On the Nature and Redshift Evolution of DLA Galaxies

Fritze - v. Alvensleben, U. (ufritze@uni-sw.gwdg.de), Lindner, U., Möller, C.S. and Fricke, K.J.
Universitäts – Sternwarte Göttingen

Abstract. We extend our spiral galaxy models that successfully describe nearby template spectra as well as the redshift evolution of CFRS and HDF spirals to include – in a chemically consistent way – the redshift evolution of a series of individual elements. Comparison with observed DLA abundances shows that DLAs might well be the progenitors of present-day spiral types Sa through Sd. Our models bridge the gap between high redshift DLA and nearby spiral HII region abundances. The slow redshift evolution of DLA abundances is a natural consequence of the long SF timescales for disks, the scatter at any redshift reflects the range of SF timescales from early to late spiral types. We claim that while at high redshift all spiral progenitor types seem to give rise to DLA absorption, towards low redshifts, the early type spirals seem to drop out of DLA samples due to low gas and/or high metal and dust content. Model implications for the spectrophotometric properties of the DLA galaxy population are discussed in the context of campaigns for the optical identifications of DLA galaxies both at low and high redshift.

1. Introduction

The basis for the work presented here is our set of chemically consistent spiral galaxy models with a range of Star Formation Histories (**SFHs**) specifying the spectral types *Sa*, *Sb*, *Sc*, *Sd*. Our models are very simple 1-zone models without any dynamics meant to describe global quantities of average galaxies of the respective types. Our approach is to use the simplest models possible with the smallest number of parameters in order to see how far we can get and what kind of sophistications are required by a comparison with observed galaxy properties.

Our unified spectrophotometric and chemical evolutionary synthesis models allow to have a large number of observational constraints – spectrophotometric properties including gaseous emission and stellar absorption features as well as ISM abundances – to restrict the small number of model parameters, basically the IMF and the SFH. While in the local Universe a 1–1 - correspondance between spectral types and morphological types is a long-standing matter of fact it is also clear that this correspondance has to break down at some yet unknown stage when going back towards the earliest phases of galaxy evolution and formation.

The choice of SFHs for the various spectral types is determined by a number of observational constraints. These include type-averaged luminosities, colours from UV through NIR for nearby galaxy samples, emission and absorption line properties, template spectra, and HII region abundances that our model galaxies have to match after a Hubble time as well as a comparison with observed galaxy luminosities and colours over a large redshift range (cf. Möller *et al.* 1999).

Here, we present the chemical evolution aspect of our spectroscopically successful spiral galaxy models and compare to abundances for a series of elements observed in Damped Lyα (**DLA**) Absorbers over the redshift range from z ~ 0.4 through z $\gtrsim 4.4$, which corresponds to lookback times of more than 90 % of the age of the Universe. Originally, DLA absorption was thought to arise in intervening (proto-)galactic disks along the lines of sight to distant QSOs (Wolfe 1988). This view is supported by arguments based on mass estimes from column densities and absorber sizes at z $\sim 2-3$ as well as by kinematic features consistent with rotation at velocities of order 200 km s^{-1} (Prochaska & Wolfe 1997a, b, 1998). More recently, on the basis of [α/Fe] and [N/O] abundance ratios and their large scatter, an origin of DLA absorption in dwarf or low surface brightness galaxies is also discussed (Matteucci *et al.* 1997, Vladilo 1998, Jimenez *et al.* 1999). Our aim is to see, if and in how far very simple spiral galaxy models are compatible with the observed DLA abundance evolution over the large redshift range accessible. In this context it does not matter if DLA galaxies at the highest redshifts are not yet fully assembled massive disks but rather consist of galactic building blocks as suggested by Haehnelt *et al.* (1998). Our SFHs in this case are meant to describe SF in all the fragments bound to end up in one disk by z = 0.

In a second step, we then present the spectrophotometric properties of those galaxy models that succesfully describe the DLA galaxy population and discuss them in the context of the large campaigns designed to optically identify DLA galaxies both at low and at high redshift.

