Ionization, excitation, and abundance ratios in $z \sim 2-3$ star-forming galaxies with KBSS-MOSFIRE

Allison Strom (Caltech)
Chuck Steidel (Caltech), Gwen Rudie (Carnegie), Naveen Reddy (UC Riverside)
Ryan Trainor (UC Berkeley), Rachel Theios (Caltech)
The Keck Baryonic Structure Survey (KBSS)

Specifically designed to investigate IGM/CGM and galaxies

Centered on 15 of the brightest quasars in the sky (total area = 0.24 deg\(^2\))

Spectroscopic observations:

- 2354 with rest-UV spectra (LRIS)
- 1097 with rest-optical spectra

732 galaxies with \( z \approx 2-2.7 \) have at least one MOSFIRE spectrum

275 galaxies with good detections of all strong diagnostic emission lines

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Typical $z \sim 2-3$ star-forming galaxies in the KBSS

- median stellar mass: $10^{10} \, M_\odot$
- median SFR: $25 \, M_\odot$/yr
- median E(B-V): 0.29 ($\times 2$ at H$\alpha$)
- electron density: $\sim 200$-$300 \, \text{cm}^{-3}$
The [NII]-BPT diagram at $z \sim 2-3$ with KBSS

Strom et al. (in prep.)

349 galaxies

log([OIII]5007/Hβ)

log([NII]λ6585/Hα)

[OIII]/Hβ, [NII]/Ha
[OIII]/Hβ, [NII]/Ha lim.
AGN
median [OIII]/Hβ
$z \sim 2.3$ fit
90% SDSS contour
K01 max. starburst

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The $[\text{NII}]-\text{BPT}$ diagram at $z \sim 2-3$ with KBSS

Strom et al. (in prep.)

Sanders et al. (2015) MOSDEF

349 galaxies

$\log([\text{OIII}]\lambda 5007/\text{H} \beta)$

$\log([\text{NII}]\lambda 6585/\text{H} \alpha)$
The $[SII]$-BPT diagram at $z \sim 2-3$ with KBSS

Strom et al. (in prep.)

331 galaxies

$\log([OIII]/\lambda5007/H\beta)$

$\log([SII]/H\alpha)$
The [SII]-BPT diagram at $z \sim 2-3$ with KBSS

- [SII]-BPT diagram with KBSS
- 331 galaxies
- [OIII]/Hβ, [SII]/Ha
- [OIII]/Hβ, [SII]/Ha lim.
- AGN
- Median [OIII]/Hβ
- $z \sim 2.3$ fit
- 90% SDSS contour
- K01 max. starburst

Strom et al. (in prep.)
Sanders et al. (2015)
MOSDEF
What causes the [NII]-BPT offset and no change elsewhere?

adapted from Kewley et al. (2013)
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- higher electron density
- enhanced $N/O$ ratios
- harder ionizing radiation

![Graph showing the relationship between $[\text{OIII}]/\text{H}\beta$ and $[\text{NII}]/\text{H}\alpha$.]
What causes the [NII]-BPT offset and no change elsewhere?

adapted from Kewley et al. (2013)

higher electron density
enhanced N/O ratios
harder ionizing radiation
What causes the [NII]-BPT offset and no change elsewhere?

adapted from Kewley et al. (2013)

- higher electron density
- enhanced N/O ratios
- harder ionizing radiation
- larger ionization parameter
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The properties of “offset” galaxies provide clues

Allison Strom, 3D-HST Conference: Physics
High-z galaxies show similar N/O ratios

Steidel, Rudie, Strom et al. (2014)

Strom et al. (in prep.)

247 galaxies

log(N/O) [N2O2]

12+log(O/H) [O3N2]

log (N/O)

12+log(O/H)

 PMC09+this paper
 AM2013
 Dop2013
 Pil2012
 CL2001

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High-z galaxies show similar N/O ratios

Steidel, Rudie, Strom et al. (2014)

Allison Strom, 3D-HST Conference: Physics
High-z galaxies show similar N/O ratios

247 galaxies

WISP
Masters et al. (2014)

fit to all KBSS galaxies

Strom et al. (in prep.)
Rest-UV observations of KBSS require harder EUV

Steidel, Strom, et al. (in prep.)

KBSS–LM1 Composite
S99–v00–z002–IMF2.0, $E_{B-V}=0.184$
BPASSv2–z002, $E_{B-V}=0.186$
Harder EUV spectra naturally reproduce observations

$\log(\text{[NII]}/\text{H}\alpha)$ vs $\log(\text{[SII]}/\text{H}\alpha)$

$\log \Gamma = [-3.5,-2.0], Z = 0.3-0.6 Z_{\odot}$
- S99, z002, $n_e = 300$
- BPASS, z002, $n_e = 300$

Strom et al. (in prep.)
O32 vs. R23: a look at only O and H

Maiolino et al. (2008)

247 galaxies dust-corrected

Strom et al. (in prep.)
O32 vs. R23: a look at only O and H

Strom et al. (in prep.)

log\(\Gamma = [-3.5, -2.0]\), \(Z = 0.3-0.6 Z_{\odot}\)
- S99, z002, \(n_e = 300\)
- BPASS, z002, \(n_e = 300\)
The most offset galaxies have the highest $\Gamma$.
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$\Gamma = n_\gamma / n_H$

$\log \Gamma \approx -2.9$
The most offset galaxies have the highest $\Gamma$.

$$\Gamma = n_\gamma / n_H$$

$\log \Gamma \approx -2.9$

$\log \Gamma \approx -3.1$
What are the physical reasons for the differences and similarities?
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1. **similar N/O ratios as seen at z~0:** No significant difference between z~2 and z~0 is observed as a function of metallicity.

2. **harder ionizing radiation:** The same stellar population and photoionization models used to reproduce the KBSS [NII]-BPT locus also match the parameter space occupied by KBSS galaxies in the [SII]-BPT and O32-R23 diagrams.
1. **similar N/O ratios as seen at z~0**: No significant difference between z~2 and z~0 is observed as a function of metallicity.

2. **harder ionizing radiation**: The same stellar population and photoionization models used to reproduce the KBSS [NII]-BPT locus also match the parameter space occupied by KBSS galaxies in the [SII]-BPT and O32-R23 diagrams.

3. **(slightly) larger ionization parameters**: High-z galaxies appear to have uniformly higher O32 with the most offset galaxies exhibiting the most extreme values, which imply higher ionization parameters.