KOALA–AAOmega Manual

Volume I: User Guide

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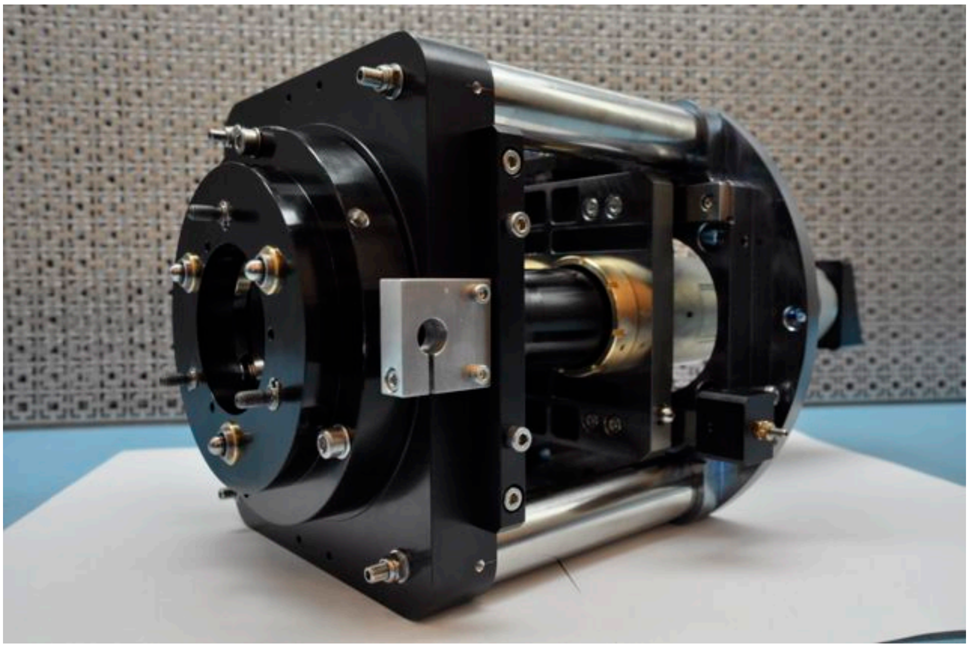

Please read How to use this manual on the inside of the cover.

Parts of this manual:

Volume I: User Guide

Volume II: Support Manual

Guide for AAO staff and Troubleshooting Instructions.

Australian Government
Department of Industry, Innovation and Science

AAO

The Australian Astronomical Observatory
www.aao.gov.au

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How to use this manual

This AAO Instrument Manual is designed to be a complete reference for the typical user. It is divided into parts, with each part relevant for a particular phase of a program:

Part I Material relevant for preparing a proposal. An overview of the instrument, its capabilities and its overheads is provided.

Part II Material relevant for preparing for awarded time, including details on creating an observing plan, what information or observation description files must be prepared in advance, and other practicalities.

Part III How to operate the instrument and other tasks required at the telescope. Users should be familiar with this part in advance, but certainly need not memorise the whole thing.

Part IV Overview of reducing data.

Part V Supplementary information relevant only to a few observers. This section is often offered as a separate download on the website.

The division of the manual means it is not necessary to read and understand more than one part at any one time.

The manual has been designed with print and on-screen readers in mind, and has hyperlinks throughout to aid in quickly navigating the document.

The AAO welcomes and appreciates feedback on this document. Errors, mistakes, omissions, etc, cannot be corrected if we are not aware of them. Talk to your support astronomer. Printed copies of these manuals are kept in the observing control rooms, and users are invited to mark changes or problems directly on those copies.

Part I

Overview of KOALA and AAOmega

This part is a section of the larger KOALA–AAOmega manual, which is available from the website.
http://www.aao.gov.au/science/instruments/current/koala/overview

Chapter 1

KOALA Overview

KOALA, the Kilofibre Optical AAT Lenslet Array, is a wide-field, high efficiency, integral-field unit designed for use with the bench mounted AAOmega spectrograph on the AAT. The KOALA "front end" is described here, and the AAOmega spectrograph is described in the next chapter, AAOmega Overview.

KOALA has 1000 hexagonal lenslets arranged in a rectangular array. The field of view is selectable between either 15.3×28.3 arcsec with 0.7″ spatial sampling or 27.4×50.6 arcsec with 1.25″ sampling. To achieve this, KOALA uses a telecentric double-lenslet array fed by interchangeable fore-optics. The IFU is mounted at the f/8 Cassegrain focus and feeds AAOmega via a 31m fibre run.

KOALA benefits from all of the flexibility of the reconfigurable AAOmega spectrograph. The double beam spectrograph provides user selectable wavelength coverage and resolution using a series of movable, interchangeable gratings. A set of low, medium, and high resolution gratings provide $R \sim 1,000$, $R \sim 5,000$ and $R \sim 10,000$ across the wavelength range 330 nm to 1000 nm. Full spectral coverage is possible in a single exposure with the low-resolution gratings.

The overall efficiency of KOALA, AAOmega and the AAT is about 4% at 3700 Å and 18% at 6563 Å in the standard setup.

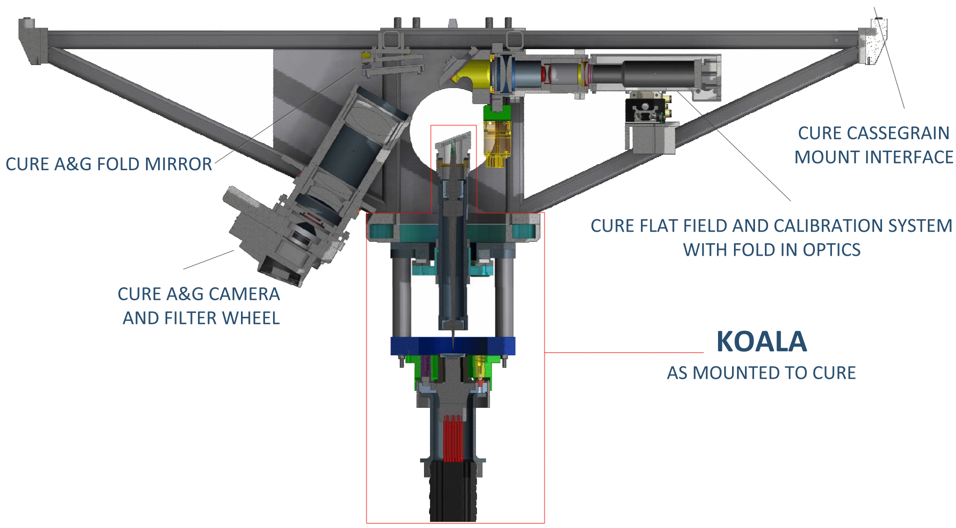


Figure 1.1: *Cross Section of KOALA and CURE.*

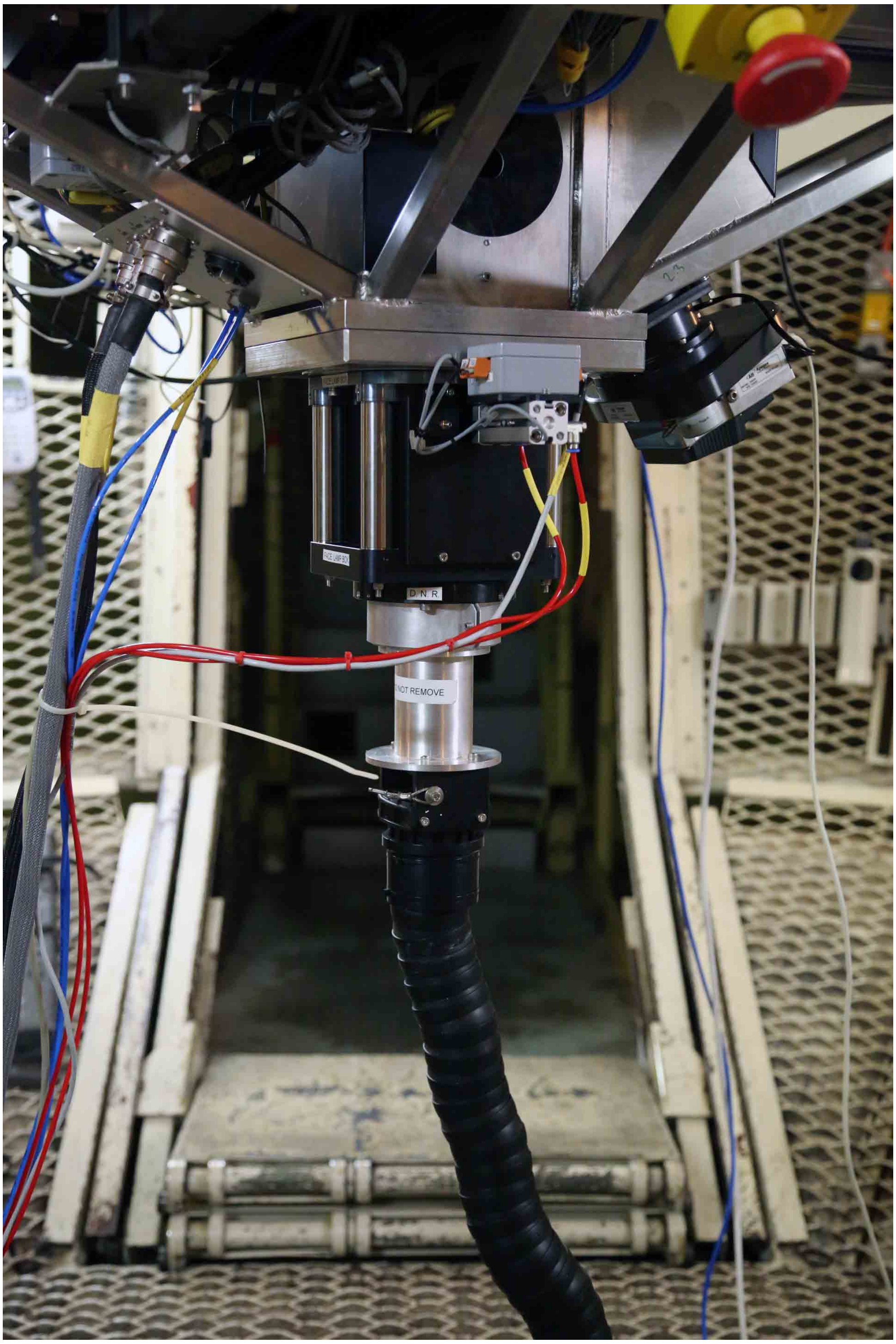


Figure 1.2: *The KOALA head unit installed in the Cassegrain cage of the AAT.*

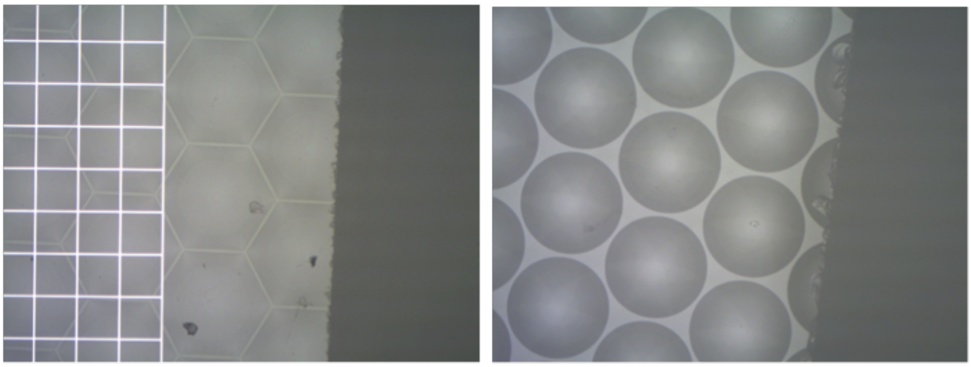


Figure 1.3: *The KOALA micro lens arrays. The left image shows the SUSS hexagonal lenslets which face the sk, with a 100-micron grid overlaid. The right image shows the second, circular lenslet array which faces the fibres.*

1.1 Micro-lens Array

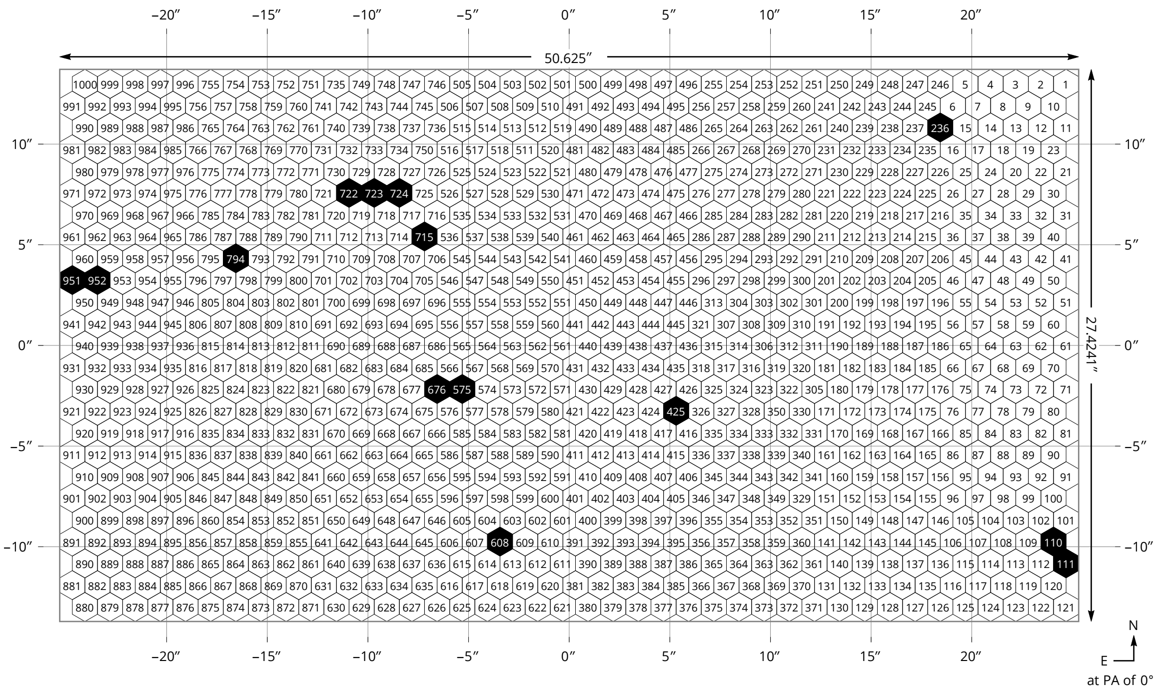
KOALA uses a double microlens array to feed the fibres (shown in Figure 1.3. In principle it is possible to feed a fibre array directly by placing it at the (magnified) focal plane, but a microlens array offers two significant advantages. First, a microlens array has close to 100% filling-factor, whereas a fibre array has a limited filling factor due to the fibre cladding and packing. Secondly, a microlens array can be used to form a pupil-image on the face of the fibre, and therefore the coupling into the fibre is more efficient because both the pupil image size and the focal ratio can be matched to those required for efficient coupling into the fibre.

Two options were considered for the KOALA: a single microlens and a double microlens. A single microlens is the simplest system and is the system that has been traditionally used to feed fibre IFUs. The double microlens system is novel and offers the advantage that the fibres feed is always telecentric, thus minimising losses.

1.2 Focal plane and field of view

KOALA offers a rectangular field of view with a selectable scale. The 1000 lenslets of the focal plane are laid out in a rectangle of 40×25 lenslets, or an aspect ratio of 0.54 (see Figure 1.4). The field of view is selectable between 15.3×28.3 arcsec and 27.4×50.6 arcsec, with spatial sampling of 0.7 arcsec and 1.25 arcsec, respectively. The field is oriented such that at position angle of 0°, the long axis is east-west (see Figure 1.5). The position angle is measured north-through east. For mechanical reasons, the position angle is restricted to the range 0° to 180° (additional range is redundant).

Each lenslet covers a hexagonal patch on the sky, and the lenslets contiguously cover the field of view. The fill factor of the lenslets is 96%. The sampling of either 0.7 arcsec or 1.25 arcsec is centre-to-centre.



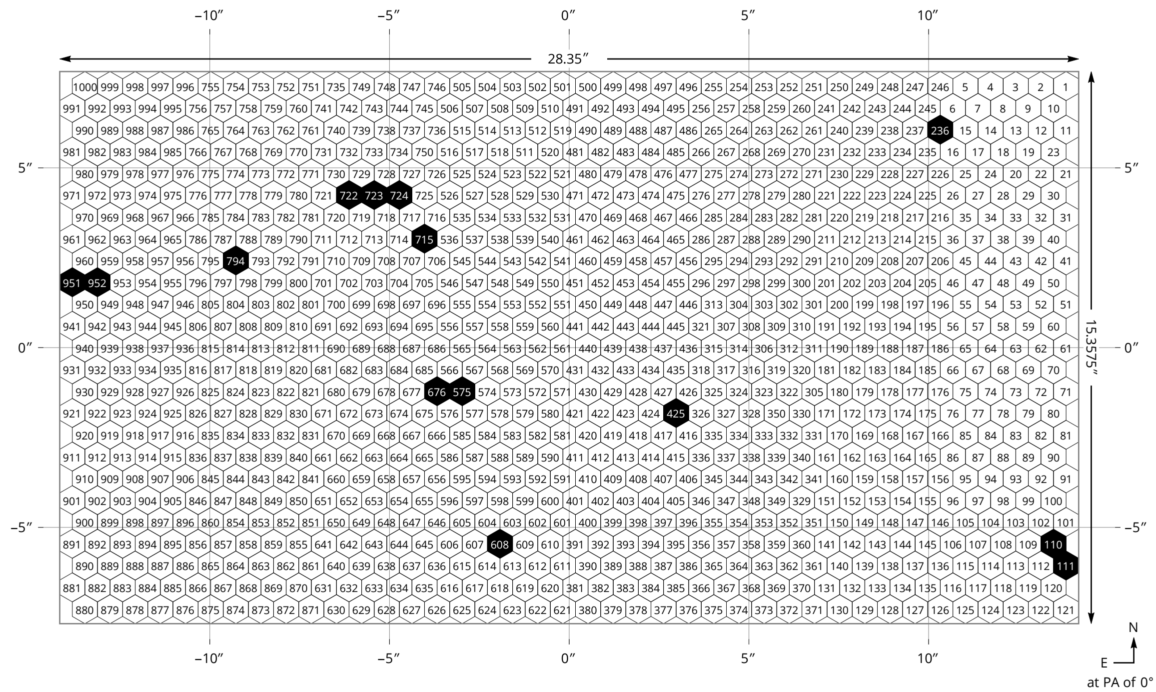


Figure 1.4: *Layout of KOALA Lenslets. The top shows the FoV in the wide field of view configuration (1.25″sampling), and the bottom in the narrow FoV configuration (0.7″sampling). Dead fibres/lenslets (as known on 11 October 2017) are shown in black.*

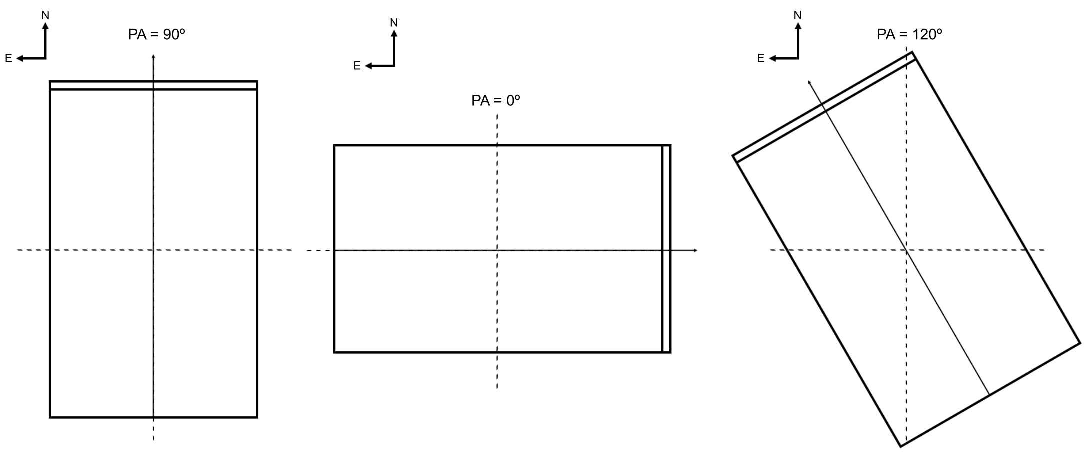


Figure 1.5: *Orientation of the KOALA rectangular field of view for position angles (PA) of* 90° *(south-north)* 0° *(east-west) and* 120°.

