N. Arimoto & W. Duschl (eds.),
Studies of Galaxies in the Young Universe with New Generation Telescope
Japan-German Seminar (JSPS-DFG), 2001, Sendai

High Redshift Galaxies in the FORS Deep Field

I. Appenzeller[1], D. Mehlert[1], S. Noll[1], R. Bender[3], A. Böhm[2], A. Gabasch[3], J. Heidt[1], U. Hopp[3], K. Jäger[2], S. Seitz[3], and the FDF Team[1,2,3,4]

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

Abstract

We present a progress report on a spectroscopic investigation of high-redshift galaxies in the FORS Deep Field (FDF). The results obtained so far show clear evidence for evolutionary effects with cosmic age in the FDF star burst galaxies in the redshift range 2 < z < 4.6. Most conspicuous is an increase of Lyman line emission and a decrease of the metallic line absorption strength and of the heavy element content with redshift. However, even the most extreme Lyα galaxies show metal absorption lines in their spectra. The angular distribution of the galaxies as well as the redshift distribution indicate significant clustering already at redshifts $z > 3$.

1 The FORS Deep Field

When the ESO VLT started its operations with Unit Telescope No.1 (Antu) the first focal plane instrument to be installed was FORS1, a low-dispersion spectrograph/camera/polarimeter combination for observing very faint objects (see e.g. Appenzeller et al., 1998). FORS1 was soon joined by an almost identical copy (FORS2) at the VLT UT2. Both instruments were designed and built jointly by the Heidelberg State Observatory (LSW) and the University Observatories of Göttingen and München (USG and USM) in close cooperation with ESO. For their effort the three German institutes received a certain amount of guaranteed observing time with these instruments, which is being used for several different scientific studies in the fields of interest of the three institutes. The largest of these projects is the FORS Deep Field (FDF) program (Appenzeller et al. 2000), which again is being carried out jointly by LSW, USG and USM. The FDF is a very deep look into the southern sky at the position $\alpha = 01^h06^m04^s$ and $\delta = -25^o45'46''$ near the South Galactic Pole. The field covers approximately the FOV of a single FORS frame (6.8 $\times$ 6.8 arcmin^2). It was selected to exclude visible foreground galaxy clusters and (to avoid straylight and detector saturation effects on medium duration exposures) stars brighter than $\approx$ 19 mag. Further section criteria were a low galactic extinction and the presence of a z > 3 QSO. As a first step the FDF team spent more than 40 hours of FORS integration time to obtain very deep images in the U, B, g, R, I, z, and two narrow filter bands (cf. Heidt et al. 2000). In addition we obtained (less deep) J and K NIR images with the SOFI instrument at ESO's NTT on La Silla. Although our images do not quite reach the same limiting magnitudes as the Hubble Deep Fields, because of the larger area, in the FDF more faint galaxies ($\approx 10^4$) are detected than in the two HDFs combined. A colour image of the FDF based on B, R, and I frames is reproduced in Fig. 1.

