Massachusetts Institute of Technology
Wallace Astrophysical Observatory

1997 Jul 29 / S. Slivan

Instrument User's Guide

Lynxx 2000 CCD camera with PFE-1 flip-mirror assembly and 0.5× telecompressor lens mounted on WAO C14's.

`$Revision: 991.0 $`

Objective:

- Describe how to use the Lynxx 2000 camera as instrument on the WAO C14's, including focusing.

Prerequisites:

- Familiarity with the basics of using the WAO C14's (power-on, movement in RA and Dec, finderscope, fine-motion controls, focus control, accessory kit).
- Familiarity with the basics of using a Macintosh PC (power-on, Desktop, pull-down menus, Finder, trackball, active vs. inactive windows).

Contents

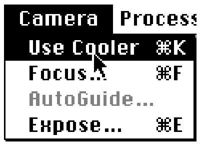
---

1 Starting up

1. Power on the control computer. Check the UT clock time on the computer and make sure it's within 1 second of UTC. Adjust it if necessary using `Control Panels\Date and Time`.
2. Activate the `Lynxx 2k 32-bit` application on the desktop.

This will, by default, put all your saved image files on the desktop, where you can see 'em and most easily keep track of what you've really saved. You'll also be able to explicitly specify a different location for your image files if you like.

3. Once you've started the control program, choose `Camera\Use Cooler` and then allow at least 15 minutes of cool-down time for the camera to reach thermal equilibrium before taking any "keeper" images.



The CCD cooler is designed to reduce the operating temperature to 50 °C below the ambient air temperature. Each 10 °C drop in operating temperature represents an increase in limiting magnitude of about 1 mag., so the colder the night the better the thermal noise characteristics of your images!

2 Focusing

In order to obtain the best possible data from your images you must pay some attention to getting the best possible focus. (In other words, if the focus sucks so will your results!) Unlike focusing when viewing through an eyepiece or a 35mm single-lens-reflex camera, when focusing the CCD camera you'll not able to directly observe the image to determine its quality, and it may take a little practice to get the knack of dealing with the delay between when you make an adjustment and when you see its effect on the display screen.

We can reduce (but not eliminate) the delay by choosing a focus star bright enough to be well-exposed with only a short ($\approx$ 0.1 sec) integration time, and also by only digitizing a smaller part of the image that still contains the star.

1. Be sure one of the glass filters is in the filter holder even if it's just a colorless one! Normally with CCD's you'll use V or R.

   The focus without any filter is substantially different from that with a filter because of refraction by the glass. The "Johnson" photometric filters that came with the PFE-1 filter holder (U, B, V, R, I, and "C") were specifically manufactured using a uniform thickness of glass to minimize the focus change necessary when switching among them. However, keep in mind that if you use a filter that's not part of this set you'll need to make certain to refocus since it'll likely be a different thickness.

2. Select a star of about mag. +2.5 to +3.5 to be your "focus star". Pick one that's well above the horizon, to avoid seeing or scintillation problems that occur near the horizon.

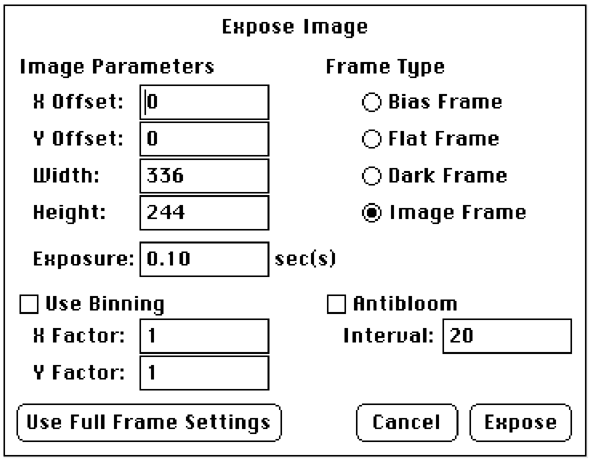
   The idea is to pick a star that's bright enough that a short exposure gets you enough signal to focus, but not so bright that it completely saturates the detector and "blooms" on the image. For this combination of instrument, telescope, and observing site a star about 1 to 2 magnitudes brighter than the limiting visual magnitude $m_{\rm eye}$ seems to work well, leading to the "typical" magnitude range suggested above. If you want to determine and record the actual limiting visual magnitude (in general this is a good idea!) there's a chart of the Little Dipper in the Atlas Supplements with visual magnitudes that you may find useful.

