Data reduction II
Photometry with IRAF

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Research workshop on evolved stars
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Introduction

- See the introduction to IRAF talk
- Text in **yellow** is for typing into IRAF terminal
- In my slides IRAF terminals are black or papaya colour

Why data *reduction*?

- We need to subtract – or reduce – instrumental effects and background contamination.

Reducing instrumental effects:

- **BIAS**: image with ‘zero’ exposure time.
  Estimate of the real zero of the CCD.

- **FLAT**: image of a uniformly illuminated surface.
  Estimate sensitivity difference throughout the CCD + dust grains, scratches etc.

- **DARK**: image with the same exposure time of the science image with the shutter closed.
  Estimate the level of background current.

More is more

- Each of the counts on the images has an associated uncertainty.
- If we take n images, each with an uncertainty σ_i, the uncertainty on the average will be $\sigma_i/\sqrt{n}$.
- Therefore, the first step in data reduction is to calculate the average for BIAS, FLAT, and DARK images.

More is more

- Each of the counts on the images has an associated uncertainty.
- If we take n images, each with an uncertainty σ_i, the uncertainty on the average will be $\sigma_i/\sqrt{n}$.
- Therefore, the first step in data reduction is to calculate the average for BIAS, FLAT, and DARK images.

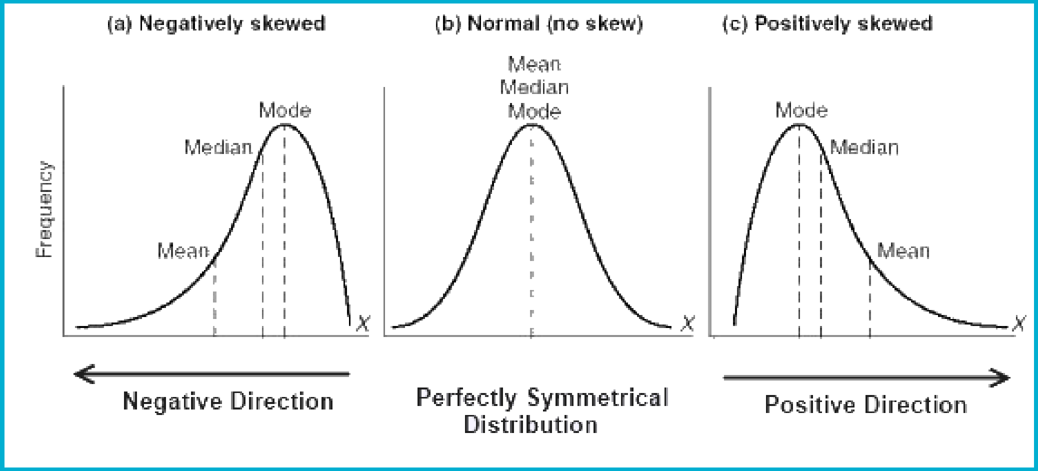
  BIAS: not available for 65 cm telescope.

  FLAT: master flat has already been created.

  DARK: we need to calculate the median dark.

Mean or median?

- Either of those can be representative of a distribution – which one should we use?
- The mean is sensitive to outliers – the median is robust against outliers.
- The mean is not descriptive for skewed distributions.
- Give preference to the **median**!



IRAF – **I**mage **R**eduction and **A**nalysis **F**acility

- We'll use the package

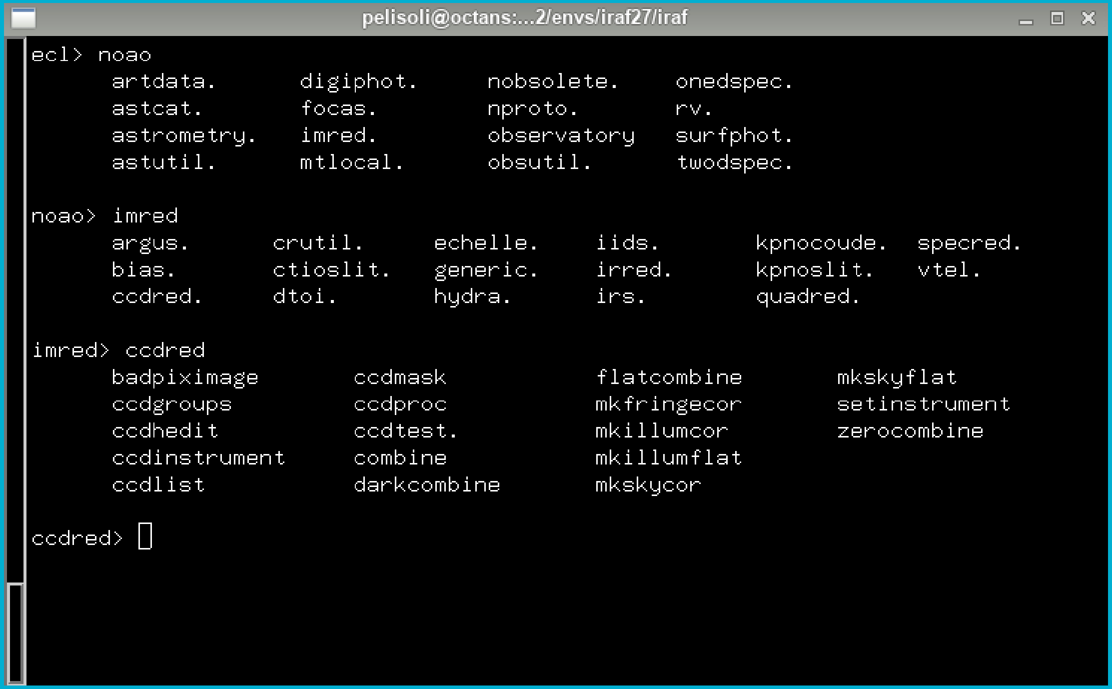
noao.imred.ccdred

for the data reduction, and

noao.digiphot.daophot

for the photometry.

- Load each part of the packages by typing their name followed by enter.



Preparing working directory

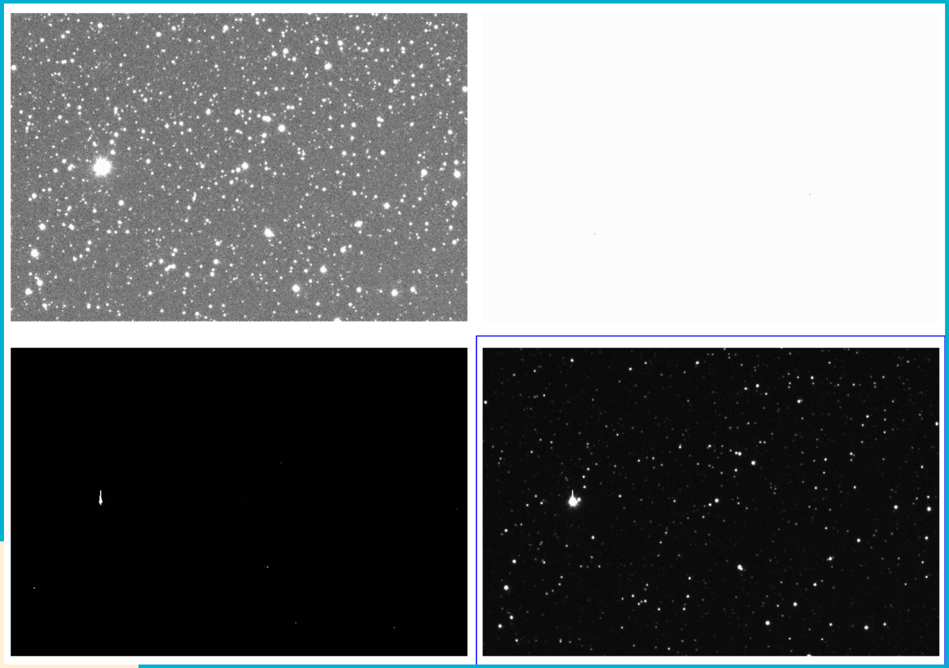
- Always have a copy of original raw data!

- **!mkdir reduction**
- **!mkdir reduction_copy**

- All the files that we work with have to be in the same directory:
  - science frames
  - masterflats (same filters as your science frames!)
  - darks

Check your data

epar display



```
                                  Image Reduction and Analysis Facility
PACKAGE = tv
   TASK = display

image   =                         image to be displayed
frame   =                      1  frame to be written into
(bpmask =                   BPM)  bad pixel mask
(bpdispl=                  none)  bad pixel display (none|overlay|interpolate)
(bpcolor=                   red)  bad pixel colors
(overlay=                      )  overlay mask
(ocolors=                 green)  overlay colors
(erase  =                   yes)  erase frame
(border_=                    no)  erase unfilled area of window
(select_=                   yes)  display frame being loaded
(repeat =                    no)  repeat previous display parameters
(fill   =                    no)  scale image to fit display window
(zscale =                   yes)  display range of greylevels near median
(contras=                  0.25)  contrast adjustment for zscale algorithm
(zrange =                   yes)  display full image intensity range
(zmask  =                      )  sample mask
(nsample=                  1000)  maximum number of sample pixels to use
(xcenter=                   0.5)  display window horizontal center
(ycenter=                   0.5)  display window vertical center
(xsize  =                    1.)  display window horizontal size
(ysize  =                    1.)  display window vertical size
(xmag   =                    1.)  display window horizontal magnification
(ymag   =                    1.)  display window vertical magnification
(order  =                     0)  spatial interpolator order (0=replicate, 1=linear)
(z1     =                      )  minimum greylevel to be displayed
(z2     =                      )  maximum greylevel to be displayed
(ztrans =                   log)  greylevel transformation (linear|log|none|user)
(lutfile=                      )  file containing user defined look up table
(mode   =                    ql)
```

Play around with these default values to get an image you're happy with

display (image name)

Check (all) your data

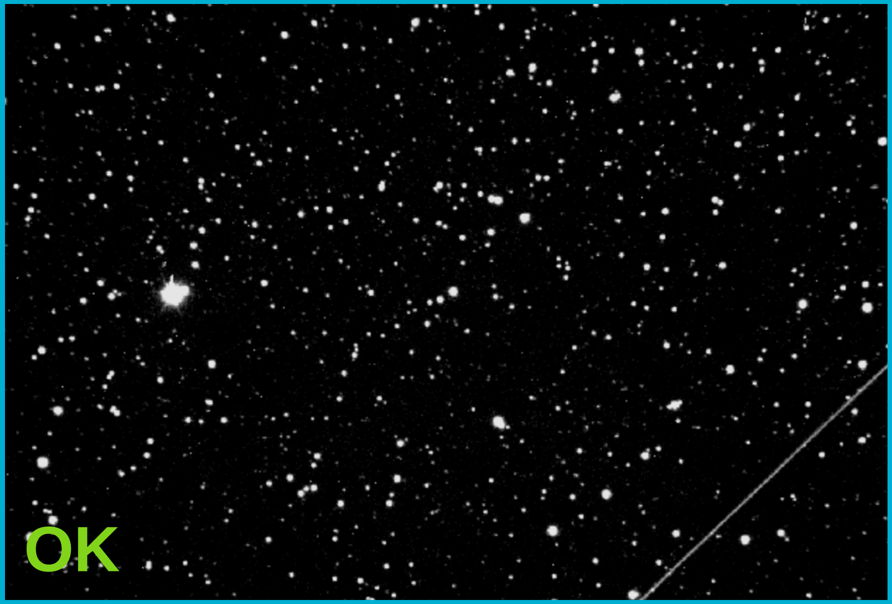
- All data is already in the same directory

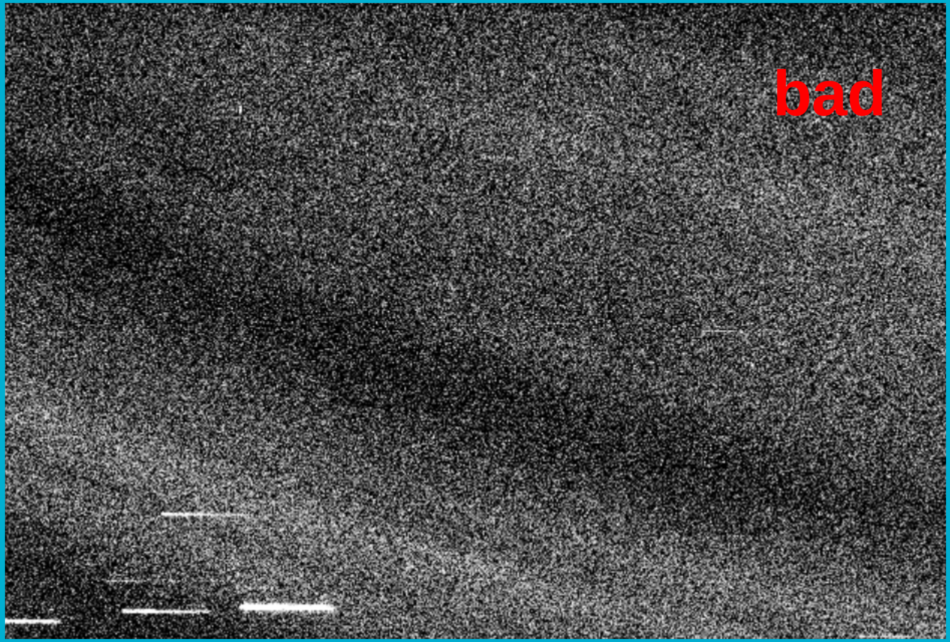
  !ds9 &

- Creat a list with science frames.
  ls filename*.fits > list_science

- Display images in ds9 and relocate useless frames
  imexam @list_science 1
  (n next frame
  p previous frame
  q quit)

- Remove useless science frames: clouds? Satellites? tracking problems? Etc.
  But avoid removing unnecessarily!!


OK


bad

Master flat

- The master flats have already been created, but it is good practice to inspect them.

