DAZLE on the VLT

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We report on the commissioning and first observing run of the VLT visitor instrument DAZLE. DAZLE (Dark Ages 'Z' Lyman Explorer), is an innovative near-infrared narrowband imager optimised to detect faint emission lines between the intense hydroxyl (OH) airglow emission lines that dominate the terrestrial night sky in the wavelength range 0.8–1.8 microns. The scientific goal is to detect redshifted Lyman-α line emission from hydrogen gas ionised by the young stars in galaxies at redshifts greater than 7.5.

How and when the first galaxies formed are questions at the forefront of work in both observational and theoretical cosmology. In recent years the observational horizon has expanded rapidly and radically for those observing distant galaxies. Large-format red-sensitive detectors on wide-field imaging instruments, the new generation of 8-m-class telescopes such as the VLT and the refurbished 2.5-m Hubble Space Telescope (HST), have pushed the limits to which we can routinely detect star-forming distant galaxies progressively from redshifts of one to beyond six.

At redshift greater than seven, we probe the first 5 % of the history of the Universe, 700 million years after the Big Bang. Recently the search for young forming galaxies at redshifts greater than seven has taken on a new urgency with the remarkable recent WMAP satellite detection of polarisation in the cosmic microwave background, which indicates that there must be a significant source of ionising radiation in the redshift range $z = 7$–14. There is also supporting evidence for high rates of star formation in some galaxies up to $z \sim 10$ from the detection of old stars in $z = 6$ galaxies using the Spitzer satellite.

At the highest redshifts currently accessible, narrow-band emission lines searches using the Lyman-α emission line, from ionised hydrogen, with a rest frame wavelength of 121.6 nm, have pushed from redshifts of four (Hu and McMahon, 1996) progressively to higher redshifts and now routinely reach the boundary of Silicon-based optical detector technology at $z = 6.5$–7.0 (e.g. Iye et al. 2006). However tempered with the above successes, we have rapidly reached a watershed in the study of the high-redshift galaxies. On the ground, this is due to the inherent difficulty of detecting faint continuum emission due to the steadily increasing brightness of the night sky as one goes to redder and redder wavelengths.

The success in detecting galaxies at higher and higher redshifts using redshifted Lyman-α emission from ionised hydrogen makes it worthwhile to consider whether it is feasible to extend such searches beyond the limits of conventional Silicon-based CCD detectors used in optical astronomy and move into the near-infrared regime of HgCdTe detectors. However, in the range 1.0 to 1.8 microns, the terrestrial night sky is 10–100 times brighter than in the optical, due to intense hydroxyl (OH) airglow emission lines. In a seminal paper, Maihara et al. (1993) showed that these OH lines are extremely narrow with widths of less than 20 km/sec and, moreover, between the OH airglow line emission the background sky was 1/50th the average flux due to these lines.

To capitalise on this dark background, one needs to observe the sky at a spectral resolution of 1000 with special narrowband filters that are ten times narrower than filters normally used in the optical regime. The VLT visitor instrument, DAZLE (Dark Ages 'Z' Lyman-α Explorer, Horton et al. 2004) is designed to image between these night sky emission lines and to detect faint extraterrestrial emission lines between the intense hydroxyl airglow emission lines that dominate the terrestrial night sky in the wavelength range 0.8–1.8 microns. Prior to the DAZLE project it was considered impossible to manufacture large high-throughput interference filters with this resolution and good out-of-band blocking.

The DAZLE instrument

The original proposal was to mount DAZLE at the Cassegrain focus of the Gemini South telescope, and initial work was directed towards this goal. However, following the announcement in July 2001, that the UK would be joining ESO, the design effort was redirected to mounting DAZLE on the Nasmyth visitor focus of the VLT on UT3 (Melipal). The design of DAZLE was a collaboration between the Institute of Astronomy, Cambridge, and the Anglo-Australian Observatory.

The DAZLE instrument was designed to be mounted on the Nasmyth platform of Melipal (UT3). It does not directly contact the Nasmyth rotator and the instrument has its own motorised derotator. The instrument is shown in Figure 1 mounted on UT3. The instrument consists of an f/15 collimator that delivers light from the VLT Nasmyth field to a fold mirror. To turn the beam through 90 degrees, a filter/mask wheel assembly contains the narrowband filters and mask, a cold stop, a motorised derotator and a downward-looking cryogenic camera. The cryogenic camera operates at liquid nitrogen temperatures. The complete instrument is enclosed in a cold room, maintained at –40 °C.

The technical specification of DAZLE is summarised in Table 1.

Integration of DAZLE onto the Nasmyth platform of UT3 was completed successfully prior to the start of the scheduled commissioning nights on 30 and 31 October 2006. We ensured that the integration of DAZLE on Paranal had minimal impact on ESO staff effort by shipping by boat to Antofagasta the major components of DAZLE already assembled within a standard 40 ft (12.2 m) ISO shipping container. Figure 2 shows the DAZLE commissioning team including ESO staff in the Melipal (UT3) control room.

