European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME

PERIOD: **102A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title

Category: **A–6**

Super Massive Black Holes as signposts of galaxy overdensities at the edge of re-ionization: FORS2 observations of i-band dropouts around the z=6.31 QSO SDSSJ1030+0524.

2. Abstract / Total Time Requested

Total Amount of Time: 0 nights VM, 37.5 hours SM

We propose FORS2 multi-object spectroscopic observations of $z\approx6$ galaxy candidates around the bright z=6.31 QSO SDSS J1030+0524. The targets, selected to have colors $i-z\geq1.3$ and photometric redshift z≈6, form an extended overdensity within ≈3−4 projected physical Mpc from the QSO, especially in the north-west region: 16 of them will be observed with **three FORS2 masks of ten hours each**, along with a similar number of lower priority candidates. Our aim is to discover galaxies at the redshift of the quasar, including the first candidate "satellite" AGN observed at that redshift. **These observations will allow us to confirm the most promising Large Scale Structure around a z∼6 QSO discovered so far, and investigate the spatial 3D-distribution and the spectral properties of its member galaxies/AGN.**

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	102	FORS2	12.5h	mar	g	0.8	CLR	s	
B	102	FORS2	12.5h	mar	g	0.8	CLR	s	
C	102	FORS2	12.5h	mar	g	0.8	CLR	s	

4. Number of nights/hours

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:		

5. Special remarks:

6. Principal Investigator: Marco Mignoli, marco.mignoli@oabo.inaf.it, I, INAF - Osservatorio Astronomico di Bologna

6a. Co-investigators:

R.	Gilli	INAF - Osservatorio Astronomico di Bologna,I
E.	Vanzella	INAF - Osservatorio Astronomico di Bologna,I
R.	Decarli	INAF - Osservatorio Astronomico di Bologna,I
B.	Balmaverde	Scuola Normale di Pisa,I

7. Description of the proposed programme

A – Scientific Rationale: Super-Massive Black Holes (SMBHs), found at the center of distant (z>6) and very luminous (>10^{47}erg/s) QSOs, are among the most challenging astronomical objects ever observed[1,2]. Simulations suggest that these accreting $10^{9-10} M_\odot$ SMBHs formed and grew in the densest regions of the early Universe, that would evolve into local massive galaxy clusters[3,4,5]. Measuring the environment of $z \gtrsim 6$ AGN is a key observational probe to distinguish among the competing theories proposed to explain the early SMBH formation, but the search for galaxy overdensities has been inconclusive so far[6,7]. Most of these studies used small-FoV instruments, like the 3'×3' HST-ACS, or 7'×7' imagers at best[8,9]. A serious concern is then whether those data could really probe the large scale structure surrounding the QSO, as such angular sizes correspond to separations of 1-2 physical Mpc, where the central QSO negative feedback should be most effective[10].
The above considerations motivated us to obtain deep (r≃28; i≃27; z≃25) optical imaging in four fields around luminous $z \sim 6$ SDSS QSO, with the wide-field (25×25 sq.arcmin, i.e. 8x8 pMpc^2 at z=6) LBC camera at the Large Binocular Telescope (LBT). Our study revealed evidence for large-scale overdensities of Lyman Break Galaxy (LBG) candidates around the four QSOs. Specifically, we found an i-band dropout overdensity in *all fields*, with a significance of 3.7σ when combining the 4 fields[11], and the spatial distribution of the i-dropouts was found to be highly asymmetric, in agreement with cosmological simulations[3,5]. 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[12]. In 2016 we obtained deep (Y_{AB}=24.5, J_{AB}=24) near-IR imaging of the J1030 field with WIRCAM (FoV of 21×21 sq.arcmin) at the CFHT. Using these new observations, together with archival Spitzer-IRAC data, we pushed the selection of z∼6 galaxy candidates to fainter fluxes, measured photometric redshifts, and improved the rejection of contaminants, confirming a significant asymmetry in the distribution of the z∼6 galaxy candidates and reinforcing the large scale overdensity estimate (now >4σ)[13]. The presence of this overdensity appears to be confirmed also on smaller scales by our recent analysis of a 6.4hr VLT-MUSE pointing on J1030. We measured the redshift for 102 objects within the MUSE FoV, and discovered two faint ($f_{Ly\alpha} \sim 3-4\times10^{-18} erg\,cm^{-2}\,s^{-1}$; $L_{Ly\alpha} \sim 1.5-2\times10^{42} erg\,s^{-1}$) 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[14]. Based on the luminosity function of faint $z \sim 6$ LAEs measured in the Hubble Ultra-Deep Field[15], one would expect about 0.4 such objects within the small 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 ∼2σ level. To increase the significance of such a detection, a spectroscopy campaign over a large field of view is required, and the above results further strengthen the case of the J1030 field as an **ideal sky region to perform a spectroscopic investigation of the environment around distant (z>6) and luminous QSOs.**
In 2015 (Cycle 17) we were granted a Chandra Large Program (LP) to observe for 500ks the J1030 field with the 17'x17' ACIS-I camera (PI R. Gilli). The observations started at the end of January 2017 and now the whole 500ks data set have been reduced and analyzed. The main objectives of our Chandra LP were: i) get the highest quality X-ray spectrum of a $z > 6$ QSO to study its physical properties; ii) **verify the existence of candidate satellite AGN around SDSS J1030**, and iii) obtain a deep X-ray survey down to $f_{0.5-2} \approx 9\times10^{-17}$erg cm^{-2} s^{-1}that would add to those already in place to increase the statistics of faint and obscured AGN and study their cosmological evolution, especially at high redshifts. The first objective has been already addressed, and the results published[16]. To accomplish the other goals we generated source catalogs in the 0.5-7 keV (full), 0.5-2 keV (soft), and 2-7 keV (hard) X-ray bands down to limiting fluxes of $1.7, 0.9, 3.3\times10^{-16}$erg cm^{-2} s^{-1}, respectively. A preliminary but robust source catalog of 280 X-ray sources detected with more than four counts in the 0.5-7 keV band is being used as a working catalog.

