Massachusetts Institute of Technology
Wallace Astrophysical Observatory

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Instrument User's Guide
Lynxx2000 CCD camera with PFE-1 filter holder, mounted on WAO 12-cm astrograph.

`$Revision: 991.0 $`

Objective:

- Describe how to use the Lynxx 2000 camera as instrument on the WAO 12-cm astrograph, including focusing.

Prerequisites:

- Familiarity with the basics of using the WAO 12-cm astrograph (power-on, movement in RA and Dec, wide-field finderscope and faint-object finderscope, guidescope, drive corrector, accessory kit).
- Familiarity with the basics of using a Macintosh PC (power-on, Desktop, pull-down menus, Finder, trackball, active vs. inactive windows).

Contents

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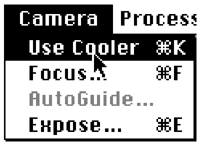
1 Starting up

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 the filter you intend to use for your images is in the filter holder! Normally with CCD's you'll use V or R.

The astrograph is a refractor and thus subject to chromatic aberration by the objective lens, leading to two main practical considerations with respect to use of filters:

- It's especially important to use one of the color filters because otherwise the chromatic aberration will bloat your star images, which in turn will lead to noisier astrometry and/or photometry. Avoid using a colorless filter for astrograph images.
- If your observing program uses more than one filter, for sharpest images you'd need to refocus after each filter change. But this can take a substantial amount of time; the tradeoff you'd need to consider here is time-efficiency vs. image focus quality.

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. +1.0 to +2.0 to be your "focus star". Pick one that's well above the horizon, to avoid seeing or scintillation problems that occur near the horizon.

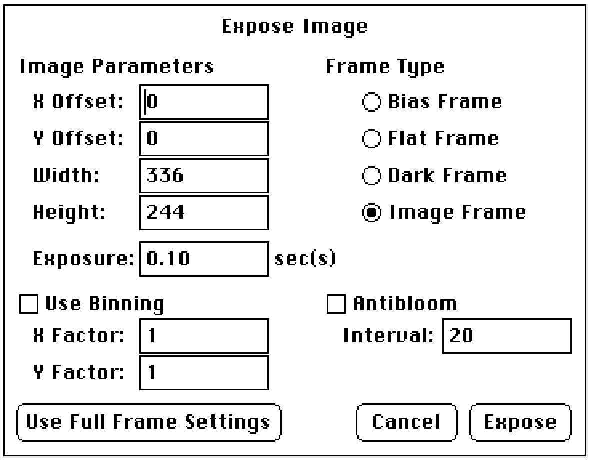
   The idea is to pick a star that's bright enough that a short exposure gets you enough signal to focus, but not so bright that it completely saturates the detector and "blooms" on the image. For this combination of instrument, telescope, and observing site a star about 2.5 to 3.5 magnitudes brighter than 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. To acquire the star in the CCD field, first center the star on the crosshair of the wide-field finder, then on the crosshair of the faint-object finder.

   The focus for the astrograph will probably have been left as it was when the previous user finished observing. This normally will be fairly close to, but not necessarily right on, the correct focus for your own observing. 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, make an 0.1 second trial exposure as follows:

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

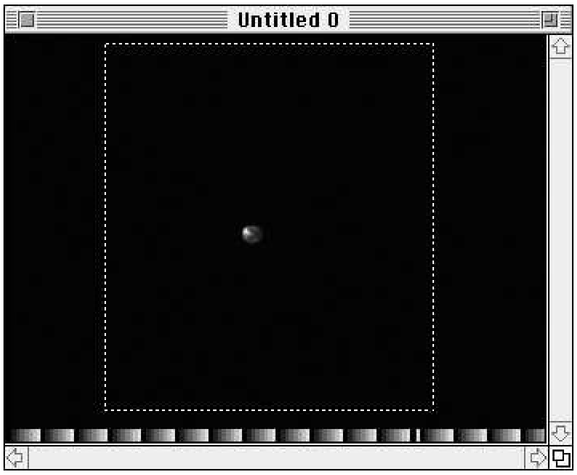
   (b) Set the desired exposure time, which the first time through will already be the default of 0.1 second.

