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Klaus fibre conversion at Mount Wilson in 2018 June

Steven J. Hale
The University of Birmingham, Edgbaston, Birmingham B15 2TT

2018 August 24

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High-Resolution Optical-Spectroscopy Group

School of Physics and Astronomy
The University of Birmingham
Edgbaston, Birmingham B15 2TT, United Kingdom
Telephone: +44-121-414-4551

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Abstract

Klaus was converted to accept a fibre-optic input, and a Sky-Watcher Solarquest mount was installed to provide a dedicated light feed. The new feed bypasses all of the tower optics and electronics, and so has resolved all ongoing issues with these systems.

Contents

1 Introduction

Steven Hale visited Mount Wilson from 2018 June 28 to July 10. The most recent previous visit was in 2016 September where tests were run on converting the instrument to use a fibre light feed from a dedicated mount at the top of the tower, separate from the main cœlostat [1]. The purpose of this visit was to continue on from those original tests and permanently convert Klaus to accept a fibre feed from its own dedicated mount.

Klaus was the eleventh spectrometer built by the group, and was installed at Mount Wilson in 1996 June [2, 3]. The design is the same as Jabba, the two-magnet spectrometer installed at Carnarvon in 1994 [4] as a student PhD project [5]. Klaus has suffered several problems over the last decade, with continual mirror and beam alignment issues [6, 7], followed by ongoing failures of the tower autoguider system [8, 9]. The intermittent guider problems were exacerbated in 2013 when the primary mirror was damaged and never realuminised [8]. Converting Klaus to a fibre feed from a dedicated mount, bypassing all of the tower optics and electronics, will resolve all of these issues.

Section 2 first discusses the Sky-Watcher Solarquest AltAz mount and establishes the performance is adequate for our requirements. Section 3 then goes on to detail the optical conversion required, and Section 4 the optimisation of various system parameters. Finally Section 5 provides some examples of data quality achieved via the new light feed during the site visit.

2 Solarquest Mount Performance

The most recent previous visit was in 2016 September where tests were run on converting the instrument to use a fibre light feed from a dedicated mount at the top of the tower, separate from the main cœlostat [1]. The mount was a *Sky-watcher HEQ5-Pro* with a standard tripod. A binocular arrangement was used to both collect light into the fibre, and also onto a *Starlight Express Superstar* CCD camera which was used for guiding. Images from the camera were processed using OpenCV (Open-source Computer-Vision) library to determine the centroid position of the Sun, and that position passed to a custom PID controller written in Python to determine the required motor speeds for guiding.

Whilst the guiding performance achieved was very good, the automation of the HEQ5-Pro is not yet ready to be deployed in active service. The mount does not have absolute position sensors, and so it was required to manually start the system each morning by moving the mount by hand until the Sun was inside the field of view of the guide camera. Adding inertial position sensors and completing the code required for full automation is subject to further work. Since the tower dome at Mount Wilson is not automated, and requires a daily observer to open, move, and close the dome, it is not necessary to use a fully automated telescope mount. The recently released (2018 May) Sky-Watcher Solarquest AltAz mount is perfect for this scenario. The Solarquest mount includes *Heliofind Solar Alignment Technology* to provide almost complete automation and make it particularly easy to use.

The only user controls on the mount are an 8-way slide switch and a power button. When the mount is turned on, it acquires a GPS fix to provide location and time, from which it can calculate the expected position of the Sun. The mount drives to the expected altitude determined using a digital accelerometer measuring the direction of the gravitational force. It then slews clockwise until the Sun is acquired in the built-in quadrant-photodiode based autoguider. The 8-way slide switch can then be used to adjust the final guiding position offset. In order to prevent the attached cables and fibre becoming wrapped around the tripod, it is necessary to ensure the mount is pointing to the left of the Sun at startup and so limit the amount of clockwise rotation required to acquire the Sun.

It is not clear from the manufacturers specifications exactly what the expected guiding performance should be, or how the mount handles cloud. It is therefore necessary to run some tests and ensure that the performance of the mount is adequate for our requirements. The Starlight Express Superstar CCD camera used previously was attached to the mount and used to collect images throughout a partially clear day in Birmingham. The centroid positions of the solar disc were again measured using OpenCV, with the results shown in Figure 1. Figure 2 shows histograms of the performance during the clear sky periods calibrated in arcseconds based on the 80 mm camera focal length and 4.65 µm square pixels. The red dashed-line indicates the equivalent Gaussian profile for the measured mean and standard-deviation.

In order to test the tracking performance during overcast weather, the guider was covered between 1130 to 1230 to simulate cloudy conditions. The mount appears to continue tracking in azimuth, with expected reduced performance compared to active guiding, but stops driving in altitude. The mount successfully pulls back into the original guiding position once the guider was uncovered at 1230, after which scattered cloud continued for the rest of the day. If clouds exist for sufficiently long enough for the Sun to move completely outside of the guider field of view in altitude, then it is likely that the mount will not be able to continue guiding automatically. However, during such bad weather the data are unlikely to be acceptable anyway.

During clear conditions the mount guides to better than $36''$ FWHM. This is not as good as the FWHM of $14''$ achieved with the Sky-watcher HEQ5-Pro in 2016 September [1], however

