Multi-object fibre spectroscopy at the WHT: Performance enhancements of AF2+WYFFOS

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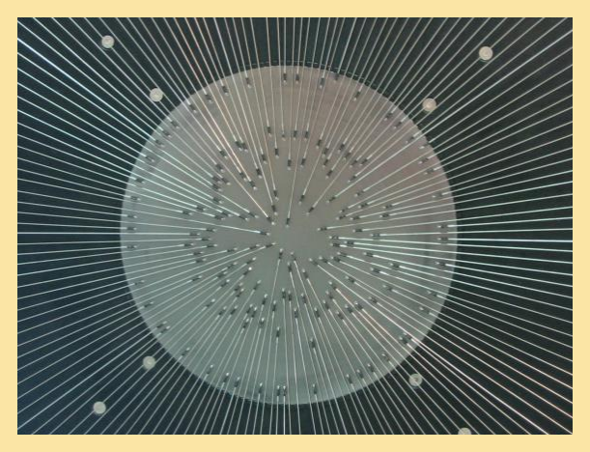


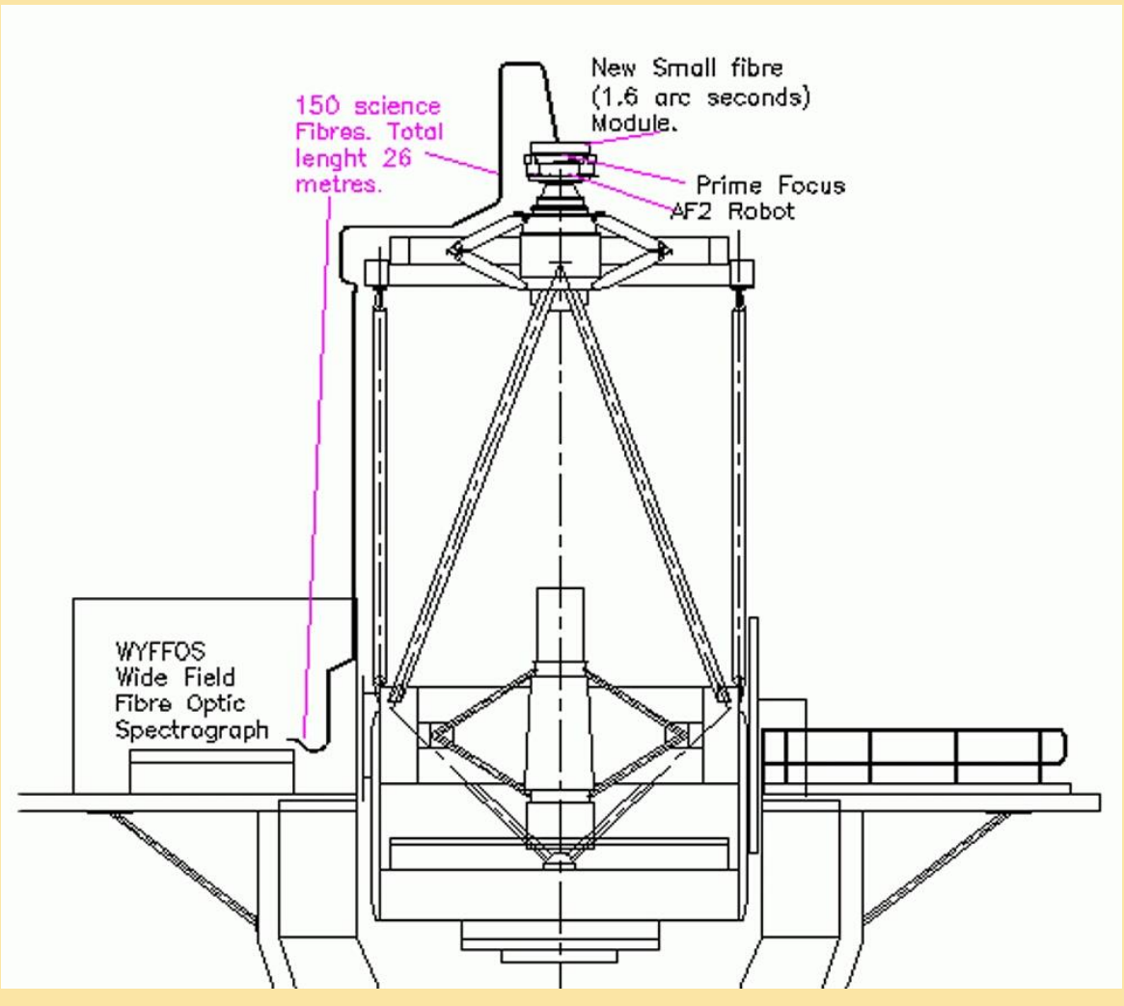
Abstract.

