Lecture 11

November 15, 2018

Lab 6

News

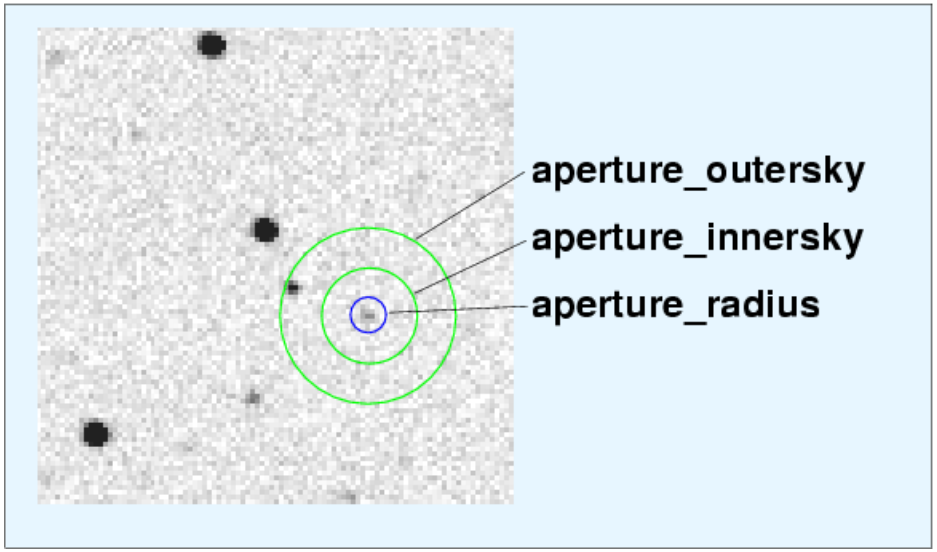
- Lecture is on Tuesday next week.
- Labs 3 and 4
  - Handed back next week (I hope).
- Lab 6 (Color-Magnitude Diagram)
  - Observing on this Friday; then ends.
    - I will email the Monday, Tuesday, and Wednesday groups telling them which data to use.
  - Email me your instrumental color-magnitude diagram by Wednesday, November 21
  - Entire lab due: November 29

Color-Magnitude Diagram of an Open Cluster

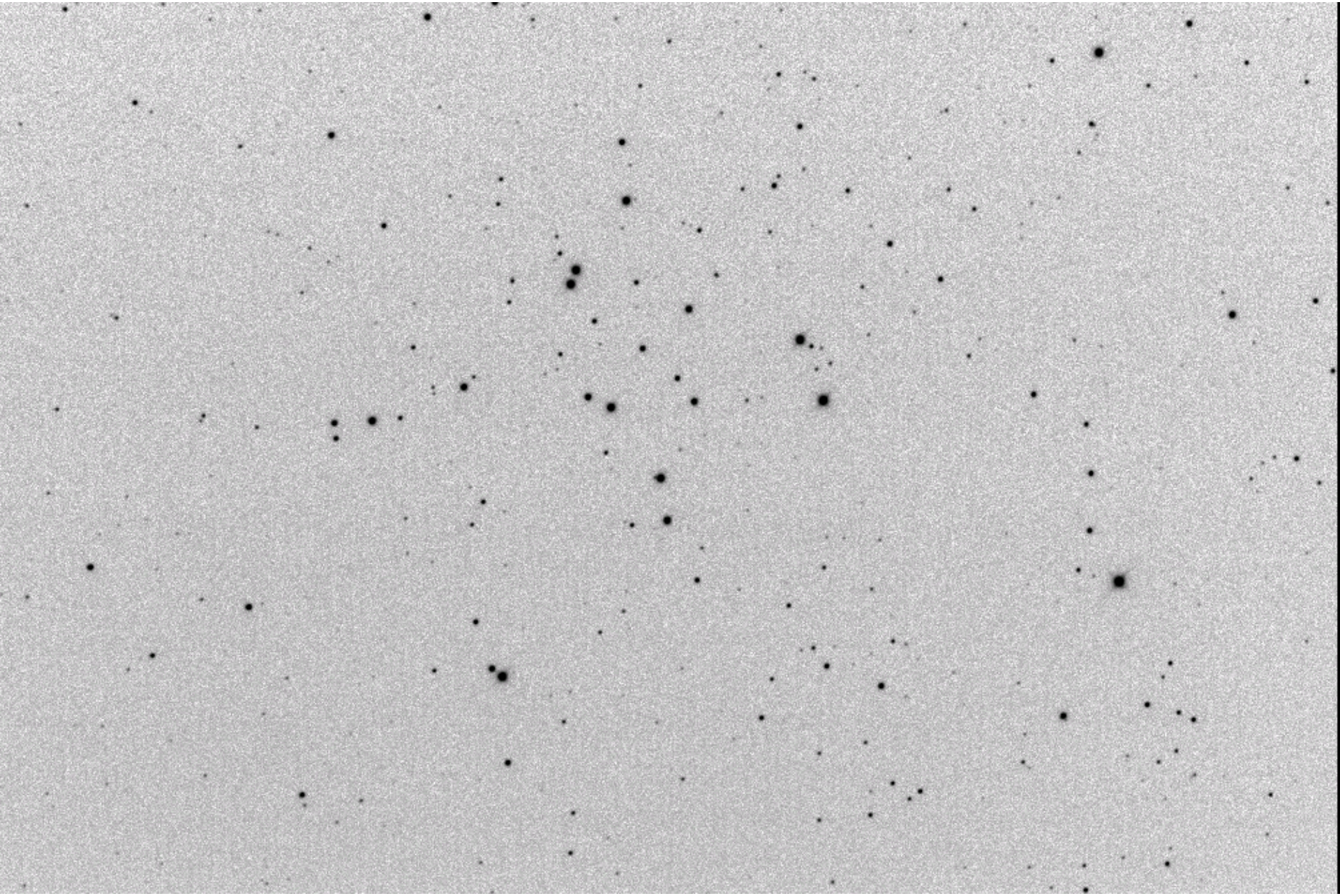
- Plot stellar color versus brightness for stars in a cluster (a gravitationally bound group of stars that formed at the same time and are at the same distance).
- Determine cluster properties
  - Distance
  - Age
  - Open star cluster (and globular star clusters) have been our principal tools to understand stellar structure and evolution.

Measuring Stellar Brightness

- One Method: Aperture Photometry
  - Add up signal in pixels within a circular aperture centered on the star.
  - Subtract the contribution from the sky, estimated from pixels in a surrounding annulus.
    - Need a "robust" average sky value that removes the effect of any stars present.
  - (Relatively) simple.
  - How big to make the aperture?