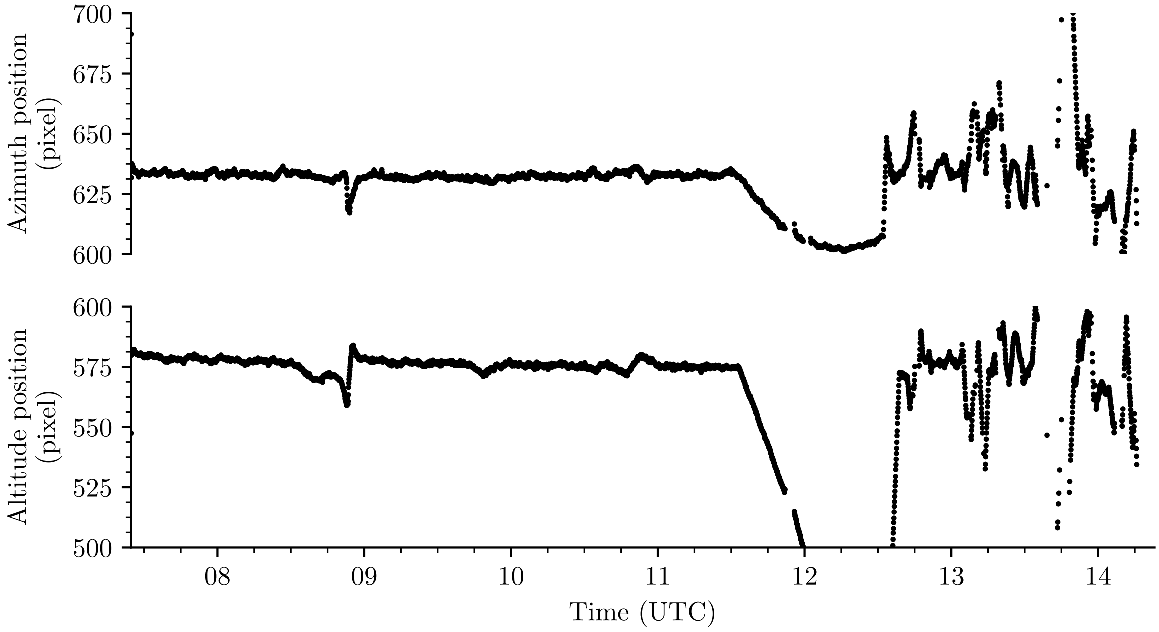

Figure 1: Solar centroid position, azimuth and altitude, in pixels. The guider was covered between 1130 and 1230 to test the tracking performance in overcast conditions. After 1230 was scattered cloud for the rest of the day.

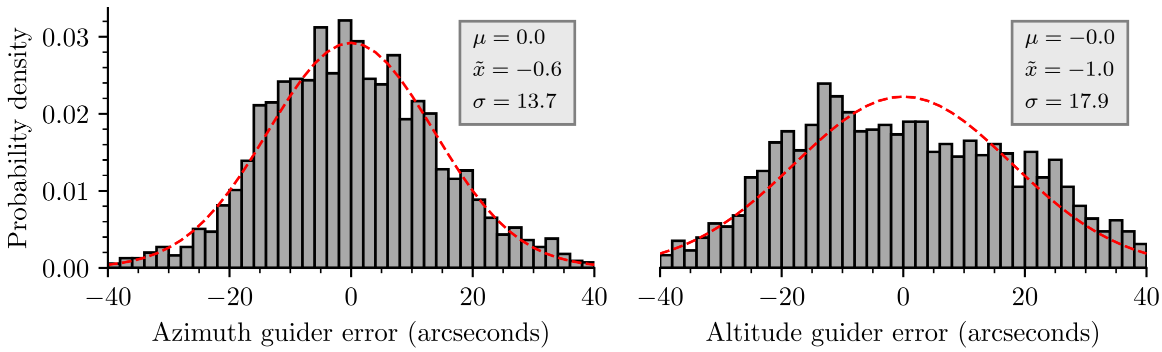

Figure 2: Histogram of guiding performance during clear conditions. The red dashed-line indicates the equivalent Gaussian profile for the measured mean and standard-deviation.

it is more than sufficient for the requirements of keeping a solar image centred on the end of a 1 mm fibre. We can be confident that the Solarquest will provide acceptable performance during clear conditions, and will be robust enough to continue tracking through scattered cloud without manual observer intervention after the initial morning start-up has been completed. When first acquiring the Sun, the guider automatically gets the mount almost exactly centred on the fibre. Only a small nudge of one or both axes should be required using the 8-way slide switch to ensure there is no vignetting and the system is ready to run for the day.

In the next section, we will look at the optical modifications made to Klaus to accept fibre input, and then go on to consider calibration and tuning of the system parameters.