Chapter 2

AAOmega Overview

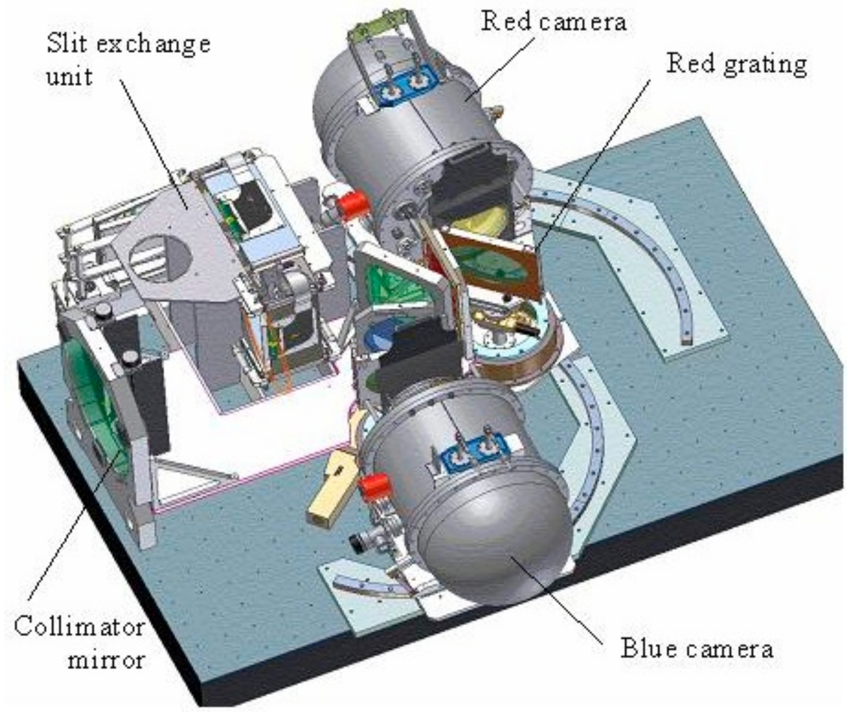


Figure 2.1: *Physical layout of the AAOmega spectrograph.*

AAOmega is a dual-beam spectrograph. Science fibres are arranged into a pseudo-slit which feeds into a single collimator and then separates into the blue and red arms of the system via a dichroic beam splitter. There are two dichroics, one operates at 570nm and one at 670nm. Each arm of AAOmega uses one of a selection of Volume Phase Holographic (VPH) gratings. The system shutter is in front of the fibre pseudo-slit, so both cameras must use the same exposure time.

AAOmega can be configured to observe the entire optical spectrum over the wavelength range 370nm-900nm, with a small overlap between the red and blue arms around the dichroic wavelength (570 or 670nm). The grating set available allows a range of resolutions between $R \sim 1,000$ and $R \sim 10,000$. The fibre spectra are recorded onto the 2K×4K E2V CCDs with light dispersed along the 2K axis (not the 4K axis). Hence, at low resolution the entire accessible spectral range is recorded at once, but at higher resolutions the user must tune the wavelength range to that which best suits their requirements.

AAOmega uses Volume-Phase Holographic (VPH) transmission gratings. These have flexible blaze angles. Each grating has a specific design blaze angle which will give the absolute maximum efficiency with that grating (the super blaze). This peak efficiency reduces smoothly with wavelength away from that. The usual setup for most programs is therefore to have the grating set at its super blaze angle and the camera at twice this angle to centre the maximum efficiency wavelength on the CCD. The complication comes when the observer wishes to observe at a central wavelength which is some distance away from the super blaze angle for the grating. This would mean observing with the grating and camera angles highly asymmetric, and therefore operating on the low efficiency (and rapidly falling) part of the blaze envelope for the grating. The solution is to tune the grating and camera angles to new values. This shift in the grating angle will shift the blaze profile away from the super blaze, flattening the steep wings of the super blaze envelope and boosting system performance at the desired wavelength(s), with the expense of a slight reduction in overall peak performance in comparison to the super blaze setting.

2.1 References

- “AAOmega: a scientific and optical overview” : Saunders et al. 2004 SPIE 5492 389
- “AAOmega: a multipurpose fiber-fed spectrograph for the AAT” : Smith et al. 2004 SPIE 5492 410
- “Performance of AAOmega: the AAT multi-purpose fiber-fed spectrograph” : Sharp et al. 2006 SPIE 6269E 14, arXiv:astro-ph/0606137
- “Optimal Extraction of Fibre Optic Spectroscopy” : Sharp & Birchall 2010 PASA 27(1) 91, arXiv:0912.0558
- “Sky subtraction at the Poisson limit with fibre-optic multi-object spectroscopy” : Sharp & Parkinson MNRAS, 2010, 408, 2495

Part II

Preparing for observing

This part is a section of the larger KOALA–AAOmega manual, which is available from the website.
http://www.aao.gov.au/science/instruments/current/koala/overview

Chapter 3

In advance of your observing run

1. Contact your support astronomer (see the AAT Schedule). Make sure you discuss with them:
   - What your program is and your observing strategy, including exposure times;
   - Recent performance of the instrument (e.g., how fast will field reconfiguration times be for 2dF);
   - Any questions you have about observation description files, which must be prepared in advance (e.g., `.FLD` files for 2dF, finder charts for KOALA, observing scripts, etc.);
   - Which particular mode/setup you plan to use for your program.
   - When you will be arriving at the telescope or remote observing site.
2. Fill out your Travel Form, *regardless of whether you will be observing remotely or at the AAT*. This allows the AAO to make appropriate reservations, etc.
3. Read this documentation, especially Parts II: Preparing for observing and III: Observing with KOALA+AAOmega. Users of 2dF *must* be prepared to use `configure` at the telescope.
4. You should plan to arrive early, preferably the day before your first night on the telescope, especially if this will be your first observing run with this particular instrument/telescope. This will give you time to discuss your program with your support astronomer in detail, familiarise yourself with the data reduction software, and the computing and observing system at the telescope or remote observing site.
5. If observing with 2dF, prepare your `.FLD` configuration files. If observing with another instrument, prepare finding charts for your targets. Preparing `.FLD` files is a complex task, and should not be left until the last minute.

Astronomers are *strongly* encouraged to reduce their data in real time at the telescope. Although such "quick-look" reductions often require revisiting afterwards, they are crucial to ensuring the best quality data is obtained. AAOmega and HERMES data are reduced using the `2dfdr` software environment. Reduction facilities are available at the AAT and via the remote observing system, but users may wish to download and run the software e.g., on their laptop. The 2dfdr webpage provides all necessary links and information for the data reduction task.

Chapter 4

Preparing to Observe with KOALA

4.1 Finding Charts and Target Acquisition

Positive target acquisition with KOALA is best accomplished with finding charts. Good finding charts should

- show an area of the sky about 3–5 arcminutes on a side,
- resemble the V-band image,
- show North and East,
- be centred on the acquisition star, *not the final target*, unless no acquisition star is used,
- should include a separate image of the final science target[1] (if it is not visible on the finder image above),
- include offsets from the acquisition star to the target in arcseconds on the sky (this can be done with Python script `offset_star`),
- include the coordinates (in HH MM SS.SS, DD MM SS.SS format) of both target and acquisition star,
- print well in black and white.

KOALA on the AAT can accurately acquire an unresolved, < 18 mag target in about 5 minutes. The accuracy/repeatability of the acquisition is better than 1.0 arcsec night to night, and less than a few arcseconds run to run. Fainter and/or unresolved targets will be less accurately acquired.

For more accurate acquisitions, and for faint or diffuse targets, an offset star must first be acquired. A nearby ($r < 200$ arcsec) bright ($10 < m_V < 14$) star is acquired and imaged with KOALA. With the telescope guiding, a guided offset is performed to the science target. A world-coordinate system can then be created *a priori* for the final data using the star in the acquisition frame as a reference.

4.2 Dithering on target and offset skies

It is recommended to dither the telescope a small amount between each exposure in order to reduce the impact of defects in the instrument on your data. Dithering will help fill in dead

[1] It is often helpful to include an overlay of the KOALA FoV centred on the target, and also showing any offset sky positions to be used.

lenslets/fibres in the array, and reduce the imprint of the instrument characteristics on the final data.

There are several options for how the instrument could be dithered. It is possible to dither the telescope by an integer number of lenslets such that the footprint of the lenslet array is kept the same. Such an approach greatly simplifies the combining of the data because no sub-division or spatial rebinning of the lenslets are required as part of the combination (but corrections for chromatic differential atmospheric refraction will eliminate this advantage). Alternately, dithers whose size are not an integer multiple of the lenslet size could be used. This might make it possible to recover some spatial resolution (in good seeing) but make combining the data more complex.

A guide for preparing offsets of an integer number of lenslets can be found in § 11.3: Dithering on target and mosaicing large targets on page 48. Such offsets can be complex, but our Python script `koala_offsets` provides these numbers for any given position angle (see § 11.3: Dithering on target and mosaicing large targets).

A drizzling algorithm (kindly provided by the SAMI team) for combining multiple dithered frames onto a regular square pixel grid is available, regardless of dithering approach chosen. See Part IV: Data Reduction for more information. Which method is best will depend on the goals of your program, and on the plan for the data reduction.

In any case, in 2017 a complete new set of Python scripts has been created for reducing KOALA data. See Part IV: Data Reduction for more information.

In addition to dithering on target, it is often recommended to take separate, blank-sky observations for sky subtracting the science data. Separate skies should be taken if either

- the science target will fill the KOALA Field of view, leaving few or no lenslets sampling pure sky, or
- very accurate sky subtraction is crucial to the success of your science.

Each of these will have an impact on the noise in your final data, which should be carefully considered. The most accurate sky subtraction can be achieved with offset skies. Nod-and-shuffle observations are not possible with KOALA because there is no room on the detector for storing the simultaneous sky data. Talk to your support astronomer if you have any questions as to the best method of sky subtraction for your program.

4.3 Calibration Requirements

What calibrations are required will depend on your particular science case, so it is best to discuss your specific requirements with your support astronomer when planning your observing.

Below is a description of various calibration data and what data quality each calibration can deliver.

4.3.1 Available Calibrations

Approximate overheads for each calibration are shown in parenthesis.

Fibre Flat Field (3 minutes/frame) Used to find and trace the fibre spectra across the detector, and (sometimes) for chromatic flat fielding. Finding and tracing the fibre spectra produces a *tramline map* that is the input for all of the spectral extraction. KOALA uses the CURE calibration lamps, which provide an f/8 feed with a central obstruction designed to mimic the AAT primary. The accuracy of the internal calibration lamp for chromatic flat-fielding[2], and for high-precision measurements of the fibre-spectra profile on the detector is not known, but should be very good.

[2] Chromatic flat-fielding corrects for varying spectral response between fibres

Dome Flat (~12 minutes) This is a flat field illuminated through the telescope, improving the feed aperture ratio of the fibres and spectrograph. These flats can be used for fibre tramline mapping and chromatic flat-fielding. The chromatic flatfielding accuracy is much improved over Fibre Flat Fields, with a relative accuracy of $\sim 1\,\%$.

Arc (3 minutes/frame) Used to determine the wavelength solution for the system. The primary lamps available are FeAr and CuAr. If additional lines are required, e.g., to calibrate high resolution data, talk to your support astronomer about the possibility of using the chimney lamps.

Detector Flat (~20 minutes) Also known as a "long slit flat". Such flats are taken by manually defocusing the spectrograph, or installing a mask in front of the fibre pseudo-slit. This provides fairly uniform illumination, which can be used to remove pixel-to-pixel sensitivity variations in the detectors.

Offset Sky A blank sky observation to use for sky-subtraction. These observations can also be used as a spatial flat-field, i.e., to correct fibre-to-fibre total throughput variations.

Twilight Flat (~20 minutes during twilight) Used to spatially flat-field the data. May also be useful for tramline mapping, and chromatic flat-fielding.

Flux Standard (8–15 minutes) A flux standard is needed to provide an absolute spectrophotometric calibration.

Telluric Standard (8–15 minutes) Needed to remove atmospheric OH absorption, which can be highly variable at Siding Spring Observatory.

Bias Frames Although all frames include an overscan region to measure the bias level, separate 2D bias may be taken. These were important for removing cosmetic defects in the original AAOmega blue CCD. However, with the current detectors these frames should not be used. They will only contribute to the overall noise budget without improving the results.

Dark Frame The AAO's detectors display a small but measurable dark current. Dark slides make it possible to take dark frames during the day. Typically 20 or more frames are required to make a significant improvement in the data reduction, but it is possible to scale dark frames for different length exposures.

4.3.2 Minimum Requirements

The minimum requirement for producing scientifically valid data with KOALA is a fibre-flat and an arc for each night/wavelength setup used. `2dfdr` will require these two files as a minimum to reduce data.

With these minimum calibrations, one can expect at best a 10% relative flux calibration accuracy. Sky subtraction will be limited by the flux calibration accuracy, and by the amount of pure sky within each KOALA observation.

4.3.3 Typical Requirements

Typically, observers using KOALA will want to take the following calibrations:

Calibration Type	Cadence	Notes
Arc	Start & End of night	2–3 repeats
Fibre Flat	Start & End of night	2–3 repeats, ideally dome flats
Twilight Flat	Start of night and/or end of night	3–5 repeats
Flux Standard	1–4 per night	2–3 repeats, can be done in twilight
Telluric standard	Once per target	can also serve as flux standard
Offset Sky	Once per target	needed only if the target is larger than FoV
Dark Frames	once per run	>20 repeats

Under good conditions, the above calibrations should deliver at least $\sim 10\%$ absolute spectrophotometry and ~few percent relative flux calibration, and reasonable sky subtraction.

As mentioned before, with the current detector bias frames should not be used, as they only contribute to the overall noise budget without improving the results.

Fibre flats and arcs should be the same for the narrow and wide KOALA modes. However, this has not been tested yet, and in any case it does not hurt to take a separate series of flats and arcs for each KOALA mode in the afternoon/morning.

Chapter 5

Preparing to observe with AAOmega

AAOmega is a tunable dual-beam spectrograph. The slit units (one for each 2dF field plate, and one each for SAMI and KOALA) each contain the science fibres arranged into a pseudo-slit. Light from the slit units is fed into a single collimator and then separate into the Blue and Red arms of the system via a dichroic beam splitter. There are two dichroics, one operates at 570 nm and one at 670 nm. Each arm of AAOmega uses a separate Volume Phase Holographic grating (VPH), the choice of which dictates the resolution and wavelength range covered.

5.1 Selecting an AAOmega setup

AAOmega can be configured to observe the entire optical spectrum over the wavelength range 370 nm – 900 nm, with a small overlap between the red and blue arms around the dichroic wavelength (570 or 670 nm). The grating set available allows a range of resolutions between $R \sim$1,000 and $R \sim$10,000. At low resolution the entire accessible spectral range is recorded at once, but at higher resolutions the user must tune the wavelength range to that which best suits their requirements.

The full list of gratings can be found in the Table 5.1. An on-line AAOmega Grating calculator is available in the proposal webpage to simplify the process. The direct link to the on-line AAOmega Grating calculator is http://oldweb.aao.gov.au/cgi-bin/aaomega_calc.cgi.

5.1.1 Considerations in set-up selection

1. Grating changes will not be performed during the night, only during the afternoon. Wavelength changes can be performed during the night, but there is an overhead.

2. Where possible, the blue arm of the system should be set to allow the strong 557.7 nm skyline to fall within the observed spectral range. This will allow sky subtraction and fibre throughput calibration without the need for twilight flat fields or dedicated offset sky frames.

3. It is not required to have the two arms of the system overlapping in wavelength. However, leaving some overlap allows spectra to be spliced together.

4. **Spectral curvature**. As with all spectrographs, the spectra follow curved paths on the CCDs and wavelength is not a constant function of X-pixel position between fibres. At low resolution this is barely noticed. However, at higher spectral resolutions there is a small mismatch between the observed wavelength of the central and outer fibres. This range of wavelengths is given in the AAOmega Grating calculator.

5. Departures from the standard *default* values for each grating are acceptable.

Table 5.1: *The AAOmega grating set.*

Grating	Blaze [nm]	Useful wavelengths [nm]	Coverage (single shot) [nm]	Angle [degrees]	Dispersion [nm/pix]	MOS Resolution [R]
580V	450	370 to 580	210	8	0.1	1300
385R	700	560 to 880	320	8	0.16	1300
1700B	400	370 to 450	65	18	0.033	3500
1500V	475	425 to 600	75	20 - 25	0.037	3700
1000R	675	550 to 800	110	18 - 22.5	0.057	3400
1000I	875	800 to 950	110	22.5 - 25	0.057	4400
3200B	400	360 to 450	25	37.5 - 45	0.014	8000
2500V	500	450 to 580	35	37.5 - 45	0.018	8000
2000R	650	580 to 725	45	37.5 - 45	0.023	8000
1700I	750	725 to 850	50	37.5 - 45	0.028	8000
1700D	860	845 to 900	40	47 - 48	0.024	10000

6. **Blaze angle**. The collimator-to-VPH and VPH-to-camera angles are typically set to be equal. This gives the peak system throughput at the central wavelength, with a slow role off to shorter and longer wavelengths. For certain applications, one may wish to operate with an asymmetry in these angles which will boost the system sensitivity at shorter/longer wavelengths, but at the expense of sensitivity at longer/shorter wavelengths. Read the notes below (Section 5.2), or call your support astronomer for a discussion of this very important concept which is specific to VPH gratings.

7. (2dF only) Due to the long fibre run (38m prime focus to coude west) and the optics of the 2dF prime focus corrector, the system throughput below 370 nm is very poor and there is little point attempting to observe at shorter wavelengths.

8. **High resolution Ca III observations**. The 1700D grating is specifically designed for observation of the Ca III lines at ∼860nm. It gives a better response at this wavelength than the 1700I grating. However, it cannot be used at any other central wavelength. When observing the Ca III there is no advantage to observing with the 1700I grating over 1700D. If one wishes to observe at high resolution at red wavelength, but away from Ca III, then 1700I must be used.

9. **For Service Applications** consider the use of standard grating configurations as the probability of service observations being successfully undertaken is significantly higher for these settings

10. **Ghost reflections**. Like all diffraction gratings, the VPH gratings do induce some artifacts in the observed spectra. The dominant artifact is a prominent ghost reflection (essentially an out of focus 0th order image of the slit). The gratings are designed to throw the ghost out of the field of view for the most commonly used wavelength setups. For more unusual settings the user MUST visually check an arc frame to ensure that there are no ghost images that would damage critical wavelength ranges.

5.2 Blaze Angles for VPH gratings

AAOmega uses Volume-Phase Holographic (VPH) transmission gratings. These have flexible blaze angles. Each grating has a specific design blaze angle which will give the absolute maximum efficiency with that grating (the super blaze). This peak efficiency reduces smoothly with wavelength away from that. The usual setup for most programs is therefore to have the grating set at its super blaze angle and the camera at twice this angle to centre the maximum efficiency wavelength on the CCD. The complication comes when the observer wishes to observe at a central wavelength which is some distance away from the super blaze angle for the grating. This would mean observing with the grating and camera angles highly asymmetric, and therefore operating on the low efficiency (and rapidly falling) part of the blaze envelope for the grating. The solution is to tune the grating and camera angles to new values. This shift in the grating angle will shift the blaze profile away from the super blaze, flattening the steep wings of the super blaze envelope and boosting system performance at the desired wavelength(s), with the expense of a slight reduction in overall peak performance in comparison to the super blaze setting.

Part III

Observing with KOALA+AAOmega

The AAO typically provides a support astronomer for the start of your observing run—the first night at least. Therefore, while it is important to be familiar with the contents of this Part, there will be expert support at the telescope to help guide you through observing.

Chapter 6

Outline of observing

This chapter is simply a quick overview with links to the various detailed descriptions elsewhere in this document.

6.1 During the Afternoon

1. Confirm Instrument Setup and preparation with support astronomer/afternoon tech.
   (a) Check the correct gratings and dichroic are installed and correctly reported in the instrument control task — § 7.4: AAOmega Spectrograph Control.
   (b) Check the central wavelengths are set correctly — § 7.4: AAOmega Spectrograph Control.
   (c) Check with your afternoon technician that the vacuum gauges are off, and that no lights are on in the spectrograph room.

2. Confirm computing setup.
   (a) Make sure you are ready to reduce data with a recent/current version of `2dfdr` on either an AAT data reduction machine or your laptop. Note the best version to use is typically that on the AAT computing system — Chapter 15: Basic Reductions.
   (b) If you will be using your personal computer, make sure you know how to access files in the appropriate directories on the AAT computer system — Chapter 13: Getting the data

3. Confirm suitability of finder charts, check coordinates and offsets from offset stars (if required). — § 4.1: Finding Charts and Target Acquisition

4. Ask for the instrument/telescope to be released by AAT staff before using the observing interface.

5. Check/set the Proposal ID in the control task — § 9.1: Setting the Proposal ID.

6. Take dark or bias calibrations if needed with the dark slides in place — Chapter 12: Collecting Calibration Data

7. After 4 pm, and after checking with the afternoon technician, the dome lights can be put out.
   (a) Check that there are no lights left on in the dome. Note that the visitor gallery lights are on a timer, and switch off automatically a few minutes after the main lights are out.

8. Final spectrograph preparation
   (a) Focus the spectrograph — § 9.3: Focusing the Spectrograph
   (b) Confirm the data quality — § 9.4: Data Quality Checks
9. Take a flat-field frame and use it to set up the KOALA Realtime Viewer for use in focusing and acquisition — Chapter 8: KOALA Realtime Viewer

6.2 During Twilight

1. Immediately after sunset, take a series of twilight flats — § 12.2.4: Twilight Flat Fields. Make sure the night assistant knows in advance that you will need twilight frames at sunset.
2. If time allows, the night assistant will take a DIMM measurement. This generally does not impact observing.
3. Focus the telescope — Chapter 10: Focusing the Telescope.
4. Observe a spectrophotometric standard star.

6.3 Science Observing

1. Acquire the field/target — § 11.2: Field Acquisition.
2. Take data — § 7.3: CCD Control Window
3. Dither as necessary between science frames — § 11.3: Dithering on target and mosaicing large targets.
4. Take offset skies if needed — § 11.4: Offsetting to Sky.

6.4 At the end of the night

1. Start sequences of calibrations if required. Generally, calibrations can run until about 9 am (except when an instrument change is scheduled). Occasionally, day-time activities will require the instrument much sooner. Check with the night assistant.

6.5 At the end of the run

1. Make copies of the data suitable to take away — § 13.2: Taking away data.

Chapter 7

The Observing GUI

Most modern AAT instruments are controlled by a variant of the `tdfct` control task first developed for 2dF. This control task runs on a linux machine at the AAT. Remote observers will connect to this machine via VNC from the remote observing site.