AF2+WYFFOS is the multiobject 1º-field fibre-fed spectrograph at the prime focus of the 4.2m WHT. Its demand had been decreasing in the course of the years, with observers often reporting an overall throughput well below that expected. Given the strategic importance of multi-fibre spectroscopy for the WHT future, with the coming of WEAVE, during 2013 and 2014 ING staff carried out an end-to-end analysis of the reasons that caused the loss of photons. The developments addressed target-acquisition/positioning/guiding, focal plane geometry, optical transmission and overall system throughput measurements. A new 4kx4k low-fringing CCD has been provided for WYFFOS.

AF2 performance has improved very significantly as a result of these enhancements, and we believe that, as a wide-field multi-object spectroscopy facility at the WHT, it is ready to perform as a useful precursor and science test-bed for WEAVE surveys. http://www.ing.iac.es/astronomy/instruments/af2/.

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)



Target-acquisition improvements

Target acquisition is one of the trickiest aspects of multi-fibre spectroscopy.
Aperture losses due to the seeing are easily aggravated by positional errors.

On-sky raster tests showed that fibres were not well centred on target positions but **offset by up to ~1.3“ (rms~0.9”,90 percentile 1.16“).** See Figure 2.

Unacceptably large offsets that can cause the **loss of the ~70% of the flux.** See Figure 1.

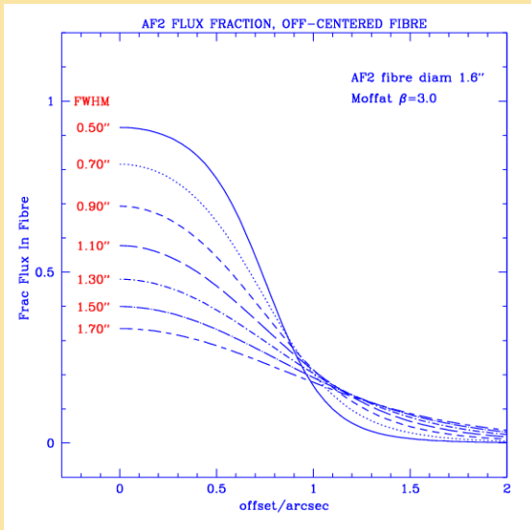


Figure 1. Fractional flux from a point source that makes it into the 1.6-arcsec AF2 fibres decreases with the offset between target and fibre centre. Curves are shown for different seeing values

WHY??

SOURCES OF FIBRE POSITIONAL ERRORS:

1.Astrometric errors
2.Differential refraction
3.Acquisition + guiding errors
4.Errors in the field distortion map
5.Mechanical robot errors

