Towards Integrated Modelling: Full Image Simulations for WEAVE.

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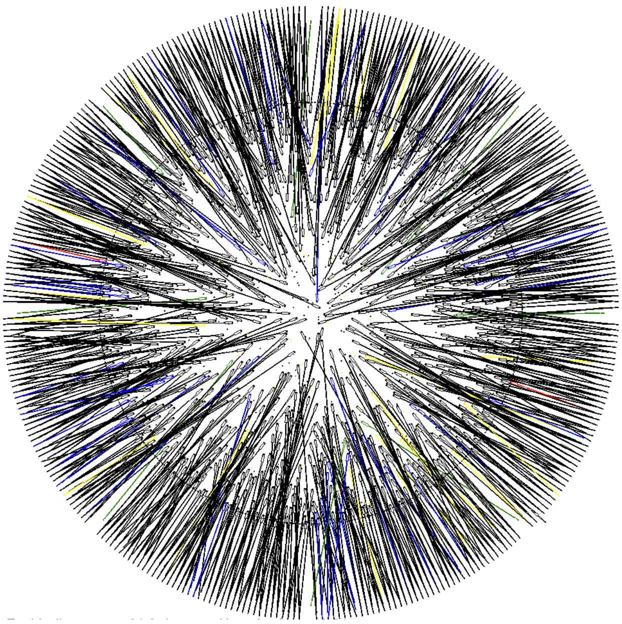
ABSTRACT

We present an integrated end-end simulation of the spectral images that will be obtained by the weave spectrograph, which aims to include full modelling of all effects from the top of the atmosphere to the detector. These data are based in input spectra from a combination of library spectra and synthetic models, and will be used to provide inputs for an end-end test of the full weave data pipeline and archive systems, prior to 1st light of the instrument.
Keywords: Multi-Object Spectroscopy, Fibre Optics, High Resolution Spectroscopy

INTRODUCTION



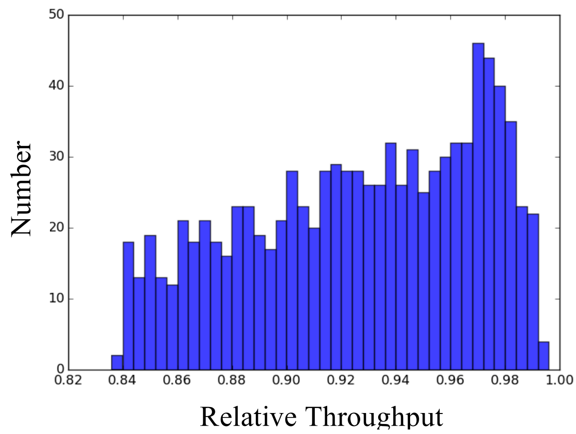


Figure 1: (left) Example configured field[5] used in the simulation. Fibres allocated to sky are shown in blue, guide fibres in yellow. The 8 gaps around the field due to the presence of the guide fibre retractors are clearly visible. (right) the distribution of throughput variations for light entering the fibres in the telescope focal plane.

WEAVE is a next-generation multi-object spectrograph under construction for the 4.2 William Herschel Telescope (WHT) at Isaac Newton Group of telescopes on the island of La Palma. WEAVE will provide the WHT with a new well-

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corrected 2 degree field of view at prime-focus, with a flat, near-telecentric focal plane and scope for a 1 Tonne prime focus instrument package. A buffered pick-and-place positioner system[1] (similar to AAOs 2dF[2]) will allow up to 1000 individual fibres to be deployed at the focal plane (Figure 1), with a pair of off-the-shelf linear robots working in concert to allow reconfiguration of the 2nd plate within the time required for a 55 minute observation. The positioner also supports two Integral Field modes. Fibres from the prime focus are routed down the telescope to a dual-beam spectrograph located in the GHRIL room on the Nasmyth platform which will support up to 1000 1.3" fibres to give full coverage from 366nm to 950nm at R~5000 or ranges at R~20000 (See Ref [3] for a more detailed project overview).

