Homework 2: IRAF version

Install IRAF: these clear instructions work well

https://faculty1.coloradocollege.edu/~sburns/courses/18-19/pc362/Anaconda_IRAF_install.html

Note that for every session you need to activate Python 2.7:

$ source activate iraf27

Homework 2: IRAF version

Start IRAF in the iraf directory you set up with the *"cl"* command

Go to the directory with the images:

cl>imhead framename lo+

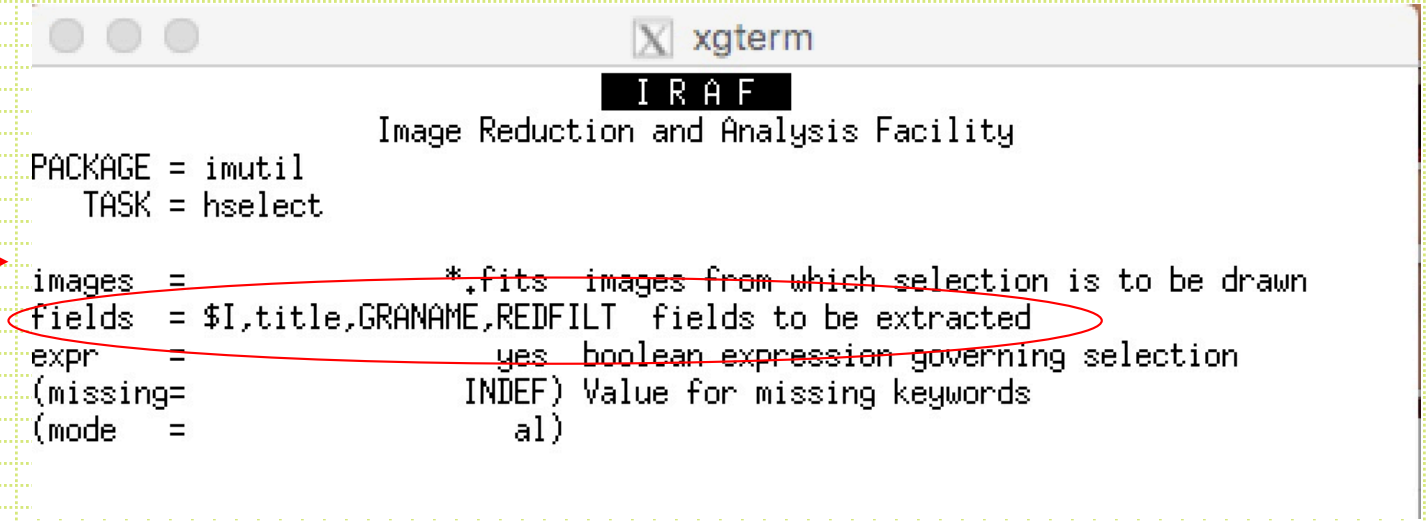
will list the full header for one frame. GRANAME='mirror' is direct imaging mode, REDFILT='B' means the B filter was selected and in the beam

```
ecl> imhead lris0305 lo+
lris0305[2248,2048][real]: M92 B 180s
No bad pixels, min=0., max=65535.
Line storage mode, physdim [2248,2048], length of user area 4131 s.u.
Created Thu 10:47:20 31-Jan-2019, Last modified Wed 13:48:45 31-Mar-2004
Pixel file "lris0305.fits" [ok]
EXTEND  =                    F / File may contain extensions
ORIGIN  = 'NOAO-IRAF FITS Image Kernel December 2001' / FITS file originator
DATE    = '2004-03-31T21:48:45' / Date FITS file was generated
IRAF-TLM= '13:48:45 (31/03/2004)' / Time of last modification
DATAMIN =           0.000000E0 / Minimum data value
DATAMAX =           6.553500E4 / Maximum data value
OBJECT  = 'M92 B 180s'         / Name of the object observed
IRAF-MAX=           6.553500E4  /  DATA MAX
IRAF-MIN=           0.000000E0  /  DATA MIN
TRAPDOOR= 'open    '           /
SLITNAME= 'direct  '           /
SLITMASK=                    1 /
GRANAME = 'mirror  '           /
GRATING =                    1 /
GRANGLE =          13.54401779 /
REDFILT = 'B       '           /
REDFNUM =                    2 /
REDFOCUS=       2059.84228516 /
LAMPS   = '0,0,0,0 '           /
TEMPDET =         -99.79941559 /
TV1FPOS =         259.98611450 /
UT      = '14:42:40.75'         /
AIRMASS =           1.30860332 /
TARGNAME= 'm92     '           /
RA      = '17:15:31.40'         /
DEC     = '43:05:13.00'         /
EQUINOX =        1950.00000000 /
AZ      =         -45.64705767 /
EL      =          49.78864653 /
HA      = '+02:37:13.89'        /
ST      = '19:54:14.44'         /
ROTMODE = 'position angle'      /
ROTPPOSN=       -113.12925587 /
ROTPOSN =         -0.00017639 /
TELFOCUS=          0.00123932 /
SECFOCUS=          0.00136090 /
TUBETEMP=         -1.51647997 /
SIMULATE=                    F /
TELESCOP= 'Keck II '           /
PMFM    =          0.00000000 /
PONAME  = 'LRIS    '           /
FRAMENO =                  305 /
OBSNUM  =                  305 /
OUTFILE = 'lris    '           /
OUTDIR  = '/sdata203/lris8/may1597/' /
TTIME   =                  240 /
EXPOSURE=                  240 /
ELAPTIME=                  240 /
AUTOSHUT=                    T /
NUMAMPS =                    2 /
AMPLIST = '2,1,0,0 '           /
VOFFSET0=                  156 /
VOFFSET1=                  152 /
CCDGAIN =                    F /
REDXFLIP=                    T /
IMTYPE  = 'TWOAMPTOP'          /
PREPIX  =                   21 /
PRELINE =                    0 /
POSTPIX =                   79 /
POSTLINE=                    0 /
ERASLINE=                    0 /
KEEPPREP=                    1 /
PREFLUSH=                    0 /
OVRFLUSH=                    0 /
BINNING = '1, 1    '           /
WINDOW  = '0,0,0,2048,2048'    /
COMMENT = '* This image was generated by the Low Resolution Imaging         '
COMMENT = '* Spectrograph                                                   '
COMMENT = 'RUN-SPECIFIC COMMENTS FOLLOW                                     '
COMMENT = '-----------------------------------------------------------------'
COMMENT = '                                                                 '
HISTORY '15/05/97'           /
```

Homework 2: IRAF version

hselect can be used to pull out the fields you are interested in

cl>epar hselect →



This selection lists the file name, title, grating selection and filter

Note the title incorrectly stated the R filter for some of the frames

```
ecl> hselect
images from which selection is to be drawn (*.fits):
fields to be extracted ($I,title,GRANAME,REDFILT):
boolean expression governing selection (yes):
lris0031.fits   "twilight B some clouds"        mirror  B
lris0071.fits   "Draco B  15s"  mirror  B
lris0085.fits   "B twilights"   mirror  B
lris0232.fits   "B dflats"      mirror  B
lris0305.fits   "M92 B 180s"    mirror  B
lris0320.fits   "R twilights near M92"  mirror  B
ecl>
```

These are the fields asked for in the homework: $I, title, EXPOSURE, EL, ROTPPOSN

you can have the information written out to a text file using the Unix redirect command

*cl> hselect *.fits >lrisheader.txt*

```
ecl> hselect *fits
fields to be extracted ($I,title,exp): $I,title,EXPOSURE,EL,ROTPPOSN
boolean expression governing selection (yes):
lris0031.fits   "twilight B some clouds"        30      78.73476196     58.87942
184
lris0071.fits   "Draco B  15s"  30      48.00023107     -145.03545135
lris0085.fits   "B twilights"   20      40.21095264     -119.44008007
lris0232.fits   "B dflats"      10      45.00000101     0.00000000
lris0305.fits   "M92 B 180s"    240     49.78864653     -113.12925587
lris0320.fits   "R twilights near M92"  2       43.93964358     -105.16907077
```

Image statistics: imstat

cl>epar imstat

xgterm

```
                                  I R A F
                Image Reduction and Analysis Facility
PACKAGE = imutil
   TASK = imstatistics

images  =                *.fits  List of input images
(fields = image,mean,mode,stddev) Fields to be printed
(lower  =                    0.) Lower limit for pixel values
(upper  =                65550.) Upper limit for pixel values
(nclip  =                     0) Number of clipping iterations
(lsigma =                    3.) Lower side clipping factor in sigma
(usigma =                    3.) Upper side clipping factor in sigma
(binwidt=                   0.1) Bin width of histogram in sigma
(format =                   yes) Format output and print column labels ?
(cache  =                    no) Cache image in memory ?
(mode   =                    al)
```

