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ROTATION OF A HIGH-REDSHIFT GALAXY AND MOLECULAR HYDROGEN

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Abstract. The importance of the discovery of molecular hydrogen in high- redshift damped Lyα systems is discussed from the kinematical point of view. The application of a method due to Lanzetta and Bowen for inferring the global kinematics of an absorption system on the case of the damped absorption system towards PKS 0528−250 is presented. It is shown that plausible rotation velocity is obtained when kinematics of molecular hydrogen as the dynamically coldest components of any disk galaxy. The comparison with other recent results is given, together with the prospect of future such investigations.

1. INTRODUCTION

Since the last National Conference at which the question of presence of molecular hydrogen in high-redshift normal galaxies was reviewed (Ćirković 1996), there have been several related developments of relevance for the subject. Thus, in this review, it is my aim not only to update the investigations of the $z = 2.81$ damped Lyα (henceforth DLA) system toward bright QSO 0528–250, but also to discuss related findings pertaining to other protogalactic systems and our understanding of the early galactic evolution in general. In particular, it is interesting to try to increase the number of observed characteristics of DLA systems which are useful for comparison with the known populations of galactic objects, in order to test the standard view that these absorption systems are caused by young galactic disks (e.g. Wolfe *et al.* 1986).

Besides existence of stratified phases of ISM, the existence of rotation signatures in the DLA systems is another of the crucial tests of interpretation of these objects as disks of normal galaxies. If the former test is still not satisfactorily passed by these objects, the situation with the latter is somewhat better, although it is much more difficult to observationally implement. The problem, in brief, is to detect emission from the DLA system at satisfactorily strong level that the impact parameter of the QSO line-of-sight can be accurately determined, and to have associated metal absorption which will show the characteristic shifts around the redshift of the thickest hydrogen component.

2. CASE OF THE ABSORBER TOWARD QSO 0528–250

We hereby present further application of the method of detecting such signatures by examination of the profile of the metal absorption lines arising from the absorbing galaxy in relation to the systemic redshift of the absorber toward QSO 0528–250. The metal lines are obtained from the same high-resolution spectra of this DLA system which was used for the H_2 studies at high redshift (Ćirković 1996, and references therein). Systemic redshift is inferred from the recent detection of the absorber in emission by Møller and Warren (1993a, b). The kinematics of this particular absorber is especially interesting, since the best tracer of the densest component of the gaseous content of presumed galaxy—molecular hydrogen—is directly detected in the absorber. Therefore, a method of Lanzetta and Bowen (1992) can be applied with most certainty to this system. Contrary to a recent claim (Lu, Sargent and Barlow 1997), this method gives satisfactory result for the inferred circular velocity of this absorber, thus giving a better insight into properties of this early galactic population. Kinematics of other metal species detected is also presented and briefly discussed.

The definite solution of the problem of origin of the DLA systems has significant consequences for many astrophysical problems, particularly on clarification of the structure formation rate. If the stratification and delineation of specific subsystems in normal galaxies had been completed by the redshift of $z \sim 2.8$, this has profound consequences for the debate on the origin of Lyα absorption systems. Specifically, it gives support to the idea that a population (not necessarily of constant comoving density) of Lyα absorbers accompanies normal galaxies from the very earliest moments of their history, thus constituting a fraction of the Lyα forest even at high redshifts. This high-z absorber population would be, in this case, a progenitor of the low-z halo absorbers detected by Spinrad *et al.* (1993), Lanzetta *et al.* (1995), Chen *et al.* (1998) and others. It might have constituted a minority of the high-z Lyα clouds, but its very existence is significant.

3. INFERRED ROTATIONAL VELOCITY OF THE ABSORBER

The emission from the $z = 2.81$ DLA system toward 0528–250 was extensively studied by Møller and Warren (1993a, b; Warren and Møller 1996) in the course of their long-term project of identification of DLA systems in emission. Three Lyα sources were detected within half of an arcminute angular distance from the QSO line-of-sight. For $q_0 = 0.1$, the distances (in kiloparsecs) of sources named S1, S2 and S3 are, respectively, $9.2h^{-1}$, $66.4h^{-1}$ and $116.2h^{-1}$; in the $q_0 = 0.5$ case, impact parameters are even smaller roughly by a third. Møller and Warren conclude that the absorption arises in S1, mainly because of its close proximity to the QSO line of sight.

