Integration, Commissioning and Performance of the UK FMOS Spectrograph

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ABSTRACT

The UK FMOS spectrograph forms part of Subaru's FMOS multi-object infrared spectroscopy facility. The spectrograph was shipped to Hilo in component form in August of 2007. We describe the integration sequence for the spectrograph, the results of cooldown tests using a new chiller unit fitted to the spectrograph at the telescope, and alignment tests of the spectrograph, gratings and OH-suppression masks. We present the first-light observations for the spectrograph from May 2008.

Keywords: Fiber Spectroscopy; Infrared Spectroscopy; Multi-Object Spectroscopy; VPH Gratings; OH-Suppression.

1. INTRODUCTION

The UK FMOS[1] project is part of a joint Japanese, Australian and UK initiative to provide the prime focus of the Japanese Subaru telescope with a 400 optical fibre multi-object capability in the near Infra-Red part of the spectrum (specifically the J and H bands). The FMOS instrumentation consists of a pair of OH-suppression spectrographs[1,2], together with a new prime focus unit with an IR corrector and a 400 optical fibre multi-object positioner, this work package was a collaboration between the Japanese project staff and the AAO, Australia. The fibre system was built in at the University of Durham and the two near Infra-Red spectrographs were being built jointly in the UK (Oxford University and RAL) and Japan (Kyoto). The UK spectrograph was shipped to Hilo and assembled at the summit in September 2007. We describe the integration process in Section 2. Cold-testing of the spectrograph with a new chiller unit is described in Section 3. A throughput measurement is described in Section 4 and first-light observations from May 2008 are described in Section 5. We summarise our work with an outline schedule for completion of the project in Section 6.

2. SHIPPING AND INTEGRATION

With dimensions of roughly 3mx2mx2.4m, the spectrograph is too large to be shipped intact or lifted to the location of the spectrograph room within the Subaru telescope enclosure. The spectrograph was therefore disassembled to component subsystems for shipping and reassembled at the telescope over a period of 10 days in September 2008. In particular, the aperture through which items can be craned up to the spectrograph floor limits individual items to around 1.7mx1.7m (Fig 1), which had to be accommodated into the design of the spectrograph. The Camera lens-assembly was shipped intact outside the camera dewar, but all other optical components were removed from their mounts for protection during shipping. During assembly the two large mirrors were cleaned using First Contact[3] solution to remove particulates that had accumulated during the extensive laboratory testing period in Oxford (Fig 2).

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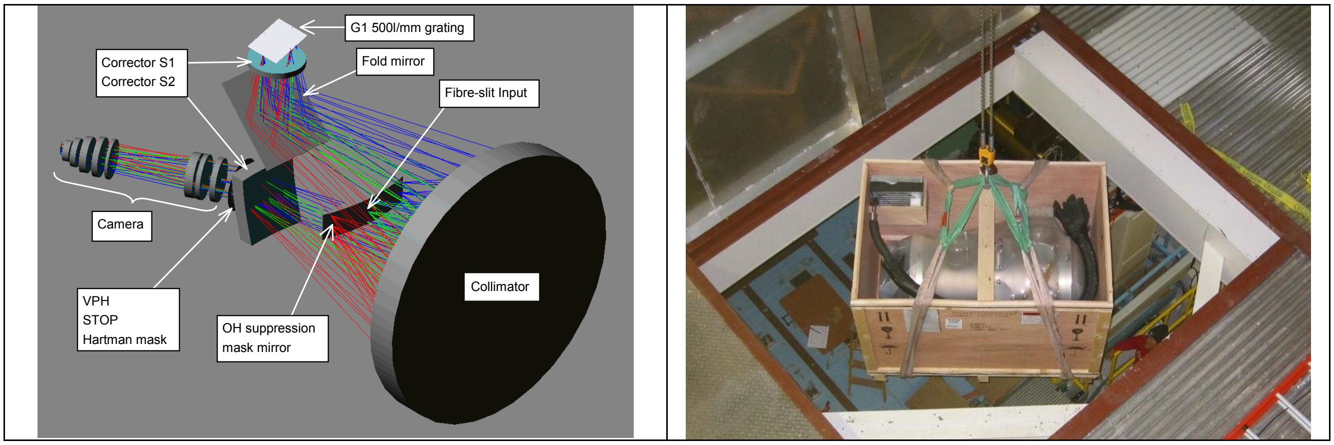

Figure 1 (left) Outline design of the spectrograph. The collimator diameter is 1.5m. (right) The Camera dewar being lifted through the access hatch to the IR TUE level spectrograph floor, illustrating the access restrictions that influenced the spectrograph design.