The control task for KOALA is closely related to that used for other AAT instruments including HERMES and other AAOmega instruments, so it may be familiar for users of those instruments.

Typically, the AAT technicians will start the control task for you.

If the KOALA control task is not running in the control room, it is necessary to check with the afternoon tech before starting it.

7.1 Main Window

The Main Window is primarily just a status display. Sub-windows that control various parts of the observing system can be brought up using the more buttons under each subtask box in the middle of the window.

Other useful items in this window:

Messages The bottom portion of the window is the primary message readout for the system. Error messages and a log of recent activity is written here. The text of all error dialogs are also printed here (with a red background).

Change FoV The Commands → KOALA Wide Field of View menu item is used to change the KOALA Field of View from narrow to wide (see § 1.2: Focal plane and field of view). The current status of the FoV is shown in the title bar

7.2 Telescope Control Window

The telescope should not be moved/slewed without first checking with the night assistant.

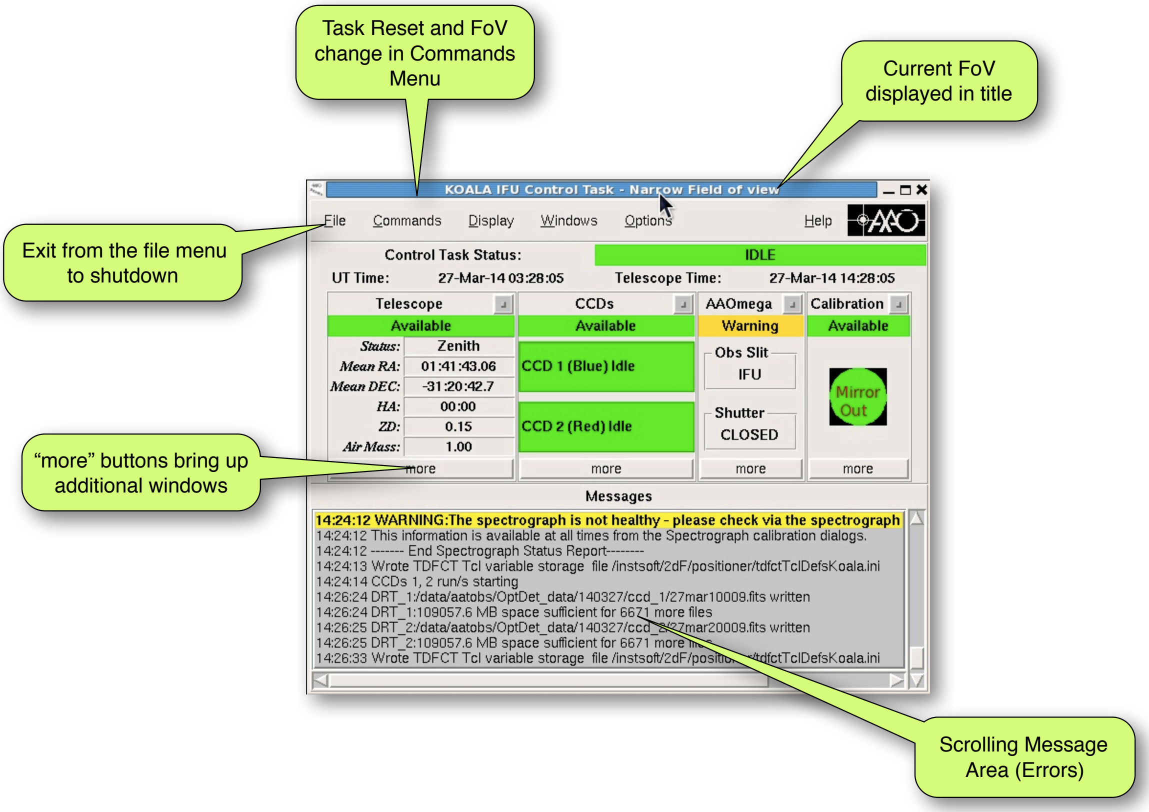


Figure 7.1: Main window of the KOALA instrument control task.

The Telescope Control Window is used to move the telescope and telescope focus. Usually, this is best used for entering coordinates of the next target for observing and slewing the telescope when ready. It is also possible to offset the telescope and change the telescope focus using the other tabs. However, only the night assistant can do guided offsets, so it is best to coordinate moving the telescope with the night assistant. (See also § 11.3: Dithering on target and mosaicing large targets).

The window also provides status information on the telescope's current position.

7.3 CCD Control Window

Data acquisition is controlled via the CCD Control window (Figure 7.3).

Observation Type

A series of select buttons determine the observation type. They are:

Object Take a regular science frame of the target(s).

Dark Take a dark frame. Note (on AAOmega) this is best done with the dark slides closed.

Bias Take a zero length frame (flushes the detector, then reads it out as normal.)

Offset Sky Used for an offset sky frame (for sky subtraction and/or throughput calibration).

Offset Flat This is used for twilight flat-fields (it might also be used for a dome flat, but make sure to keep a log!)

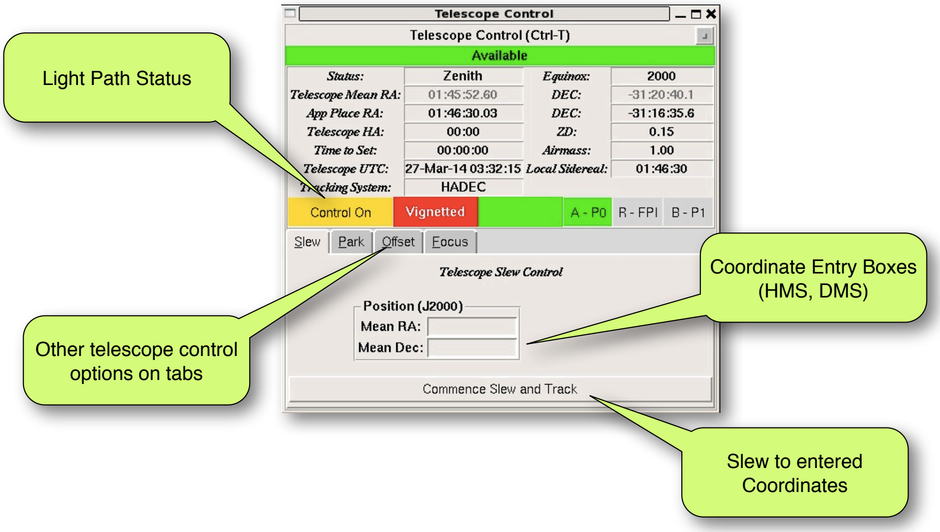


Figure 7.2: The KOALA Telescope Control GUI.

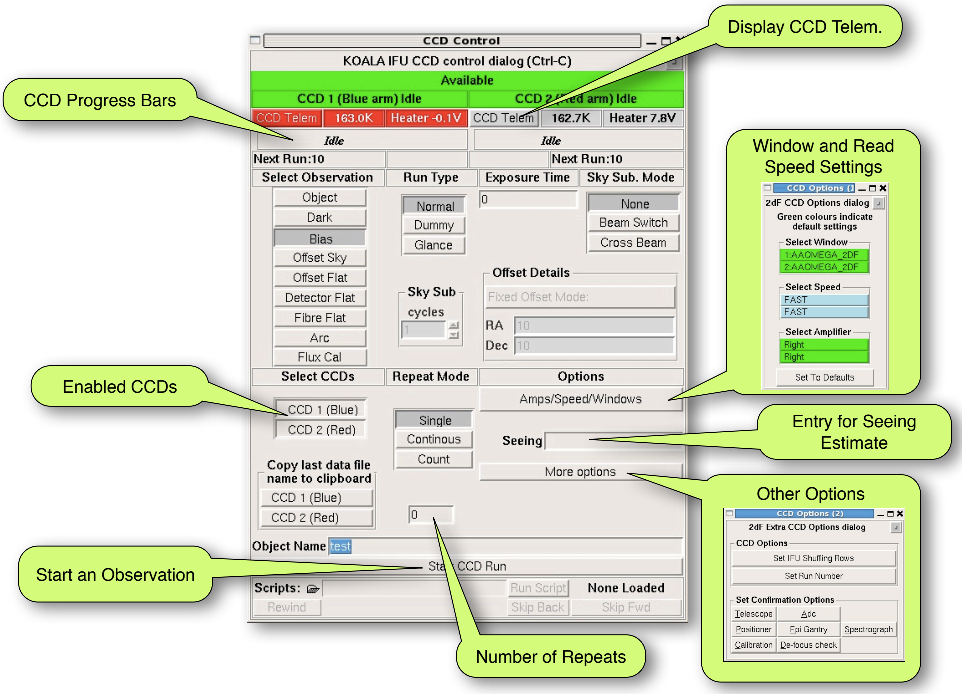


Figure 7.3: The KOALA CCD Control GUI

Detector Flat This is used for flatfielding the detector response. To achieve correct illumination for these data, see § 12.2.3: Detector Flat Fields.

Fibre Flat This is the standard "flat-field". These files are used in the data reduction to find fibre tramlines (spectra) across the detector, and also to take out variations in response with wavelength.

Arc The standard wavelength calibration frame. The lamp to use is selected after the Start CCD Run button has been pressed.

Flux Cal This identifies the frame as having a flux standard in it. For 2dF, the software will ask you to identify which fibre the flux standard is illuminating.

Table 7.1: *Observation types and corresponding FITS Header types.*

Type	OBSTYPE
Object	MFOBJECT
Dark	DARK
Bias	BIAS
Offset Sky	MFSKY
Offset Flat	SFLAT
Detector Flat	DFLAT
Fibre Flat	MFFFF
Arc	MFARC
Flux Cal	MFFLX

The observation type is included in the FITS header OBSTYPE, and as a binary table extension to aid the data reduction software. The keyword is set as shown in Table 7.1.

Run Types
Next, the type of run can also be selected.

Normal A normal run is taken. These data are archived and stored in the regular data directories.

Dummy These data are written to a separate dummy directory, and are not archived.

Glance In this case, the CCD readout is displayed on screen, but not saved.

Exposure Time
The exposure time is set in the next box. For HERMES, separate exposure times for each camera can be defined.

Select CCDs
Each toggle button enables/disables the corresponding CCD (arm). Typically, all should be selected.

Repeat Mode
The Repeat Mode selection can be a Single frame, Continuous frames (until manually stopped) or a Count number of repeats. The number is set in the box below Count

Options

Amps/Speed/Windows Brings up a separate window with options for selecting CCD readout amplifiers, windows, and read speed.

Plot Fibre Errors (2dF Only) When selected, this causes a plot to be displayed upon starting an observing sequence which shows the difference between the physical location of the fibres on the plate and the actual location of the targets. The difference is the result of atmospheric affects not accounted for by the 2dF corrector.

Object Name
This box can be used to set the object name. Note for 2dF and SAMI, this will be set automatically (but can be overridden after starting an exposure in the CCD Run/Wait dialog box.

Start CCD Run
Starts the requested exposure. If the requested frame requires lamps, a box will appear

where the specific lamps required can be selected. Calibration flaps, if needed, will automatically be closed (and opened at the end of the exposure, unless they are requested to be left closed.)

Scripts
The final section of the CCD Control window provides the scripting interface which is described in Chapter 17: Scripted Operations.

7.3.1 CCD Run Wait Dialog

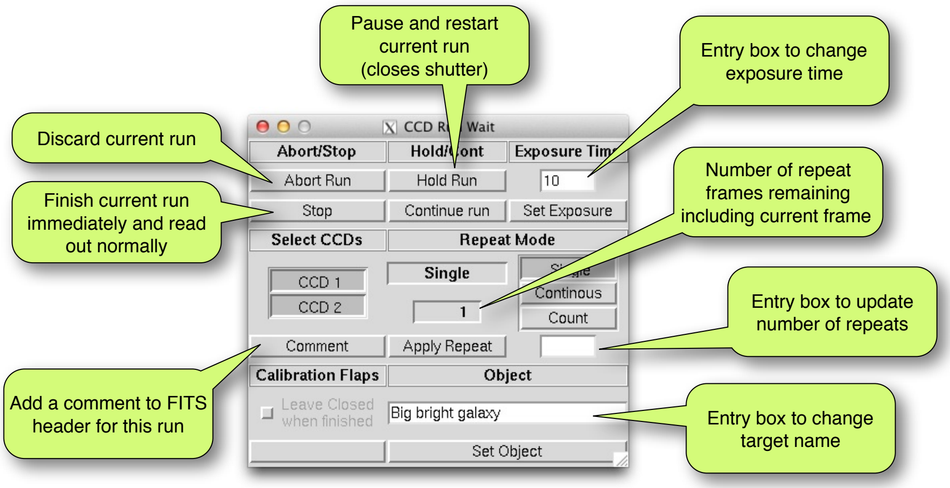


Figure 7.4: *The CCD Run Wait dialog box, which allows changing of settings for the currently exposing run.*

After starting a run, the CCD Run Wait dialog box will appear. This includes options for changing options for the current run.

Abort/Stop Abort Run and Stop both end the current exposure immediately. The latter will read out the data as normal, but the former will simply discard the data (useful if a mistake has been made in setting up an exposure).

Hold/Cont Hold Run and Continue Run pause and continue an exposure by simply closing the shutter and stopping the exposure clock. Useful for pausing during passing cloud. Note, however, that cosmic rays and dark current will continue to build up even while the shutter is closed.

Exposure Time The total exposure time can be changed by entering a new value and clicking Set Exposure.

Repeat Mode The number of remaining repeats is shown in the grey box under Repeat Mode. This includes the current exposure (the number is decremented *at the end of readout*—"1" means the last frame is currently exposing/reading out). The number of repeats can be changed by entering a number in the corresponding white box, and clicking Apply Repeat.

Comment can be used to add a comment to the header of the current frame.

Calibration Flaps For calibration exposures, it is possible to change whether the calibration flaps will be opened after the exposure (really only relevant for 2dF, where the flaps take some time to operate).

Object Finally, the object name (for the header) can be changed by typing a new name in the box and clicking Set Object.

7.4 AAOmega Spectrograph Control

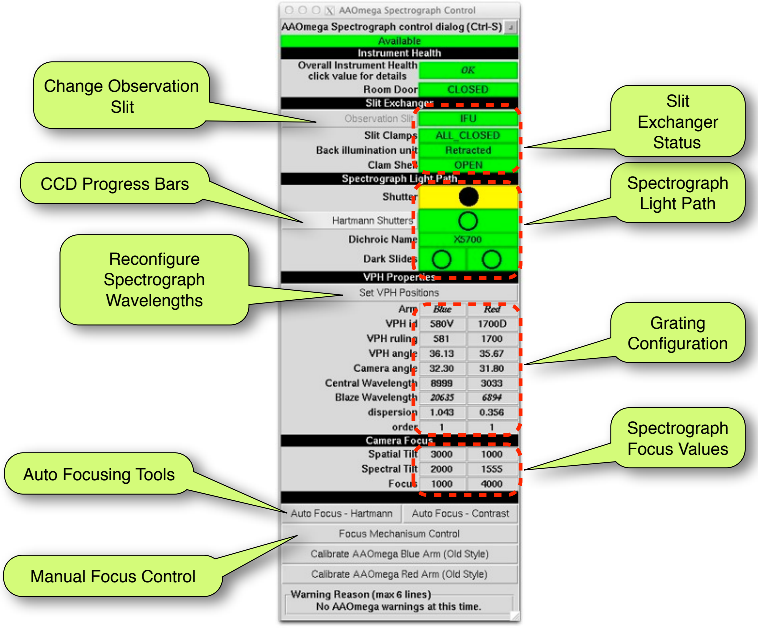


Figure 7.5: *The AAOmega Spectrograph control interface.*

The AAOmega Spectrograph Control window provides both the interface for re-configuring the spectrograph as well as a current status display.

Observation Slit button selects which slit is in the observation position (independently of the 2dF tumbler). This is disabled for KOALA and SPIRAL[1].

Hartmann Shutters button reveals a menu for manually closing and opening the Hartmann shutters used for focusing.

Set VPH Positions button provides options for reconfiguring the central wavelengths of both arms of the spectrograph. Note wavelengths are shown in angstroms.

Camera Focus
The final sections provide tools for focusing the spectrograph.

Autof Focus buttons will start a semi-automatic focusing proceedure (see § 9.3).

Focus Mechanism Control can be used to move the spectrograph focus to previously determined values.

[1]If the slit displayed is incorrect, see the troubleshooting guide in the support manual

7.5 Calibration Control Window

The KOALA Calibration Control Window (see Figure 7.6) allows to check and control the lamp and flaps status.

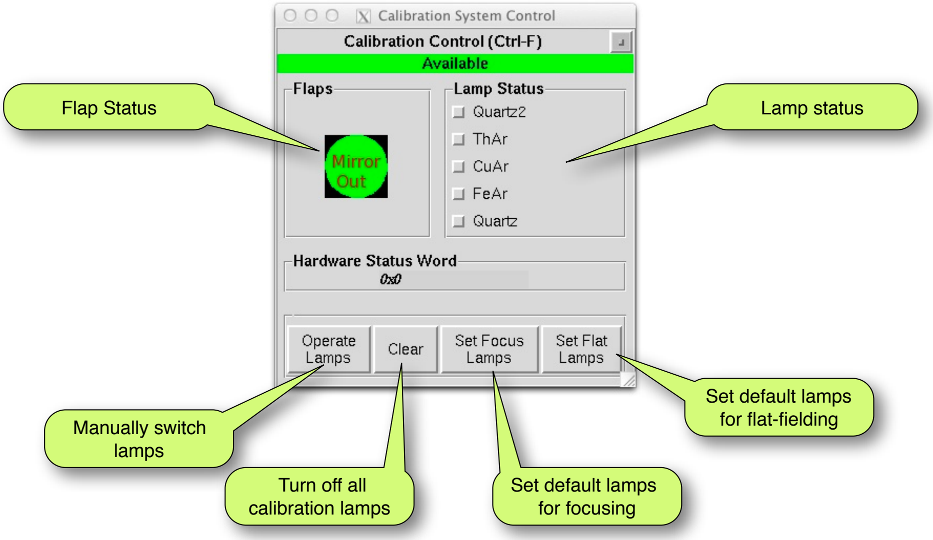


Figure 7.6: *The KOALA Calibration Control Window.*

Flap status Shows if the mirror is in (for flats/arcs) or out (for anything else).

Lamp status Shows which calibration lamps are on.

Operate Lamps Manually switch lamps.

Clear Turns off all calibration lamps.

Set Focus Lamps Set default lamps for focusing using the Hartmann method.

Set Flat Lamps Set default lamps for flat-fielding and for focusing using the contrast method.

Chapter 8

KOALA Realtime Viewer

The KOALA Realtime Viewer is a separate software tool which can be configured to do immediate, quick-look reconstructions of the KOALA field of view. This tool is very useful for field acquisition, as it runs independently of the regular data reduction tasks, and provides a collapsed, on-sky image of a KOALA raw file in about 20 seconds.

The Viewer runs independently of the observing system, and therefore must be started separately. This is done on the observing terminal:

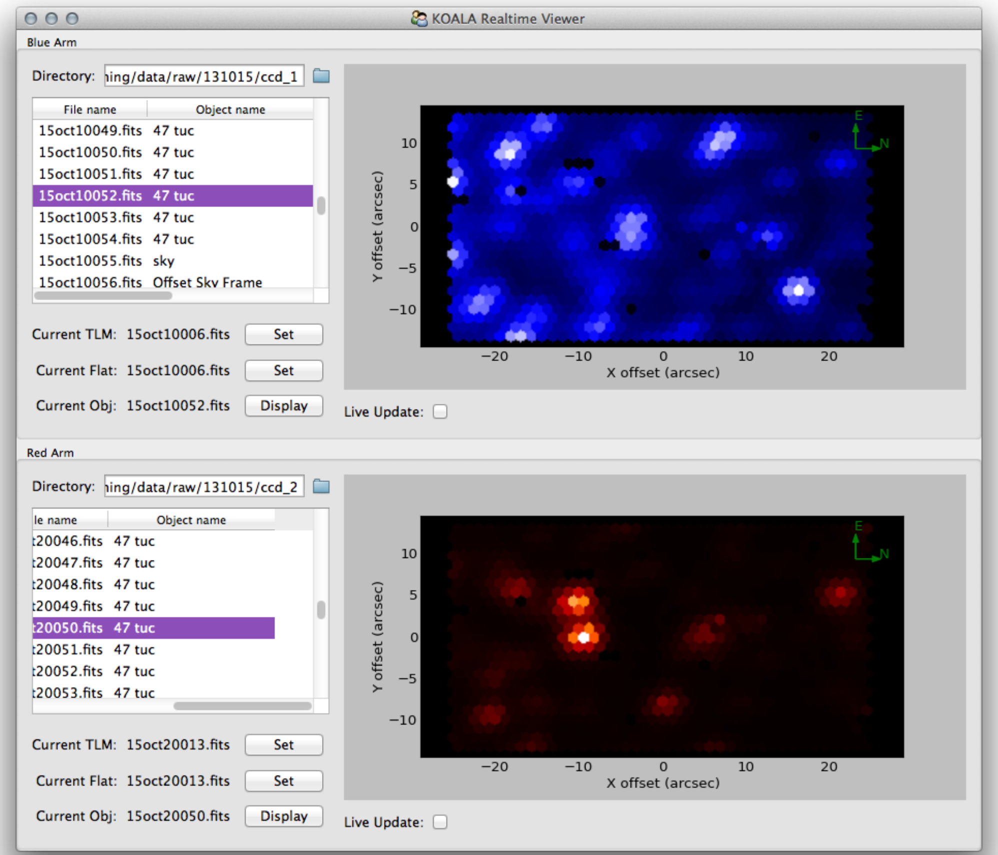


Figure 8.1: *The main window of the KOALA Realtime image reconstruction utility.*

```
aatlxy> cd /instsoft/instusers/aatinst/koala_realtime
aatlxy> ./KoalaRealTime &
```

When the Viewer comes up, it is broken into two identical sections, one for each arm.

