

Data reduction II

Photometry with IRAF

Tiina Liimets (tiina.liimets@asu.cas.cz Office nr 209)

Research workshop on evolved stars

01.09.2022

Introduction

- Veronika's introduction to IRAF
- Text in **yellow** is for typing in IRAF terminal
- In my slides IRAF terminals are black or papaya color

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

More is better

- 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 σ_i/\sqrt{n} .
- Therefore, the first step in data reduction is to calculate the average for BIAS, FLAT, and DARK images.

More is better

- 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 σ_i/\sqrt{n} .
- Therefore, the first step in data reduction is to calculate the average for BIAS, FLAT, and DARK images.

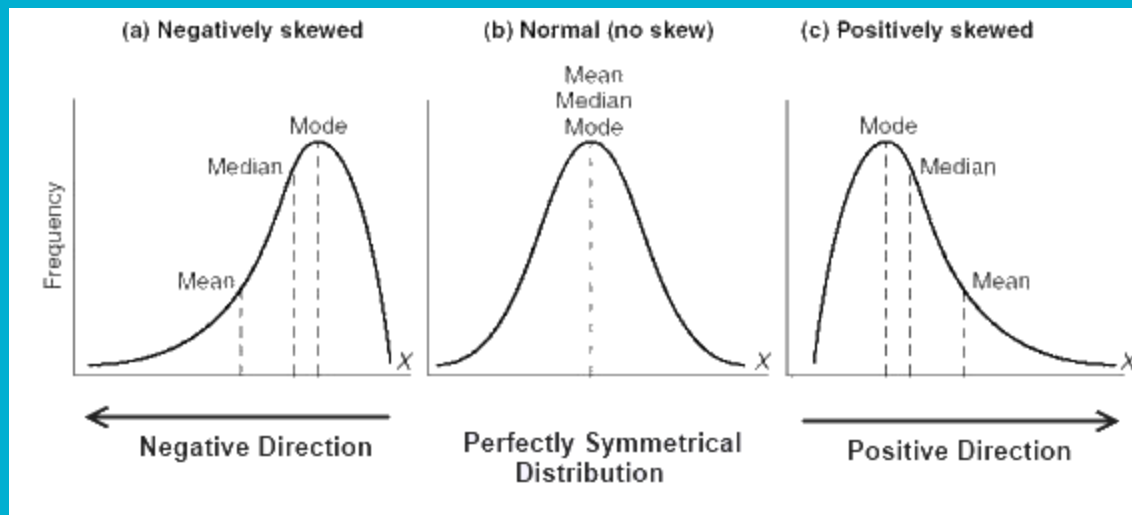
BIAS: not available for 65 cm telescope.

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 – Image Reduction and Analysis Facility

- 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.

```
pelisoli@octans:...2/envs/iraf27/iraf
ec1> noao
  artdata.      digiphot.      noobsolete.    onedspec.
  astcat.       focas.         nproto.        rv.
  astrometry.  imred.         observatory    surfphot.
  astutil.     mtlocal.      obsutil.       twodspec.

noao> imred
  argus.        crutil.        echelle.       iids.          kpnocoude.    specred.
  bias.         ctioslit.      generic.       irred.         kpnoslit.     vtel.
  ccdred.       dtol.         hydra.         irs.           quadred.

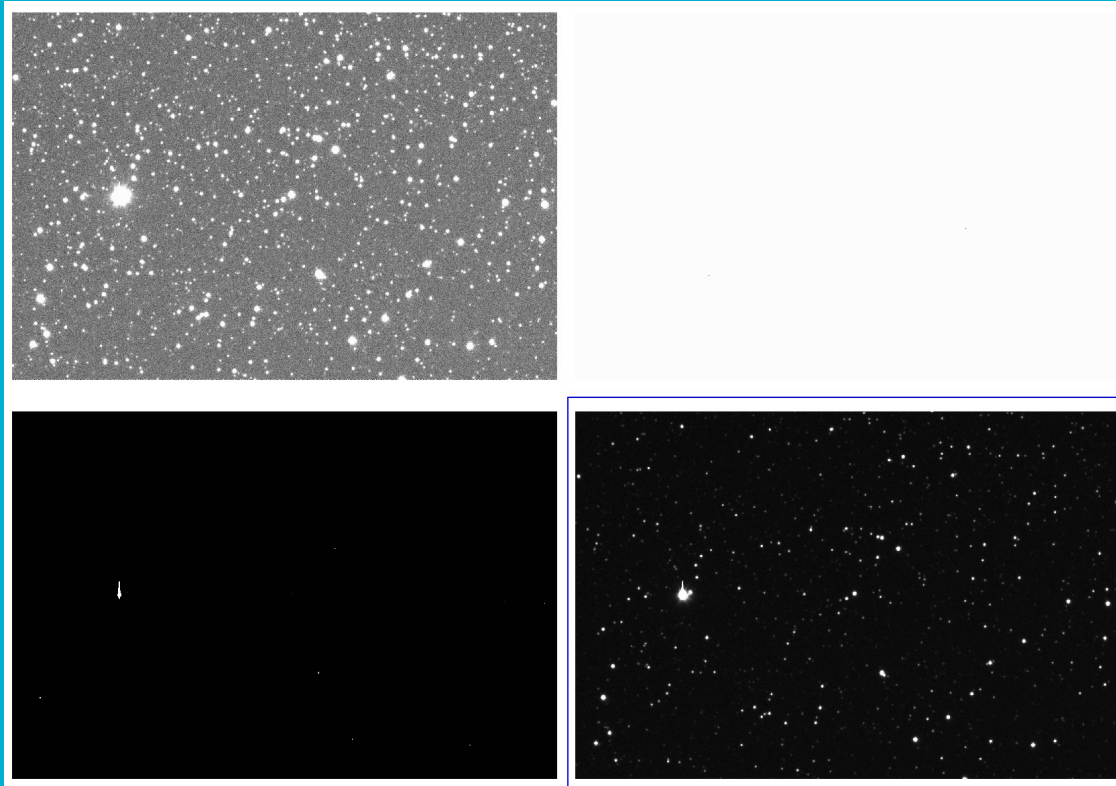
imred> ccdred
  badpiximage    ccdmask        flatcombine    mkskyflat
  ccdgroups      ccdproc        mkfringecon    setinstrument
  ccdhedit       ccdtest.      mkillumcor     zerocombine
  ccdinstrument  combine        mkillumflat
  ccdlist        darkcombine    mkskycon

ccdred> 
```

Preparing working directory

- Always have a copy of original raw data!
- **! mkdir reduction**
- All the files that we work with have to be in the same directory:
 - science frames
 - masterflats (same filters as your science frames)
 - darks

How to properly see your data!!!!



- Full flux range of the CCD is usually up to 65 000 ADUs.
Make sure you see them all!
- Good initial guess is to display flux range near mean.
(use **imstat** to get the mean value)

How to properly see your data!!!!