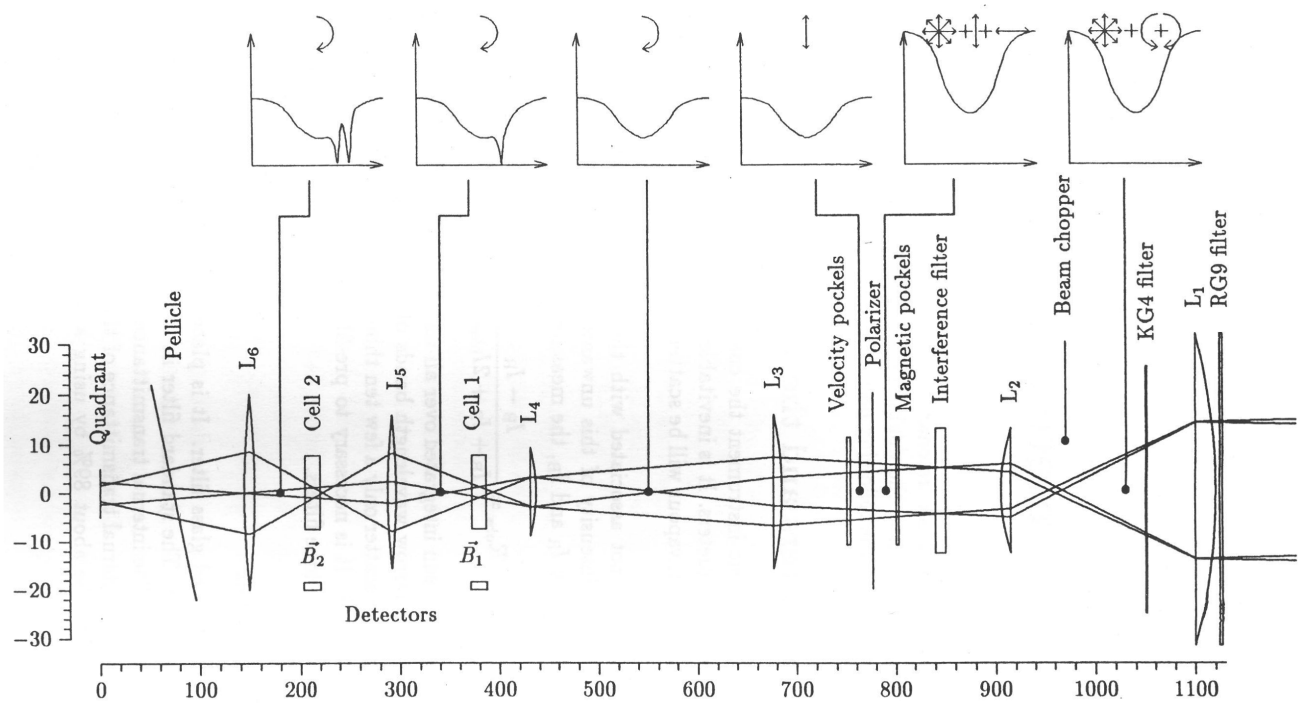

Figure 3: The Jabba double-field spectrometer optical configuration. Dimensions are in millimetres. The spectral intensity and polarisation state in the vicinity of the incident Fraunhofer line is shown at various locations along the optical path. The lenses are defined in Table 1. Reproduced from Lewis (1996) [5].

Table 1: The Jabba double-field spectrometer lenses. Reproduced from Lewis (1996) [5].

Lens	f (mm)	ϕ (mm)	Manufacturer	Part Number
1	150	63	Spindler & Hoyer	32 2228
2	50.8	25.4	Newport	PAC040
3	250	31.5	Spindler & Hoyer	32 2272
4	50	18	Spindler & Hoyer	32 2265
5	40	31.5	Spindler & Hoyer	31 1339
6	50	40	Spindler & Hoyer	31 1340
Detectors	20	21	Comar	20AF21

3 Fibre Conversion

Klaus was the eleventh spectrometer built by the group, and was installed at Mount Wilson in 1996 June [2, 3]. The design is the same as Jabba, the two-magnet spectrometer installed at Carnarvon in 1994 [4] as a student PhD project [5]. The vapour cell in the aft oven failed several years ago, and the magnet and oven assembly itself later removed in 2015 December [10], and so Klaus is now operated in the more typical single-magnet mode. The aft oven was later used throughout 2017 at Izaña during additional fibre performance trials [11, 12].

The new input stage that is installed on the Solarquest mount is based around a Thorlabs FT1000EMT fibre terminated with SMA connectors. The core diameter is 1.0 mm and the numerical aperture is 0.39. The objective lens is a Thorlabs AC254-030-B-ML achromatic doublet with focal length of 30 mm and diameter 25.4 mm. The lens and fibre are protected by an initial infra-red filter, a Sloan Digital Sky Survey (SDSS) “i′2” manufactured by Astrodon in the USA.

This filter has a bandwidth of approximately 700 nm to 850 nm with near 100 % transmission at 770 nm.

The original Jabba double-field spectrometer optical configuration is shown in Figure 3. The lenses, labelled L1 through L6, are defined in Table 1. Light is collected through a 30 mm aperture by the objective lens L1 and recollimated by L2 in a Keplerian telescope configuration, producing a beam approximately 12 mm in diameter with 0.8° divergence. Lens L3 produces a solar image on L4 immediately before the first magnet assembly. L4 is a Fabry lens intended to change the imaging of the system such that the image formed in the vapour cell is of the objective aperture rather than the Sun. The Fabry lens partially scrambles the solar image and reduces the effect of so-called Doppler Imaging inside the vapour cell. All four lenses, L1–L4, were removed and replaced with just two new lenses. The fibre output has been mounted at the shared focal plane between the original L1 and L2 lenses. Lens L2 has been replaced with a Thorlabs AC254-030-B-ML lens with focal length of 30 mm and diameter 25.4 mm, the same lens as used at the input of the fibre. The collimated fibre output beam has a larger diameter than the original configuration, but a similar divergence at 0.95°. Reducing the focal length to decrease the beam diameter results in unacceptably high beam divergence through the optical components sensitive to off-axis angle. Lens L4 is replaced by a Thorlabs AC254-100-B-ML lens with focal length of 100 mm and diameter 25.4 mm, which focuses the collimated beam into the vapour cell. The effect of the Fabry lens is no longer required since image scrambling is achieved via the optical fibre. The two Schott RG9 and KG4 filters have been replaced with the single SDSS "i′2" filter at the input of the fibre. The original RG9 and KG4 combination offers only 62 % transmission at 770 nm, and so the new filter compensates for the slightly reduced objective aperture. The power (in mW) entering the spectrometer through the fibre is approximately the same as before.

The beam collimation and subsequent focus produced by the new L2 and L4 lenses was checked by removing both the 1.5 nm interference filter and the forward oven. With the narrow filter removed it is possible to observe the beam through the spectrometer and so inspect and optimise the focus at the centre of the potassium cell, after which the filter and oven were reinstalled. No other changes were made to Klaus.

In the next section, we will look at tuning the Pockels-cell supply voltage and the temperature of the vapour cell, and then finally check the data quality achieved with the new light feed system.

4 Calibration and Tuning

4.1 Pockels-cell voltage

The Pockels-cell driver is adjusted via a dial on the front panel that is uncalibrated. The technique to optimise the output voltage involves slewing through a range of voltages, and watching the polarisation ratio to find the maximum. The driver was scanned from 260 to 360 on the dial, and the results are shown in Figure 4. The initial setting was 300, and this was increased to 315. Perhaps 320 is closer to the centre of the ratio plateau. The fluctuation in ratio caused by the solar oscillations during the scan make the exact location of the peak uncertain.

