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Elemental Abundance Estimates at High Redshifts

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Abstract. We observed a small sample of quasars at high redshift (z≥3) to estimate the elemental abundance in the early universe. The enrichment of the line emitting gas was investigated using the emission line ratio of NV 1240 / CIV 1548 and NV 1240 / HeII 1640 as well as of MgII 2798 / FeII UV. We make use of the different enrichment processes of primary elements like carbon to secondary elements (nitrogen) or of α-elements like magnesium compared to iron. Our results indicate supersolar elemental abundances which indicates that the first star formation epoch can be date to at least $z_f \simeq 10$ (H_o=65 km s^{-1} Mpc^{-1}, Ω_M=0.3, Ω_Λ=0.7).

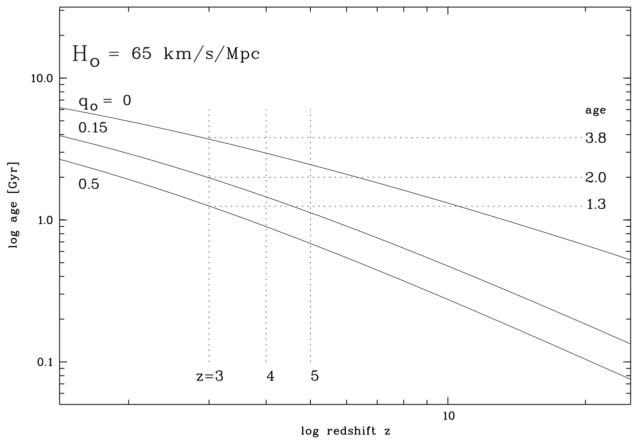

Fig. 1. For $H_o = 65$ km s^{-1} Mpc^{-1} and three different values of q_o the age of the universe is shown as a function of redshift. For the quasar sample we observed the age of the universe was of the order of 2 Gyrs and less.

1. Introduction

Quasars are among the most luminous objects in the universe. Hence they can be studied up to the highest redshifts. Assuming the gas of quasars is related to the interstellar medium of the host galaxy it can be used as tracer of the first star formation epoch in the universe.

One approach is to use the prominent quasar emission lines as cosmological probes, while analysis of their narrow intrinsic absorption lines offers an alternative method (cf. accompanying poster by Hamann & Dietrich). It was shown that NV 1240 vs. CIV 1549 and NV 1240 vs. HeII 1640 provide information about the chemical composition of the gas (cf. Hamann & Ferland 1999 for a review).

Studies of quasars at high redshift (z≥3) provide evidence for significantly enhanced metallicities up to an order of magnitude compared to solar metallicities (cf. Hamann & Ferland 1992, 1993; Ferland et al. 1996; Korista et al. 1996; Pettini 1999; Dietrich & Wilhelm-Erkens 2000). Redshifts of z≥3.0 corresponds to an age of the universe which is only about 10 to 15% of its current age (assuming H_o=65 km s^{-1} Mpc^{-1}, Ω_M=0.3, Ω_Λ=0.7; cf. Carroll, Press, & Turner 1992; Carlberg et al. 1999; Perlmutter et al. 1999). The derived supersolar metallicities indicates a violent star formation phase and are of great interest for dating this epoch to test cosmological models.

Only very few quasars at redshifts larger than 3.0 were observed for the wavelength region covering MgII 2798 to Hβ, [OIII]4959,5007 (Hill et al. 1993; Elston et al. 1994; Kawara et al. 1996; Taniguchi et al. 1997; Murayama et al. 1998; Thompson et al. 1999).

2. Motivation

The key of the approach using emission line ratios to estimate the metallicity are the different time scales of the enrichment of gas with α-elements (O, Ne, Mg, Si), or carbon as an additional primary element, nitrogen as a secondary element, and especially iron. While α-elements are produced predominantly in massive stars on short time scales ($\tau_{evol} \simeq 2\,10^6$ until 10^7 yrs) the production of carbon and nitrogen is ascribed to massive and intermediate mass stars which evolve on significant longer time scales. In contrast to the more continuous enrichment process of the interstellar gas with those elements the release of the dominant amount of iron is delayed by ≈1 Gyr. The main source of iron is given by SN Ia explosions which are ascribed stars of intermediate mass in binary systems (cf. Wheeler, Sneden, & Truran 1989) while the iron abundance in SN II ejecta rather low (e.g. Yoshii et al. 1996; Yoshii et al. 1998). Therefore, the line ratio of α-element emission and iron emission can be used as a cosmological clock.

