Flatfield images

Today, we're going to look at the issue of "flatfield images". What are they, and why do we need to take them? What can we do with them?

The images for today's exercises can be found in the `$dd/sep20_2003` directory. Make sure that you make copies of all these images in your own directory. So, after you log in, you might execute these commands, which

- change to my home directory
- list all the files there
- remove them (since they aren't needed for today's class)
- copy all the files from the `$dd/sep20_2003` directory
- list all the files -- which we will use today

```
[phys445@spiff ~]$ cd richmond
[phys445@spiff richmond]$ ls
dark30_001.fit  dark30_005.fit  dark30_009.fit  Q_prof.dat  test2.fit  v585.his
dark30_002.fit  dark30_006.fit  dark30_010.fit  Q_prof.fit  test3.fit
dark30_003.fit  dark30_007.fit  dark_avg.fit    Q_prof.plt  test4.fit
dark30_004.fit  dark30_008.fit  dark_med.fit    test1.fit   v585.fit
[phys445@spiff ~]$ cd richmond
[phys445@spiff richmond]$ ls
dark30_001.fit  dark30_004.fit  dark30_007.fit  dark30_010.fit  v585.fit
dark30_002.fit  dark30_005.fit  dark30_008.fit  dark_avg.fit    v585.his
dark30_003.fit  dark30_006.fit  dark30_009.fit  dark_med.fit
[phys445@spiff richmond]$ rm *
[phys445@spiff richmond]$ ls
[phys445@spiff richmond]$ cp $dd/sep20_2003/* .
cp: omitting directory `/home/richmond/classes_www/phys445/data/sep20_2003/dark'
cp: omitting directory `/home/richmond/classes_www/phys445/data/sep20_2003/raw'
cp: omitting directory `/home/richmond/classes_www/phys445/data/sep20_2003/red'
cp: omitting directory `/home/richmond/classes_www/phys445/data/sep20_2003/unuse
d'
[phys445@spiff richmond]$ ls
dark30_001.fit  dark4_002.fit      flatclear_003.fit    flatclear_x_004.fit
dark30_002.fit  dark4_003.fit      flatclear_004.fit    flatclear_x_005.fit
dark30_003.fit  dark4_004.fit      flatclear_005.fit    flatclear_x_006.fit
dark30_004.fit  dark4_005.fit      flatclear_006.fit    flatclear_x_007.fit
dark30_005.fit  dark4_006.fit      flatclear_007.fit    flatclear_x_008.fit
dark30_006.fit  dark4_007.fit      flatclear_008.fit    flatclear_x_009.fit
dark30_007.fit  dark4_008.fit      flatclear_009.fit    flatclear_x_010.fit
dark30_008.fit  dark4_009.fit      flatclear_010.fit    v585.fit
dark30_009.fit  dark4_010.fit      flatclear_x_001.fit
dark30_010.fit  flatclear_001.fit  flatclear_x_002.fit
dark4_001.fit   flatclear_002.fit  flatclear_x_003.fit
```

When you have reached this point, please pause, and look around. If someone nearby is having problems, please help him or her to reach this point.

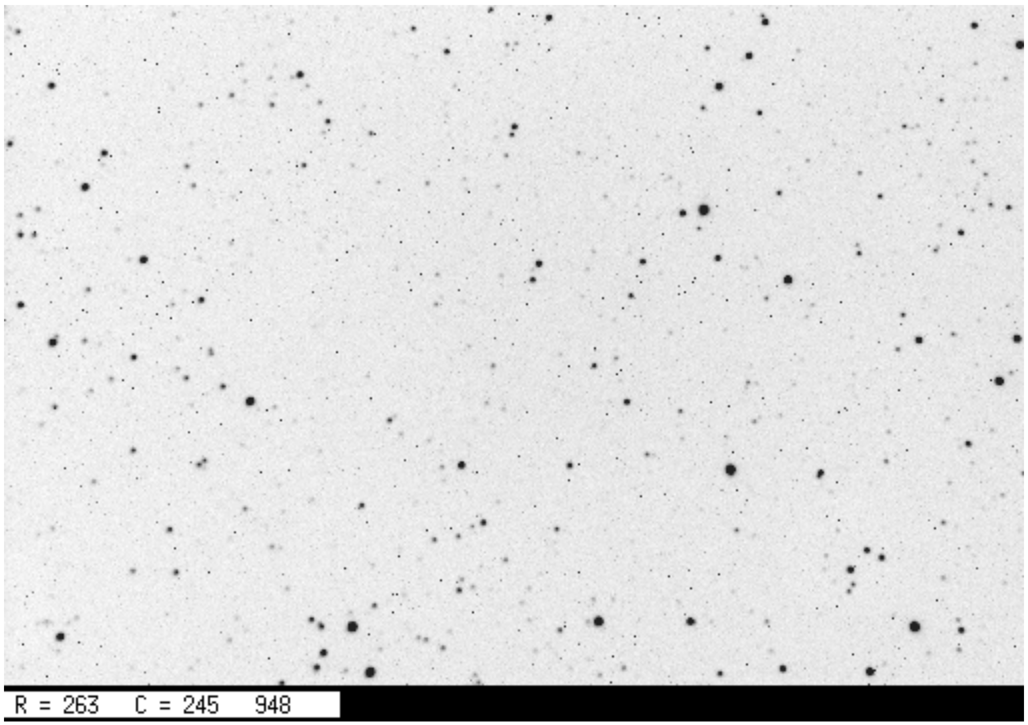
Examine carefully the background of a raw image

Today, let's take another look at one of the "target images" take on Sep 20, 2003. Make sure that you have a fresh copy of the file `v585.fit` in your directory.

