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LETTER

Letter to the Editor

HS 1603+3820: a bright $z_{\rm em} = 2.51$ quasar with a very rich heavy element absorption spectrum

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Abstract. During the course of Hamburg/CfA Bright Quasar Survey we discovered a bright ($B = 15.9$), high redshift ($z_{\rm em} = 2.51$) quasar HS 1603+3820. The quasar has a rich complex of C IV absorbers, containing at least five systems, all within 3000 km s^{-1} from one another. Despite large ejection velocity ($v_{\rm ej} > 5000$ km s^{-1} for all components) the complex is likely to be associated with the quasar. There are at least three more associated heavy element absorbers, two of which have $z_{\rm abs} > z_{\rm em}$. Together, they make one of the richest known complexes of associated heavy element absorbers, and the richest in objects with $B < 16$. The combination of redshift, brightness, richness of the metal absorption spectrum and richness of the associated absorption is unmatched among known quasars.

Key words: galaxies: intergalactic medium – galaxies: quasars: absorption lines – galaxies: quasars: individual: HS 1603+3820

1. Introduction

Quasars often exhibit narrow heavy element absorption lines near their emission redshift. One possible explanation for the origin of these systems is that they arise in clouds of matter associated with galaxies in the clusters surrounding the quasars. Alternate possibility is that they originate in the clouds that are physically associated with the quasars themselves. It has been shown that both these scenarios may be true (e.g. Ellingson et al. 1994; Hamann et al. 1997a).

Clusters of absorbers of any type are of particular interest. On one hand, clustering properties of intervening systems depend strongly on the type of absorbers, while on the other hand complexes of associated absorbers give a unique opportunity to analyze the properties of their hosts and of the quasar emission.

The stumbling block in such studies is the fact that bright high redshift quasars with rich absorption are rare (for examples of such systems see, e.g., Morris et al. 1986; Foltz et al. 1987; Petitjean et al. 1994; Hamann et al. 1997a; Lespine & Petitjean 1997; Petitjean & Srianand 1999). There are only a few quasars known with more than just a handful of associated absorption systems which are bright enough to perform high resolution spectral analysis.

In this paper we present a bright $z_{\rm em} = 2.51$ quasar HS 1603+3820 (α_{1950} = 16:03:07.7, δ_{1950} = +38:20:07) with a very rich metal absorption spectrum. It was discovered during the course of the Hamburg/CfA Bright Quasar Survey (Hagen et al. 1995; Dobrzycki et al. 1996). Quasar candidates in the survey are selected from the objective prism spectra taken with the Hamburg Schmidt telescope at Calar Alto, Spain. Follow-up low resolution spectroscopy is performed with the 1.5-m Tillinghast reflector with the FAST spectrograph at Fred Lawrence Whipple Observatory on Mount Hopkins, Arizona.

The discovery spectrum and other basic information on HS 1603+3820 will be presented in the forthcoming survey paper (Engels et al. 1999). In this paper we present a more detailed analysis of the MMT spectrum of HS 1603+3820. Its very unusual properties prompted us to make the quasar available to interested researchers prior to the publication of the survey.

To our knowledge, there are no radio or X-ray sources near the position of HS 1603+3820.

The finding chart for HS 1603+3820 is shown on Fig. 1. HS 1603+3820 was selected for followup studies because of its unusually high brightness ($B = 15.9$) for a high-z quasar and because the discovery spectrum hinted that there could be absorption systems in the vicinity of the emission lines.

Observations performed with the Multiple Mirror Telescope[1] revealed a very rich heavy element absorption spectrum. Several metal systems, both intervening and associated, are present, including a couple of systems with $z_{\rm abs} > z_{\rm em}$. A unique feature is a rich complex of at least five C IV absorbers near the emission redshift of the quasar.

This paper is organized as follows. In Sect. 2 we present the MMT observations of HS 1603+3820. In Sect. 3 we present the metal absorption systems. In Sect. 4 we discuss the of C IV absorbers at $z_{\rm abs} \approx z_{\rm em}$ and present arguments that they likely

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[1] MMT is a joint facility of the Smithsonian Institution and the University of Arizona.