4.2 Cell oven temperature

The temperature controller used in Mount Wilson is one of the older models, and not the new digital controller used at many other sites. There is little information about this particular unit, but it is similar to the unit originally built and documented for Narrabri [13].

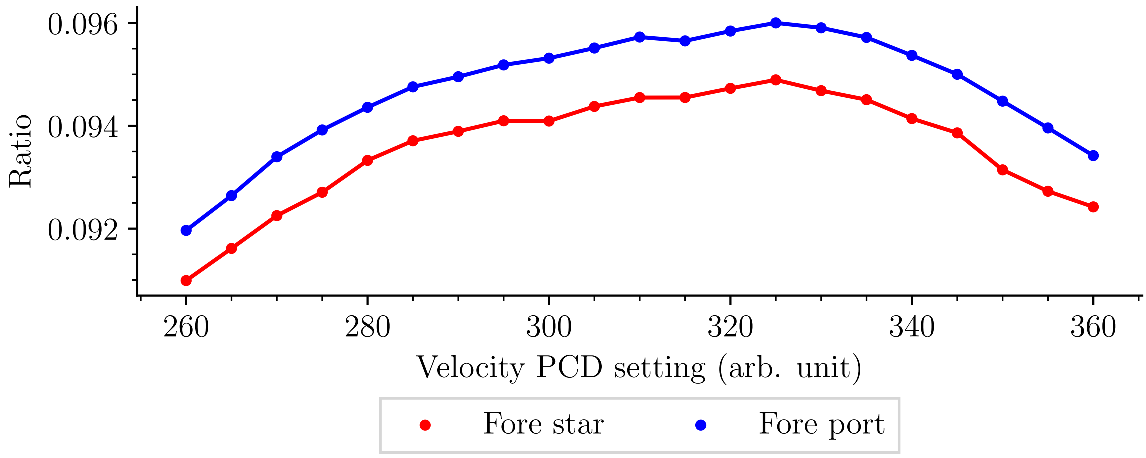

Figure 4: Velocity Pockels cell optimisation.

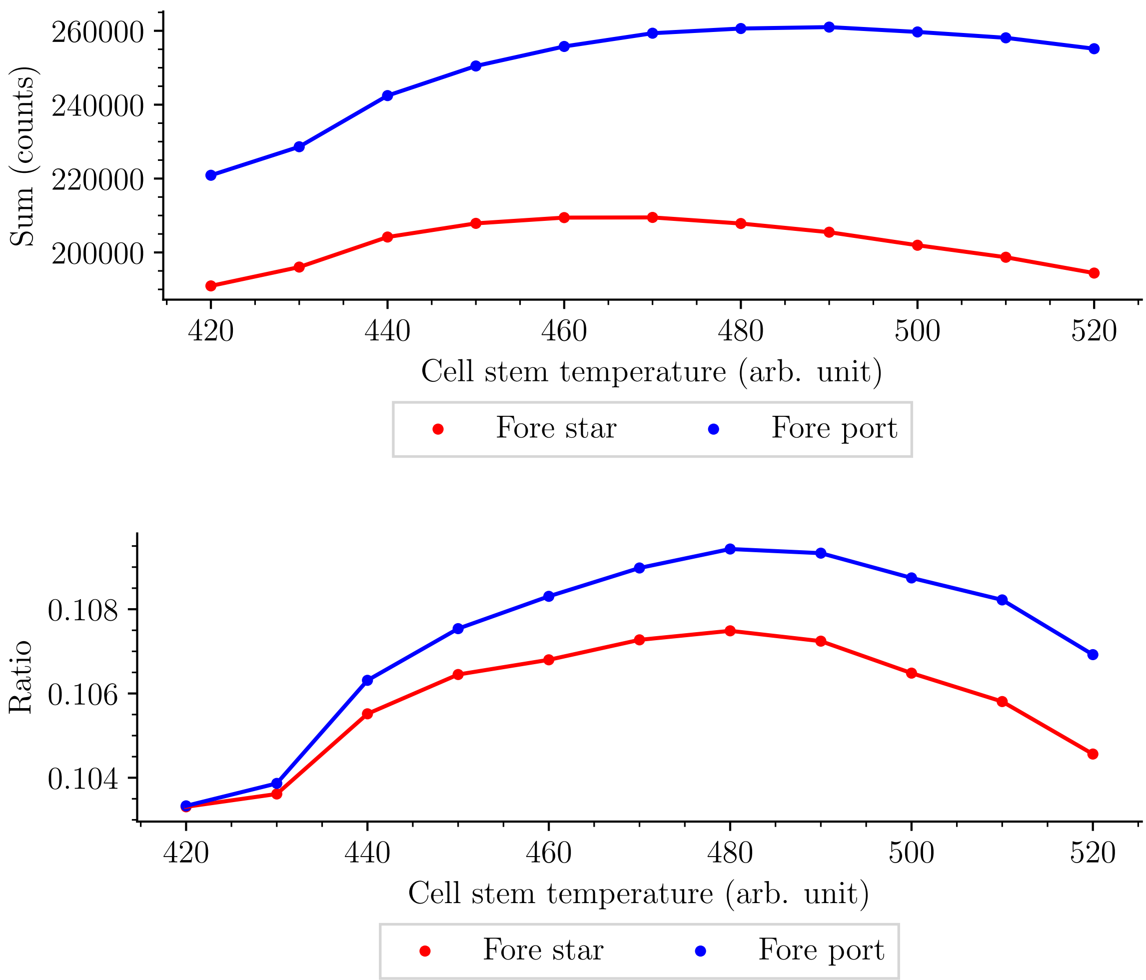

Figure 5: Vapour cell temperature optimisation. Top: Variation in total scattering intensity (sum). Bottom: Variation in scattering ratio.

