

Optical Photometry

”The crash course”

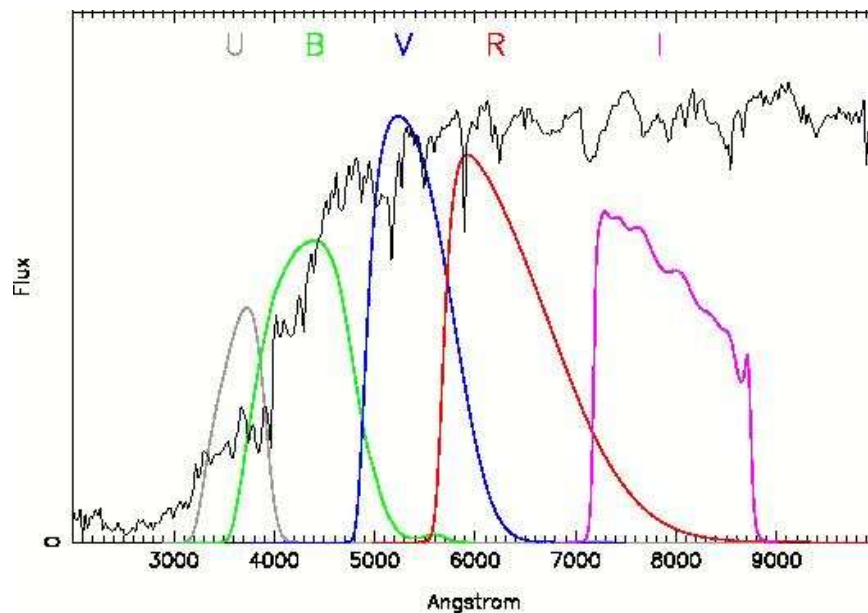
Tomas Dahlen

Aim: Measure the luminosity of your objects
in broad-band optical filters

Optical: Wave-lengths about 3500Å - 9000Å

Typical broad-band filters: U,B,V,R,I

Software: IRAF & SExtractor



Optical Photometry

A number of different frames are needed in order to get well calibrated images on which the photometry of your science objects can be measured:

- 1: Bias frames
- 2: Bad pixel masks
- 3: Flat-fields
- 4: Standard stars
- 5: Science frames
- (6: Super-flats)
- (7: Dark frames)
- (8: Fringe frames)

Optical Photometry

1: Bias frames

The bias is an offset of a few hundred counts added to the ccd before start of exposure. This bias must be subtracted from all images.

This is done in two parts

- 1) The ccd has an overscan region which do not see the sky - from this the offset value for each line can be determined and subtracted
- 2) A bias frame is created which is used to correct for any spatial gradient or structure of the offset.

How to create a bias frame:

Take ~10 frames with 0 second exposure time at beginning of night and ~10 after the nights observations.

Use IRAF task **zerocombine** to combine the frames to an averaged bias frame.

Use IRAF task **ccdproc** to correct all other images for the bias - this includes subtracting the overscan region and remove structure using the bias frame.

At this time, the images are also trimmed so that the overscan region is excluded from the remaining reduction steps.

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1: Bias frames

CREATING A BIAS FRAME USING ZEROCOMBINE

In IRAF, go to the ccdred page and type

```
cc> epar zerocombine
```

thereafter edit input, output etc. and run the task by typing " :go "

