Star Formation of a LBG Candidate at z = 8.3

None Assigned

ABSTRACT

Lyman break galaxies have been found at redshift 8-10 in the past decade. However, only few of them have [CII] detection. We propose to utilize the high sensitivity of ALMA to detect [CII] emission in one of the candidates. This candidate is first discovered by HFF and later detected with [OIII] emission using ALMA. It has spectroscopic redshift at ~8.3 with uncertainty less than 0.001. It is one of the most promising source because it has star formation rate up to 199 Msun/yr and thus more likely to have strong [CII] emission. Our proposed observational setup provides enough sensitivity to detect [CII] lines. With less sensitivity, it is still possible that we can detect a continuum. This observation will also confirm the redshift obtained by previous researches and unveil the relation between star formation rate and [CII] line at such high redshift. The [CII] line and continuum can also help us understand the properties of dust and gas in this candidate. The altogether understanding can give us a more thorough comprehension of early universe.

PI NAME:	Yu-Hsuan Teng & Li-Hsin Chen			**SCIENCE CATEGORY:**	Cosmology and the High Redshift Universe
ESTIMATED 12M TIME:	**11.3 h**	**ESTIMATED ACA TIME:**	**0.0 h**	**ESTIMATED NON-STANDARD MODE TIME (12-M):**	**0.0 h**
CO-PI NAME(S): (Large & VLBI Proposals only)					
CO-INVESTIGATOR NAME(S):					
DUPLICATE OBSERVATION JUSTIFICATION:					

REPRESENTATIVE SCIENCE GOALS (UP TO FIRST 30)

SCIENCE GOAL	POSITION	BAND	ANG.RES.(")	LAS.(")	ACA?	NON-STANDARD MODE
Tuning for [CII] line detection	J2000 04:16:09.4008, -24:05:35.448	5	0.050	0.093	N	N
Total # Science Goals : 1						

SCHEDULING TIME CONSTRAINTS	NONE	**TIME ESTIMATES OVERRIDDEN ?**	No

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PI: Yu-Hsuan Teng and Li-Hsin Chen

Introduction

With the rapidly-evolving observational techniques, we are now able to detect $z > 6$ galaxies and study the conditions near the epoch of reionization (Starck, D. P. 2016). The direct information of the early universe obtained by observing high-z galaxies leads us to a more complete knowledge of the cosmic star formation history along with the whole picture of galaxy formation and evolution. With the high resolution and sensitivity in far-IR and mm of ALMA, we can hopefully confirm existing galaxy candidates at $z > 8$ with spectroscopy.

The [CII] fine structure line at $158\mu m$ can be useful for tracing the interstellar medium (ISM) in high-z galaxies, since it is the dominant cooling line of the neutral interstellar gas. It is believed that the majority of [CII] emission in distant galaxies are originated from atomic ISM or photo-dominated regions near young stars (e.g. Gullberg et al. 2015). As a result, the luminosity of [CII] can provide us with unbiased SFR estimates against dust extinction. Moreover, it is currently one of the few observable star-formation rate (SFR) indicators at high redshift. Both observation- and simulation-based studies have revealed a correlation between [CII] luminosity and SFR. Capak et al. (2015) has established the direct relation between SFR and L[CII] from the observational data with $z < 6$. The simulations for galaxies with $z \sim 8$ in Lagache et al. (2018) also show clear relation albeit with a larger scatter of $\sim 0.5dex$.

It is generally believed that the UV radiation from active star-forming galaxies at $z > 8$ are the major reionizing sources (e.g. Konno et al. 2014, Robertson et al. 2015, Starck, D. P. 2016, Ishigaki et al. 2018). However, observations of accelerated decline in the SFR density (SFRD) at $z > 8$ have not yet been verified. Since most galaxy candidates with $z > 8$ are only selected by photometry, there is a lack of spectroscopic data, which leads to difficulties on determining accurate redshifts and cosmic SFRD. In addition, although dusty star-forming galaxies have been proved to contribute significantly to the cosmic SFRD at z ∼ 1–2 (e.g. Reddy et al. 2008), the dust nature of early galaxies and the physical conditions in the ISM at high redshift are still unknown. Therefore, the far-IR continuum of high-z galaxies observed with ALMA would also be helpful to constrain the contribution of dust-obscured star-forming galaxies to the cosmic SFRD at high redshift.