Directory
The directory automatically defaults to the expected location of the observing directory for the current UT date. If this is not correct, a new directory can be selected by clicking on the folder icon.

File List
The list of files and their Object Names (from the FITS header) are displayed. The selected file in this list is used for the actions below.

Current TLM
The Tram-Line Map or TLM is used to extract the spectra from the raw CCD. A well illuminated Fibre-Flat-Field should be used to set the TLM. Select an appropriate TLM in the list above, and then choose Set. After some processing, a new plot window will appear which has the tramlines overlaid on the spectra. It is necessary to zoom in the window to check that the tramline mapping has been done correctly.[1]

NOTE:
The tramline mapping is fairly rudimentary, and not interactive. If the computed tramline map is incorrect, try using a different run (possibly from a previous night), exposure time, lamp, etc. The map should really only change significantly when the instrument has been taken off the telescope.

Current Flat
Some rudimentary spatial flatfielding is done if an appropriate file is Set here. When the viewer is first started, no-flatfielding correction is done.

Current Obj
The reconstructed image (on the sky) of the selected file is displayed on the right hand side of the Viewer. Selecting a different file and clicking Display will cause a new reconstruction to be generated.

Live Update
When this check box is ticked, the software will automatically display a reconstruction for each new file as it appears in the directory.

The right hand side displays the reconstructed image. Overlaid is a compass rose showing the orientation of the field on the sky. The software also tries to fit a Gaussian to all images displayed, and shows the results for the best fitting FWHM and offsets (X and Y in pixels, and E and N in arcsec) of the Gaussian from the centre (most useful for focusing the telescope and centering stars).

NOTE:
The best fitting FWHM and offsets of the Gaussian from the centre are also listed in the terminal window. We have observed that sometimes the information provided in the KOALA Realtime Viewer is NOT correct, but those provided in the terminal window are.

---

[1] The tramline map is cached on disk between sessions, so if the viewer is restarted for some reason, it is not necessary to reselect a file, although no file will be listed after restarting.

Chapter 9

Preparing the instrument

9.1 Setting the Proposal ID

At the start of each night, or for each service program executed, it is necessary to appropriately set the Proposal ID within the control task. This is written to the FITS headers, and used in the data archiving system to appropriately determine proprietary periods and access permissions. Therefore it is important that it be set correctly.

The Proposal ID can be set/updated by choosing Commands → Set Proposal ID in the control task Main Window. Options in the Set Proposal ID window should be used as follows:

AAO Visitor Mode Most regular proposals should use this option. Select the appropriate year, sememster, and then enter the ID (last 3 digits of your proposal ID) in the box. Click Calculate, and confirm that the Proposal ID shown at the top matches your proposal ID.

Service Mode For service mode observations. This must be set for every service program, so will usually be reset multiple times during the night. Proceed as above.

Calibration For calibration files which are non-proprietary. Relevant for taking darks, biases, calibraitons to be shared between service programs, other test data.

Enable Manual Entry Should only be used in special cases. Telescope staff wishing to test the instrument should use this option and entrer "TEST" if a more relevant entry cannot be made.

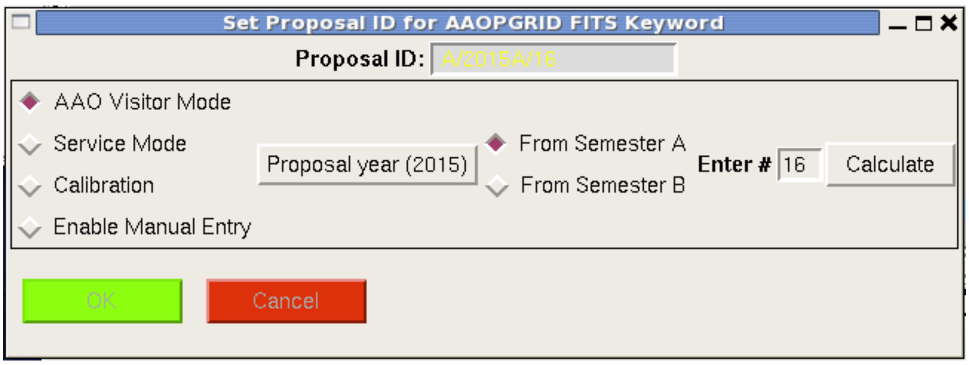


__Figure 9.1:__ The proposal ID window is used to set or change the proposal ID for subsequent runs taken with the system.

9.2 Set Grating angles and wavelengths

The AAOmega grating angles and central wavelengths can be set automatically using the AAOmega Spectrograph control window — § 7.4: AAOmega Spectrograph Control.

9.3 Focusing the Spectrograph

Focusing HERMES and AAOmega can be accomplished using either shifts of the positions of arc-lines in Hartmann pairs (phase detection) or by looking at the sharpness of fibre tramlines in a flat-field frame (contrast detection). In theory, both methods should deliver the same focus values, but in practice one of the two methods is generally preferred, as listed below:

Instrument	Preferred Focus Method
2dF+HERMES	Hartmann
KOALA (low res)	Hartmann
KOALA (hi res)	Contrast[1]
SAMI	Hartmann[2]
2dF+AAOmega	Hartmann

For SAMI and KOALA, one should generally use the Hartmann focus first. Tramline contrast should be at least 50%, if it isn't (more likely with high-resolution gratings), try the contrast focus, but check for deterioration in spectral focus (hence reducing spectral resolution). Sometimes an intermediate focus between the two methods provides the best compromise.

Regardless of the method chosen, the process is semi-automatic, and the procedure the same regardless of method.

1. Unless the frames are to be archived, change the Run Type to Dummy in the CCD Control window.

2. In the Spectrograph Control window, choose either Auto Focus – Hartmann or Auto Focus – Contrast as appropriate.

3. The Automatic Focus window will also pop up at the start of the script. This displays the Piston, Spectral tilt and Spatial tilt for each camera/CCD of the spectrograph. Note down the starting positions listed at Current H/W Position before starting in case of trouble.

4. Choose Start Data Collection to start the automatic process. Depending on the focus method, several option boxes will appear requesting additional information. In the case of using the contrast method, typically 9 exposures work well if we have first focused using the Hartmann method. The "Focus Step Size" can be also reduced to 25 (default number is 50). For more accurate (but more time consuming) focusing using the contrast method, use 17 exposures and a "Focus Step Size" of 10.

5. While the script proceeds, check that the read out CCD frames are sensible, i.e., sufficient exposure, little/no saturation, etc.

6. (*Contrast Detection Only*) A window will appear showing the results of the focus run on each camera. These must be reviewed (see below) and dismissed before proceeding.

[1] KOALA with high-resolution gratings can be tricky to focus well. Good tramline contrast (> 50%) is important, but straight contrast focus can lead to poor spectral resolution. Consider a compromise between the two methods if necessary.

[2] Contrast focus not well tested with SAMI.

7. Once the script has completed, new settings will appear at Suggested new settings. The Apply All button will bring these suggested settings into effect (subsets of the settings can be applied using the corresponding Apply buttons).

8. (*Hartmann Focus Only*) Although in theory a single run of either method should provide the best focus, in practice the Hartmann method must be repeated until the focus converges and all results are "in spec".

9.4 Data Quality Checks

Once the instrument is fully configured, it is critical to check the quality of the resulting data. These checks ensure that you will be able to maximise the scientific value of your data. It may be necessary to adjust settings and iterate these checks if everything is not satisfactory.

Focus Arc-lines should have the expected resolution, typically 2–3 pixels FWHM, everywhere on the detector. Fibre spectra should be well resolved in a flatfield frame (particularly important for SAMI and KOALA).

Detector Position Check that no spectra fall off the edge of the detector at the top or bottom of the image.

Detector Defects Check that no detector defects affect key portions of the data. Typically, this is best done by reducing a flat and arc frame with `2dfdr` to find the wavelength solution. Adjust the central wavelength settings as necessary.

Grating Ghosts Particularly for non-standard AAOmega settings, grating ghosts and other reflections within the spectrograph can appear on the detector. If these are present, check that they do not interfere with crucial spectral features, and adjust the central wavelength settings as necessary. This will probably require comparing reduced and un-reduced frames to decide where the ghosts appear on the detector.

Necessary calibration sky-lines Particularly for the standard AAOmega 580V grating, check that the sky emission line at $\lambda 5577$ angstroms is included in all spectra. If this cannot be accommodated, then offset skies may be necessary.

Chapter 10

Focusing the Telescope

KOALA is perhaps the most difficult AAT instrument to focus because of the need to reconstruct the IFU in order to measure the PSF. However, the KOALA real time viewer (see Chapter 8: KOALA Realtime Viewer) makes this relatively straight-forward.

Focusing can be done well before nautical twilight ends to avoid impacting observing time. Choosing a bright ($m_V < 8.0$) star allows to start doing this 20 minutes after sunset.

1. Frames must be taken as normal (not dummy) to be found by the realtime viewer.
2. Use the NARROW field of view for getting better results.
3. For minimizing waiting time focus frames can taken using the "KOALA_BINNED" window and the normal speed (71 s, § 11.1: Acquisition Mode vs Science Mode)[1].
4. Have the night assistant slew to and acquire in the normal way a convenient SNAFU star or a bright ($m_V < 8.0$) spectrophotometric star. Guiding is not necessary.
5. Use the telescope control interface (or ask your night assistant) to set the focus values as you step through. Start with a value around 50.0 mm.
6. Include the focus setting in the object name of each frame to simplify reviewing the focus in the realtime viewer.
7. Take an object frame. Exposures of 2–5s are generally good.
8. Reconstruct the images with the realtime viewer, and read off the FWHM of the star in both the blue and red ccds. The FWHM value in the blue ccd is usually larger than the FWHM value in the red ccd because of the effect of atmospheric differential refraction.
9. Offset the focus by 0.2 mm, and then repeat from step 6.
10. Use the Python script `koala_focus.py` available in `aatlxy` to get the focus value and an estimation of the seeing (see Figure 10.1)
11. When a suitable minimum is found, set the focus there. The night assistant will record this in the electronic log.
12. Remember to put back the window to "AAOMEGA_2dF" (and the field of view to WIDE in case you need this).

[1] Ideally, the "KOALA_BINNED" window and the ultra-fast speed should be used. However, because of current instabilities in the red detector (that might make needed to restart AAOmega from the scratch), this is not be possible.

An additional, faster procedure to focus the AAT is using the acquisition camera (see Section 11.2), but this has to be done with the help of the night assistant and has the extra caveat of knowing the focus offset between the acquisition camera (TVDIRECT) and KOALA, which slightly varies every time KOALA is put back to the telescope. In October 2017, the offset between was TVDIRECT-KOALA = 0.8 mm, but in February 2018 this offset was TVDIRECT-KOALA = 0.2 mm.

The method to focus the telescope using the guiding camera is very easy: ask the night assistant to go to a ~8 magnitude star. Using 1 second exposures (not shorter than that!), ask the night assistant to check the size of the stars at different focus values, starting at around 50.5 mm. Repeat till get a suitable minimum for the focus value. Use the Python script `koala_focus.py` available in `aatlxy` (see Figure 10.1) to help on this, choosing options “TV 1x1” (no binning, resolution of 0.16 arcsec/pixel) or “TV 2x2” (binning x2, resolution of 0.32 arcsec/pixel).

The $f/8$ top end used by KOALA has a good focus model and is temperature compensated, so the focus should not need to be checked or changed through the night, even with large slews. Do consider checking the focus if the seeing improves dramatically.

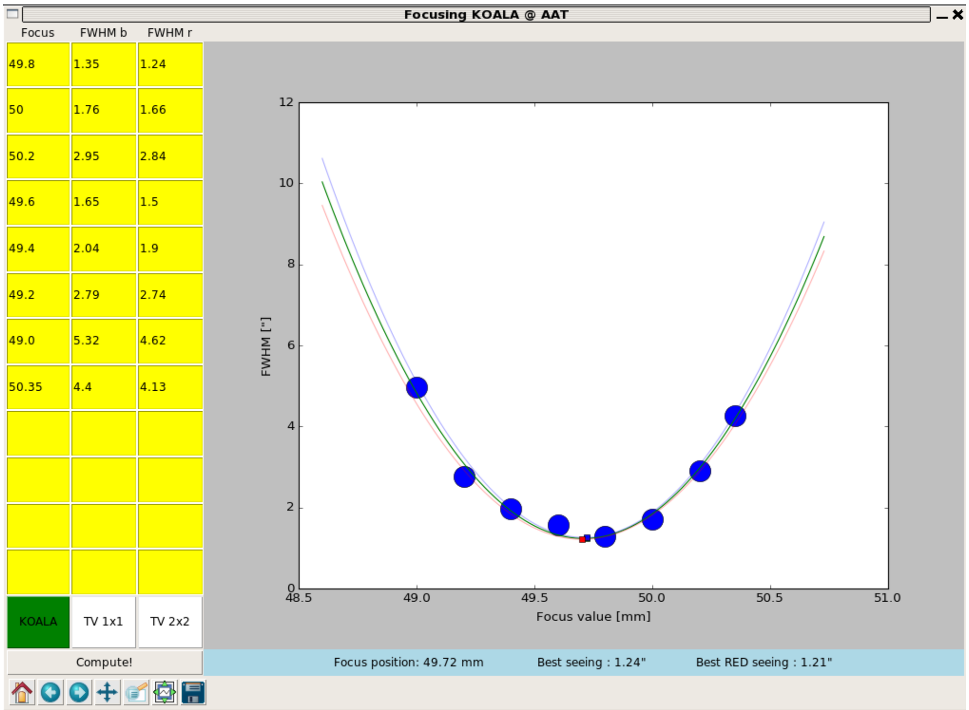


Figure 10.1: *Window of the Python script* `koala_focus.py` *that helps to estimate the focus of the telescope and the best seeing. The columns “Focus”, “FWHM b”, and “FWHM r” compile the focus position, the FWHM of the blue ccd and the FWHM of the red ccd (both given by the KOALA real time viewer, see Chapter 8: KOALA Realtime Viewer), respectively, for a exposure. Click in “Compute!” to fit a second order polynomial fit to the data. Three fits are made: one for the blue data (blue line), other for the red data (red line) and another for the average FWHM values (green line). The fit to the red values will provide better results than the fit to the blue values because of the effect of atmospheric differential refraction. The big blue circles are the average FWHM in each focus position. Small blue and red squares indicate the minimum value of the fit for the blue and red data, respectively. This tool can be also used for focusing the acquisition camera. For this choose options “TV 1x1” (no binning, resolution of 0.16 arcsec/pixel) or “TV 2x2” (binning x2, resolution of 0.32 arcsec/pixel) and for “FWHM b”, and “FWHM r” type the values giving by the moffat fitting of a star in an image from the acquisition camera, as provided by the night assistant.*

Chapter 11

Science Observing with KOALA

11.1 Acquisition Mode vs Science Mode

With the KOALA realtime viewer (see Chapter 8: KOALA Realtime Viewer), it is feasible to rapidly take acquisition images of stars and brighter galaxies to check centering, field orientation, seeing, telescope focus, etc. KOALA acquisition images are best taken using the "acquisition mode", which is not actually a mode, but a series of settings in the CCD controller. The settings are accessed by clicking the Amps/Speed/Windows button in the CCD Control Window. The two standard situations are shown in Table 11.1.

Table 11.1: *CCD Readout settings for Observing and Acqusition with KOALA.*

Setting	Normal Observing	Acquisition Mode	Ultrafast (*)
Window	AAOMEGA_2DF	KOALA_BINNED	KOALA_BINNED
Read Speed	Normal	Normal	Ultra-Fast
Readout Amps	Right (B) / Left (R)	Right (B) / Left (R)	Right (B) / Left (R)
(Readout Time)	127s	71s	15s

(*) Because of current instabilities in the red detector (that might make needed to restart AAOmega from the scratch), using the Ultra-Fast read speed is currently NOT recommended.

Don't forget to set the options back before starting a science exposure—once an exposure has started these cannot be changed.

NOTE:
Currently acquisition images cannot be reduced, e.g., for use to centroid on a star. However, this should be possible with future releases of `2dfdr`.

11.2 Field Acquisition

NOTE:
These instructions assume that one is doing acquisition and guiding with the A&G Unit. For KOALA, it is also possible to use CURE for acquisition and guiding. CURE is designed to be very stiff, and may provide better tracking for fields observed over many hours (where flexure is a concern), but does not offer a simple mechanism for doing guided offsets, which are common in KOALA observing.

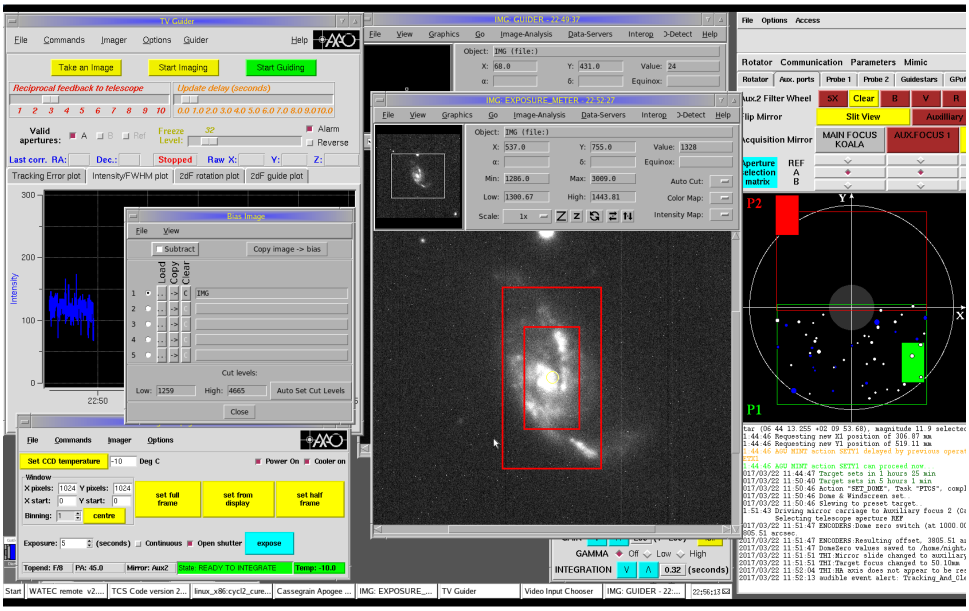


Figure 11.1: *Night Assistant A&G Unit Window. This includes the FoV for both the narrow and wide KOALA modes (red boxes).*

1. Well in advance of the acquisition, tell the night assistant that you will be acquiring a new field. Type the coordinates of your object in the KOALA Telescope Control GUI (see Section 7.2 and Figure 7.2) or give the night assistant the finder chart for the new field[1]. Point out the coordinates of the first thing to be acquired (probably an acquisition/offset star), the position angle to be used (be sure you are using the right PA, as defined in Section 1.2 and Figure 1.5), and if there will need to be a guided offset (from acquisition star to science target).

2. When ready, slew the telescope or have the night assistant slew the telescope to the new field (this can safely be done while the last exposure of the previous field is reading out).

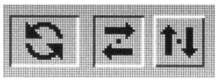
3. Once at the new field, the night assistant will take a frame with the acquisition camera (see Figure 11.1), and use it to identify your target.[2]

    - The camera has a field of view of 2.74 arcminutes (with the full window), and can reach a depth of $\sim$ 20th mag in 10 seconds.

[1] Remote observers will need to get their finder charts to the night assistant, e.g. via email.

[2] If you are observing remotely from AAO North Ryde, you can see this window opening the "`VNC AAT Acquisition`" icon in the desktop of `aaolxremote`. This VNC connection will allow you to see all that the night assistant is doing, although because of security reasons it does not allow you to interact with it.

- Be sure there is no filter in the camera to achieve this!
- The pixel scale is 0.16″/pix if the binning factor is 1 (no binning). Using binning x2 the pixel scale is 0.32″/pix. This is useful for computing the seeing.
- The camera rotates with the instrument, so the direction of north will depend on the PA. There is a compass rose on the right hand display of the night assistants console—the rotate option and left-right flip must be selected in the SkyCat window to match the image to this compass rose:



- Positive identification of the acquisition star/target, particularly in a dense field, can take some time.

4. Once you are happy with the position of your object within the KOALA field of view, ask the night assistant to start guiding using a nearby start and the guider. You can start your science exposure when the telescope is guiding.

If your object is too faint to be seen in the A&G camera, you need offsets from a nearby star to center the field. Follow these steps:

1. First, compute the offsets from your chosen star to the center of your field. You can use the Python script `offset_star.py` available in `aatlxy` (see Figure 11.2) for computing these offsets.

2. Take an acquisition image with KOALA, and confirm that the star is centered. If not[3], have the night assistant make a guided offset to centre the star and take another image. Iterate until you are satisfied.

3. Have the night assistant perform the guided offset provided by Python script `offset_star.py` from acquisition star to target. Check that the new telescope coordinates approximately match those of your target (telescope model coordinates can often be out by several arc-seconds, but not by 10s of arcseconds).

4. The science target is now acquired. Ask the night assistant to start guiding using a nearby start and the guider. You can start your science exposure when the telescope is guiding.