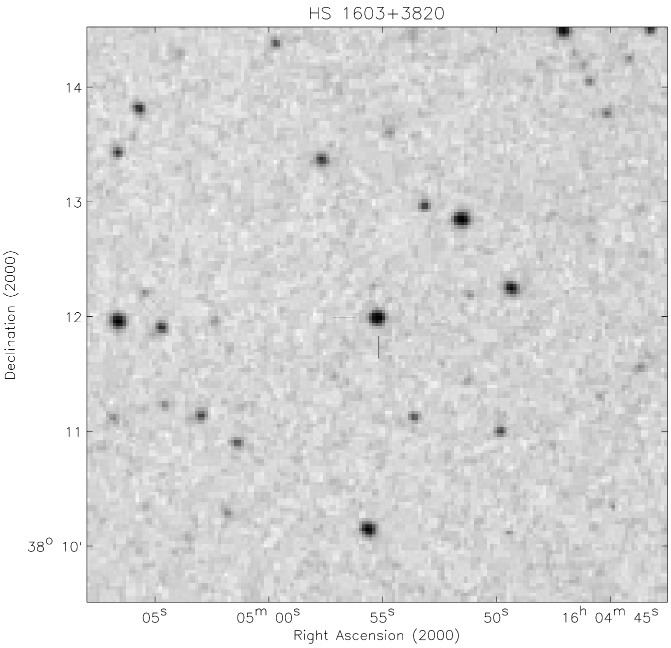

Fig. 1. The finding chart for HS 1603+3820.

are associated with the quasar. We summarize our results in Sect. 5.

2. Observations

Spectra presented here were obtained during two nights, April 12–13, 1997, at the Multiple Mirror Telescope (MMT) on Mt. Hopkins, Arizona. We used the Blue Channel spectrograph, with the 1200 l/mm grating in first order, 1.25×3 arcsec slit and the 3k×1k Loral CCD, binned by two in the spatial direction. Weather and seeing were very good during both nights. The wavelength range of 3530–5050 Å, which contains the Ly-α forest part of the HS 1603+3820 spectrum, was observed for the total of 3300 seconds during two nights. On the second night another 1200 second exposure was obtained for the wavelength range containing the CIV emission line, 4840–6350 Å. Spectra have 0.495 Å/pixel binning and spectral resolution of $\sim$3 pixels. The S/N ratio per resolution element in the "Ly-α spectrum" varies from $\sim$40 to $\sim$100, and in the "CIV spectrum" it is roughly uniform at the level of 45–50.

Continua were fitted to the spectra and the absorption line lists were generated following the procedure similar to outlined in Scott et al. (1999a, 1999b), where one can also find the analysis of the Ly-α forest spectrum of HS 1603+3820. Interested researchers can access the line lists (as well as finding chart and the spectra – both plots and digital versions) on the World Wide Web at http://hea-www.harvard.edu/QEDT/Papers/hs1603/.

Full spectra can be seen in Figs. 2 and 3. Fig. 4 shows in detail the vicinity of the Ly-α and CIV emission lines.

It has to be noted that the continuum level in the region near 4250 Å, which occurs near the peak of the Ly-α emission line, is quite uncertain, making the emission redshift of the quasar somewhat uncertain, since an important part of the line is seriously affected by complex absorption. (Please note that this absorption is *not* related to Broad Absorption Line phenomenon – the absorption lines affecting the Ly-α emission profile are not Ly-α.) We adopted the emission redshift of the quasar of 2.51, keeping in mind the well known fact that broad emission lines of quasars can be blueshifted by as much as $\sim$1000 km s^{-1} with respect to "true" quasar redshift, as determined from narrow forbidden lines (see e.g. Espey 1993). It should be noted (and it will be discussed in a little more detail below) that there are absorption lines at redshift as high as 2.55, but they clearly are on the red wing of the emission lines, well past the peak emission.

3. Heavy element absorption systems

As expected in a quasar with $z_{\rm em} = 2.51$, there are numerous absorption features in the Ly-α forest part of the spectrum. The Ly-α forest of HS 1603+3820 has been included in the large sample of Scott et al. (1999b). In the present paper we concentrate on the heavy element absorption lines, presence of which is clearly seen on top of the emission lines and redwards of the Ly-α emission.

