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Jabba fibre conversion at Carnarvon in 2018 April

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2018 June 22

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Abstract

Jabba was offline due to an internal water leak destroying the main power and signal pass-through PCBs at the rear of the spectrometer. Repairs were completed, including new PCBs and cabling, to bring Jabba back online. The aft starboard Peltier-effect thermoelectric coolers were replaced. Mark-V and Jabba were removed from the mount. Mark-V has been moved into storage, and Jabba reinstalled in the electronics area at the rear of the dome fed by an optical fibre where it no longer requires water cooling. Additional repair work was completed to the mount RA drive transmission including replacing the stepper motor and gearbox, and also replacing the RA potentiometer encoder and signal cable. A new UPS was installed. Ongoing issues with the fibre conversion require further work.

Contents

1 Introduction

Steven Hale and Eddie Ross visited Carnarvon from 2018 April 9 to April 30. The most recent previous visit was in 2016 August where a water leak inside Jabba was diagnosed as the cause of ongoing temperature sensor and detector output problems [1]. The water leak had caused corrosion to the rear electrical connections PCB, and temporary repairs were made to the board to allow the site to continue operation. The purpose of this visit was to replace the temporary repairs with permanent upgrades, and to convert Jabba to a fibre-based light-feed.

Jabba was first installed in 1994 [2] as a student PhD project [3]. Jabba was the first to trial a two-magnet design, and it was operated as the secondary instrument at Carnarvon. Jabba has experienced a troubled life. Carnarvon was upgraded with new control electronics (the “Zoo”) in 2002 [4]. In 2005 a major storm caused flood damage to the dome [5, 6] and despite repair attempts Jabba was eventually returned to Birmingham in 2006 for a full refit [7]. Jabba was eventually returned in 2009 [8] where successful operation saw it become the primary instrument and the retirement of Mark-V. A new digital mount controller was installed in 2011 [9], and new data acquisition electronics in 2013 [10]. Carnarvon closed down for most of 2014 due to nearby construction work [11], and was offline for some time in 2015 due to problems with the shutter drive motor [12]. Jabba experienced further problems in 2016 due to failed optical filters [13] and a major coolant leak [1] eventually taking the site offline permanently.

During this visit, the work was carried out in two phases. The first phase was to complete the repairs to the known issues, followed by the second phase which consisted of removing both Mark-V and Jabba from the mount and implementing the Jabba fibre conversion. Moving Jabba down into the air-conditioned electronics-room would eliminate the need for water-cooling of the base-plate, and also make the instrumentation much simpler to maintain going forward. Working on a bench in moderate temperatures is much easier than working on the mount in the hostile environment of the hot dome.

Section 2 first discusses the repairs that were completed resolving the known problems. Section 3 then goes on to detail the removal, conversion, and recommissioning of Jabba with the fibre-based light-feed. In Sections 4, 5, and 6 we show results from optimisation and calibration during commissioning. Finally in Section 7 we show data quality and discuss ongoing problems at the site.

2 Initial Repairs

The computer in Carnarvon crashed and would not restart on 2017 November 12. Configuring a new PC in Birmingham was delayed due to a site visit to Las Campanas already arranged for the end of November. On December 13 a spare PC, phy-hrs-91, was installed with the latest CentOS7 on two spare 80GB HDDs in RAID1, and configured with the BiSON Zoo. The PC was shipped to Carnarvon on December 20, but due to delays over Christmas and New Year holidays it was not installed until 2018 January 4. The computer did not make it to Carnarvon undamaged. The 8-port RS232 PCI interface card did not work, and shortly afterwards one of the old 80GB HDDs failed. A new RS232 card was shipped to Carnarvon, and data acquisition finally recommenced with a degraded RAID array on January 18.

On this visit, both HDDs were replaced with new 500GB drives, and the array and filesystem were resized to fill the increased available space. The GRUB2 bootloader was installed on both disks, and the system was verified as being able to boot from either drive in the event of disk failure.

The connections feed-through PCBs at the rear of Jabba were found in 2016 August to be damaged by a long-term slow coolant leak [1]. Some of the damage was able to be repaired but many of the temperature and data signals failed again shortly afterwards. Two new PCBs were installed on this visit, resolving most of the electrical problems. The forward starboard detector was not providing a temperature signal, and this was identified as a broken DET-F cable. The aft port and aft oven bottom temperatures had no thermal control, and this was identified as a broken DRIVE-A cable. Both cables were replaced as documented in BTR-325 [14] and BTR-335 [15]. The Peltier thermoelectric coolers were also replaced in the aft starboard detector due to poor thermal control. Both heat sink fans in the two temperature controllers had seized, resulting in heat sink temperatures over 60 °C. All four fans were replaced, stabilising the heat sink temperatures at approximately 40 °C.

The mount RA transmission mechanism was found to be very loose — it had almost completely fallen apart. One of the bearings that holds the pivoting motor mount in place had failed completely. This is most likely to be the cause of recent intensity steps appearing in the data. A spare bearing was installed and several screws tightened, restoring the drive to normal operation. The combined RA motor and gearbox was also later found to be having difficulty slewing the mount back to the sunrise position. The motor and gearbox were replaced with the spare, and there have been no further issues with the RA drive.

The mount RA potentiometer encoder had been experiencing issues for some time, with spurious position angles causing difficulty with mount pointing. The cable terminations at the encoder were found to be degraded with broken insulation and almost completely corroded conductors. The potentiometer itself was also found to be in poor condition. Both the potentiometer and the cable were replaced as documented in BTR-348 [9] and BTR-349 [16]. No further mount pointing issues have been logged.

The rain detector has occasionally been behaving erratically resulting in false rain alerts. On this visit the detector was verified to be operating normally when splashed with water, and no false alerts were observed. The rain detector was last replaced in 2016 March [13]. It is not clear what is causing the periods of poor operation.

The Digitech Computer 1500VA UPS was tested and found to provide zero seconds of backup power once the mains supply was removed. The batteries were last replaced in 2016 March [13]. The unit was running rather hot, and so it was decided to replace the whole device rather than purchase further replacement batteries. A new Upsonic Power ESAT 15 UPS was purchased from the local Carnarvon computer shop *Leading Edge Computers*, now trading as a *Betta Home Living* franchise. The device arrived after the site visit had finished, and so it was later installed by Les Bateman and not tested as part of these repairs.

