Near-Infrared Spectroscopy of K-Selected Star-Forming Galaxies at z~2 with MOIRCS

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Abstract

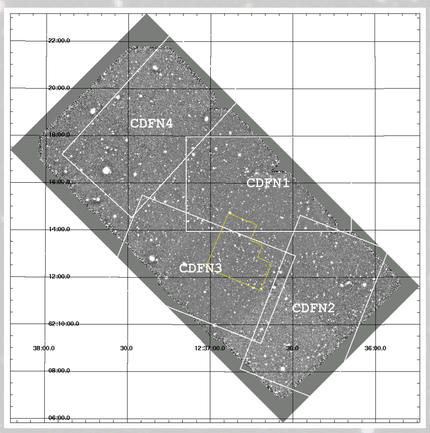
We present the results of near-infrared multi-object spectroscopic observations for 37 star-forming galaxies at z~2. The observations are conducted with Multi-Object InfraRed Camera and Spectrograph (MOIRCS) on the Subaru Telescope. The sample is drawn from the Ks-band selected catalog of the MOIRCS Deep Survey (MODS) in the GOODS-N region. About half of our samples are selected from the publicly available MIPS 24μm-source catalog.

Hα emission lines were detected from 23 galaxies, of which the median redshift is 2.12. We derived the star formation rates (SFRs) from extinction-corrected Hα luminosities and compared them with stellar masses estimated by SED fitting using multi-band photometric data covering across UV and near-infrared wavelengths. The comparison shows no correlation between SFR and stellar mass. Some galaxies with stellar mass smaller than ~10^{10} $M_\odot$ show SFR higher than ~100 $M_\odot$ yr^{-1}. The specific SFRs (SSFRs) of these galaxies are remarkably high; galaxies which have SSFR higher than ~10^{-8} yr^{-1} are found in 8 of the present sample. The large SFR implies the possibility that the high SSFR galaxies significantly contribute to the cosmic SFR density of the universe at z~2. We found that the cosmic SFR density of these high SSFR galaxies is 0.091 (+0.019/-0.034) $M_\odot$ yr^{-1} Mpc^{-3}. From the best-fit parameters of SED fitting for these high SSFR galaxies, we found that the average age of the stellar populations is younger than 100 Myr and that the average attenuation by dust is larger than E(B-V) ~ 0.3 mag. The metallicity of the high SSFR galaxies, which is estimated from N2 index, is larger than that expected from the mass-metallicity relation of UV-selected galaxies at z~2 by Erb et al. 2006.

Sample Selection and Observations

Star-forming BzK Galaxies

- 4 masks in MOIRCS Deep Field (MODS)
- K-selected star-forming galaxy at z~2 with $K_{s,AB}$ < 23 ($M_* > 10^{10} M_\odot$ @z~2)
- X-ray galaxies are excluded.
- $F_{HB} < 1.4 \times 10^{-16}$ erg cm^{-2} s^{-1} ($L_{HB} < 10^{42}$ erg s^{-1} @z~2)
- MIPS selected galaxies (Chary et al. in prep.)
- S_{24} > 80μJy: 18 ($L_{IR} > 10^{11} L_\odot$ @z~2)
- S_{24} < 80μJy: 19

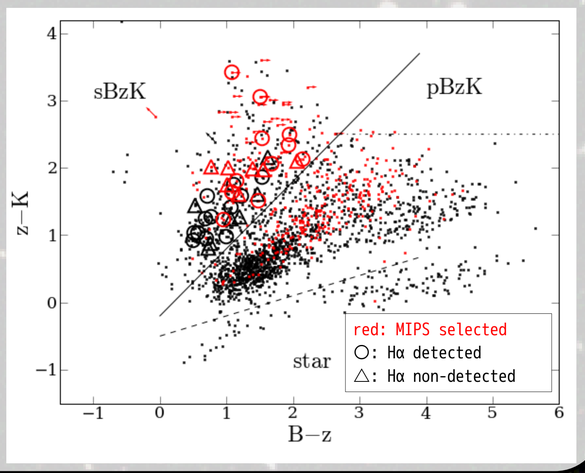


Observations

- Date: 2007 March 24-27
- Instrument: MOIRCS MOS-mode
- Grism: HK500 (1.3-2.3μm, R~500 with 0.8" slit width)
- Exposure time: 160-310 min