Astronomers typically display images in an inverted mode, so that stars appear as black objects on a white background. It's easier to pick out very faint detail that way. So, display the target frame like so:

```
tv v585.fit z=900 l=1000 invert
```

It should look like this:



Hmmm. There are lots of hot pixels, but we know how to get rid of them. Is there anything ELSE wrong with the image?

Display the image again, this time with a much smaller range, **l = 100** instead of **l = 1000**. This will enhance very subtle features in the background.

```
tv v585.fit z=900 l=100
```

Note that you don't need to (and shouldn't) provide the **invert** keyword this time; the **tv** command remembers the display mode and keeps using the last one you specified.

1. Display the image with the parameters shown above.
2. What sort of defects or funny things do you see?

When you reach this point, stop and look around. If someone nearby hasn't reached here yet, offer to help. If someone nearby has reached this point, too, then discuss your answers.

Variations in sensitivity across the focal plane

The problem is that some (all?) instruments are imperfect. When I write "instruments", I mean the combination of optics and detector. Several different problems commonly cause variations in sensitivity across the focal plane; if those variations are not corrected, they end up as errors in the measured magnitudes of stars and other celestial sources.

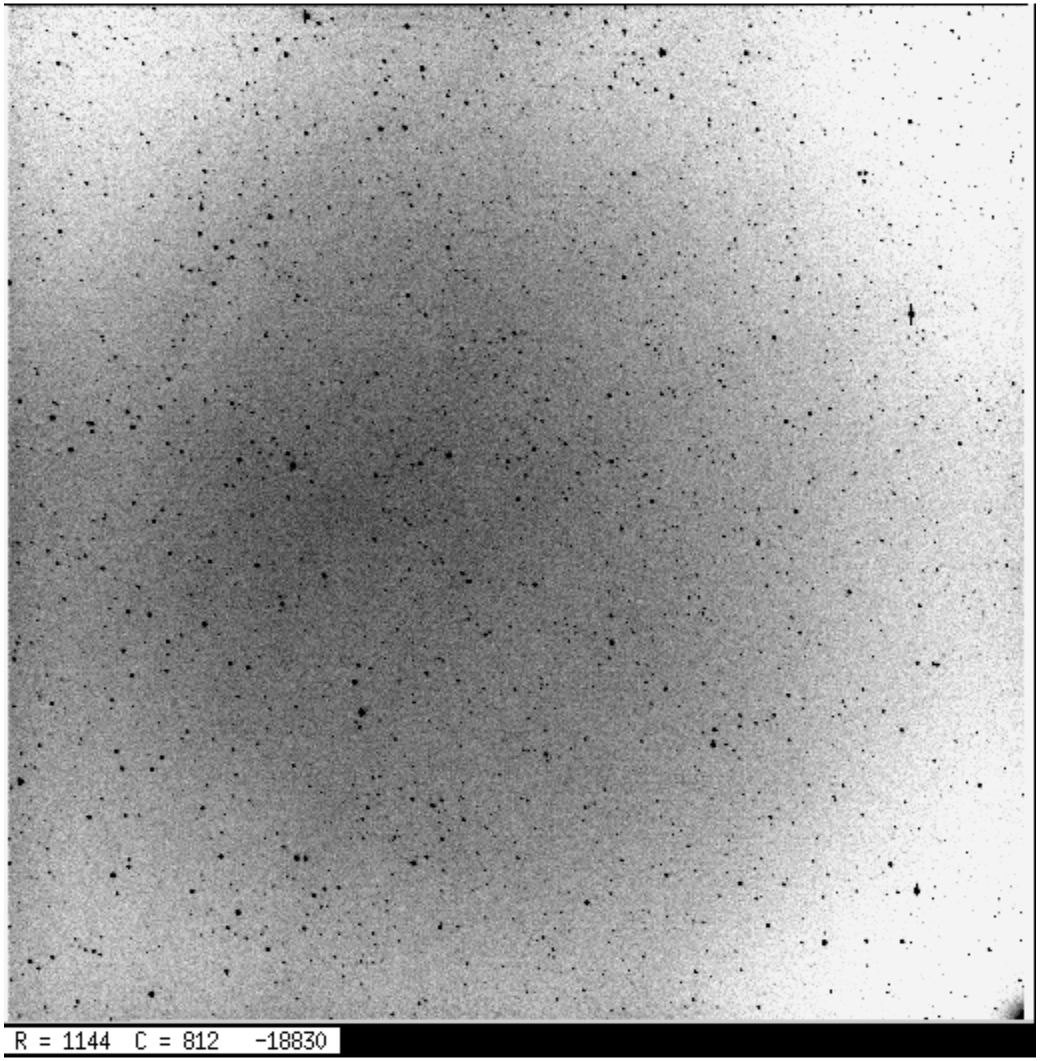
The three main culprits are

- vignetting in the optics
- intrinsic and surface defects of the CCD
- shadows cast by dust

