# Telescope Users' Instructions

## Observatory Access

Trained users will be issued with a code for the key-safe by the door to the roof, where the observatory keys are kept. The observatory keys must be put back in the safe after each session and on no account may they leave the building. Keys on the blue fob are for the main lock on the roof door and the telescope dome; keys on the green fob are for the bottom lock on the roof door. Always remember to indicate that you are working in the observatory by using the magnetic sign on the roof door (for security and safety reasons).

Undergraduates undertaking projects on the telescopes will be given appropriate training as part of their introduction to the project. PhysSoc members and other individuals wishing to use the telescopes should seek permission from a responsible member of academic staff (directly or via the PhysSoc astronomy secretary). All users must sign the safety form to indicate they have received the requisite training (which may be conducted by a designated student trainer).

**Note that students observing as part of their project have priority over all others.**

Attending a telescope training session and signing the safety form entitles you to use the observatory without supervision, but does not entitle you to supervise others who have not yet attended a training session. That entitlement, which includes the ability to train others, may be granted upon successfully demonstrating that you have gained sufficient experience of safe working, and completion of a telescope trainer form.

Failure to work in a safe manner or misuse of the observatory equipment may lead to your entitlement to use the telescope being immediately withdrawn.

## Building Access / Out of Hours Working

Students who have been trained and signed the telescope user safety form are permitted to use the observatory outside normal working hours, provided they adhere to the rules and guidelines. The key-safe contains a key to the building, which students may take during the day if they plan to use the observatory that evening or the following weekend. They must write their name in the notebook in the safe and replace the key immediately after their observing session. Undergraduates using the telescopes as part of their project may be able to obtain a building key for the duration of their project.

Anyone entering the Physics building outside normal working hours, i.e. after 18:00, at weekends, and on University/public holidays, must use a designated out-of-hours entrance and sign in the book kept for the purpose on the table by that door (this is a fire-safety requirement). The alarm must be operated according to the instructions displayed near the key pad (this is a security requirement). Trained telescope users may obtain a building alarm code from Mark Thomas in the Finance Office. On leaving the building, persons should sign-out. As a concession, persons already working in the building at 18:00 on working days need only sign in if they continue to work after 19:30.

## Safety

- Only people who have attended a telescope training session and signed the safety form are allowed to use the telescopes.
- You must always work in pairs and must have a mobile phone with you.
- Wear suitable warm clothing and have a torch.
- Set the sign on the door to the roof to show that the observatory is in use.
- Do not venture outside of the railed area of the roof.
- Assess the strength of the wind. Do not use the telescopes in strong winds.
- Take care when entering the observatory; there is a step and reduced door height.
- Read and understand the School's Emergency Procedures, on the wall of each observatory.
- Do not leave the dome open if it is likely to rain.
- Never point the telescope anywhere near the sun.
- If the telescope is moving, it can be immediately stopped by pressing any of the arrow keys on the handset.

# Observing

This guide sets out the procedures involved in carrying out an observing session on the telescope. It describes the preliminary steps, such as the alignment and focussing of the telescope, observational procedures, including usage of the CCD camera, and the processing of the resulting images. The material is roughly in the order in which the procedures will usually be performed.

Some of the material below is labelled ***Advanced***. If you are observing relatively bright sources for fun, or just becoming acquainted with the observatory, these more involved techniques may be skipped. Users undertaking projects or observing faint targets should take careful note of the more detailed instructions.

## Preparation

Once inside the dome:

- Turn on all of the 4 power sockets (2 on the wall by the computer and two on the telescope pillar), the dome-rotation unit and boot the computer.
- Open the upper dome slit, leaving the handle pointing up to avoid it hitting the power supply. Open the lower section of the dome.
- Take the cover off the telescope and remove the dust caps from the telescope and finder.
- Turn on the telescope mount drive.

Following this sequence reduces the risk of getting dust or water on the telescope optics, and means you do not need to handle the telescope after it has been turned on.

## Getting Started

After turning the telescope mount on, look at the handset. It will either ask you (1) if you want to 'wake up' the telescope (if the previous user hibernated the mount, as recommended), or (2) to carry out an alignment.

During these initial stages, the handset will also ask you to confirm the time. The telescope is linked to a GPS unit which provides an accurate time and location. However, **you must be patient and wait (for up to a minute) for the GPS to link up and display the correct time on the handset**. Do not manually adjust the time. It is vital that the telescope is set at the correct time, otherwise the telescope pointing will be inaccurate. The time is displayed as UTC (UK local time in winter, one hour behind in summer).

