ASTR 4880/PHYS 5880 — Fall 2008 — Dr. Morrison

Lab 3, Due: November 24, 2008

# 1 Linearity Test

In Part 1 of this lab, you will use the sequence of flat lamp exposures that we took on November 6 (UT) to investigate the onset of nonlinearity and saturation in CCD3. A copy of the first page of that evening's log sheet is attached. The images are in the *astro1* directory `/mnt/vol01/ndm/iraf/course/F2008/20081106flats` with the file names that we gave them that evening, except that I have changed the file name extensions to `.fits`.

For initial processing of the images, do the following.

1. Combine the five biases to form a median bias with *imcombine*.
2. Form the median of the set of three flats taken at each exposure time.
3. Subtract the median bias from each median flat.

Now the flat images are ready for the linearity study.

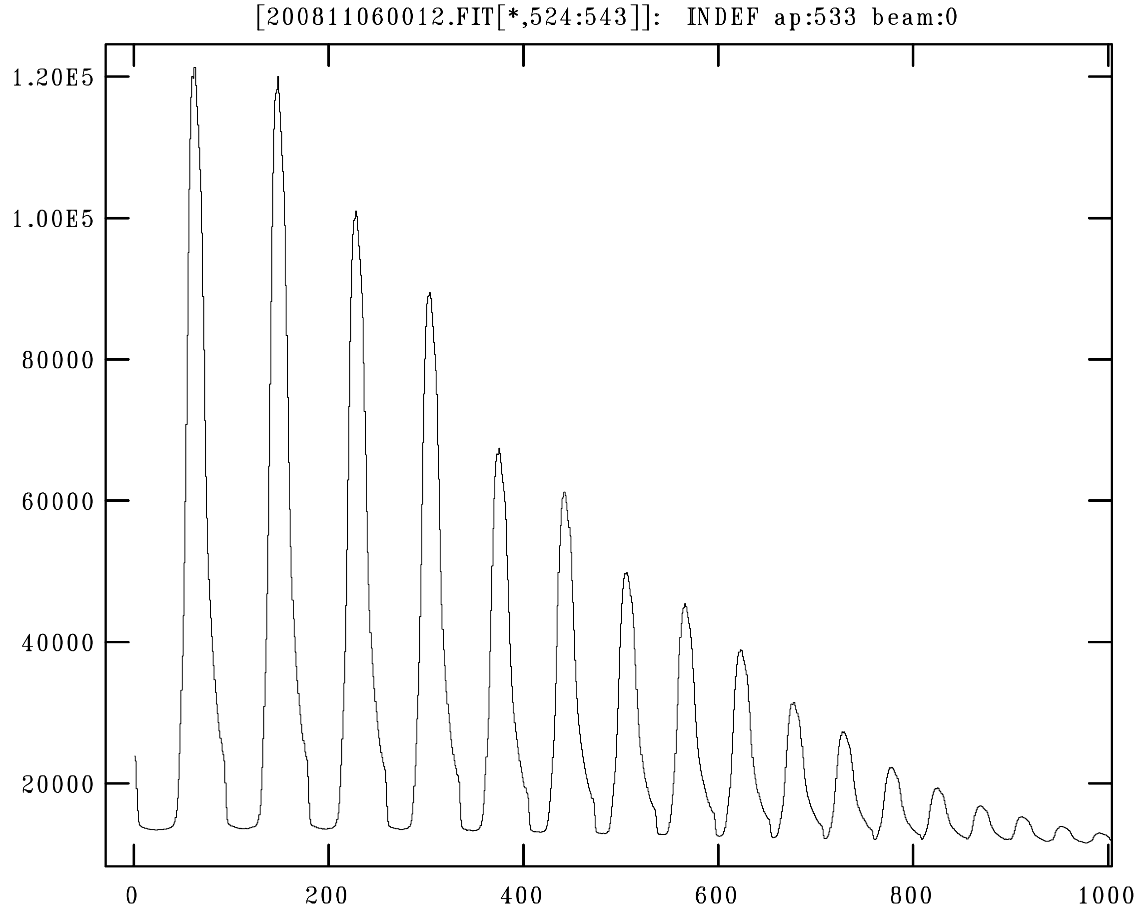
Linearity is a highly desirable property of CCD's. It means that the number of counted electrons is precisely proportional to the number of incident photons. A good way to study this property would be to acquire a set of exposures with a range of exposure times at a constant light level. In that case, the number of incident photons would be proportional to the exposure time, and the relationship between counted electrons (which is related to the number of ADU's through the gain of the CCD) and exposure time could be used to test whether the number of detected photons is also precisely proportional to the exposure time.