B – Immediate Objective: • **Identification of galaxies at the redshift of the QSO.**
We propose to obtain FORS2-MOS spectroscopy of z≃6.3 candidate galaxies in the field of the quasar SDSS 1030+0524 at z=6.31. The faint targets (z_{AB} in the range 24.5−25.5) form an extended overdensity at ≈3 Mpc north-west of the central QSO: 16 out of 21 robust high redshift candidates in the J1030 field with photometric redshift z≈6 and colors $i - z \geq 1.3$ (see Balmaverde et al. 2017 and Figure 1, left), along with 16 secondary candidates (i-dropouts with SED best fitted by a stellar template at z=0 or galaxy template at low redshift, and bluer LBGs, with 1.1<$i-z$<1.3), will be included in three masks of 10 hours each (see Figure 1). The choice of including in the masks also a similar number of lower priority targets is a low-risk investment that may pay fruitful dividends: 1) acquiring spectra of suspected contaminants will test the efficiency in rejecting them of our photometric technique; 2) the use of a color selection too stringent could lead to the removal of useful sources since it is not uncommon to find Lyα emitters among those that do not meet the photometric selection criteria[17].
These observations will allow us to confirm the most promising Large Scale Structure around a z∼6 QSO discovered so far, and investigate the spatial 3D-distribution and the spectral properties of its member galaxies. The mere confirmation of such a large scale structure around a luminous QSO would provide the most stringent constraints to date to models of BH growth and galaxy formation within primeval overdensity fields. In addition, we will have the opportunity to compare the spectral properties of the galaxies that inhabit the large scale structure (i.e. Lyα EWs distribution, UV-continuum slopes) with those of field galaxies, probing environmental effects on early galaxy assembly.

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

• Identification of a possible satellite AGN at z>6

Our observations may discover the first satellite AGN at redshift greater than six. In our 500ks Chandra observation we find five net counts, associated with LBG #23132 (see inset of Figure 1). If confirmed, this would be the best "satellite" AGN candidate 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. The FORS2 observations would be able to confirm the nature of this source. Because of the many complex physical processes involved in the build-up of early galaxies and their SMBHs, the expected number of satellite AGN with M_{BH}∼$10^{6-7}M_{\odot}$ in simulated overdense structures may vary by orders of magnitude[5,18]. Our detection would represent the very first observational constraint to model the efficiency of BH fueling in early large scale structures[10].

