Excerpts from the First Five Years of VLT Science (1999-2004)

A. Renzini (ESO)

So, five years have passed since the first VLT Unit Telescope was offered to the scientific community on April first, 1999. Much indeed has occurred in the meantime on Paranal, within the ESO community, and in Astronomy worldwide. In several fields progress has been breathtaking, and the VLT has played a rapidly increasing role in pushing ahead the frontier of our knowledge in virtually every major direction, from planetary systems to cosmology.

The scope of this brief article is to highlight some representative results so far obtained with the VLT. But how to select among the 2000 projects[1] so far scheduled at the VLT, and the over 600 papers that have appeared in refereed journals as of February 29, 2004? Moreover, since it takes time to reduce data, analyze them, write the papers, and get them through the refereeing process, one can safely say that what has appeared so far is but a small fraction of what is already in the *pipeline*. The major impact of the VLT is indeed yet to come! Even from these first five years.

Anyway, aware of the risk of making just few friends and disappointing many, I decided to pick one representative result for each of the seven VLT instruments that have so far been offered to the community. In doing so I will follow the sequence in which these instruments were deployed.

FORS-1, the first VLT instrument, is also the only optical instrument on the VLT that allows polarimetric measurements. Exploiting this niche, two teams were first in measuring the polarization of the afterglow light of a gamma ray burst (GRB), within just 40 days of the inauguration of the Paranal Observatory (Wijers et al. 1999; Covino et al. 1999). While this early result already contributed to narrow down the choice among GRB models, this was just the first of a long series of GRB observations at Paranal, to the point that today the large majority of the known redshifts of GRB afterglows have been measured with the VLT. Yet, with the advent of the robotic telescopes now deployed on La Silla (see *The Messenger* **113**, 40 and 45), and the VLT being offered in Rapid Response Mode, there are good reasons to expect major new breakthroughs in this field from the VLT.

ISAAC, the "infrared workhorse", soon came second. Deep infrared imaging was expected to open a new window over the distant universe, and it did, while the VLT operational paradigm helped a lot. Indeed, Service Mode observing was implemented at the VLT in order to have for each observing condition the best programmes that could exploit them. In this way, almost 100 hours of Service Mode observations with better

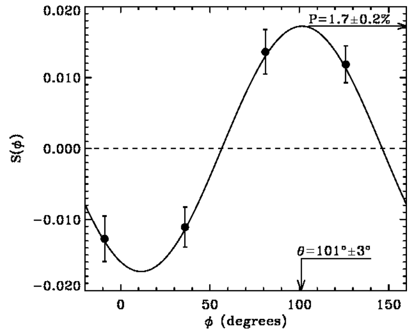


Figure 2: The polarization fraction of the afterglow of the GRB 990510 as a function of position angle (Covino et al. 1999). Data from FORS-1.

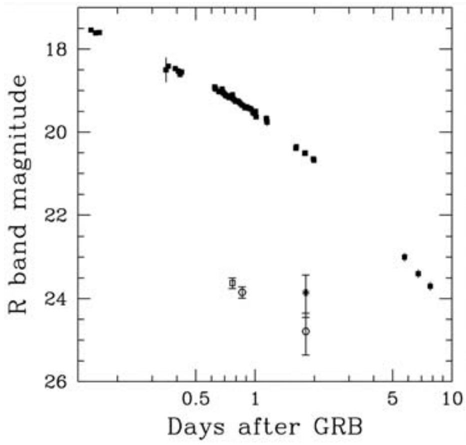


Figure 1: The *R*-band light curve of the afterglow of the GRB 990510 showing the variation of the total flux (filled symbols) while open symbols refer to the polarized flux only, given by the product of the total flux times the polarized fraction, about 1.7% (Wijers et al. 1999). Polarization data taken with FORS-1.