The temperature controller is adjusted via dials on the front panel that are uncalibrated. The technique to optimise the vapour cell temperature involves slewing through a range of temperatures, and watching the intensity of the scattered light from the cell to find the maximum. The initial settings for the vapour cell temperature were 470 for the stem of the cell, and 570 for the top of the cell cube. These settings produce approximately 94.7 °C and 115.5 °C respectively. A temperature difference of around 20 °C is maintained between the stem and the cube of the cell to ensure that the solid potassium remains within the stem, and the windows of the cell cube remain clear.

The cell stem was scanned from 420 to 520, corresponding to temperatures of 84.9 °C to 104.7 °C, while maintaining the cell cube at approximately 20 °C above the stem. The results are shown in Figure 5. The scattering intensity (sum) from the two detectors peaks at different temperatures. The port detector peaks at a higher temperature, and has a higher overall intensity, both of which are indicative of the port detector having a slightly larger aperture than the starboard detector. The port detector suggests an ideal temperature setting of 490, whilst the starboard detector peaks at 460. The ratio from both the detectors peaks at 480, and this is approximately in the middle of the temperatures suggested by the sum. The final settings for the vapour cell were 480 for the stem of the cell, and 580 for the top of the cell cube, producing approximately 96.6 °C and 117.5 °C respectively.

The hot to cold ratio was measured at 6.0 for the starboard detector, and 5.8 for the port detector. This is a noticeable improvement on the previous configuration, where during the visit in 2016 September [1], the hot to cold ratio was measured to be 3.7 for the starboard detector, and 4.0 for the port detector. However, the performance is still degraded from 2005 where the hot to cold ratio was measured to be 8.4 [6, 14]. The vapour cell is noticeably discoloured, and replacing it with a new cell would likely return the performance to previous levels.

In the next section, we will look at data quality achieved via the fibre and new optical configuration.

5 Data Quality

A selection of observational days during the site visit are shown in Figures 6, 7, 8, 9, 10, and 11. Both the low and high frequency FOM (figure of merit) are very good. The low frequency performance is particularly impressive. The optical configuration of Klaus is now the same as the prototype instrumentation running at Izaña [11, 12], except Klaus switches polarisation states using a Pockels-effect cell whereas the prototype instrument is trialling an LCD variable retarder at a reduced switching rate. It is clear the higher switching rate is better at removing the effects of atmospheric scintillation, since the background noise level seen here is considerably better than from the lower switching rate at Izaña.

The data show none of the low frequency or noise issues experienced at Carnarvon during the Jabba fibre conversion in 2018 April [15]. When converting Jabba, only lenses L1 and L2 were removed, and L2 replaced with the same Thorlabs AC254-030-B-ML achromatic doublet used during this conversion. Jabba should have L3 removed and L4 replaced with an AC254-100-B-ML during the next visit to Carnarvon in order to resolve the remaining issues.

The continuing success of this observing configuration is dependent on how well the initial alignment is done each morning. It is tricky and requires patience, but with a little practice becomes straightforward. The Solarquest guider automatically gets the mount in almost exactly the right position, and so only a small nudge of one or both axes should be required.

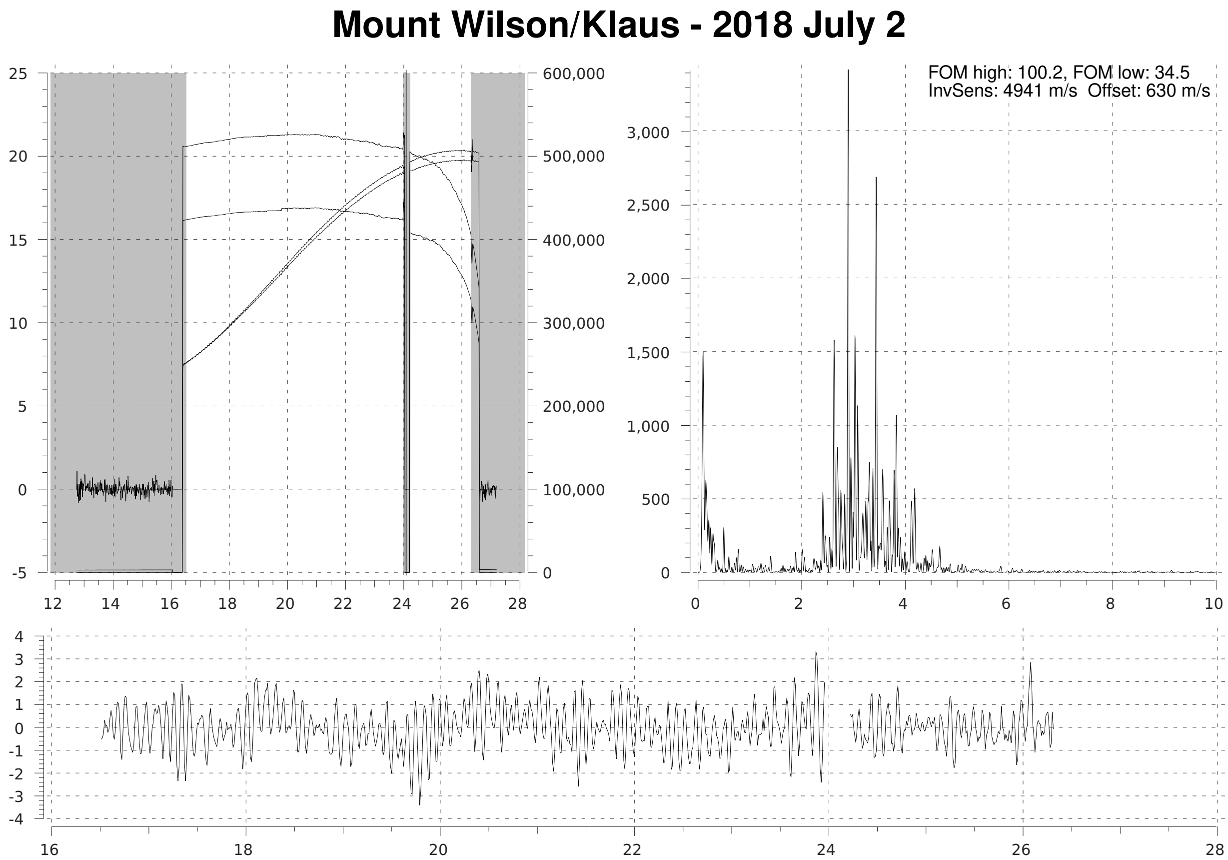

Figure 6: Data from 2018 July 2.