Initial realignment of the spectrograph was achieved using a green laser pointer (532nm) mounted at the location of the fibre slit to allow the gratings and Schmidt correctors to be correctly located on the optical axis of the system. The laser was then replaced with a test fiber slit unit, and the positions of the 2^{nd} and 3^{rd} order images of the fibers on the mask mirrors used to set the mirror positions according to index marks that were fabricated above and below the useful extent of the mask lines.

Figure 2 (top) The fold mirrot surface before (left), during (center) and after (right) cleaning with First Contact solution. (Bottom) Cleaning of the 1.5m collimator mirror: The polymer film coat can be removed as a single piece.

The overall vertical tilt of the camera was adjusted to bring the extreme fibers within the detector image. Using a halogen white light illumination source for the fibers, the camera focus was then adjusted to bring the mask surface into focus, and finally the slit position was adjusted with an Ar spectral source to bring the fiber spectra into focus on the mask surface and at the camera focal plane. Alignment of the mask mirrors themselves is achieved by means of manual adjustments when the spectrograph is warm. Focus of the slit and tip/tilt/focus of the detector stage within the camera are maintained from the instrument control software. An initial wavelength scale was fit to the two mask mirror images across the slit to check the relative positioning, but this showed a scale error of around 10% in the mask pattern. This error was traced to a software error in the code used to generate the contact print for the mask etching (see ref [3]), so the mask mirrors were returned to Oxford for recoating and replaced with silver coated spares for the remainder of the run.

3. COOLDOWN TESTS

Final testing of the spectrograph in Oxford was seriously limited by the performance of our adopted chiller unit, a refurbished Polycold PFC400. Although the chiller unit appeared to be operating correctly, the best result achieved was an internal spectrograph temperature of -18°C with a very slow cooldown rate (about 1 week). A thorough investigation of the detailed design of the insulation panels and the plenum chamber (see ref [1]) suggested some modifications, but no significant improvement was obtained. The chiller unit is designed as a water vapour cryopump for semiconductor growth applications, not as an air chiller, but repeated calculations suggest that the overall thermal balance should have been within range for the unit. It was concluded that the chiller unit itself was at fault, and a newer unit, model PFC 1102, with a much higher cooling power was installed at the telescope. The results of the first cold-test of the spectrograph are shown in Figure 3. The PFC 1102 is connected to the spectrograph environmental control PLC, and servoed to limit the cooldown rate. The rate is set to 1°C/hour, but the influx of each pulse of cold dry air causes an overshoot, and an actual cooldown rate of 1.5°C/hour, which is acceptable. The duty cycle of the chiller in this setup is around 10%, suggesting that a much larger instrument could be cooled in this way if desired.