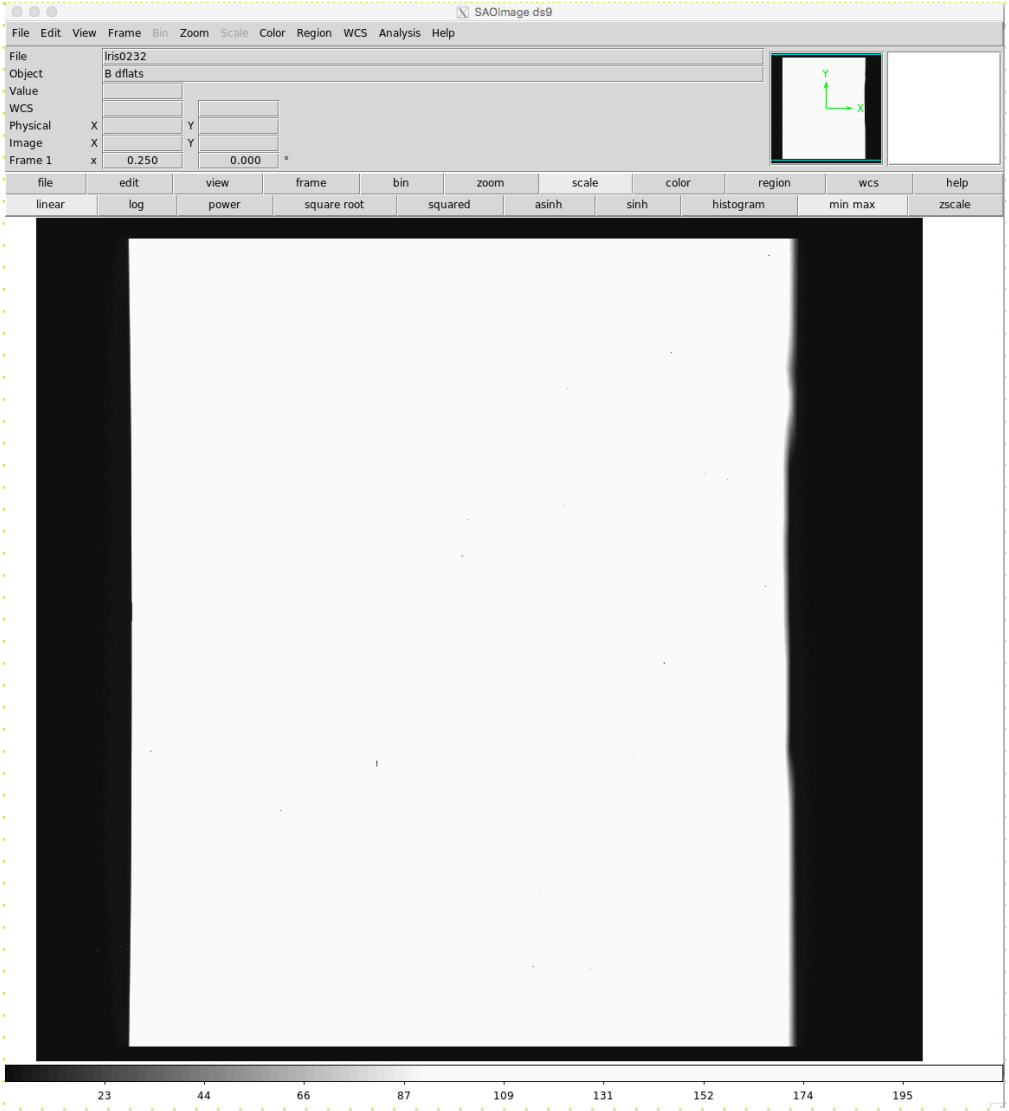
*cl>imstat *.fits*

Note the saturated frame 0085

```
#               IMAGE      MEAN      MODE    STDDEV
        lris0031.fits    10045.    12663.     5319.
        lris0071.fits     1101.     1103.      968.
        lris0085.fits    48976.    65358.    27812.
        lris0232.fits     8211.     1062.     4245.
        lris0305.fits     3897.     4680.     2895.
        lris0320.fits    10949.    13806.     5840.
```

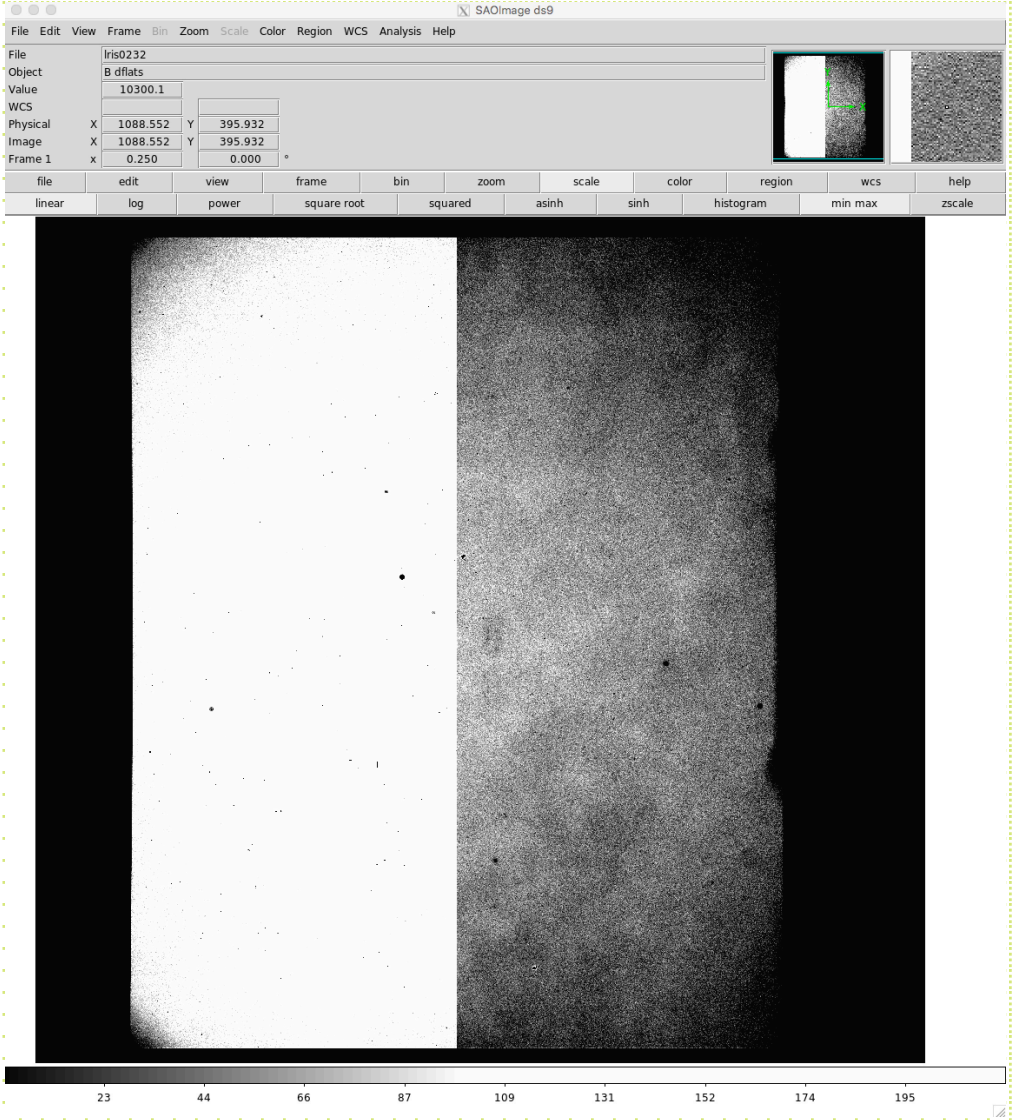
Bias correction

cl> display lris0232 (default zscale and zrange)



Bias correction

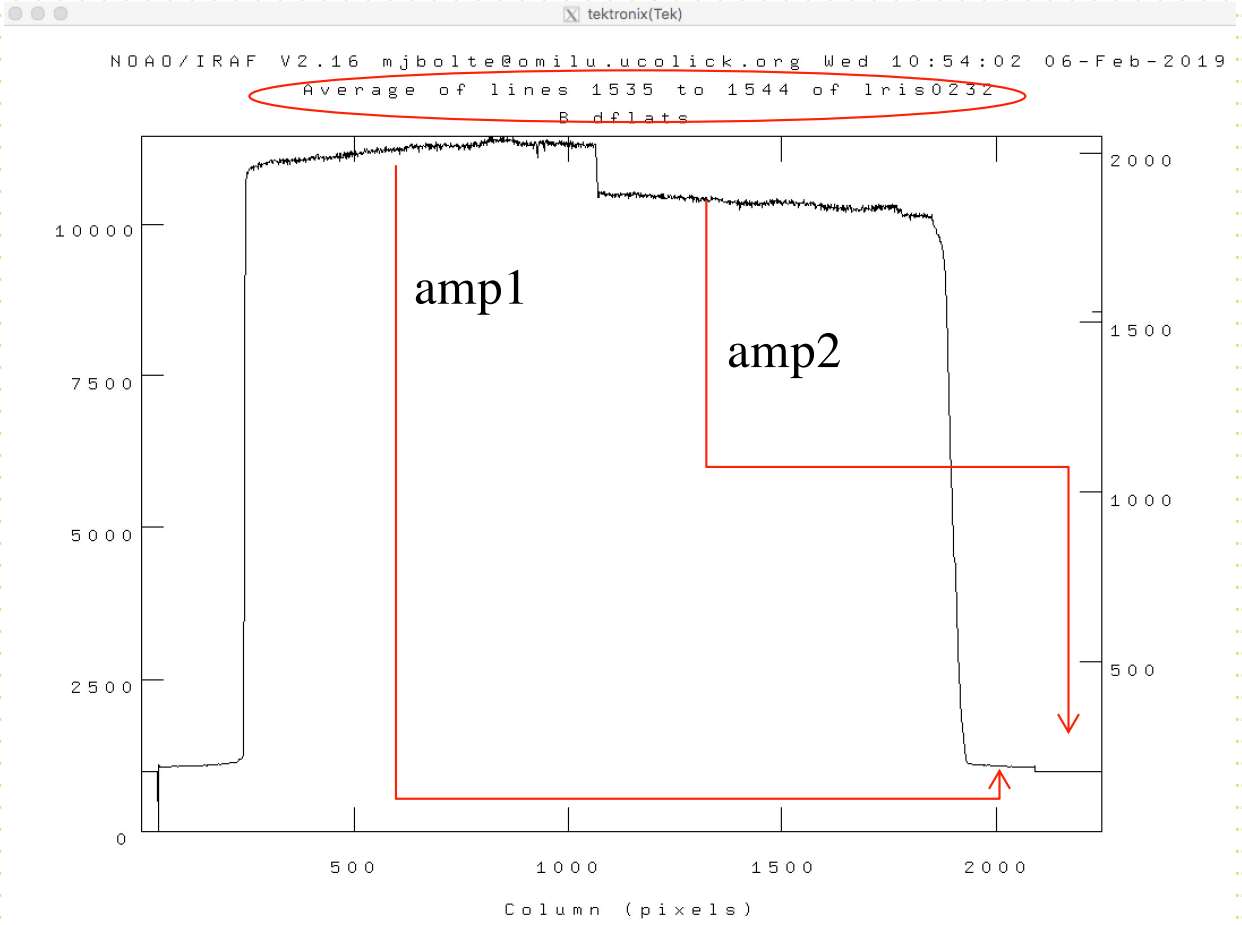
cl> display lris0232 zs- zr- z1=9500 z2=11700



