# Lyα envelopes of z=4.5 quasars

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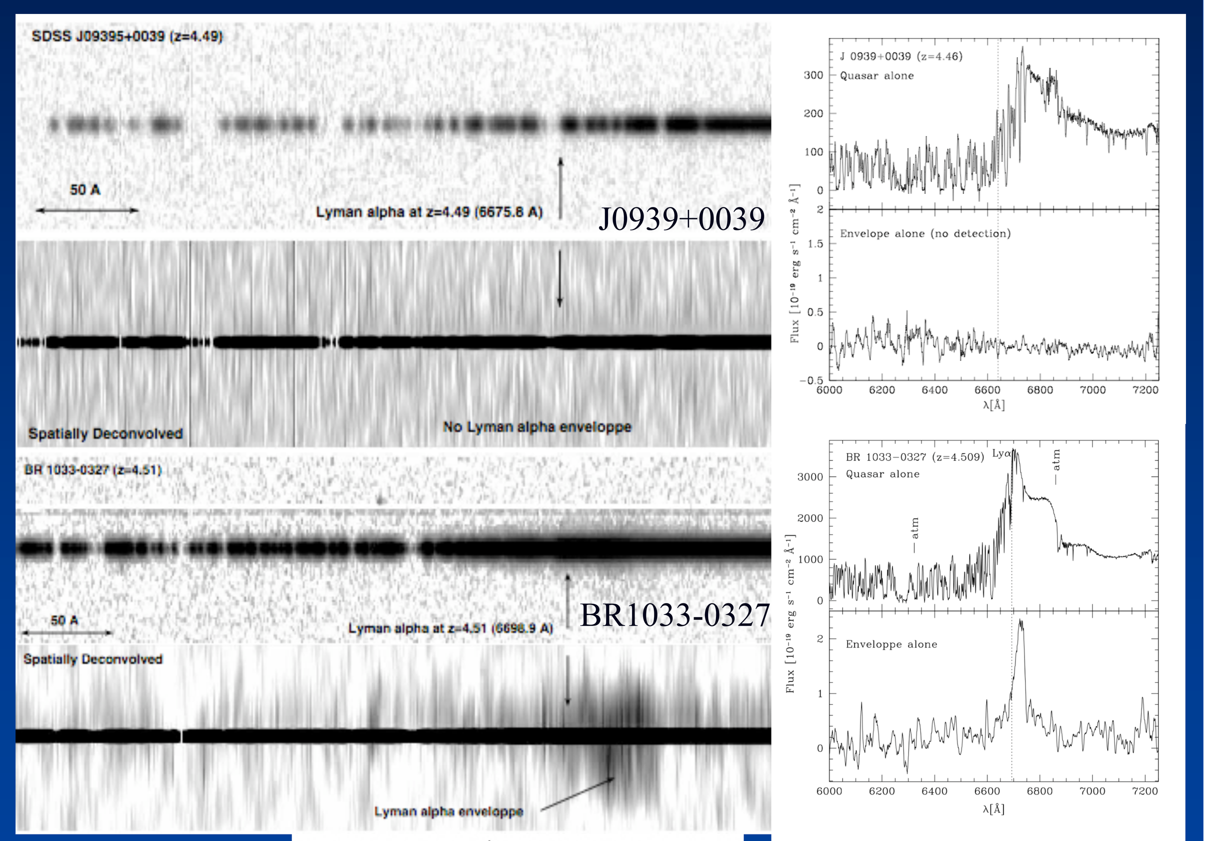
## The context:

The ionizing source causing the emission of the Lyα « blobs » (observed by e.g. Matsuda et al. 2004, ApJ 128, 569) remains a matter of debate. While a large fraction of them seem to host a quasar, the UV radiation of which may ionize the surrounding cool gas (Geach et al. 2009, arXiv:0904.0452), the real cause of their Lyα emission might rather be due to cold accretions streams (Dijkstra & Loeb 2009, arXiv:0902.2999). In the latter view, the presence of a quasar is coincidental, and any correlation between the quasar luminosity and that of the blob just results from the larger probability of finding a brighter AGN in a more massive halo. Using very deep spectroscopy, we looked for Lyα emission around optically detected quasars with various intrinsic luminosities at $4.49 < z < 4.59$, i.e. in a spectral region devoid of telluric emission lines. The quasars observed are all radio quiet and have $-26.2 < M_R < -29.8$.