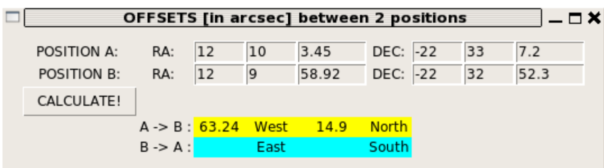


Figure 11.2: *Window of the Python script* `offset_star.py`, *that allows to calculate the offsets from a reference star to the center of the field. Just type the coordinates and click* `CALCULATE!`, *the computed values will appeared within the yellow boxes.*

NOTE:
Acquiring a new field requires a lot of interaction between the astronomer and their friendly night assistant. Going over the process with the night assistant in advance will greatly reduce stress on both sides.

---

[3] If stars are repeatedly not falling in the centre, then it may be necessary to re-measure the APOFF. See the support manual for more help.

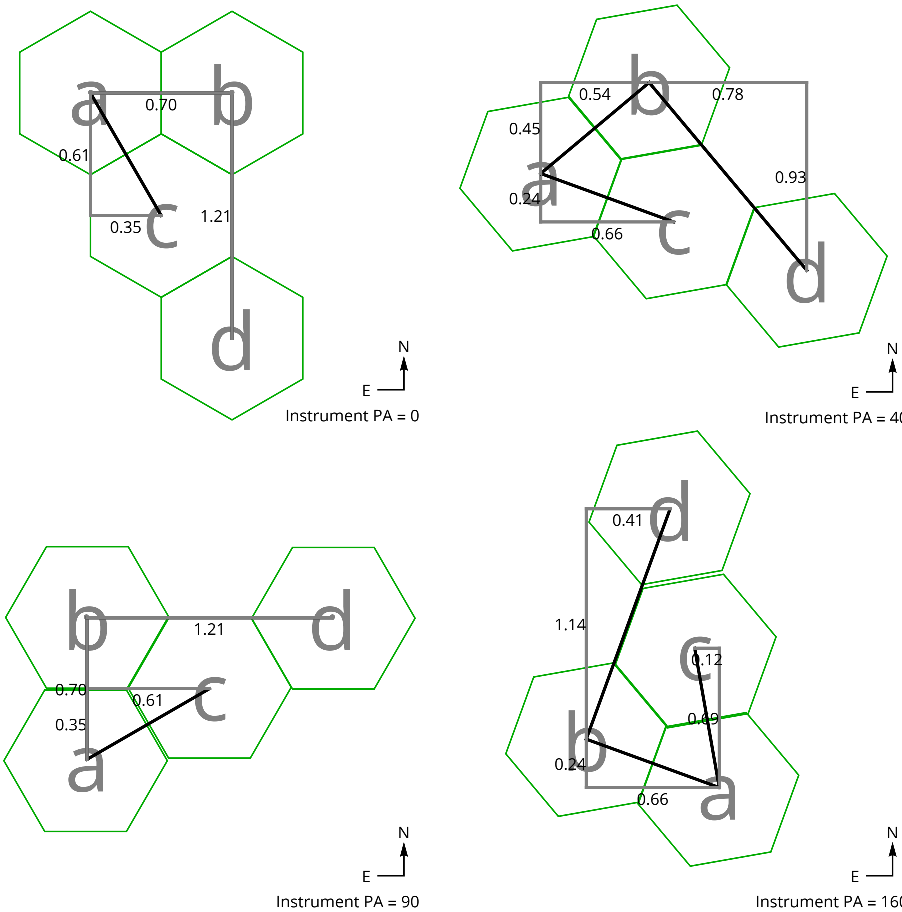


Figure 11.3: *Diagram of a few lenslets and dither offsets for four different instrument position angles. The Python script* `koala_offsets.py` *can be used for computing the offsets between lenslets.*

11.3 Dithering on target and mosaicing large targets

Dithering on target is generally crucial to your observations in order to overcome dead pixels and other structure inherent to the instrument (see § 4.2: Dithering on target and offset skies). Accurate dithering is achieved by having the night assistant do guided offsets.

As part of the data reduction, you have the option of using a drizzling approach to combine multiple frames and rebin the data onto a grid of square pixels (convenient for subsequent analysis). If you plan to use this approach (and most people should!), then dithering by integer lenslets is generally not needed (or recommended) and instead it is easy enough to simply dither by, e.g., 2″in each of the cardinal directions.

To dither in units of lenslets, use the formula shown in Table 11.2 and the corresponding diagram in Figure 11.3. These equations are included in the Python script `koala_offsets.py` available in `aatlxy` (see Figure 11.4).

For the formula compiled in Table 11.2, s, is the lenslet spacing/scale in arcseconds: 0.7″ for the narrow field of view, and 1.25″ for the wide field of view. Be careful of the signs, and do not drop the signs coming from the trig functions. For offsets that are negative, then they are in the opposite sense: i.e. a negative north offset is a south offset. The computed offsets can be scaled up for multiple pixel dithers. Working out offsets in advance, particularly if they are complicated, is highly recommended.

Guided offsets can also be used to mosaic over a target larger than the field of view.

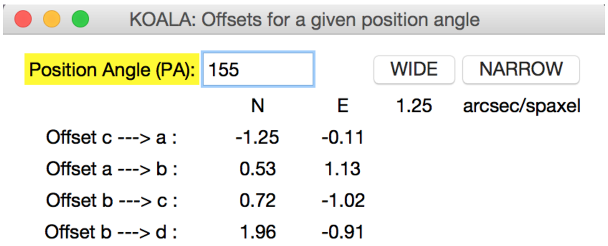


Figure 11.4: *Window of the Python script* `koala_offsets.py`, *that allows to calculate the offsets between adjacent lenslents, as indicated in Figure 11.3 and in Table 11.2. Just type the position angle (PA, 155° in this example) and click in the* `WIDE` *or* `NARROW` *button accordingly to the KOALA mode you are using. The offsets between adjacent lenslents are then provided (numbers for the wide mode are given in this example, the scale 1.25 arcsec/spaxel is also shown).*

Table 11.2: *Formula to work out offsets to dither the field of view between lenslets. s is the pixel scale in arcseconds, either 0.7″or 1.25″. All of the worked examples are for the 0.7″scale.*

		Examples at PA			
		0°	40°	90°	160°
To move from a → b:					
North Offset:	$s \cdot \sin(pa)$	0.00″	0.45″	0.70″	0.24″
East Offset:	$-s \cdot \cos(pa)$	−0.70″	−0.54″	0.00″	0.66″
To move from a → c:					
North Offset:	$-s \cdot \sin(60 - pa)$	−0.61″	−0.24″	0.35″	0.69″
East Offset:	$-s \cdot \cos(60 - pa)$	−0.35″	−0.66″	−0.61″	0.12″
To move from b → d:					
North Offset:	$-\sqrt{3} \cdot s \cdot \cos(pa)$	−1.21″	−0.93″	0.00″	1.14″
East Offset:	$-\sqrt{3} \cdot s \cdot \sin(pa)$	0.00″	−0.78″	−1.21″	−0.41″

11.4 Offsetting to Sky

For blank sky observations, guided offsets are not generally required. Unguided offsets are faster. It is, however, advisable to confirm that the offsets given really will provide blank sky using imaging data. Proceed as follows:

1. While the previous exposure is reading out, have night assistant offset the telescope by the required amount (there is no need to offset the guide probe unless guiding is required.[4])

2. Take the sky exposure.

3. While the sky exposure reads out, have the night assistant reverse the offset of the telescope.

4. Confirm that the night assistant has restarted the guiding.

5. If this target exposure is to be at a different dither position than the previous target exposure, you should now perform a guided offset as described above in § 11.3: Dithering on target and mosaicing large targets.

[4]The AAT generally will track to within a few arcsec over periods of 15 minutes or more without guiding. Therefore guiding on blank sky is really only necessary if there is a problem with AAT tracking, or exceptionally precise placement of the sky field is required.

Chapter 12

Collecting Calibration Data

Collecting most calibration data is fairly self explanatory—one need simply to select the appropriate calibration type in the CCD Control Window (§ 7.3), set an appropriate exposure time (Table 12.1) and start the run. Less straightforward options and calibrations are described here.

12.1 Dark Frames

Dark frames require the dark slides to be in place to ensure absolute darkness. The slides must be manually operated, which can be done by the AAT staff.

It is advisable to wait ~ 30 minutes or more after the slides have been installed before starting dark frames to reduce the impact of persistence on the data.

12.2 Flat Fields

12.2.1 Multi-Fibre Flat Fields (FLATs)

Multi-Fibre Flat Fields are taken using the quartz lamp in the calibration unit. This illuminates the flaps below the corrector.

Issues are: saturation in the red, count level in the blue, and dichroic features in the lamps. Also note that, due to the change in gain, saturation occurs at a different level with different readout speeds. See Table 12.1 for estimated Flat Setups and Exposure Times, but **always check** your first few calibration data sets carefully.

NOTE: NEVER mix quartz lamps!, this will create an illumination that not only varies in intensity across the FoV, but also in spectral response, and would be useless as a flat field.

NOTE: The flat field lamps require a few moments to warm up to their operation temperature. This is of the order of the time required for the flats to close. However, if the flaps are left closed between observations, the flat lamps may not reach their intended stable illumination spectrum before the exposure is started.

12.2.2 Dome Flat Fields

Although these are important for 2dF and SAMI, dome flat fields are not critical for KOALA, but it never hurts to take 2-3 of these during the afternoon if there is enough time.

Just ask the afternoon technician or your friendly night assistant to move the telescope (**after checking both the mirror and the dust covers are open!**) to the designated dome flat position. For KOALA they also have to switch on a lamp in the dome.

As October 2017, the KOALA CCD GUI does not have an option for ”DOME FLAT”, so take them using ”OBJECT”. Around 3 minutes for the standard low- and intermediate-resolution

Table 12.1: *Typical exposure times for KOALA. These are estimates only, check your data carefully! Exposures for the narrow FoV are three times longer.*

FoV	Calibration	Exposure Time	Comments
	Red/385R		
Wide	CuAr ARC	0.1s	Some lines saturated.
Wide	Fibre Flat	2s	
Wide	Dome Flat	45s	
	Blue/580V		
Wide	CuAr ARC	1-3s	
Wide	Fibre Flat	10s	
Wide	Dome Flat	300s	
	Red/1000R and 1000I		
Wide	ARC	2s	
Wide	Fibre Flat	10s	
Wide	Dome Flat	200s	
	Blue/1700B and 1500V		
Wide	CuAr ARC	2s	
Wide	Fibre Flat	30s	

gratings should be enough (45 seconds for 385R), but **always check** the results your are obtaining (average of ∼20.000 – 30.000 counts). This can be tricky in the blue end if using 580V.

12.2.3 Detector Flat Fields

Detector flat fields can be taken using AAOmega by either defocusing the spectrograph or installing a diffuser in front of the slit. Defocusing the spectrograph is easiest, but the diffuser provides better data.

For the defocusing method, (1) defocus the spectrograph by ∼3000 μm in piston using the Focus Mechanism Control (see § 7.4), (2) take Detector Flat runs as required (see § 7.3). (3) *Do not forget* to return the position of the spectrograph to the correct focus values once you have taken your Detector Flat Fields.

For the diffuser method, talk to your support astronomer. An AAT staff member will need to install the diffusing paper in front of the slit inside the AAOmega room.

Ideally, obtain the detector flats BEFORE focusing the spectrograph.

12.2.4 Twilight Flat Fields

Twilight flat fields are useful for measuring and removing total fibre-to-fibre throughput variations and variations in chromatic fibre-to-fibre responses (although the latter is usually done with a standard Fibre Flat Field).

Twilight Flats can be taken as follows:

1. Confirm in advance with the night assistant and/or afternoon technician that you want to take twilight flats immediately after sunset so they can arrange to have the dome open and ready to go in time.

2. Check that the light path is clear[1]—usual culprits are the primary mirror cover and (for KOALA) the central dust cover.

[1] It is in fact possible to take twilight flats with some counts with the mirror cover closed!

3. Have the night assistant point the telescope approximately 100 degrees from the setting sun (typically about 1 hour east of zenith), and start it tracking.

4. Take an series of Offset Flat runs. Between each, have your friendly night assistant offset the telescope by ~ 60 arcsec to reduce the chance of contaminating all of your flats with a bright star. Once you have the exposure time right, a good rule of thumb is to double the length of each successive run to get approximately constant counts as the twilight fades.

5. Tests in February 2018 allowed to confirm skyflats can be obtained under clear skies even 30-45 minutes before the sunset, just using a 1-1.5s exposition time.
IMPORTANT: Before doing this get confirmation from the afternoon technician that no sunlight is coming into the dome!

12.3 Wavelength Calibration Frames (ARCs)

Wavelength calibration (or ARC) frames are taken using the lamps in the calibration unit. These illuminate the flaps below the corrector. KOALA has three arc lamps: Copper-Argon (CuAr), Iron-Argon (FeAr) and Thorium-Argon (ThAr). They cannot be used simultaneously.

Typical exposition times for arcs in KOALA are very short (1-2 seconds, see Table 12.1).

NOTE: The ThAr lamps should **NOT** be used with low resolution data as the Thorium lines are weak but numerous and will confuse `2dfdr` and hinder the accuracy of the wavelength solution.

If you need long arc exposure times in one arm, **check that the other CCD is not saturated**. If so, you should take **two arc exposures, one per arm**, to get good calibration frames.

As KOALA fibres are fixed (they are not for 2dF or SAMI) there is not a need of taking an arc or a flat for each sky position. All arcs and flats can be taken during the afternoon. They should be retaken in case any change is introduced to the spectrograph (e.g., changing the central wavelength). It is also recommended to take another set at the end of the night.

Chapter 13

Getting the data

13.1 Where are the data?

Data taken with AAOmega is available on the AAT control room computer systems at:

```
/data_lxy/aatobs/OptDet_data/YYMMDD/CCD_N
/data_lxy/aatobs/OptDet_dummy/YYMMDD/CCD_N
```

Note that `YYMMDD` is the UT date (start of night) and N is for either CCD "1" (blue) or CCD "2" (red). Regular data files (in `OptDet_data` are named with a convention like `15apr10023.fits` for run 23 of CCD1, or `15apr20023.fits` for the corresponding frame of CCD2. Dummy data files have filenames consisting of a single lowercase letter starting at "a", e.g., `a.fits`, `b.fits`, etc.

A large scratch disk is available for use the data reduction computers at the AAT. This is at e.g., `/data/aat/visitor2`. From October 2017, this disk is accessed from `aattxh` and `aattxe`, as all is network connected. Data should *not* be reduced in the home directories.

NOTE:
This scratch disk must be considered volatile. It is not backed up. Inactive accounts are removed after 30 days, and in some cases data may be removed the day after a given run.

13.2 Taking away data

A typical night's data tends to be 2–10 GB, depending on the number of frames, etc. By far, the easiest option is to copy data onto a personal laptop. If observing at the AAT it is also possible to connect an external USB disk to retrieve the data. The observatory also provides DVDs if needed. If you are following these two last options, talk to the afternoon technician or the night assistant about this well in advance.

For computers connected to the network within the AAT control room, or in the Remote Observing room in North Ryde, the data can be copied via `scp`, `sftp` or `rsync` directly from the AAT computer system via, e.g.,

```
aatlxh> scp -r visitor2@aatlxh:/data_lxy/aatobs/OptDet_data/130123/* my-data-dir/
aatlxh> rsync -rv -avz --exclude="drt_temp*" --modify-window=1
        visitor2@aatlxh:/data_lxy/aatobs/OptDet_data/130123/* my-data-dir/
```

Programs which support `scp` or `sftp` are freely available for windows computers as well.

Alternately, data can be copied from the AAT computer system directly to external computers via e.g., `scp`, `sftp`, `ftp`, etc. This is convenient to send the data to your home institution if your institution allows incoming connections.

Part IV

Data Reduction

The best quality data can only be produced with a careful understanding of the data reduction issues and their impact on the particular science goals of interest.

Chapter 14

Reducing KOALA Data

14.1 Overview

Reducing KOALA data generally consists of the following major tasks:

1. Running all data through the `2dfdr` data reduction pipeline.
2. Applying secondary calibrations:
   - Fibre-to-fibre throughput calibration (or spatial flatfielding)
   - Applying sky subtraction, either using offset sky frames or by marking sky fibres within the KOALA FoV of object frames and re-reducing with `2dfdr`.
3. Combining individual frames onto a regular output grid with drizzling.

The steps above will be treated individually in subsequent sections of this chapter.

As of this writing, software is not available for all of these steps. As with any instrument, the best quality data can only be produced with a careful understanding of the data reduction issues and their impact on the particular science goals of interest. Very good results can be achieved with software currently available, but there is certainly not any "one-click" option for data reduction.

Before continuing, it is useful to understand some of the issues present in reducing integral-field spectroscopic data, and KOALA data in particular.

14.1.1 Flatfielding

The word "flatfielding" can mean several different things in the context of KOALA data:

Detector Flatfielding The pixel-to-pixel variations in throughput of the CCD detectors. In KOALA+AAOmega data, detector flatfielding is achieved using a "Long-Slit Flat".

Fibre-to-fibre spectral response The spectral response of the fibres can vary (i.e. if illuminated with a white light source, each fibre may produce a slightly different spectrum at the detector). In KOALA, this is typically removed using a "Fibre-Flat-Field".

Spatial Flat-fielding The total throughputs of individual fibres can vary relative to one another. Typically, this can be corrected using a twilight flat or dome flat.

14.1.2 Sky Subtraction

Accurate sky subtraction is a very difficult problem, and IFU data offer no exceptions. In particular, if the object fills or nearly fills the field of view, then a separate "offset sky" observation will be necessary to measure and remove the sky emission.

For KOALA, the following should be kept in mind:

- If offset skys are necessary, then some time must be taken away from the science target to observe the sky.
- If sky spectra from different spatial positions on the IFU/detector are to be combined to improve signal-to-noise, it is important to keep in mind that the spectral PSF of the instrument varies, so sky subtraction accuracy will be limited unless the PSF of all the data are matched first.
- The science spectra a highly correlated, so PCA and some other secondary sky subtraction techniques are inappropriate.
- The time variability of the sky can limit subtraction accuracy with offset skies, as they are necessarily not contiguous in time.

14.1.3 Atmospheric Refraction

Atmospheric refraction varies with wavelength. For integral-field spectroscopy such as KOALA, this means that the spatial position of an object, e.g., a star, will appear to shift as a function of wavelength. The size and direction of this shift depends on the air-mass and azimuth of the observations, and on the properties (temperature, humidity, pressure) of the atmosphere above the telescope. Across the optical wavelength rage accessible to KOALA, the size of such a shift can be several arcseconds or more.

Typically, the size and direction of the shift introduced by differential atmospheric refraction can be accurately modeled, and need not be fit.

Without correcting for atmospheric refraction, a single spatial spectrum in the output data will not correspond to a single spatial location within the galaxy, and therefore is not representative of the physical nature of anything!

14.1.4 Combining data

Combining integral-field spectroscopy is much more complex than simply adding together spectra or median combining images with offsets. The situation is made more complex by

- The problem of atmospheric refraction (see previous section), and
- the non-rectangular (hexagonal) sampling of KOALA.

A good way to handle combining data is to consider and address several problems at once using a process often called "drizzling". In this process, flux from each input pixel is positioned according to both the affects of atmospheric refraction and any offsets/dithering between frames. Once positioned, the flux from the input pixel is then distributed across corresponding pixels of the output grid. This is addressed in much greater detail in Sharp, et. al., MNRAS, 446, 1551 (2015).

14.2 The 2dfdr pipeline

`2dfdr` provides high quality extraction and wavelength calibration of AAOmega spectra. For KOALA, it is able to:

- remove bias levels using overscan or 2D bias frames;
- subtract dark current using separate dark frames (not recommended);
- correct the pixel-to-pixel response of the detector (detector flat-fielding);
- trace the fibre spectra across the detector (known as "tramlining");
- extract spectra identified with the "tramlines" using a variety of methods, including Gaussian weighted and "optimal" extractions (the later simultaneously solves for the flux in each spectrum while accounting for cross talk and scattered light);
- identify arc lines and wavelength calibrate the spectra;
- provide limited quality spatial flat-fielding by measuring sky emission lines in either the science data or offset sky frames;
- provide fibre spectral response corrections;
- sky subtract data where fibres within the field of view are used as sky (only with external identification of such fibres, see below);

The spectral extraction is particularly difficult and important for KOALA data. KOALA spectra typically have a 2–2.5 pixel FWHM, and are separated on the detector by only about 3.5 pixels. Therefore, there is considerable crosstalk between spectra. Furthermore, PSF is not only a complex function (typically two-Gaussians plus a Lorentzian) but varies across the extent of the detector. Finally, the extraction can account for scattered light, typically most relevant in the flat-field frames.

Currently, `2dfdr` does not provide:

- Sky subtraction using offset-skies
- Any kind of data combining for KOALA data (other than BIAS and DARK frames)
- flux calibration
- cube/image reconstruction

Instead, these must be done with separate software as described below.

Instructions on getting started with `2dfdr` can be found in Chapter 15: Basic Reductions. More detailed help and instructions for using `2dfdr` can be found within the application itself using it's built in help system.

14.3 Sky subtraction using internal fibres

Python software for selecting KOALA fibres to be used as sky is available in the `koala_sky_selector` bundle. Review the contents of `koala_visualise.py`.

This is python code which allows you to interactively select the sky fibres after a first pass 2dfdr reduction. Once done, the file will need to be re-reduced in 2dfdr.

The function to use or adapt is `quick_ha_sky_edit`, which displays a narrow band image around Ha and allows fibres to be interactively marked as sky. NOTE that the raw file is updated (changed) immediately on clicking in the image—you might want to have a copy. This function could be adapted for other wavelengths, or to collapse the whole cube instead of just a narrow region.