Vignetting

A perfect optical system would lead every incoming photon to its proper place on the focal plane. If pointed at a uniform source of diffuse light, the entire focal plane would receive equal amounts of light. In the real world, some portions of the focal plane get more light than others. Usually, the central portions get a bit more than the outer edges.

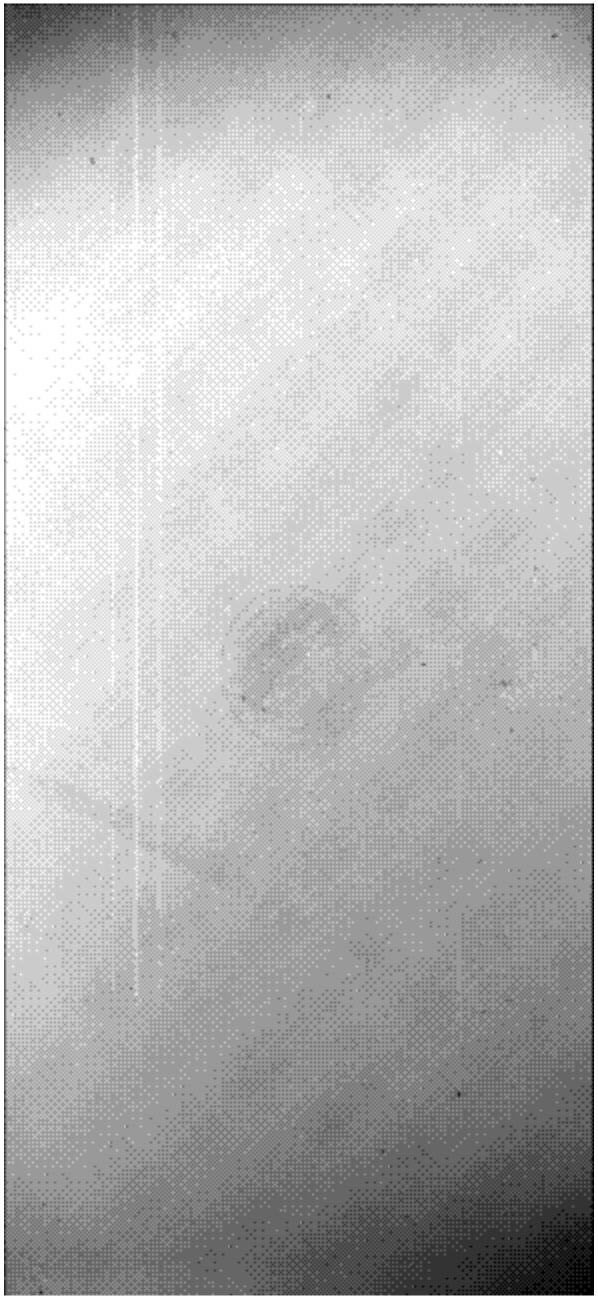
Here's an example: a raw I-band image taken by one of the TASS Mark IV cameras . The field of view is very large, about 4 degrees on a side.



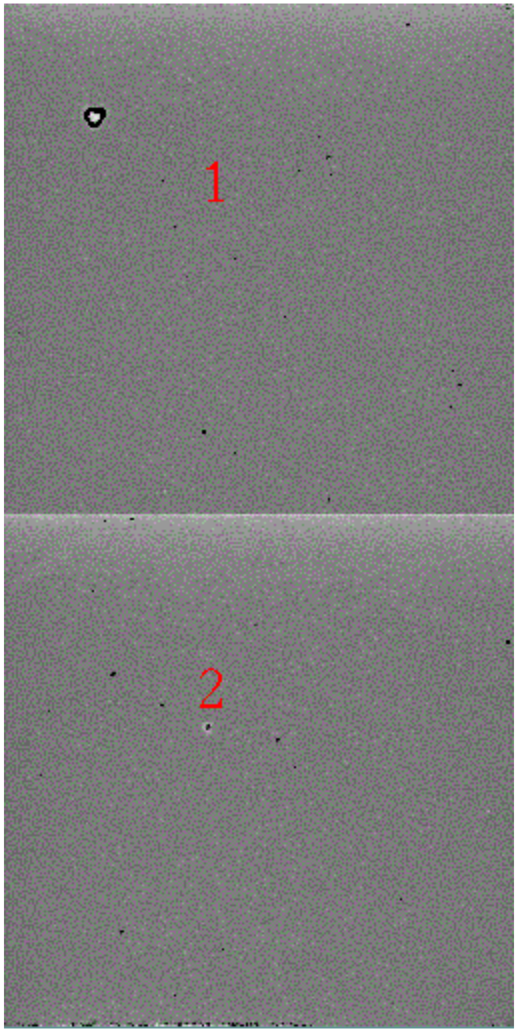
You can download and examine the image itself, if you wish. Be careful, though: it's a big image, roughly 2048x2048, so if you want to see the whole thing, you'll need to use **zoom=0.25** as part of your **tv** command.