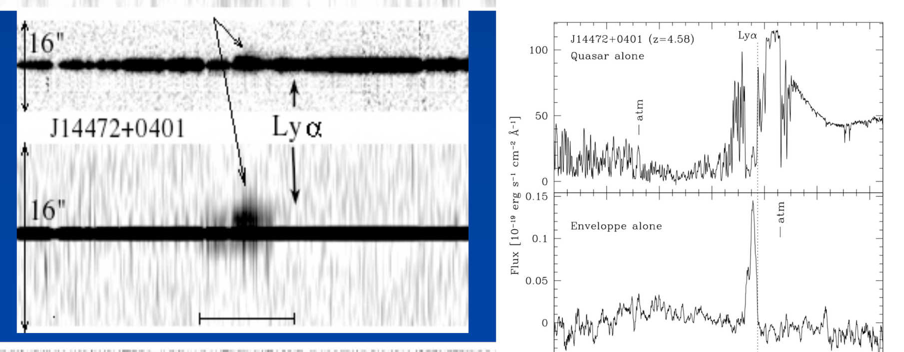
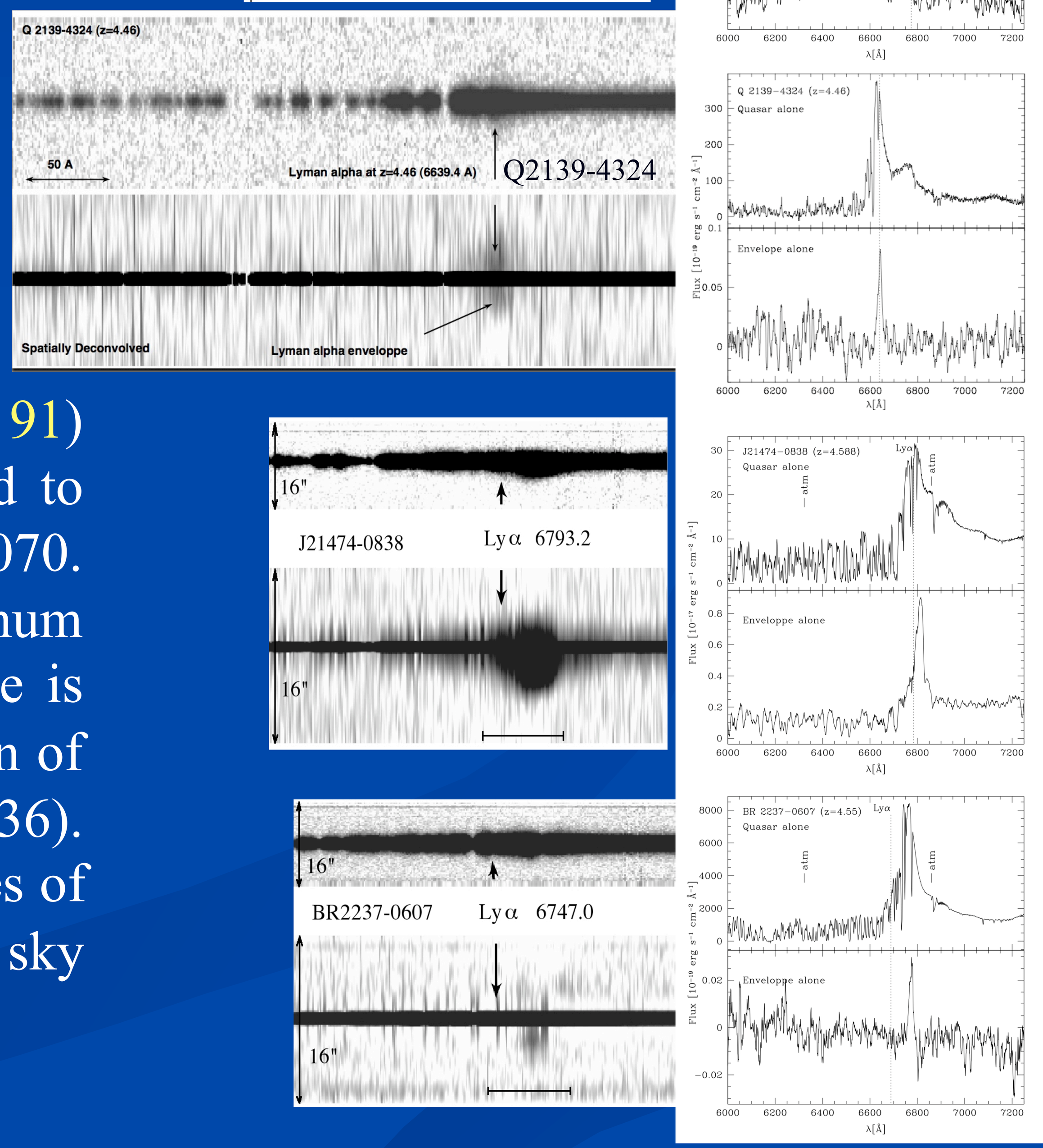




**Fig. 1 – Left: Combined and sky-subtracted FORS2 spectra of the 6 quasars observed (top) and spatially deconvolved spectra (bottom), showing the Lyα emission much better. - Right: Quasar spectrum (top) and spatially integrated spectrum of the envelope (bottom), smoothed with an 8 Å boxcar.**




## The questions:

- What is the frequency of these envelopes around RQQs?
- What are their typical size and surface brightness?
- What are their luminosities, and luminosity function?
- What are their shapes and kinematics?
- Are the envelope luminosity and size related to the QSO luminosity, and how?