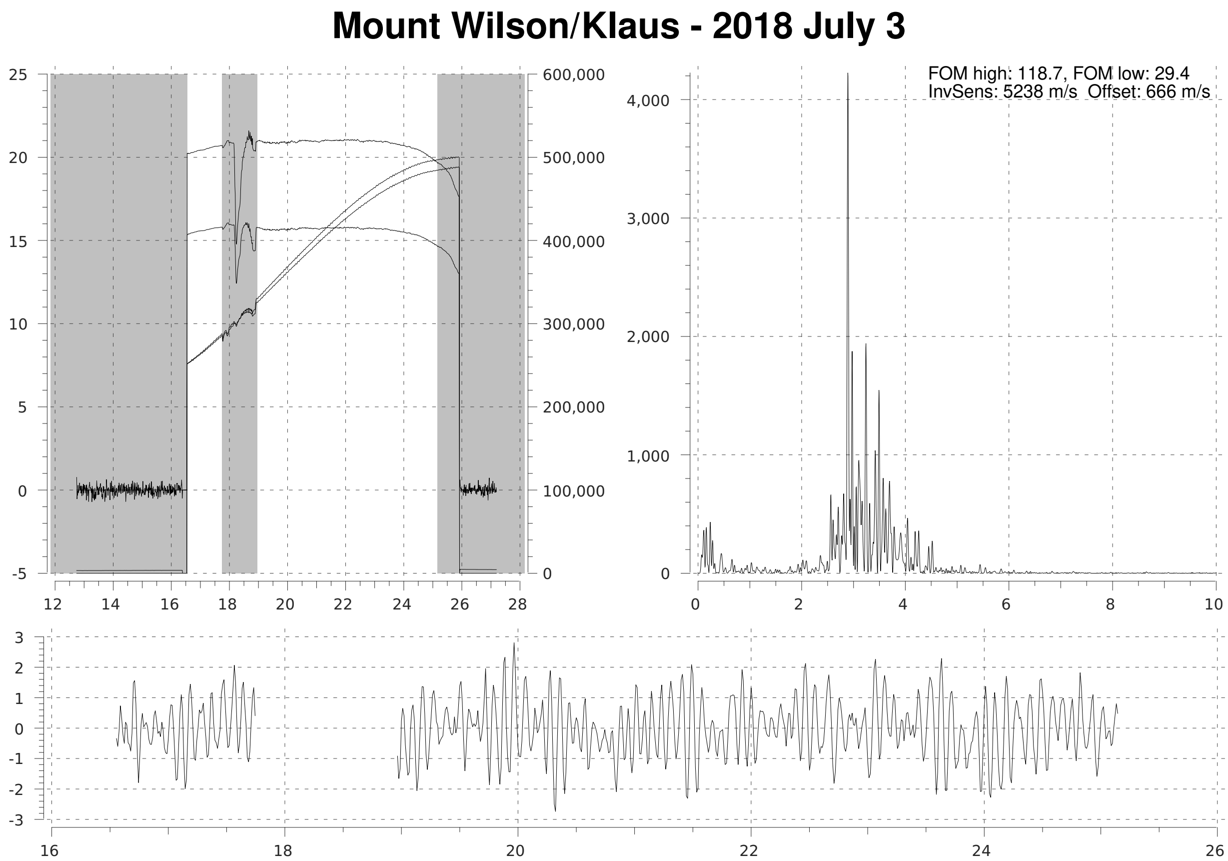

Figure 7: Data from 2018 July 3.