With repairs completed and the basic operation of the site verified, the Jabba fibre conversion could begin. The conversion is discussed in the next section.

3 Fibre Conversion

3.1 Mount Preparation

The mount in Carnarvon supports three instruments. On the top of the mount is Mark-V, the primary spectrometer. The instrument and its supporting electronics were damaged in 2005 during a heavy rain storm, where it was discovered that the rain detector was non-operational meaning the dome did not close [5, 6]. Despite attempts at repair, Mark-V was eventually decommissioned in 2011, having not collected any useful data since 2009 [9]. The electronics and cabling were removed from the rack, but Mark-V itself remained installed on the mount.

On the bottom of the mount, hung upside-down, is Spectrometer-J, codenamed Jabba. Jabba, the secondary spectrometer, was also damaged during the storm in 2005 and was removed and returned to Birmingham for repair in 2006 [7]. The refit took two and a half years, and Jabba was returned to Carnarvon in 2009 [8], where it took over the role as primary instrumentation.

Table 1: The Jabba double-field spectrometer lenses. Reproduced from Lewis (1996) [3].

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

The centre box in the middle of the mount holds the two-dimensional gradient monitor (2DGM) [17]. While the gradient monitor part of the device has long since been decommissioned, the unit itself is still required since it provides both the coarse and fine guider telescopes used by the mount controller.

Jabba was unbolted from the mount and lowered down the ladder by attaching ropes to the front, as described in BTR-323 [8]. Once Jabba was removed, it was possible to also temporarily remove the 2DGM and gain access to the mounting bolts for Mark-V and remove it from the mount. The 2DGM was reinstalled, and Mark-V was moved to our storage shipping container near the OTC museum.

The subsequent nearly-empty mount was balanced as well as possible by moving the counterweights attached to the yoke. The balance is poor in declination since the 2DGM is very rear-heavy. BTR-323 [8] describes counterweights that were previously attached to the front of the 2DGM, but it was not obvious how these weights could fit. The balance in RA is affected by the declination angle, and varies between perfect and a tendency to move back to zero hour-angle. Ideally, rather than balancing the 2DGM in declination, the 2DGM should be removed and replaced by a simple and lightweight fine guider telescope as used at our other sites. Despite the relatively poor balance, the mount has not shown any drive issues.

The new input stage installed on the 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. The new filter and replacement optics are discussed next.

3.2 Jabba Reinstallation

With Jabba removed from the mount, all the cabling for the supporting electronics were also untangled and removed. Some reorganisation of the electronics rack was made in order to simplify access and connectivity. The two mains controllers were moved to the bottom shelf, and the two temperature controllers moved near the top. The potentiometer-encoder-to-serial-adaptor (PESA [18]) was moved next to the mount controller as these form a logical unit.

The big metal storage crate, and a big box of cables, were moved to the storage shipping container near the OTC museum. This cleared room behind the pier to install some free-standing metal shelving bought from the Carnarvon Mitre 10 hardware store, onto which Jabba was placed. It would be ideal to also remove the water tank, but doing so requires considerably

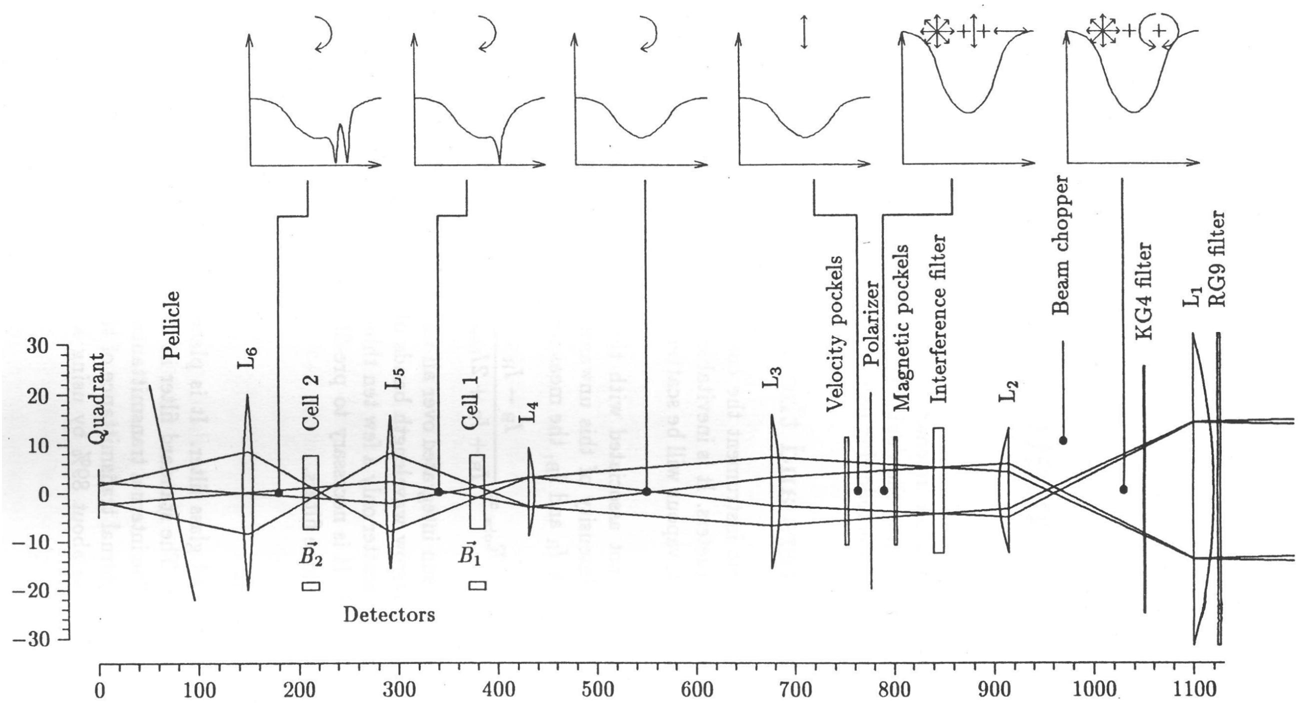


Figure 1: The Jabba double-field spectrometer optical configuration. Dimensions are in millimetres. The spectral intensity and polarisation state in the vicinity of the incident Fraunhofer line is shown at various locations along the optical path. The lenses are defined in Table 1. Reproduced from Lewis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

more effort since it will be necessary to first move the electronics rack out of the way before the tank can be moved.