User’s responsibility

ING’s responsibility

BEFORE

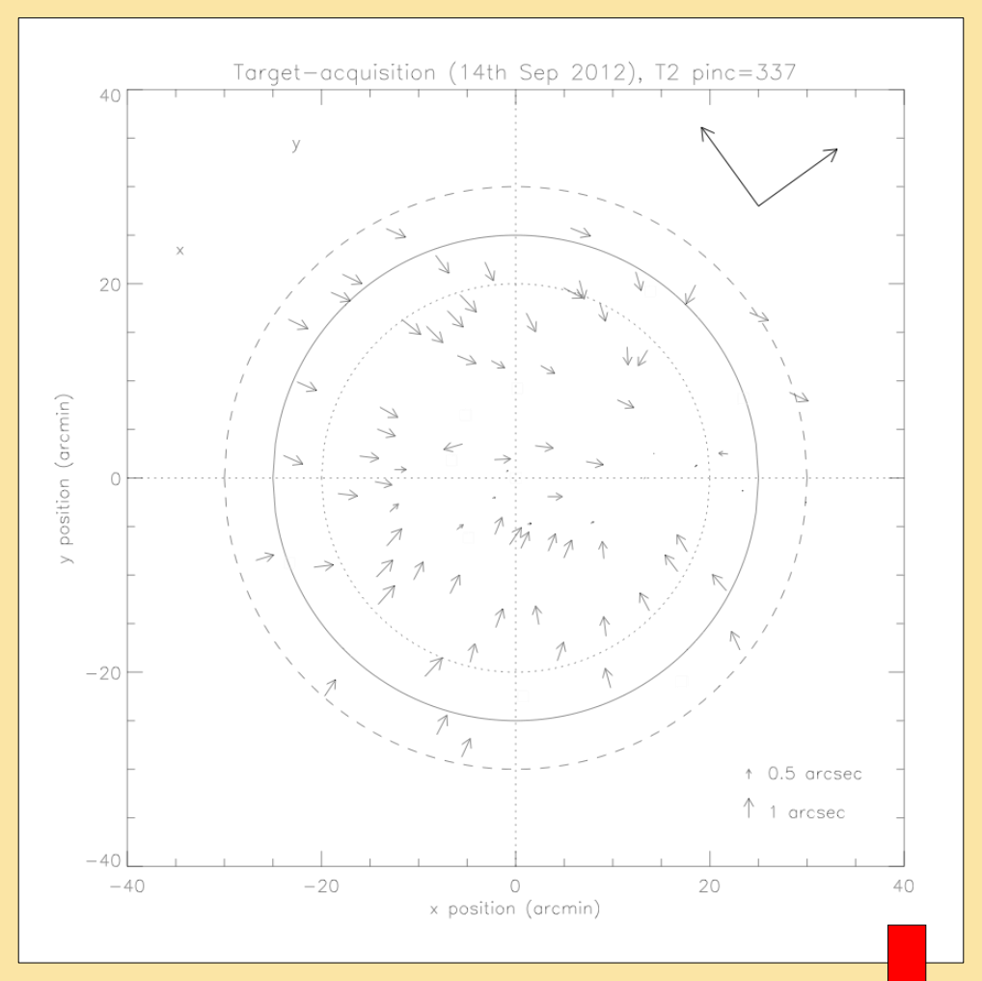


Figure 2. Fibre positioning error pattern BEFORE enhancements. **(rms~0.9”,90 percentile 1.16“)** Dotted line: 20 arcmin radius. Solid line: 25 arcmin radius. Dashed line: 30 arcmin radius.

New acquisition + guiding tool

Improving the acquisition procedures leads to an improvement of the fibre centring.

Previous acquisition+guiding procedures:
-Manual acquisition: visual estimation of offsets to centre the star in the fibres ➔ Subjective + not accurate + time consuming.
-Guiding only in one stars ➔ higher guiding errors
-Acquisition errors up to 0.5” in translation.

`FibreGuider`, the new acquisition+guiding tool:
-**Automates the acquisition process by finding, and applying to the telescope control system, the translation and rotation offsets that optimally centre the reference stars on the fiducial fibres**
-**Allows guiding with all (or a selected subset) the fiducial stars**
-**Acquisition errors < 0.2” in translation and negligible in rotation**

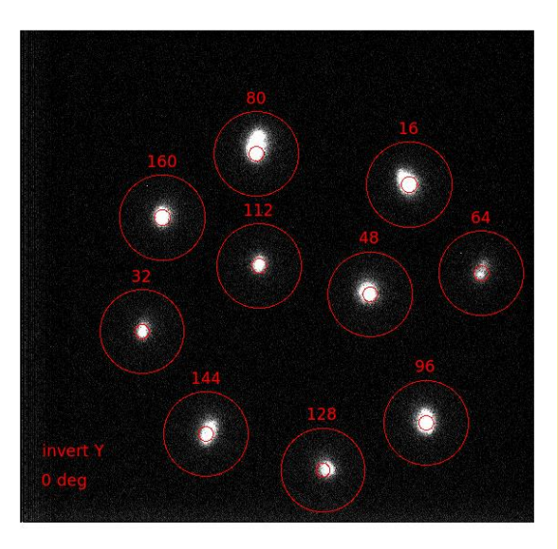
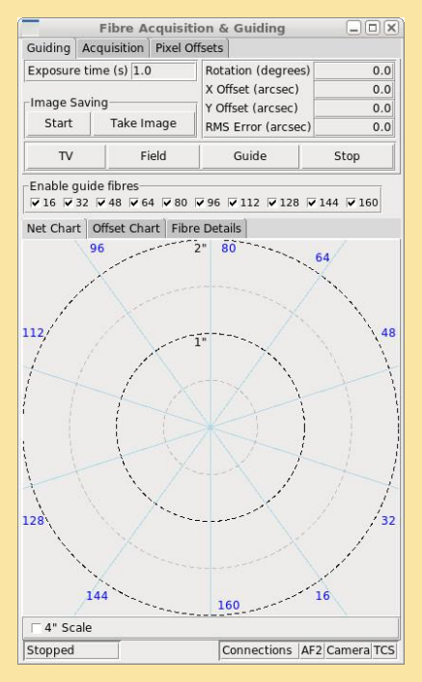


Figure 3. Field acquisition image showing the centring of the fiducial stars onto the the fiducial bundles.