3. With the flip-mirror in the "visual" position, acquire the star in the CCD field, and do a preliminary focus by eye in the acquisition eyepiece.

   This preliminary focus made visually through the acquisition eyepiece will be fairly close to correct focus for the camera but not necessarily right on depending on how correct (or properly-corrected) your vision is! For definitive final focusing we'll need to use actual images as seen by the camera.

4. So that we can check the signal we're getting from the star and figure out what exposure time and greyscale setting we'll want to use for our focusing frames, flip the mirror (so that the CCD can now see the star) and make an 0.1 second trial exposure as follows:

   (a) Choose `Camera\Expose` which brings up the `Expose Image` control window.



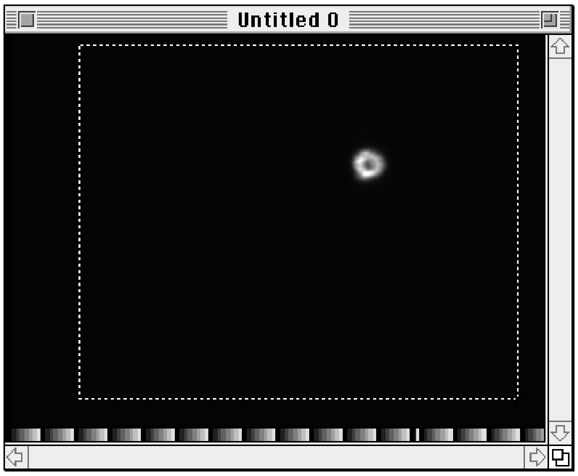
   (b) Set the desired exposure time, which the first time through will already be the default of 0.1 second.

   (c) Click on `Expose` (or just hit ⟨RETURN⟩) at which time you should hear the click of the shutter opening and closing, followed by display of your star on the screen.

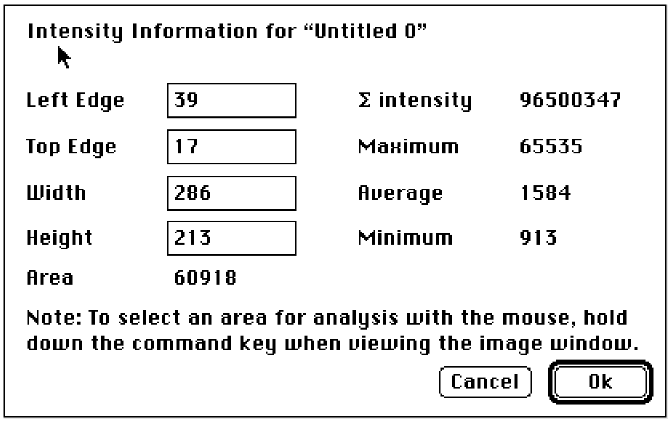
A sufficiently out-of-focus image will appear as a "doughnut" shape owing to the secondary mirror obstruction of this Schmidt-Cassegrain design of telescope.

5. Check for proper exposure as follows:

   (a) ⌘-drag an "analysis box" in the image to define the region to be analyzed. Make it a big box because we also want to measure the mean background pixel value.



   (b) Choose `Process\Analyze Intensity`, which computes the minimum, maximum, and average pixel values within the analysis box you selected.



   (c) Check out the `Maximum` pixel value. The goal is to have the image of your star "well-exposed" (say, at least 32000 ADU, which is about 50% of full-scale) but not overexposed all the way to to saturation, which on these (16-bit) cameras is 65535 ADU.

   (d) Click `OK` to close the window.

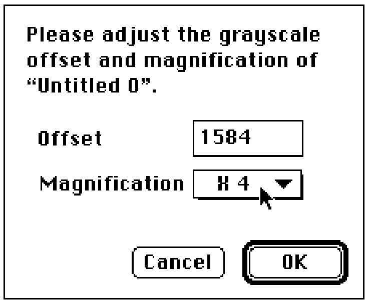
   If your focus star is well-exposed you're all set to proceed! Otherwise you'll need to repeat steps 4 and 5, and adjust your trial exposure time up or down as necessary.