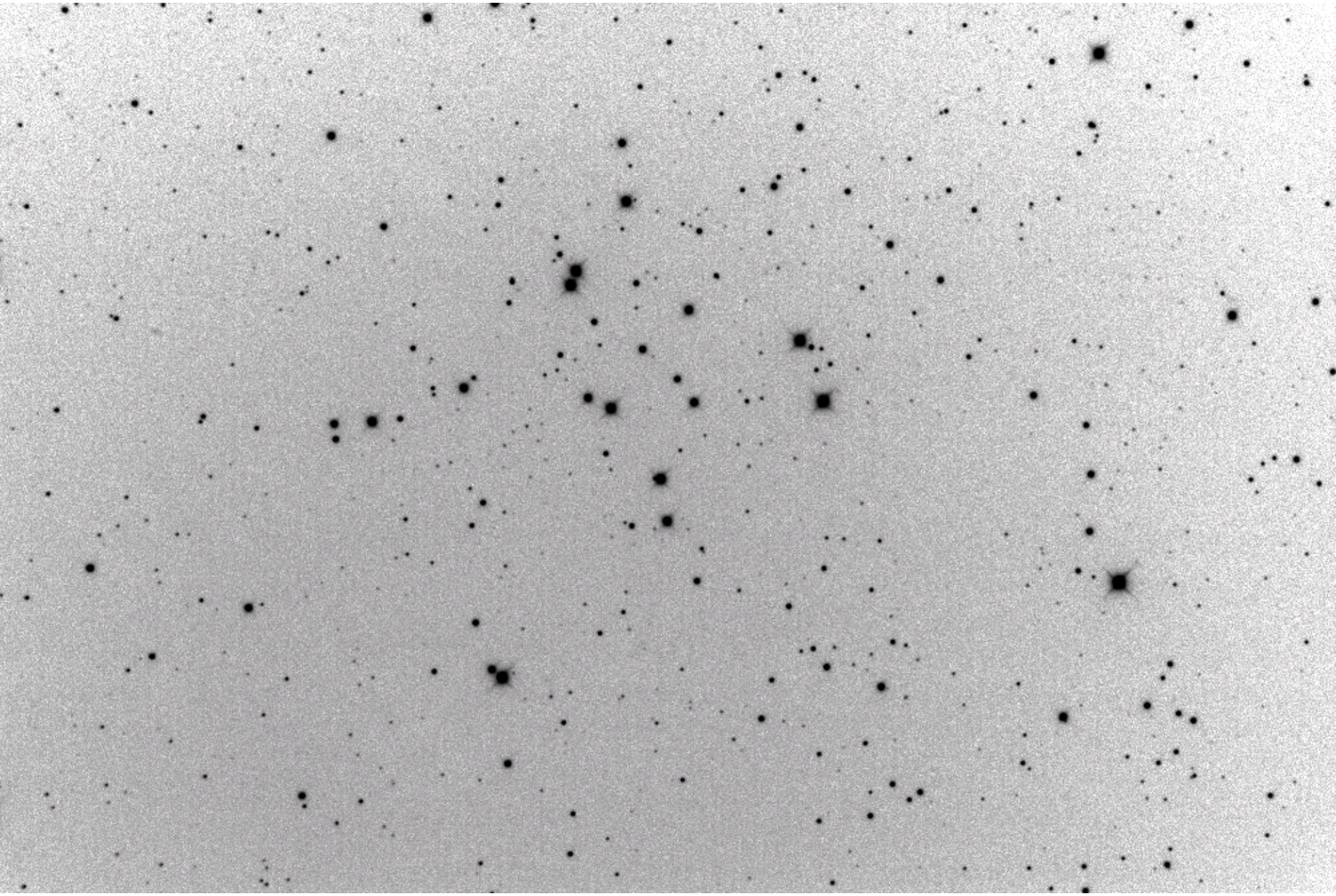


M34 V 7 sec unflattened



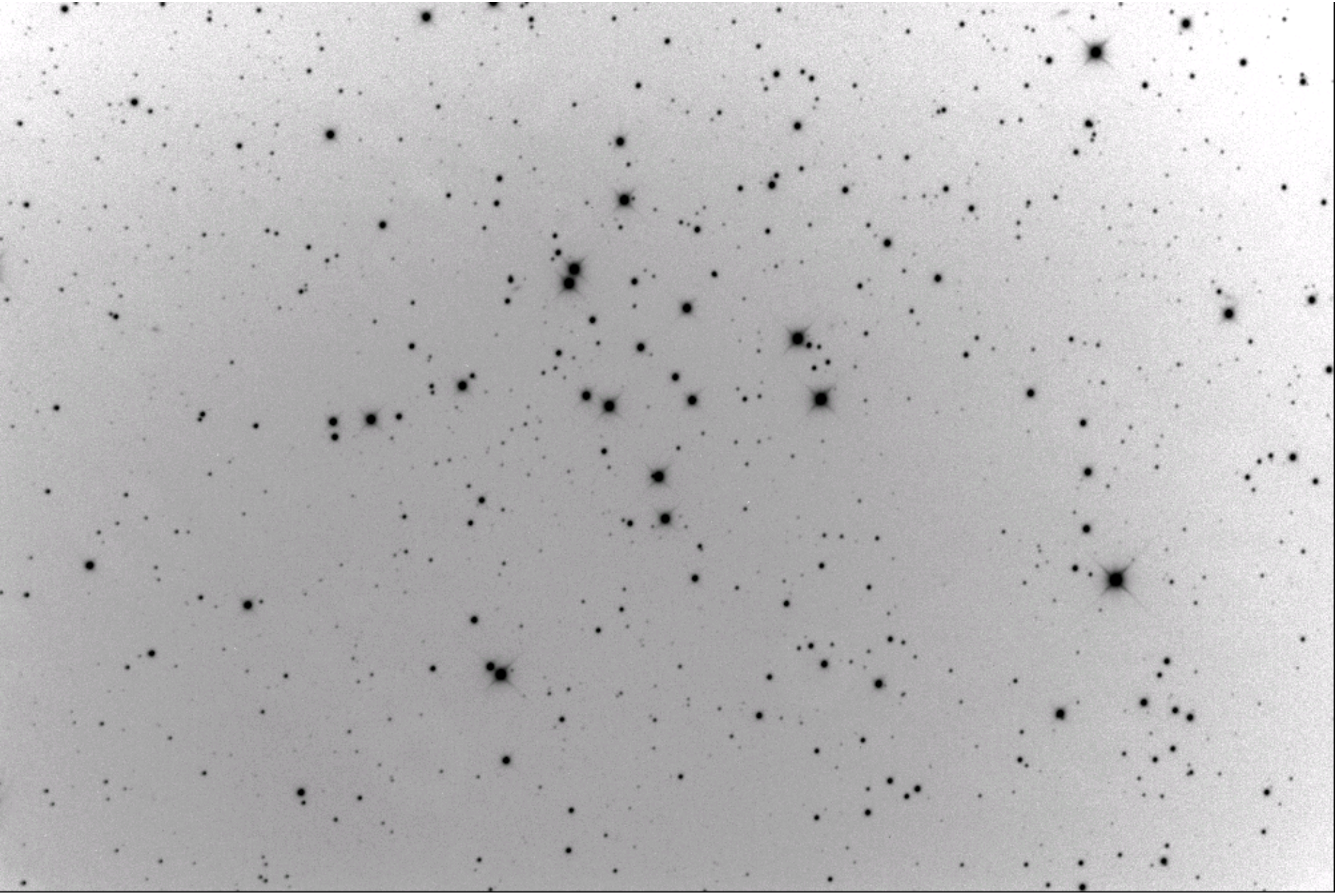
One field approximately centered on M34.

M34 V 45 sec unflattened



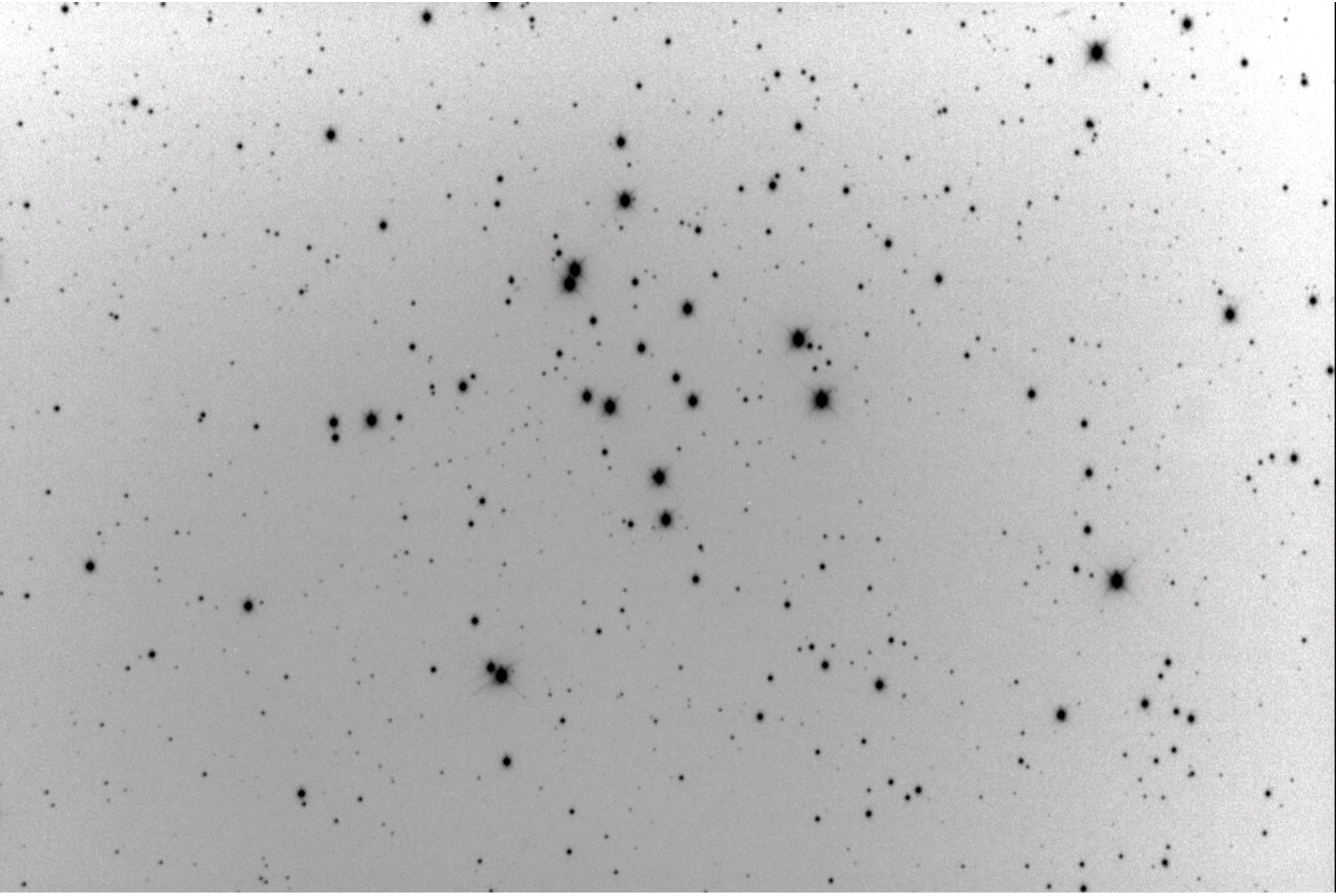
One field approximately centered on M34.

M34 V 300 sec unflattened



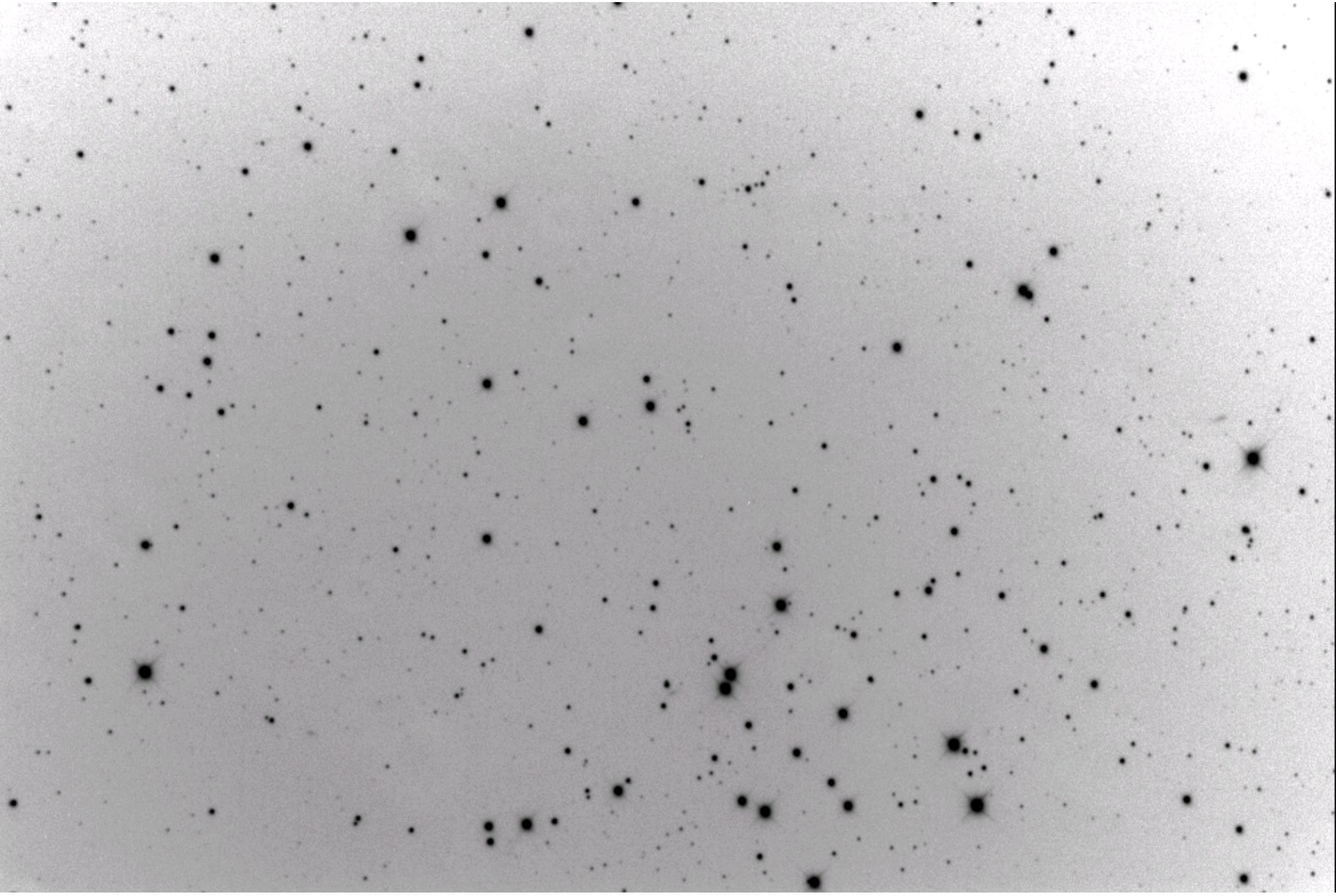
One field approximately centered on M34.

M34 B 300 sec unflattened



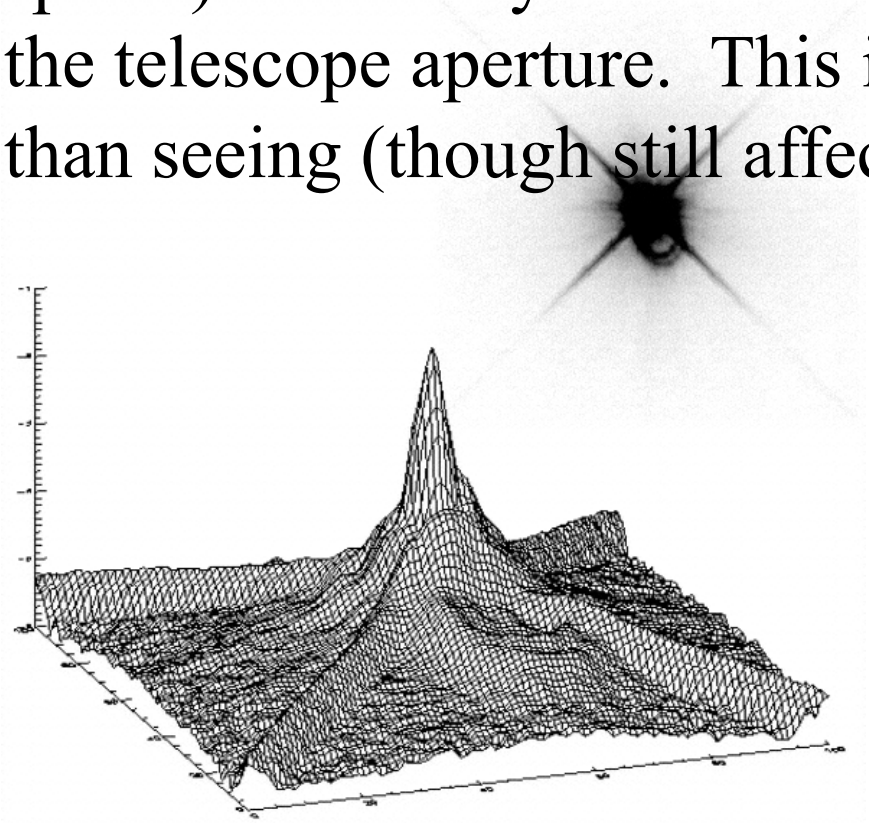
Faint stars have less signal than in V.