2. A Chemically Consistent Chemical Evolution Model

As opposed to star clusters which basically form their stars "all at the same time", i.e. within $\sim 10^5$ yr, any stellar system with a SFH more extended than this is expected to feature finite distributions both in age and metallicity. Our spectrophotometric and chemical evolutionary synthesis models are **chemically consistent** in the sense that we account for the increasing initial metallicity of successive generations of stars. We keep track of the ISM abundance at birth of each star and use various sets of input physics for metallicities in the range $-2.5 \leq$ [Fe/H] $\leq +0.3$. In particular, we use stellar evolutionary tracks

and lifetimes from the Padova group (Bressan *et al.* 1993, Fagotto *et al.* 1994 a, b, c for $0.6 \leq m_* \leq 120\ M_\odot$, and from Chabrier & Baraffe 1997 for $m_* \leq 0.5\ M_\odot$, stellar yields and remnant masses from v. d. Hoek & Groenewegen (1997) for $m_* \leq 8\ M_\odot$ and from Woosley & Weaver (1995) for stars $12 \leq m_* \leq 40\ M_\odot$, and model atmosphere spectra and colour calibrations from Lejeune *et al.* (1998). SNIa contributions are included as described by Matteucci & Greggio (1986) and Matteucci & Tornambè (1987) with SNIa yields from Nomoto *et al.* (1997).
We use a Salpeter IMF and SFHs for the various spiral types as follows:

$$\begin{array}{ll} Sa\ ...\ Sc & \Psi(\mathrm{t}) \sim \frac{\mathrm{G}}{\mathrm{M}}(\mathrm{t}) \\ Sd & \Psi(\mathrm{t}) \sim \mathrm{const.} \end{array}$$

(G: gas mass, M: total mass). Characteristic timescales for SF t_* as defined by $\int_0^{t_*} \Psi \cdot dt = 0.63 \cdot G(t=0)$ are

$$\begin{array}{llrll} t_* & \sim & 2 & \mathrm{Gyr} & Sa \\ t_* & \sim & 3 & \mathrm{Gyr} & Sb \\ t_* & \sim & 10 & \mathrm{Gyr} & Sc \\ t_* & \sim & 16 & \mathrm{Gyr} & Sd \end{array}$$

Our models have a strong analytic power in the sense that they allow to trace back the luminosity contributions to any wavelength band as well as the enrichment contributions to any chemical element of different stellar masses, spectral types, luminosity classes, metallicity subpopulations, nucleosynthetic origins (PNe, SNI, SNII, single stars, binaries, ...) as a function of time or redshift.

While for the spectro-cosmological evolution cosmological and evolutionary corrections as well as the effect of attenuation have to be considered, the chemo-cosmological evolution simply results from a 1-1-transformation of galaxy age into redshift (we use a standard cosmology $(\mathrm{H_o},\ \Omega_\mathrm{o},\ \Lambda_\mathrm{o}) = (75,\ 1,\ 0)$ and assume galaxy formation at $z_\mathrm{form} = 5$).

The above SFHs were chosen as to give agreement after a Hubble time of evolution with average colours for the galaxy types *Sa*, *Sb*, *Sc*, *Sd* from the RC3 and template spectra from Kennicutt (1992). In most nearby spirals HII region abundances show negative gradients with galactocentric radius and even at a given radius within a galaxy, there may be considerable scatter among abundances of individual HII regions. Geometrical considerations by Phillipps & Edmunds (1996) and Edmunds & Phillipps (1997) show that for an arbitrary sightline featuring DLA absorption the most probable galactocentric distance to pass through an intervening galaxy disk is around 1 R_e. At the same time, 1 R_e seems to be a reasonable radius for HII region abundances

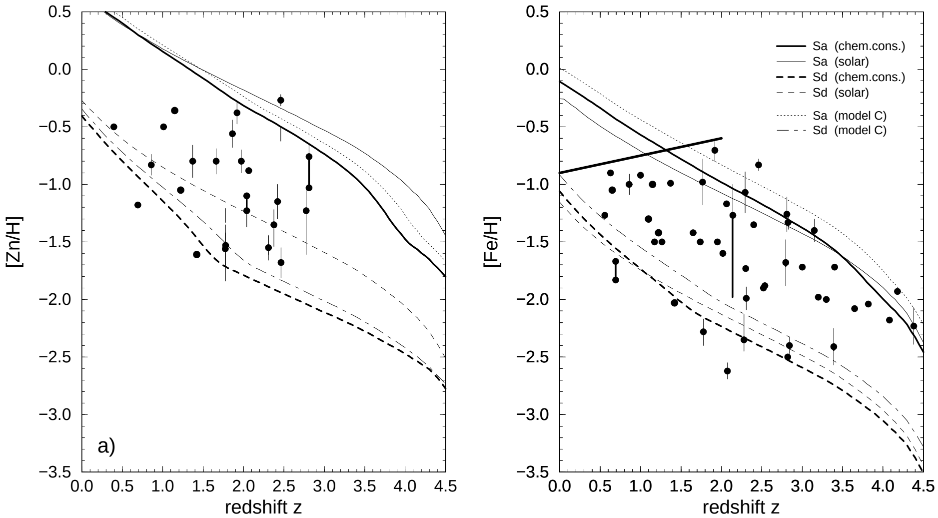

Figure 1. Redshift evolution of [Zn/H] (1a) and [Fe/H] (1b) for models Sa and Sd compared to observed DLA abundances.