Figure 1: DAZLE being mounted on the VLT UT3 (Melipal) visitor focus.

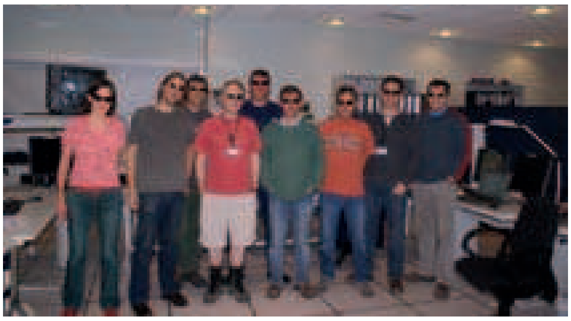

Figure 2: DAZLE Commissioning team including ESO staff in the VLT UT3 (Melipal) control room.

Detector array	Rockwell Hawaii-2; 2048 × 2048 pixels
Spatial scale	0.2 arcsec per pixel
Field of view	6.8 arcmin × 6.8 arcmin
Central wavelength	1.056, 1.063 microns
Peak transmission	72 %
Spectral resolution	1200
Bandwidth (FWHM)	9 ångströms
Redshift of Lyman-α	7.70

Table 1: The technical specification of DAZLE.

First results

Data from a science verification observation is shown in Figure 3. Science verification for the DAZLE programme involved the determination of the filter throughputs and sky background via observations of spectrophotometric standards with IR coverage from the FORS2 calibration plan. In addition we selected a quasar with a redshift that placed the narrow forbidden [O III] 5007 Å line within the bandpass of one of the filters. Figure 3 shows images of the $z = 1.110$ quasar. The [O III] 5007 Å line has a predicted observed wavelength of 1056.5 nm. The left-hand image is through the NB 1056 nm filter and the right-hand image is through the NB 1063 nm filter. The quasar is clearly detected in the 1056 nm filter centred on the predicted wavelength of redshifted [O III] whereas the quasar is undetected in the 1063 nm image.

The science programme was carried out primarily on the nine nights from 2 to 10 November. Around 0.5 nights were lost over two nights due to high wind when UT3 was closed. Apart from this, no observing time was lost due to DAZLE or the VLT systems. During the remaining time we accumulated a total on-sky integration time of 69 hrs excluding time spent on calibration such as spectrophotometric standards and twilight flats. Twilight flat observations were started soon after sunset each night and science observations would commence before the end of astronomical twilight.

The measured seeing in our images during the run ranged from 0.4 arcsec to 1.3 arcsecs. As proposed, we executed the shallow survey when the seeing was poor. The two deep survey pointings in the GOODs-South field have exposures of 10 hours per filter. The on-sky measured sensitivity of DAZLE, which includes detector (Rockwell HgCdTe HAWAII-2) dark current, read-out noise, instrument and sky background, gives a 5σ sensitivity of 3–5 × 10^{-18} erg s^{-1} cm^{-2} in 10 hours in a 1 arcsecond aperture.

A dark-corrected, flat-fielded image in the 1056 nm filter of the GOODS-South field can be seen in Figure 4. We are reasonably confident that we were seeing the 'true' sky background because we could see rings of very marginally higher background due to expected faint OH lines encroaching on the wings of the filter transmission profile. Figure 5 shows a 'colour-magnitude' diagram for objects detected in the 1056 nm filter image of the GOODS-South field. Objects with an emission line in the 1056 nm filter will have a positive flux excess. One such object is shown in Figure 6. The object is detected in the 1063 nm filter, but absent in the 1056 nm image. Based on the colours in the COMBO-17 survey, the galaxy has a photometric redshift of 0.606. Therefore this object is most likely a galaxy with a redshifted H-α line emission in the 1063 nm filter at redshift of 0.62.

Acknowledgements

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References

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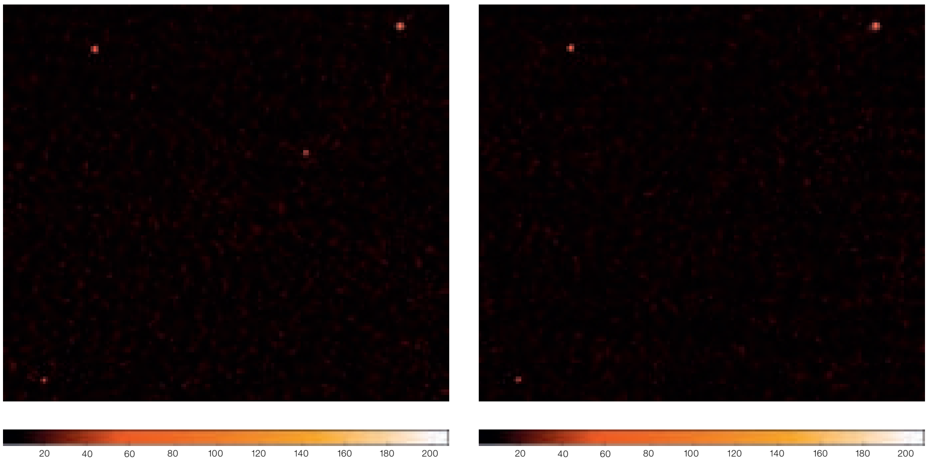

Figure 3: DAZLE images of the quasar (z = 1.11) taken in the narrow 1056 nm filter (left) and in the 1063 nm filter (right), showing the prominent [O III] emission line in the 1056 nm filter.