   (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.

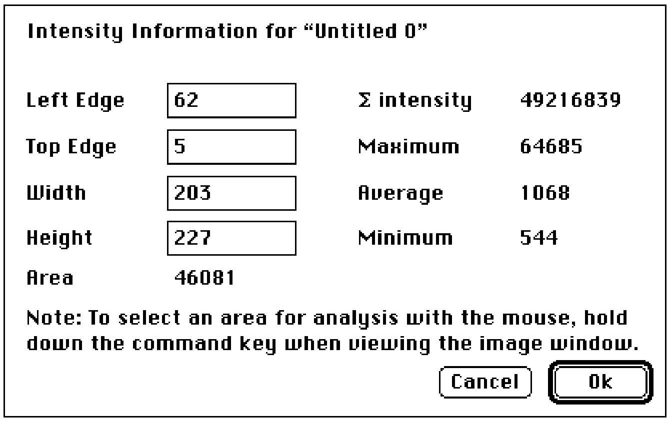
A sufficiently out-of-focus image will appear as a “disc” shape since there’s no secondary mirror obstruction of the objective lens.

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.

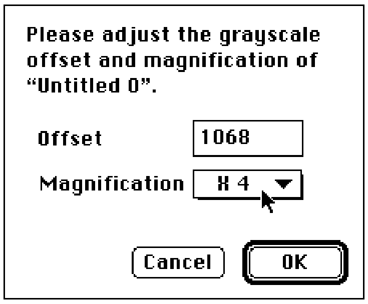
If your focus star is well-exposed you’re all set to proceed! Otherwise you’ll need to repeat steps 4 and 5, and adjust your trial exposure time up or down as necessary.

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.

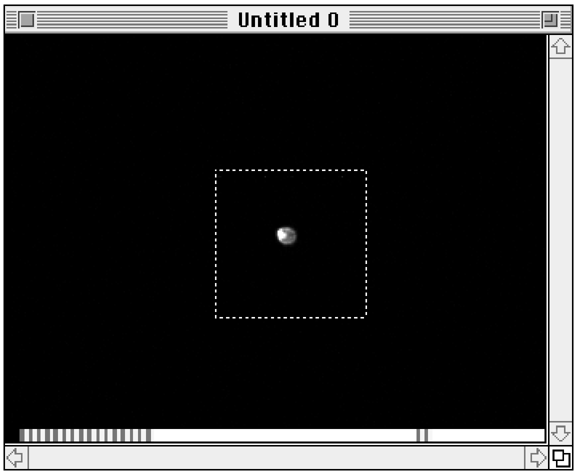
7. In order to better be able to see changes in the image as you mess with the focus, choose `View\Greyscale...` so you can adjust the brightness and contrast of the displayed image.



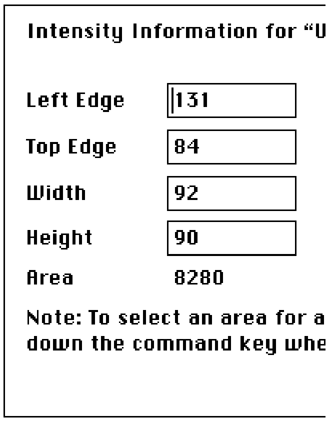
   (a) Set the `Offset` (black) value to the `Average` pixel value (background level) you recorded from the intensity analysis of your trial exposure.
   (b) Set the `Magnification` (contrast) value to `X 4`.
   (c) Click `OK` to "make it so"!

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" (such as it is).