3. Observations

We observed a sample of 16 quasars at Calar Alto Observatory/Spain (3.5 m), McDonald Observatory/USA (2.7 m), and at Paranal/Chile (VLT 8.2 m). The spectral resolution generally amounts to $\approx$5 Å. Only the spectra recorded with FORS 1 attached to the VLT UT 1 using a low resolution grism have a resolution of $\approx$25 Å. The strongest lines in the spectra are Lyα, CIV1549, CIII]1909, and the broad λ1400 Å feature. In addition several important diagnostic lines are visible like OVI1034, OI1304, CII1335, HeII1640, OIII]1663, and for some quasars even the intercombination line of NIII]1750.
Furthermore, we studied six bright quasars with redshifts z$\simeq$3.4 in the near infrared domain (1.0 to 2.5μm). We observed the quasars with SofI attached to the 3.5 m NTT at La Silla/ESO (Oct. 1999). In contrast to earlier studies we covered the restframe wavelength range $\lambda\lambda 2100 - 5600$Å continuously which is of crucial importance for reliable continuum fits. The spectral resolution amounts to Δv $\simeq$ 100 km s^{-1} in the quasars' restframe.

4. Results

We used the emission-line profile of CIV 1549 as a template profile to measure the line flux. Since CIV1549, NV1240, and HeII1640 are high ionization lines this approach can be justified. The diagnostic line ratios NV1240/CIV1549 and NV1240/HeII 1640 were calculated. Both line ratios are in good agreement with the results obtained by Hamann & Ferland (1992,1993) for quasars at similar redshift (Fig. 2). The average line ratio amounts to NV1240/CIV1549 = (0.7$\pm$0.3) and NV1240/HeII1640 = (5.9$\pm$3.6).
The observed line ratios are obviously larger than those which are expected for normal physical conditions in the emission line gas and solar metallicities (Fig. 2). The line ratios NV1240/CIV1549 and NV1240/HeII1640 were analysed within the frame work of a rapid star formation scenario presented by Hamann & Ferland (1992, 1993, 1999) indicating super-solar abundances. We estimate a metallicity of $Z \simeq 8\,Z_\odot$ based on NV/CIV and NV/HeII. For several quasars of our sample we could also use OVI1034 and the intercombination lines OIII]1663, NIII]1750, and CIII]1909 to obtain the relative abundances. These line ratios indicate although with larger scatter supersolar metallicities consistent with those estimated using NV/CIV and NV/HeII (Dietrich & Wilhelm-Erkens 2000).

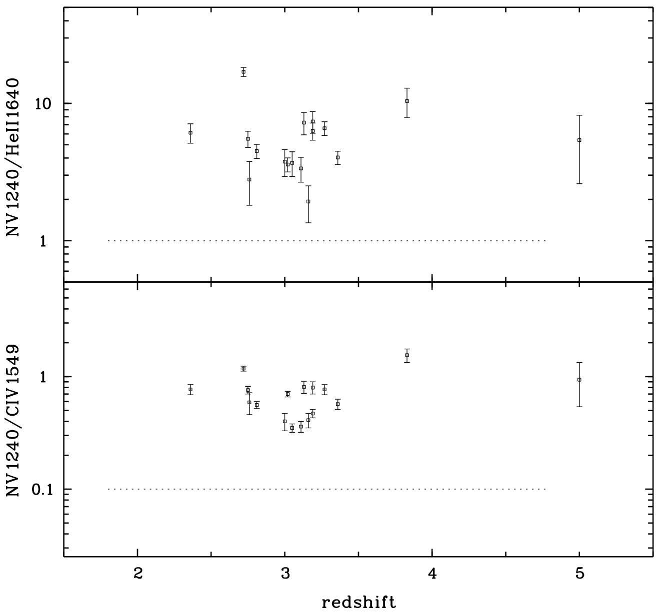

Fig. 2. NV1240/CIV1549 and NV1240/HeII1640 as a function of redshift. The dotted lines indicate the expected line ratios assuming solar metallicity.

Since the dominant release of iron is delayed by $\approx$1 Gyr with respect to that of α-elements the Fe/α ratio is of great interest. For a more detailed discussion see the accompanying poster by Hamann & Dietrich. The MgII 2798 and the ultraviolet FeII emission provides strong emission features to measure the line ratio α-element vs. iron.

