# The near and far environment around the z=6.31 QSO SDSS1030+0524

**2018.1.00719.S**


**ABSTRACT**

Theory predicts that supermassive black holes at z>6 should form and evolve within the densest environments at that time. These environments are expected to be traced by large galaxy overdensities whose observational evidence is still controversial. Among all the ~200 QSOs known at z~6, the field around SDSS J1030+0524 shows the most convincing evidence for both a large- and small-scale galaxy overdensity around it, and features the best multi-band coverage for a prompt identification and physical characterization of the companion galaxies.
We propose a 7-pointing ALMA mosaic at 1.2mm around the z=6.31 QSO SDSS J1030+0524, complemented by another deep pointing centered on the QSO to study its close galaxy companions and determine the physical properties of the QSO host. To study the QSO environment at larger separations, we also propose five pointings centered on the best z~6 galaxy candidates in the field (one already confirmed by optical spectrocopy) to precisely measure their redshifts through [CII] emission and confirm their membership to the QSO large scale structure.
Partial resubmission of the filler project 2017.1.01606.S (Pi:Gilli), yet unobserved, but not timed-out.



| | | | | | |
|---|---|---|---|---|---|
| **PI NAME:** | Marco Mignoli | | | **SCIENCE CATEGORY:** | Cosmology and the High Redshift Universe |
| **ESTIMATED 12M TIME:** | **18.0 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):** | Roberto Gilli; Roberto Decarli; Barbara Balmaverde; Riccardo Nanni; Cristian Vignali; Marcella Massardi; Elisabetta Liuzzo; Eros Vanzella; Simona Gallerani; Andrea Comastri | | | | |
| **DUPLICATE OBSERVATION JUSTIFICATION:** | | | | | |


**REPRESENTATIVE SCIENCE GOALS (UP TO FIRST 30)**

| SCIENCE GOAL | POSITION | BAND | ANG.RES.(") | LAS.(") | ACA? | NON-STANDARD MODE |
|---|---|---|---|---|---|---|
| mosaic | ICRS 10:30:27.1019, 05:24:54.955 | 6 | 1.350 - 0.700 | 3.000 | N | N |
| central QSO | ICRS 10:30:27.1019, 05:24:54.955 | 6 | 0.400 - 0.200 | 1.000 | N | N |
| Setup #1 | ICRS 10:30:00.9000, 05:31:14.300 | 6 | 1.300 - 0.700 | 3.000 | N | N |
| Setup #2 | ICRS 10:30:00.9000, 05:31:14.300 | 6 | 1.300 - 0.700 | 3.000 | N | N |
| Setup #3 | ICRS 10:30:00.9000, 05:31:14.300 | 6 | 1.300 - 0.700 | 3.000 | N | N |
| Setup #4 | ICRS 10:30:00.9000, 05:31:14.300 | 6 | 1.300 - 0.700 | 3.000 | N | N |
| Total # Science Goals : 6 | | | | | | |

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

# 1 Scientific justification

Super-Massive Black Holes (SMBHs, $M_{\rm SMBH} = 10^{9-10}\,{\rm M}_\odot$) in high redshift ($z$>6), luminous (>$10^{47}$ erg/s) QSOs are expected to form and grow in the densest regions of the early Universe[1,2,3]. Their environment thus represents an observational laboratory where competing theories of early SMBH formation can be tested. The search for galaxy overdensities around $z$>6 QSOs, however, has been inconclusive so far[4,5], possibly due to the limited area investigated (e.g., $3'\times3'$ with HST-ACS, or $7'\times7'$ imagers at best[6,7]). Large scale structures (LSS, >1−2 physical Mpc) might, in fact, be missed in such observations, especially if the overdensities are all but symmetric[1,8].

These considerations motivated us to undertake an extensive observational campaign that used sensitive ($r\simeq28$; $i\simeq27$; $z\simeq25$), wide–field optical imaging (at LBT–LBC with FoV $25'\times25'$, i.e. 8x8 pMpc$^2$ at $z$=6) to search for galaxy overdensities around 4 QSOs at $z\sim6$[9]. Possible galaxy associations were identified via color selection criteria. Our search resulted in a 3.7$\sigma$ signature of overdensity from the combination of all the fields. The field around the $z$=6.31 QSO SDSS J1030+0524 (hereafter J1030) was the most overdense of the four, reinforcing the finding of previous small-scale studies with ACS[10]. We expanded on our survey by the means of deep near-infrared ($Y_{AB}$=24.5; $J_{AB}$=24 with CHFT–WIRCAM) and mid-infrared imaging (with *Spitzer*–IRAC), as well as integral field observations with VLT-MUSE (6.4hr), and targeted Multi-Object Spectroscopy with the Keck telescope. This allowed us to push our galaxy selection to fainter fluxes, and directly measure redshifts for >100 galaxies in the field. This strengthened the case for an overdensity around J1030 (now >4$\sigma$)[11]. More importantly, we discovered two faint ($L_{Ly\alpha}\sim 1.5-2\times10^{42}$ erg s$^{-1}$) Ly$\alpha$ emitters (LAE) at z=6.219 and z=6.335 – i.e. at 5 and 2.5 pMpc from the QSO, respectively – that reside in its LSS[12]. Based on the luminosity function of faint $z\sim6$ LAEs measured in the Hubble Ultra-Deep Field[13], one would expect about 0.4 such objects within the volume covered by a single MUSE pointing. Therefore, the evidence for a *spectroscopic* overdensity in the proximity of the central QSO is significant at the $\sim2\sigma$ level. In 2015 (Cycle 17) we were granted a Chandra Large Program to observe for 500ks the J1030 field with the $17'\times17'$ ACIS-I camera (PI R. Gilli). This resulted in the highest–quality X-ray spectrum of a $z$>6 QSO to date[14] and in the compilation of a source catalog in the 0.5-7 keV X-ray band down to limiting fluxes of $1.7\times10^{-16}$erg cm$^{-2}$ s$^{-1}$.

The field of J1030 is now arguably the best studied among the 200+ QSOs discovered at $z$>5.7 (∼60% observable with ALMA; follow the link for an updated compilation). Furthermore, J1030 is the $z$>6 QSO with deepest X-ray coverage, based on our 500ks Chandra Large Program, the 4th deepest X-ray survey in general to date. A summary of all available data products and of their areal coverage and depth is visible at our project website http://www.oabo.inaf.it/∼LBTz6/1030. The growing evidence pointing toward the presence of a galaxy overdensity both at small and large scales makes **J1030 the prime choice for environment studies among the $z > 6$ QSO family.**

# 2 Proposed observations and immediate objectives

Recently, a survey of 25 QSOs at $z\sim6$ with ALMA targeting the [CII]158$\mu m$ line (the main coolant of the cold ISM) revealed four [CII]-emitting companion galaxies at the same redshift ($\Delta z < 0.01$) and with projected separations <70 kpc as the QSOs[15]. These highly star-forming galaxies elude selections based on optical/NIR data, due to a combination of redshift and intrinsic dust obscuration, so that only ALMA could discover them. The abundance of companion galaxies greatly exceeds what is expected from the average density of [CII] emitters at $z$>6[16], giving further evidence of the existence of galaxy overdensities around high-z QSOs, as expected from theoretical models.

Motivated by these findings, here we propose to use ALMA to further corroborate the evidence for an overdensity around J1030. We propose a two-faced approach, searching for both close and large–separation companions.