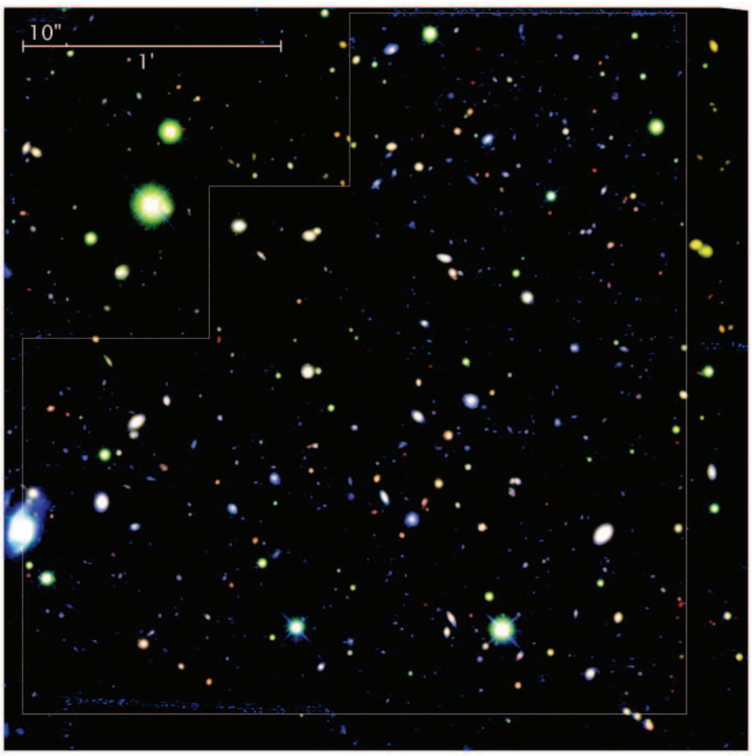


Figure 3: Three-colour composite image of the Hubble Deep Field South (HDFS) obtained combining the WFPC2 I_{814} image with the *J* and *K* band images from ISAAC (Labbé et al. 2003).

[1] This number (2000 projects) refers to the "scheduled" programmes from Period 63 up to and including Period 73. When comparing it to the number of VLT papers one should bear in mind that not all "Category C" programmes in Service Mode get carried out, and that there has barely been time for publishing papers based on data taken during the last two periods (over 500 programmes).

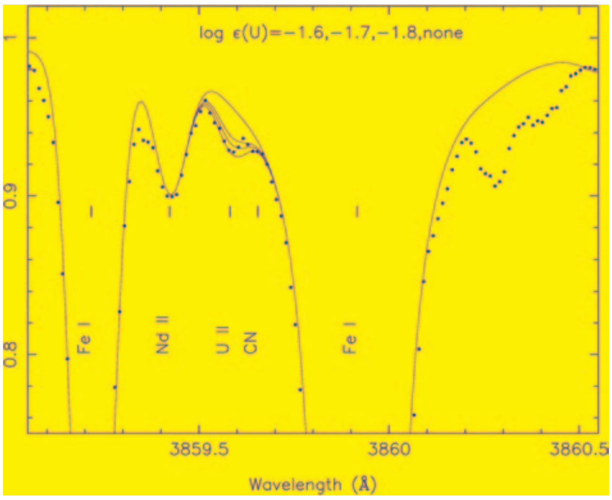


Figure 4: The UVES spectrum of the very metal poor star CS31082 including the U II line at 385.959 nm (dotted line). The solid lines show various synthetic spectra with three different uranium abundances as indicated (Cayrel et al. 2001).

than 0″.4 seeing were dedicated to the FIRES project, thus complementing HST on the HDF-South, and revealing a new population of massive galaxies at high redshift (Labbé et al. 2003) that had escaped detection by the ultraviolet-dropout technique.

UVES, the high-resolution optical spectrograph, started in the following year (2000), calling into action much of the stellar and QSO communities. Thanks to its unique response in the blue and near-ultraviolet, UVES allowed the first measurement of the Thorium/Uranium ratio in an old, very metal-poor star (Cayrel et al. 2001), thus offering a new opportunity for accurately dating the age of our Milky Way galaxy.