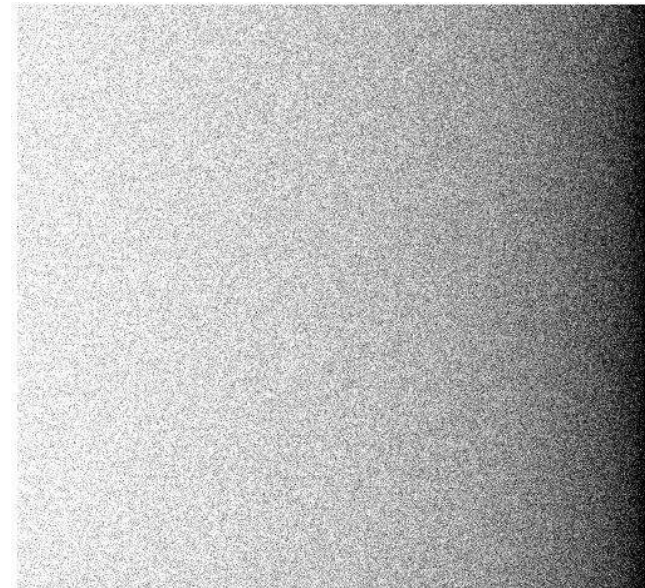
```
PACKAGE = ccdred
```

```
TASK = zerocombine
```

```
input = @inlist.cat List of zero level images to combine
(output = Zero060703.fits) Output zero level name
(combine= average) Type of combine operation
(reject = minmax) Type of rejection
(ccdtype= zero) CCD image type to combine
(process= no) Process images before combining?
(delete = no) Delete input images after combining?
(clobber= no) Clobber existing output image?
(scale = none) Image scaling
(statsec= ) Image section for computing statistics
(nlow = 1) minmax: Number of low pixels to reject
(nhigh = 1) minmax: Number of high pixels to reject
(nkeep = 1) Minimum to keep (pos) or maximum to reject (neg)
(mclip = yes) Use median in sigma clipping algorithms?
(lsigma = 3.) Lower sigma clipping factor
(hsigma = 3.) Upper sigma clipping factor
(rdnoise= 0.) ccdclip: CCD readout noise (electrons)
(gain = 1.) ccdclip: CCD gain (electrons/DN)
(snoise = 0.) ccdclip: Sensitivity noise (fraction)
(pclip = -0.5) pclip: Percentile clipping parameter
(blank = 0.) Value if there are no pixels
(mode = ql)
```



Science image before trimming



Averaged bias frame after trimming

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SUBTRACT BIAS AND TRIM ALL YOUR REMAINING IMAGES USING ccdproc

In IRAF, go to the ccdred page and type

```
cc> epar ccdproc
```

thereafter edit input, output etc. and run the task by typing " :go "

```
PACKAGE = ccdred
```

```
TASK = ccdproc
```

```
images =      @input.cat List of CCD images to correct
(output =    @output.cat) 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=   yes) Apply overscan strip correction?
(trim =     yes) Trim the image?
(zerocor=   yes) Apply zero level correction?
(darkcor=   no) Apply dark count correction?
(flatcor=   no) 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=   [2054:2101,10:2045]) Overscan strip image section
(trimsec=   [51:2002,51:2002]) Trim data section
(zero =     Zero060703.fits) Zero level calibration image
(dark =     ) Dark count calibration image
(flat =     ) 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?
(funcnio=   chebyshev) 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)
```



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2: Masks

A ccd often has a number of bad pixels that we do not want to include in our investigation. These bad pixels often consist of columns or part of columns. A bad pixel mask can be used in the data reduction to exclude the pixels we do not want to use.

To create a bad pixel mask:

- 1) Take an image with high counts, e.g., a flat-field image and identify the bad pixels/bad columns.
- 2) Make a copy of any (trimmed) image and set all pixels in this to zero using IRAF task **imreplace**.
- 3) Give pixel value 1 to all bad pixels that you have identified using imreplace.
- 4) Transform the mask to the correct format
(change the ".fits"-file to a ".pl"-file using
IRAF task **imcopy**:
imcopy Badpixelmap.fits Badpixelmap.pl)



Bad pixel mask

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3: Flat-fields

The response/sensitivity of the detector is not uniform but varies from pixel to pixel and on large scale. The response is also wave-length dependent and will therefore depend on filter. To overcome this, one observes a source with uniform illumination to create a flat-field image. This can thereafter be used to correct the images for the variations.

How:

Observe the twilight sky at dusk and dawn.

Suitable blank fields to observe are listed at the telescope.

Make sure you get significant counts, ~60-70% of saturation.

Get as many images as possible, with at least 4 images in each filters you will use during the night.

Rotate to ccd 90 degrees between each exposure so that gradients in the twilight can be averaged out.

Remember that the sky brightness changes quickly

Alternative:

If you are not able to take twilight sky flats due to e.g., bad weather, then you can use "Dome-flats". Here the inside of the telescope dome is illuminated and used instead of the twilight sky.