to compare to our global 1-zone models. The agreement of average HII region abundances for various galaxy types at 1 R_e as measured by Zaritsky *et al.* (1994), Oey & Kennicutt (1993), van Zee *et al.* (1998), and Ferguson (1998) with model ISM abundances after a Hubble time confirms our choice of SFHs.

3. Abundance Evolution of Spiral Galaxy Models and DLA Observations

High resolution spectra are required to fully resolve the velocity structure and derive precise heavy element abundances in DLA absorption systems. In recent years, a large number of precise abundances have been determined for elements C, N, O, Al, Si, S, Cr, Mn, Fe, Ni, Zn, ... in a large number of DLAs over the redshift range z $\sim$ 0.4 through z $\gtrsim$ 4.4 (Boissé *et al.* 1998, Lu *et al.* 1993, 1996, Pettini *et al.* 1994, 1999, Prochaska & Wolfe 1997, de la Varga & Reimers 1999). For the comparison with the redshift evolution of our models we have carefully referred all published DLA abundances to one homogeneous set of oscillator strengths and solar reference values (see Lindner *et al.* 1999 for details).

Fig. 1 shows the redshift evolution of our "slowest evolution" *Sd* and our "fastest evolution" *Sa* models in comparison with the available [Zn/H] (1a) and [Fe/H] (1b) abundances in DLAs. *Sb* and *Sc* models are omitted to avoid confusion, their abundance evolution runs in between those of the *Sa* and *Sd* models. Lindner *et al.* (1999) present a more extensive comparison including all those 8 elements for which abundances are measured in a reasonable number of DLAs.

As compared to models using solar metallicity input physics only (thin lines), the chemically consistent models (heavy lines) show significant differences ranging up to 1.0 dex for some elements. Changes in the explosion energy (Woosley & Weaver's model C) are considerably less important. It should be noted that no scaling or additional parameters are introduced. Using SFHs, IMF, and yields, as desribed above, results in absolute model abundances.

The conclusions we draw from this comparison (including all elements) are the following:

- $Sa - Sd$ models bracket the redshift evolution of DLA abundances from z $\geq$ 4.4 to z $\sim$ 0.4,

- models bridge the gap from high-z DLAs to nearby spiral HII region abundances,

- the weak redshift evolution of DLA abundances is a natural result of the long SF timescales for disks galaxies,

- the range of SF timescales t_* for near-by spirals from *Sa* through *Sd* fully explains the abundance scatter among DLAs at fixed redshift.

This means that from the point of view of abundance evolution over more than 90% of the age of the Universe normal spiral galaxies (or their progenitors) are perfectly consistent with DLA observations. This does not exclude the possibility that some starbursting dwarfs or LSBs may also give rise to DLA absorption. Moreover, as indicated by the heavy line in Fig. 1b, the early type spirals that well seem to be present in high-z DLA samples seem to drop out of low-z DLA samples. At the same time as delimiting the region in abundance vs. redshift space where DLA absorbers seem to occur, the heavy line in Fig. 1b. corresponds to a gas-to-total mass ratio of 0.5 in our galaxy models. Indeed, low-z DLAs are observed to generally have low N(HI) (e.g. Lanzetta *et al.* 1997).

Our prediction from the comparison of models with data is that while at high redshift (z $\gtrsim$ 2) the DLA absorbing galaxy population may well comprise early as well as late type (proto-)spirals, the low redshift (z $\lesssim$ 1.5) DLA absorption systems seem to have their origin in late-type gas-rich and metal-poor spirals. A bias against high metallicity and/or dust content in low-z DLA absorbing galaxies has been suspected e.g. by Steidel *et al.* (1997). In our view, the drop of the global gas content that clearly goes together with increasing metallicity in nearby spirals may add yet another reason: at low gas content the probability is significantly reduced that an arbitrary sightline through the galaxy goes through a region with high enough HI column density for DLA absorption.