Our experiment departs from this ideal in two ways: the shortest exposures may deviate from their nominal values because of the response time of the shutter; and the brightness of the flat lamp is variable. Therefore, in this lab we will carry out a test that is more limited, but still a strong test of linearity: we will use the relative heights of the peaks in the cross-sectional plot of the flat lamp frames, as a function of order number. Such a plot is shown in Figure 1. The relative peak heights depend on the temperature of the lamp (which presumably radiates as a black body), the blaze function of the cross disperser, the efficiency of the échelle grating as a function of order number, and the efficiency of the optical fiber and other optical components of the spectrograph system as a function of wavelength. But, if the detector is linear, they do not depend on the exposure level.

## Procedure

The basic technique for comparing images will be to overplot them with the task *splot*. Set the task parameter *dispaxis* so that *splot* will plot your images perpendicular to the dispersion of the échelle grating. More suggestions:

Figure 1: Cross-sectional plot of one of the 0.5-s flats with `nsum = 20`. The plot window has been zoomed in to the left-hand half of the image. For your analysis, you may want to zoom in even more. In this example, the original file name extension is used.



- Add together 20 rows (`:nsum 20` in the graphics window) for better signal-to-noise ratio and use the same 20 rows throughout the lab. In the example in Figure 1, the fifth peak from the left is lower than it should be (why?). Make sure the peak heights follow a smoother progression than in this example; if not, choose a different set of 20 rows.

- For easier comparison, normalize all the images to their values in a chosen region in the first (least-exposed, shortest-wavelength, highest-numbered) order where the signal is reasonably uniform. Task: *noao.imred.generic.normalize*. Set the parameter *sample* to your chosen image section and leave the parameters *norm, lower,* and *upper* unchanged.

- Now you should be able to see the onset of nonlinearity at the highest signal levels in the 4-second exposures. For best detection, divide the median 4-second exposure by the median 2-second exposure and plot the averaged 20 rows of the quotient image.

## Questions to Answer

1. What is the signal level in the original image at which the values in the quotient image depart from 1? The `'m'` key of *splot* may be helpful here.
2. At this point, what is the percentage departure from linearity?
3. Is there a reason other than detector nonlinearity why the quotient image might differ from unity? What about a slight shift in the position of the peaks between the two images? What do you think the correct expanation is?
4. Is there anything special about the 20 rows you chose? To check, repeat all your steps with another set of 20 rows in a different part of the CCD.

# 2 Data Reduction

In this part, we will return to using the spectra taken on 22 October 2007. They are in the *astro1* directory `/mnt/vol01/ndm/iraf/course/F2008/`. We will carry out the initial steps of data reduction as demonstrated in class. First, though, we need to do preliminary processing of the images.

## Pre-processing

1. Construct the median of all ten bias and the median of all ten blue flat exposures.
2. Subtract (*imarith*) the median bias from the star image you will process, and also from the Th-Ar image just before and just after it. You'll need the Th-Ar image in Lab 4. Each student will work on a different star as follows.

Table 1: Stellar spectra

| Student | Star | RA (2000) | Dec. (2000) |
|---|---|---|---|
| Davidson | $\alpha$ (alpha) Cyg | 20:41:26 | +45:16:49 |
| Gray | 9 Cep | 21:37:55 | +62:04:55 |
| Harrod | HR 1035 | 03:29:04 | +59:56:25 |
| Matteson | HR 1040 | 03:29:55 | +58:52:43 |
| Norton | $\epsilon$ (epsilon) Ori | 05:36:13 | -01:12:07 |

3. Using *hedit*, add keywords *RA*, *dec*, and *epoch* to the image header of your stellar spectrum using colons as in Table 1.

4. In IRAF, open the *twodspec:apextract* package. As demonstrated in class, use *apedit* to define the aperture and the background for the third and fourth peaks from the left in your median blue flat. In the middle of the spectrum, they are located at $x \simeq 300$ and 370, respectively.
5. Trace the two apertures with *aptrace*.
6. Using the flat as a reference, edit and trace the same apertures for the spectrum of your star.
7. Using *apsum*, extract the spectra of the flat and the star.
8. Divide the flat by its own median with *normflat*.
9. Using the `'t'` key in *splot*, fit a high-order cubic spline to both apertures of the flat.
10. Divide the star by the fitted function. Trim off any spiky pixels from the end by means of an image section. You now have a spectrum that is ready for wavelength calibration.