We propose to observe the [CII] transition and far-IR continuum of a robust $z \sim 8$ Lyman-break galaxy candidate (Laporte et al. 2015, Tamura et al. 2018) with ALMA Band-5. With this observation, we plan to (1) study the properties of gas and dust, (2) confirm the cosmological redshift, and (3) compare the derived SFR or SFRD with existing samples at $z \sim 8$. We plan to set a sensitivity for detecting the [CII] line as our first priority. We estimate the exact values (in Technical Justification) by the SFR-$L_{[CII]}$ relation and [CII] linewidths derived in Capak et al. (2015). The angular resolution and continuum flux are estimated based on the proposed physical size of our target in Laporte et al. (2015) and the IR continuum flux measured in Tamura et al. (2018).

$z > 8$ Galaxy Sample

To study C[II] line emission with ALMA of the galaxies in the early universe, it is easier to start with bright galaxies since they are more likely to be detected by observational instruments available currently. In the past decade, there are some $z > 8$ galaxy detected by extragalactic surveys like *Hubble Ultra-Deep Field* and the Hubble Frontier Field program (Bouwens et al. 2016; Ishigaki et al. 2015, 2018; Laporte et al. 2015; Oesch et al. 2014, 2018). Some of these $z > 8$ galaxy candidates have been further observed with spectroscopy. However, most of these candidates are not observable by ALMA due to the location of them or are just too faint to be detected by ALMA. There is one galaxy which is detected with both photometry and spectroscopy from the literatures. We briefly summarize the current understanding of this galaxy in the following paragraph.

MACSJ0416.1_Y1—This galaxy is first detected by HFF (Laporte et al. 2015) using Lyman break technique. Its multiband image is shown in Fig. 1 and the best-fit SED is shown in Fig. 2. It has a photometric redshift of $z = 8.57^{+0.33}_{-0.47}$ based on SED fitting. Tamura et al. (2018) detected 850 μm continuum emission of this galaxy, and unexpectedly, they also detected an [OIII] 88 μm emission line, which constrained the redshift of this galaxy to $z = 8.3118 \pm 0.0003$. The star formation rate based on UV photometry is roughly 12.9 $M_{\odot}$/yr without dust extinction correction. Tamura et al. (2018) calculated IR SFR with different dust extinction model and derived a value from 13.2 $M_{\odot}$/yr to 199 $M_{\odot}$/yr. From the estimated SFR, we can estimate the strength of [CII] emission line. De Looze et al. (2011) found a linear relation between $L_{[CII]}$ and SFR using nearby galaxies. Capak et al. (2015) analyzed galaxies at $z \sim 5$–6 and found similar trend (see Fig. 4). Based on this relation and the adopted SFR of 13.2 $M_{\odot}$/yr from Tamura et al. (2018), the estimated $L_{[CII]}$ is $1.26 \times 10^{8} L_{\odot}$. This value is then used for the calculation of sensitivity (see Technical Justification). Note that this estimation doesn't consider dust extinction correction.

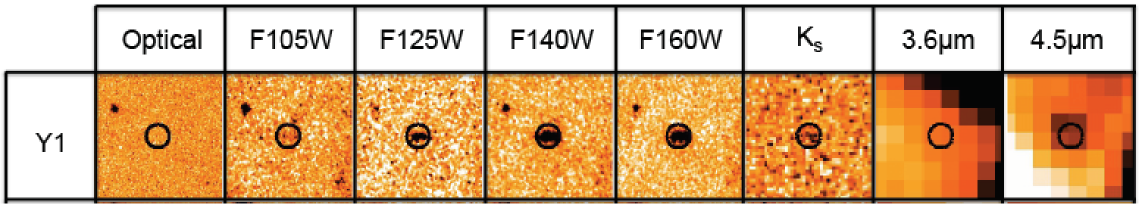

Figure 1: Multi-band images of MACSJ0416.1_Y1 (adopted from Laporte et al. 2015). There is a clear drop of flux between F125W and F105W which is consistent with a galaxy at $z \sim 8$.

Description of observation

We propose to observe at 203 GHz which corresponds to $z = 8.3118$. The [OIII] line detected in Tamura et al. (2018) has a line width of 140 km/s. The galaxies at $z \sim 5-6$ with [CII] detections have line widths of $\sim$ 200 km/s (Capak et al. 2015). Here We assume a larger line width of 200 km/s since the origins of [OIII] emission and [CII] emission may come from different parts of the galaxy.