## 2.1 The search for close galaxy companions

We propose a 7-pointing mosaic to cover the entire square arcmin around the QSO, i.e. the same region observed by MUSE, and a deeper single pointing centered on the QSO. The rms contours of the proposed observations are shown in Fig.1. They will allow detection of [CII] at z=6.31 down to $L_{[CII]} = (1.4, 2, 10) \times 10^8\ L_\odot$ within radii of 18, 80 and 170 kpc from the QSO, respectively. With the resolution of $\sim$0.3″, adopted for the central deeper pointing, we will be able to separate sources on the sky with projected distances down to 1 kpc, which is not possible with the existing shallow ALMA archival data (1″ FWHM).

Our main science goals are: i) quantifying the galaxy overdensity around the QSO and study the physical properties of these companions, and ii) investigate the physical properties of the QSO host.

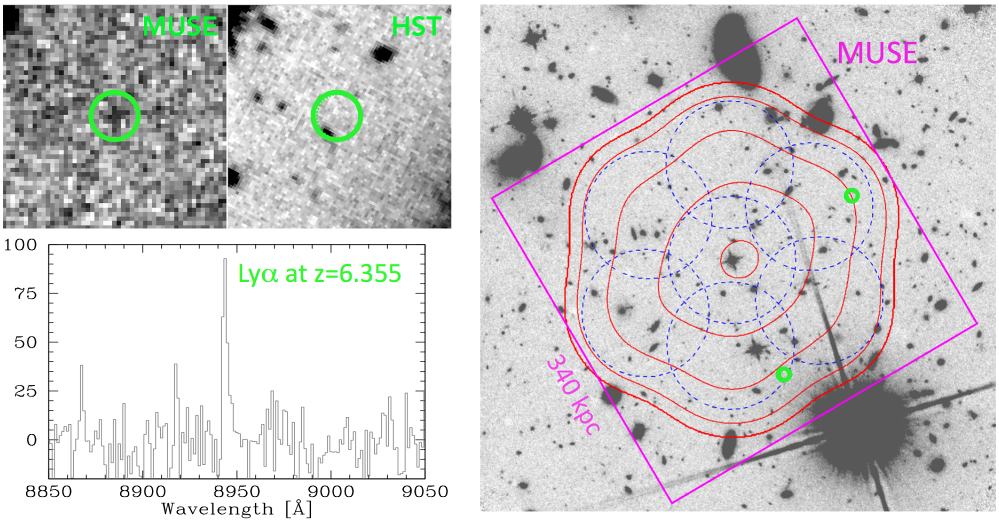


Figure 1: Left: *Cutouts (10″×10″ each) and spectrum (in units of* $10^{-20} erg/cm^2/s/Å$*) of one of the two z∼6.3 LAEs discovered by MUSE. The cutouts show the MUSE cube sliced around the Lyα position and the HST F160W image, respectively.* Right: *Layout of the proposed ALMA pointings (blue dashed circles; diameter=beam FWHM) and [CII]-sensitivity map (red contours) overplotted to the HST image. The contours (from inside out) correspond to an rms of 0.17, 0.25, 0.4, 0.75 and 1.2 mJy/beam per 40 km/s bandwidth. The magenta square represents the MUSE FoV, with the positions of the two LAEs associated to the QSO environment shown in green.*

Our immediate objectives are the following:

**Galaxy overdensity.** We will identify galaxies associated to the QSO through [CII] detection and probe the overdensity around the QSO. Given the chosen spectral setup and mosaic FoV we will be able to identify objects within $\Delta z$=±0.05 (±2.5 pMpc radial) from the QSO. By extrapolating the results of Decarli[15] (0.16 companions per ALMA FoV) and considering that our deeper observations will sample fainter, and hence more abundant [CII] emitters[16], we expect to detect more than one companion in our mosaic. The [CII]-line and continuum detections will be used to estimate SFR and dust masses of the detected companion galaxies. The deep optical-through mid-IR coverage available will allow us to perform SED fitting and get stellar masses. Thanks to our deep X-ray data, we will search for the presence of companions hosting moderately-luminous AGN down to $L_X$=5×10$^{43}$ erg s$^{-1}$. Depending on the adopted feedback and BH fueling recipes, our simulations[17] predict that up to ≈3 companion galaxies should contain SMBHs with $M_{SMBH}$∼10$^7$ $M_\odot$ nearly accreting at the Eddington limit, hence powering AGN with $L_X$∼10$^{44}$ erg/s. The combined detection of [CII] and X-ray emission from even a single source would represent a major discovery in the field of early SMBH and structure formation.

**QSO host.** We will measure the dust content and SFR of the host. Our proposed observations have best sensitivity at the QSO position, reaching a >4 better sensitivity and superior angular resolution than the existing band 6 observation (∼8 min on-source time at 1″ resolution). This will prompt the current ≈3$\sigma$ detection of the dust continuum to a whopping >13 $\sigma$ (no significant flux losses are expected due to the increased resolution since $z$>6 QSOs have sizes comparable with the requested beam of 0.3″ [18]). We will also investigate the presence of extended emission on scales <6 kpc that could not be seen in the archival data, searching for outflow signatures, similar to those found in the well known z=6.42 QSO J1148+5251[19,20], and for [CII] emission from large gas clumps irradiated by the QSO that are expected to be in merging with its host.

## 2.2 The confirmation of galaxy/AGN candidate in the Large Scale Structure

We propose to obtain pointed ALMA band-6 observations of five $z$≃6.3 galaxy candidate in the LSS of J1030. We extracted the targets from 21 robust high redshift candidates with photometric redshift z≈6 and colors $i$-$z$≥1.3 (see Balmaverde et al. 2017[11]). The redshift uncertainty of the photo-$z$ techniques are large (typically Δz≈0.8 at 3$\sigma$), so we need accurate spectroscopic redshift measurements to distinguish between proto-cluster members (within Δ$z$∼0.15 from the QSO) and foreground objects. The strongest UV emission line, commonly used to measure the redshift in distant objects, is Ly$\alpha$ at $\lambda_{rest}$=1216Å. This feature at $z$∼6 is redshifted in a region of the spectrum strongly affected by sky emission lines. Moreover, UV bright galaxies (as in our sample) typically are more massive, dustier, and chemically enriched, and consequently they show lower Ly$\alpha$ equivalent widths with respect to Ly$\alpha$ emitters (LAEs)[21]. Indeed, our experience with Keck/DEIMOS resulted in only one confirmed candidate (out of 9; see Fig. 2, inset) despite several hours of integration with a 10m class telescope. On the positive side, none of our observed targets turned out to be a foreground object. Therefore, the only viable way to precisely measure the redshift of our candidates is in the sub-mm band, targeting the [CII] emission line. This is one of most luminous emission line in primeval galaxies, produced in star forming regions and only with ALMA we would be able to obtain the detection of a spectral feature in a reasonable amount of time. The 5 proposed targets include: a) the LBG already confirmed within QSO LSS, $z_{spec}$≈6.3, but due to the absence of strong Ly$\alpha$ and low spectrum S/N, we will use the [CII] detection to pinpoint the redshift and derive more precise physical properties; b) the LBG associated with a Chandra X-ray source (see inset of Fig. 2): if confirmed, this would be the best "satellite" AGN around a z∼6 QSO known to date, as well as the first moderately luminous ($L_{2-10} \approx 10^{44}$erg s$^{-1}$) AGN discovered at z>6; c) three LBGs with well constrained photometric redshifts (phot-$z$>6) and highest star formation rates (derived from the UV rest frame flux and not corrected for dust absorption) among our candidates.