   The shortest reliable exposure time is 0.05 second. If your chosen focus star overexposes at 0.05 second then you need to choose a fainter focus star.

   (Hint: you can keep using the same analysis box without having to redefine a new one each time. To display the outline of the "current" box to make sure your star hasn't drifted outside use ⟨SHIFT⟩-⌘)

6. Once you've determined the exposure time you'll use record it in your notebook, and also record the `Average` pixel value for the image, which will be essentially the background intensity.

7. In order to better be able to see changes in the image as you mess with the focus, choose `View\Greyscale...` so you can adjust the brightness and contrast of the displayed image.



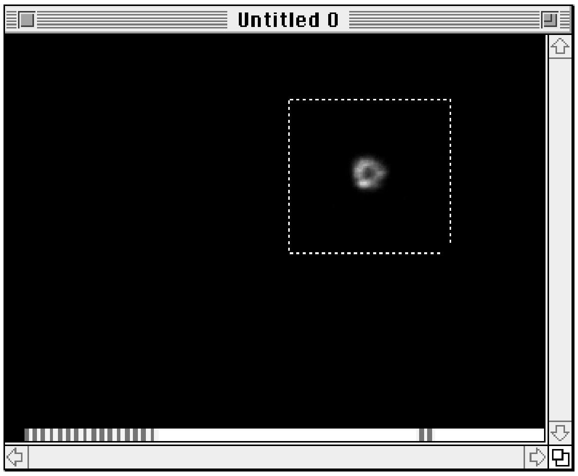
   (a) Set the `Offset` (black) value to the `Average` pixel value (background level) you recorded from the intensity analysis of your trial exposure.

   (b) Set the `Magnification` (contrast) value to `X 4`.

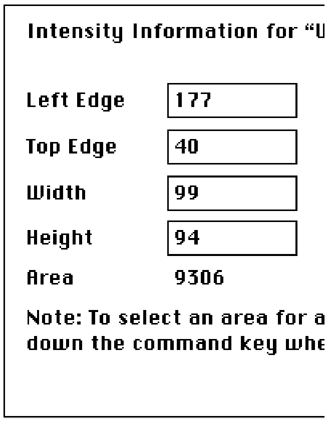
   (c) Click `OK` to "make it so"!

8. Now select a smaller analysis box around the star, about 100 by 100 pixels.

   This is going to be the smaller region we actually image during focusing to speed up the readout/display cycle, but it still has to be big enough to allow for the annoying image shift as you adjust the focus mechanism.



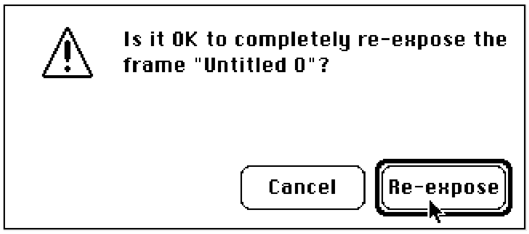
9. Choose `Process\Analyze Intensity`, and record the four box parameters `Left Edge`, `Top Edge`, `Width`, and `Height`.



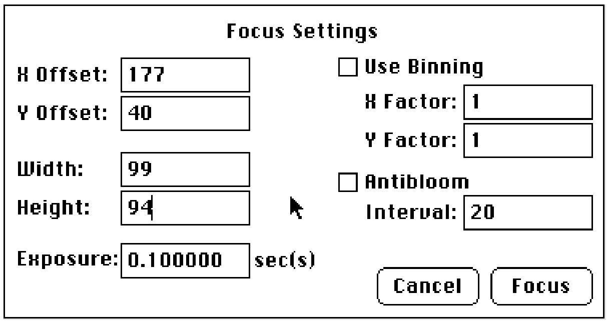
10. Choose `View\Magnify` to enlarge the image display.

    To reach the telescope focus knob you'll need to stand away from the computer display screen, so magnifying the image helps you to still be able to see what's going on from back there!

