Multi-object spectroscopy data reduction: the AF2+WYFFOS pipeline

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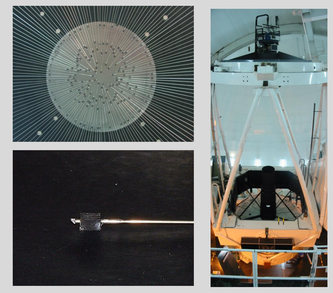
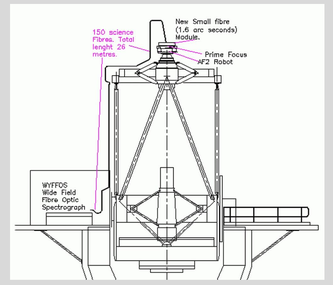


Abstract.
The scientific productivity of complex instrumentation depends strongly on the availability of data-reduction pipelines. In the case of AF2+WYFFOS, the multi-object fibre-fed spectrograph at the WHT prime focus. In the past, the non-availability of a dedicated pipeline has hindered full scientific exploitation of the AF2 data.
An IDL-based pipeline has been developed to overcome this. It performs full reduction of AF2+WYFFOS data, including fibre-to-fibre sensitivity corrections and optimal extraction, with provision for quick-look.

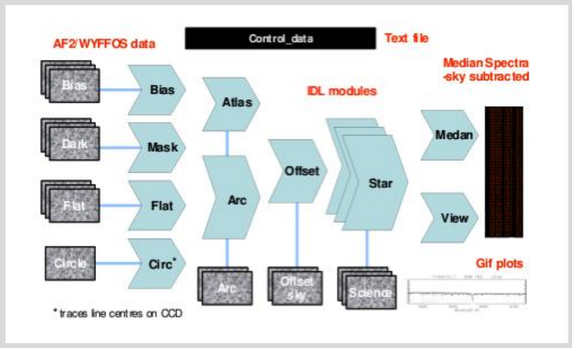
AF2+WYFFOS characteristics

Field of View	1 degree (useful 40 arcmin)
MOS multiplex	150 science fibre + 10 fiducial bundles
MOS fibre aperture	1.6" science fibres + 8" fiducial bundles
Wavelength coverage	3700 – 9600 Å
Spectral resolution	R = 400 – 4000 in reflection mode R = 10000 – 11000 in echelle mode
Detectors	Red+4 (4k x 4k, red-sensitive, low-fringing) WHTWFC (two 2k x 4k chip EEV, blue sensitive)



Pipeline process

The pipeline consists of a series of modules, written in IDL, which perform each step in the data reduction process



Main steps of data reduction:

1. Set up directories and load raw data + create/edit **control files**
2. Run calibration modules: **Bias, Mask, Flat, Circ**
3. Perform wavelength calibration: **Arc, Atlas**
4. Extract offset sky spectra, transform spectra onto a common wavelength base and find median of offset sky observations: **Offset**
5. Extract science target spectra, transform spectra onto a common wavelength base, and subtract median sky spectra: **Star**
6. Create median of all spectra of each target: **Medan**

1. Reduction block preparation + control files

The data reduction is organized in **reduction blocks (RB)**, defined by a project directory and a parameter control file.

Project directory

- data — AF2+WYFFOS raw data
- int — Intermediate pipeline products
- log — Pipeline log files
- spec — Output spectra in fits files + ASCII table
- temp — Output spectra in gif format

Control_data file

- Data that vary for each RB — Key parameters, options, data field numbers
- Data that vary for each AF2+WYFFOS setup — E.g. Related to wavelenght calibration
- Quasi-standard parameters — Do not generally vary from the default values.

2. Calibration modules

- **Bias module:** creates a median bias frame to debias other calibration frames and science images
- **Mask module:** determines the minimum dark current per pixel + create a mask of hot pixels above a specified cut-off level
- **Flat module:** calculates the median of a set of debiased flat images, after each individual flat has been scaled according to their mean value.
- **Circ module:** traces the spatial position of the spectra produced by each fibre using as input sky or lamp flat frames. It also evaluates and stores the median value of the signal level midway between fibre spectra, to later compensate for the effect of scattered light in the CCD.