- right-click to save the image "tass_i.fit"

Intrinsic and surface defects of the CCD
: Sometimes, one region of the silicon is just more sensitive to light than others. Thinned, back-illuminated chips are prone to showing artefacts due to the grinding, polishing and etching of their surfaces.

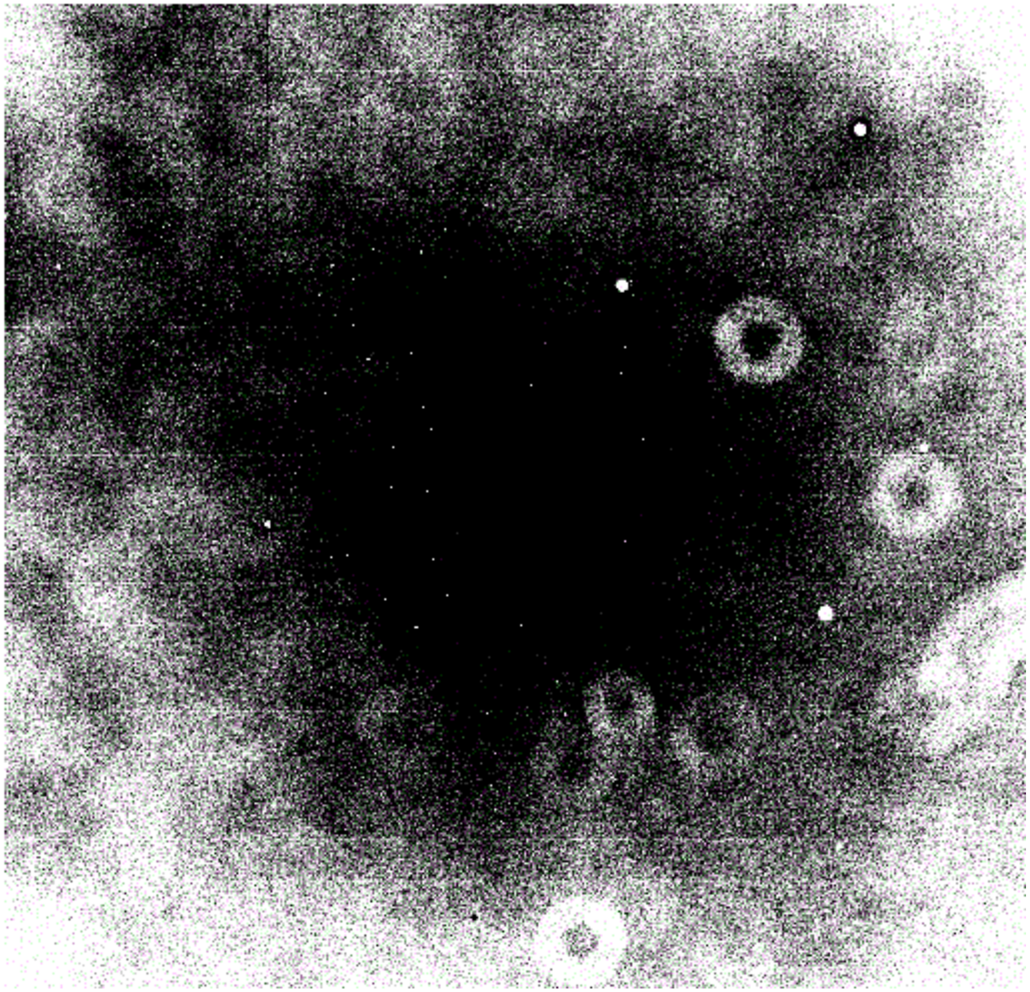


Some CCDs may have been nearly perfect when first made, but, over the years, have accumulated layers of oil, grease, or other contaminants. Little specks of dirt and dust can also sit on the chip, blocking most of the light from reaching the pixels below. Here are a couple of closeups of quadrants 1 and 2 of the Dandicam CCD camera.