MOTIVATION FOR THE SIMULATOR

In the initial spectrograph concept design, the aim was to arrive at a design with ~3 pixels sampling of the fibre core images with a weak contribution to the image spread from the optical design itself. The resolution specifications were modelled on this basis, so that the specifications were for recovered resolution, rather than that obtained from the simple grating equation. Contour maps of the expected recovered resolution, generated from Zemax with input fibre images, are shown in Figure 2 below for the low-resolution mode[4].

The variations seen below imply that fibres at different slit positions will deliver variations in the quality of the output spectra, and these should be taken into account by the WEAVE data processing pipelines. We therefore decided to implement a full image simulation for WEAVE, to provide an accurate indication of the nature of the data for the pipeline development, and an early view of the likely quality of the final data for the WEAVE science teams.

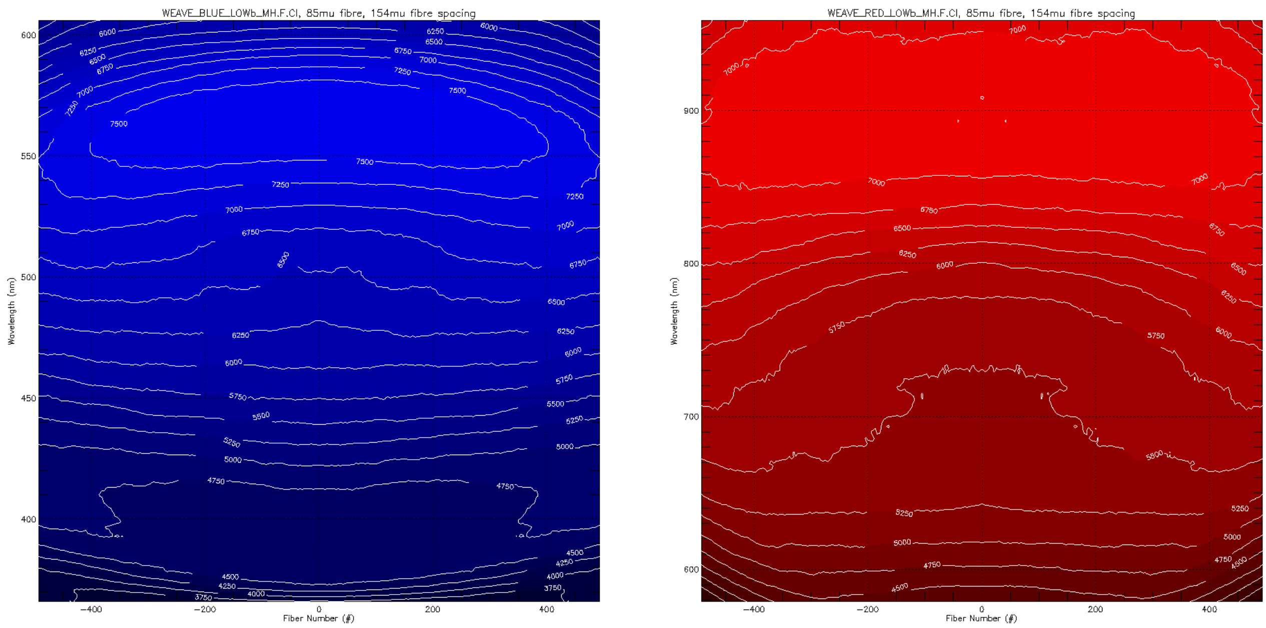

Figure 2: (Reproduced from [4]) Resolution maps for the LR mode of the WEAVE spectrograph for the blue and red cameras, obtained from ZEMAX ray tracing of a fibre core image and application of a Rayleigh criterion to the images.