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
(bpdiscpl= 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
(nsampl= 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)
```

epar display

Choose the parameters well!

Play around with it!

< this is good average guess

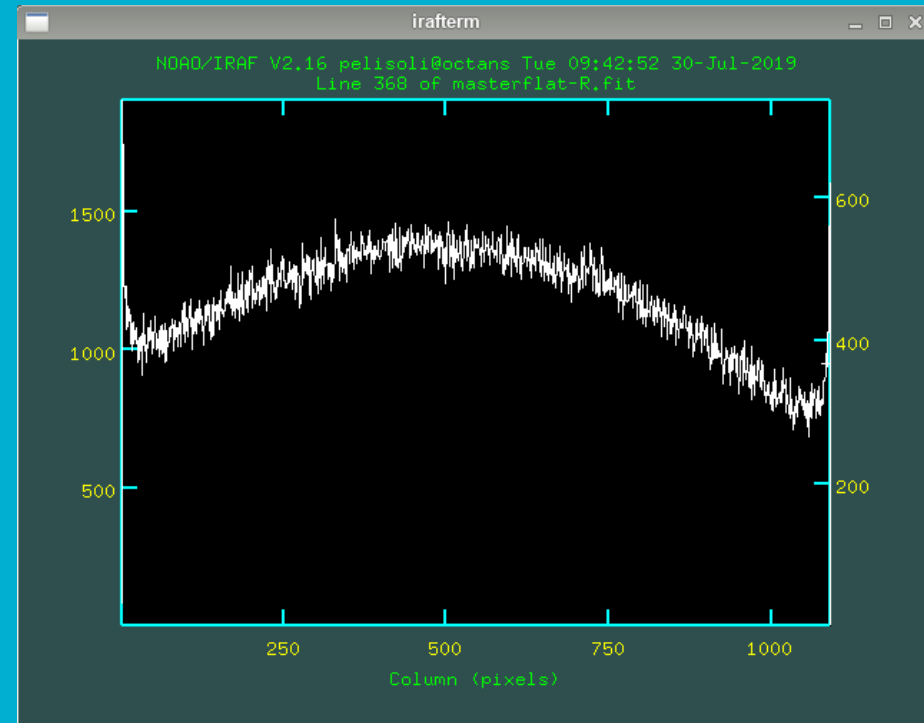
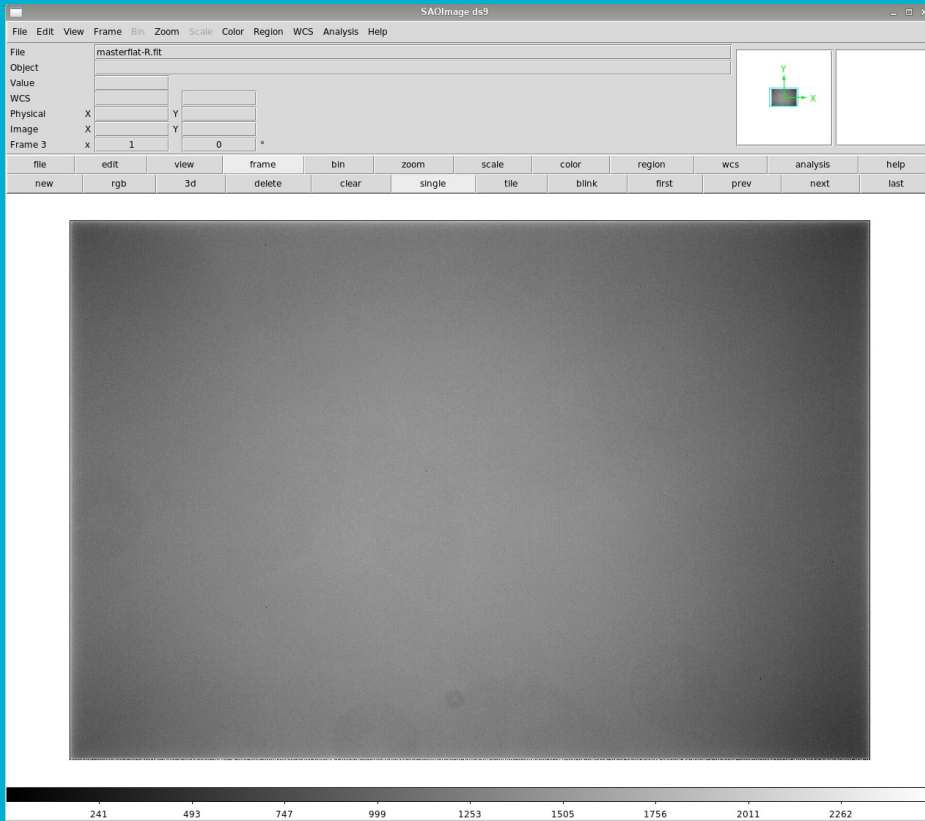
Check your data

- All data is already in the same directory
- Remove useless science frames: clouds, satellites, tracking problems, etc.
- Create a list with science frames.
ls filename*.fits > list_science
- Display images in ds9 and relocate useless frames
Open ds9, if not already open: **!ds9 &**
Set proper parameters in display: **epar display**
imexam @list_science 1
(n next frame
p previous frame
q quit)

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
- Check image statistics:
imstat masterflat-R.fit

Master flat



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**
Multiple frames: **hsl Object*fits \$!,exptime yes**
("exptime" is the fits header keyword)
- Which dark images should we use?
imhead df-* lo+ | grep EXPTIME or **hsl**
- Create a list (text document) containing the names of the dark frames using the same exposure time as the science images.

Creating a master dark - epar darkcombine

Check
parameters!

Ccdtype has
to be empty!
Just put space.

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
Image Reduction and Analysis Facility
PACKAGE = ccdred
TASK = darkcombine

input = [
(output =
(combine=
(reject =
(ccdtype=
(process=
(delete =
(clobber=
(scale =
(statsec=
(nlow =
(nhigh =
(nkeep =
(mclip =
(lsigma =
(hsigma =
(rdnoise=
(gain =
(snoise =
(pclip =
(blank =
(mode =
:go
```

@dark List of dark images to combine
Dark) Output dark image root name
median) Type of combine operation
sigclip) Type of rejection
) CCD image type to combine
no) Process images before combining?
no) Delete input images after combining?
no) Clobber existing output image?
exposure) Image scaling
) Image section for computing statistics
0) minmax: Number of low pixels to reject
1) minmax: Number of high pixels to reject
1) Minimum to keep (pos) or maximum to reject (neg)
yes) Use median in sigma clipping algorithms?
5.) Lower sigma clipping factor
5.) Upper sigma clipping factor
0.) ccdclip: CCD readout noise (electrons)
1.3) ccdclip: CCD gain (electrons/DN)
0.) ccdclip: Sensitivity noise (fraction)
-0.5) pclip: Percentile clipping parameter
0.) Value if there are no pixels
ql)

@[name of the list you've created]