Once Jabba was in place on the new shelving, the instrumentation cabling was reinstalled. All temperature control and detector signals were verified as operational. The air conditioner maintains the electronics room at a steady 23 °C, and at this temperature the detector Peltiers can easily maintain the photodiodes at 20 °C with no need for water cooling of the spectrometer chassis.

The original Jabba double-field spectrometer optical configuration is shown in Figure 1. The lenses, labelled L1 through L6, are defined in Table 1. Light is collected 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. Both L1, L2, and the filters have been removed. 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 unacceptable beam divergence. The two Schott RG9 and KG4 filters have been replaced with the single SDSS "i′2" filter at the input of the fibre. This filter has a bandwidth of approximately 700 nm to 850 nm with near 100 % transmission at 770 nm. The original RG9 and KG4 combination offers only 62 % transmission at 770 nm, and so the new filter compensates for the reduced objective aperture. The power (in mW) entering the spectrometer through the fibre is approximately the same as before.

The beam collimation produced by the new L2 lens 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

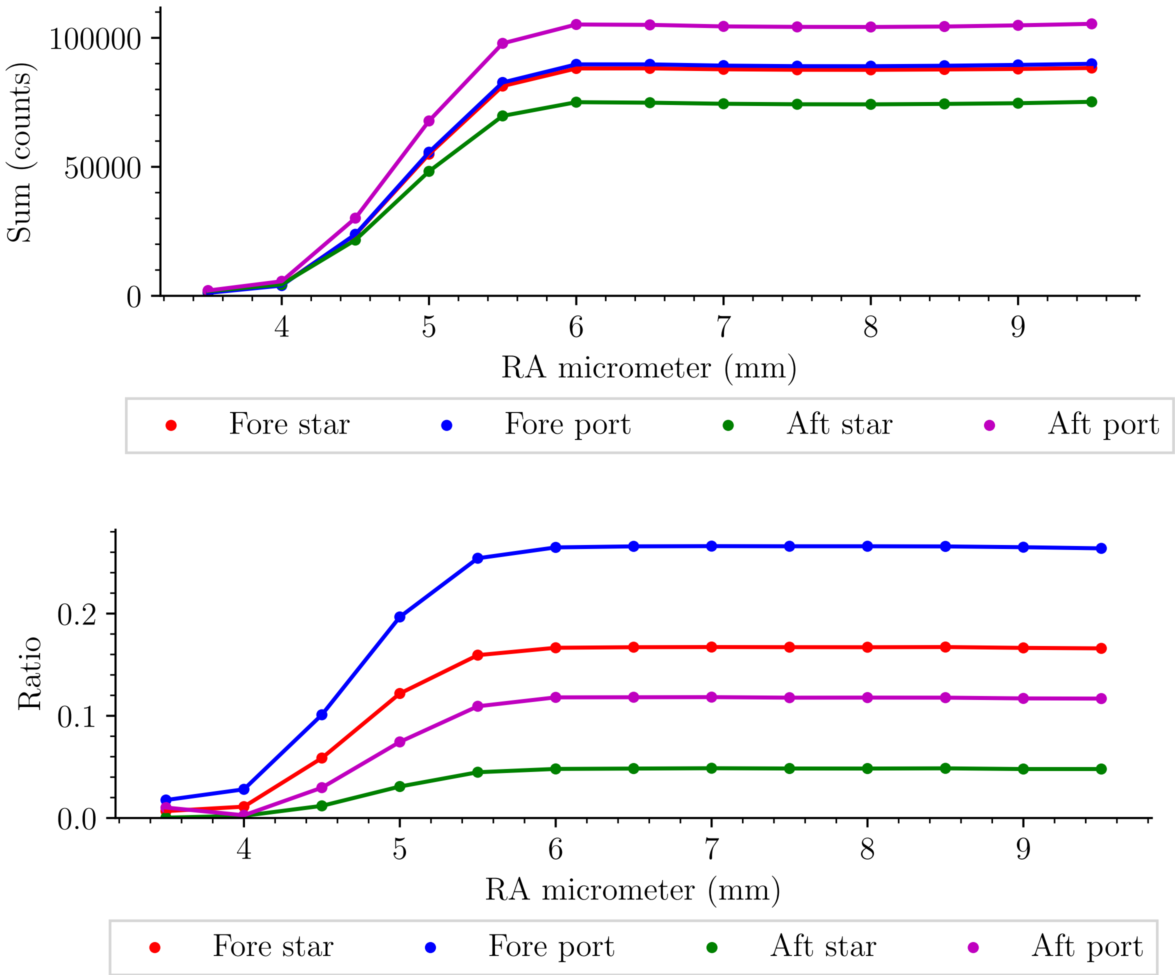


Figure 2: RA guider micrometer scan. 1 mm of micrometer travel is approximately 0.3° change in angle. The final setting was selected as 8.0 mm.

forward potassium cell, after which the filter and oven were reinstalled. No other changes were made to Jabba.

We will now continue in Sections 4 through 6 to discuss optimisation of the guider alignment and the polarisation optics.

4 Guider Alignment

The 2DGM provides a guider telescope consisting of an objective lens and a quadrant photodiode. The lens is mounted on a gimbal allowing two micrometers to adjust alignment in right-ascension and in declination. To convert micrometer settings into angles we need to know the distance from the micrometer to the pivot point. In RA this distance is approximately 190 mm, meaning that 3.3 mm corresponds to a shift of 1°. In declination the distance is slightly longer at approximately 215 mm, meaning a shift of 1° is 3.75 mm of micrometer travel.