If we accept that S1 is the absorbing galaxy, its emission redshift ($z_{em} = 2.8136 \pm 0.0005$) is clearly slightly higher than the damped Lyα absorption redshift, if defined as the absorbing redshift of the molecular component ($z_{ab} = 2.8107798 \pm 0.0000019$). This means that the diffuse cloud causing the absorption (Ćirković *et al.* 1999) is moving toward us along the QSO sightline. That would, in turn, mean that the projected rotational velocity of the S1 galaxy is pointing toward us.

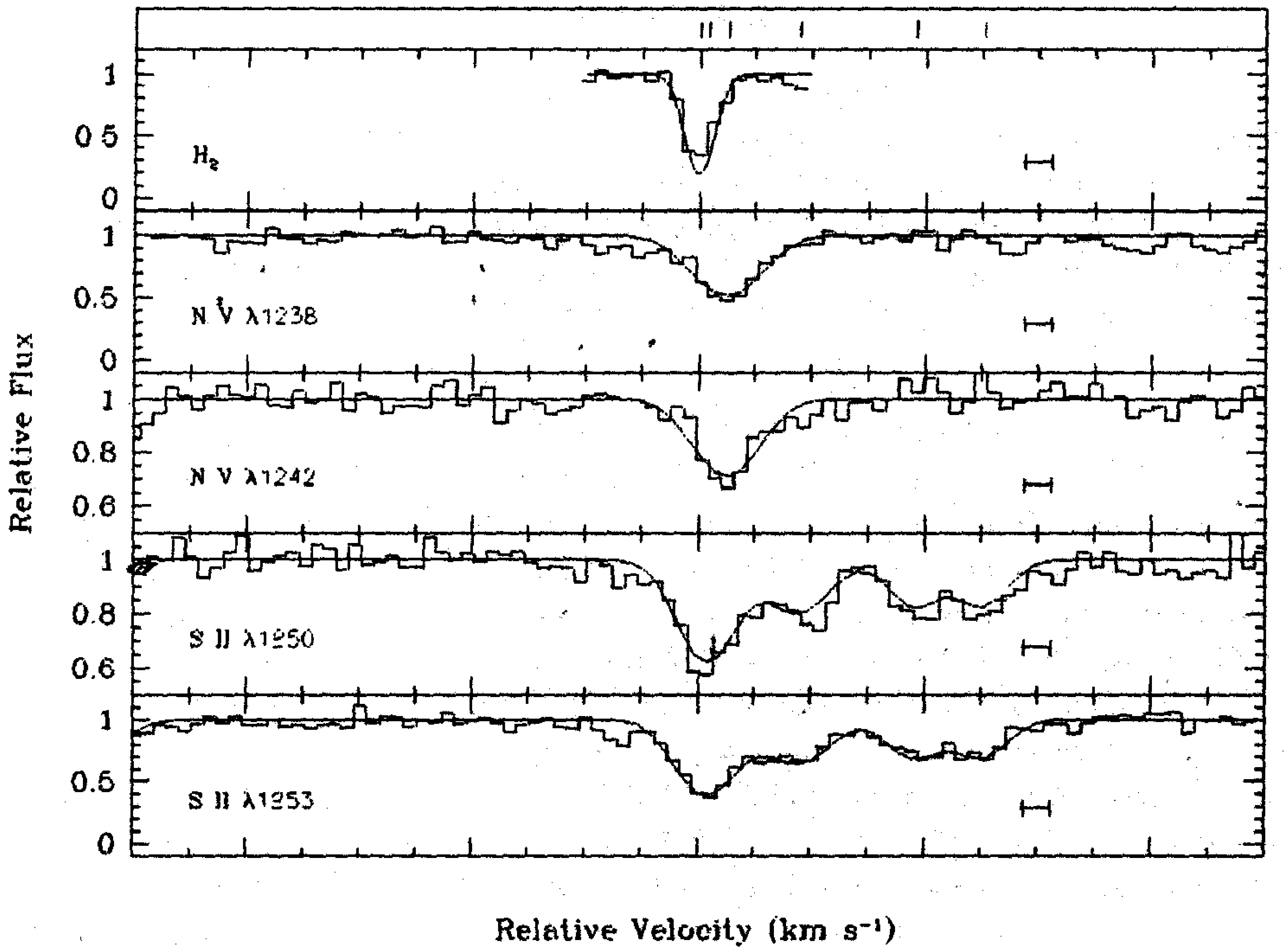

Fig. 1. Spectra of various absorption features in the $z = 2.8108$ DLA system toward 0528−250, normalized to unit continuum level.