“:go” + enter

Creating a master dark -

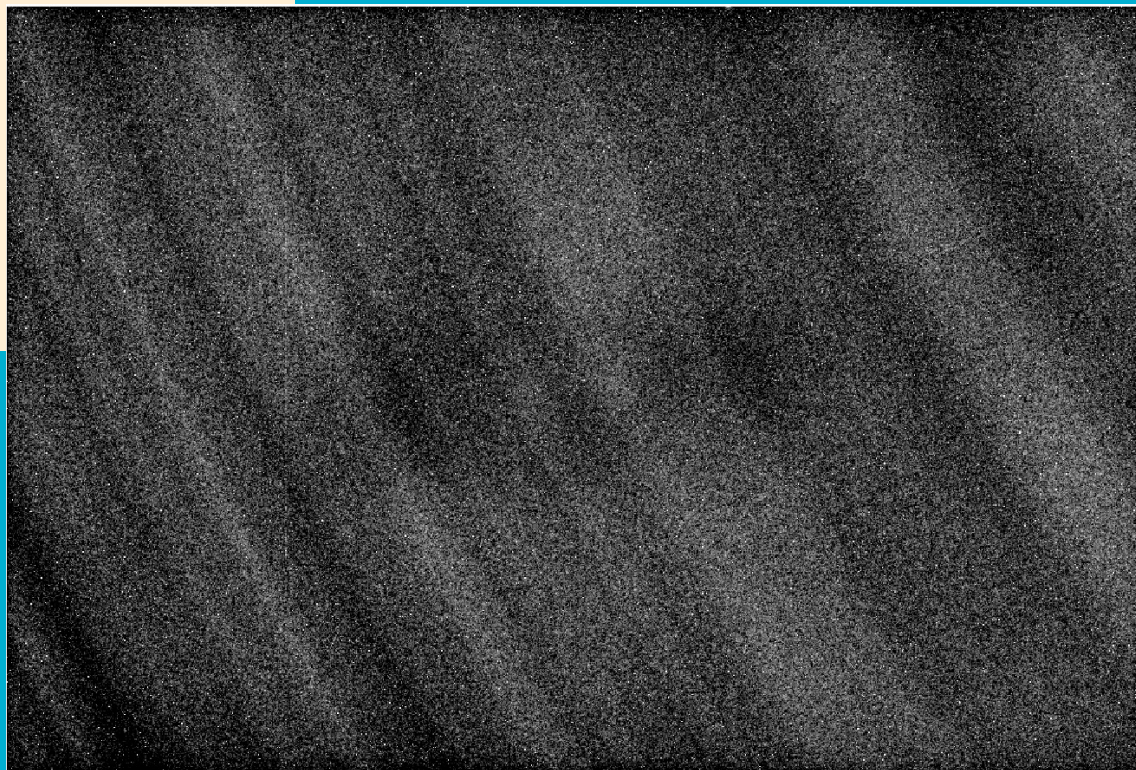
```
Aug 30 16:01: IMCOMBINE
combine = median, scale = exposure, zero = none, weight = none
reject = sigclip, mclip = yes, nkeep = 1
lsigma = 5., hsigma = 5.
blank = 0.
```

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 - ccdproc

Check parameters!

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
Image Reduction and Analysis Facility
PACKAGE = ccdred
TASK = ccdproc

images = [] @Vings List of CCD images to correct
(output = c//@Vings) List of output CCD images
(ccdtype= ) CCD image type to correct
(max_cac= 0) Maximum image caching memory (in Mbytes)
(noproc = no) List processing steps only?

(fixpix = no) Fix bad CCD lines and columns?
(oversca= no) Apply overscan strip correction?
(trim = no) Trim the image?
(zeroeor= no) Apply zero level correction?
(darkcor= yes) Apply dark count correction?
(flatcor= yes) Apply flat field correction?
(illumco= no) Apply illumination correction?
(fringec= no) Apply fringe correction?
(readcor= no) Convert zero level image to readout correction?
(scancor= no) Convert flat field image to scan correction?

(readaxi= line) Read out axis (column|line)
(fixfile= ) File describing the bad lines and columns
(biassec= ) Overscan strip image section
(trimsec= ) Trim data section
More
ESC-? for HELP
```

Continues ...

Reducing the science images 2 - 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?
(funcio= 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
```

Reducing the science images 3

ccdproc in action

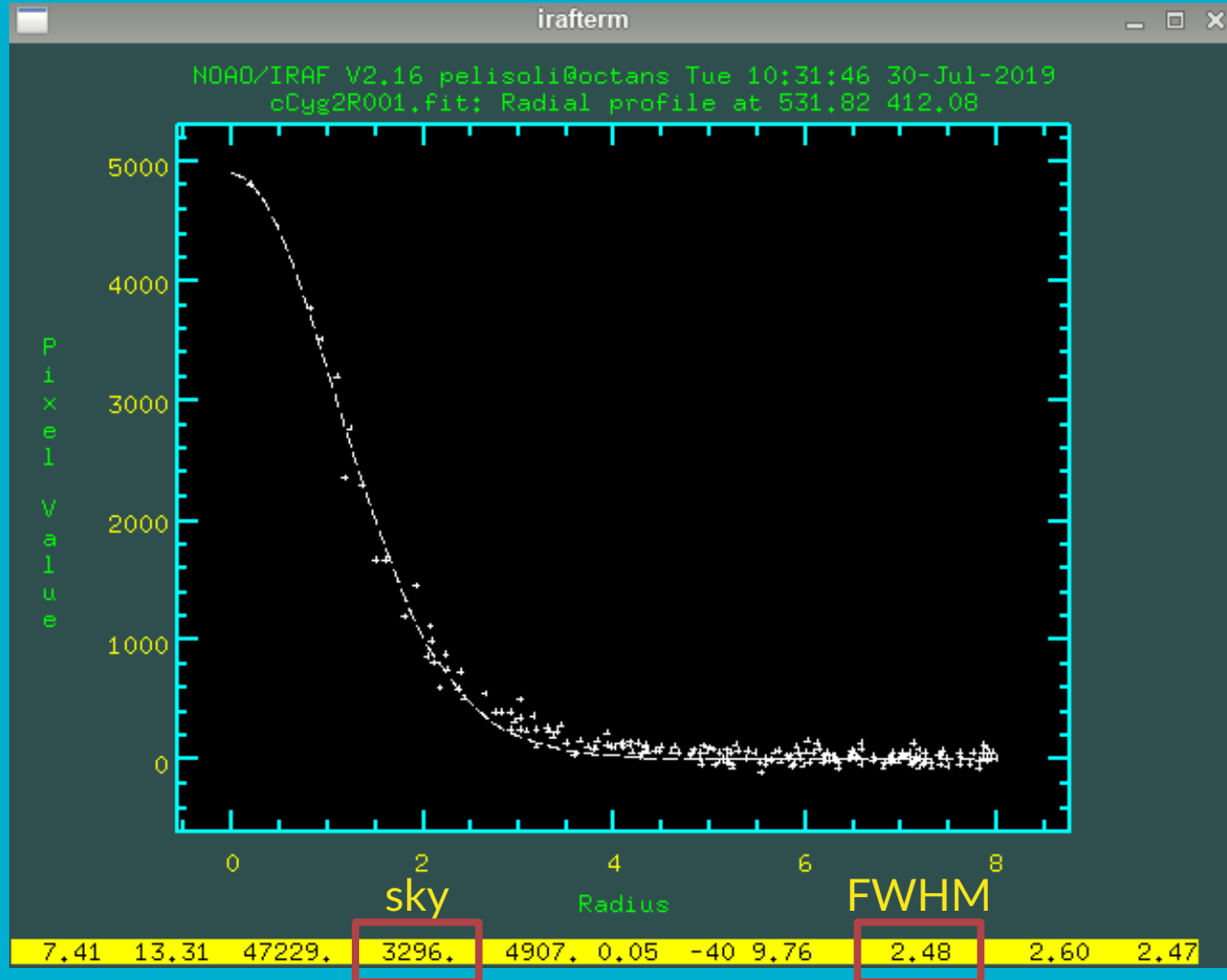
```
ale=28645.95
Object_3__R_0028.fits: Aug 30 16:19 Dark count correction image is Dark.fits with
h scale=1.
Object_3__R_0028.fits: Aug 30 16:19 Flat field image is masterflat-R.fit with sc
ale=28645.95
Object_3__R_0029.fits: Aug 30 16:20 Dark count correction image is Dark.fits with
h scale=1.
Object_3__R_0029.fits: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

- Check what you got! Reduced files start with “c”
 - 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



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.

$$\begin{aligned} \text{sky} &= 415. \\ \text{sigma} &= 20.4 \end{aligned}$$

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

DAOFIND (to find the stars coordinates)

“cCyg*fits” selects many files

In which image(s)
to run it