Metal systems in the spectrum were searched for in two ways. First, an attempt was made to interactively identify all absorption lines redwards of the Ly-α emission line. Second, heavy element line searching code METALS, written by Jill Bechtold and kindly provided to us by the author, was applied. In all, thirteen heavy element absorption systems were found, though the reality of two of them is somewhat shaky. Notes on individual systems follow.

$\langle z_{\rm abs}\rangle = 1.8882$: This is the first of the two uncertain systems. Its identification relies primarily on the presence of a doublet which has the wavelength ratio matching the ratio for the CIV doublet. Though this match is indeed very good, both lines are possible blends with lines from other systems. Two other identified lines, NV(1242) and FeII(1608), are also blends with lines from other systems. The wavelength corresponding to the Ly-α line lies outside of the spectrum.

$\langle z_{\rm abs}\rangle = 1.9650, 2.0703, 2.1762$: All these systems are unambiguously identified, showing well resolved Ly-α, CIV, and other lines.

$\langle z_{\rm abs}\rangle = 2.4189, 2.4270, 2.4367, 2.4420, 2.4523$: These are the confirmed systems that have their CIV lines in the complex in the blended region near 5320 Å. See Sect. 4 below for a more detailed discussion of the complex.

$\langle z_{\rm abs}\rangle = 2.4794$: This is a very strong system, just below the emission redshift of the quasar. As many as seventeen absorption lines belonging to this system were identified. The SiII(1526) line lies inside the CIV complex near 5320 Å, but is easily recognizable. Very strong Ly-α and CIV lines are prominent on Fig. 4. The Ly-α absorption line, which is somewhat asymmetric on the red wing, is in fact a blend of (at least) two lines: very strong Ly-α proper, and a weaker line, which appears to be a member of another metal system(s).

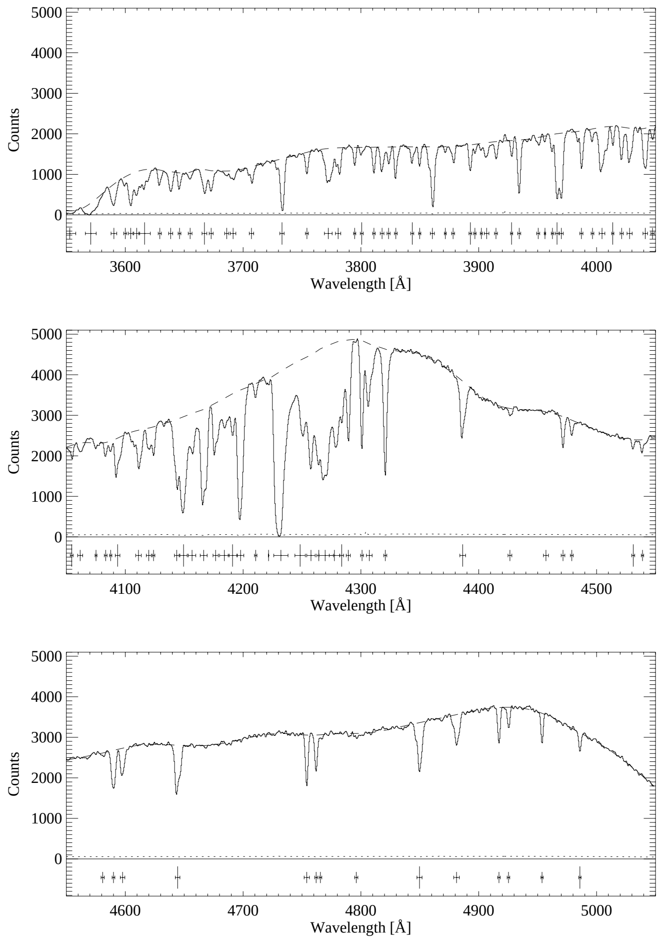

Fig. 2. The "Ly-α" spectrum of HS 1603+3820. The dotted line shows 1σ uncertainty, the dashed line shows the continuum it. Tick marks under the spectrum show the absorption lines. The spectrum was smoothed with a 3-pixel box.

