Serb. Astron. J. № 161 (2000), 5 – 8

UDC 524.7-7
Original scientific paper

KINEMATICS OF A HIGH-REDSHIFT GALAXY: A CASE STUDY

M. M. Ćirković

Astronomical Observatory, Volgina 7, 11160 Belgrade-74, Yugoslavia
and
Dept. of Physics & Astronomy, SUNY at Stony Brook, Stony Brook, NY 11794-3800, USA

(Received: February 23, 2000)

SUMMARY: A kinematics of a $z = 2.81$ galaxy toward bright QSO 0528−250, as inferred from the absorption spectroscopy is discussed. There are sufficient arguments for a far-reaching conclusion that we are observing an older, unevolved version of the local Galactic interstellar medium.

1. INTRODUCTION ABSORBER TOWARD 0528−250

Damped Lyα (henceforth DLA) system located at $z = 2.81$ towards bright quasar PKS 0528−250 has been a target of extensive investigations for more than a decade (e.g. Foltz, Chaffee and Black 1988; Møller and Warren 1993a, b; Srianand and Petitjean 1998). It is an associated DLA system, with absorption redshift slightly larger than the QSO emission redshift, high neutral hydrogen column density ($\log N_{\rm HI} = 21.1 \pm 0.3$ cm^{-2}) and complicated ionization structure to be discussed further in this paper. This DLA system is interesting since it is one of only two DLA systems in which the molecular hydrogen absorption has been detected so far. This conclusion is suprising in light of the richness of the low-redshift and the local universe in H_2 (e.g. Imamura and Sofue 1997).

The elucidation of this question is important for ascertaining whether the standard picture of DLA systems as gas-rich disks of early spiral galaxies or protogalactic disks is consistent with all facets of our observational data (e.g. Wolfe *et al.* 1986; Lanzetta, Wolfe and Turnshek 1989).

Molecular content of this absorber has been already discussed (Ćirković 1996; Srianand and Petitjean 1998; Ćirković *et al.* 1999). The emphasis of the present discussion will, therefore, be put on the important role played by other chemical species detected in determining the physical properties of the absorbing object.

2. INFERRED ROTATIONAL VELOCITY OF THE ABSORBING GALAXY

Although it is not the main goal of this paper, the importance of kinematical information extracted from the absorption lines is emphasized by the inference of rotational velocity of the DLA disk (more details to be found in Lanzetta and Ćirković 1999). Assuming that the spectral component containing molecular hydrogen traces the coldest (in dynamical sense!) physical component of the gas in the DLA disk, we can use the observations of Lyα emission from this object to obtain its projected rotational velocity. This is another application of the method of Lu, Sargent and Barlow (1997) for determination of rotational velocities of high-redshift protogalactic (or young galactic) disks. It is obviously dependent

Table 1. Rotational populations and other parameter estimates.

Component	z	σ_z ($\times 10^{-6}$)	v^{a} (km s^{-1})	b (km s^{-1})	σ_b (km s^{-1})	Ion	$\log N$ (cm^{-2})	$\sigma_{\log N}$ (cm^{-2})
1	2.810804	1.9	0.0	2.78	0.09	H_2	18.66	0.24
2	2.810910	18.0	8.3	31.65	1.97	N^{+4}	...	...
						S^+	15.22	0.02
3	2.811122	17.3	25.0	36.65	2.00	N^{+4}	13.99	0.02
						S^+	...	...
4	2.811937	33.2	89.2	34.66	4.42	N^{+4}	...	...
						S^+	14.92	0.04
5	2.813244	53.3	191.9	27.00	5.96	N^{+4}	...	...
						S^+	14.77	0.07
6	2.814001	56.7	251.7	27.52	5.48	N^{+4}	...	...
						S^+	14.77	0.07

[a] Velocity relative to $z = 2.810804$.

on the detection of relevant absorbing object *in emission*, the condition which is realized only in a couple of targets (for a review, see Djorgovski 1997). In this particular case, we may take advantage of (i) good observations of Møller and Warren (1993a, b; Warren and Møller 1996) which established the presence of a Lyα emitting source (denoted by S1) at close proximity (only $9.2h^{-1}$ kpc, for $q_0 = 0.1$) to the QSO line-of-sight; and (ii) existence of H_2 as the best tracer of the component at rest with respect to the disk as a whole.

The difference between the Lyα emission of S1 and the molecular hydrogen component indicates projected velocity

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

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_{cir} of a typical $L \sim L_*$ galactic disk in the local universe (e.g. Binney and Tremaine 1987; Samurović 1998). Thus, this result is compatible with the conventional interpretation of the damped Lyα systems as high-redshift analogues of the present-day spiral galaxies (see also Prochaska and Wolfe 1997).

3. KINEMATICS OF THE METAL LINES

The observed profiles of identified absorption lines may give information about the geometrical configuration of the absorbers. Assuming the centroid of the single H_2 component to be at zero velocity (as in Fig. 1), the strongest velocity component detected in S II (component 2, using the notation in Ćirković *et al.* 1999, as shown in Table 1.) attains 8.3 ± 2.0 km s^{-1} and the only component detected in N V (component 3) is at 25.0 ± 2.0 km s^{-1}. The weaker velocity components detected in S II (components 4 through 6) occur with velocities ranging from 89 ± 4 to 252 ± 5 km s^{-1} with respect to the molecular velocity component (component 1). These velocity splittings are all similar to or smaller than the v_{rot} in Eq. (1), when deprojection is assumed.