Often it is useful to turn off the auto grayscale and set z1 (pixel value set to white) and z2 (pixel value set to black) by hand after looking at the image levels

cl>implot lris0232

This is a cut across the flat field in the previous page averaging 10 lines. You can see the prescan, the active areas of the CCD read from two amplifiers and the overscan for each amp



Colbias (ran script lblue_2amp.cl)

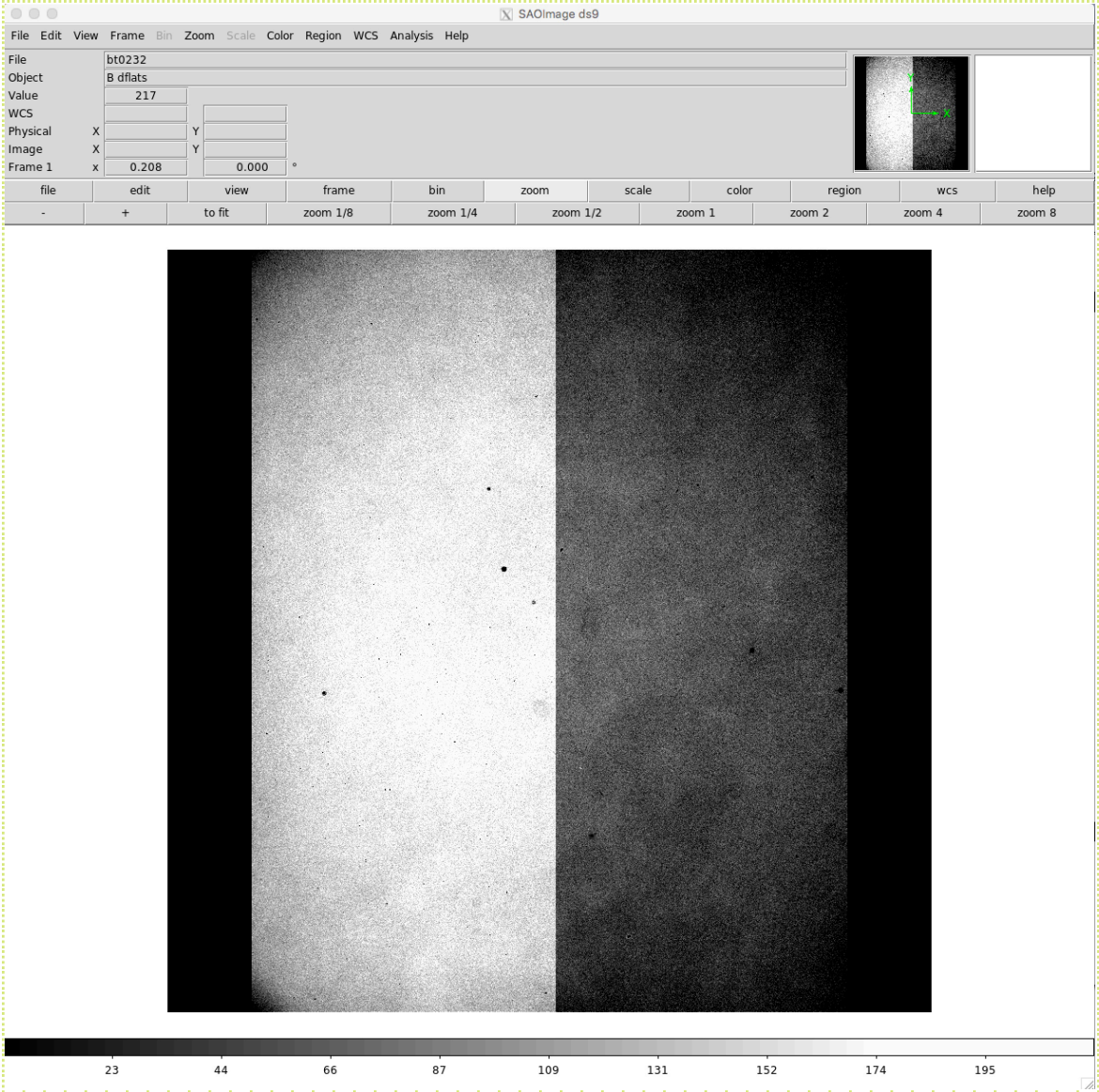
This is the resulting image with both overscans fit along columns and subtracted then the image trimmed to active area.

I usually output a new fits file renamed to indicate the reduction status, e.g.:

lris0086.fits -> bt0086.fits

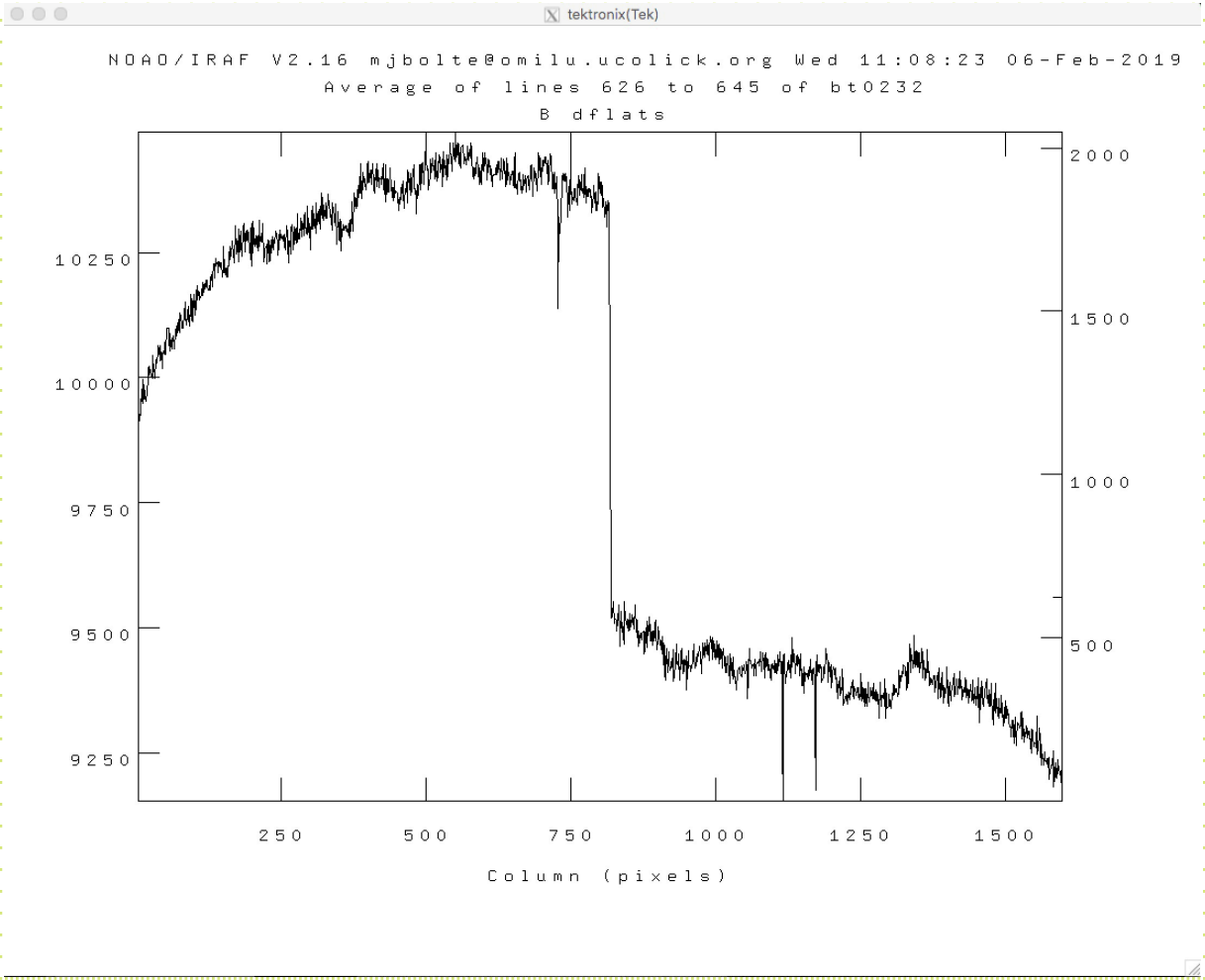
raw

bias corrected and trimmed



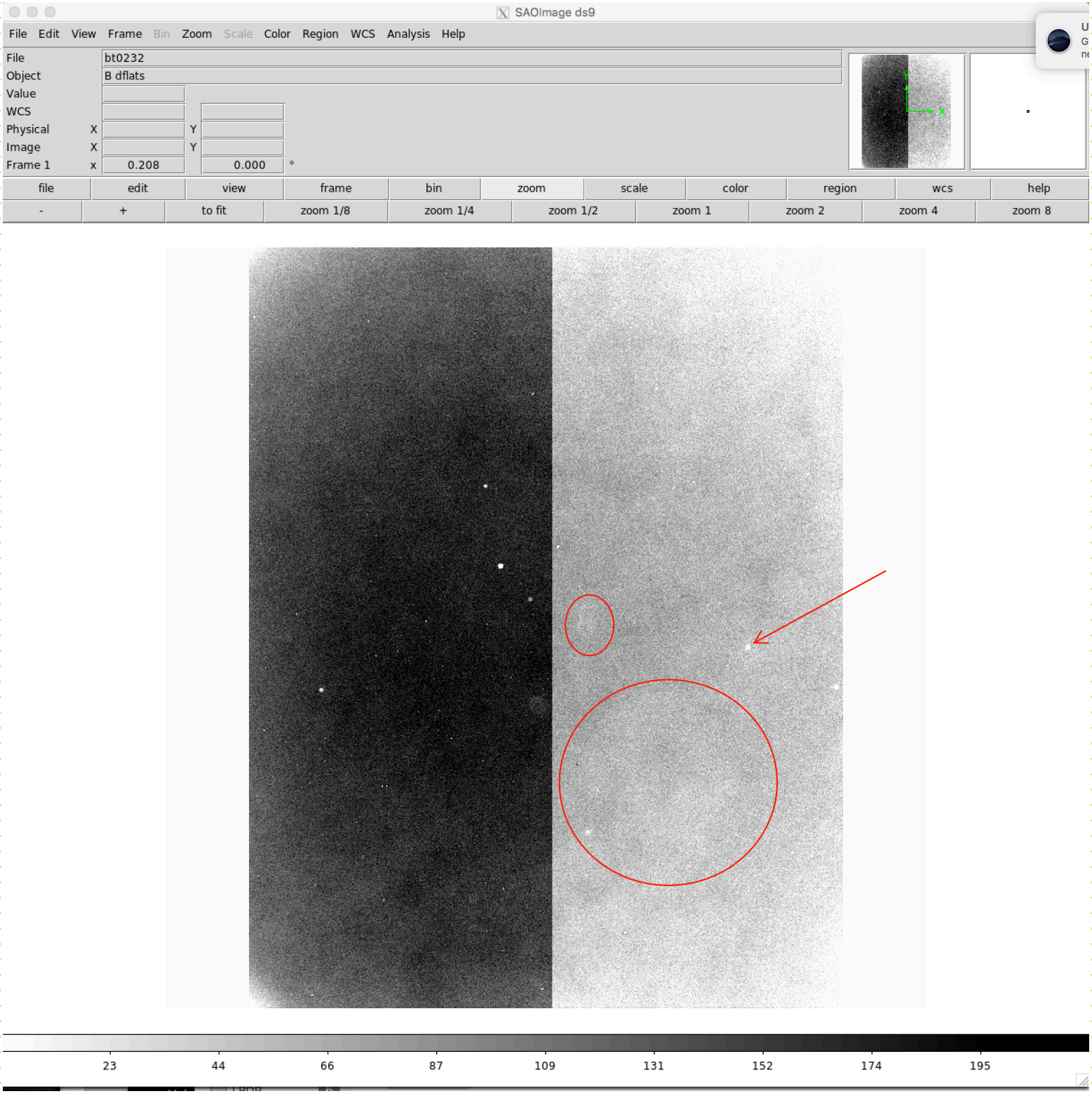
Cut through btxxx.fits

Difference here due to amplifier gain difference rather than bias offset (offset should be corrected)



This is a dome flat after bias correction and timming. Can see:

- amplifier gain difference,
- LRIS vignetting,
- out-of-focus dust,
- in-focus dust on CCD,
- thickness variations
- dust on tertiary



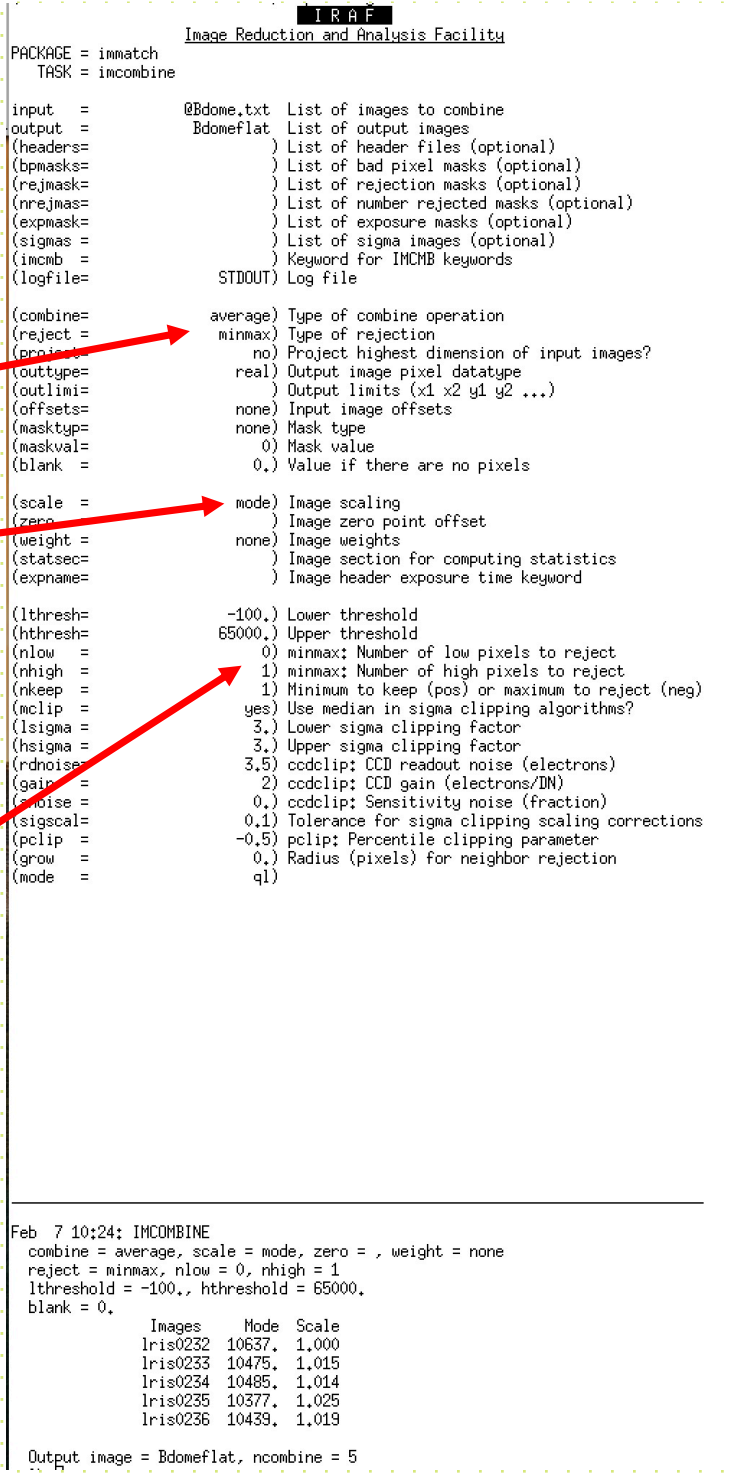
Combine dome flats and twilight flats separately

I usually create some files that list frames of the different types. For example, Bdome.txt is a list of the dome flats. In IRAF you can use the "@" symbol to act on all the frames in the list

```
ecl> cat Bdome.txt
lris0232
lris0233
lris0234
lris0235
lris0236
ecl> imstat @Bdome.txt
#               IMAGE      MEAN      MODE    STDDEV
             lris0232     8211.     1062.     4245.
             lris0233     8085.     1044.     4171.
             lris0234     8096.     1045.     4178.
             lris0235     8014.     1033.     4130.
             lris0236     8059.     1040.     4156.
```

Five dome flats combined using averaging with min-max rejection for each (i,j) pixel and scaling each frame by the mode of the counts.
The scaling in this case corrects for small changes in the flat-field lamp brightness