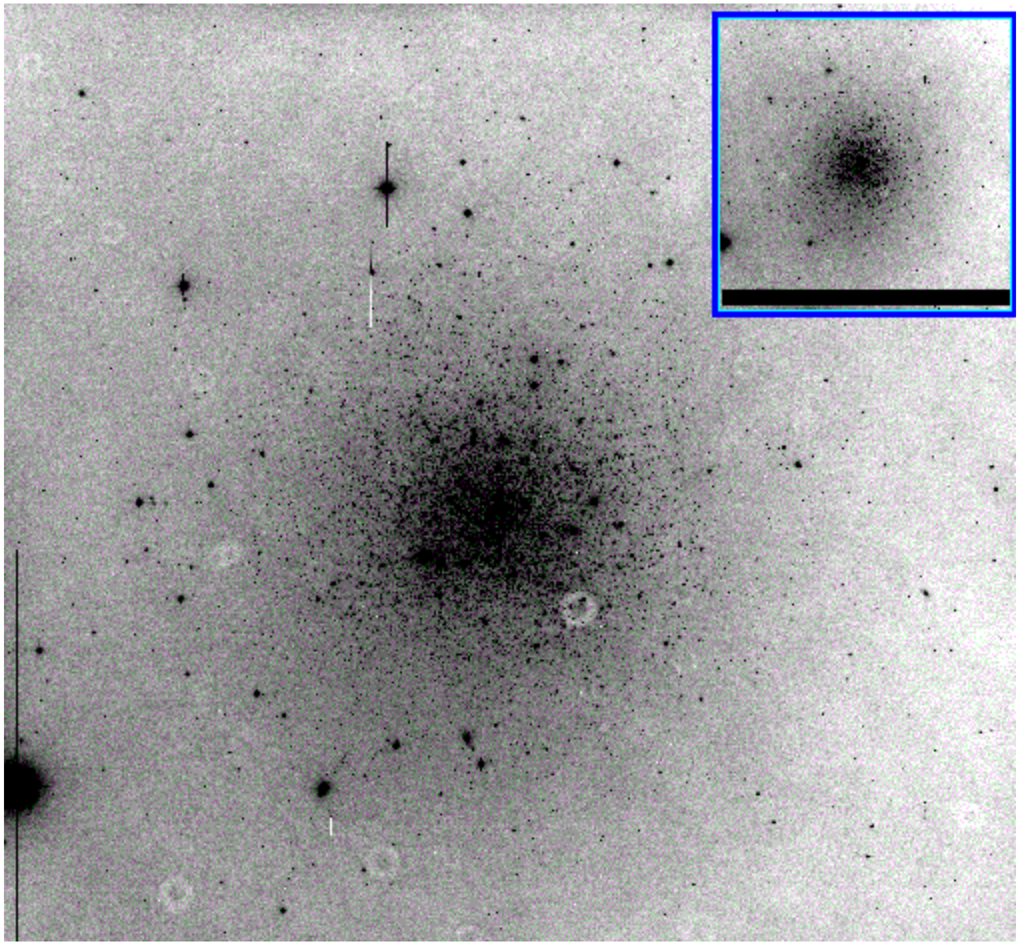


Dust particles in the optical path

Dust gets everywhere. Any particles which stick to the optical surfaces -- the lenses a focal reducer or field flattener, or the optical window in front of the CCD itself -- will cast shadows on the focal plane. Diffraction turns these shadows into the oh-so-familiar "dust donuts". Here are examples from the MDM 1.3m telescope at Kitt Peak:



and the 1-m telescope at Las Campanas in Chile:



The "Flatfield" -- in theory

The problem boils down to this imagine a very simple CCD, consisting of just two pixels. Suppose that the pixel on the left is a bit less sensitive than that on the right. I point my camera at a blank white wall. I **ought** to see this:

```
          left pixel            right pixel
        --------------        ----------------
           100 counts            100 counts
```

But instead, the CCD **actually** records this:

```
          left pixel             right pixel
        --------------         ----------------
             95                      100
```

Evidently, the left-hand pixel is slightly less sensitive to light, by 5 percent. This is a problem if we're trying to make precise measurements of stellar brightness. Suppose I look at two stars, A and B, which are really the same brightness. But if star A falls on the left-hand pixel, and star B on the right-hand pixel, I won't see that; instead, I will measure fewer counts from star A:

```
           star A                  star B
        --------------         ----------------
            9,500                  10,000
```

3. Is there any way to correct the measured quantities so that they accurately reflect the actual incoming signals from the stars?

Sure! It's not too hard, either. All I need to do is divide each pixel's measured value by its relative sensitivity, like this:

```
           star A                  star B
        --------------         ----------------
 measured    9,500                  10,000

         divided by             divided by

 relative
 sensitivity   0.95                   1.00

         ===========            ============

  corrected   10,000                 10,000
```

So, the theory of "flatfields" goes like this:

- Before the night starts ...
  - take a picture of a uniform, bright scene: a "flatfield image"
  - use the pixel values of this "flatfield" to define the relative sensitivity of each pixel
- During the night ....
  - take pictures of stars, galaxies, etc.
- Afterwards ...
  - divide the pictures of stars by the "flatfield" image to correct for differences in sensitivity

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The Flatfield -- in practice

There are a few complications:

Where can you find a uniform, bright source of light?