Using the quasars at z$\simeq$3.4 we computed an average spectrum which is displayed in Fig. 3; in addition the mean quasar spectrum of Francis et al. (1991) is shown. Even the spectra differ in the continuum slope, obviously the strength of the FeII emission features in our quasars at redshift z$\simeq$3.4 is comparable to that of quasars at low redshift (LBQS-sample). This indicates that the metallicity at high redshifts is comparable to those at lower redshift. Taking into account the results of Thompson et al. (1999) the relative strength of the FeII emission indicates that the epoch of the first star formation begun at a redshift of $z_f \simeq 10$ ($H_o = 65$ km $^{-1}$ Mpc^{-1}, Ω_M=0.3).

For a universe with Ω_M=1 (Einstein, de Sitter) the evolutionary time scale has to be of the order of less than or approximately $\sim$0.5 Gyr. For longer time scales the redshift of the first star forming epoch is larger than z$\simeq$10. For z$\geq$4 the age of the universe starts to become less than the evolutionary time scale. Generally, the Einstein, de Sitter case requires z$\geq$10 and $H_o \leq 40$ km s^{-1} Mpc^{-1}. More reasonable estimates are provided by models characterized by Ω_M=0.3 (open universe), Ω_M=0.3, Ω_Λ=0.7 (flat, Λ dominated universe, cf. Carlberg et al. 1999; Perlmutter et al. 1999), and H_o=65 km s^{-1} Mpc^{-1}. For an evolutionary time scale of $\tau_{evol} = 1$ Gyr the first major star formation should have taken place at $z_f \simeq 6$ to 10. For

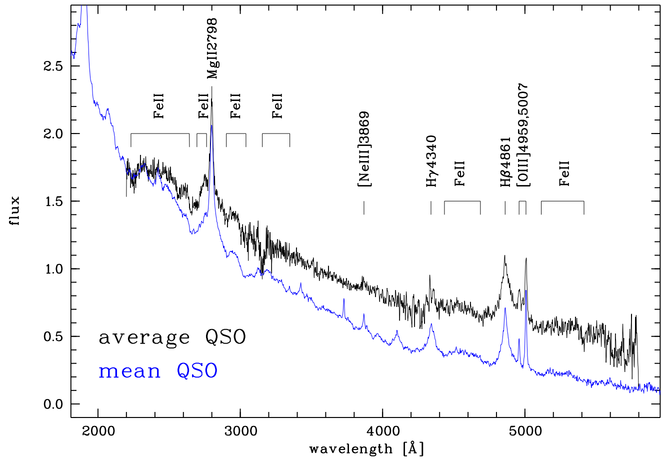

Fig. 3. Comparison of our average quasar spectrum with a mean spectrum of lower redshift quasars (Francis et al. 1991).

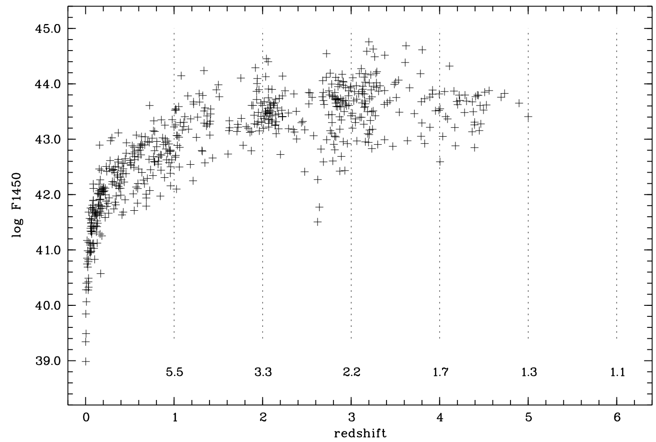

Fig. 4. $F_\lambda(1450)$ as a function of redshift of the quasar sample we are studying. The vertical dotted lines indicate the age of the universe at the corresponding redshift (H_o=65 km s^{-1} Mpc^{-1}, q_o=0.15).

z≥4 an evolutionary time scale of ∼1 Gyr would indicate z_f ≥10.

5. Future Work

Currently, we are studying a sample of more than 400 quasars which cover 0≤z≤5 (cf. Fig. 4). We are investigating these quasars for evolutionary effects of parameters like emission line properties (strength, width, ratios) or elemental abundances correlated with redshift or luminosity. Composite spectra will be computed for dedicated redshift and luminosity ranges. These composite spectra will be compared with spectra of low luminosity AGN like Seyfert galaxies in the local universe, too.

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