11. Choose `Camera\Focus...` to open the `Focus Settings` window.



(answer `Re-expose` to the annoying "OK to re-expose?" Mac-nagging)



(a) Set the four subframe parameters `X Offset`, `Y Offset`, `Width`, and `Height`, to the values you just recorded from the small analysis box. (You can use the ⟨TAB⟩ key to advance fields quickly)

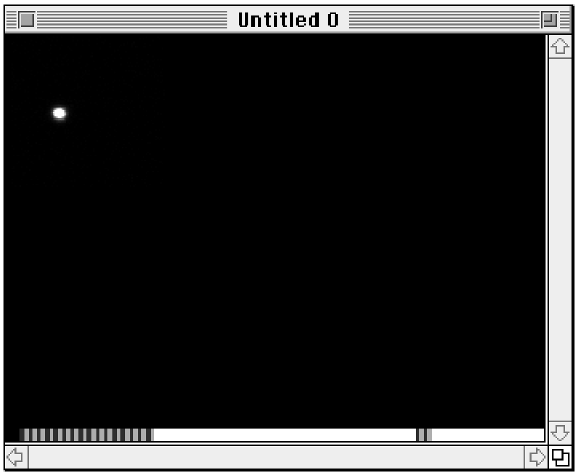
(b) set the exposure time to the value you determined earlier

12. When you click on `Focus` the system will repeat an expose/display cycle, displaying the subframe in the upper-left corner of the screen.

    If the star has drifted and is running off an edge of your box, use the telescope control paddle to bring it back to the center.

Do this *gently* using the "G" setting (guide, the slowest speed) on the control paddle! A 100-pixel box spans only about 90″ on each side, and the guide speed motions move the scope about 6″/sec in RA and 18″/sec in Dec, so guide motions will move the star the distance of the whole box in 15 and 5 seconds, respectively. (The "S" speed motions, on the other hand, are 2× faster in Dec and 15× faster in RA, which can rapidly lose you your star completely!)

To focus, watch the image display while adjusting the telescope focus until you have a star image as small and sharp as you can get it (which is often not an easy thing to determine).



Each time you make a focus adjustment, be sure to wait for any telescope vibrations you've caused to damp out before judging the quality of your focus images.

You'll find there exists a range of distance that the focus can be changed without making a visible change in the images, because the smallest images will be significantly larger than the theoretical size of the diffraction disc.

If the seeing is poor you'll find it difficult to determine "best" focus; this should tell you something about what will happen to your images (and to your results) as the seeing changes.

There's some evidence that using the cooling fans on the Lynxx2000 cameras may shake the camera on the telescope, depending on the orientation of the scope and how well-adjusted the clamping is. If the sharpest star images you can get exhibit streakiness in the Dec direction (usually vertical), rather then settling down as a circular blot, try unplugging the fan power and see if that makes a difference. If so, you'll have to choose between having either lower dark current or more circular images, and so may want to ask the advice of any experienced observers who happen to be around!

13. To stop the focus cycle move the cursor into the image window and click the left mouse button.

14. Once you're finished focusing, choose `View\Reduce` to restore the image display to its regular un-magnified size for target field acquisition.

One final note on focusing: as the telescope and instrument cool down during the night their relative optical distances will change, which will change the focus. Depending on the needs of your observing program this may present you something of a dilemma having to choose between

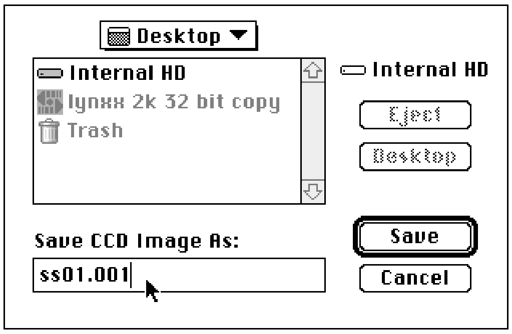
- refocusing at the cost of having to suspend data image acquisition for the time it takes to move off your object to a focus star, refocus, and then return to your target object, or
- continuing to take data on your object without refocusing (or possibly by hazarding a crude refocusing "on the fly") at the cost of probably not having the best focus possible.

3 Observing information

- For time efficiency you can use `⌘-E` instead of pulling down `Camera\Expose` to start a camera exposure.
- To write image files you want to keep use "`File\Save As`" so that you can specify a unique file name for each image.