• Project Status and Legacy Value

Our team is leading a major observational effort in the SDSS J1030 field by either collecting or re-analyzing multi-band data from the international facilities. We extensively imaged the field at both in optical (LBT/LBC *riz*) and near-IR (CFHT/WIRCAM *YJ*). The field is part of the Multiwavelength Chile-Yale survey (MUSYC[19]), that provides additional imaging in *UBVRIzJHK* and has been also entirely observed by Spitzer IRAC. The QSO has been observed by HST-ACS and WCF3, VLT-MUSE, ALMA and the VLA. Our 500Ks Chandra observation of the J1030 field represents the 4th deepest X-ray survey to date after the 7Ms CDFS and 2Ms CDFN and the first deep X-ray survey in a highly-biased region of the early Universe. In 2017 we also obtained Priority C (filler) additional programs with both ALMA and JVLA. A summary of all available data products and of their areal coverage and depth is visible at the project website http://www.oabo.inaf.it/∼LBTz6/1030. The same webpage is being used to release the optical/near-IR data products, on which this proposal is mainly based, the Chandra 0.5Ms data products, and will be used to release also all the FORS2 spectra here requested. The proposed program represents a crucial step to fully exploit the scientific potential of the data accumulated around the SDSS J1030 field by our group and will allow us to understand the impact of growing SMBHs at the re-ionization epoch on their large scale environment.

References: 1. Mortlock et al. 2011, Nature, 474, 716; 2. Wu et al. 2015, Nature, 518, 512; 3. Overzier et al. 2009, MNRAS, 394, 577; 4. Angulo et al. 2012, MNRAS, 425, 2722; 5. Costa et al. 2014, MNRAS, 439, 2146; 6. Banados et al. 2013, ApJ, 773, 178; 7. Mazzucchelli et al. 2017 ApJ, 834, 83; 8. Kim et al. 2009 ApJ, 695, 809; 9. Husband et al. 2013 MNRAS, 432, 2869; 10. Costa et al. 2014 MNRAS, 444, 2355; 11. **Morselli et al. 2014**, A&A, 568A, 1; 12. Stiavelli et al. 2005, ApJ, 622L, 1; 13. **Balmaverde et al. 2017**, A&A 606A, 23; 14. **Mignoli et al.**, A&A. in prep; 15. Drake et al. 2017, A&A, 608, A6; 16. **Nanni et al. 2018**, A&A (arXiv:1802.05613) 17. Toshikawa et al. 2012, ApJ, 750, 137; 18. Barai et al. 2018, MNRAS, 473, 4003. 19. Gawiser et al. 2006, ApJS, 162, 1.

Attachments (Figures)