There are two common methods. The first is take pictures of the sky around dusk or dawn: "twilight flats". It's tricky, because there's only a brief period of ten minutes or so during which the sky remains bright enough to hide stars, yet faint enough to prevent the CCD from saturating. The other idea is to take pictures of a blank screen or panel attached to the inside of the dome: "dome flats." You have much more control over these.

How high does the signal have to be in a flatfield image?

The statistical variation from one picture to the next will scale as the inverse square root of the number of electrons recorded in each pixel. If each pixel has 100 electrons, then a rough estimate of the random variation in each pixel's value (from one picture to the next) is

```
uncertainty = 1.0 / sqrt(100)

            =  0.1   =  10 percent
```

If you want to do work at the 1 percent level, you need to gather roughly 10,000 electrons in each pixel of the flatfield image.

It's a bit more complicated than this, but a good rule of thumb is "take flatfield images which are around 1/4 to 1/2 of the saturation level." For the RIT cameras, anywhere between 10,000 and 20,000 counts per pixel is pretty good.

How can you get a true measure of sensitivity to LIGHT?

You have to remove

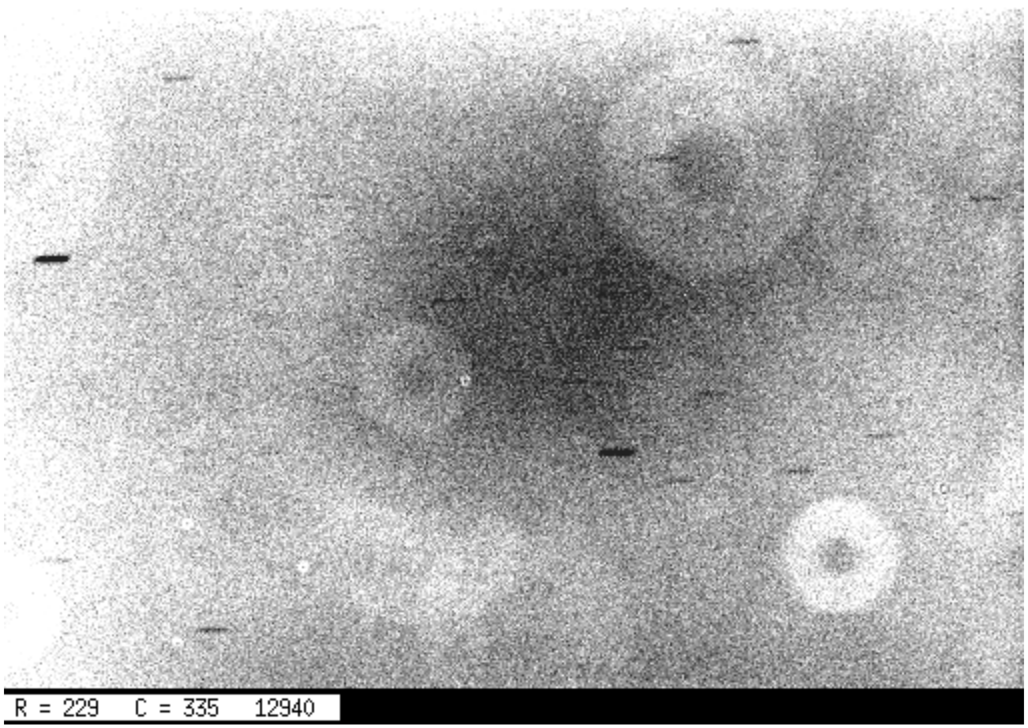
- the zero-point value (which appears in zero-second dark exposures)
- the electrons knocked free due to thermal motions (which grow with time)

If you don't, they your map of sensitivity isn't accurate.

Fortunately, this is easy to fix: just take a set of dark frames with the same exposure time as your flatfield images, create a master dark, and subtract that master dark from all flatfield frames before any further processing.

How can you avoid cosmic rays, or other contamination?

This is important, especially if you take twilight flats. Look at this example of a twilight flat taken at the RIT Observatory on Sep 20, 2003:



The short horizontal streaks are due to stars which were bright enough to appear above the relatively bright sky level. They are trailed because the telescope's tracking was turned off (oops).

Again, there is a relatively simple solution: take a number (10 or more) of flatfield images, and (after subtracting the master dark from each one) create a "master flat" by taking the median of the set, on a pixel-by-pixel basis.