```
pehsoli@octans:...2/envs/iraf27/iraf
IRAF
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

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
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.?)
```

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.
 - Define an aperture large enough to contain your star in all the images.
 - Best option when the field is not crowded.
 - Problems: you are adding more noise, not feasible in crowded fields.

```
|reflect|wra  
1,tv,physica  
or HELP
```

DAOFIND (datapars)

“:q” to go back

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
Image Reduction and Analysis Facility
PACKAGE = daophot
TASK = datapars

(scale = 1.) Image scale in units per pixel
(fwhmpsf= 2.5) FWHM of the PSF in scale units
(emissio= yes) Features are positive?
(sigma = 20.) Standard deviation of background in counts
(datamin= INDEF) Minimum good data value
(datamax= INDEF) Maximum good data value
(noise = poisson) Noise model
(ccdread= ) CCD readout noise image header keyword
(gain = GAIN) CCD gain image header keyword
(readnoi= 0.) CCD readout noise in electrons
(epadu = 1.3) Gain in electrons per count
(exposur= EXPTIME) Exposure time image header keyword
(airmass= ) Airmass image header keyword
(filter = FILTER) Filter image header keyword
(obstime= UT) Time of observation image header keyword
(itime = 1.) Exposure time
(xairmas= INDEF) Airmass
(ifilter= INDEF) Filter
(otime = INDEF) Time of observation
(mode = ql)

ESC-? for HELP
```

DAOFIND (findpars)

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
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 c0bject_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         = c0bject_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 SHARPL0      = 0.2                     number     %-23.7g
#K SHARPHI      = 1.                     number     %-23.7g
#K ROUNDL0      = -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
444.739 7.588 0.848 0.488 0.450 0.088 6

```

DAOFIND (tdump - *massaging* 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)

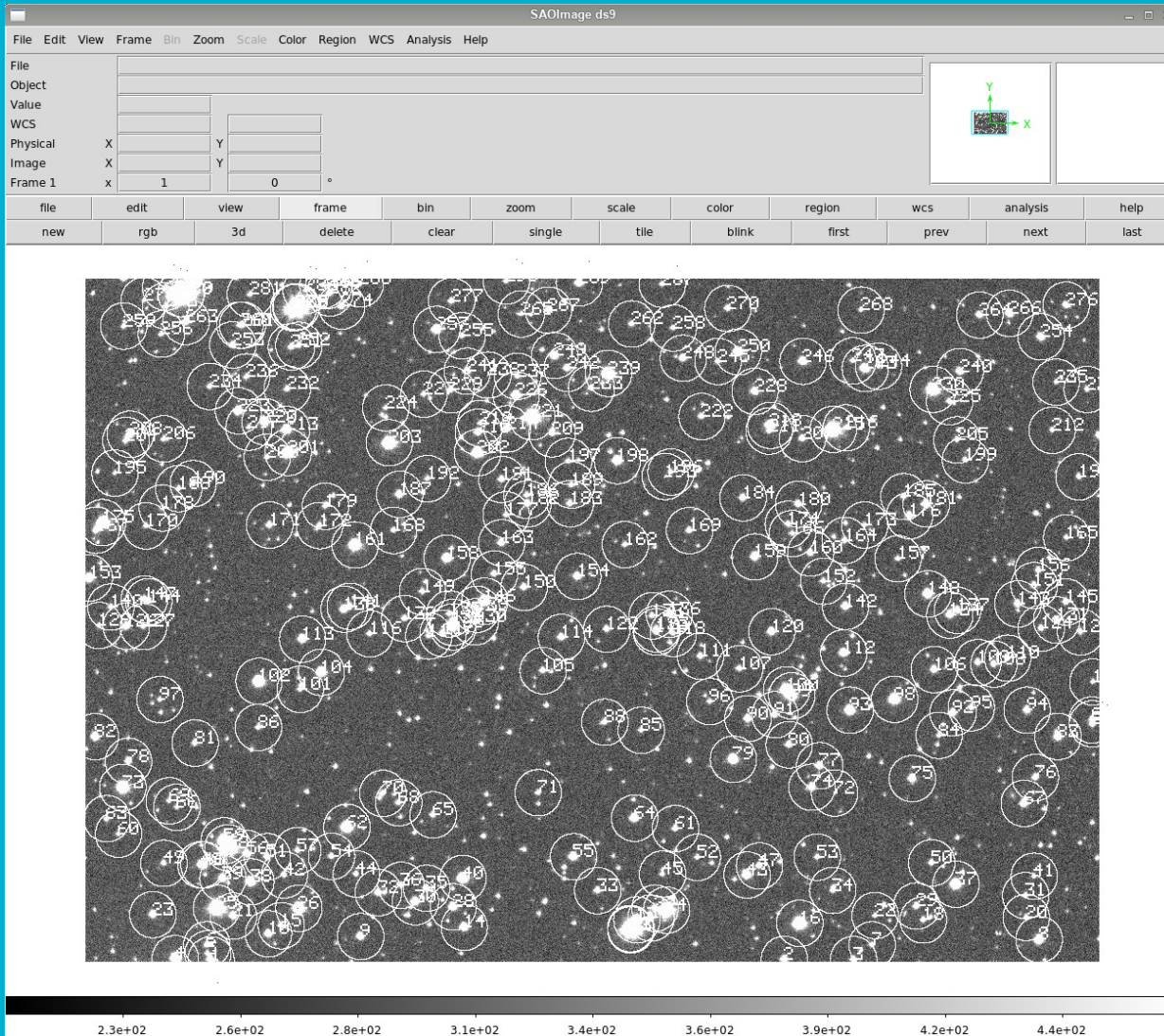
DAOFIND (tvmark: to display the found stars)

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
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> █
```

DAOFIND (tvmark)



Photometry

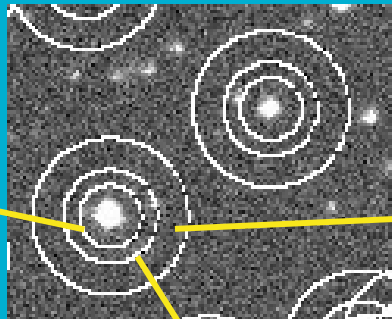
- tvmark is also useful to help us define the aperture, annulus, and dannulus

NB!

tvmark: radii

Phot: aperture, annulus, dannulus

Aperture (radii): where the flux of the star will be measured.
Usually $\sim 2.5 \times \text{FWHM}$



Dannulus: width of the ring to count the background.
 $\sim 5-10$ pixels

Annulus (radii): distance at which to start counting the background.