Also useful is `copy_sky` which simply copies sky allocations from one raw file to another: useful when most of the sky fibres are the same and you dont want to manually click them all again.

14.4 Sky subtraction using offset skies

As of this writing, no software exists to do this.

14.5 Combining and cube reconstruction

Currently, the only option for combining frames and reconstructing a cube is provided by the SAMI Python Package. The `koala-cubing` branch of this software is available from `https://bitbucket.org/james_t_allen/sami-package/branch/koala-cubing`.

An example script that makes use of this package to drizzle together a series of KOALA observations is available on the KOALA Data Reduction page of the AAO website. Offsets must be provided by hand, at least currently (although there may be some complications when dealing with the DAR, and of course measuring them rather than using the ones from the telescope is generally safer if possible).

14.5.1 Getting the software

The koala cubing code is part of the SAMI package, but in its own branch. With mercurial installed, the package can be downloaded with the following shell command:

```
> hg clone -u koala-cubing https://bitbucket.org/james_t_allen/sami-package sami
```

You can update with the following command (run inside the sami directory), should any changes be made to the repository.

```
> hg pull -u
```

Once downloaded, switch to the `sami/utils` directory and run the following

```
> make all
```

Youll need to make sure the `sami` directory is in your python path (this can most easily be achieved by running

```
> export PYTHONPATH=/path/to/directory/containing/sami
```

before starting python or running any scripts. Alternately, you can modify the `sys.path.append` line in the example script.

14.5.2 Current Limitations

There are several limitations in using the SAMI Python Package to drizzle KOALA data:

- KOALA fibres are assumed to be round instead of their true hexagonal shape.
- Chromatic differential atmospheric refraction is not corrected.
- Combining a cube requires considerable ram. Combining 3-6 full KOALA cubes could require many gigabytes of ram.

Chapter 15

Basic Reductions

2dfdr is the AAO's generic data reduction package for all of the observatory's fibre based spectrographs. 2dfdr currently has modes that reduce data for a number of instruments including 2dF, SPIRAL, KOALA and SAMI feeds for AAOmega, 2dF+HERMES, and 6dF on the UK Schmidt.

NOTE:
2dfdr is rapidly evolving as more is learned about the various data formats. Therefore, one should regularly check 2dfdr release page for updates:

`http://www.aao.gov.au/science/software/2dfdr`

15.1 Install 2dfdr

The software is available as a set of binary executables available for Linux and Mac operating systems. The source code is also available.

Download the software from the 2dfdr release page. We also advise signing up for the mailing list at that page so you can be notified of updates.

`http://www.aao.gov.au/science/software/2dfdr`

Unpack the tar file and extract the software to your chosen software directory:

```
laptop> tar -xvz -f 2dfdr-linux-5.33.tgz
```

Then, you should add the executable to your PATH to make it easy to start. This is best done by adding a line to your `.cshrc` or `.bash_profile` file as appropriate:

```
# for csh
set path = ($path /path/to/software/2dfdr_install/bin)
```

```
# for bash
export PATH=/path/to/software/2dfdr_install/bin:$PATH
```

15.2 Set up a Directory Structure

2dfdr should be run in a separate working directory for each set of observations with a particular field plate. A meaningful directory structure for your observing run can save a lot of heartache later on. An example directory structure might be:

```
Observing95june05/
    night1/
        field1/
        field1b/
        field2/
        field3/
    night2/
        field1/
        field4/
```

Note that due to the way the flat and arc frames are used, each independent observation (i.e. with a different configuration of the fibres on the field plate) will require a new directory, even if all you have done is tweak the positions of fibre on a previously observed configuration. Once the AAOmega slit wheel is moved with a change of field plate, a new set of flats and arcs are required for the reduction. Data from multiple repeats of the same field, or for fields that contain some repeat observations can be automatically combined, but this is done after the full reduction of data for each field.

Data from the blue and red arms can be reduced in the same directory, but this is often not easy to work with and so most users create separate `ccd_1` and `ccd_2` sub-directories with blue and red data, respectively.

Reduction using `2dfdr` depends on the use of a file naming convention in which the name has a root that is the same for all files. The root name is followed by a four-digit integer run number. Raw data from the AAT conforms to this convention with names of the form `13apr10001.fits` (for blue, CCD 1), `13apr20001.fits` (for red, CCD 2). Data from the archive also conforms to the convention though the names are changed to `run0001.fts`, etc. Usually only in the case of BIAS and DARK frames, it may be necessary to rename files to the same root in order to combine these calibrations from data taken across several nights.

If you have bias or dark calibration files, these need to be reduced in a separate directory, e.g.,

```
Observing95june05/
             bias/
             dark/
```

The reduced, combined output `BIAScombined.fits` or `DARKcombined.fits` can then be then copied into the working directory of the science data before beginning the reductions.

15.3 Starting the software

Move to your working directory of choice and then the software can be started with the command:

```
laptop> drcontrol
```

This brings up the Front Page window (shown in Figure 15.1) from which you can select from existing data reduction prescriptions. These prescriptions are stored in `.idx` files. Additional configurations are available by ticking the List all idx files box.

If you already know which `.idx` file you wish to use you can start with the command:

```
laptop> drcontrol ###.idx
```

The default `.idx` files are all stored at

```
/path/to/software/2dfdr_install/share/2dfdr/*.idx
```

Users, if required, can make a copy of these instrument (`.idx`) files in the local directory and modify them to set their own reduction preferences. Not all grating configurations currently have corresponding `.idx` files.

These commands bring up the main `2dfdr` window shown in Figure 15.2.

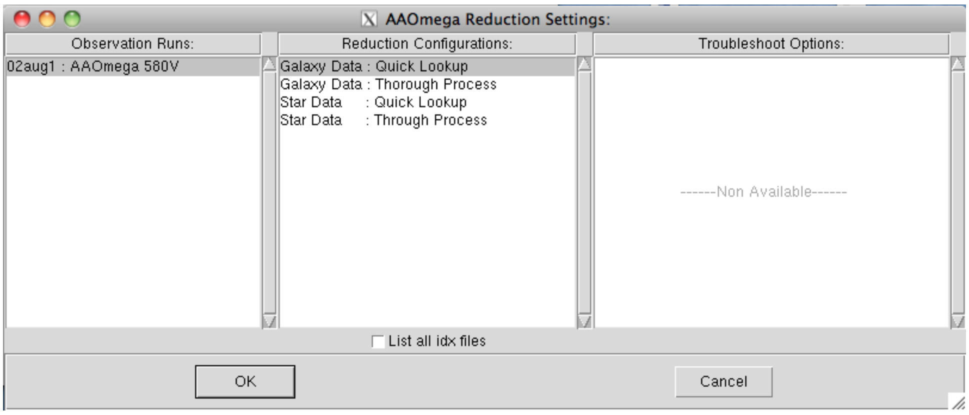


Figure 15.1: Reduction configuration chooser window shown on 2dfdr startup.

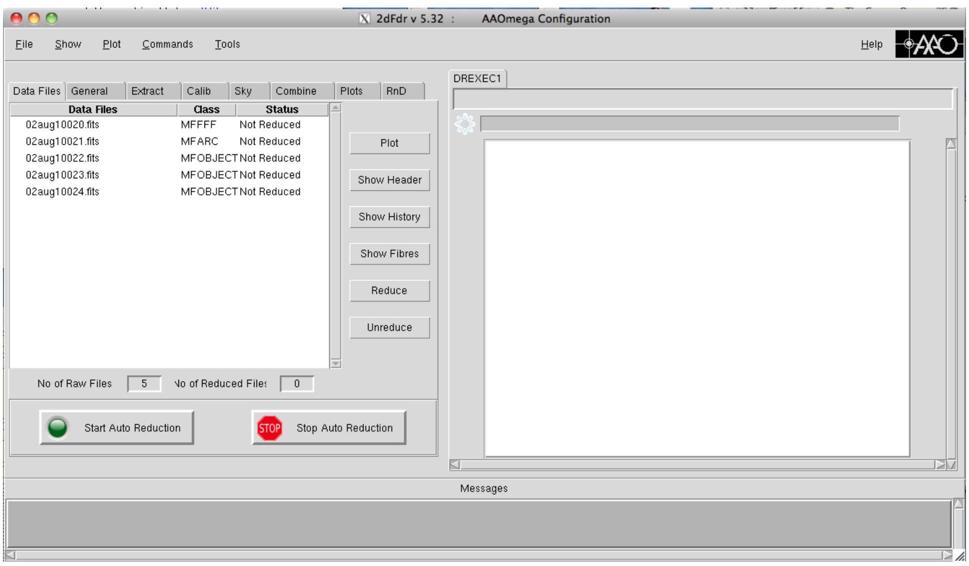


Figure 15.2: The 2dfdr main window.

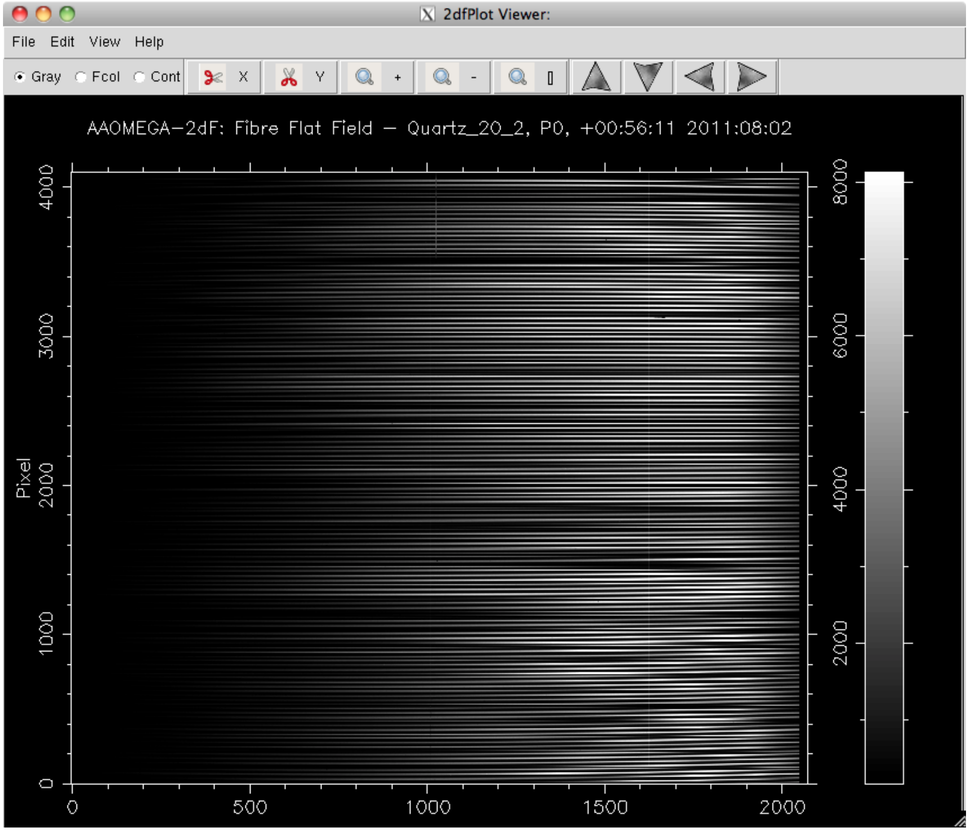


Figure 15.3: *2dfdr Plot window showing a raw AAOmega Fibre flat field.*

15.4 Getting Started

The basic files needed to reduce AAOmega data are:

MFFFF — a multi-fibre flat field exposure These exposures are made with a quartz lamp that provides a uniform spectrum. They are used to flat-field the spectral response, and to find the centre and profile of each spectrum.

MFARC — an arc exposure These exposures are made with lamps having various known emission lines. They are used to calibrate the central wavelength and dispersion.

MFOBJECT — one or more science frames The science data to be reduced. This data must be taken with the same setup as the flat and arc frames.

Additional frames of various types may be needed to accurately reduce science data, these are the minimum required for `2dfdr` to produce output.

In the main window shows the recognised files in the working directory, their class and their reduction status. Figure 15.2 shows that the first file, Run 20, is file 02aug10020.fits (which is run 20 for ccd1 from 2nd August). The file is a Multi-Fibre Fibre Flat Field (class MFFFF) frame. The file has not yet been reduced and so the status is Not Reduced.

If we select a file and hit the Plot button to the right of the file information, we can see the 2D image shown in Figure 15.3. This is useful to check that everything looks okay. Note that the full CCD is 2kx4k and so many of the displays you will see during reduction are heavily aliased and will often show strange artifacts which are simply not in the data. Use the Q key to exit the plot window.

The user should be able to simply hit the Start Auto Reduction button, in the bottom left corner, to reduce all the data in the current working directory.

The process runs as follows:

1. Reduce any and all multi-fibre flat field frames
2. Reduce any and all arc frames
3. Re-reduce the flat field frames using the accurate wavelength solution obtained from the arc frame reduction to compute a better average illumination correction
4. Reduce any and all science frames
5. Combine the science frames (if requested in the options)

When the process is complete your working directory will contain a set of `*red.fits` files which are the reduced data, and the combined data will be in the `dateccd_combined.fits` file. The formats of these multi-extension files are described in detail in Chapter **??**.

If your data overlap in wavelength it is possible to splice them together using the ”Splice Red & Blue” option under the Commands menu.

15.5 Using the GUI

15.5.1 Plotting

When in plot mode, the keyboard shortcuts available are listed in Table 15.1.

Table 15.1: *`2dfdr` Plot Commands.*

Key	Description
`G`	Grayscale Plot. A grayscale image of all the data.
`F`	False colour plot. Same but with false colour.
`C`	Contour Plot.
`$`	Magnitude Diagnostic. This plot shows a series of diagnostic plots showing detected counts against input magnitudes. It is useful for diagnosing positioning accuracy and throughput.
`I J`	Line plot through cursor position in X or Y (respectively).
`K L`	Histogram plot through cursor position in X or Y (respectively).
`< >`	Move up/down in zoomed plot, or next/previous cut plot (spectra).
`3 4`	Move left/right in zoomed plot.
`%`	Scale to 95th percentile values.
`M`	Scale to maximum and minimum values.
`Z O`	Zoom in or out by a factor of two. Note that tramline plots are only zoomed in the vertical axis.
`P`	Recentre the plot at the current cursor position.
`R`	Restore the original plot area and scaling.
`[ ]`	Select corners of a region to expand or zoom in on.
`Q`	Close the plot window.
`?`	Display help.
`space`	Report position and values for current cursor position.

Keyboard commands for the plot window are shown below. This help for the plot window can be recalled using the “?” key from within the plot tool.

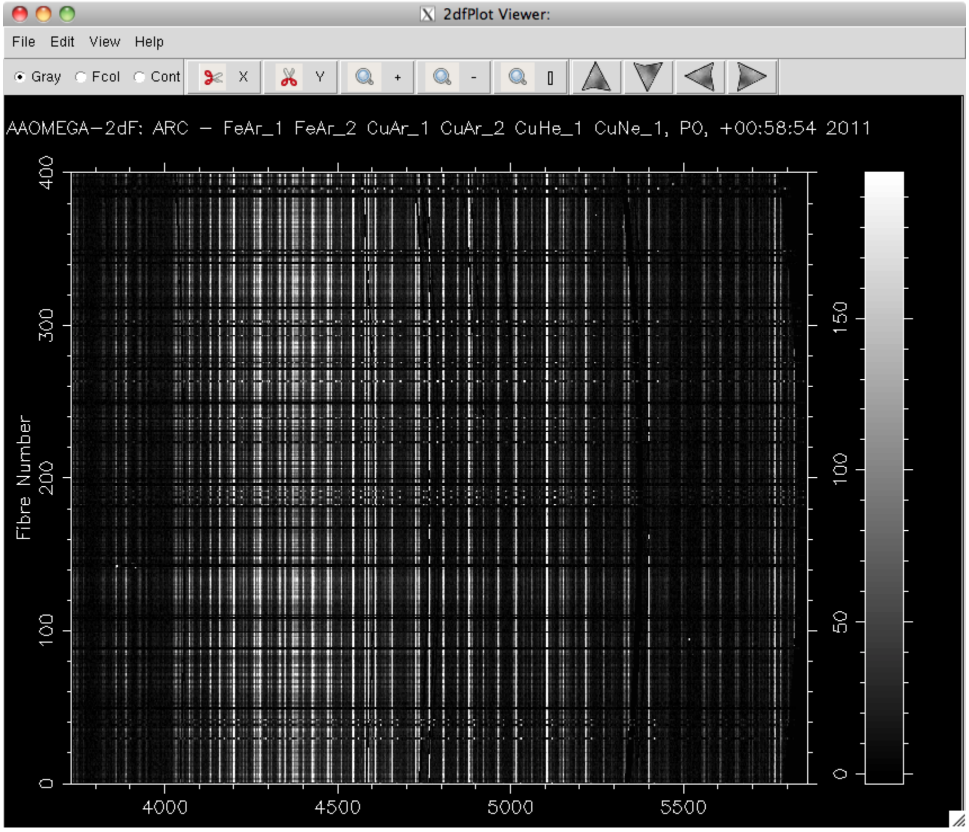


Figure 15.4: *The 2dfdr plot window can display a variety of information for both raw and reduced files.*

15.5.2 Setting Reduction Options

General The General tab covers preprocessing options which are applied prior to extraction of the spectra.

Extract The extraction tab deals with parameters related to the extraction of the fibre traces from the raw 2D CCD frame

Calib The calibration tab includes wavelength and flux calibration options

Sky Sky subtraction options are included on the Sky tab.

Combine Options for combining data from multiple observations.

Plots Options for the plotting tool, and options to display certain diagnostic plots during reduction.

RnD This tab contains special options which are still under development. Contact your instrument scientist for more information.

15.6 Combining Data

Data from multiple observations of the same fields, and also data from multiple observations of separate fibre configurations (usually with some overlap in the targets, which is being performed to increase a sub-set of exposures times) is routinely performed by `2dfdr`.

Typically the data from each camera (red and blue) is combined separately before the spectra are spliced into one continuous spectrum.

Combining of reduced files occurs in 'Auto Reduction' mode when all local object frames have been processed. It can also be done manually using the Commands → Combine Reduced Runs menu item. The 2dfdr combine algorithm combines data based on either object name or object location. (RA and DEC) That is, fibres having the same name (or location) are added and normalised to produce the output. This is to include all objects, whether they are contained within every frame or only a sub-set of the frames. The combine has the following features:

- Multiple configurations of the same field can be combined together when objects are in common. Note that this can result in more spectra than the instrument can produce in one exposure.
- Only fibre types 'S' (sky) and 'P' (program) fibres are combined. This includes cases in which a fibre has been disabled part way through a field observation, so only good data is combined. Other fibres such as unused and parked fibres have all values set to zero.
- The first spectra will be all those from the first frame in the combine including unused/parked and sky fibres. Any additional spectra will be only sky and program spectra from objects in subsequent frames and not present in the first frame. if the data combined are all from the same configuration there will be no difference in the fibre count.
- All the fibre table extension information is properly propoagated. Additional fibres are numbered beginning from the last fibre of the first frame. So for AAOmega, the first 400 fibres will be from the first frame, and fibre 401 and beyond will be additional fibres from subsequent frames (if any).
- Variances are handled properly.
- An attempt is made to correct for differences in transparency between exposures. This is controlled by the option.

NOTE:
Currently the combined file exposure time is NOT set properly. Exposure time is given in only one place for a file, the value of the .fits header keyword 'EXPOSED'. This exposure time applies to all fibres within the file. When fibres are combined, this keyword is copied from the first frame—no attempt is made at setting it properly.

15.7 2dfdr FAQ

Is it possible to look at the data after each reduction step in 2dfdr?
One can turn on various automatic plot options—the fitted tramlines, the fit to the scattered light background and the profile fits during extraction (with the FIT method), the throughput map and the subtracted sky under the plot tab. If you want to look at the raw extracted spectra (i.e. before calibration/sky-subtraction), select the `*ex.fits` files and use the Plot button to see the extraction once the reductions are complete.
How does the sky-emission-line throughput calibration work in 2dfdr?
All sky lines are used. Sky-line pixels are identified by plotting the wavelength derivative of the flux—those with large derivatives are identified as sky-emission-line-pixels. Obviously if your wavelength range contains no sky lines (e.g., at high-dispersion in the blue) this option should not be used! In that case twilight flats and/or offset sky frames will be needed. Note, it is only possible to do twilight flats for a maximum of 4 fields a night, two at the start and two

at the end, since the fields must be pre-configured in order to take twilight flats, and the flat is not relevant once fibres have been moved, even if the field is reconfigured at a later date.

What does flat-fielding mean in `2dfdr`?

There are three-meanings. The first is the dispersed white-light fibre spectra used to fit the tramlines. This is what is usually referred to as the 'FLAT'. The second meaning is 'pixel-to-pixel CCD flat field' otherwise known as a 'longslit flat'. The third meaning is 'spectral/fibre flat-field', where extracted object spectra are divided by extracted, normalized, white light spectra (this is usually the same data as that used for the tramlines). Given the uniformity of modern CCDs, the 'spectral flat-field' is often sufficient for correcting pixel-to-pixel variations in the CCD.

How can one omit 'sky' fibres which contain objects in `2dfdr`?

Normally this should not be necessary as `2dfdr` takes a median sky, and clips outliers. If you really must, create a file called '`skyfibres.dat`' in the working directory, listing the numbers (one per line) of the fibres you wish to use for sky. `2dfdr` will then use this file, in preference to the headers, when you reduce (or re-reduce) the data.

How does `2dfdr` handle flexure?