Fibre Acquisition & Guiding
Guiding | Acquisition | Pixel Offsets
Exposure time (s) 1.0
Rotation (degrees) 0.0
X Offset (arcsec) 0.0
Y Offset (arcsec) 0.0
RMS Error (arcsec) 0.0
Image Saving: Start | Take Image
TV | Field | Guide | Stop
Enable guide fibres: ☑ 16 ☑ 32 ☑ 48 ☑ 64 ☑ 80 ☑ 96 ☑ 112 ☑ 128 ☑ 144 ☑ 160
Net Chart | Offset Chart | Fibre Details
☐ 4" Scale
Stopped
Connections | AF2 | Camera | TCS

Figure 4. FibreGuider acquisition tool.GUI.

AFTER

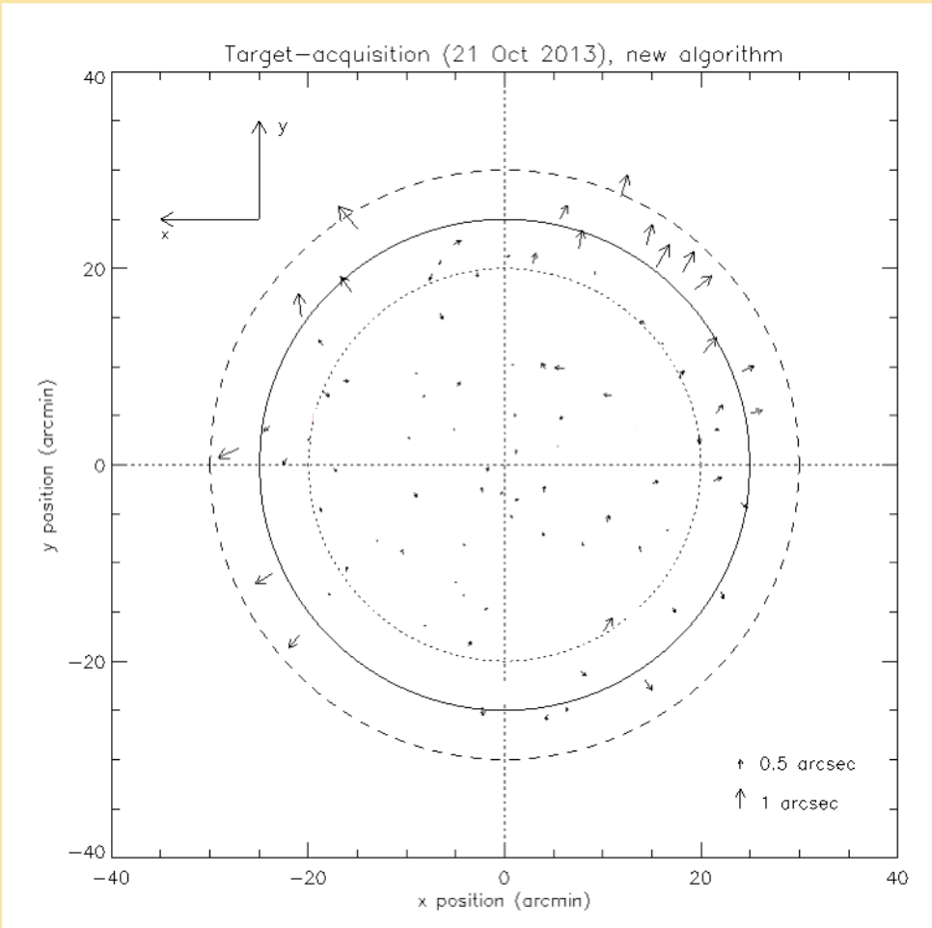


Figure 5. Fibre positioning error pattern AFTER enhancements **(rms~0.26”,90 percentile 0.39“)**. Dotted line: 20 arcmin radius. Solid line: 25 arcmin radius. Dashed line: 30 arcmin radius.