The two micrometers were reset to the centre of their travel, and the fibre installed on the mount with a close mechanical alignment done by eye. Subsequent tuning suggested an initial fibre alignment, again done by eye, estimated the ideal guider micrometer settings to be 7.0 mm in right-ascension and 3.0 mm in declination. Figures 2 and 3 show alignment scans across

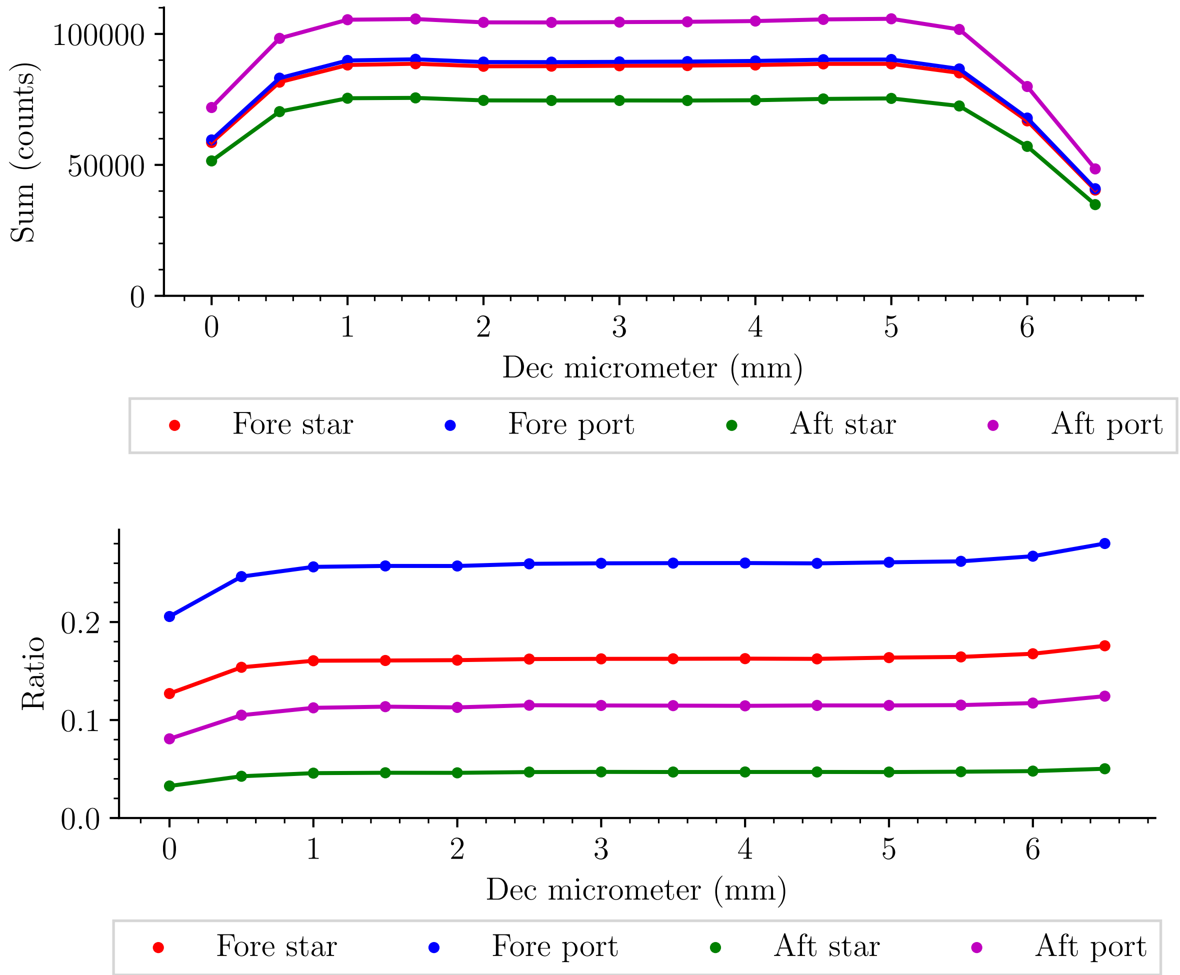


Figure 3: Declination guider micrometer scan. 1 mm of micrometer travel is approximately 0.27° change in angle. The final setting was selected as 3.0 mm.

the fibre in both RA and declination respectively. The final micrometer values were selected as 8.0 mm in RA and 3.0 mm in declination, close to the initial estimates. Part of the RA scan is lost off the end of the micrometer travel. We can assume that both RA and dec are symmetric with approximately 2.0 mm of travel either side of the centre of the fibre, making the total unvignetted field of view 1.1° as expected for the 30 mm focal length objective lens.

When Jabba was installed in 2009, the pointing sensitivity was measured to be approximately $0.018\,\mathrm{m\,s^{-1}}$ / arcsec in RA for the forward starboard detector [8]. When using a fibre there is now very little change in either the sum or ratio until the image of the Sun begins to vignette at the edge of the fibre core. Noise caused by guider fluctuations has been reduced to essentially zero.

5 Linear Polariser Alignment

The linear polariser, mounted between the two Pockels cells in Figure 1 on page 5, failed by becoming a piece of plain clear plastic and was removed in 2016 August [1]. A spare was not available for replacement, and so a temporary part was fabricated from the “lens” of a pair of polarising sunglasses. On this visit, the sunglasses filter was removed and a new piece of HN32 installed. It is not clear what caused the original polariser to fail. In 2016 March a fault with

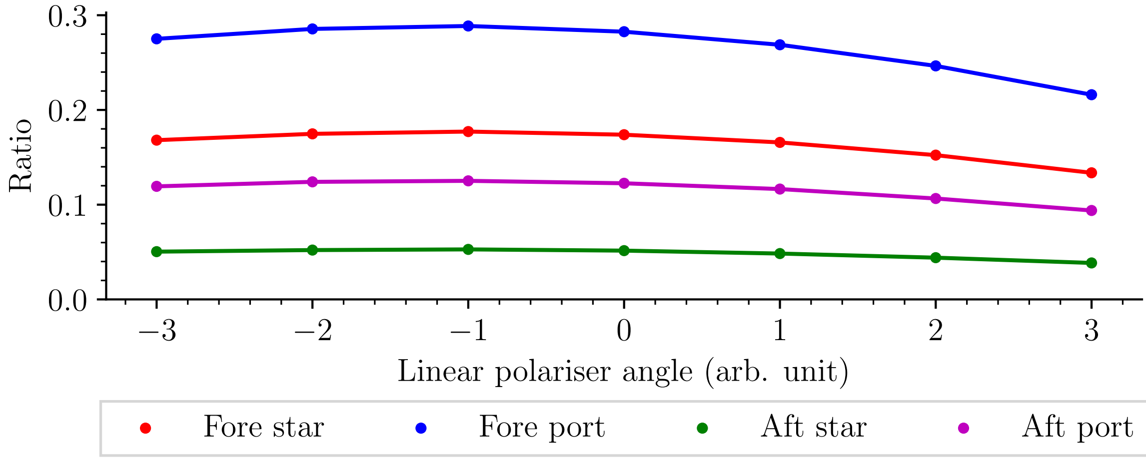


Figure 4: Linear polariser alignment. The final setting was selected as −1 on the marked scale.