FORS-2, the non-identical twin of FORS-1, was deployed along with UVES on UT2/Kueyen. The main difference with respect to FORS-1 is in its higher multiplex capability. Thanks to its mask-exchange unit, over 50 spectra at a time can be obtained, more than a factor of two over FORS-1. Soon it was also upgraded with a red-optimized CCD, virtually free of fringing, making it perhaps the most powerful red-optimized optical spectrograph now in operation. Ideal for the spectroscopic study of red high-redshift galaxies, FORS-2 played the prime role in the "K20 Survey" (Cimatti et al. 2002), which has revealed a population of infrared-bright, massive galaxies beyond redshift 1.5, whose existence was unexpected by most theories of galaxy formation.

NACO, the NAOS/CONICA adaptive optics camera and spectrograph, represented quite a jump in complexity with respect to the first group of instruments. Using very early Commissioning and Science Verification data it soon led in 2002 to one of the most spectacular astronomical discoveries in recent years: tracing the 15.2 yr orbit of a star around the supermassive black hole (BH) at the centre of the Milky Way, accurately mapping its passage at the "periastron" just 17 light hours away from the BH, and allowing a most precise measurement of its mass, $(3.7 \pm 1.5) \cdot 10^6$ solar masses (Schödel et al. 2002).

FLAMES, the fibre multi-object facility feeding two spectrographs (UVES and GIRAFFE) came next. With the OzPoz positioner, FLAMES sends 130 fibres to GIRAFFE and 8 to UVES, allowing the simultaneous observation of as many targets at a time, with medium ($R < 20{,}000$) and high resolution (40,000), respectively. In this case there is little embarrassment in selecting the highlight, because so far only one team has been able to submit papers based on FLAMES data. In just a few shots during FLAMES Science Verification more medium- and high-resolution spectra of red giants in the globular cluster NGC 2808 were obtained than ever before in a single cluster. Cacciari et al. (2003) mapped the H-α emission along the red giant branch, thus starting to collect basic information on the chromospheric-like activity in these stars, that sooner or later may shed light on the still mysterious origin of red giant winds. Using

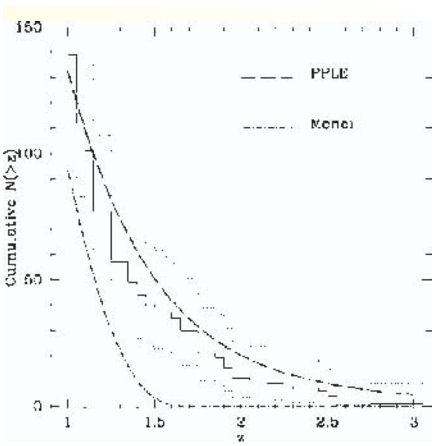


Figure 5: The redshift distribution of $K < 20$ objects at $z > 1$ from the K20 survey (Cimatti et al. 2002). The solid histogram refers to the observed distribution along with its $\pm 3\,\sigma$ confidence range (dotted lines). The theoretical predictions for a Pure Luminosity Evolution model (PLE, dashed line) and a typical CDM semi-analytical model (dot-dashed line) are also shown. Data mostly from FORS-2.

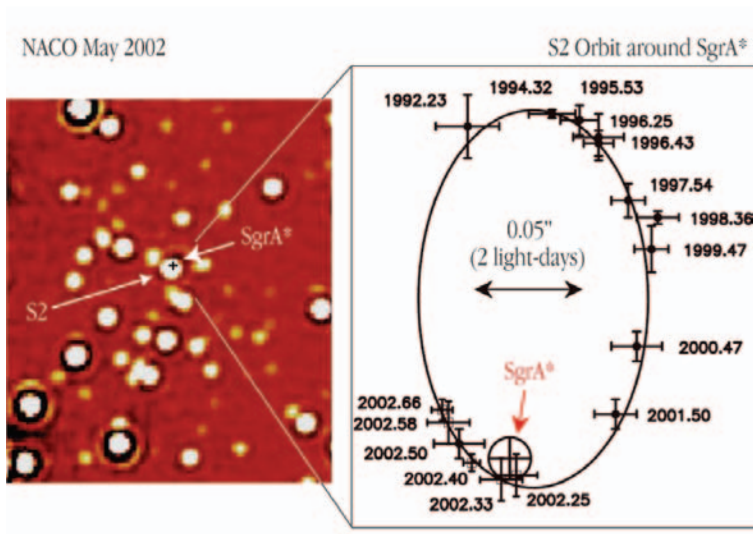


Figure 6: The orbit of the S2 star around the supermassive black hole at the Galactic centre. Data points for 2002 were all obtained from NACO observations (Shödel et al. 2002).

the same data the same team also measured the Sodium abundance in the cluster giants, finding star-to-star variations that apparently do not correlate with luminosity, implying a likely primordial origin for the variations of this p-process element (Carretta et al. 2003).

