 複数の分子ガス成分, 黒コントア: 星形成領域, オレンジ: 星の面輝度分布 (2.5"x2.5")

We might be witnessing an elliptical under (late?) formation, but

- What are the SFR and extinction in SF regions, especially hidden SF regions?
- What are ages/generation of them? i.e. SF history? (Mstar, EW, gas metallicity,,,) <= IFU obs of Ha, Hb, etc
- higher angular resolution is desirable <= further ALMA obs?
- We don't see lower transition CO line <= JVLA

More serious problems are:

- Absolute Astrometry
- Velocity system/resolution (in optical/NIR)

2) Another ALMA continuum sources at $z \sim 1.5$

NIR K-band image

B-band image

ALMA 1.3mm

Circle : $r=5'' \sim 40$ kpc

A: ALMA source $z_{sp}=1.45$, E: ALMA source $z_{ph}=1.55$,

B: $z_{ph}=1.40$, C:possible ALMA source $z_{ph}=1.54$, D: $z_{ph}=1.08$

Tidal tail in A?

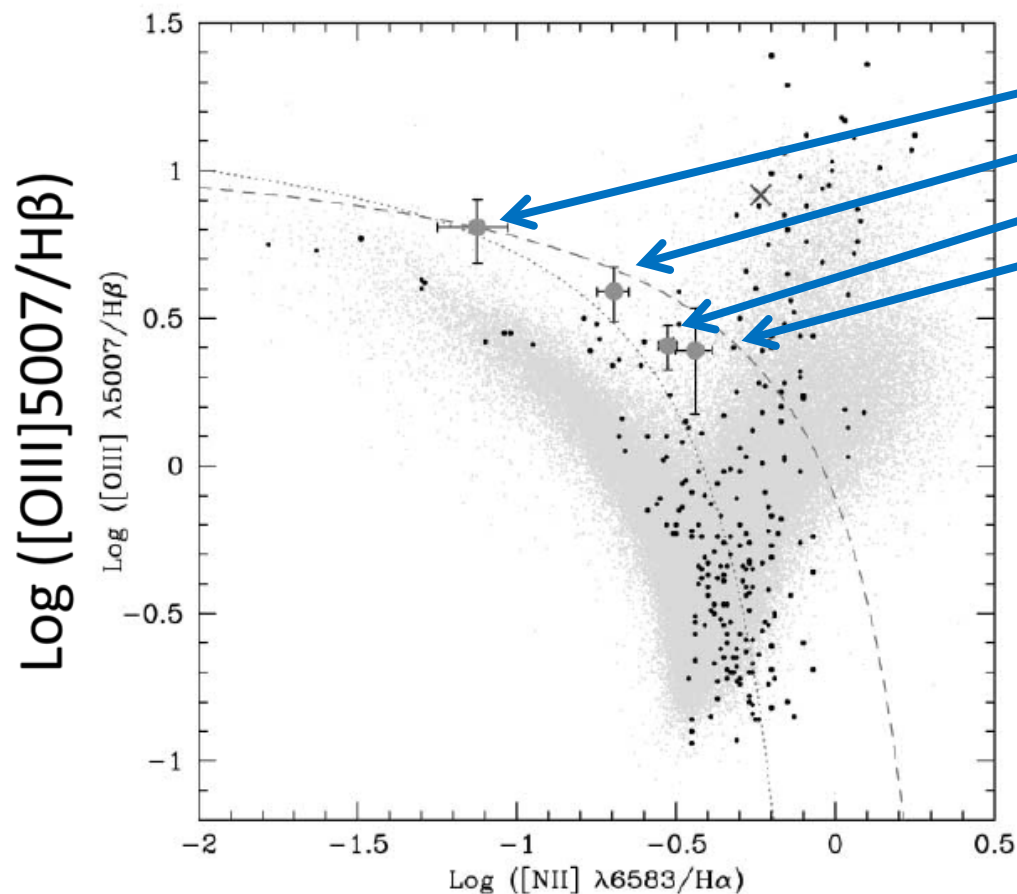
Merging into a giant galaxy??

But,

- We don't know the precise spectroscopic redshifts for many galaxies
 - <= IFU (or Multi-slit?) sp. Obs
- Molecular gas masses of other components
 - <= further ALMA obs

3) AGN & SF connection or peculiar nature of SF at the epoch?