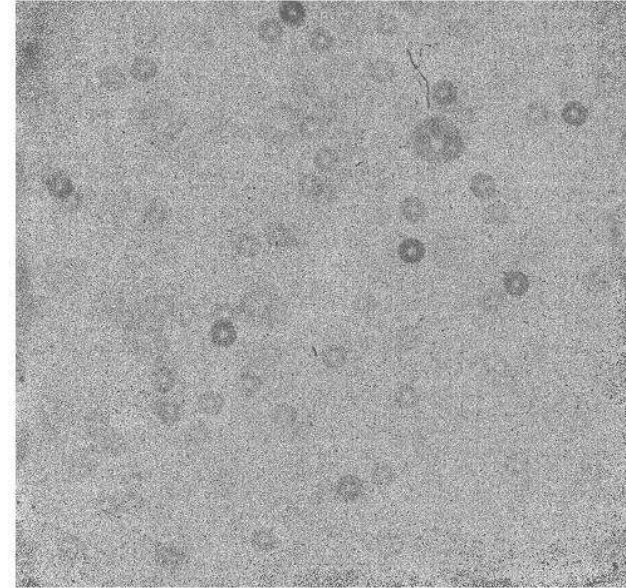
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3: Flat-fields

Use IRAF package **flatcombine** to combine the individual flat-field images. Make one flat-field image for each band and each night.

```
PACKAGE = ccdred  
TASK = flatcombine
```

```
input = @Inlist_FilterR.cat List of flat field images to combine  
(output = Flat_B_060703.fits) Output flat field root name  
(combine= average) Type of combine operation  
(reject = avsigclip) Type of rejection  
(ccdtype= flat) CCD image type to combine  
(process= no) Process images before combining?  
(subsets= yes) Combine images by subset parameter?  
(delete = no) Delete input images after combining?  
(clobber= no) Clobber existing output image?  
(scale = mode) Image scaling  
(statsec= ) Image section for computing statistics  
(nlow = 1) minmax: Number of low pixels to reject  
(nhigh = 1) minmax: Number of high pixels to reject  
(nkeep = 1) Minimum to keep (pos) or maximum to reject (neg)  
(mclip = yes) Use median in sigma clipping algorithms?  
(lsigma = 3.) Lower sigma clipping factor  
(hsigma = 3.) Upper sigma clipping factor  
(rdnoise= 0.) ccdclip: CCD readout noise (electrons)  
(gain = 1.) ccdclip: CCD gain (electrons/DN)  
(snoise = 0.) ccdclip: Sensitivity noise (fraction)  
(pclip = -0.5) pclip: Percentile clipping parameter  
(blank = 1.) Value if there are no pixels  
(mode = ql)
```



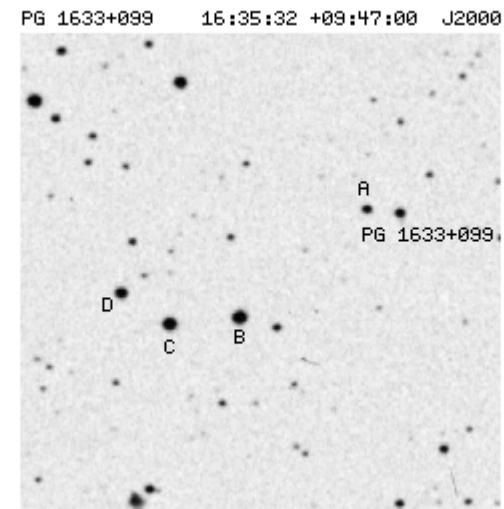
Averaged flat-field image in R band

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4: Standard stars

Now we have the frames needed for making high quality science images of your objects. However, once you have your science frames, you need to calibrate these so that you can measure the magnitude of your objects. Standard stars with known magnitudes are used for this calibration.

- * Select your standard stars as close to your science object as possible.
- * For optical, use e.g., the Landolt catalogue (available on the web).
- * If possible, choose standard fields with more than one standard star.
- * Observe the standard stars in all filters that you are using during the night.
- * Start the evening with observing the standards - since these are fairly bright, you can start before the sky is completely dark.
- * Repeat standard star observations every ~1.5h or so.
- * Standard stars are relatively bright, so exposure times ranges from a few seconds to ~10s of sec.
- * Use the exposure time calculators to estimate exposure times (or check recommended times on web page).
- * Make sure standards are not saturated (especially if seeing changes)



Standard stars: Landolt 109 area

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4: Standard stars

How to make the calibration (after have made the final reduction steps described later).