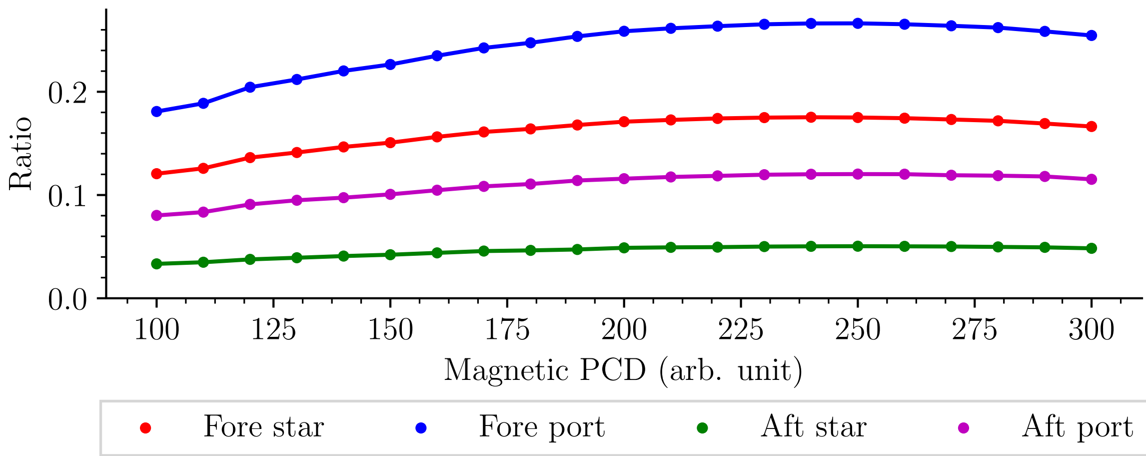


Figure 5: Magnetic Pockels cell calibration.

the KG4 infra-red filter was found [13]. The filter had become cloudy, almost opaque, and so it was removed without a replacement being available. Possibly the increase in infra-red passing through the spectrometer may have contributed to the subsequent degradation of the polariser.

The mount for the polariser has a small rotational adjustment with a total of seven major tick marks. These were considered to be ±3 units either side of the centre position. The ratio from each detector was logged at each major tick mark, and the results are shown in Figure 4. The ratio was maximised at the −1 position, and this was selected as the final set point for the polariser alignment.

6 Pockels-cell Calibration

The velocity Pockels cell is L14, and the magnetic Pockels cell is L13. When Jabba was reinstalled in 2009 it was discovered that one of the four SHV cables was missing a connector, and so only the velocity Pockels cell was powered [8]. New cables were shipped after the site visit and installed by Les Schultz.

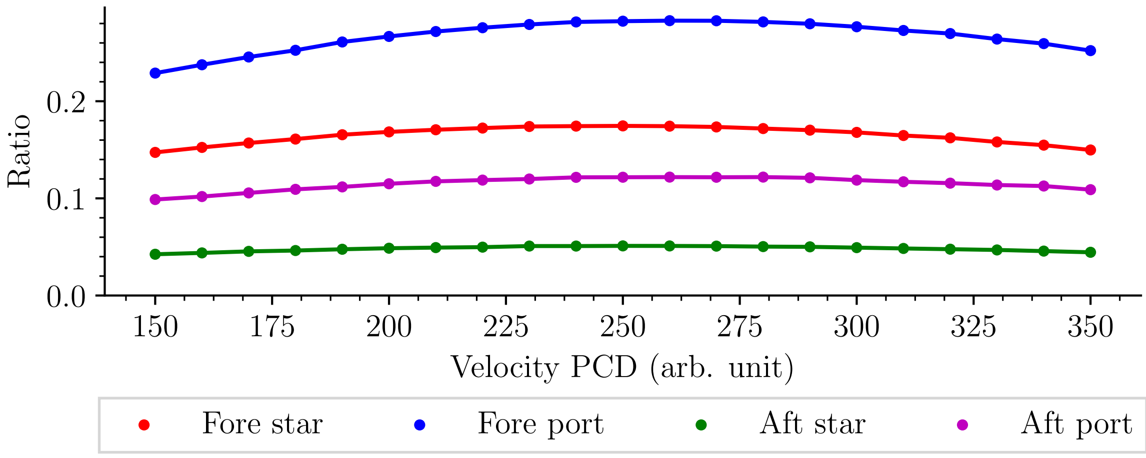


Figure 6: Velocity Pockels cell calibration.

During the diagnosis of the intensity problems in 2016 August, the two Pockels cells were swapped over to check for possible issues with the drivers or the cells themselves. Cell L14 was then removed, leaving just L13 remaining in the velocity position [1]. Neither of the two cells were found to be defective, and so on this visit the cells were returned to their original positions and the drive voltages optimised.