In this case, reject only the highest pixel value for the 5-frame stack (with dome flats this will only be cosmic rays)



Combining twilight flats I

- make a file with list of twilight flats (Btwi.txt)
- check headers for spectrometer mode (“mirror”) and filter (“B”)
- check count levels and discard from list saturated objects or those with mode >45000 where linearity may be a problem
- Note – would usually do with the bias corrected and trimmed images

```
ecl> hselect @Btwi.txt
fields to be extracted (-"$I,title,GRNAME,REDFILT):
boolean expression governing selection (yes):
"twilight B some clouds"        B
"twilight B some clouds"        B
"twilight B some clouds"        B
"twilight B some clouds"        B
"B twilights"   B
"B twilights"   B
"B twilights"   B
"B twilights"   B
"B twilights"   B
"B tflat"       B
"B tflat"       B
"B tflat"       B
"B tflat"       B
"B tflat"       B
"B tflat"       B
"B tflat"       B
"R twilights near M92"  B
"R twilights near M92"  B
"R twilights near M92"  B
"R twilights near M92"  B
"R twilights near M92"  B
"R twilights near M92"  B
"R twilights near M92"  B
"R twilights near M92"  B
"R twilights near M92"  B
ecl> imstat @Btwi
ERROR: Cannot open file (Btwi)
ecl> imstat @Btwi.txt
#                IMAGE      MEAN      MODE    STDDEV
              lris0031    10045.    12663.     5319.
              lris0032    16550.     1372.     9143.
              lris0033    25032.    31973.    14127.
              lris0034    28537.    36596.    16185.
              lris0085    48976.    65358.    27812.
              lris0086    24636.    31462.    13871.
              lris0087    15549.     1284.     8540.
              lris0088    11863.    15053.     6378.
              lris0089    17621.     1466.     9758.
              lris0254    23479.    29835.    13189.
              lris0255    21371.    27058.    11953.
              lris0256    15549.     1285.     8539.
              lris0257    13071.    16704.     7087.
              lris0258     8968.     1172.     4680.
              lris0259     9473.     1222.     4980.
              lris0260     9718.    12896.     5125.
              lris0316    18911.    25621.    10532.
              lris0317    14239.     1170.     7780.
              lris0318    15317.     1263.     8405.
              lris0319    14566.     1198.     7963.
              lris0320    10949.    13806.     5840.
              lris0321    15980.     1321.     8793.
              lris0322    23829.    30276.    13399.
              lris0323    18295.    22996.    10154.
              lris0324    27330.     772.9    15458.
```

Combine twilight flats II

- Average with minmax rejection set asymmetrically to preferentially reject high counts in the pixel stack to eliminate stars and galaxies in the combined image
- For this case where the mean counts vary significantly between frames it is very important to scale images to the mode of the counts before doing the average and minmax rejection. Otherwise frames with high counts would be completely rejected.

```
                                  I R A F
                Image Reduction and Analysis Facility
PACKAGE = immatch
   TASK = imcombine

input   =            @Btwi.txt  List of images to combine
output  =             Btwiflat  List of output images
(headers=                     ) List of header files (optional)
(bpmasks=                     ) List of bad pixel masks (optional)
(rejmask=                     ) List of rejection masks (optional)
(nrejmas=                     ) List of number rejected masks (optional)
(expmask=                     ) List of exposure masks (optional)
(sigmas =                     ) List of sigma images (optional)
(imcmb  =                     ) Keyword for IMCMB keywords
(logfile=                STDOUT) Log file

(combine=                average) Type of combine operation
(reject =                minmax) Type of rejection
(proj   =                    no) Project highest dimension of input images?
(outtype=                  real) Output image pixel datatype
(outlimi=                     ) Output limits (x1 x2 y1 y2 ...)
(offsets=                  none) Input image offsets
(masktyp=                  none) Mask type
(maskval=                     0) Mask value
(blank  =                    0.) Value if there are no pixels

(scale  =                  mode) Image scaling
(zero   =                     ) Image zero point offset
(weight =                  none) Image weights
(statsec=                     ) Image section for computing statistics
(expname=                     ) Image header exposure time keyword

(lthresh=                 -100.) Lower threshold
(hthresh=                65000.) Upper threshold
(nlow   =                     2) minmax: Number of low pixels to reject
(nhigh  =                     6) minmax: Number of high pixels to reject
(nkeep  =                     1) Minimum to keep (pos) or maximum to reject (neg)
(mclip  =                   yes) Use median in sigma clipping algorithms?
(lsigma =                    3.) Lower sigma clipping factor
(hsigma =                    3.) Upper sigma clipping factor
(rdnoise=                   3.5) ccdclip: CCD readout noise (electrons)
(gain   =                     2) ccdclip: CCD gain (electrons/DN)
(snoise =                    0.) ccdclip: Sensitivity noise (fraction)
(sigscal=                   0.1) Tolerance for sigma clipping scaling corrections
(pclip  =                  -0.5) pclip: Percentile clipping parameter
(grow   =                    0.) Radius (pixels) for neighbor rejection
(mode   =                    ql)
```

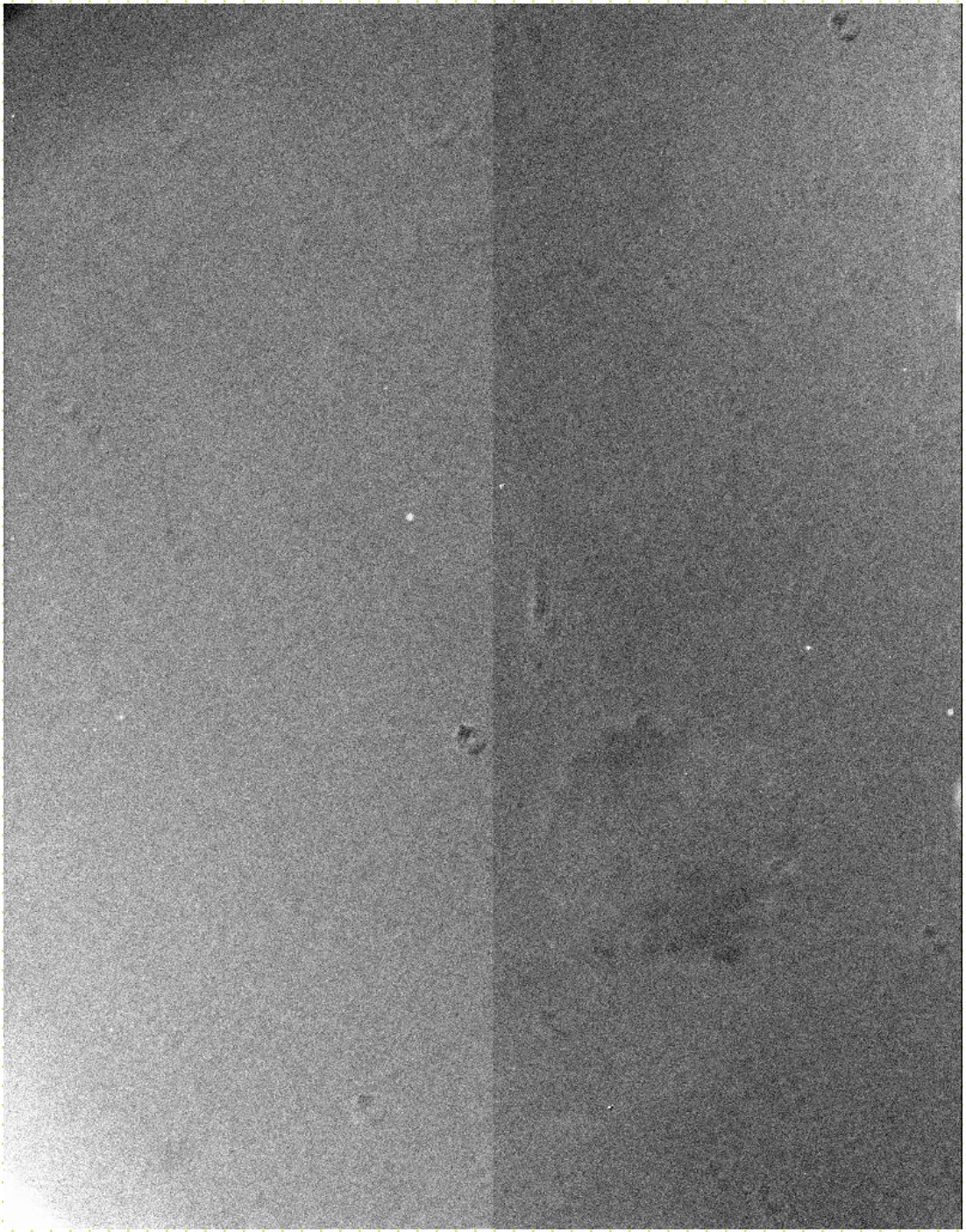
```
Feb  7 10:58: IMCOMBINE
  combine = average, scale = mode, zero = , weight = none
  reject = minmax, nlow = 2, nhigh = 6
  lthreshold = -100., hthreshold = 65000.
  blank = 0.
                Images     Mode  Scale
                 bt0031  11768.  1.000
                 bt0032  20249.  0.581
                 bt0033  31332.  0.376
                 bt0034  35893.  0.328
                 bt0086  30753.  0.383
                 bt0087  18945.  0.621
                 bt0088  14168.  0.831
                 bt0089  21647.  0.544
                 bt0254  29268.  0.402
                 bt0255  26585.  0.443
                 bt0256  18937.  0.621
                 bt0257  15730.  0.748
                 bt0258  10396.  1.132
                 bt0259  11050.  1.065
                 bt0260  11383.  1.034
                 bt0316  23299.  0.505
                 bt0317  17184.  0.685
                 bt0318  18593.  0.633
                 bt0319  17637.  0.667
                 bt0320  12896.  0.913
                 bt0321  19479.  0.604
                 bt0322  29777.  0.395
                 bt0323  22487.  0.523
                 bt0324  34317.  0.343

  Output image = Btwiflat, ncombine = 24
```