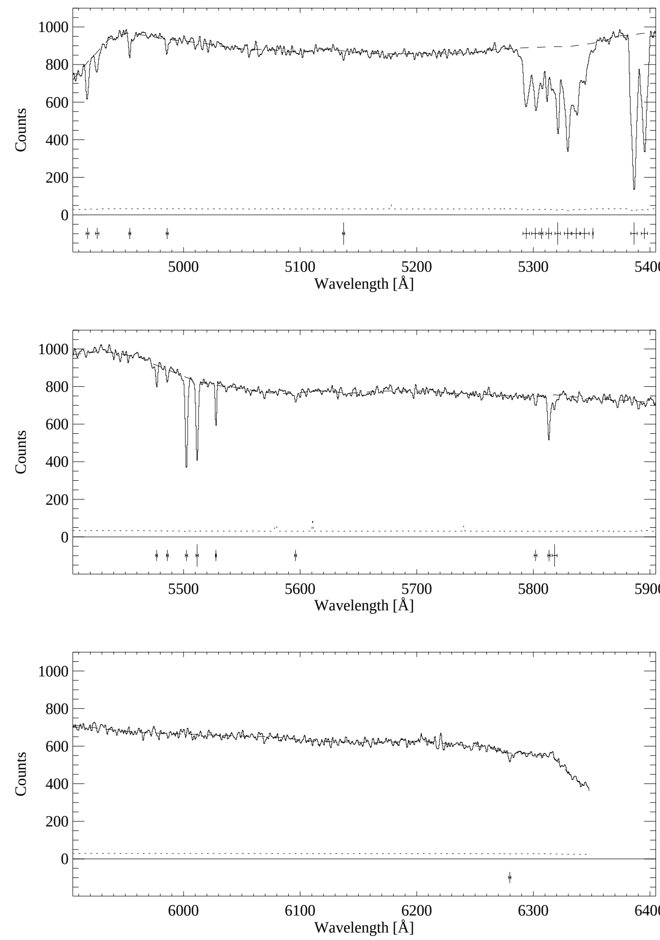

Fig. 3. The "C IV" spectrum of HS 1603+3820. See caption of Fig. 2 for details.

$\langle z_{\rm abs}\rangle = 2.5114$: This is the second of the two uncertain systems. If it is real, it is almost exactly a $z_{\rm abs} = z_{\rm em}$ system. It has six lines at correct wavelengths, including three Si II lines. The Ly-α line lies in the middle of the blended region near 4250 Å. There is, however, no significant C IV absorption. Dotted marker on the lower panel of Fig. 4 shows the expected location of the C IV doublet; the 5σ rest equivalent width threshold at this location is 0.07 Å. Also, there are two other issues that make the identification of this system uncertain. First, the system appears to contain a somewhat unusual combination of lines. Second, the ratios of line strengths of the Si II lines appear to be incorrect (Morton 1991). Acknowledging that especially the second of these problems casts doubts on the reality of this system, we hesitate, however, to entirely discard it, since the identified Si II lines may be blended with other lines, not to mention the fact that the environment in the vicinity of the quasar central engine is likely to be highly unusual.

$\langle z_{\rm abs}\rangle = 2.5374, 2.5541$: These are the two systems with $z_{\rm abs} > z_{\rm em}$ seen in the spectrum of HS 1603+3820. Both systems have Ly-α, C IV, and other metal lines clearly resolved. See below for discussion.

4. Complex of metal systems at $z_{\rm abs} \approx z_{\rm em}$: intervening or associated?

The most interesting feature in the spectrum of HS 1603+3820 is the large number of systems with $z_{\rm abs} \approx z_{\rm em}$. Nine of the metal systems are within 8000 km s^{-1} of the quasar emission redshift. Of these, the most spectacular is a complex of at least five C IV absorption systems, all within 3000 km s^{-1} from one another. Other systems may be present in the complex, but limited resolution of our data does not allow us to claim that at a reasonable level of confidence.

The average ejection velocity of the complex, i.e. displacement from the redshift of the quasar in velocity units, is $\sim$6500 km s^{-1}. In principle, large ejection velocities would indicate that these systems are intervening, i.e. are not associated physically with the quasar. On the other hand, convincing arguments were presented (Hamann et al. 1997b, Richards et al. 1999) that absorbers with much larger ejection velocities could be intrinsic to the quasar.