INPUT PSF IMAGES

We began by generating geometric monchromatic images from zemax for each fibre at 9 wavelengths in each mode of the spectrograph. These images include the effects of vignetting within the spectrograph optics, but do not include scattered light effects. We sampled 10,000,000 rays for each image in order to be sensitive to the wings of the psfs to provide an accurate indication of the crosstalk between adjacent fibre images. Each image is sampled over a 25x25 grid of 15 micron detector pixels. Figure 3 shows the central regions of the 9 psfs for the blue arm of the low resolution mode, for the central fibre (upper set) and the extreme fibre at the slit-end (lower set).

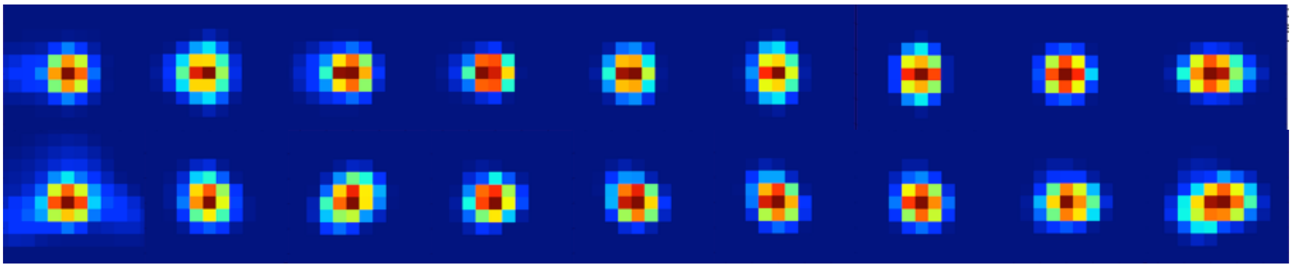

Figure 3: PSF images for the blue camera in low resolution mode at (left-to-right) 366, 390, 424, 457, 490, 520,549,578 and 606nm, respectively. Images shown are for the central (1, top) and extreme (480, bottom) fibres in the slit unit.

INTERPOLATION SCHEME

For each fibre, we interpolate between the 9 ZEMAX PSFs with low-order polynomials to generate a set of 20000 25x25 pixel PSFs covering the full wavelength range for that mode with a wavelength interval that is linear in detector pixel space. We generate this basis by mapping a high-resolution sky spectrum (see below) into this range with appropriate sampling achieved by a simple spline interpolation. Since the individual PSFs from ZEMAX are automatically centered on the peak intensity, each of these 20000 grids is then resampled into the real detector coordinate system using a rectangular bivariate spline of order 2 from the SciPy interpolation package. As a cross-check on the validity of this scheme, we compared a number of mid-range interpolated PSF images with the 'true' counterparts from ZEMAX.

INPUT TARGET SPECTRA

We take a simulated weave target field and generate the full fibre configuration using WEAVE's configure software[5]. We calculate the throughput loss for each fibre corresponding to its position in the focal plane, arising from the radial vignetting variation in the prime focus corrector, and the mis-match between the input chief ray and the angle of the fibre button at this position in the field, as this varies with the radial position and the non-radial position angle of the fibre. For targets not assigned to sky positions we then assign a random object type, magnitude and radial velocity: for low-resolution stars, the input spectra are currently generated from the XShooter spectral library[6]. For high-resolution stars we use the models generated for 4MOST[7]. For input AGN spectra we use low-resolution spectra from Kinney & Calzetti[8]. For galactic stars we assign magnitudes in the range $15 < v < 20$, and a toy-model velocity distribution model. For AGN we assign magnitudes in the range $20 < v < 24$ and redshifts in the range $0.5 < z < 1.5$. At present these are intended to be indicative, rather than representative, and will be refined as we move towards a full end-to-end simulation run. Each image is then generated as a set of 3x20 minute exposures with 2 full 6kx6k CCDs for each camera, together with arc (ThAr spectrum from the KPNO atlas[9]) and flat (blackbody spectrum) images in sequence to test the full data pipeline. Each spectrum is generated with appropriate photon noise, sky background and sky noise, resampled to the same input wavelength basis as our PSF grid, and scaled at each wavelength by the expected weave throughput and sky transmission profile (from ESO's skycalc[10,11]). A sub-area of the 3-image (1hour integration) stack for a single observation is shown in Figure 4.