- Display the flat:

  display masterflat-R.fit

- Plot the flat:

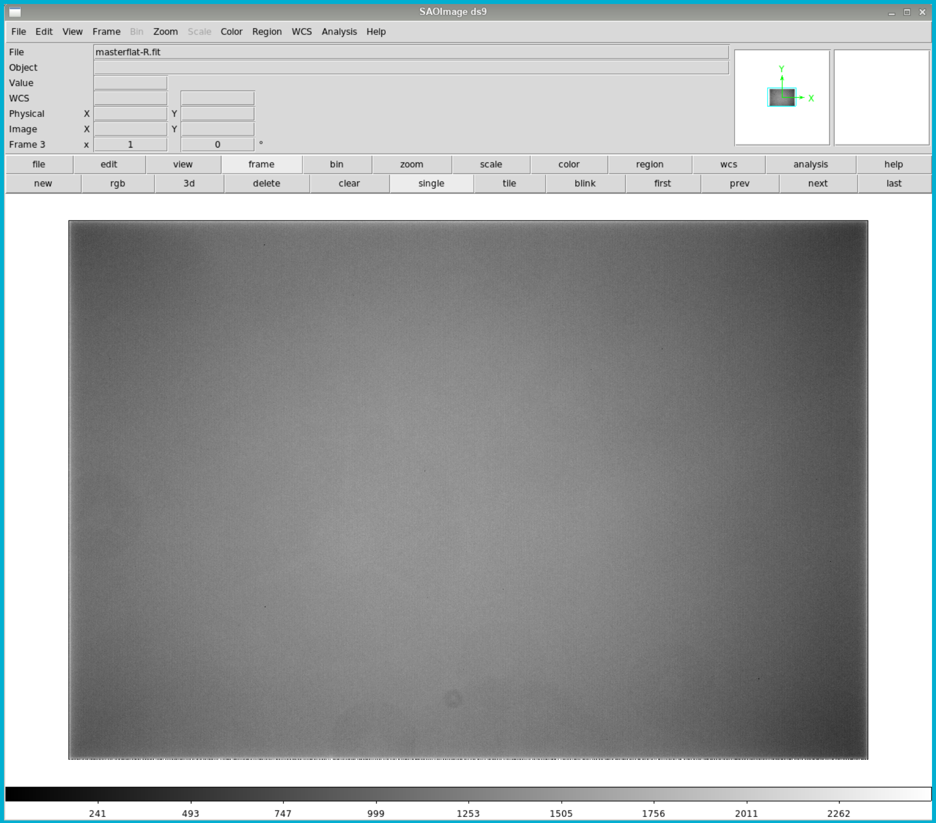
  implot masterflat-R.fit

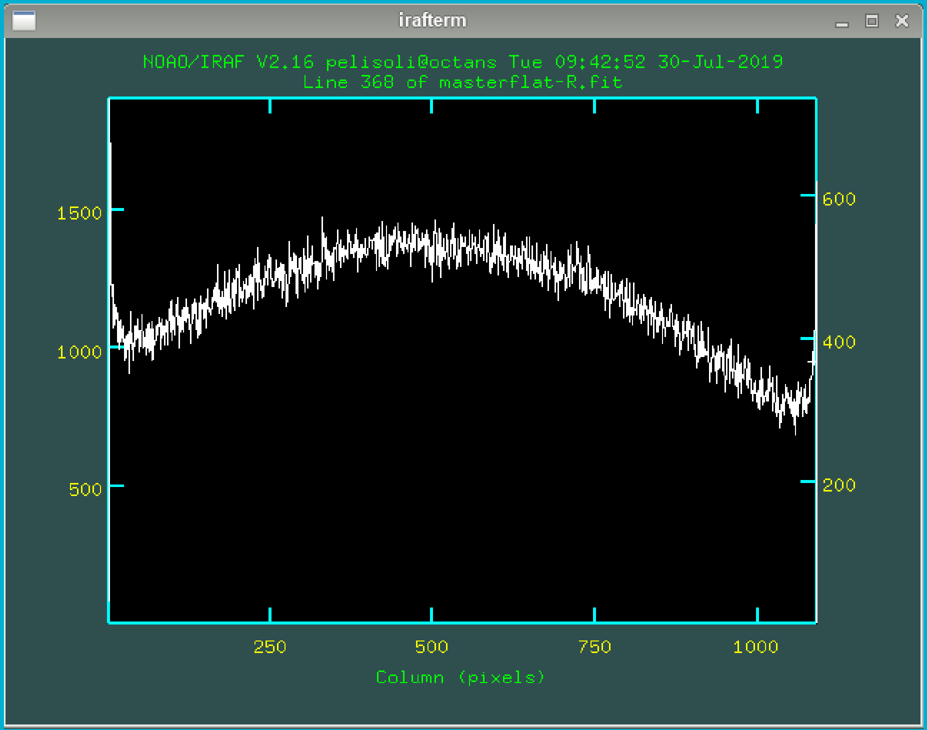
  ‘l’ and ‘c’ to switch axes

- Check image statistics:

  imstat masterflat-R.fit

Master flat


SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File
masterflat-R.fit
Object
Value
WCS
Physical
Image
Frame 3
file edit view frame bin zoom scale color region wcs analysis help
new rgb 3d delete clear single tile blink first prev next last
241 493 747 999 1253 1505 1756 2011 2262


irafterm
NOAO/IRAF V2.16 pelisoli@octans Tue 09:42:52 30-Jul-2019
Line 368 of masterflat-R.fit
1500
1000
500
600
400
200
250 500 750 1000
Column (pixels)

Creating a master dark

- What is the exposure time of the images we will analyse?
  Check the header!
  Single frame: **`imhead [image name] lo+ | page`**
  Multible frames: **`hsel Object*fits $I,exptime yes`**
  (“exptime” is the fits header keword)

- Which dark images should we use?
  `imhead df-* lo+ | grep EXPTIME` or **`hsel`**

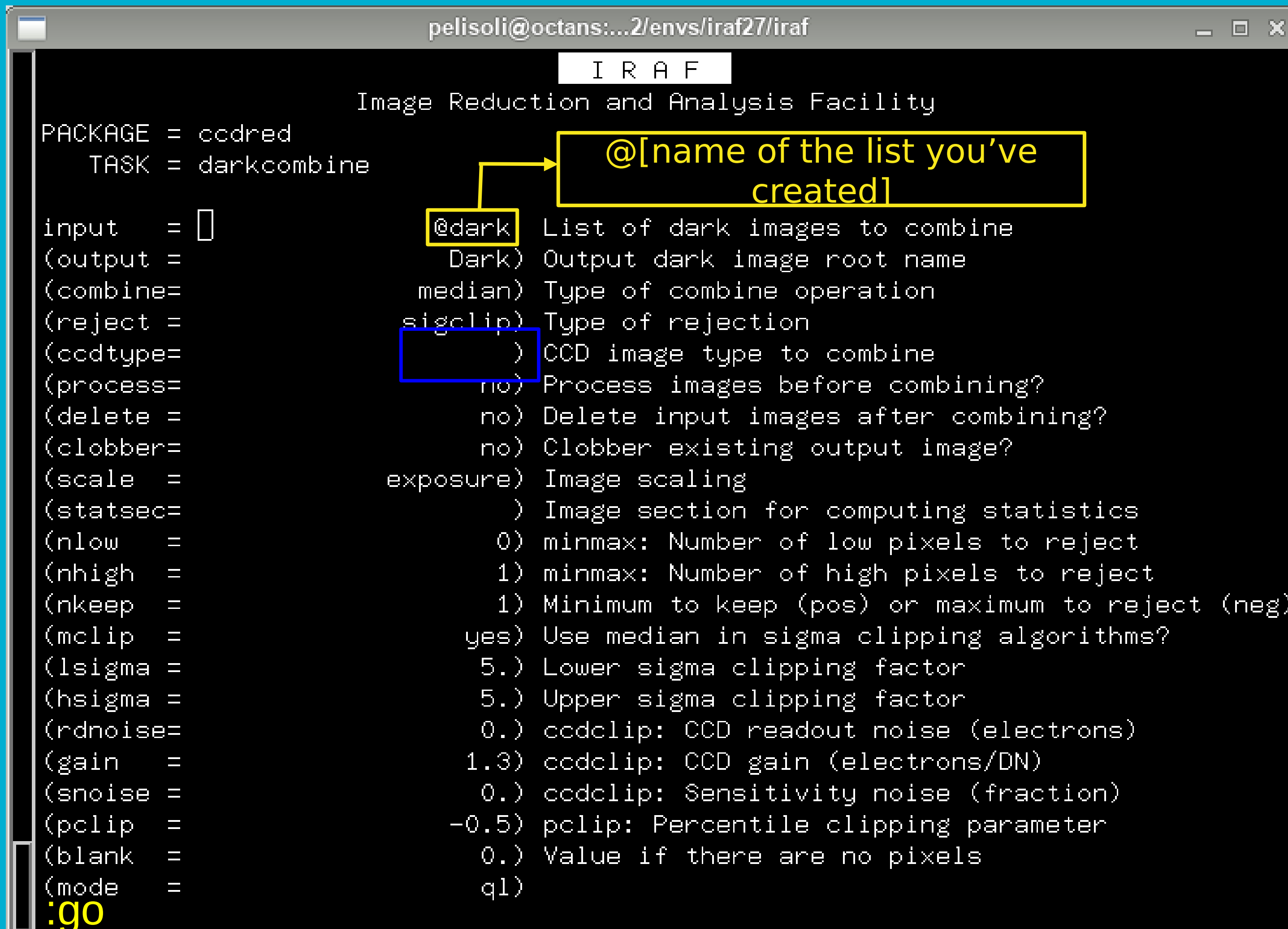
- Create a list (text document) containing the names of the dark frames using the same exposure time as the science images.

  Ls df* > df_60s_list

Creating a master dark – epar darkcombine

Check parameters!

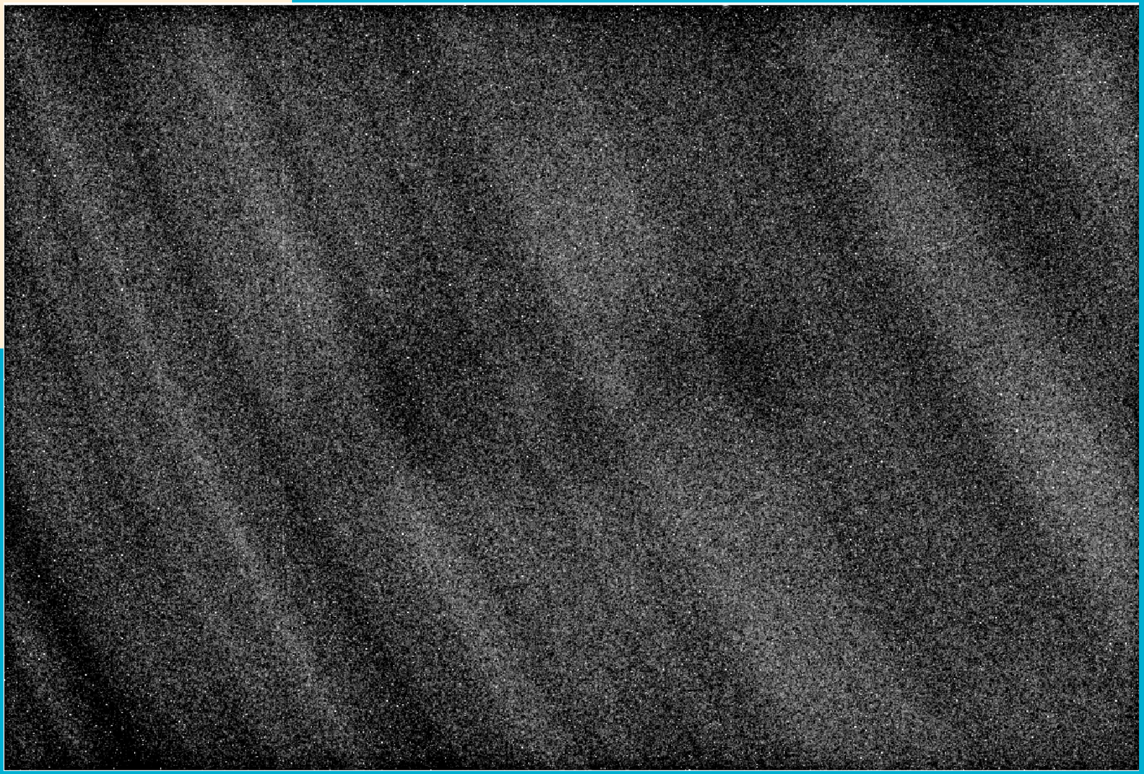
ccdtype has to be empty! Just put space.



