MUSE Spectroscopy of a very High Redshift Radio-Loud QSO and Giant Lyman-α Nebula

Nathan Roche, Andrew Humphrey, Patricio Lagos, Polychronis Papaderos, *et al.*.

Instituto de Astrofísica e Ciências do Espaço, Centro de Astrofísica da Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal. nathan.roche@astro.up.pt, nathanroche@mac.com

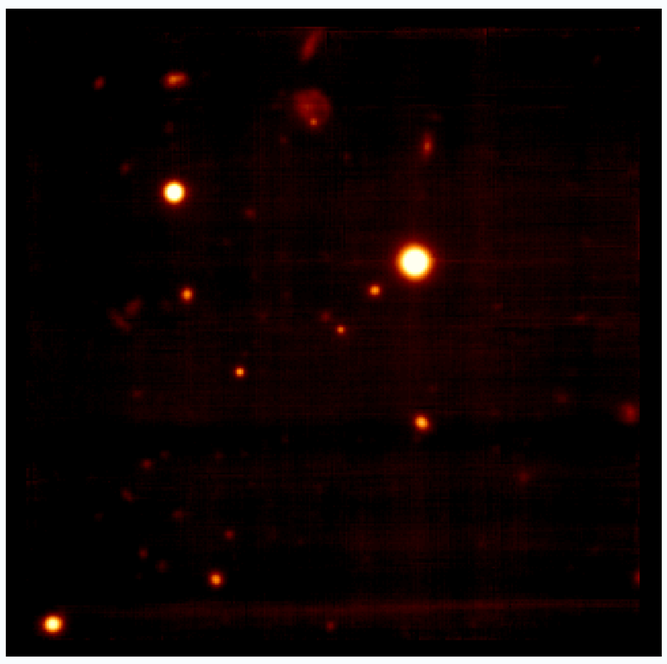
Abstract

We present initial findings from our very deep (11 hr) VLT MUSE (Multi Unit Spectroscopic Explorer) observations of one of the highest redshift known radio-loud QSOs, SDSS J2228+0110 at $z = 5.9$. The spectra show a strong Lyman-α emission line with total flux 5×10^{-16} erg cm^{-2}s^{-1}, centred at $\lambda \simeq 8388$Å. Whereas the UV continuum from the AGN is compact, the Lyman-α emission is much more extended, forming a halo of diameter ~ 25 kpc. A continuum subtracted Lyman-α image can be fit with a point source plus a (more luminous) low-index (0.71) Sersic profile, with half-light radius 5.9 kpc and slightly offset. With $L_{Ly\alpha} > 10^{44}$ erg s^{-1} this is one of the very highest redshift giant Lyman-α nebulae. Kinematic mapping of Lyman-α does not show large velocity shifts between the central source and nebula, but there is a rotational velocity gradient across the AGN.

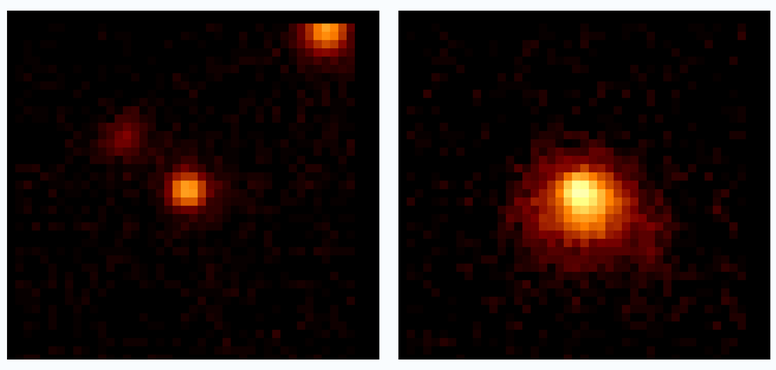
Introduction/Observations

The QSO SDSS J2228+0110, optically faint but with strong Lyman-α emission, was identified with a mJy 1.4 GHz source making this one of the highest redshift radio-loud AGN [1][2]. As part of a study of giant Lyman-α nebulae (e.g.[3]) we obtained a long-slit spectrum of this galaxy with GTC-OSIRIS and found evidence the Lyman-α emission is extended [4]. To follow we proposed and obtained (summer 2015) integral field spectroscopy with MUSE on the VLT, 44 exposures, 11.1 hours, and are now analysing the data. MUSE covers 1 square arcmin and 4750–9350Å in a large data cube with 0.2 arcsec ×1.25Å pixels.

Imaging



MUSE image from our data summed over 7050–9350Å , showing the full 60 × 60 arcsec field-of-view, the target galaxy in centre.