Updated distortion map

New distortion map parameters determined empirically using telescope raster tests.

New pincushion coefficient **q=320 rad^{-2}**

The focal plane geometry is **now accurate to better than 0.25 arcsec at 20 arcmin radius field of view** and to better than 0.05 arcsec over the central 10 arcmin radius.

Previous distortion map, with a pincushion coefficient q = 337.7, was responsible of ~80% of the fibre offsets inside the central 20 arcmin radius field of view.

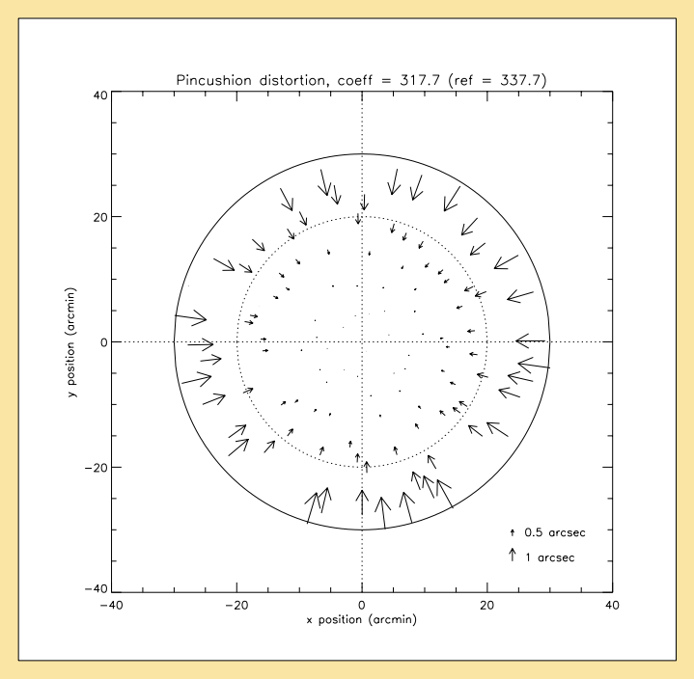


Figure 6. Offsets of fibre positions in the plate for a particular fibre configuration. The begining of the arrows show the position with pincushion value is 337.7, and the end of the arrow the position when it is 317.7. Dashed line: 20 arcmin radius. Solid line: 30 arcmin radius.

Mechanical robot precision

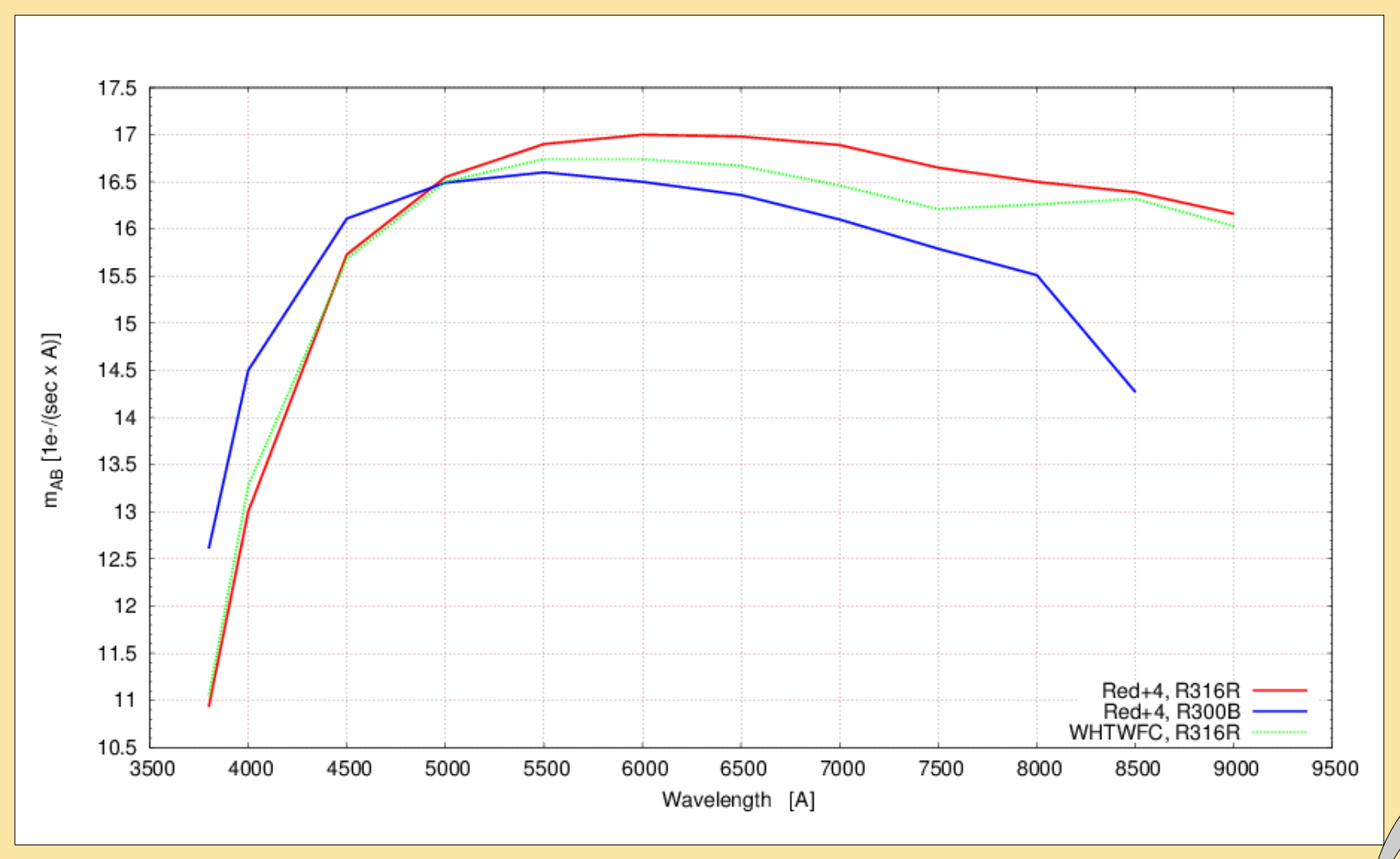
Repeatability is excellent: 95% percentile error of 0.17”. Contribution of mechanical errors to the fibre positioning is small, however some improvements have been performed.

