SF2A 2010
S. Boissier, M. Heydari-Malayeri, R. Samadi and D. Valls-Gabaud (eds)

A SINFONI INTEGRAL FIELD SPECTROSCOPY SURVEY FOR GALAXY COUNTERPARTS TO DAMPED LYMAN-α SYSTEMS

C. Péroux[1], N. Bouché[2], V. P. Kulkarni[2], D. G. York[3] and G. Vladilo[4]

Abstract. Details of processes through which galaxies convert their gas into stars need to be studied in order to obtain a complete picture of galaxy formation. One way to tackle these phenomena is to relate the H I gas and the stars in galaxies. Here, we present dynamical properties of Damped and sub-Damped Lyman-α Systems identified in H-α emission with VLT/SINFONI at near infra-red wavelengths. While the DLA towards Q0302−223 is found to be dispersion-dominated, the sub-DLA towards Q1009−0026 shows clear signatures of rotation. We use a proxy to circular velocity to estimate the mass of the halo in which the sub-DLA resides and find $M_{halo}=10^{12.6}$ $M_\odot$. We also derive dynamical masses of these objects, and find $M_{dyn}=10^{10.3}$ $M_\odot$ and $10^{10.9}$ $M_\odot$. For one of the two systems (towards Q0302−223), we are able to derive a stellar mass of $M_*=10^{9.5}$ $M_\odot$ from Spectral Energy Distribution fit. The gas fraction in this object is $1/3^{rd}$, comparable to similar objects at these redshifts. Our work illustrates that detailed studies of quasar absorbers can offer entirely new insights into our knowledge of the interaction between stars and the interstellar gas in galaxies.

Keywords: galaxies: kinematics and dynamics, quasars: absorption lines, quasars: individual: Q0302−223, Q1009−0026

1 Introduction

Tremendous progress has been made over the last decade in establishing a broad cosmological framework in which galaxies and large-scale structure develop hierarchically over time, as a result of gravitational instabilities in the density field. The next challenge is to understand the physical processes of the formation of galaxies and structures and their interactions with the medium surrounding them. Of particular importance are the processes through which these galaxies accrete gas and subsequently form stars (Putman et al. 2009). The accretion of baryonic gas is complex. Recently, several teams (Birnboim & Dekel 2003, Keres et al. 2005) have realized that, in halos with mass $< 10^{11.5-12}$ $M_\odot$, baryonic accretion may not involve the traditional shock heating process of White & Rees (1978). Similarly, details of processes through which galaxies convert their gas into stars are still poorly understood. But the observational evidences for accretion are scarce. A related signature is that the total amount of neutral gas in the Universe, Ω_{HI}, is almost constant over most of the cosmic time (Prochaska, Herbert-Fort & Wolfe 2005, Péroux et al. 2005, Noterdaeme et al. 2009), unlike the history of the star formation rate which peaks around z=1 (Hopkins & Beacom 2006 and references therein). This shows the importance of ongoing global gas accretion and the conversion of atomic gas to molecular gas in the star formation process (Hopkins, Rao & Turnshek 2005, Bauermeister et al. 2010).

One way to tackle these problems is to relate the H I gas and the stars in galaxies. While radio observations now provide detailed constraints on the H I content of large sample of galaxies (Zwaan et al. 2005), they are still limited to redshift z∼0. Conversely, the study of quasar absorbers, the galaxies probed by the absorption they produce in a background quasar spectrum, is insensitive to the redshift of the object (Wolfe et al. 1995). Indeed, the H I content of the strongest of these quasar absorbers, the so-called Damped Lyman-α systems (DLAs), have been measured in samples of several hundreds of objects from the Sloan Digital Sky Survey (SDSS). However, studying the stellar content of these systems has proven very challenging until now.

---

[1] Laboratoire d'Astrophysique de Marseille, OAMP, Université Aix-Marseille & CNRS, 38 rue Frédéric Joliot Curie, 13388 Marseille cedex 13, France

[2] Department of Physics, University of California, Santa Barbara, CA 93106, USA.

[3] Dept. of Astronomy and Astrophysics, Univ. of Chicago, 5640 S. Ellis Ave, Chicago, IL 60637, USA.

[4] Osservatorio Astronomico di Trieste - INAF, Via Tiepolo 11 34143 Trieste, Italy.

Table 1. Summary of the properties of two absorber galaxies detected with SINFONI.