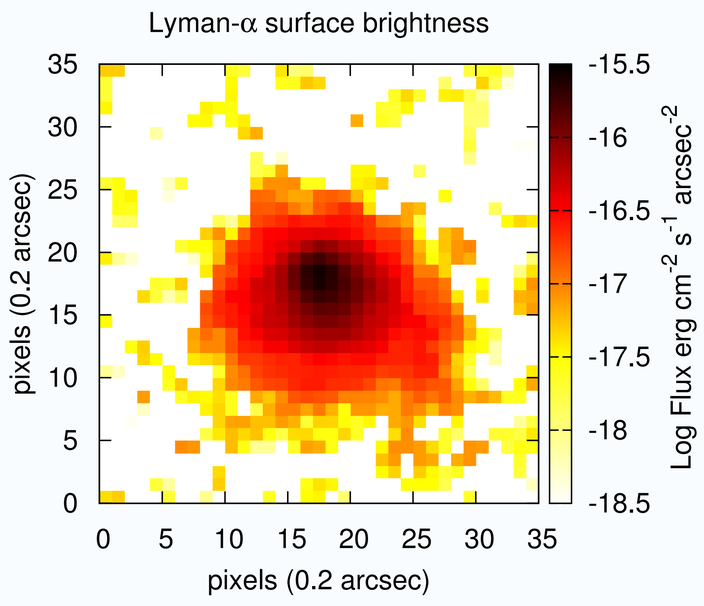


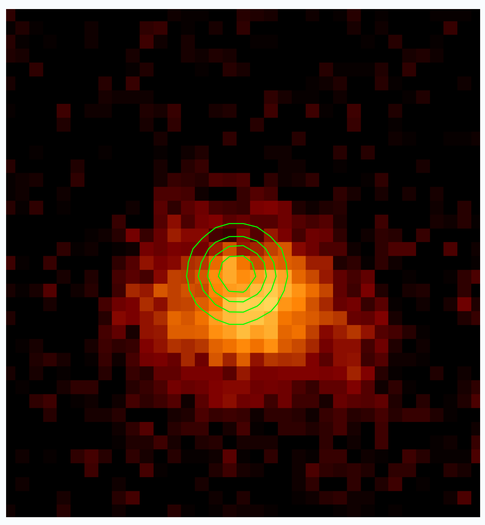
LEFT: Image of the QSO (centre) in rest-frame UV continuum (8450-8550Å observed), showing 8×8 arcsec. The continuum profile appears consistent with a point-source (seeing 0.61 arcsec). RIGHT: Continuum-subtracted Lyman − α (8369–8429Å) image for the same area, confirming there is an extended emission nebula, diameter at least 4 arcsec (24 kpc)

The Lyman-α image was fitted (*Galfit*) with a point source (1.60×10^{-16} erg cm^{-2}s^{-1}) plus a low-index $n = 0.71$ Sersic model, half-light radius 0.99 arcsec = 5.9 kpc, axis ratio 0.71, PA 86°, and a greater flux 3.67×10^{-16} erg cm^{-2}s^{-1}.

Morphology

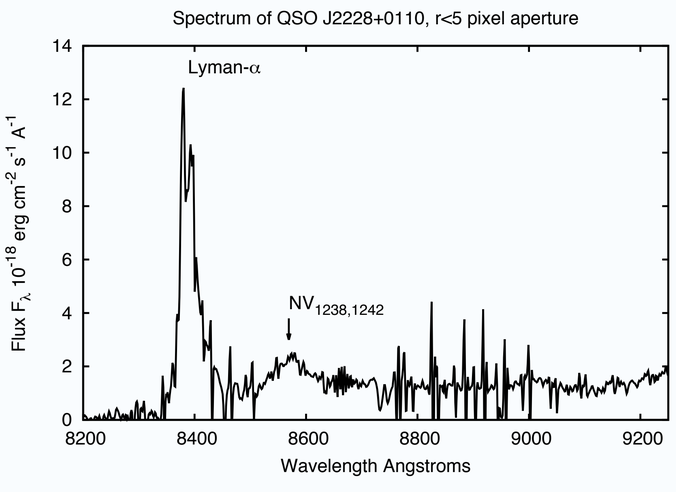
The nebular (from Sersic fit) flux corresponds to a high Lyman-α luminosity 1.5×10^{44} erg s^{-1}, and the surface brightness, a few 10^{-17} erg cm^{-2}s^{-1}arcsec^{-2}, matches luminous giant nebulae at $2 < z < 3$ [3] when de-redshifted.