- **Improved fibre centroiding algorithm for the iterative fibre placement sequence:** more accurate and stable centroiding, especially with damaged or dirty fibres.
- **Implementation of a bi-dimensional algorithm to compensate the correction of residual systematic errors in the positioning of the fibres**: it corrects ~80% of the mechanical systematic errors vs the 15% correction of the previous algorithm.

Overall system throughput measurements

The throughput of AF2/WYFFOS was measured during February and May 2013, for grating/CCD combinations: R300B / Red+4; R316R / Red+ and R316R / WHTWFC.

Figure 7: Observed m_{AB} zeropoint for the whole system: atmosphere, telescope, prime focus corrector, AF2, WYFFOS and detector. The red and blue curves are for the R316R and R300B gratings respectively, with the Red+4 CCD. The green curve is for the R316R grating, with WHTWFC. The differences between the red and blue curves are consistent with the known differences in grating efficiencies.



- Comparisons of empirical throughout calculated from the 2013 data sets and the theoretical values results in a empirical throughput of:
- **only 1% in the U-band**
- **37% in the B-band**
- 65% for V-band
- 69% for R-band
- 99% for I-band

- Comparison with throughput measurements in 2004 show some degradation in the blue throughput (<450nm): ~1.5 mag, a factor of 4 in flux.

Fibre input-end microprism inspection

All fibre input-end microprisms were examined with a microscope to inspect and inventory the quality of each fibre, which can be degraded by possible damage to prisms, accumulated dirt and debris, increased opacity of optical cements, etc.