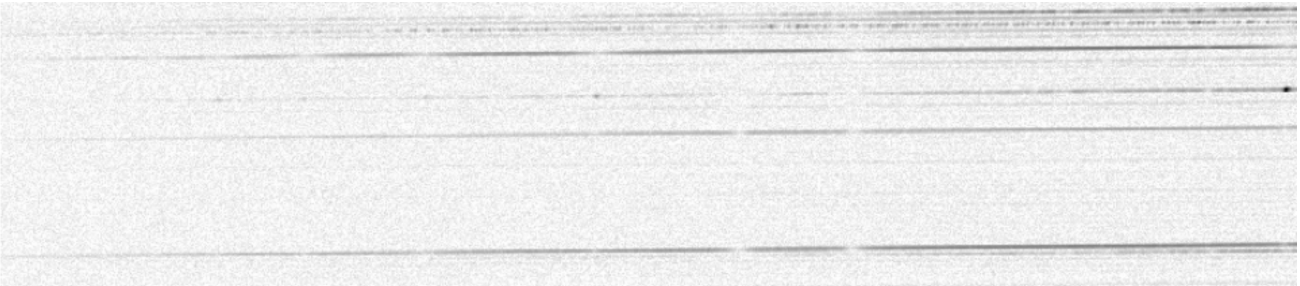

Figure 4: Sub-area of the low-wavelength chip in the blue camera showing the area around the 4000 Angstrom break for a subset of the spectra in a combined 1 hour exposure at low-resolution. Balmer absorption features are clearly visible, as are the Calcium H and K lines and some extra-galactic emission features in AGN spectra.

PROCESSED DATA

The output data from the simulator, including bias frames, flat-field images, arc spectra and images with only every third fibre illuminated (to allow a full tracing of the spatial PSF for each fibre) and science frames, were passed to CASU and run through the current prototype of the WEAVE core pipeline system (CPS)[12]. Figure 5 shows the final extracted spectrum (after wavelength calibration and sky-subtraction) of an 18th magnitude representation of a BVII star (input spectrum was HD 34797 from the XShooter Spectral Library[17]).