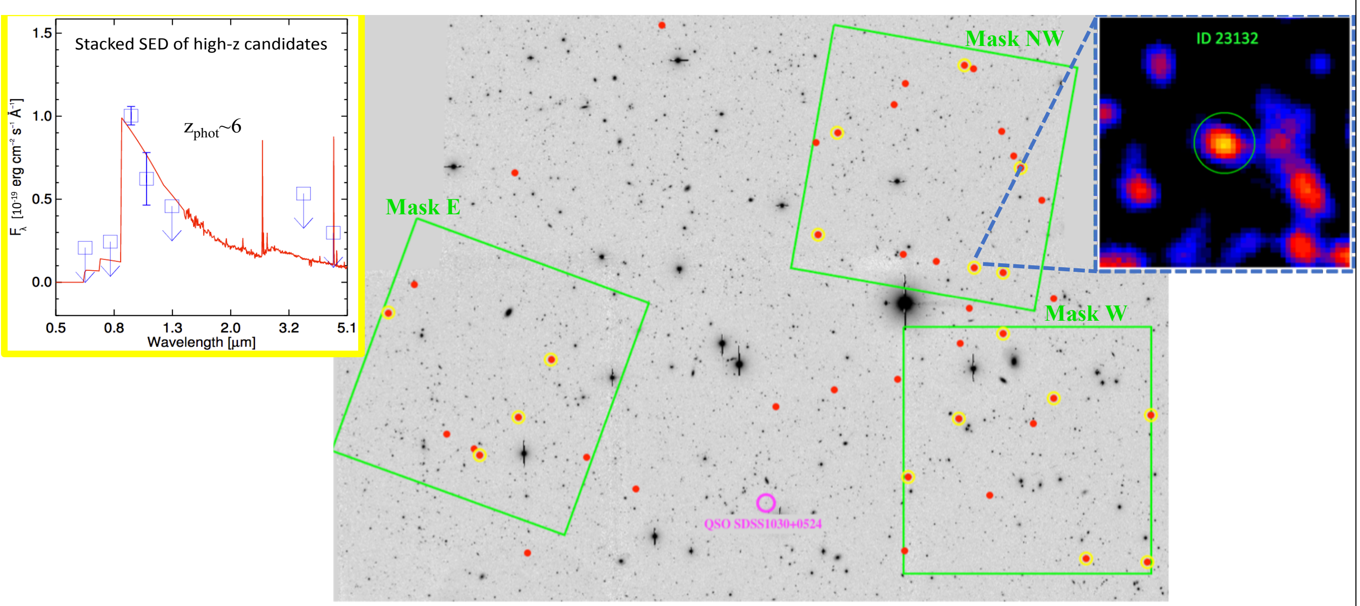

Figure 1: LBC z-band image of the upper region of the J1030 field. North is up and East is to the left. The large yellow circles highlight the best high-z galaxy candidates selected in Balmaverde et al. 2017, while the red dots mark secondary candidate (see text). The preliminary masks layout is showed in green. Left Inset: Stacked SED of the high priority z∼6 LBG candidates. The sharp drop in the SED indicates that a large fraction of these objects are robust high-redshift galaxy candidates. Right Inset: 25”×25” smoothed zoom of the 0.5-7 keV Chandra ACIS-I image, highlighting the X-ray detection of the LBG # 23132.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: Although dark time would be optimal for the proposed deep spectroscopy, in order to reduce as much as possible the sky background, also gray time may be acceptable for grism 600z.

Time Justification: (including seeing overhead)

We use FORS2 equipped with MIT red-optimized CCD to perform multi-object spectroscopy of candidate high-z galaxies selected as i-dropouts in the J1030 field. We adopt grism 600Z+23 to observe the wavelength range 7500÷10300Å and cover the redshifted Lyα position for $z > 5.15$. In order to estimate the exposure time needed to achieve the required S/N, we run the ETC (version P102) assuming a 0.8″seeing, 1.0″slit, dark time, and providing a LBG template spectrum as input (with z_{AB}=25.20). We adopted a simulated LBG spectrum with the correct Lyα decrement (DA) expected at redhift ∼6.3. In 10 hours (on target) of exposure time we obtain a continuum S/N per resolution element of ≈5, redward of the Lyα break, and also emission lines with flux of 3×10^{-18}erg cm^{-2} s^{-1}and FWHM of≈8Å are detectable with S/N>5 per resolution element. Therefore, three MXU masks will allow us to sample the spatial distribution of the z∼6.3 candidate galaxies in the *i*-dropouts overdensity detected around the bright central QSO (see Figure 1) and measure their spectroscopic features, like the Lyα continuum break and the Lyα emission line. We emphasize that, for galaxies at redshift∼6.3, the flux redward of Lyα is higher than that expected on the basis of the observed broad-band magnitude, since the intergalactic medium significantly absorbs the continuum at λ<1216Å×(1+z) and ≈20% of the z-bandpass covers the Lyα forest region. The members of our team have extended and well documented experience with VLT spectroscopy of faint high-z galaxies: we estimate that LBG spectra with continuum S/N≈3−5 can provide redshift measurements with errors of 0.02−0.05 also in absence of a strong Lyα emission line. This precision (Δz=0.05 at z=6 correspond to ≈3 pMpc) will allow us to unambiguously place the targets within the LSS around the QSO SDSS 1030+0524. For the five targets with z_{AB}>25.2, we expect to get a redshift measurement through the detection of Lyα in emission. The selected high-z galaxy candidates have absolute UV magnitudes in the range [−21.3,−20.5], with a mean value of −20.9: at these luminosities the fraction of strong (EW>25Å) Lyα emitters among z∼6 LBGs is debated, ranging from ∼10% to ∼50% (see de Barros et al. 2017, A&A 608, A123 and references therein). Nevertheless, since these LAE fractions refer to a high EW threshold (>25Å), with our exposure time we expect to detect Lyα in emission down to lower EWs, allowing a redshift measurements for most of our faintest targets. However, an important outcome of this proposal will be precisely the determination of the fraction of strong Lyα emitters in a biased envinroment.