At least $2.5 \times \text{FWHM}$
 $\sim 4 \times \text{FWHM}$ in our example

* For a Gaussian distribution:
 $\text{FWHM} = 2.35\sigma$
99.99% of the light is contained within
 $4\sigma = 1.7\text{FWHM}$

PHOT

```
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,physical)
(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
```

List of reduced R (or V) images.

NB!
One coordinate file for all frames

PHOT (centerpars)

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
Image Reduction and Analysis Facility
PACKAGE = daophot
TASK = centerpars

(calgori=  centroid) Centering algorithm
(cbox = 5.) Centering box width in scale units
(cthresh= 0.) Centering threshold in sigma above background
(minsnra= 1.) Minimum signal-to-noise ratio for centering algo
(cmaxite= 10) Maximum iterations for centering algorithm
(maxshif= 1.) Maximum center shift in scale units
(clean = no) Symmetry clean before centering
(rclean = 1.) Cleaning radius in scale units
(rclip = 2.) Clipping radius in scale units
(kclean = 3.) K-sigma rejection criterion in skysigma
(mkcente= no) Mark the computed center
(mode = ql)

ESC-? for HELP
```

PHOT (fitskypars)

Your data
specific!

```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
Image Reduction and Analysis Facility
PACKAGE = daophot
TASK = fitskypars

(salgori=  mode) Sky fitting algorithm
(annulus= 15.) Inner radius of sky annulus in scale units
(dannulu= 10.) Width of sky annulus in scale units
(skyvalu= 415.) User sky value
(smaxite= 20) Maximum number of sky fitting iterations
(sloclip= 0.) Lower clipping factor in percent
(shiclip= 0.) Upper clipping factor in percent
(snrejec= 50) Maximum number of sky fitting rejection iteratio
(sloreje= 3.) Lower K-sigma rejection limit in sky sigma
(shireje= 3.) Upper K-sigma rejection limit in sky sigma
(khist = 3.) Half width of histogram in sky sigma
(binsize= 0.1) Binsize of histogram in sky sigma
(smooth = no) Boxcar smooth the histogram
(rgrow = 0.) Region growing radius in scale units
(mksky = no) Mark sky annuli on the display
(mode = ql)

ESC-? for HELP
```

PHOT

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

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.

Lots of numbers on the screen
but not always.

```
c0bject_3__R_0039.fits  55.77  728.58  1632.988  16.255  ok  
c0bject_3__R_0039.fits  117.80  724.61  1630.774  15.417  ok  
c0bject_3__R_0039.fits  157.64  724.52  1629.492  14.740  ok  
c0bject_3__R_0039.fits  488.41  726.61  1622.06  15.953  ok  
c0bject_3__R_0039.fits  600.71  725.55  1630.802  14.261  ok  
c0bject_3__R_0039.fits   39.93  727.46  1623.682  15.590  ok  
c0bject_3__R_0039.fits  535.45  726.53  1639.767  14.240  ok  
c0bject_3__R_0039.fits  546.02  726.52  1630.498  13.923  ok  
c0bject_3__R_0039.fits   31.74  729.13  1628.021  15.771  ok  
c0bject_3__R_0039.fits  375.03  728.29  1632.699  16.592  ok  
c0bject_3__R_0039.fits  409.29  727.89  1621.293  15.092  ok  
c0bject_3__R_0039.fits  585.08  727.53  1646.165  14.111  ok  
c0bject_3__R_0039.fits  134.08  728.71  1629.078  15.446  ok  
c0bject_3__R_0039.fits  257.49  729.09  1633.361  15.320  ok  
c0bject_3__R_0039.fits  731.43  728.55  1622.969  13.429  ok  
c0bject_3__R_0039.fits  979.61  729.73  1629.34  INDEF  err  
c0bject_3__R_0039.fits  277.56  731.54  1627.014  INDEF  err  
c0bject_3__R_0039.fits  891.51  730.55  1630.98  INDEF  err  
c0bject_3__R_0039.fits   76.90  732.82  1636.415  INDEF  err  
c0bject_3__R_0039.fits  352.86  734.45  1613.267  INDEF  err  
c0bject_3__R_0039.fits  808.50  734.55  1631.013  INDEF  err  
c0bject_3__R_0039.fits  823.97  735.11  1624.323  INDEF  err  
daophot>
```

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 CTRESHOLD = 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        ##  errors   \
#F %-14.3f              %-11.3f  %-8.3f   %-8.3f   %-8.3f      %-15.3f      %-5d %-9s  \
#
#N MSKY                 STDEV     SKEW     NSKY     NSREJ       SIER SERROR  \
#U counts               counts    counts   npix     npix        ##  errors   \
#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        ##  errors   \
#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 (*massaging* 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

```
NUISE      t poisson                      model      %-23s
daophot> tdump @Rmag_files columns=c4,c7,c8,c29,c30,c31 > R_mags
ERROR: Table `@Rmag_files' does not exist or cannot be opened.
daophot> □
```

* if tdump refuses to read from a list, use awk to create a file with one tdump per line:

! ls *mag.1 | awk '{printf "tdump %s columns=c4,c5,c6,c29,c30,c28 >> R_mags\n", \$1}' > get_mags

```
daophot> ! more get_mags
tdump c0bject_3__R_0001.fits.mag.1 columns=c4,c7,c8,c29,c30,c31 >> R_mags
tdump c0bject_3__R_0002.fits.mag.1 columns=c4,c7,c8,c29,c30,c31 >> R_mags
tdump c0bject_3__R_0003.fits.mag.1 columns=c4,c7,c8,c29,c30,c31 >> R_mags
```

cl < get_mags (this is minimal IRAF scripting)

- Check what you got (next slide).

PHOT (file R_mags)

- A VERY LARGE TEXT FILE
35k lines