":go" + enter

Creating a master dark –

```
Aug 30 16:01: IMCOMBINE
  combine = median, scale = exposure, zero = none, weight = none
  reject = sigclip, mclip = yes, nkeep = 1
  lsigma = 5., hsigma = 5.
  blank = 0.
                Images
       df60s__0001.fits
       df60s__0002.fits
       df60s__0003.fits
       df60s__0004.fits
       df60s__0005.fits
       df60s__0006.fits
       df60s__0007.fits
       df60s__0008.fits
       df60s__0009.fits
       df60s__0010.fits

  Output image = Dark, ncombine = 10
```



- Check what you got!
  display
  imstat

Reducing the science images

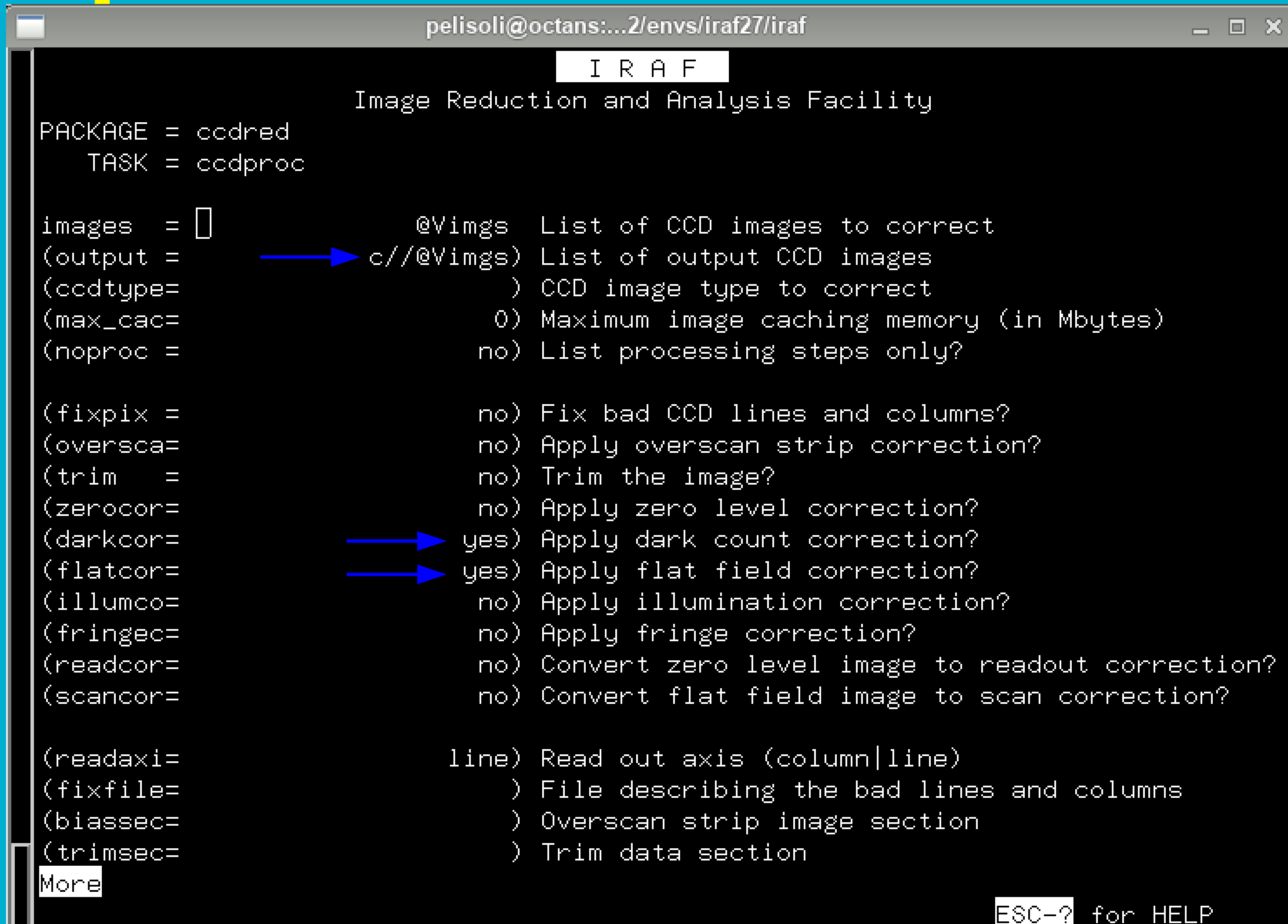
- We have images on two different filters: R or V.
  You have to use the correct master flat for each of them.
- Make a list containing the R images, and another containing the V images, e.g.

```
ls Cyg2*R*.fit > Rimgs
ls Cyg2*V*.fit > Vimgs
```

- Use the task **ccdproc** to divide the images by the flat and subtract the dark current. Do it separately for R and V images.

Reducing the science images 1 - epar ccdproc

Check parameters!



Continues ...

Reducing the science images 2 - epar ccdproc

pelisoli@octans:...2/envs/iraf27/iraf

```
                              I R A F
                    Image Reduction and Analysis Facility
PACKAGE = ccdred
   TASK = ccdproc
More
(zero   =                             ) Zero level calibration image
(dark   =                   Dark.fits) Dark count calibration image
(flat   =            masterflat-V.fit) Flat field images
(illum  =                             ) Illumination correction images
(fringe =                             ) Fringe correction images
(minrepl=                          1.) Minimum flat field value
(scantyp=                   shortscan) Scan type (shortscan|longscan)
(nscan  =                           1) Number of short scan lines

(interac=                          no) Fit overscan interactively?
(functio=                    legendre) Fitting function
(order  =                           1) Number of polynomial terms or spline pieces
(sample =                           *) Sample points to fit
(naverag=                           1) Number of sample points to combine
(niterat=                           1) Number of rejection iterations
(low_rej=                          3.) Low sigma rejection factor
(high_re=                          3.) High sigma rejection factor
(grow   =                          0.) Rejection growing radius
(mode   =                          ql)

                                                          ESC-? for HELP
```

:go

Reducing the science images 3

ccdproc in action

```
ale=28645.95
Object_3__R_0028.fits: Aug 30 16:19 Dark count correction image is Dark.fits wit
h scale=1.
Object_3__R_0028.fits: Aug 30 16:19 Flat field image is masterflat-R.fit with sc
ale=28645.95
Object_3__R_0029.fits: Aug 30 16:20 Dark count correction image is Dark.fits wit
h scale=1.
Object_3__R_0029.fits: Aug 30 16:20 Flat field image is masterflat-R.fit with sc
ale=28645.95
Object_3__R_0030.fits: Aug 30 16:20 Dark count correction image is Dark.fits wit
```

- **Check what you got!** Reduced files start with “c”
  ls
  display
  imstat (raw vs reduced frame)
  imhead (reduction steps added into the end of the fits header)

Photometry

- Now that the images have been reduced, we can perform photometry.
- The first step is to run the task `daofind`, which will find the stars in our images.
- There are a few parameters we need to measure in our image to best setup daofind: the sky and the **F**(ull)**W**(idth)**H**(alf)**M**(aximum)
- For that, display an image at the beginning of the sequence, middle, and end:

```
display cCyg2R001.fit 1
display cCyg2R111.fit 2
display cCyg2R223.fit 3
```

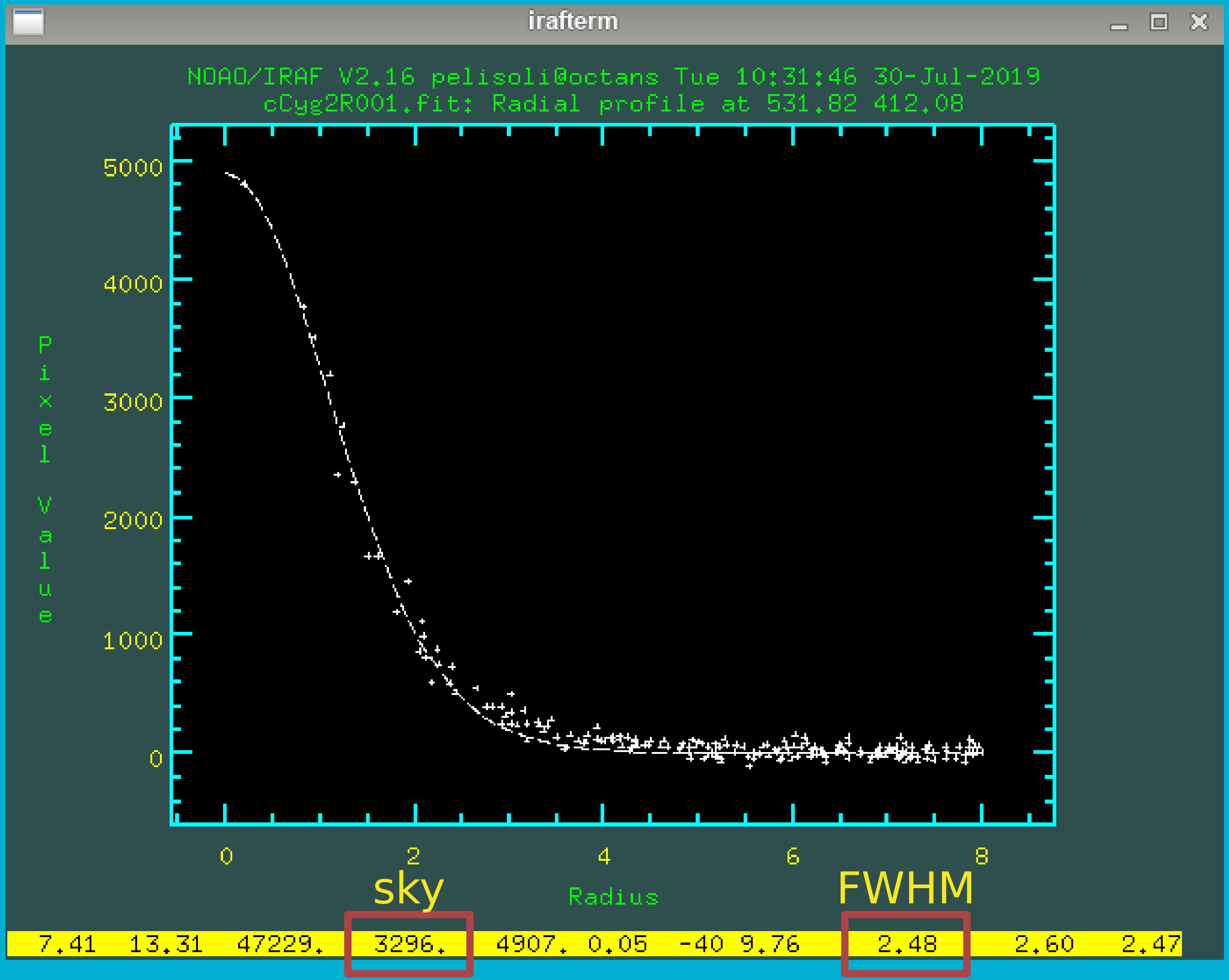
- Use the task **`imexamine`** – choose a relatively bright star near the centre of the image. Centre the cursor on this star.

r → display the radial profile

e → show contours

a → write measurements to the screen

Photometry



irafterm
NOAO/IRAF V2.16 pelisoli@octans Tue 10:31:46 30-Jul-2019
cCyg2R001.fit: Radial profile at 531.82 412.08
5000
4000
3000
2000
1000
0
Pixel Value
0
2
4
6
8
Radius
sky
FWHM
7.41 13.31 47229. 3296. 4907. 0.05 -40 9.76 2.48 2.60 2.47

Photometry

- Check the sky values in the three images. We will use this to set our initial guess for the background. The value of sigma is in turn the square-root of the background (assuming Poissonic noise).

  If the values are very different, use the median; if they are similar, use the mean.

  E. g.

  sky = 415.
  sigma = 20.4

- Check the FWHM in the three images. We will use this to set the aperture and the sky region for the photometry.

epar DAOFIND (to find the stars coordinates)

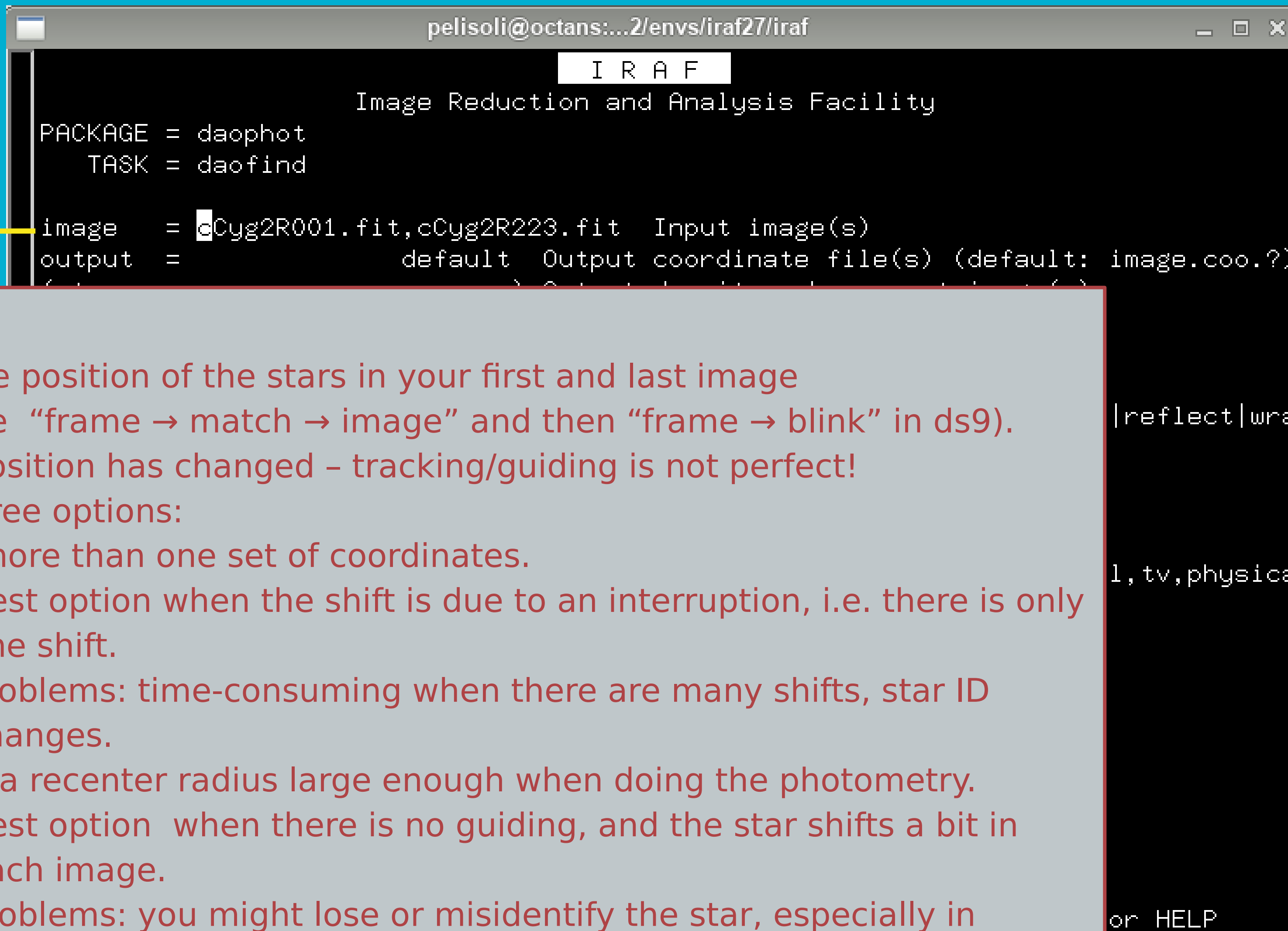
“cTarget...*fits” selects many files

In which image(s) to run it

```
pelisoli@octans:...2/envs/iraf27/iraf

                             I R A F
                 Image Reduction and Analysis Facility
PACKAGE = daophot
   TASK = daofind

image   = cCyg2R001.fit,cCyg2R223.fit  Input image(s)
output  =             default  Output coordinate file(s) (default: image.coo.?)
(starmap=                    ) Output density enhancement image(s)
(skymap =                    ) Output sky image(s)
(datapar=  :e                ) Data dependent parameters
(findpar=  :e                ) Object detection parameters
(boundar=             nearest) Boundary extension (constant|nearest|reflect|wra
(constan=                  0.) Constant for boundary extension
(interac=                  no) Interactive mode?
(icomman=                    ) Image cursor: [x y wcs] key [cmd]
(gcomman=                    ) Graphics cursor: [x y wcs] key [cmd]
(wcsout =           )_.wcsout) The output coordinate system (logical,tv,physica
(cache  =            )_.cache) Cache the image pixels?
(verify =           )_.verify) Verify critical daofind parameters?
(update =           )_.update) Update critical daofind parameters?
(verbose=          )_.verbose) Print daofind messages?
(graphic=         )_.graphics) Graphics device
(display=          )_.display) Display device
(mode   =                  ql)

                                                        ESC-? for HELP
```