Quasar	$z_{\rm abs}$	$\log N(H\ i)$ [atoms/cm^2]	[Zn/H] [km/s]	F(H-α) [erg/s/cm^2]	Lum(H-α) [erg/s]	SFR ^{a} [M$_\odot$/yr]
Q0302−223	1.009	$20.36^{+0.11}_{-0.11}$	-0.51 ± 0.12	$7.7\pm2.7\times10^{-17}$	$4.1\pm1.4\times10^{41}$	1.8 ± 0.6
Q1009−0026	0.887	$19.48\ ^{+0.05}_{-0.06}$	$+0.25\pm0.06$	$17.1\pm6.0\times10^{-17}$	$6.6\pm2.3\times10^{41}$	2.9 ± 1.0

^{a}**:** The SFR estimates are not corrected for dust extinction.

2 SINFONI detections of H-α emission

The observations presented were carried out at the European Southern Observatory with the near-infrared field spectrometer SINFONI on Unit 4 of the Very Large Telescope. In Péroux et al. (2010a), we have reported two secure detections of the redshifted H-α emission of high H I column density quasar absorbers: a DLA with log $N(H\ i)$=20.36±0.11 at $z_{\rm abs}$=1.009 towards Q0302−223 and a sub-DLA with log $N(H\ i)$=$19.48^{+0.05}_{-0.06}$ at $z_{\rm abs}$=0.887 towards Q1009−0026 (see Table 1). We detect galaxies associated with the quasar absorbers at impact parameters of 25 and 39 kpc away from the quasar sightlines, respectively.

For field Q0302−223 where the quasar is bright enough, we have used the quasar itself as a natural guide star for adaptive optics in order to improve the spatial resolution (see Table 1). The two data sets have a resulting Point Spread Function (PSF) of 0.7" and 1.0". Both the objects in our study have well-determined absorption line properties determined from spectra of the background quasars. Thus, the metallicities are well-determined for both of our target absorbers. An estimate of the emission metallicities is made based on the N II/ H-α parameter (Pettini & Pagel 2004): the galaxy with the smaller absorption line metallicity also has the smaller emission-line metallicity. The absorber toward Q0302−223 is the more gas-rich absorber, while that toward Q1009−0026 is the more metal-rich absorber.

Using the H-α luminosity we then derived the star formation rate assuming the Kennicutt (1998) flux conversion corrected to a Chabrier (2003) initial mass function. We find low star formation rates (not corrected for dust extinction), of 1.8±0.6 and 2.9±1.0 M$_\odot$/yr (see Table 1). These values of star formation rates are among the lowest that have ever been possible to detect in quasar absorber searches with ground-based observations at z∼1 and 2.

3 Kinematics and mass estimates

In addition to the identification and redshift confirmation of the galaxy responsible for the quasar absorbers, the SINFONI data allow for a study of the dynamical properties of the galaxies (Péroux et al. 2010b). We find that galaxy associated with the DLA identified towards Q0302−223 shows little signs of rotation and significant amounts of dispersions. Moreover, the light profile and morphology provide further evidence that this galaxy is dispersion dominated, albeit it already has a disky morphology. This is indicative of a young object which is confirmed by results from a SED fit or could be due to the blending of the two components detected with HST interacting together. On the contrary, the galaxy associated with the sub-DLA towards Q1009−0026 has a morphology and kinematics consistent with that of a disk, with a normal dispersion profile peaking at the center and flattening out in the outer-parts. This object shows clear signatures of rotation with systematic velocity gradients which is not typical of local disk galaxies, but the systematic gradient still favors a spiral galaxy. It remains to be understood why such high $N(H\ i)$ column densities are found at large impact parameters (up to b=39kpc) from galaxies. The results of these are shown in Table 2.

Overall, we conclude that of the two absorbers studied, the less metal-rich absorber toward Q0302−223 arises in a gas-rich system with H-α luminosity consistent with that of a disk, while the more metal-rich absorber toward Q1009−0026 arises in a lower gas mass system but with higher total mass showing clear signs of rotation. With the limitations of small number statistics, our findings are consistent with the suggestion (Khare et al. 2007; Kulkarni et al. 2007) that the metal-rich sub-DLAs may arise in more massive galaxies compared to the DLAs, which are usually metal-poor by comparison. Our work illustrates that detailed studies of quasar absorbers can offer entirely new insights into our knowledge of the interaction between stars and the interstellar gas in galaxies.