M34 2nd field V 300 sec unflattened



Measuring Stellar Brightness

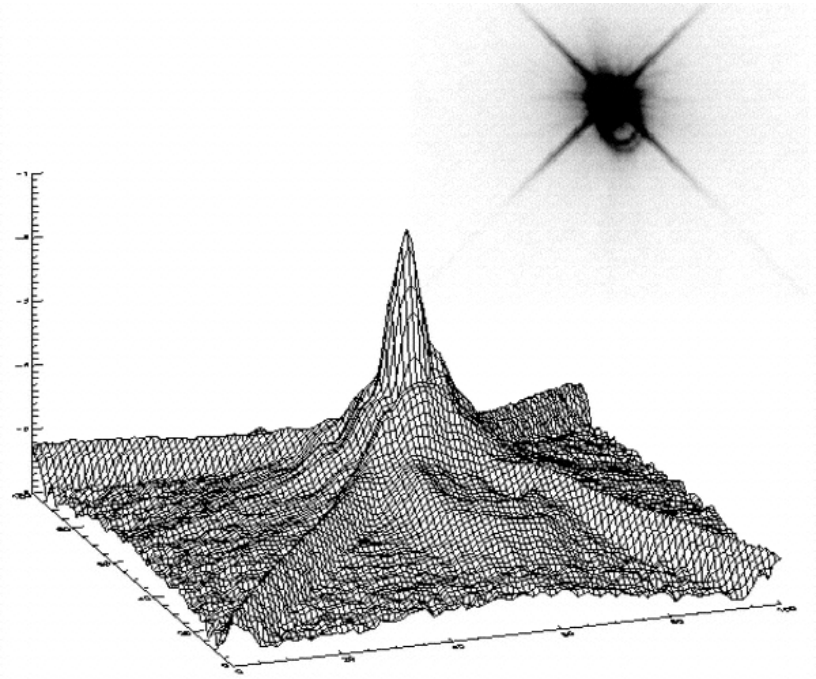
- Another method of measuring stellar brightness uses the shape of a stellar image – the PSF
  - For space telescopes (such as HST), the core (and spikes) are mostly determined by diffraction due to the telescope aperture. This is less variable with time than seeing (though still affected by focus changes).



Stellar "point spread function" (PSF) for the Space Telescope Imaging Spectrograph (O'Dowd & Urry 2005)

Measuring Stellar Brightness

- PSF-fitting method:
  - Fit a functional form for the PSF plus a constant sky to the pixel values. Volume under the function is a measure of the stellar brightness.
  - Bright pixels in the core have the highest weight in the fit ➔ better S/N.
  - Can measure overlapping stars by simultaneously fitting two PSFs.
  - But greater complexity and higher computational cost.



Stellar Photometry in Images

- Steps
  - Correction of image to a uniform, linear response.
  - Identify and determine positions of stars.
  - Measure the brightness of each star.
    - Do the above two steps with the DAOPHOT software package, which searches for stars in an image and measures their location and brightness.
    - Will measure each image separately since combining images is complex when some clouds are present.

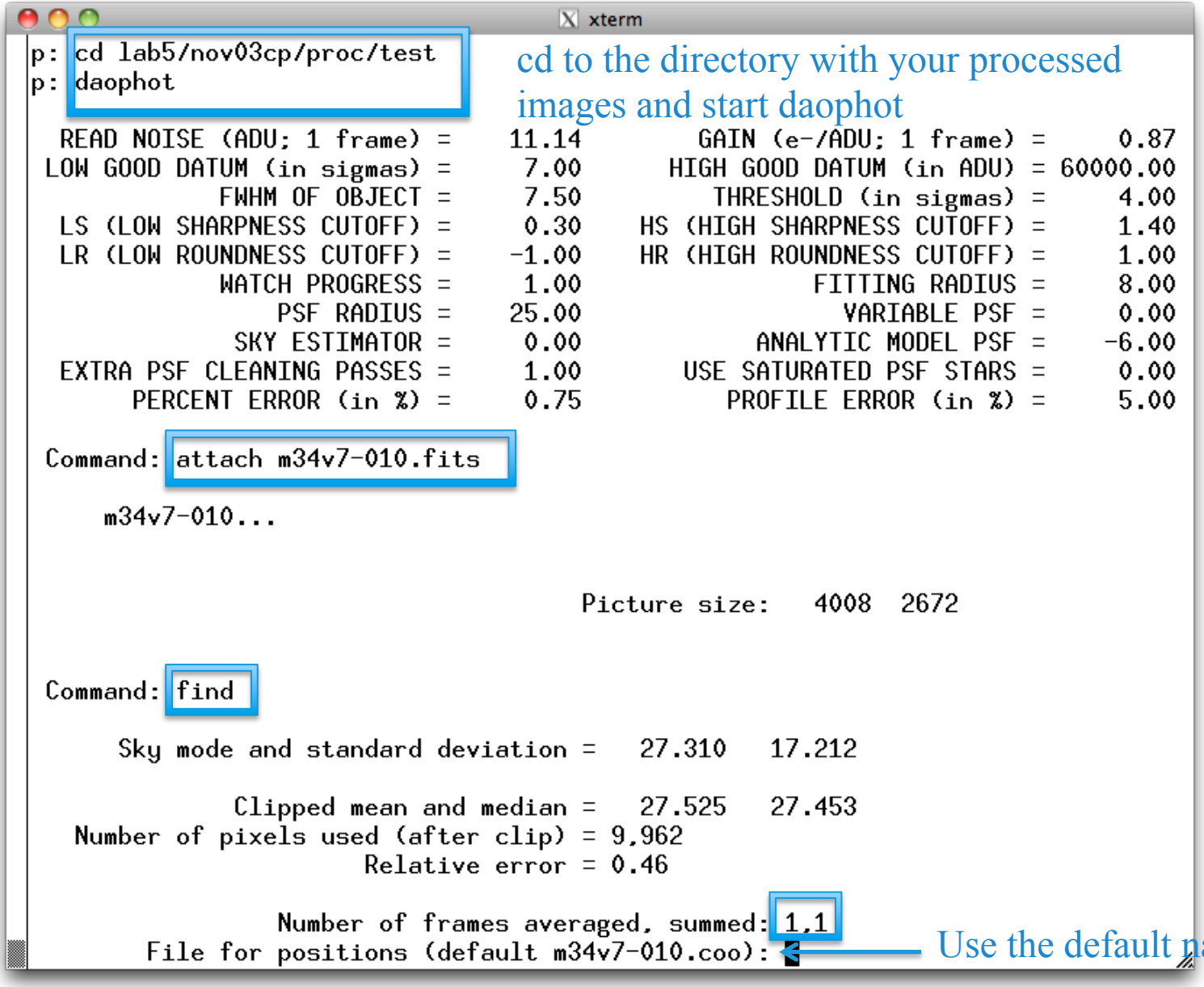
DAOPHOT/ALLSTAR Package

- Finds stars in images and does both aperture and psf-fitting photometry.
- Run in a Unix/Linux terminal window.
- Command line driven programs (i.e., you type in commands), so are less intuitive to use.
- Start-up files initialize parameters.
  - daophot.opt: sets the gain, read noise, and typical FWHM of stars (plus other more esoteric things)
  - photo.opt: sets the aperture and sky annulus radii
  - allstar.opt: sets some parameters for the psf-fitting photometry

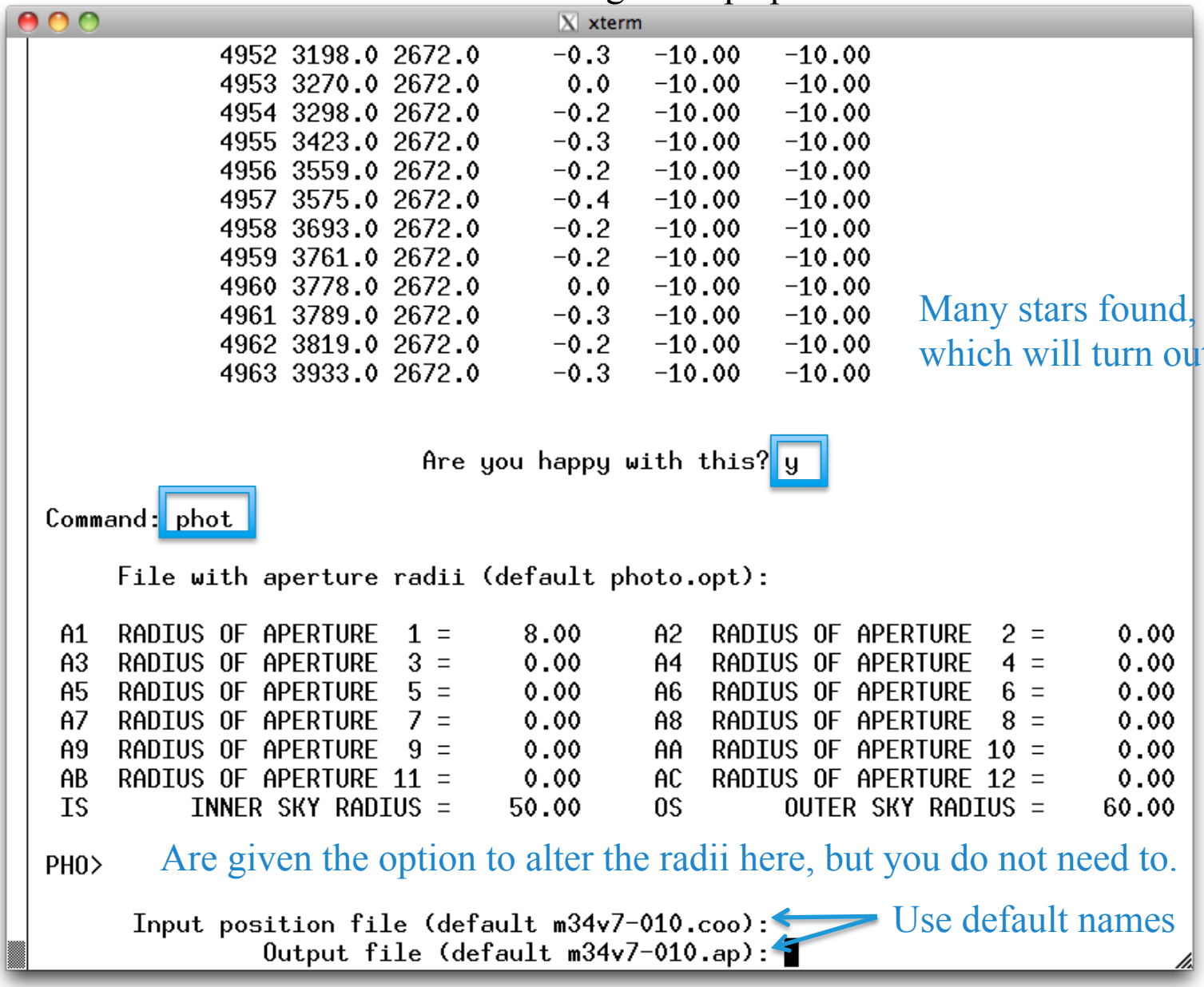
DAOPHOT/ALLSTAR Package

- Daophot program finds stars in images and does aperture photometry.
  - Produces a number of files for each image, the most important of which is filename.ap, which contains the aperture photometry of the stars found in the image.