Table 1: *Pointed $z\sim$ 6.3 galaxy/AGN candidates.*

| # | ID[1] | RA [J2000] | DEC [J2000] | $z$[1] [AB] | SFR [$M_\odot$/yr] | $S_\nu$([CII]) [mJy] | $S_\nu$(cont) [mJy] |
|---|---|---|---|---|---|---|---|
| 1 | 22914[2] | 10:30:00.90 | +05:31:14.3 | 25.4 | 12.0 | 1.7 | 0.05 |
| 2 | 23132[3] | 10:30:04.10 | +05:31:23.4 | 25.4 | 12.0 | 1.7 | 0.05 |
| 3 | 21438 | 10:31:08.77 | +05:30:08.0 | 25.0 | 17.4 | 2.4 | 0.07 |
| 4 | 25971 | 10:29:58.98 | +05:34:07.8 | 25.0 | 17.4 | 2.4 | 0.07 |
| 5 | 06250 | 10:30:11.20 | +05:19:08.5 | 25.2 | 14.5 | 2.0 | 0.06 |

[1] from z-band LBC catalog (Morselli+14); [2] $z_{spec}$ ≈6.3; [3] X-ray source

Our main goals are:

**Detect the [CII] line and precisely measure the redshift.** This will confirm the goodness of our selection criteria, our photometric redshift measurement, and the observability of the [CII] line with the proposed ALMA observing strategy. If the profile of the [CII] line is well defined, we plan to derive the dynamical gas masses (from the [C II] velocity dispersion and the size of the emitting region).

**Detect or constrain the continuum luminosity**, originated by the reprocessing of UV photons by dust. This continuum is expected to be bright, as the targeted LBGs are highly star–forming.

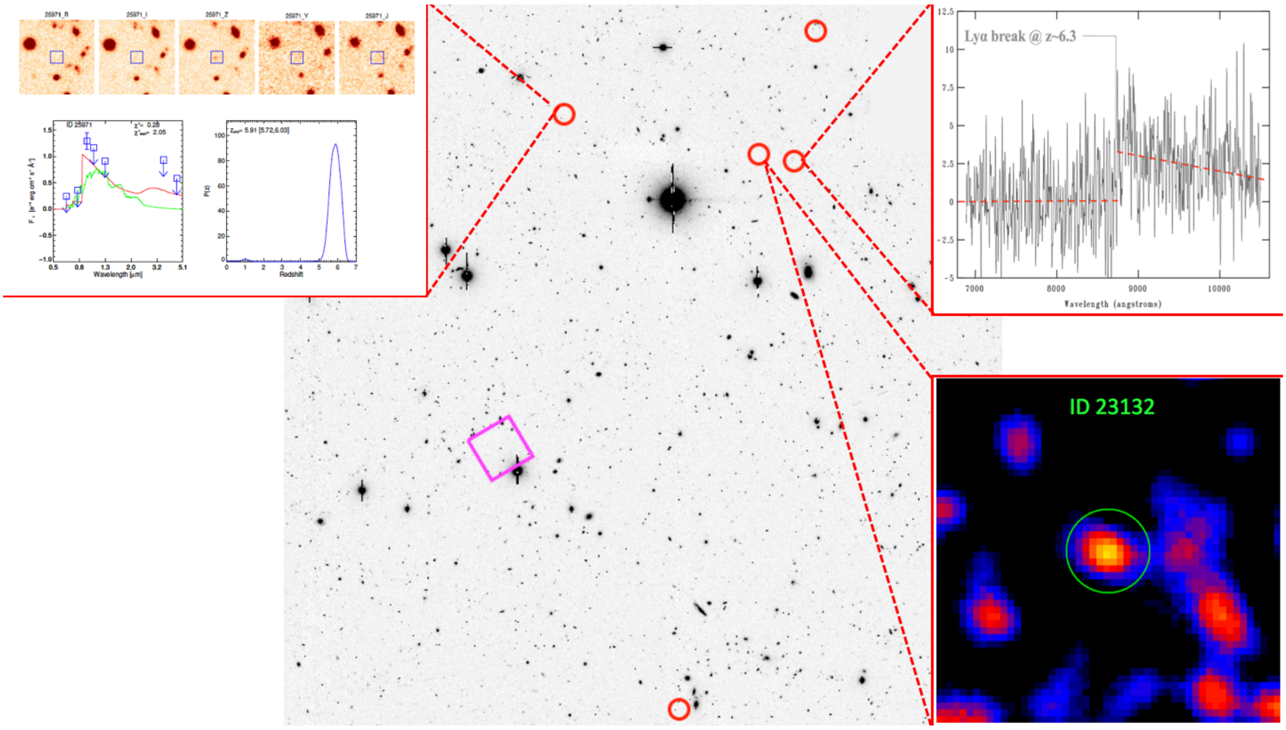


Figure 2: *LBC z-band image of part of the J1030 field. North is up and East is to the left. The image is 16 arcmin across (i.e. 5 pMpc at z∼6). The red circles indicate the five pointed targets and the magenta square the MUSE FoV around the QSO.* Left Inset: *SED and photo-z PDF of one of the high priority z∼6.3 LBG candidates.* Top right inset: *Keck spectrum of the z≃6.3 LBG # 22914.* Bottom right inset: *25″×25″ smoothed 0.5-7 keV Chandra image around the LBG # 23132.*

Along with the redshift confirmation, the possibility to compare the properties of the galaxies that inhabit the large scale structure with those of the galaxies in the inner region of the overdensity (observed within the central mosaic), will provide a unique perspective for understanding the high-z galaxies formation in different environments (i.e. with or without the presence of a strong UV background).

**References:** 1. Overzier et al. 2009, MNRAS, 394, 577; 2. Angulo et al. 2012, MNRAS, 425, 2722; 3. Costa et al. 2014, MNRAS, 439, 2146; 4. Banados et al. 2013, ApJ, 773, 178; 5. Mazzucchelli et al. 2017, ApJ, 834, 83; 6. Kim et al. 2009, ApJ, 695, 809; 7. Husband et al. 2013, MNRAS, 432, 2869; 8. Costa et al. 2014, MNRAS, 444, 2355; 9. **Morselli et al. 2014**, A&A, 568A, 1; 10. Stiavelli et al. 2005, ApJ, 622L, 1; 11. **Balmaverde et al. 2017**, A&A 606A, 23; 12. **Mignoli et al.**, A&A. in prep; 13. Drake et al. 2017, A&A, 608, A6; 14. **Nanni et al. 2018**, A&A (arXiv:1802.05613); 15. **Decarli et al.** 2017, Nature, 545, 457; 16. Aravena et al. 2016, ApJ, 833, 71; 17. Barai et al. 2018, MNRAS, 473, 4003; 18. Venemans et al. 2016, ApJ, 816, 37; 19. Maiolino et al. 2012, MNRAS, 425, L66; 20. Cicone et al. 2015, A&A, 574A, 14; 20. Vanzella et al. 2009, ApJ, 695, 1163.