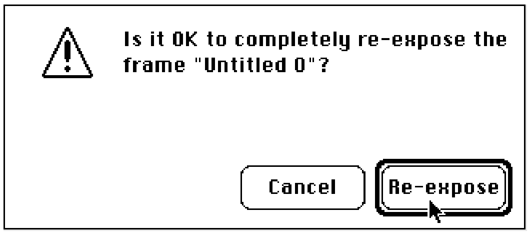
9. Choose `Process\Analyze Intensity`, and record the four box parameters `Left Edge`, `Top Edge`, `Width`, and `Height`.



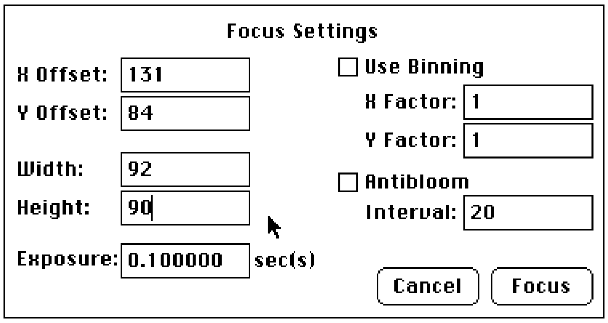
10. Choose `View\Magnify` *twice* to enlarge the image display.

    To reach the camera focus screws 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)



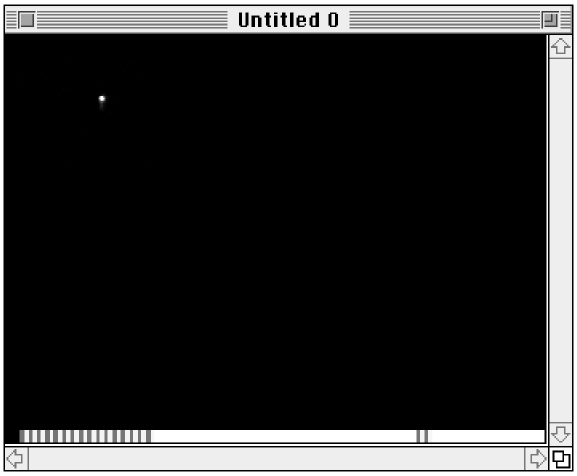
    (a) Set the four subframe parameters `X Offset`, `Y Offset`, `Width`, and `Height`, to the values you just recorded from the small analysis box. (You can use the ⟨TAB⟩ key to advance fields quickly)
    (b) set the exposure time to the value you determined earlier

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 a side edge of your box, use the drive corrector control paddle “guide” buttons to bring it back to the center.

Be patient when using the "guide" motions! A 100-pixel box spans about 270″ on each side, but the guide speed motions move the scope only about 4″/sec in RA, at which rate moving the star the distance of the whole box takes more than 70 seconds.

To focus, watch the image display while adjusting the camera 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).



How to adjust the astrograph focus There are four hand-adjustable screws on the back end of the astrograph, one at each corner of the metal plate to which the CCD camera is attached. You focus by turning these screws to change the distance between the objective lens and the camera. Springs hold the plate away from the astrograph housing at the distance you set.

- When focusing try to keep the camera perpendicular to the optical axis by making the same adjustments to all four screws.
- The screws are of finite length, and if you unscrew them too far they *will* fall out of the nuts on the inside of the astrograph housing! (at which point the washers and springs leap out onto the floor and scurry off to hide) The total travel of the screws, from all the way in to all the way out, is only about 10-11 turns.
- The focus distance with a filter will be near the midpoint of adjustment screw travel. If you need to "start from scratch" looking for the focus distance, tighten the screws all the way in and then bring each one out 4 full turns.
- Once you're nearer to focus make your adjustments in $\frac{1}{4}$- or $\frac{1}{8}$-turn increments.

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 or shakiness 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` *twice* 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.