```

ec1> ! 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
FMHPSF      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           873.61200000000002 2.2690000000000001 INDEF INDEF 0.
2           479.97500000000002 4.4000000000000001 INDEF INDEF 0.
3           926.37500000000001 4.7750000000000002 INDEF INDEF 0.
4           805.61200000000002 5.969 INDEF INDEF 0.
5           1052.827 6.4620000000000001 INDEF INDEF 0.
6           111.693 7.5130000000000001 0.0850000000000001 7576.389000000001
7           446.73000000000002 8.5370000000000002 15.107 0.0860000000000002 9064.937000000001
8           467.37500000000001 9.3930000000000002 14.522 0.0500000000000001 15535.020000000001
9           841.016 9.3240000000000001 15.351 0.0930000000000002 7234.9
10          561.41499999999999 11.537 15.115 0.0660000000000001 8993.307000000001
**          38.872000000000001 12.329 14.189 0.0290000000000001 21102.71
           454.489 14.105 15.024 0.0770000000000001 9782.393000000002
           115.163 14.212 0.0290000000000001 20669.920000000001
           50.548000000000001 13.927 0.0220000000000001 26861.27
           79.581000000000002 14.898 0.0540000000000001 10984.86
           446.578 17.705000000000001 12.8 0.0080000000000001 75871.37
           17.421000000000001 18.34200000000001 15.831 0.116 4652.417000000002
           1012.429 17.28 15.579 0.0970000000000001 5865.323000000001

```

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

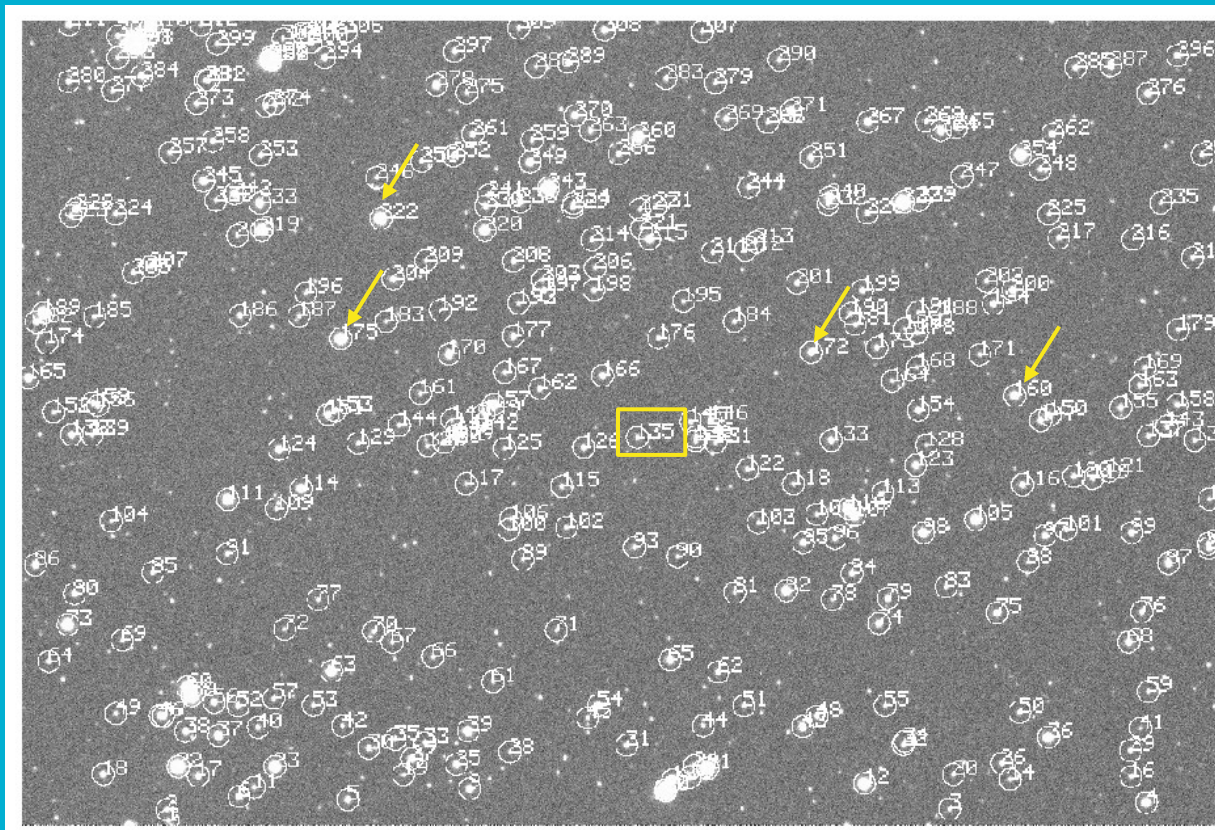
```

daophot> ! more R_mags
c0bject_3__R_0001s.fits1 2.2690000000000001 -0.2770000000000001
c0bject_3__R_0001s.fits2 4.4000000000000001 0.116
c0bject_3__R_0001s.fits3 4.7750000000000002 0.128
c0bject_3__R_0001s.fits4 5.969 -0.0740000000000002

```

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)

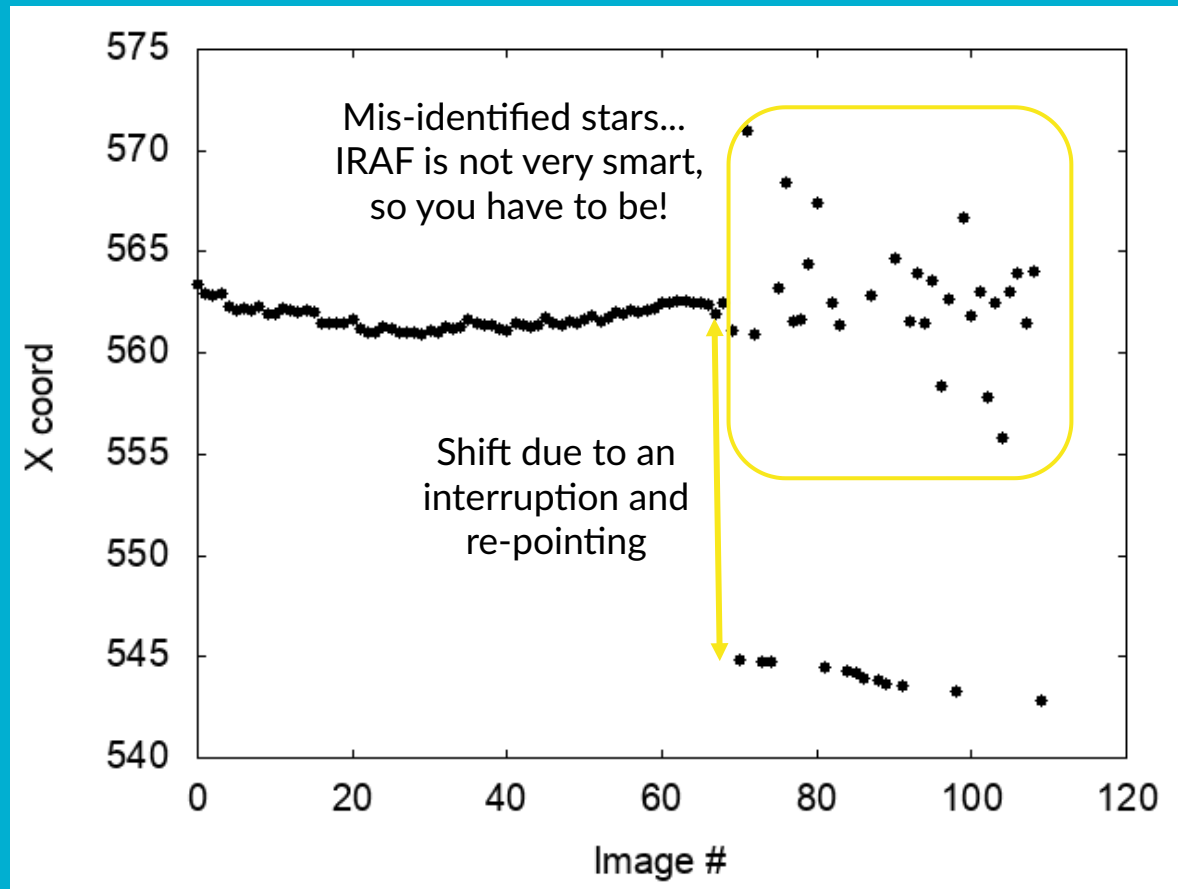
- Copy the photometry of the star and each comparison into separate files.