# 2018.1.00719.S

SG : 1 of 6 mosaic Band 6

7-pointing ALMA mosaic at 1.2mm around z=6.31 QSO SDSS J1030+0524

Science Goal Parameters

| Ang.Res. | LAS | Requested RMS | RMS Bandwidth | Rep.Freq. | Cont. RMS | Cont. Bandwidth | Poln.Prod. | Non-standard mode |
|---|---|---|---|---|---|---|---|---|
| 1.3500" - 0.7000" | 3.0" | 250 µJy, 2.5 mK-9.3 mK | 40 km/s, 34.6 MHz | 1895.376750 GHz | 16.954 µJy, 169.2 µK-629.5 µK | 7.425 GHz | XX,YY | No |

Use of 12m Array (43 antennas)

| t_total(all configs) | t_science(C43-2) | t_total() | Imaged area | #12m pointing | 12m Mosaic spacing | HPBW | t_per_point | Data Vol | Avg. Data Rate |
|---|---|---|---|---|---|---|---|---|---|
| 9.0 h | 5.7 h | 0.0 h | 28" x 28" | 7 | 15.7 arcsec | 22.5 " | 2963.4 s | 546.5 GB | 20.2 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 | 1895.376750 | CII 2P3/2-2P1/2 | 3840 | 1875.00 MHz | 1.129 MHz | 2168.2 km/s | 1.305 km/s | 153 |
| 2 | 1908.536550 | continuum | 3840 | 1875.00 MHz | 1.129 MHz | 2153.3 km/s | 1.296 km/s | 154 |
| 3 | 1803.623700 | continuum | 3840 | 1875.00 MHz | 1.129 MHz | 2278.5 km/s | 1.372 km/s | 146 |
| 4 | 1789.001700 | continuum | 3840 | 1875.00 MHz | 1128.906 kHz | 2297.1 km/s | 1.383 km/s | 145 |

1 Target

| No. | Target | Ra,Dec ( ICRS ) | V,def,frame --OR--z |
|---|---|---|---|
| 1 | 1-SDSSJ1030+0524 | 10:30:27, 05:24:54 | 288780.94 km/s,hel,RELATIVIS... |

Expected Source Properties

| | Peak Flux | SNR | Linewidth | RMS (over 1/3 linewidth) | linewidth / bandwidth used for sensitivity | Pol. | Pol. SNR |
|---|---|---|---|---|---|---|---|
| Line | 800.00 uJy | 4.2 | 200 k... | 192.41 µJy, 7.1 ... | 5.00 | 0.0% | 0.0 |
| Continuum | 0.00 uJy | 0.0 | | | | 0.0% | 0.0 |

Dynamic range (cont flux/line rms): N/A

1 Tuning

| Tuning | Target | Rep. Freq. Sky GHz | RMS (Rep. Freq.) | RMS Achieved |
|---|---|---|---|---|
| 1 | 1 | 259.250000 | 248.4 µJy, 9.2 mK | 233.76 uJy - 248.40 uJy |

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

[CII]158um line:

We aim at detecting [CII] emission from the star forming (SFR~0.1-100 Msun/yr), metal-rich (0.1-0.5 solar) galaxies that are expected to surrounding the central z=6.31 QSO. To predict their [CII] luminosity. we used Eq.1 in Yue+15, based on the modeling developed by
Vallini+13,+15 and Pallottini+17, which combines SFR and metallicity to predict the [CII] emission. Based on our simulations, about 5 objects within 170kpc (projected)
from the QSO are expected to have L_[CII]>2e8 Lsun. By assuming a line width of
200 km/s (similar to what is observed for other galaxies at z~5-6, Capak+15, Decarli+17)
we expect a [CII] peak flux density of 0.8 mJy for a galaxy at z=6.31 with L_CII=2e8 L_sun.
We then request a sensitivity of 0.25 mJy over a 40 km/s bandwidth to detect the peak line
emission at S/N~3.2 and detect the whole line at S/N > 6. Based on the adopted geometry of our 7-pointing mosaic, the on-source time to achieve this sensitivity over a region of 28"x28", is ~49min per pointing. Including overheads, this correspond to ~9 hr in total.

Continuum

We will use the spectral regions free from the [CII] line emission to detect the continuum emission of our sources, by integrating over a spectral range of ~7.4 Ghz. With the adopted geometry for our mosaic and based on the exposure per pointing needed to achive the requested sensitivity for [CII] detection, we reach a sensitivity of 17 uJy/beam over the inner 28"x28" portion of the mosaic.

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

The sources targeted in this study are relatively small galaxies at z~6.3. HST imaging of these and similar sources suggests that their angular scales are comparable or smaller than 1 arcsec. Our project is a detection experiment, so compact array configurations are required to avoid out-resolving the [CII] emission. We therefore ask for C43-1 or C43-2 configurations, which would yield a synthesized beam of 0.7"-1.3" at 1.2mm, consistent with or larger than the expected size of our targets.

## Justification for use of Non-nyquist sampling.

We have chosen a 7-pointing mosaic pattern with a spacing equal to 70% of antenna beamsize
since this extend the mosaic area up to 1arcmin2, which is the field covered by MUSE data
that we want to observe. This non-Nyquist sampling is fine for our goals, since we are not
searching for extended structures that need a uniform background sensitivity. We are indeed
interested in likely-pointlike sources distributed across our mosaic. A similar, 7-pointing mosaic with spacing equal to 70-75% of the antenna beamsize, has been also used by Walter+16 and Aravena+16 to permform a band6 deep survey in the Hubble Ultra Deep Field.

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

We will use 4 basebands in FDM with a bandwidth of 1.875 GHz and a
spectral resolution averaged to 2 km/s. This avoids exceeding the
maximum allowed datarate and guarantees an excellent sampling of the line
profile (e.g. over ~100 channels) for the brightest lines.

The CII 2P3/2-2P1/2 transition will fall in baseband 1
The other basebands will be used for continuum observations.

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SG : 2 of 6 central QSO Band 6

Deep pointing centered on z=6.31 QSO SDSS J1030+0524

Science Goal Parameters

| Ang.Res. | LAS | Requested RMS | RMS Bandwidth | Rep.Freq. | Cont. RMS | Cont. Bandwidth | Poln.Prod. | Non-standard mode |
|---|---|---|---|---|---|---|---|---|
| 0.4000" - 0.2000" | 1.0" | 220 µJy, 25 mK-100.1 mK | 40 km/s, 34.6 MHz | 1895.376750 GHz | 14.95 µJy, 1.7 mK-6.8 mK | 7.425 GHz | XX,YY | No |

Use of 12m Array (43 antennas)

| t_total(all configs) | t_science(C43-4,C4... | t_total() | Imaged area | #12m pointing | 12m Mosaic spacing | HPBW | t_per_point | Data Vol | Avg. Data Rate |
|---|---|---|---|---|---|---|---|---|---|
| 2.4 h | 1.5 h | 0.0 h | 7.5 " | 1 | offset | 22.5 " | 5322.0 s | 142.5 GB | 20.1 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 | 1895.376750 | CII 2P3/2-2P1/2 | 3840 | 1875.00 MHz | 1.129 MHz | 2168.2 km/s | 1.305 km/s | 153 |
| 2 | 1908.536550 | continuum | 3840 | 1875.00 MHz | 1.129 MHz | 2153.3 km/s | 1.296 km/s | 154 |
| 3 | 1803.623700 | continuum | 3840 | 1875.00 MHz | 1.129 MHz | 2278.5 km/s | 1.372 km/s | 146 |
| 4 | 1789.001700 | continuum | 3840 | 1875.00 MHz | 1128.906 kHz | 2297.1 km/s | 1.383 km/s | 145 |