I usually do some experiments like:

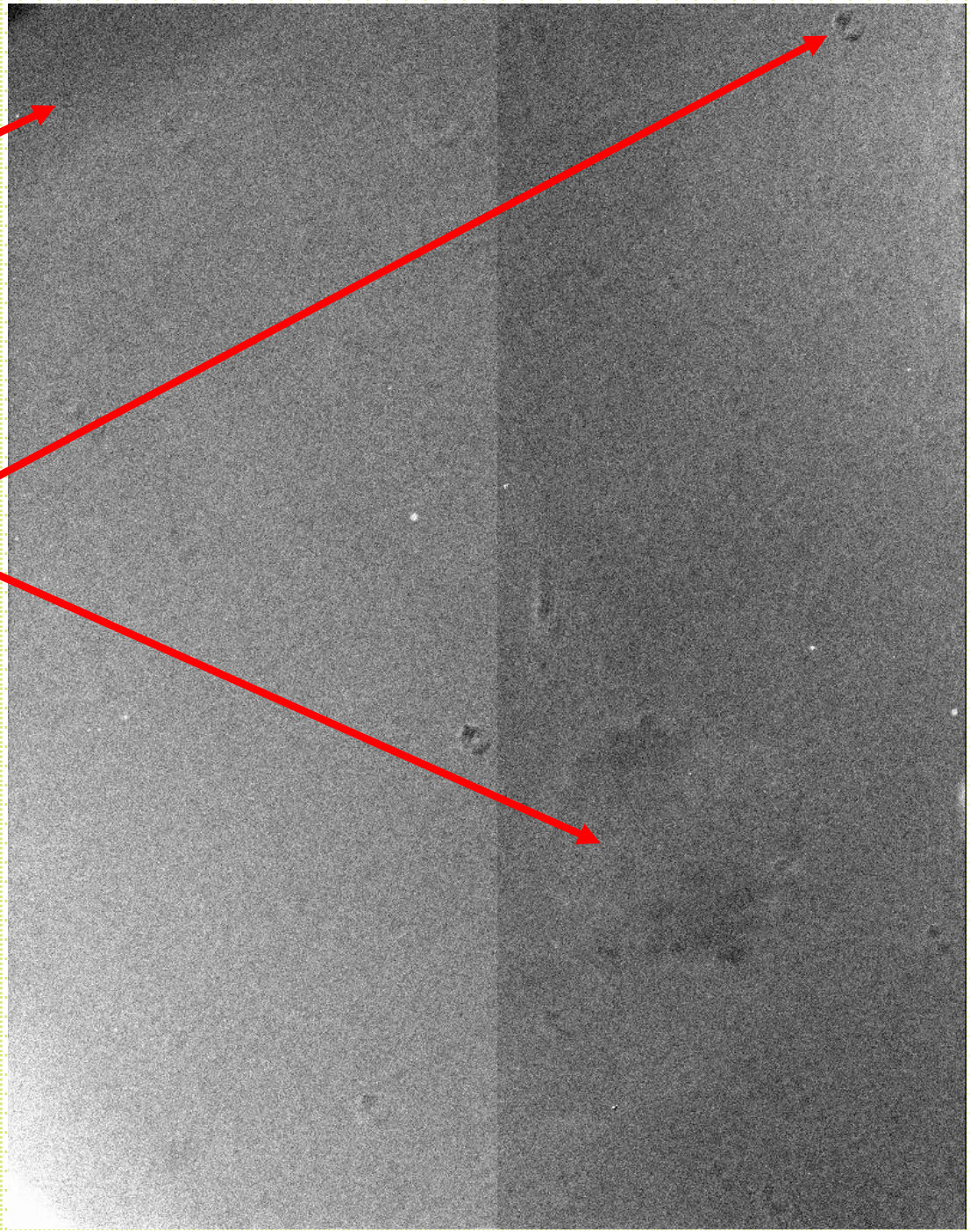
- combining evening flats and morning flats separately to see if dust showed up on a filter or mirror during the night
- divide the final combined dome flat by the final combined twilight to see if all the stars and galaxies were adequately removed in the twilights

This is the result of Dome/Twilight normalized to 1 (*imdivide*), displayed with z1=0.98 z2=1.02



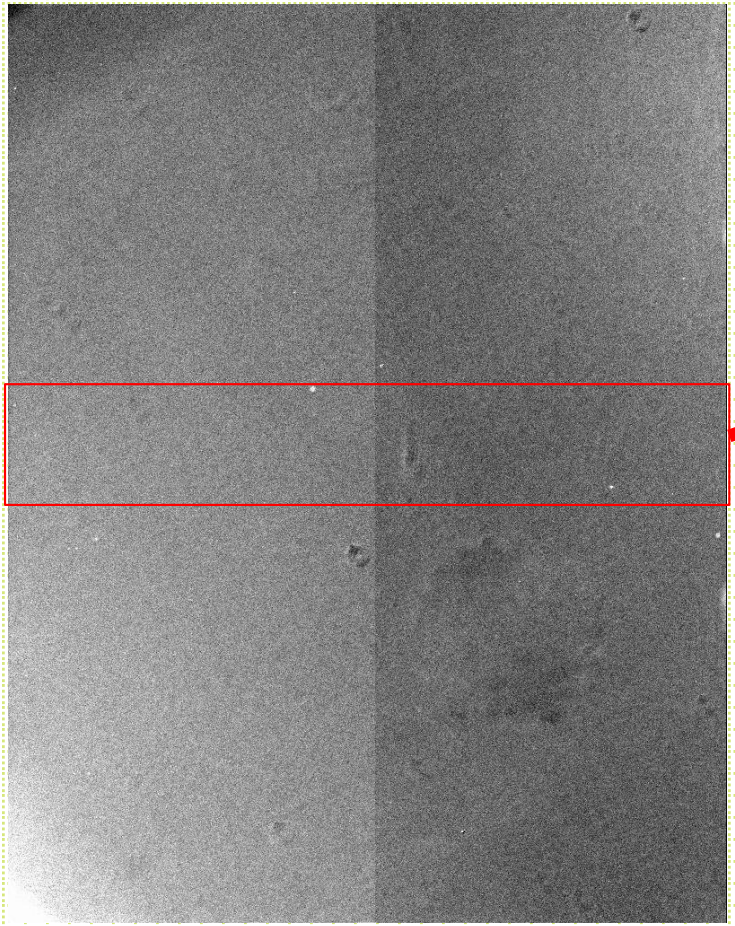
You can see some features:

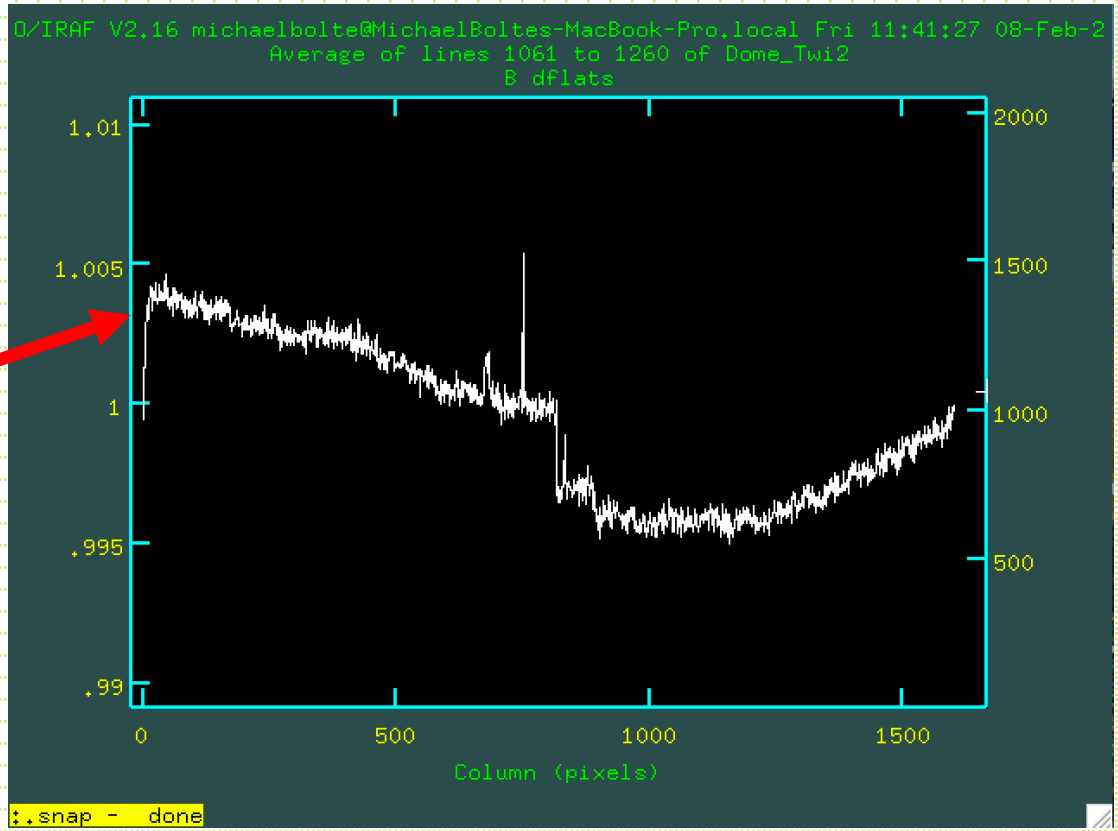
- Difference in vignetting between the domes and twilights (twilights will better model the program images)
- Residuals from filter dust (small donuts) and tertiary/secondary dust (large donuts) due to (1) different illuminations of dome flat and twilight flat, (2) instrument flexure between telescope position/instrument rotation for the dome flat and twilight flats
- Possibly some low-level residuals from stars and galaxies that did not get 100% removed when combining twilight flats. I make a few twilight flats using larger and larger number for max reject and see when the flat no longer changes
- Imperfect correction of gain difference between amplifiers