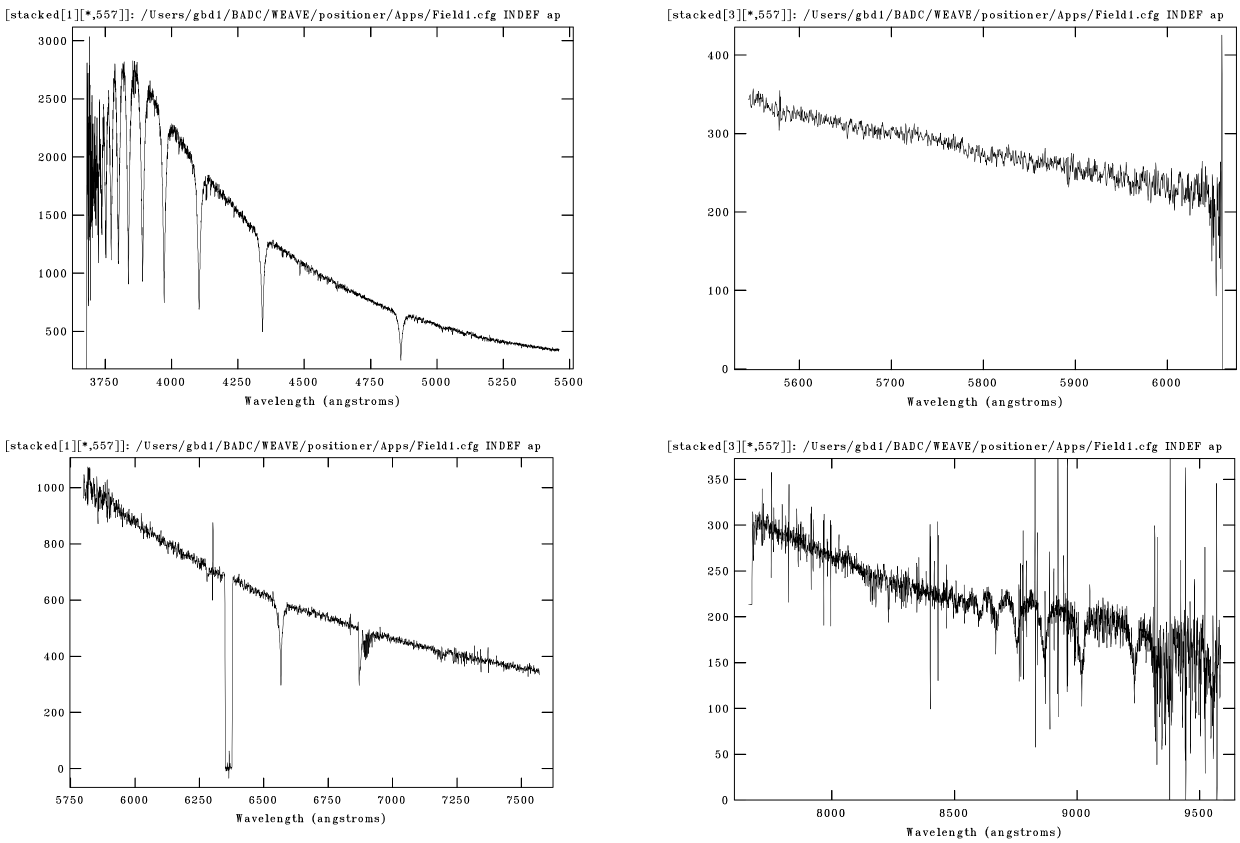

Figure 5: Simulated spectrum from fibre 82 of the image refered to in Figure 4, processed through an early version of the WEAVE CPS pipeline at CASU. The input star is HD 34797 from the Xshooter Spectral Library, scaled to 18th magnitude for a 1 hour exposure.

Since the two primary objectives of the simulation were to validate the instrument performance in terms of sky subtraction quality and spectral crosstalk, we give two further illustrations: In Figure 6 we show the residuals from a sky fibre after the data pipeline has extracted the best estimate of the sky from the ensemble of sky fibres in the image, and accounted for the illumination variations as derived from the flat field frame.