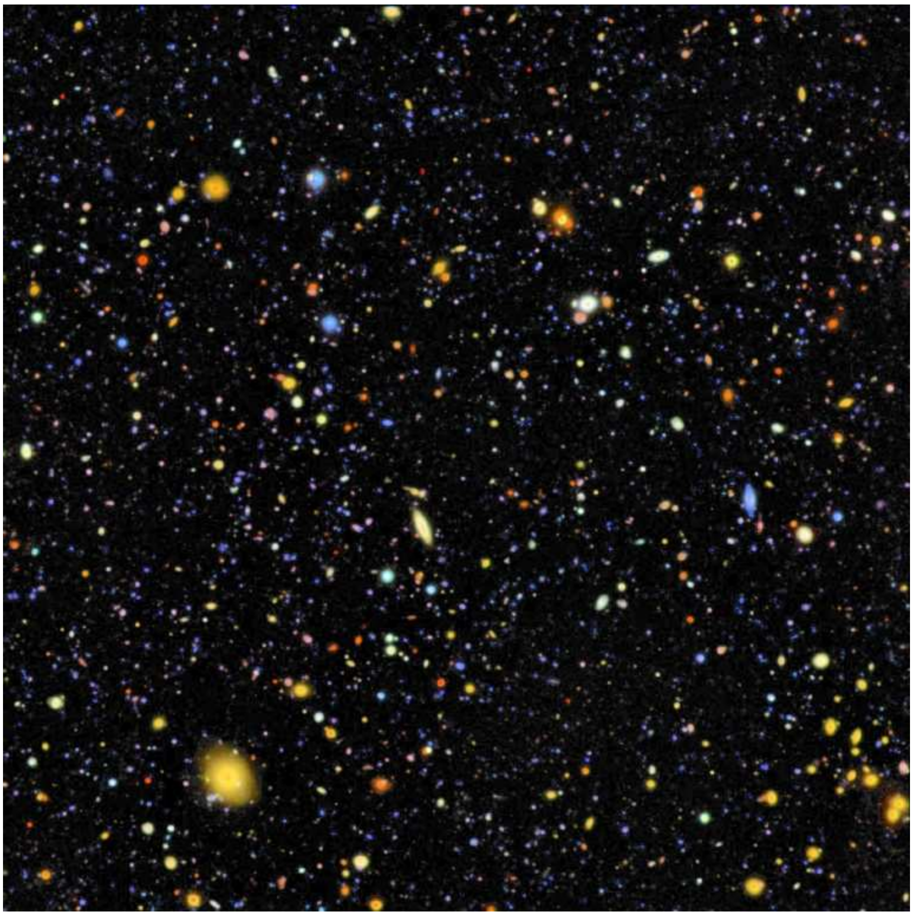

Figure 1: BRI Colour composite image of the FORS Deep Field

2 Photometric and Spectroscopic Redshifts

While the reduction of the FORS frames is straightforward for the brighter magnitudes, the large ratio between the sky flux and the object flux makes an accurate photometry at the faint end a complex procedure. Therefore, improvements of the photometric reduction are still in progress. As soon as an accurate and reliable data product has been achieved a photometric catalog of the FDF galaxies will be published. But some basic statistical properties of the FDF galaxies could already be derived on the basis of a preliminary photometric catalog. In particular we have calculated preliminary (but reasonably accurate, see below) photometric redshifts for about 4000 FDF objects (cf. Bender et al. 2001). The (photometric) redshift distribution of these objects is given in Fig. 2.

In addition to the photometric program we have started to obtain low-dispersion and medium dispersion spectra of a sample of galaxies selected on the basis of the photometric redshifts. The medium dispersion spectra are being used to study the evolution of the kinematical properties of the galaxies with cosmic age. First results of this study can be found in Ziegler et al. (2001). The low-dispersion spectra are being analysed to obtain information on the population and chemical evolution in the FDF galaxy sample. Some first results of this latter program are described in the present paper.

Up to now we obtained about 400 low-resolution (R $\approx$ 200) spectra. For 203 of these objects (with I-band magnitudes between 18.0 and 26.4) we were able to derive spectroscopic redshifts in the range $0.1 \leq z \leq 4.6$. The remaining spectra either have an

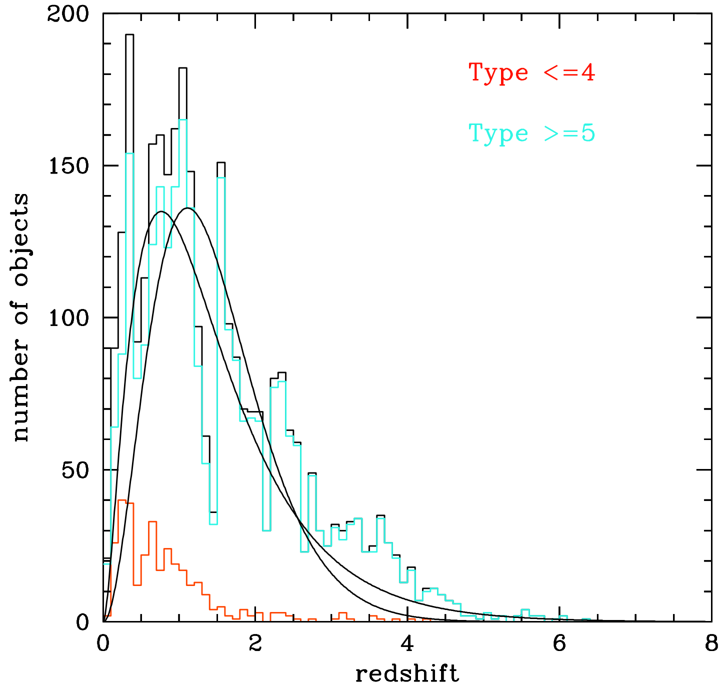

Figure 2: Distribution of the photometric redshifts of the galaxies with good photometric data in the FDF (black histogram). The red and blue histograms indicate the distribution separated into early type (E and S0) and late type galaxies (classified on the basis of the observed SEDs), respectively. For comparison we also included the corresponding smoothed distributions for the HDF-N and the HDF-S (smooth curves).