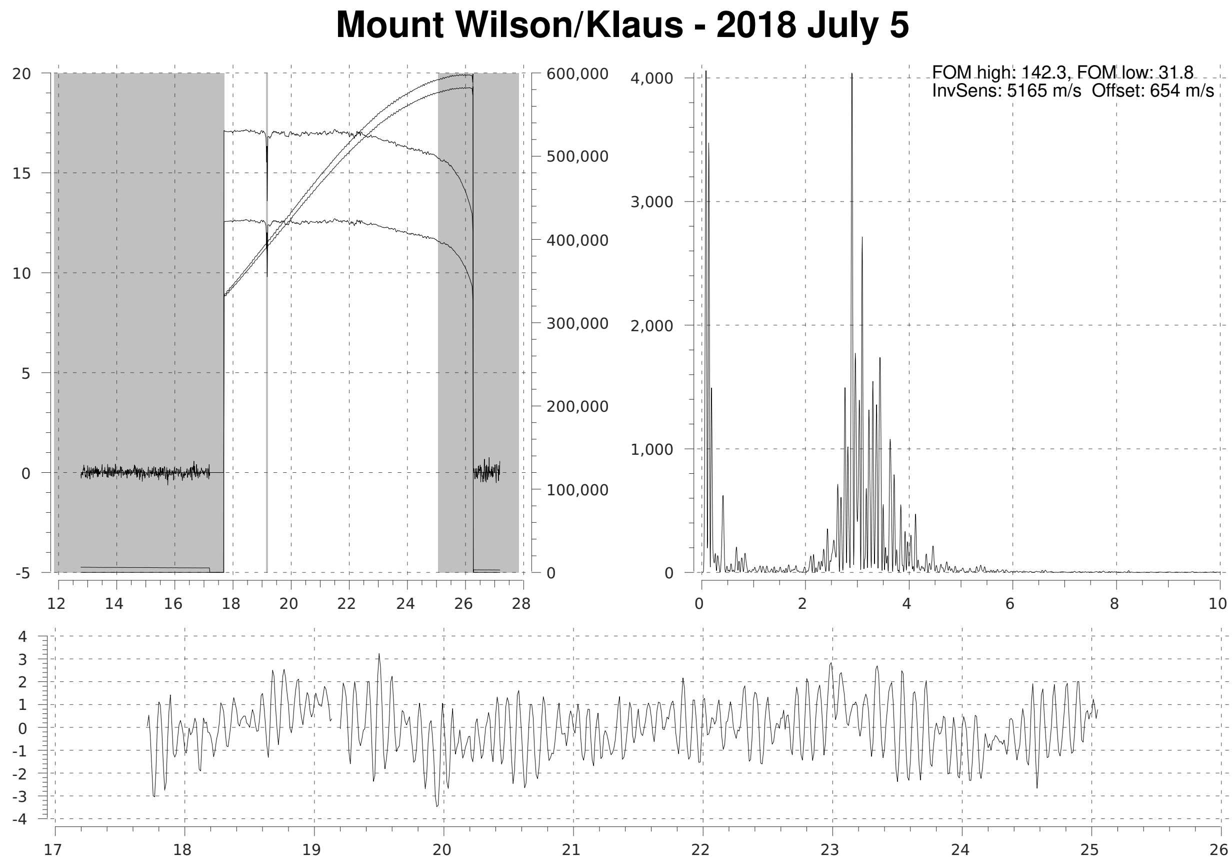

Figure 8: Data from 2018 July 5.

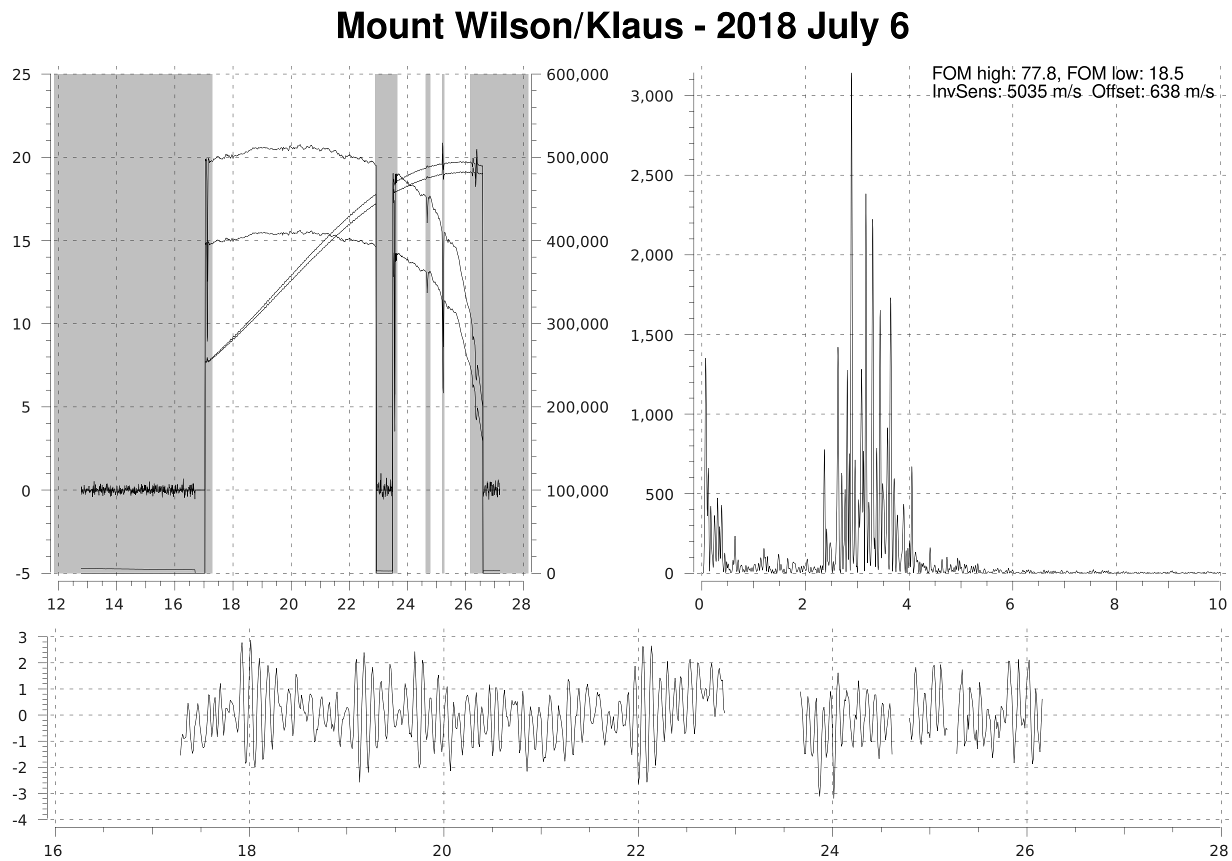

Figure 9: Data from 2018 July 6.