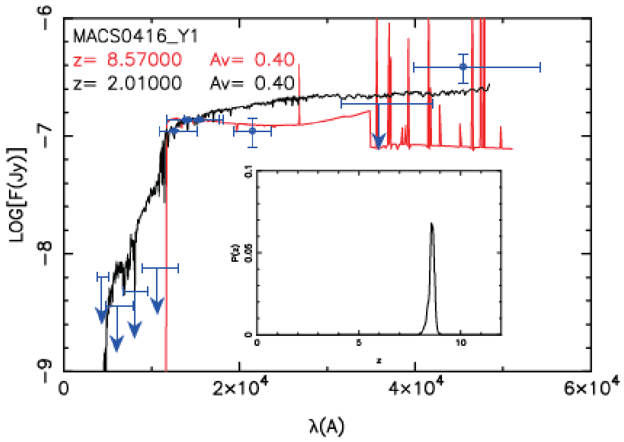

Figure 2: The best fit SED of MACSJ0416.1_Y1 (adopted from Laporte et al. 2015). The photometric redshift is $z = 8.57^{+0.33}_{-0.47}$.

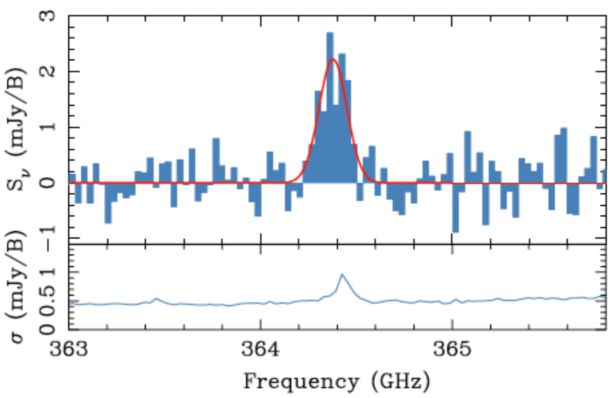

Figure 3: The [OIII] line with the best fit Gaussian function after subtraction of continuum (adopted from Tamura et al. 2018). The redshift is $z = 8.3118 \pm 0.0003$ based on this fitting.

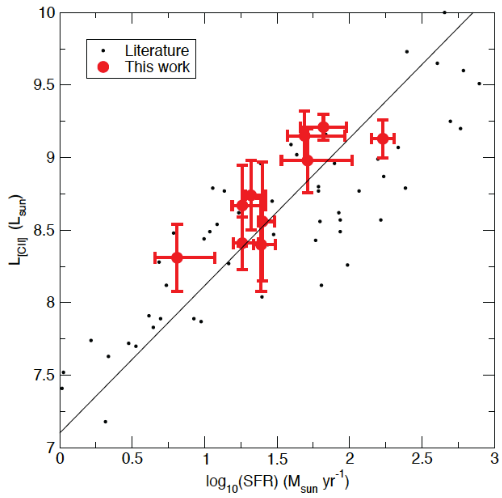

Figure 4: $L_{[CII]}$–SFR (adopted from Capak et al. 2015). The red solid circles along with the error bars are the ALMA detections of [CII] line. The black dots are galaxies samples in De Looze et al. (2011). and the solid line represents the best fit of those data points.

Science Goals

Redshift Confirmation

In addition to photo-z estimate, the spectral redshift of our target has also been suggested by a [OIII] $88\mu m$ line detection found in surprise in a continuum-focused observation (Tamura et al. 2018). The redshift of this galaxy candidate can be clearly confirmed if the redshifted [CII] line is also detected. This is critical for future observations and studies on star-forming galaxies with higher redshifts, which could be the most promising sources of reionization.

Gas and Dust Properties

With the detected [CII] flux, we can then estimate the total mass and the distribution of neutral gas. The [CII] linewidths can also imply the kinematics of these gas, which thereby leads to the estimate of its dynamical mass. Furthermore, our continuum sensitivity of $\sim 14.7\mu Jy$ is plausible to probe the obscured star formation, which may provide information of the dust content or extinction properties at high-z.

Cosmic SFRD

Extended SFR measurement on $z > 8$ galaxies is a crucial step toward the confirmation of cosmic SFRD. The detection of [CII] line can lead us to a new estimate of the SFR of this galaxy candidate, which can then be compared with those indicated by UV or IR, and also with those of other galaxies at similar redshift. Finally, we can verify if there exists an accelerated decline of SFRD around $z > 8$.