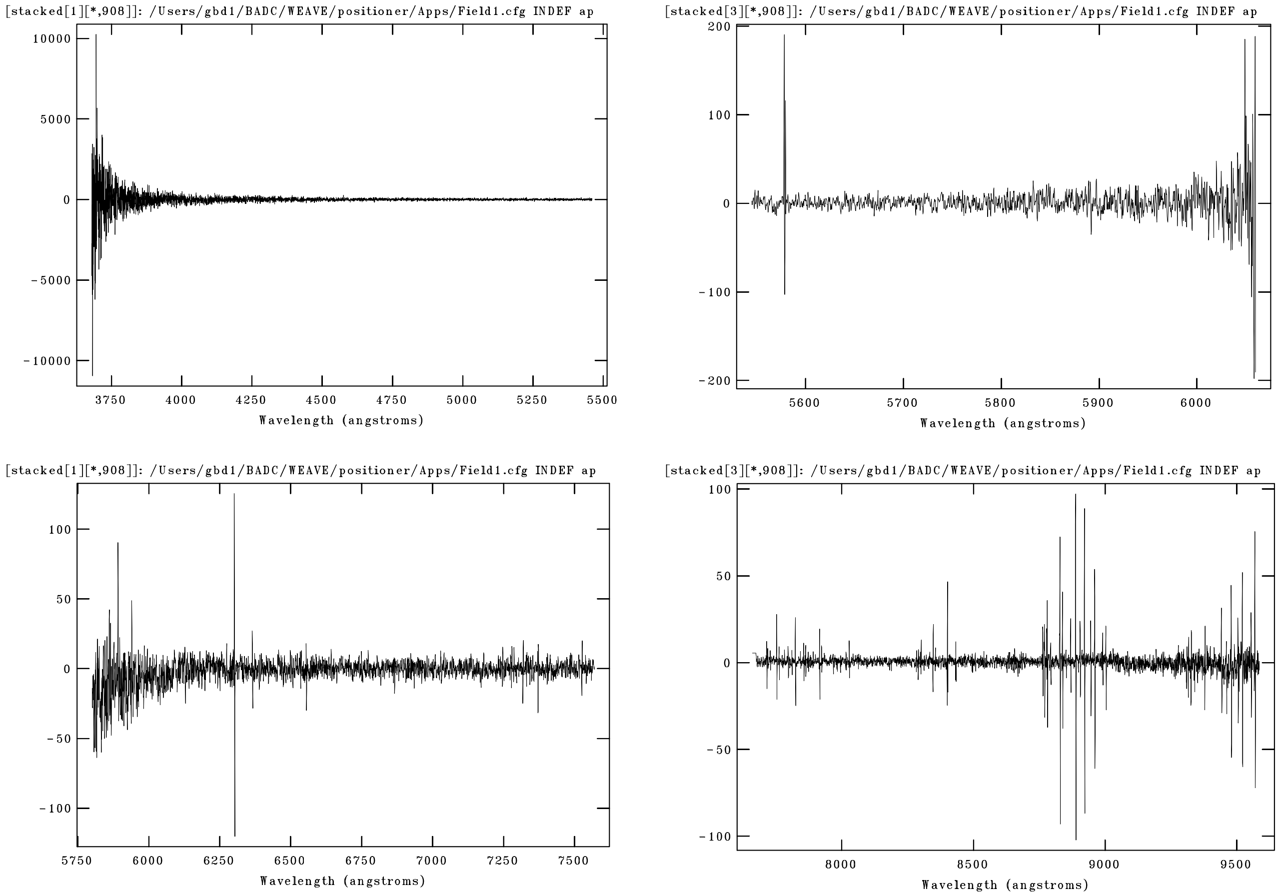

Figure 6: Extracted sky-subtracted sky spectra from one of the sky fibres close to the end of the slit. The residuals are consistent with the expected Poisson noise in the spectra, even after correction for the varying vignetting factors present in the different fibres in the simulation. The increased noise level in the region of the dichroic is obvious.

In Figures 7 and 8, we show examples of spectra where bright and faint sources fall in adjacent fibres at the slit, illustrating that there remains no significant crosstalk in the extracted spectra. In the upper panel we show the spectrum of a 15th magnitude B star taken from Fibre 336, which is 300 fibres out from the centre of the slit, together with the spectrum of a 21.8 magnitude galaxy in the adjacent fibre.

There is no evidence of significant crosstalk in the output galaxy spectrum. As a caution, we note that this is a simulation of the as-designed spectrograph, and there are clearly many milestones to be achieved in manufacture and integration before these predictions are realized on sky. Nevertheless we consider these to be a good indication that WEAVE should be capable of delivering on its design requirements.

