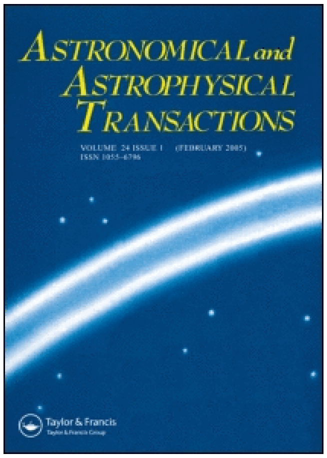


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# DUST FORMATION IN DAMPED LY$\alpha$ SYSTEMS

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A one-zone spectrophotometric and chemical evolution scenario of spiral galaxies incorporating dust formation is briefly described, and a self-consistent closed box chemical model of the gaseous disks (corrected on dust depletion) is presented. Comparison of the calculated abundances with the observed in damped Ly$\alpha$ systems shows first, that at least a fraction of DLA absorptions can be attributed to spiral galaxies, and that the dust is a nessasary physical ingredient of galaxy evolution model strongly affecting the observed abundance pattern and photometric properties.

*Keywords*: Galaxies: chemo-spectrophotometric evolution of spiral galaxies, dust evolution – Quasars: damped Ly$\alpha$ systems

## 1 INTRODUCTION

Damped Ly$\alpha$ (DLA) systems is a class of QSO absorbers with a hydrogen column density N(HI)$> 2 \times 10^{20}\,\mathrm{cm}^{-2}$. They are responsible for the strongest absorptions in the spectra of distant quasars, and are traditionally assumed to be the progenitors of present day galaxies observed at early stages of their evolution.

There is no general agreement on the nature of the hosting galaxies (protogalaxies). It is difficult to detect DLA galaxies in emission because of their apparent faintness and proximity to the quasar image. To date, it has been possible to identify morphologies of only 23 low-redshift galaxies, which presumably give rise to damped Ly$\alpha$ absorptions. Among them compact dwarf galaxies, spirals, S0, and low surface brightness galaxies are present, with spirals to form a third of the sample. Intuitively it seems plausible that galaxies of different types can be discriminated by chemical composition of their gas content manifested in absorptions. Chemical evolution scenarios developed in several groups have demonstrated that, within the uncertainties of both observational data and evolutionary models, DLA systems may be practically equally presented by absorptions in spiral (Ferrini *et al.*, 1997; Lindner *et al.*, 1998), low surface brightness (Jimenez *et al.*, 1999), and dwarf irregular galaxies (Matteucci *et al.*, 1997; Pilyugin, 1999). In these scenarios it was implicitly assumed that all trace elements contribute to the absorptions, without separation those which can condense in the solid phase (dust grains). It is known, however, that the presence of dust changes dramatically relative abundances in gas phase due to depletion, and thus can strongly influence the overall pattern of chemical enrichment of galaxies. Using [Zn/H] ratio as a probe of

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metallicity, and [Cr/Zn] and [Fe/Zn] ratios as a measure of dust content, Pettini *et al.* (1997) have shown that the pattern of chemical composition in DLA systems indicates that they are already polluted with dust. On theoretical side this issue has been addressed only recently in framework of a chemical evolution model with a simplified description of element depletion (Hou *et al.*, 2001). In general, the amount of dust and their characteristics vary with the galactic type – well known examples are the Milky Way-type and SMC/LMC-type dust – and can, in principle, differ among galaxies of the same morphological type. This suggests, that formation of dust particles and the respected depleted element abundance patterns have to be calculated self-consistently, *i.e.* the rates of dust production and destruction must be treated consistently with the overall star formation and chemical history of a galaxy. For this purpose we attempted such a self-consistent description, which matches several observables of galactic evolution, such as their colors, SNe Ia/II rates, global metallicities and differential abundances, and gas content – and thus restricts the range of free parameters of the model (Kasimova and Shchekinov, 2002). In this contribution we present an example of one-zone spectrophotometric and chemical evolution of spiral galaxies calculated in framework of our model, and compare calculated abundances corrected on dust depletion with those observed in DLA systems at redshifts $z = 0$–5.

In next section we describe briefly our model, and show an illustrative example in Section 3; summary is given in Section 4.

## 2 MODEL

Our model is based on the evolutionary synthesis code PEGASE.2 (Fioc, Rocca-Volmerange 1997), what we have modified to incorporate all necessary ingredients for calculation of chemical evolution and dust production; no Instantaneous Recycling Approximation is used not only in stellar evolution, but in calculation of dust formation as well.