Quantitatively: take a cut across columns averaging over lines

- Overall trend with amplitude of ~1% is illumination difference dome vs twilight
- Jump at amplifier switch is ~0.5%

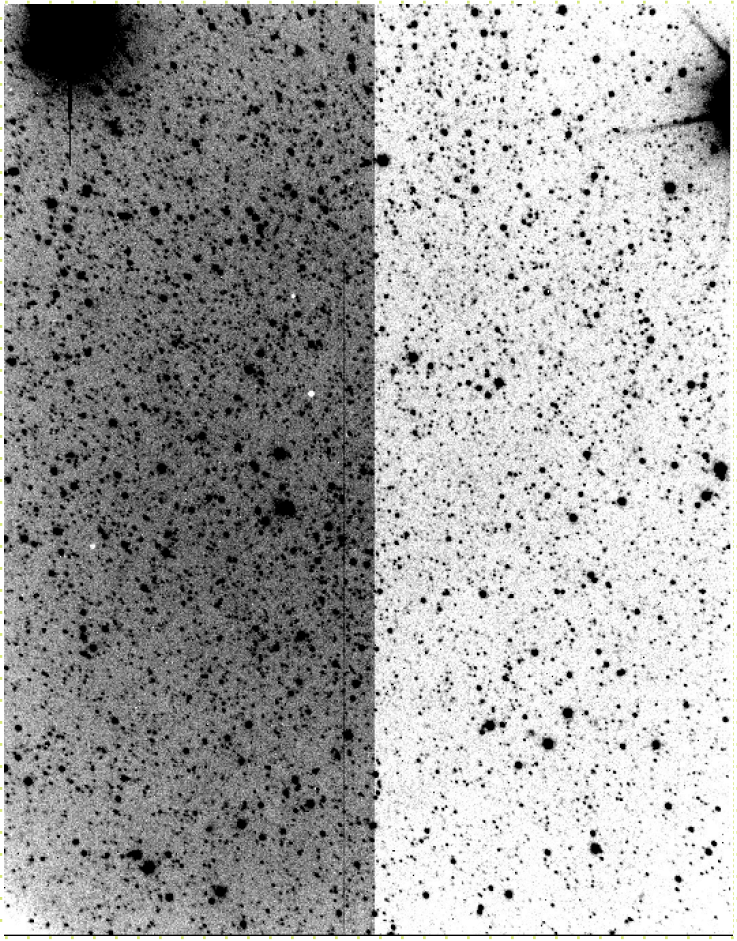




Flat-field a program frame

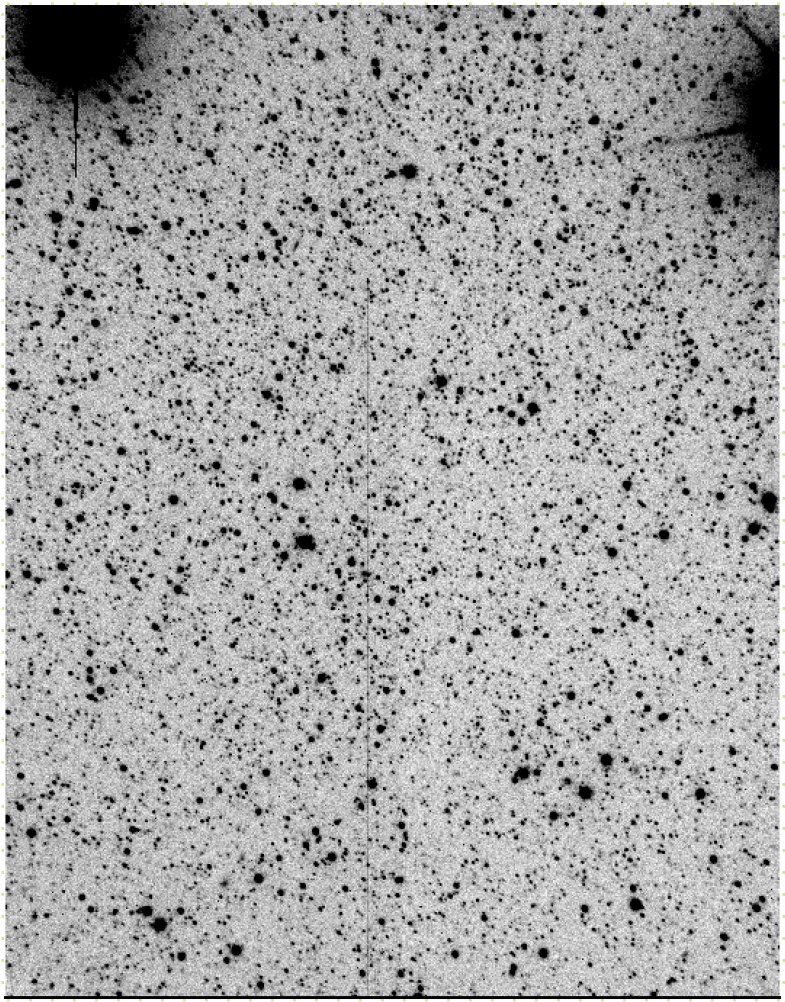
For this case, have enough twilight frames, 24 with average counts of 40,000 e-/pixel (inverse gain is 2 e-/ADU), = 960,000 total detected e-. So, the S/N for the flat-field determination is: SQRT(960,000)/960,000 = 0.001 = 0.1%