Erb et al. 2006, ApJ 644, 813 NIR spectroscopy of SF galaxies at $z \sim 2$



such objects are rare
In the local universe

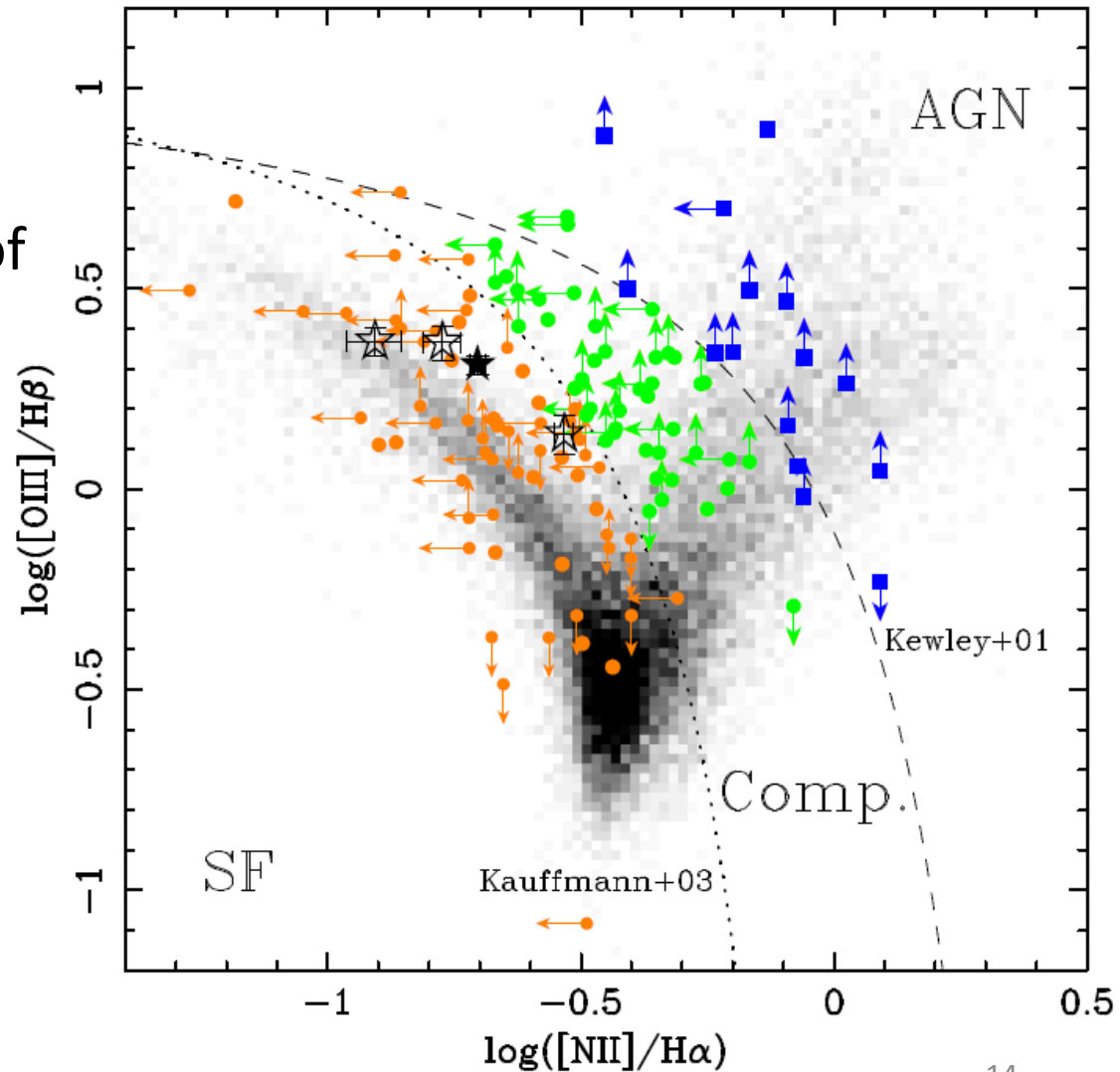
- Are these major population at high redshifts?
- Contamination of AGN and SF?
- some peculiar nature of SF? (higher n_e , higher U , ... <= top-heavy IMF??)

Log ([NII]6584/H α)

FIG. 1.—[O III]/H β vs. [N II]/H α diagnostic diagram. The four galaxies in our sample for which we have measurements of all four lines are shown by the large gray filled circles. The $z = 2.2$ galaxy discussed by van Dokkum et al. (2005), which shows evidence of an AGN or shock ionization by a wind, is shown by the cross. The small gray dots represent $\sim 96,000$ objects from the SDSS, and the small black filled circles are the local starburst galaxies studied by Kewley et al. (2001b). The dashed line shows the maximum theoretical starburst line of Kewley et al. (2001a); for realistic combinations of metallicity and ionization parameter, star-forming galaxies fall below and to the left of this line. The dotted line is

These are major population at $z \sim 1.5$

Large sample obtained with FMOS reveals the presence of many such objects at $z \sim 1.5$, and the stacking data points are close to the 'composite spectrum' region.



Note: X-ray sources are excluded from the sample.

One (good) example

HST ACS + WFC3 image 5"x5"

One component may be an AGN and the other a normal SF region?

Or

AGN + unusual SF gal? (Feedback to SF?)

Or

both components show unusual spectra, suggesting different physical condition of SF regions?

<= IFU Ha, Hb, [OIII] etc obs

Specifications required

- I assumed (multi-object) IFU spectrograph (Q1,Q4), but 'own' wide field NIR imager would be necessary
 - FOV of IFU: Size of galaxies ~2-3"
 - Angular resolution:
 - 1-2 kpc (or slightly smaller?) would be good enough (at least currently) to study galaxy internal structure (cf. clump ~ 1 kpc?)
- ⇒ 0.1-0.3 " resolution (Q2)
- ALMA AngRes=0.2" ⇔ Max Ang Size 15?times
- Sensitivity:
 - current limit seems to be a few $\times 10^{-17}$ cgs or much more(?) (for emission line) => high throughput is important

Specifications required (cont)

- wavelength coverage:
 - around [OII]3727 to [NII]6584 (or [SII]6716/6731)
- Spectral resolution: $R \sim 1000-3000$
 - ↔ much higher resolution ALMA
- FoV: 14' would be wide enough (1/4 of FMOS FoV)
- Multiplicity : depending on the sensitivity, but
 - at least ~ 20 Ha detected galaxies
 - in $15' \phi$ according to FMOS obs

Too many specifications ■ ■ ■

IFUs on Subaru w/GLAO

- survey of SF galaxies at the epoch with IFUs
- local counterpart sample by MaNGA
- ⇔ TMT(Q3?)
- sensitivity and wavelength coverage would be important
- astrometry and velocity match for multi-wavelength observations
- ~8 years later. Too late?? (KMOS etc)
Need some new unique capability??