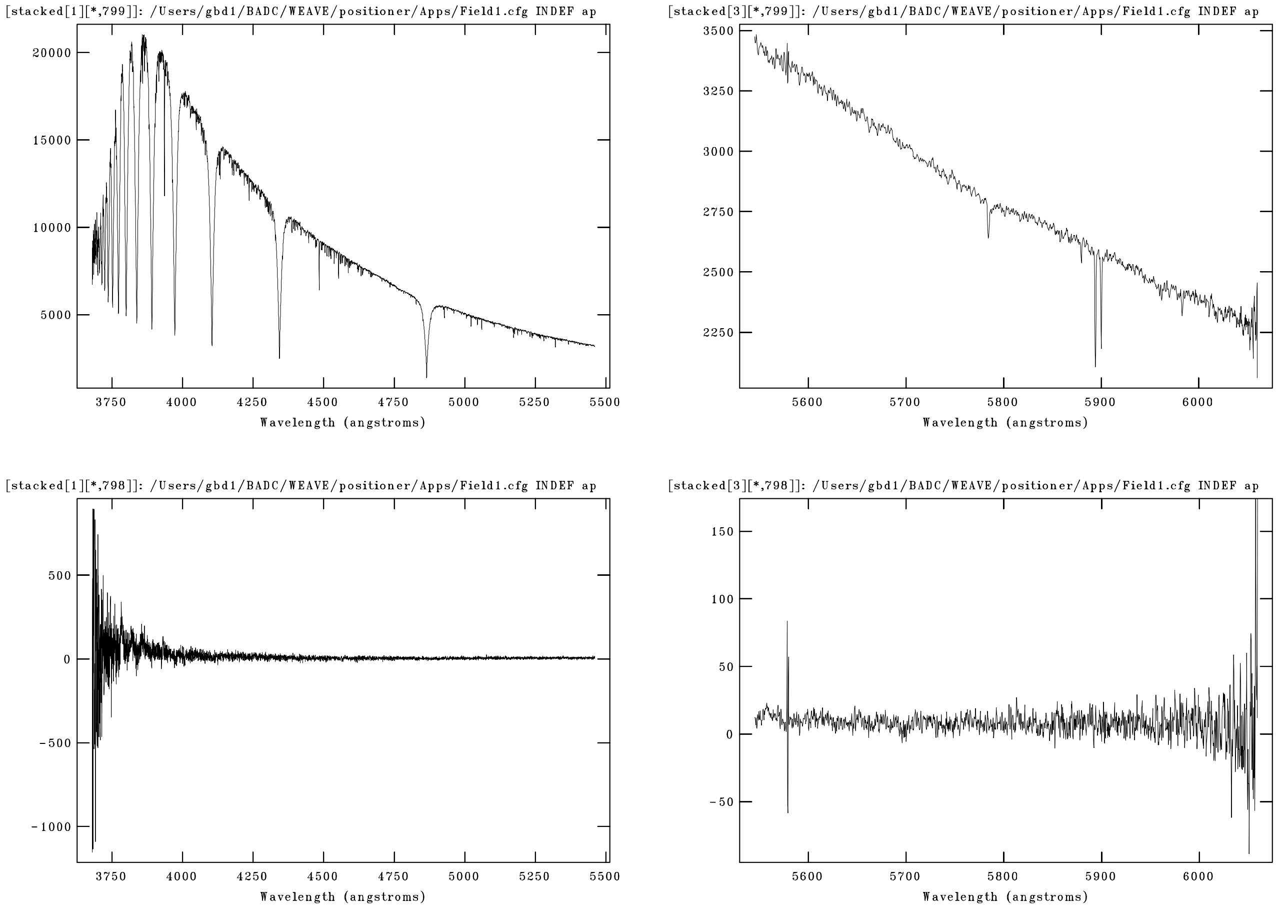

Figure 7: Blue arm spectra for fibres 336 (top) and 335 (bottom). 336 contains a spectrum of HD147550 scaled to a V-band magnitude of 15.1, while the adjacent fibre 335 containes a high-redshift starburst galaxy template scaled to V=21.8.