insufficient S/N or they fall into the redshift interval 1.4< z <2.2 where the lack of strong spectral features makes it difficult to derive good redshifts from low-resolution spectra. A comparison of the spectroscopic and photometric redshifts is given in Fig. 3. Except for the QSOs and some objects with poor or incomplete photometry near the edge of the field the agreement between the two methods is quite good. So far most effort has been devoted to the spectra of 66 objects with $2.00 \leq z \leq 4.58$. For many of these objects we were able to secure high-quality spectra with good S/N (see e.g. Figs. 4 and 5).

3 Population and Chemical Properties

As evident also from Fig. 2, at high redshifts our sample is strongly dominated by late type and star burst galaxies. This is to be expected for an optically selected sample, since with instruments like FORS we are observing mainly the rest-frame UV radiation of the distant galaxies. However, although all high-z spectra are dominated by a population of massive hot stars, the detailed spectral properties show clear differences and systematic trends with redshift (i.e. cosmic age). While at $z \approx 2$ the spectra tend to be dominated by absorption lines, with increasing z Lyα emission tends to become stronger. Furthermore, a comparison with synthetic spectra (taken, e.g., from Leitherer et al. 2001) shows that good fits to the FDF high-redshift galaxy spectra in most cases are possible only with sub-solar metallicities, with the metallicity decreasing on average with increasing z. Our enlarged sample of FDF galaxies also confirms a trend noted earlier by Mehlert et al. (2001) that the equivalent width of the CIV resonance line in distant galaxies decreases

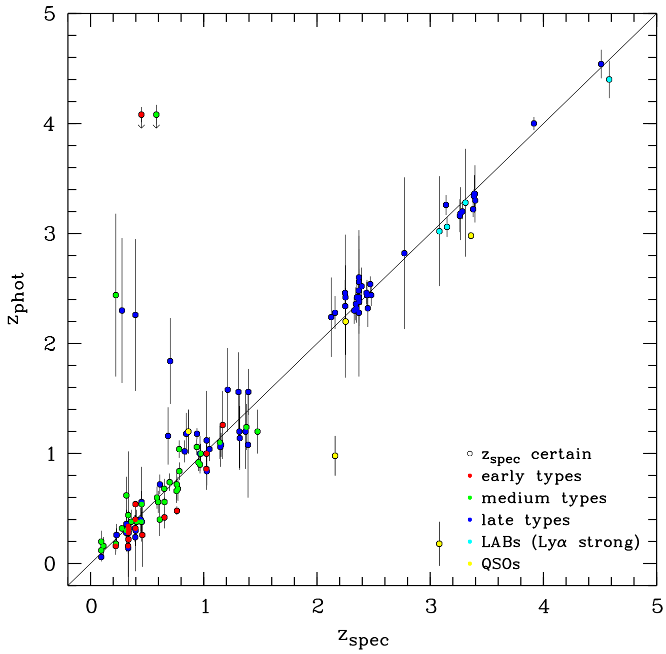

Figure 3: Comparison of photometric and spectroscopically determined redshifts in the FDF. The objects with discrepant redshifts are either QSOs (which are not represented in our template spectra) or objects with poor or incomplete photometry near the edge of the field