AAOmega and HERMES are bench mounted spectrographs in a stable thermal environment. For AAOmega, there is a small shift (~ 0.5 pixels per night) of the spectra due to boiling away of the liquid nitrogen coolant over a night. To retain the possibility of correcting for this the "shift and rotate" option allows the tramline map to be tweaked to the data. For instruments with regular (~ 1 per hour) calibrations, such as 2dF+AAOmega, the effect is effectively mitigated. Users of other instruments may wish to use the "shift and rotate" option.

Can one save `2dfdr` parameter settings?

No, but you can create `.idx` files with these settings preset if you are an experienced user.

Can one combine frames BEFORE sky subtraction in `2dfdr`?

No. If you want to experiment with this turn sky-subtraction off completely and do your own processing on the final individual spectra. If you get better results than `2dfdr`, let us know. Most previous efforts at this have failed, and AAOmega has been seen to give 1% sky subtraction. If you care at this level then ask your support astronomer about "Nod and Shuffle" observations.

Part V

Supplementary information

Chapter 16

AAOmega CCDs and Grating Efficiencies

16.1 AAOmega CCDs

Each arm of the AAOmega system is equipped with a 2kx4k E2V CCD detector and an AAO2 CCD controller. A new blue-sensitive, standard silicon, CCD was installed in March 2014. The red arm CCD is a new bulk silicon, multi-layer coated device installed in August 2014. Both CCDs can be driven in a charge shuffling mode.

Tables 16.1 and 16.2 show the gain, readout noise, and readout times for the various readout modes. All readout modes are considered scientifically useful, however, only Fast and Normal have been used extensively to date and so there is little experience with other modes, with the exception that Ultrafast is typically used for focusing the system and for special purposes, such as sets of raster scan exposures to check the precision of target acquisition.

Some important considerations in planning AAOmega observations are:

- Single amplifier (right amp.) is currently the default mode of operation, pending full commissioning of the dual readout mode.
- In the blue, and particularly at high resolution or during dark of moon, observations can become read noise limited if integrations are short. Hence longer exposures may be required and the slower read-out modes should be considered.
- Following the installation of the new blue CCD, the detector can be dark current-limited for integrations longer than 40 minutes. Dark frames are provided to subtract this current.
- The different readout speeds produce different saturation characteristics (due to gain changes altering the system from "CCD full well" to "AD converter saturation" states). The high-gain Ultrafast and Fast modes are CCD full well saturation limited (so the CCD image will be saturated before the nominal limit of 65536 is reached), all other speeds are Analog-to-Digital Converter (ADC) limited for saturation ($2^{16} = 65536$). Check your data carefully when using these CCD readout modes to ensure safe values. The gain of 2 in NORMAL mode does mean that one needs 10,000-20,000 counts to get accurate statistics for flatfielding.
- Ultrafast mode is very noisy, due to the high readout rate, and is only intended for use during day-time setup. This mode can be unstable, and *is not recommended for science observations or during the night.*

Table 16.1: Parameters for the AAOmega Blue EEV CCD as of March 2014
Dark 2.0 e/pix/hr (after post power up stabilisation, 4hr)

Mode	Readout time (sec)	Gain (e^-/ADU)	Read Noise (e^-)
Left Amp			
Ultrafast	21	4.7	8.84
Fast	75	2.86	5.03
Normal	111	1.9	3.7
Slow	145	1.2	3.03
Xtraslow	403	0.29	2.33
Right Amp			
Ultrafast	21	4.73	8.46
Fast	75	2.84	4.93
Normal	111	1.88	3.61
Slow	145	1.17	3.03
Xtraslow	403	0.29	2.3

- The CCDs can be windowed or binned to reduce readout times, broadly in proportion to the size of the reduced window. If this mode is required, raise it with your support astronomer well in advance of your observing run.
- Lamp characteristics, filters and dichroic responses change with time (due to being swapped around and, occasionally, exploded) and so the user must determine which set they require for their observations. Saturation in the red (see note above), blue response and structure in the dichroic reflectors on the lamps are the major considerations.

  A full set of flat field exposure should be taken at the start of the run and reduced. Check the raw images, in the SkyCat displays, for count levels at or near 65536 (less for fast or ultra-fast modes) and check the `2dfdr` reduced data to ensure that there are no poor dichroic response features (the reduction will require an ARC frame to be taken to allow the secondary wavelength scrunch, bad columns in the blue will complicate this assessment).

16.2 AAOmega Grating Efficiencies

At the lowest resolution AAOmega can be configured to observe the entire optical spectrum over the wavelength range 370nm-900nm, with a small overlap between the red and blue arms around the dichroic wavelength (570 or 670nm). Changing the gratings allows a range of resolutions up to R 10,000, with correspondingly shorter wavelength coverage. The efficiency curves for the AAOmega gratings are given below. All measurements were taken prior to AR coating, so all quoted efficiencies should be increased by a factor of 1.08. All curves are approximate, with a 25mm aperture used to test the efficiencies. The different curves for each grating correspond to different grating angles; users can select whatever grating angle is most suitable for their observations. Note that the test may have been done with the grating (and hence slant angle) reversed with respect to the grating calculator. Note that altering the grating angle also has a 2nd-order effect on resolution and wavelength coverage; this becomes significant at high dispersion.

Table 16.2: Parameters for the AAOmega Red EEV CCD as of August 2014
Dark 1.8 e/pix/hr (after post power up stabilisation, 4hr)

Mode	Readout time (sec)	Gain (e^-/ADU)	Read Noise (e^-)
Left Amp			
Ultrafast	21	5.45	9.87
Fast	75	3.03	5.15
Normal	111	2.0	4.13
Slow	145	1.7	4.4
Xtraslow	403	0.327	2.62
Right Amp			
Ultrafast	21	4.93	8.67
Fast	75	2.7	4.72
Normal	111	1.99	4.25
Slow	145	1.22	3.15
Xtraslow	403	0.31	3.05

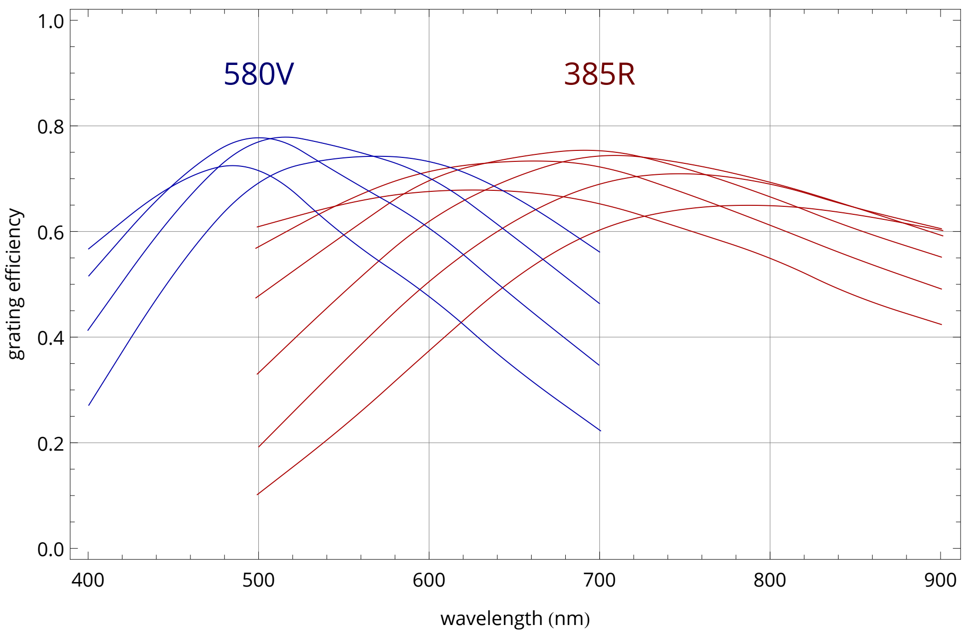


Figure 16.1: *Efficiency of the Low-Resolution Gratings. For each grating, distinct lines show the efficiency at a range of central wavelength settings.*

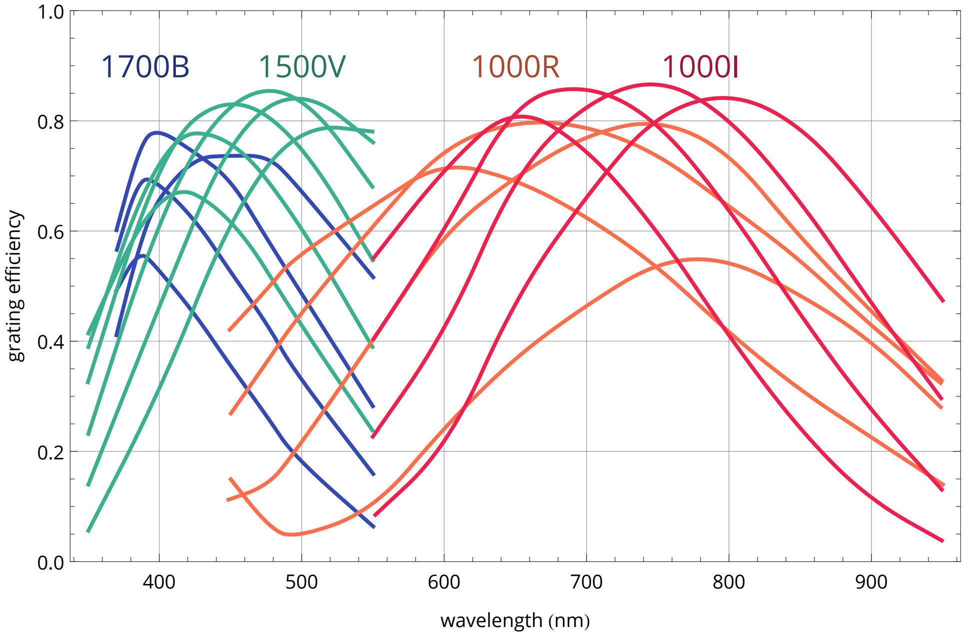


Figure 16.2: *Efficiency of the Mid-Resolution Gratings. For each grating, distinct lines show the efficiency at a range of central wavelength settings.*

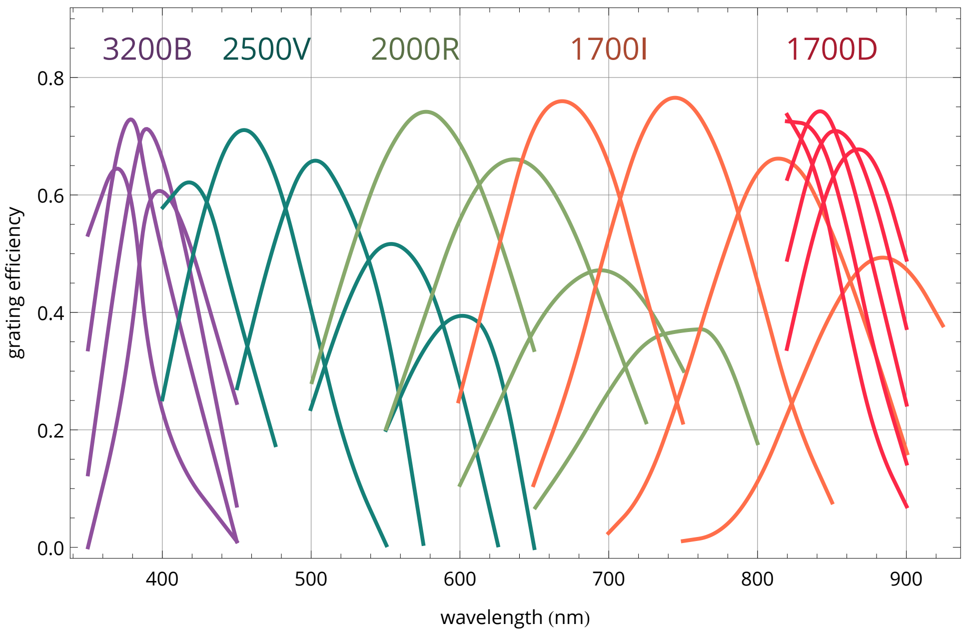


Figure 16.3: *Efficiency of the High-Resolution Gratings. For each grating, distinct lines show the efficiency at a range of central wavelength settings.*

Chapter 17

Scripted Operations

The 2dF control task now implements a simple scripting language. The intention of the feature is to allow the automation of common sequences, both common to the various instruments or on a observer specific basic. These scripts work in all 2dF control task instrument modes (2dF/AAOmega, SPIRAL, SAMI, KOALA and HERMES), but some commands are instrument mode specific.

The scripting language is simple, and does not contain any "programming control" structures (loops, if statements etc). But it is sufficient for many common repetitive tasks, such as running standard observation sequences. If you have a need for complex observing scripts that can't be done with this language, please contact the AAO Software Group who may be able to help you.

As the language is new (August 2013), it may still change a little or be extended a bit more.

This section documents the scripting language and how to use these scripts.

There are two ways of selecting scripts to run. First there are a set of standard scripts which can be selected quickly. Alternatively, you can load scripts from files as required.

17.1 Standard scripts

There are a number of standards scripts. These are available from a menu entry - `Commands->Standard Obs Scripts`. Just select the script of interest from that sub-menu. It will start running immediately, but all these scripts prompt for user input or acknowledgment before running any command which takes an exposure or moves the instruments or telescope.

The sfollowing standard scripts are provided:

Menu Entry	Script	Description
3x3 raster	3x3_raster	Implements a 3 x 3 telescope raster, taking observation at each point. The script prompts the user for the exposure time and telescope offset size. It does a total of 11 OBJECT observations of the specified exposure time. It does an initial observation frame at the centre position, the 9 frames of the raster and an extra one at the centre position.
5x5 raster	5x5_raster	As per 3x3, but implements a 5x5 raster, generating 27 frames.
Take Focus Frames	focus_data_acquire	Prompts the user for an exposure time, and then takes 2 arc exposures, with the appropiate lamps switched on for a standard Hartmann focus frame. The first exposure has hartmann shutter 1 closed, the second has hartmann shutter 2 closed. It then opens both hartmann shutters. This script is used by the new automatic focus procedure available from the Spectrograph Control window

More standard scripts will be added as devised.

17.2 Script file Locations

Scripts (other then the standard scripts above) are located in a defined directory tree found in one of two locations. The program first looks in the directory `obsscripts` in the user's home directory (normally `~aatinst`). It then looks in the sub-directory `obsscripts` of the directory located by the `TDFCT_DIR` environment variable. This later directory is the set of scripts released with the program and any user written scripts placed here will be lost when the program is next updated. The former directory should be used for user written scripts.

Within these directories, there are a number of sub-directories. Scripts must be placed in the appropriate sub-directory to be seen. The table below describes the sub-directories:

Sub-directory	Description
all	Scripts in this directory are available in all 2dF control task instrument modes.
aaomega_2df	Only used when running 2dF and AAOmega
hermes	Only used when running HERMES
ifu	Only used when running SPIRAL
koala	Only used when running KOALA
sami	Only used when running SAMI

17.3 Selecting the script

Scripts are loaded and run from the CCD Control Interface of the 2dF control dialog. The two rows of buttons etc. at the bottom of the window are used. Please see figure 17.1.

Use the open-file button - 🗁 - just next to the "Scripts:" label, to open a dialog to enable selection of a script file to run. The resulting dialog (see figure 17.2) shows the list of available files in the standard locations. Hover the mouse over an entry to see the full name of the file (note, a script of the same base name can appear in different directories, and you will need to hover to work out which is which). Select the radio button next to the file name to select that script. Alternatively, you can select "Script Specified Below" to allow you to enter any file name using the file browser below that button.

Select the `Continue` button to load the chosen file. The file is parsed at this point and any errors in the format of the file should be detected immediately.

Warning - if you change the file, you must re-select it to cause it to be reloaded.

17.4 Running the script

Figure 17.3 explains the buttons of the script controls area. One particular thing to watch is that to run a script, you must invoke the `Run Script` button rather then the `Start CCD Run` button just above it.

When the script is actually running, these buttons not active.

A script can be paused at various points. If doing a CCD observation, a "Pause Script" button is available. Any dialog produced by the script and the `WAIT CONFIG` command allow scripts to be paused. If you continue the script after pausing, the next command in the script will be invoked, unless you skip/rewind to another location. A script will also pause if an error occurs whilst running the script.

In rare cases, a script may stop due to an error without the script control buttons being made active again. If you can work out what is triggering this, please report it as a fault. To recover from such cases, invoke `Commands -> Unlock Script` from the control task menu bar.

17.5 The Scripting Language

This section describes the language itself, to enable authoring and editing of scripts.

17.5.1 Basic Syntax

The script language is very simple. A file contains a set of commands, one per line. A command is represented by a token. Tokens can be written in upper or lower case, as desired. Commands can have arguments, which are separated by spaces. Command arguments may be other tokens, quoted strings, integer or floating point numbers. Integer and floating point numbers may be represented directly or via variables.

Some command arguments are lists enclosed in `[` and `]` characters. Items within such lists are comma separated.

A hash (`#`) character introduces a comment. Any text after this character until the end of the line will be ignored.

17.5.2 Observing Commands

Observing commands are used to take CCD exposures. Script commands exist which will execute each of the standard exposure commands supported by the Control Task. Each of the commands listed in the table below take one or more of the following forms:

```
<command>
<command> <time_spec>
<command> <time_spec> <count>
<command> <time_spec> <lamp_spec>
<command> <time_spec> <lamp_spec>  <count>
```

Where:

`<command>` Is the command name, from the table below.

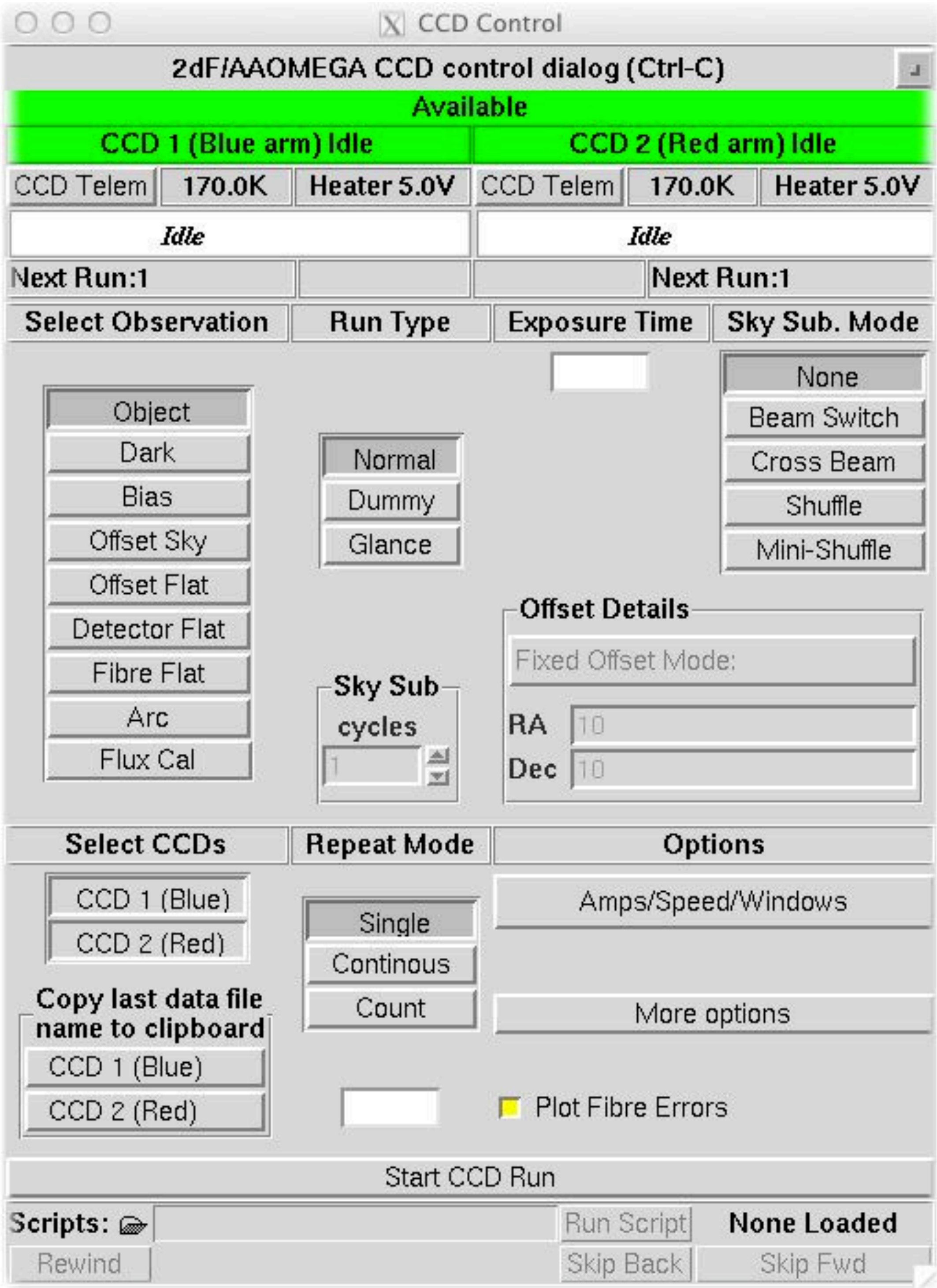


Figure 17.1: *Control Task CCD Dialog - the script control interface can be seen at the bottom.*

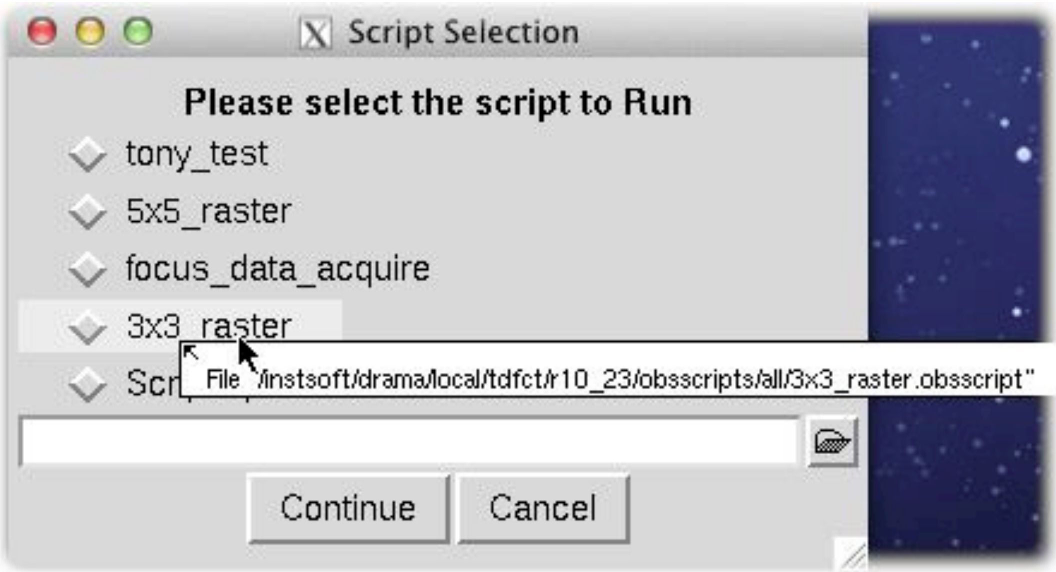


Figure 17.2: The script file list dialog - hover the mouse over a name to see the full file name.