1 Target

| No. | Target | Ra,Dec ( ICRS ) | V,def,frame --OR--z |
|---|---|---|---|
| 1 | 1-SDSSJ1030+0524 | 10:30:27, 05:24:54 | 288780.94 km/s,hel,RELATIVIS... |

Expected Source Properties

| | Peak Flux | SNR | Linewidth | RMS (over 1/3 linewidth) | linewidth / bandwidth used for sensitivity | Pol. | Pol. SNR |
|---|---|---|---|---|---|---|---|
| Line | 800.00 uJy | 4.7 | 200 k... | 169.66 µJy, 77.... | 5.00 | 0.0% | 0.0 |
| Continuum | 150.00 uJy | 10.0 | | | | 0.0% | 0.0 |

Dynamic range (cont flux/line rms): 0.7

1 Tuning

| Tuning | Target | Rep. Freq. Sky GHz | RMS (Rep. Freq.) | RMS Achieved |
|---|---|---|---|---|
| 1 | 1 | 259.250000 | 219.03 µJy, 99.6 mK | 206.12 uJy - 219.03 uJy |

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

In the previous science goal we justified the request of obtaining a mosaic with
a sensitivity of 0.25 mJy over a 40 km/s bandwidth to detect the peak [CII] line
emission at S/N~3.2 and detect the whole line at S/N > 6 for galaxies with L_CII>3e8 Lsun at z=6.31. Here we focus on fainter objects and on the detection of the QSO itself, which went
undetected in the archival pointing in [CII] and was only marginally detected (at ~3sigma) in the continuum. In order to detect the QSO with high significance we aim at going at least a factor
of four deeper than archival data. By adding a pointing with rms=0.22 mJy/beam over a 40 km/s bandwidth, we will get a final sensitivity at the center of the mosaic of ~0.16 mJy/beam over
a 40 km/s, which will allow detection of L=1.3 Lsun at z=6.3 (assuming again fwhm=200 km/s).
The final, combined rms of the continuum, computed over a 7.4 GHz band, will be 11 uJy, which
should allow detection of the QSO host with S/N>13 if the tentative archival detection is real.
This additional pointing requires an exposure of 2.5hrs including overheads, bringing the total time request to 11.9hrs

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

We require a synthesized beam FWHM of ~0.3 arcsec. This will allow us to separate objects down to 1.8 projected kpc. Significantly poorer resolutions, e.g. 1" as in the existing archival data of this field, would completely blend the numerous objects expected at <5.7 projected kpc from the QSO. Significantly smaller resolutions will likely resolve out the flux of the QSO host itself, which we aim to detect. Indeed, typical FHWM sizes measured for z~6 QSO are 0.2-0.4". We note that any resolution in the range 0.2-0.4" is fully acceptable for our goals, which is achievable with a standard array

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

We will use 4 basebands in FDM with a bandwidth of 1.875 GHz and a spectral resolution averaged to 2 km/s. This avoids exceeding the maximum allowed datarate and guarantees an excellent sampling of the line profile (e.g. over ~100 channels) for the brightest lines.

The CII 2P3/2-2P1/2 transition will fall in baseband 1. The other basebands will be used for continuum observations.

# 2018.1.00719.S

SG : 3 of 6 Setup #1 Band 6

Observation of [CII] in 5 galaxies in the field of J1030. Setup #1.

Science Goal Parameters

| Ang.Res. | LAS | Requested RMS | RMS Bandwidth | Rep.Freq. | Cont. RMS | Cont. Bandwidth | Poln.Prod. | Non-standard mode |
|---|---|---|---|---|---|---|---|---|
| 1.3000" - 0.7000" | 3.0" | 410 µJy, 4.4 mK-15.3 mK | 99.9 km/s, 86.1 MHz | 1894.915591 GHz | 43.392 µJy, 469.8 µK-1.6 mK | 7.490 GHz | XX,YY | No |

Use of 12m Array (43 antennas)

| t_total(all configs) | t_science(C43-2) | t_total() | Imaged area | #12m pointing | 12m Mosaic spacing | HPBW | t_per_point | Data Vol | Avg. Data Rate |
|---|---|---|---|---|---|---|---|---|---|
| 1.7 h | 0.9 h | 0.0 h | 7.5 " | 5 | offset | 22.5 " | 665.1 s | 46.3 GB | 9.7 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 | 1894.915591 | setup 1a | 3840 | 1875.00 MHz | 1938.477 kHz | 2174.4 km/s | 2.248 km/s | 133 |
| 2 | 1908.622961 | setup 1b | 3840 | 1875.00 MHz | 1938.477 kHz | 2158.8 km/s | 2.232 km/s | 134 |
| 3 | 1785.256633 | setup 1c | 3840 | 1875.00 MHz | 1938.477 kHz | 2308.0 km/s | 2.386 km/s | 126 |
| 4 | 1798.964003 | setup 1d | 3840 | 1875.00 MHz | 1938.477 kHz | 2290.4 km/s | 2.368 km/s | 127 |

5 Targets

| No. | Target | Ra,Dec ( ICRS ) | V,def,frame --OR--z |
|---|---|---|---|
| 1 | 1-ID_22914 | 10:30:00, 05:31:14 | 258893.08 km/s,lsrk,RADIO |
| 2 | 2-ID_23132 | 10:30:04, 05:31:23 | 258781.18 km/s,lsrk,RADIO |
| 3 | 3-ID_21438 | 10:31:08, 05:30:08 | 258781.18 km/s,lsrk,RADIO |
| 4 | 4-ID_25971 | 10:29:58, 05:34:07 | 258781.18 km/s,lsrk,RADIO |
| 5 | 5-ID_06250 | 10:30:11, 05:19:08 | 258781.18 km/s,lsrk,RADIO |

Expected Source Properties

| | Peak Flux | SNR | Linewidth | RMS (over 1/3 linewidth) | linewidth / bandwidth used for sensitivity | Pol. | Pol. SNR |
|---|---|---|---|---|---|---|---|
| Line | 1.66 mJy | 4.1 | 300 k... | 404.41 µJy, 15.... | 3.00 | 0.0% | 0.0 |
| Continuum | 50.00 uJy | 1.2 | | | | 0.0% | 0.0 |

Dynamic range (cont flux/line rms): 0.2

1 Tuning

| Tuning | Target | Rep. Freq. Sky GHz | RMS (Rep. Freq.) | RMS Achieved |
|---|---|---|---|---|
| 1 | 1,2,3,4,5 | 259.222379 | 393.09 µJy, 14.6 mK | 370.47 uJy - 393.09 uJy |

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue below.