```
! 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
```

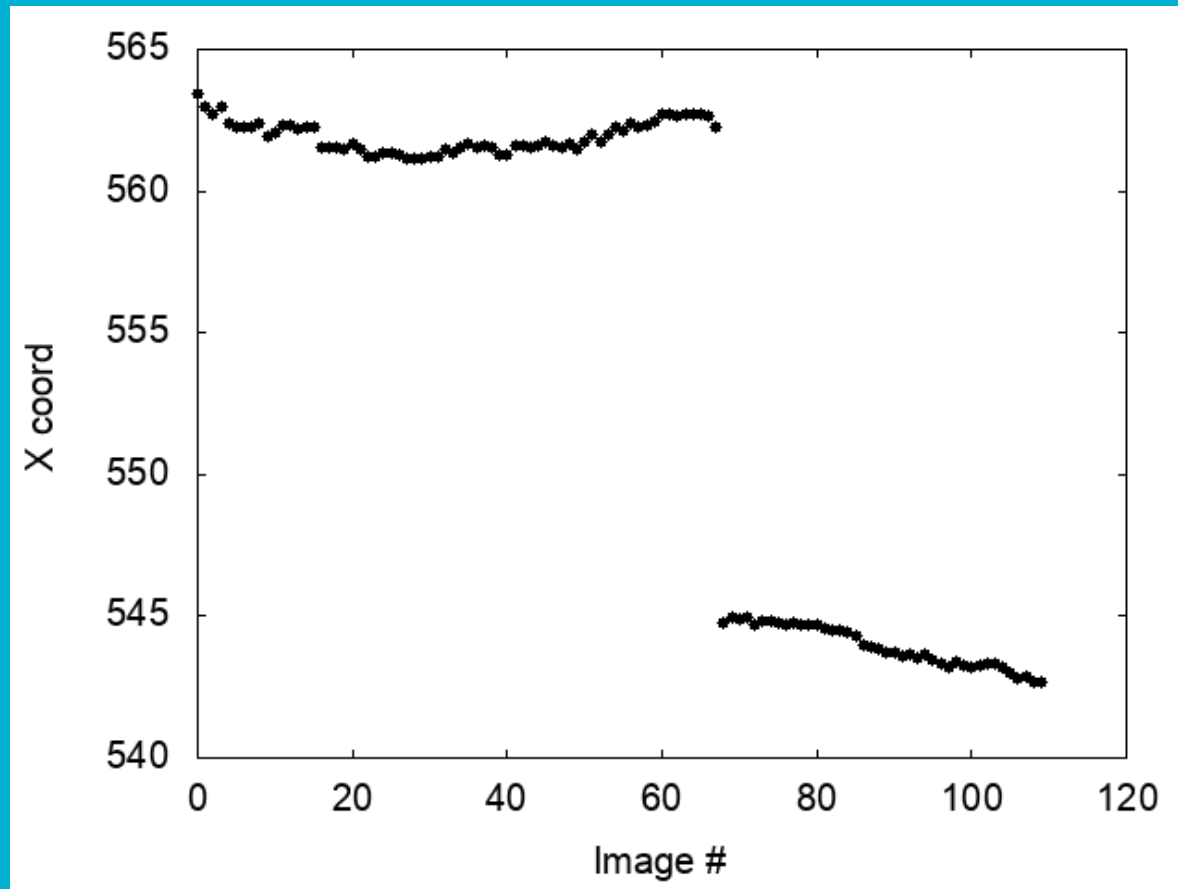
 Replace with correct IDs

- 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

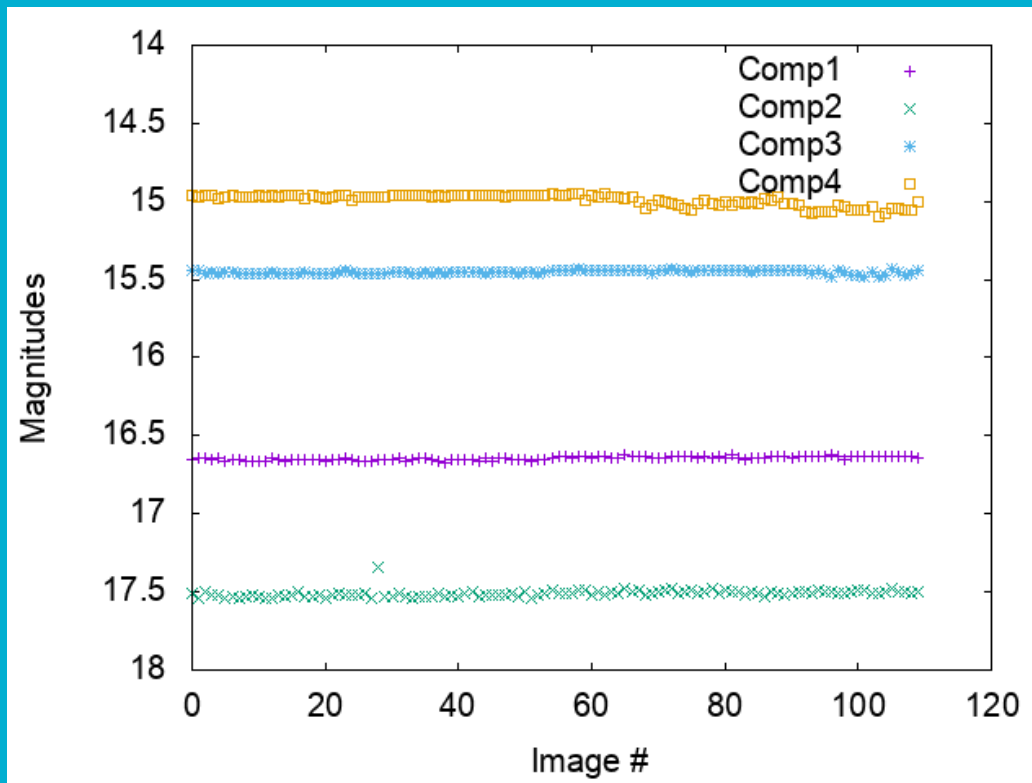


Photometry



Photometry

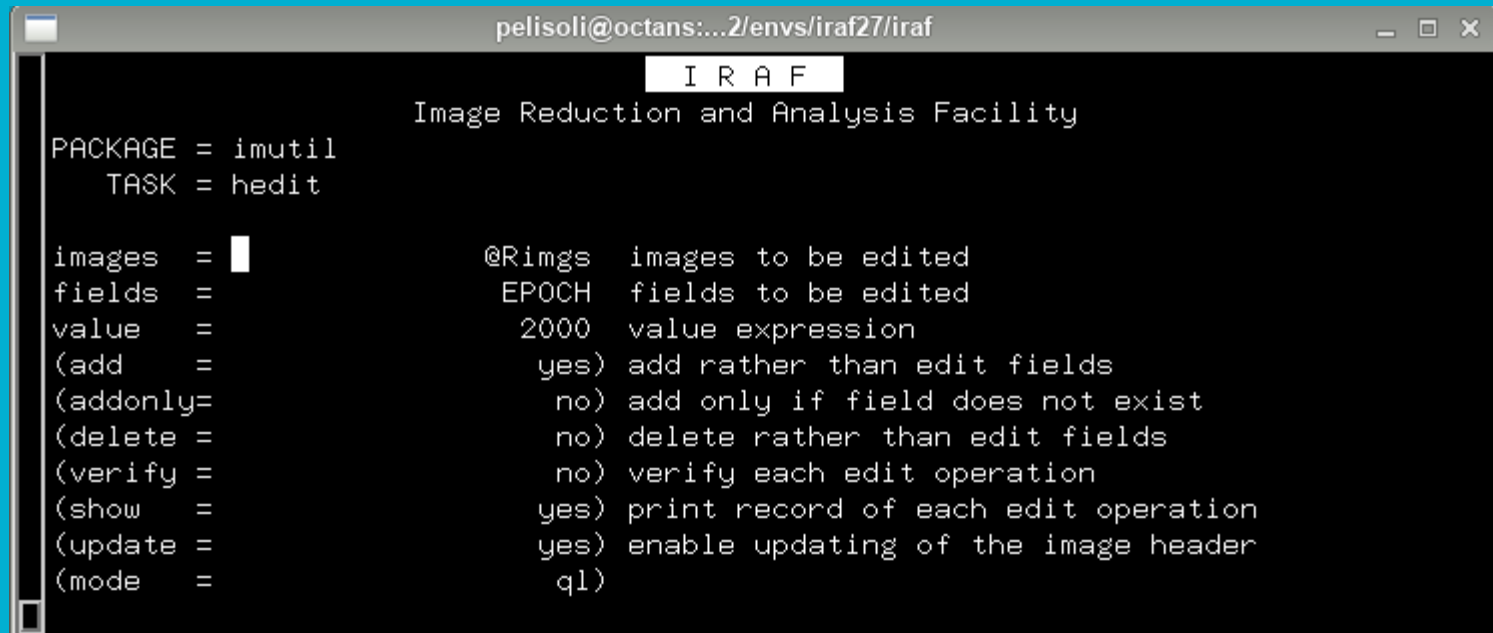
- Another good check is to plot the magnitudes of your comparison stars. They have to be fairly constant!



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.