If the telescope has been hibernated prior to you 'waking' it up, it should already be aligned. If it was not hibernated, you can simply select 'Last Alignment' from the list of possible calibrations; this should recall the prior alignment. If you have trouble with inaccurate pointing, check the handset time is correct. If it is, you may need to perform an alignment calibration (see below).

## Flip-box

If the flip-box is installed, it may be used to direct the light path to the eyepiece or CCD camera as required. To avoid confusion, ensure that the flip-box mirror is set in the correct position!

## Using the CCD Camera

***Advanced:*** *this section may by skipped by users who only intend to observe using an eyepiece.*

To use the CCD camera, start up the CCD interface software, named 'SXV_M25C', from the PC desktop. Press ctrl-z to open the exposure window. Enter the desired exposure time (from one hundredth of a second for a very bright star or planet, to a minute for faint sources. Click 'Take Photo' when you are ready.

There are various other options which are fairly self-explanatory. However, two deserve special mention. First, in order for images to be saved you **must ensure the 'Auto-Save Image' check-box is checked**. These auto-saved images will be automatically saved in the 'autosave' folder, linked from the desktop. Second, it is sometimes useful to take multiple images. To achieve this, check the 'Continuous Mode' box and select the desired number of exposures below it. If this is set to 1 it will continue to take images indefinitely, until ctrl-z or the escape key are pressed; this is useful when acquiring targets or focussing. Selecting a number of exposures greater than one, but not checking the 'Continuous Mode' box will result in the exposures being merged into one image, which is rarely useful.

The telescope can typically track accurately for ~30 seconds, after which, images will start to become trailed (i.e. stars will have extended shapes, instead of being circular points). To obtain a deeper image there are several options: (1) take multiple, shorter exposures then shift and combine these using dedicated software, or (2) train the periodic error correction or use the auto-guider and active optics unit (see below in 'Advanced Usage and Tips').

Ensure you keep a careful log of all your observations, including observation time, image number, exposure time, target name, weather conditions and any other relevant notes. Avoid wasting time when you could be obtaining data, but do take time to check that your images contain your target and are of sufficient quality otherwise you will be disappointed the next day. Better to have some useable data than lots of unusable data.

## Alignment Calibration

***Advanced**: If you wish to improve the telescope pointing, and are sufficiently confident at identifying stars, then carry out the following procedure (also see p.20 of the mount manual).*

Choose a '2 star' alignment from the options presented upon switching the mount on.

The first step in the re-alignment process is for the telescope to locate the switch positions (approximately pointing at Polaris). Following the instructions on the handset, the telescope will move slowly and making a clicking noise when it has found them.

The handset now lists stars it suggests for the first alignment star. Once selected (the first is usually the best option), the scope will move to point at that star, based on its current alignment. Usually the relevant star will be close to the centre of the finder scope. If not, the handset time may be wrong, or the previous alignment attempt may have been incorrect.

You should then centre the star using the arrow keys on the keypad, first in the finder scope, then in the eyepiece or CCD field of view (see the CCD operating instructions above; for casual observations, centring the star in the finder scope or eyepiece will be sufficient). To change the speed the telescope moves at, press the 'rate' button on the handset followed by a number 1-9. 1 selects the slowest speed, while 9 is the fastest.

If the star does not look like a compact point, but more like a light donut with a dark centre, the telescope needs focussing. Changing the focus alters the pointing of the telescope, so it is worth pausing to carrying out focussing (see below) before continuing with the alignment procedure.

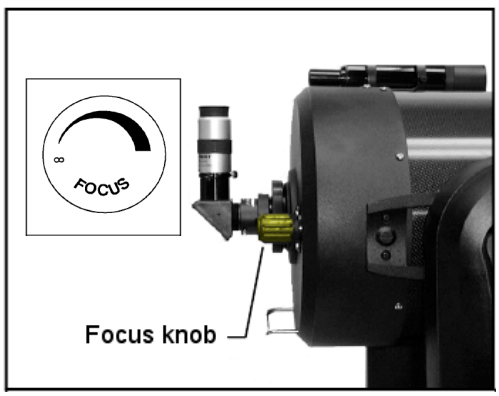
Once you have aligned the first star (perhaps after focussing), press `enter' then 'align' on the handset. You will now be instructed to choose another star; simply repeat the procedure you carried out for the first star.

Once the 2 stars have been aligned, the handset gives the opportunity to add 'calibration stars', to further improve the pointing accuracy. Adding several calibration stars is advisable, but not necessary for casual observers. The procedure for adding these stars is identical to that above.

It is also possible to replace alignment and calibration stars without cycling the mount power and performing a full alignment. See p.22 of the mount manual for details.

Under no circumstances should you adjust the physical alignment of the mount (i.e. performing a polar align, adjusting the various knobs on the mount) without consulting a responsible member of staff.

