The Stellar Population of High Redshift Galaxies

Dörte Mehlert[1], Stefan Noll[1], Immo Appenzeller[1], and the FDF team[1,2,3,4]

[1] Landessternwarte Heidelberg, [2] Universitäts-Sternwarte München,
[3] Universitäts-Sternwarte Göttingen, [4] ESO Garching, [5] MPIA Heidelberg

1 The Project

The consortium of the institutes listed above, which combined forces to built the FORS instruments at the ESO VLT used a significant fraction of their guaranteed observing time to observe a "FORS Deep Field". One of the scientific objectives of the FDF is to study the dependence of the physical properties of galaxies on the cosmic age. Hence we obtained deep multi-band images of the FDF as well as spectra of a subsample of galaxies in the FDF. With these spectroscopic data we will investigate the stellar population (age of the starburst, IMF, metallicity, dust reddening) of distant galaxies with the aim of deriving new information on the evolution of the young universe.

2 The Observations

During 3 nights of MOS observations with FORS2 at the VLT we obtained 389 object spectra. Using the grism 150I and a slitwidth of 1" we covered the spectral range from $\lambda = 3000...9200$ Å with a spectral scale of 5 Å/pixel. Depending on the object magnitude the integration times ranged between 2 and 10 hours with average seeing of 0.69". Standard reduction (bias subtraction, flatfielding, cosmic ray elimination, sky subtraction, rebinning, etc.), was performed using MIDAS routines.

3 First Results

For $\approx$ 203 objects we have spectra with sufficient S/N to determine the type and redshift. Among these we found 169 galaxies, 71 with $z > 1$. Fig. 1 shows a typical spectrum of a high redshift galaxy ($z = 2.437$) in our sample. The most prominent feature is the Ly_α absorption line. Additionally several metal absorption lines can be identified. Furthermore the intense (rest frame) UV continua indicates intensive starburst activity.

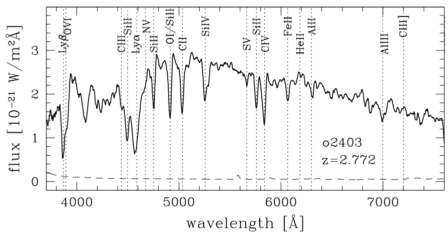

Fig. 1: *Spectrum of a distant ($z = 2.772$) galaxy in the FDF with a S/N $\approx$ 35 per resolution element (= 5 pixel). The dashed line indicates the noise level, which varies with wavelength due to the night sky spectrum and the wavelength dependent instrumental efficiency. The position of some prominent spectral lines are indicated by the vertical dotted lines.*

In Fig. 2 we present a comparison of three of our galaxies with synthetic spectra from Leitherer et al. (2001), showing the spectral region of the CIV resonance line. For galaxy 1747 ($z = 2.37$) and 2403 ($z = 2.77$) the spectral features of CIV are well represented by the solar and LMC model, respectively. On the other hand, for galaxy 2160 ($z = 3.26$) neither the solar nor the LMC models fit the observed feature. Hence we conclude that the metallicity of object 2160 is much lower than the LMC value.

Note that with increasing redshift the galaxies' metallicity seems to decrease. To investigate this trend for the whole sample we measured the equivalent width (EW) of the two prominent stellar absorption lines CIV and SiIV. To increase the sample we included measurements for some galaxies in the field of the lensing cluster 1E0657, the HDF-S and the AXAF Deep Field, which we had observed during FORS commissioning runs with the same spectroscopic setup as described above.

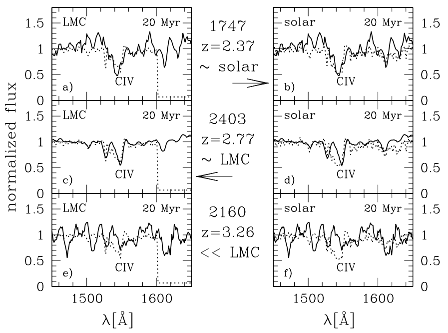

Fig. 2: *Comparison between the observed spectra of galaxy 1747, 2403, 2160 (solid line) and synthetic spectra from Leitherer et al. (2001; dotted line). The synthetic spectra are based on 20 Myr old starbursts with continuous star formation (1 $M_\odot/yr$) and the parameter $\alpha_{IMF} = 2.35$ and M_{up} = 100$_\odot$. The left and right panels indicate models with LMC and solar metallicity, respectively.*

Fig. 3a shows that for $z > 1$, EW(CIV) increases with decreasing redshift. A weighted χ^2 fit gives a slope of $\alpha = -1.44 \pm 0.16$ (dashed line). Including the measured EW of 5 nearby ($z = 0$) starburst galaxies, arbitrarily chosen from the IUE archive, extends the trend to the local universe. A weighted χ^2 fit gives a slope of $\alpha = -1.14 \pm 0.12$ (solid line).