General formula for a galaxy's magnitude in filter i:

$$m_i = -2.5 \log(DN / \text{exp}) + ZP_i$$

DN = Counts of object as measured by e.g., PHOT or SExtractor

exp = exposure time

ZP_i = Zero-Point that we want to determine

For the standard stars, we know what m_i should be and can therefore determine ZP_i

However the Zero-point is dependent on airmass,
where airmass = $1/\cos(z)$, and z =zenith distance.

An object straight above (airmass=1), will appear brighter than
an object that is low on the sky (airmass~1.5).

This is due to the extinction in the Earth's atmosphere.

The extinction is wave-length dependent and affects
shorter wave-lengths more.

If you only have 'one' science image and you have the standard star image at the
same airmass - then you can use this standard since both have same airmass.

In a real case, you will often want to combine images taken at different airmasses.

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4: Standard stars

Example on how to calculate a common Zero-Point:

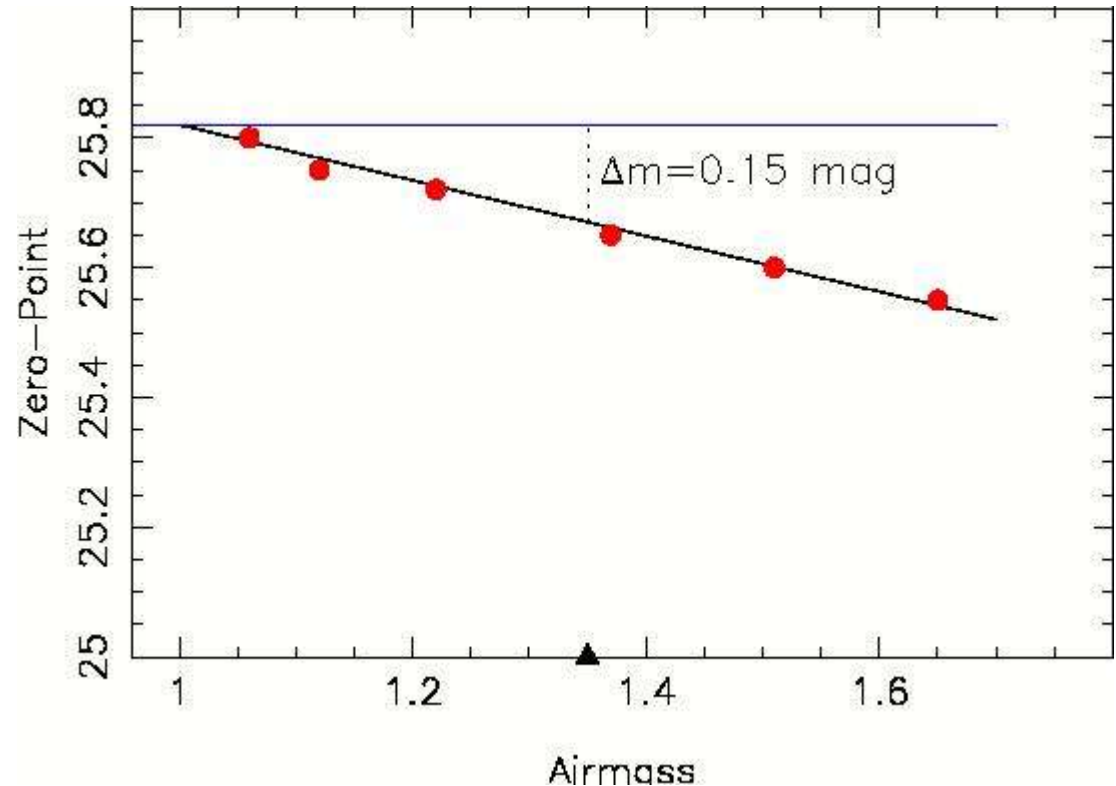
Dots in figure shows measured ZP' vs. airmass

Fit a line to the ZP's

Use a final ZP that is the intersection of this line with airmass=1, here ZP=25.82.

Each science image is then corrected to the ZP at airmass=1.

For example, an object at airmass=1.35 (triangle in figure), will be 0.15 mag too faint compared to the airmass=1 ZP.



Therefore this image should be multiplied by a factor

$$f=10^{0.4*m}=1.148 \text{ (using IRAF **imarith**)}$$

After all images have been multiplied by their individual correction factors, they will all have the same ZP and can therefore be combined to a single image.