  > If you accidentally use "`File\Save`" instead you'll overwrite the previously-saved file!

- To make your life *much* easier when you process and analyze your images with IRAF, for image file names use the observer's initials and "night number", and then for the extension use image sequence number in an unbroken sequence starting with "1" as in the sample here:



- While observing keep an eye on the size of your stellar images: if it seems they've gotten a lot blobbier over time then either the focus has changed, or the seeing has deteriorated, or both.
- For photometry, all target objects must be far enough from the edge of the frame so that there's room for a surrounding annulus (ring) of clear sky that'll be used for measuring the background signal near the object. In most cases keeping target objects about 4 "star image widths" away from any edge should be enough.
- As you work through your observing program be aware of and check frequently for possible overexposure! (especially sneaky causes like decreasing airmass as an object rises)
- WARNING: at present we know of no way to abort an integration in progress. So if you mean to start a 60-second exposure and actually start one for 600 seconds instead you'll have a bit of a wait. Whenever you enter a new exposure time double-check for typos *before* hitting `OK` or ⟨RETURN⟩!

3.1 Issues of image file data management

[SECTION TO BE WRITTEN]

- *what are the possible problems?*
- *where to put images?*
- *when to put them there?*
- *how to put them there?*
  - *microfloppy diskettes (8 images each)*
  - *AppleTalk network*
  - *EtherNet network*

3.2 Off-Axis Guiding

The spiffy Byers upgraded tracking motor drives we have on the C14's are as good as they come, and given our typical seeing conditions they allow you to shoot exposures as long as two to three minutes unguided before your images will start to smear in the east-west direction.

But if you want to shoot longer exposures without smearing you'll need to Assert Your Superior Will over the tracking mechanism and manually compensate for inaccuracies. This isn't a casual undertaking; a *lot* of work is necessary to achieve little to no trailing of long-exposure images taken through the telescope, but it's necessary if you don't want smeared images to adversely affect your results. For the best possible tracking you use the momentary rate control buttons on the drive's hand paddle to manually **guide** the telescope tracking by making minor adjustments in right ascension during the exposure.[1]

In order to guide, you need a way to establish a reference in or very near the field to be able to detect image drift, preferably at a higher magnification than is equivalent to the image scale of your CCD optics. To guide an exposure a high-magnification eyepiece with illuminated crosshairs is used in an **off-axis guider** to allow tracking on a convenient **guide star**. The off-axis guider uses a small prism to divert the light from a star just off the edge of the field-of-view of the PFE-1 acquisition eyepiece out into the illuminated crosshair eyepiece. This scheme allows you to monitor the guide star through the C14 while still making your CCD exposure through the C14 at "prime focus".

The first of several challenges is positioning the telescope, guider, and camera so that a sufficiently bright guide star the correct distance from your target object is centered on the crosshairs of the off-axis guider, while at the same time lining up the CCD on your target field. In actual practice this task is not at all straightforward and takes some tinkering. You can make your life a lot easier by using the following approach:

1. (While planning) The "guider-capable area" is the region within which you can adjust the guider around your target and acquire a guide star without moving the main telescope. Use a star chart and properly-scaled "field template" of the visible frame area and the radius of the location of the off-axis prism, to identify candidate guide stars that are the proper distance from the target. Your first-choice star is the brightest one available!

[1] Corrections in declination shouldn't be needed if the polar alignment of the mount is sufficiently accurate. And if they are and it isn't, the C14 control paddles have Dec fine-motion buttons as well.