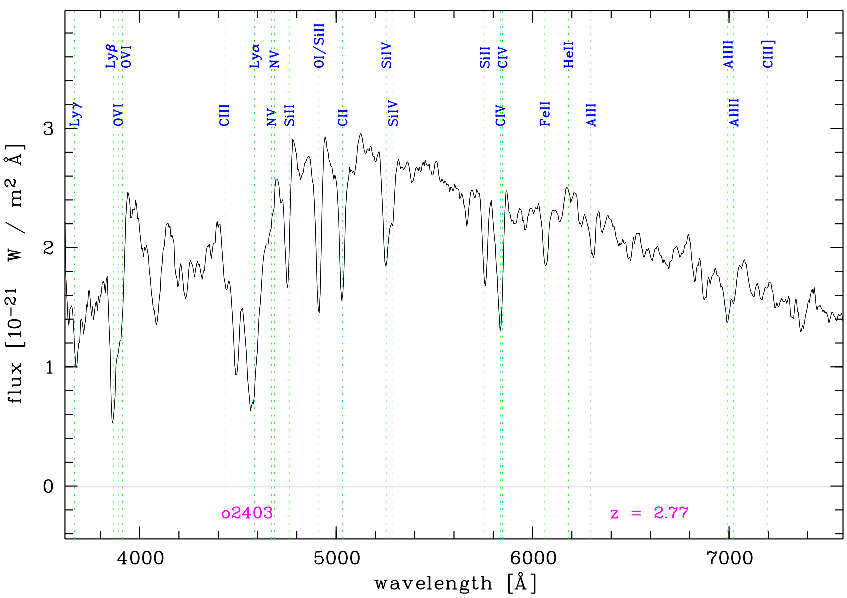

Figure 4: Example of a low-resolution spectrum of a z = 2.77 FDF-galaxy. The total integration time for this galaxy was about 10 hours, yielding a S/N ≈ 50.

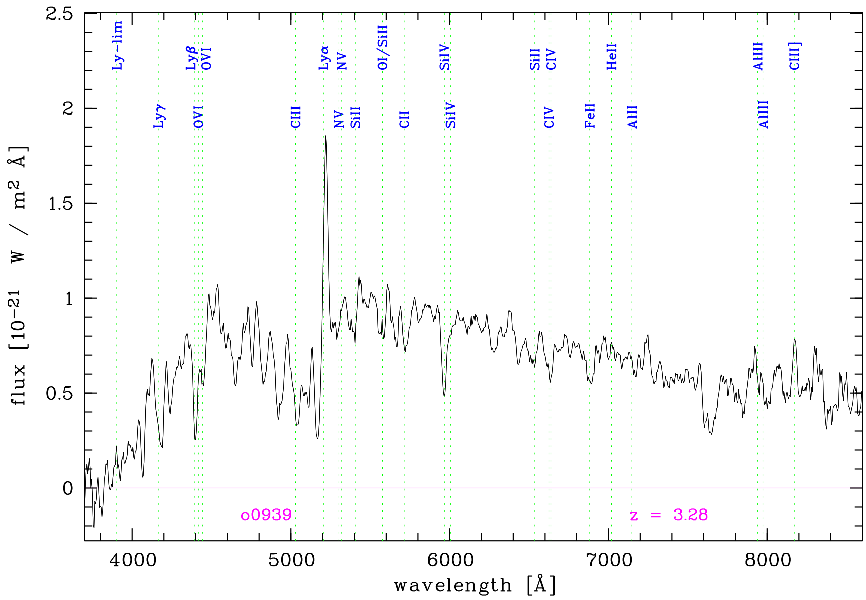

Figure 5: Low-resolution spectrum of a z = 3.28 star burst galaxy in the FDF (integration time ≈ 8 hours, S/N ≈ 25)

with increasing z (Fig. 6a). According to Mehlert et al. (2001a, 2001b) this may reflect the expected rapid increase of the metallicity after the onset of star formation in the early universe, which is evident e.g. from the analysis of damped Lyα systems (cf. Savaglio et al. 2001). Fig. 6d shows that the observed effect is not due to a luminosity effect as all high-z star burst galaxies show a low CIV equivalent width, regardless of their luminosity. The fact that the SiIV line strength does not show a dependence on redshift may be due to the stronger population dependence of this line which may mask any z-dependence.

4 Lyα Emission Galaxies

Several of our galaxies have very strong Lyα emission and a relatively weak continuum. On short exposure spectra of these objects only the Lyα line is visible. However, in all cases where a sufficient S/N could be reached these spectra also show clear evidence for metallic absorption lines, sometimes with P Cyg profiles (Fig. 7). This rules out that the phenomenon of the Lyα galaxies is caused by the absence of metals. A more likely cause of the strong Lyα emission may be a lower dust content and thus a higher escape probability of the Lyα radiation from these objects, caused indirectly by the (compared to local star burst galaxies) lower metallicity of the high-z galaxies.

