Predicting Spectral Properties of DLA Galaxies

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Abstract. Comparison of our chemically consistent models for spiral galaxies with observed DLA abundances shows that at high redshift DLA galaxies may well be the progenitors of normal spiral disks of all types from Sa through Sd. Towards lower redshifts \( z \leq 1.5 \) however, early type spirals drop out of DLA samples due to low gas or and high dust content. We use the spectrophotometric aspects of our unified spectral, chemical, and cosmological evolution models to predict expected luminosities in different bands for DLA galaxies at various redshifts and compare to the few optical identifications available.

1 Introduction

Within the framework of our unified spectrophotometric, chemical and cosmological modelling of galaxies of various types we use the Star Formation Histories (SFHs) that gave satisfactory agreement of global galaxy colors, emission and absorption features with observations of galaxies nearby and up to high redshifts to study the chemical abundance evolution they imply. These models define various galaxy types in terms of their respective SFHs immediately give – without any additional parameters – good agreement, after a Hubble time, with HII region abundances in nearby galaxies. We then investigate the redshift evolution of a number of individual element abundances in the ISM of our spiral galaxy models and compare them to observed DLA abundances. From this comparison we derive our predictions as to the galaxy types that give rise to DLA absorption as well as for their spectrophotometric properties, both at low and high redshift.

2 Chemically Consistent Chemical, Spectral and Cosmological Galaxy Evolution Models

Our unified chemical and spectrophotometric evolutionary synthesis models describe the spectrophotometric evolution in terms of spectra (UV – NIR), luminosities, and colours and – at the same time – the chemical evolution of a number of ISM element abundances, including SNIa contributions, as a function of time. When combined with a cosmological model specified by the parameters \( H_0, \Omega_0, \Lambda_0 \) and a redshift of galaxy formation \( z_{\text{form}} \), we obtain all quantities as a function of redshift, in case of spectrophotometric properties including evolutionary and cosmological corrections as well as the effect of attenuation by intergalactic hydrogen randomly distributed along the lines of sight to very distant objects (Madau 1995).
Our models are chemically consistent in the sense that we keep track of ISM abundances at birth of each star and account for the increasing initial metallicity of successive generations of stars by using different sets of input physics, i.e. stellar evolutionary tracks, stellar spectra, colour calibrations, yields, lifetimes, and remnant masses, for a range of metallicities $-2.3 \leq [\text{Fe/H}] \leq +0.3$. The models have a strong analytic power and directly show the luminosity contributions to any wavelength band and the enrichment contributions to any chemical element due to different stellar masses, spectral types, luminosity classes, metallicity subpopulations, and nucleosynthetic origins (PNe, SNI, SNII, single stars, binaries, ...), and all this as a function of time or redshift. On the other hand, they are simple 1-zone closed box models without any spatial resolution or dynamics included. While the ISM is assumed to be instantaneously and ideally mixed at any time, the finite lifetime of the stars before they give back enriched material to the ISM is fully taken into account.

We use stellar evolutionary tracks from the Padova Group (Bressan et al. 1993, Fagotto et al. 1994a, b, c) for stars in the mass range $0.6 \leq m_\ast \leq 120 \, M_\odot$, and from Chabrier & Baraffe (1997) for $m_\ast \leq 0.5 \, M_\odot$, stellar model atmosphere spectra from Lejeune et al. (1998), and stellar yields from v. d. Hoek & Groenewegen (1997) for $m_\ast \leq 8 \, M_\odot$, from Woosley & Weaver (1995) for stars with $12 \leq m_\ast \leq 40 \, M_\odot$, and from Nomoto et al. (1997) for SNIa (cf. Lindner et al. 1999). We caution that the metallicity dependence of these yields, of the explosion energies, lifetimes, mass loss rates, etc. are not fully understood at present.

Parameters in our models are the IMF and the SFH. We use a Scalo IMF and SFHs appropriate for the different galaxy types. For spirals Sa, ..., Sc the SFR is a linear function of the gas-to-total-mass ratio $\Psi(t) \sim \frac{\dot{M}}{M}(t)$, while for our Sd model we adopt a constant SFR. Constants are chosen as to result in characteristic timescales for SF $t_\ast$ (with $t_\ast$ defined via $\int_0^{t_\ast} \Psi \cdot dt = 0.63 \cdot G(t = 0)$) of 2, 3, 10, and 16 Gyr for galaxy types Sa, Sb, Sc, Sd, respectively.

These SFHs provide agreement with nearby galaxy samples and templates of the respective spiral types in terms of colours (RC3), template spectra (Kennicutt 1992), and characteristic HII region abundances, i.e. HII region abundances as observed at $\sim 1 \, R_e$ (Zaritsky et al. 1994, Oey & Kennicutt 1993, Ferguson et al. 1998). Those are the ones to be compared to our 1-zone models as well as to DLA abundances (Phillipps & Edmunds 1996).