It is possible to use tabulated values of the slope, but it is recommended to actually do the fit.

The airmass at the start of each exposure is given in the image header

For long exposures, it is possible to calculate an 'effective' airmass using IRAF task **setairmass**

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5: Science frames

Doing good science on your images requires sufficient Signal-to-Noise (S/N), where

$$S/N = S / \sqrt{S + \text{var}(\text{background}) + \text{var}(\text{readout}) + \text{var}(\text{dark})}$$

where $\text{var}(\text{background})$ is square of background noise (readout noise/dark current noise)

To get high S/N you need sufficient exposure time. When applying for telescope time you should have applied for (and hopefully gotten) the required time to reach desired S/N.

In normal cases you should go for $S/N > 10$ (for faintest objects / sub-objects)

Planning and executing observations:

1) Divide your available exposure time into sub exposures, in normal cases at least four.

E.g., One hour available on target time is divided into four 15 min exposures.

2) Check with the exposure time calculator that you do not risk to saturate the detector.

If this is the case, divide into more sub exposures.

3) Offset the telescope between each sub exposure. This is because you do not want objects to fall on the same pixels in the different exposures (due to 'bad pixels', super flat/fringe frame creation, etc). For a four image set, you may e.g., offset telescope 10 arcsec between each exposure moving in a square pattern.

4) If you are observing objects spread out over the whole field-of-view (e.g., a galaxy cluster), you can also rotate the ccd 90 degrees between exposures. This could help average out gradients in the sky background.

5) After taking an exposure, make a check that objects are not saturated, if they are, change exposure time.

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(6: Super-flats)

Sometimes there are additional gradients in the background sky that are not corrected for by the flat-fielding. If you have a sufficient number of science images, that are properly offset between exposures, then these can be used to create a median image representing the actual sky at the position of your target (e.g., IRAF task **combine**).

This median image is thereafter smoothed to represent the large scale gradients (smoothing with IRAF task **mkskycor**).

Finally, this super-flat is then used for the illumination correction when using IRAF **ccdproc**.

For most purposes, the standard flat fielding is sufficient.

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(7: Dark frames)

The dark current may cause a false signal in your exposure. In order to check this, you may take a dark frames with the same exposure time as your science images.

Subtract the bias from the dark frames and investigate the residual signal. Is the signal so high that it has to be subtracted from the science images?

For modern ccds used for broad band imaging this is not the case (and is not necessary to check).

If corrections are needed, then there is an IRAF task **darkcombine** that creates the dark frame

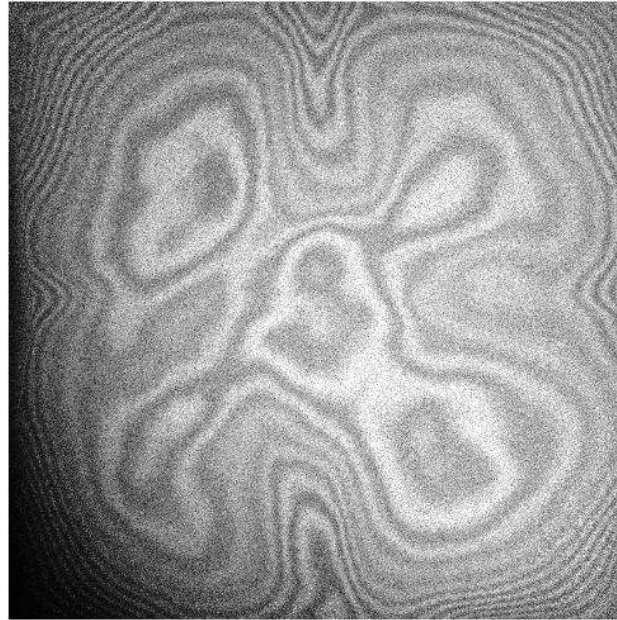
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(8: Fringe frames)