The nontrivial parameters for these tasks are listed below. It's OK to do both the aperture editing and the tracing step with *aptrace*.

```
PACKAGE = apextract
   TASK = apedit
...

(interac=                 yes) Run task interactively?
(find   =                  no) Find apertures?
(recente=                  no) Recenter apertures?
(resize =                  no) Resize apertures?
(edit   =                 yes) Edit apertures?

(line   =               INDEF) Dispersion line
(nsum   =                  10) Number of dispersion lines to sum or median
(width  =                 35.) Profile centering width
```

In *aptrace*, don't forget to examine the residuals of the fit with the `'j'` key and adjust the order of the fitted polynomial until the residuals are randomly distributed. You may wish to use a `spline3` fitting function.

```
PACKAGE = apextract
   TASK = apsum

...

(apertur=                    ) Apertures
```

```
(format =            multispec) Extracted spectra format

...

(profile=                     ) List of aperture profile images

(interac=                   no) Run task interactively?
(find   =                   no) Find apertures?
(recente=                   no) Recenter apertures?
(resize =                   no) Resize apertures?
(edit   =                   no) Edit apertures?
(trace  =                   no) Trace apertures?
(fittrac=                   no) Fit the traced points interactively?
(extract=                  yes) Extract apertures?
(extras =                   no) Extract sky, sigma, etc.?

...

(backgro=                  fit) Background to subtract (none|average|fit)
(weights=             variance) Extraction weights (none|variance)
(pfit   =                fit1d) Profile fitting type (fit1d|fit2d)
(clean  =                  yes) Detect and replace bad pixels?
(skybox =                    1) Box car smoothing length for sky
(saturat=                INDEF) Saturation level
(readnoi=                    8) Read out noise sigma (photons)
(gain   =                    6) Photon gain (photons/data number)
(lsigma =                   4.) Lower rejection threshold
(usigma =                   4.) Upper rejection threshold
(nsubaps=                    1) Number of subapertures per aperture
(mode   =                   ql)


PACKAGE = generic
   TASK = normflat

(norm   =                INDEF) Normalization if not INDEF
(minflat=                   1.) Minimum data value to use in the flat field
(sample_=                   []) Sample section for determining normalization
```

## 3 Your Report

Everything in this section of the instructions for Lab 1 also applies to this lab. Always be sure to include enough figures and tables to enable the reader to replicate your work and diagnose errors, if any.

CCD Observing Log of Ritter Observatory

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Echelle settings** | | UT Date: 6 Nov 2008 | Observer: NDM, AMG, JWD, MPN/ENH | | **LDS Settings** | | |
| X-Disp Tilt: 208.0 | $\lambda_c$: Hα | Exposure: 20081105 | Temp. (°C): 22.8 | RH (%): 55 | Grating: 6 | $\lambda_c$: Hα | Tilt: 4° |
| Echelle Tilt: 22.25 | Slit: 275 | Sky Conditions: clear | | | Slit: 255 | Temp.: -87.5°C | Focus: 5.81 |

| Exp # | Start Time (UT) | Dur (s) | HA Start | E/L | Object | Sp. Type | V Mag | ADU's (/pix) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 1-5 | 0:29 | 0 | | E | Bias | | | 509 | |
| 6-10 | 0:33 | 20 | | E | Blue Flat | | | 4751 | |
| 11-15 | 0:41 | 0.5 | | E | Red Flat | | | 4729 | |
| 16-18 | 0:42 | 0.25 | | E | " | | | 2762 | exposures for linearity test |
| 19-21 | 0:44 | 1 | | E | " | | | 8323 | |
| 22-24 | 0:45 | 2 | | E | " | | | 15723 | |
| 25-27 | 0:46 | 4 | | E | " | | | 21605 | |
| 28 | 1:02 | 300 | | E | Th-Ar | | | | |
| 29 | 1:09 | 300 | +1:55 | E | alpha Cyg | A2Ia | 1.25 | 842 | #30 Th-Ar 1:15 |
| 31 | 1:39 | 300 | +3:16 | E | alpha Aql | A7V | 0.8 | 773 | #32 Th-Ar 1:45 |
| 33 | 2:03 | 300 | -1:09 | E | alpha Cas | K0IIIa | 2.23 | 738 | #34 Th-Ar 2:09 |
| 35 | 2:29 | 600 | +1:07 | E | iota Cep | K0III | 3.50 | 658 | #36 Th-Ar 2:40 |
| 37 | 2:54 | 900 | -0:34 | E | gamma Cas | B0IV | 2.47 | 935 | #38 Th-Ar 3:10 |
| 39 | 3:30 | 3600 | +1:58 | E | HR8752 | G0Iab | 5.00 | 639 | Students left after starting this one ... #40 4:31 Th-Ar |
| 41 | 4:41 | 3600 | +2:09 | E | LQ And | B4Vne | 6.5 | 530 | #42 5:44 Th-Ar |
| 43 | 6:05 | 3600 | +1:11 | E | 9 Per | A2 Ia | 5.2 | 618 | #44 7:06 Th-Ar |
| 45 | 7:30 | 1800 | +1:29 | E | HR 1035 | B9 Ia | 4.2 | 645 | #46 8:01 Th-Ar |
| 47 | 8:19 | 1800 | +0:53 | E | alpha Cam | O9.5 Ia | 4.3 | 606 | #48 8:50 Th-Ar |
| 49 | 9:05 | 900 | +1:32 | E | epsilon Aur | A9 Ia | 3.0 | 723 | #50 9:22 Th-Ar |