4 Clustering

Although the overall redshift distribution of our FDF galaxies is similar to that of the HDF galaxies, Fig. 2 shows overdensities near about z = 2.3 and z = 3.4. These overdensities are confirmed by the spectroscopic data. Moreover, a preliminary analysis shows that the objects near these redshift maxima are not randomly distributed over the field. Hence, we conclude that the redshift clustering results from the cosmic large scale structure in

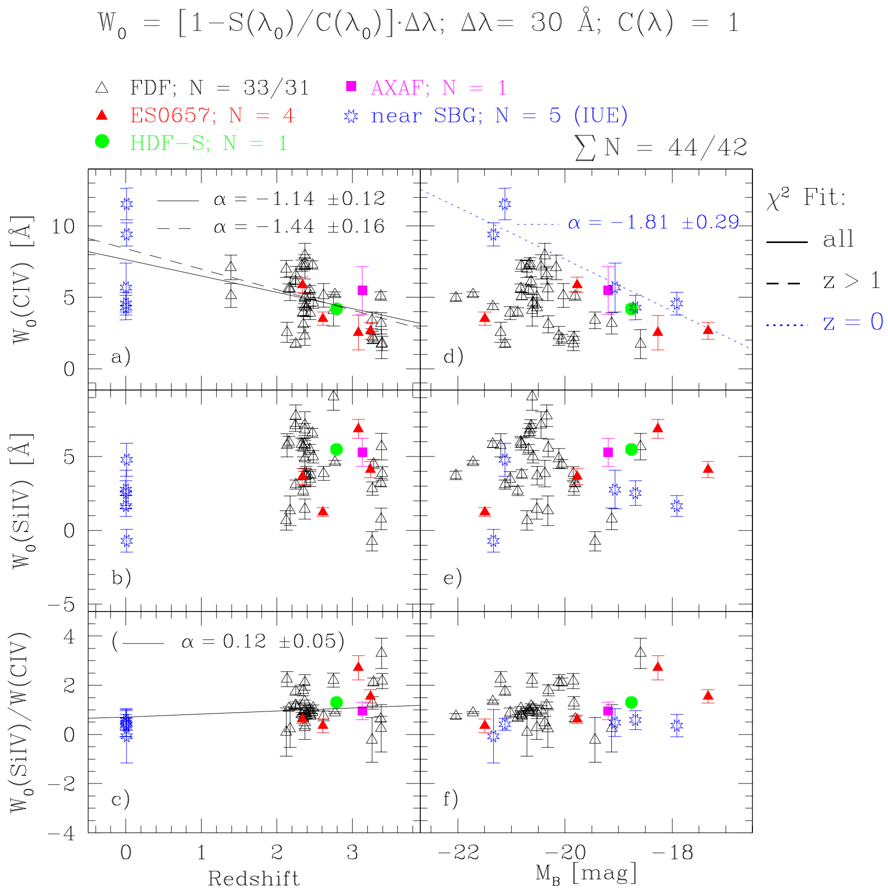

Figure 6: Equivalent widths of the CIV 1550 and SiIV 1400 blends as a function of the redshift and of the luminosity for FDF galaxies. Also included are data points for some local star burst galaxies and high-z galaxies from various smaller samples indicated above the figure (from Mehlert et al. 2001b)

the direction of the FDF. Interestingly two of the five QSOs found in the FDF have also redshifts near 2.1, while a third QSO has a redshift close to 3.36 (Fig. 3). Furthermore, as shown in Fig. 8, there are several galaxies close to the $z = 3.36$ quasar which show enhanced emission corresponding to the wavelength of Lyα at this redshift.

5 Conclusions

The galaxies in the FORS Deep Field obviously form an valuable sample for studying the evolution of stellar populations and the chemical abundances in the early universe. A first spectroscopic analysis of this shows evidence for various evolutionary effects in the early universe, such as an increase of Lyman line emission and a decrease of the metallic absorption strength and the heavy element content with redshift. However, even the extreme Lyα galaxies show metal absorption lines in their spectra. The angular distribution of the galaxies as well as their redshift distribution indicate the occurrence of clustering even at high redshifts. This investigation is still in progress and the spectroscopic observations and various other studies of the FDF galaxies and quasars are being continued. A more detailed account of our results will be published elsewhere in due time.