Version 2 of the pipeline will be released on July 2014. It includes a series of enhancements with respect to the v1.02 version. The most important are listed below:

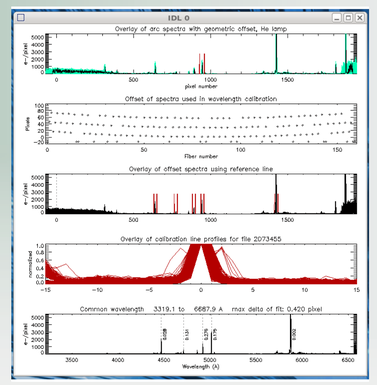
1. **Alllows the user to reduce data with either the old WHTWFC or the new Red+4 detectors.**
2. **Output data products are in a format compatible with IRAF.**
3. **Circ module includes an algorithm that calculates more accurate fibre traces along the whole CCD, combining extrapolation and Gaussian fitting to individual fibres.**

A future version will include improvements like:
- **A more user-friendly routine for the wavelength calibration.**
- **An algorithm for a more accurate sky subtraction based on a principal component analysis (PCA)**
- **Modular pipeline routines that can be used for reducing data of other MOS spectrograph and through other pipelines.**

3. Wavelength calibration

Arc + atlas modules:

1. Estimate the dispersion-axis offsets as function of the fibre number across the CCD, using as reference a strong arc line in the middle of the spectral range selected by the user.
1. Identify the approximate pixel location in the dispersion direction and exact wavelengths for a set of well-separated unsaturated lines in the arc spectra, using as a reference a predefined table of arc-line data
1. Estimate the precise position of the arc line peaks by fitting Gaussian profiles over a section of the spectrum encompassing each peak.
1. Determine the coefficients of a cubic polynomial of wavelength against pixel number for each fibre.



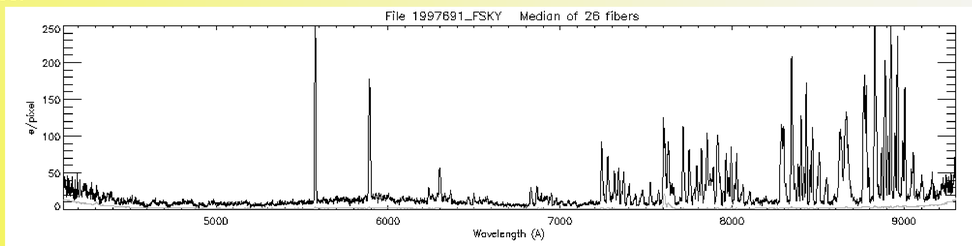
4. Sky spectra

The pipeline allows to choose between two options for the sky background estimation:

1. Estimate a median sky spectrum from a number of sky allocated fibres.
2. Estimate the sky spectra of each individual fibre from the median of a series of offset sky observations.

Currently, there are three options for sky subtraction:
1. The median or offset sky spectrum is subtracted from the target spectrum
2. The median or offset sky spectrum is scaled prior to subtraction
3. The median or offset sky is scaled and the output spectrum is masked over strong sky lines.

We are working in the implementation of a more robust method for the sky subtraction based on a principal component analysis (PCA) described in Wild & Hewett (2005), which takes advantages of the correlation in the form of the sky-subtraction residuals present in each spectrum.



5. Science spectra extraction + spectra combination

Star module performs the science spectra extraction, and then produces a sky subtracted output spectra on a common wavelength.
- The process used for **optimal extraction** of the spectra follows the algorithm given by Horne (1986). It uses a weighting function, which is the normalised spatial profile at a given wavelength. **The pipeline estimates the spatial profile by taking a boxcar average of a flat image in the wavelength direction.**
- The effect of masked pixels in the CCD image is corrected. Excessive noise at individual pixels of the line spectrum introduced typically by cosmic ray hits is also taken into account.
- The effect of scattered light is reduced by subtracting, prior to the extraction of the spectra, the local background signal level estimated by linearly interpolating the median signal recorded between adjacent fibre spectra by the Circ module.

Medan module reads the output spectra for each science observation in a RB and evaluates the median spectra for each fibre. Spectra are normalised to their mean value before the median is calculated to compensate for variations in seeing between frames.