Based on our previous experience with FORS2 and also on the outcome of the P2PP tool, overheads for observations with FORS2 amount to ≈25%. Therefore, the total amount of required time is 37.5 hours.

8a. Telescope Justification:

An 8-10m class telescope is necessary to obtain redshift identification for the faint (z_{AB}≈25), z∼6 galaxy candidate we propose to observe. FORS2 is the best optical spectrograph for red objects (>8000Å) available at ESO, since the alternative optical instrument (MUSE) should ask for too many pointings due to its limited FoV. The nature of the targets (blue and young star-forming galaxies) exclude also a near-infrared multi-object spectrograph (i.e. KMOS), because they are extremely faint in the near-IR bands.

8b. Observing Mode Justification (visitor or service):

Long integration times, stable seeing requirements, and transparency conditions are needed and therefore service observing is preferred.

8c. Calibration Request:

Standard Calibration

9. Report on the use of ESO facilities during the last 2 years

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

Walter et al. (Proposal #077.A-0797(A)) proposed similar FORS2 observations in the J1030 field, targeting candidate high-z galaxies, selected from previous deep multiband VLT imaging, in a small region of about 38 $arcmin^2$ around the quasar. We retrieved the data from the ESO archive but, since their targets were selected in vicinity of the quasar SDSS 1030+0524, there is no overlap between their data and our z$\sim$6 galaxy candidates. Moreover, the Walter et al. candidates show different photometric properties from our i-band dropouts, having bluer (i-z) colors and being detected in the r-filter.

9b. GTO/Public Survey Duplications:

10. Applicant's publications related to the subject of this application during the last 2 years

Morselli, L., **Mignoli, M., Gilli, R.**, et al., 2014, A&A, 568A, 1: *Primordial environment of super massive black holes: large-scale galaxy overdensities around z$\sim$6 quasars with LBT*

Balmaverde, B., Gilli, R., Mignoli, M., et al., 2017, A&A, 606A, 23: *Primordial environment of supermassive black holes. II. Deep Y- and J-band images around the z=6.3 quasar SDSS J1030+0524*

Nanni, R., Gilli, R., Vignali, C., Mignoli, M., et al., 2018, A&A in press (arXiv:1802.05613): *The 500 ks Chandra observation of the z=6.31 QSO SDSS J1030+0524*

Decarli, R., Walter, F., Venemans, B.P., et al., 2017, Nature 545, 457: *Rapidly star-forming galaxies adjacent to quasars at redshifts exceeding 6*

Mazzucchelli, C., Bañados, E., **Decarli, R.**, et al., 2017, ApJ, 834, 83: *No Overdensity of Lyman-Alpha Emitting Galaxies around a Quasar at z$\sim$5.7*

Vanzella, E., Nonino, M., [...] **Mignoli, M.**, [...] **Gilli, R.** ,et al., 2018, MNRAS, 476, L15: *Direct Lyman continuum and Lyα escape observed at redshift 4*

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	J1030+0524-NW	10 30 27	+05 24 55	12.5	≈25.2		z_{AB} mag	
B	J1030+0524-W	10 30 27	+05 24 55	12.5	≈25.2		z_{AB} mag	
C	J1030+0524-E	10 30 27	+05 24 55	12.5	≈25.2		z_{AB} mag	

Target Notes: The first priority mask (J1030+0524-NW) includes the possible “satellite AGN” at z>6

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
102	FORS2	A	Detector	MIT
102	FORS2	A	MOS	GRISM 150I+27/OG590
102	FORS2	B	Detector	MIT
102	FORS2	B	MOS	GRISM 150I+27/OG590
102	FORS2	C	Detector	MIT
102	FORS2	C	MOS	GRISM 150I+27/OG590

6b. Co-investigators:

...continued from Box 6a.

N.	Cappelluti	Miami University,Physics,US
R.	Nanni	Universita di Bologna, Dipartimento di Astronomia,I
C.	Vignali	Universita di Bologna, Dipartimento di Astronomia,I