DAOFIND

**The very best is to align your images.
We will do it on Friday.**



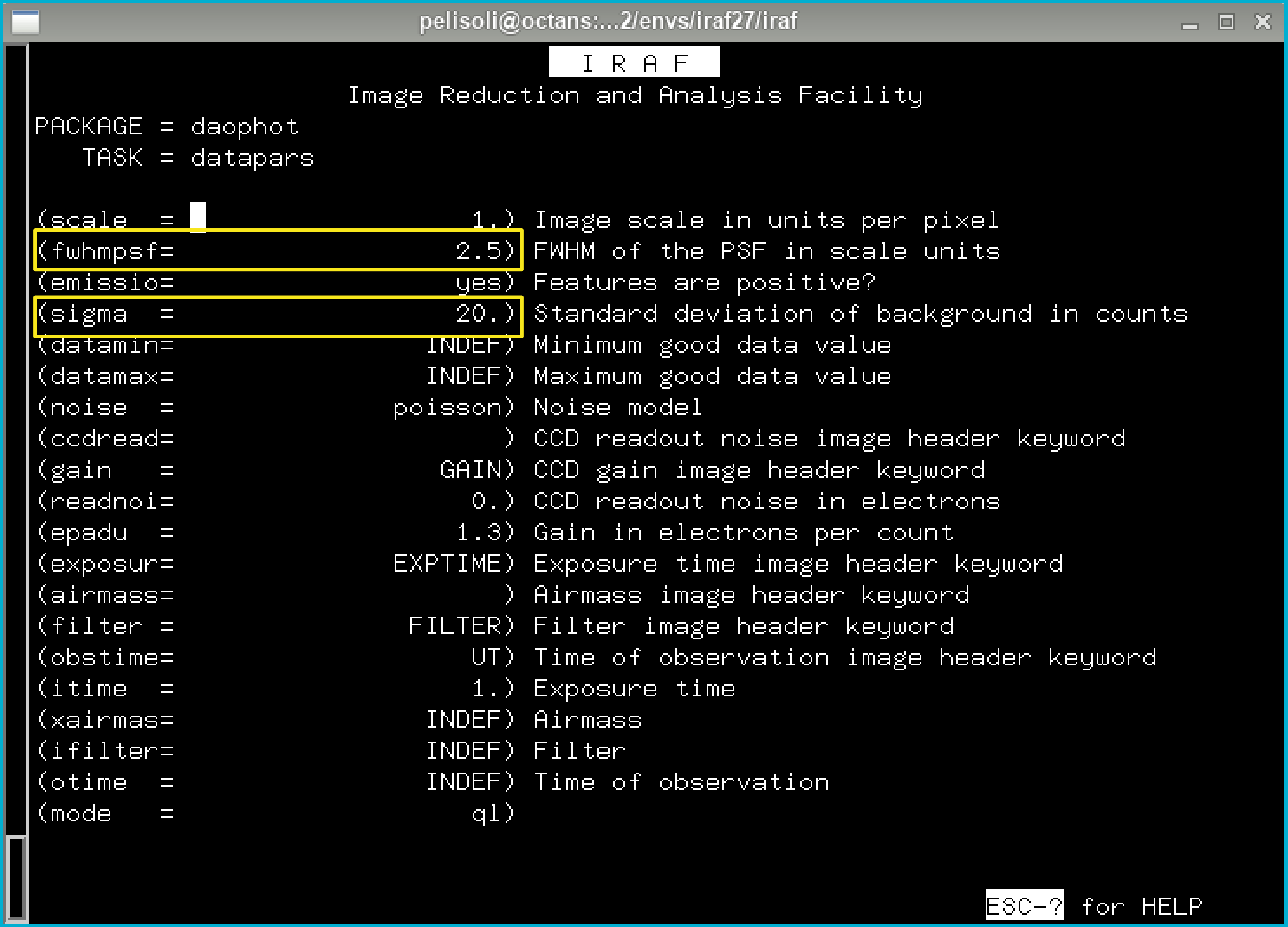
In which image(s) to run it

WARNING!

- Compare the position of the stars in your first and last image (you can use “frame → match → image” and then “frame → blink” in ds9).
- Likely the position has changed – tracking/guiding is not perfect!
- You have three options:
  - Have more than one set of coordinates.
    - Best option when the shift is due to an interruption, i.e. there is only one shift.
    - Problems: time-consuming when there are many shifts, star ID changes.
  - Define a recenter radius large enough when doing the photometry.
    - Best option when there is no guiding, and the star shifts a bit in each image.
    - Problems: you might lose or misidentify the star, especially in crowded fields.

DAOFIND (datapars)

“:q” to go back



DAOFIND (findpars)

```
pelisoli@octans:...2/envs/iraf27/iraf
                                      I R A F
                       Image Reduction and Analysis Facility
PACKAGE = daophot
   TASK = findpars

(thresho=                      5.) Threshold in sigma for feature detection
(nsigma =                     1.5) Width of convolution kernel in sigma
(ratio  =                      1.) Ratio of minor to major axis of Gaussian kernel
(theta  =                      0.) Position angle of major axis of Gaussian kernel
(sharplo=                     0.2) Lower bound on sharpness for feature detection
(sharphi=                      1.) Upper bound on sharpness for  feature detection
(roundlo=                     -1.) Lower bound on roundness for feature detection
(roundhi=                      1.) Upper bound on roundness for feature detection
(mkdetec=                      no) Mark detections on the image display?
(mode   =                      ql)

                                                                 ESC-? for HELP
```

How many sigma above the background. Usually a value between 4 and 6 is good for finding all stars. To restrict to brighter stars, use a larger value.

DAOFIND *in action*

```
FWHM of features in scale units (2.7) (CR or value):
        New FWHM of features: 2.7 scale units  2.7 pixels
Standard deviation of background in counts (41.2) (CR or value):
        New standard deviation of background: 41.2 counts
Detection threshold in sigma (5.) (CR or value):
        New detection threshold: 5. sigma 206. counts
Minimum good data value (INDEF) (CR or value):
        New minimum good data value: INDEF counts
Maximum good data value (INDEF) (CR or value):
```

- You might see this. Press enter.

- Depending on the IRAF version you might see a lot of numbers running on the screen.

```
  545.99    726.55    -2.242   0.472  -0.116   0.189  1041
   32.06    729.13    -0.228   0.405  -0.511   0.681  1042
  375.02    728.18    -0.400   0.666   0.236   0.077  1043
  409.17    727.93    -0.678   0.499  -0.359   0.170  1044
  585.04    727.64    -2.160   0.528  -0.154   0.232  1045
  134.03    728.76    -0.790   0.513  -0.763   0.001  1046
  257.36    728.97    -0.835   0.457  -0.790  -0.208  1047
  731.38    728.65    -2.831   0.506  -0.287   0.054  1048
  979.69    729.83    -0.357   0.692   0.231  -0.168  1049
  277.59    731.73    -0.727   0.545  -0.608   0.211  1050
  891.52    730.58    -2.332   0.534  -0.400  -0.022  1051
   77.04    733.07    -0.427   0.515  -0.025   0.528  1052
  352.91    734.49    -1.049   0.523  -0.457   0.251  1053
  808.54    734.80    -1.416   0.538   0.224   0.123  1054
  823.96    735.24    -1.343   0.631   0.210   0.406  1055

threshold: 206. relerr: 1.190  0.2 <= sharp <= 1.  -1. <= round <= 1.

daophot>
```

DAOFIND (outputs)

- Text files: *.fits.coo.1
- Check what you got (e.g **! more filename**)

```
daophot> ! more cObject_3__R_0001.fits.coo.1
#K IRAF       = NOAO/IRAFV2.16          version    %-23s
#K USER       = sinope                  name       %-23s
#K HOST       = sinope-ThinkPad-X280    computer   %-23s
#K DATE       = 2022-08-31              yyyy-mm-dd %-23s
#K TIME       = 09:41:37                hh:mm:ss   %-23s
#K PACKAGE    = apphot                  name       %-23s
#K TASK       = daofind                 name       %-23s
#
#K SCALE      = 1.                      units      %-23.7g
#K FWHMPSF    = 2.7                     scaleunit  %-23.7g
#K EMISSION   = yes                     switch     %-23b
#K DATAMIN    = INDEF                   counts     %-23.7g
#K DATAMAX    = INDEF                   counts     %-23.7g
#K EXPOSURE   = ""                      keyword    %-23s
#K AIRMASS    = ""                      keyword    %-23s
#K FILTER     = FILTER                  keyword    %-23s
#K OBSTIME    = UT                      keyword    %-23s
#
#K NOISE      = poisson                 model      %-23s
#K SIGMA      = 41.2                    counts     %-23.7g
#K GAIN       = GAIN                    keyword    %-23s
#K EPADU      = 1.3                     e-/adu     %-23.7g
#K CCDREAD    = ""                      keyword    %-23s
#K READNOISE  = 0.                      e-         %-23.7g
#
#K IMAGE      = cObject_3__R_0001.fits  imagename  %-23s
#K FWHMPSF    = 2.7                     scaleunit  %-23.7g
#K THRESHOLD  = 5.                      sigma      %-23.7g
#K NSIGMA     = 1.5                     sigma      %-23.7g
#K RATIO      = 1.                      number     %-23.7g
#K THETA      = 0.                      degrees    %-23.7g
#
#K SHARPLO    = 0.2                     number     %-23.7g
#K SHARPHI    = 1.                      number     %-23.7g
#K ROUNDLO    = -1.                     number     %-23.7g
#K ROUNDHI    = 1.                      number     %-23.7g
#
#N XCENTER    YCENTER    MAG       SHARPNESS    SROUND       GROUND       ID         \
#U pixels     pixels     #         #            #            #            #          \
#F %-13.3f    %-10.3f    %-9.3f    %-12.3f      %-12.3f      %-12.3f      %-6d       \
#
   873.889    2.343      -0.477    0.697        -0.288       0.298        1
   479.859    4.346      -0.008    0.662        -0.377       -0.587       2
   926.247    4.867      -0.732    0.584        0.344        0.009        3
   805.686    6.033      -0.296    0.514        -0.417       0.162        4
   1052.871   6.328      -1.039    0.556        -0.131       0.102        5
```

DAOFIND (tdump – *massasing* text files)

- To check the stars that have been found, let’s mark them on the image.
- First, dump the coordinates and the ID of the stars onto a file (choose one coordinate file):

```
tdump cCyg2R001.fit.coo.1 columns=c1,c2,c7 > coordsR
```

- Check what you got: **! more coordsR**
- You might need to check the name of the columns:

```
tprint [FILE].coo.1 | less
```

”q” to exit

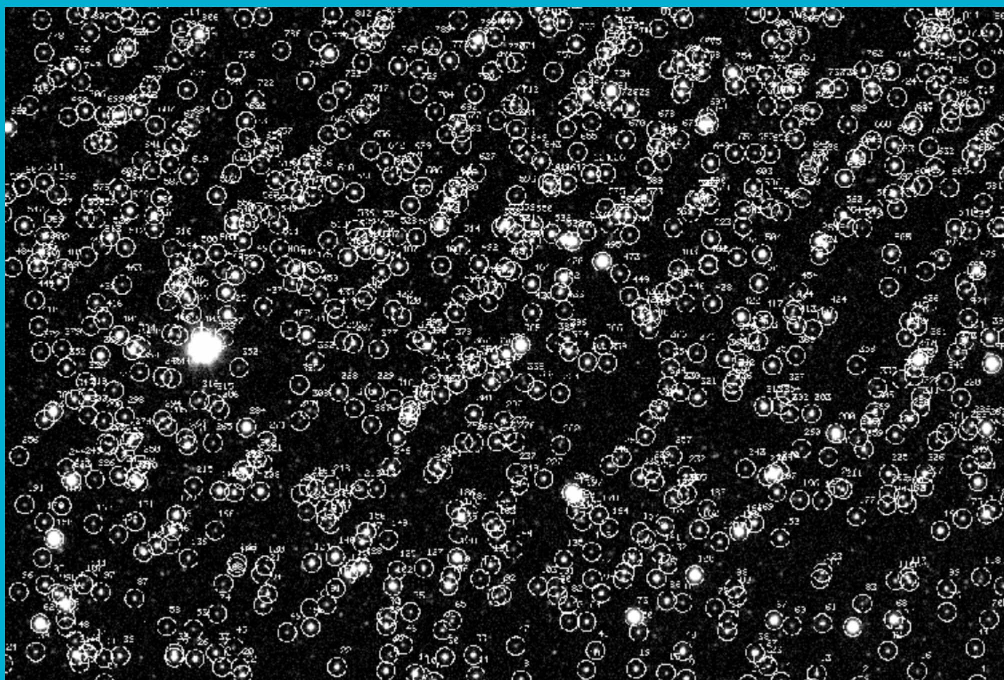
- Edit the parameters of the task **tvmark** (next slide)