DAOPHOT – the *attach* command specifies the image to measure



DAOPHOT – the *find* command finds the stars in the image

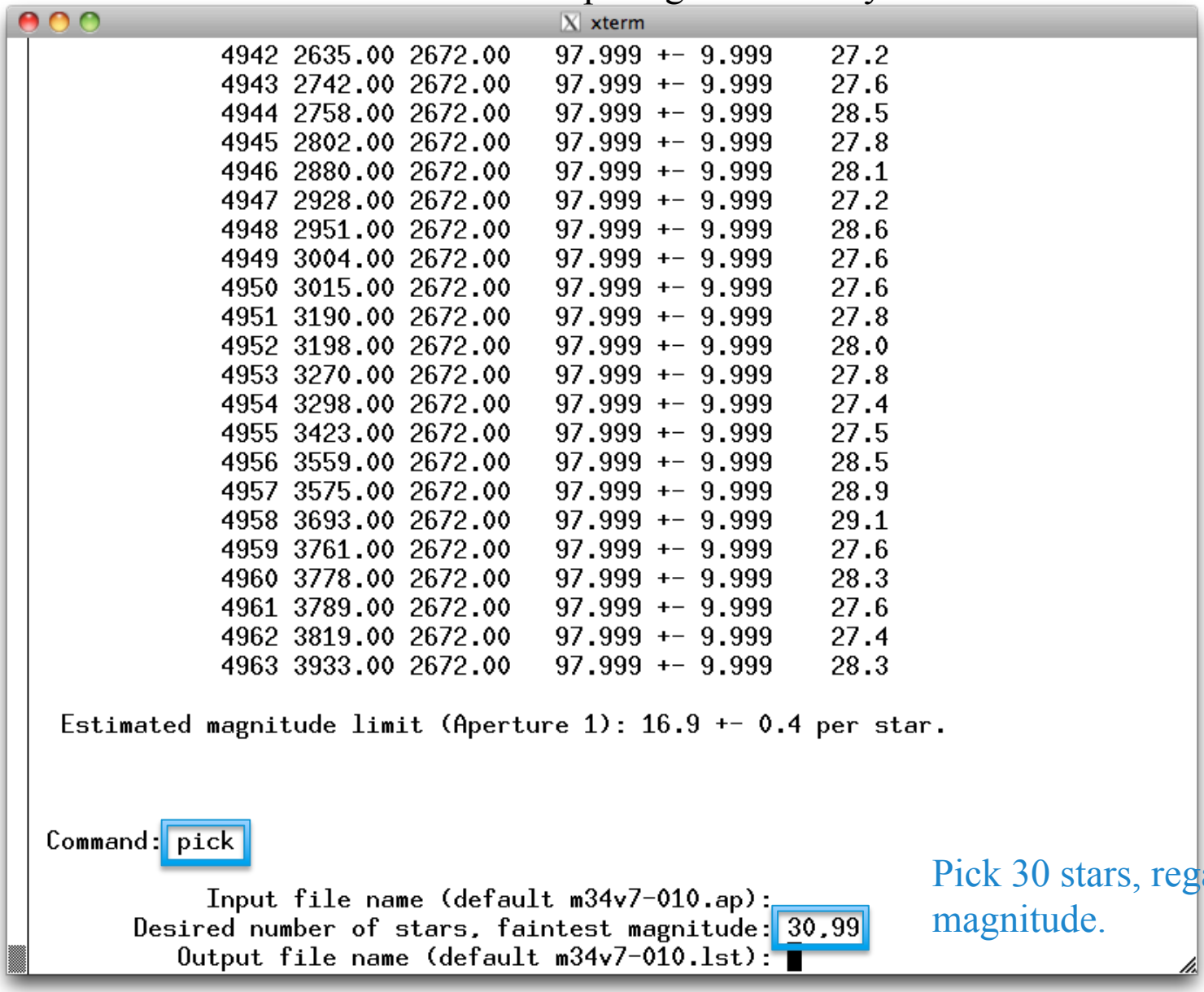


Many stars found, some of which will turn out to be noise.

Are given the option to alter the radii here, but you do not need to.

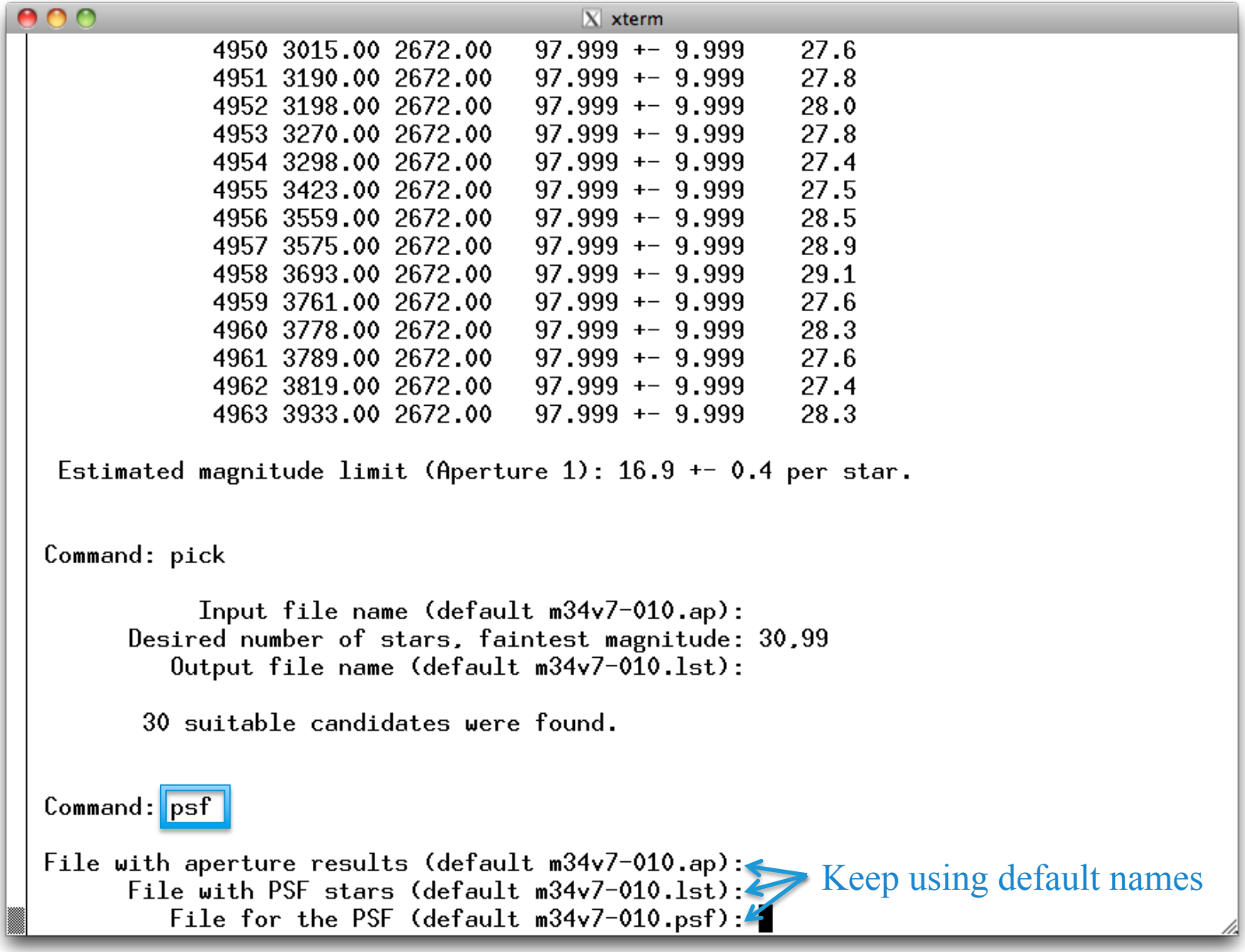
Use default names

DAOPHOT – the *phot* command performs aperture photometry

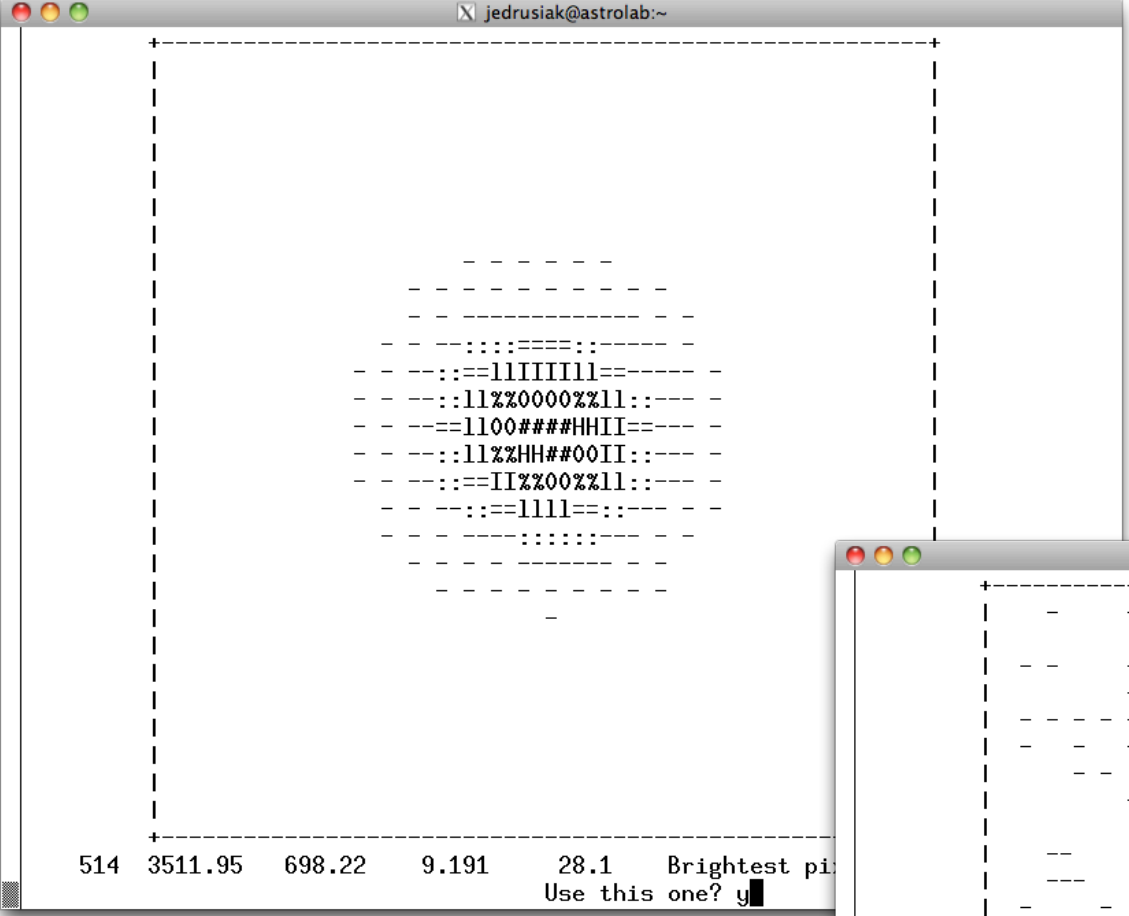


Pick 30 stars, regardless of magnitude.