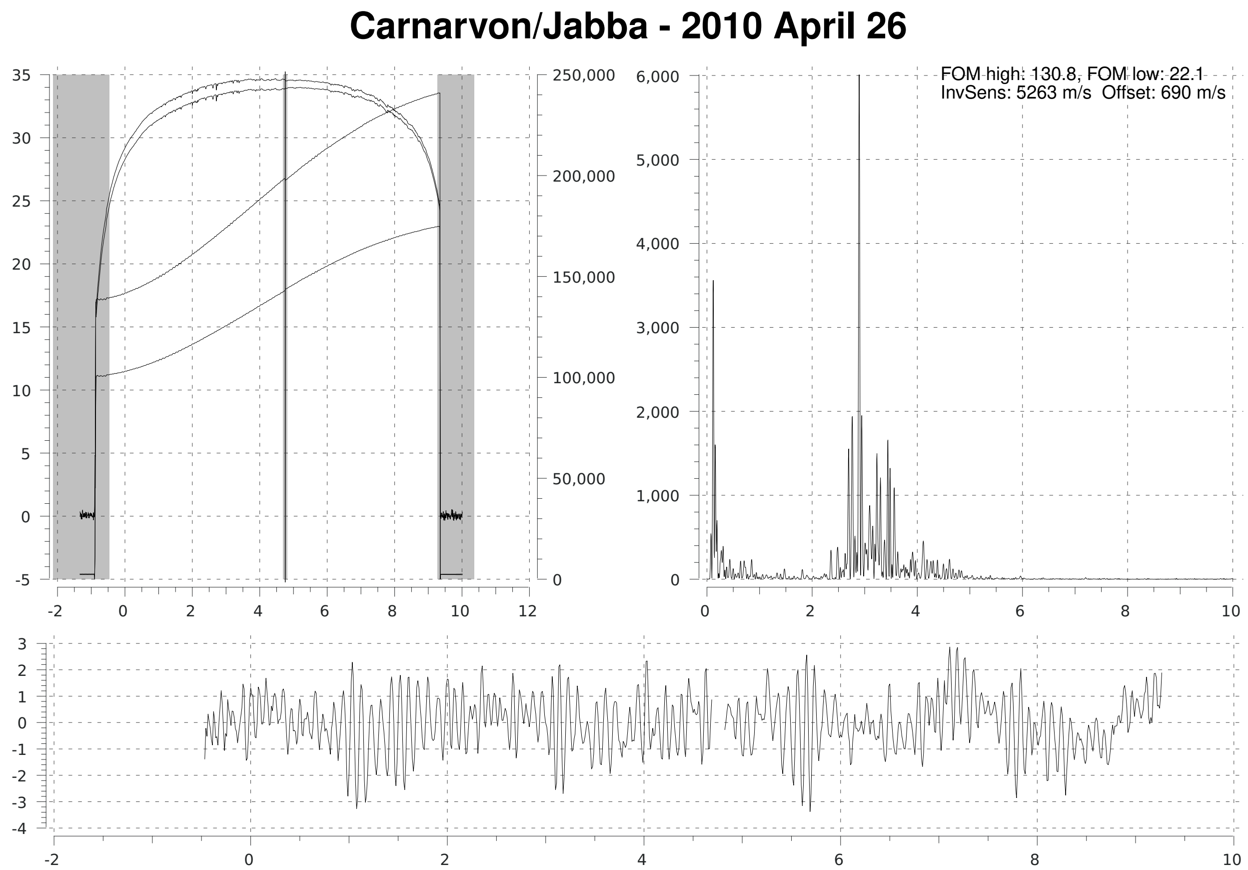
It is not possible to directly optimise the optimum voltage for the magnetic Pockels cell. Instead, the cell has to be moved behind the linear polariser where the standard velocity ratio can be measured. It is important to also move the supply cables, so that the whole final circuit of driver-cables-cell is checked at once. The drive voltage can then be scanned to find the voltage at which the ratio is maximum, and this is shown in Figure 5. The driver dial setting is not calibrated to voltage and is an arbitrary unit. The initial setting was 170, and the ratio was found to be maximised at a setting of 250. It is likely that the magnetic Pockels cell voltage has never been optimised due to the cable issues found during the installation. The solar magnetic data from Jabba is likely unusable from 2009 onwards! Following optimisation cell L13 was returned to the magnetic position in front of the linear polariser.

The voltage scan of cell L14 in the velocity position is shown in Figure 6. The initial setting was 260, and the ratio was found to be maximised at this same value. No change was made to the velocity cell voltage.

The optical fibre installed during this visit is not specified to maintain polarisation. The solar circular polarisation states required to measure the solar mean magnetic field (SMMF) may not be maintained by the fibre, and so the magnetic Pockels cell may no longer be performing correctly. The effect on circular polarisation by the fibre should be tested, and possibly the magnetic Pockels cell removed again on a subsequent site visit.

7 Data Quality

The fibre conversion and system tuning was completed on 2018 April 20, one week before the scheduled end of the site visit. The weather was particularly cloudy, and only one day was clear for data acquisition. Figures 7 and 8 show data from 2018 April 26 for the forward and aft vapour cells, respectively. For comparison the data quality from the same day in 2010 is included, which is shortly after Jabba was reinstalled in 2009 and serves as a quality benchmark.