DAOFIND (tvmark: to display the found stars)

```
pelisoli@octans:...2/envs/iraf27/iraf
                                   I R A F
                     Image Reduction and Analysis Facility
PACKAGE = tv
   TASK = tvmark

frame   =                     1  Default frame number for display
coords  =               coordsR  Input coordinate list
(logfile=                     ) Output log file
(autolog=                   no) Automatically log each marking command
(outimag=                     ) Output snapped image
(deletio=                     ) Output coordinate deletions list
(command=                     ) Image cursor: [x y wcs] key [cmd]
(mark   =               circle) The mark type
(radii  =                   25) Radii in image pixels of concentric circles
(lengths=                    0) Lengths and width in image pixels of concentric
(font   =               raster) Default font
(color  =                    0) Gray level of marks to be drawn
(label  =                  yes) Label the marked coordinates
(number =                   no) Number the marked coordinates
(nxoffse=                    0) X offset in display pixels of number
(nyoffse=                    0) Y offset in display pixels of number
(pointsi=                    3) Size of mark type point in display pixels
(txsize =                    2) Size of text and numbers in font units
(toleran=                  1.5) Tolerance for deleting coordinates in image pixe
(interac=                   no) Mode of use
(mode   =                   ql)

ccdred> 
```

display cObject...
epar tvmark
:go

DAOFIND (tvmark)



Open coords file to check the index of the identified stars
(left: xcoord, middle:ycoord, right:index)

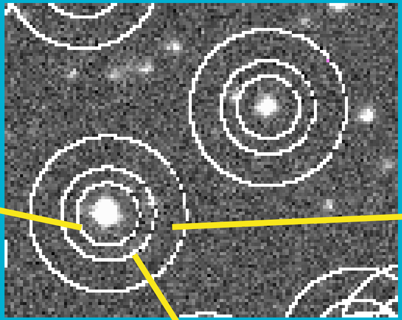
```
IMAGE    t cObject_3__R_0001.fits  imagename  %-23s
FWHMPSF  d 2.99  scaleunit  %-23.7g
THRESHOL d 5.  sigma      %-23.7g
NSIGMA   d 1.5  sigma      %-23.7g
RATIO    d 1.  number     %-23.7g
THETA    d 0.  degrees    %-23.7g
SHARPLO  d 0.2  number     %-23.7g
SHARPHI  d 1.  number     %-23.7g
ROUNDLO  d -1.  number     %-23.7g
ROUNDHI  d 1.  number     %-23.7g
     873.8750000000001    2.324000000000001     1
     926.2460000000001    4.868000000000001     2
               805.685                6.041     3
              1052.876    6.328000000000001     4
               111.774    7.526000000000001     5
     467.2890000000001    9.291000000000002     6
     840.9600000000001    9.282000000000001     7
     561.2710000000001               11.463     8
     738.9200000000002               12.226     9
     454.5820000000001               13.999    10
     512.4170000000001    15.12500000000001    11
     260.6510000000001    16.36800000000001    12
     879.6440000000002               17.477    13
     446.6380000000001    17.81800000000001    14
     717.2380000000001                18.39    15
     988.0510000000002               20.317    16
     415.3870000000001    20.69100000000001    17
     631.1070000000003               22.039    18
               684.696               23.028    19
               257.866               23.876    20
     238.7500000000001    25.00800000000001    21
               362.548    25.02800000000001    22
     826.6200000000001    25.66300000000001    23
     89.46600000000002              113.635   107
     240.0990000000001              114.563   108
     979.6470000000002              117.214   109
```

Photometry

- `tvmark` is also useful to help us define the aperture, annulus, and dannulus

NB!
tvmark: radii
Phot: aperture, annulus, dannulus

Aperture (<u>radii</u>): where the flux of the star will be measured.
Usually ~2.5 x FWHM



Dannulus: <u>width</u> of the ring to count the background.
~5-10 pixels

Annulus (<u>radii</u>): distance at which to start counting the background.
At least 2.5 x FWHM
<u>~4 x FWHM in our example</u>

* For a Gaussian distribution:
FWHM = 2.35σ
99.99% of the light is contained within 4σ = 1.7FWHM

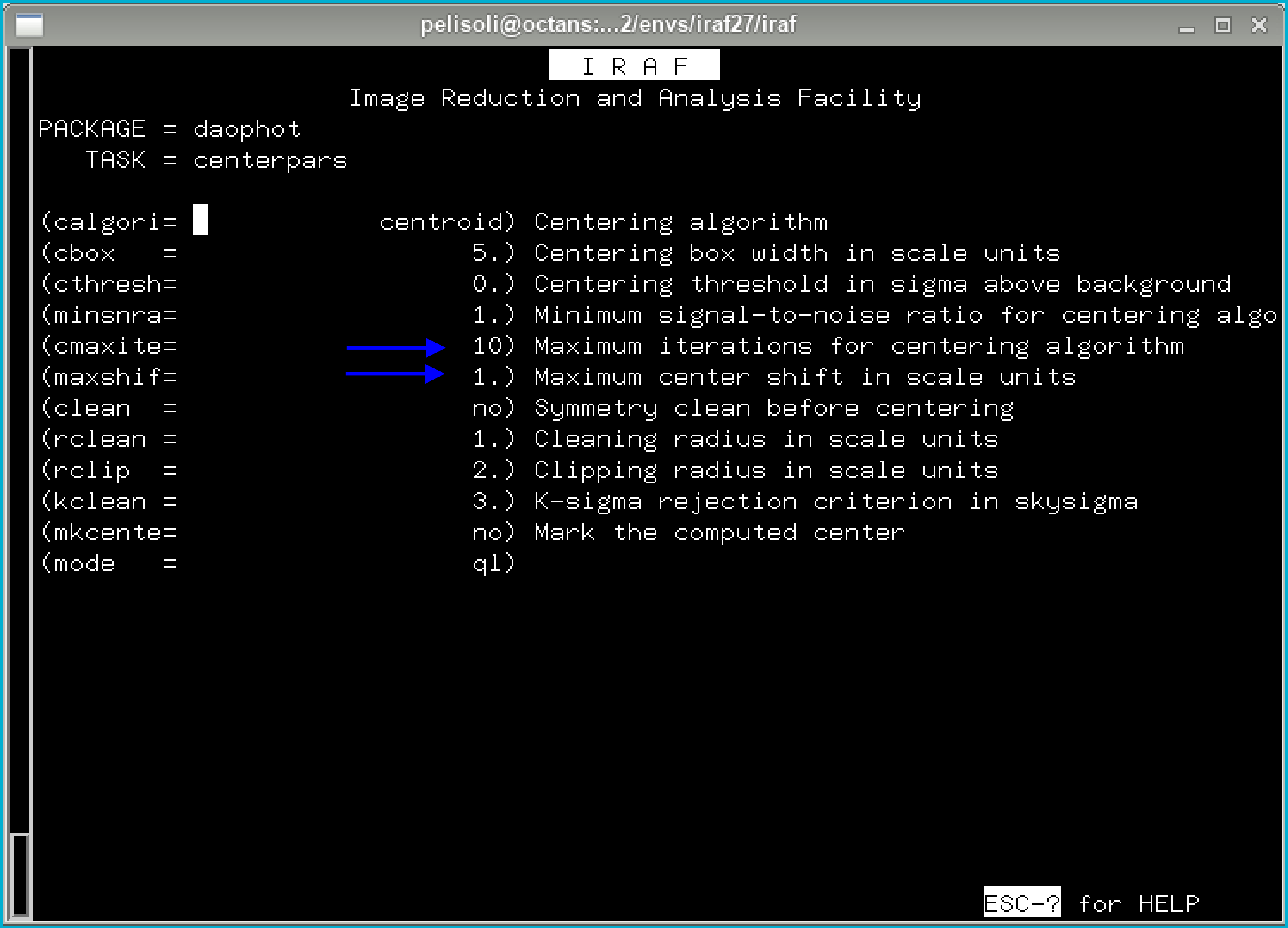
DAOPHOT – epar phot

List of reduced R (or V) images.

NB!
One coordinate file for all frames

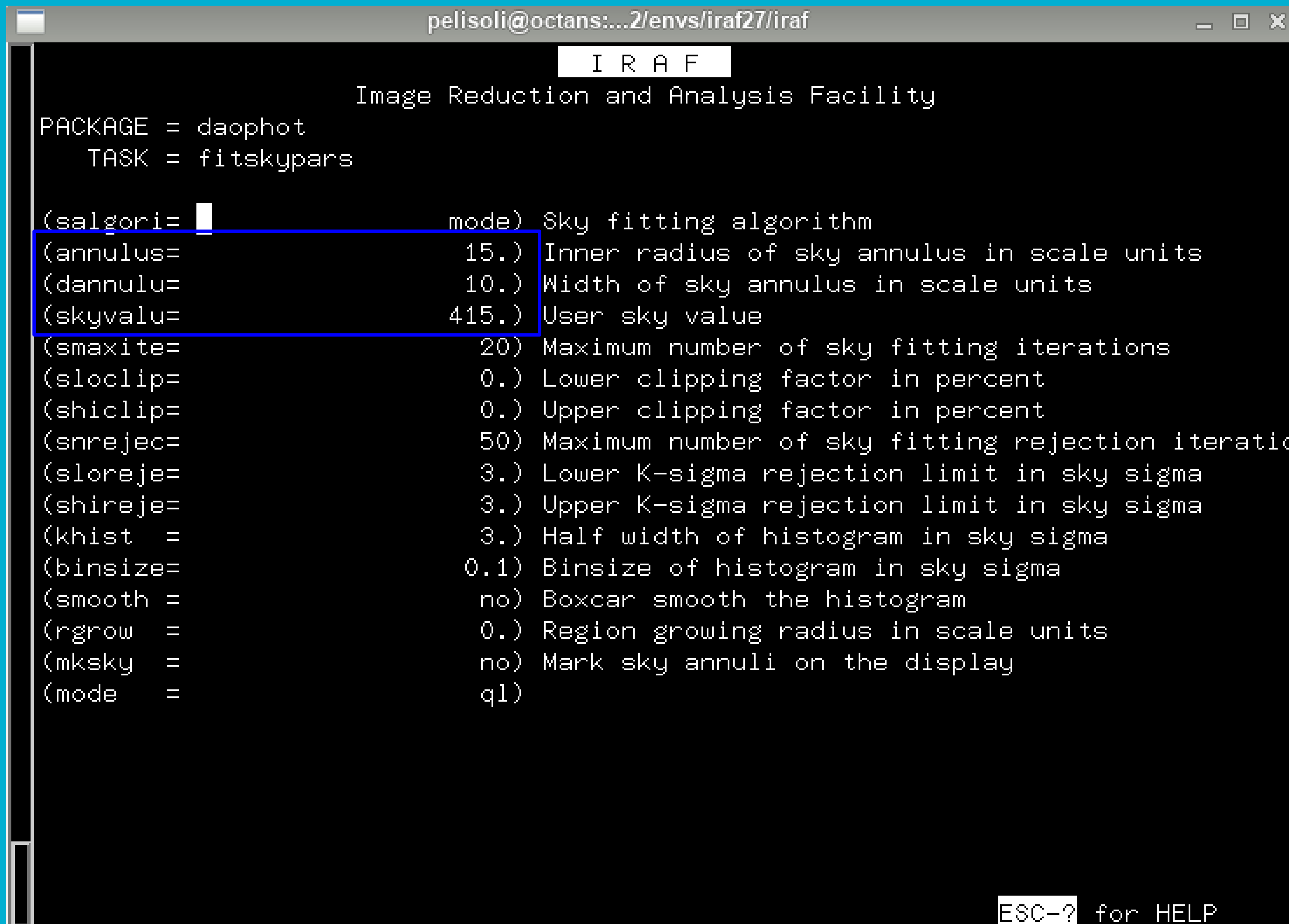
```
pelisoli@octans:...2/envs/iraf27/iraf

                                  I R A F
                    Image Reduction and Analysis Facility
PACKAGE = daophot
   TASK = phot

image   =          @cimgsR_beg  Input image(s)
coords  =  cCyg2R001.fit.coo.1  Input coordinate list(s) (default: image.coo.?)
output  =              default  Output photometry file(s) (default: image.mag.?)
skyfile =                       Input sky value file(s)
(plotfil=                     ) Output plot metacode file
(datapar=                     ) Data dependent parameters
(centerp=  :e                 ) Centering parameters
(fitskyp=  :e                 ) Sky fitting parameters
(photpar=  :e                 ) Photometry parameters
(interac=                   no) Interactive mode?
(radplot=                   no) Plot the radial profiles?
(icomman=                     ) Image cursor: [x y wcs] key [cmd]
(gcomman=                     ) Graphics cursor: [x y wcs] key [cmd]
(wcsin  =            )_.wcsin) The input coordinate system (logical,tv,physical
(wcsout =           )_.wcsout) The output coordinate system (logical,tv,physica
(cache  =            )_.cache) Cache the input image pixels in memory?
(verify =           )_.verify) Verify critical phot parameters?
(update =           )_.update) Update critical phot parameters?
(verbose=          )_.verbose) Print phot messages?
(graphic=         )_.graphics) Graphics device
(display=          )_.display) Display device
More
                                                        ESC-? for HELP
```

DAOPHOT (centerpars)