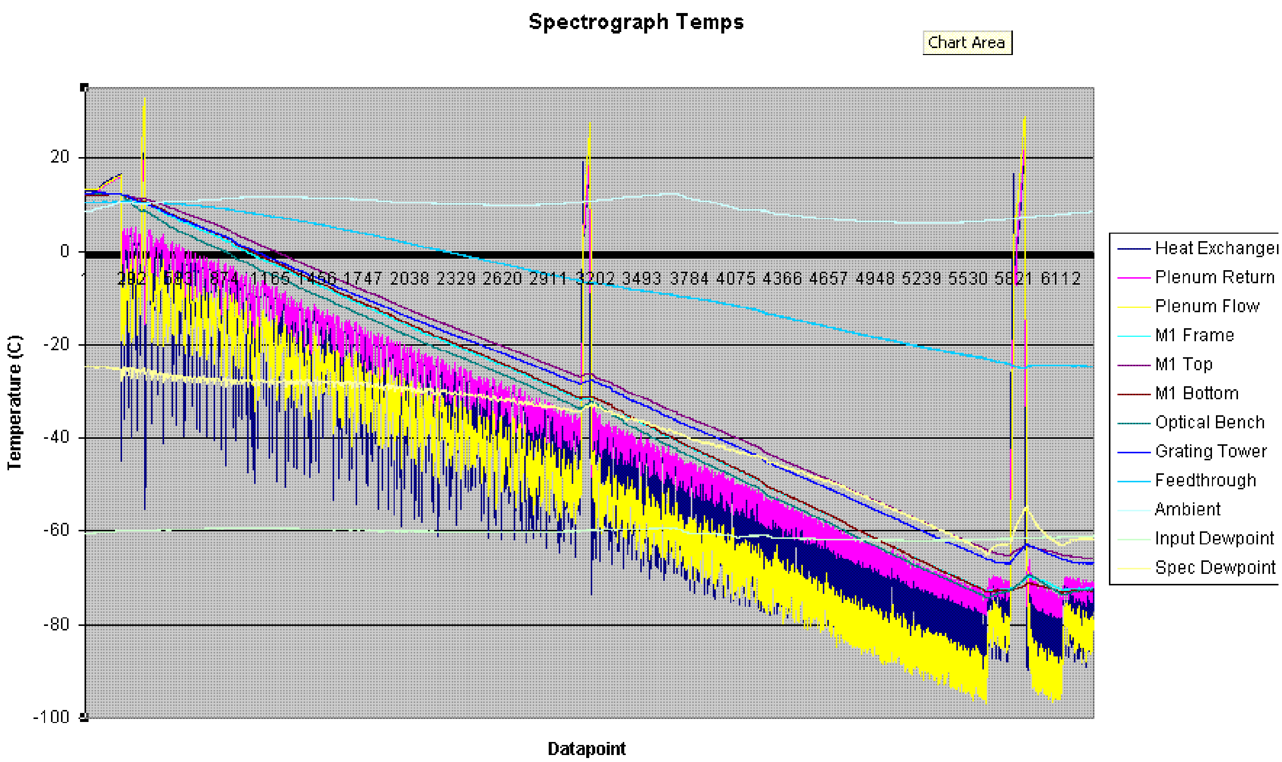

Figure 3: Cooldown of the spectrograph using the PFC1102 chiller unit. The interval between datapoints is 1 minute. The spikes at 24 hour intervals are the effect of the default defrost cycle implemented within the PLC. The 'Feedthrough' represents the temperature of the electronics connection panel, located 1/3rd of the way through the insulation layer.

After cooldown, there are a number of adjustments required to ready the spectrograph for observations: First the camera focus needs to be adjusted to compensate for the warm-cold dimension change of the spectrograph. Then the slit focus needs to be adjusted to bring the spectra back into focus on the camera and the mask mirrors. Finally the primary grating mosaic needs to be adjusted to bring the four separate spectral images back into alignment (Figure 4).

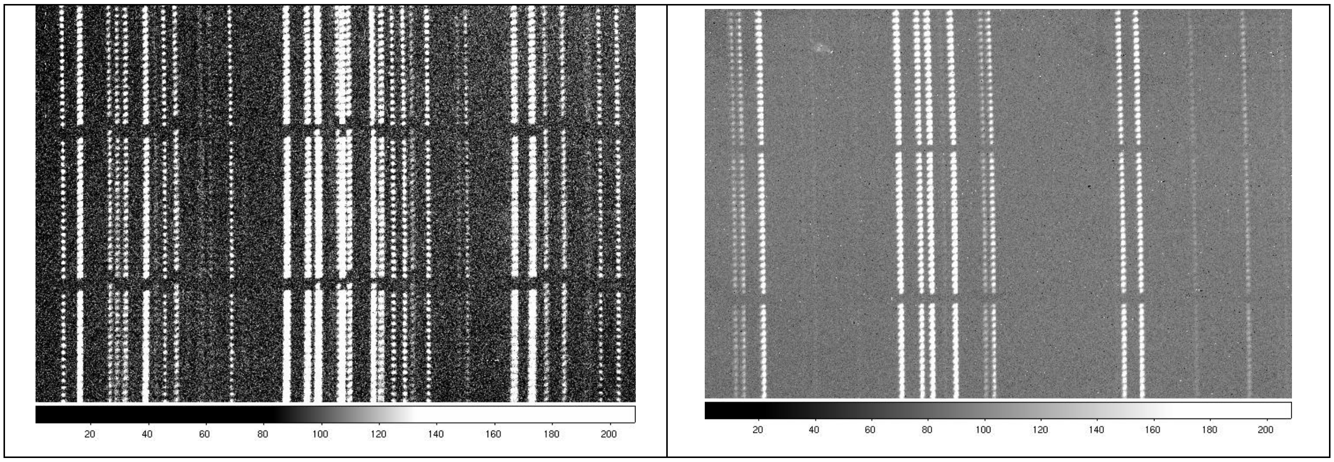

Figure 4: (left) An image of part of the H-band showing the break-up of the fiber images due to thermal relaxation of the grating assembly. (right) The same region of the spectrum after the grating alignments have been corrected for the thermal shifts. (Note that these images use a mask mirror that has not been etched, so that there are no OH gaps in the spectra. There is some residual variation of image quality in the vertical direction as the mask mirror itself was not perfectly aligned at this point.