Of the three methods for distinguishing between intrinsic and intervening systems (see Barlow & Sargent 1997, Hamann et al. 1997a, and references therein) – details of shapes of absorption lines, temporal variability of line strengths, and partial

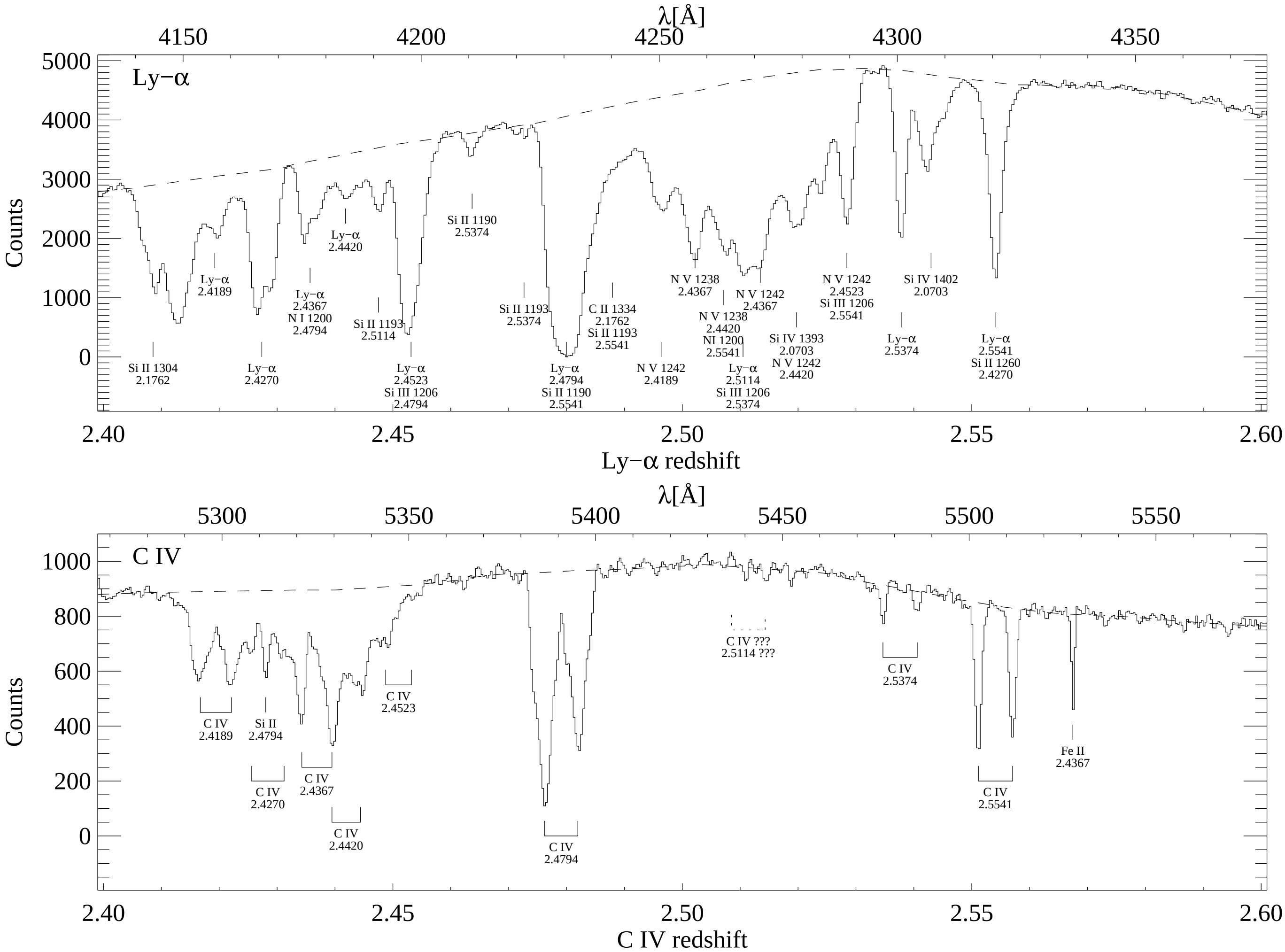

Fig. 4. The vicinity of Ly-α (top panel) and C IV (bottom panel) emission lines, plotted in the same redshift range. Dashed line shows the adopted continuum. Lines from identified metal systems are marked. Note: the complex of C IV absorbers at $z_{\rm abs} = 2.41$–2.45, very strong system at $z_{\rm abs} = 2.4794$, two systems on the red wings of the emission lines at $z_{\rm abs} = 2.5374$ and $z_{\rm abs} = 2.5541$, and missing C IV absorption for the uncertain system at $z_{\rm abs} = 2.5114$ (its expected location is marked with dotted line). See text for discussion.