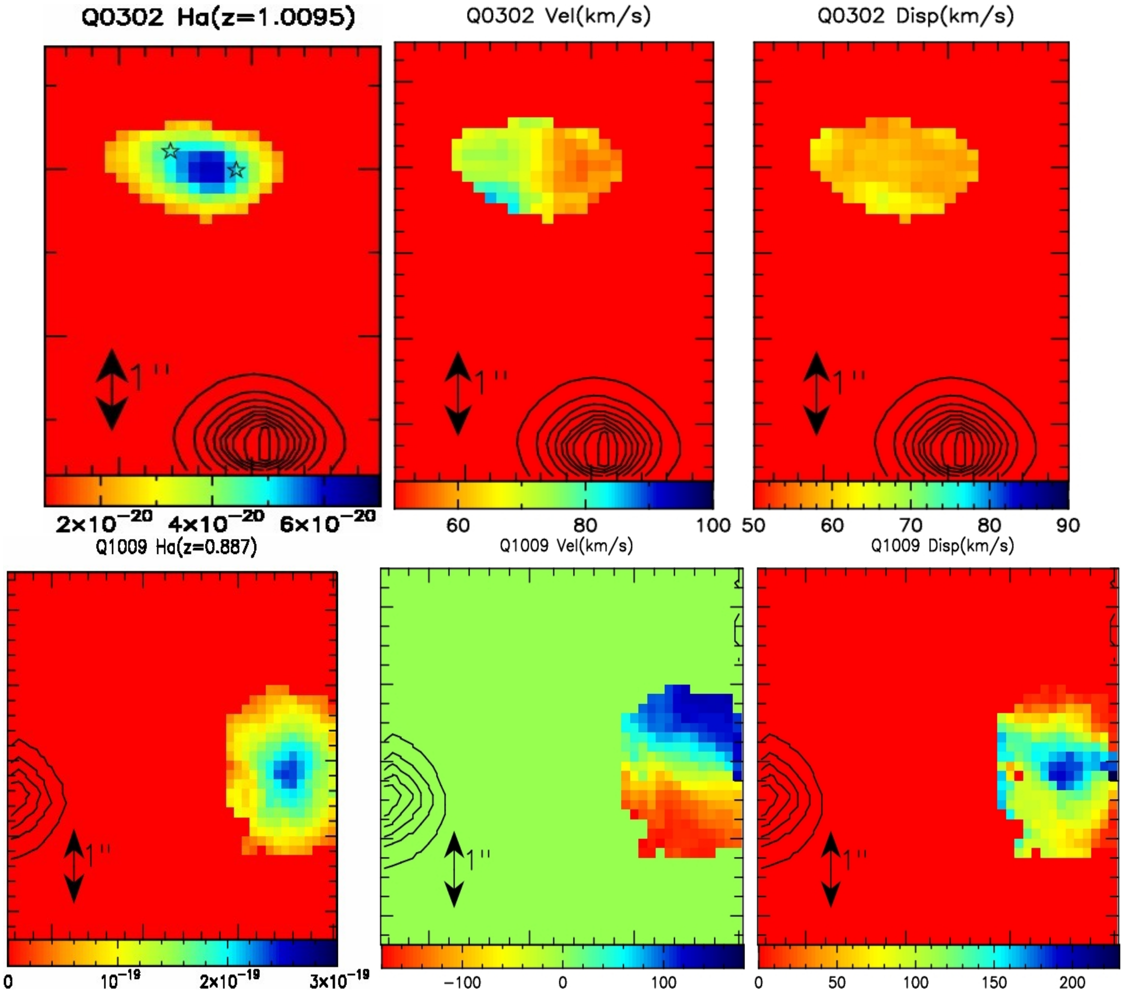

Fig. 1. H-α flux map, H-α velocity field and H-α velocity dispersion maps of the two quasar absorbers. The colour-scale indicates the flux in erg/s/cm^2 in the H-α flux map on the left and the velocities or velocity dispersions in km/s for the middle and right set of panels. North is up and east is to the left. The thin lined, black contours indicate the position of the quasar and the arrow represents 1 arcsec which corresponds to 8.1 kpc in the case of Q0302−223 and 7.8 kpc in the case of Q1009−0026. The system at the top (Q0302−223) is dispersion-dominated with H-α luminosity consistent with that of a disk. The system at the bottom (Q1009−0026) shows a blueshifted and redshifted component of the gas on its velocity map. This pattern is a clear characteristic of a rotating disk.

4 Conclusions

In conclusion, the observational set-up of SINFONI has demonstrated the power of integral field spectroscopy for deriving a number of emission properties for quasar absorbers, a type of high-redshift galaxies that have been difficult to identify in the past. Detailed dynamical properties of these galaxies with known gas characteristics could be derived. These new tools are now available to systematically study these objects. We find that the two absorbers studied here have kinematical properties similar to other galaxies studied in the same way at these and others redshifts (Epinat et al. 2009, Förster-Schreiber et al. 2006, Genzel et al. 2006, Förster-Schreiber et al. 2009).

We would like to thank the LOC for organising a very enjoyable meeting.

References

Bauermeister, A., Blitz, L. & Ma, C., 2010, ApJ, 717, 323

Table 2. Kinematic properties and mass estimates of the two $N(H\ i)$ absorbers detected.