Data Reduction

We use our own data reduction pipeline script for MOIRCS (**MCSMDP; MOIRCS MOS Data Pipelines**), which is available at;
http://www.astr.tohoku.ac.jp/~tomohiro/MCSMDP

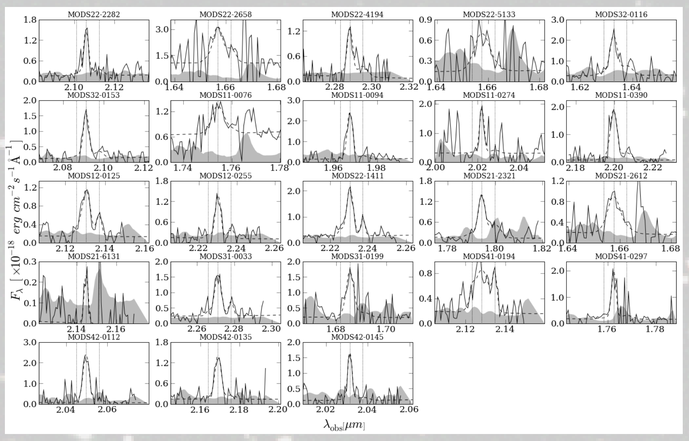


Data Analysis

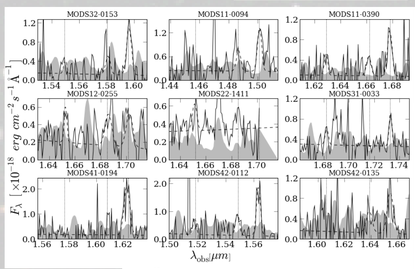
Emission Lines

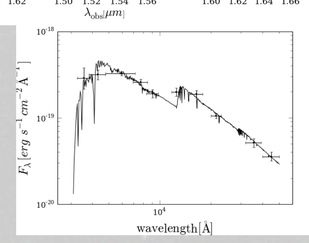
	observed	Hα	rate	[NII]	[OIII]	Hβ
S_{24}>80μJy	18	11	61%	3	4	3
S_{24}<80μJy	19	12	63%	0	4	1
total	37	23	62%	3	8	4

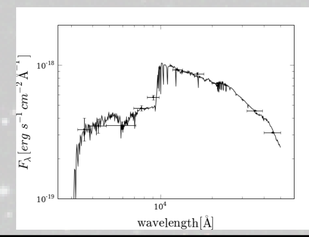
[NII]-Hα



[OIII]-Hβ







Stellar Population Parameters

- U (MOSAIC/KPNO), BViz (ACS/HST), JHK (MOIRCS/Subaru), 3.6, 4.5μm (IRAC/SST) with 1.6" aperture magnitude
- Hα flux is subtracted from H or K band magnitude
- SED model(GALAXEV); IMF: Chabrier et al. 2003; SFH: exponenially declining τ-model; extinction: Calzetti+ 2000

Results and Discussion

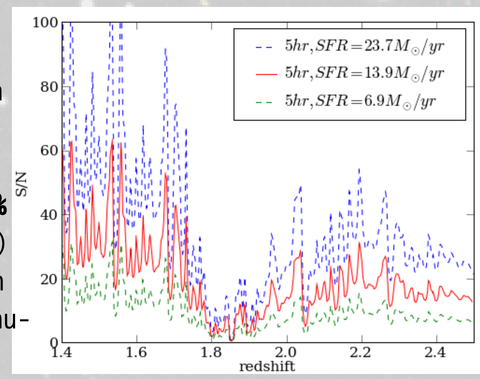
Redshift Distribution

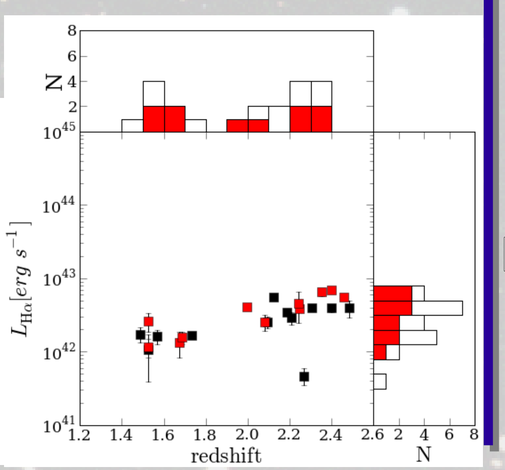
- **redshift range: 1.4 < z < 2.5**
  - $\langle z \rangle_{median}$ ~ 2.12

Photometric redshift of the non-emission line galaxies are also in the same redshift.