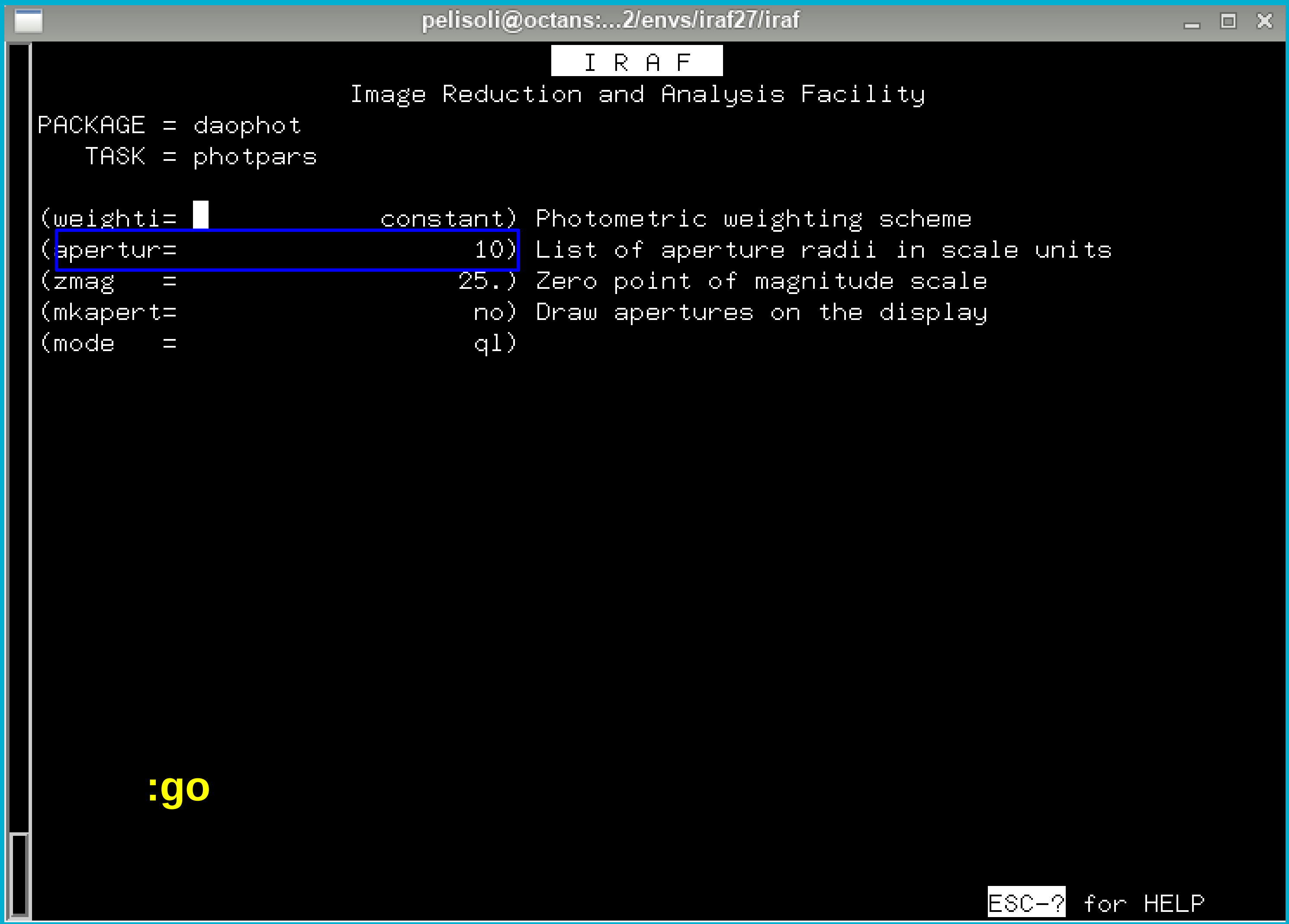


PHOT (fitskypars)

Your data specific!



PHOT


pelisoli@octans:...2/envs/iraf27/iraf
I R A F
Image Reduction and Analysis Facility
PACKAGE = daophot
TASK = photpars
(weighti= constant) Photometric weighting scheme
(apertur= 10) List of aperture radii in scale units
(zmag = 25.) Zero point of magnitude scale
(mkapert= no) Draw apertures on the display
(mode = ql)
:go
ESC-? for HELP

PHOT *in action*

```
Centering algorithm (centroid) (CR or value):
        New centering algorithm: centroid
Centering box width in scale units (5.) (CR or value):
        New centering box width: 5. scale units  5. pixels
Sky fitting algorithm (mode) (CR or value):
        Sky fitting algorithm: mode
Inner radius of sky annulus in scale units (10.8) (CR or value):
        New inner radius of sky annulus: 10.8 scale units 10.8 pixels
Width of the sky annulus in scale units (5.) (CR or value):
        New width of the sky annulus: 5. scale units 5. pixels
File/list of aperture radii in scale units (6.8) (CR or value):
        Aperture radius 1: 6.8 scale units 6.8 pixels
Standard deviation of background in counts (41.2) (CR
```

Possibly have to confirm your parameters.

```
cObject_3__R_0039.fits    117.80    724.61   1630.774    15.417   ok
cObject_3__R_0039.fits    157.64    724.52   1629.492    14.740   ok
cObject_3__R_0039.fits    488.41    726.61    1622.06    15.953   ok
cObject_3__R_0039.fits    600.71    725.55   1630.802    14.261   ok
cObject_3__R_0039.fits     39.93    727.46   1623.682    15.590   ok
cObject_3__R_0039.fits    535.45    726.53   1639.767    14.240   ok
cObject_3__R_0039.fits    546.02    726.52   1630.498    13.923   ok
cObject_3__R_0039.fits     31.74    729.13   1628.021    15.771   ok
cObject_3__R_0039.fits    375.03    728.29   1632.699    16.592   ok
cObject_3__R_0039.fits    409.29    727.89   1621.293    15.092   ok
cObject_3__R_0039.fits    585.08    727.53   1646.165    14.111   ok
cObject_3__R_0039.fits    134.08    728.71   1629.078    15.446   ok
cObject_3__R_0039.fits    257.49    729.09   1633.361    15.320   ok
cObject_3__R_0039.fits    731.43    728.55   1622.969    13.429   ok
cObject_3__R_0039.fits    979.61    729.73    1629.34     INDEF   err
cObject_3__R_0039.fits    277.56    731.54   1627.014     INDEF   err
cObject_3__R_0039.fits    891.51    730.55    1630.98     INDEF   err
cObject_3__R_0039.fits     76.90    732.82   1636.415     INDEF   err
cObject_3__R_0039.fits    352.86    734.45   1613.267     INDEF   err
cObject_3__R_0039.fits    808.50    734.55   1631.013     INDEF   err
cObject_3__R_0039.fits    823.97    735.11   1624.323     INDEF   err
daophot>
```

Lots of numbers on the screen but not always.

PHOT (outputs)

- Text files: *.fits.coo.1.mag.1 or *mag.2 if done twice
- Check what you got (e.g **! more filename**)

IMPORTANT COLUMNS

c4 = star ID
c5 = x coordinate
c6 = y coordinate
c29 = magnitude
c30 = magnitude error
c28= flux.

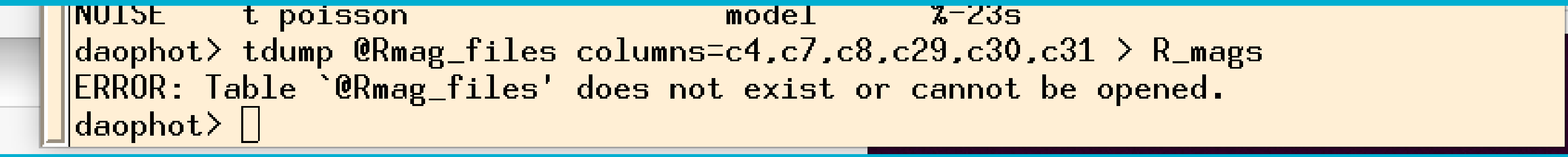
```
#K CTHRESHOLD = 0.                              sigma      %-23.7g
#K MINSNRATIO = 1.                              number     %-23.7g
#K CMAXITER   = 10                              number     %-23d
#K MAXSHIFT   = 1.                              scaleunit  %-23.7g
#K CLEAN      = no                              switch     %-23b
#K RCLEAN     = 1.                              scaleunit  %-23.7g
#K RCLIP      = 2.                              scaleunit  %-23.7g
#K KCLEAN     = 3.                              sigma      %-23.7g
#
#K SALGORITHM = mode                            algorithm  %-23s
#K ANNULUS    = 10.8                            scaleunit  %-23.7g
#K DANNULUS   = 5.                              scaleunit  %-23.7g
#K SKYVALUE   = 1697.                           counts     %-23.7g
#K KHIST      = 3.                              sigma      %-23.7g
#K BINSIZE    = 0.1                             sigma      %-23.7g
#K SMOOTH     = no                              switch     %-23b
#K SMAXITER   = 10                              number     %-23d
#K SLOCLIP    = 0.                              percent    %-23.7g
#K SHICLIP    = 0.                              percent    %-23.7g
#K SNREJECT   = 50                              number     %-23d
#K SLOREJECT  = 3.                              sigma      %-23.7g
#K SHIREJECT  = 3.                              sigma      %-23.7g
#K RGROW      = 0.                              scaleunit  %-23.7g
#
#K WEIGHTING  = constant                        model      %-23s
#K APERTURES  = 6.8                             scaleunit  %-23s
#K ZMAG       = 25.                             zeropoint  %-23.7g
#
#N IMAGE                  XINIT      YINIT       ID    COORDS                  LID    \
#U imagename              pixels     pixels      ##    filename                ##     \
#F %-23s                  %-10.3f    %-10.3f     %-6d  %-23s                   %-6d
#
#N XCENTER    YCENTER     XSHIFT  YSHIFT  XERR    YERR            CIER CERROR   \
#U pixels     pixels      pixels  pixels  pixels  pixels          ##   cerrors  \
#F %-14.3f    %-11.3f     %-8.3f  %-8.3f  %-8.3f  %-15.3f         %-5d %-9s
#
#N MSKY           STDEV          SSKEW          NSKY    NSREJ     SIER SERROR   \
#U counts         counts         counts         npix    npix      ##   serrors  \
#F %-18.7g        %-15.7g        %-15.7g        %-7d    %-9d      %-5d %-9s
#
#N ITIME          XAIRMASS       IFILTER                OTIME                   \
#U timeunit       number         name                   timeunit                \
#F %-18.7g        %-15.7g        %-23s                  %-23s
#
#N RAPERT   SUM           AREA       FLUX           MAG     MERR   PIER PERROR   \
#U scale    counts        pixels     counts         mag     mag    ##   perrors  \
#F %-12.2f  %-14.7g       %-11.7g    %-14.7g        %-7.3f  %-6.3f %-5d %-9s
#
cObject_3__R_0001.fits 873.889   2.343      1      cObject_3__R_0001.fits.1      \
   873.612     2.269       -0.277  -0.074  0.011   0.012             102  EdgeImage \
   1672.762       42.76828       11.56399        216     10        0    NoError   \
   1.             INDEF          R                      00:41:07.186            \
   6.80     0.            0.         0.             INDEF   INDEF  301  OffImage
cObject_3__R_0001.fits 479.859   4.346      2      cObject_3__R_0001.fits.2      \
   479.975     4.400       0.116   0.054   0.011   0.017             0    NoError   \
   1664.66        45.23207       25.39543        216     33        0    NoError   \
   1.             INDEF          R                      00:41:07.186            \
```

Photometry (text files)

- Dump the photometry into a text file:

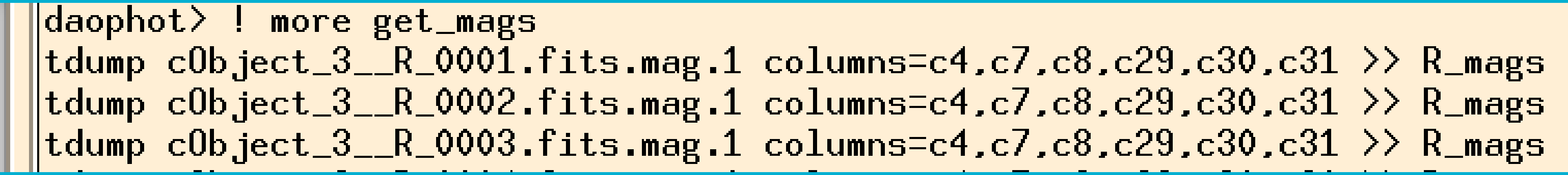
  Make a list of photometry files: **`ls *R*mag.1 > Rmag_files`**

  `tdump @Rmag_files columns=c4,c5,c6,c29,c30,c28 > R_mags`



* if tdump refuses to read from a list, use txdump as follows:

txdump @Vmag_files fields=ID,XCENTER,YCENTER,FLUX,MAG,MERR > R_mags



- Check what you got (next slide).