## Focusing the Telescope




If you are using the eyepiece, focussing is simply a matter of adjusting the focus to give a clear image in the eyepiece. The focus knob is on the back of the main tube (surrounded by an orange circle).

It may take some time to get clear focus but this will be essential to your observations. It is important to be patient, as turning the focus knob too quickly could result in passing over the ideal focus. As stated in the calibration section, unfocussed stars typically appear as 'donuts' of light. Turn the focus knob to reduce the size of these donuts until they resemble compact points.

Only move the focus knob by small amounts (fractions of a revolution) at a time, leaving time for vibrations to dissipate before judging the focus. Note

that occasionally the telescope is focussed on terrestrial targets (e.g. during open days), so stars may sometimes be very out of focus: increase the exposure time and look for large, faint donuts.

***Advanced***: If you intend to use the CCD camera, you should perform the focus on the CCD. This is easiest if you set continuous mode (with number of exposures equal to 1), in which case a new image is readout every few seconds. Disable auto-save mode for the duration of focusing. Ensure the exposure time is short enough that the star is not saturated. There is a dedicated focus tool in the CCD control software, but this is not very useful as the target usually moves too much during focusing.

## Calibration Images

***Advanced****: If you are observing with the CCD camera you should obtain some special images with which to calibrate your target images.*

**Dark/bias frames**: These are used to subtract the signal in the CCD images that is present even when no light is incident on the detector. To obtain them, put the telescope cover on and take a set of ~7 exposures with the minimum exposure time possible (one thousandth of a second).

**Flat-fields**: These are used to correct for variation in pixel sensitivity and the presence of dust and other contamination on the optics. To obtain them, point the telescope at a blank patch of sky at twilight and take an exposure. Adjust the exposure time so that the image has sufficient counts (~20,000) but is not saturated. It should be a fairly uniform grey with faint, darker `donut' shapes visible do to out-of-focus dust. When the correct exposure time has been determined, take a set of ~7 exposures. If you cannot obtain sky flats, images of an evenly illuminated part of the observatory dome may suffice.

## Acquiring Targets

There are several ways to point the telescope at a target: using the various object lists available on the handset, manually entering RA and Dec coordinates on the handset, or using ECU (see below). If the target is bright enough to see in the finderscope, it may be manually centred using the direction buttons on the handset. The speed at which the telescope moves is controlled by pressing the 'Rate' button and then a number: 1 is slowest, 9 is fastest. Once at the centre of the finderscope crosshairs the target should be within the field-of-view of the CCD and eyepiece. If not, due to a misalignment of the finderscope, then it may be necessary to search for the target by driving the telescope around in a small pattern.

***Advanced****:* In order to ensure that faint objects are located on the CCD, for long-exposure imaging, some extra steps are advisable. Firstly, you should ensure you have a good pointing alignment. Then, you can do a `Precise GoTo' using the handset (see p. 26 of the manual). This involves first centring the telescope on a star near the target (automatically selected by the handset). The telescope then only needs to make a small, and therefore accurate, offset to the target location. It is also possible to `sync' the telescope to a star in ECU before moving to the target, but be aware that this option is untested. To avoid disappointment, it is very wise to inspect your images as you take them to ensure they contain your target and are of sufficient depth and quality. This is helped by the semi-automatic data reduction process described below.

## Finderscope alignment

***Advanced****: If you find that the finderscope is not precisely aligned with the CCD, i.e. an object centred in the crosshairs is not centred on the CCD, it may be carefully adjusted*.

Once you have centred a bright star on the CCD (e.g. during precise pointing calibration or focusing) you may carefully adjust finderscope alignment using the two screws on the side of the finderscope mount. However, rather than adjusting the finderscope so that the star is exactly centred, it is better to make half the necessary adjustment each time, such that the globally correct alignment is approached by iteration. Note that the crosshairs can be adjusted to align with the telescope directions of motion by rotating the finderscope eyepiece.

## ECU (Earth Centred Universe) software

The ECU software is accessible from an icon on the PC desktop. It is a planetarium program useful for identifying suitable targets. ECU can communicate with the mount to point the telescope at a target. Once opened, select the 'Telescope' option from the menubar and, from the drop-down menu, click 'Enable Telescope Interface'. A set of crosshairs will appear on the sky map, indicating where the telescope is pointing.

ECU has an extensive catalogue of potential targets, which can be centred via the 'Centre' menu. Once the target has been selected, the ECU display will be centred on the chosen object. Clicking on this object will bring up another menu from which you can select 'Centre Scope'; this will slew the telescope to the target. As with the handset, the pointing depends on the accuracy of the stored alignment. However, pointing accuracy can be improved by telling ECU, on the object menu, to 'Sync Scope' once the object is centred in the eyepiece/CCD; this will update the pointing model and should improve the accuracy of subsequent centring on nearby targets. However, using the handset's 'Precise GoTo' option is currently the recommended method for accurate acquisitions.