3 Comparison with observed DLA Abundances

High resolution spectroscopy has provided precise element abundances for C, N, O, Al, Si, S, Cr, Mn, Fe, Ni, Zn, ... for a large number of DLAs over the redshift range from $z \sim 0.4$ through $z \gtrsim 4.4$ (see e.g. Pettini this conf., Boissé et al. 1998, Lu et al. 1993, 1996, Pettini et al. 1994, 1998, Prochaska & Wolfe 1997, de la Varga & Reimers this conf.). We have carefully referred all abundances to one homogeneous set of oscillator strengths and solar reference values.

A comparison of the redshift evolution of our models with observed DLA abundances is presented in Fig. 1a. for the example of $[\text{Zn/H}]$ which is not
affected by depletion onto dust grains, and in Fig. 1b, for [Fe/H] which, under
local conditions, is significantly depleted. For an extensive comparison including
many elements as well as for a detailed description of our models see Lindner et al. (1999).

The comparison for all elements available yields the following results: Sa – Sd
models bracket redshift evolution of DLA abundances from \( z \gtrsim 4.4 \) 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 consequence of the long SF timescales for spiral galaxies,
and the range of SF timescales for near-by spirals from Sa through Sd
fully explains the abundance scatter among DLAs at fixed redshift.

We thus conclude that from the point of view of their chemical abundance
history DLA galaxies might well be the progenitors of normal spirals,
although we cannot some starbursting dwarfs or giant LSB galaxies among the
DLA galaxy population (see also Lindner et al. this conf., Lindner et al. 1999).

Beyond the overall agreement between abundances given by our spiral galaxy
models and by high resolution DLA data, inspection of Figs 1a, b reveals that
while at high redshift, DLA data fill all the range between our rapid evolution
Sa and slow evolution Sd models, this seems no longer to be the case at low
redshift. Below \( z \lesssim 1 \) data points tend to fall close to our late type models. This
is elucidated by the straight line in Fig. 1b which – at the same time – marks
the 50% global gas-to-total mass ratio in our models. The number of DLAs at

Fig. 1. Redshift evolution of [Zn/H] (1a) and of [Fe/H] (1b). Heavy lines are for our
chemically consistent models, this lines are for models using solar metallicity input
physics only. For clarity, only our Sa and Sd models are depicted, the evolution of Sb
and Sc models falls between the latter.
z ≲ 1, however, is still quite small. If confirmed by further DLA detections at low redshift, this would indicate that the composition of the DLA galaxy population changes with redshift. While at high redshift the progenitors of all spiral types from Sa through Sd give rise to DLA absorption, the early type spirals drop out of the DLA sample towards lower redshift due to too scarce gas content or/and too high dust content. Indeed, low-z DLAs are observed to have low hydrogen column densities as compared to their high-z counterparts (Meyer et al. 1995). This has important consequences for the prospects of optically identifying the galaxies responsible for DLA absorption.

4 Predictions for Spectral Properties of DLA Galaxies

Average luminosities of early spiral types Sa ($\langle M_B \rangle = -19.7 \pm 1.2$) are brighter than those of late types Sd ($\langle M_B \rangle = -17.7 \pm 1.5$), although their luminosity ranges slightly overlap (e.g. Sandage & Tammann 1985). On average, spirals are significantly fainter than $L^*$. We can now use the spectrophotometric results from our models to predict average apparent luminosities in various passbands for our model galaxies as a function of redshift, including evolutionary and cosmological corrections and attenuation (cf. Möller, F.-v.A., Fricke 1998) and find the intriguing result that early type spirals in the redshift range $z \sim 2 - 3$ have about the same apparent magnitudes in all 3 bands $B$, $R$, $K$ as the intrinsically fainter late type spirals Sd at the lowest redshifts $z \sim 0.5$ where DLA absorption is seen.

![Fig. 2. Redshift evolution of apparent magnitudes R(2a) and K (2b) for average Sa and Sd galaxies. ◊ galaxies in cluster with DLA absorber (Steidel et al. 1998), △ DLA candidate (Steidel et al. 1995), ○ DLA candidates (Aragon – Salamanca et al. 1996).]
In view of these luminosities expected for typical spirals of various types we understand why deep surveys could not detect DLA galaxies at $z \sim 2 - 3$ down to $R \sim 25.5$ (Steidel et al. 1998), and only detected 2 candidates for 10 DLA systems in the range $1.5 \lesssim z \lesssim 2.5$ down to $K \sim 21.5$ (Aragon - Salamanca et al. 1996). An average luminosity $S_a$, if responsible for a DLA at $z \lesssim 1.5$, would easily have been detected in these surveys. DLA candidates identified by Steidel et al. (1994, 1995) indeed have $M_B \lesssim -19$ mag typical of (late-type) spirals.

**To conclude:** The change in the DLA galaxy population from progenitors of all spiral types at high-z to only late-type spirals (and possibly even LSB galaxies) towards low-z, that we derive from the comparison of observed DLA abundances with our chemically consistent spiral galaxy models leads to the prediction that, **on average, the low-z DLA galaxies should be about as faint in B, $R$, and $K$ as the brighter part of the high-z DLA population.**

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