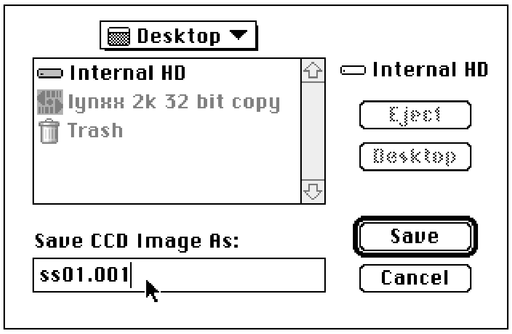
3 Observing information

- 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 Guiding

The tracking motor drive on the astrograph isn't anywhere *near* as spiffy as those now on the C14's, and irregularities in the tracking will cause your image to smear in the east-west direction if exposures of about a minute or longer are left to themselves. Smeared images will adversely affect your results, so if you want good results you'll need to Assert Your Superior Will over the mechanism and manually compensate for the poor tracking. For consistent tracking you use the momentary rate control buttons on the drive corrector'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, at a higher magnification than is equivalent to the image scale of the CCD optics. For this purpose the astrograph has a *guidescope* mounted on the main tube along with its two finder scopes. This scheme allows you to monitor a guide star through the guidescope while simultaneously making your CCD exposure through the astrograph main optics. To guide

[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, we're in trouble because the Dec "fine-tuning" mechanical control on the astrograph isn't "fine" enough for guiding!

an exposure, a high-power eyepiece with illuminated crosshairs is used in the guidescope to allow tracking on a convenient *guide star*. The guidescope's focal length is 700mm, so using a high-power 12.5mm illuminated crosshair guiding eyepiece together with a 2× Barlow lens gives a guiding magnification of 112×.

While the task of finding a guide star and lining up on it while keeping the object you wish to photograph in your field is in principle not too complicated, in actual practice it takes some tinkering. You can make your life a little to a lot easier by using the following technique:

1. (While planning) The "guidescope-capable area" is the region within which you can adjust and point the guidescope around your target without moving the main telescope. Use the properly-scaled "field template" of the visible frame and guidescope-capable areas with your field finder chart photocopied from the *Uranometria 2000.0* star atlas to identify the brightest candidate guide stars that are close enough to the target. To adjust the relative orientation of the guidescope field to the imaged field you use the alignment screws in the guidescope rear mounting ring. (Have a TA show you how, and be careful not to loosen the screws so far that the guidescope falls out!)

2. (At the telescope) After you've located the target field and have acquired your object in the CCD field, view the candidate guide stars through the *wide-field finderscope*, to check which ones are bright enough. Stars too faint to be visible through the wide-field finderscope are likely to be too faint to successfully use as guide stars.

3. Start with the 40mm eyepiece from the accessory kit in the "eyepiece neck" of the guidescope, to get the widest field. It's a friction mount (no set screw), so you'll need to remove and install guidescope eyepieces *gently* and take care that you don't disturb the pointing of the astrograph.

4. Choose a remaining candidate guide star (hopefully you still have at least one left at this point) and look through the finderscope to ascertain its position relative to the target object (which is at the center of the finderscope). Adjust the alignment screws of the guidescope and orient it so that it's pointing radially *opposite* the direction in which the guide star appears to be from the object in the finderscope. Locate the guide star in the 40mm field, and center it. Focus on the guide star by adjusting the rack-and-pinion focus knob on the guidescope in front of the eyepiece.

5. **Make sure your camera's still seeing the target field** by shooting a short unguided test exposure. If not then you probably disturbed the astrograph pointing while fiddling with the guidescope. You'll have to move back to your target and try Step 4 again. (Just as well you find this out now rather than guide a several-minute exposure on the wrong field...)

6. Switch to the high-power (12.5mm) illuminated crosshair eyepiece and 2× Barlow lens from the accessory kit. The crosshairs of the guiding eyepiece are illuminated by a red LED mounted in the side of the housing. A cord connected to the LED is to be plugged into the 9-volt battery pack from the photo kit, which has an on/off switch and brightness control. 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. Put the guide star on the crosshair intersection (some classier 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.

7. Now, all that's left (!) is the task of actually *doing* the guiding. **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 drive corrector rate buttons. (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]

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.

[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, 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.

> 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.

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`