# Data Reduction

The raw images produced by the CCD require processing ('reduction') to produce high quality images. In order to reduce the data, you will ideally have obtained bias and flat-field frames (see above). If these are not available, reasonable results can sometimes be obtained by using bias and flat frames from another recent observing session.

The recommended way of processing your images is to use the AstroImageJ software, which is installed on the dome computer and freely available for use elsewhere. See the AstroImageJ manual for guidance on reducing your data. There is also a MATLAB script that may be used or adapted as required, at least for the simpler reduction steps. Other tools are available online.

The standard reduction steps include bias subtraction, flatfielding, filter demosaicing, image alignment, coaddition, astrometry. How far along this list you need to go depends on your goals.

**Bias subtraction** A raw CCD image includes an approximately uniform level that is unrelated to the amount of incident light. This introduces extra pixel-to-pixel variations, as well as affecting photometry. Subtracting a 'bias' image therefore improves the quality of the image.

**Flatfielding** The edges of the field of view are slightly vignetted, particularly by the auto-guider pick-off mirror. In addition, the pixels of the CCD all have slightly different sensitivities. The result is that a given star will produce an image of different apparent brightness, depending on its location on the CCD. The solution is to divide each image by a 'flat' image of a uniform light source, e.g. the twilight sky.

**Bayer filter** The pixels of the CCD are covered by a 'Bayer filter'. This restricts the range of wavelengths each pixel is sensitive to, such that each 2x2 group pixels contains one red, two green and one blue pixel. This results in the 'waffle' pattern seen in many raw images, and makes examining the raw images difficult. The pixels must be demosaiced to produce clean images for each wavelength range.

**Alignment** Due to the imperfect tracking of the telescope, repeated images will be offset from one another. If required, they can be aligned by matching the positions of a few objects.

**Coaddition** To improve image quality, detect faint objects, or cover a wide area, it may be necessary to combine multiple exposures into a single image. The different filters may also be combined to produce colour images.

**Astrometry** In order to measure object positions, or identify known objects in an image, one must determine a mapping between the pixels and a standard coordinate system.

Note that AstroImageJ can be configured to reduce images automatically as they are taken, which may be convenient for checking your images during an observing session.

## A Typical CCD Observing Session

- Arrive at the telescope around sunset.
- Follow the startup procedure.
- Take set of bias frames.
- Take set of flat-fields (may not be perfect if focussing required later).
- When first stars become visible, check pointing alignment by acquiring one.
- Check focus on this star, adjust focus if necessary.
- If focus adjusted and still light enough, take another set of (dithered) flat-fields.
- Perform pointing alignment if required.
- Acquire first target (using handset or ECU, possibly first synching on a nearby bright star).
- Take science exposures (check for depth and trailing, use a variety of exposure times).
- While waiting for exposures, reduce previous images to check data quality.
- Acquire next target, and continue as before.
- When observations are complete, follow the shutdown procedure.

## Ending your Observing Session

When you have finished you need to leave the observatory in a safe condition. Essentially just do what you did at the start, but in reverse order. It is important to HIBERNATE the telescope before turning it off; this will vastly reduce the start-up time for the following observer as doing this will retain the current calibration.

- Backup your observations to a USB key, external drive or university storage space.
- Shut down the computer.
- Slew the telescope to its home position (e.g. using Menu → Utilities → Home → Goto).
- **Hibernate** the telescope: select Menu → Utilities → Hibernate.
- Turn off the telescope drive.
- Put the lens covers back on the main telescope and on the finder.
- Put the plastic cover over the telescope.
- Close the upper and lower dome shutters.
- Turn off all the power. In particular remember to turn off the dome rotation unit, the two sockets on the telescope pillar, the two sockets by the computer.
- Lock the dome and return the keys to the key safe.

## Advanced Usage and Tips

The following topics are not necessary for casual observing, but may be of interest to those keen to get the best possible observations.

### Periodic Error Correction

This enables sharp long-exposure images by manually training the telescope to correct for periodic errors in the tracking gears. See p. 48 of the telescope manual for details.

### Autoguider and active optics unit

The telescope is equipped with an autoguider and active optics unit although it has not seen much use yet. If you would like to try using it, please take care and report any success!

## Further information

The telescope website contains further information, including manuals, specific details about the telescope, reduction scripts, analysis software and links to other useful resources.

See http://www.nottingham.ac.uk/astronomy/telescope/