Multi-Fiber Spectroscopy at the Observatorio “Guillermo Haro”

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**Abstract.** Within a collaborative program between INAOE and Durham University, we present a project to adapt the fiber-positioning system AUTOFIB-1.5 (Af-1.5) to the 2.1-m telescope at the Observatorio “Guillermo Haro” in Cananea, Son., Mexico. Af-1.5 is a robot that moves in the x, y & z directions to position 55 fibers across a field plate. It was built at Durham University as a prototype for the William Herschel Telescope (WHT) prime-focus fiber-positioning system AUTOFIB-2. Af-1.5 has been used on the WHT during two observing runs and its performance has been extensively evaluated in the laboratory. The 2.1-m Cananea telescope with a new corrector system will provide a 47.8-arcmin field of view. The corrector mounting is also the mechanical interface between the telescope and the fiber positioner. Af-1.5 fiber diameters are equivalent to 2.1 arcsec, the positioning accuracy to 0.2 arcsec and the minimum fiber separation to 16 arcsec. In the first stage the multi-fiber system will be used with a low-resolution fiber bench spectrograph to study the satellite dynamics around elliptical galaxies to determine the mass and extension of dark galactic halos.
1. Introduction

AUTOFIB-1.5 (Af-1.5) was designed and built at Durham University as a prototype for the prime-focus automated fiber positioner, AUTOFIB-2 (Af-2), for the 4.2-m WHT (Parry & Lewis 1990). Based on the original AUTOFIB system for the Anglo–Australian Observatory, Af-1.5 incorporated several new design features including a viewing system that allows a fiber and the object it is trying to acquire to be seen simultaneously, an improvement in positioning accuracy and in the minimum distance between fibers. Af-1.5 operates at the Cassegrain focus and was commissioned on the WHT telescope in 1989 February and 1990 April. The lessons learnt in building the prototype were folded into the plans for Af-2 which now is routinely used at the prime focus of the WHT.

Af-1.5 has 55 spectroscopic fibers and 8 guide fibers, which can be arranged on a field plate of 380 mm. However, the Cananea telescope field of view is 47.8 arcmin, which corresponds to a 360-mm diameter field. The fiber core diameter is 260 μm, and the fiber is of the polymide-coated type with an outer diameter of 315 μm. Polymicro high-OH all-silica fiber is used for the spectrograph fibers. At the input end a microprism of 1.2-mm side length is cemented onto the polished end face so that the light traveling normal to the field plate is reflected into the fiber, which is held parallel to the field-plate. The top half of the instrument is a pick-and-place robot, which places the fibers in the desired position one at a time. The robot consists of an x–y positioning table which carries an electromagnetic gripper which can be moved in the z direction so that a fiber can be lifted above the others when it is moved from one place to another.

Given its characteristics, Af-1.5 is an instrument that can be used on a 2-m class telescope, where the scales of allocation time allow projects to be carried out that can fully exploit the multi-object capability. The goal of this project is to turn Af-1.5 into a stand-alone instrument routinely used at the Cananea telescope. To achieve this, building an interface for the 2.1-m telescope and a new spectrograph are required. The project can be divided into two main parts, the first regarding the fiber positioner and its interface with the telescope, and the second regarding the spectrograph. In the following section we present all the work done to achieve our goal.

2. Telescope Interface

The f/12 Ritchey–Chrétien telescope optics (Cornejo & Malacara 1973), with an f/2.7 primary, was built at the INAOE optical workshop. The telescope has a one component field-flattening system which gives a 30-arcmin field, however its back focal distance was too short to feed the fiber positioner. Furthermore, the image size at the edge of the field was bigger than the fiber’s diameter.

A two-component system was required to flatten the field and to correct for astigmatism. The design, by S. Vázquez, also corrects for chromatic aberration and is formed by an LF5 meniscus-type lens, and a bi-concave lens. The two 360-mm diameter corrector components give a 47.8-arcmin corrected field with an image size of less than 115 μm, equivalent to less than 1 arcsec over the field and a 157-mm back focal distance, enough to feed Af-1.5.
With the new corrector, the field of view of Af-1.5 will be as large as the maximum field achievable given the telescopes rotator diameter. The 260-μm diameter fibers will be equivalent to 2.1 arcsec, the 30-μm positioning accuracy to 0.2 arcsec, and the fibers can be placed as close as 2 mm, equivalent to 16 arcsec.