covering of quasars by the absorbers – only the third can be applied in our case. The first is precluded by insufficient resolution of our data. The second was made impossible by decommissioning of the MMT, since we could not observe the quasar again with the same telescope/detector combination, which is a standard approach in such a case. We can, however, attempt to estimate whether at least one of the systems in the complex obscures the emission source in the quasar entirely. If it does not, it is a strong indication that the cloud in which the absorption system originates is physically associated with the quasar.

The C IV doublet at $\langle z_{\rm abs}\rangle = 2.4189$, which has $v_{\rm ej} \approx 8000\,{\rm km\,s^{-1}}$, is at the high ejection velocity end of the C IV complex. The lines from this doublet fulfill all the conditions needed for the quasar covering factor criterion: they are satisfactorily well resolved, they are markedly broader than the spectrum resolution, and they are not contaminated by absorption lines from any other known systems. If these two lines are indeed resolved, we find the C IV(1548)/C IV(1550) ratio in this system to be close to 1, which indicates that the system is optically thick. At the same time, the lines do not reach zero intensity in their bottoms, which suggests that the cloud in which the lines originate does not obscure the entire continuum emitting source. That in turn suggests that this absorption system is intrinsic to the quasar. The lower ejection velocity systems in the complex also do not reach zero intensity, which makes it reasonable to assume that they are also associated with the quasar (even though we cannot unambiguously establish whether they are saturated).

There are three (or four, if one includes the uncertain $z_{\rm abs} = z_{\rm em}$ system) other heavy element systems with ejection velocities lower than the complex. Two of these systems are clearly infalling: even if the emission redshift of the quasar is indeed underestimated by as much as $1000\,{\rm km\,s^{-1}}$, these systems still have $z_{\rm abs} > z_{\rm em}$; their infall velocities are $\sim$2000 and $\sim$3600 ${\rm km\,s^{-1}}$ with respect to adopted emission redshift of the quasar.

Arguments presented above suggest that all eight (or nine) systems are physically associated with the quasar. If this is the case, then all systems need to be considered as one large associated absorption complex, with dispersion of $\sim$4300 km s^{-1}.

It appears that the absorption originates in clouds in the immediate vicinity of the quasar. The ejection velocities and the velocity dispersion of the complex (both of the order of thousands of km s^{-1}) appear to be too high to interpret the absorbers as originating in the halos of galaxies in the quasar host cluster.

5. Summary

The combination of high redshift, brightness, richness of the heavy element absorption – and associated absorption in particular – in the spectrum of HS 1603+3820 is truly unique. Eleven confirmed C IV systems in the spectrum of HS 1603+3820 ranks among the richest known. The York catalog (York et al. 1991, Richards et al. 1999) contains only 10 other quasars with a greater number of absorbers. Of these quasars, only two (Q0958+551 and Q1225+317) are of comparable brightness, but both are at considerably lower redshifts.

HS 1603+3820 is even more spectacular when associated absorption spectrum is concerned. York's catalog contains only three quasars which have eight or more systems within 8000 km s^{-1} of the emission redshift (Q1037–270, Q1511+091 and Q1556+335). All three are much fainter; among QSOs brighter than 16 mag no object comes close to HS 1603+3820.

We can hypothesize that since none of the absorbers in the complex appears to be drastically different than the other ones they all may have been produced by a single event in the quasar's past, and that they may represent the velocity dispersion of shells of matter ejected during this event. On the other hand, the spectrum also contains an absorber which is much stronger than the systems from the complex, as well as two infalling absorbers, which indicate that the environment of HS 1603+3820 is more complicated.

We stress that this paper presents an analysis based on the observations in relatively low resolution. Our conclusions are by necessity mostly qualitative since the resolution is inadequate for performing detailed studies of chemical composition or velocity structure of the individual systems. High resolution studies of the complex will be of special interest, since it is heavily blended in our data and it is very likely that high resolution spectrum will reveal more absorption systems. HS 1603+3820 is very bright for a $z = 2.51$ quasar and is therefore an excellent candidate for such observations.

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