4. The Spectrophotometric Aspect of DLA Galaxies

If confirmed by a larger sample of low-z DLAs, this prediction has important implications for the possibility of optical identifications. Locally, early type spirals are brighter by ~ 1.5 mag in B on average than late-type spirals despite the fact that any spiral type shows a range in luminosity with considerable overlap between different types (e.g. Sandage *et al.* 1985).

We can now use the spectro-cosmological aspect of our evolutionary models as e.g. presented by Möller *et al.* (*this volume*) to predict the range of apparent magnitudes and colours expected for DLA absorbing galaxies at various redshifts. We find the intriguing result that in all three bands B, $\mathcal{R}$, and K the intrinsically brighter early-type spirals show almost the same apparent luminosities at z $\sim 2-3$ as the intrinsically fainter average late-type *Sd* galaxies at z ~ 0.5.

	Sa		**Sd**	
	z ~ 0.5	z $\sim 2-3$	z ~ 0.5	z $\sim 2-3$
B	22.5	24 – 25	25.5	29 – 30.5
$\mathcal{R}$	21	24	24.5	29
K	18.5	21.4 – 22	22	26 – 27

We thus would **not** expect low-z DLA galaxies to be more easily identified than at least the brighter ones among the high-z DLAs. On the basis of these luminosities we understand the non-detection of DLA galaxies at z $\sim$ 3 down to $\mathcal{R}$ $\sim$ 25.5 (Steidel *et al.* 1998) and the small number of DLA candidates (2/10) at $1.5 \leq z \leq 2.5$ to K $\sim$ 21 by Aragon - Salamanca *et al.* (1996). The galaxies identified by Steidel *et al.* (1994, 1995) as candidates for DLA absorbers at $z_{abs} = 0.6922,\ 0.3950,\ 0.7568,$ and 0.8596 indeed have luminosities $-19.5 \lesssim M_B \lesssim -19.0$ typical of late-type spirals. However, for their sample of 7 DLA identifications in the range $0.4 \lesssim z \lesssim 1$ Le Brun *et al.* (1997) find a variety of morphologies: spirals as well as compact and

LSB objects. At high redshift, Djorgovski *et al.* (1996) and Djorgovski (1998) report identifications of a bright disk galaxy ($M_B \sim -20.4$) with SFR $\gtrsim 8 M_\odot yr^{-1}$ in agreement with our models at $z \sim 3.15$, and of an $M_B \sim -19.5$ galaxy with low SFR at $z \sim 4.1$. The two early-type DLA galaxies ($S0$) put foreward by Lanzetta *et al.* (1997) at $z = 0.16377$ and by Miller *et al.* (1999) (NGC 4203 at $z = 0$) both show counterrotating gas disks. HI mapping shows NGC 4203 to be abnormally gas-rich (van Driel *et al.* 1988). These two cases raise the issue that recent accretion or merging may provide favourable conditions for DLA absorption.

5. Conclusions and Outlook

We use very simple spiral galaxy models with standard IMF and SFHs chosen as to agree with chemical and spectrophotmetric properties of nearby galaxies as well as with the observed redshift evolution of luminosities and colours. When combined with a chemically consistent description of their chemical evolution and a standard cosmology, we find good agreement with the observed redshift evolution of DLA abundances over more than 90 % of the Hubble time. We claim that at $z \gtrsim 1.5$ all spiral types can give rise to DLA absorption while towards lower redshifts only the gas-rich metal-poor late spiral types do so. The spectrophotometric properties given by our models for average spiral types are consistent with the few optical identifications of DLA galaxies both at low and high-z in large observing programs.

Clearly, these simple models are a first approach only, a more realistic treatment including infall and dynamical evolution has to follow.

Acknowledgements

UFvA and CSM gratefully acknowledge partial financial support to attend the Conference. We warmly thank the organisers for a particularly fruitful and inspiring Conference.