Create a flatfield frame for Sep 20, 2003

Okay, so give it a try. Do the following:

4. make sure that you have the files from the `sep20_2003` directory with names like `flatclear_x*.fit` and like `dark4_*.fit`; they are dark frames with the same exposure time (4 seconds) as the flatfield frames
5. display one image, `flatclear_x_001.fit`. Look at it with different contrast levels -- note the typical pixel values. What is the mean pixel value in the entire image?
6. use the **median** command to create a "master dark" from the 4-second dark exposures. What is the mean value of this "master dark" image?
7. subtract this "master dark" from each of the flatfield images
8. display the image `flatclear_x_001.fit` again and verify that the typical pixel levels are now a bit lower than they were originally. What is the mean pixel value in the entire image now?
9. calculate the mean value of each flatfield image, using the **mn** command. Make sure that you have already subtracted the dark frame first. If you want to avoid having to type 10 different commands to run the **mn** program 10 times, you might try this shortcut:

```
[phys445@spiff richmond]$ ls flatclear_x_*.fit
flatclear_x_001.fit  flatclear_x_005.fit  flatclear_x_009.fit
flatclear_x_002.fit  flatclear_x_006.fit  flatclear_x_010.fit
flatclear_x_003.fit  flatclear_x_007.fit
flatclear_x_004.fit  flatclear_x_008.fit
[phys445@spiff richmond]$ for i in flatclear_x_*.fit
> do
> mn $i
> done
mean=19992.89 rms=236.79 sum=3466767745 npixels=173400
mean=18857.46 rms=218.50 sum=3269884241 npixels=173400
mean=17799.21 rms=200.20 sum=3086383329 npixels=173400
mean=16800.15 rms=195.93 sum=2913145821 npixels=173400
mean=15844.71 rms=183.23 sum=2747471955 npixels=173400
mean=14939.03 rms=180.74 sum=2590427188 npixels=173400
mean=14087.56 rms=200.47 sum=2442783690 npixels=173400
mean=13282.78 rms=203.19 sum=2303234106 npixels=173400
mean=12518.93 rms=215.14 sum=2170782378 npixels=173400
mean=11793.69 rms=141.78 sum=2045025994 npixels=173400
[phys445@spiff richmond]$
```

Notice that the mean level in each image decreases through the sequence. The sky was getting darker as I was taking these images. If we tried to compute a median value for one particular pixel -- say, (100, 100) -- from these images in their current state, we'd have a problem: that pixel would always be brightest in the the first image, and faintest in the last image, just because the average light level is highest in the first image.

10. use the **median** command to create a "master flat" from all the dark-subtracted flatfield frames. Run the command like this, in order to see what it is doing explicitly:

```
median flatclear_x_*.fit outfile=master_flat.fit verbose
```

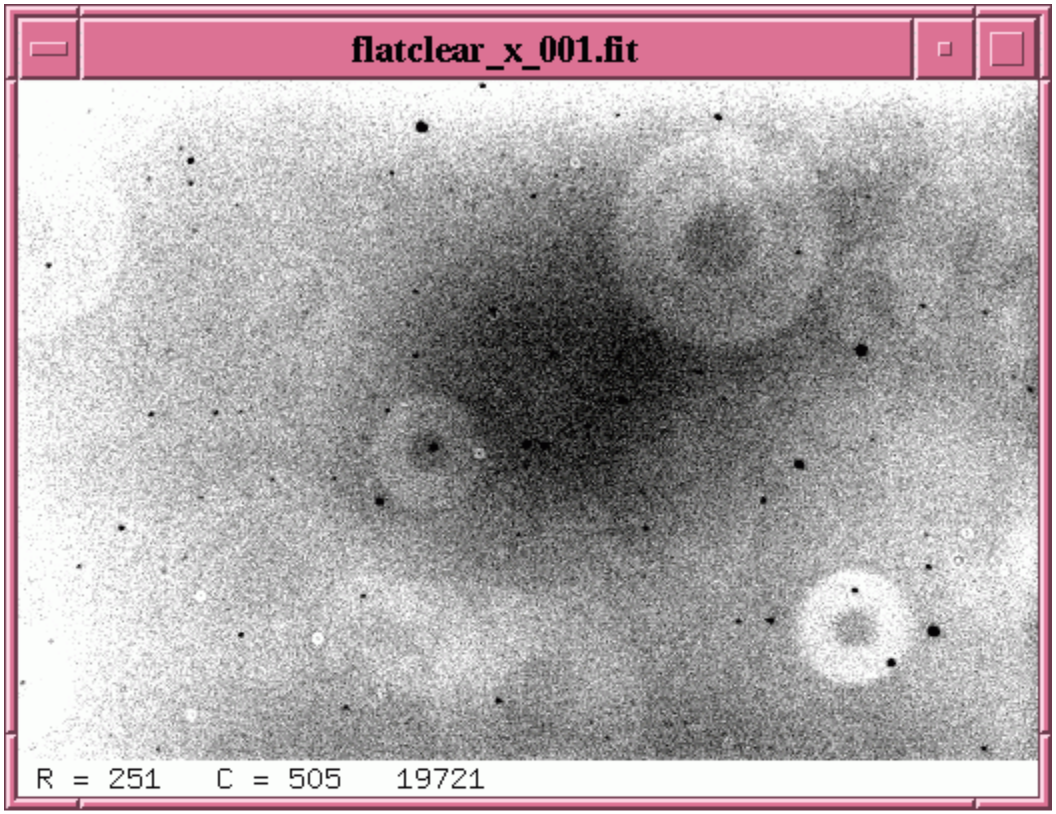
The **median** command will first re-scale all the flatfield images so that they have the same average value; only then will it look at each pixel to pick the middle value from the entire set of images. In order to do this re-scaling properly, the **median** program uses the results of the **mn** commands you ran earlier.