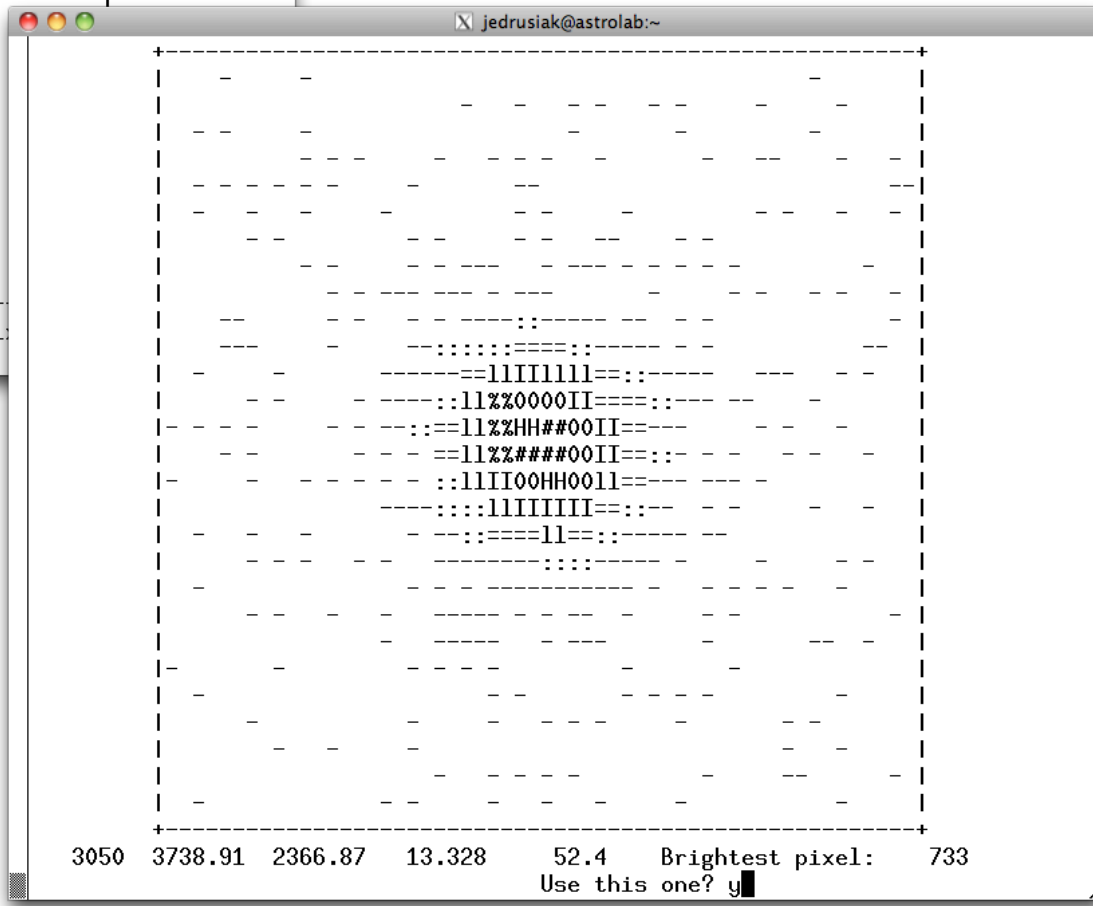
DAOPHOT – *pick* chooses bright, unsaturated stars to determine the psf

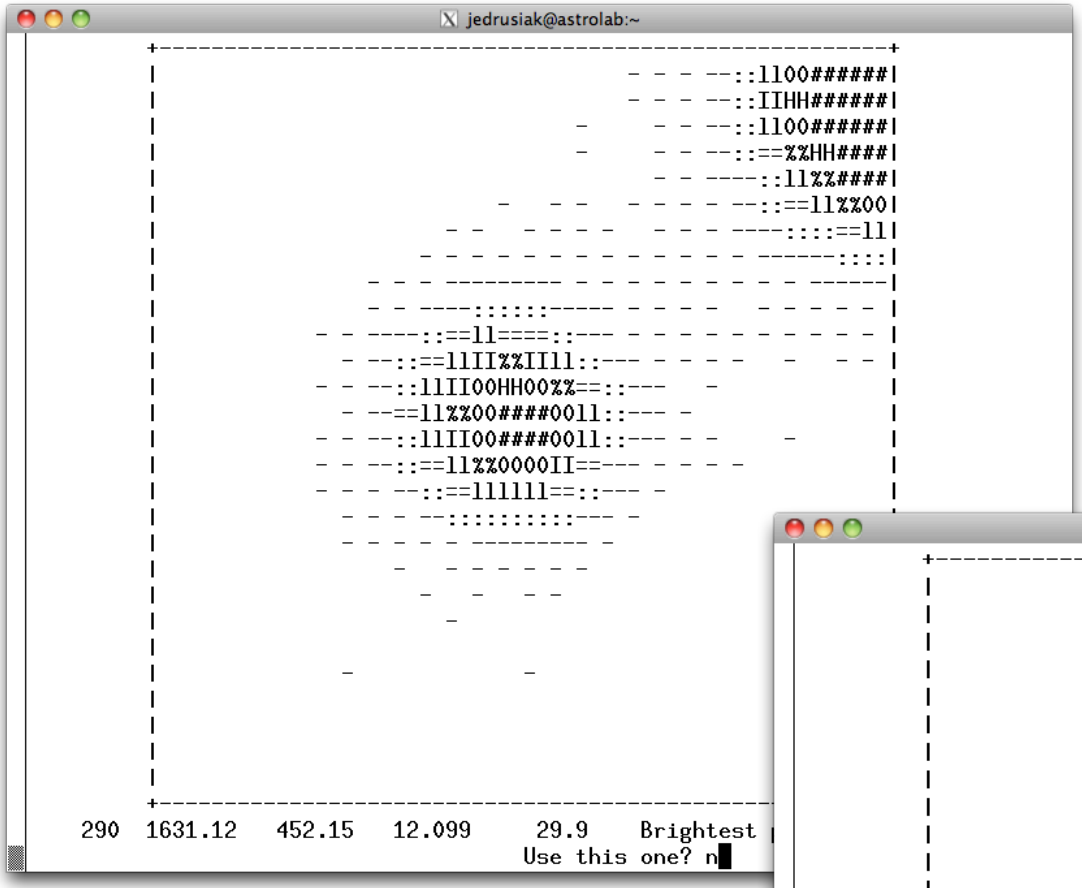


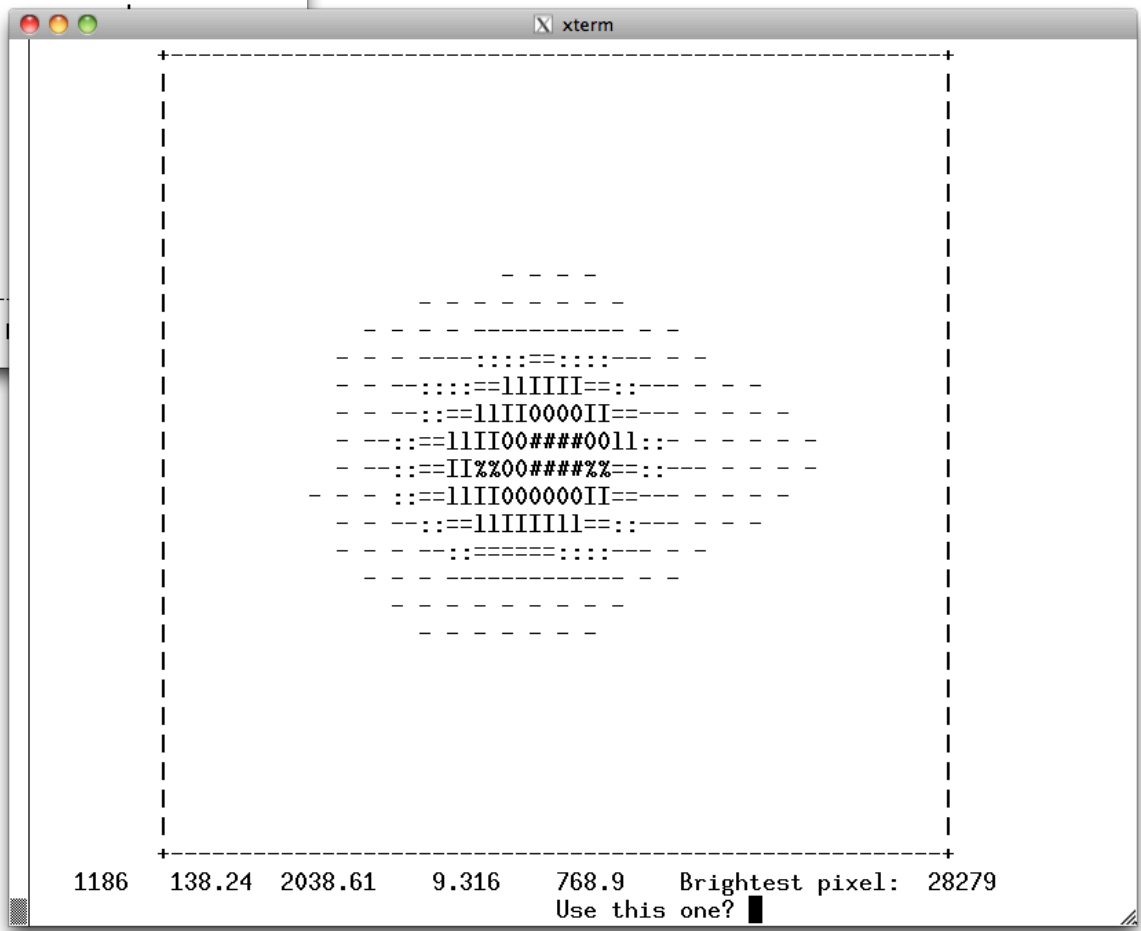
DAOPHOT – *psf* uses the picked stars to determine the psf. It shows a simple plot of each star and you decide whether to use it or not.



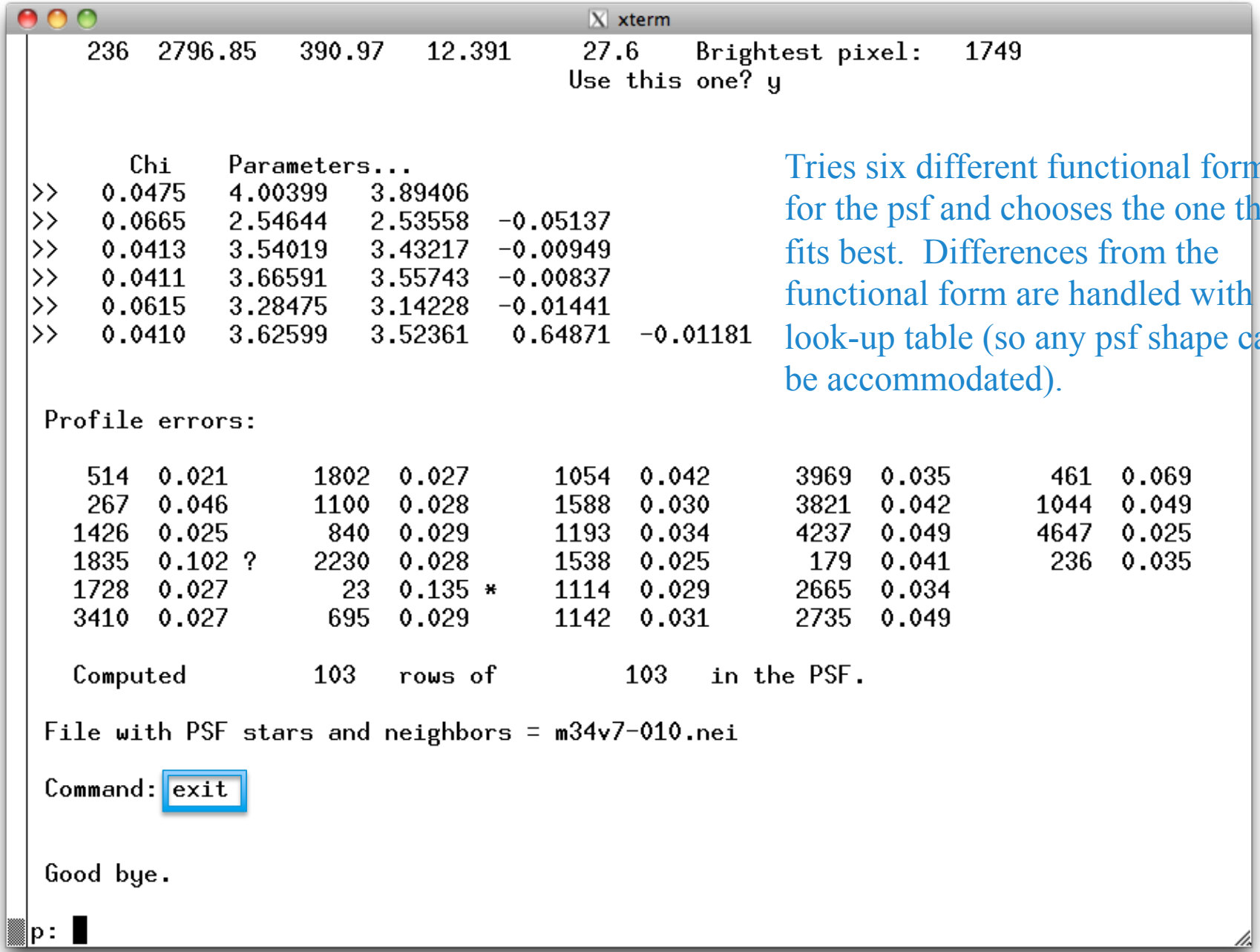
Want bright, isolated stars. These are OK.