Quasar	sin i	v/σ	$r_{1/2}$ ["]	Σ_{SFR} [$M_\odot$/yr/kpc^2]	M_{dyn} [$M_\odot$]	Σ_{gas} [$M_\odot$/pc^2]	M_{gas} [$M_\odot$]	M_{halo} [$M_\odot$]	M_* [$M_\odot$]
Q0302−223[a]	0.88	0.19	0.7	0.13	$10^{10.3}$	$10^{1.9}$	$10^{9.1}$	–	$10^{9.5}$
Q1009−0026	0.60	1.45	0.5	0.31	$10^{10.9}$	$10^{2.2}$	$10^{9.2}$	$10^{12.6}$	–

Note: The inclination is the main source of uncertainties and is estimated to be around 30%.

[a]**:** The higher-resolution HST/WFPC2 data from Le Brun et al. (1997) clearly shows that the object is subdivided into two sub-components, consistent with the elongated shape seen in the SINFONI data presented here. In this table, however, the object is treated as only one.

Birnboim, Y. & Dekel, A., 2003, MNRAS, 345, 349

Epinat, B., Contini, T., Le Fevre, O., Vergani, D., Garilli, B., Amram, P., Queyrel, J., Tasca, L. & Tresse, L., 2009, A&A, 504, 789

Förster Schreiber, N. M., Genzel, R., Lehnert, M. D., Bouché, N., Verma, A., Erb, D. K., Shapley, A. E., Steidel, C. C., Davies, R., Lutz, D., Nesvadba, N., Tacconi, L. J., Eisenhauer, F., Abuter, R., Gilbert, A., Gillessen, S. & Sternberg, A., 2006, ApJ, 645, 1062

Förster Schreiber, N. M., Genzel, R., Bouché, N., Cresci, G., Davies, R., Buschkamp, P., Shapiro, K., Tacconi, L. J., Hicks, E. K. S., Genel, S., Shapley, A. E., Erb, D. K., Steidel, C. C., Lutz, D., Eisenhauer, F., Gillessen, S., Sternberg, A., Renzini, A., Cimatti, A., Daddi, E., Kurk, J., Lilly, S., Kong, X., Lehnert, M. D., Nesvadba, N., Verma, A., McCracken, H., Arimoto, N., Mignoli, M., Onodera, M., 2009, ApJ, 706, 1375

Hopkins, A. M., Rao, S. M. & Turnshek, D. A., 2005, ApJ, 630, 108

Hopkins, A. M. & Beacom, J. F., 2006, ApJ, 651, 142

Keres, D., Katz, N., Weinberg, D. H. & Davé, R., 2005, MNRAS, 363, 2

Khare, P., Kulkarni, V. P., Péroux, C., York, D. G., Lauroesch, J. T. & Meiring, J. D., 2007, A&A, 464, 487

Kulkarni, V. P., Khare, P., Péroux, C., York, D. G., Lauroesch, J. T. & Meiring, J. D., 2007, ApJ, 661, 88

Le Brun, V., Bergeron, J., Boisse, P., Deharveng, J. M., 1997, A&A, 321, 733

Mo, H. J. & White, S. D. M., 2002, MNRAS, 336, 112

Noterdaeme, P., Petitjean, P., Ledoux, C., Srianand, R., 2009, A&A, 505, 1087

Péroux, C., McMahon, R. G., Storrie-Lombardi, L. J. & Irwin, M., 2003, MNRAS, 346, 1103

Péroux, C., Dessauges-Zavadsky, M., D'Odorico, S., Kim, T. S. & McMahon, R. G., 2005, MNRAS, 363, 479

Péroux, C., Bouché, N., Kulkarni, V. P., York, D. G. & Vladilo, G. 2010a, in press (astro-ph/1009.0025)

Péroux, C., Bouché, N., Kulkarni, V. P., York, D. G. & Vladilo, G. 2010b, in press (astro-ph/1009.0027)

Pettini, M., Ellison, S. L., Steidel, C. C., Shapley, A. E. & Bowen, D. V., 2000, ApJ, 532, 65

Pettini, M & Pagel, B. E. J., 2004, MNRAS, 348L, 59

Prochaska, J. X., Herbert-Fort, S. & Wolfe, A. M., 2005, ApJ, 635, 123

Putman, M.E., et al. 2009, "How do galaxies accrete gas and form stars?", The Astronomy & Astrophysics Decadal Survey 2010

White, S. D. M. & Rees, M. J., 1978, MNRAS, 183, 341

Wolfe, A. M., Lanzetta, K. M., Foltz, C. B. & Chaffee, F. H., 1995, ApJ, 454, 698

Zwaan, M. A., Meyer, M. J., Staveley-Smith, L.; & Webster, R. L., 2005, MNRAS, 359L, 30