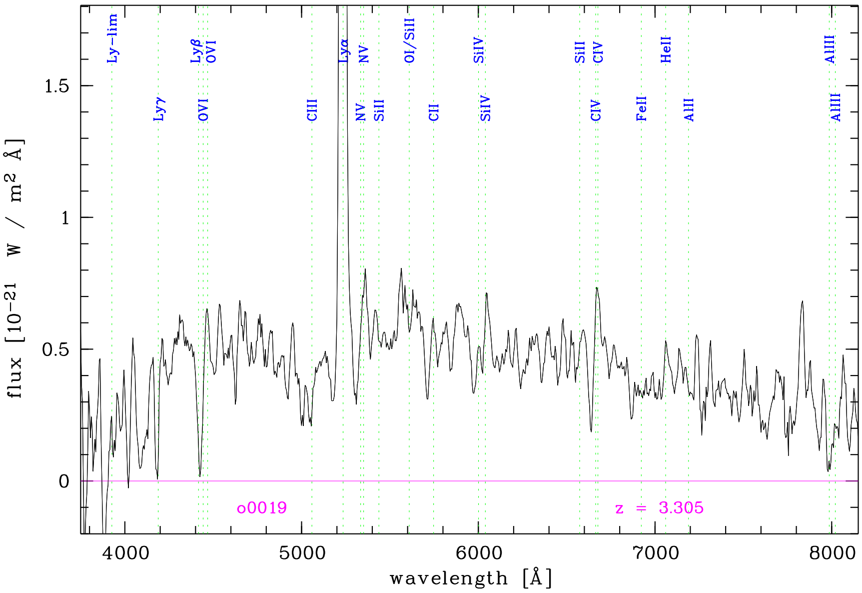

Figure 7: Spectrum of a Lyα galaxy (EW(Lyα) > 300 Å) in the FDF. Note the conspicuous P Cyg profiles of CIV and other metallic lines.

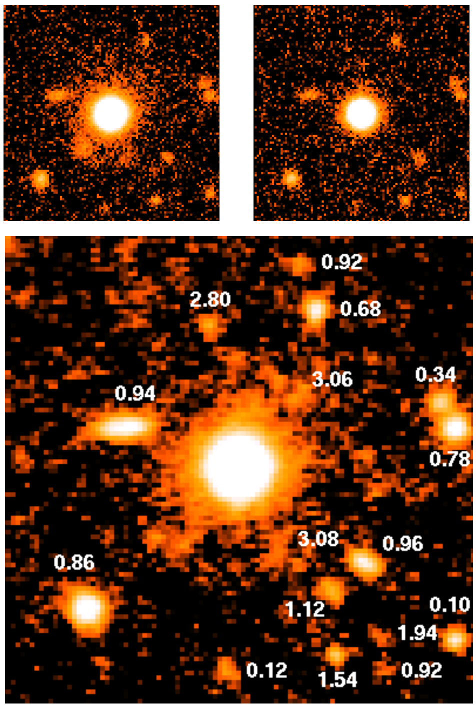

Figure 8: I-band image of the environment of the $z = 3.36$ quasar Q0103-260 in the FORS Deep Field (lower image) and narrow-band images taken in the wavelength band of the QSO's Lyα emission (upper left) and in an adjacent wavelength band (upper right). The FOV of all three images is 20"×20". The numbers in the lower image give the photometric redshifts of some of the galaxies. Note that two of the galaxies near the QSO have photometric redshifts of the same order as the QSO, while two additional galaxies (just below the QSO) show enhanced emission at the wavelength of Lyα at the QSO's redshift.

Acknowledgements

This research has been supported by the German Science Foundation (DFG) within the framework of the SFBs 375 and 439 and by the German Federal Ministry of Education and Research (VF Groundbased Astronomy and Astrophysics). One of the authors (I.A.) gratefully acknowledges a DFG travel grant which made it possible to present these results at the Sendai workshop.

References

1. Appenzeller, I., Fricke, K., Fürtig, W., et al. 1998, The Messenger **94**, 1
2. Appenzeller, I., Bender, R., Böhm, A., et al. 2000, The Messenger **100**, 44
3. Bender, R., Appenzeller, I., Böhm, A., et al. 2001, Proc. ESO/ECF/STScI Workshop on Deep Fields, p. 327
4. Heidt, J., Appenzeller, I., Bender, R., et al. 2001, Reviews in Modern Astronomy **14**, 209
5. Leitherer, C., Leao, J.R.S., Heckman, T.M., et al. 2001, Ap.J. 550, 724
6. Mehlert, D., Seitz, S., Saglia, R.P., et al. 2001a, Astron. Astrophys. (in press)
7. Mehlert, D., Noll, S., Appenzeller, I., et al. 2001b, Proc. MPA/ESO/MPE/USM Joint Astronomy Conference on " Lighthouses of the Universe" (in press)
8. Savaglio, S., Panagia, N., Stiavelli, M. 2001, Proc. Conference on Cosmic Evolution and Galaxy Formation, J. Franco et al. eds., ASP Conference Ser. (in press)
9. Ziegler, B.L., Böhm, A., Fricke, K.J., et al. 2001, ApJ (submitted)