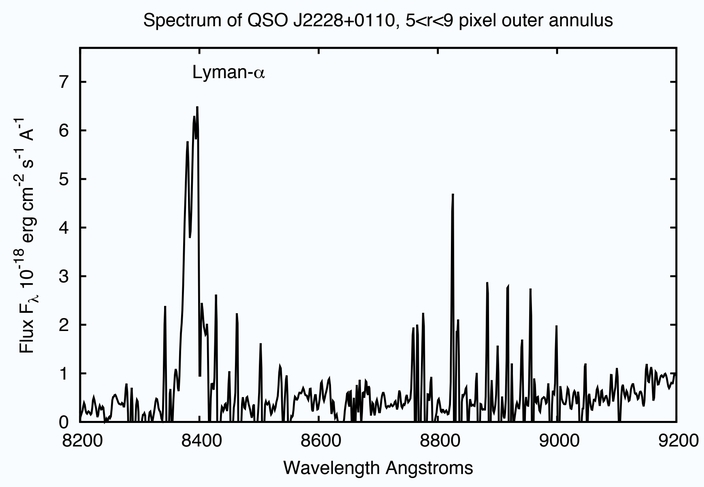
Lyman-α image with the fitted point-source subtracted (but shown by contours), to show only the extended nebula; it is offset 0.5 arcsec SSW from the point-source, and more complex in structure.

Spectra



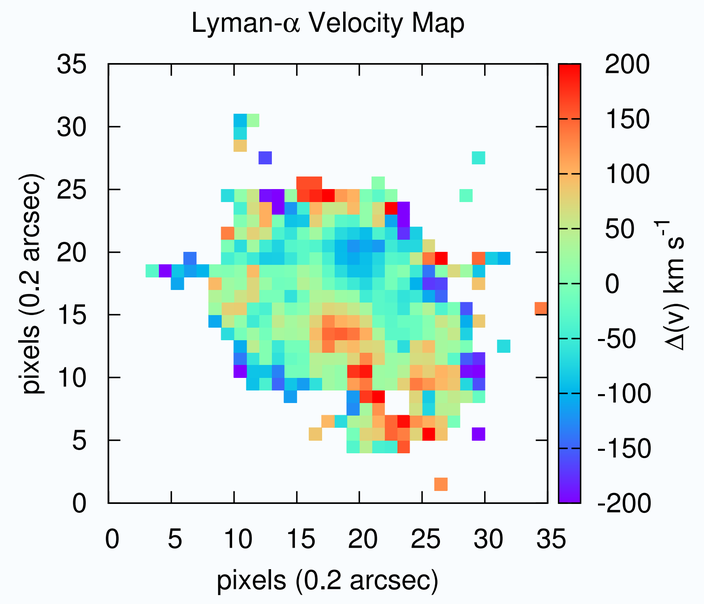
The AGN spectrum from the MUSE data in a $r < 5$ pixel aperture shows Lyman-α at $\lambda = 8388$Å (giving redshift as $z = 5.9018$), with flux 3.1×10^{-16} erg cm^{-2}s^{-1} and FWHM about 32Å(1140 km s^{-1}), continuum with a sharp Lyman break, and broad NV 1238,1242 emission.

Spectra2



This spectrum, extracted in an outer $5 < r < 9$ pixel aperture (mostly nebular emission) shows Lyman-α at the same wavelength, flux 1.7×10^{-16} erg cm^{-2}s^{-1} and FWHM still broad, about 28Å, but with much less flux at other wavelengths. In both spectra and throughout the Lyman-α peak is split at about 8386Å

Kinematics



We fit to the Lyman-α profile in the sky-subtracted spectrum of each spatial pixel, with the same methods as in our study of PKS 1934-63 [5], and from the resulting grid of wavelengths map the line-of-sight velocity shift. For this object we do not find any large velocity difference between the AGN and nebula, or a gradient across the nebula; but in the central region there is a N-S or NNW-SSE velocity gradient across the AGN, spanning at least 5Å, 180 km s^{-1}, in a pattern suggestive of rotation (possibly in a plane perpendicular to the nebula's long axis).

References

[1] Zeimann G. *et al.*, 2011, ApJ 736, 57.
[2] Cao H.-M. *et al.*, 2014, A&A 563, 111.
[3] Heckman T.M. *et al.*, 1991, ApJ 379, 78.
[4] Roche N.D. *et al.*, 2014, MNRAS 443, 3795.
[5] Roche N.D. *et al.*, 2016, MNRAS accepted, arXiv 1604.00309