Draco field with bias correction and triming



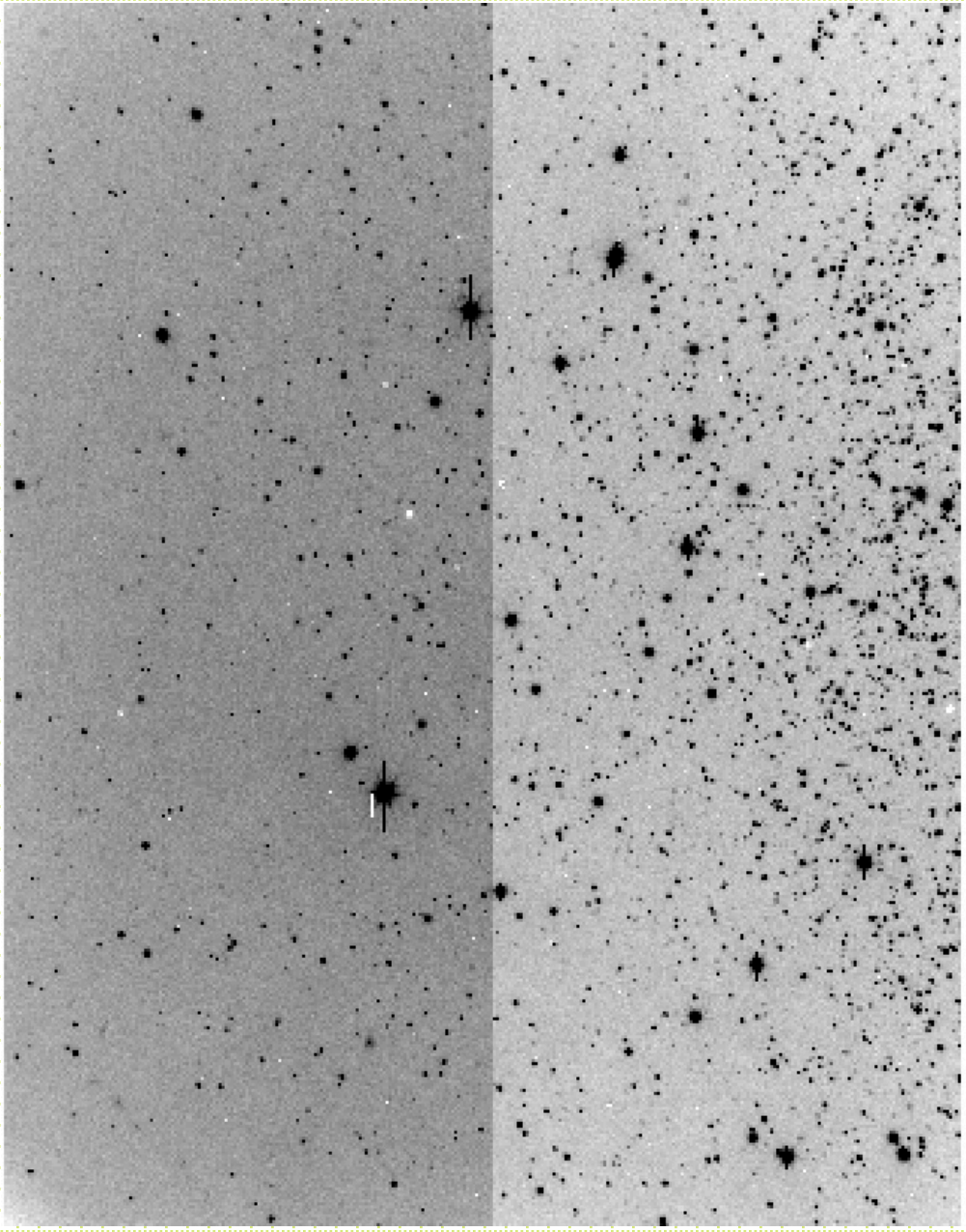
Draco 600s B exposure flat-fielded

Looks fine, but a little hard to evaluate with all the stars

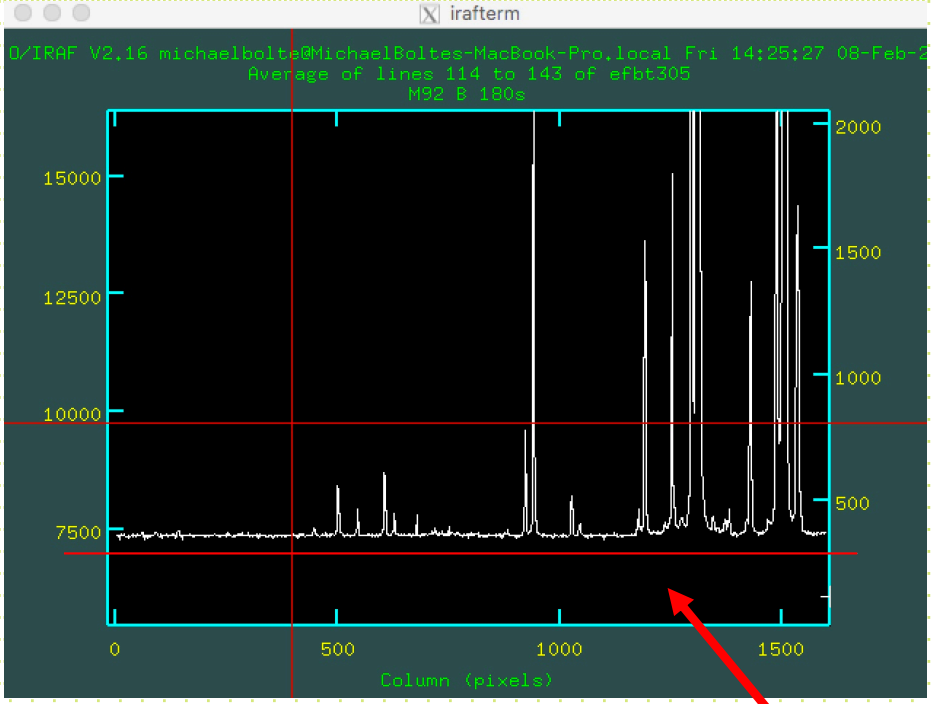


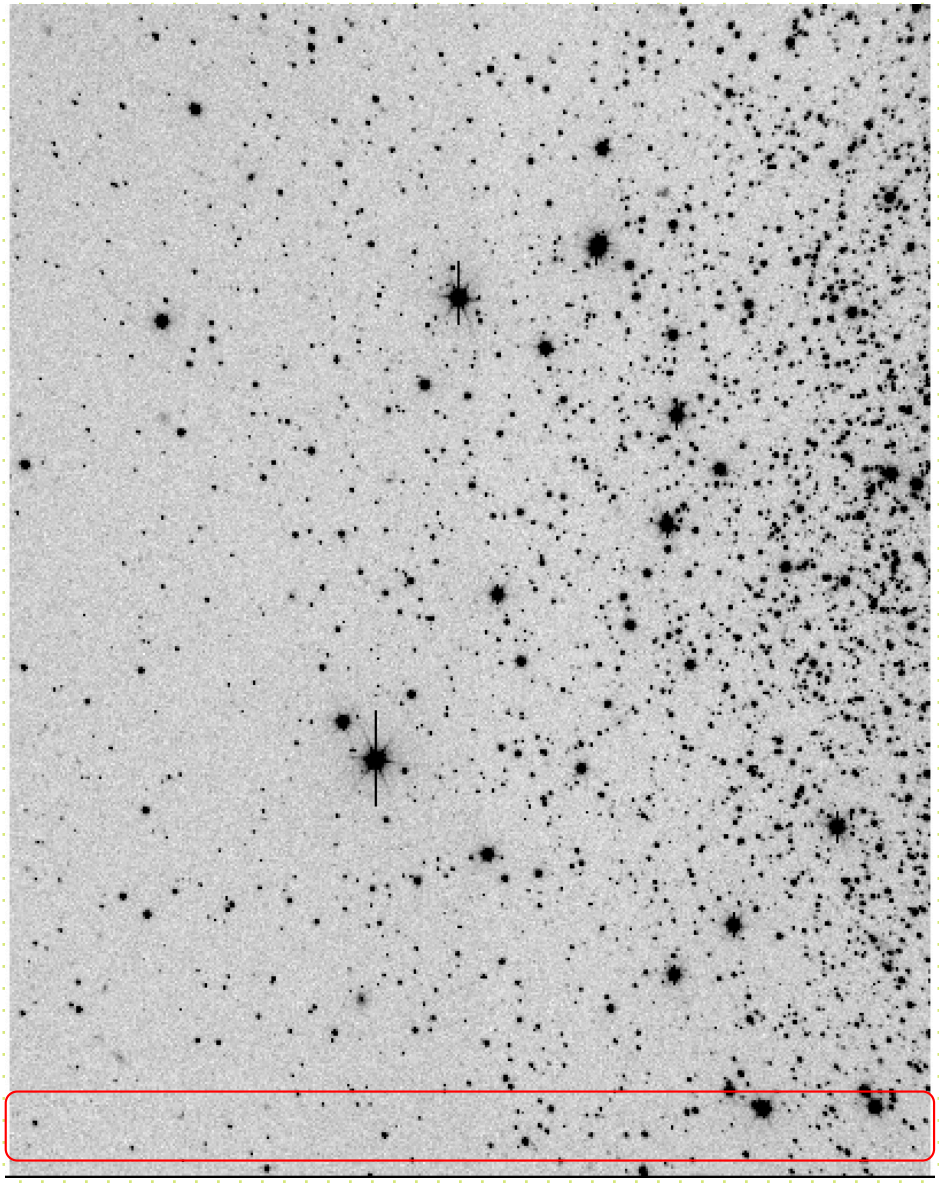
M92 180 second B frame

Bias corrected
and trimmed



M92 flat-fielded





Cut across columns looks flat including corners

M92

imexam and "m"

```
imfilter> imexam
#            SECTION     NPIX      MEAN    MEDIAN    STDDEV       MIN       MAX
   [322:326,779:783]       25    7363.    7366.     104.7     7185.     7577.
   [102:106,995:999]       25    7369.    7386.     90.53     7214.     7545.
    [78:82,1083:1087]      25    7375.    7341.     93.12     7240.     7551.
    [64:68,1483:1487]      25    7355.    7351.     106.8     7219.     7610.
    [76:80,1433:1437]      25    7407.    7405.     102.1     7280.     7670.
 [178:182,1367:1371]       25    7344.    7346.     79.16     7166.     7532.
 [418:422,1137:1141]       25    7367.    7376.     83.33     7219.     7535.
 [444:448,1075:1079]       25    7370.    7374.     99.37     7146.     7561.
   [322:326,801:805]       25    7380.    7379.     74.49     7239.     7563.
   [302:306,777:781]       25    7395.    7388.     69.87     7220.     7517.
   [196:200,551:555]       25    7341.    7348.     97.21     7157.     7591.
   [422:426,391:395]       25    7358.    7350.     104.2     7133.     7506.
 [108:112,1007:1011]       25    7362.    7348.     77.34     7224.     7546.
    [76:80,1091:1095]      25    7385.    7371.     90.96     7236.     7635.
    [38:42,1097:1101]      25    7414.    7391.      112.     7235.     7609.
    [56:60,1025:1029]      25    7370.    7366.     75.68     7155.     7510.
 [174:178,1167:1171]       25    7388.    7413.     93.25     7143.     7587.
[1032:1036,1205:1209]       25    7429.    7455.     101.1     7208.     7631.
[1018:1022,1195:1199]       25    8286.    7761.     1293.     7349.     12356.
 [682:686,1239:1243]       25    7385.    7383.     62.16     7253.     7521.
 [442:446,1129:1133]       25    7373.    7368.     82.98     7155.     7526.
```

Look at the pixel count statistics from 5x5 boxes on the "sky". shot noise in the sky ~SQRT(7360)=86e- is consistent with STDDEV of the 25 pixel boxes so poor flat-fielding is not contributing to pixel-to-pixel noise