- **expected detection rate ~ 87.7%**
  - 1.8×10^{42}ergs s^{-1} (84% quantile)

The galaxies without Hα detection have smaller SFR and/or more attenuated than those we observed.



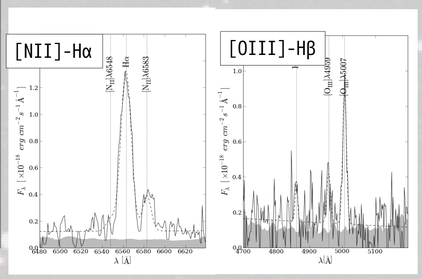


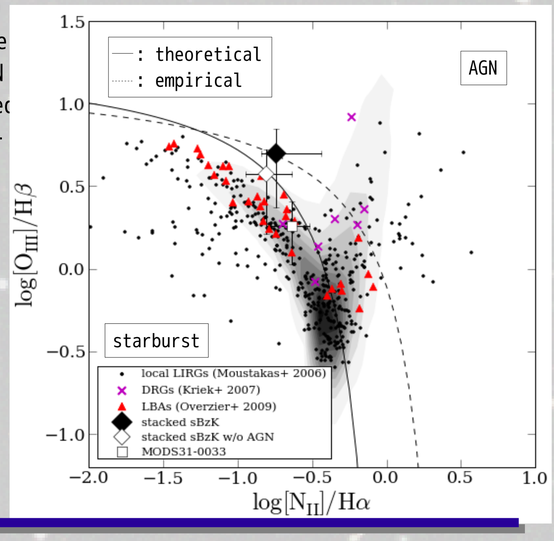
AGN diagnostics

- **BPT diagram ([OIII]/Hβ-[NII]/Hα)**

Stacked spectrum is located on the theoretical line. If we exclude AGN candidate (MODS41-0194), the stacked line slightly move below the empiricalline.

- Offset to upper left: low metal
- Offset to upper right: common in high-z?





Extinction Correction

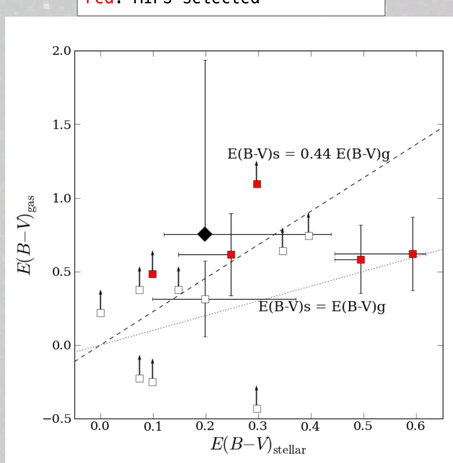
- **Balmer decrement**

Attenuation estimated from Hβ/Hα ratio assuming Calzetti et al. (2000) extinction curve.

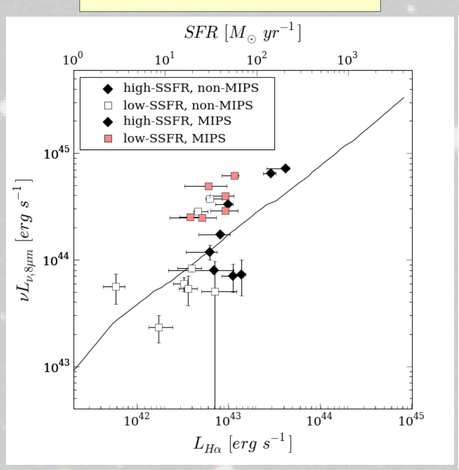
- **Calzetti (2001) relation**
  - $E(B-V)_{stellar} = 0.44 E(B-V)_{gas}$

Balmer decrement of stacked spectrum agrees with Calzetti relation.
SFR(IR)s and SFR(Hα)s with Calzetti relation for ULIRGs are consistent, while for LIRGs SFR(Hα)s with equal extinction agree with SFR(IR).