These stars should not be used to determine the psf.



Tries six different functional forms for the psf and chooses the one that fits best. Differences from the functional form are handled with a look-up table (so any psf shape can be accommodated).

DAOPHOT – *exit* returns to the Unix command line

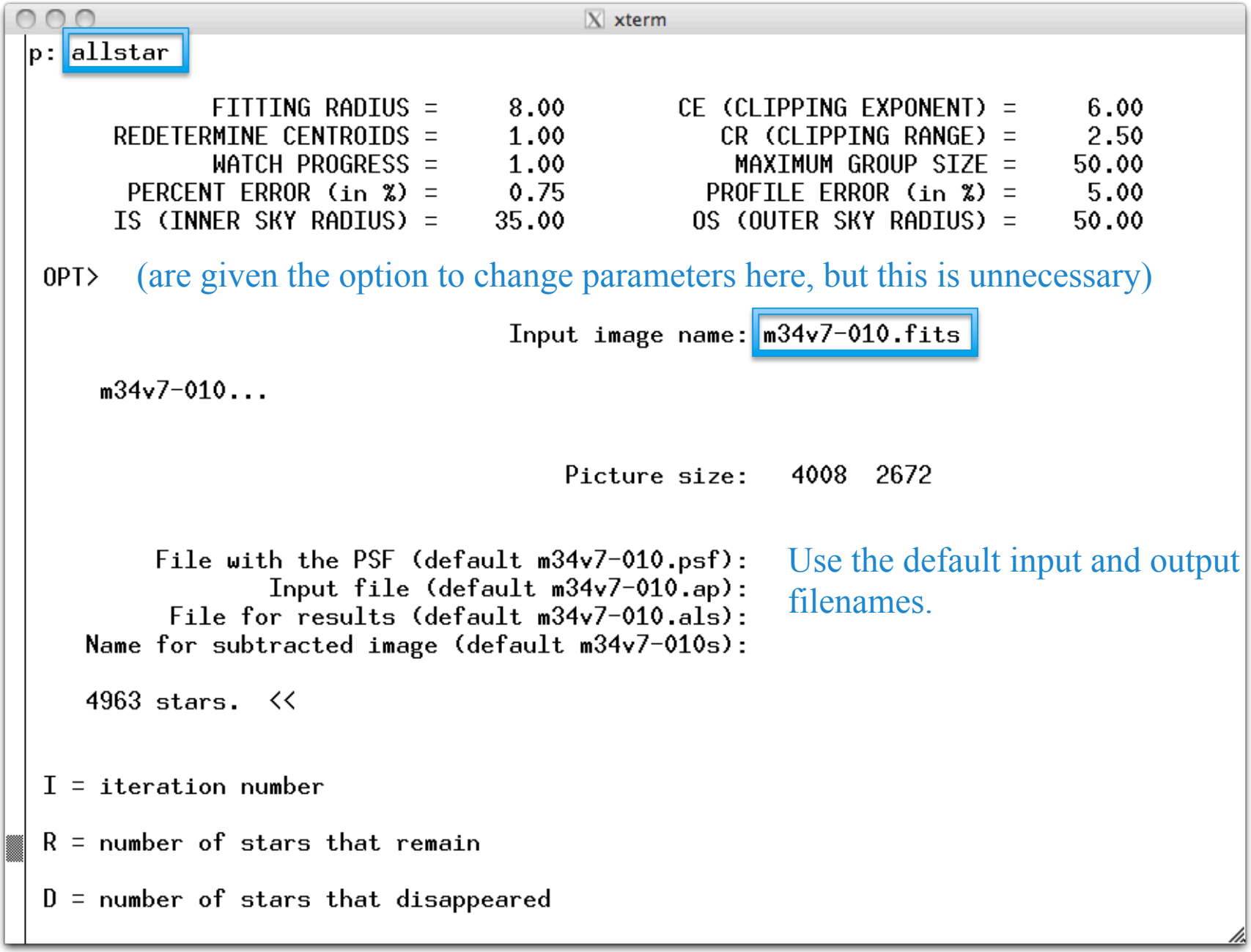
DAOPHOT/ALLSTAR Package

- Daophot program finds stars in images and does aperture photometry.
  - Produces a number of files for each image, the most important of which is filename.ap, which contains the aperture photometry of the stars found in the image.

```
p: more m34ev7-009.ap
 NL    NX    NY  LOWBAD HIGHBAD  THRESH     AP1  PH/ADU  RNOISE    FRAD
  2  2004  1336    31.1 60000.0   67.88    6.00    1.78   15.50    4.00


     1  995.000    1.000   97.999
      152.349 11.81  0.01  9.9999

     2  425.770    8.040   15.980
      153.462 12.28  0.00  0.0396

     3  873.000   25.090   16.480
      151.738 12.22  0.02  0.0598

     4 1252.420   55.100   15.006
      154.789 12.78  0.02  0.0176

     5 1830.990   65.220   16.636
      161.665 13.64  0.00  0.0762
```

DAOPHOT/ALLSTAR Package

- Daophot program finds stars in images and does aperture photometry.
  - Produces a number of files for each image, the most important of which is filename.ap, which contains the aperture photometry of the stars found in the image.
- Allstar program takes the list of stars with aperture photometry and measures brightnesses using psf-fitting photometry.



ALLSTAR – does the psf-fitting photometry

xterm

```
I = iteration number

R = number of stars that remain

D = number of stars that disappeared

C = number of stars that converged


     I        R        D        C
     1     4963        0        0  <<
     2     4963        0        0  <<
     3     4963        0        0  <<
     4     4800       89       74  <<
     5     4203      194      566  <<
     6     3002      703     1258  <<
     7     2148     1436     1379  <<
     8     1508     1820     1635  <<
     9     1179     2111     1673  <<
    10      946     2319     1698  <<
    11      702     2537     1724  <<
    12      477     2744     1742  <<
    13      292     2915     1756  <<
    14      131     3063     1769  <<
    15       46     3139     1778  <<
    16       39     3139     1785  <<
    17       29     3139     1795  <<
    18       24     3139     1800  <<
    19       14     3139     1810  <<
    20       14     3139     1810  <<
    21       12     3139     1812  <<
```

ALLSTAR fits all of the stars in the image simultaneously, so overlapping stars are handled correctly (assuming that both stars are in the input list). The solution is done iteratively.

DAOPHOT/ALLSTAR Package

- Daophot program finds stars in images and does aperture photometry.
- Allstar program takes the list of stars with aperture photometry and measures brightnesses using psf-fitting photometry.
  - Produces the file filename.als with the photometry.

```
p: more m34ev7-009.als
 NL    NX    NY  LOWBAD HIGHBAD  THRESH     AP1  PH/ADU  RNOISE    FRAD
  1  2004  1336    31.1 60000.0   67.88    6.00    1.78   15.50    4.00

      2  425.784    8.097   15.842   0.0319  153.258       4.    0.809   -0.231
      3  873.033   25.118   16.388   0.0412  152.051       4.    0.638   -0.262
      5 1831.009   65.199   16.443   0.0504  161.033       4.    0.752   -0.567
      7   28.090   75.584   14.973   0.0266  158.046       4.    1.398   -0.566
     12  935.358  101.587   13.640   0.0145  153.754       4.    1.904   -0.478
     16  616.994  158.965   15.384   0.0246  153.930       4.    0.915   -0.559
     21  474.005  205.141   16.326   0.0430  154.094       4.    0.713   -0.432
     27 1932.841  264.414   16.510   0.0631  162.679       4.    0.895   -0.569
     28  722.355  267.434   12.934   0.0132  154.070       4.    2.481   -0.529
     30  301.696  278.430   13.178   0.0171  156.263       4.    2.892   -0.748
     32  232.085  304.477   16.335   0.0428  156.518       4.    0.698   -0.513
```

DAOPHOT/ALLSTAR Package

- Daophot program finds stars in images and does aperture photometry.
- Allstar program takes the list of stars with aperture photometry and measures brightnesses using psf-fitting photometry.
  - Produces the file filename.als with the photometry.
  - Also produces filename**s**.fits, which is the original image with the fitted psf's subtracted.