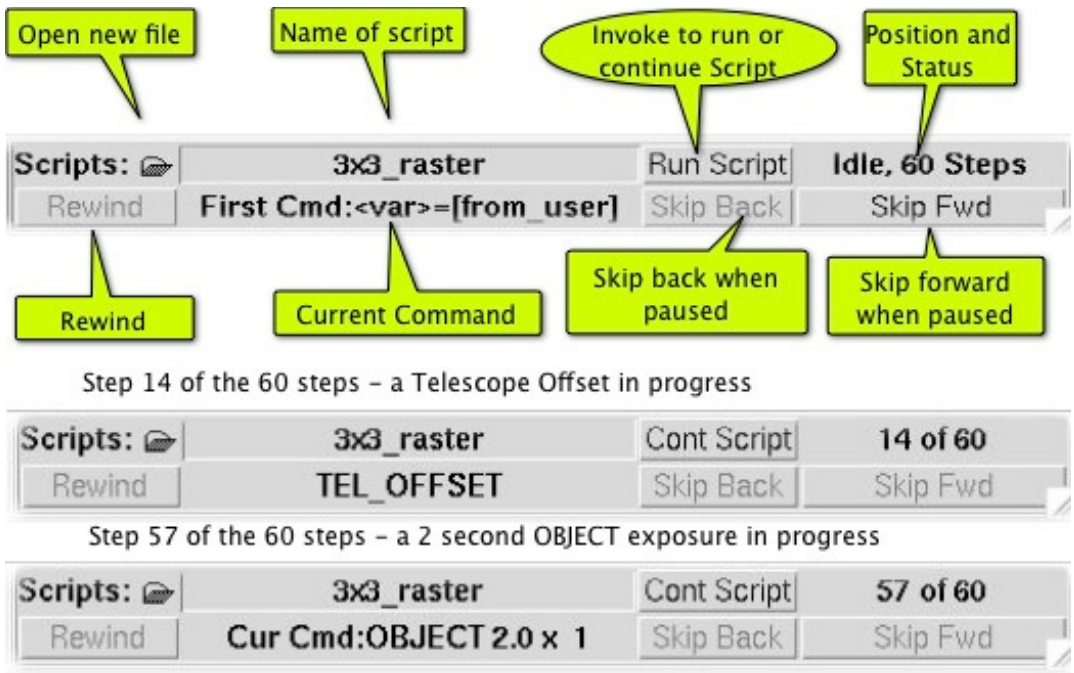


***Figure 17.3:** Script control buttons and indicators. The first image is what you see on loading a script, then two examples show the status part way through a script.*

`<time_spec>` Is an exposure time specification. Normally a floating point exposure time in seconds. Details below.

`<count>` Is the number of exposures of this type to do. Defaults to 1.

`<lamp_spec>` Is a specification of the lamps to be turned on for `<command>`'s that use calibration lamps. Details below.

All commands except the BIAS command requies the exposure time to be specified.

CCD commands
The table below lists the various CCD commands and indicates if a lamp specification is required:

Command	Lamp Spec	Description
OBJECT	No	Takes a normal (on target) exposure.
BIAS	No	Takes a bias frame (shutter closed, zero second exposure). The exposure time is not required or accepted.
DARK	No	Takes a dark frame (shutter not opened).
SKY	No	Takes an offset sky exposure. The observer must arrange for the telescope to be offset to sky.
FFLAT	Flat Lamp	Takes a fibre flat field exposure.
DFLAT	Flat Lamp	Takes a detector flat field exposure. (For AAOmega, this is a defocused flat, the observer must defocus the spectrograph first and restore it afterwards (a command is available). For HERMES, this is a dithered flat)
SFLAT	No	Takes a sky flat exposure. This is normally a twilight flat. The user is responsible for acquiring twilight.
ARC	Arc Lamp	Takes an arc exposure.

Exposure time specificatons

In most cases, a single exposure time is all that is required, and you just enter a positive real number. In HERMES, it is possible to specify a different exposure time for each arm. This is done as follows

```
[ <blue_arm>, <green_arm>, <red_arm>, <infrared_arm> ]
```

Where each value (e.g. `blue_arm`) is an exposure time in seconds (real number). This is most likely to be required for HERMES flat fields. For example, instead of:

```
FLAT 100 [ QTZ1 ]
```

You might specify:

```
FLAT [150, 120, 100, 80] [ QTZ1 ]
```

Lamp Specifications
A lamp specification is a comma list of lamp names inclosed in “[” and “]”. There are flat field lamp sets and arc lamp sets. The actual set of lamps which are available depends on the instrument in use (in particular, the focus point). The lamps sets for 2dF, Cassagrain (SPIRAL/KOALA) and prime focus (SAMI) are different. The table below lists the various specifications and indicates which are available for which instrument.

Lamp Spec	2dF	SPIRAL	KOALA	SAMI
Qtz1 (or Quartz1)	20W No.1	Chimney	TBD	Yes
Qtz2 (or Quartz2)	20W No.2	N/A	TBD	No
Qtz3 (or Quartz3)	75W (UV)	N/A	TBD	No
Qtz4 (or Quartz4)	50W No.2	N/A	TBD	No
Quartz_Def	50W No. 2	Chimney (check)	TBD	Yes (check)
ThAr1	Yes	Chimney	TBD	Yes
ThAr2	Yes	Fore-Optics	TBD	No
ThXe1	N/A	N/A	TBD	TBD
ThXe2	N/A	N/A	TBD	No
CuAr1	Yes	Chimney	TBD	No
CuAr2	Yes	Fore-Optics	TBD	No
FeAr1	Yes	Chimney	TBD	TBD
FeAr2	Yes	Fore-Optics	TBD	No
CuHe (or Helium)	Yes	Chimney	TBD	TBD
CuNe	Yes	Chimney	TBD	TBD
Focus	Yes	Yes	Yes	Yes

Below are some examples of lamp specifications:

```
[Qtz1, Qtz2]
[ThAr1, ThAr2, FeAr1, CuHe]
[Quartz_Def]
[Focus]
```

FOCUS is a special case rather then a lamp. It causes the lamps appropiate for taking spectrograph hartmann focus frames to be turned on. For AAOmega, all arc lamps except the thorium lamps are turned on. For HERMES, only the ThXe lamps are turned on. This allows the writing of spectrograph focus scripts which works with all instruments.

17.5.3 2dF Plate configuration

Commands are available to work with 2dF plate configurations. You can start plate configurations (or parking of fibres), wait for configuration to complete and tumble the field plate. The normal sequence would be to start a configuration, do other operations and then wait for your configuration to complete before tumbling.

One of the following commands can be used to start a fibre configuration:

```
CONFIGURE <file> NOTWEAK
CONFIGURE <file> TWEAK FOR PROPOSAL
CONFIGURE <file> TWEAK FOR PROPOSAL DURATION <d>
CONFIGURE <file> TWEAK FOR OFFSET <n>
CONFIGURE <file> TWEAK FOR OFFSET <n> DURATION <d>
CONFIGURE <file> TWEAK FOR TIME <abstime>
CONFIGURE <file> TWEAK FOR TIME <abstime> DURATION <d>
```

In the above, `<file>` is the name of the fibre configuration file. <d> is a real number duration in hours for the exposure, to be presumed for the tweak. If not specified, the current control task default is used. <n> is an offset in minutes from the current time to the defined middle point of the exposures on this plate (the tweak time). `<abstime>` is an absolute local time to be the tweak time.

The `PARK` command can be used to park all fibres on a plate.

The `WAIT CONFIG` command causes the script to pause until a configuration is complete. The user can abort (pause) the script during this wait if required.

The `TUMBLE` command will exchange the 2dF plates and slits in the spectrograph. If an argument is specified, it is the number of the plate to place in the configure position (0 or 1). Otherwise, the plate is tumbled to the other plate.

The file specification can be the full path name of a file, but the default of `$CONFIG_DIR/*.sds` is applied, e.g. a file type of `sds` in the directory specified by the `CONFIG_DIR` environment variable (`/instsoft/2dF`). You can also specify environment variables using the `$<varname>` format. Some configuration file name examples are

```
/instsoft/2dF/config/small_circle.sds
small_circle
small_circle.sds
$CONFIG_FILES/small_circle.sds
$CONFIG_FILES/oct13/small_circle.sds
```

Some examples of the use of these commands are given below.

```
PARK
WAIT CONFIG
TUMBLE 1
CONFIGURE configfile.sds notweak
TUMBLE
CONFIGURE configfile.sds tweak for offset 155
CONFIGURE configfile.sds tweak for PROPOSAL
CONFIGURE configfile.sds tweak for time 21:55:34
CONFIGURE configfile.sds notweak
CONFIGURE configfile.sds tweak for offset 155 duration 1.5
CONFIGURE configfile.sds tweak for PROPOSAL duration 0.5
CONFIGURE configfile.sds tweak for time 01:05:30 duration 3
```

All of the above commands are rejected if not running with 2dF.

17.5.4 SAMI plate configuration

The `CONFIGFILE` command is used to specify a SAMI plate configuration file. File name formats as per the 2dF CONFIGURE command above, except for being `.csv` files. For example.

```
CONFIGFILE samiconfigfile.csv
```

17.5.5 User Interaction from scripots

A script can interact with the user. The `WAIT` user command will create a dialog window containing its string argument and wait for the user to acknowledge it. One example of using this might be to pause a script for telescope acquisition of a field or guiding adjustments. The user can also pause the script whilst the dialog is up.

The `MSG` command is used to write a message to the control task scrolling message area. A script writer may use this to log information.

Examples of these are:

```
Wait "are we guiding now?"
Msg "Starting first set of exposures"
```

17.5.6 FITS Header items and commands

You can add FITS header items to CCD frame data files from a script. These items are recorded in all subsequent frames taken by the script, unless you explicitly clear them. Only simple real number and string items can be created.

The `FITSR` command is used to create real number items. The first argument is the header item name, the second is the value and the optional third item is the comment for the item.

The `FITSS` command is used to create string items. The first argument is the header item name, the second is the value and the optional third item is the comment for the item.

The comments are quoted strings.

The `FITSCLR` command will clear ALL items created with the above commands.

Examples of these commands are:

```
fitsclr
fitss SRASTERT "3x3" "Raster type"
fitsr SROFFSET 1 "Telescope Offset step in raster"
```

Various FITS header items are added automatically to data files when running a script.

Keyword	Description
SFILE	Written in any observation FITS file taken from a script, contains the script file name.
SLINENUM	Written in any observation FITS file taken from a scripot, contains the script file line number.
SLOFFRA	Written if the TEL_OFFSET command has been used, contains the RA offset applied.
SLOFFDEC	Written if the TEL_OFFSET command has been used, contains the Dec offset applied.

17.5.7 Other Commands

The CCD command is used to specify which CCDs are selected for the following CCD Exposure commands in the script. It takes one argument, a CCD number (1 to 2 for AAOmega, 1 to 4 for HERMES) or the token ALL to indicate all CCDs are to be selected.

The TEL_OFFSET command is used to offset the telescope. It takes two real number arguments, being the offset to apply to the telescope in arc-seconds on the tangent plane in RA and Dec. The last offset specified by this command is written to the FITS header of any data file created after this point using the SLOFFRA and SLOFFDEC keywords. These keywords can be cleared with the FITSCLR command and will be cleared when the script completes.

The SPEC_FOC_OFFSET command is used to offset the spectrograph focus (piston). It takes one or two real number arguments. If two arguments, they are offsets for each of the blue and red arms of AAOmega. If only one argument, it is used for both red and blue arms. **THIS COMMAND IS NOT YET IMPLEMENTED FOR HERMES**.

The HARTMANN command is used to control the spectrograph hartmann shutters. The single argument should be ”1” or ”2” to indicate the hartmann that should be closed, or ”OPEN” to open both.

Some examples are given below.

```
CCD 1
CCD 2
CCD ALL
TEL_OFFSET 5.0 10.0
SPEC_FOC_OFFSET 100
SPEC_FOC_OFFSET -100 -200
HARTMANN 1
HARTMANN 2
HARTMANN OPEN
```

17.5.8 Script Variables

The scripting language implements a very simple scheme for numeric variables. Most integer or floating point values can be replaced by a reference to a variable using the format `${varname}`. Variable names are simple names, can’t start with a number but can otherwise contain numbers and alphabetic characters.

Variables can be given values directly in the script using the “`name = <value>`” format. Alternatively, a script can request that the user set the value for a variable at run time, using the “`name = prompt <<usertext>>`” format, where `<<usertext>>` is some text (a quoted string) to be used in the prompt dialog. If a variable already has a value when it is prompted for, that value will be the default value for the variable and will be shown in the prompt.

The special readonly variable `${__ExpTime}` can be used to obtain the current exposure time. For example:

```
myvar1 = 10
myvar2 = 14.3
myoffset = prompt "Please enter the offset in arc seconds"
# The following grabs the current exposure time.
exptime = ${__ExpTime}
# Prompt for a new exposure time offering the current time as the default.
exptime = prompt "Please enter the exposure time in seconds"
tel_offset ${myoffset} ${myoffset}
object ${exptime}
```

Any place where you can use a variable, you can replace that by the variable multiplied by a real number. This can be useful for scripts doing rasters, for example, where you can ask the user to enter the offset basic size and then multiple it by the right units as you do your raster. E.g.

```
# Move off to the top left
tel_offset -1*${myoffset} -1*${myoffset}
object ${exptime}
# Move right by one unit to get the middle top position
tel_offset ${myoffset} 0
# Move right by one unit to get the right top position
tel_offset ${myoffset} 0
object ${exptime}
# Move down by one unit and left by two to get the left
tel_offset -2*${myoffset} ${myoffset}
```

17.6 Example Scripts

17.6.1 Instrument Focus Example

A script is used as part of a new automatic focus procedure. Its job is to collect the data required, operating the hartmann shutters as needed. Below is the script used by the Automatic Focus procedure.

```
#  focus.obsscript
#
# Description:
#     This script takes the required set of  focus observations.
#
#     The user is prompted for the exposure time.
#     The Hartmann 1 shutter is closed
#      An arc exposure is taken with the appropiate lamps on. (depends on instrument mode)
#     The Hartmann 2 shutter is closed (1 is opened).
#      An arc exposure is taken with the appropiate lamps on. (depends on instrument mode)
#     The Hartmann shutters are opened.
#
#    It will prompt for the exposure time
#
#
# FITS Keywords set by scripting system when running this script"
#    SFILE       -> Script file name
#    SLINENUM    -> Line in script which took observation.
#
wait "This script will take the observations required to focus the spectrograph"
# Default exposure time is current exposure time.
exptime = ${__ExpTime}
exptime = prompt "AAOmega Focus:Please enter the exposure time in seconds"
hartmann 1
arc ${exptime} [Focus]
hartmann 2
arc ${exptime} [Focus]
hartmann open
```

17.6.2 Raster Example

Below is a complete documented example for implementation of a 3x3 raster. This script prompts the user for the exposure time for each observation done and the size of the offset.

```
#  3x3_raster.obsscript
#
# Description:
#     This script implements a 3x3 raster
#
#    22 exposures are done, start point, 3x3 and again at the start point
#
#    It will prompt for the exposure time
#    It will prompt for the size of the offset
#
# FITS Keywords set by script:
#    SRASTERT   -> Raster type, set to 3x3
#    SROFFSET   -> Telescope offset used in raster
#    SRRAOFF    -> Offset of telescope from raster start position, RA.
#    SRDECOFF   -> Offset of telescope from raster start position, DEC.
#    SRASTERN   -> File number raster in sequence.
#
# FITS Keywords set by scripting system when running this script"
#    SFILE       -> Script file name
#    SLINENUM    -> Line in script which took observation.
#    SLOFFRA     -> Last telescope offset done in script - Dec.
#    SLOFFDEC    -> Last telescope offset done in script - RA.
#                     SLOFFRA/SLOFFDEC are not set for the first exposure.
#
#

myoffset = prompt "3x3 Raster:Please enter the offset in arc seconds"
exptime = prompt "3x3 Raster:Please enter the exposure time in seconds"

fitss SRASTERT "3x3" "Raster type"
fitsr SROFFSET ${myoffset} "Telescope Offset step in raster"

# Grab an image at the centre.
fitsr SRRAOFF 0 "Telescope Offset from raster start point, RA"
fitsr SRDECOFF 0 "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 1 "Image number in raster - 1 to 11"
object ${exptime}

# # # # # #
#
# We are going to do three lines.  Move off to the top left
#
tel_offset -1*${myoffset} -1*${myoffset}

fitsr SRRAOFF -1*${myoffset} "Telescope Offset from raster start point, RA"
fitsr SRDECOFF -1*${myoffset} "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 2 "Image number in raster - 1 to 11"
object ${exptime}

# Move right by one unit to get the middle top position
tel_offset ${myoffset} 0

fitsr SRRAOFF 0 "Telescope Offset from raster start point, RA"
fitsr SRDECOFF -1*${myoffset} "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 3 "Image number in raster - 1 to 11"
object ${exptime}

# Move right by one unit to get the right top position
tel_offset ${myoffset} 0

fitsr SRRAOFF ${myoffset} "Telescope Offset from raster start point, RA"
fitsr SRDECOFF -1*${myoffset} "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 4 "Image number in raster - 1 to 11"
object ${exptime}

# # # # # #
```

```
# Move down by one unit and left by two to get the left
tel_offset -2*${myoffset} ${myoffset}

fitsr SRRAOFF -1*${myoffset} "Telescope Offset from raster start point, RA"
fitsr SRDECOFF 0 "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 5 "Image number in raster - 1 to 11"
object ${exptime}


# Move right by one unit, should be back in the centre
tel_offset 1*${myoffset} 0
fitsr SRRAOFF  0 "Telescope Offset from raster start point, RA"
fitsr SRDECOFF 0 "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 6 "Image number in raster - 1 to 11"
object ${exptime}



# Move right by one unit, to get the right
tel_offset ${myoffset} 0
fitsr SRRAOFF  0 "Telescope Offset from raster start point, RA"
fitsr SRDECOFF 0 "Telescope Offset from raster start point, Dec"

fitsr SRRAOFF  ${myoffset} "Telescope Offset from raster start point, RA"
fitsr SRDECOFF 0 "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 7 "Image number in raster - 1 to 11"
object ${exptime}

# # # # # #
# Move down by one unit and left by two to get the bottom left
tel_offset -2*${myoffset} ${myoffset}

fitsr SRRAOFF -1*${myoffset} "Telescope Offset from raster start point, RA"
fitsr SRDECOFF ${myoffset} "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 8 "Image number in raster - 1 to 11"
object ${exptime}

# Move right by one unit to get the bottom middle position
tel_offset ${myoffset} 0

fitsr SRRAOFF  0 "Telescope Offset from raster start point, RA"
fitsr SRDECOFF ${myoffset} "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 9 "Image number in raster - 1 to 11"
object ${exptime}

# Move right by one unit to get the bottom right
tel_offset ${myoffset} 0

fitsr SRRAOFF  ${myoffset} "Telescope Offset from raster start point, RA"
fitsr SRDECOFF ${myoffset} "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 10 "Image number in raster - 1 to 11"
object ${exptime}

# # # # # #
# Move back to the centre
tel_offset -1*${myoffset}  -1*${myoffset}

fitsr SRRAOFF  0 "Telescope Offset from raster start point, RA"
fitsr SRDECOFF 0 "Telescope Offset from raster start point, Dec"
fitsr SRASTERN 11 "Image number in raster - 1 to 11"
object ${exptime}
```

Chapter 18

Log of major changes to KOALA

Listed below are changes made to KOALA or other aspects of the telescope which could affect the performance of KOALA.

Date	Change	Impact
	Commissioning Complete	
	Blue CCD replaced	
	Red CCD replaced	
26 March 2015	Orientation of the KOALA field in fibre table corrected.	Data prior to this date must be rotated by 90°.
29 March 2015	Fibre swap of 305 & 306 corrected.	Data before this date will report incorrect positions for fibres 305 and 306. Their positions should be exchanged.