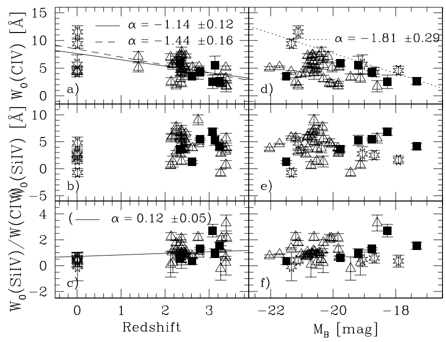

Fig. 3: *Measured CIV 1550 and SiIV 1400 rest frame equivalent widths as well as their ratio SiIV/CIV versus redshift (a, b, c) and absolute B-magnitude (d, e, f). The absolute magnitudes are determined with $H_0 = 50\,\mathrm{km/s/Mpc}$ and $q_0 = 0.5$. For the k-correction we used values provided by Möller et al. (2001). Evolutionary corrections are not applied. Open triangles: FDF galaxies; filled squares: Galaxies in the field of the cluster 1E0657, in the HDF-S and the AXAF Deep Field, respectively (see text); stars: Nearby starburst galaxies. Dashed line, solid line, dotted line: weighted χ^2 for objects with $z > 1$ only, for all shown galaxies and for the local ones ($z > 1$), respectively.*

Fig 4a and b show that both EW(CIV) and EW(SiIV) mainly depend on the metallicity of the stellar population but only little on the age of a starburst. Hence the existing anticorrelation of EW(CIV) with z indicates an increase of metallicity with decreasing redshift (i.e., increasing age of the universe). A similar behavior has been found for damped Lyα systems (Savaglio et al. 2001).

The fact that for SiIV no correlation with z is present may be due to the fact that EW(CIV) is universally present for O supergiants, main sequence stars and dwarfs, while EW(SiIV) is luminosity dependent and decreases rapidly from supergiants to dwarfs (Walborn & Panek 1984; Pauldrach et al. 1990).

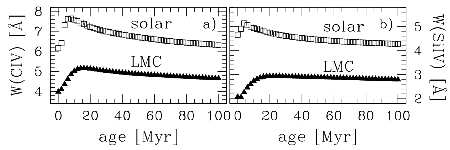

Fig. 4: *Measured CIV 1550 (a) and SiIV 1400 (b) equivalent widths within the synthetic spectra of Leitherer et al. (2001) versus the age of the starburst. Open squares and filled triangles correspond to solar and LMC metallicity, respectively.*

Therefore the SiIV is more strongly affected by population differences (i.e., stellar age differences) than the CIV line. EW(SiIV) has its maximum in B0/B1 stars, while EW(CIV) is mainly universally present in O and bright B stars (e.g., Leitherer, et al. 1995). Hence the ratio of EW(SiIV)/EW(CIV) contains information about the star formation history (instantaneous or continuous) and the stellar population itself (e.g., IMF and cutoff masses). Unfortunately the different parameters that determine the value of EW(SiIV)/EW(CIV) cannot be disentangled easily. As seen in Fig. 3c the ratios of EW(SiIV)/EW(CIV) show a weak trend corresponding to an increasing ratio with z seems (a weighted χ^2 fit gives $\alpha = 0.12 \pm 0.05$). This could be understood in terms of increase of the relative importance of continuous star formation (decrease of instantaneous starbursts) at low z. Finally, Figs. 3d to f show that there is no overall dependence of the measured equivalent width on the galaxies' luminosity. If, in fact, EW(CIV) is mainly determined by the metallicity, the nearby starburst galaxies seem to follow the well known local metallicity-luminosity relation (e.g. Kobulnicky & Zaritsky 1998), while the high-z galaxies seem not to conform this relation. As also found for Lyman break galaxies by Pettini et al. (2001), the high-z galaxies investigated in this paper seem to be overluminous for their metallicity (EW(CIV)), which may indicate that their mass-to-light ratios are low compared to present-day galaxies.

4 Conclusions

• Our observed high-z galaxy spectra agree with synthetic ones.
• EW(CIV) is a good indicator for the galaxies metallicity.
• Our high-z starburst galaxies show increasing metal content with decreasing redshift and are overluminous for their metallicity compared with local starburst galaxies.

References

1. Kobulnicky, H.A., Zaritsky, D. 1998, ApJ, 511, 188
2. Leitherer, C., Leao, J.R.S., Heckman, T.M., et al. 2001, ApJ, 550, 724
3. Leitherer, C., Robert, C., Heckman, T.M. 1995, ApJS, 99, 173
4. Möller, C.S., Fritze-v.Alvensleben, U., Fricke, K.J. 2001, A&A, submitted
5. Pauldrach, A. W. A., Puls, J., Kudritzki, R.-P., Butler, K. 1990, A&A 228, 125
6. Pettini, M., Shapley, A.E., Steidel, C.C., et al. 2001, ApJ, in press
7. Savaglio, S., Panagia, N., Stiavelli, M. 2001, in ASP Conference Series, Cosmic evolution and galaxy formation: Structure, Interactions, and Feedback, eds. J. Franco, E. Terlevich, O. Lopez-Cruz, I. Aretxaga, in press
8. Walborn, N. R., Panek, R. J. 1984, ApJL 280, L27