Components 1, 2 and 3 may all come from the same giant cloud or complex. The velocity shifts of the ionized species relative to the molecular component may be due to "champagne flows" as the ionized gas is forced away from the molecular cloud due to its increased pressure; the velocities are similar to those of such flows in the blister H II regions in our Galaxy (Zuckerman 1973; Balick, Gammon and Hjellming 1974). The observed positive velocities of the components 2 and 3 would then place the ionizing object on the far side of the molecular cloud, consistent with the QSO being the ionizing source (but not proving it). The most highly ionized positively identified species (N V) has the largest velocity. A similar correlation of velocity with ionization potential is seen, for example, in the Orion Nebula (O'Dell and Wen 1992), but such gradients must be governed by the exact geometrical configuration of the ionizing source and the cloud, which is still difficult to model satisfactorily.

The higher-velocity components (4, 5 and 6) are presumably clouds at different locations within the same intervening galaxy. The distribution of projected velocities of the individual clouds can be used to infer the general nature of the velocity field of the ISM in the intervening galaxy (Lanzetta and Bowen 1992).

If components 1, 2 and 3 are treated as one cloud, then there are four clouds roughly equally spaced in velocity, which (weakly) suggests a radial velocity field. If, instead, the first three components are separate clouds, far apart physically, then the velocity distribution is more like that expected from

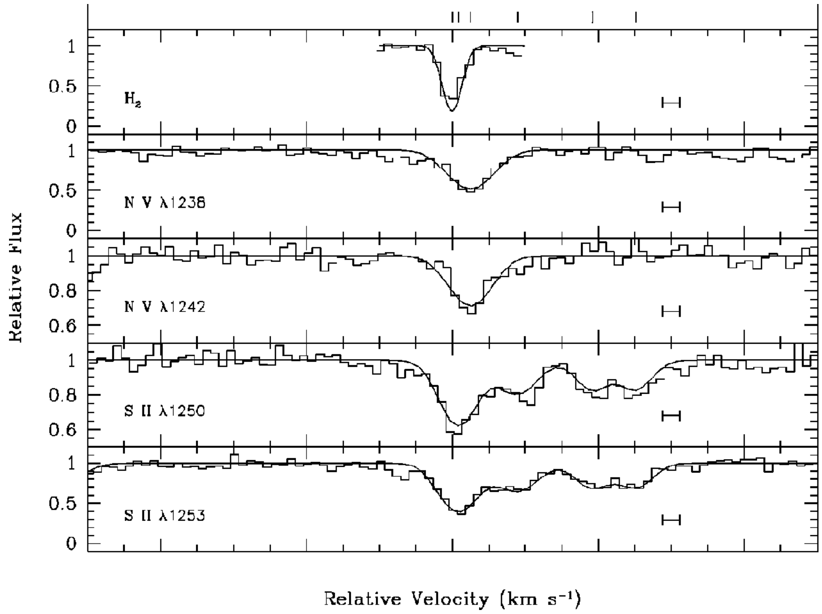

Fig. 1. *Spectra of various absorption features in the* $z = 2.8108$ *DLA system toward 0528−250, normalized to unit continuum level.*

a rotational velocity field in a highly inclined galaxy. This would be similar to the 21 cm absorption systems at $z = 0.5240$ toward 0235−164 and at $z = 0.3950$ toward 1229−021 studied by Lanzetta and Bowen (1992). Parenthetically, such a high inclined disk is more plausible in the light of absence of "silhouette" fluorescent emission, as reported by Möller and Warren (1993b).

4. CONCLUSION AND PROSPECTS

As already mentioned, recently another DLA absorber (the $z = 1.97$ DLA system toward 0013−004) with positively identified H_2 has been detected (Ge and Bechtold 1997). Future surveys will, hopefully, find more similar systems, where the molecular hydrogen could be used to fix the local reference frame for all kinematical measurements. It would be interesting to obtain the detailed kinematical analysis of the DLA system toward 0013−004 to check for consistency with the results whose part has been presented here. Several similar investigations are currently in progress (Lu, private communication). For the moment, we can say that available data present further confirmation of the standard picture of the DLA systems as protogalactic or early galactic disks. On the theoretical side, detailed modeling of the associated DLA systems will be necessary before we can issue any judgement on the question whether peculiar kinematics seen, for instance, in the DLA absorber toward 0528−250 are caused by the physical proximity of the QSO or by the intrinsic processes connected, perhaps, with early bursts of star formation.

Acknowledgements –It is a pleasure to express gratitude to Prof. Kenneth M. Lanzetta whose observational results were essential for this work. The author also wholeheartedly acknowledges Srdjan Samurović for a plethora of useful suggestions and Nataša Stanić for kindly providing some important references.

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КИНЕМАТИКА ГАЛАКСИЈЕ НА ВИСОКОМ ЦРВЕНОМ ПОМАКУ: ТИПИЧАН СЛУЧАЈ

М. М. Ћирковић

Астрономска опсерваторија, Волгина 7, 11160 Београд-74, Југославија
и
Dept. of Physics & Astronomy, SUNY at Stony Brook, Stony Brook, NY 11794-3800, USA

УДК 524.7-7
Оригинални научни рад

У овом раду разматра се кинематика галаксије лоциране на $z = 2.81$ у правцу сјајног квазара 0528−250, изведена из апсорпционе спектроскопије. Постоји довољно аргумента за далекосежни закључак да у овом случају посматрамо старију, слабије еволуирану верзију локалног Галактичког међузвезданог материјала.