4. THROUGHPUT MEASUREMENTS

At the start of the May 2008 commissioning run there was an opportunity to measure the total instrument throughput for both FMOS spectrographs. During a Cassegrain instrument exchange, a calibrated blackbody source was placed on the telescope observing floor and used to illuminate the corrector and fiber positioner. An example of the continuum spectral image is shown in Figure 5 (The revised H-band OH mask mirror was replaced in January of 2008).

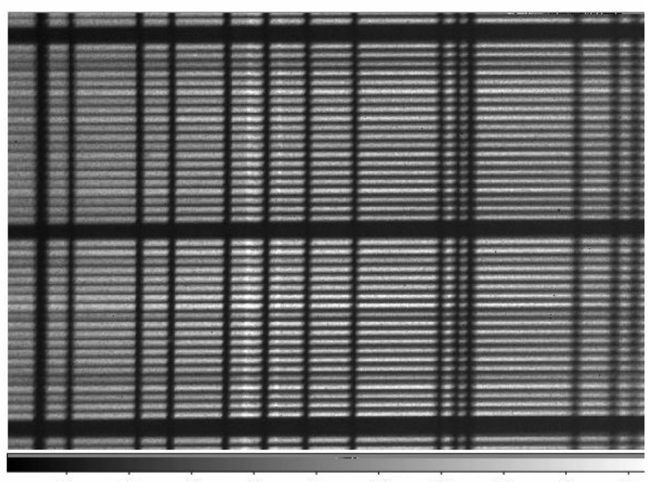

Figure 5: Continuum spectral image from the blackbody source described in the text. The mask lines and spectra are in good focus, consistent with the predicted image quality for the spectrograph[1]. The emission line in the center of the image is a dome fluorescent light that was not present during the actual throughput measurement.

The geometry of the setup is a 15mm aperture blackbody source at 1000°C located 20m away from the focal plane. The fiber aperture is 100 microns, with an f/2.1 acceptance angle, and the blackbody source produces a narrow beam. Flux measurements from the two spectrographs were in excellent agreement. At a wavelength of 1.33 microns, we measured 16,000 ADU within a 7x10 pixel box centered on a single central fiber spectrum from a 50.6s effective exposure with a gain of 2.1e^{-}/ADU (these numbers are for the Kyoto-built IRS1, but are consistent with measurements from the UK IRS2. The implied total system throughput is around 30% at this wavelength, which compares well to the theoretical maximum throughput value of 36% at this wavelength (see Figure 6).