```
pelisoli@octans:...2/envs/iraf27/iraf
IRAF
Image Reduction and Analysis Facility
PACKAGE = imutil
TASK = hedit

images =  @Rings images to be edited
fields = EPOCH fields to be edited
value = 2000 value expression
(add = yes) add rather than edit fields
(addonly= no) add only if field does not exist
(delete = no) delete rather than edit fields
(verify = no) verify each edit operation
(show = yes) print record of each edit operation
(update = yes) enable updating of the image header
(mode = ql)
```

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 (setl1listimages)
obsid    =                               Observatory to set, list, or image default
images   =                               List of images
(verbose=          no) Verbose output?

(observa=          andrejov) 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
jdo: 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
IRAF
Image Reduction and Analysis Facility
PACKAGE = onedspec
TASK = setjd

images = @Rings 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 Heliocentric 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

This may not work!

Newer IRAF should have ondrejov in the predefined list > super! If not, we will do it together.

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+=$6;n++;} END {print sum/n;}' R_star
```

- Then subtract it from each value:  replace with calculated average
! awk '{printf "%7.4f %6.4f\n", \$6-18.7529, \$7}' R_star > mag_star
(**6**: mag column, **7**: 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
```

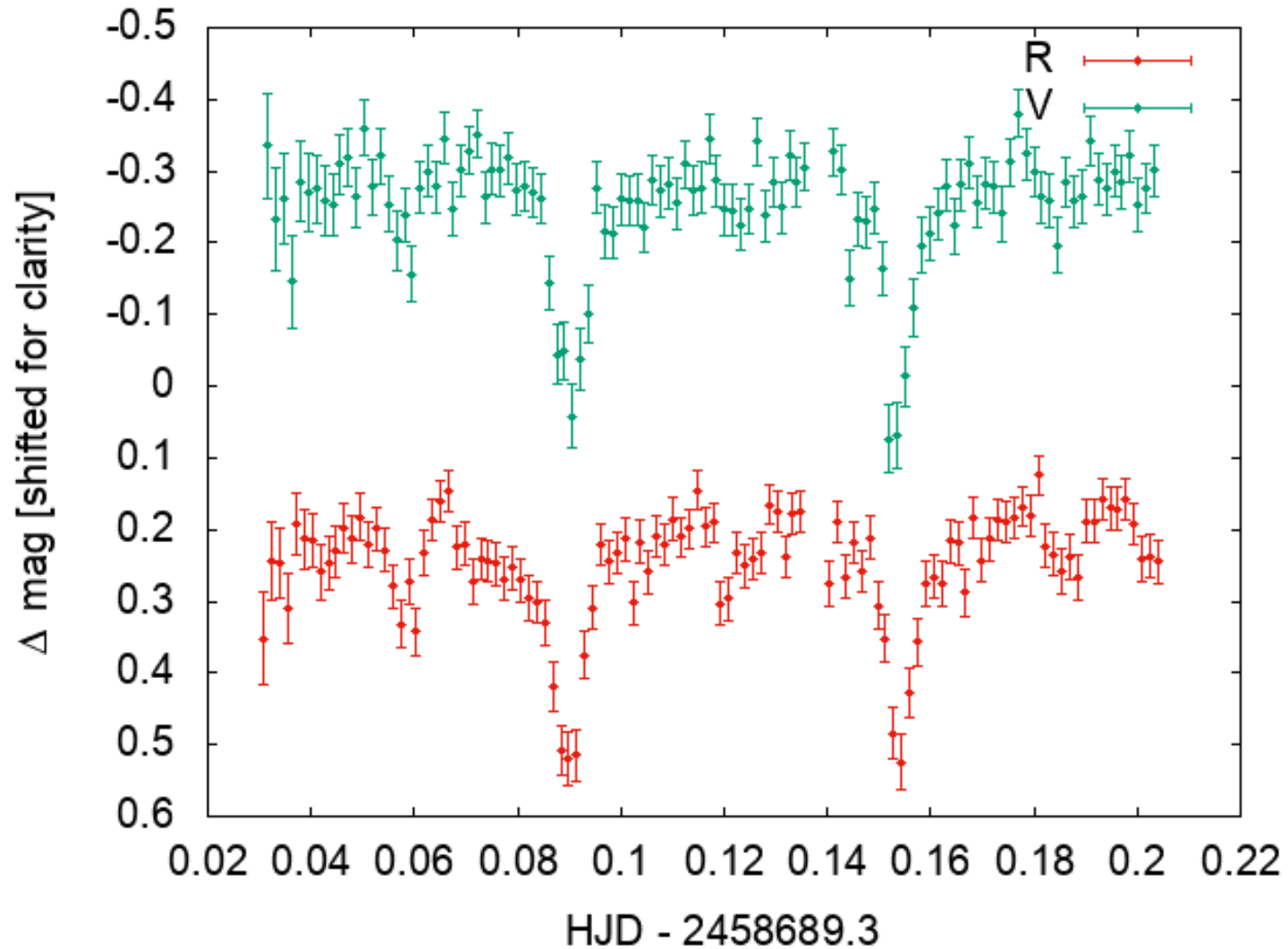
Building the light curve

- 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 task **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) execute 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).