Original 7-second, V-band image

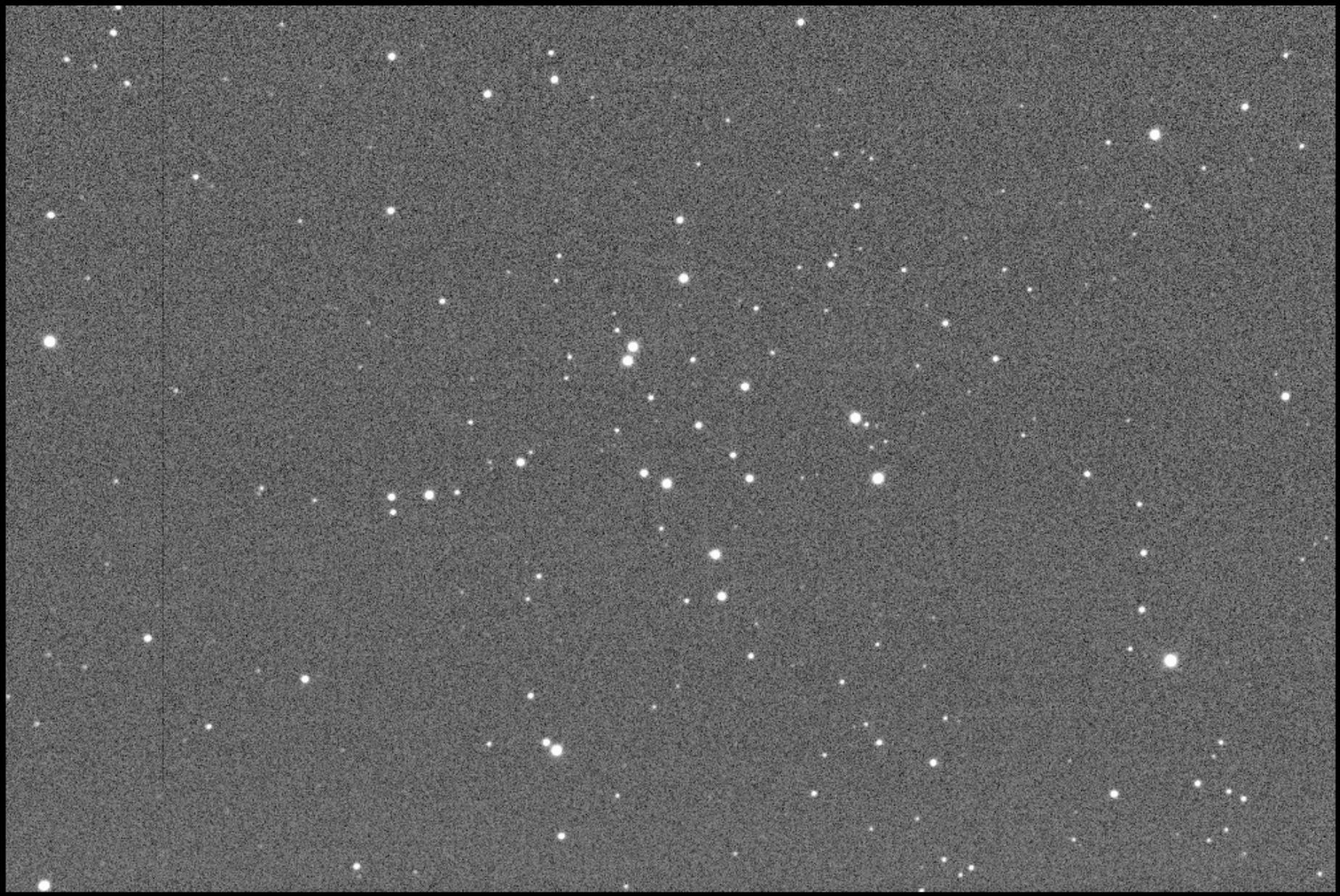
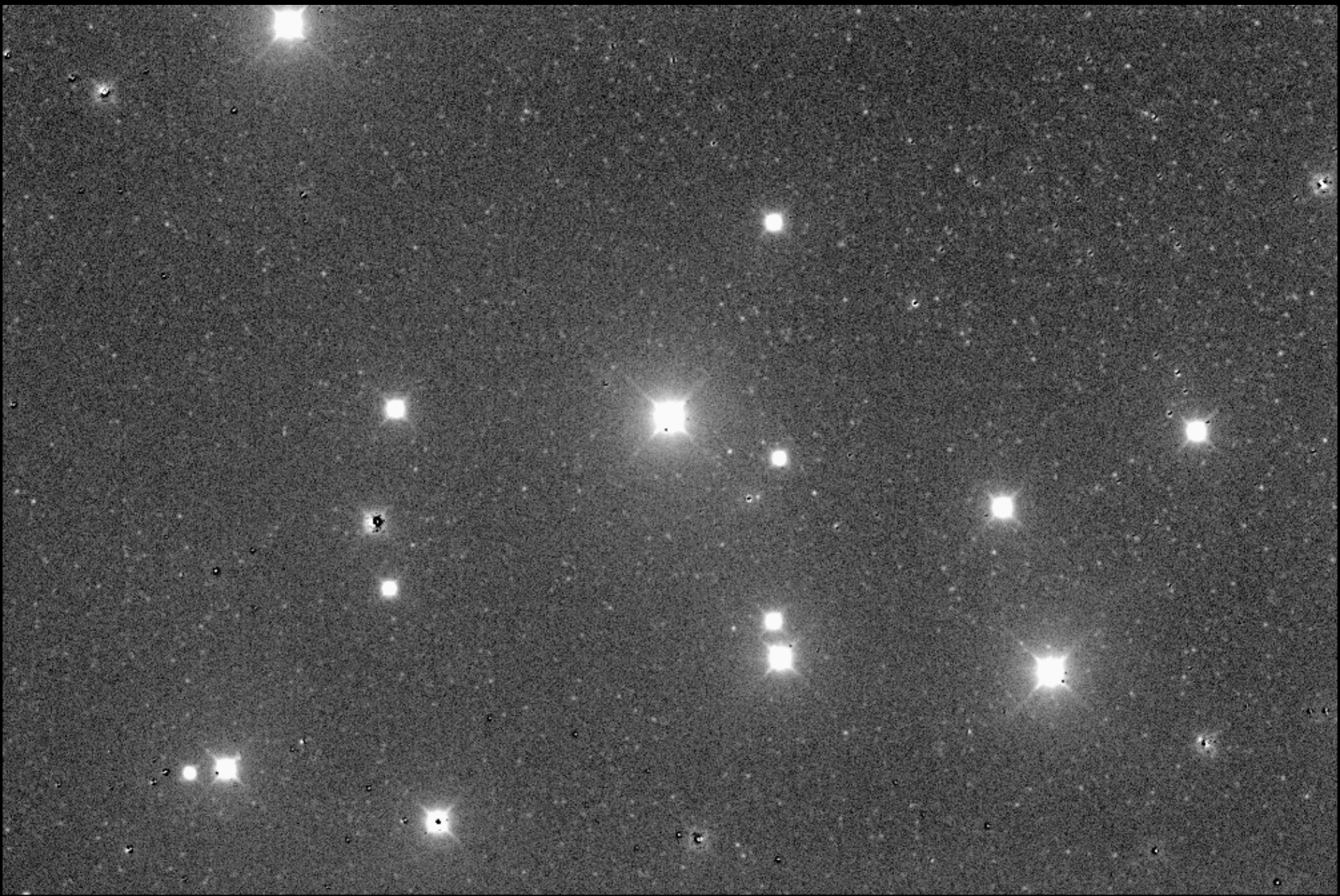


Image with the fitted psf's subtracted – produced by Allstar

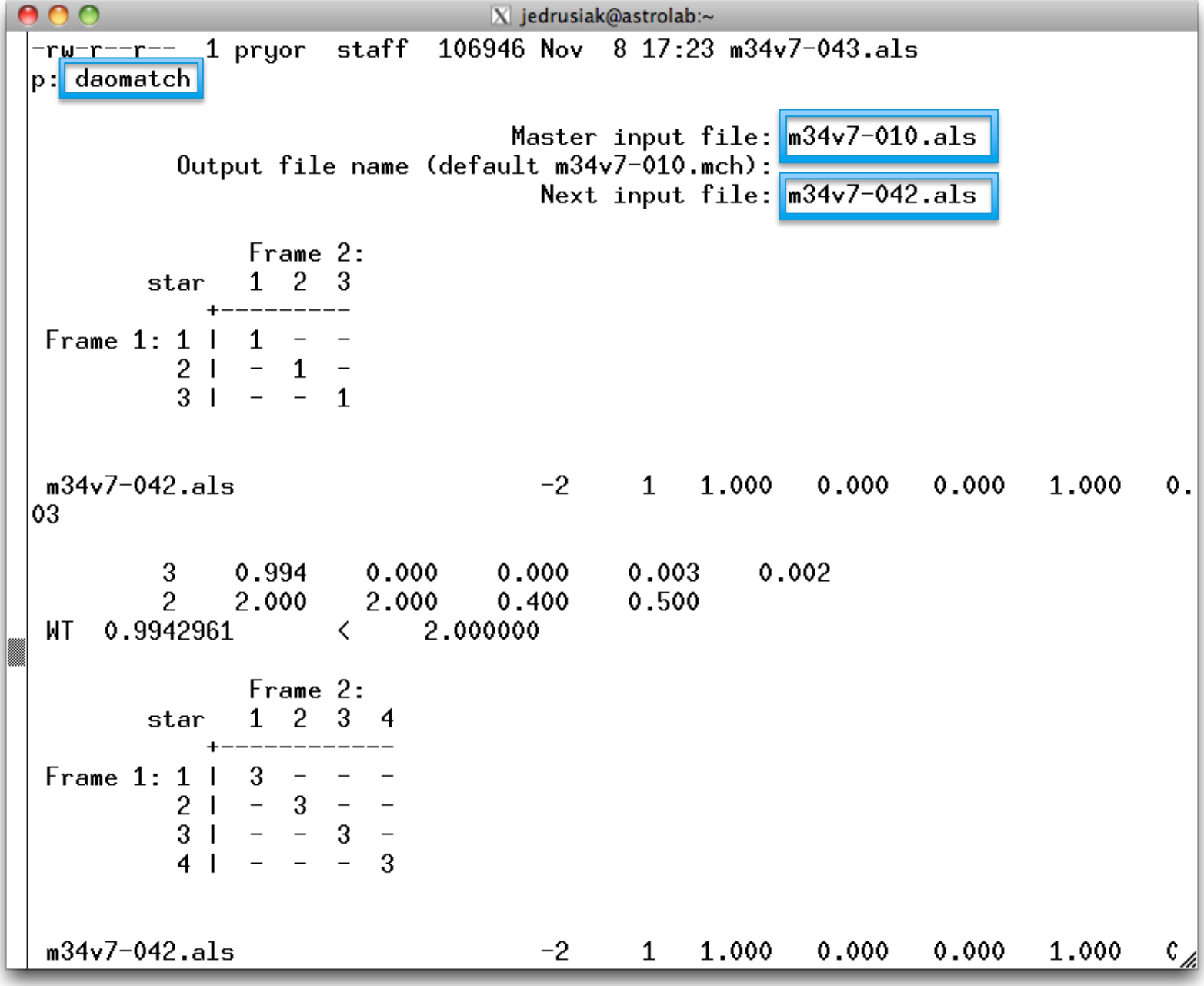
Long exposure, V-band image

Fitted psf's subtracted. Note saturated stars are not fitted.

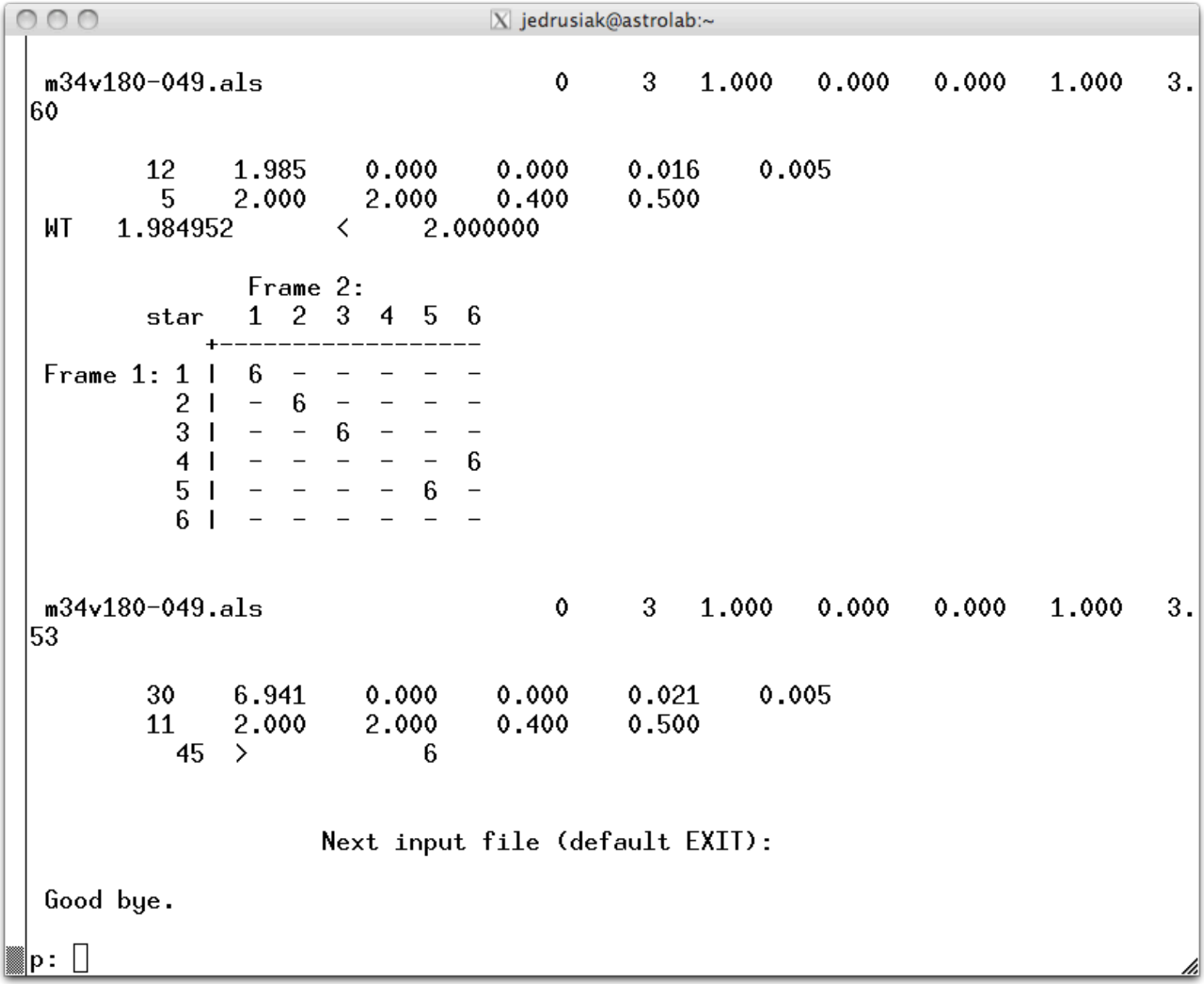


DAOPHOT/ALLSTAR Package

- Daophot program finds stars in images and does aperture photometry.
- Allstar program takes the list of stars with aperture photometry and measures brightnesses using psf-fitting photometry.
- Daomatch and Daomaster programs handle the job of combining output from multiple images.
  - First combine all exposure times from both fields for each filter separately.



daomatch begins the process of matching stars in the ALLSTAR output files for each image