We use a piecewise IMF in the form given by Kroupa (2001) with the lower and upper limits 0.1 and 120 $M_\odot$, respectively, and a Schmidt star formation law $\Psi \propto M_g^q$. The star formation history and IMF have been chosen to reach an agreement between the modeled and observed integrated colors (Buta *et al.*, 1994; 1995), SNe Ia/II rates (Cappellaro *et al.*, 1999), and metal abundances in HII regions of spiral galaxies.

In our model the evolution of stars and gas is described in a usual way, but the fraction of an element which is locked up in solid form depends on the details of dust evolution. Several processes are taken into account: dust condensation in the ejecta of SNe Ia/II, dust grain growth by accretion onto preexisting grains in dense molecular clouds, dust destruction by SNe shock waves, and ejection of dust by interstellar radiation pressure and galactic wind. In general, galactic dust content is described by the following equation (Dwek 1998):

$$
\begin{aligned}
\frac{\mathrm{d}}{\mathrm{d}t}\sigma_{\mathrm{dust}}(X,t) = {} & -Z_{\mathrm{dust}}(X,t)\Psi(t) + \int_{M_l}^{M_{b1}} \Psi(t-\tau(M))\varphi(M)\frac{M_{\mathrm{ej}}(X,M)}{M_{\mathrm{av}}}\mathrm{d}M \\
& + A\frac{\delta^I(X)M_{\mathrm{ej}}(X)}{M_{\mathrm{av}}}\int_{M_{b1}}^{M_{b2}}\varphi(M_b)\mathrm{d}M_b\int_{\mu_m}^{0.5} f(\mu)\Psi(t-\tau(\mu M_b))\mathrm{d}\mu \\
& + (1-A)\int_{M_{b1}}^{M_{b2}}\Psi(t-\tau(M))\varphi(M)\frac{M_{\mathrm{ej}}(X,M,Z)}{M_{\mathrm{av}}}\mathrm{d}M \\
& + \int_{M_{b2}}^{M_u}\Psi(t-\tau(M))\varphi(M)\frac{\delta^{II}(x)M_{\mathrm{ej}}(X,M,Z)}{M_{\mathrm{av}}}\mathrm{d}M
\end{aligned}
$$

$$- \frac{\sigma_{\rm dust}(X,t)}{\tau_{SNR}(X,t)} + \frac{\sigma_{\rm dust}(X,t)(1-\sigma_{\rm dust}(X,t)/\sigma_{\rm tot}(X,t))}{\tau_{\rm accr}(X,t)} - \left(\frac{\rm d}{{\rm d}t}\sigma_{\rm tot}(X,t)\right)_{\rm outflow}, \qquad (1)$$

where $\sigma_{\rm tot}(X,t)$ is the total (gas and dust) mass of a stable element $X$, $\sigma_{\rm dust}(X,t)$ is the same for the dust phase of the element $X$ only; $\phi(t)$, $\Psi(M)$ are the star formation rate and initial mass function; the parameters $\delta^{I}(X)$, $\delta^{II}(X)$ represent the condensation efficiency of the element $X$ in type SNe Ia and type SNe II respectively, and the, parameter $A$ determines the fraction of binary systems giving rise to SNe Ia explosions. The last three terms in Eq. (1) describe the rate at which the element $X$ in condensed phase is transformed into gas phase when dust is destroyed by SNs, the accretion rate of the element $X$ onto dust grains, and the rate at which the element $X$ in condensed phase is swept out of a galaxy by galactic wind and interstellar radiation pressure. In our model Eq. (1) is solved along with the equations describing spectrophotometric and chemical behavior of the system with metallicity dependent yields.

## 3 RESULTS

Here we briefly present our best fit model for spiral galaxies within the framework of a one-zone closed scenario, which reproduces successfully UBVRI colors (with a self-consistent correction for extinction) and oxygen abundance in HII zones of nowadays galaxies (the latter is shown in Fig. 1), the fraction of binary stars giving rise to SNe Ia events is in the interval [0.05–0.1]. In this model we accepted $q = 1$, and a piecewise Kroupa IMF with the exponents $n = 1.8$ at $m \leq 0.5$, $n = 2.7$ at $m \leq 1$, $n = 2.35$ at $m \leq 3$, and $n = 2.6$ at $m > 3$.