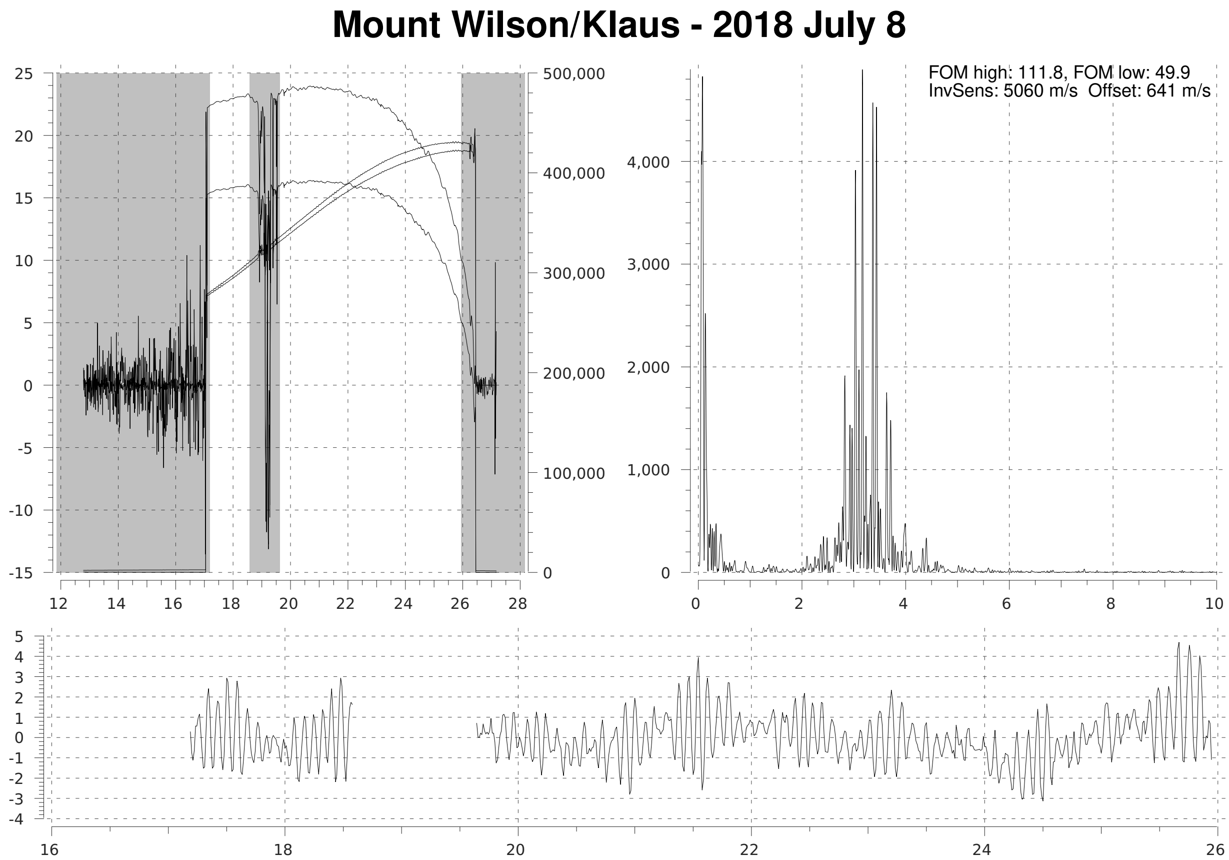

Figure 10: Data from 2018 July 8.

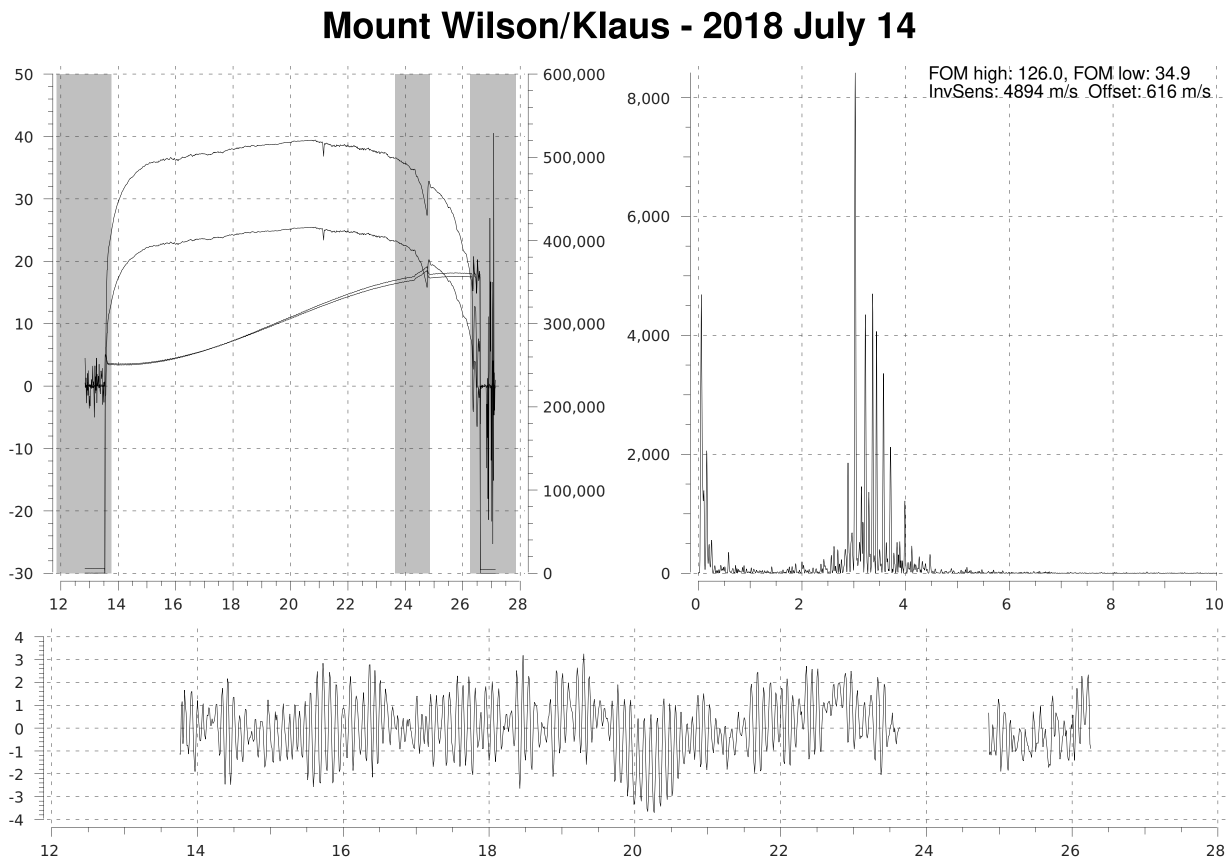

Figure 11: Data from 2018 July 14.

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