PHOT (file R_mags)

—

- A VERY LARGE TEXT FILE 35k lines

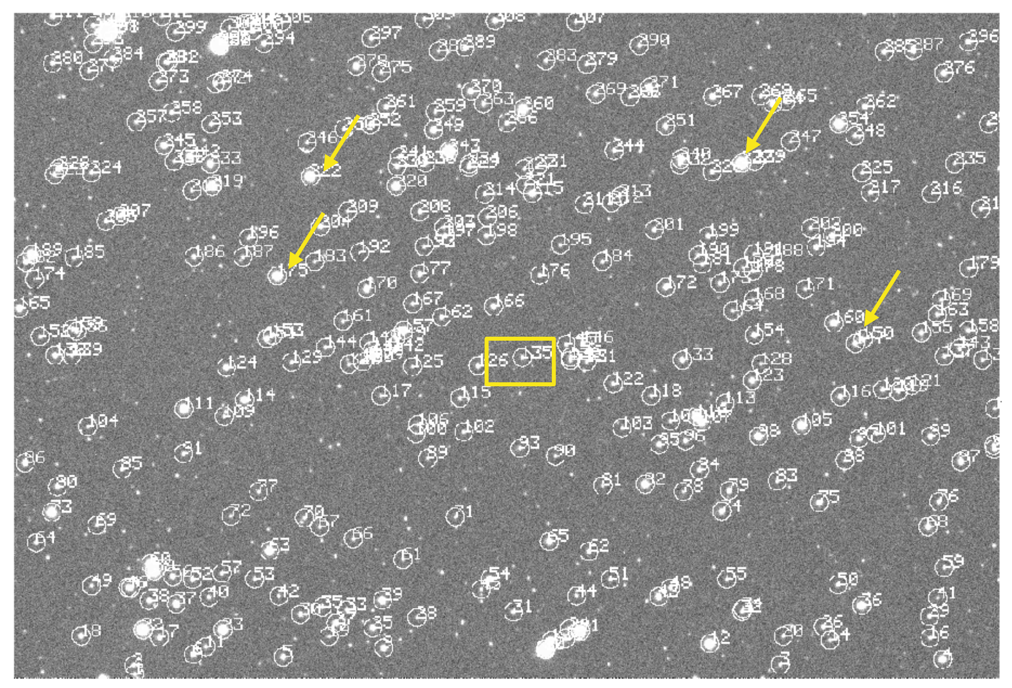
Or filename + star ID
This is a problem.
Contact Tiina

```
ecl> ! more R_mags
c4                 I              %5d   ""
c6                 D           %15.13g  ""
c7                 D             %8.6g  ""
c29                D           %16.14g  ""
c30                D             %6.5g  ""
c28                D            %10.8g  ""
IRAF      t NOAO/IRAFV2.16            version     %-23s
USER      t sinope                    name        %-23s
HOST      t sinope-ThinkPad-X280      computer    %-23s
DATE      t 2022-08-31                yyyy-mm-dd  %-23s
TIME      d 10:51:26  hh:mm:ss   %-23s
PACKAGE   t apphot                    name        %-23s
TASK      t phot                      name        %-23s
SCALE     d 1.  units      %-23.7g
FWHMPSF   d 2.7  scaleunit  %-23.7g
EMISSION  t yes                       switch      %-23b
DATAMIN   d INDEF  counts     %-23.7g
DATAMAX   d INDEF  counts     %-23.7g
EXPOSURE  t ''  keyword    %-23s
AIRMASS   t ''  keyword    %-23s
FILTER    t FILTER                    keyword     %-23s
OBSTIME   t UT                        keyword     %-23s
NOISE     t poisson                   model       %-23s
SIGMA     d 41.2  counts      %-23.7g
GAIN      t GAIN                      keyword     %-23s
EPADU     d 1.3  e-/adu     %-23.7g
CCDREAD   t ''  keyword    %-23s
READNOIS  d 0.  e-         %-23.7g
CALGORIT  t centroid                  algorithm   %-23s
CBOXWIDT  d 5.  scaleunit  %-23.7g
CTHRESHO  d 0.  sigma      %-23.7g
MINSNRAT  d 1.  number     %-23.7g
CMAXITER  i 10  number     %-23d
MAXSHIFT  d 1.  scaleunit  %-23.7g
CLEAN     t no                        switch      %-23b
RCLEAN    d 1.  scaleunit  %-23.7g
RCLIP     d 2.  scaleunit  %-23.7g
KCLEAN    d 3.  sigma      %-23.7g
SALGORIT  t mode                      algorithm   %-23s
ANNULUS   d 10.8  scaleunit  %-23.7g
DANNULUS  d 5.  scaleunit  %-23.7g
SKYVALUE  d 1697.  counts     %-23.7g
KHIST     d 3.  sigma      %-23.7g
BINSIZE   d 0.1  sigma      %-23.7g
SMOOTH    t no                        switch      %-23b
SMAXITER  i 10  number     %-23d
SLOCLIP   d 0.  percent    %-23.7g
SHICLIP   d 0.  percent    %-23.7g
SNREJECT  i 50  number     %-23d
SLOREJEC  d 3.  sigma      %-23.7g
SHIREJEC  d 3.  sigma      %-23.7g
RGROW     d 0.  scaleunit  %-23.7g
WEIGHTIN  t constant                  model       %-23s
APERTURE  d 6.8  scaleunit  %-23s
ZMAG      d 25.  zeropoint  %-23.7g
    1   873.6120000000002   2.269000000000001    INDEF    INDEF                 0.
    2   479.9750000000002   4.400000000000001    INDEF    INDEF                 0.
    3   926.3750000000001   4.775000000000002    INDEF    INDEF                 0.
    4   805.6120000000002               5.969    INDEF    INDEF                 0.
    5            1052.827   6.462000000000001    INDEF    INDEF                 0.
    6             111.693   7.513000000000001   15.301    0.08500000000000001   7576.389000000001
    7   446.7300000000002   8.537000000000002   15.107    0.08600000000000002   9064.937000000001
    8   467.3750000000001   9.393000000000002   14.522    0.05000000000000001   15535.02000000001
    9             841.016   9.324000000000001   15.351    0.09300000000000002   7234.9
   10   561.4149999999999              11.537   15.115    0.06600000000000001   8993.307000000001
        738.8720000000001              12.329   14.189    0.02900000000000001   21102.71
                  454.489              14.105   15.024    0.07700000000000001   9782.393000000002
        512.4570000000001              15.163   14.212    0.02900000000000001   20669.92000000001
        260.5480000000001   16.42600000000001   13.927    0.02200000000000001   26861.27
        879.5810000000002   17.44600000000001   14.898    0.05400000000000001   10984.86
                  446.578   17.70500000000001   12.8      0.008000000000000001  75871.37
        717.4210000000001   18.34200000000001   15.831    0.116                 4652.417000000002
   18            1012.429               17.28   15.579    0.09700000000000001   5865.323000000001
```

```
daophot> ! more R_mags
cObject_3__R_0001s.fits1    2.269000000000001   -0.2770000000000001
cObject_3__R_0001s.fits2    4.400000000000001                 0.116
cObject_3__R_0001s.fits3    4.775000000000002                 0.128
cObject_3__R_0001s.fits4                5.969  -0.07400000000000002
```

Photometry

- Check the ID of your star and of a few comparison stars with `tvmark`.
  https://aladin.u-strasbg.fr/AladinLite/ might be useful to help identify your star.
- Comparison stars are needed to remove background variations from the light curve.



Photometry (more *massaging* of text files)

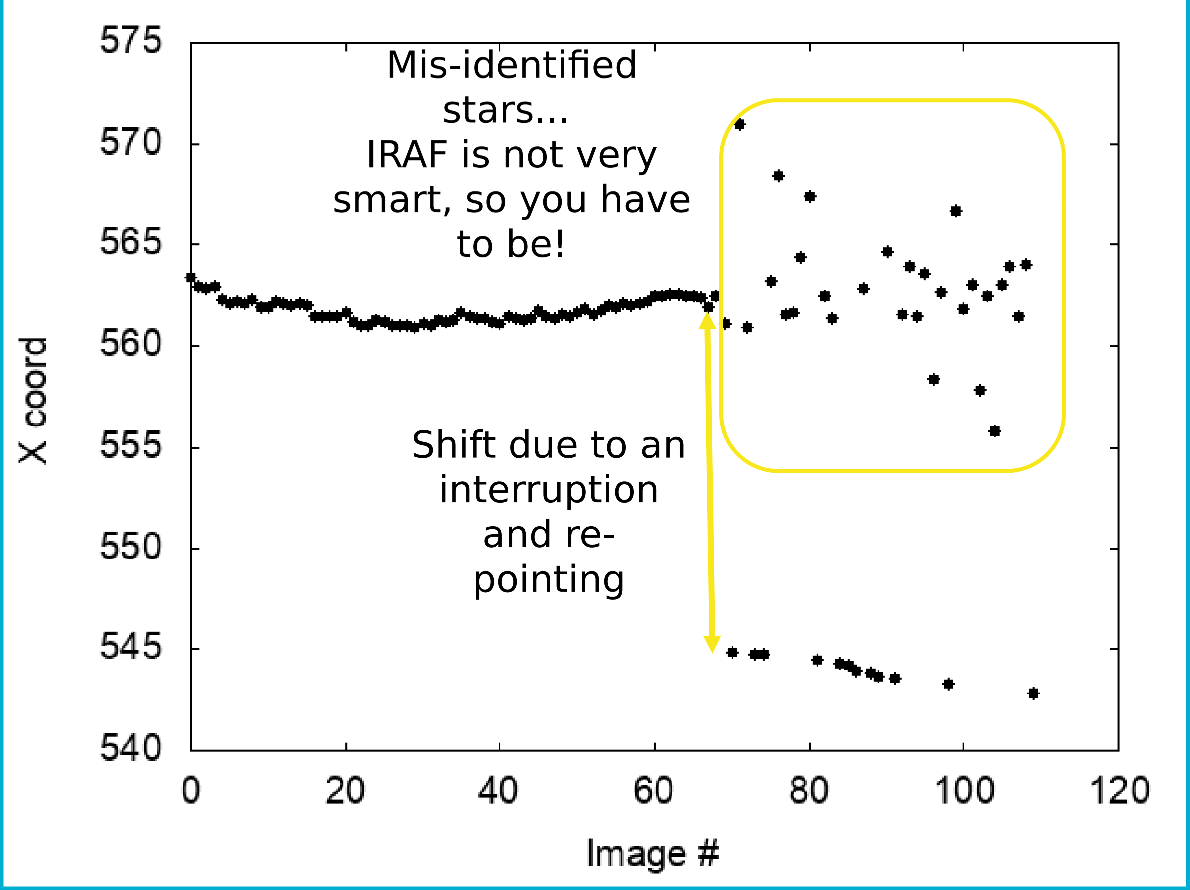
- Copy the photometry of the star and each comparison into separate files.

```
! awk '{if ($1==135) print;}' R_mags > R_star
! awk '{if ($1==160) print;}' R_mags > R_comp1
! awk '{if ($1==172) print;}' R_mags > R_comp2
! awk '{if ($1==175) print;}' R_mags > R_comp3
! awk '{if ($1==222) print;}' R_mags > R_comp4
```

Replace with correct IDs

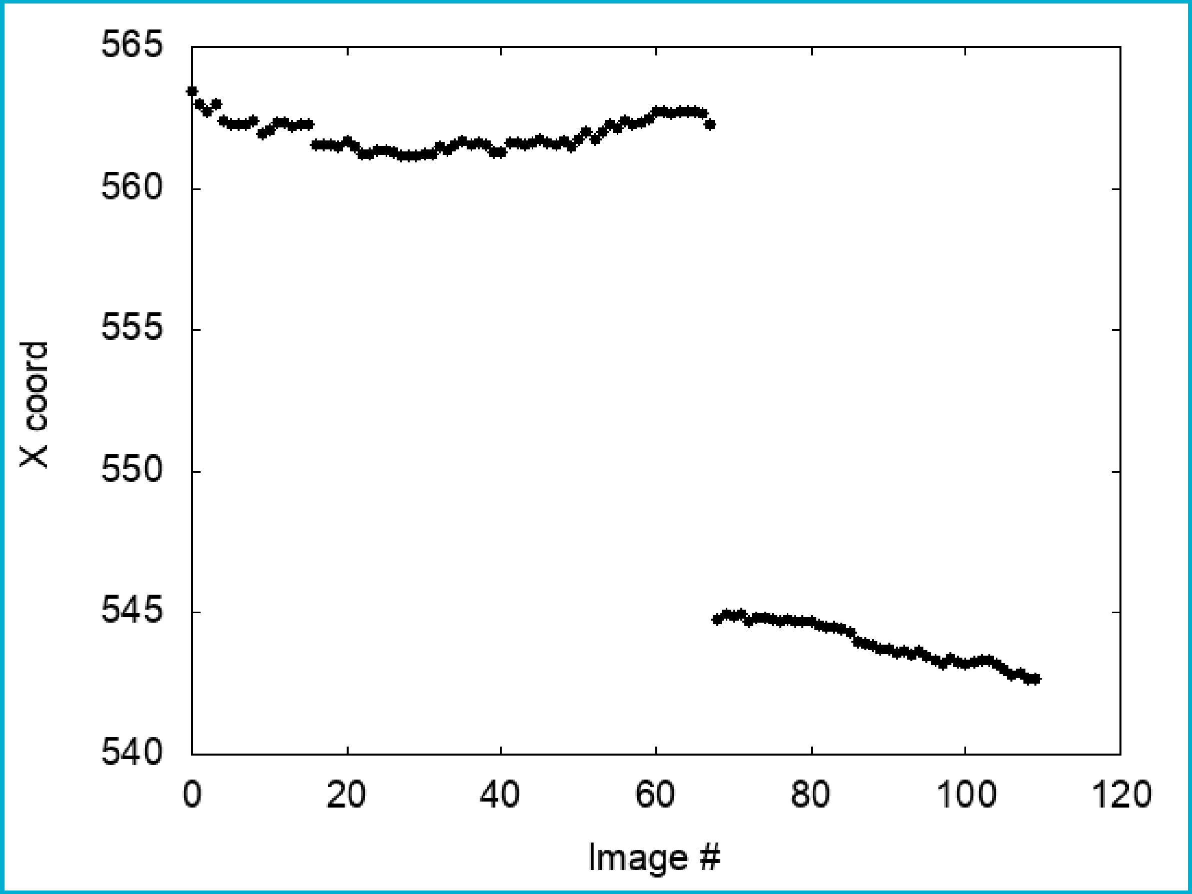
- It is a good sanity check to plot the x and y coordinates of each star, to make sure it was correctly identified in all images.