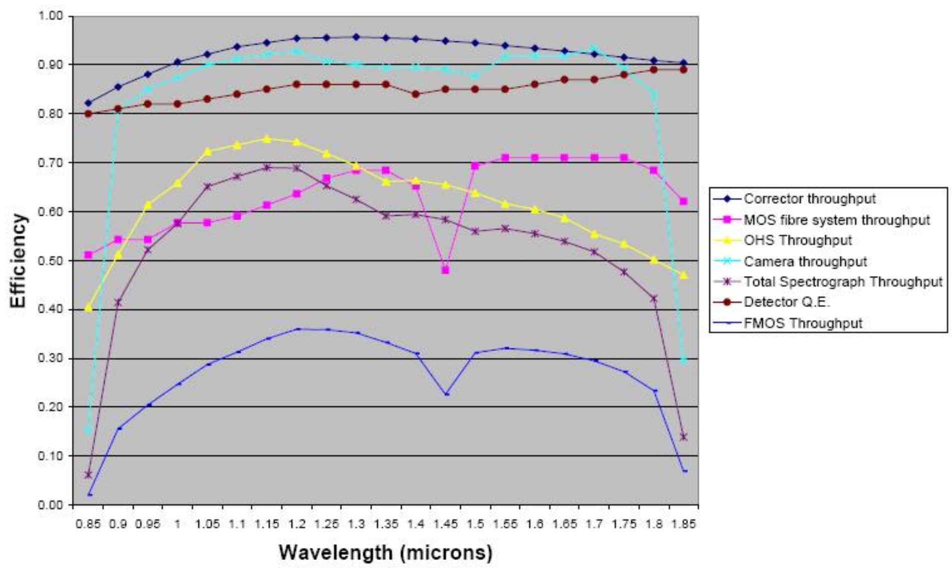

Figure 6: Theoretical limits on the instrument throughput derived from individual component performances for the full FMOS system. The lower blue line is an estimate of the maximum throughput in the high resolution mode that corresponds to the black-body throughput test described in the text. The predicted maximum value at 1.33 microns is 36%, compared to a measured value of 30% in our tests.

5. FIRST LIGHT OBSERVATIONS

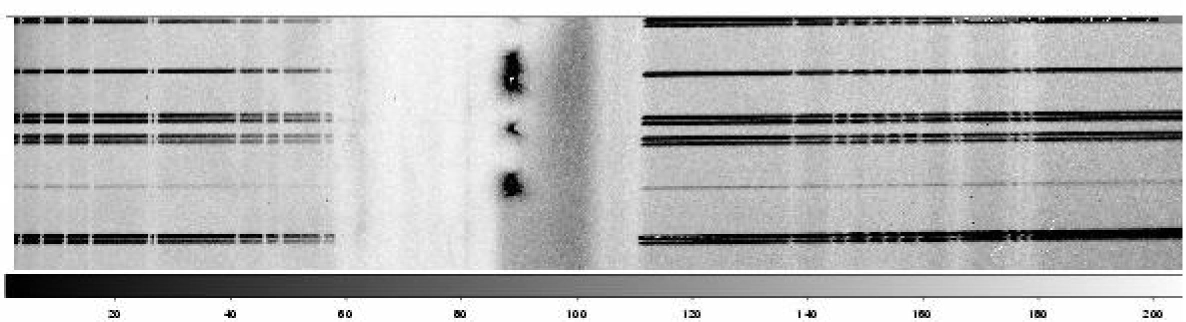

Figure 7: Image of a continuum spectrum taken across the slit location using a test fiber slit. 10 fiber spectra can be seen here with a 2:1:2: :2:1:2 configuration. The OH lines in the J-band (right hand side of the image) are clearly not well-matched to the H-band focus, and there is a residual tilt about the wavelength axis of the J-band mirror which was not corrected due to a lack of time. The images of the fibers can clearly be seen at the location of the slit, and there remains some vertical displacement of the slit with respect to the image.

The second replacement OH mask mirror was installed at the start of the May 2008 commissioning period, although minor issues with the detector controller made it impossible to complete the mirror alignment before the spectrograph had to be cooled for work on-sky. A continuum image taken across the position of the slit (Fig 7) was used to check the apparent wavelength scale of the two mask mirrors to check that they were within the adjustment range of the alignment. A simple spline fit to the data (Figure 8) shows an offset between the two mirrors of around 100Å, corresponding to just under 4mm of relative adjustment required to bring the two sets of OH line masks onto a common wavelength scale. This is within the useable range of adjustment of the system, and will be implemented in June 2008.

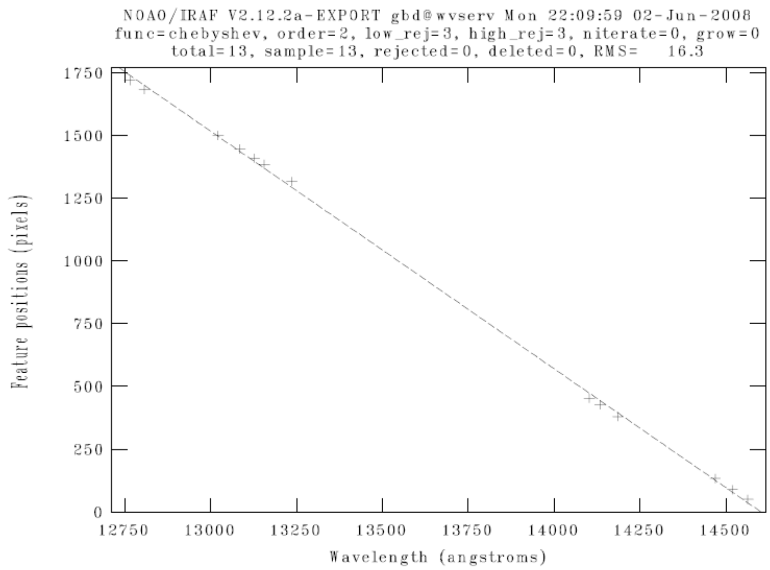

Figure 8: A simple linear fit to the positions of the masked OH-lines in the image of Figure 7. The discontinuity in the wavelength solution is arouns 100Å, and within the available adjustment of the mirror positions.