## The observations and their analysis:

6 RQQs were observed in ESO Periods 79 (April-Sept. 2007, see Courbin et al. 2008, A&A 488, 91) and 81 (April-Sept. 2008) in service mode with the FORS2 multi-object spectrograph attached to VLT-UT1. We used the ESO grism G1200R+93 with a 2'' slit, providing a resolving power R=1070. The order separating filter GG435+81 gives a spectral coverage 6000 to 7200 Å, with a maximum efficiency coïnciding with the redshifted Lyα wavelength, ~6700 Å. The multi-slit MXU mode is used, allowing to observe at once the quasar and several stars dedicated to a precise determination of the spectral PSF, in view of an efficient spatial deconvolution (Courbin et al. 2000, ApJ 529, 1136). This allows us to separate well the quasar spectrum from that of the envelope. 8 × 1300s exposures of each object were taken, giving a total integration times of 10400s. The 2D spectra were then sky subtracted, co-added and spatially deconvolved (see Figure 1).

## The answers given by the 6 objects observed to date:

- Envelopes discovered around 5 out of 6 radio quiet quasars; therefore, they are quite common, if not ubiquitous. (Interestingly, in J14472+0401, deep absorption in the QSO spectrum coincides with Lyα emission in the envelope).
- They are large: 40 to 90 kpc and have various surface brightnesses, from $5 \times 10^{-21}$ to $2 \times 10^{-17}$ erg s$^{-1}$ cm$^{-2}$ ''$^{-2}$ .
- Their luminosities range from $10^{41}$ to a few $10^{44}$ erg s$^{-1}$.
- Their shape may be strongly asymmetric, and the emission line has FWHM from 21 to 50 Å (900 to 2200 km s$^{-1}$).
- Lyα luminosity of the envelope correlates well with that of the Broad Line Region, with the notable exception of BR2237-0607, the brightest quasar in our sample (see Figure 2).

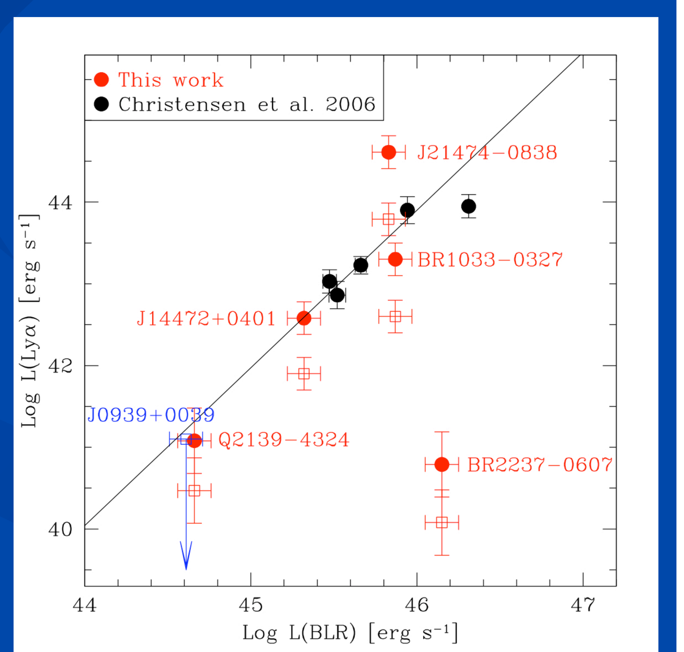



**Fig. 2** – Lya total luminosity of the envelope versus the luminosity of the BLR. Open and full red dots refer to luminosities observed and corrected for slit clipping.