In the case of 0528−250 absorber, the metal absorption line profiles are "edge-leading" asymmetric (Lanzetta and Bowen 1992), which is clearly visible in Figure 1. Now, the real advantage of this DLA system is the presence of definite tracer of the densest ISM component: molecular hydrogen (Foltz, Chaffee and Black 1988; Ćirković *et al.* 1999). This measurement anchors the absorption redshift. The velocity spread between this component and the components in which metal ions S II or N V are present, is discussed in the next Section. The difference between the Lyα emission of S1 and the molecular hydrogen component indicates projected velocity

$$v_{\rm rot} = 220 \pm 40 \ \ {\rm km\,s^{-1}}. \qquad (1)$$

This is not only consistent with the estimate of 190 ± 50 km s^{-1} (Warren and Møller 1996), but also with expected circular velocity $V_{\rm cir}$ of a typical $L \sim L_*$ galactic disk in the local universe (e.g. Binney and Tremaine 1987; Samurović 1998).

With $h = 0.75$ and $q_0 = 0.1$, the impact parameter of the galaxy S1 is 13.8 kpc. The corresponding dynamical mass is then $\geq 1.55 \times 10^{11} M_\odot$, similar to what has been measured for local galaxies and similar to the value for the DLA system investigated by Lu *et al.* (1997), although at smaller impact parameter than theirs, which may show that this DLA system is a more centrally concentrated galaxy (possibly reflecting difference in morphological type).

4. DISCUSSION

Kinematic study of the galaxy located at $z = 2.81$ along the line of sight to the QSO 0528−250, detected in both emission and absorption, indicates rotational velocity of $v_{\rm rot} \simeq 220$ km s^{-1}, characteristic for rotating disks of normal galaxies. The result in Eq. (1) agrees very well with the general statistical prediction of Prochaska and Wolfe (1997) which gives a most likely circular velocity of a generic DLA system at a redshift of about $z = 2.5$ as

$$v_{\rm rot}^{\rm DLA}(z \sim 2.5) \simeq 250\,{\rm km\,s^{-1}}. \qquad (2)$$

The merits of this method can not, of course, still be definitely tested, but it is significant that in two available cases (Lu *et al.* 1997 and this work) the results obtained are quite persuasive from the point of view of our knowledge on the dynamics of galactic disks and the general picture of the nature of DLA systems. Further investigation is necessary in order to increase the sample of DLA systems whose kinematics could be studied in this way (cf. Prochaska and Wolfe 1998).

In the recent publication, Lu *et al.* (1997) claim that, although the method of investigating metal absorption lines with relation to the systemic redshift works in the case of the DLA system toward 2233−1310, it does not show any kinematic evidence for galactic rotation. Here, we show that in view of new observations, such claim is incorrect. On the contrary, the DLA system toward 0528−250 is the second case of successful application of this method to the problem of rotation of early galactic disks.

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References

Binney, J. and Tremaine, S.: 1987, Galactic dynamics (Princeton: Princeton University Press).

Chen, H.-W., Lanzetta, K.M., Webb, J.K. and Barcons, X.: 1998, *Astrophys. J.*, **498**, 77.

Ćirković, M.M.: 1996, in Proceedings of the XI National Conference of Yugoslav Astronomers (Belgrade: *Publ. Astron. Obs. Belgrade*), 25.

Ćirković, M.M., Lanzetta, K.M., Baldwin, J., Williger, G. and Carswell, R.F.: 1999, *Astrophys. J.*, submitted.

Foltz, C.B., Chaffee, F.H. and Black, J.H.: 1988, *Astrophys. J.*, **324**, 267.

Lanzetta, K.M. and Bowen, D.: 1992, *Astrophys. J.*, **391**, 48.

Lanzetta, K.M., Bowen, D.V., Tytler, D., and Webb, J.K.: 1995, *Astrophys. J.*, **442**, 538.

Lu, L., Sargent, W.L.W. and Barlow, T.A.: 1997, *Astrophys. J.*, **484**, 131.

Møller, P. and Warren, S.J.: 1993a, *Astron. Astrophys.*, **270**, 43.

Møller, P. and Warren, S.J.: 1993b, in Observational Cosmology, ed. G. Chincarini, A. Iovino, T. Maccacaro, and D. Maccagni (San Francisco: ASP Conference Series), 598.

Prochaska, J.X. and Wolfe, A.M.: 1997, *Astrophys. J.*, **487**, 73.

Samurović, S.: 1998, M.Sc. thesis (University of Belgrade).

Spinrad, H., *et al.*: 1993, *Astron. J.*, **106**, 1.

Warren, S.J. and Møller, P.: 1996, *Astron. Astrophys.*, **311**, 25.

Wolfe, A.M., Turnshek, D.A., Smith, H.E., and Cohen, R.D.: 1986, *Astrophys. J. Suppl.*, **61**, 249.