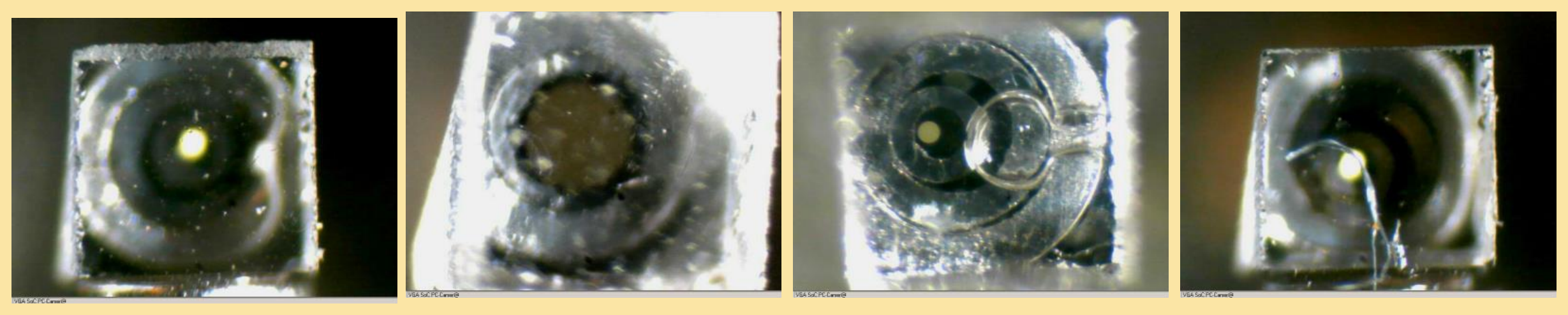


Figure 8. Some of the worst examples of photos showing the prism top surface of some of the fibres. The magnification was adjusted to an intermediate value (1.8) to show the entire prism with some margin around the edges. It is possible to see defects on the prism first surface as some stains, scratches, glue bubbles.

Manufacturing defects, stains and prism chips in 60 fibres have been identified and classified as potentially damaging to throughput, image profile or positioning accuracy.
Solution:
Do nothing. Cosmetic defects do not appear to correlate with fibre throughput.

Fibre throughput and FRD measurements

The absolute throughput of the fibres was measured in laboratory by injecting an f/3 laser beam at the entrance of the fibres and measuring the power at the end. Two laser wavelengths were used to characterize the fibres at the red (635 nm) and in the blue (404 nm). The laser beam sizes at the fibre ends were also measured to compute focal ratio degradation of the fibres. We present preliminary results.

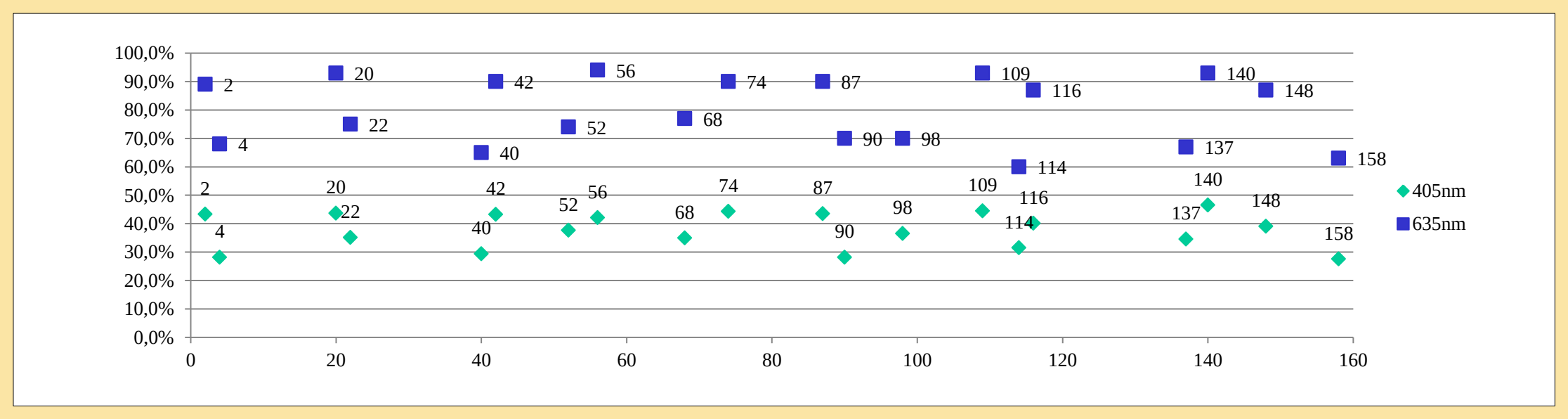


Figure 9. Preliminary results of science fibre throughput measured in-lab at 635nm (blue points) and 404nm (green), given as the ratio of the output vs input power.

-Average measured throughput of the fibres at **635 nm is 84%**
-Preliminary thoughput measurements at **404nm**: average value for the measured sample **is ~37%**

➔ Fibre throughput much worse in blue than in red.

Measurements of reflectivity and cleaning of optical surfaces

Inspection and cleaning of all optical surfaces (fold mirror, primary mirror, relay mirror) inside the WYFFOS spectrograph were performed. The reflectivity was measured with a CT7 reflectometer and were confirmed by measuring the power of a blue laser (405 nm) after each optical element.