VIMOS, the last comer, is also perhaps the most complex instrument on the VLT. It is indeed made of four identical spectrographs and cameras, allowing both wide-field imaging and high multiplex multi-object spectroscopy. VIMOS has been optimized to be primarily a redshift machine, able to deliver up to 800 spectra per exposure. The VIRMOS Consortium that built the instrument had an early start with its guaranteed time in the fall of 2002. They thus begun their VIMOS VLT Deep Survey (VVDS), collected over 20,000 spectra at a rate of more than 1000 per night, and started to trace the large scale structure all the way to redshift 1.5 (Le Fevre et al. 2004). After a major intervention to eliminate some mechanical problems (August-November 2003), VIMOS is now working at full steam, delivering images and spectra at a frightening rate. Some say mapping the universe is just a matter of time.

As mentioned at the beginning, what we have seen published so far is just the tip of the iceberg. Most of the VLT data taken to date, especially with the last three instruments, is still on disks rather than papers. Most is yet to come, and probably the best too. After all, the VLT is young: it has just concluded its kindergarten years.

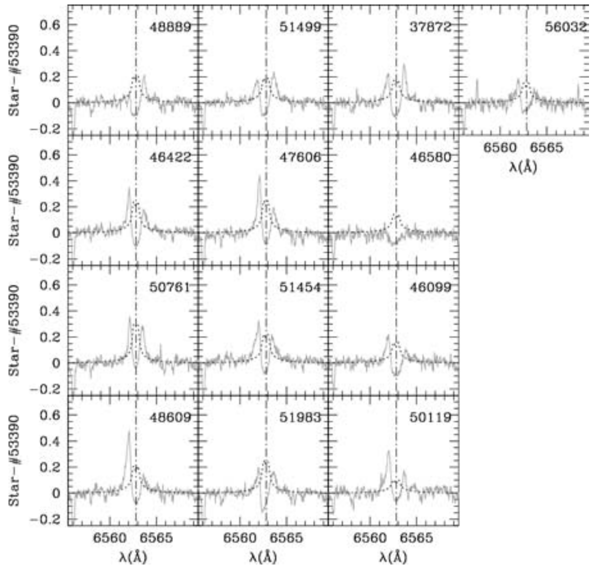
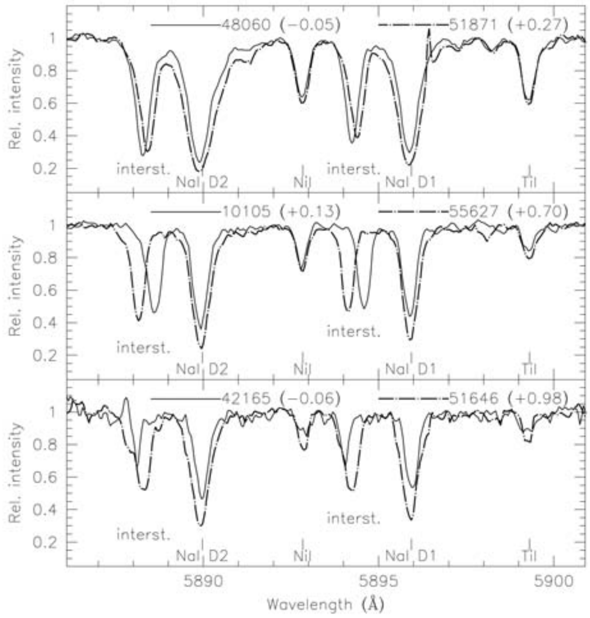


Figure 7: The Hα line profiles for a sample of red giants near the tip of the Red Giant Branch of the globular cluster NGC 2808 as observed by FLAMES/UVES (Cacciari et al. 2003). The solid line is obtained by subtracting the spectrum of a reference star from the spectrum of each of the programme stars. The dotted line shows the difference of the corresponding theoretical (model atmosphere) profiles where chromosphere/wind effects are ignored. This illustrates at once the presence of chromosphere/wind effects along with large star-to-star variations.