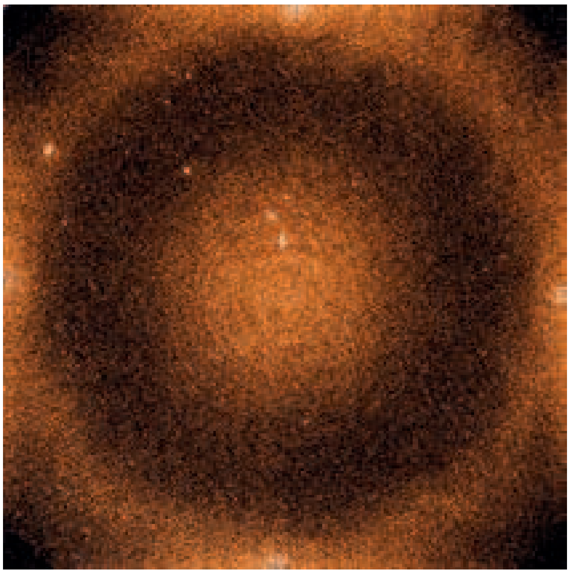

Figure 4 (left): 10-hour DAZLE image of the GOOD-South field in the 1056 nm filter.

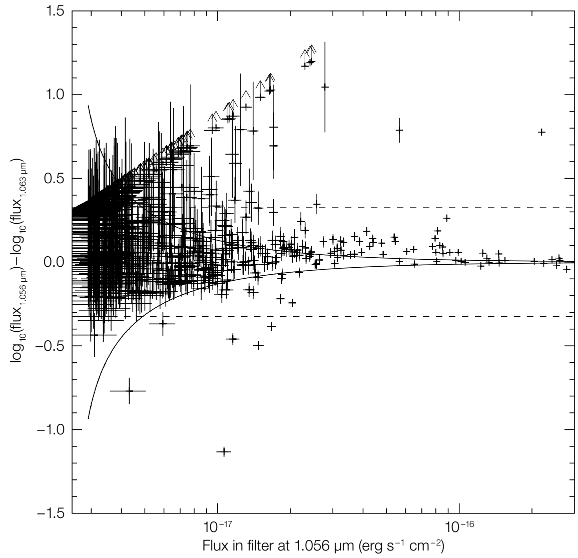

Figure 5: A DAZLE 'colour magnitude' diagram of the objects in the GOODS-South field positively detected in the 1056 nm filter.

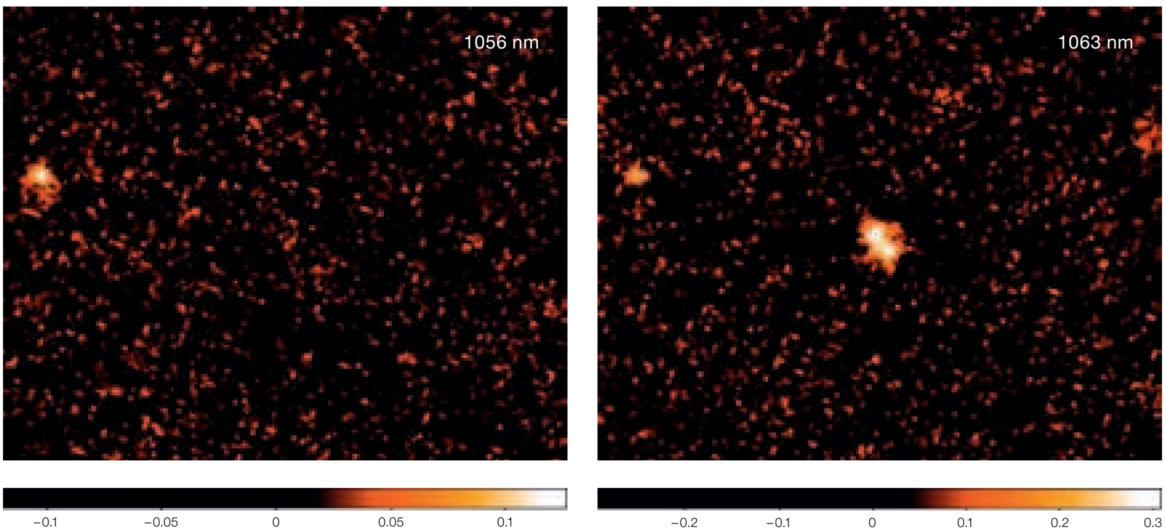

Figure 6: DAZLE images in the 1056 nm and 1063 nm filter showing an emission-line galaxy in the 1063 nm filter with an assumed redshift of 0.62 for H-α.