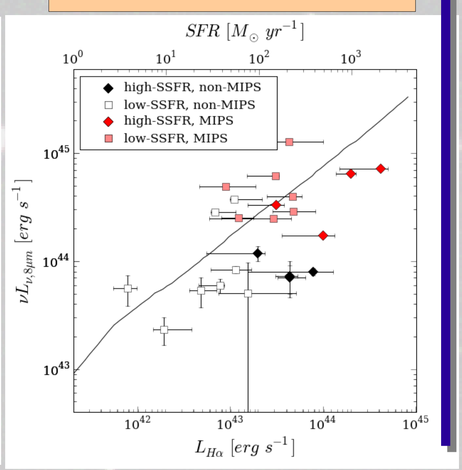
◆: stacked
□: Hβ detected / upper limit
red: MIPS selected



equal extinction



Calzetti (2001) relation



SFR and Stellar Mass, Age

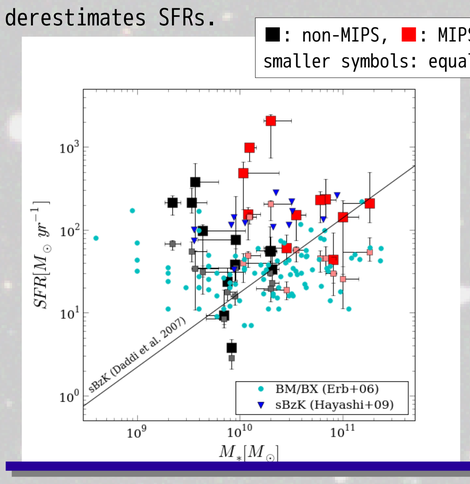
- **No correlation between SFR and stellar mass**

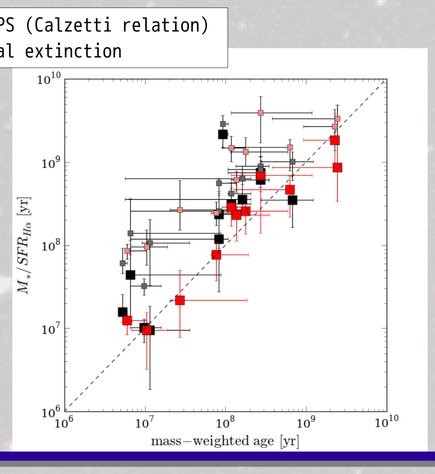
SFRs(UV) of sBzK (Daddi et al. 2007) and SFRs(Hα) of BM/BX (equal extinction; Erb et al. 2006) have tight correlation with the stellar masses. SFRs(Hα) (Calzetti relation; Hayashi et al. 2009) are higher than those of BM/BX.
SFRs(Hα) with equal extinction correction are similar value as BM/BX galaxies.

- **M*/SFR and mass-weighed age (average age weighted by SFR)**

Both values are consistent for Calzetti relation, while equal extinction underestimates SFRs.

■: non-MIPS, ■: MIPS (Calzetti relation)
smaller symbols: equal extinction





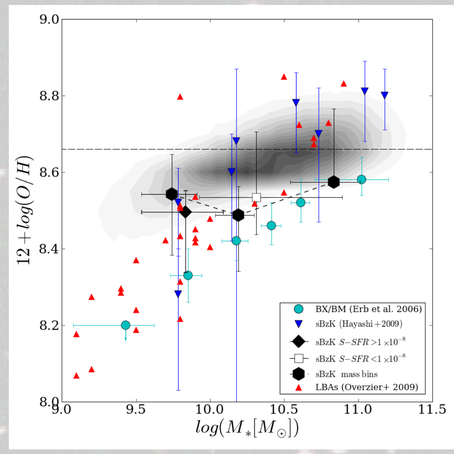
Mass-Metallicity Relation

- **High-z galaxies**

BM/BX have lower M-Z relation than local, but sBzK have higher metllicity than BM/BX

- **Low-z galaxies**

Although SDSS galaxies have higher M-Z, local UV-selected galaxies (LBAs) have lower M-Z.



Contribution to Cosmic SFR density

	sBzK, Ks<23	observed	Hα	number		SFR density	
				S-SFR>10^{-8}	S-SFR<10^{-8}	S-SFR>10^{-8}	S-SFR<10^{-8}
MIPS	92	18	11	4	7	0.048	0.043
non-MIPS	354	19	12	4	8	0.014	0.014
total	446	37	23	8	15	0.091	0.028

- **Total SFR density**

If we take the expected detection rate (87.7%), total SFR density is $0.136^{+0.026}_{-0.039}$ $M_\odot yr^{-1} Mpc^{-3}$, which is consistent with the previous works.

- **Contribution of high-SSFR galaxies**

The high SSFR galaxies contribute to 76% of total SFR density at z~2.