Photometry



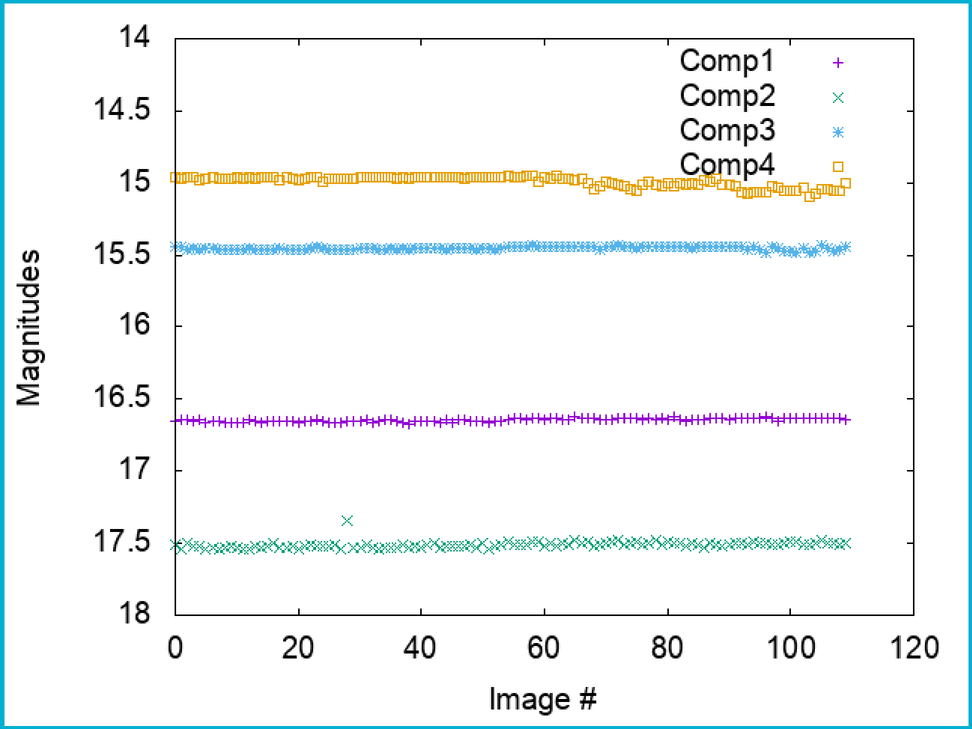
Mis-identified stars...
IRAF is not very smart, so you have to be!
Shift due to an interruption and re-pointing
X coord
Image #
575
570
565
560
555
550
545
540
0
20
40
60
80
100
120

Photometry



Photometry

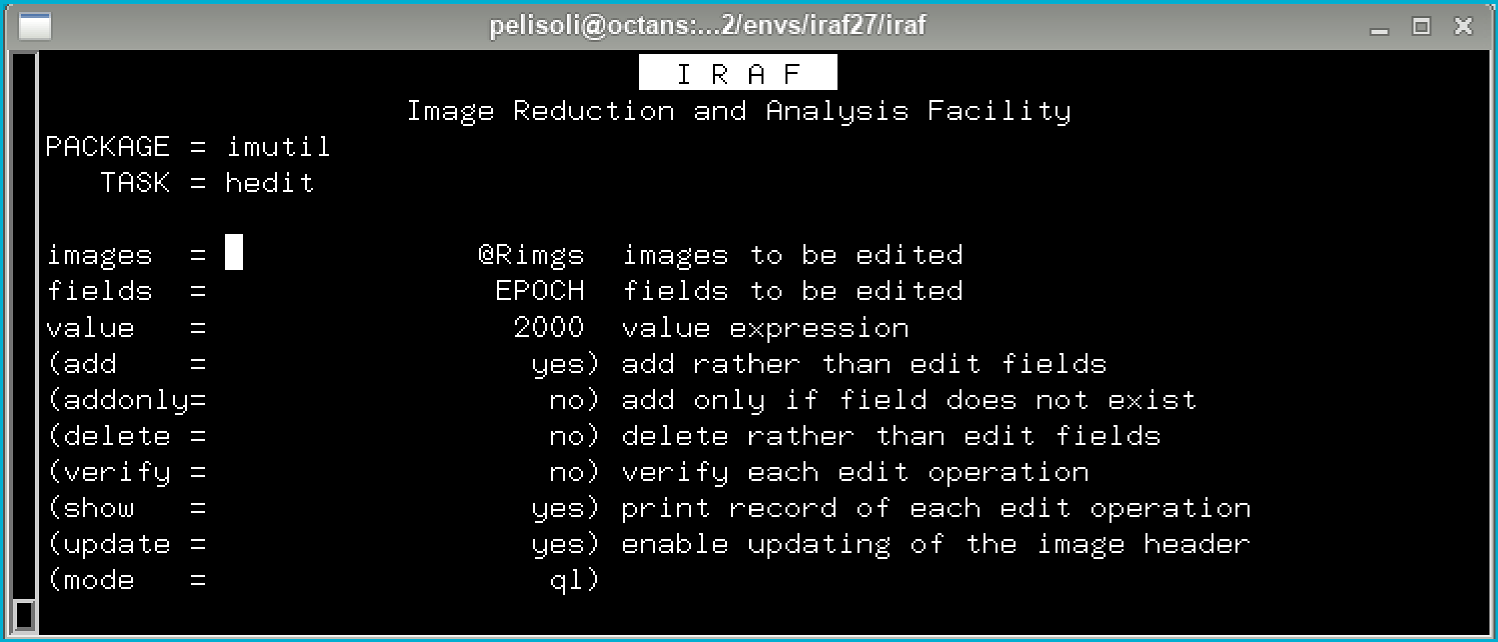
- Another good check is to plot the magnitudes of your comparison stars.
  They have to be fairly constant!



Building the light curve

RA and DEC in a format
279.8767083356 (18h:39m:30.4s)
-5.902749998734 (-5d:54m:09.8s)

- To turn our measurements into a light curve, we need the times for each observation. We will use the task **setjd** to obtain that.
- The headers of our images are missing one important information: coordinates (RA, DEC, Epoch). Use the task **hedit** to add those to all images.



Building the light curve

- We also need to set the observatory parameters to be used for `setjd`. We do that with the task **observatory**:

```
xgterm
                              I R A F
                    Image Reduction and Analysis Facility
PACKAGE = noao
   TASK = observatory

command =                          set   Command (set|list|images)
obsid   =                                Observatory to set, list, or image default
images  =                                List of images
(verbose=                          no)   Verbose output?

(observa=                    ondrejov)   Observatory identification
(name   =                            )   Observatory name
(longitu=                    14.78364)   Observatory longitude (degrees)
(latitud=                   49.910556)   Observatory latitude (degrees)
(altitud=                        528.)   Observatory altitude (meters)
(timezon=                         -1.)   Observatory time zone
override=                                Observatory identification
(mode   =                          ql)
```

Exit “ctrl+d” or “:go”

Building the light curve (setjd)

```
het: McDonald Observatory - Hobby-Eberly Telescope
jcdo: Jack C. Davis Observatory, Western Nevada College
lno: Langkawi National Observatory
obspars:  Use parameters from OBSERVATORY task

Observatory identification (ondrejov):
```

```
pelisoli@octans:...2/envs/iraf27/iraf
                              I R A F
              Image Reduction and Analysis Facility
PACKAGE = onedspec
   TASK = setjd

images  =                   @Rimgs  Images
(observa=                 obspars) Observatory of observation
(date   =                date-obs) Date of observation keyword
(time   =                      ut) Time of observation keyword
(exposur=                 exptime) Exposure time keyword
(ra     =                      ra) Right ascension (hours) keyword
(dec    =                     dec) Declination (degrees) keyword
(epoch  =                   epoch) Epoch (years) keyword

(jd     =                      jd) Output Julian date keyword
(hjd    =                     hjd) Output Helocentric Julian date keyword
(ljd    =                     ljd) Output local Julian date keyword

(utdate =                     yes) Is observation date UT?
(uttime =                     yes) Is observation time UT?
(listonl=                      no) List only without modifying images?
(mode   =                      ql)

                                                    ESC-? for HELP
```

Hold down the enter key until all images have been done.

`setjd > R_jd`   (R_jd is an output file. Check it!)

Building the light curve

Check your column numbers! Might be different.

- To do differential photometry, we need to normalise the magnitudes of the star and of the comparison stars. First, check what is the average magnitude (6th column):

```
! awk '{sum+=$5;n++} END {print sum/n;}' R_star
```

- Then subtract it from each value: replace with calculated average

```
! awk '{printf "%7.4f %6.4f\n", $5-18.7529, $6}' R_star > mag_star
```

(5: mag column, 6: mag error column)

- Repeat that for all the comparison stars, and combine them into one file:

```
! paste mag_comp1 mag_comp2 mag_comp3 mag_comp4 > all_comp
```

- Average the comparison stars:

```
! awk '{printf "%7.4f %6.4f\n", ($1+$3+$5+$7)/4.0, sqrt($2*$2+$4*$4+$6*$6+$8*$8)}' all_comp > mag_comp
```

Building the light curve

- Combine the magnitudes of the star and the comparison magnitude:

```
! paste mag_star mag_comp > comb_mag
```

- Subtract the comparison from the star to remove background variations:

```
! awk '{printf "%7.4f %6.4f\n", ($1-$3), sqrt($2*$2+$4*$4)}'
comb_mag > diff_mag
```

- Select the column containing the Heliocentric Julian Date from the file created with setjd:

```
awk '!/#/ {print $3}' R_jd > R_hjd
```

(Type this in a regular terminal. Does not work in IRAF)

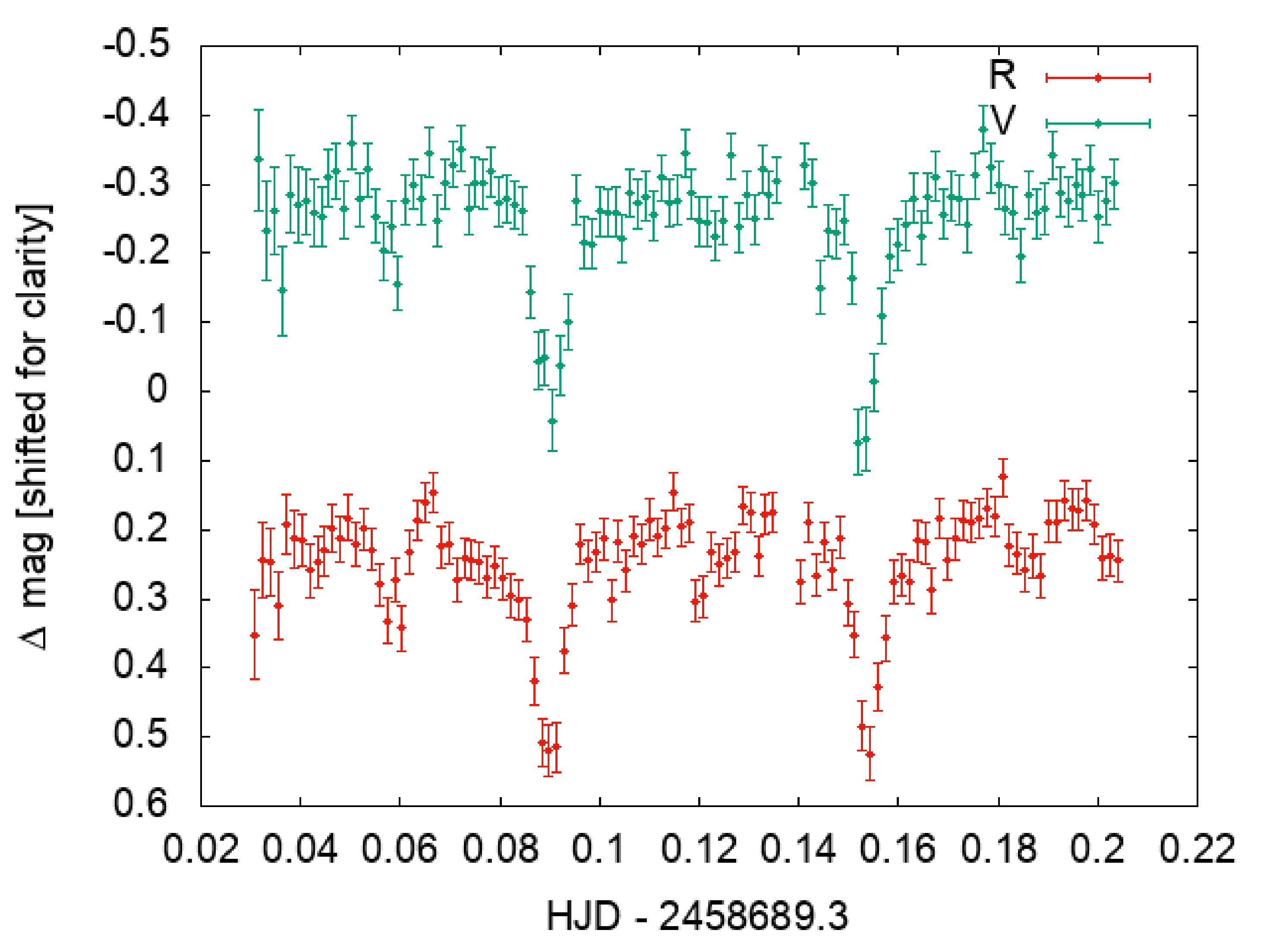
- Combine that with the magnitude to obtain the lightcurve:

```
! paste R_hjd diff_mag > R_lightcurve
```

Voilà! Now you have a light curve.

Repeat the same for the other filter.

Light curves



Photometry – summary

- Create master files for bias, flat, and dark (`zerocombine`, `flatcombine`, `darkcombine`).
- Reduce the science images using `ccdproc`.
- Measure sky and FWHM with `imexamine`.
- Use the dask `daofind` to find the stars; do not forget to change the `datapars` according to your measurements, and set the threshold in `findpars`.
- Use the task `phot` to do the photometry; do not forget to update `centerpars`, `fitskypars` and `photpars`.
- Check ID for your star and comparison stars using `display` and `tvmark`.
- Inspect the coordinates for the star and comparison stars to guarantee there was no misidentification.
- Inspect the magnitudes of the comparison stars; they should be fairly constant.
- Use `observatory` and `setjd` to obtain the times of observation.
- Paste the times and differential magnitude (star - averaged comparison) into one file to obtain the light curve.

Optional task

- We did a lot by hand, but:

  1) excecute the IRAF commands from IRAF terminal
  display filename.fits frame=1 zscale=yes zrange=yes
  Very useful to save the reduction steps/commands into a text file!
  Easy to redo or use as template in the future.

  2) Create your own IRAF tasks/scripts (more complicated).