The 'first light' images for the spectrograph were taken on the night of May 15th, 2008 as part of on-going commissioning for the fiber positioner. These are fields of stars that were set-up using the default parameters for the individual spine positions, and these have not yet been calibrated fully. While guide-star tests were taking place with Echidna, we first observed some sky spectra (i.e. no field configuration applied to the spines), and noticed that the OH lines were within one fiber diameter of their corresponding lines on the H-band mask mirror, on the basis of 'coarse' alignment using a visual match of the 532nm 3rd order light from the laser pointer to an index mark on the mirror. We therefore decided to adjust the grating alignment within the mosaic to shift the images onto the masked regions to check the correspondence of the mask to the true wavelength scale of the instrument. This was achieved, such that the OH lines disappeared over the full 220nm range of the central portions of the image, but confirmed a slight rotation of the mask mirror about its pole which had been noted during alignment, but not yet corrected.

The image is shown in Figure 9. This is a 180s exposure of a cluster field of bright stars to be used for positioner calibration testing. There is a strong variation in the intensity of different stars in the image, confirming the need for calibration, as expected. The extracted spectrum for one of the brighter stars is shown in Figure 10. This star is around 15th magnitude in R. The gaps in the spectrum due to the OH-mask lines can clearly be distinguished from actual spectral features due to the noise signatures.

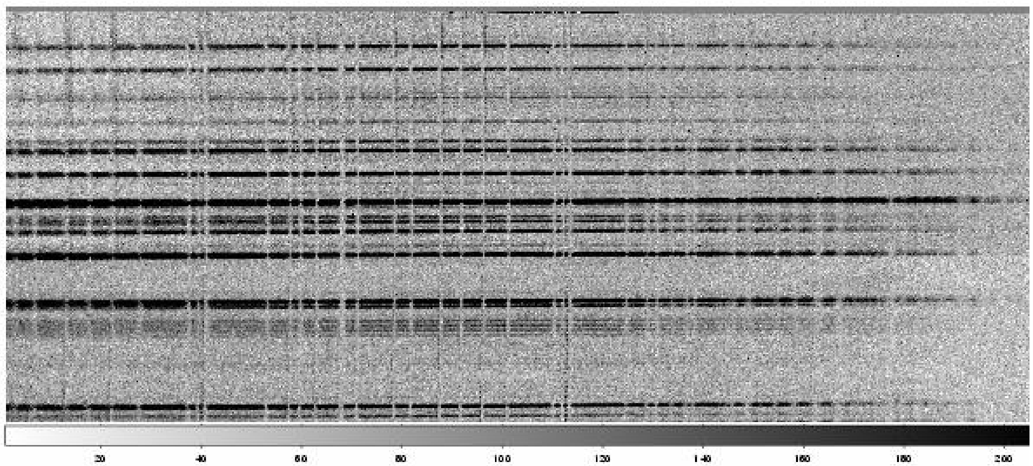

Figure 9: First light image for the spectrograph. This image is the full width of the central portion of the detector. The atmospheric trough at the beginning of the H-band is at the right, and wavelength increases to the left. The spectra of several stars can be seen, together with the 'missing' regions due to the OH suppression mask. At the top and bottom of the image the OH emission features themselves begin to reappear due to a slight rotation of the mask that was noted during the initial alignment.