Optical element	365nm	404nm	464nm	522nm	624nm	760nm	970nm
Fold mirror	20.4	36.5	85.0	92.9	91.5	93.3	92.4
Primary mirror	85.2	93.7	100.0	100.0	97.6	100.0	68.7
Relay mirror	89.4	96.8	100.0	100.0	98.2	100.0	51.0

Would explain most of the blue throughput loss!!

Fold mirror reflectivity at 365nm and 404nm lower than theoretical values (~95%)
Possible reasons:
- Coating ageing (affect to all optical surfaces and wavelengths)
- **Rusting layer on the fold mirror, becoming worst with time.**

Solution:
- **Recoating the fold mirror**

Other enhancements

New Red+4 detector

A new e2v 231-84 4kx4k, red-sensitive, fringe-suppression CCD, Red+4 was successfully commissioned in semester 2013A. The AF2+WYFFOS users can benefit from its ultra-low fringing (<1% at 850 nm), and 10-30% better sensitivity in the red.

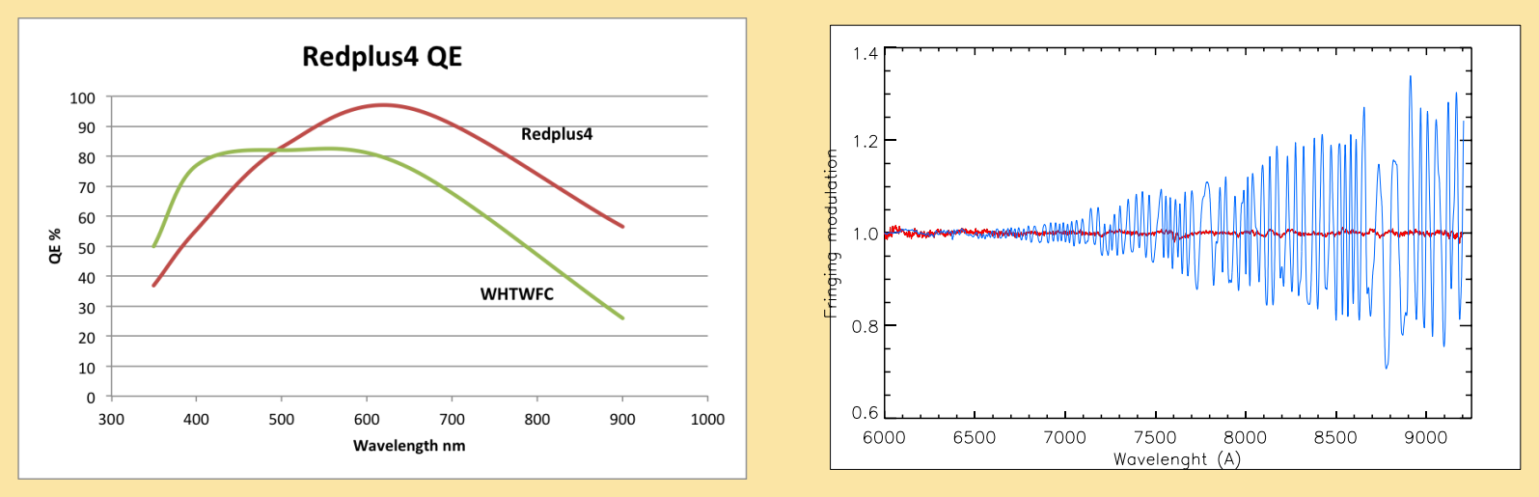


Figure 10. Quantum efficiencies (left) and fringing level (right) of the new Red+4 detector (red)and its predecessor the WHTWFC (green, blue)

New calibration lamps

Previous calibration lamp set: He, Hg and Ne arc-calibration + W continuum

NEW

- **QTH lamp** replaces W lamp. It enhances flux in the blue by a factor of 1.7.
- **Th-Ar hollow cathod arc lamp** for the redder echelle modes. It improves radial velocity precision in the red.
- **Cd + Zn arc lamps**. They improve wavelenght calibration capabilities in the bluest echelle orders.

New data reduction pipeline

An **IDL-based pipeline** has been developed to perform full reduction of AF2+WYFFOS data, including fibre-to-fibre sensitivity corrections and optimal extraction, with provision for quick-look. Version v2 of the pipeline is already available for AF2 users to download at http://www.ing.iac.es/astronomy/instruments/af2/reduction.html.
See SPIE paper 9149-96, "Multi-object spectroscopy data reduction: the AF2+WYFFOS pipeline".