SFR–$L_{[CII]}$ Relation at $z > 6$

Although a direct SFR-L[CII] relation was constructed in Capak et al. (2015) for $5 < z < 6$, it has been found to be dependent strongly on the metallicity (e.g. Vallini et al. 2015, Olsen et al. 2017). Additionally, recent observations and simulations at $z \sim 8$ both show a larger dispersion in the SFR-L[CII] relation (Lagache et al. 2018). From the proposed IR continuum, the derived metallicity may be helpful for constructing a more precise relation among [CII] luminosity, metallicity, and SFR at high redshift.

References

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None Assigned

SG : 1 of 1 Tuning for [CII] line detectioı Band 5

Science Goal Parameters

Ang.Res.	LAS	Requested RMS	RMS Bandwidth	Rep.Freq.	Cont. RMS	Cont. Bandwidth	Poln.Prod.	Non-standard mode
0.0500"	0.1"	55 µJy, 646.4 mK	200 km/s, 136.1 MHz	204.000000 GHz	14.777 µJy, 173.7 mK	1.875 GHz	XX,YY	No

Use of 12m Array (43 antennas)

t_total(all configs)	t_science(C43-8)	t_total()	Imaged area	#12m pointing	12m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate
11.3 h	4.5 h	0.0 h	9.5 "	1	offset	28.5 "	16437.9 s	88.3 GB	3.1 MB/s

Use of ACA 7m Array (10 antennas) and TP Array

t_total(ACA)	t_total(7m)	t_total(TP)	Imaged area	#7m pointing	7m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate

Spectral Setup : Spectral Line

BB	Center Freq Rest GHz	spw name	Eff #Ch p.p.	Bandwidth	Resolution	Vel. Bandwidth	Vel. Res.	Res. El. per FWHM
1	204.000000	CII	3840	1875.00 MHz	3904.297 kHz	2755.6 km/s	5.738 km/s	35

1 Target

No.	Target	Ra,Dec (J2000)	V,def,frame --OR--z
1	1-MACSJ0416.1_Y1	04:16:09, -24:05:35	0.00 km/s,lsrk,RADIO

Expected Source Properties

	Peak Flux	SNR	Linewidth	RMS (over 1/3 linewidth)	linewidth / bandwidtl used for sensitivity	Pol.	Pol. SNR
Line	330.00 uJy	3.5	200 k...	95 µJy, 1.1 K	1.00	0.0%	0.0
Continuum	15.89 uJy	1.1				0.0%	0.0

Dynamic range (cont flux/line rms): 0.3

1 Tuning

Tuning	Target	Rep. Freq. Sky GHz	RMS (Rep. Freq.)	RMS Achieved
1	1	204.000000	54.85 µJy, 644.6 mK	54.85 uJy - 54.85 uJy

Justification for requested RMS and resulting S/N (and for spectral lines the bandwidth selected) for the sensitivity calculation.

As mentioned in the Scientific Justification, Tamura et al. (2018) detected [OIII] line and constrained the redshift to 8.3118. Thus, we only set up one tuning for [CII] detection.

The expected [CII] line luminosity is 1.782e8 Lsun. At z = 8.3118 and current cosmological parameters, this leads to line intensity of 66 [mJy km/s].

The [OIII] line detected in Tamura et al. (2018) has a line width of 140 km/s. The galaxies at z ~ 5-6 with [CII] detections have line widths of ~ 200 km/s (Capak et al. 2015). Here We assume a larger line width of 200 km/s since the origins of [OIII] emission and [CII] emission may come from different parts of the galaxy.

We assume a flat line profile and the resulting line intensity is 330 uJy over a linewidth of 200 km/s. We request a 6 sigma detection over this 200 km/s range. The requested rms is then 55 uJy.

Following the dust continuum detection in Tamura et al. (2018), we estimate the continuum flux to be ~15.9 uJy assuming dust temperature of 50 K to be consistent with the temperature Tamura et al. (2018) used for estimation of star formation rate. However, the continuum may not have high enough S/N to secure a detection. We emphasize that our main target is [CII] emission line, thus, the detection of continuum is a bonus if possible.

Justification of the chosen angular resolution and largest angular scale for the source(s) in this Science Goal.

Laporte et al. (2015) gave an estimate of the source to have a physical size of 0.44 kpc. At z = 8.3118, this corresponds to 0.093 arcsec. We request an angular resolution of 0.05 arcsec to make sure there is sufficient sensitivity.

Justification of the correlator set-up with particular reference to the number of spectral resolution elements per line width.

We choose a spectral resolution of ~6 km/s which is enough to resolve the line profile of [CII].