References

Aragon – Salamanca, A., Ellis, R. S., O'Brien, K. S., 1996, MN 281, 945
Boissé, P., Le Brun, V., Bergeron, J., Deharveng, J.-M., 1998, A&A 333, 841
Bressan, A., Fagotto, F., Bertelli, G., Chiosi, C., 1993, A&AS 100, 647
Le Brun, V., Bergeron, J., Boissé, P., Deharveng, J. M., 1997, A&A 321, 733
Chabrier, G., Baraffe, I., 1997, A&A 327, 1039

Djorgovski, S. G., 1997, in *Structure and Evolution of the IGM from QSO Absorption Lines* eds. P. Petitjean, S. Charlot, Editions Frontières, p. 303
Djorgovski, S. G., Pahre, M. A., Bechtold, J., Elston, R., 1996, Nat 382, 234
van Driel, W., van Woerden, H., Gallagher, J.S., Schwarz, U.J., 1988, A&A 191, 201
Edmunds, M. G., Phillipps, S., 1997, MN 292, 733
Fagotto, F., Bressan, A., Bertelli, G., Chiosi, C., 1994 A&AS 104, 365
Fagotto, F., Bressan, A., Bertelli, G., Chiosi, C., 1994 A&AS 105, 29 + 39
Ferguson, A. M. N., Gallagher, J. S., Wyse, R. F. G., 1998, AJ 116, 673
Haehnelt, M. G., Steinmetz, M., Rauch, M., 1998, ApJ 495, 647
v. d. Hoek, L. B., Groenewegen, M. A. T., 1997, A&AS 123, 305
Jimenez, R., Bowen, D. V., Matteucci, F., 1999, ApJ 514, L83
Kennicutt, R. C., 1992, ApJS 79, 255
Lanzetta, K. M., Wolfe, A. M., Altan, H., *et al.* , 1997, AJ, 114, 1337
Lejeune, T., Cuisinier, F., Buser, R., 1998, A&AS 125, 229
Lindner, U., Fritze – v. Alvensleben, U., Fricke, K. J., 1999, A&A 341, 709
Lu, L., Wolfe, A. M., Turnshek, D. A., Lanzetta, K. M., 1993, ApJS 84, 1
Lu, L., Sargent, W. L. W., Barlow, T. A., Churchill, C. W., Vogt, S. S., 1996, ApJS 107, 475
Matteuci, F., Greggio, L., 1986, A&A 154, 279
Matteuci, F., Tornambè, A., 1987, A&A 185, 51
Matteucci, F., Molaro, P., Vladilo, G., 1997, A&A 321, 45
Miller, E. D., Knezek, P.M., Bregman, J. N., 1999, ApJ 510, L95
Möller, C. S., Fritze – v. Alvensleben, U., Fricke, K. J., 1997, STScI Symp. Ser. 11
Möller, C. S., Fritze – v. Alvensleben, U., Fricke, K. J., 1999, in *The Birth of Galaxies*, *in press*
Nomoto, K., Iwamoto, K., Nakasto, N., *et al.* , 1997, Nucl. Phys. A, A621
Oey, M. S., Kennicutt, R. C., 1993, ApJ 411, 137
Pettini, M., Smith, L. J., Hunstead, R. W., King, D. L., 1994, ApJ 426, 79
Pettini, M., Ellison, S. L., Steidel, C. C., Bowen, D. V., 1999, ApJ, 510, 576
Phillipps, S., Edmunds, M. G., 1996, MN 281, 362
Prochaska, J. X., Wolfe, A. M., 1997a, ApJ 474, 140
Prochaska, J. X., Wolfe, A. M., 1997b, ApJ 487, 73
Prochaska, J. X., Wolfe, A. M., 1998, ApJ 507, 113
Sandage, A., Binggeli, B., Tammann, G. A., 1985, AJ 90, 395 + 1759
Steidel, C. C., Pettini, M., Dickinson, M., Persson, S. E., 1994, AJ 108, 2046
Steidel, C. C., Bowen, D. V., Blades, J. C., Dickinson, M., 1995, ApJ 440, L45
Steidel, C. C., Dickinson, M., Meyer, D. M., Adelberger, K. L., Sembach, K. R., 1997, ApJ 480, 568
Steidel, C. C., Adelberger, K. L., Dickinson, M., Giavalisco, M., Pettini, M., Kellogg, M., 1998, ApJ 492, 428
de la Varga, A., Reimers, D., 1999, in *Chemical Evolution from Zero to High Redshift*, *in press*
Vladilo, G., 1998, ApJ 493, 583
Wolfe, A. M., 1988, in *QSO Absorption Lines: Probing the Universe*, eds. C. Blades, D. Turnshek, C. Norman, Cambridge University Press, p. 297
Woosley, S. E., Weaver, T. A., 1995, ApJS 101, 181
Zaritsky, D., Kennicutt, R. C., Huchra, J. P., 1994, ApJ 420, 87
van Zee, L., Salzer, J. J., Haynes, M. P., O'Donoghue, A. A., Balonek, T. J., 1998, AJ 116, 2805