Keep entering files until have done all of them for a given filter (V or B)

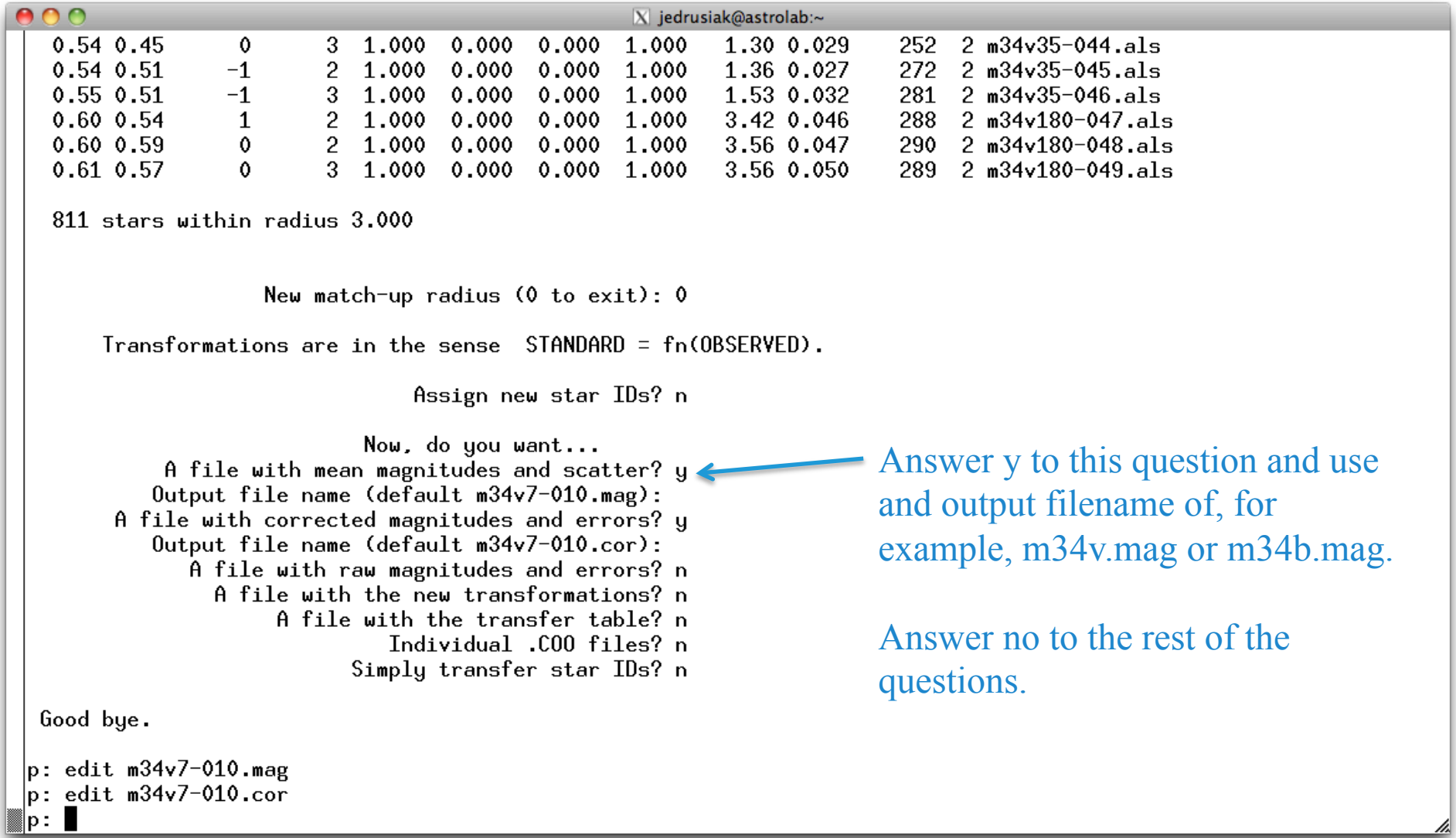
daomaster finishes the job of matching the stars in the "als" files.

jedrusiak@astrolab:~

```
p: daomaster

     MONGO version


                File with list of input files: m34v7-010.mch

 9 input files

Maximum permitted number of stars in the master list: 500,000

  Minimum number, minimum fraction, enough frames: 3,0.33,3
                                  Maximum sigma: 10.

            Desired degrees of freedom ---

               2:  Translations only
               4:  Translations, rotation, and scale
               6:  Six-constant linear transformation
              12:  Quadratic transformation
              20:  Cubic transformation

                                     Your choice: 6
                          Critical match-up radius: 3.0

 0.55 0.47     -2      1  1.000  0.000  0.000  1.000   0.03 0.017    236  2 m34v7-042.als
 0.57 0.50     -2      1  1.000  0.000  0.000  1.000  -0.86 0.026    156  2 m34v7-043.als
 0.54 0.45      0      3  1.000  0.000  0.000  1.000   1.30 0.029    252  2 m34v35-044.als
 0.54 0.51     -1      2  1.000  0.000  0.000  1.000   1.36 0.027    272  2 m34v35-045.als
 0.55 0.51     -1      3  1.000  0.000  0.000  1.000   1.53 0.032    281  2 m34v35-046.als
 0.60 0.54      1      2  1.000  0.000  0.000  1.000   3.42 0.046    288  2 m34v180-047.als
```

Keep stars that appear in one or more images (so should answer first input with 1,0.16,1).

Actually use 2 here.

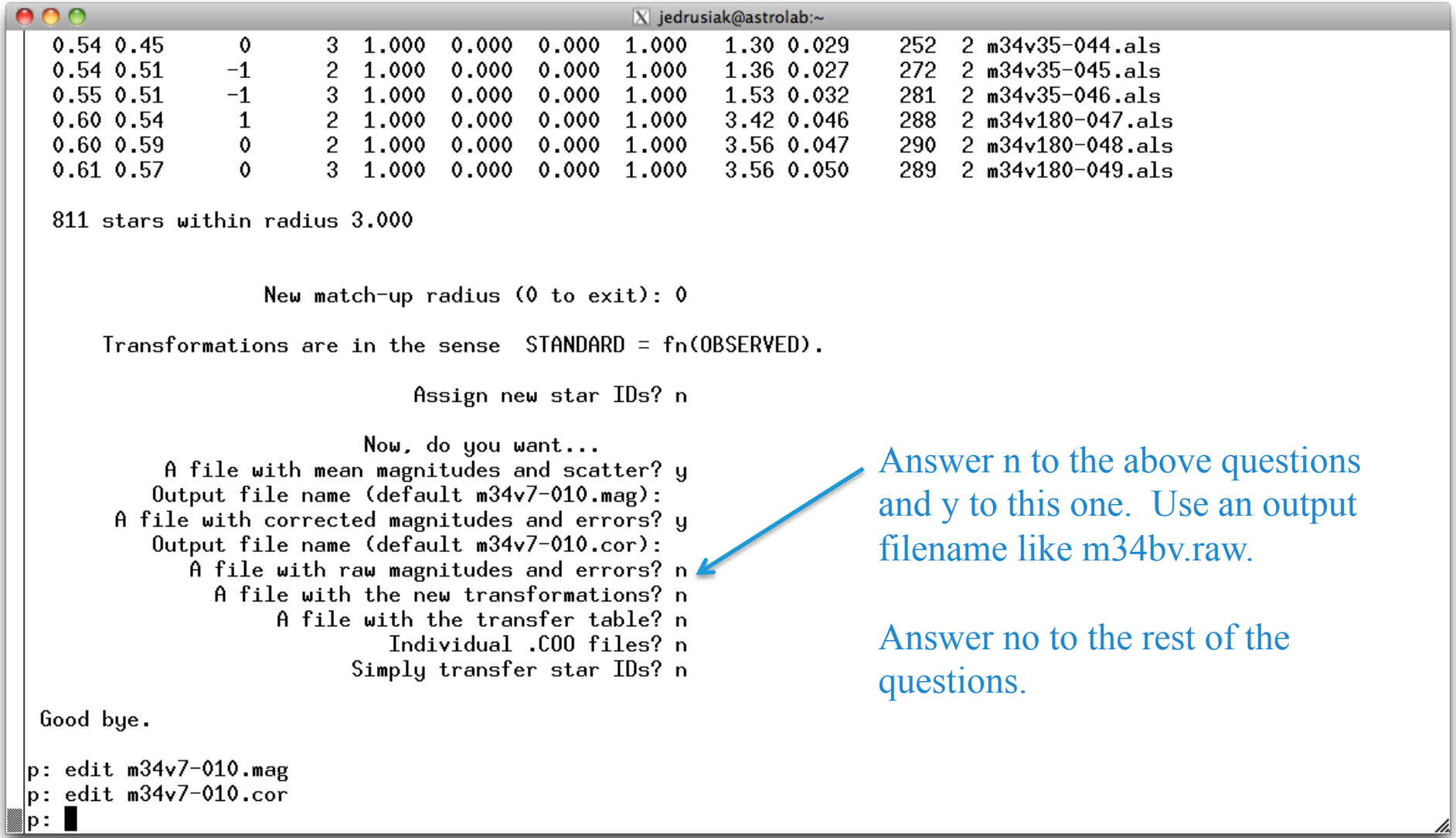


Answer y to this question and use and output filename of, for example, m34v.mag or m34b.mag.

Answer no to the rest of the questions.

DAOPHOT/ALLSTAR Package

- Daophot program finds stars in images and does aperture photometry.
- Allstar program takes the list of stars with aperture photometry and measures brightnesses using psf-fitting photometry.
- Daomatch and Daomaster programs handle the job of combining output from multiple images.
  - First combine all exposure times from both fields for each filter separately.
  - Then combine the combined V and B photometry into a file that keeps both instrumental magnitudes.



Answer n to the above questions and y to this one. Use an output filename like m34bv.raw.

Answer no to the rest of the questions.

DAOPHOT/ALLSTAR Package

- Daomatch and Daomaster programs handle the job of combining output from multiple images.
  - First combine all exposure times from both fields for each filter separately.
  - Then combine the combined V and B photometry into a file that keeps both instrumental magnitudes.

```
p: more M34bv.raw
 NL    NX    NY  LOWBAD HIGHBAD  THRESH     AP1  PH/ADU  RNOISE    FRAD
  1  2004  1336  -500.0 60000.0   83.13    6.00    1.78   15.50    4.00

     1   -6.040 1381.071  16.7460   0.0373  17.2080   0.0474   1.0530  -0.4945
     2    0.874 1957.021  15.4050   0.0154  15.6720   0.0166   1.3535  -0.2675
     3    1.133 1602.247  17.8290   0.0786  18.6260   0.1708   0.9330  -1.6125
     4    1.325  771.538  16.1970   0.0210  16.9070   0.0321   1.0095  -0.6415
     5    3.636 1158.937  15.3510   0.0133  15.8030   0.0126   1.5440  -0.5310
     6    5.074 1638.648  16.6380   0.0331  17.1250   0.0373   0.9255  -0.3760
     7    9.995 1070.020  15.2160   0.0130  15.5690   0.0106   1.6215  -0.5795
     8   11.265  392.488  17.5940   0.0804  17.8790   0.1000   1.1820  -0.8500
     9   12.723  523.524  13.4860   0.0156  14.2920   0.0098   3.0075  -0.7750
    10   19.449  970.575  17.1510   0.0534  17.6280   0.0583   1.0435  -0.3095
    11   21.628 1092.049  16.1150   0.0163  16.4610   0.0175   1.0925  -0.4065
    12   21.908  113.231  17.0120   0.0491  17.4360   0.0622   1.1580  -0.8630
    13   24.524 1111.436  17.9820   0.1128  18.3800   0.1471   1.1310  -1.0085
```

DAOPHOT/ALLSTAR Package

- Read the m34bv.raw (or whatever) file into excel (or your other favorite data-manipulation language).
  - Compute a column that is b-v.
  - Plot v vs b-v. (Remember to make the axes go the right way and include uncertainties on the points.)

M34 instrumental (v, b-v) color-magnitude diagram. 1,235 stars