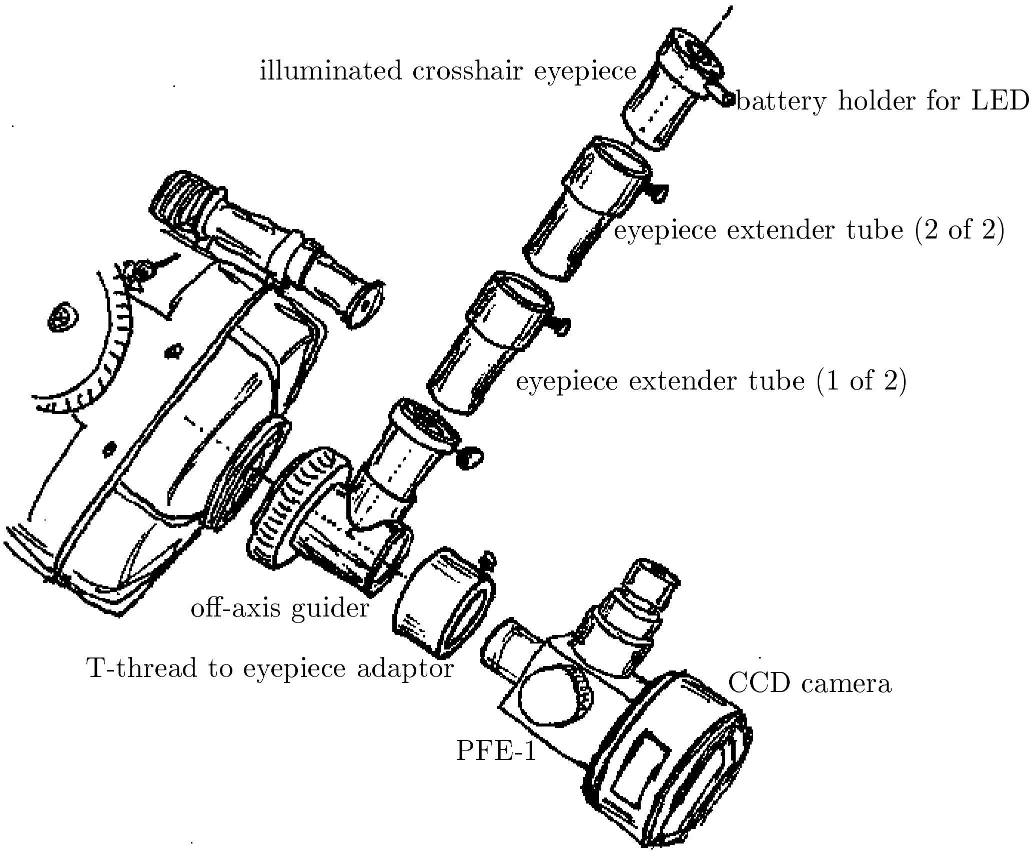


Figure 1: Configuration for “guided prime focus” imaging

2. (At the telescope) The guider, T-thread adaptor, and CCD camera are attached to the C14 rear cell as shown in Figure 1. Start with the 40mm eyepiece from the accessory kit in the spot for the guiding eyepiece, so you'll have the widest field when you start guide star acquisition. Note that if you use the 0.5× telecompressor coupler for the PFE-1, you'll also need to use the two eyepiece extenders shown in the Figure 1 (or one extender plus the diagonal mirror from the accessory kit) in the off-axis guider eyepiece mount to be able to focus the guide star.

3. Focus the CCD on a bright object as usual, and then acquire your target object.

4. Next you need to figure out in which direction to orient the neck of the off-axis guider so that you can pick up your guide star. Two ways to do this:

   (a) View the candidate guide star through the finderscope to ascertain its direction from the target object at the center. Note that stars that are too faint to see through the finder scope will very likely prove a real challenge to successful use as guide stars. (But then again, you may not have the luxury of choosing anything brighter...)

   (b) Invert your finder chart showing the candidate guide star, so that it matches the inverted orientation seen by the guider, and use it to ascertain the guide star's direction from the target object.

5. Loosen the slip-ring of the guider and rotate the guider body until the neck is pointing radially in the same direction as the guide star appears to be from the object, as determined in the previous step. Try to match the angle as closely as you possibly can!

6. Focus the 40mm eyepiece in the guider neck on the guide star field by raising or lowering the eyepiece and/or the eyepiece extender tubes in the guider neck, *NOT* by refocusing the C14! Changing the C14's setting would mess up the camera focus.

7. Locate the guide star in the 40mm field, and center it using the telescope's fine-motion controls.

   The "Orion Ultra-Guider" we're using on shed C14 #4 has a slightly-adjustable pick-off prism which might help you center the guide star. To move the prism loosen the two set screws near where the guider neck is attached to the main body. (Figure 1 shows a basic generic non-adjustable model.)