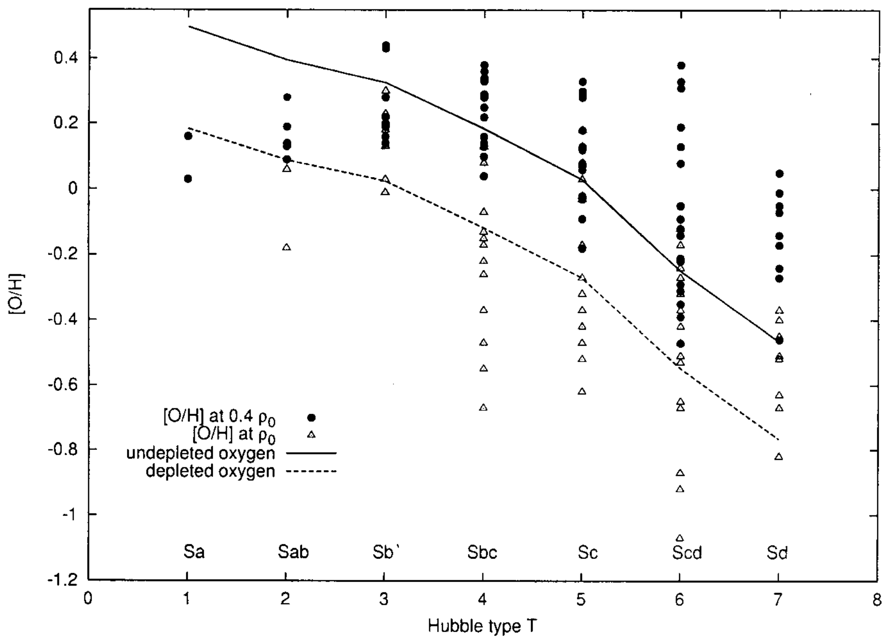


FIGURE 1 A comparison of calculated oxygen abundance (lines) with oxygen abundance observed in HII regions of external spiral galaxies (circles and triangles).

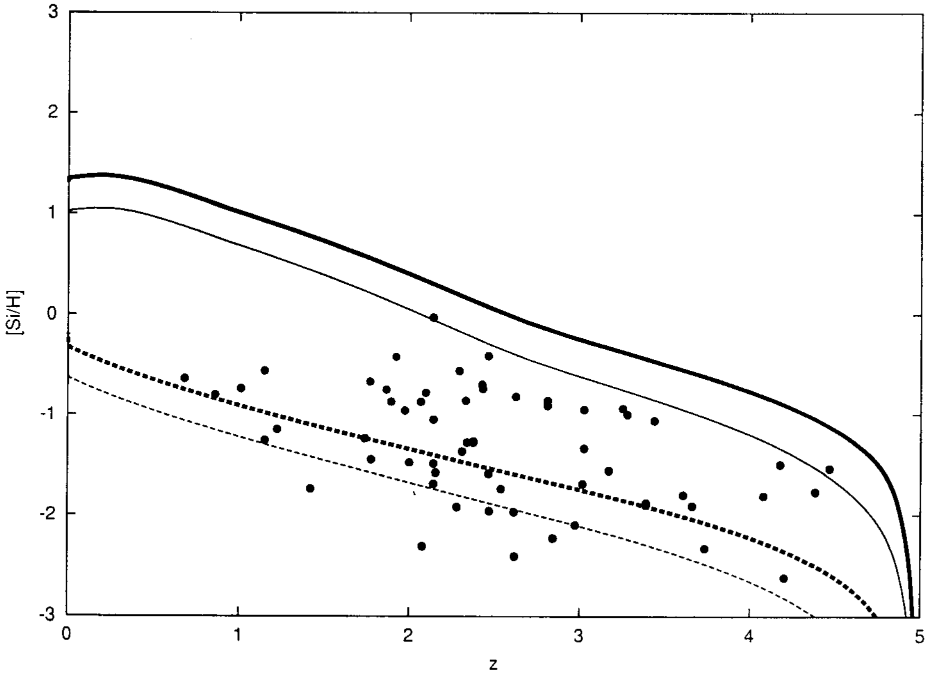


FIGURE 2 A redshift dependent Si abundance for spiral galaxies from Sa (solid) to Sd (dashed), for depleted (thin lines) and undepleted (thick lines) abundances; filled circles show observed DLA abundances; the cosmology: $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, $\Omega_\Lambda = 0.65$, $\Omega_m = 0.35$.