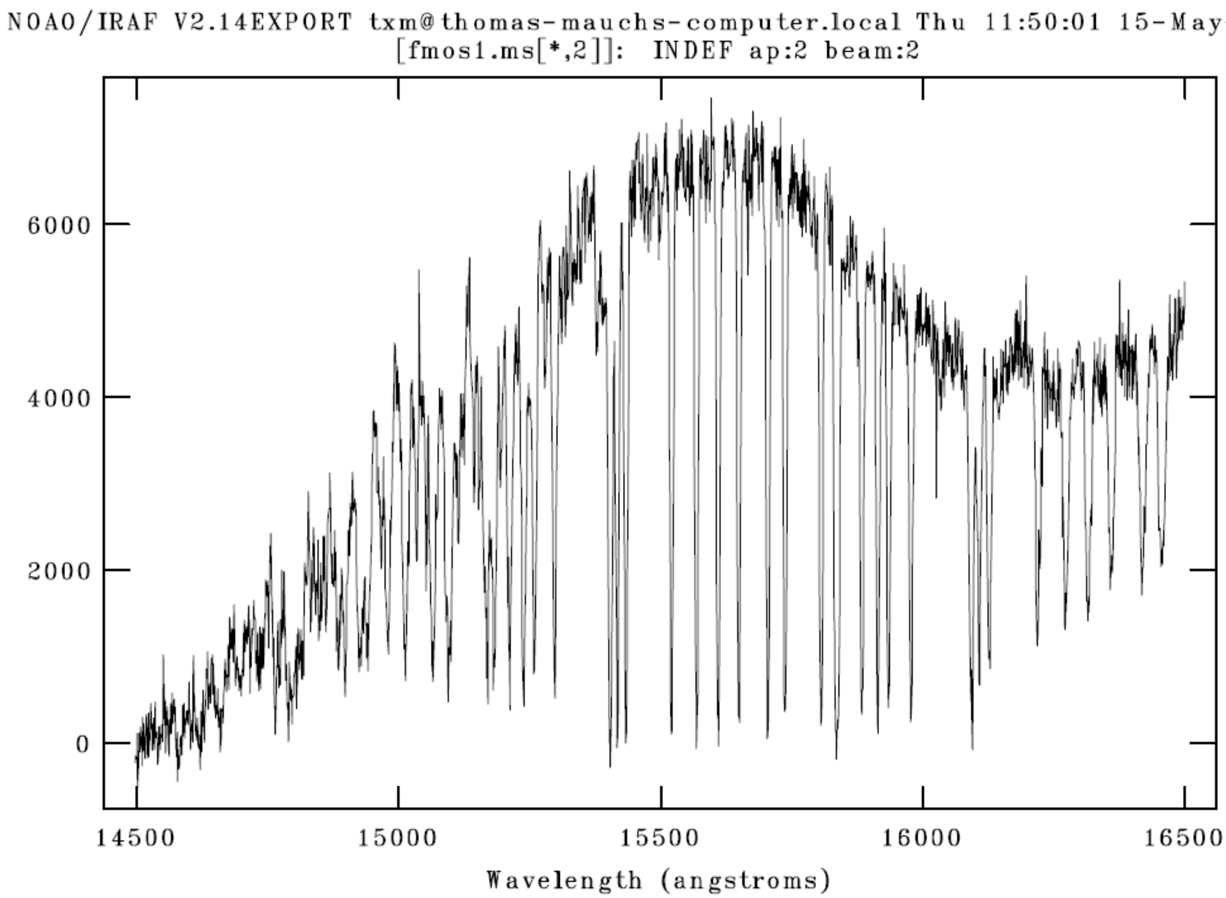

Figure 10: The extracted spectrum of one of the brighter stars in the first light image, with an approximate wavelength scale applied for reference.

6. SUMMARY AND FURTHER WORK

We have presented initial commissioning results from the UK FMOS spectrograph, part of Subaru's FMOS facility. The spectrograph has achieved its optical performance and the thermal control system is easily capable of achieving the goal temperature of 200K to reduce the internal thermal background from the instrument. The manufacturing technology for the OH suppression masks has achieved an excellent match to the true wavelength scale at the intermediate focus within the spectrograph, giving a good prospect for the OH suppression once the low-resolution mode is commissioned. The overall system throughput appears to be around 30% peak, close to the theoretical performance of the optical elements in the system. Over the next few months we expect to complete commissioning and enter the science verification phase. For the spectrograph, this means a complete alignment of the mask mirrors to a common wavelength scale on a common spherical surface, commissioning of the low-resolution mode using the secondary VPH grating in the system, and complete integration of the spectrograph control system with the instrument observation control computer (OBCP). We expect that the majority of this work will be completed by the time of the SPIE meeting.

The science verification phase includes understanding the treatment of the OH suppression mask in the data reduction, determining the limiting performance of the instrument for faint spectra, and providing the observing system with default calibration for focus offsets between different observing modes. We expect the majority of this work to be completed by the end of 2008, over a small number of further engineering nights in parallel with further commissioning work on ECHIDNA.

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