8. View the CCD field through the acquisition eyepiece and adjust the orientation of the camera from its now-probably-cockeyed angle back to where you want it by loosening the set screw on the T-thread adaptor and rotating the camera. Be careful not to let the camera fall out!

9. Also make sure the target object is still in the field of view of the CCD camera! If it was but now it isn't something above wasn't done quite right; perhaps the guider neck angle needs to be adjusted or maybe your field template isn't scaled properly. You'll have figure out what's wrong, move back to your target, and try again.

10. Once you simultaneously have your CCD field in the right place *and* have the guide star centered in the 40mm eyepiece, replace the 40mm eyepiece with the higher-magnification 12mm illuminated crosshair eyepiece from the accessory kit. Refocus on the guide star field as before, by raising or lowering the eyepiece and/or the eyepiece extender tubes in the guider neck.

The crosshairs of the guiding eyepiece are illuminated by a red LED mounted in the side of the eyepiece housing. The on/off switch and brightness control for the LED is on the outside end of the silver battery housing.

11. Adjust the brightness of the LED to a level suitable for your guide star, but don't illuminate the crosshairs any more intensely than necessary.

    When you're finished observing you'll need to make very sure to turn off the LED so you don't drain the batteries!

12. Use the fine-motion controls to put the guide star on the crosshair intersection. (Some eyepieces have double crosshairs, which some find more convenient as they form a "box" in which you can put the star.) You'll find it helpful to orient the crosshairs so that movement along one crosshair corresponds to RA and movement along the other corresponds to declination.

YOUR GUIDING TASK is to keep your guide star centered on the intersection of the crosshairs *continuously for the entire duration of the exposure*, by making position adjustments with the control paddle. (Meanwhile, your partner casually strolls away to get more cocoa.) Make sure you know which way the paddle buttons will move the star before you start. Have fun!

> Seriously, guiding is an intrinsically demanding task, and getting good images will depend in part on how well you can deal with the mental and physical fatigue as you work to keep the guide star on the crosshair. It's all the more draining when the exposure is longer, or you're stuck having to use a faint guide star, or you're standing or sitting in an uncomfortable position, or you're tired, or it's hours past your last meal, or you're cold. The latter three of these at least are in principle under your control, and so for the sake of getting good data when you go out to observe you should make sure you're *awake*, *fed*, *warmly dressed*, and bring along a "night lunch" of some kind.

4 Recording calibration frames

4.1 How many calibration images?

We recommend that you expose and save at least 5 images of each type of calibration frame you take.

> You want multiple calibration images so that you can average them together later to reduce the random noise superimposed on the calibration signal you're trying to record. In general, averaging n images will reduce random noise by a factor of $\sqrt{n}$.
>
> In practice, you should actually record an extra frame for a total of $n+1$ images. Why? Because this gives you a way to throw out pixels contaminated by a cosmic ray hit during integration or readout. A cosmic ray turns any pixels it hits full on as it passes through the detector, and if the signal from these contaminated pixels gets into your calibration images then the resulting image artifacts will be passed on to each and every data image you process! So to throw out cosmic ray hits you combine $n+1$ images but for each pixel you *reject* (i.e. discard) the pixel from whichever of the images has the maximum value. If there's a cosmic ray hit, it'll have the maximum value and therefore will be rejected. The remaining n values will be averaged, reducing the random noise by $\sqrt{n}$. [2]

[2] This "reject one pixel" strategy works fine provided that different cosmic rays in different images all affect different pixels. At higher altitudes (such as at mountaintop observatories) where the cosmic ray flux is greater,

4.2 What kinds of calibration images?

There are three basic types of calibration frames: **0biases** ("zero-biases", or often just **biases**), **darks**, and **flats**.

0bias frames: easy, fast, and crucial!

Always take 5 0bias frames, one set per session, for all data taken at same chip temperature.

> A "zero bias" image is a zero-second integration with the shutter kept closed, which records the readout noise. The signal depends on the temperatures of the chip and the readout electronics.

To set up a 0bias frame on the Lynxx 2000:

1. Choose `Camera\Expose`
2. Click on `Bias Frame`. The exposure time will change to `N/A`.

   When you "expose" the chip will just be read out—the shutter won't open and there'll be no delay from integration time.