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

The targeted galaxies have optical z-band magnitudes of 25.4-24.8 mag (AB system). The corresponding flux density at the observed continuum redwards of Ly-a is 0.30-0.52 uJy (corrected for a ~20% flux density drop in the broad band photometry due to the Gunn-Peterson absorption already encapsulated in the z-band throughput). From this estimate, we infer the unobscured star formation rate (SFR_unobs) following Kennicutt & Evans (2012): log SFR_unobs [Msun/yr] = log nu L_nu [erg/s] - 43.55 = 12-20 Msun/yr. These SFR estimates are used to infer the continuum luminosity (assuming SFR_obs ~ SFR_unobs) and the [CII] luminosities (following known scaling relations, see e.g. de Looze et al. 2014; Herrera-Camus et al. 2015, 2018). The [CII] luminosities are in the range 5.0e8-8.6e8 Lsun, corresponding to a peak flux density of 1.66-1.98 mJy, assuming a box-car line profile with a line width of 300 km/s (see, e.g., Capak et al. 2015). Our sensitivity request is driven by the need to securely detect even the faintest of these lines at >4-sigma in 1/3 of the line, or ~7-sigma over the entire line width. This results in a target rms of 0.41 mJy/beam per 100 km/s (for comparison, all the [CII] emitters in the Capak+15 sample of Ly-a emitters at z~5.7 would be easily detected at our sensitivity requirement). Due to the uncertainties in the scalings, we opt for the same sensitivity request for all the 5 sources in our sample.
The predicted 1.2mm continuum flux density is based on the assumption that the dust emission is well modeled with a modified black body with Tdust=40 K and beta=1.6. A lower Tdust would lead to brighter 1.2mm flux densities. The collapsed cubes of our observations will be combined with the other three frequency settings on the same sources, yielding a 2x increase in S/N. We note that the IR continuum information is not a main scientific driver for this project.

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

The sources targeted in this study are relatively small galaxies at z~6.3. HST imaging of these and similar sources suggests that their angular scales are comparable or smaller than 1 arcsec. Our project is a detection experiment, so compact array configurations are required to avoid out-resolving the [CII] emission. We therefore ask for C43-1 or C43-2 configurations, which would yield a synthesized beam of 0.7"-1.5" at 1.2mm, consistent with or larger than the expected size of our targets.

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

We propose a spectral scan at 1.2 mm, in order to maximize the [CII] redshift coverage. With only four contiguous setups, we will be able to detect [CII] emission in a continuous window z=5.974 - 6.837. This will encompass any potential large-scale structure associated with the quasar J1030. Furthermore, it will provide [CII] coverage over a signifcant cosmic volume (~380 cMpc3 per pointing) to put constraints on the background number counts of [CII] emitters at z~6. The expected lines widths are of the order of ~300 km/s, but lines as narrow as ~50-70 km/s have been reported. In order to maximize spectral coverage and to retain spectral information on the line profiles, we thus opt to use the full 1.875 GHz bandwidth for each SPW, and a resampling of 4 native channels per saved spectral resolution element (~2 km/s).

# 2018.1.00719.S

SG : 4 of 6    Setup #2    Band 6

Observation of [CII] in 5 galaxies in the field of J1030. Setup #2.

## Science Goal Parameters

| Ang.Res. | LAS | Requested RMS | RMS Bandwidth | Rep.Freq. | Cont. RMS | Cont. Bandwidth | Poln.Prod. | Non-standard mode |
|---|---|---|---|---|---|---|---|---|
| 1.3000" - 0.7000" | 3.0" | 410 µJy, 4.3 mK-14.9 mK | 100 km/s, 87.5 MHz | 1922.330330 GHz | 42.374 µJy, 445.7 µK-1.5 mK | 7.490 GHz | XX,YY | No |

## Use of 12m Array (43 antennas)

| t_total(all configs) | t_science(C43-2) | t_total() | Imaged area | #12m pointing | 12m Mosaic spacing | HPBW | t_per_point | Data Vol | Avg. Data Rate |
|---|---|---|---|---|---|---|---|---|---|
| 1.7 h | 0.9 h | 0.0 h | 7.4 " | 5 | offset | 22.2 " | 665.1 s | 46.3 GB | 9.7 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 | 1922.330330 | setup 2a | 3840 | 1875.00 MHz | 1938.477 kHz | 2143.4 km/s | 2.216 km/s | 135 |
| 2 | 1936.037700 | setup 2b | 3840 | 1875.00 MHz | 1938.477 kHz | 2128.2 km/s | 2.200 km/s | 136 |
| 3 | 1812.671372 | setup 2c | 3840 | 1875.00 MHz | 1938.477 kHz | 2273.1 km/s | 2.350 km/s | 128 |
| 4 | 1826.378742 | setup 2d | 3840 | 1875.00 MHz | 1938.477 kHz | 2256.0 km/s | 2.332 km/s | 129 |

## 5 Targets

| No. | Target | Ra,Dec ( ICRS ) | V,def,frame --OR--z |
|---|---|---|---|
| 1 | 1-ID_22914 | 10:30:00, 05:31:14 | 258893.08 km/s,lsrk,RADIO |
| 2 | 2-ID_23132 | 10:30:04, 05:31:23 | 258781.18 km/s,lsrk,RADIO |
| 3 | 3-ID_21438 | 10:31:08, 05:30:08 | 258781.18 km/s,lsrk,RADIO |
| 4 | 4-ID_25971 | 10:29:58, 05:34:07 | 258781.18 km/s,lsrk,RADIO |
| 5 | 5-ID_06250 | 10:30:11, 05:19:08 | 258781.18 km/s,lsrk,RADIO |

## Expected Source Properties

| | Peak Flux | SNR | Linewidth | RMS (over 1/3 linewidth) | linewidth / bandwidth used for sensitivity | Pol. | Pol. SNR |
|---|---|---|---|---|---|---|---|
| Line | 1.66 mJy | 4.2 | 300 k... | 392.1 µJy, 14.2 ... | 3.00 | 0.0% | 0.0 |
| Continuum | 50.00 uJy | 1.2 | | | | 0.0% | 0.0 |

Dynamic range (cont flux/line rms): 0.2

## 1 Tuning

| Tuning | Target | Rep. Freq. Sky GHz | RMS (Rep. Freq.) | RMS Achieved |
|---|---|---|---|---|
| 1 | 1,2,3,4,5 | 262.972685 | 401.94 µJy, 14.5 mK | 388.08 uJy - 478.16 uJy |

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue below.

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

The targeted galaxies have optical z-band magnitudes of 25.4-24.8 mag (AB system). The corresponding flux density at the observed continuum redwards of Ly-a is 0.30-0.52 uJy (corrected for a ~20% flux density drop in the broad band photometry due to the Gunn-Peterson absorption already encapsulated in the z-band throughput). From this estimate, we infer the unobscured star formation rate (SFR_unobs) following Kennicutt & Evans (2012): log SFR_unobs [Msun/yr] = log nu L_nu [erg/s] - 43.55 = 12-20 Msun/yr. These SFR estimates are used to infer the continuum luminosity (assuming SFR_obs ~ SFR_unobs) and the [CII] luminosities (following known scaling relations, see e.g. de Looze et al. 2014; Herrera-Camus et al. 2015, 2018). The [CII] luminosities are in the range 5.0e8-8.6e8 Lsun, corresponding to a peak flux density of 1.66-1.98 mJy, assuming a box-car line profile with a line width of 300 km/s (see, e.g., Capak et al. 2015). Our sensitivity request is driven by the need to securely detect even the faintest of these lines at >4-sigma in 1/3 of the line, or ~7-sigma over the entire line width. This results in a target rms of 0.41 mJy/beam per 100 km/s (for comparison, all the [CII] emitters in the Capak+15 sample of Ly-a emitters at z~5.7 would be easily detected at our sensitivity requirement). Due to the uncertainties in the scalings, we opt for the same sensitivity request for all the 5 sources in our sample.
The predicted 1.2mm continuum flux density is based on the assumption that the dust emission is well modeled with a modified black body with Tdust=40 K and beta=1.6. A lower Tdust would lead to brighter 1.2mm flux densities. The collapsed cubes of our observations will be combined with the other three frequency settings on the same sources, yielding a 2x increase in S/N. We note that the IR continuum information is not a main scientific driver for this project.