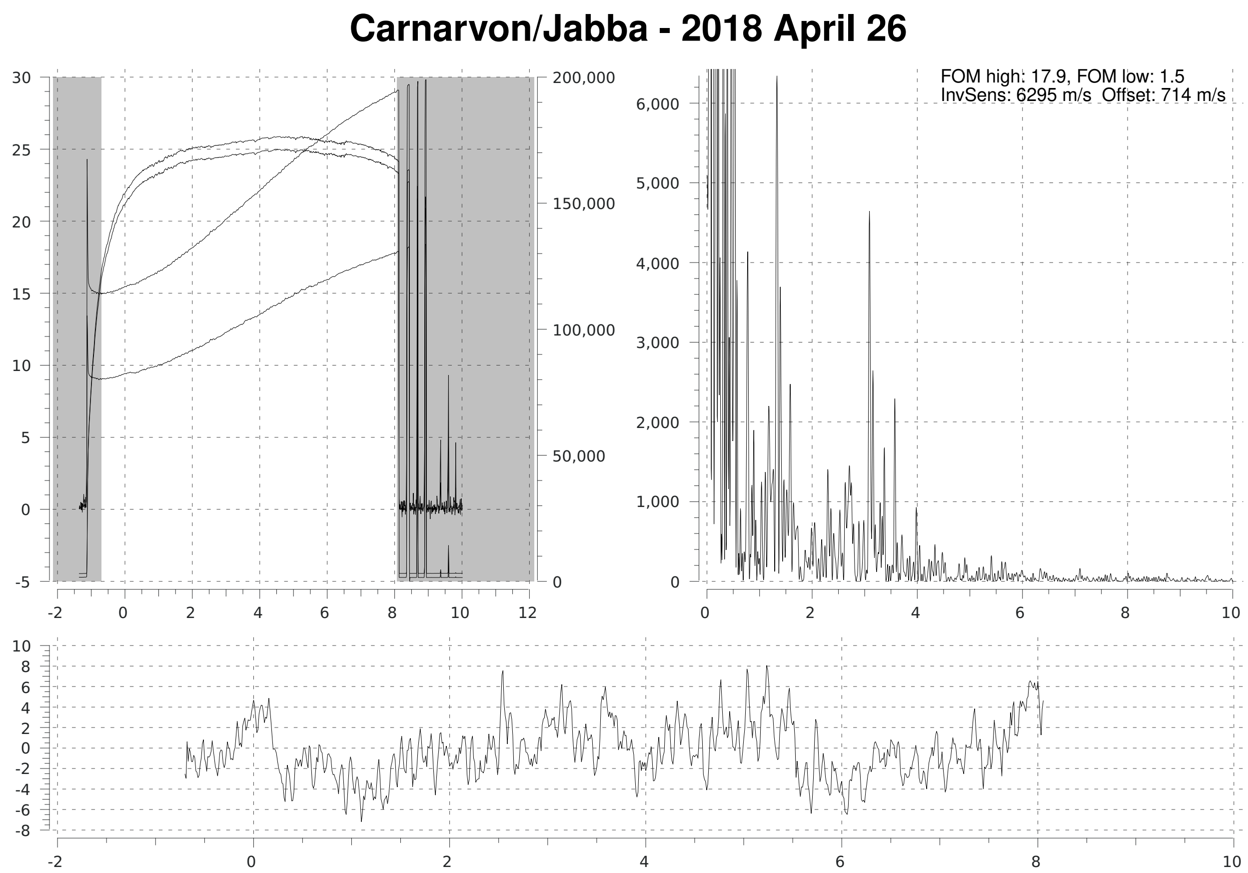


Figure 7: Data from the forward cell. Top: 2010 April 26, shortly after Jabba was reinstalled in 2009. This can be considered a quality benchmark to be achieved. Bottom: 2018 April 26, collected via the fibre conversion.

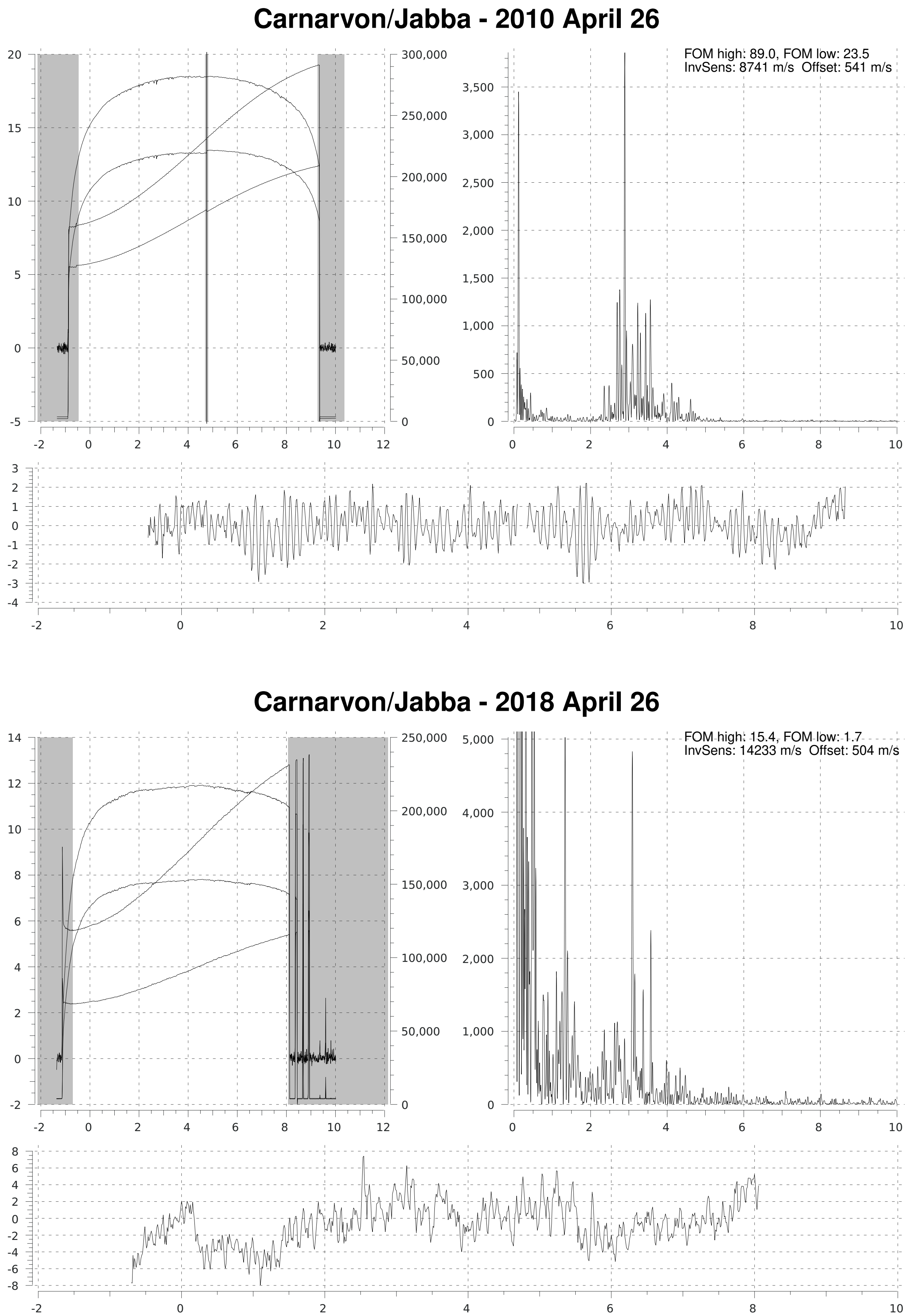


Figure 8: Data from the aft cell. Top: 2010 April 26, shortly after Jabba was reinstalled in 2009. This can be considered a quality benchmark to be achieved. Bottom: 2018 April 26, collected via the fibre conversion.

Clearly the data are poor. The inverse sensitivity is much higher (i.e., worse) and the noise levels are poor. There are a number of possible reasons for this, which are discussed below.