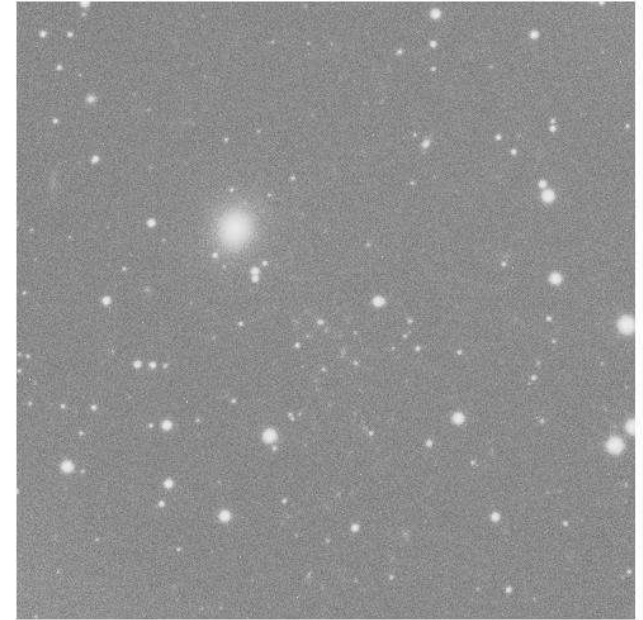
Emission by atmospheric OH may cause a fringe pattern in images taken with long wave-length filters (i-band, z-band) which has to be corrected for. The strength of the fringe pattern increases with exposure time. It may also vary during the night.



Single science image
with fringes



Fringe frame created by
taking median of a number of
science images



Science image after subtracting
fringe frame (and combining
a number of images)

Create the fringe frame by taking the median of the science frames. These should have the same exposure times, otherwise you can normalize all frames to one second.

If the science images are properly offset, then objects will not be visible in the fringe frame and you will get something like the middle image above.

Subtract this fringe pattern from your science images (properly scaled to the correct exp time).

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Final reduction steps

PACKAGE = ccdred
TASK = ccdproc

You should now have all images needed for the final reduction.

0) What you have are bias subtracted and trimmed flat-fields, standard star images, science images, and a bad pixel mask (for i-band also a fringe frame).

1) Run IRAF task **ccdproc** on the standard star and science images.

2) Make the standard star calibration described earlier

3) Correct science images for airmass so that they get a common zero-point

4) Next step is to align your images (sub exposures). First you should rotate back any images that were rotated between exposures. Then align images using IRAF task **imalign**.

5) The final step is to combine the aligned images using IRAF task **combine** (or **imcombine**).

6) Switch to your preferred photometry package to measure the magnitudes (for example SExtractor)

images = @input.cat List of CCD images to correct
(output = @output.cat) List of output CCD images
(ccdtype=) CCD image type to correct
(max_cac= 0) Maximum image caching memory (in Mbytes)
(noprocs = no) List processing steps only?

(fixpix = yes) Fix bad CCD lines and columns?
(oversca= no) Apply overscan strip correction?
(trim = no) Trim the image?
(zerocor= no) Apply zero level correction?
(darkcor= no) 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= Badpixelmap.pl) File describing the bad lines and columns
(biassec=) Overscan strip image section
(trimsec=) Trim data section
(zero =) Zero level calibration image
(dark =) Dark count calibration image
(flat = Flat_B_060703.fits) 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= chebyshev) 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)

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Misc

*) If you are observing extragalactic objects, you need to correct for galactic extinction. This is done after the final steps described on previous slide. Multiply your images by a factor calculated from the extinction values given on e.g., the NED web site:

NASA/IPAC EXTRAGALACTIC DATABASE

Searching NED for object "ABELL 2100"

Galactic Extinction (Burstein & Heiles): $A_B = 0.040$ mag; 1982AJ.....87.1165B

Galactic Extinction (Schlegel et al.): $A_B = 0.072$ mag; 1998ApJ...500..525S

$E(B-V) = 0.017$ mag.

The values listed below are calculated following Schlegel et al. Appendix B.

See Notes on Galactic Extinction for important caveats.

Bandpass	U	B	V	R	I	J	H	K	L'
Wavelength [um]	0.34	0.44	0.54	0.65	0.80	1.27	1.67	2.22	3.81
A_λ [mag]	0.091	0.072	0.055	0.045	0.032	0.015	0.010	0.006	0.003

*) Have a 'Back-up' program

*) Scale images to 1s (keep track of total exposure time).

*) Take notes during night (weather, seeing etc.)

*) Check web for guides on IRAF and SExtractor:

<http://iraf.noao.edu/iraf/web/docs/docmain.html>

http://terapix.iap.fr/rubrique.php?id_rubrique=91/

*)

*)