Non-telecentricity is unavoidable in a wide field corrector with two elements and a back focal distance of about 150 mm. At the edge of the field the principal ray is at an angle of 6.46°. The half angle of the f/12 beam is 2.4°, so an extreme ray hits the focal plane at an angle of 8.86°, which is equivalent to f/3.2. A way to compensate this effect is to use prisms at the ends of the fibers which have a tilt of 6.46°/2=3.23° built in so that they are 3.23° off at the center and the edge and correct half way out. This would make the extreme rays enter the fibers at 5.7°, which is equivalent to f/5. However, for the first stage of this project we will start with the fibers as they were built originally with right-angled prisms at the ends of the fibers. Changing the right-angled prisms to prisms with an appropriate tilt will be postponed for a future update.

The two elements of the corrector system were built at the INAOE optical workshop. To minimize losses due to reflection, each surface was coated with a broad-band anti-reflection coating (BBAR) by Denton Vacuum Inc. The LF5 transmittance of a witness sample with and without coating on both surfaces was measured by using a spectrophotometer. The results show that with the anti-reflection coating there is an improvement of more than 10%.

3. Mechanical Interface

The corrector mounting, designed by R. Langarica, is also the mechanical interface between the telescope and the fiber positioner. The mounting was aluminum cast and subsequently machined at the INAOE mechanical workshop. Finite Elements Analysis was carried out during the design stage to minimize flexure of the mounting and to estimate possible flexures of the fiber positioner. Considering the extreme case of the mounting and Af-1.5 at a horizontal position and with the boundary condition that Af-1.5 flange is fixed, the results show that in the worst case the flexure expected is very small. The mounting has not been tested at the telescope as we decided it would be better to test it in combination with Af-1.5, because testing requires a large x–y system, which will be available with it.

4. Optical Interface

Two cameras are required for the optical interface: one for acquisition and guidance and a second for closed-loop fiber positioning. INAOE has two SBIG (ST6 and ST7) Peltier-cooled cameras with the corresponding control PCs available for this project. The very sensitive 765×510 pixel ST7 camera with 9×9 μm pixel size will be used for acquisition and guiding. While the 375×242 pixel ST6 camera with 23×27 μm pixel size will be used for closed-loop fiber positioning.

The coherent bundle will be projected onto one of the CCD camera via optical rails and relay lenses inside a light-tight box. Similarly, for the guide fibers an optical arrangement to relay the guide-fiber image is needed. While
the spectroscopic fibers are 14 m long, the guide fibers are much shorter, so the 
CCD cameras and their optics must be located close to Af-1.5. The coherent 
bundle in particular is very short, which imposes severe limits on the location 
of the CCD systems and optics. Software enhancements are required to fully 
integrate these two new cameras to the fiber-positioner control system, although 
it is possible to operate Af-1.5 without making any changes to its software.

5. Spectrograph

At the first stage the multi-fiber system will be used with a low-resolution fiber 
bench spectrograph to study the satellite dynamics around elliptical galaxies to 
determine the mass and extension of dark galactic halos. For this project we 
need to measure relative velocities between the galaxy candidates to the primary 
galaxy of about 500 km s$^{-1}$, requiring a spectrograph with a resolution, $\Delta \lambda$, of 
about 1 nm.

The Af-1.5 fiber focal-ratio degradation performance has been measured in 
the optics laboratory (Carrasco 1992). For an $f/11.4$ input beam, the output 
beam for all the fibers will be within an $f/5$ beam. For the spectrograph design 
an $f/4$ fiber output beam was assumed. A Nikon $f = 135$ mm, $f/2$ lens will 
be use as a collimator and a Nikon $f = 85$ mm, $f/1.4$ camera lens will be 
use in combination with a 1200-line mm$^{-1}$ grating, blazed at 600 nm with a 
blaze angle of $21^\circ 06'$. The angle between the collimator and the camera is $50^\circ$ 
(45.95/-4.05 deg). The slit width is given by the fiber core diameter of 260 $\mu$m 
(2.1 arcsec). The detector will be a 1024\times1024 pixel ($24 \mu$m \times $24 \mu$m) Tektronix 
chip. With these components each fiber will be projected onto 4.7 pixels in the 
spectral direction and 6.8 pixels in the spatial direction. Forty-five fibers can be 
arranged along a 17-mm slit without vignetting.

The spectrograph has been tested in the optics laboratory by Ren Deqing, 
using a Pixtor 416XT 768\times512 pixel ($9 \mu$m \times $9 \mu$m) detector. The measured 
resolution is $\Delta \lambda = 1.1$ nm, the anamorphic factor is 1.46, and the free spectral 
range is 240 nm, centered at 540 nm. The spectral-line $G$-band (430 nm), $H_\beta$ 
(486.1 nm), Mg $\iota$ (517.1nm), Na $\iota$ (5889,5895 nm), and $H_\alpha$ (656.3 nm) are within 
this spectral range. The spectrograph resolution is limited by the fiber size, as 
expected.

References

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Part 3: Two-Dimensional Fiber Spectroscopy