11. run the **mn** command on your "master flat" image, like this:

```
mn master_flat.fit
```

    to compute the average value of pixels in the "master flat"; we'll need that later ...

12. display this "master flat". How does it look? If you display the "master flat" right on top of the image `flatclear_x_001.fit`, then flip the two images to bring each to the front quickly, you'll get a VERY good idea of the difference between them. Click on the image below to see a blinking comparison of a single flatfield image and the master flatfield image.



13. you should see a "dust donut" in the lower-right corner of the flatfield frame. By what percent does the sensitivity change as you go from outside the donut, to the ring itself, to the interior of the donut?

14. compare the typical pixel level near the center of the image to the pixel values in the upper-left corner. By

what percentage does the sensitivity change?

Now, with both a "master dark" image, and a "master flat" image, you are ready to reduce the raw target image of V585 Lyrae. This is the same procedure you'll use on your own target images.

14. make a copy of the `v585.fit` image, just in case something goes wrong.

    ```
    cp v585.fit v585_raw.fit
    ```

15. the `v585.fit` image has an exposure time of 30 seconds, so you'll need to create a master dark frame from the dark images which have an exposure time of 30 seconds.

    ```
    median dark30*.fit outfile=master_dark_30.fit
    ```

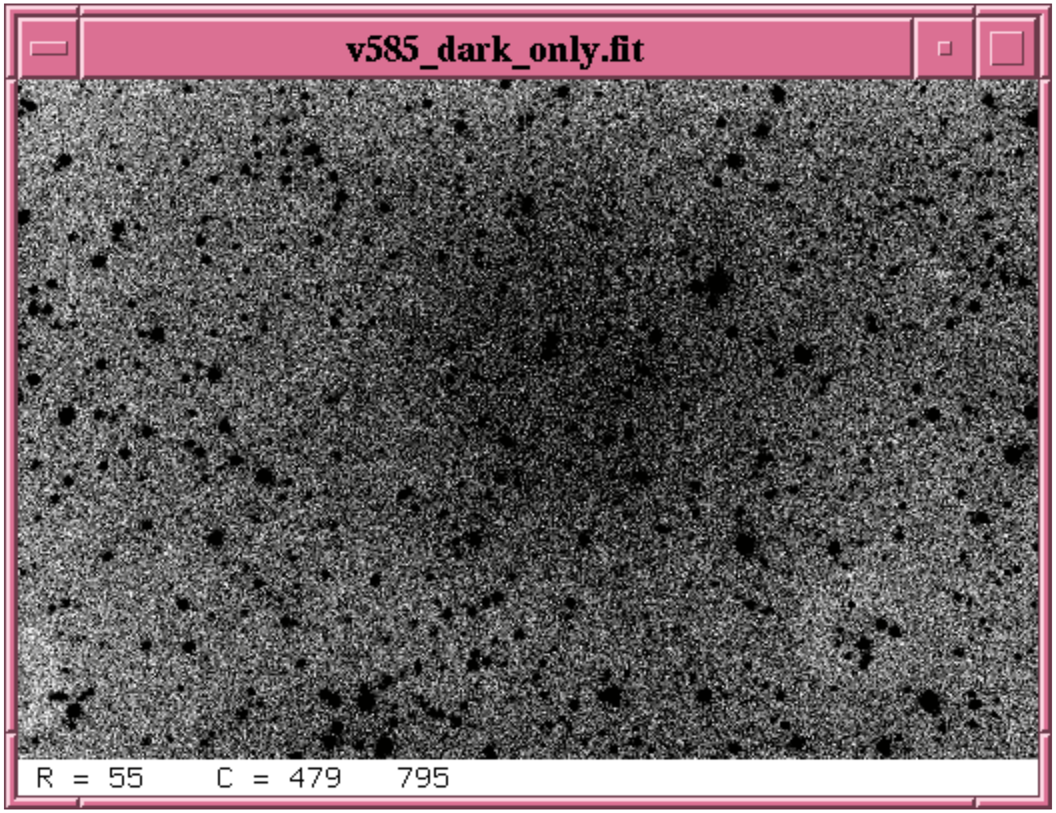
16. subtract this "30-second master dark" image from the `v585.fit` image

17. divide the dark-subtracted `v585.fit` image by the "master flat" frame. The command to do this looks something like

    ```
    div v585.fit master_flat.fit flat
    ```

    Don't forget the final keyword **flat** at the end of this command!

18. display the processed and raw versions of the target frame side-by-side. Look at them carefully. Vary the display parameters `l=` and `z=` of the **tv** command to highlight faint features in the background.



If all went well, you should see faint defects in the raw image -- variations in the background level from center to corners, and dust donuts -- but no such defects in the processed version. Did it work?

For more information

- The Observational Mishaps page is full of wisdom and experience.