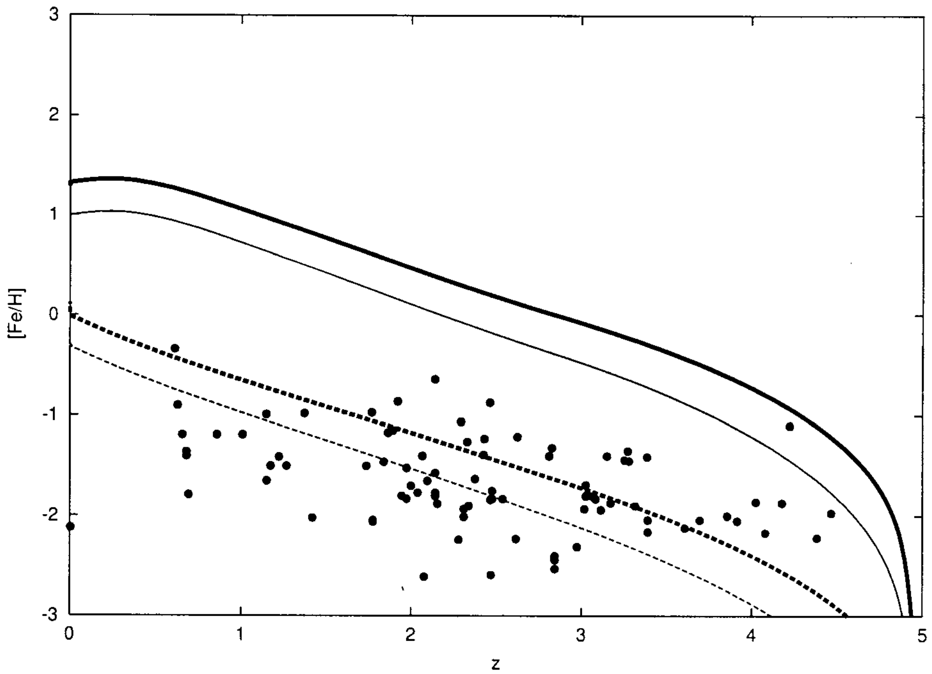


FIGURE 3 A redshift dependent Fe abundance for spiral galaxies from Sa (solid) to Sd (dashed), for depleted (thin lines) and undepleted (thick lines) abundances; filled circles show observed DLA abundances; the cosmology: $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, $\Omega_\Lambda = 0.65$, $\Omega_m = 0.35$.

In Figures 2 and 3 a redshift dependence of Si and Fe abundances in gas phase are shown for the galaxy types in the interval from Sa (solid) to Sd (dashed), with thin lines for depleted and thick lines for undepleted abundances. It is obviously seen that models with depleted abundances do fit the observations better, although the observed Si and Fe are still underabundant in comparison with the calculated values. This trend is observed for all the elements involved in our model (Al, S, Si, O, Fe, Cr, Zn, Mn, Ni), and can be connected with a selection againts luminous galaxies (Steidel *et al.*, 1997). However, in a forthcoming paper, for explanation of such a behavior, we will present arguments in favor of physical mechanisms acting in open models.

## 4 CONCLUSIONS

We presented here calculations of chemical evolution of spiral galaxies in framework of a one-zone closed box scenario, with solid phase (dust grains) involved self-consistently, *i.e.* calculated simultaneously with the equations of chemical evolution – a detailed description and justification of our model, which admits in general open scenarious and a redshift dependent set of governing ingredients, can be found in a separate paper (Kasimova and Shchekinov, 2002). A comparison of the modeled results with observations of several trace elements Al, S, Si, O, Fe, Cr, Zn, Mn, Ni (with only silicon and iron shown here) demonstrates that:

1. Abundance pattern as a tracer of chemical evolution of DLA systems are strongly influenced by selective depletion on dust grains, and thus only those models where dust physics is explicitely included can adequately describe DLA absorptions.
2. The closeness of the calculated and observed DLA abundances indicates that spiral galaxies Sa through Sd can well produce DLA absorptions in a whole range of redshifts $0 < z < 5$. However, given the uncertainties of both observational data and physical inputs in evolutionary models (such as star formation history, initial mass function, inflow/outflow regimes, etc), one cannot exclude that other galaxy types may contribute to DLA absorptions.

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