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

The sources targeted in this study are relatively small galaxies at z~6.3. HST imaging of these and similar sources suggests that their angular scales are comparable or smaller than 1 arcsec. Our project is a detection experiment, so compact array configurations are required to avoid out-resolving the [CII] emission. We therefore ask for C43-1 or C43-2 configurations, which would yield a synthesized beam of 0.7"-1.5" at 1.2mm, consistent with or larger than the expected size of our targets.

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

We propose a spectral scan at 1.2 mm, in order to maximize the [CII] redshift coverage. With only four contiguous setups, we will be able to detect [CII] emission in a continuous window z=5.974 - 6.837. This will encompass any potential large-scale structure associated with the quasar J1030. Furthermore, it will provide [CII] coverage over a signifcant cosmic volume (~380 cMpc3 per pointing) to put constraints on the background number counts of [CII] emitters at z~6. The expected lines widths are of the order of ~300 km/s, but lines as narrow as ~50-70 km/s have been reported. In order to maximize spectral coverage and to retain spectral information on the line profiles, we thus opt to use the full 1.875 GHz bandwidth for each SPW, and a resampling of 4 native channels per saved spectral resolution element (~2 km/s).

# 2018.1.00719.S

SG : 5 of 6 Setup #3 Band 6

Observation of [CII] in 5 galaxies in the field of J1030. Setup #3.

Science Goal Parameters

| Ang.Res. | LAS | Requested RMS | RMS Bandwidth | Rep.Freq. | Cont. RMS | Cont. Bandwidth | Poln.Prod. | Non-standard mode |
|---|---|---|---|---|---|---|---|---|
| 1.3000" - 0.7000" | 3.0" | 410 µJy, 4.2 mK-14.5 mK | 100 km/s, 88.7 MHz | 1949.745070 GHz | 43.184 µJy, 441.6 µK-1.5 mK | 7.490 GHz | XX,YY | No |

Use of 12m Array (43 antennas)

| t_total(all configs) | t_science(C43-2) | t_total() | Imaged area | #12m pointing | 12m Mosaic spacing | HPBW | t_per_point | Data Vol | Avg. Data Rate |
|---|---|---|---|---|---|---|---|---|---|
| 1.7 h | 0.9 h | 0.0 h | 7.3 " | 5 | offset | 21.9 " | 665.1 s | 46.3 GB | 9.7 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 | 1949.745070 | setup 3a | 3840 | 1875.00 MHz | 1938.477 kHz | 2113.3 km/s | 2.185 km/s | 137 |
| 2 | 1963.452440 | setup 3b | 3840 | 1875.00 MHz | 1938.477 kHz | 2098.5 km/s | 2.170 km/s | 138 |
| 3 | 1840.086112 | setup 3c | 3840 | 1875.00 MHz | 1938.477 kHz | 2239.2 km/s | 2.315 km/s | 130 |
| 4 | 1853.793482 | setup 3d | 3840 | 1875.00 MHz | 1938.477 kHz | 2222.7 km/s | 2.298 km/s | 131 |

5 Targets

| No. | Target | Ra,Dec ( ICRS ) | V,def,frame --OR--z |
|---|---|---|---|
| 1 | 1-ID_22914 | 10:30:00, 05:31:14 | 258893.08 km/s,lsrk,RADIO |
| 2 | 2-ID_23132 | 10:30:04, 05:31:23 | 258781.18 km/s,lsrk,RADIO |
| 3 | 3-ID_21438 | 10:31:08, 05:30:08 | 258781.18 km/s,lsrk,RADIO |
| 4 | 4-ID_25971 | 10:29:58, 05:34:07 | 258781.18 km/s,lsrk,RADIO |
| 5 | 5-ID_06250 | 10:30:11, 05:19:08 | 258781.18 km/s,lsrk,RADIO |

Expected Source Properties

| | Peak Flux | SNR | Linewidth | RMS (over 1/3 linewidth) | linewidth / bandwidth used for sensitivity | Pol. | Pol. SNR |
|---|---|---|---|---|---|---|---|
| Line | 1.66 mJy | 4.2 | 300 k... | 396.77 µJy, 14 mK | 3.00 | 0.0% | 0.0 |
| Continuum | 50.00 uJy | 1.2 | | | | 0.0% | 0.0 |

Dynamic range (cont flux/line rms): 0.2

1 Tuning

| Tuning | Target | Rep. Freq. Sky GHz | RMS (Rep. Freq.) | RMS Achieved |
|---|---|---|---|---|
| 1 | 1,2,3,4,5 | 266.722992 | 399.46 µJy, 14.0 mK | 372.28 uJy - 399.46 uJy |

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue below.

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

The targeted galaxies have optical z-band magnitudes of 25.4-24.8 mag (AB system). The corresponding flux density at the observed continuum redwards of Ly-a is 0.30-0.52 uJy (corrected for a ~20% flux density drop in the broad band photometry due to the Gunn-Peterson absorption already encapsulated in the z-band throughput). From this estimate, we infer the unobscured star formation rate (SFR_unobs) following Kennicutt & Evans (2012): log SFR_unobs [Msun/yr] = log nu L_nu [erg/s] - 43.55 = 12-20 Msun/yr. These SFR estimates are used to infer the continuum luminosity (assuming SFR_obs ~ SFR_unobs) and the [CII] luminosities (following known scaling relations, see e.g. de Looze et al. 2014; Herrera-Camus et al. 2015, 2018). The [CII] luminosities are in the range 5.0e8-8.6e8 Lsun, corresponding to a peak flux density of 1.66-1.98 mJy, assuming a box-car line profile with a line width of 300 km/s (see, e.g., Capak et al. 2015). Our sensitivity request is driven by the need to securely detect even the faintest of these lines at >4-sigma in 1/3 of the line, or ~7-sigma over the entire line width. This results in a target rms of 0.41 mJy/beam per 100 km/s (for comparison, all the [CII] emitters in the Capak+15 sample of Ly-a emitters at z~5.7 would be easily detected at our sensitivity requirement). Due to the uncertainties in the scalings, we opt for the same sensitivity request for all the 5 sources in our sample.

The predicted 1.2mm continuum flux density is based on the assumption that the dust emission is well modeled with a modified black body with Tdust=40 K and beta=1.6. A lower Tdust would lead to brighter 1.2mm flux densities. The collapsed cubes of our observations will be combined with the other three frequency settings on the same sources, yielding a 2x increase in S/N. We note that the IR continuum information is not a main scientific driver for this project.

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

The sources targeted in this study are relatively small galaxies at z~6.3. HST imaging of these and similar sources suggests that their angular scales are comparable or smaller than 1 arcsec. Our project is a detection experiment, so compact array configurations are required to avoid out-resolving the [CII] emission. We therefore ask for C43-1 or C43-2 configurations, which would yield a synthesized beam of 0.7"-1.5" at 1.2mm, consistent with or larger than the expected size of our targets.