Figure 8: Three representative pairs of FLAMES/GIRAFFE spectra showing the variation of the strength of the Sodium D doublet for stars near the tip of the red giant branch (RGB) of the globular cluster NGC 2808 (top panel), about midway between the horizontal branch and RGB tip (middle panel), and (lower panel) near the horizontal branch (Carretta et al. 2003). Note the sizable star to star variations in the intensity of the Na D lines.



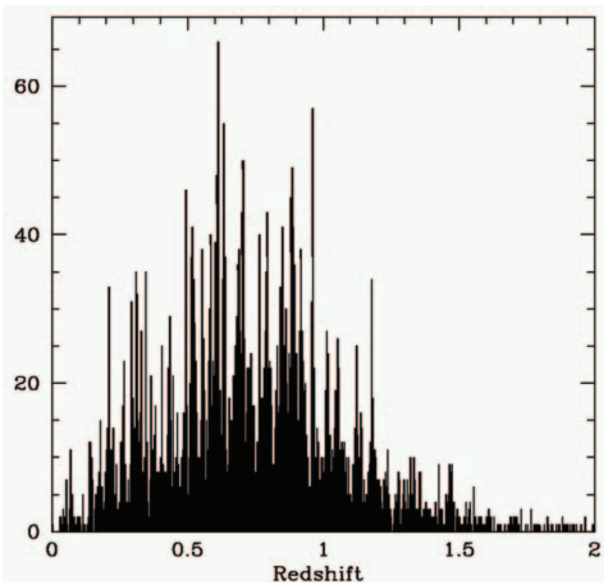


Figure 9: The redshift distribution of galaxies in the VLT VIMOS Deep Survey field VVDS-0226-04 (Le Fèvre et al. 2004). A total of 5010 $I_{AB} < 24$ galaxies are included in the histogram, which shows that large scale structure peaks are well traced all the way to $z \sim 1.5$.

References

Cacciari, C., Bragaglia, A., Rossetti, E., Fusi Pecci, F., Mulas, G., Carretta, E., Gratton, R.G., Momany, Y., Pasquini, L. 2003, astro-ph/0309685

Carretta, E., Bragaglia, A., Cacciari, C., Rossetti, E. 2003, astro-ph/0309021

Cayrel, R., Hill, V., Beers, T. C., Barbuy, B., Spite, M., Spite, F., Plez, B., Andersen, J., Bonifacio, P., Francois, P., et al. 2001, Nature, 409, 691

Cimatti, A., Pozzetti, L., Mignoli, M., Daddi, E., Menci, N., Poli, F., Fontana, A., Renzini, A., Zamorani, G., Broadhurst, T., et al. 2002, A&A, 391, L1

Covino, S., Lazzati, D., Ghisellini, G., Saracco, P., Campana, S., Chincarini, G., di Serego, S., Cimatti, A., Vanzi, L., Pasquini, L. 1999, A&A, 348, L1

Labbé, I., Franx, M., Rudnick, G., Schreiber, N.M.F., Rix, H.-W., Moorwood, A., van Dokkum, P.G., van der Werf, P., Röttgering, H., van Starkenburg, L., et al. 2003, AJ, 125, 1107

Le Fevre, O., Vettolani, G., Maccagni, D., Picat, J.P., and the VVDS Team, 2004, astro-ph/0402203

Schödel, R., Ott, T., Genzel, R., Hofmann, R., Lehnert, M., Eckart, A., Mouawad, N., Alexander, T., Reid, M.J., Lenzen, R., et al. 2002, Nature, 419, 694

Wijers, R.A.M. J., Vreeswijk, P.M., Galama, T.J., Rol, E., van Paradijs, J., Kouveliotou, C., Giblin, T., Masetti, N., Palazzi, E., Pian, E., et al. 1999, ApJ, 523, L33