   NOTE: Taking a 0bias frame seems to reset the exposure time for subsequent images back to the default of 0.1 second. We are annoyed.

dark frames: easy, crucial for good photometry, tedious and most important for longer exposures.

Always take dark frames for any data images exposed for ≥ 1 second. (Can punt dark frames for exposure times of 1 second or less because the dark signal will be buried in the noise of the 0bias/readout signal.)

A set of 5 dark frames per exposure time per session (for all data taken at same chip temperature) is recommended if you're doing photometry. In a pinch, 3 frames is the absolute minimum and should still be suitable for astrometry.

> A "dark frame" is a timed integration with the shutter kept closed, which records integrated thermal noise or "dark counts". In principle, the detector response *should* be linear in which case dark counts *should* scale linearly with integration time. In actual practice, if you need a wide range of dark integration times it's safer to record multiple sets of integration times that match those of your data frames (which in this case includes your **flat frames**, if any) than to trust that linear scaling will work over a large range.

To set up a dark frame on the Lynxx 2000:

1. Choose `Camera\Expose`
2. Click on `Dark Frame`
3. Set the desired exposure time

   When you "expose" the timed integration begins but the shutter won't open.

---

the same basic strategy will work but it might be necessary to take several of these "extra" images so that the corresponding larger number of highest pixel values can be discarded.

flat frames: flat frames can be used to eke out the maximum possible accuracy from photometry, but it takes a fair amount of extra work to get good ones, and not-good ones can actually make things worse! Since the cameras we'll use in 12.410 are already intrinsically very "flat" owing to their being new, let's plan to *not* worry about taking flat frames at least for now. Instead, just try and keep your target objects near the same place on each frame if possible.

But sometime on your way to becoming a famous observational astronomer you'll be expected to have a clue about flats, so here's the scoop:

> A "flat frame" is a regular shuttered exposure of a uniform illuminated featureless surface of some kind, such as a white projection screen or a "blank" twilight sky, through the same optics (filter, etc.) as your data images. A flat records pixel-to-pixel variations in detector sensitivity, which signal includes intrinsic variability of different areas of detector as well as dust or other obstructions in the optical system. Dust or lint will appear out-of-focus and thus as a doughnut-shaped (if secondary mirror obstruction) or disc-shaped (unobstructed objective) area, whose size depends on the distance from the focal surface. Note that the flat frame is not only filter-dependent but is also focus-dependent!
>
> Flats recorded using an artificially-lit screen are typically called "dome flats". They're straightforward to record if such a screen is available, but for picky work the use of artificial light can lead to imperfect flattening because the spectral characteristics of that illumination will be different from those of the background sky on your data images. An alternative is to shoot "sky flats" using the twilight sky and pointing opposite the rising/setting Sun, but this is more complicated to pull off because the sky brightness during twilight changes rapidly, making it difficult to maintain a constant signal level for all the individual flat images. Plus your observing session must include either dusk or dawn, and you have to make sure the field you aim at doesn't have any stars bright enough to show up (or clouds) lurking within it. Dusk has the particular additional problem of no information for where to set the focus since you won't have started observing yet!

To take flats you'd shoot one set per optical system change, which includes changes of filters and of focal length. (Strictly speaking this also includes focus changes.)

To shoot flat frames with the Lynxx 2000:

1. Set up the flat field of choice (screen or twilight)
2. Treat just like an image frame, adjusting illumination and/or exposure time until you get average counts in the range 32000–52000 (i.e. between 50% and 80% of saturation).
3. Be sure to go back and shoot dark frames for your flats!

> You may have noticed we're specifically avoiding the `Flat Frame` option in the `Expose Image` window. It seems to do some kind of normalization to the image after it's read out, but (a) in absence of any clear documentation of what it actually does do to our images, (b) in absence of any actual *need* for the program to do *anything* weird to our flat frames, and (c) the fact that it opens up a mysterious `Console` window that doesn't have an off button, the party line on `Flat Frame` option is: "punt".

5 Shutting up

If you used an illuminated crosshair eyepiece, make *very* sure to turn off the LED so you don't drain the batteries!

Deactivate the control program by choosing `File\Quit`