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

We propose a spectral scan at 1.2 mm, in order to maximize the [CII] redshift coverage. With only four contiguous setups, we will be able to detect [CII] emission in a continuous window z=5.974 - 6.837. This will encompass any potential large-scale structure associated with the quasar J1030. Furthermore, it will provide [CII] coverage over a signifcant cosmic volume (~380 cMpc3 per pointing) to put constraints on the background number counts of [CII] emitters at z~6. The expected lines widths are of the order of ~300 km/s, but lines as narrow as ~50-70 km/s have been reported. In order to maximize spectral coverage and to retain spectral information on the line profiles, we thus opt to use the full 1.875 GHz bandwidth for each SPW, and a resampling of 4 native channels per saved spectral resolution element (~2 km/s).

# 2018.1.00719.S

SG : 6 of 6 Setup #4 Band 6

Observation of [CII] in 5 galaxies in the field of J1030. Setup #4.

Science Goal Parameters

| Ang.Res. | LAS | Requested RMS | RMS Bandwidth | Rep.Freq. | Cont. RMS | Cont. Bandwidth | Poln.Prod. | Non-standard mode |
|---|---|---|---|---|---|---|---|---|
| 1.3000" - 0.7000" | 3.0" | 410 µJy, 4.1 mK-14.1 mK | 100 km/s, 90 MHz | 1977.159809 GHz | 43.617 µJy, 433.7 µK-1.5 mK | 7.490 GHz | XX,YY | No |

Use of 12m Array (43 antennas)

| t_total(all configs) | t_science(C43-2) | t_total() | Imaged area | #12m pointing | 12m Mosaic spacing | HPBW | t_per_point | Data Vol | Avg. Data Rate |
|---|---|---|---|---|---|---|---|---|---|
| 1.7 h | 0.9 h | 0.0 h | 7.2 " | 5 | offset | 21.6 " | 665.1 s | 46.3 GB | 9.7 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 | 1977.159809 | setup 4a | 3840 | 1875.00 MHz | 1938.477 kHz | 2084.0 km/s | 2.155 km/s | 139 |
| 2 | 1990.867179 | setup 4b | 3840 | 1875.00 MHz | 1938.477 kHz | 2069.6 km/s | 2.140 km/s | 140 |
| 3 | 1867.500851 | setup 4c | 3840 | 1875.00 MHz | 1938.477 kHz | 2206.3 km/s | 2.281 km/s | 132 |
| 4 | 1881.208221 | setup 4d | 3840 | 1875.00 MHz | 1938.477 kHz | 2190.3 km/s | 2.264 km/s | 132 |

5 Targets

| No. | Target | Ra,Dec ( ICRS ) | V,def,frame --OR--z |
|---|---|---|---|
| 1 | 1-ID_22914 | 10:30:00, 05:31:14 | 258893.08 km/s,lsrk,RADIO |
| 2 | 2-ID_23132 | 10:30:04, 05:31:23 | 258781.18 km/s,lsrk,RADIO |
| 3 | 3-ID_21438 | 10:31:08, 05:30:08 | 258781.18 km/s,lsrk,RADIO |
| 4 | 4-ID_25971 | 10:29:58, 05:34:07 | 258781.18 km/s,lsrk,RADIO |
| 5 | 5-ID_06250 | 10:30:11, 05:19:08 | 258781.18 km/s,lsrk,RADIO |

Expected Source Properties

| | Peak Flux | SNR | Linewidth | RMS (over 1/3 linewidth) | linewidth / bandwidth used for sensitivity | Pol. | Pol. SNR |
|---|---|---|---|---|---|---|---|
| Line | 1.66 mJy | 4.2 | 300 k... | 397.96 µJy, 13.... | 3.00 | 0.0% | 0.0 |
| Continuum | 50.00 uJy | 1.1 | | | | 0.0% | 0.0 |

Dynamic range (cont flux/line rms): 0.2

1 Tuning

| Tuning | Target | Rep. Freq. Sky GHz | RMS (Rep. Freq.) | RMS Achieved |
|---|---|---|---|---|
| 1 | 1,2,3,4,5 | 270.473298 | 399.5 µJy, 13.6 mK | 376.23 uJy - 404.85 uJy |

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue below.

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

The targeted galaxies have optical z-band magnitudes of 25.4-24.8 mag (AB system). The corresponding flux density at the observed continuum redwards of Ly-a is 0.30-0.52 uJy (corrected for a ~20% flux density drop in the broad band photometry due to the Gunn-Peterson absorption already encapsulated in the z-band throughput). From this estimate, we infer the unobscured star formation rate (SFR_unobs) following Kennicutt & Evans (2012): log SFR_unobs [Msun/yr] = log nu L_nu [erg/s] - 43.55 = 12-20 Msun/yr. These SFR estimates are used to infer the continuum luminosity (assuming SFR_obs ~ SFR_unobs) and the [CII] luminosities (following known scaling relations, see e.g. de Looze et al. 2014; Herrera-Camus et al. 2015, 2018). The [CII] luminosities are in the range 5.0e8-8.6e8 Lsun, corresponding to a peak flux density of 1.66-1.98 mJy, assuming a box-car line profile with a line width of 300 km/s (see, e.g., Capak et al. 2015). Our sensitivity request is driven by the need to securely detect even the faintest of these lines at >4-sigma in 1/3 of the line, or ~7-sigma over the entire line width. This results in a target rms of 0.41 mJy/beam per 100 km/s (for comparison, all the [CII] emitters in the Capak+15 sample of Ly-a emitters at z~5.7 would be easily detected at our sensitivity requirement). Due to the uncertainties in the scalings, we opt for the same sensitivity request for all the 5 sources in our sample.

The predicted 1.2mm continuum flux density is based on the assumption that the dust emission is well modeled with a modified black body with Tdust=40 K and beta=1.6. A lower Tdust would lead to brighter 1.2mm flux densities. The collapsed cubes of our observations will be combined with the other three frequency settings on the same sources, yielding a 2x increase in S/N. We note that the IR continuum information is not a main scientific driver for this project.

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

The sources targeted in this study are relatively small galaxies at z~6.3. HST imaging of these and similar sources suggests that their angular scales are comparable or smaller than 1 arcsec. Our project is a detection experiment, so compact array configurations are required to avoid out-resolving the [CII] emission. We therefore ask for C43-1 or C43-2 configurations, which would yield a synthesized beam of 0.7"-1.5" at 1.2mm, consistent with or larger than the expected size of our targets.

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

We propose a spectral scan at 1.2 mm, in order to maximize the [CII] redshift coverage. With only four contiguous setups, we will be able to detect [CII] emission in a continuous window z=5.974 - 6.837. This will encompass any potential large-scale structure associated with the quasar J1030. Furthermore, it will provide [CII] coverage over a signifcant cosmic volume (~380 cMpc3 per pointing) to put constraints on the background number counts of [CII] emitters at z~6. The expected lines widths are of the order of ~300 km/s, but lines as narrow as ~50-70 km/s have been reported. In order to maximize spectral coverage and to retain spectral information on the line profiles, we thus opt to use the full 1.875 GHz bandwidth for each SPW, and a resampling of 4 native channels per saved spectral resolution element (~2 km/s).