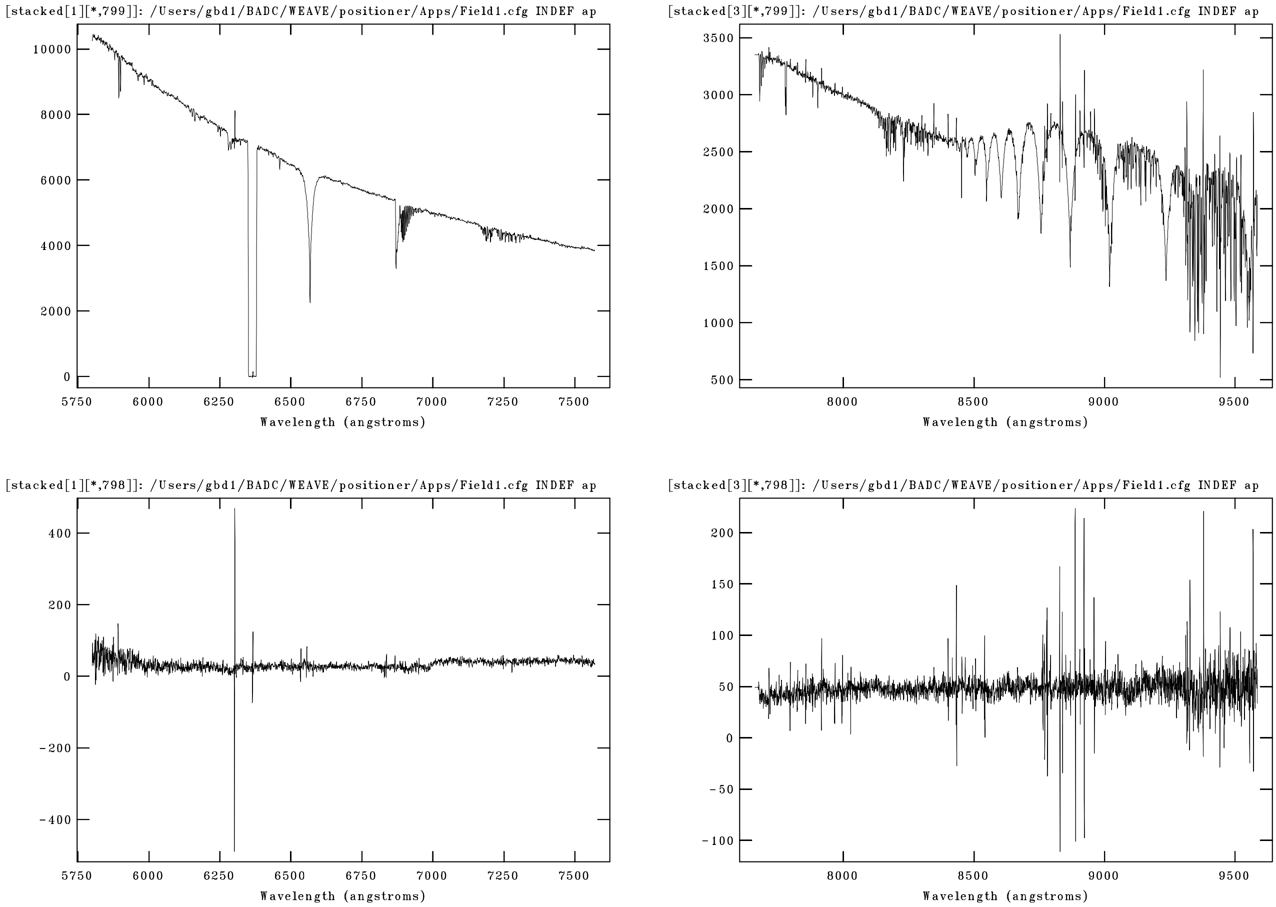

Figure 8: Red arm spectra for the same two fibres as Figure 7. The Calcium H and K lines are clearly visible around 7000 Angstoms in the galaxy spectrum, but there is no significant contamination from the 7-magnitudes brighter object in the adjacent fibre.

ACKNOWLEDGEMENTS

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