**Discussion**: One would naively expect that a tight correlation between the BLR and envelope luminosities argue in favour of the « heating » mechanism (i.e. photo-ionization by the UV flux of the AGN) predicted by e.g. Haiman & Rees (1981, ApJ 556, 87) and advocated by Geach et al. (2009). On the contrary, the « cooling » scenario does not foresee any direct, causal relation between the AGN luminosity (if any) and the blob luminosity, since the cold gas is shielded from the central UV source because of its filamentary geometry. Therefore, in a sample of « blobs » selected as companions to quasars, one would expect, at best, only a loose correlation, via the mass of the DM halo in which they reside: the more massive the halo, the brighter the blob, but also the brighter the QSO (statistically). It is interesting that our deep observations do not yield any correlation between the size of the envelope and the AGN luminosity (Fig. 3) - another possible argument in favour of the « cooling » mechaninsm. On the other hand, it is difficult to conclude from Fig. 2 - which shows a tight relation between the BLR and blob luminosities - in favour of the « heating » mechanism, because of the striking exception of BR2237-0607, and because of the strongly asymmetric blob shapes, which make slit clipping factors extremely uncertain. Narrow-band imaging observations are mandatory to get a reliable enough estimate of the blob luminosity, as well as crucial information on the morphology. Only such observations will tell whether the BLR and blob luminosities are closely related or not.

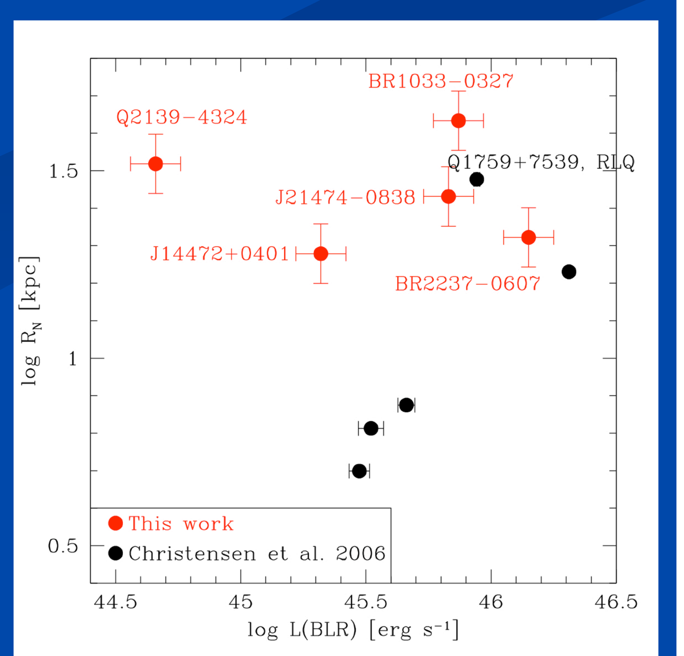



**Fig. 3** – Size of the envelope versus the luminosity of the BLR.

| Object | $\lambda$ [Å] | mean $F_\lambda$ [erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$] | FWHM [Å] | Extent ('';kpc) | Surface brightness [erg s$^{-1}$ cm$^{-2}$ ''$^{-2}$] | $1-\sigma$ detection limit [erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$] |
|---|---|---|---|---|---|---|
| SDSS J0939+0039 | – | – | – | – | – | $2.0 \times 10^{-20}$ |
| BR 1033−0327 | $6725.0 \pm 0.5$ | $4.0(\pm0.4) \times 10^{-19}$ | $50 \pm 10$ | 13; 86 | $7.7(\pm0.8) \times 10^{-19}$ | $2.7 \times 10^{-20}$ |
| SDSS J14472+0401 | $6756.3 \pm 0.5$ | $1.3(\pm0.1) \times 10^{-19}$ | $30 \pm 3$ | 6; 38 | $3.3(\pm0.4) \times 10^{-19}$ | $6.1 \times 10^{-21}$ |
| Q 2139−4324 | $6641.0 \pm 0.3$ | $7.2(\pm1.4) \times 10^{-21}$ | $22 \pm 2$ | 10; 66 | $8.0(\pm1.6) \times 10^{-21}$ | $2.5 \times 10^{-21}$ |
| SDSS J21474−0838 | $6808.2 \pm 1.0$ | $6.2(\pm1.2) \times 10^{-18}$ | $50 \pm 8$ | 8; 53 | $1.8(\pm0.5) \times 10^{-17}$ | $1.1 \times 10^{-19}$ |
| BR 2237−0607 | $6773.6 \pm 2.0$ | $2.9(\pm0.7) \times 10^{-21}$ | $21 \pm 2$ | 7; 42 | $4.6(\pm1.5) \times 10^{-21}$ | $4.0 \times 10^{-22}$ |

**Table 1 – Main properties of our Lyα envelopes. The 1-σ detection limit is the standard deviation of the background (after smoothing with a boxcar of 8 Å) integrated along the whole slit, but it is given per Å. Surface brightness is integrated in wavelength and given per arcsec².**