7.1 Low counts

As discussed earlier, the total power entering the spectrometer after all filters is expected to be similar before and after the fibre conversion. The original configuration for Jabba provides 0.32 mW exiting from the 1.5 nm interference filter. At the same point, the fibre configuration is expected to achieve 0.27 mW since the filters provide improved transmission which compensates for the reduced aperture. The sum from the forward cell is lower than expected based on this slight reduction to input power. The cause of this is likely to be internal vignetting inside Jabba caused by the larger diameter quasi-parallel beam from the fibre output. Whilst the Pockels cell and filters have adequate clear aperture, lens L3 and to a greater extent L4, are too small. The output from the fibre is uniform and has lost all spatial information from the incident solar image, and so this vignetting does not cause any problems except for the loss of radiant flux.

The reduced counts will have an impact on the signal to noise ratio, however the loss is insufficient to explain such a large increase in the white noise level visible at high frequencies (above five minutes). The issue of reduced counts is not considered to be a significant cause of the poor data quality.

7.2 Non-resonantly scattered light

Whilst the total light level is important, the signal-to-noise ratio is instead dominated by the ratio of resonantly scattered light to non-resonantly scattered light. A high total count rate will still produce poor data quality if the background non-resonantly scattered light level is high. Minimising the non-resonantly scattered light is critical to successful operation of a resonant-scattering spectrometer. A measure of this value is the hot-to-cold ratio. If the vapour cell is cooled to ambient temperature then resonant scattering is almost completely eliminated, and so the remaining signal from the scattering detectors can be considered to be entirely a measure of non-resonantly scattered light. There will of course also be some dark current from the photodiodes but this is minimal. With the cell hot, at the normal operating temperature, the signal is a combination of resonantly scattered and non-resonantly scattered light, allowing an estimate of the signal-to-noise to be made.

The larger diameter quasi-parallel beam from the fibre output is likely causing an increase in non-resonantly scattered light. If the beam is too large at L4 then it will over-fill the aperture through the magnet and into the oven cavity. This has the effect of illuminating the inside of the magnet and filling the oven cavity with diffuse light. A solution to this could be to add an aperture to reduce the beam diameter before it enters the magnet, at the expense of further reducing the total light level. A better solution would be to replace both L3 and L4 with a different lens suitable for converging the larger beam diameter into the cell, ensuring that the beam is sufficiently converged at the entrance to the magnet. Unfortunately a measure of the hot-to-cold ratio was not taken during the site visit, and so it can not be said for certain that this is the cause of the increased white noise level, but it is most likely.

7.3 Cell misalignment and interaction

The noise at low frequency (below five minutes) is more concerning. If the image of the Sun at the input stage to the fibre is too large, and close to filling or over-filling the fibre-core, then vignetting will occur. Avoiding vignetting at this point in the system is critical since it is essential to ensure light from all areas on the solar disc enter the spectrometer. We know from the guider alignment scans (Figures 2 and 3) that there is sufficient unvignetted field of view providing a large area of stability in terms of guider offset. We can be confident that the low frequency noise is not caused at the fibre input stage, and must instead be due to issues within the spectrometer.

It is well established that the two vapour cell ovens inside Jabba are not perfectly aligned. Previous guider scans indicate slightly different preferred micrometer settings between the two cells [13]. With the fibre-feed it is no longer possible to infer any internal misalignment via guider scans. However, what we can see from the guider scans is that the two forward scattering detectors provide very similar counts, whilst the two aft detectors provide very different counts. We expect the detectors from each cell to be similar, within the constrains of amplifier gain precision. The output from the aft scattering detectors should be slightly higher than forward since they are sampling further into the wings of the potassium absorption line, i.e., closer to the continuum. The aft cell misalignment causes the beam passing through the cell to be effectively offset to one side, meaning one detector experiences a lower vapour optical depth producing a higher signal, and the other a larger vapour optical depth resulting in a lower signal. There is not considered to be any reason why this should cause an increase in low frequency noise level.

The sensitivity of the two port detectors is greater than the sensitivity of the two starboard detectors, and again this is known previously and not a new issue [8]. When imaging the Sun through the spectrometer it is not expected for the port and starboard detectors to have the same sensitivity, due to Doppler imaging. Additionally, the effect should be reversed between the forward and aft cells as the image of the Sun is reversed by lens L5. Analysis of the double-field data does indeed show this reversal of sensitivity, meaning that the detectors are spatially sensitive to different parts of the sun and to different heights in the solar atmosphere [19]. The both aft detectors have lower sensitivity due to the larger magnetic field strength in comparison with the forward cell. The reason for the overall increase in sensitivity on one side of the spectrometer has, as yet, been unexplained. It should be noted that Klaus at Mount Wilson, the only other two-magnet spectrometer, also showed a difference in sensitivity between the two detectors when two vapour cells were present.

With the fibre-feed installed all spatial information from the incident solar image is lost, and so the ratio from the forward port and starboard detectors should be identical. This has been shown during other fibre-feed tests at Mount Wilson and Izaña [20, 21, 22]. The ratio from the aft port and starboard detectors should also be identical, but at a lower sensitivity than the forward cell due to the larger magnetic field strength. That the port and starboard ratios are not identical indicates there is a problem. During testing at Izaña it was observed that back-reflections from a transmission-monitor caused significant changes in the measured ratio from the port and starboard detectors. The cause is not fully understood, but the issue is likely to be changes in polarisation of the back-reflected beam re-entering the cell and adding counts to the wrong polarisation data acquisition channel. Jabba does not have a transmission monitor installed, but it is likely that back-reflections from the aft cell are causing the issues with the forward cell. It is not clear what could be causes similar issues in the aft cell. Poor control of the light trap at the exit of the aft cell could be causing similar back-reflections. Potentially reflections between the two cells could be causing an interaction in both cells. As the ratio changes throughout the day, such interference could be the cause of the issues at low frequency, although again it is not clear why this should be such a catastrophic issue now with the fibre when it was only a curiosity when Jabba was pointed directly at the Sun. The first test would be to remove the aft cell and observe the affect on the data from the forward cell. Potentially it could be sufficient to block the beam at the entrance to the aft magnet, although it should be noted that completely eliminating reflected NIR is tricky, and so removing the cell would be preferable.

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